COUNTERPOINT

Avionics 2021

THE FIRST REVIEW OF THIS MARKET FROM COUNTERPOINT

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1. EXECUTIVE SUMMARY

A significant challenge in undertaking this report was first to define the scope of avionics. Traditionalists may say that avionics is confined by the real estate within the cockpit, i.e., the dashboard, or by the primary functions of navigation, communication and surveillance adding in intelligence and specific mission functions for military applications.

We have elected to include a broader scope definition that captures a number of dynamic shifts including the greater role of software-based functions, sharing and/or partitioning of computing resources, the improvements in sensors technology and the role of data and data fusion in improving both health management and situational awareness.

Equally, we note that the airborne infrastructure required to support avionics today spreads far beyond the cockpit in terms of data transmission and communication, the use of remote data concentrators and the role that high speed, broad bandwidth networks play in achieving new levels of mission performance in real time.

Avionics has always functioned 'beyond the cockpit' in terms of Air Traffic Control, but today the number of external links and the associated data traffic is growing significantly. This is driven by such factors as the need for more autonomous flight (ADS-B), satellite navigation means (GPS), download/upload links in real time, SATCOM based communications and services, and the ability to provide in flight health and performance monitoring.

A further growth driver within the commercial sector surrounds passenger expectations of having an 'office in the sky' experience that includes wi-fi, video on demand, communications, shopping etc.

The second challenge was to scope the size of the avionics market in dollar terms and to be able to attribute this to the various phases of the product life cycle. In addition to forward fit OE supply there are upgrades, retrofits, regulatory mandates, software loads, database updates all at periodic intervals throughout the long life of the platform. The avionics market is challenging in terms of clearly identifying all of the revenue streams generated through the life cycle of the product or service offering.

The tables below show the total avionics market sector as being worth $23.8 billion in 2019, falling to $17.3 billion in 2020. The report identifies the market segmented into 11 product groups or avionics functions which we have broadened beyond traditional areas to include digital services and sensors for example.

Our estimates for the total avionics market size are shown in the table below which identifies the major avionic sub-system categories together with revenues split between OE, aftermarket, and third-party MRO.

2019 Avionics Market	OE	Aftermarket	3rd party MRO	TOTAL
Software	492	880	37	**1,410**
IMA	812	997	100	**1,908**
FMS	585	935	106	**1,626**
Auto-pilot	254	320	91	**665**
Display	1,796	3,404	751	**5,951**
Navigation	789	1,266	182	**2,237**
Communications	525	901	128	**1,554**
Surveillance	640	1,093	104	**1,837**
Data	472	1,013	112	**1,597**
Mission	508	1,553	125	**2,185**
Sensors	964	1,688	222	**2,875**
Grand Total	**7,837**	**14,050**	**1,958**	**23,846**

2020 Avionics Market	OE	Aftermarket	3rd party MRO	TOTAL
Software	362	608	18	**988**
IMA	631	746	60	**1,437**
FMS	374	530	56	**960**
Auto-pilot	178	188	53	**419**
Display	1,288	2,294	386	**3,968**
Navigation	561	914	107	**1,582**
Communications	384	585	73	**1,042**
Surveillance	485	768	58	**1,310**
Data	337	654	64	**1,054**
Mission	454	1,516	68	**2,038**
Sensors	755	1,617	113	**2,485**
Grand Total	**5,808**	**10,419**	**1,057**	**17,283**

Our analysis breaks out the total aftermarket market which equates to $16.0 billion in 2019, falling to $11.5 billion in 2020. This is an important sector as it operates independently of the OE forward fit cycle and it is comprised of many discrete opportunities.

The dichotomy represented by the in-service life of the airframe (decades) vs. that of modern electronic avionics (several years) generates a significant retrofit and upgrade market. A consequence of this is an avionics market with multiple insertion point opportunities arising at any one point in time.

It is equally clear that the OEM constructors and the OE avionics suppliers are not always as attentive to customers' needs when it is some decades since they acquired the platform.

The result of this situation is the presence of a wide array of 3rd party providers (i.e., non-OEM) who offer a range of services including COTS products, STC products, Stockists, Distributors, software support, data analytics and installation services.

In terms of retrofit/upgrade and maintenance of legacy aircraft, we note the effect that the Covid-19 pandemic will likely have on airlines who elect to retire their older/legacy aircraft earlier than originally planned. This could act to reduce the retrofit market potential, certainly in the short to medium term. It is not yet clear at the time of writing just how many aircraft will return to service from storage.

Within the report we have identified 55 suppliers of avionics, but it would not be practical to identify all of the 3rd party providers. Nevertheless, we have included estimates for these services based upon fleet activity, age, utilisation etc.

Avionics can be impacted by airworthiness regulatory changes over time. It can take years to upgrade the equipment installed in existing fleets to comply with mandatory or attrition-based notices that come into force. Key changes in recent years include the need to adopt greater navigation performance (FANS/Next Gen) largely through to the adoption of GPS based systems, the Reduced Vertical Separation Minima (RVSM) necessary to reflect increasingly congested air traffic, the adoption of Traffic Collision Avoidance Systems (TCAS) and the move to a more autonomous flight regime enabled via ADS-B/A and associated transponders.

Whilst not all 'situational awareness' or surveillance aids are mandated, they have been widely adopted in order to provide pilots with better situational awareness and/or reduced workloads. These include Traffic Collision Advisory Systems (TCAS), Enhanced Ground Proximity Warning Systems (EGPWS) and Weather (WX) radar systems.

Arguably one of the major advances both within the civil and military field that significantly improves overall situational awareness is the adoption of Enhanced Vision Systems or Synthetic Vision Systems. These systems tend to take inputs from several sources (terrain databases, cameras, infra-red optics) and blend the data, i.e., data fusion, to create a layered 3D image for the pilot.

A key example of the effect that these mandates can have is the move by the Chinese airworthiness authorities to regulate that all civil aircraft operating within China are fitted with Head Up Displays by 2025.

These avionic solutions traditionally came with 'big ticket' prices reflecting the cost to design, develop, validate and certify these products that perform safety critical functions. However, a number of suppliers have been adept at offering lower cost variants with similar functionality. This is possible within the less regulated market sub-sectors including smaller business jets, general aviation, rotorcraft and military trainers where certification costs are lower. Suppliers have achieved market penetration in certain sectors by adopting a COTS approach or by pursing an STC certification route. By doing so they avoid the very high certification costs associated with large OEMs and highly regulated air transport markets.

That is not to say that the large avionic providers have ignored this market sector, quite the contrary. Honeywell services these sectors via its Bendix King subsidiary whilst both GE Aviation and Collins Aerospace have operating divisions that are focussed on servicing the business jet/GA/rotorcraft sectors.

All of the major avionics suppliers have a list of products certified for a range of platforms via the STC route.

Many suppliers have focussed upon COTS based or TSO certificated products and are clearly in tune with the lower cost market sectors. These include Garmin, Universal Avionics, Innovative Systems & Support, Genesys, Astronics and Meggitt.

These same suppliers also support legacy civil and military transport aircraft that require minor upgrades. Often these niche opportunities fall outside of the scope of the OEM constructors and the larger avionics integrators. For example, Universal Avionics offers a range of avionic upgrades for older C-130H aircraft.

The application of new technology can often be categorised as either evolutionary or revolutionary. Most airframe systems benefit from evolutionary technology that ratchets forward over time. Incremental improvements, in respect to avionics, include the ongoing improvements in SWAP (size, weight and performance) associated with electronic devices. Avionics-related computers are getting smaller, with associated increases in performance, often accompanied by lower weight and lower acquisition costs.

Thermal management techniques, which can affect the reliability and life of electronic componentry, are improving by becoming an integral part of the design of avionics e.g., active internal liquid cooling of avionics housings.

Visual cockpit display graphics have steadily improved which reflects a combination of better display media (e.g., multi-function flat panel LCD displays) and the associated software engines that drive the display graphics.

The same can be claimed for Enhanced or Synthetic Vision Systems (EVS/SVS) that often rely upon multiple sensor inputs and software that, in combination, 'stitch' together graphical representation. These SVS/EVS improvements have largely come about due to the improvements in data fusion (or interlinking) from different sensors resulting in a high fidelity 'synthesised' output graphical representation.

A step change has been provided in avionics architectures moving from federated individual avionic boxes to reliance upon common computing resources or integrated modular avionics. This integrated approach, via shared computing resources, brings with it challenges in partitioning a number of various critical avionic functions with non-critical utility functions. This in turn has introduced the need for new solutions provided by suppliers who are focussed on developing software.

We have identified the involvement of software companies, often working with the OEMs and Tier 1s, in order to develop partitioned RTOS software for the new integrated architectures. These companies typically include Wind River, Mercury Green Hill software and Lynx Software Technologies.

A major potential benefit of the IMA (Integrated Modular Avionics) approach is not just the reduction in box count but also the adoption of 'open software' architectures which allow operators and end-users to have more control over subsequent upgrades and/or functional additions in service.

Early versions of IMA utilised for the Boeing 777 and those offered via Collins ProLine Fusion and Honeywell's Primus Epic have not always adopted 'open architectures' in terms of ease of access for upgrade or adding new functionality.

Newer more 'open' IMA architectures have been successfully adopted now by a number of civil and military platforms including Boeing 787, F-35, A350, A400M. We believe that all next generation platforms will adopt an IMA approach, with open architectures, as a baseline for avionics functions.

We are less convinced by total autonomy within commercial flight (i.e., removal of the pilot) as a near term objective. Whilst the technology is clearly advancing rapidly within the automotive sector there are additional issues surrounding commercial flight, we believe. Navigation is a much greater challenge given both lateral and vertical axes to consider. Both the pilots and the passengers have significant physiological and psychological issues to contend with. The emotional barriers associated with total autonomous flight (i.e., no pilot) will be much harder to deal with, we believe.

A further potential paradigm shift in air transport technology is the rapid growth in demand for both UAVs and UAMs. The current conceptual and development phase vehicles bring with them a range of issues in terms of airworthiness approval (especially when mixed with existing air transport aircraft). Air taxis operating in congested airspace over urban areas will also require significant investment in infrastructure support (parking, storage, re-charging, servicing etc).

The various civil airspace authorities around the world are trying to generate a consistent set of airworthiness rules specifically relating to UAVs/UAMs/Drones as we write this report.

The need for low cost/high utilisation/high volume urban air vehicles will create a new set of challenges for avionics providers.

The avionics industry has undergone considerable consolidation in recent years, and we see evidence of this continuing. This will could also extend to the service providers, software specialists and 3rd party providers who are active within the avionics sector and will benefit from significant growth.

Consolidation and inward investment we see as continuing, driven by the above-trend line growth potential associated with avionics and associated services. This growth trend is supported by avionic equipment upgrade potential, the additional services that are derived from avionics-based software and data and the connected world in which all these platforms operate.

The largest avionics providers are subsidiaries of corporations that are often equal to the OEM constructors, in terms of market capitalisation, which can be a concern to the latter. Both Airbus and Boeing have, in recent years, adopted initiatives that attempt to claw back control of both IP and service offerings from within the supply chain. This OEM initiative is not unique to avionics and applies to other systems and equipment. Boeing and Airbus have used these initiatives with varying success to address what they perceive as 'monopolistic' areas such as APUs, nacelles and avionics.

From an investment perspective, we believe that avionics is an attractive market sector. The product sub-sectors are all underpinned by Intellectual Property (i.e., design to spec) requiring highly specialised engineering. The entry barriers to avionics are relatively high which restricts new entrants. We believe that the total aftermarket for avionics products and services, including significant retrofit/upgrade opportunities, is equal to the OEM forward fit market in revenue terms.

We further believe that this large aftermarket generates higher margins than the OEM forward fit market. Whilst we are not able to always identify suppliers' profitability for avionics, all of the evidence suggests that aftermarket services can generate margins from the mid/high teens and upwards.

Garmin is a classic example of a manufacturer that has quickly established a credible track record within aerospace, offering a wide range of product and services whist reporting 20%+ operating profit margins.

We do note that the profitability for large US defence contractors can be typically fall within the 10% - 12% range which, we believe, is largely due to the US government/DoD 'open book' approach to defence contract pricing.

Designing, developing and certifying critical function avionics requires high up-front investments which the OEM constructors expect the supplier to provide. In recent years, the increasing role of software has added to the overall programme risk. It also reflects why the largest avionics providers today rely more upon their software sub-contractors and out-source key elements of the software IP.

A means to reduce these high entry barriers and associated costs, adopted by many avionics suppliers, has been the successful adoption of COTs approaches to military applications and the pursuit of product certification via the STC route.

Arguably these high entry barriers are one factor in understanding why there are very few new entrants from emerging markets. Not only does a new supplier have to deal with western customers but also interpret the relevant airworthiness approval requirements (which can vary by region).

Within the report we review emerging market suppliers by major region but do not see many new entrants. We have identified a handful of avionics suppliers from emerging markets such as India, China, Russia and Brazil.

As we go to print, the Covid-19 pandemic is still far from over and the impact upon air travel in particular continues to take its toll. We have included Counterpoint's own views as to the various market sector scenarios contained in section 16 of this report.

In summary, we are drawn back to the question of how avionics will continue to grow and what are the key structural considerations. A quick summary of the key relevant points follows:

- Avionics are refreshed several times in the life of an OE platform creating many insertion opportunities and a market size that is significant relative to the OE forward fit value.
- Many suppliers have invested heavily in both COTS approach and STC certification in order to further expand their range of affordable product portfolios and to increase penetration of avionics within lower cost, less regulated aircraft sectors.
- Barriers to entry are set high requiring IP to develop critical functions within a highly regulated environment (risk and rewards are both high).
- Indications are that avionics suppliers enjoy a high level of aftermarket/OE sales ratios that generate above industry returns.
- Avionics is a relatively dynamic sector underpinned by fast moving technologies, regulations and services – successful players need to be engaged, flexible and adaptable.
- Emerging market needs for avionics products and services include; greater dependence placed upon software functions, need for autonomous platforms (and associated surveillance), improvements in sensor technologies and real time links to external services (e.g., via satellite).
- We see the need for continued consolidation will support M&A activity going forward.
- The financial houses, lessors, and airlines need their aircraft to be fitted with an up-to-date suite of avionics in order that:
  - They maintain asset values
  - They deliver the best operating efficiencies
- Emergent avionics players are likely limited to such areas as China and possibly Russia where they benefit from strong state support for aerospace.
- Military markets continue largely unaffected by Covid and we see avionics having a key role to play in maintaining the overall efficacy of 5th generation platforms such as the F35.

2. INTRODUCTION

As we initiated research into the Avionics world across the Aerospace and Defence spectrum it quickly became apparent that this is arguably the most dynamic equipment sector today in terms of evolution and change. Clearly a significant factor in this dynamic is the rapidly changing world of electronic computing and associated software.

A further major factor is the evolving regulatory environment in which Avionics operates. Congested airspace has resulted in regulatory changes including reduced vertical separation minima, NextGen or FANS-based navigation performance and the need for autonomous surveillance thereby relieving overloaded Air Traffic Control (ATC).

The military world has its own set of dynamics driven by factors such as the need for network-centric operations, multi-source data fusion, high speed data network and real time operating systems (speed of response being mission critical).

Repeatedly throughout our research we found many 'common themes' cited by industry bodies, government agencies, OEMs, suppliers and end-users alike.

These common themes included digitisation, Internet of Things, Artificial Intelligence, data fusion, 'smart' sensors, 'office in the sky', real time maintenance diagnostics, satellite based navigation and communications.

All these factors are often heavily interdependent with Avionics architectures and this report attempts to cover these within the context of the relevant sections that follow.

Avionics is in a state of continuous development driven by:

- the external platform operating environment (e.g., regulatory, network centric)
- the changes required to their architectures within the platform (IMA, distributed computing)
- the rapidly changing cost, size, power and memory of the associated electronics.
- the significant increase in the application of software replacing mechanical functions.

Modern avionics operate in a networked, digital environment that provides a multitude of terrestrial links between aircraft, satellites, ground stations, air traffic control, mission planners, and maintenance services with many of these links operating in 'real time'.

A number of avionic service providers and software developers are implementing solutions that rely upon Cloud-based computing and the emerging 5G communications network.

Avionic related 'dynamic drivers' include Increases in equipment computing power, greater flexibility and dependence upon software (especially open architectures that provide low cost upgrade paths), the ability to transmit and process tera-bytes of data, real time operating systems (RTOS), increasing levels of integration between functions (e.g. IMA architectures) and high speed data buses that link all elements of an Avionic system.

In terms of the external operating environment the need for greater safety, accuracy, operating performance and reduced pilot workload continuously drives regulatory changes that are imposed across the global Aerospace & Defence industry. These regulatory improvements are often implemented via the Avionics suite in terms of improved navigation, communications, flight management, surveillance and mission accomplishment.

As this report will show the dynamics noted above results in significant retrofit/upgrade opportunities. A modern commercial aircraft with an expected life of 30 – 40 years can expect to see its Avionics upgraded two, three or four times throughout its life.

A further notable feature, specific to Avionics, is the trend of reducing cost, weight and power consumed. As a result of this 'plug and play' Avionics, containing many of the features and performance associated with large commercial airliners, can be bought off the shelf by owners/operators of General Aviation, Rotorcraft and modest Business Jets. Prohibitively large and expensive Avionics, once found on only large commercial air transport and high specification military fighters, have reduced significantly (often referred to as Size

Weight And Performance or SWAP metrics) with a resultant increase in market penetration at the lower ends of the market.

Whilst the report will show that the Avionics industry has clearly consolidated around 3 or 4 large players there is still 50+ suppliers operating in specialised areas. Within the 50+ there are a significant number of newer players who specialise in new growth areas such as advanced electronics, software, data provision, service provision etc.

Avionics can be very broadly interpreted so it is often difficult to delineate what comprises 'Avionics' in precise terms. Equally, there is overlap and interaction between certain functions (e.g. Flight Management/Auto-Pilot/Flight Control) which can make it difficult to define exactly where Avionics starts and stops.

In preparation for this report Counterpoint Market Intelligence has sought to define the boundaries within the next section entitled 'Scope'.

3. SCOPE

As noted above, Counterpoint has undertaken to produce a report that includes the multitude of aircraft functions, both civil and military, that can be considered to be determined as 'Avionics' in general.

There are a number of key enablers or infrastructure products that relate to avionics equipment, the absence of which would render the "cockpit" to be less than optimised at best, and non-functional at worst. Examples of these, such as high-speed data-buses, remote data concentrators, integrated modular avionics computing and avionics software have therefore been considered within this report.

We also have assumed that the definition of 'Avionics equipment' can be taken to comprise hardware, firmware and software. Clearly upgrade paths exist for both firmware and software without removal of the Avionics hardware. This avoids major disruption to operators where a firmware/software upload can be performed in-situ via portable data loaders utilising high speed data transfer networks.

We purposefully emphasise the word 'cockpit' within any discussion around Avionics scope because, currently, the cockpit represents the key man/machine interface within all flying platforms (UAVs excluded!).

It would not be possible for an OEM provider of cockpit displays and interfaces to bring a product to market that had not considered the significant science that surrounds man/machine interface issues.

Essentially Counterpoint has taken the Avionics scope to include all equipment necessary for the flight crew to achieve its mission safely, reliably and within the operating parameters set by the operator (cost, on time, quality of service etc).

For a commercial flight this may be defined as a flight trajectory that navigates from A to B in the optimum time and cost (fuel burn) allowing for factors such as adverse weather conditions and traffic congestion.

For a military platform a mission may be defined as the delivery of a payload with pinpoint accuracy and for the platform to return to base undetected from the ground, sea and air. And, in the unforeseen event of detection to be able to identify all threats and to successfully engage in effective countermeasures.

One early decision was to consider the role of advanced military sensors as a key adjunct to avionics architectures. In this case we have elected to include the advanced high value sensors such as radar, electro-optics, infra-red and multi-sensor suites. These sensor suites link directly to avionics including enhanced vision systems, head up displays, electronic warfare, electronic countermeasures and target acquisition – all part of the mission.

Whilst Counterpoint has considered these military sensors to be within scope their associated sensitivity and limited available data can restrict the level of detailed analysis. Many Tier 1 defence contractors report up to 30% of their revenues as being 'classified', usually within the area of sensors development.

Included within the scope of this report are the traditional Avionics functions that we believe are largely recognised throughout the Aerospace & Defence sector. These are identified as follows:

- Integrated Modular Avionics
- Flight Management Systems
- Auto-Pilot
- Navigation
- Communications
- Radios
- Surveillance
- Mission
- Sensors
- Data

Not included within the scope of this report are the following areas:

- Space related avionics
- In-Flight Entertainment (IFE)
- Flight Control systems (although some elements of Flight Guidance/Flight Warning Computers are included within FMS systems)
- Full Authority Digital Engine Controls (Engine FADECs)
- Onboard passenger communication systems.

The cockpit also contains, in addition to the major functions described above, a significant number of relatively low value panels. These panels are typically utilised to select and/or switch between flight-related functions by the flight crew. They can be designed and manufactured by the airframers in-house and/or a diverse range of 'panel' suppliers. We have not considered these products to be within the scope of this report.

4. METHODOLOGY

All monetary values are in constant US dollars and relate to 2020.

All numbers and charts in The Report are Counterpoint estimates apart from the financial results, unless attributed otherwise.

4.1. SOURCES OF INFORMATION

Counterpoint gains intelligence from overt, publicly available sources.

We also gain information and opinions from the following sources:

- Customers of our market reports, with whom we have discussed issues arising around avionics
- Technologists in aerospace avionics companies and their customers
- Salesmen, marketers, strategic planners in the industry
- Economists in government departments and trade associations

No confidential information is contained in this report.

4.2. OUR MARKET MODEL

At the heart of our report, there is a quantitative market model and database, covering the following:

- An estimate of companies' avionics sales by product area
- Segment size and growth
- Segment shares by major company
- Overall market size and growth

- Avionics contracts by company where individually identified

We have carried out a comprehensive review of information in the public domain.

Unless otherwise stated all charts and diagrams have been derived from Counterpoint Market Intelligence's estimates.

Many companies in the avionics market do not publish figures for sales of avionics systems. Where no figures are available, Counterpoint has estimated avionics sales on the basis of current contracts. Together with an analysis based on the total numbers of aircraft delivered by the aircraft OEMs, this has enabled us to create an original market model.

In order to show the market effects of Mergers & Acquisition moves we assume that all ownership changes occur on the 1st of January in each year.

4.3. COMPANY PROFILES AND ANALYSIS OF TRENDS

The purpose of our company profile sections is not only to identify the very many companies in the market but to note and estimate some of the material that we use to analyse trends in the market. In doing this we also draw on the interviews that we have had with participants in the market over the past year.

5. GLOSSARY

The range of acronyms generated in relation to Avionics can be measured in the 1000s. We have distilled out the top 100 or so that we believe are most relevant and are utilised within this report.

ACARS	Aircraft Communications Addressing and Reporting System
ADAHRS	Air Data and Attitude Heading Reference System
ADC	Air Data Computer
ADIRS	Air Data Inertial Reference System
ADIRU	Air Data Inertial Reference Unit
ADS-A	Automatic Dependent Surveillance – Address
ADS-B	Automatic Dependent Surveillance – Broadcast
AFDX	Arinc 664. Avionics Full-Duplex Switched Ethernet (AFDX) is a data network, patented by international aircraft manufacturer Airbus.
AHRS	Attitude Heading Reference System
A/P	Autopilot. A computer-commanded system for controlling aircraft control surfaces.
ARINC 429	ARINC 429 is the Aeronautical Radio INC. (ARINC) technical standard for the predominant avionics data bus used on commercial and transport aircraft
ARINC 629	ARINC 629 bus operates as a multiple-source, multiple-sink system; each terminal can transmit and receive data from every terminal on the data bus.
A/T	Automatic throttle, also known as auto-thrust, is a system that allows a pilot to control the power setting of an aircraft's engines by specifying a desired flight characteristic, rather than manually controlling the fuel flow.
CAA	Civil Aviation Authority (UK)
CNS	Communications, Navigation, Surveillance

CNS/ATM	Communications, Navigation, Surveillance/Air Traffic Management
CV/DFDR	Cockpit Voice and Digital Flight Data Recorder
CVR	Cockpit Voice Recorder
DME	Distance Measuring Equipment. A system that provides distance information from a ground station to an aircraft.
DO-160	RTCA Document 160, Environmental Conditions and Test Procedures for Airborne Equipment.
DO-178	RTCA Document 178, Software Considerations in Airborne Systems and Equipment Certification.
EASA	European Union Aviation Safety Agency
ECM	Electronic Counter Measures
ECAM	Electronic Centralised Aircraft Monitoring
EFB	Electronic Flight Bag
EFD	Electronic Flight Display
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
EHSI	Electronic Horizontal Situation Indicator
EICAS	Engine Indication Crew Alerting System
ESM	Electronic Support Measures (typically Military)
EVS	Enhanced Vision System (e.g., HUD, Synthetic Vision Display)
FAA	Federal Aviation Authority (USA)
FADEC	Full Authority Digital Engine Control
FANS	Future Air Navigation Systems. FANS is the internationally agreed 'next-generation' plan for more efficient communication, navigation, surveillance and air traffic management (CNS/ATM), based heavily on satellite technology. The FANS modification package typically consists of the following systems: • Flight Management System software upgrade package • GPS (Global Positioning System) • SATCOM (satellite communications) • ACARS/Data Link (Aircraft Communication And Reporting System) • EFIS (Electronic Flight Instrument System) display
FDR	Flight Data Recorder
FLIR	Forward-Looking Infrared
FLTA	Forward Looking Terrain Avoidance
FMC	Flight Management Computer
FMCG	Flight Management Control Guidance
FMS	Flight Management System
FOD	Foreign Object Damage
FOG	Fibre Optical Gyro (used in inertial navigation)

GCAS	Ground Collision Avoidance System
GLNS	GPS Landing and Navigation System
GLNU	GPS Landing and Navigation Unit
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HSI	Horizontal Situation Indicator. An indicator that displays bearing, glideslope, distance, radio source, course and heading information.
HUD	Head-Up Display
IDS	(1) Integrated Display System (2) Information Display System
IFE	In-Flight Entertainment
IFF	Identification Friend or Foe
ILS	Instrument Landing System. The system provides lateral, along-course and vertical guidance to aircraft attempting a landing.
IMA	Integrated Modular Avionics
INS	Inertial Navigation System
ISIS	Integrated Standby Instrument System
LCD	Liquid Crystal Display
LRM	Line Replaceable Module
LRU	Line Replaceable Unit
MCDU	Multi-Function Control Display Unit (usually part of the FMS)
MEL	Minimum Equipment List. The list of equipment the FAA requires onboard and working on an aircraft before flying.
MFD	Multi-Function Display
MFDS	Multi-Function Display System
MLS	Microwave Landing System
MTBF	Mean Time Between Failures.
NextGen	NextGen is short for Next Generation Air Transportation System - an FAA program developed to modernise today's national airspace system with the help of the entire industry. NextGen is made up of a series of initiatives designed to make the airspace system more efficient.
PFD	(1) Primary Flight Director (2) Primary Flight Display. An EFIS presentation substituting for the ADI.
PND	Primary Navigation Display
QAR	Quick Access Recorder
RAI	Radio Altimeter Indicator
RALT	Radio Altimeter
RCVR	Receiver
RDC	Remote Data Concentrator
RDMI	Radio Distance Magnetic Indicator

RDR	Radar
RIU	Remote Interface Unit. Used to consolidate data locally and to transmit data around the aircraft via databuses.
RLG	Ring Laser Gyro (used in inertial reference navigation systems)
RMI	Radio Magnetic Indicator
R-NAV	Area Navigation (usually GPS based independent of ground aids)
RNP	Required Navigation Performance
RTCA	Radio Technical Committee on Aeronautics
RTOS	Real Time operating System (used in avionics computing for time partitions)
RVSM	Reduced Vertical Separation Minimum
Satcom	Satellite Communications
Satnav	Satellite Navigation
SSCV/DR	Solid-State Cockpit Voice/Data Recorder
SSCVR	Solid-State Cockpit Voice Recorder
SSFDR	Solid-State Flight Data Recorder
SSR	Secondary Surveillance Radar
STC	Supplemental Type Certificate
STOL	Short Take-off and Landing
SVS	Synthetic Vision System
TA	Traffic Advisory (TCAS)
TACAN	Tactical Air Navigation System, which provides azimuth and distance information to an aircraft from a fixed ground station.
TAD	Terrain Awareness Display (maps the ground terrain for avoidance purposes)
TAS	True Airspeed
TAT	Total Air Temperature.
TAWS	Terrain Awareness Warning System
TBO	Time Between Overhauls
TCAS	Traffic Alert Collision Avoidance System. This standard became mandatory in Europe for all new aircraft 2012, and for all existing aircraft in 2015. The TCAS also contains all the new ATSAW (Air Traffic Surveillance Awareness) capabilities defined by Airbus and is compliant with future US NextGen/SESAR requirements
TDR	Transponder
TSA	Transportation Security Administration
TSO	Technical Standard Order
V/NAV	Vertical Navigation
VOR	VHF Omnidirectional Radio Range. A system that provides bearing information to an aircraft

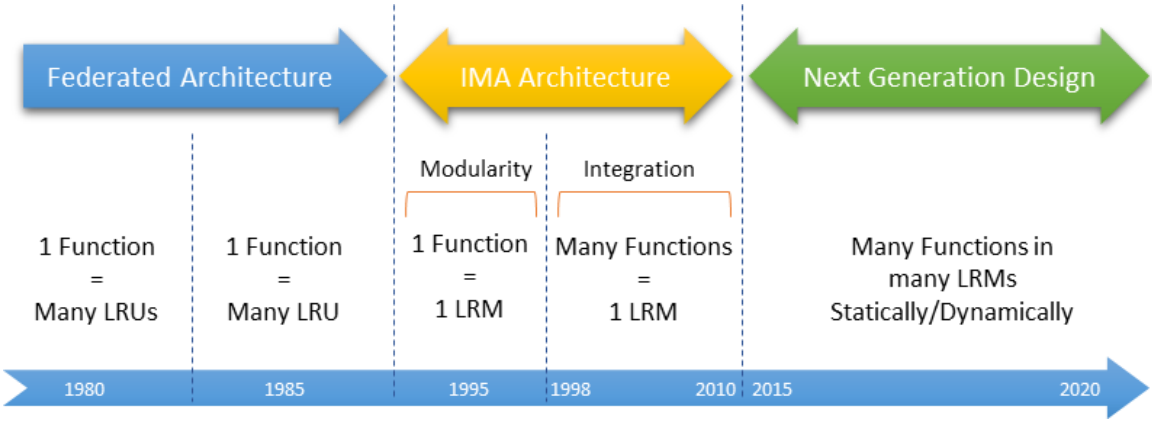
WAAS	Wide Area Augmentation System (method of differential GPS)
WRT	WXR Receiver/Transmitter
WX	Weather
WXR	Weather Radar System

6. A BRIEF HISTORY OF AVIONICS

The word Avionics was formed in the 1949 from the combination of the words 'Aviation' and 'Electronics', hence Avionics. It largely reflects the advent of 'electronic' designs adopted within the traditional areas of radios, navigation and communication.

Early flight instruments used for basic navigation were of barometric/mechanical design allowing altitude and airspeed to be displayed. This was achieved by deriving analogue inputs from pitot static tubes, angle of attack sensors and total air temperature data. Equally early 'attitude' reference displays relied upon mechanical gyroscopes that provided basic inertial reference guidance. Radio communications were based upon valves adopted from designs utilised in the 1920s and 30s. Radar was initially developed during World War 2 as a defensive aid but has subsequently been widely adopted by both civil and military platforms for surveillance functions.

Avionic products underwent an ongoing transformation with the arrival of the transistor in the 1950s. Electronics components such as transistors, diodes, capacitors and programmable memory devices allowed for the replacement of traditional heavy mechanical solutions. At that time, the avionics architecture was in a distributed analogue form, where the system had no data buses but had lots of wires. It is very difficult to modify such a system and the system itself is still chunky and heavy. Examples of platforms that adopted the distributed analogue architecture are Boeing 707, VC10, DC-9, and the original versions of the Boeing 737.



In the 1970s the arrival of cathode ray tube displays started to replace the many barometric mechanical instruments. The analogue architecture transformed into a digital system with data buses between components. Each component in this distributed digital architecture now contains its own computer and memory. Each unit has a dedicated function. However, it is still heavy, slow, and difficult to reprogram. Examples of platform that adopted the distributed digital architecture are Boeing 737NG, Boeing 767, A330, Tornado, and Sea Harrier.

As digital technology evolved, the avionics system moved into the federated digital architecture which some considered as the first generation of true digital avionics system. Under this architecture, systems communicate via a MIL-STD-1553 (STANAG 3838, or Def-Stan 00-18 Part 2) bus. Modification and reprograming are now easy. The federated digital architecture allows for a more interrelated functionality between systems that were previously independent in architectures of the past. Data transmission via buses drastically cuts down on the weight and cost that traditional point-to-point systems typically required. For instance, the United States Air Force saved approximately 1,200 pounds in wire for the B-52. The 1553

system has become so prevalent over the decades that close to 30,000 aircraft now support the standard with nearly 1 million total 1553 terminals implemented.

In the 1980s Airbus was the first OEM to adopt 'fly by wire' architecture on a commercial platform (although military platforms adopted 'fly by wire' much earlier in the 1960s).

In the 1980s and 90s Electro-optic devices such as the head-up display (HUD), forward looking infrared (FLIR), infra-red search and track and other passive infrared devices (Passive infrared sensor) have been used to provide imagery and information to the flight crew.

The 'digitisation' of Avionics really progressed throughout the 1980s and 90s with the adoption of new functions such as data recorders, flight management systems and modular avionics.

A number of platforms have adopted the 'integrated modular avionics' architecture in order to share computing resources more efficiently and to allow 'open architectures' that allow for additional functionality, upgrades etc. Typical 'IMA' examples include the F-35, Boeing 787, A350 and A400M platforms.

Since 2000, the availability of high speed data networks that link to ground stations and/or air traffic control has allowed the uploading of data in real time operating systems (RTOS) environments. This combined with a much higher degree of flight autonomy (e.g. ADS-B), has allowed the adoption of newer Avionics functions such as Traffic Collision Avoidance Systems (TCAS), Weather Radar/Mapping and Enhanced Ground Proximity Warning Systems (EGPWS).

Within the scope section above we refer to certain elements of Avionics infrastructure as key enablers. The development of high-speed data networks forms one of these key enablers we believe. Data is rarely 'static' over time and can change throughout an aircraft mission (sometimes quicker than a pilot can be expected to react). The ability of data network systems to 'fuse' data from various sources in real time and to provide an automatic response is therefore key to modern Avionics.

An example of the progress made in recent years is the comparison below between Arinc/AFDX serial data buses.

Databus standard	Avionics application	Platforms (typical)	Data processing
Arinc 429	Avionics	Boeing 737	12 Kbps
Arinc 629	Avionics/flight controls	Boeing 777	2 Mbps
Arinc 659	IMA	Boeing 777	60 Mbps
AFDX	IMA/Avionics	A350, Boeing 787	100Mbps

Arguably the biggest advance in Avionics has been the role of software in replacing hardware functions in recent years. In terms of sunk cost investment required to design, test and certify an aircraft, many believe that this could be as high as 75%/25% in favour of software for the next generation of both commercial and military platforms.

As growth in Unmanned Aerial Vehicles advance, and the degree of autonomy extends to the point where pilots are no longer necessary for many current platforms, we believe that software will play a key role in future Avionics architectures.

The tabulation below, which identifies the growth in 'lines of software code' for various applications, would appear to support this belief.

Lines of software code by application

Application	Lines of software code	Year
A320	< 1 million	1985
F-22	4 million	2000
Global Hawk UAV	8 million	2010
Boeing 787	14 million	2012
F-35	24 million	2014
Average automobile	50 – 100 million	Current
Microsoft Office	45 million	Current
Google	2,400 million	Current

7. MAJOR AVIONICS PRODUCT GROUPS

7.1. SOFTWARE/DIGITAL SERVICES

If we had compiled this report a decade or so ago the section covering software would possibly have been an adjunct at the end of this section. The fact that it is now so prominent reflects the significant increase in both software-based avionics functions and infrastructure that has occurred in recent years.

A number of leading OEMs and avionics integrators state that the development of total platform-related software accounts for between 15% and 30% of the total airframe development costs.

Software development for safety critical avionics functions can be extremely costly due to the very rigorous needs for verification, validation and certification. It is not unusual for level A software, applied in the most critical of applications, to be duplicated and each set to be written by two different teams in order to avoid common mode failures. This approach then requires separate certification processes together with the associated costs.

Avionic-related sensors located around the aircraft are now often designed to be ‘smart’ i.e., with local embedded I/O and software logic. This, in part, has been driven by the need to be able to interrogate sensor status ‘in situ’ from a health and maintenance perspective.

The firmware and hardware, upon which software is located, are continuously driven by SWAP (Size, Weight and Performance) metrics within the avionics world. Every few years improvements in electronics are available to airframe designers who are continually challenged by airframe performance needs.

It is neither practical nor affordable for airframe operators to continuously upgrade or swap out older electronics and to benefit from associated improvements in software functionality.

Software has been utilised within avionics in the last decade or so in the following areas:

- The partitioning of disparate avionic functions, with varying criticality, all operating on a common computing platform with a Real Time Operating System (RTOS).
- Software algorithms developed in order to blend navigation data from multiple sensor sources necessary to provide primary navigation
- ‘Smart’ air data sensing that allows air data sources from airframe-mounted sensors to be subject to software algorithms than can determine correct data inputs.
- Software defined radios that exhibit higher reliability/lower interference

Embedded avionic software usually requires updating on a periodic basis in order to maintain functionality and currency, and this has resulted in advances with software providers who support their product in service.

The software update need has spawned a range of products that enable software to be uploaded quickly and efficiently whenever an aircraft is located at a terminal i.e., software portable loaders, Wi-fi loaders, electronic flight bags, USB loaders etc.

In addition, there are providers of digital services providing a range of services on a periodic subscription service. These include navigation database packages (updated every 28 days typically).

Equally, many end-users/operators will need to subscribe to data or communication services (Wi-fi, Satcom) in order to allow passengers to communicate externally during the flight. These services are usually provided via satellite which requires a monthly subscription.

7.2. INTEGRATED MODULAR AVIONICS

The cockpit in any aircraft platform, be it commercial or military, is constrained in terms of space and volume. This results from the economics of flight that require continual investment in reducing weight and volume.

As a result of these constraints much of the Avionics equipment, that often requires active cooling, is located within a number of designated Avionics bays.

The heat generated by modern Avionics would make the cockpit uninhabitable if all of the equipment were to be co-located there.

A quick inspection of any commercial transport aircraft's Avionics bay, designed in recent decades, would reveal a total count of 50, 60 or 70 discrete Avionics 'boxes'. Each of these bespoke boxes contains packaging, connectors, power supplies, Input/output protocols and its own software operating system together with the algorithms appropriate to the specific utility function.

Individual suppliers of these bespoke 'boxes' have their own supply chains resulting in multiple sources of individual components.

The concept of IMA, first adopted within the military sector, is to provide a single source for all of the 'common' hardware and software elements of Avionics. By creating a software environment that can accommodate multiple 'utility' functions on a common platform, with suitably partitioned software, allows OEM airframe specifiers to dramatically reduce the overall cost and weight of the Avionics suite.

Clearly not all suppliers rushed to embrace the concept of IMA given the significant implications for both retention of Intellectual Property and the potential impact upon aftermarket revenues. Equally the suppliers' 'bill of material' will shrink given that the elements common to the core IMA will switch to the provider of the IMA, thereby reducing revenue.

Integrity issues surrounding common mode failures and software partitioning also served to slow the widespread adoption of IMA architectures.

Many of the OE IMA providers/integrators rely upon 3rd party software providers who have expertise in partitioning and embedding software that is operating in real time (RTOS). Companies such as Wind River, Lynx software Technologies and Green Hill software have all supported the development of IMA-related software.

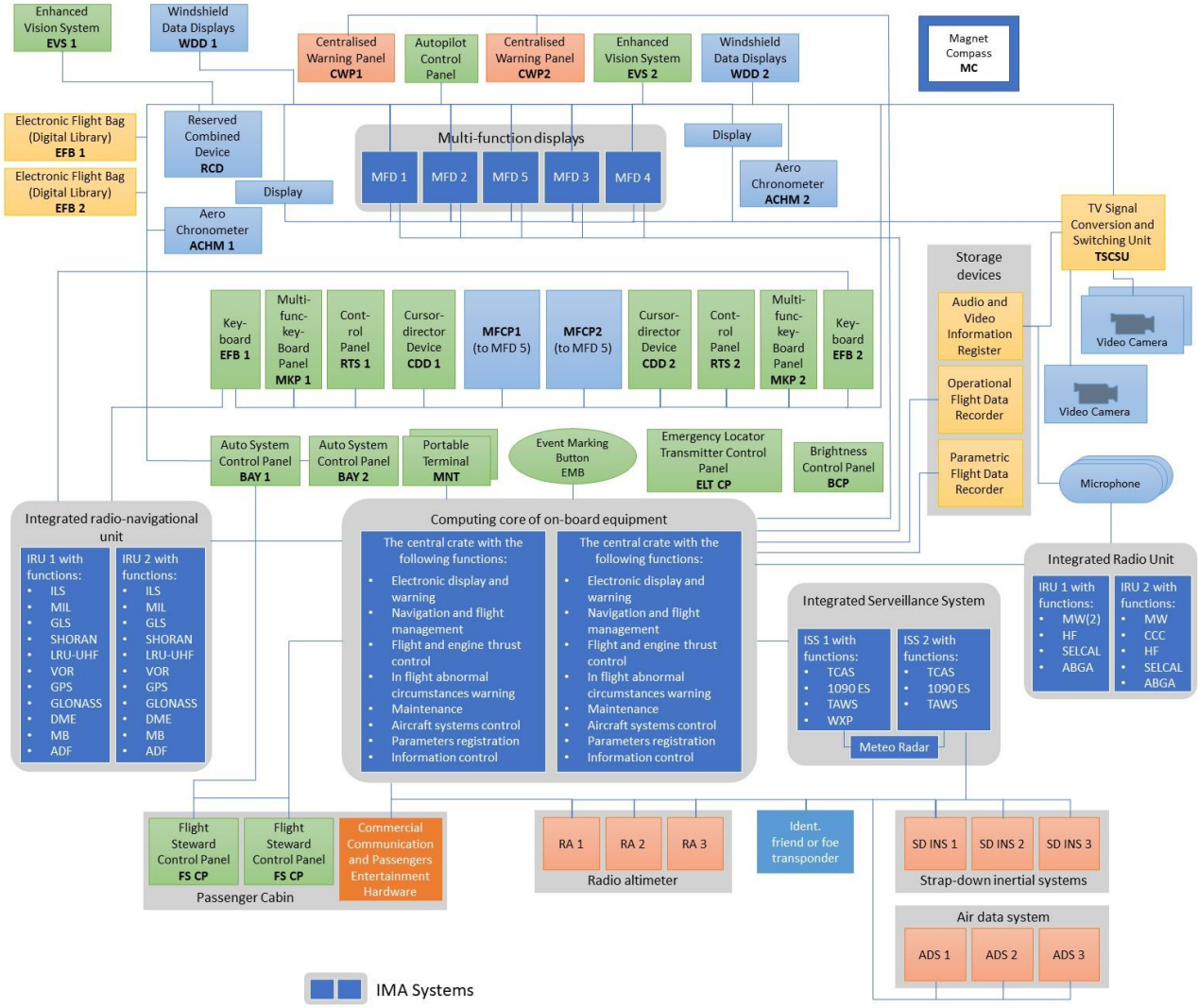
Both Honeywell and Raytheon (Collins Aerospace) will argue that their integrated cockpit offerings, as represented by Primus Epic/Apex and ProLine Fusion respectively, predate the adoption of IMA by OEM airframers.

Honeywell, Collins and Thales have all provided the market with a range of 'off the shelf' integrated cockpits that typically include displays, flight management, auto-pilot, navigation, surveillance and communication functions operating within a common computing framework.

These offerings, however, have not always adopted 'open architectures' that would allow 3rd parties to import additional utility functions (independently of the OEM).

However, this is now changing with the manufacturers of large civil aircraft forcing the adoption of 'open IMA architectures' that allow much greater flexibility and portability.

The block diagram below indicates what a modern commercial IMA architecture looks like with all of the avionics functions identified. We have highlighted those functions, be they avionic, cabin or utility, which are typically hosted and resident within the IMA computing infrastructure.



IMA architectures within military platforms derive many of the same benefits to civil applications in terms of common processing, input/output protocols and data-buses.

However, one of the main drivers within military platforms is the need to generate high speed fusion of data drawn from a number of disparate sensor systems. High performance military fighter aircraft operating within multiple threat environments are required to assess threats from land, sea or air and to take the necessary evasive action together with deployment of effective countermeasures.

The limiting factor in these scenarios can be the pilot in terms of data overload and reaction times.

The emphasis therefore from an IMA perspective is to be able to fuse the terabytes of data available from many sensors and to clearly annunciate to the pilot the available options (all within fractions of a second).

Platforms that have adopted IMA started with the Boeing 777 (Honeywell AIMS system) and include the F-22, F-35, A380, Boeing 787, A350 and A400M.

Bombardier's CSeries, now the Airbus A220, adopted Collins Pro-Line Fusion with open architecture IMA as its baseline.

Bombardier also adopted IMA for its range of Global business jets.

The Sukhoi 100 Superjet and the Comac C919 have also adopted IMA architectures.

We believe that the benefits of IMA are now well proven in service and that all 'next generation' commercial and military aircraft will adopt open IMA architectures as their baseline. The reducing cost of electronics will likely result in many of the smaller regional jets, business jets and military platforms also being in a position to adopt open IMA architectures.

Whilst major IMA/common computing providers (Honeywell, Raytheon, Thales, L3 Harris and GE Aviation) have established significant market share within the larger Aerospace & Defence sectors, the lower end of the market, in terms of platform size and value, is supported by the likes of Garmin and Universal Avionics.

The cost to develop and procure an IMA/common computing resource for these lower value platforms would be prohibitive and not justified.

However, avionics providers, such as Garmin, offer the G5000 integrated flight deck which, from a pilot's perspective, presents a seamless interface.

7.3. FLIGHT MANAGEMENT/GUIDANCE SYSTEMS

Flight Management Systems link to a number of related avionic systems in order to be able to execute satisfactorily. They require an interface with navigation systems, flight controls and the autopilot in addition, to be able to display progress with the chosen flightpath.

Over many decades of aviation development aircraft and pilots have been provided with many aids designed to assist navigation, which is described more fully in the next section.

The FMS is a specialised computer system that automates a wide variety of in-flight tasks, reducing the workload on the flight crew to the point that modern civilian aircraft no longer carry flight engineers or navigators. A primary function is in-flight management of the flight plan. Using various sensors (such as GPS and INS often backed up by radio navigation) to determine the aircraft's position, the FMS can guide the aircraft along according to the flight plan. From the cockpit, the FMS is normally controlled through a Multi-Function or Master Control Display Unit (MCDU) which incorporates a small screen and keyboard or touchscreen. The FMS sends the flight plan for display to the Electronic Flight Instrument System (EFIS), Navigation Display (ND), or Multifunction Display (MFD).

Most FMS systems contain a navigation database. The navigation database contains the elements from which the flight plan is constructed. The navigation database (NDB) is normally updated every 28 days, in order to ensure that its contents are current. Geographies can change, cities grow, skyscrapers get built etc., all of which needs to be captured within the NDB on a periodic basis.

There are a number of NDB service providers including Boeing (Jeppesen), Honeywell, GE Aviation and NAVBLUE (Airbus subsidiary) who basically provide a subscription service for various NDB services.

These NDB services can extend to include FMS software for simulators and databases for Electronic Flight Bags (EFB). The EFB is essentially a pilot's 'bag' of navigation charts, preferred routes, airport data that today is all hosted on an iPad or laptop PC.

Whilst the FMS is configured to fly the optimum flightpath consistent with airline cost and performance metrics, the airline can programme a range of preferred routes via the FMS/NDB system.

NDB providers are licenced and can only offer services if approved by the relevant authority e.g., FAA, CAA, EASA, US Air Force.

In operation the FMS 'initiates' a position derived from the various external navigation aids (VOR, DME, GPS) which it 'blends' with the on-board Inertial Reference System (IRS) which in itself is often triplicated on modern airliners.

Once an initial position has been established the flight can commence based upon achieving a successive number of 'waypoints' that, taken together, constitute the overall flight journey.

This flight path will typically be displayed upon the cockpit Navigation Display in order that the flight crew can monitor progress.

The Autopilot can be selected to execute the FMS flight path via commands to the engine throttles and the flight guidance or flight control computers.

FMS systems were first made available on the Boeing 767 (although navigation computers preceded this) followed by the Boeing 737. Airbus also has a long tradition with FMS, having offered it on its early A300/A310 aircraft and all subsequent platforms.

Airlines/pilots spend considerable amounts of time and money training with FMS systems in flight simulators. As a result of personal experience, issues with cross training and historic preferences, it is not unusual for an airframe constructor to offer more than one FMS option on a given platform. Airbus for example offers airlines/operators both the Thales/GE Aviation FMS and the Honeywell FMS systems on the A320 and A330 family of aircraft.

Military fighters do not typically have an FMS system as they are high performance platforms controlled by the pilots and need to be able to react to their environment.

Military transport aircraft on the other hand do rely upon FMS systems as they have a more predictable mission, and they need to have the navaids on board that allow them to fly in highly regulated civil air space.

7.4. NAVIGATION

In addition to basic on-board aircraft instruments (altitude, airspeed, attitude, compass), ground-based systems have also been developed to support take-off and landing. These include Instrument Landing Systems (ILS), Direction Measuring Equipment (DME), VHF Omni-directional Radar (VOR), Automatic Direction Finder (ADF).

For navigation of the aircraft between waypoints/airports, on-board navigation systems have typically consisted of Inertial Navigation Systems (INS) or Inertial Reference Systems (IRS) and, more recently, Global Positioning Systems (GPS). The latter is clearly dependent upon access to a network of satellite-based GPS signals which need to be received by the aircraft.

GPS systems are only accurate to about 15m – 30m which is not adequate for aircraft landing or traffic avoidance purposes. There are a number of regional 'enhanced' GPS services including WAAS (US), EGNOS (EU) and GLONASS (Russia) all of which provide improved positional accuracy data.

Most of the current FMS systems noted above will draw upon these services for more accurate position data.

In the 1980s the International Civil Aviation Organisation (ICAO) established the special committee on the Future Air Navigation System (FANS), charged with developing the operational concepts for the future of air traffic management (ATM). The FANS report laid the basis for the industry's future strategy for ATM through digital CNS using GPS satellites and air/ground data links.

In the 1990s Boeing announced a FANS-1 product based on the early ICAO technical work for automatic dependent surveillance (ADS) and air traffic controller - pilot data link communications (CPDLC), which it implemented in the Boeing 747-400. It used existing satellite-based ACARS communications (Inmarsat Data-2 service) and was targeted at operations in the South Pacific Oceanic region. The deployment of FANS-1 was originally justified by improving route choice and thereby reducing fuel burn.

FANS-A was later developed by Airbus for the A340 and A330. Boeing also extended the range of aircraft supported to include the Boeing 777 and 767. Together, the two products are collectively known as FANS-1/A.

Both the Airbus A350 and Boeing 787 have FANS-1/A capability.

The software associated with FANS capabilities is typically located within the aircrafts FMS system.

Significant navigation improvements have involved a transition from inertial navigation to satellite navigation using the GPS satellites. This introduces the concept of actual navigation performance (ANP). Previously, flight crews would be notified of the system being used to calculate the position (radios, or inertial systems alone). Because of the deterministic nature of the GPS satellites (constellation geometry), the navigation systems can calculate the worst-case error based on the number of satellites tuned and the

geometry of those satellites. The improvement not only provides the airplane with a much more accurate position, it also provides an alert to the flight crew should the actual navigation performance not satisfy the required navigation performance (RNP).

Airline operators need to have their FANS 1/A capable aircraft connected to both the ATN (Aeronautical Telecommunication Network) and to the Iridium and/or Inmarsat Satellite network for which there is a periodic service charge.

AirSatOne provide advanced FANS 1/A services through their Flight Deck Connect portfolio of products. Flight Deck Connect includes a connection to the Iridium and/or Inmarsat satellites for FANS 1/A (via Datalink), and Safety Voice Services, along with ancillary services (AFIS/ACARS) such as weather information, engine/airframe health and fault reports.

The avionics retrofit market has been boosted significantly by the need to make operators fleet of aircraft 'FANS compliant' in order to be able to fly the best, most economic routes.

The FANS modification package typically consists of the following systems:

- Flight Management System software upgrade package
- GPS (Global Positioning System)
- SATCOM (satellite communications)
- ACARS/Data Link (Aircraft Communication And Reporting System)
- EFIS (Electronic Flight Instrument System) display

Military aircraft need to be more 'autonomous' when it comes to navigation and minimise external links, however, all modern military platforms use GPS as a primary means of navigation.

They also have the same basic navigation tools, when compared to civil aircraft, such as IRS, radar altimeters, DME, ILS etc.

A distinct requirement for many military platforms is the requirement for low level flying at ground hugging altitudes. In this situation it is likely that the aircraft will be fitted with a Terrain Mapping database such as that provided by BAE Systems or Raytheon (commonly referred to as TERPROM) which is linked to the aircraft navigation and flight control system.

Even large military platforms such as the A400M can have a low altitude ground navigation capability as required for the German partners in the programme.

7.5. AUTO-PILOT

The first autopilot was designed by Sperry Corporation in 1914 and successfully demonstrated at a Paris Airshow by the pilot taking his hands off the control wheel and flying flat and level.

Honeywell developed a number of autopilots during WWII largely in order to reduce pilot workload.

Small aircraft (<20 seats) for short haul flights do not require an autopilot but all larger passenger aircraft are required by regulatory authorities to have one fitted.

Auto-pilots can either be one-axis (roll control or wing levellers), two axis (pitch as well as roll) or three-axis devices (pitch, roll and yaw).

Autopilots divide a flight into taxi, take-off, climb, cruise (level flight), descent, approach, and landing phases. Autopilots can automate all of these flight phases except taxi and take-off. An autopilot landing on a runway and controlling the aircraft on rollout (i.e., keeping it on the centre of the runway) is known as a CAT IIIB landing or Auto-land. This CAT IIIB facility is available on many major airports' runways today, especially at airports subject to adverse weather phenomena such as fog.

Current A/Ps (often referred to as 'George') can typically fly 80% or 90% of a long-haul route allowing the crew to focus upon route planning, EICAS messages, communications with ATC, surveillance etc.

There is a distinct difference between A/P and A/T which is simply explained as the A/P controls the flight controls for pitch, attitude etc whereas the A/T control engine for thrust. Most A/Ps can be selected in either

"thrust" mode or "speed" mode and both have their differing uses dependent upon whether the aircraft is in take-off (thrust) mode or in cruise mode (speed). In modern aircraft both A/P and A/T are effectively controlled by the FMS and link to the engines via the FADEC.

Older aircraft had a separate A/T and/or A/P avionics box but modern aircraft have the software algorithms built into the FMS with links to the Flight Control System and the engine FADECs.

Servo-motors are installed within the pilot's thrust control stand in order to control the required thrust via the thrust lever position.

Smiths (now GE Aviation), Rockwell Collins (now Collins Aerospace and part of Raytheon) and Sextant Avionique (now Thales) have all developed A/Ps in recent decades. Companies serving other than large commercial aircraft with A/P offerings include Garmin, Safran, Cobham and Universal Avionics.

7.6. DISPLAYS

A key Avionic interface for flight crew is the set of cockpit displays that annunciate all the relevant flight data necessary to execute the mission.

These displays have evolved over many decades from 'steam driven' barometric instruments (all mechanical) through cathode ray tubes to flat panel LCD devices found today in modern aircraft.

Basic flight displays found in the earliest of flying machines, such as indicators for airspeed, altitude, attitude, heading, chronometer, have now been superseded by a whole host of large format colour display data that, being flexible in terms of format, can include a multitude of permutations.

Interestingly, having worked in the industry the author has seen the 3 ATI, 4 ATI and 5 ATI standard display format (effectively 3 ATI = a 3 inch display) increase to today's large format colour displays that typically measure 10 by 15 and are replicated in 5 or 6 positions. This alone is equivalent to a 500%+ increase in cockpit display real estate!

It is not surprising that OEMs, Avionics designers and aircraft operators have been concerned at pilot overload.

The science of display formatting, often referred to as the man/machine interface, has been adopted by aircraft designers in order to avoid 'pilot overload'. Most modern Multi-function Displays can be switched to provide additional/alternative formats thereby further increasing available displayed data.

Having Multi-function displays can be a necessity in order to provide redundancy within the overall display suite in the case of a single display failure.

Modern display architectures require the consolidation of considerable amounts of mission-related data derived from multiple aircraft systems but in a common data format. This formatted data can then be used to generate symbols or graphics that can be used to drive the LED displays. Typically, therefore modern Avionic display suites include both data concentrators and graphics generators.

There is no such thing as a standard cockpit layout for display suites. However, most include a combination of the following:

- Primary Navigation Display(s) – used to show basic aircraft navigation metrics such as attitude, airspeed, altitude, heading, route, aircraft position and can be overlaid with surveillance data such as weather radar, traffic etc.
- Multi-Function Display – as above but can add or switch to provide charts, video (airport taxiing), system synoptics and health status, TCAS, WXR, EPGWS etc.
- EICAS – the Engine Indicating and Crew Alerting System display shows the status of engine thrust and other engine related parameters such as fuel status – usually a split screen to allow for both engine parameters and crew alerting prompts, system failures etc.
- ACARS – Aircraft Crew Alerting and Reporting System – not usually a stand-alone display but incorporated within an MFD noted above.

- ECAM – Electronic Centralised Aircraft Maintenance – not usually a stand-alone display but incorporated within a MFD noted above.
- Multi-function Control Display Unit (MCDU or CDU) usually provides the crew input for the FMS system e.g., route planning, alternatives etc.
- Integrated Standby Instrument – an independent back-up that, in the event of loss of primary displays, allows basic attitude, altitude and airspeed data to be generated and displayed independently.
- Mission displays (military aircraft) – these can include a multitude of options depending upon the role of the military platform including maps, charts, reconnaissance, synthetic vision for poor visibility, navigation and on-board sensor status.
- Head Up Displays (HUDS) – originally designed for military use whereby the pilot is not distracted by the suite of Head Down Displays (HDD) - they are now also being adopted on commercial aircraft in order to enhance situational awareness.
- Helmet mounted displays – almost exclusively utilised in the military field these displays have the advantage of maintaining key data in the pilot's peripheral field of vision irrespective of where his head is facing.
- Minor displays – can include radar altimeters, clocks, vertical speed indicators, pitch indicators (nose up attitude), fuel gauges, radio tuning channels etc.

A significant factor to consider is that the useful life of an airframe which can be 40, 50 or 60 years whereas the useful life of a display suite may be 10, 12 or 15 years. This results in a considerable aftermarket for retrofits and upgrades.

The main drivers for avionics display upgrades are noted within the commentary below. However, there is also a wealth of other drivers including regulatory (mandated) improvements, pilot influence, fleet commonality, cross training issues (between platforms within an operating fleet), cost of ownership, to name but a few.

A recent Avionics survey of end-users resulted in the following statement that "40 percent of our readers are looking to acquire new cockpit displays for their current fleet of aircraft, proving that new cockpit display system technology enjoys a healthy demand for retrofitting purposes. The overwhelming majority — nearly 80 percent of our readers — say that reliability is their top concern when looking to replace their current displays, while another 44 percent of respondents point to size as their primary focus when upgrading. Additionally, 41 percent of readers want LCD technology, whereas 35 percent are looking to display information about nearby air traffic in their cockpit."

7.7. SURVEILLANCE

Surveillance is arguably a subset of a number of Avionic functions including navigation, sensors and displays. However, its overall prominence has grown within both the civil and military arenas in the last couple of decades.

For civil aircraft it is known that 90%+ of accidents relate to the take-off and landing phases of any flight. Subsequent analysis of these events has shown that a lack of 'situational awareness' by the crew was often a key contributory factor (controlled flight into terrain, mid-air collisions, missed runways, aborted landings/go arounds, 'near misses' etc).

As part of the Future air Navigation (FANs) requirements it was deemed not appropriate to increase the burden on Air Traffic Controllers (ATC) with additional controls and monitoring, but instead to implement a system of 'autonomy' for each and every aircraft licenced to use congested airports.

This 'autonomy' is enabled by a proliferation of independent surveillance aids such as Traffic Collision Advisory Services, Enhanced Ground Proximity Warning Systems and Weather Radar.

In early 2000s the FAA mandated the adoption of Automatic Dependent Surveillance-Broadcast (ADS-B) as a primary technology supporting the FAA's Next Generation Air Transportation System, or NextGen. This initiative essentially shifts aircraft separation and air traffic control from ground-based radar to satellite-derived positions. Many countries have since adopted the same standards for ADS-B capability.

The ADS-B system adoption allows aircraft to be aware of each other's respective position which can be displayed on a TCAS system. Equally the aircraft can message each other via this link. It also can be used to maintain separation minima between aircraft in congested airspace.

A further protocol, known as ADS-A, is based on a one-to-one relationship between an aircraft providing ADS information and a ground facility requiring receipt of ADS messages. For example, ADS-A reports are employed in the Future Air Navigation System (FANS) using the Aircraft Communications Addressing and Reporting System (ACARS) as the communication protocol. During flight over areas without radar coverage, e.g., oceanic and polar, reports are periodically sent by an aircraft to the controlling air traffic region.

Controlled flight into terrain (CFIT) is a further major issue surrounding situational awareness that has resulted in the generation and adoption of a number of Avionic solutions including Ground Proximity Warning Systems (GPWS), Enhanced Ground Proximity Warning Systems (EGPWS) and Terrain Awareness Systems (TAWS).

TAWS is a system meant to forecast potential danger in the aircraft's path and terrain. There are warnings systems and alerts to provide caution to the flight crew of potential danger, thereby allowing them to have sufficient time to make the necessary changes to the flight path to avoid collision.

GPWS is similar to TAWS. However, it has a number of 'modes' typically one through to five which are used to determine ever increasing levels of threat and response times required. In the 1990s Honeywell developed EGPWS which has a more refined approach to steeply rising ground for example.

These systems use topographical data to 'map' the terrain and these databases need regular updating. One famous anecdote relates to Honeywell, when flight testing EGPWS, they came across one mountain that was 1000 ft higher than that registered within the database!

Military aircraft typically have need of high performance surveillance systems that need to respond in milliseconds by identifying threats as represented by other aircraft, missiles, or enemy detection systems.

Military missions often call for very low altitude approaches in order to avoid detection. These can only be achieved if the aircraft has a precise terrain database, e.g. TERPROM, and the means by which the profile can be tracked via highly responsive primary flight controls.

A typical modern multi-role fighter such as the F-35 will likely be equipped with the following sensors which are utilised as part of its overall 'surveillance' capabilities:

- Distributed Aperture System (electro-optical) – 6 off providing 360 degree all round view of incoming threats.
- High power AESA radar system that can 'look beyond the horizon'
- Electro-optical targeting system (Forward Looking Infra-red Radar (FLIR), Infra-Red Search and Track (IRST))
- Identification Friend or Foe (IFF) Radio Frequency and microwave transmitters.
- Electro-optical targeting system

Military transport aircraft will have many of the surveillance systems fitted as described for commercial aircraft above.

7.8. COMMUNICATIONS

Aircraft communications are being expanded; in fact, in recent years a new abbreviation has surfaced. CNS ATM stands for "Communication, Navigation, and Surveillance and Air Traffic Management" which was created to support modernisation of the dated and overload-prone Air Traffic Control system.

Traditionally radios have formed the communications means between aircraft and ATC. These radios operate over VHF and HF channels ensuring, where possible, clarity and adequate levels of security.

The allocation of radio spectrum is defined by the International Telecommunications Union (ITU) and relates the use of a frequency to a specific service. The ITU has assigned frequencies for use by aircraft analogue voice dialogue in parts of the 'High Frequency' (3-30 MHz) band and in the 118-137 MHz section of the wider 'Very High Frequency' range. Aircraft can use radios operating in the HF radio band for long-range

communications as the signals are reflected by the ionosphere. Unfortunately, when using HF, the link audio quality is very poor due to this long propagation of the wave. Aircraft can use radios operating in the VHF band to communicate with other radios in line-of-sight coverage. These signals do not reflect off the ionosphere or penetrate obstacles such as mountains or buildings. The advantage of VHF over HF is that the link quality is much better and there is greater reuse of the frequency channel.

Within the past two decades there has been a move to transmit both voice and data via satellites. The move to data provides for higher reliability and integrity given the potential for miscommunication and misunderstanding with analogue voice transmissions.

The addition of data link capability to HF radio is a way for aircraft operators to get additional use out of the radios they still carry in order to meet ATC rules when most communications migrate from voice to data. However, the HFDL system provides delivery of 95% of transmitted messages in three to four minutes compared to 20 to 30 seconds via satellite communications - so it is likely to be limited to providing a safety net in case of failure of satellite avionics, rather than a good alternative to satellite communications.

In the period through the 1980s and 90s ACARS (Aircraft Communications Addressing and Reporting System) was adopted as a digital datalink system for transmission of short messages between aircraft and ground stations via air-band radio or satellite.

ACARS as a term refers to the complete air and ground system, consisting of equipment on board, equipment on the ground, and a service provider.

ACARS interfaces with flight management systems (FMS), acting as the communication system for flight plans and weather information to be sent from the ground to the FMS. This enables the airline to update the FMS while in flight and allows the flight crew to evaluate new weather conditions or alternative flight plans.

UAVs and Urban Unmanned Aircraft will not rely upon communications in traditional terms but there will still be the need for interrogation between ground control and the vehicle.

7.9. MISSION SYSTEMS

Purists may argue that military mission systems are largely distinct from avionics in general. However, we have included this sub-set as we see a number of drivers for convergence between avionics and mission systems as follows:

- Common computing resources with open architectures providing a path for affordability (COTS), upgrades, and inter-operability in both civil and military arenas.
- High speed data fusion from many sensor sources that require computations in real time.
- 'Commercial Off-The-Shelf' (COTS) developments common to both civil and military mission functions.

A military avionics system is generally divided into 5 distinct sub-systems: Navigation, Communications, Sensors, Mission Systems and Displays/Controls.

In constructing this report, we have elected to deal with both and Mission Systems and Sensors, as they relate to military platform Avionics, given that the other three categories noted above are common to both civil and military platforms and have been described earlier in this report.

We have adopted the definition of 'Mission Systems' as it relates to military platforms to typically include a number of functions or sub-systems as follows:

- Stores management
  - Weapons, payload, auxiliary fuel tanks, external pods
- Specific platform roles
  - Search and rescue
  - Transport (troops, equipment)
  - Maritime patrol
  - In-flight refuelling
  - Electronic Warfare/Electronic Counter Measures

- C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance)
- ISTAR (Intelligence, Surveillance, Target Acquisition and Reconnaissance)

Unlike commercial aircraft that have a narrow range of mission objectives (transporting people and cargo from A to B) there exists a much wider range of 'mission' functions within the military arena as noted above.

Aircraft are often dedicated to specific military missions such as Maritime Patrol (P-8A, P-3C, Atlantique 2), AEW (AWACS, EMB145 AEW), AGS (JSTARS, ASTOR). These platforms are likely to have ISTAR related mission avionics including, data gathering, data fusion, communications through SATCOM or dedicated data links (encrypted or not), tactical situational awareness, and all the supporting sensors whether it be on manned or unmanned platforms.

Military transport/payload platforms such as C-130J, C-5 Galaxy, A400M and the KC-390 will have similar 'mission avionics' to those found on civil air transport aircraft because they are both manned and they fly in civil arenas. However, these platforms will often have augmented avionics to allow for threat detection, electronic countermeasures and low altitude flying capability.

Air strike platforms, such as the F-35, will have very high-speed/high-capacity data networks to allow for both the significant amounts of data, the need for data fusion between sensors and the very high speed reaction times required to negate threats and/or exploit strike targets. The F-35 features a new 1394B serial data bus with three high-speed processors that provide the aircraft with a robust, triple-redundant mission systems management network.

Rotorcraft can cover a wide variety of mission roles including search and rescue, fire-fighting, troop carrier, gunship, medevac, border patrol and cargo/payload.

The CH-47F (Chinook), for example, is an advanced multi-mission helicopter and as such contains a fully integrated, digital cockpit management system, Common Avionics Architecture System (CAAS) Cockpit and advanced cargo-handling capabilities. However, it can be utilised as part of land, sea and air operations and it has sold extensively throughout the world to many nations.

As with many military platforms that are multi-mission and/or multi-nation (e.g., CH-47K, C-130J, A400M, F-35, Typhoon, F-18, Apache AH-64) the core platform needs to be highly adaptable and this in turn requires flexible avionic architectures that can accommodate a number of diverse mission computing functions.

Hence the Open Mission Systems (OMS) initiative of the U.S. Air Force Research Laboratory "to develop industry consensus for a non-proprietary mission system architectural standard that enables affordable technical refresh and insertion, simplified mission systems integration, service reuse and interoperability, and competition across the life-cycle", focusing on the interfaces between software services and hardware subsystems, and how data is exchanged across them.

This is but one of a number of initiatives within Europe and the US to reduce costs and improve flexibility, upgrade paths, interoperability and reduce overall life cycle costs within mission computing.

A good example of a COTS approach to Mission computing was undertaken by Thales when, in 2018, they were seeking a commercial off-the-shelf (COTS) open-architecture computer for use with the company's new Elix-IR Next Generation Threat Warning System. They selected a Packaged COTS (PCOTS) pre-integrated, rugged mission computer from Curtiss-Wright's Defense Solutions division. Elix-IR is an airborne multifunction passive infrared (IR) threat warning system designed to provide enhanced mission survivability. Under the contract, Curtiss-Wright will provide Thales with a custom PCOTS rugged mission computer that combines Curtiss-Wright 3U OpenVPX single-board computers, two FPGA cards, and switches housed in a rugged chassis.

Section 14.1 of this report also looks at the positive impact that Commercial Off the Shelf (COTS) avionics is having upon the affordability of military mission equipment.

7.10. SENSOR SYSTEMS

In terms of Avionics Counterpoint has not set out to analyse avionics-related sensors in great depth in this report. However, we do recognise the significant reliance that the success of overall Avionics architectures has upon their associated sensor suite in many of the Avionics sub-systems.

We have also only given consideration to on-board sensors and not included ground-based sensors.

The following is a summary of the Avionics sub-systems and their associated sensors found in civil and military aircraft.

Avionics sub-system	Onboard Sensors	Comments
Navigation	Air data (pressure, temp)	Pitot static/Total Air Temp/Angle of Attack sensors – feed into Air Data Modules.
Inertial Reference Systems	Accelerometers Gyroscopes	Fibre optic gyro (3 axis required) Ring laser gyros Solid state gyros
Radio comms	Antennas, transceivers	Radio navigation DME/VHF/HF/VOR/LOC/ADF/SATCOM/GPS/ATC /TCAS (23 on a Boeing 787), TACAN
Surveillance	Multi-Mode Receivers, Radar FLIR, ATC/TCAS, WX Transponders	Used for TCAS, EGPWS, TERPROM, Weather Mapping. ADS-B autonomy
Flight Management Systems	NAV and IRS related sensors.	GPS, WAAS, GLONASS etc provided externally.
Mission related sensor systems	Wide array radar Distributed Aperture System Electro-optical target acquisition Forward Looking Infra-red (FLIR) Enhanced Vision Systems Multi-Colour Infrared Alerting Sensor Infra-red frequency detectors	Active electronically scanned radar (AESA) Infra-red cameras (6 on F-35) FLIR combined with Infra-red Search and Track (IRST) Cameras and video, synthetic display systems Used on A400M Defensive Aids

Sensors are subject to the same SWAP (Size, Weight and Performance) drivers as is the case with Avionics generally.

Evidence for this is shown with the F-35 platform where, only 8 years into service, all mission related onboard sensors either have been or are currently undergoing upgrade to next generation sensors.

Within the civil arena a similar pattern of sensor upgrades exists every 10 to 15 years often driven by regularity changes. These include:

- reduced vertical separation minima (RVSM) – 2,000 ft to 1,000ft
- TCAS mandates in EU/US – transponder equipped.
- Automatic dependence surveillance (ADS-B) – TCAS, ATC monitoring
- FANS/NEXT GEN navigation – controller/pilot data link communications, GPS navigation

Airlines/operators will upgrade avionics sensors to provide more efficient operations and thereby save fuel (e.g., MMRs for provision of GPS navigation).

7.11. DATA/DATA NETWORKS

We have elected to include data/data networks within this report as they represent a key part of the infrastructure without which Avionics could not function.

There are two distinct parts to this section which are as follows:

- Avionics data networks
- Avionics data products/services

7.11.1. Avionic data networks

Modern avionics are required to communicate data between the following areas of flight operations:

- related avionics functions (e.g., Communications, Navigation, Surveillance)
- related utility systems (e.g., Flight control, Fuel systems)
- other aircraft within certain ranges (e.g., ADS-B, TCAS)
- ground based air traffic control (FANS, Next Gen)
- ground based data services for monitoring, maintenance and support most modern civil aircraft have an onboard OMS with real time data downlink capability).

Within the aircraft itself the onboard data networks have evolved over many decades since the adoption of electronics. The number of data network protocols have increased over time to reflect the needs for higher speeds, higher bandwidth, new technologies (e.g., IMA, shared computing resources), data downlinks to ground based services etc.

Below is a list of the more common avionics databus protocols, with their primary applications, which include:

- Aircraft Data Network (ADN): Ethernet derivative for Commercial Aircraft
- Avionics Full-Duplex Switched Ethernet (AFDX): Specific implementation of ARINC 664 (ADN) for Commercial Aircraft e.g., Airbus A350.
- ACARS (an ARINC service) a digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite.
- ARINC 429: Generic Medium-Speed Data Sharing for Private and Commercial Aircraft. ARINC 429 is the most widely used data bus standard for aviation. The bus is capable of operating at a speed of 100 kbit/s.
- ARINC 664: defines the use of a deterministic Ethernet network as an avionic databus in aircraft like the Airbus A380, the Sukhoi Superjet 100, the A220 (formerly Bombardier CSeries), and the Boeing 787.
- ARINC 615 is a family of standards covering 'data loading', commonly used for transferring software and data to or from avionics devices. The ARINC 615 standard covers 'data loading' over ARINC 429.
- ARINC 629: Commercial Aircraft (Boeing 777). Up to 120 terminals can share the databus.
- ARINC 653 is a standard Real Time Operating System (RTOS) interface for partitioning of computer resources in the time and space domains. This standard will be found in common computing resources and IMA architectures.
- ARINC 708: Weather Radar for Commercial Aircraft
- ARINC 717: Flight Data Recorder for Commercial Aircraft
- ARINC 702A-4, a standard defining the advanced Flight Management Computer (FMC) system, was updated to add winds temperature definitions as required to support 4D trajectory operations in NextGen and Single European Sky airspace environments.
- ARINC 825: CAN bus for commercial aircraft (for example Boeing 787 and Airbus A350)
- IEEE 1394b: Military Aircraft
- MIL-STD-1553: Military Aircraft. A military standard published by the United States Department of Defense that defines the mechanical, electrical, and functional characteristics of a serial data bus.
- MIL-STD-1760: Military Aircraft. Stores Electrical Interconnection System defines a standardised electrical interface between a military aircraft and its carriage stores. High-Speed 1760 specifies a gigabit-speed interface based on Fibre Channel, operating at 1.0625 Gbit/s.
- TTP – Time-Triggered Protocol: Boeing 787, Airbus A380, Fly-By-Wire Actuation Platforms from Parker Aerospace.

It is worth noting that Aeronautical Radio Incorporated (ARINC) was founded in 1929 in order to help promote radio standards across a number of industries including Aerospace. It was acquired by Rockwell

Collins in 2013. However, it continues to service the industry at large with new protocols driven by emerging technologies.

The ARINC Standards are prepared by the Airlines Electronic Engineering Committee (AEEC) where aviation suppliers such as Collins Aerospace and GE Aviation serve as contributors in support of their airline customer base.

Some of these ARINC standards are clearly geared to support Airline operations. ARINC 702A-4 according to Arinc "will enable airlines to meet Required Time of Arrival (RTA) accuracy requirements and in particular, arrival at metering point with an accuracy of ±10 seconds. This update provides a significant improvement to the accuracy of the aircraft trajectory and it will reduce airline fuel consumption"

What does these tera-bytes of data and real time data access mean to the avionics market?

Many of the leading Avionics service providers have worked with this data in order to arrive at various services designed to 'add value' to airlines and operators. A number of these commercial data service offerings, available via monthly subscription, are described as follows:

- Collins Aerospace - **ARINCDirect Solution** – Flight planning and Weather – allows pilots to be provided with tailor made flight plans at point of departure on laptops, mobile phones or iPads. The service is intended to allow pilots to fly optimised routes allowing for traffic, weather, local ATC rules, company practices etc.
- Honeywell's **GoDirect™ Flight Bag Pro** – available as an app to pilots/flight crew, via the electronic flight bag, the subscription service allows for optimised route flight planning based upon live data in real time – it can be updated en-route to allow for changes in traffic, weather etc.
- GE Aviation promotes its **Air Mobility Platform** service that is focused upon operators of UAVs/UTMs. The Air Mobility Platform is deployed on Amazon Web Services (AWS) GovCloud to support compliance to federal requirements. It combines Unmanned Aerial Service Supplier (USS) capabilities and compliance with CAA and ANSP rules and regulations, that provide for scalable, repeatable, and economically viable advanced UAS operations.
- Thales **FlytLINK** - FlytLINK operates using Iridium Certus broadband services over a network of 66 satellites that cover 100% of the globe, including poles and oceans. FlytLINK utilises this network to provide, mobile and essential voice, text and data communications for pilots, crews and business passengers.

Counterpoint sees the market for 'data service' offerings as one of significant growth given both the enabling infrastructure around data networks, real time air to ground communication links and the demand for real time inflight services.

7.11.2. Avionic data products

Stand-alone data products have increased in recent years in part due to the growth in infrastructure described in the previous section.

Key elements such as Cockpit Voice Recorders and Flight Data Recorders have long been mandated for civil and military aircraft in order to be able to survive a major incident (unintended landing). These devices are used post-incident to provide clear evidence of events leading up to the incident. They can more often be used to help to provide evidence as to the causes of the incident.

These data products include the following by way of examples:

- Cockpit voice recorders (CVR - post flight incident analysis)
- Flight data recorders (FDR - post flight incident analysis)
- Combined voice and data recorders.
- Data acquisition units (for downloading and/or post flight analysis)
- Data Management Units (often used to consolidate data required for MFD/NDs)
- Data concentrators (often used in conjunction with IMA architectures)
- Datalink transmitters/receivers (e.g., ACARS)
- Portable data loggers (removing data from aircraft).

Most of today's recorders are designed around solid-state electronics replacing older analogue and tape-based recorders.

A switch to solid-state architectures has allowed for a significant increase in memory capacity and high speed ethernet protocols. This together with the necessary datalink technology offered via broadband services and satellite communication allows operators to exchange data throughout the flight.

Service providers such as SwiftBroadband, an IP-based packet-switched communications network, offers a symmetric 'always-on' data connection of up to 650 kbit/s two per channel for aircraft globally except for the polar regions, using the Inmarsat satellite constellation.

The increased market demand for such in-flight services has seen the following companies all offering Swiftband-style based services:

- Cobham Antenna Systems (Chelton Satcom)
- Cobham Satcom (avionics and antennas)
- CMC (antennas)
- EMS Technologies (avionics and antennas)
- Honeywell (avionics)
- Collins Aerospace (avionics)
- TECOM Industries (antennas)
- Thales (avionics)
- Thrane & Thrane (avionics)

However, one of the significant 'threats' surrounding this increased data transmission environment is that posed by cyberspace attack. Historically much of the data that is transmitted in the civil arena is unencrypted and therefore exposed to violation or alteration by unlawful groups, terrorist action etc.

Within a more connected world that utilises satellite communications extensively, the cyber-related risks have increased exponentially in recent years.

This is no longer the case within a more connected world that utilises satellite communications extensively – the cyber-related risks have all increased exponentially in recent years.

Data transmitted via satellite internet service providers, the aircraft's onboard ADS-B transponder (a/c identification, speed, altitude, GPS position etc) and the ACARS messaging system are mostly unencrypted and there is therefore a threat in terms of nefarious intentions by 3rd parties.

All major providers of avionics have adopted various cyber security processes to minimise the risk of hacking, provide secure data exchanges and continually assess the presence of threats.

In 2007, Arinc released the ARINC 823 protocol which governs the encryption of ACARS data transmissions. However, the degree to which this has been widely implemented within avionics product offerings is not clear.

The military has long engaged in developing encryption techniques for all sensitive areas of their platform avionics. Most, if not all, modern military platforms have data encryption techniques embedded within their equipment.

Currently 'military grade' encryption is generally applied to products that utilise AES-256 encryption standards.

With the exception of mandated cockpit voice and flight data devices it remains to be seen if there will be a continued need for 'discrete' stand-alone data devices. Much of the data infrastructure is around high-speed transmission, data fusion, cloud storage devices and download/upload capabilities – data related discrete boxes will be harder to justify within common computing/IMA avionics architectures.

8. AN OVERVIEW BY MARKET SUB-SECTOR

8.1. CIVIL AIR TRANSPORT

This section is intended to provide an overview of the role that avionics play within the sector. We have defined the civil sector as including larger air transport platforms from 70 seats upwards which includes most regional jets and larger turboprops.

Airlines adopt their own strategy within the marketplace, but the common factors include:

1. Safety
2. Reliability
3. On time departures and arrivals
4. Economics in terms of Direct Operating Costs
5. Asset Utilisation (useful hours of service per day/per year)
6. Passenger experience (IFE, business services, smooth flight etc).

Low-cost carriers are typically focussed upon 4 and 5 as they need a combination of low cost and maximum asset utilisation.

Long haul international carriers are more likely focussed upon 2 and 6.

1. - Safety should be common to all operators.

As a key contributor to the various key performance metrics noted above avionics has a significant role to play. Clearly gas turbine engine efficiencies and the airframe aerodynamics play by far the biggest part in an aircraft's overall economics. However, if the aircraft is unable to fly optimum routes or is regularly diverted due to a lack of the latest avionic technology, then the overall aircraft economic performance is compromised, as is its ability to arrive at the scheduled time.

Many of the FAA/CAA/EASA regulations for aircraft flying within regulated aerospace apply to civil aircraft with 20 – 30 seats or more. These regulatory conditions often apply to the performance of Communications, Navigation and Surveillance (CNS) avionic equipment.

Aircraft deemed to be FANS/Next Gen compliant are required to have Navigation systems that are accurate to within 0.1 nautical mile or better.

Aircraft need to have recognised 'autonomy' capability in terms of TCAS and an associated ADS-B compliant transponder for GPS position signals and aircraft messaging.

The major incentive to adopt and maintain these regulatory changes is to be able to fly more direct economic routes as permitted by ATC.

The author recalls, in the early days of FMS and FANS operations, working with Alaska Airlines to develop a 'direct' approach into Junneau airport (steep terrain, difficult approach). By adopting both FANS navigation performance of <0.1 nautical mile and terrain avoidance systems the Alaska pilots could fly a 'direct' approach and avoid a 15 - 20 minute detour around the hazardous terrain.

Given the number of flights per day and the 'costs' associated with the extra 20 minutes flight time this alone generated millions of dollars of fuel-related cost savings on an annualised basis.

The airline example noted above is one of numerous performance driven case studies that result in a significant upgrade/retrofit market within the civil transport sector. We mentioned earlier in this report that an airframe designed for 60,000 landings over say 40 years of useful operation could expect to see 2, 3 or 4 avionics upgrades within the platform lifetime.

Many of the avionics suppliers covered within this report have developed comprehensive 'cost/benefit analysis' models that they can use as a powerful marketing tool to exploit potential airline cost savings via avionic upgrades.

The benefits associated with upgrading avionics are not only fuel cost related but include the following:

- Investing in the latest generation of avionics help to maintain the asset value of the aircraft.
- Improved reliability of latest avionics reduces maintenance costs and associated downtime (better asset utilisation)
- Improved situational awareness, reduced pilot workload in flight (TCAS, WX, EGPWS, Synthetic vision displays, larger format flexible displays)
- Insurance costs can be lower for aircraft fitted with latest generation of avionics.
- Reduce aircraft weight by 300 – 500 lbs for a complete retrofit.
- Avoid avionics obsolescence issues.

From our modelling of the overall civil market sector, it is clear that the addressable market for retrofit avionics can be equal to the market defined by the original equipment (OE) avionic supply.

Aircraft lessors have interest in maintaining cockpit avionics to the latest available standards. This can be a factor both in terms of maintaining the asset value of the platform and making the aircraft more desirable when offering it to a prospective customer.

8.2. BUSINESS JETS

Avionics specified within business jets tends to be very similar to that specified in a large commercial aircraft.

The key performance metrics for a successful business jet are typically 100% despatch reliability (a CEO/HNWI may only require a few flights a year but he does not expect a 'no-go' situation!) coupled with shortest 'door to door' timescales.

Business jets may operate between less congested hubs or more direct airfield locations. However, they still require the necessary navigation performance to avoid weather delays, congested areas, landing delays etc.

Modern business jets have therefore adopted FMS, IMA architectures, ADS-B autonomy and navigation performance in order to operate with optimised route structures.

Of growing importance is the access to the 'office in the sky' in real time which promotes the adoption of SATCOM, high bandwidth datalink service via satellite etc.

Unlike a Boeing or Airbus aircraft where the overall avionics package is specified by the OEM from several suppliers it is more likely that business jet OEMs such as Gulfstream, Bombardier, Dassault and Embraer will procure a complete 'off the shelf' integrated avionics solution from one of the big suppliers.

A number of typical examples are shown as follows:

- Bombardier Global 5000/6000 – Honeywell Primus 2000XP suite.
- Bombardier Global 7500 – Bombardier Global Vision based upon Collins ProLine Fusion suite.
- Cessna Citation CJ1/CJ2/CJ3 – Collins ProLine Fusion (upgrade offering)
- Dassault 7X/8X – EASy flight deck based upon Honeywell II Primus Epic avionics.
- Embraer Phenom 300E – Prodigy Touch flight deck based upon Garmin 3000 avionics
- Embraer Legacy 450/550 – Collins ProLine Fusion avionic suite.
- Gulfstream 280 – Collins ProLine Fusion avionic suite
- Gulfstream 650 – Honeywell Gulfstream Planeview Primus Epic suite.

Honeywell and Collins are the big two market leaders in offering integrated avionics suites within the bizjet sector. Both Thales and GE Aviation have a presence within this sector, but they do not offer a comprehensive avionics package as Honeywell or Collins.

At the smaller end of the business jet sector companies like Garmin and Universal Avionics are establishing themselves as offering a complete 'off the shelf' avionics suite at affordable levels.

As with larger civil platforms the business jet sector has significant retrofit/upgrade potential. A business jet is usually either an expensive 'business tool' or a luxury mode of transport for high net worth individuals (or

both). For either case having the latest avionics helps to maintain asset value and promote saleability. Modern avionics also helps to promote 'curb-side appeal' which is not an insignificant factor when purchase decisions are made by high-net-worth individuals.

8.3. MILITARY FIGHTERS

Modern military fighter platforms are often multi-role in design which satisfies a number of roles including air to air, air to ground, support of larger aircraft, long range strike etc.

The oft applied acronym, C4ISR (Command, Control, Communications, Computers, Intelligence, surveillance and Reconnaissance) is used broadly within every field of military operation today.

Arguably one of the most significant impacts of C4ISR upon military aircraft is the increased need for 'interoperability'. This interoperability need effectively places the aircraft within a connected network of assets, whether they be land, sea or air based, all with the means to communicate in real time.

In terms of the impact upon avionics the most significant areas affected are as follows:

- High speed data networks with the means for data fusion (from multiple sources) and subsequent transmission.
- Sensors – cameras, electro-optical, infra-red required for reconnaissance, surveillance, electronic countermeasures, target acquisition and 360-degree field of view
- Helmet-mounted synthetic vision systems dramatically improving the pilot's situational awareness.
- Stores management computing required to manage the various role configurations in terms of payload etc.
- Mission computing necessary for overall mission planning, database memory and recording of mission performance for post-ops debriefing.

Advances in enhanced and synthetic vision systems in recent years have resulted in improvements to both head up displays and to helmet mounted displays. The F-35 pilot's helmet, as developed jointly by Collins Aerospace and Elbit, includes features such as helmet mounted display system, integrated communications, 'look and shoot' capabilities, night vision capabilities etc.

It is understood that this integrated helmet system costs the US DoD $400k per unit.

External stores can be added to a basic fighter configuration in order to extend range (external fuel tanks), increase payload delivery (mounted armaments), provide for EW measures (chaff/flare dispensers) and adopt more powerful radars for detection/avoidance (external POD mounted arrays).

Within the avionics suite there is need for 'stores management' computing in order to manage the array of mission specific external fitments.

It would appear to be extremely challenging, if not impossible, to achieve the needs of data fusion and interoperability, within a modern warfare environment, if the avionics were procured along the old lines of a discrete number of federated boxes from a multitude of suppliers each with their own bespoke architecture.

Both the F-22 and the F-35 have adopted 'common computing' resource which acts as host software for each of the utility or mission computing functions. Specialist software suppliers provide the signal-processing systems for the Integrated Core Processing (ICP) system, the F-35's central computer, which supports all of the embedded computing elements for several different aircraft subsystems, including digital signal processing (DSP) for the sensors and cockpit displays.

Where there is need for distributed and/or remote sensors throughout the aircraft platform then data is transmitted via the high-speed network. This F-35 has 144 information exchange requirements that specify the digital transactions that have to occur between the F-35 and all other US and allied aircraft operating within the theatre.

The associated avionic transceivers provide four channels of data transmission and reception at a data rate of 2 gigabits per second (Gb/s) over the F-35's extensive fibre optic network.

Military platform upgrades to avionics are also very prevalent given the extensive life of the airframes involved. If we take the F-16 as an example it has received two major upgrade programmes sponsored by the USAF as follows:

- 1980s - Multi Staged Improvement Programme (MSIP)
- 2010s - Combat Avionics Programme Extended Suite (CAPES)

In addition, Tier1 integrators, such as BAE Systems, can also offer the market various avionic upgrade options in addition to the prime contractor, which in this case is Lockheed Martin.

One significant factor that limits the scope for potential upgrades is the available onboard power and cooling capacities which cannot always match the addition of more power-hungry avionics.

Whilst upgrading power and cooling does arise, it is usually associated with a program to re-engine the platform which is a very significant upgrade.

The European multi-national Typhoon is a further example of the value in upgrades through the life of a platform.

Phase One Enhancement (P1E) enhancements included Air-to-Surface capability and the Litening 4 Laser Designating and Targeting Pod, integration of smart weapons, modern secure Identification Friend or Foe (IFF Mode 5), improved Radios and Direct Voice Input, Air-to-Surface Helmet Mounted Sight System, improved Air-to-Air capabilities including digital integration of Short Range Air-to-Air Missiles and updating the Multifunctional Information Distribution System (MIDS) Datalink to enhance interoperability among Coalition Forces.

Phase 3 Enhancements Package' (P3E), included improvements to the maintenance and mission systems and the integration of the MBDA Brimstone 2 precision missile.

In 2020 BAE Systems announced the contract to upgrade the Typhoon's radar to a much-enhanced AEAS radar providing far greater range, jamming capabilities and better threat detection.

The range of Typhoon upgrades have differing impact upon the aircraft's avionic suite. However, surveillance, displays, stores management and electronic warfare functionality are all improved as a result of the above upgrades.

8.4. MILITARY TRAINERS

Military trainers act as the 'feed in' aircraft to the fully fledged military fighter aircraft. They typically cost a fraction of the price of their big brothers. However, they need to replicate as much of the functionality as possible in order to serve as an effective trainer aircraft.

Many of the advanced trainers have dual cockpits/dual controls which means that, partly due to budget constraints, the cockpit avionics have to be simplified.

One of the latest trainers is The Boeing T-7A aircraft, selected in September 2018 to replace T-38 Talons, is a new, advanced pilot training system that is being offered, in partnership with Saab.

The T-7A cockpit features a large touchscreen screen display, digital up-front controller (UFC) as well as Hands On Throttle and Stick (HOTAS) and low-profile HUD as sidestick. In particular, the large single widescreen display echoes that of the F-35. Boeing has taken the avionics development of T-7A in-house to create a cockpit display aimed at the smart-phone savvy 'digital native' pilots of tomorrow. The interface, for example, features iPhone/Garmin G1000-like 'app' icons for different functions (checklist, fuel etc.), making for an extremely intuitive and user-friendly cockpit for student pilots, who can concentrate on flying the aircraft and the mission. The avionics suite includes synthetic radar and weapons as well as datalinks to link with other T-7As (interoperability).

Whilst the avionic suite within a trainer will include mission computing, stores management, radar systems, FLIR and electro-optical sensors, low altitude TERPROM flight profiling, much like a fighter aircraft, there is not the need for the same level of mission criticality or redundancy built into the avionics architecture.

The avionics suite within a trainer aircraft is therefore estimated to cost around one quarter (25%) to one third (33%) of that for a fully equipped fighter aircraft.

8.5. MILITARY TRANSPORTS

Although this section is entitled 'military transports', we have included large military platforms some of which are utilised for advanced early warning, long range stand-off, refuelling tankers, maritime patrol, search and rescue for example, in addition to transport.

This expanded scope reflects the move in recent decades to specify and create multi role military platforms such as the A400M and KC-390.

When describing military fighters e.g., F-35, we noted interoperability as being a key requirement. These fighter role aircraft often need to be supported in the overall networked war theatre by long range early warning aircraft and refuelling tankers etc.

Many of the large military transport aircraft have to meet the relevant civil authorities' requirements (e.g. FAA, CAA, EASA) if they are to be permitted to operate within civil arenas (which covers most of the globe). Airbus as constructor for the A400M was therefore a natural choice (notwithstanding significant subsequent programme cost overruns).

The A400M was largely designed and certificated under the auspices of the Airbus commercial organisation partly to reflect the fact that a 'commercial approach' was deemed to be cost effective and, from an avionics perspective, much of the design was directly based upon the A380 aircraft.

Notwithstanding the read across from the A380 for certain of the A400M's avionics, such as the IMA computing resources and the large format cockpit displays, the mission specific computing and sensors required were all procured separately from lead avionic suppliers such as Thales/Diehl, Honeywell and Collins Aerospace.

Many military transport aircraft have been adapted from civil platforms e.g., KC-135 tanker (Boeing 707), Poseidon P-8 (Boeing 737NG), KC-46 tanker (Boeing 767), Airbus CN 235 MPA (CN235), and as a result, bring with them a suite of commercial avionics.

These platforms are then (heavily) modified to accommodate all of the mission specific avionics which will vary depending upon the role of the platform i.e., search and rescue, maritime patrol, advanced early warning (AEW), transport of troops and armaments, medevac etc.

Some of the electronic computing solutions that either interface or form part of the on-board avionics suite include:

- Flight Management Systems (e.g., A400M, Embraer C-390)
- Common computing core/IMA (e.g., A400M)
- Enhanced Vision Systems for night operations
- Hose and drogue control computer (in-flight refuelling)
- Large array long range radar (early warning)
- Stores management computer (armaments, payload, drop tanks, PODS)
- Mission computer (flight pre-planning, nav database, terrain data, post mission data downloads)
- Electronic Counter Measures (chaff, flares, radar jamming)
- Electronic Warfare (radar warning systems, laser warning systems, missile warning systems)

One of the modern military platforms, the Embraer C-390, is facilitated with an integrated avionics system and fly-by-wire flight control. Avionics includes two head-up displays (HUD), self defence systems and night-vision goggles (NVG).

The core avionics is provided by Collins Aerospace and based upon their Pro Line Fusion avionic suite.

The Embraer C-390 can be equipped with a complete self-protection package (SPS) to increase the level of survival. Detection & Control with 360 ° coverage: Radar Warning Receiver (RWR) Laser Warning System

(LWS) Missile Warning System (MAWS), Chaff & Flare Directional Infrared Counter Measures (DIRCM), Infrared / Optical Optics and Enhanced Vision System (EVS)

The Embraer C-390 can also be equipped with a complete set of equipment to support the Search & Rescue mission: Removable Electro-Optical / Infrared pod (EO / IR); Removable internal fuel tank to expand the range or time at the station.

Procurement of avionics for military transports is still somewhat fragmented across many specialist suppliers. This largely reflects the specialised nature of the equipment and the limited size of the addressable market.

Again, using the Embraer C-390 Millennium platform as an example, the following is a tabulation of the avionics supplied:

Embraer C-390 Millennium Avionics

Avionic – Equipment and sensors	Supplier
Flight and data management	Collins Pro Line Fusion flight deck
Mission computers	AEL Sistemas SA
Data Acquisition Systems	Curtiss Wright Defense Solutions
Radio communication equipment	Collins Aerospace
Transceivers: M3AR software VHF/UHF	Rohde & Schwarz
Weapons Countermeasures: Self-protection suite	AEL Sistemas SA
Weapons Countermeasures: Ballistics protection	Aerotron Industria e Comercio
Surveillance/Air Defense Radar: Mission radar system	Leonardo Defence Electronics
Collision Avoidance System: TCAS traffic management computer	ACSS (Thales and L3)
Inertial systems: Hybrid GPS & inertial ref system	Northrop Grumman Litef GmbH

The above table reflects 10 separate supplier contracts required for the C-390 avionics suite. However, this does not include either optional equipment (e.g. in-flight refuelling computers) or specific role equipment that will result in additional contracts and suppliers.

This section would not be complete without reference to arguably the most successful military workhorse in history; the C-130 together with its many variants.

First introduced in 1954 the C130 Hercules has a total of 13 variants and has been exported to 23 nations around the world. Around 2,500 aircraft have been supplied with over 1,600 still in active service today.

The early C-130H had a cockpit that was entirely mechanical with barometric instruments throughout. Navigation was derived from multiple mechanical gyro meters supported by air data provided by pitot static tubes.

The cockpit of the C-130 has been upgraded many times within its life from barometric instruments through cathode ray displays to flat panel LCD displays.

Two of the most significant C-130 avionics upgrades are identified as follows:

- 2000 - Boeing was awarded a contract to upgrade 464 C-130Js via the Aircraft Modification Programme (AMP) budgeted at $7 million per aircraft (although it cost considerably more). The upgrade includes Communication, Navigation, Surveillance/ Air Traffic Management (CNAS/ATM) compliance, which is required in order to fly in civil airspace. It features night-vision compatible digital displays, and the 737 commercial airliner's proven flight management system. NOTE: This programme has suffered significant delays and reduction in scope as a result of cost overruns and issues surrounding the value of the enhancements.
- 2019 - Air Force Life Cycle Management awarded a $500 million contract to L-3 Platform Integration for the C-130H Avionics Modernisation Program (AMP). Increment 2. L-3 will upgrade the Air Force C-130H Combat Delivery (CD) fleet of 176 C-130H aircraft, which includes the C-130H1, C-130H2, C-130H2.5, C-130H3, and LC-130H variants of the C-130H.

Notwithstanding the issues surrounding the C130 AMP programmes, it is clear that USAF alone has budgeted a total in excess of $2.5bn for C-130 upgrades. Add to this the upgrades of C-130 fleets operating within the other 23 nations and it is not difficult to see an upgrade market potential in excess of $5bn for this one platform.

There is a significant avionics upgrade/retrofit market for military transport platforms given their very long in-service life (often 50 - 60 years or more).

Many of the in-service military transport platforms have benefitted from significant upgrades in recent years including:

- C-130J (AMP programme - avionics)
- C-5 Galaxy (Avionics and Engine)
- C-17 Globemaster (Block 21 upgrade to ADS-B for operations in civil airspace)
- C-27 transport (Next Generation including revised avionics)
- CN-235 (Phoenix version offered with upgraded Honeywell avionics)
- Antonov AN22 (AN22A has upgraded radio and navigation)
- Alenia G-222 transport (multiple incremental avionics upgrades to radio, radar, auto-pilot and nav systems).

Counterpoint believes that the military transport market for upgraded avionics will continue to be attractive and to grow given that the examples above represent only the major programmes. These aircraft are typically operated by many nations throughout the world each of whom have their own budgets for continuing the life of their in-service fleets (as opposed to very costly platform replacements).

8.6. HELICOPTERS

Avionics fit within rotorcraft platforms are considerably simpler than their fixed wing counterparts. helicopters operate over much shorter ranges at lower speeds and they do not exceed altitudes of around 8,000 ft. They therefore operate within a much-reduced envelope which results in simpler avionics architectures.

A rotorcraft can typically have an FMS with Autopilot and a heading and attitude reference system. It will not have the same levels of system redundancy found in large civil fixed wing platforms as the certification requirements are nowhere near as stringent.

However, the above is only a general statement. The role of the helicopter platform can determine the level of navigation performance required and the acceptable levels of avionic availability.

The CAA and EASA have introduced navigation required minima for GPS equipped rotorcraft that operate with civil passengers in the North Sea (e.g., shuttling people between oil rigs).

A further consideration that can impact avionics standards is the need for rotorcraft to utilise airports that are also used by fixed wing aircraft. As recent as 2020 SESAR (Single European Sky Aviation Research) was working to define how instrument flight rules (IFR) procedures designed specifically for rotorcraft can enable their access to airports without impacting fixed-wing commercial traffic. The flight trials were conducted by ENAV (the Italian ANSP - Air Navigation Service Provider), in collaboration with Leonardo Helicopters Division within the framework of SESAR 2020 project on enhanced runway throughput.

Rotorcraft avionics generally need to be very cost sensitive given that the platform sells for a fraction of that for a fixed wing civil air transport platform. Many OEM manufacturers list a range of avionics as ‘optional’. Equally, many avionics suppliers offer standard products that can be approved for use via the Supplemental Type Certification (STC) process.

In order to emphasise the level of activity undertaken via the STC route within the rotorcraft sector we looked at a 6-month period of airworthiness approved STCs and identified 30 approvals listed as follows:

- 27-Oct-20 - PAC45A Audio System for Black Hawk Upgrade #AudioSystem
- 23-Oct-20 - Avionics Upgrade for UH-60A Black Hawk #Genesys
- 15-Sep-20 - Ultra Small Embedded Computer for eVTOL Taxi #SmallComputer

- 14-Sep-20 - Canadian Avionics for New Border Protection H125s #AudioSystem
- 11-Sep-20 - Radar Altimeter for AS350 #altimeter
- 10-Sep-20 - GPMS Foresight HUMS for AS350B3 #HUMS
- 05-Sep-20 - Kapture Cockpit and Flight Data Recorder #Kapture
- 03-Sep-20 - Garmin Glass Cockpit for the MD520N #garmin
- 27-Jul-20 - Part 25 and Part 29 ADS-B in Brazil #ADSB
- 23-Jul-20 - Internet, Video, and Voice for Helicopters #VSAT
- 23-Jul-20 - RoadRunner EFI Upgrade for Bell 212 and 412 #roadrunner
- 17-Jul-20 - EASA Certification for Honeywell EGPWS in AW139 #oilandgas
- 14-Jul-20 - Flight Deck VL-60 for Commercial Black Hawk #BlackHawk
- 08-Jul-20 - Ground Helipad Assisted Take-off #autopilot
- 06-Jul-20 - Leonardo Osprey AESA Radar #Osprey
- 06-Jul-20 - Garmin Multi-function Display for Helicopters #GI275
- 01-Jul-20 - 500th AN/APG-78 Fire Control Radar #Longbow
- 18-Jun-20 - Data Recorder with Altimeter Interface for R44 #R44
- 02-Jun-20 - Garmin OnePak for New Bell Helicopters #Garmin
- 01-Jun-20 - Garmin GFC 600H for Airbus H125 #Garmin
- 30-May-20 - Flight Testing for Genesys Cockpit on Black Hawk #GlassCockpit
- 21-May-20 - Helmet-Mounted Display for Safe Landings #SafeLanding
- 16-May-20 - NVG Upgrade for the Helicopter Institute
- 03-May-20 - 7-inch Portable Aviation GPS aera 760 #Aera760
- 01-May-20 - Crash-Hardened Recoverable Data Module RDM-300 #FlightRecorder
- 26-Mar-20 - FAA Part 27 Approval for Appareo transponders #ADSB
- 13-Mar-20 - Garmin G5000H Glass Cockpit for KAI Surion #GlassCockpit
- 06-Mar-20 - Lido Surface Data NEXTView EASA Certification #terrain

It is immediately apparent that this STC route is well served by suppliers including Garmin, Genesys, Leonardo (Selex), in addition to Honeywell, Thales and Collins.

It is sometimes difficult to refer to a 'standard fit' for rotorcraft avionics as there is a wide range of 'options' and a very active Buyer Furnished Equipment market for these products.

Partly as a result of the low-cost targets mentioned above the rotorcraft avionics market benefits from 'commercial off the shelf' (COTS) offerings. This COTS approach to low-cost avionics is described in section 14.1 of this report.

Many avionics suppliers have therefore developed a range of avionics products, whether they be COTS or STC route, which are targeted for the rotorcraft market.

Suppliers with a strong presence in rotorcraft offering COTS/STC products include:

- Honeywell (via its Bendix king subsidiary)
- Collins Aerospace
- Meggitt
- Universal Avionics
- GE Aviation
- Curtiss-Wright
- Thales/Diehl Avionics
- Garmin Avionics

- Genesys

Collins, for example, offers its 'HeliSure' flight Situational Awareness and Cockpit Display solutions. With 3D visualisation of high-resolution terrain data on large-format Primary Flight Displays, the HeliSure family of products feature an intuitive interface with scalability across multiple platform types and sizes, all while optimising size, weight, power and cost for a breadth of rotary-wing solutions.

Note the emphasis in the paragraph above upon a family of scalable products for a breadth of rotary-wing solutions. Many suppliers can only make commercial sense of the rotorcraft avionic market when they develop products for numerous platforms.

In terms of military role platforms there is clearly an additional level of avionics required when compared to civil variants that is role dependent.

Military helicopters fulfil a number of roles including troop deployment, medevac, search and rescue, fire-fighting, low level support etc.

An Apache AH-64, for example, will be fitted with additional avionics and sensors, including target acquisition radar, fire and forget radar, night vision systems for displays and HUDs, enhanced vision systems (via infra-red sensors), radar jammers and electronic countermeasures (ECM).

These specialised military avionics also have a range of suppliers that develop a range of military sensitive avionic products including:

- Lockheed Martin
- Northrop Grumman
- Honeywell
- ITT Aerospace
- General Dynamics
- Raytheon
- L3 Harris
- BAE Systems
- Elbit

By way of example the Boeing Chinook CH-47, one of the largest operational military transport rotorcraft in current service, is fitted with the following avionics and sensors:

The cockpit accommodates two pilots and an observer.

- Boeing and Honeywell developed the advanced digital cockpit.
- The cockpit is equipped with multifunction liquid crystal displays and electronic flight instruments.
- The crew is equipped with ANVIS-7 night-vision goggles from Elbit and the cockpit is night-vision-goggle (NVG)-compatible.
- The communications suite includes jam-resistant HF and UHF radio systems developed and supplied by Collins Aerospace and Raytheon.
- The helicopter features AN/APX-100 identification friend or foe (IFF) interrogator from Honeywell.
- In 2008 Northrop Grumman was awarded a contract to equip the Royal Netherlands Air Force's (RNLAF) CH-47Fs with the AAR-54 missile warning system.
- The special forces MH-47E, is fitted with the ATK AN/AAR-47 missile approach warner, Northrop Grumman ALQ-162 Shadowbox jammer, ITT ALQ-136(V) pulse jammer, Raytheon APR-39A radar warner and BAE Systems Integrated Defense Solutions (formerly Tracor) M-130 chaff and flare dispenser.

Many military helicopters are also fitted with similar range of avionics, ECM and EW systems.

Yet again Counterpoint sees considerable opportunities for upgrades and retrofit relating to avionics within the overall rotorcraft sector (both civil and military)

Certification and regulatory authorities, such as EASA, provides guidance on incorporating avionics upgrades to rotorcraft (categorised as 'major' or 'minor').

This EASA list can be found at rotorcraft@easa.europa.eu and identifies 30+ test/installation requirements for a wide range of upgrades including GNSS, GPS, TCAS, TAWS, WX, XPDR Mode S, ADS-B in, Enhanced Vision Systems, Synthetic Vision Systems, Datalinks, Antenna, Radio, SATCOM, VDR, CVR, Mission Radio, Obstacle detection, Laser devices etc.

Significant avionic upgrades to rotorcraft platforms in recent years include the following:

- Chinook (1,200 built) ; 400 US Army Chinooks 'digitised' in 2003, Selex upgraded avionics on 16 Italian air force units, US Army selected Boeing to upgrade avionics on 50 Chinooks in 2011 ($24m).
- Apache AH-64 (2,400 built): a $1.9 billion five-year contract was signed in 1996 to upgrade 232 AH-64As into AH-64Ds (including avionics and sensors); Elbit provided Target Acquisition Designation Sight/Pilot Night Vision Sensor System and Integrated Helmet and Display Sighting System for Greek air force (19 units at a cost of $34 million) ; In 2014, it was announced that new targeting and surveillance sensors were under development to provide high-resolution colour imagery to crews, replacing older low definition black-and-white imaging systems; 2018, the Netherlands decided to upgrade all their AH-64Ds to the latest AH-64E configuration through a Foreign Military Sales contract with the US, along with 17 APG-78 fire control radar units.
- Sikorsky UH-60 Black Hawk (4,000 built); Upgrade to UH-60M in 2006 incorporates upgraded T700-GE-701D engines, improved rotor blades, and state of the art electronic instrumentation, Integrated Vehicle Health Management System (IVHMS) compute and aircraft navigation control – 1,227 platforms upgraded at a budgeted cost of $1.3 billion; a further upgrade in 2008 included UH-60M with fly-by-wire system and Common Avionics Architecture System (CAAS) cockpit suite.

Many of these helicopters are operated in many other countries, in addition to the US, and they have contracted their own avionics upgrades often independently of the OEM supplier. Whilst the USA is a significant market for retrofits/upgrades we believe that there are equal opportunities represented outside of the US.

8.7. UNMANNED AERIAL VEHICLES/UNMANNED AIR MOBILITY

We believe that this sector of the market breaks down into several distinct sub-sectors as follows:

- Military UAVs (reconnaissance, networked theatres, payload delivery)
- UAVs/drones (commercial operations, payload delivery)
- Air mobility/air taxis (passengers)

The nascent UAV/UAM market for avionics should represent an area for high growth in terms of numerous new platforms and developments seeking to meet a highly diverse set of end needs.

Common threads across all platforms operating within this sector are arguably 'autonomy', or significantly reduced dependence upon flight crew, and an emphasis upon navigation performance, reliability and safety (at affordable costs).

Irrespective of emerging propulsive technologies (e.g., electrical, hydrogen, solar), within a carbon neutral environment, a significant challenge for avionics is focussed upon very low-cost vehicles operating in congested airspace often centred above urban populations.

Regulatory authorities around the world are wrestling with this issue as we compile this report in early 2020.

A further major challenge is the need for 'infrastructure' for the plethora of air taxis and delivery drones being planned. Developers of these UAVs/UAMs will need infrastructure (airports, route structures, service centres, air traffic control etc) and certification rules before there can be any mass market take up.

In terms of military UAVs in operation today, special mission vehicles, such as the Global Hawk, have already seen significant operational service in the past 10 years or so. We have analysed the avionic/sensor suite on this platform and it is clear that the sensor suite predominates whilst the man/machine interface products are all redundant (no pilot, displays, voice, physical interfaces etc).

Given the Global Hawk's need to acquire precision data for reconnaissance or target data, it follows that its own navigation systems need to be highly accurate. We understand that the Global Hawk relies upon augmented GPS for its primary navigation needs.

UAVs designed to deliver payloads, whether for military purposes or for Amazon, will require navigation accuracy significantly greater than the 0.1 nautical mile stipulated under current FANS/Next Gen fixed wing transport aircraft needs.

We believe that the key avionics technologies necessary to adequately support the growing UAV/UAM sector will need to include the following:

- High-performance low-cost navigation accuracy significantly greater than 0.1 nautical mile based upon augmented GPS
- ADS capability for complete vehicle autonomy – receive and transmit
- High speed data links air to ground via satellite (narrow bandwidth as no IFE etc)
- Scaled-down FMS for preferred route structures, approved air corridors etc.• Limited on-board data recording for post event analysis.
- Military-grade sensors subject to mission and role (EW, ECM, Infra-red, Optical, Cameras etc)

UAMs or Air Taxis may require 'office in the sky' facilities dependent upon range and time in the air. This will require that the avionics suite can accommodate SATCOM and high speed datalinks.

It is difficult to predict with any degree of accuracy the value of this sector given its nascent development. Counterpoint has therefore included known UAVs that are currently in commercial and military operation.

What is clear is that this emergent UAM sector has drawn in huge investment funds often from new players that could alter the traditional avionics supply chain.

The following are listed, by way of examples of new entrants/projects, from a list of 60 new platform/service developers around the world who announced the following events in 2020:

- 2020: Volocopter and ADAC Luftrettung have announced that ADAC Luftrettung has reserved two VoloCity electric vertical take-off and landing (eVTOL) aircraft.
- 2020: Honeywell working with companies in UAS and UAM, including Vertical Aerospace, Volocopter, Jaunt Air Mobility, Pipistrel, and the motor maker DENSO.
- 2020: Los Angeles is pressing ahead with plans to integrate eVTOL aircraft into its public transportation network with the launch of its Urban Air Mobility Partnership.
- eVTOL aircraft developer Joby Aviation will acquire part of Uber, essentially absorbing its project aimed at building an ecosystem for urban air mobility.
- 2020: Choose Paris Region, Groupe ADP, and RATP Groupe have launched a global call for expressions of interest to develop urban air mobility (UAM) in the region of Paris, France.
- 2020: AiRXOS has announced its new fully faceted drone solution for customers in the energy industry. The system allows for organisations to plan, schedule, operate, and monitor all areas of a drone fleet using one simple platform.
- 2020: Eve Urban Air Mobility Solutions (Eve) has been spun off from Embraer as a new, independent company dedicated to accelerating the urban air mobility ecosystem. The company is developing the certification of an electric vertical take-off and landing vehicle (eVTOL) and the services and support network, as well as working on the creation of urban air traffic management solutions.
- 2020: Hyundai's planned all-electric S-A1 aircraft is projected to offer range of 60 miles, speeds of up to 180 mph and a cruising altitude of between 1,000 and 2,000 feet. The aircraft, which features four sets of rotors for vertical lift and four propellers for cruise flight, will seat four passengers. Hyundai says the aircraft's batteries will need between five and seven minutes to recharge.
- 2020: Toyota Motor Corp. was announced as the lead investor in a $590 million Series C financing round for Joby Aviation. The Japanese company has invested $394 million in the California-based start-up and will

provide manufacturing and quality control support of its S4 eVTOL, which Joby says will be ready to enter service in 2023.

- 2020: Wisk, an urban air mobility (UAM) company behind the world's first all-electric, self-flying air taxi, is teaming up with NASA engineers to focus on the safe integration of autonomous aircraft systems into national air traffic patterns.

Certain automotive manufacturers see themselves as playing a significant role in the promotion and development of UAMs alongside a rash of new platform developers.

Service providers such as Uber also are investing heavily to support the development of UAMs, although Uber has now sold its principal activity in this area (see above).

City authorities (e.g., Paris, Los Angeles, New York) are also playing a key role in helping to develop the infrastructure for UAMs.

From an avionics perspective there will need to be approved new route structures in order to cover the myriad of local Air Mobility traffic patterns surrounding urban areas which already have airports close by.

It is equally clear that the relevant airworthiness authorities around the world need to issue airworthiness standards necessary to safely implement and control operations for UAMs in civil aerospace. This we understand is currently work in progress with bodies such as the FAA, EASA and CAA.

We expect the low-cost avionics developers such as Garmin, Universal Avionics, Innovative Systems & Support and Bendix King (Honeywell) and CMC Electronics (TransDigm) to be in the best position to offer 'off the shelf' low cost integrated avionics suites for UAMs.

Counterpoint believes that low-cost accessible air taxi transport for the masses (UAMs) could still be some years, if not decades, away given the time it may take to design and implement the associated infrastructure.

9. THE IMPACT OF COVID-19

COVID-19 is having a massive effect impact on the aerospace sector, and there is still a great deal of uncertainty about when the commercial aerospace industry will start to recover and what the recovery will look like. Nevertheless, we have produced 10-year forecasts under three scenarios, most likely, best case, and worst case, which are outlined below. We show pre-COVID-19 forecasts as a baseline to show the impact of the COVID-19 pandemic on the industry.

The scale of the crisis

It is now clear that the Covid-19 crisis is the most serious to hit the industry in a generation and that recovery will take years. It is likely that the industry will be permanently altered as a result.

Although commercial aerospace will clearly take the biggest hit, the crisis will also cause a worldwide recession, and this will depress all sectors of the aerospace industry, at least until world economic growth recovers. It is likely that this will not be fully possible until the need for social distancing disappears.

Increased Government debt is likely to be a longer-lasting problem, which may constrain economic growth and may also curtail expense defence expenditure.

Commercial Aerospace

- Some consensus is emerging - it now seems clear that the impact of this crisis will be long-lasting and profound. A V-shaped recovery is looking extremely unlikely.
- It is becoming increasingly clear that social distancing and mass air travel are fundamentally in tension. To eliminate the need for social distancing will require either a vaccine to be administered to a large proportion of the world's population, and the incidence of Covid-19 to fall to very low levels and effective treatments are developed so that people are prepared to live with a limited risk of contracting the disease. No-one knows how long this will take, so for the moment uncertainty reigns, although the process of recovery has now begun with mass vaccination programmes starting in most countries.

- Air traffic; there seems to be an emerging consensus that air traffic will take to 2024/2025 to recover to 2019 levels; short haul will recover first, although there are a wide range of forecasts available.
- Airlines; failures and consolidation are likely, which will hit the aircraft OEMs' order books
- Commercial aircraft production:
  - very uncertain but aircraft production rates have now settled at 40% below 2019, having suffered varying degrees of interruption including in some cases complete shut-down. Further cuts look possible in 2021, although the picture sin single aisles is muddied by the Boeing 737MAX situation.
  - Demand has not completely dried up; airlines have contractual commitments with the aircraft OEMs and many airlines are receiving Government bail outs.
- Single aisle versus twin aisle; the trend away from twin aisle to single aisle looks set to continue
  - Lower long-haul demand will mean relatively fewer widebodies required
  - Single aisle substitution for widebodies on medium distance routes likely to be accelerated by lower seat demand
- Boeing versus Airbus
  - In the new environment Airbus looks to have a much better product range
  - two successful single aisle models; A220 and A320neo versus the compromised 737MAX
  - we think that Boeing will be under pressure to develop an all-new single aisle, financial pressures notwithstanding
  - However, at the corporate level, Boeing does have an advantage over Airbus in that it has a significantly larger military business
  - Although this has not been necessary so far, we believe that both Boeing and Airbus will receive government support if necessary, to ensure survival
- Fuel price
  - low oil prices look set to persist and low fuel prices undermine the business case for purchasing new aircraft – this is particularly likely to be a drag on demand for new single aisles, although engine maintenance considerations make the situation more nuanced as is discussed in this report
  - there is a chance that the financial consequences of the low oil price could lead to political instability and conflicts, which could lead to oil price spikes and volatility
- Aftermarket; this will be hit very hard (see more detailed analysis later in this section of the report);
  - initially by drastically reduced aircraft utilisation
  - then by the expected surge in aircraft retirements, which will mean a potentially much-increased supply of used serviceable material (again discussed in detail in this report0

<u>Business jets/General aviation</u>

- Business jets/general aviation have also be hit hard but not as hard as commercial
  - The large cabin business jet market has traditionally been strongly correlated with oil prices.
  - The small/medium business jet market has traditionally been strongly correlated with corporate profits and equities indices.
  - Recovery may be stimulated by the perceived risks and hassle of commercial travel – we are already seeing a recovery to almost pre-Covid-19 levels in hours flown on small/medium business jets (but not large cabin jets)
  - In this environment more consolidation may occur – Bombardier, now a pure-play business jet manufacturer, could be a possible takeover target.

<u>Commercial helicopters</u>

- This already depressed sector has been hit hard but again nothing like commercial aerospace
  - Similar dynamics to business jets/general aviation – large commercial helicopters exposed to off-shore oil
  - The industry is already consolidated

Military programmes

- The sector which is least exposed to Covid-19
  - In 2020, production was down, around 10% down vs forecast, mainly due to supply chain problems
  - Thereafter good growth in the US, the world's largest defence market
  - We think other domestic defence markets will generally hold up, at least in the short term, as governments seek to support their aerospace industries, but major export markets particularly in the Middle East likely to be hit by Government spending constraints.

Suppliers

- All suppliers with significant commercial aerospace exposure will be under pressure
  - Suppliers are having to manage a 40%+ reduction in commercial programme production rates
  - Company failures are possible and further consolidation is likely
  - If practical, either the OEMs or their key tier-1 suppliers will step in to take over contracts in the event of a company failure
  - But the supply chain cannot rely on the aircraft OEMs for monetary support – the OEMs are focussed on conserving cash
  - In the past the OEMs went to great lengths to preserve the supply chain, e.g. Airbus acquiring Alestis, PFW, to ensure it could ramp up production and keep to its customer commitments. Now it is completely different – production is ramping down and customers do not want the aircraft.
  - Now, the supply chain is largely on its own and it is up to the suppliers themselves to sort out the supply chain
- However, in the short term most suppliers have been able to survive helped by Government loans and furlough schemes etc.
- Once short-term support measures come to an end, company failures and consolidation are more likely. We think private equity and financial buyers will pay a significant role.
  - Private equity/financial buyers are likely to be significant players on both sides of the Atlantic particularly at tier 2 and below.
  - However, some PE buyers may find the margins too low even though there will be a sales growth story.
- It is clear now that permanent job losses have occurred at all levels in the supply chain.
- This crisis will probably have long-term effects on the shape of the supply chain, both OE and aftermarket. The process is likely to occur in three phases
  - Measures to preserve liquidity to buy time (this is phase we are currently in and it is now coming to an end)
  - Restructuring (likely to start in 2021)
  - Creating value
- In the short term, the principal drivers have been the need to conserve cash to maintain liquidity and to ensure that supply chains maintain the capability to deliver what is needed.
  - An example of this was Airbus's decision taken in June 2020 to cancel plans to in-source production of nacelles for the PW1000G engined version of the A320neo. Airbus said it had been forced to cancel the in-sourcing project due to the coronavirus crisis, which "leaves Airbus with no choice than to revisit all current and future product development activities to protect our cash."

Aftermarket

At the beginning of 2021, in-service fleets and utilisation have stabilised but a high number of aircraft remain in storage. In 2021 we expect better predictability in comparison to 2020 which brought significant reductions to MRO activity as airlines reduced their route networks, service frequencies, and ultimately flying hours leading to the storing and retiring of aircraft within their fleets.

To offset losses and cash spending, airlines have reduced discretionary MRO including deferring much of their upcoming cash-intensive aircraft airframe, line, component, and engine maintenance. In turn, an

airline's continuing airworthiness maintenance practice has shifted to one of storage, preservation, and eventual service return, representing a reduced cost burden as much of it can be managed and performed in-house. Recognising that the return of pre-COVID-19 traffic levels remains unlikely in the short-to-medium-term, airlines continue to announce retirements of certain types from their fleets. Some salient aftermarket activities and potential trends given the current market situation are identified below:

- We expect MRO spend to be 55% - 65% of 2019 MRO spend in 2021. 2020 MRO spend was approximately 50% of 2019 MRO spend.
  - Airframe maintenance continues to see the largest reduction, followed by engine, line, and component maintenance.
  - Used component providers have seen airframe component demand fall drastically as airlines rely heavily on their own inventory and stored fleet to get by. This has negatively impacted used component pricing.
  - Component poaching from existing airline fleets has become a trend for larger aircraft components.
  - Given this activity, airline technical teams are exercising diligence in component record keeping, maintaining best practice in electronic and paper component record trails.
  - While airlines can preserve cash with discretionary maintenance, certain maintenance is time limited. For example, landing gears and airframe heavy checks. If deferred, such maintenance will be a necessity for a return to service, a factor of continuing airworthiness.
- Many MROs have now renegotiated maintenance rates for term maintenance contracts with customers.
- OEM MROs have prioritised in-service pre-existing service issues and have accelerated fixes to eradicate such issues completely, or within a timeframe.
  - Pre-Covid, we believe that some OEMs were burdened by these fixes, and workforce priority favoured them. This was causing in-shop delays and increased turnaround times, particularly for engine OEMs.
  - We think this proactive work could benefit OEM MRO services as they ramp-up to pre-Covid throughput, with the ability to prioritise scheduled maintenance activity.
- Used Serviceable Material (USM) was a very tight market pre-COVID. Retirements and airline aircraft storage will lead to greater availability and use of new available USM to serve remaining aircraft fleets.
  - Although some specialists have bought assets for part-out to stockpile, mass recycling of aircraft and repairing components for onward use has not been a trend. It is estimated that any new influx of USM could occur towards the end of 2021 although a significant surge is expected later.
  - Future availability of USM could bring about a market equilibrium. This trend will apply for many assets, and it will likely have a further knock-on effect to new component pricing.
  - We expect new and USM component price pressures in some twin-aisle aircraft markets, particularly those with no recognised freighter variant, or established freighter fleet.
  - OEMs might be more active in asset acquisition to boost USM inventories. We think that OEMs are actively advertising the use of USM during maintenance.
- There are aircraft sectors that are inherently more resilient, such as military operations and freight. In business jet markets, operations have remained stable, albeit with operations moving to smaller aircraft, reduced distances, and overall operational time.

Increases in the aftermarket during 2021 are likely to occur because of an increase in short-haul operations, increasing utilisation, a settled and rising in-service single-aisle fleet, the continuation of freight operations, and also unavoidable maintenance. We still envisage a depleted fleet with slower return to service for twin-aisles and very large aircraft, owing to greater restrictions and burdens of travelling internationally, although repurposed twin-aisles for freight continue to offer some upside.

10. MARKET SIZE AND SEGMENTATION

Our estimates for the total avionics market size are shown in the table below which identifies the major avionic sub-system categories together with revenues split between OE, retrofit, spares and repairs.

2019 Avionics Market	OE	Aftermarket	3rd party MRO	TOTAL
Software	492	880	37	**1,410**
IMA	812	997	100	**1,908**
FMS	585	935	106	**1,626**
Auto-pilot	254	320	91	**665**
Display	1,796	3,404	751	**5,951**
Navigation	789	1,266	182	**2,237**
Communications	525	901	128	**1,554**
Surveillance	640	1,093	104	**1,837**
Data	472	1,013	112	**1,597**
Mission	508	1,553	125	**2,185**
Sensors	964	1,688	222	**2,875**
Grand Total	**7,837**	**14,050**	**1,958**	**23,846**

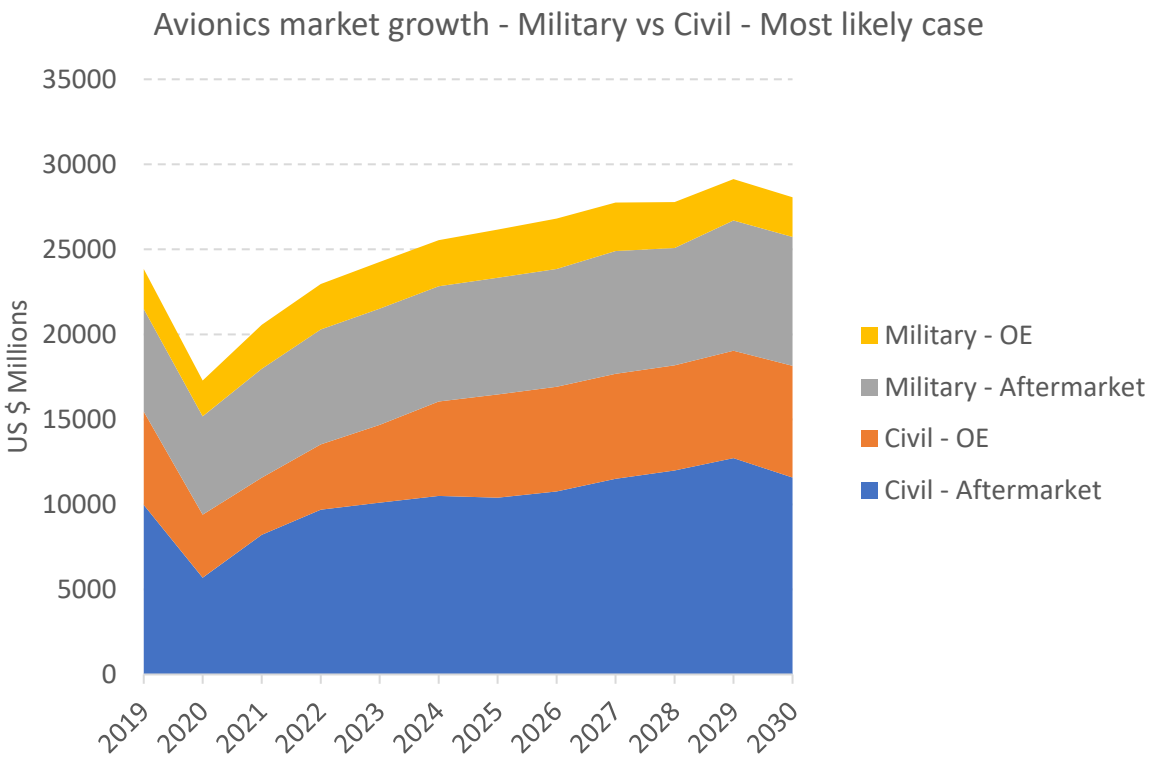
2020 Avionics Market	OE	Aftermarket	3rd party MRO	TOTAL
Software	362	608	18	**988**
IMA	631	746	60	**1,437**
FMS	374	530	56	**960**
Auto-pilot	178	188	53	**419**
Display	1,288	2,294	386	**3,968**
Navigation	561	914	107	**1,582**
Communications	384	585	73	**1,042**
Surveillance	485	768	58	**1,310**
Data	337	654	64	**1,054**
Mission	454	1,516	68	**2,038**
Sensors	755	1,617	113	**2,485**
Grand Total	**5,808**	**10,419**	**1,057**	**17,283**

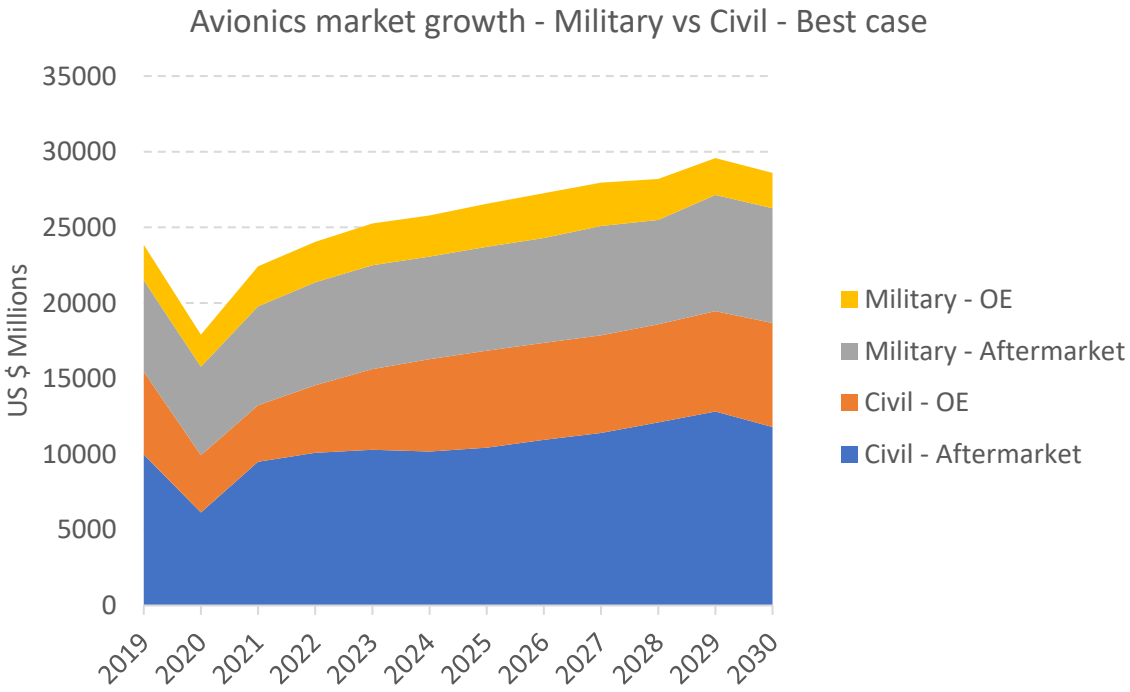
10.1. MARKET SIZE AND GROWTH

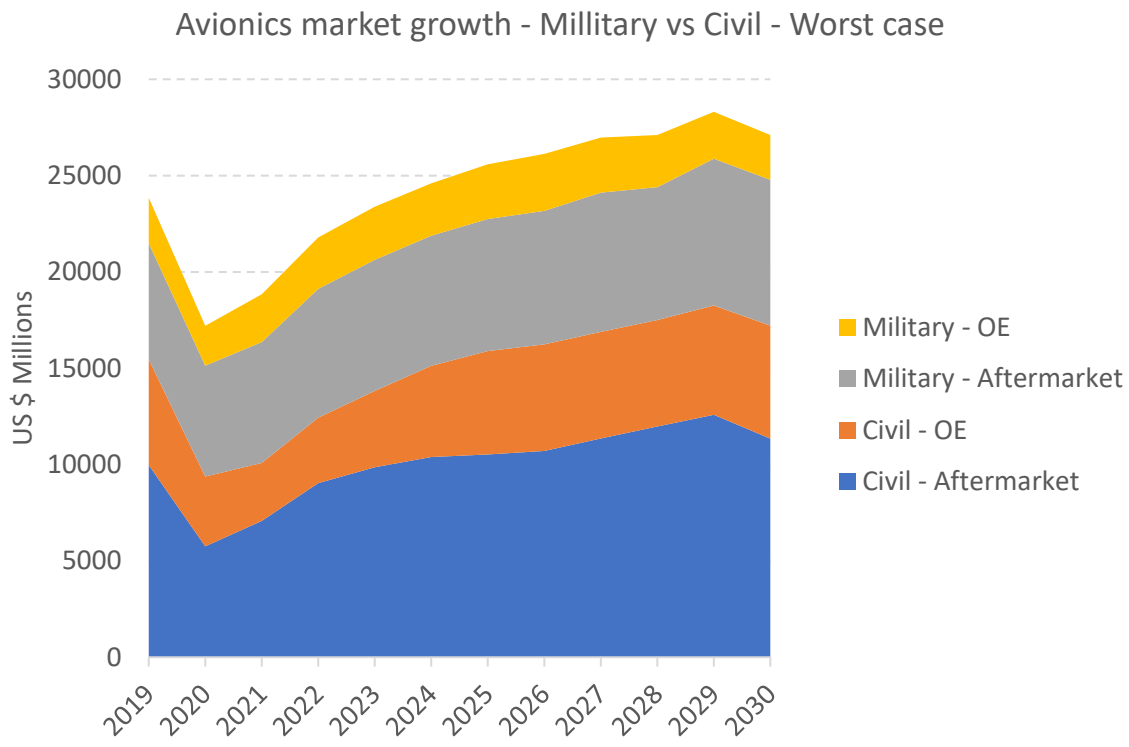
10.1.1. Overall market growth trends

OE vs Aftermarket

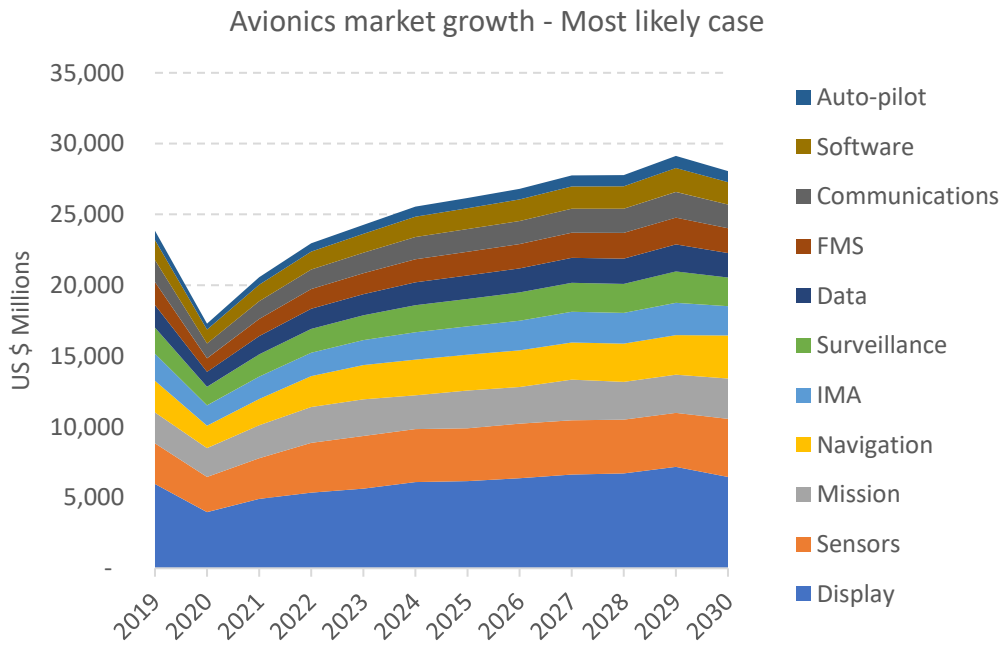
Avionics market size $ millions	2019	2020
Civil - OE	5,487	3,706
Civil - Aftermarket	9,977	5,694
Military - OE	2,350	2,102
Military - Aftermarket	6,032	5,781
Grand total	**23,846**	**17,283**

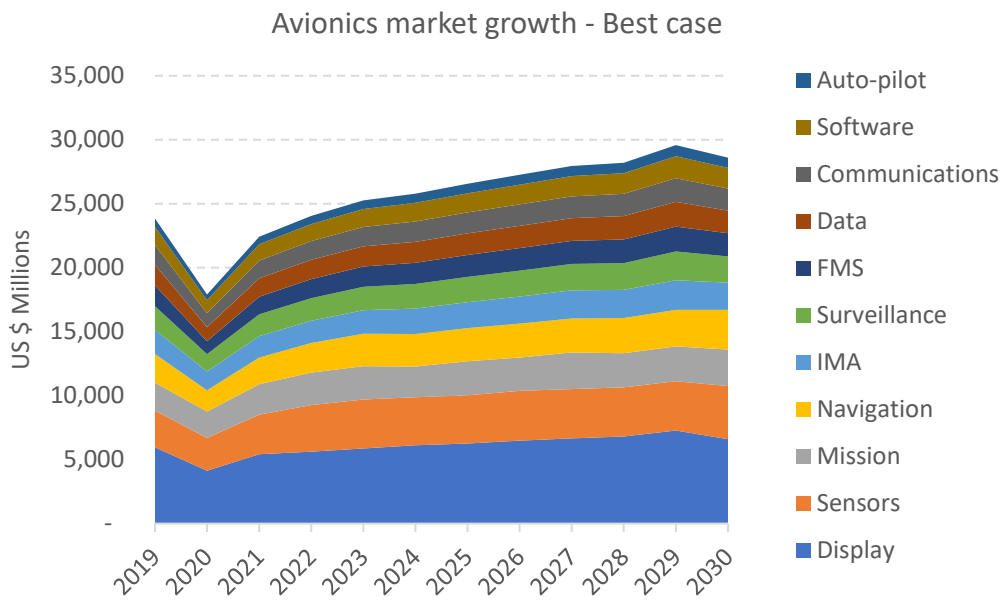


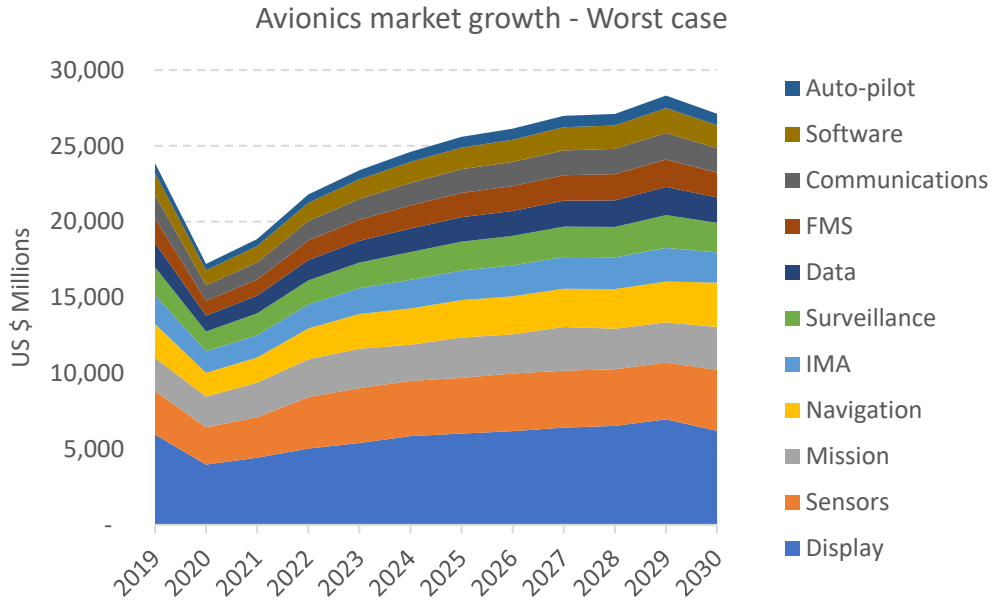




Growth by type of equipment

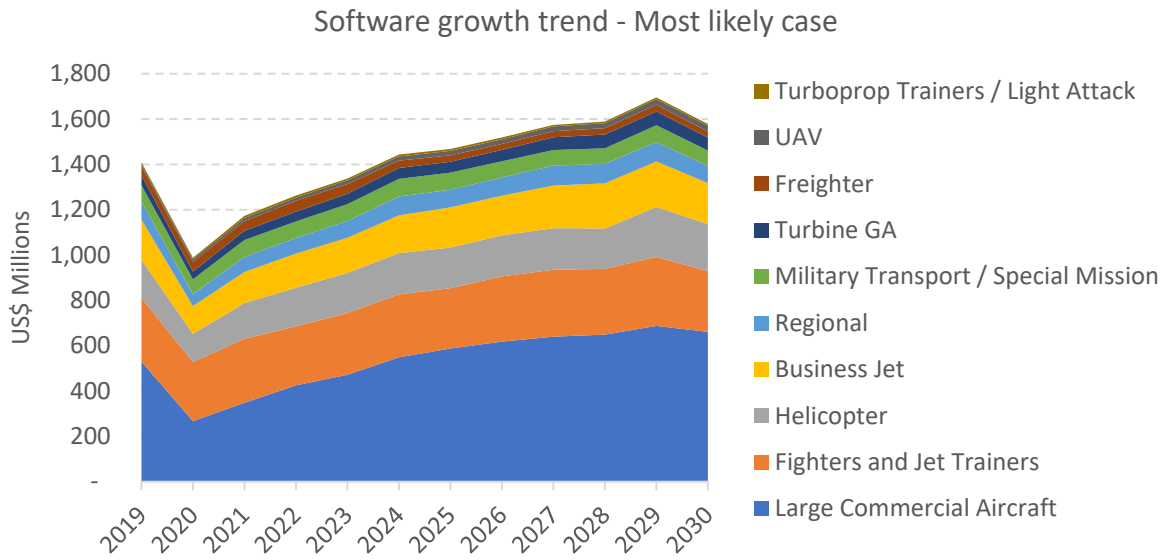


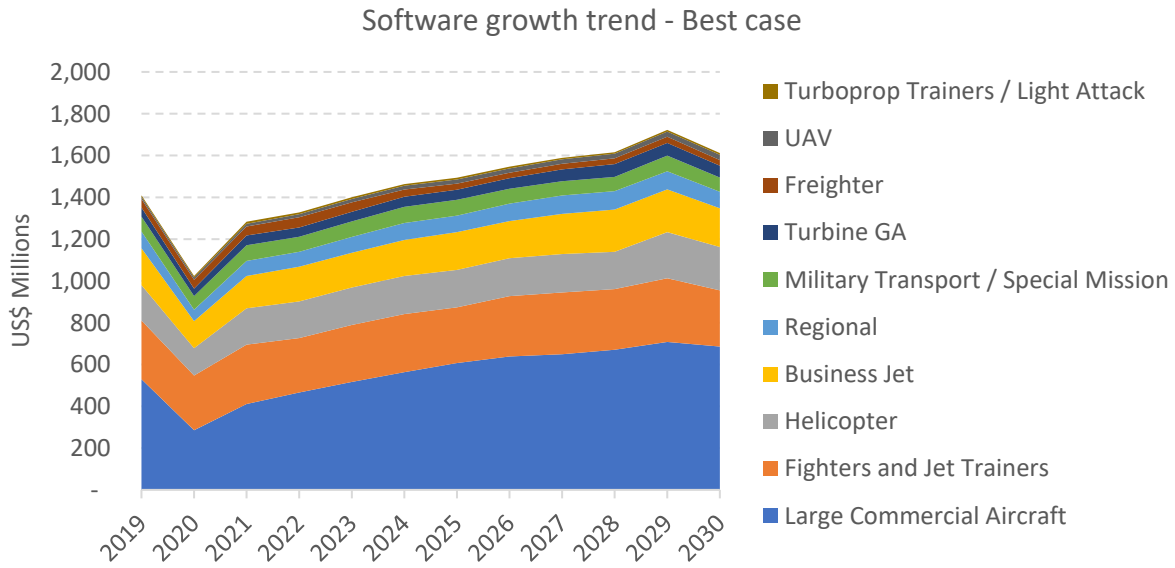


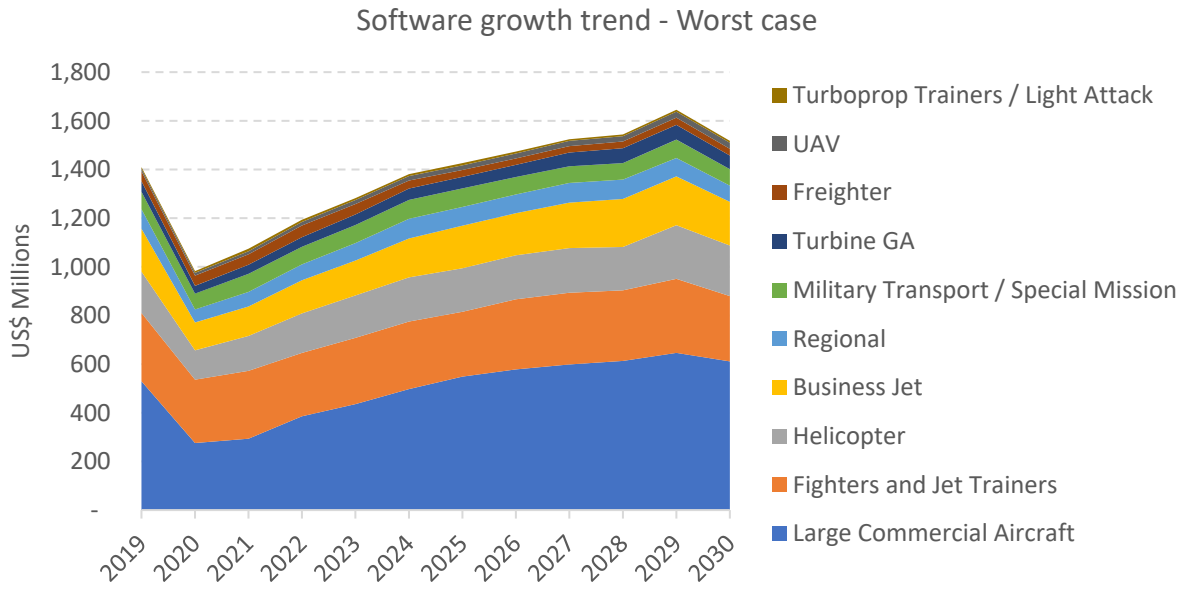


10.1.2. Software

Software market $ millions	2019	2020
Business Jet	176	123
Fighters and Jet Trainers	281	261
Freighter	41	42
Helicopter	169	124
Large Commercial Aircraft	530	267
Military Transport / Special Mission	72	65
Regional	80	53
Turbine GA	43	34
Turboprop Trainers / Light Attack	7	7
UAV	10	11
Grand Total	**1,410**	**988**

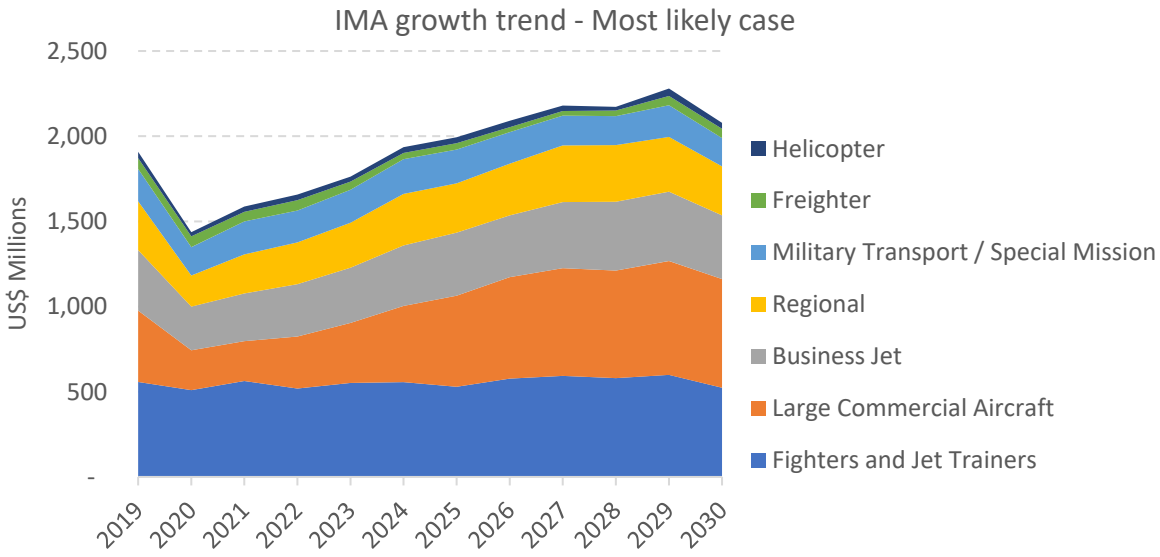


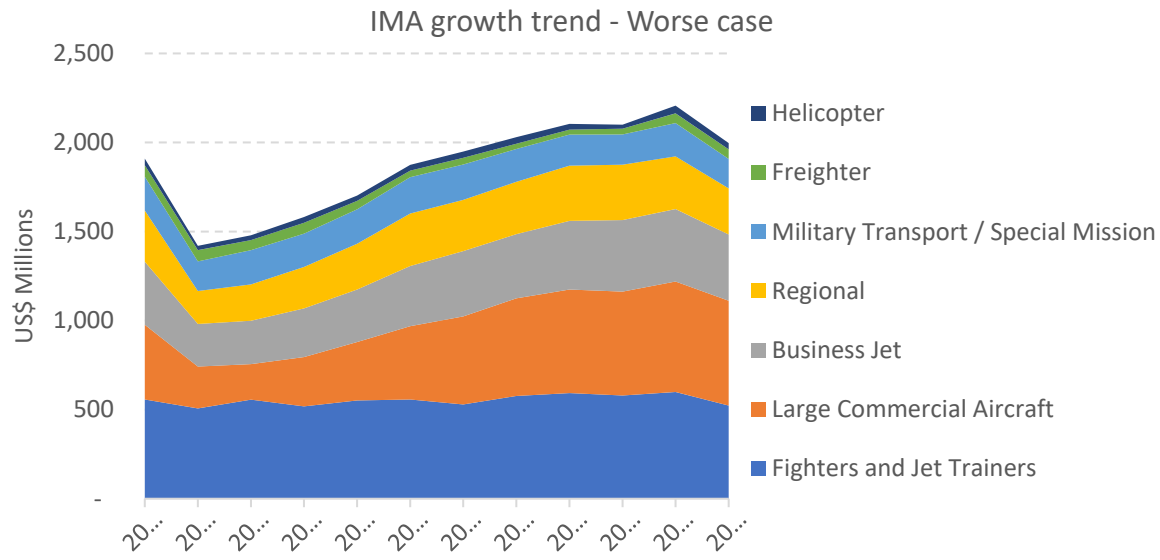


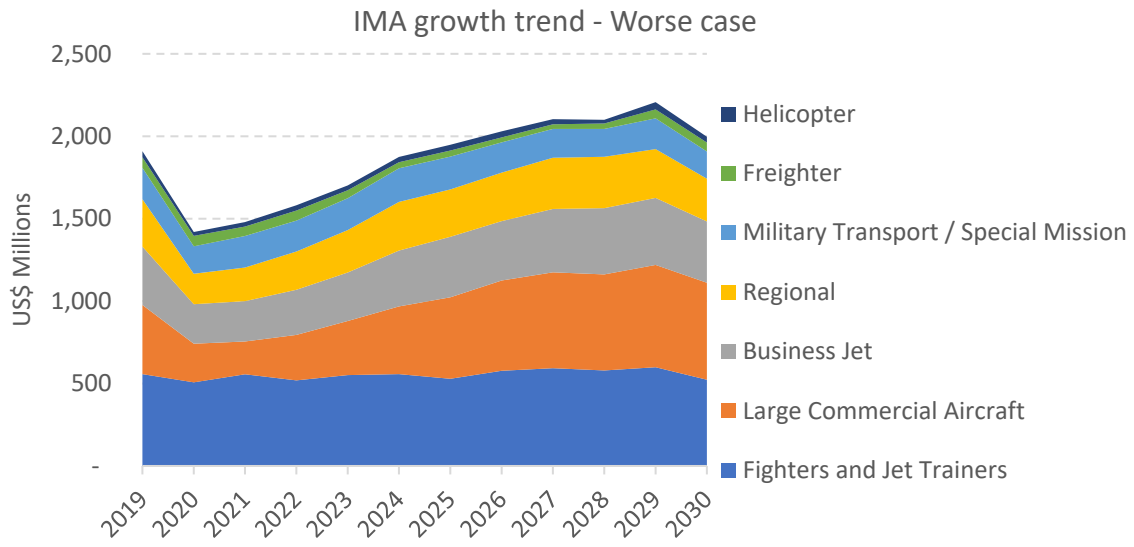


10.1.3. IMA

IMA market $ millions	2019	2020
Business Jet	354	256
Fighters and Jet Trainers	557	509
Freighter	64	63
Helicopter	37	25
Large Commercial Aircraft	420	234
Military Transport / Special Mission	189	167
Regional	287	183
Grand Total	**1,908**	**1,437**

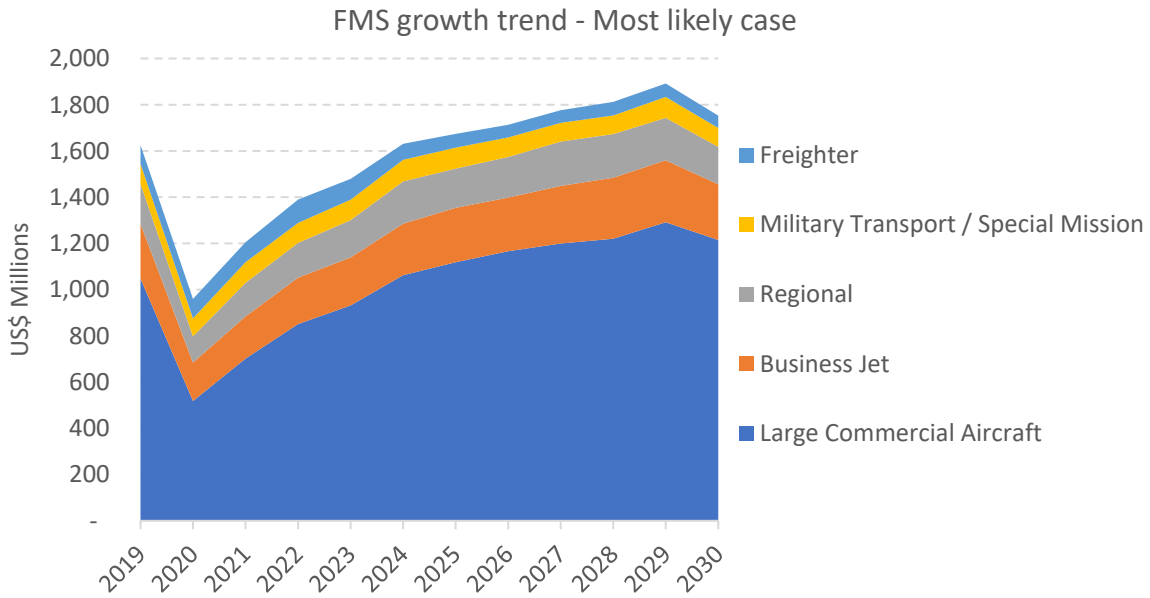


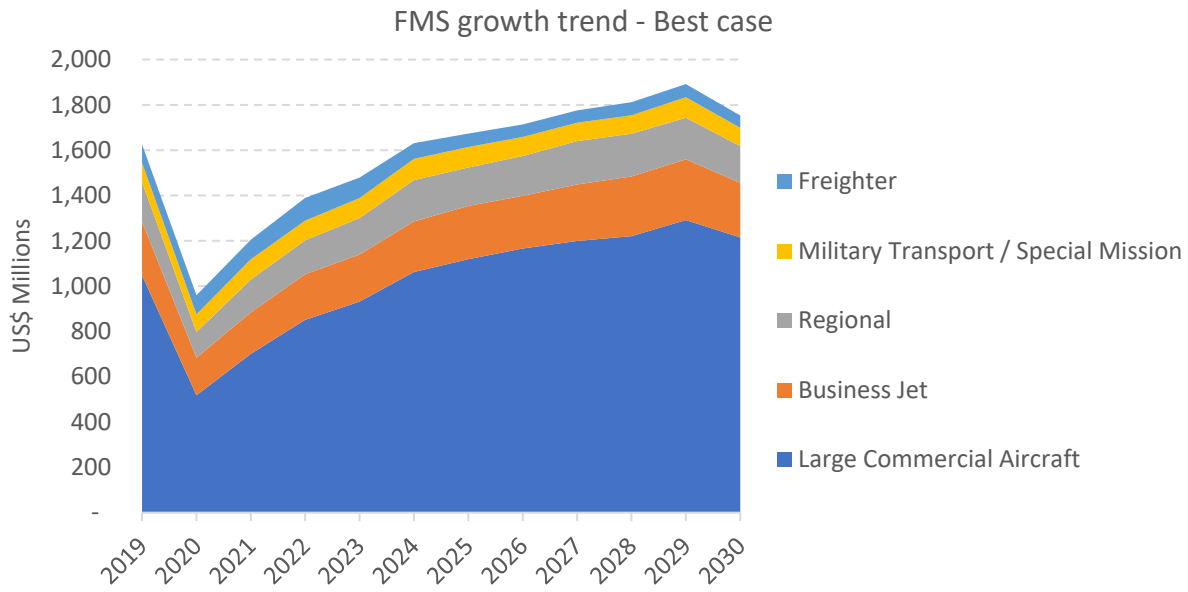


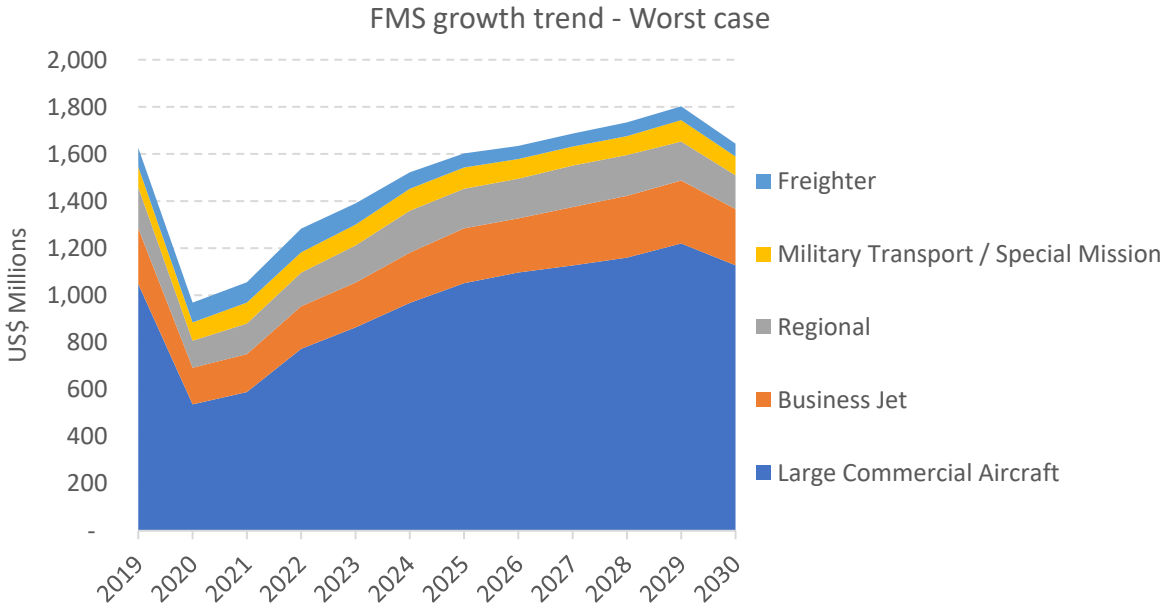


10.1.4. FMS

FMS market $ millions	2019	2020
Business Jet	237	166
Freighter	81	84
Large Commercial Aircraft	1,048	518
Military Transport / Special Mission	86	78
Regional	174	113
Grand Total	**1,626**	**960**



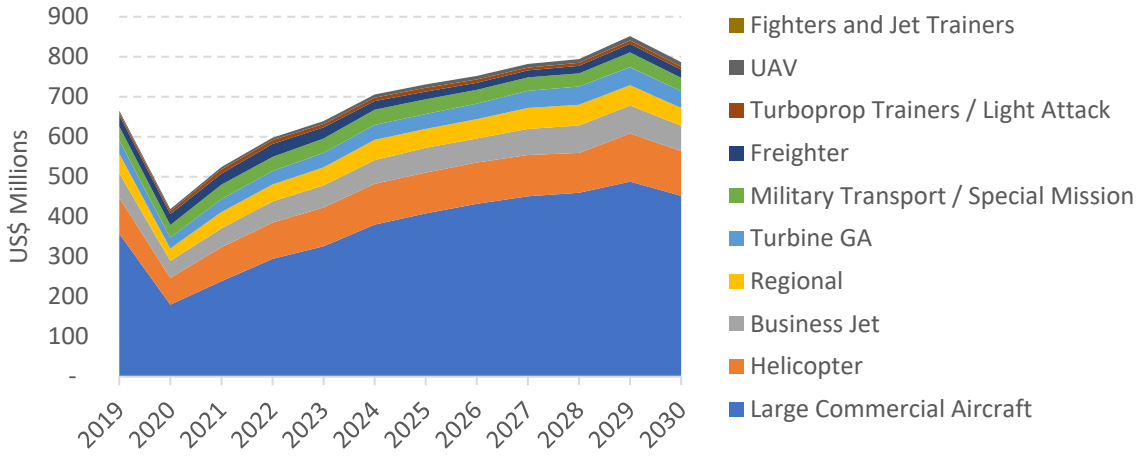




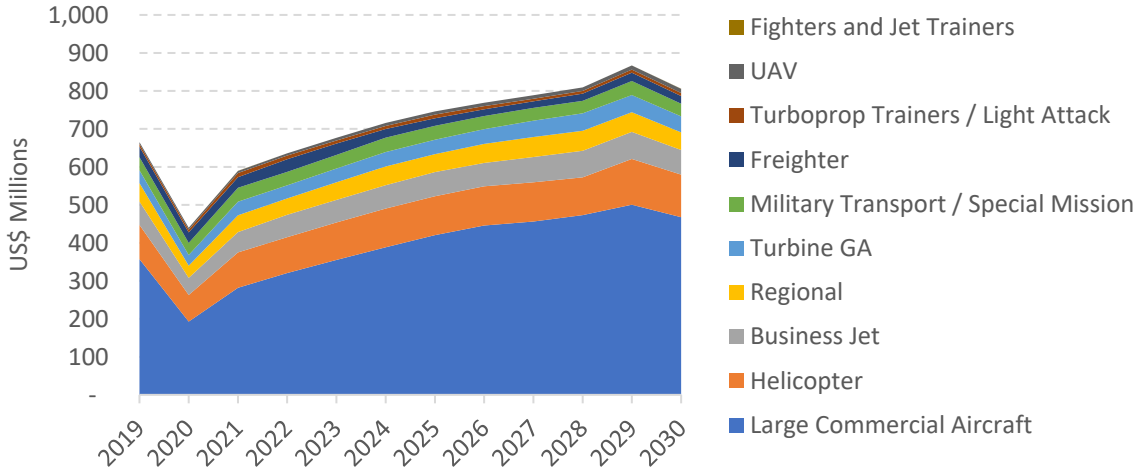
10.1.5. Auto-pilot

Auto-pilot market $ millions	2019	2020
Business Jet	61	43
Fighters and Jet Trainers	0	0
Freighter	28	28
Helicopter	90	67
Large Commercial Aircraft	357	180
Military Transport / Special Mission	35	32
Regional	49	31
Turbine GA	34	27
Turboprop Trainers / Light Attack	7	7
UAV	4	5
Grand Total	**665**	**419**

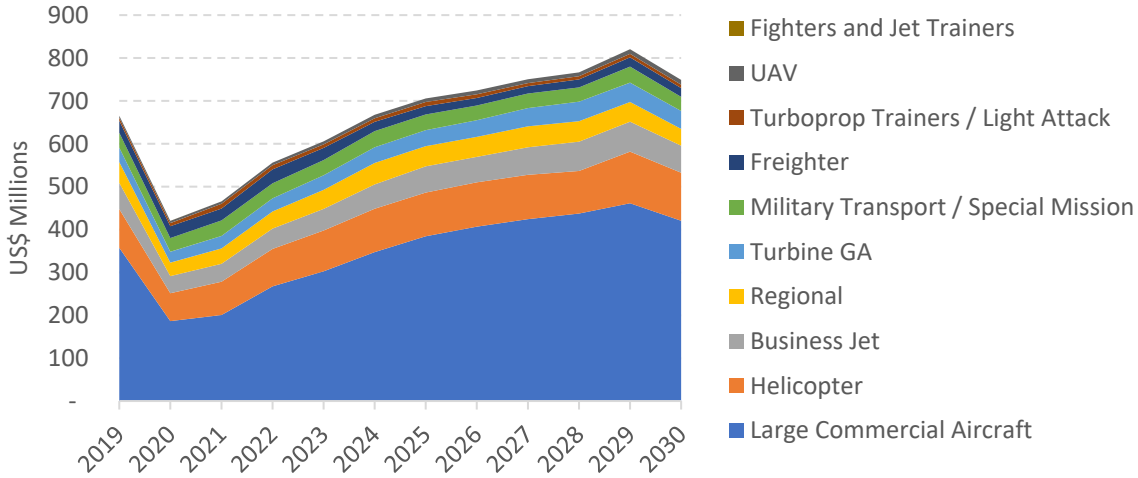
Auto-pilot growth trend - Most likely case



Auto-pilot growth trend - Best case

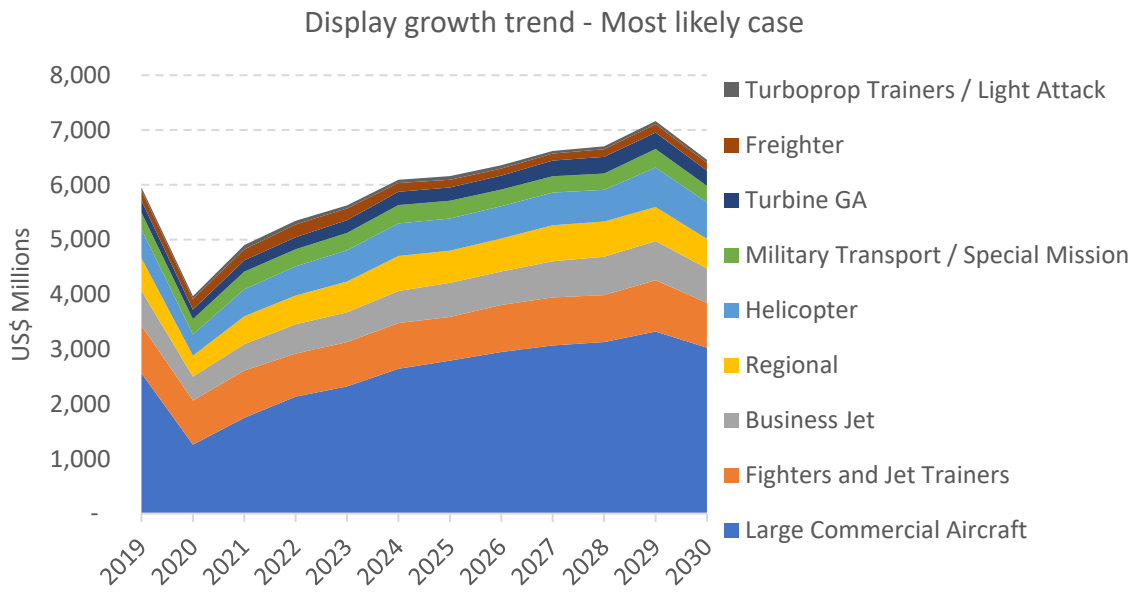


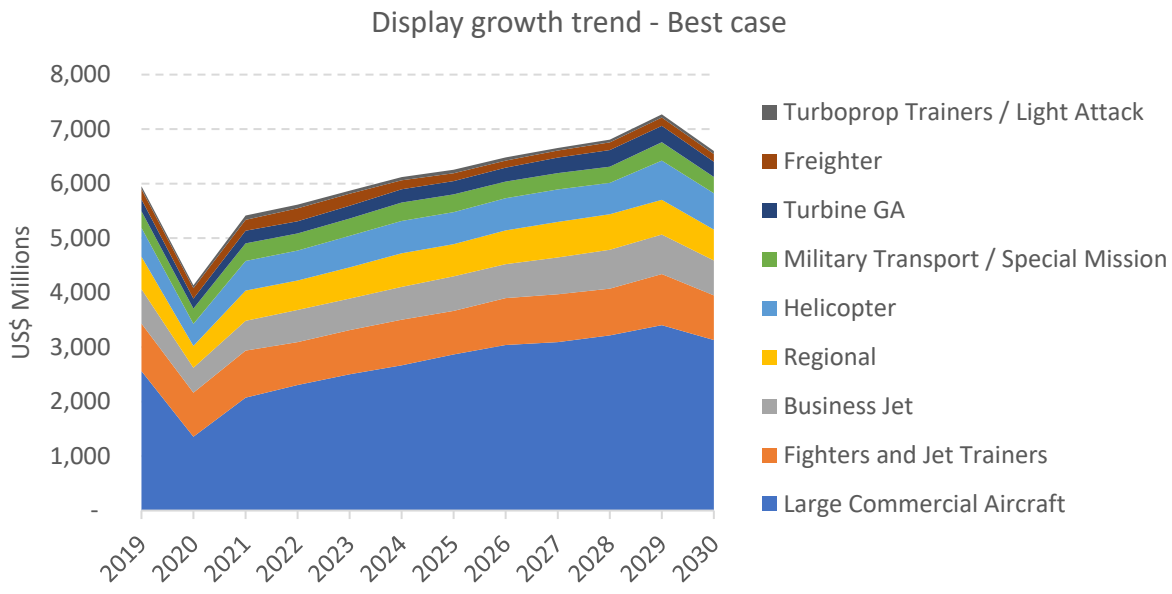
Auto-pilot growth trend - Worst case

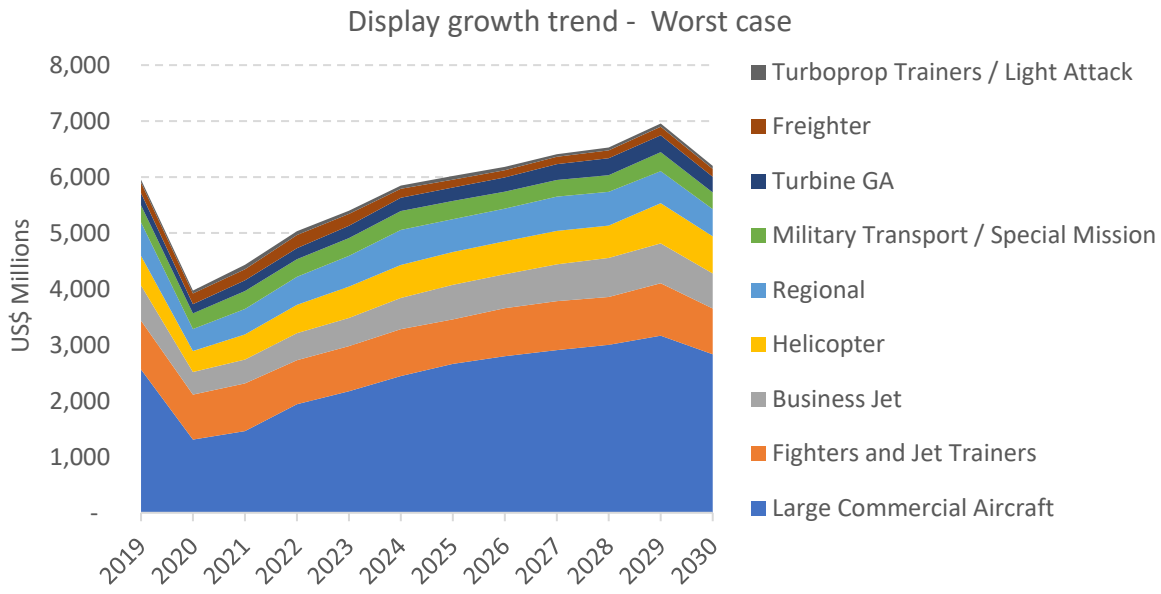


10.1.6. Displays

Displays market $ millions	2019	2020
Business Jet	631	433
Fighters and Jet Trainers	872	807
Freighter	187	191
Helicopter	528	386
Large Commercial Aircraft	2,560	1,257
Military Transport / Special Mission	304	280
Regional	597	385
Turbine GA	220	174
Turboprop Trainers / Light Attack	52	53
Grand Total	**5,951**	**3,968**

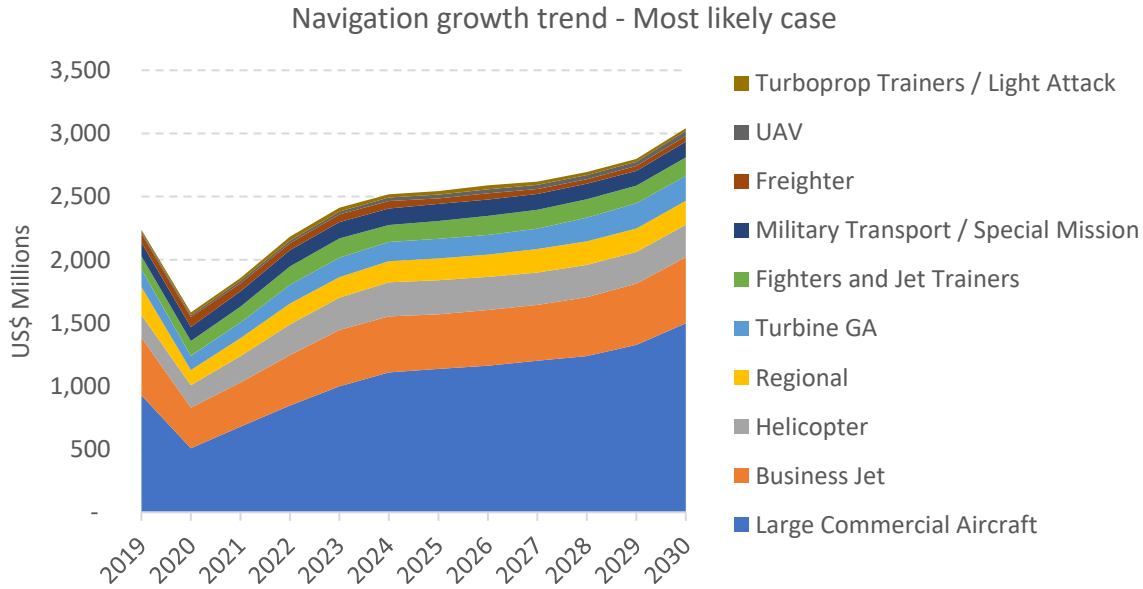


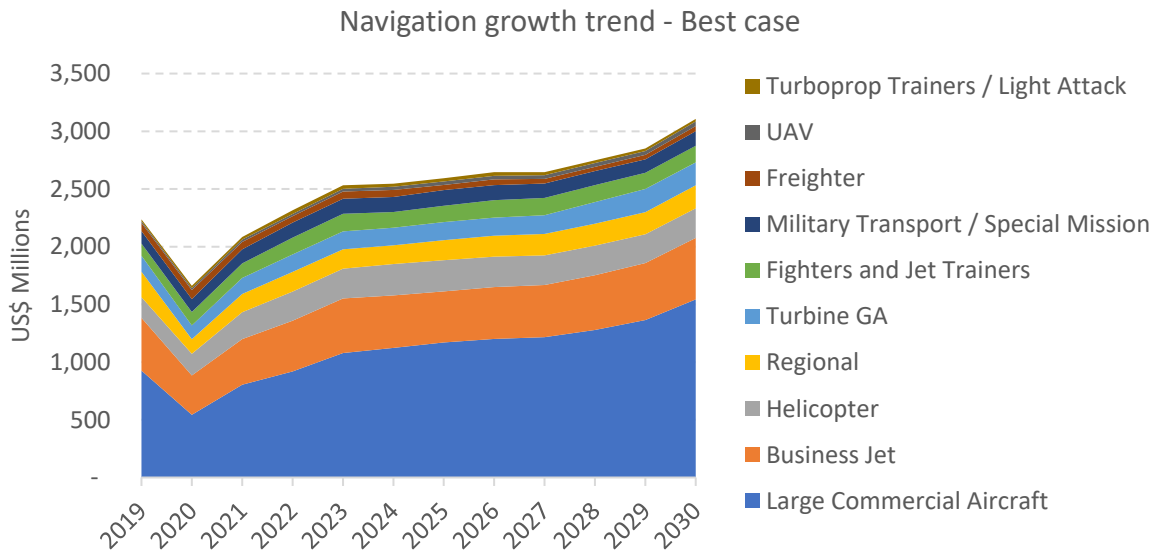


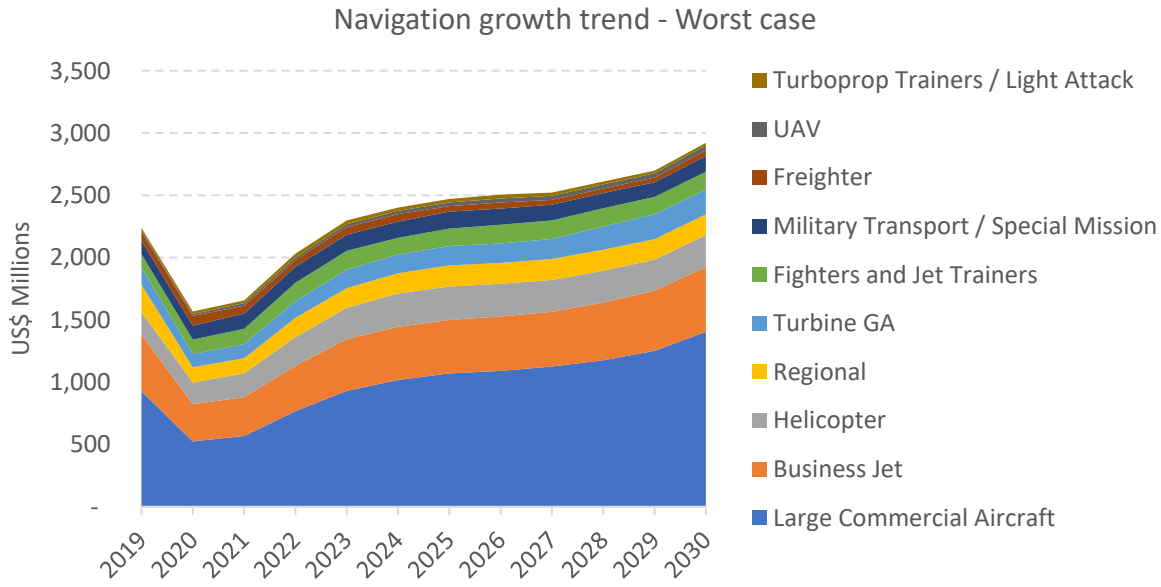


10.1.7. Navigation

Navigation market $ millions	2019	2020
Business Jet	458	322
Fighters and Jet Trainers	105	116
Freighter	70	79
Helicopter	179	178
Large Commercial Aircraft	926	506
Military Transport / Special Mission	109	111
Regional	221	120
Turbine GA	138	114
Turboprop Trainers / Light Attack	16	21
UAV	15	16
Grand Total	**2,237**	**1,582**



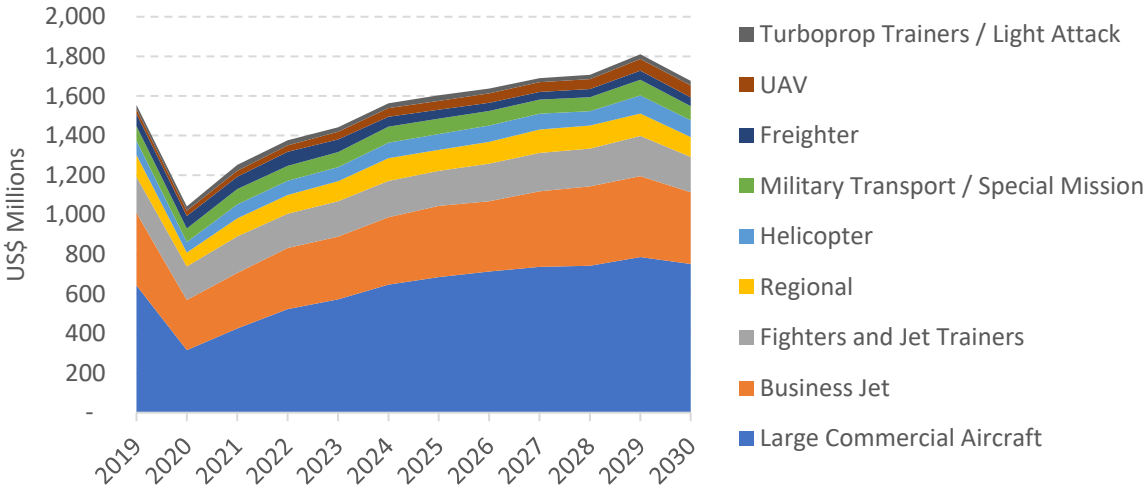




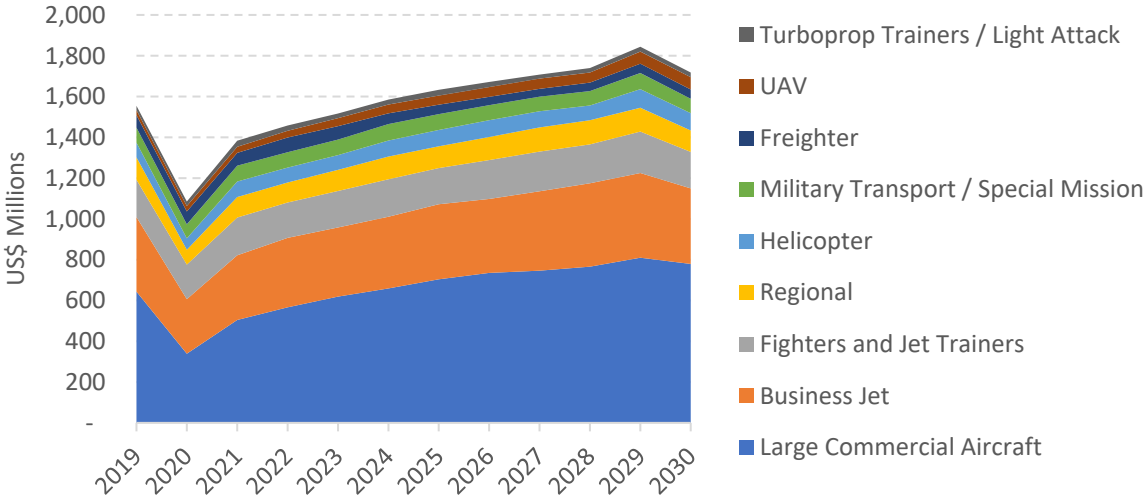
10.1.8. Communication

Communications market $ millions	2019	2020
Business Jet	366	253
Fighters and Jet Trainers	183	169
Freighter	61	63
Helicopter	72	53
Large Commercial Aircraft	643	316
Military Transport / Special Mission	74	69
Regional	110	70
Turboprop Trainers / Light Attack	21	22
UAV	24	27
Grand Total	**1,554**	**1,042**

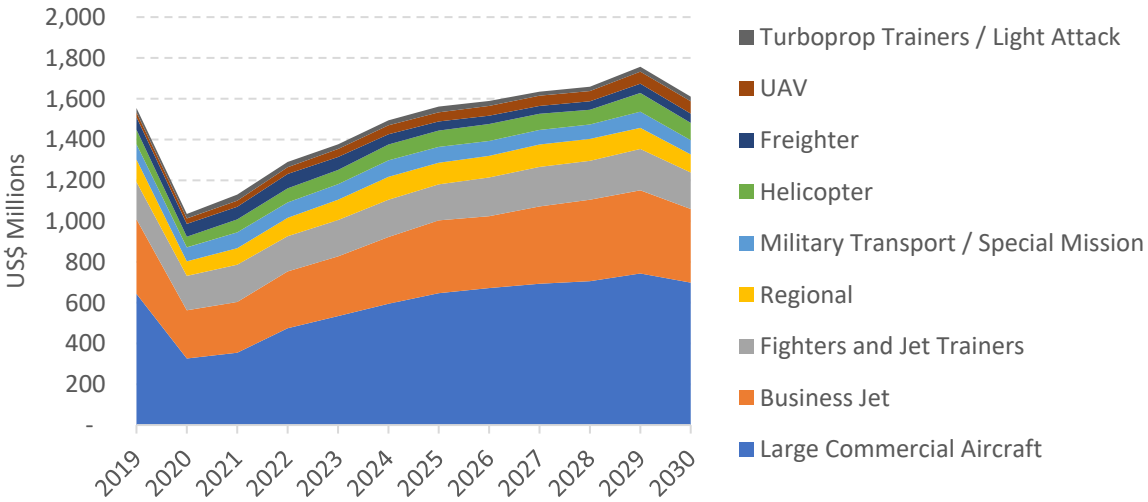
Communications growth trend - Most likely case



Communications growth trend - Best case

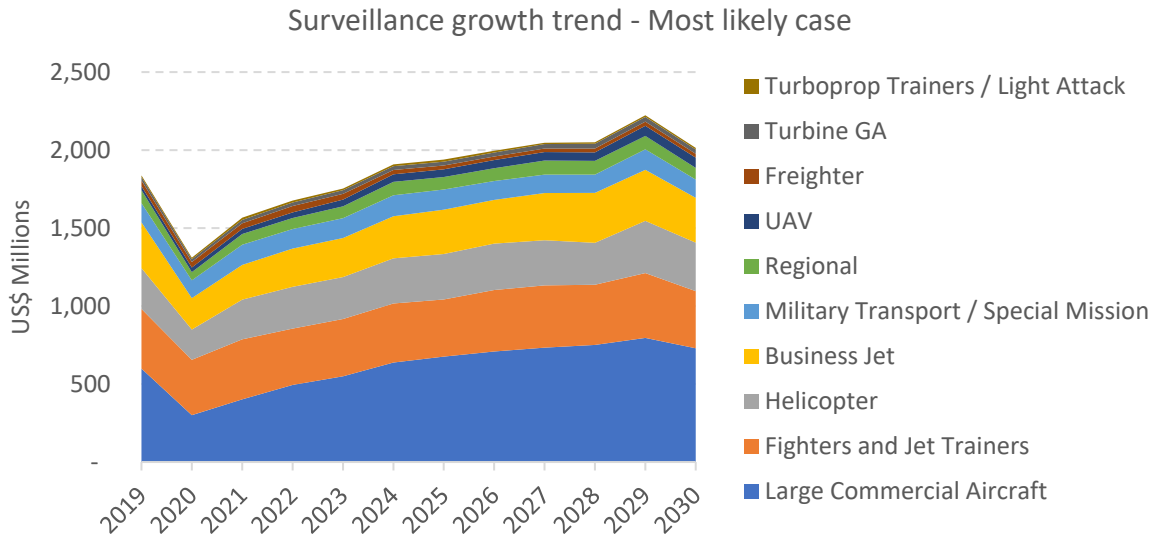


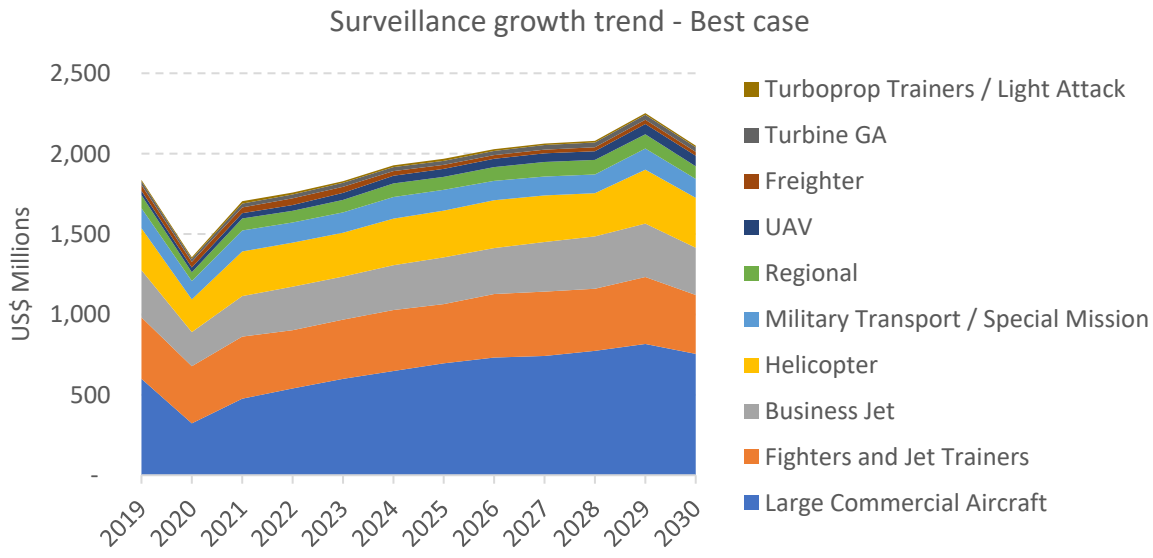
Communications growth trend - Worst case

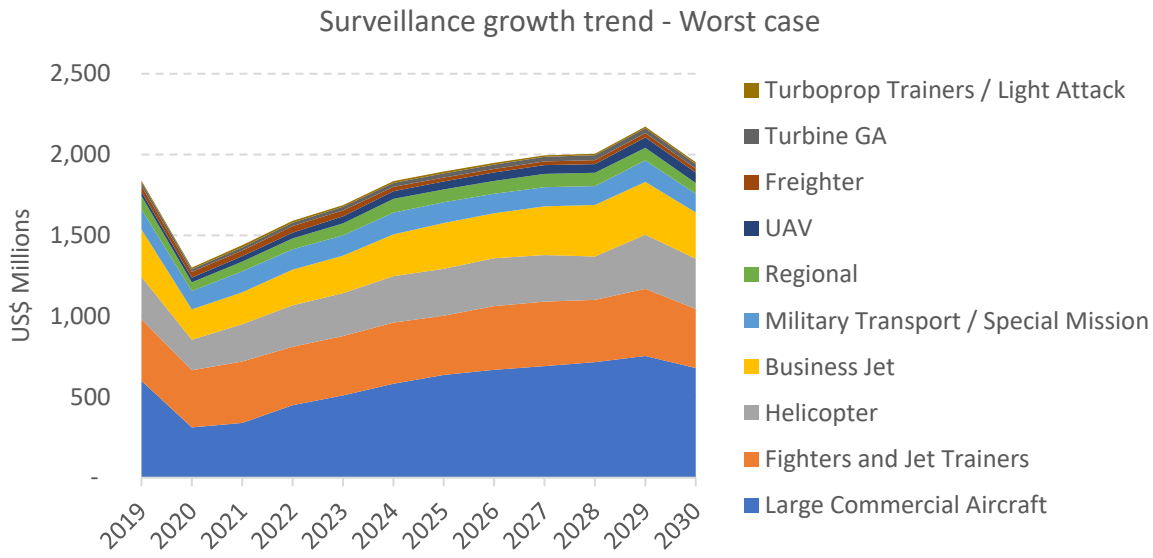


10.1.9. Surveillance

Surveillance market $ millions	2019	2020
Business Jet	293	202
Fighters and Jet Trainers	383	355
Freighter	36	35
Helicopter	261	194
Large Commercial Aircraft	599	301
Military Transport / Special Mission	124	114
Regional	82	53
Turbine GA	23	18
Turboprop Trainers / Light Attack	10	10
UAV	26	30
Grand Total	**1,837**	**1,310**

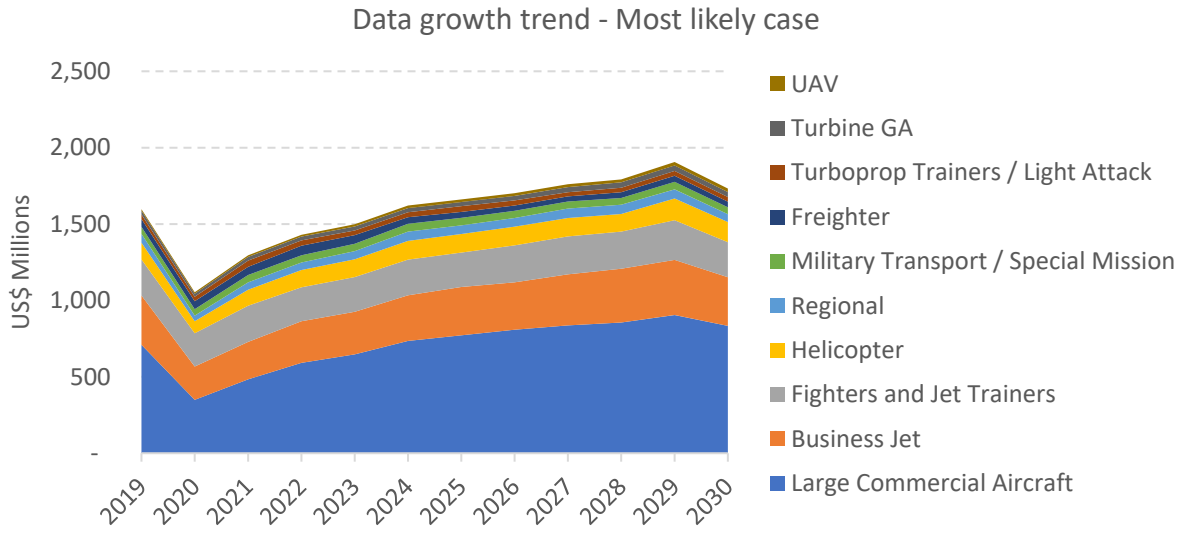


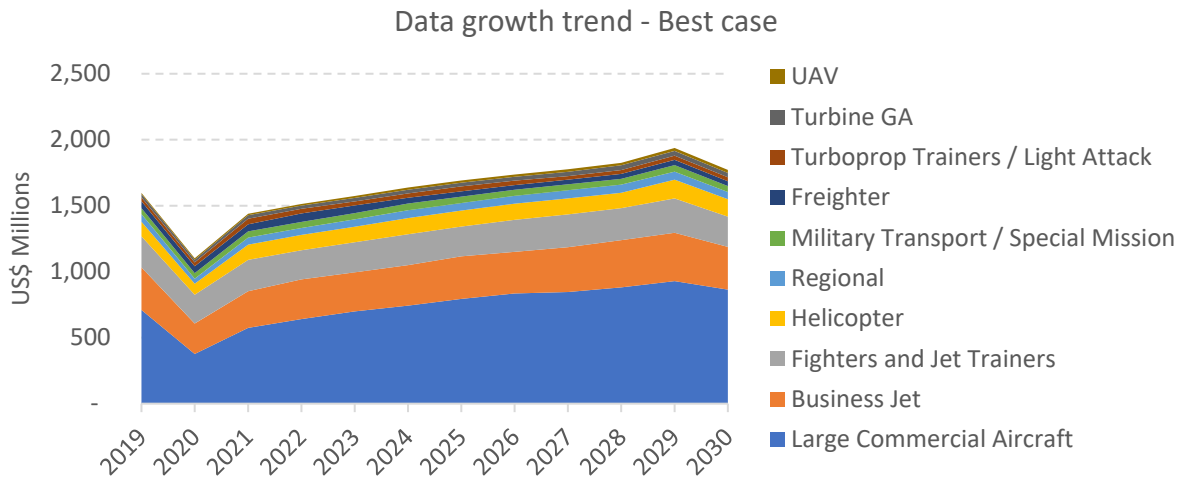


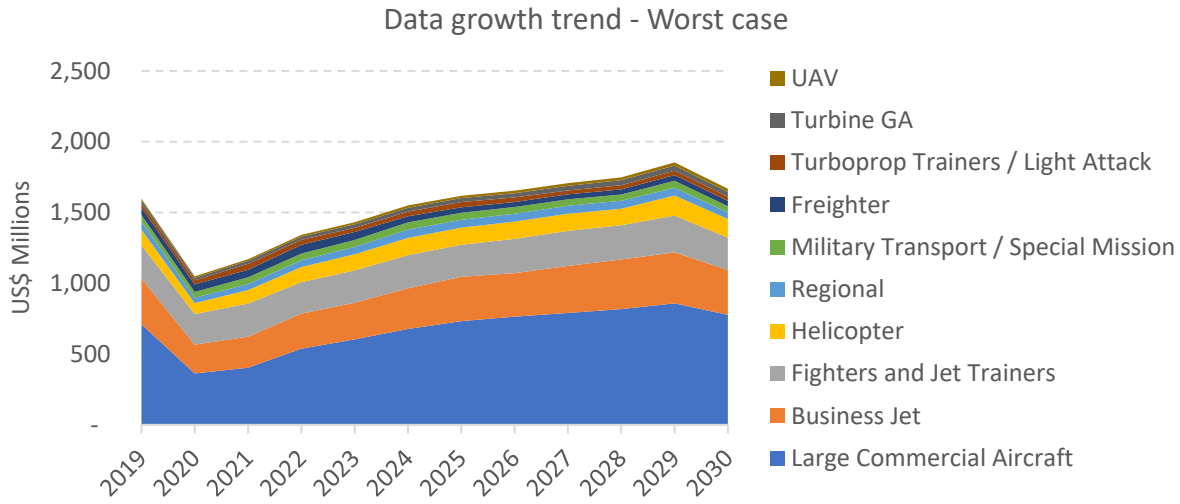


10.1.10. Data

Data market $ millions	2019	2020
Business Jet	323	218
Fighters and Jet Trainers	235	217
Freighter	52	52
Helicopter	110	79
Large Commercial Aircraft	710	349
Military Transport / Special Mission	45	42
Regional	58	37
Turbine GA	25	20
Turboprop Trainers / Light Attack	29	29
UAV	9	10
Grand Total	**1,597**	**1,054**

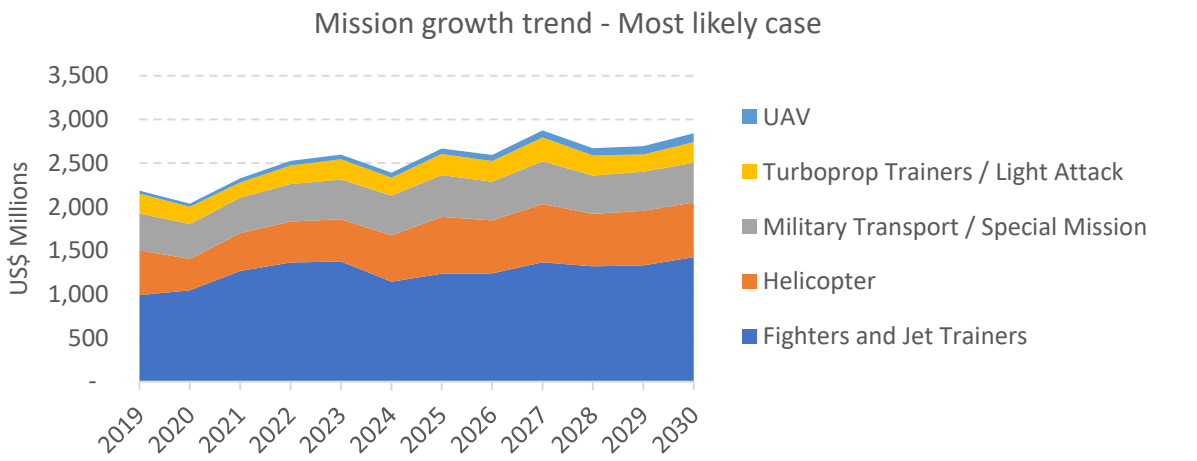


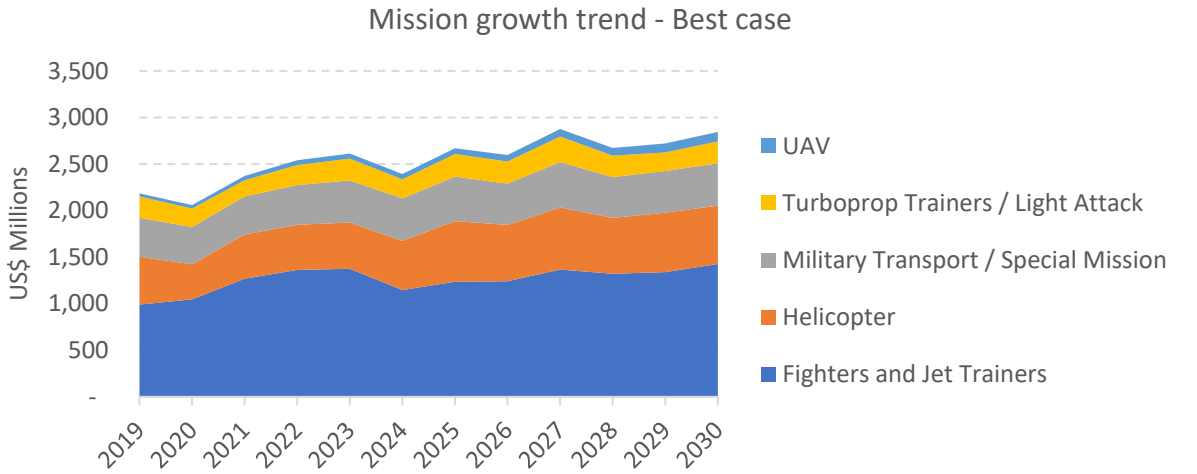


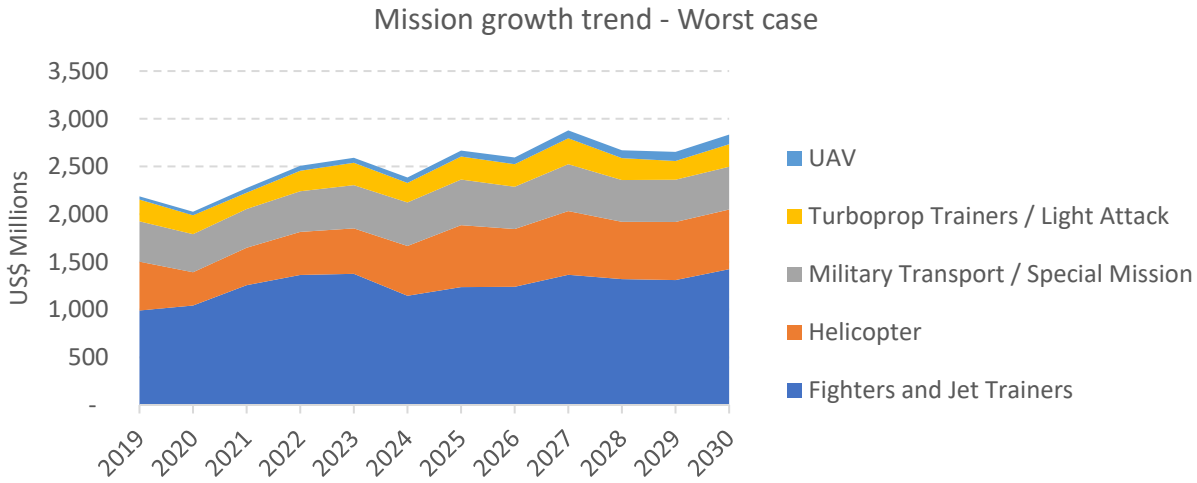


10.1.11. Mission

Mission market $ millions	2019	2020
Fighters and Jet Trainers	990	1,046
Helicopter	513	357
Military Transport / Special Mission	421	400
Turboprop Trainers / Light Attack	228	198
UAV	34	37
Grand Total	**2,185**	**2,038**

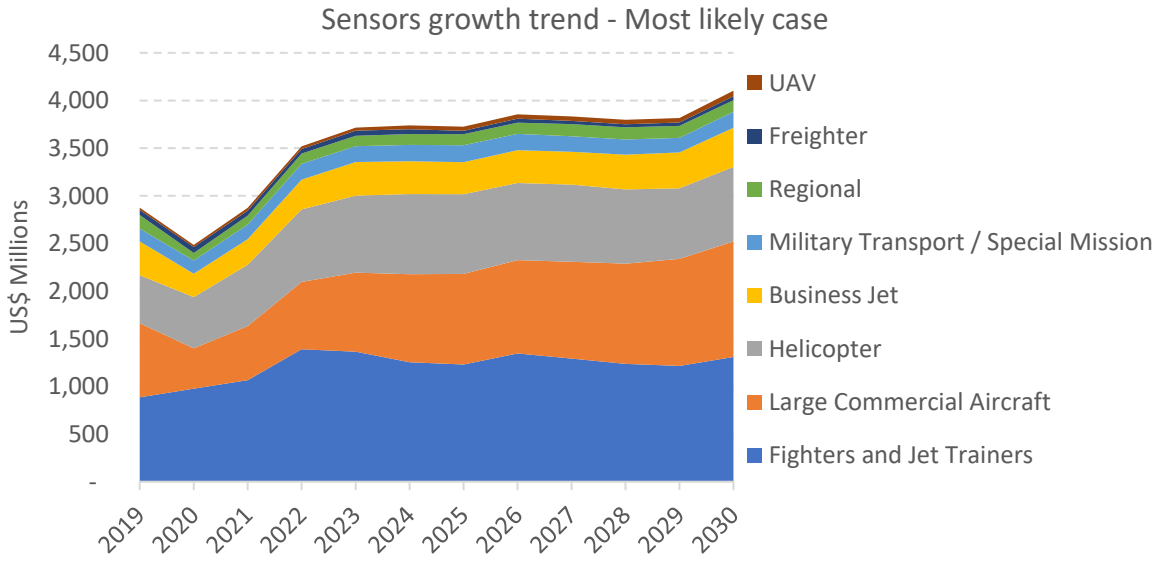


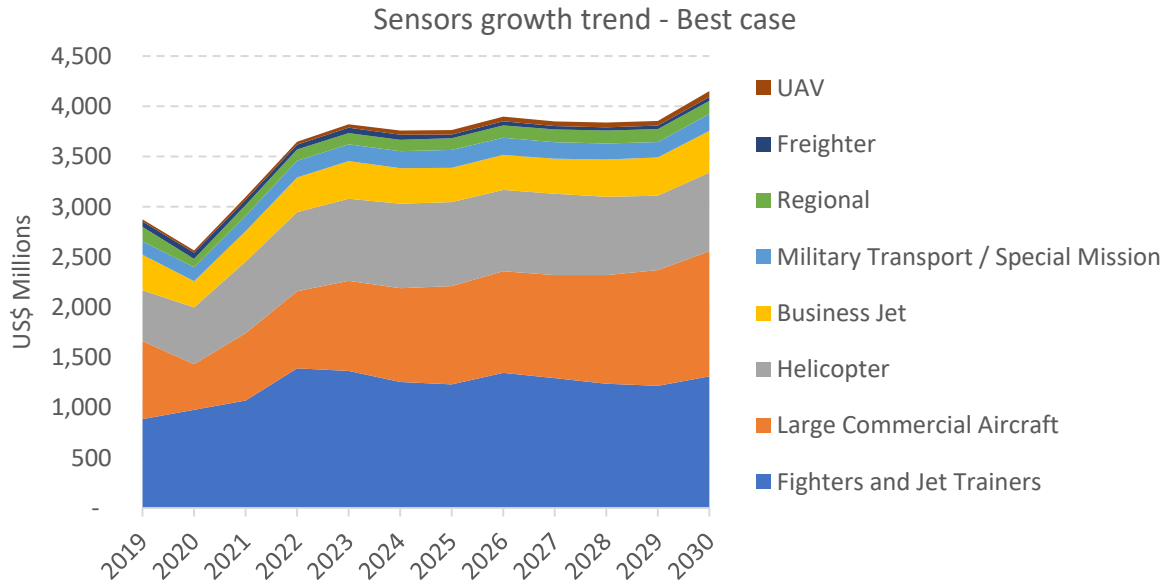


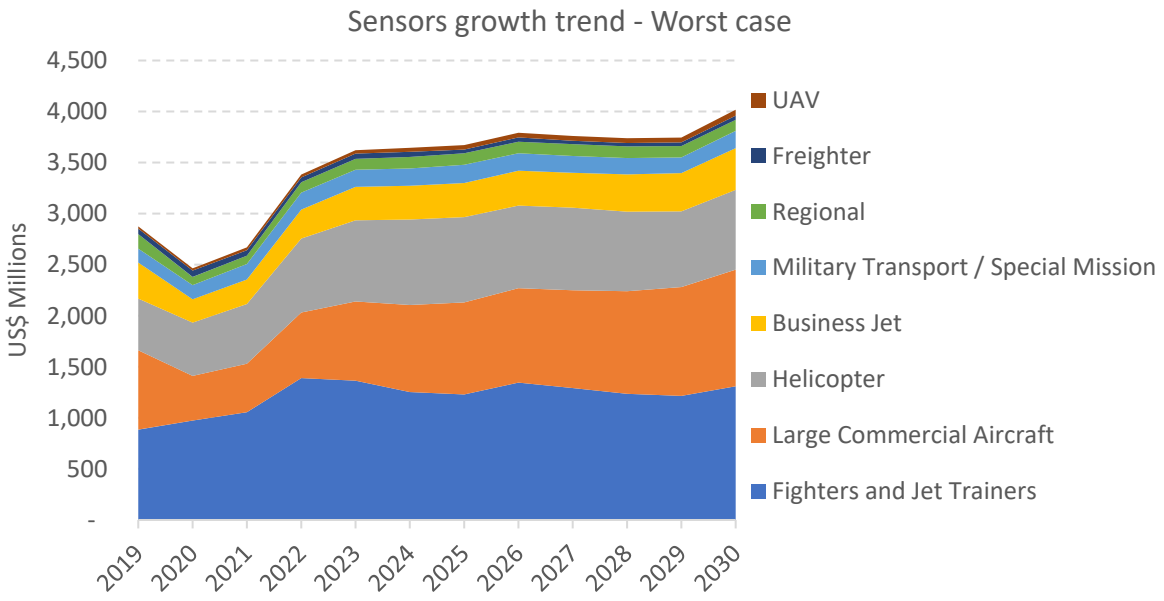


10.1.12. Sensors

Sensors market $ millions	2019	2020
Business Jet	354	246
Fighters and Jet Trainers	885	977
Freighter	54	62
Helicopter	505	537
Large Commercial Aircraft	777	423
Military Transport / Special Mission	134	139
Regional	143	79
UAV	22	23
Grand Total	**2,875**	**2,485**







11. MARKET SHARE ANALYSIS

The market shares in this section are calculated including R&D, Funded work, classified work (Non-OE fit). We also add back in eliminations (sales Tier 2 to Tier 1 to Integrator) so that the sales numbers in the tables reflect actual company sales.

However, this does mean that the market segment totals shown in these tables are greater than those shown in Section 10, which show the total market size and segmentation. The market size estimates are taken from our SQL model, which is linked to aircraft platform OE and aftermarket sales. These do not include funded R&D work and also by definition exclude inert-company sales in the avionics supply chain.

11.1. SUPPLIER CAPABILITY MATRIX

The table below shows the 55 suppliers that we have identified within the avionics sector. We have identified in which product sub-sectors each of these suppliers is a participant (denoted in blue).

AVIONICS SUPPLIERS MATRIX														
			SOFTWARE, DIGITAL	INTEGRATED MODULAR AVIONICS		FLIGHT MANAGEMENT SYSTEM	AUTO PILOT	DISPLAYS	NAVIGATION	COMMUNICATIONS	SURVEILLANCE	DATA	MISSION SYSTEM	SENSORS
Avionics manufacturer		Parent	AV software, EFBs, services	Computing, shared services	RIUs, AfdX, Utils Man't	Computers, MCDUs	Auto throttle	Computing, MFDs, PFDs, HUDs, Standby, Instruments	Inertial, AHRS, ADIRS, Air Data, Doppler, GPS	Radios, Satcom, Datalinks	ADS-B, TCAS, GCAS, EGPWS, Weather Radar, EVS, ISR	Onboard Info Sys, ACMS, FDRs, CDRs, Charts	Mission computing, stores man't, ECM, Data fusion	C4ISR, AESA Radar, Def Aids, DAS, ESM, IFF
ACSS (Thales & L3 JV)	France/US	JV									■			
AEL Sistemas (Elbit)	Brazil	Private						■	■		■		■	
Astronics Corporation	USA	NASDAQ	■							■		■		
AVIC Aviation (Aviage JV with GE)	China	Listed		■	■	■		■				■		
BAE Systems	UK	Listed	■				■				■		■	■
Bharat Electronics	India	listed										■	■	■
Boeing Jeppesen	USA	Listed										■		
CCX Technologies	USA	Private	■											
Cobham Avonics/Mission Systems	UK	PE					■			■			■	■
Collins Aerospace	USA	Listed	■	■	■	■	■	■	■	■	■	■	■	■
Curtiss Wright	USA	Listed							■			■		
Diehl Aerospace	Germany	Family		■	■			■						
Elbit Systems	Israel	Listed						■		■	■		■	■
Ensco Inc	USA	Private	■											
FLIR Systems	USA	Listed									■			■
Garmin	USA	Listed				■	■	■	■	■	■	■		
GE Aviation	USA	Listed	■	■	■	■	■	■	■			■	■	
General Dynamics	USA	Listed	■										■	■
Genesys Aerosystems	USA	Listed					■	■	■	■				
Genova Technologies	USA	Private	■											
Green Hills Software	USA	Private	■											
HAL Hindustan Aeronautics	India	Listed						■	■	■			■	■
Hensoldt GmbH	Germany	Listed									■	■		
Honeywell	USA	Listed	■	■	■	■	■	■	■	■	■	■	■	■
Innovative Systems and Support	USA	Listed				■	■	■	■					
Jewell Instruments	USA	Private						■						
Kontron Inc (S&T Group)	USA	Listed parent	■							■				
L3 Harris	USA	Listed						■		■	■	■	■	■
Leonardo	Italy	Listed							■	■	■		■	■
Lockheed Martin	USA	Listed	■	■				■					■	■
Lynx Software Technologies	USA	Private	■											
Mannarino systems and software	Spain	Private	■											
Meggitt	UK	Listed						■	■					
Mercury Systems	USA	Listed	■	■				■			■		■	■
Moog Avionic Instruments	USA	Listed						■						
Northrop Grumman	USA	Listed	■	■					■				■	■
Performance Software Corp	USA	Private	■											
Radio Electronic Technologies	Russia	Listed								■			■	
Raytheon Intelligence and Space	USA	Listed	■					■		■			■	■
Rohde and Schwarz	Germany	Private								■				
Saab	Sweden	Listed	■	■		■		■		■			■	
Safran	France	Listed					■		■			■		
Sierra Nevada Corporation	USA	Private							■		■		■	
Tecnobit	Spain	Oesia											■	■
Teledyne Technologies	USA	Listed	■							■	■	■		■
Thales	France	Listed	■	■	■	■	■	■	■		■			■
TransDigm	USA	Listed												
Aerosonic	USA	Listed							■					
CMC Electronics	Canada	Listed	■			■	■	■	■		■			
Scio Teq	Belgium	Listed						■						
Ultra Electronics	UK	Listed												■
Universal Avionics (Elbit)	USA	Listed parent				■		■		■	■	■		
Wind River	USA	PE	■											

There are a number of avionics providers that we have identified but not included within this report because they are either small or they largely operate outside of the scope as defined.

A number of these are noted as follows:

- Avidyne Corporation located in FL, USA and focussed upon displays.
- Becker Avionics – located in Germany at Karlsruhe and focussed upon Nav/Transponder products.
- Cuonics GmbH, Germany, provider of avionic services
- Dynon Avionics – located in WA, USA and focussed upon the GA market sector.
- Trimble – located in CA, USA provides GNSS receivers

- uAvionix – located in MT, USA, provides transponders and nav equipment for UAS/UAVs

11.2. OVERALL AVIONICS MARKET

We have analysed the avionics supply chain to provide the market leaders in each of the avionics sub-groups. The first tabulation below shows the overall avionics market leadership by market share percentage based upon their estimated revenues in 2019.

AVIONICS SUPPLIERS - OVERALL	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	4,824	18%	3,495	18%
Honeywell	3,455	13%	2,365	12%
Thales	1,830	7%	1,230	6%
Raytheon Intelligence Systems	1,806	7%	1,871	10%
L3 Harris	1,274	5%	1,150	6%
GE Aviation	1,214	5%	830	4%
Northrop Grumman	1,187	5%	1,225	6%
BAE Systems	883	3%	832	4%
Garmin	735	3%	623	3%
Lockheed Martin	625	2%	590	3%
Others	8,265	32%	4,742	25%
TOTAL	**26,097**	**100%**	**18,953**	**100%**

The pandemic has caused a reordering as commercial sales have been dramatically affected by the Covid-19 pandemic. The commentary below refers to the 2019 market shares as at this stage we view 2020 as an aberration, but it is now clear that commercial sales will take some time to recover.

Collins Aerospace has been considered separately from its sister division, Raytheon Intelligence Systems, as they both tend to operate independently in the two sectors of commercial and defence.

Collins having benefitted from the combination of Rockwell Collins, B/E Aerospace and Goodrich Aerospace in recent years is now the clear market leader we believe.

Honeywell at No 2 has not benefitted from avionic related acquisitions in recent years, however, its organic growth has helped to sustain its position.

Thales believes that it is positioned as No 3 in avionics in the world today which we concur with.

A number of the large US defence contractors then take up the positions by market share.

It is interesting to note that Garmin, a relative newcomer, is now within the Top 10 avionics providers.

11.3. SOFTWARE, DIGITAL SOLUTIONS

We have estimated that the provision of avionic related software and digital services now accounts for 7% - 8% of the total avionics market.

We believe that this is an important growth sector and most of the large avionics suppliers are represented in the table below. The growth is coming from many areas but includes data analytics, data provision, flight planning, maintenance data, configuration control data, training, software upgrades and simulation support.

SOFTWARE, DIGITAL SOLUTIONS	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	300	18%	199	18%
BAE Systems	240	15%	220	20%
Honeywell	220	14%	140	13%
Raytheon Intelligence Systems	140	9%	135	12%
Mercury Systems	115	7%	108	10%
Northrop Grumman	84	5%	78	7%
Thales	50	3%	32	3%
Lockheed Martin	75	5%	65	6%
GE Aviation	70	4%	46	4%
General Dynamics	55	3%	50	5%
Others	278	17%	19	2%
TOTALS	**1,627**	**100%**	**1,092**	**100%**

Many of the smaller software service providers fall outside of the top 10 however, many of these smaller service providers support their customers that are included above.

It is notable that there are a number of new entrants within the supplier matrix (see above) that have not traditionally been active in avionics.

Equally there are a number of major airlines who offer this level of service support to smaller fleet operators. However, these fall outside the scope of this report.

11.4. IMA/COMPUTING PLATFORMS

The tabulation below includes those providers of IMA and avionics computing platforms where 3rd party functions can be hosted.

IMA	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	505	18%	374	23%
Honeywell	435	15%	320	20%
Thales	288	14%	212	13%
GE Aviation	315	9%	230	14%
Northrop Grumman	155	7%	161	10%
Lockheed Martin	125	5%	120	7%
Mercury Systems	75	3%	75	5%
Diehl Avionics	100	5%	70	4%
Saab	45	4%	42	3%
Others	118	17%	14	1%
TOTALS	**2,169**	**100%**	**1,618**	**100%**

We have included allowances for both Collins and Honeywell in respect to their respective ProLine Fusion and Primus Epic offerings although these have not always reflected open architecture approaches or have been designed to host 3rd party functions. They have however utilised modular avionics computing resources that lie at the heart of an integrated avionic cockpit.

The top 6 suppliers have content on Boeing 777, 787, A380, A350, Boeing 777X, F-22, F-35, A400M, G500/600 platforms which all reflect IMA style avionic architectures.

Mercury Systems is a significant supplier of common computing software offering Real Time Operating System (RTOS) partitioning for critical applications.

11.5. FLIGHT MANAGEMENT SYSTEMS

The following lists the top suppliers of Flight Management Systems which includes the Flight Management Computing system, Master Control Display Units (MCDUs), where applicable, and in certain avionics architectures there is a Flight Control interface unit.

The FMS system will also have interfaces with the aircraft navigation systems and the autopilot.

At the lower end of the market suppliers offer an “all in one” FMS unit that includes input interface, nav database, computation, links to the navigation system and auto-pilot etc.

FLIGHT MANAGEMENT SYSTEM	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	500	29%	320	30%
Honeywell	425	24%	255	24%
Thales	335	19%	200	19%
GE Aviation	245	14%	145	14%
CMC Electronics (TransDigm)	60	3%	48	4%
Saab	25	1%	23	2%
Garmin	25	1%	21	2%
Others	108	6%	55	5%
TOTALS	**1,746**	**100%**	**1,067**	**100%**

The top 4 FMS providers are Collins, Honeywell, Thales and GE Aviation that account for 92% of the FMS market sector.

FMS is therefore a consolidated sector which to some degree reflects the significant investment required to develop a full authority FMS and the associated barriers to entry in terms of criticality, safety and performance.

Both Collins and Honeywell benefit from packaging their FMS within their respective ProLine Fusion and Primus Epic avionics offering.

Smaller providers of FMS stand-alone products include Garmin, Universal Avionics, CMC Electronics and IS&S solutions.

11.6. AUTOPILOT SYSTEMS

Autopilot systems are typically linked to the FMS system and the Flight Control System in terms of flight guidance, and to the Engine Controls (FADEC) in terms of engine thrust control.

AUTO PILOT	2019		2020	
Company	Revenues $m	Market share	Revenues $m	Market share
Collins Aerospace	170	24%	117	25%
Thales	115	16%	75	16%
Honeywell	110	16%	70	15%
GE Aviation	65	9%	42	9%
Safran	38	5%	25	5%
Cobham Avionics/Mission Systems	25	4%	20	4%
Garmin	25	4%	21	4%
BAE Systems	20	3%	19	4%
CMC Electronics (TransDigm)	15	2%	11	2%
Genesys Aerosystems	5	1%	4	1%
Others	114	16%	66	14%
TOTALS	**702**	**100%**	**470**	**100%**

The top four suppliers, Collins, Honeywell, GE Aviation and Thales account for 76% of the Autopilot sub-sector within avionics.

Thales has developed a strong position in recent years based upon its position both at Airbus and within the EU military market.

Safran has also developed capability within its Electronic Systems division and arguably benefits from having a strong position within Engine Controls.

Whilst BAE systems divested its avionics business some years ago it retained its auto-pilot capabilities for military applications. BAE also has a strong market position with Engine related FADEC control systems.

11.7. DISPLAYS

Displays represents one of the largest avionics sub-sectors and is a much more fragmented sector in terms of number of suppliers.

DISPLAYS	2019		2020	
Company	Revenues $m	Market share	Revenues $m	Market share
Collins Aerospace	1,350	21%	925	21%
Honeywell	970	15%	650	15%
Thales	638	10%	425	10%
Garmin	360	6%	305	7%
Elbit Systems	294	5%	275	6%
L3 Harris	287	4%	260	6%
Raytheon Intelligence Systems	245	4%	255	6%
GE Aviation	228	4%	150	3%
CMC Electronics (TransDigm)	185	3%	130	3%
Diehl Avionics	150	2%	95	2%
Mercury Systems	105	2%	105	2%
Lockheed Martin	85	1%	80	2%
Others	1,490	23%	683	16%
TOTALS	**6,387**	**100%**	**4,338**	**100%**

Displays includes a wide range of product functions including multi-function displays, primary navigation, electronic flight instrumentation, engine and fuel displays, standby displays and surveillance displays.

Modern cockpits tend to have a much higher level of integration within avionics resulting in fewer large format flat panel displays. As product reliability associated with flat panel LCD technology has improved OEM constructors can rely on fewer larger multi-function formats.

The top 3 suppliers, Collins, Honeywell and Thales represent a combined 53% market share of the display sub-sector.

The display sector has grown in recent years given the need for greater surveillance/situational awareness and the application of HUDs within commercial platforms.

However, in the medium/long-term increasing autonomy and less dependence upon pilots may reverse this trend.

11.8. NAVIGATION

Navigation is one of the major avionic functions requiring a significant level of redundancy and incorporating a number of differing technologies.

Navigation has to encompass a range of needs from inter-continental long haul flights to landing a military platform on a moving surface such as an aircraft carrier.

Consequently, there are a significant number of suppliers within this avionic sub-sector many of whom represent only a fraction of the market.

NAVIGATION	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	550	23%	405	23%
Honeywell	375	16%	270	15%
Northrop Grumman	275	11%	286	16%
L3 Harris	215	9%	195	11%
Thales	150	6%	105	6%
Safran	106	4%	75	4%
GE Aviation	101	4%	70	4%
Garmin	75	3%	64	4%
Curtiss Wright	70	3%	80	5%
CMC Electronics (TransDigm)	60	3%	45	3%
Leonardo	37	2%	35	2%
Aerosonic (TransDigm)	25	1%	20	1%
Others	354	15%	94	5%
TOTAL	**2,393**	**100%**	**1,744**	**100%**

The top 4 suppliers, Collins, Honeywell, Northrop Grumman and L3 Harris account for 64% of the navigation sub-sector in terms of market share.

Northrop Grumman achieved the No 3 position largely due to its acquisition of Litton Industries in 2001.

Navigation technology has evolved in recent decades from mechanical gyros (including RLGs, FOGs) to solid state devices which currently do not always meet the strict performance criteria necessary for primary navigation needs. However, it has allowed new entrants to offer solid state inertial reference units for platforms such as missiles, UAVs, rotorcraft and smaller aircraft.

11.9. COMMUNICATIONS

Radio based communication systems have been around for a century or more and still today are utilised for use in many aircraft.

Software defined radios together with a range of security and encryption means have recently been developed in order to allow safer, more reliable communications.

Data exchange communications systems, such as the industry wide ACARS system, have also been developed by suppliers.

COMMUNICATIONS	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Collins Aerospace	475	28%	400	35%
Honeywell	175	10%	115	10%
Raytheon Intelligence Systems	140	8%	146	13%
Cobham Avionics/Mission Systems	125	7%	95	8%
L3 Harris	89	5%	80	7%
Garmin	75	4%	64	6%
Rohde and Schwarz	75	4%	70	6%
Saab	65	4%	60	5%
Radio Electronic Technologies	55	3%	37	3%
Teledyne Controls	36	2%	26	2%
Others	360	22%	60	5%
TOTAL	**1,670**	**100%**	**1,153**	**100%**

Collins Aerospace (Rockwell Collins) can trace its roots back 80 or more years to early airborne radios. Honeywell, via its Bendix King subsidiary, also has a long history within airborne radio communications.

Raytheon, Cobham and L3Harris have developed satellite-based security encrypted communications solutions for the defence market. Securitising transmitted data has taken on greater importance in recent decades within the military arena in order to avoid terrorist interference. These 3 companies also support commercial platforms where the threat of terrorist interference has increased in recent years.

Specialist communications providers such as Rohde and Schwarz and RET continue to develop software based digital communications solutions.

11.10. SURVEILLANCE

We elected early on in the design of this report to include Surveillance as a significant sub-sector given that it represents a significant growth path for suppliers. The emphasis upon improving situational awareness and reducing pilot workload all ties back to safety and survivability.

Within the past two decades there has been a number of airworthiness mandates directly related to surveillance (i.e. RVSM, TCAS, EGPWS). Operational efficiencies require that operators can complete a mission in reduced visibility and poor environments hence the proliferation of Enhanced Visual Systems (EVS) and Weather Radar systems.

SURVEILLANCE	2019		2020	
Company	Revenues $m	Market share	Revenues $m	Market share
Collins Aerospace	387	19%	285	20%
Honeywell	315	16%	225	16%
Thales	194	10%	135	9%
L3 Harris	176	9%	155	11%
Garmin	125	6%	106	7%
Hensoldt GmbH	120	6%	110	8%
Leonardo	110	5%	105	7%
ACSS (Thales & L3 JV)	89	4%	62	4%
BAE Systems	103	5%	98	7%
Teledyne Controls	46	2%	34	2%
Others	344	17%	135	9%
TOTAL	**2,009**	**100%**	**1,450**	**100%**

Given the note above many suppliers have developed a range of avionic product solutions to help operators improve efficiencies, safety and mission reliability.

This sub-sector is more fragmented as it has spawned a number of discrete solutions many of which can be retrofitted to existing aircraft.

We believe that the ratio of retrofit to OE forward fit revenues is in the order of 55%/45% in recent years.

The top four suppliers, Collins, Honeywell, Thales and L3Harris represented 55% of the surveillance sub-sector in 2019.

11.11. DATA

Data is a sub-sector that can be difficult to define in terms of hardware and software (i.e. data service providers).

Airborne data can be navigation based, communication based, maintenance based and analytically based in terms of say aircraft operating efficiencies.

Within the military field multiple data sources result in "data fusion" which is required as part of an effective network-centric operating arena.

Within this report we have included airborne avionic related data loaders, avionic data networks, data recorders, Quick Access Recorders (QARS) and data concentrators to fall within scope.

DATA	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Boeing Jeppesen	400	19%	205	18%
Collins Aerospace	270	16%	195	17%
Honeywell	205	10%	140	12%
Curtiss-Wright	150	9%	140	12%
L3 Harris	120	6%	105	9%
GE Aviation	102	6%	70	6%
Garmin	50	5%	42	4%
Hensoldt GmbH	45	4%	41	4%
Safran	45	5%	30	3%
Astronics Corporation	41	2%	29	3%
Others	254	17%	154	13%
TOTAL	**1,671**	**100%**	**1,151**	**100%**

The inclusion of Boeing Jeppesen, as a data service provider, can be debated however we note that a number of FMS/NAV providers including Collins, Honeywell and GE Aviation all provide data services necessary to support their hardware.

This one exception aside all of the suppliers identified within the table above provide avionic data hardware in its many forms (e.g. voice data recorders, flight data recorders, data loggers, data transfer terminals, data storage, data concentrators, quick access recorders etc).

If we look at the top 4four data hardware suppliers, Collins, Honeywell, Curtiss-Wright and L3 Harris they account for 47% of the revenues in 2019, which suggests that this is a relatively fragmented sub-sector.

11.12. MISSION SYSTEMS

In compiling this report, we have adopted a broad definition of mission systems to include mission (command and control), stores management, electronic warfare, threat detection, countermeasures, and surveillance.

MISSION SYSTEM	2019		2020	
Company	**Revenues $m**	**Market share**	**Revenues $m**	**Market share**
Raytheon Intelligence and Space	346	14%	360	17%
BAE Systems	340	14%	325	15%
Northrop Grumman	325	13%	338	16%
Lockheed Martin	215	9%	205	9%
L3 Harris	167	7%	155	7%
General Dynamics	130	5%	123	6%
Collins Aerospace	107	4%	95	4%
Cobham Avionics/Mission Systems	89	4%	83	4%
GE Aviation	88	4%	77	4%
Saab	84	3%	79	4%
Honeywell	80	3%	65	3%
Elbit Systems	75	3%	70	3%
Leonardo	59	2%	56	3%
Others	375	15%	137	6%
TOTAL	**2,480**	**100%**	**2,168**	**100%**

The top four suppliers account for 53% of revenues in 2019, which we would expect within the military sector where one might expect greater national fragmentation.

Notwithstanding this we note that the above suppliers appear regularly as main suppliers on platforms that are either multi-national or enjoy significant foreign military sales (e.g., F-35, F-18, F-15, F-16, C-130J, Apache AH-64, A400M, Chinook, Blackhawk).

Raytheon Intelligence Systems does not have the distraction of being a platform constructor which we believe helps it to be the No 1 supplier within mission systems.

BAE Systems has a strong presence in the US and therefore ranks 2nd in this sub-sector.

Both Honeywell and Collins, who dominate many of the commercial sub-sectors, appear much lower in the military rankings.

Northrop Grumman, Lockheed Martin, L3Harris and General Dynamics are all strongly positioned as US defence contractors within mission systems.

11.13. SENSORS

We believe that the lines that differentiate sensors from avionics are becoming heavily blurred and that sensor development is a key enabler of avionics performance.

Communications, Navigation and Surveillance are able to deliver improved performance and reliability thru the advancement of sensor technologies. Equally we see sensor technology becoming digitised (solid state) and smart (e.g., AESA radar, Air data modules).

Within this report we have defined sensors to include air data, radar, infra-red, electro-optical, inertial, lasers, and cameras/videos. We have not included basic generic sensors for position, pressure, temperature, etc.

SENSORS	2019		2020	
Company	Revenues $m	Market share	Revenues $m	Market share
Raytheon Intelligence and Space	975	30%	975	36%
Northrop Grumman	348	11%	362	13%
L3 Harris	220	7%	200	7%
Collins Aerospace	210	6%	180	7%
BAE Systems	180	6%	170	6%
Honeywell	145	4%	115	4%
Lockheed Martin	125	4%	120	4%
General Dynamics	120	4%	113	4%
Mercury Systems	85	3%	95	4%
Elbit Systems	80	2%	75	3%
Cobham Avionics/Mission Systems	70	2%	65	2%
Thales	60	2%	46	2%
Others	625	19%	186	7%
TOTAL	**3,243**	**100%**	**2,702**	**100%**

The top four suppliers Raytheon, Northrop Grumman, L3 Harris and Collins accounted for 57% of total revenues generated within this sub-sector in 2019.

Raytheon is a clear market leader with sensors developed for all sectors of the military market including missiles, UAVs, rotorcraft, fighters, trainers and military transport.

Collins benefitted from the acquisition of Goodrich which had a market leading position in air data sensors.

Mercury Systems is a provider of software solutions that further emphasises the fact that sensors are becoming digitally controlled and often encapsulate ‘smart’ peripheral capabilities.

12. MARKET DYNAMICS

12.1. OEM CONSTRUCTOR FORWARD FIT

OEM constructors clearly have a vested interest in ensuring that their platforms, designed for 60,000 landings or 30, 40, or 50 years of in-service operation, can be maintained throughout the life cycle. Within avionics, where computing resources can become obsolete every 5 - 10 years, the challenge for the OEM becomes significant. Equally, the OEM has to deal with the ever changing regulatory environment, which is largely concerned with maintaining safety in ever more congested airspace.

Thus, the OEM constructors need to take into account all of the above factors when designing and certificating their chosen avionics architecture at the outset (as the componentry and products will likely change several times through the life cycle value of the asset).

OEM constructors’ approaches to the sourcing and development of Avionics varies greatly depending upon the role of the platform, performance requirements and affordability issues.

Some 'common threads' facing OEMs that we see across most sectors are summarised as follows:

- The role of the OEM specifier vs that of the Avionic provider: OEMs have overall responsibility for 'integration and certification' of the platform. However, they are highly dependent upon the Avionic integrator. We see OEMs 'branding' their cockpits, but the avionics remain ProLine Fusion (Collins), Primus Epic (Honeywell) or similar derivatives.
- The drive to reduce cost of ownership via the adoption of 'open computing' architectures. This allows for modifications and upgrades in service by customers without incurring significant 3rd party costs.
- Avoidance of built-in obsolescence issues at the avionics design stage – i.e., life cycle ownership issues.
- Greater drive for the adoption of common industry standards/COTS approach to sourcing Avionic-related software and firmware e.g., rotorcraft, business jets, GA, small regional aircraft.
- Commercial OEMs limiting the amount of Buyer Furnished Equipment (BFE) associated with cockpit avionics (which results in dual certification costs) – i.e., affordability issues.
- Concerns over security, cyber-attacks and data abuse within an increasingly networked digital operating environment – i.e., safety, security.
- Provision for greater overall autonomy of the platform operating within a networked environment (e.g., independence from ATC, data fusion within battlefields, office in the sky, health and usage monitoring in real time)

In 2019 the aviation trade body International Air Transport Association (IATA) listed its top seven trends within Aviation which included 'cockpit connectivity'.

This 'cockpit connectivity' covers a wide range of communications, networks and data linkers via satellite, ATC etc. allowing OEMs to plan for the necessary infrastructure to support increased demands for In Flight Entertainment (IFE), 'office in the sky' services, exchange of real time maintenance data and autonomous data for decision making purposes.

Civil OEM constructors also have a role to play in maintaining/upgrading their in-service and forward fit avionics throughout the respective platform life cycles. Much of this is through necessity i.e., mandated and/or regulatory changes and partly it is to ensure that they maintain sales through offering a competitive product that is not limited by avionics obsolescence issues.

Boeing for example offers an Avionics upgrade service as part of Boeing Services. Boeing delivers more than 600 avionics Service Bulletin (SB) solutions every year, which it claims, are preferred by regulators over more restrictive supplemental type certificate (STC) solutions. Boeing SB solutions also integrate technical publications, maintenance-related documents, and airworthiness artefacts in a manger that minimises additional recurring maintenance tasks.

Boeing claims the following benefits are available via its Boeing Avionic Support Services business:

- Gain efficiency by navigating the best route from airport to airport in all weather conditions.
- Increase awareness and satisfy regulatory requirements with surveillance solutions that include ADS-B Out, TCAS, and MMR.
- Increase pilot effectiveness with the same heads-up and large-display systems used on the 787 Dreamliner.
- Meet emerging needs with our world-class, 24/7 customer and technical support.
- Asset value retention with Boeing solutions for leased aircraft.

Airbus similarly offers Avionics support services that are geared to maintaining airworthiness, type approval etc. They focus upon 'air traffic management' services with the following specific examples on offer:

- Communication: data link & SATCOM needs with FANS A+/B+, Iridium or Inmarsat solutions
- Navigation: optimised flight paths with RNP-AR
- Surveillance: collision avoidance and automatic data broadcasting with the ADS-B Out.

Like Airbus and Boeing other commercial OEMs, including business jet and regional manufacturers, also have a vested interest in maintaining their avionic suites to current standards.

The asset value of an aircraft is dictated by a number of factors including usage but also by having the latest standard of avionics fitted. All leaseholders and financial institutions that deal with second-hand aircraft place significant emphasis upon the standard of avionics fit having been maintained to current industry standards.

Equally many leaseholders, operators and end-users have a preference for aircraft that have avionics upgrades designed and approved by the OEM provider as holder of the original certification approvals (as opposed to an upgrade via an STC or 3rd party product installer).

The OEM constructor may undertake the installation of the new avionics themselves or, as is often the case, will work with an approved 3rd party such as Honeywell, Collins Aerospace, Lufthansa Technik etc.

Within the military arena, the emphasis for OEM constructors is often driven by the national budget process that dictates the success or otherwise of platforms that are expected to operate for decades in service. Budget reviews can increase, decrease or discontinue platform budget allocations.

Military programmes can be summarily cancelled at differing stages of development or heavily curtailed in production as has happened in recent decades (e.g., Nimrod, CAH66 Commanche, IAI Lavi, Grumman XP50, F-20 Tigershark, General Dynamics F111-B).

OEM constructors within the military sector find it necessary to actively participate within the prevailing geo-political arenas that can have a significant impact upon their YoY investment needs.

The larger military OEMs will typically spend considerable time and resources canvassing local government bodies regarding R&D needs, local employment needs, security of Intellectual Property, investment needs, national security needs etc.

Equally the same OEMs will need to look beyond their national boundaries to locate risk-sharing partners in seeking to develop new platforms.

Recently Boeing teamed with Saab to offer the USAF a new trainer, now designated T-7A, which resulted in the award of a $10 billion contract for up to 2,000 aircraft. Embraer elected to partner with Boeing in 2012 in order to develop its C-390 Millennium military transport plane although in 2019 Boeing pulled out of this partnership due to internal issues. The Airbus-led consortium for the A400M involves 8 national partners all of whom are risk sharing and are committed to purchasing varying numbers of the aircraft.

Military OEM constructors will often take an active role in upgrading their initial fit avionics computing and sensor suite in order to maintain performance and to continue to attract Foreign Military Sales (FMS). This is clearly the case with, for example, F-35, C-130J, Apache AH-64, Typhoon, which all have significant sales potential outside of their countries of origin.

One aspect of large defence OEM constructors, both at the airframe and the avionic/electronics level, is the degree to which we found similar levels of profitability across many of the suppliers. This level of profitability was consistently within the 10% – 12% range and we believe that this may well reflect the ‘open book’ accounting policies dictated by the large defence consumers e.g., US DoD, USAF, USN, US Army. This open book cost-plus policy applies to suppliers at Tier 1 and Tier 2 levels and can constrain levels of profits that can be realised from military contracts.

Both civil and military OEM constructors work very closely with major avionic providers such as Honeywell, Collins Aerospace, Thales, GE Aviation, L3 Harris, Northrop Grumman, General Dynamics, Raytheon Intelligent Systems. This largely reflects the fact that the major providers have a vast pool of experience to draw from and that the performance of today’s modern avionics and sensors have a significant impact upon the overall performance of the platform.

12.2. AIRCRAFT OEM IN-SOURCING VS OUT-SOURCING

In 2017 Boeing announced its investment in creating a facility that would operate to develop in-house avionics solutions to meet Boeing’s future needs.

This we believe was partly a response to its experience with the 787 whereby it placed much greater reliance upon its key suppliers to develop larger integrated systems solutions. One result of this initiative was to place greater power and control in the hands of its supply chain.

Many suppliers, including avionics providers, were provided an opportunity to leverage improved commercial conditions not only with Boeing but also with the airline end-user community.

Boeing has subsequently sought to bring a number of equipment-related design and development capabilities in-house.

Boeing stood up its AvionX division in July 2018 with the focus on development and production of avionics systems for navigation, flight controls and information systems. It was widely expected that the target was the New Mid-market Aircraft (NMA) slated for EIS around 2025.

Both in-production and aftermarket opportunities are being researched by AvionX. The new subsidiary is located in Plano, Texas, the headquarters for Boeing Global Services, which will oversee AvionX.

Clearly the combination of the 737 MAX issues, the pandemic and the demise of the NMA may well have set this initiative back some years.

The barriers to entry to avionics are very high and it remains to be seen if Boeing can offer the market avionics products at competitive or attractive levels or if the Airlines/end-users will accept these products from an OEM constructor (previous moves have met with considerable resistance).

We note that all of the subsequent Boeing press articles have indicated that reviewing 'aftermarket services' is the priority for AvioniX as opposed to developing OEM avionic products.

Airbus also has an 'avionic'" division. However, this sits within its spacecraft business unit and it is entirely focussed upon developing and sourcing avionics products for satellite launches and EU-funded space programmes.

Airbus does include 'upgrades' within the list of commercial services provided to the commercial aftermarket and these include the following options:

- Communication: data link & SATCOM needs with FANS A+/B+, Iridium or Inmarsat solutions
- Navigation: optimised flight paths with RNP-AR
- Surveillance: collision avoidance and automatic data broadcasting with the ADS-B Out.

We are not aware of any similar moves by Embraer, Bombardier, Gulfstream or ATR to create in-house avionics design and development capabilities.

Within the military arena there are likely to be fewer commercial reasons for bringing avionics in-house. However, there may be sourcing or security reasons for generating capabilities 'in-house' where IP can be better protected.

BAE Systems, as an OEM constructor, sold its avionics business to Finmeccanica (now Leonardo) some years ago and, whilst it retains capabilities in commercial flight controls, FADECs and military EW, we do not see any moves to move back into mainstream commercial or military avionics.

Lockheed Martin, as an OEM constructor for the F-35 platform, has developed a number of key avionic/sensor capabilities in-house. These include Auto Ground Collision Avoidance, Electro-Optical Targeting System (EOTS) and mission computers.

The Auto GCAS, has been developed jointly by Lockheed Martin Skunk Works®, the Air Force Research Laboratory and NASA, is designed to reduce incidents of what is known as controlled flight into terrain, or CFIT. According to U.S. Air Force statistics, CFIT incidents account for 26% of aircraft losses and a staggering 75% of all F-16 pilot fatalities.

The Auto-GCAS development was therefore driven by national safety needs within a specific application for a specific mission role.

Within the military rotorcraft sector, Leonardo owns Selex as an avionics subsidiary. Selex Inc. provides navigation and precision landing equipment vital for successful mission execution in all weather conditions. Selex offers VOR, DME and TACAN as part of its precision landing capabilities. Leonardo Inc. describes its avionics capabilities as communication, navigation, identification, and surveillance (CNIS) avionics systems. They specialise in High Frequency (HF), Very High Frequency and Ultra High Frequency (V/UHF) radio

systems for commercial and military application as well as Identification Friend or Foe (IFF) transponders for military use.

However, it is equally clear that the range of mainstream rotorcraft within Leonardo's portfolio, be they military or civil, rely upon avionics providers such as Honeywell, Collins, Meggitt, and Thales for the vast majority of their avionic suites. Selex does not appear to materially benefit from being a favoured 'in-house' provider.

In summary we do not foresee any significant or emerging threat posed by the OEM constructors to the avionics suppliers in terms of a change to in-sourcing. There will always be exceptions especially in the military sector driven by national sensitivities, need to protect IP etc.

We see the biggest attraction within the civil sector is for the OEM Constructors to achieve a greater market share of the lucrative upgrade and retrofit market. Arguably the jury is still out as to whether Airlines and end-users will view this as a better service proposition relative to the current status quo.

12.3. RETROFIT/UPGRADES

Within this report we identify a number of key drivers for the need to retrofit or upgrade avionics within both commercial and military aircraft over time. These can be summarised as follows:

- Technology improvements (e.g., Flat panel LCD displays replacing CRT displays)
- Obsolescence avoidance (e.g., production of older qualified computing components ceases)
- Reduced pilot workload (e.g., FMS, Integrated functions, data fusion)
- Improved situational awareness (e.g., TCAS, Weather radar, EGPWS, EVS)
- Future Air Navigation performance requirements (e.g., MMRs, FMS, GPS Navigation)
- Mandatory/regulatory changes from Airworthiness authorities (e.g., RVSM, TCAS, ADS-B, FANS etc)
- Improved operating efficiencies (e.g. Data analytics, onboard services, improved Nav performance)

It is clear that many avionics suppliers have developed products and services necessary to support this attractive market sector, which operates somewhat independently of the forward fit OEM cycle.

We say 'attractive' market sector because the retrofit/upgrade market is fragmented and presents many access points (opportunities). Airline operators can come under time pressures to comply with airworthiness requirements, and they will also need to minimise downtime associated with the retrofit so 'price' may not always be the key determinant in the supplier selection process.

One example of these changes is the adoption of Multi-Mode Receivers (MMRs) in the past decade or so. Installation of an MMR can help an aircraft overcome problems associated with multipath interference, and support advanced navigation standards, such as GLS CAT II/III and WAAS LPV. The MMR combines the previously separate modes of VOR, DME, AFD and introduces satellite-based GPS into one receiver to cover all primary navigation needs for the aircraft.

The MMR thus saves weight, cost and should result in reduced maintenance costs compared with a number of older discrete Nav systems.

We estimate that about 50% of MMRs are sold to the OEM constructor and 50% are supplied to the retrofit market.

In 2019, Collins said it has sold approximately 10,000 MMRs, more than 7,000 of which have been delivered. Honeywell says it has sold about 3,000 MMRs and delivered 1,600 units; and Thales says it's won more than 3,000 MMR orders from 40 airlines.

This report sets out a number of forecast scenarios that continue to unfold as the world continues to deal with the Covid-19 pandemic. It is becoming increasingly clear that airlines and operators are having to retire aircraft, in some cases prematurely, in order to reflect significantly reduced capacity demand and the need for newer aircraft with improved operating efficiencies.

Many of these aircraft would have been prime candidates for improvements to their avionics over time. The aircraft most affected by these early retirements (as opposed to just storage which will reverse once

demand improves) include Boeing 747-400s, A340s, A380s, Boeing 777-200s, early versions of Boeing 737NGs and A320s.

In the previous section we noted that OEM constructors have a vested interest in maintaining avionics standards through the life cycle of their respective platform offerings. OEM constructors therefore offer a range of in-service support for their products once the warranty period has expired.

However, these services can vary (size of fleet, location of fleet, stock availability, urgency, timing etc) and whilst the OEM constructors will typically offer regulatory, mandatory, advisory notes, service bulletins, technical publications, recommended performance upgrades etc, they do not always include sourcing of parts, associated installation services and aircraft re-commissioning services.

Much of this work needs to be performed in the field at airline depots or at line 1 maintenance depots – the OEM constructors simply do not have the infrastructure to support this level of aftermarket service.

Aside from OEM constructor services, the avionics market is supported by many avionics providers who offer their own upgraded products via the Supplemental Type Certificate (STC) route.

Also, the OEM constructor is unlikely to invest significant sums in updating 'out of production' series aircraft platforms. Often the only option available to operators of out of production aircraft is via 3rd party aftermarket service providers.

The STC approval route allows 3rd party providers to offer customers of a certain 'type' an additional or upgraded avionic product, and once approved, can offer the STC product to all operators of the particular platform type.

Whilst it is difficult to quantify the market specifically for STC products it is supported by most avionics providers (i.e. they nearly all offer a range of STC solutions) and these STC products are available for hundreds of in-service platforms.

Many smaller business jets, GA aircraft and rotorcraft are offered by the OEM constructor with a 'minimum fit' of avionics necessary to achieve aircraft certification. However, owners/operators can enhance their basic avionics suite via the STC route.

We have analysed the STC market in order to provide examples of how prolific this sector can be.

In the following example we selected the older Boeing 737 classic and 737NG (500/600/700/800) to see what STCs are on offer from various vendors by way of upgrades.

Boeing 737 Classic/500/600/700/800 avionics upgrades

Service Provider	Product upgrade offerings (STC)	OEM/STC holder
ASM Inc	TAWS, Next Gen Nav, MFD, EGPWS, DADC, DFDR, GPS	Honeywell, Universal Avionics, ASCC, GE Aviation, IS&S
Avionics Support Group (ASG)	EFB, SATCOM, ELS/EHS Transponder, SSCVR with ACARS.	Honeywell, Cobham, Collins,
Honeywell	FMS, Flight recorders, Weather radar system, High speed SAT comms, Comms management Unit, Runway Awareness Advisory System	Honeywell
HS Aviation	GNSS/SBAS is an independent GPS system that allows aircraft to meet the RNP requirements for en-route and terminal approach. Other upgrades include CPLDC, SSCVR DATALINK, VHF/VDL-2 Datalink, SATCOM, FANS 1A, WIFI and IFE upgrades.	CMC (TransDigm)
Standard Aero	Flight data recorders, UNS-1C FMS, TCAS, High speed internet and Comms router	Triumph (ex-Fairchild Controls business), Universal Avionics, Honeywell, Aircell.

Teledyne	E - Airborne Data Loader (nav data base loader).	Teledyne
SEA Aerospace	RDR 4B Weather Radar, SATCOM system, Cockpit Door Surveillance System (CDSS)	Honeywell, Cobham, Collins
Mid Canada	4 Display EFI-890R Large Panel Smart Displays, Dual UNS-1FW WAAS LPV FMS, Class A TAWS, Vision 1 Synthetic Vision System, Automatic Dependent Surveillance, Electronic Passenger Briefing System	Universal
IS&S (offeror and installer).	FAA Certifies Flat Panel Display System (FPDS) For Classic Boeing 737. STC Covers Installation on -300, -400, and -500 Models.	Innovative System & Support
KF Aerospace	EFIS displays, Head Up Displays,	Collins, Universal

The above is only a small sample of the number of service providers that offer avionic upgrades and retrofits to older Boeing 737s. Most other legacy platforms still in service will have a similar range of STC product offerings.

The service providers noted in the table above will usually specify the STC type approval together with the equipment needed, any rewiring or structural modifications required and the total number of hours necessary to install the upgrade.

Most of the national airworthiness authorities publish a list of approved STCs usually identifying the platform type, product function and STC holder.

One further note of caution relates to the effects of the current Covid-19 pandemic. The impact upon OEM build rate recovery is not yet entirely clear. However, consensus is growing around both narrow body and wide body recovery rates.

What is less certain is the degree to which the parked/stored fleet returns to service. Many airlines faced with reduced capacity and the higher operating costs associated with older platforms may not return all of their stored fleet to service.

This could have a significant impact upon the retrofit/upgrade market in reducing the size of the addressable market.

We have analysed the parked stored fleet at end of 2020, and we have identified those aircraft platforms with >50% of the fleet in storage and > average age of 15 years.

We note the following platforms fall within this category:

A300-600, A310-200/300, A330-200, A321ceo, A380, A340-300-500-600, Boeing 757-200, 747-8, 747-400, 767-300, 737–200/300/400/500/600, 777-300, 767-400ER, ATR72, ATR42.

Many of these aircraft may not re-enter service and these typically represent the target market for retrofit/upgrade avionic providers.

Within the military sector the STC approach is very similar with avionics suppliers often engineering the STC approval (as the Holder) and then utilising 3rd parties to install the upgraded equipment together with any necessary mods to the existing wiring, airframe etc.

Requests for military upgrades can come from the operators which in this case is usually the relevant services arm e.g., US DoD, USAF, MoD, Luftwaffe etc. This is certainly the case for older aircraft and out of production aircraft.

This report does not include the GA market in any detail. However, it is a very fertile market for upgrades. Many suppliers including Aspen, Garmin, Gensys and Avidyne offer a wide range of STC type approved products including ADS-B, flat panel displays, autopilots, basic FMS navigation, engine monitors etc. These products can be purchased for as little as $2,000 for a simple ADs-B transponder through to $10,000 - $15,000 for an integrated display suite. Installation by a 3rd party provider will add to these costs.

Counterpoint believes that the upgrade market is significant, in terms of revenues, relative to the OEM forward fit. However, it operates over a different timing cycle and it is therefore attractive to many avionics

suppliers. All of the evidence from suppliers' financial reports indicates that the upgrade market generates higher profit margins than the equivalent OEM forward fit supply, adding to its attractiveness.

Further we do not see any significant impact from the pandemic upon the military upgrade market. However, the civil market sector for upgrades/retrofits will likely reduce owing to earlier than planned retirements of legacy platforms.

12.4. AVIONICS SERVICE SUPPORT MODELS

Support services associated with avionic products, as distinct from both mid-life upgrades and spares/repairs, is a relatively new and growing market. It has grown largely as a result of the need for the following:

- Primary navigation databases, as part of an FMS, that require updating on a monthly basis
- Terrain, weather and ground data for EGPWS/TERPROM/WX systems.
- Download and analysis of onboard generated avionic system data (health monitoring, predictive maintenance, trouble-shooting etc).
- Broadband wi-fi and internet services via SATCOM and satellite systems for mobiles, video on demand, 'office in the sky' services.
- Software upgrades for debugging, performance upgrades, new regulations (think Apple iPhone!)

Honeywell Avionics, for example, offers its range of 'connected services' as part of its avionic portal. Within this connected service are seven offerings, all of which can be purchased via monthly subscription, including:

- Navigation database loading
- Maintenance support and planning
- Cabin services (wi-fi, SATCOM etc)
- Configuration maintenance (firmware/software upgrades to avionic equipment)
- Camp trending (statistical analyses of on-board generated data)
- Forge billing and subscriptions (data used for optimisation, cyber-security and maintenance)
- Sky Connect (digital mapping for displays and aircraft tracking in real time via Iridium satellite)

Each of the main avionics suppliers offer similar in service support packages that allow equipment configuration, optimisation, data-bases, maintenance and in-flight support services to be realised in real time via a periodic subscription.

The OEM constructors have equally played a role in developing support service offerings. When Boeing developed the Boeing 787 it offered customers its 'Goldcare' package which essentially is a 'fly by the hour' price agreement taking into consideration maintenance, spares, repairs, overhaul, technical support etc.

Suppliers selected to provide the main systems and equipment on the Boeing 787 were also required to commit to 'fly by the hour' pricing as part of the Goldcare offering.

More recently Boeing has offered the market 'MyBoeingFleet' which covers parts, maintenance, flight operations, analytics, consulting and training.

Airbus offers an equivalent to Boeing's Goldcare with its 'Total Support Package' as part of its commitment to costed Flight Hour Agreements.

Further down the avionics supply chain there are many providers of in-flight avionic service support.

- Cobham SATCOM's core portfolio of SwiftBroadband solutions, ranging from the AVIATOR 200, 300 and 350 to the AVIATOR 700 and 700D and the new AVIATOR S series, provides in-flight connectivity to support a host of advanced applications including cockpit voice dialling in addition to in-flight calling, email and internet browsing for passengers.
- Thales offers its "Avio" range of support services that extends to include:
  - Avio hardware and software support/upgrades
  - Avio cyber security software

  - Avio data for maintenance and optimisation needs
  - Avio EFB solutions
- Collins Aerospace's ARINCDirect flight support services offer a single, comprehensive suite of services and support for flight operations – from take-off to landing. The ARINCDirect flight support services provide flight planning, international trip support, cabin connectivity and flight operations management.

There are fewer examples of service subscription offerings within the military sector. For many years military OEM constructors and their associated suppliers have offered 'Performance Based logistics' (PBL) support contracts which largely extends to costed flight hour support including spares, repairs, overhauls, exchange units etc.

Two significant service provisions, offered on a periodic basis, within the military arena include TERPROM updates, or ground terrain mapping, for low altitude missions and the availability of software upgrades associated with mission and stores computing.

12.5. AFTERMARKET

The previous two sections of this report have considered both retrofit/upgrade offerings and in-service support subscriptions which are both arguably sub-sets of the overall avionics aftermarket.

This section will consider the aftermarket in terms of sustaining the in-service avionic equipment over its life cycle by way of traditional repairs, spares, MRO and support logistics.

Avionics related computers do not suffer traditional 'wear and tear' although they are subject to vibration and environmental effects. Equally software, once verified and installed, does not typically wear or break in service.

Frequent thermal cycling can adversely affect electronic equipment and over time componentry and boards can fail, however, significant improvements with the design of componentry and improved mounting techniques (anti-vibration) has improved the reliability of electronics significantly.

The adoption by avionics designers of 'active' as opposed to 'passive' cooling has also had a beneficial effect upon premature failure rates of electronic equipment (especially around notorious hotspots).

In reviewing avionic equipment failure rates, it is clear that many of the issues that arise within the cockpit on the systems synoptic pages are often defects and/or bugs as opposed to hard failures.

These defects or bugs can often be resolved by a soft or hard reset or, upon further investigation, they can relate to false sensor related signals.

Nevertheless, many elements of an avionic suite are considered mission critical or safety critical and avionics designers have achieved the requisite levels of reliability by incorporating redundancy (e.g., multi-cockpit displays, triple inertial reference systems, dual FMS, dual air data systems etc).

One common factor amongst most, if not all avionics, is their modular design and common interface connectors. This means that rack-mounted (avionics bay) or cockpit-mounted products are easily removed and replaced. Unlike certain systems and structures parts that are much more inaccessible a faulty avionic LRU can often be replaced in the time take to turn the aircraft around between flights (assuming that a replacement unit is available locally).

This in turn generates a significant market for the number of loaners or exchange units required within avionics.

A quick look at 3rd party service providers will show that they carry significant inventory in terms of loaner and exchange units. The service provider usually carries a significant number of OEM or manufacturers approvals necessary to offer exchange unit and repair services.

All of these 3rd party service providers need to have repair station approval such as FAR 145 or EASA 145 certification in order to operate.

Faulty or failed avionics units cannot usually be repaired 'on the spot'. Unlike mechanical products, where a seal or bearing can often be changed locally with minimum equipment, avionic LRUs require specialised tools, diagnosis sets, electronic test equipment and clean or 'white room' assembly conditions.

There is a significant investment required to set up such a repair and overhaul shop to support avionics. Again, if you look at many of the major avionic suppliers, they will often have many 'support centres' or 'technical support centres', but far fewer actual repair and overhaul stations.

Hence the need for OEMs and manufacturers to approve local 3rd party avionic repair houses (which have sprung up all around the globe).

Some of the significant 3rd party avionic support centres, many of which operate via approvals from the OEM manufacturers, include the following:

- Haeco Group (Avionics division)
- Standard Aero (Avionics)
- Lufthansa Technik Avionics
- TAP maintenance and engineering (supports Embraer)
- OGMA Aviation services
- LOT Aircraft maintenance services
- TAG maintenance services
- Cincinnati Avionics (US)
- Flite electronics
- Scandinavian Avionics (SA Group)
- British Airways Avionics Engineering
- Aero Dienst Germany
- Aerospace Maintenance Solutions (OH)
- Ontic Services
- Commander Instruments and Avionics (US)

The avionics aftermarket, as defined by repairs and overhauls, represents a significant proportion of the overall avionics market and is estimated to be $16.0 billion in 2019, falling to $11.5 billion in 2020 It will be interesting to note if and how the traditional electronics repair houses will include software services given the growing proportion of software within avionics.

13. MARKET STRUCTURE

13.1. THE ROLE OF THE AIRCRAFT OEMS

In section 12.1 we reviewed the role of the aircraft OEMs in terms of forward fit of avionics and the need to be proactive in upgrading their products and capabilities over the life cycle.

From a market structure perspective, it is clear that recent consolidation and M&A activity has resulted in there now being a number of avionics providers whose parent companies are equal or larger in size than many aircraft OEMs.

Raytheon (Collins Aerospace), GE Aviation, BAE Systems, Northrop Grumman, Honeywell, General Dynamics and L3 Harris all have market capitalisations measured in the 10s of $ billions.

The examples above all provide avionics solutions to the aircraft OEMs and arguably wield significant 'supplier power especially where they also offer key equipment such as engines, sensitive electronics and critical infrastructure (e.g. software, sensors).

The aircraft OEMs' approach to these structural challenges varies but some have sought to strike 'strategic relationships' where key technologies are concerned.

Boeing's approach on the 787 was to select far fewer key systems suppliers (i.e. bigger packages) who shared in the investment to develop the 787 platform.

For the 787 avionics suite Boeing selected GE Aviation (Smiths), Collins Aerospace (Rockwell Collins) and Honeywell with each being responsible for significant parts of the entire avionics package.

Airbus arguably has a leaning towards Thales as a primary source of cockpit avionics. However, on A350 both Honeywell and Collins Aerospace were selected for avionics sub-systems.

Military aircraft OEMs need to recognise national security interests when it comes to sourcing sensitive defence-related products such as avionics, electronics and sensors. The real degree to which this is a factor in source selection can be hard to identify. However, a quick review of the F-35s avionics, electronics and sensors will show that whilst the majority of the equipment is US-sourced, offshore companies such as BAE Systems, UK (electronic warfare suite) and Elbit, Israel (jointly with Collins Aerospace for the helmet mounted display) have been selected to supply very sensitive equipment.

The F-35 is a multi-national programme with eight international partners all of whom need to be provided with a proportionate amount of workshare usually related to purchase commitments (interestingly BAE Systems is a partner in F-35, but Israel is not).

Notwithstanding procurement strategies for avionics as outlined above, all aircraft OEMs appear to have one thing in common when it comes to specifying new platforms – they all adopt a process that allows for significant input from their respective end-user groups – usually the pilots and operators.

This process of engagement between aircraft OEMs and airline groups, lease companies and operators, (potential purchasers) at the outset of a new platform development, is an established process.

This aircraft OEMs/customer engagement process reflects the degree to which the avionic suite is recognised as the critical man/machine interface for the entire operation of the aircraft platform. It also reflects the fact that pilots are still a very powerful voice within the industry – ignore them at your peril!

The other major focus for all OEM constructors, civil and military, is the need to work with the recognised bodies within the industry that have influence and control over the entire operational life cycle of their product.

There are many national and industrial bodies that have influence and control over areas of research, development, certification, regulatory, operational and environmental issues.

The major bodies that exercise particular influence over the avionics aspects of the airframe are identified as follows:

- Airworthiness authorities (e.g., FAA, EASA, CAA)
  - These National Airworthiness Authorities control the issuance of airframe certifications for airworthiness as well as Supplemental Type Certificates.
- International Civil Aviation Organisation – defining the needs of Future Air Navigation (FANS)
  - See Global Air Navigation Plan 2013 – 2028
- EUROCONTROL – responsible for Air Traffic Control within Europe (41 member states)
- Radio Telecommunications Control Authority – sets RTCA standards across the industry
  - Sets industry wide standards for IMA, common computing and software.
- Many national research projects that will dictate future technology needs
- EU 'Clean sky' project focussed upon emissions
  - NASA's funded Advanced Air Transport Technology (AATT) programme includes Electrical Aircraft Propulsion project (EAP)
- Airlines Electronic Engineering Committee (AEEC) undertaking the development of an industry roadmap for the use of Internet Protocol v6 in air-to-ground data communications
- Defense Advanced Research Projects Agency (DARPA)'s Aircrew Labour In-Cockpit Automation System (ALIAS) program – using Robots as back-up pilots.

- Jan 2020: The US Air Force (USAF) launched three studies on future communications, innovation in space, and the unintended consequences of using autonomous systems, the results of which will shape the service's research investments.

The role of aircraft OEMs, from an avionics perspective, can therefore be summarised as maintaining engagement with the very many stakeholders in both the civil and military sectors in which electronic/digital technology can advance very much more quickly than other more mature technologies.

13.2. BUYER FURNISHED EQUIPMENT (BFE) VS SUPPLIER FURNISHED EQUIPMENT (SFE)

The concept of Buyer Furnished Equipment, that is providing the customer with an option relating to supplier source allowing for a level of 'customisation', has been around for many decades.

Pilots, crew and passengers do not usually have any engagement with 80% - 90% of an aircraft's systems. However, in both the cockpit and the cabin this is not the case where man/machine engagement is much higher.

For those avionics where there is usually a high level of pilot or crew interaction or operational influence there will inevitably be preferences. Similar to the computing world, in which we are either Windows or Mac users, you will hear pilots having a preference for either Honeywell or Collins.

Airlines can have a strong operational preference based upon issues around pilot/crew training, spares stocking, cross fleet cockpit commonality.

Typical avionic equipment for which there is a BFE option are listed as follows:

- Radio communications
- HF communications
- SATCOM
- Cockpit Voice recorder
- Flight Data Recorder
- Digital Data Acquisition Units
- Flight Management Systems (reducing in prevalence)
- Standby Attitude Indicator
- Multi-mode receiver
- Weather Radar
- TCAS
- Radio Altimeter System
- Automatic Direction finder

The main flight displays, auto-pilot, common computing services, primary navigation and data-buses all tend to be SFE as they represent the essential part of the aircraft operation.

Usually, the aircraft OEM will sell an 'SFE' aircraft at a price and will have negotiated all of the BFE options with the suppliers. The airline/end-user can then specify these BFE items from the list at a pre-agreed price for inclusion in order to arrive at an overall customised aircraft price i.e., SFE plus BFE.

There are more BFE options within the cabin in IFE, seats and galleys where airlines and passengers can have stronger preferences.

In terms of overall platform costs we estimate the following for SFE vs BFE

- Assuming a $50m flyaway price for a narrow-body aircraft, the BFE-costed equipment will typically range from $1m to $2.5m, (2% - 5%) and of this total approximately 60% - 65% will represent cabin customisation.
- For a $100m wide-body aircraft, customisation costs will range from $8.0m - $12.0m (8% - 12%), and of this total approximately 70% - 80% will be represented by cabin customisation costs.

A major issue for the aircraft OEM is the very high costs associated with certificating and maintaining two separate options.

Many within the industry refer to BFE as either being 'brand' oriented (i.e., cabin, IFE, seats) or 'operations' oriented (i.e., data recorders, FMS, radio communications).

We see the OEM market as offering fewer avionic BFE options going forward due to the prohibitive costs associated with the development of software based avionic products.

Both Airbus and Boeing continue to offer the market an option of either a Thales or Honeywell FMS for their commercial platforms. However, we see the trend for offering two FMS systems (expensive to certificate) as reducing.

For other avionics-related products where there is an option offered such as TCAS, Weather Radar, ADS-B, Displays, multi-mode transceivers, much of the development and certification costs have often already been borne by the supplier (often via a COTS approach that spreads the investment over many platforms).

The suppliers can also pursue the STC route, independent of the aircraft OEM, in order to have their equipment certified for a specific platform or family of aircraft.

BFE has even less of a presence within the military field although multi-national platforms tend to experience end-user or national preferences.

13.3. ROLE OF AIRLINES (END-USERS)

Section 13.2 discussed one significant role of the airline within the area of BFE equipment preferences and selection.

At the outset of a completely new airframe development, it is normal practice for the aircraft OEM to seek early engagement with a range of airlines and seek their inputs as a representative user group that will effectively influence the avionics architecture and overall cockpit layout.

Many of these user groups will typically have 20 or 30 different airline'/end-users representatives involved at the development phase.

Equally, these user groups may also involve personnel drawn from the airline representing pilots, crew, maintenance personnel, financiers and engineers.

This, in part, reflects the differing needs of, for example, the narrow body market (e.g., Boeing 737, A320) where the market can be segmented into:

- Low-cost carrier/single airframe
- Feed in for international network operators/fleet operators
- Aircraft lessors
- Short haul/high route density
- Medium haul/low route density
- Transnational vs domestic

The aircraft OEM has to ensure that the tens of billions of dollars of investment that is required to develop an aircraft is 'right first time' and that it has mass market appeal – getting it wrong can be very costly once the platform is certificated and in service.

There is therefore a strong ongoing bond and relationship forged between OEM constructors and airlines that typically pervades throughout the entire product life cycle.

The significance of this interface between OEMs and Airlines is that avionics today acts both as the 'hub' for many airline 'operational' issues such crew training (expensive), efficient route structures, reporting, data, maintenance and safety as well as providing infrastructure for passenger 'brand related functions such as IFE, Cabin comms and SATCOM.

The major airlines also play a significant role in the upgrade and retrofit market when avionics require changes whether it be for mandated airworthiness reasons or for improved operational efficiencies. Major

airlines typically invest in engineering resources, maintenance shops, repair and overhaul facilities which means that they are well equipped to undertake retrofit/upgrade work.

They work both with the aircraft OEMs and the suppliers to facilitate the upgrade work both to their own fleets of aircraft. This can also involve the airline in obtaining Supplemental Type Certificate (STC) approval from the national airworthiness bodies that control equipment modifications.

Many of the larger airlines such as Lufthansa, United Airlines and British Airways will offer these services to the smaller airlines that cannot afford to invest in the facilities necessary to undertake retrofit/upgrade work.

13.4. SYSTEMS INTEGRATORS/TIER1S/TIER2S

Avionic suppliers have been at the forefront of avionic related technology advances taking place every few years which is juxtaposed with the development cycle of a typical airframe which typically needs to 'evolve' over its 30, 40 or 50-year life cycle.

This apparent technology/platform 'disconnect' has to be managed in part by suppliers who work to bridge the void between frequent avionic developments and long cycle airframes that operate in a heavily regulated industry requiring the very highest level of safety standards.

In terms of avionics some of the technology advances that have impacted the overall supply chain are noted as follows:

- Barometric > Cathode ray tube > LED flat panel > Synthetic Vision Systems
- Analogue to digital based avionic implementation.
- Data bandwidths have grown exponentially from 100KBs to GBs/TBs in 20 years.
- Real Time Operating Systems for e.g., partitioning in IMA
- ASICs to FPGAs (flexible programming)
- Lines of software code typically increased 100-fold in 20 - 30 years.
- Solid state sensors replacing mechanical analogue devices.
- Fibre optic data transmissions replacing copper wiring.
- Development of satellite-based GPS navigation systems
- Development of autonomous systems for enhanced situational awareness
- Software-based radio communications.

This is not an exhaustive list, but it does represent the extent of the technology related challenges that have been confronting Avionic suppliers in recent decades.

A significant mechanism adopted by OEMs, suppliers and airlines is the design of avionics architectures that allow for 'technology insertion' upgrades over time as product technology evolves.

Technology insertion can be at many different levels. A complete cockpit upgrade typically includes replacing the old analogue multi-instrumented flight decks with a digital flat panel suite comprising integrated functions (LED displays, FMS, Nav, Comms, Surveillance).

A simple technology insertion may be limited to a new 'box' that can be introduced as a 'plug and play' upgrade where, from an aircraft perspective, all of the interfaces, e.g. I/O, connectors, wiring, sensors, mechanical interfaces etc., are entirely compatible with the existing avionic architecture.

Cockpit 'real estate', as represented by the total viewing area, will often need freeing up in order to accommodate new or additional functions such as TCAS, EGPWS or Weather radar. Suppliers have proved themselves adept at consolidating and/or integrating multiple display formats in a single unit.

Suppliers have had to adopt a number of avionic-derived processes in order to successfully compete within the avionics sector. These processes which often form part of the suppliers 'core competences' include the following:

- Understanding of man/machine interface sciences

- Design for product/component obsolescence
- Commercial Off -The-Shelf (COTS) design capabilities
- Software code design, verification, validation and certification processes
- Data fusion/integration from multiple sources (e.g., synthetic imaging).
- Multiple avionic/utility functions operating in 'real time' within a software partitioned environment.
- Supplemental Type Certification process (approved engineering and test facilities)
- 'Life-time buy' procurement processes
- Legacy product support processes

A quick review of the major avionics integrators (e.g. Honeywell, Collins Aerospace, Thales, GE Aviation) shows a similar approach in that they all promote avionics around a number of themes with equal emphasis as follows:

- Avionics as providers of integrated cockpit suites
- Avionics by individual function e.g., FMS, NAV, Comms, Surveillance
- Avionics by way of retrofit and upgrade (Technology Insertion, STC, COTS)
- Avionics by way of life cycle support in service.

This, we believe, supports the evidence outlined within this report that avionic suppliers are required to focus on more than just forward fit OEM potential with technology insertions, upgrades, major retrofits, data services and through life cycle support, all representing important revenue generating sub-sectors within the overall avionic market.

13.5. SUPPLEMENTAL TYPE CERTIFICATE (STC) PROVIDERS

A supplemental type certificate (STC) is a national aviation authority-approved major modification to an existing type-certified aircraft. In the United States issuance of such certificates is under the purview of the Federal Aviation Administration (FAA) and in Europe it is controlled by the European equivalent, EASA. The STC applicant must show compliance to the same regulations as the original type design, for the area affected by the modification.

From a supplier's perspective, the STC route is often the only affordable and practical means to bring a new product to market. With major new platforms only coming along every 10 or 20 years the means for many suppliers to generate revenues is by offering products directly to the end-users.

Often these 'regulatory' or 'optional' product offerings fall outside of the focus of the OEM constructor. Plainly speaking they can become an unnecessary distraction for the OEM constructor who would otherwise have to devote valuable engineering resources to develop discrete product solutions, market them accordingly and facilitate their installation.

This has, in effect, spawned a whole range of discrete product offerings provided by many avionic suppliers.

A further consideration is the affordability of these discrete product functions which, at the less regulated end of the aviation market, can be provided via an STC certificate at a much lower cost than a bespoke solution.

A quick look at any National Airworthiness register will usually reveal hundreds of approved STCs by product function that apply to those aircraft operating within that nation's airworthiness jurisdiction.

Globally today there are thousands of STC products available at any one time.

The FAA alone lists 1000s of STCs and it is apparent that a majority of these STCs apply to GA, smaller business jets, rotorcraft and military trainers.

Within the avionics supply chain most providers of engineered avionics (both small and large) will have a range of STC products available.

The STC market is attractive to many suppliers because it is largely de-coupled from the OEM forward fit market and it therefore acts as a cyclical counter to OE build rates.

13.6. 3RD PARTY SERVICE PROVIDERS (SOFTWARE/DATA)

Third party service providers represent a growing element within the avionics market. Clearly both availability of aircraft systems related data and greater reliance upon software-based functions has increased significantly in the past decade or so.

As often the case with a paradigm shift within an industry there is an opportunity or requirement for new players with different skill sets.

This is to some degree the case within avionics. Within the supplier matrix there are now a number of software providers who are actively engaged in developing avionics solutions often in partnership with OEM constructors or suppliers.

Some of these software base providers are listed as follows:

- Ensco Inc
- Green Hill Software
- Genova Technologies
- Lynx Software Technologies
- Mercury Systems
- Performance Software Corp
- Mannarino systems and software
- Wind River systems

These companies provide a range of software services with the largest consumers of software by avionic function include:

- Integrated modular avionics or common computing resources requiring partitioned software.
- Graphics generation (data fusion) for flat panel displays
- Flight management systems

Many of these software companies also offer related services to the Aerospace & Defence sector including cloud-based storage (for analysis), cyber security and certified software for COTS use in military applications.

In section XX we referred to providers of data services having commercialised their offerings by way of monthly subscription from end-users.

These service providers include offerings such as the following:

- Navigation database updates for FMS systems (typically every month)
- Download, storage and analysis of aircraft system derived data for trends, predictive maintenance action.
  - This is often a ‘real time’ service given the availability of high speed data connections via satellite
- Satellite data connections for cabin services e.g. mobiles, e-mails, video on demand etc.
- Terrain mapping databases for EPGWS/TERPROM.

Equally there are a similar number of service offerings from the OEM suppliers in addition to 3rd party providers. Many of the major avionics suppliers typically offer the above services to the airlines and end-users.

OEM constructors can also offer similar services e.g., Boeing acquired Jeppesen which provides many airlines with monthly navigation updates. Airbus also offers an equivalent navigation database service via its NAVBLUE distributor.

From a market perspective we observe that all players, from the OEM constructor through to the Tier 3 specialist provider, have recognised both the potential growth and value associated with digital/data services. They are all increasing their offerings to the relevant market sectors accordingly.

13.7. SUPPLIER CONSOLIDATION AND OWNERSHIP

There has been significant consolidation within the avionics industry in recent decades which appears to be continuing.

Some of the major historical consolidation moves include the following:

- 2000: Northrop Grumman acquired Litton Industries
- 2001: Northrop Grumman acquires Litef GmbH
- 2007: GE Aviation acquired Smiths Aerospace (2007) who had acquired Lear Siegler (1998)
- 2005: Finmeccanica (now Leonardo) acquires BAE systems Avionics – renamed Selex
- 2010: Raytheon acquires Applied Signal Technology
- 2017: Rockwell Collins acquires B/E Aerospace (interiors and cabin systems).
- 2018: Elbit Systems acquires Universal Avionics
- 2019: TransDigm acquired Esterline (2019) which in turn had acquired Barco Aviation (2015) and CMC Electronics (2007)
- 2018: L3 and Harris agree to merge their businesses.
- 2018: Raytheon acquires Collins Aerospace (2019) which had only recently acquired Rockwell Collins.
- 2019: Thales to Acquire the Helmet Mounted Display and Motion Tracking Businesses of Gentex Corp.
- 2020: Moog Inc. has completed the acquisition of Genesys Aerosystems for a purchase price of approximately $77.7 million.
- 2021: Teledyne Technologies to acquire FLIR systems for $8 billion (closing expected mid-2021). FLIR makes infra-red sensors for defence and industrial uses.
- 2021: Eaton to acquire Cobham Mission Systems (CMS). CMS is not a significant avionics provider but has mission related capabilities.

It is equally notable that the leading avionics providers are also investing in non-traditional avionics companies that are able to bring AI, digital services, data analytics, Internet of Things and software services to the aviation industry.

Examples of these include the following:

- 2021: Software firm Wind River is teaming with Curtiss-Wright [CW] to offer a new cyber security and anti-tamper solution to be integrated on aerospace and defence capabilities
- 2018: Thales to acquire Guavus a pioneer in developing Machine Intelligent, big data analytics platforms for aviation, rail and transport applications.
- 2012: GE Aviation acquired Austin Digital, a privately owned, Texas-based supplier of flight operations data analysis. Austin Digital's flight operations capabilities strengthen GE's services offerings with integrated solutions for aviation customers around the world.
- 2010: Rockwell Collins to acquire Anzus, Inc., a privately owned developer of software that enables high-speed tactical data link processing and sensor correlation for the U.S. Department of Defense as well as foreign governments.

We see a continuing trend for the traditional avionics houses to either acquire, form JVs or invest internally in order to access the 'new skill-sets' associated with modern avionics which can fall outside their existing core competencies. These new skills involve developing critical software on proprietary processors, digitisation of operations, real time operating systems, data analytics, artificial intelligence (learning) and the Internet of Things.

In reviewing the ownership and parentage of the companies identified within our supplier capability matrix we have noted the following in terms of the make-up and structure:

- Compared to other areas of aviation, including aero-structures, engine and airframe systems, we see very limited ownership of avionics businesses by Private Equity.

- This we believe is unusual in that many PE companies seek engineering-led businesses that generate Intellectual Property and have solid aftermarket potential – all features found within the avionics sector.
- There are a number of large corporations which have increasingly strong leverage relative to the aircraft OEMs who are the customers for their avionics e.g., Raytheon Technologies, Honeywell, GE Aviation, Northrop Grumman, General Dynamics.
- Out of 55 companies that we have identified we note that 12 today are still privately held and therefore represent a potential opportunity for investment at some stage.
- 30 of the avionics businesses are located or headquartered within the USA and there are a further 16 businesses located within the EU (including UK).
- The balance of 9 businesses are located in Israel, Brazil, Russia, India and China.

14. TECHNOLOGY TRENDS

14.1. COMMERCIAL OFF-THE-SHELF (COTS) AVIONICS

"A bespoke hand cut tailor made suit for $750 or one off the peg for $250?"

The above is analogous to the Avionics market where, since around 2000, a significant number of Avionics suppliers have offered customers 'commercial off-the-shelf' (COTS) avionics products and packages.

A commercial off the shelf product is defined as one that has not been designed and certificated for a specific customer platform i.e., it is potentially suitable for a multitude of customers and platforms.

A further definition of COTS is provided by EASA/Thales as "Component, integrated circuit, or subsystem developed by a supplier for multiple customers, whose design and configuration are controlled by the supplier's or an industry specification".

RTCA DO-178B defines COTS as "Commercially available applications sold by vendors through public catalogue listings".

The primary driver for this approach has been cost and affordability issues. This is particularly the case for low volume OEM manufacturers (e.g., helicopters, business jets, GA) that cannot afford to invest in a bespoke avionics solutions.

Equally, operators of aircraft requiring retrofit/upgrade of avionics cannot afford to invest in a bespoke solution and they are therefore reliant upon COTS providers.

The military sector was the first to consider the application of COTS products developed for commercial applications and adapted/adopted for military applications. This is especially the case for rotorcraft, trainers, military transport and UAVs.

For example, the FMS utilised by Boeing as part of major upgrade programmes for both the C-130J and the Poseidon P-8 is essentially the same FMS as developed by GE Aviation for the Boeing 737. This approach allows GE to avoid having to recover a large tranche of development costs already consumed by the 737 development.

Another good COTS example is the application of both Voice and Flight Data Recorders. These devices operate in a similar way irrespective of the platform in which they are located. Most suppliers of these products offer them within many different market sectors as essentially a 'COTS' product.

However, there are other issues to consider in terms of traceability, integrity, certification and safety when adopting a COTS approach. The regulatory authorities are concerned at just how rigorous a process has been followed in sourcing, developing and testing COTS products (at component level) especially in regard to the approvals for the appropriate levels of software criticality (defined by RTCA DO-178 as A, B, C or D).

The cost benefit can be seen if we consider the likely total recurring cost of a bespoke avionic suite (for a mid-size commercial jet) that typically falls within the range of $1m to $1.5m whereas Avionics suppliers can offer an 'off the shelf' integrated COTS based avionics package for $300K to $800k.

The increasing cost of bespoke avionics suites has largely been driven by the increased software content that brings with it very high validation and certification costs. This problem is further exacerbated when the associated market volume expectations, for a single platform, are relatively low and development costs have to be amortised over a small base.

It is therefore understandable that airframe manufacturers, both civil and military, are attracted to COTS offerings.

The FAA, EASA and one of the industry governing bodies, RTCA DO-178B (software standards), has identified issues surrounding COTS which include:

- Clear certification path for COTS products relating to the correct level of software for application criticality (level D is the lowest with level A being the most critical).
- Transparency of product source and software codification for commercially based products (e.g. Microsoft, Windows NT, LinuX etc).
- Lack of evidence for compliance to RTCA DO-178B for COTS products

It is unlikely that large civil airframe manufacturers would adopt a COTS approach to sourcing Avionics for their next generation aircraft, however, it is possible that lower level D criticality functions could be COTS sourced.

Smaller aircraft and military platforms that do not require certification to the same levels of criticality as large commercial aircraft are more able to adopt a COTS approach.

Notwithstanding the ongoing issues noted above with certification standards the market for off the shelf COTS solutions has increased significantly within the past decade or so.

There are a number of suppliers who offer a wide range of off the shelf COTS products that are designed to meet a significant part of a market sub-sector or a fleet wide retrofit/upgrade need.

In early 2000, Honeywell was offering its Versatile Integrated Avionics (VIA) as a mature, flexible, general purpose processor developed for the commercial airline market. VIA also has direct applications for military aircraft and offers a commercial-off-the-shelf (COTS) solution. The VIA offering has been developed from Honeywell's Aircraft Information Management system (AIMs) used on the Boeing 777.

Offering the market a COTS-based avionics computing platform allows for open architectures and upgrade paths for future utility applications that do not require the airliner or operator to have to revert to the original Airframe manufacturer (thereby avoiding significant costs).

We have included a tabulation of a sample of COTS suppliers with products and end applications noted where known:

Supplier	COTS offering	Typical sectors/platforms/upgrades
Honeywell (Bendix King)	AeroNav GPS/Nav/Com/MFD combined unit AeroVue™ Touch display	General Aviation, Business jets, Rotorcraft Cessna family of aircraft
Collins	Special Mission Processor (in development). Open architecture utility host computer incorporating compatibility with COTS FCS 7000 Flight Control system (FMS, Nav, Displays, A/P etc)	Military/C-130 upgrades C-130, KC-135, E-3, E-8, CN235
Thales	Deployable ILS for USAF airfields (COTS) FlytX Avionics	The Thales D-ILS is a COTS system based on Thales ILS 420 H160, Rotorcraft, VRT500
GE Aviation	Displays, IRUs, Recorders Flight Deck upgrade	All platforms C130 AMP (based on 737 Avionics

Garmin	G5000 integrated flight deck Garmin Autoland Garmin GTS 8000 TCAS	Beechjet 400, Citation XLS Cirrus, Piper, Daher Cessna Citation
Universal Avionics	Integrated Flight Deck (FMS, NAV, Displays, Comms) EFI 890R flight Displays	Airbus Super Puma C130-J
Curtiss Wright	Mission Computers (COTS) Flight Data Recorders	Military rotorcraft, trainers Multiple platforms
IS &S	Next Gen FMS system Displays (various)	GA, business jets, Cargo a/c Retrofits upgrades
Meggitt	3 ATI LCD Displays ADAHRU	Civil & Military platforms Civil & Military platforms
L3 Harris	Displays, Recorders, Nav	All platforms

The list above is NOT exhaustive and is only a small sample of both suppliers and their products that are offered to the market via catalogues, brochures and via distributors – hence defined as COTS products.

Although not identified within the table above another sector that draws heavily upon the use of COTS avionics is the space sector. Single platform space programmes do not have the funds available to design and build a bespoke Avionics solution for each and every mission.

OEM airframe manufacturers are not always focussed upon replacing or upgrading obsolete cockpit Avionics which has resulted in many suppliers, 3rd parties and Airlines investing in COTS products.

In summary, we see the COTS approach to Avionics as a means to achieve much greater market penetration within low volume sectors. In terms of Avionic functionality, it also means that small business jets, GA, Rotorcraft and military platforms can be provided with Next Gen navigation performance, similar to that found on a modern airliner say, but at affordable levels.

14.2. INTEGRATED AVIONICS

The potential benefits associated with an integrated avionics approach have been discussed in recent decades. Reducing the number of individual avionics computers by exploiting as many common features as possible, and standardisation can result in significant cost savings, reduced maintenance and spares holdings and reductions in both weight and volume.

Examples of an integrated approach to avionics were developed in the 1990s by Collins Aerospace and Honeywell with their ProLine Fusion and Primus Epic offerings respectively.

These integrated avionics offerings were largely targeted at OEMs within the business jet, GA and rotorcraft sectors where there is much greater pricing pressure. However, these integrated offerings contained proprietary software and were considered to be ‘closed architectures’ by all 3rd parties (including the OEM customer).

Thus updates, additional functionality, changes to databases etc all required approval and installation by the original manufacturer usually at considerable cost.

Large commercial aircraft and military platforms

Increasing pressures from constructors, owners and operators, resulted in Boeing, amongst others, pursuing more open architectures. Boeing adopted the Boeing 777 Aircraft Information management System (AIMS) developed by Honeywell which hosts the following avionic functions:

- Cockpit displays system
- Flight management system
- Thrust management system (Autothrottle)
- Aircraft condition monitoring system
- Data communication management (Datalink)
- Flight deck communication

- Central maintenance system
- Flight data acquisition system

However, the Boeing 777 AIMS is still a closed architecture that is proprietary to Honeywell and can only be modified with the OEMs approval.

With the Boeing 787 Boeing contracted Smiths (now GE Aviation) in order to develop a more open architecture 'common core processing' (CCS) system. This is essentially an extension to the Boeing 777 AIMS system with greater flexibility in adding additional utility functions and to date it hosts around 60 utility functions in total all operating on a common backplane with common I/O etc.

Boeing claims that by adopting the CCS approach on the 787 they have saved 2,000 lbs of weigh and have eliminated 100 LRUs.

These benefits also derive from the approach taken at the outset of the platform design. The 787 also adopted Remote Data Concentrators located at strategic points throughout the aircraft. By consolidating all of the utility data gathering via common concentrators (which connect via a standard databus to the CCS) further savings are realised in terms of reduced wiring and connectors throughout the aircraft.

Within the military field both the F-22 and the F-35 have adopted an integrated approach to avionics. This integrated approach, whilst driven by weight and volume considerations, is also required in order to minimise cooling requirements associated with high power military electronics and the integrated approach also generates benefits in terms of high-speed data fusion. This latter factor is key in terms of fulfilling the F-35's interoperability needs within a complex war theatre supported by land, sea and air.

Other recent examples of IMA architectures include the A380, A400M and the A350.

In the last 10 years, the mainstream IMA definition has incorporated time and space partitioned software environments based on the ARINC 653 standard. During this period, software complexity has increased significantly. The ARINC 653 extended IMA definition has enabled the development of common software infrastructure to enhance complex systems management and enable greater software reuse.

In terms of the future many believe that a significant goal should be to realise IMA as a 'platform', much as a PC or laptop today is a computing platform, which hosts different software functions all operating in segmented space and partitioned time. Data is packaged and sent over a standard network between the functions that require it.

A key benefit of this approach has to be to allow the 'end-user' ease of access in terms of adding functionality whether that be utility software functions, apps or 3rd party developed software – much as you can today with your laptop computer.

Within the IMA world 3rd party software developers are playing an increasing role in providing both the core software platforms and the associated utility functions (see section 11.6).

Counterpoint expects to see significantly increased adoption of IMA concepts not only to save weight and cost at the outset but also to avoid obsolescence and to significantly improve life cycle cost of ownership.

In the past 20+ years or so there has been an 'integrated avionic package' offering from two of the market leaders; Collins Aerospace (Rockwell Collins) and Honeywell.

Business jet, GA and helicopters

The market for integrated avionics offerings, which can be both forward fit and retrofit/upgrade, is typically limited to the business jet, GA and rotorcraft sectors. There are a few notable exceptions, which are highlighted later in this section.

For the first 10 years or so both Collins and Honeywell offered the market their ProLine Fusion cockpits and Primus Epic cockpits respectively and they both quickly benefited from gaining considerable market share.

In around 2010 Garmin stepped into this sector with its G1000 offering which was targeted at replacing the older CRT displays embedded in the earlier ProLine and Primus cockpits.

A key market driver for this approach to offer a complete one stop shop integrated cockpit was affordability. Many of the business jet/GA OEMs cannot afford a bespoke avionic suite for each of their platforms – the development and certification costs are prohibitively high.

Equally, many of these airframe OEMs do not have the depth of engineering resources and capabilities necessary to procure a set of modern avionics functions that require integration within the airframe and subsequent certification.

A further consideration evolves around life cycle ownership and maintenance. Digital electronic avionics carries with them obsolescence issues whereby commercial electronic components can cease to be produced any number of times during the life of a typical airframe. This can bring with it a major headache for operators/owners.

A cost-effective solution is to allow the avionics provider/integrator to manage the avionic supply chain and ensure that there is an adequate upgrade path both for future functionality improvements and to avoid costly obsolescence problems.

Many of these integrated avionic offerings have a common core but are tailored to their end platform applications. The certification route adopted is often via Supplemental Type Certificate (STC) which is a very cost-effective approach. The offeror will be spreading these STC costs across a multiple range of platforms, a family of aircraft derivatives and any number of operators.

Given the above issues it is not surprising that both Collins and Honeywell quickly established themselves as market leaders with their integrated offerings.

These offerings are very competitively priced given that they have evolved over 20 years and incorporate all of the regulatory requirements, newer technologies and considerably greater functionality than was available in 2000.

These integrated avionic offerings have evolved over the past 20 years to now include TCAS, Weather Radar, GPWS, flat panel LCD displays, Enhanced/Synthetic Vision Systems, Head Up Displays, ease of route planning (via FMS) and data reporting/downloading.

Garmin entered the market around 2010 with its G1000/G3000 offerings aimed at FAR Part 23 aircraft which weight less than 25,000 lbs. More recently they have certified their G5000 offering which is FAR Part 25 compliant (i.e. 25,000 lbs+).

In terms of upgrade or retrofit both Collins and Honeywell offer their latest Proline and Primus Epic suites at prices upwards of $500k to $1,200K whereas Garmin has priced its fully loaded G5000, with its extensive range of functions, very competitively at around $500K.

On top of this, an operator seeking to upgrade or retrofit will need to consider installation costs. Service providers such as Elliott Aviation will install a G5000 cockpit into a Cessna Citation for around $80K.

Whilst these three providers have established themselves as leaders there are others who also offer an integrated avionics package as follows:

- Thales offers its FlytX package, but this does not appear to include the same range of functionality on offer from others.
- Universal Avionics offers a ‘flight deck’ package for platforms including King Air 90/100/200/300/350, Bombardier Challenger CL-600/601, Cessna Citation I/SP 501, II 550, II/SP551, III 650, VII, Dassault Falcon 900, Gulfstream GII - GV, Learjet 45, 55, 60.

We list the following avionics functions as being typical of what is contained within the latest offering for each of the main suppliers:

- Collins Aerospace Pro Line Fusion (King Air 360 ER)
  - Intuitive graphical touch-screen flight planning
  - High-resolution Synthetic Vision System (SVS) with patented airport dome graphics
  - Convenient pre-sets to reconfigure all three displays with a single touch
  - Full multi-sensor flight management system

  - Integrated touch screen checklists
  - Available automatic wireless database and chart uploads
  - Open and scalable architecture for future upgrades and mandates
  - NextGen and precision GPS capabilities: DO-260B compliant ADS-B, SBAS-capable GNSS, localiser performance with vertical guidance (LPV) approaches, radius-to-fix (RF) legs
- Honeywell Primus Epic 2 (for the Pilatus PC-24)
  - Advanced navigation and situational awareness. Honeywell's SmartView synthetic vision, Interactive Navigation and Airport Moving Maps optimise safety by increasing situational awareness, reducing pilot workload regardless of outside visibility.
  - Four 12-inch colour LCD displays. The integrated cockpit system features two Primary Flight Displays and two Multifunction Displays that are user friendly and lessen pilot workload. These displays also offer scalable window views, charts, maps and aircraft system details that make glancing across controls effortless.
  - Primus Epic 2.0 includes the latest communication systems, providing operators with an easy path to the mandated Automatic Dependent Surveillance-Broadcast Out system. The system also supports Cockpit Display of Traffic Information, which combines a map view with location information on other aircraft in a plane's vicinity, while in the air or on the ground.
- Garmin G5000
  - Engineered to reduce workload, improve situational awareness and give flight crews the tools to enhance safety and efficiency
  - Large, high-resolution colour screens depict aircraft performance, navigation, weather, terrain and traffic information with easy-to-interpret displays.
  - A proven, digital attitude and heading reference system delivers high-precision data for the instruments on the Primary Flight Displays (PFD).
  - Moving-map graphics on the Multi-Function Display (MFD) show the aircraft’s current position relative to navigational aids, airways, flight plan routings.
  - Plus, with the addition of optional Garmin SVT™ synthetic vision technology, pilots see a realistic 3-D view of topographic features surrounding their aircraft.
- Universal Avionics “Flight Deck”
  - Flight Management; 2 - UNS-1Fw FMSs with 5" CDUs
  - Display Suite; 3 - EFI-890R 8.9" flat panel displays
  - Situational Awareness; 1 - Vision-1™ Synthetic Vision System, 1 - Terrain Awareness and Warning System (TAWS), 2 - Application Server Units (ASU)
  - Radio Tuning and Communications; 2 - Radio Control Units (RCU), 1 - UniLink™ 701 Communications Management Unit

When considering a retrofit or upgrade the newer more modern equipment will typically deliver lower power requirements, lower operating costs, improved service support and weight savings. Garmin claims to save 150lbs of weight by upgrading a Cessna citation to the G5000 cockpit in terms of wiring and hardware.

In terms of the range of platforms that have been fitted with integrated avionic offerings from the three key suppliers we have tabulated the following, which is not an exhaustive list, but it does cover many of the major applicable platforms.

Collins Pro line Fusion (all variants)	Honeywell Primus Epic (all variants)	Garmin G500, G600, G1000, G3000, G5000
Beechcraft King Air 350	Learjet 40	Daher TBM 700
Beechcraft B200GT	Hawker 800	Cessna Citation Mustang
Dassault Falcon 50	Dassault Falcon 900	Cessna Citation XLS
Dassault Falcon 2000	Dassault Falcon 7X	Embraer Phenom 100/300
Global Express 5000	Pilatus PC-24	HondaJet
Global Express 7500	AW-139 rotorcraft	Beechcraft C90 King Air
Global Express 6000	Embraer 2Gen E-Jet family	Piperjet
Learjet 60XR	Gulfstream G300/350	Bell 505 rotorcraft
Airbus A220 family	Gulfstream G500/G550	TacAir F-5 military fighter
Embraer C-390 Millennium transport	Gulfstream G600/G650	BO 105 rotorcraft
	Cessna Citation Hemisphere	Diamond DA42
CL515 Firefighter (de Havilland)	Cessna Citation X	Beech 1900D
Airbus CN295 military transport	UPS A300s (52 off)	Shorts SD360
TRJ728 Turboprop (Turkey)	Dornier SeaWings	Dash 6 Twin Otter

Whilst the main market for 'off the shelf' integrated avionics offerings is business jets, GA and rotorcraft there are exceptions. Above we note that there are regional and large commercial jets (Gen2 E jets, A220 family), military transports (C-390 Millennium, CN295) and legacy fleets such as UPS's A300 fleet.

14.3. DATA FUSION

Data fusion is not a new concept and has been researched by a number of industry and academic bodies for the past 10 - 15 years or so.

Equally, real world applications exist in modern day fighters, e.g., F-35, where common computing processing and high-speed data networks allow much greater levels of data fusion derived from multiple sensor sources.

There are essentially separate growth paths to be considered from the different perspective of military and commercial sectors each of which has its own set of distinct needs.

More recently, military developments with common processing, high speed networks and continuing demands for interoperability within the theatre of war have increased the emphasis upon the need for more data fusion.

Data are largely derived from sensors and the U.S. defence industry have been pursuing several major programs that depend on enabling radar, infrared systems, and other sensors to work together such that they combine their strengths and mitigate their weaknesses to create a sensor network that is greater than the sum of its parts.

With these kinds of dynamics in mind, Raytheon weapons developers are currently testing an emerging technology called Common Open Secure Mission Computer (COSMC). The concept is to replace federated functional computer systems with a data-fusion architecture to handle multi-function needs, by bringing them together.

Increased automation and AI-enabled computing can ease the 'cognitive' burden upon military crews by performing time and energy consuming procedural functions autonomously, all while leaving human decision makers in the irreplaceable role of command and control. This way, dynamic, capable human problem solving can be more fully and effectively leveraged in combat. In summary, pilots will be able to make faster and better decisions.

Also, another parallel can be found with the F-35's computer-enabled 'sensor-fusion' process wherein otherwise disaggregated feeds of time-sensitive sensor data are organised into a single, integrated screen

for pilots. Navigational, sensor and targeting data can be analysed in relation to one another to offer pilots more complete, structured information.

Within commercial platform operations Multi-Sensor Data Fusion concepts can be used to maximise the meaningful information extracted from disparate data sources to obtain enhanced diagnostic and prognostic information regarding the health and condition of airframe systems and, perhaps most importantly, the gas turbine engine.

Onboard Maintenance Systems are a growing feature of many commercial platforms which allow diagnostic and prognostic analysis to be conducted in real time with potential action items downloaded to service centres ahead of landing.

Airlines have long been somewhat critical of the tera-bytes of data now available that costs in terms of data download and storage - so where is the value generated, they ask?

Data fusion models are now being developed to generate a 'digital double' that is in effect a simulation of the physical asset (component/LRU) in digitised terms. Artificial intelligence can be utilised to allow for a more accurate predictive model that 'learns' from in-service experience (defects, wear rates, collateral damage etc).

Counterpoint believes that a combination of smart sensors, data fusion in real time and the application of artificial intelligence will be utilised to both alleviate pilot workload and aid decision making as well as help with health and usage monitoring/predictive maintenance.

14.4. AUTONOMOUS FLIGHT/'PILOTLESS' COCKPIT

Starting with a parallel industry, current autonomous car programmes expect to have to test, drive and simulate millions of miles of driving under a wide range of test conditions (traffic congestion, motorway, climate extremes, hazardous snow, ice and fog, mixed vehicle types etc).

As with autonomous automobiles, or any vehicles that transport a human cargo, there is a very high degree (and associated cost) of software development, validation, verification and certification required for autonomous operations.

The same infrastructure and software development requirements will apply to the numerous current air mobility platforms under development. It is not clear that many of these air mobility platform developers have fully absorbed the enormity of this challenge (looking at projected timescales for in-service commercial revenues) which is more to do with the airspace infrastructure and associated regulatory authorities than it is with the platform itself.

Many advances have been made in recent years with military autonomous rotorcraft programmes. A few specific examples are noted

- Airbus Helicopters announced Nov 2020 that it successfully performed autonomous take-off and landing (ATOL) from a moving deck using its Vertivision Surveillance Rotorcraft 700 (VSR700) optionally piloted vehicle (OPV).
- Northrop Grumman in 2009 introduced into service the MQ-8 Fire Scout as an unmanned autonomous helicopter developed for use by the United States Armed Forces to provide reconnaissance, situational awareness, aerial fire support and precision targeting support for ground, air and sea forces.
- Boeing, in 2020, completed flight tests with five high-performance surrogate jets operating autonomously in Cloncurry, Australia. Boeing's autonomy technology, including on-board command and control and data sharing capabilities, were tested using the 3.4-meter (11-foot) aircraft. They stated that "the tests demonstrated success in applying artificial intelligence algorithms to 'teach' the aircraft's brain to understand what is required of it. The data link capabilities enabled the aircraft to communicate with the other platforms so that they could collaborate to achieve a mission."

Avionics systems necessary for UAVs to complete an airborne mission have been in existence for some two decades or more. Without a pilot in the airborne mission loop, UAV avionics do not require man/machine interface devices such as displays and voice communication systems.

Equally, the UAV avionics systems that are required such as navigation, stores management, flight guidance and surveillance do not need the high levels of redundancy associated with passenger carrying aircraft. A significant caveat to this statement is that higher levels of redundancy may be required if the UAV platform needs to operate in civil aerospace.

However, despite success within the military unmanned arena, we expect to see bigger challenges yet to come in terms of civil autonomous flight with passengers on-board and no pilot directly in the loop.

Airbus successfully tested autonomous take offs with an A320 early in 2020. It also states that whilst its autonomous project "is to improve flight operations and overall aircraft performance, pilots will remain at the heart of operations. Autonomous technologies are paramount to supporting pilots, enabling them to focus less on aircraft operation and more on strategic decision-making and mission management".

Airbus is clearly not prepared currently to plan around removing pilots from autonomous flight development.

In 2017 Boeing acquired Aurora Flight Sciences Corporation, a world-class innovator, developer and manufacturer of advanced aerospace platforms including expertise in autonomous flight control for UAVs.

In 2019 Boeing's flying taxi completed its first test flight. Boeing is developing the autonomous, multi-rotor passenger air vehicle (PAV) as part of the Boeing NeXt urban air mobility program. PAV is an electric vertical take-off and landing (eVTOL) aircraft designed to provide on-demand mobility. During the pilotless test flight, the aircraft completed controlled take-off, hover and landing whilst Aurora tested the vehicle's autonomous functions and ground control systems.

Interestingly, Boeing's Pilot and Technicians forecast, issued in Nov 2020, shows no reduction in pilot demand for the next 20 years. This suggests that they do not see large commercial airliners flying in complete autonomous control for at least two decades.

Neither Airbus nor Boeing would wish to create unnecessary controversy amongst pilots' unions who are still a very powerful and influential body within the aviation industry.

Equally, whilst there is multiple redundancy within avionics/flight control architecture, many of which are now FBW/PBW, the fact remains that when all the computers fail it is only the pilot that can perform the 'last ditch' efforts to land the plane safely.

In summary, Counterpoint sees continued advances within autonomous vehicles for military applications with the emphasis upon avionics needs including:

- Continued advances in common mission computing resources
- increased data fusion via high-speed networks
- artificial intelligence to help platforms 'learn' mission roles
- improved sensors/smart sensors to support improved mission performance
- intra-platform interoperability to enhance overall war theatre performance.

The route for total autonomy within the commercial arena is less clear in terms of both technologies and timescales. The needs of high density, air mobility taxis concentrated in urban areas may well be on a different certification path to that currently being pursued by large civil platforms.

The pressures facing both small air mobility UAMs and large commercial aircraft tend to be predominantly achieving carbon neutral footprints. It therefore remains to be seen if autonomy/pilotless air vehicles will attract sufficient interest/investment given the more urgent need to switch to alternative energy sources.

14.5. SENSOR DEVELOPMENT

Most avionics are dependent upon inputs from sensors in order to function in both civil and military platforms.

Many of the regulatory imposed improvements in recent decades (e.g., RVSM, FANS/Next Gen, ADS-B, TCAS, EGPWS) are dependent upon upgraded sensor performance especially around navigation, communications, autonomous dependence and surveillance.

State of the art transponders form a key sensor technology within autonomous operations, surveillance and identification functions. In 2010 EADS (now Airbus) launched the lightweight LTR 400-A transponder which can be used both for military applications to identify friendly units, as well as in civilian air traffic control. The unit operates to the latest civilian air traffic control standard, Mode S "Enhanced Surveillance", and, together with the QRTK3-NG encryption and decryption computer, can also be used in all military modes.

Within the military arena high performance aircraft are dependent upon AESA radars, electro-optical cameras, infra-red sensors and lasers for a range of EW/ECM functions.

Counterpoint has compiled a separate report that considers the high growth of airborne sensors in recent years used for a range of functions including health and usage monitoring, predictive maintenance and data reporting.

Growth in sensors from 100s on early generation narrow body aircraft to 1000s now found on a modern large commercial aircraft has also been accompanied by new sensor technology development.

Many mechanical sensors have been replaced with solid state versions which typically reduces weight cost and volume.

Large complex 3-axis mechanical gyros, used for primary navigation, can now realistically be replaced by solid state versions that are a fraction of the cost.

Honeywell's third-generation air data inertial reference system (ADIRS) with digital gyros provides high system reliability and performance with reduced operation and maintenance in a 4 modular concept unit package. This solid-state inertial platform can be retrofitted with minimum aircraft wiring changes and interfaces with existing 4MCU standard fittings - it is therefore targeted at the upgrade market.

The application of electronics has allowed for the development of 'smart sensors' with intelligent communications and high-speed data interfaces.

Collins Aerospace latest generation of SmartProbe® Air Data Systems combine multi-function probes and air data computers with stall warning and protection for a superior air data system. The Collins SmartProbe Air Data System is a comprehensive, RVSM-compliant air data solution suited for a variety of new aircraft platforms and upgrade programs. Because each SmartProbe unit features its own air data computer to calculate air data parameters, the need for pneumatic tubing and some of the electrical wiring is eliminated.

Thales claims to be a world leader in airborne optronics and has recently developed a family of advanced pods for reconnaissance and surveillance. The TALIOS pod combines targeting and tactical recce capabilities in a single pod. It delivers unmatched image quality, including colour imagery, and disruptive capabilities such as Permanent Vision™ and embedded artificial intelligence to provide combat aircraft pilots and ground forces with reliable situational awareness in real time. The THALIOS pod went into active service on the Dassault Rafael in 2018.

In recent years, Thales has also worked with the UK MoD to develop Elix-IRTM which is a passive multi-function threat warning system using wide-spectrum colour infra-red sensing technology to deliver simultaneous and unimpeded Missile Approach Warning (MAW), Hostile Fire Indication (HFI) and situational awareness from a single sensor system to increase overall platform survivability and mitigate risk to life. Crews are constantly updated about threat types and locations, with 360° spherical IR imagery to improve situational awareness. Elix-IRTM is suitable for a wide range of aircraft including helicopters, transport aircraft, UAVs and business jets. It is available in airframe-mounted and podded configurations.

Whilst the F-35 has only been in service some 9 years there are currently a number of key sensor upgrades taking place as part of Lockheed's Continuous Capability Development and Delivery (C2D2) programme. Some of the key examples of this are as follows:

- Raytheon selected in 2018 by Lockheed Martin to produce the next generation electro-optical distributed aperture systems (EO-DAS) for the Lockheed Martin F-35 besting incumbent Northrop Grumman.
- The SDB II upgrade massively advances sensing technology with a tri-mode seeker able to use all-weather millimetre wave technology, semi-active laser targeting and infrared guidance, an innovation which also favours the kind of data-sharing being sought.

- Israeli upgrades to F-35 (Dec 2020). The DAS system is networked with the F-35s Electro-Optical Targeting system. That Electro-Optical Targeting system is a high-fidelity, long-range sensor intended to find enemy targets before the F-35 itself can be seen by any enemies. Merging this sensor system with advanced EW is a likely focus of Israel's F-35s upgrades.

In Jun 2019, Lockheed Martin stated that the F-35 Block 4 upgrade might lead to an F-35 that blurs the line between a fifth-generation fighter - characterised by stealth and sensor fusion - and a sixth-generation one, which at least currently is seen as having advanced network capabilities that could give the pilot control over external weapons, drones and sensors.

Many of these sensor upgrades and/or new technology 'smart' sensors require associated software upgrades in order for their effective installation and use. We consider the impact of software upgrades, be they avionic, computing or sensor driven, within the next section of this report.

In summary, Counterpoint sees advancing sensor technology development as one of the key growth drivers in enhancing improvements in navigation performance, operating costs, mission effectiveness, electronic warfare, and through life cycle costs (health and usage monitoring/predictive maintenance).

Specifically, within avionics we see continued above trend growth in:

- close coupling between remote sensors and avionic computing
- distributed or local computing at the sensor (i.e., 'smart' sensing)
- sensor data concentrators connected to high-speed networks (larger airframes and military platforms)
- high speed network connectivity for sensors
- military sensors (e.g., EASA Radar, Synthetic Vision Systems, IFF, threat detection, AI applied to sensor data for 'learning').

14.6. SOFTWARE DEVELOPMENT/DIGITAL SERVICES

In recent years, the total cost of developing a new platform, whether it be civil or military, has seen a far greater proportion of overall budgeted costs apportioned to software development.

The numbers vary greatly depending upon the role of the platform, but it is now expected that software development can account for between 15% and 40% of total development costs.

The main systems that account for a large proportion of this software development are listed as follows:

- Avionics (navigation, communications, surveillance)
- Mission computing (military platforms)
- Flight Control Systems (FBW/PBW)
- Engine controls (e.g., FADECs)
- Utility control functions (e.g., landing gear, ECS, power generation and distribution etc)
- IFE, Cabin services (commercial aircraft)
- Electronic countermeasures/Electronic warfare (military platforms).

Following the successful development and entry into service of any one of these software-dependent systems, there is then the need to maintain and update the software and associated databases.

Avionics is one of the main drivers for software updates largely because avionics represents the link with both the environment and ground- based systems that change over time.

A quick look at the avionics supplier listing contained within section 11.1 will show around 10 avionics software businesses that 10 or 20 years ago would not have featured in this listing.

However, these software suppliers represent only a part of the total software picture. These suppliers are largely focussed upon the Aerospace and Defense sector. There are global software brands which also service the A & D sectors amongst many others. Aerospace & Defence software solutions providers within these global leaders include Dassault Systemes, Microsoft, Autodesk, Cadence Design Systems, Ansys, Siemens PLM software, Synopsis, Hexagon, SAP and Adobe.

These software providers offer a wide range of general services, some of which relate to avionics, including Aviation Maintenance Management, Air Traffic Management applications, Flight operations software, Quality management system, Financials, HR, Procurement etc.

Equally, many of these lead software houses are engaged with the aerospace OEMs such as Airbus, Boeing, Honeywell, Collins Aerospace, Thales in developing a range of Aerospace & Defence solutions including secure Cloud storage, Cybersecurity protection, future common computing architectures, testing and verification of software for critical applications, 5G network service provision, and the application of Artificial Intelligence.

Cybersecurity risks possibly prevent Aerospace & Defence firms from embracing the Cloud in its current form. Still, GE Digital is pushing ahead with Cloud initiatives like Predix to reshape the Aerospace & Defence market with device connectivity solutions for predictive maintenance.

The switch from analogue to digital in recent decades has resulted in millions of lines of code now underpinning a modern aircraft platform (see table at the end of section 6). Specifically, within Avionics software has been utilised in a number of key areas. A few of the key examples are listed as follows:

- Integrated Modular Avionics or 'common computing' platforms - now being adopted widely in both civil and military platforms - standard software code acting as the common backplane for a wide range of utility functions - designed around 'open architectures' that allow the utility functions (hosted in partitioned software) to be added to/modified/upgraded by 3rd party owners/operators.
- Navigation – modern FMS systems derive their highly accurate position "output" from multiple navigation input sources including inertial reference systems, Radio nav, DME, ILS, VOR, GPS etc. The FMS typically utilises Kalman filters, i.e., software code, in order to 'blend' all of these inputs to arrive at a statistically sound and accurate output of position.
- Air data – used to derive altitude, air speed, angle of attack from multiple sensor probes. These probes can sometimes provide inconsistent data (failure, icing, FOD etc) in which case software algorithms are applied in order to provide voting logic and sanity checks in order to eliminate the spurious data.
- LED/flat panel displays – usually driven by high-speed graphics engines or symbol generators which are embedded in software.
- Synthetic Vision Systems – often a digitised blend of inputs from electro-optic, infra-red or laser sensors creating a potential 360-degree field of view.
- Software Defined Radios – benefits include standard platforms, ease of upgrade and re-use, in-situ re-programming to add features and provide 'future-state' assurance.

Once the software is embedded in hardware and certificated for use in service comes the challenge of maintaining the software, providing updates, maintaining databases, avoiding obsolescence issues (definitely a major design criterion) and being able to achieve all of the above without disrupting aircraft in active service.

As a result of this objective the industry has developed range of computer peripherals, wi-fi connections and high-speed data loaders that can be easily connected and software uploaded whist the aircraft is located at the terminal.

The proliferation of software and data in recent years, and their application to avionics and systems, has led to a significant number of subscription services being offered to end-users and operators.

These service providers are not restricted to the platform manufacturer or the OEM/Tier 1 integrator and they can also include airlines, software houses and 3rd party specialist providers.

A list of typical software/data service offerings provided by different vendors is as follows:

- Boeing Jeppesen, Honeywell and GE Aviation all offer a monthly update subscription service for the FMS navigation database (airport terminals, route structures, changing landscapes etc) which has to be periodically updated (usually every 28 days).
- Universal Avionics offer a range of subscription services including FMS nav databases, however, they have retained NavBlue as their preferred sub-contractor for packaging and distributing this service.

- Lufthansa also offers a similar FMS nav service via its Lido FMS brand which provides an update on a 28 day cycle.
- Thales offers its ATM Cybersecurity Solutions that advocates a holistic approach and offers solutions based on business risks i.e. Protect, Detect, Respond, Recover. Thales has combined its expertise in cybersecurity and Air Traffic Management to deliver business solutions for ANSPs, airports and other critical operators in the aviation domain.
- Collins Aerospace offers 'software only' Mission Flight Management Software (MFMS-1000) which provides global civil airspace access with seamless integration of existing mission flight management capabilities in a portable software only solution.
- 2018 - Avionica and GE Aviation announced that they have expanded their partnership by forming a joint venture. The JV allows the companies to accelerate edge processing and wireless connectivity to maximise the value of aircraft data. The JV combines Avionica's suite of flight data management solutions, which includes Wi-Fi, cellular and satellite connectivity, with GE Aviation's analytics expertise to address customer needs in flight analytics, aircraft health management and flight operations. Avionica's satellite and cellular wireless technologies support the transfer of flight data sets with global coverage, economical cost and easy installation.
- Nov 2020 - Curtiss-Wright's Defense Solutions division announced that its recently acquired business, PacStar, a leading developer and supplier of advanced communications solutions for the U.S. Department of Defense (DoD), has released IQ-Core Software v5 containing major advances in management of Commercial Solutions for Classified (CSfC) systems, tactical radios, and vehicle-based networks. The release also includes upgrades in its support of open management standards and performance enhancements.

Counterpoint believes that the proliferation of software suppliers entering the Aerospace & Defence sector in the past decade or two reflects the greater investment and reliance placed by Avionics suppliers upon software solutions both at the initial platform development phase and the subsequent life cycle maintenance, upgrade and retrofit cycle.

We have already noted that software development represents 15% - 30% of the total airframe development cost. We therefore expect to see that the in-service support demand for software services will also likely grow from a relatively low base today to support double digit CAGRs.

14.7. CYBERSECURITY

With the proliferation of software and data comes the increased threat from security breaches.

The 'connected world' within both civil and military avionics arenas will generate an exponential increase in security threats similar to what we see in online banking and shopping.

It is neither practical nor sensible, within this report, to outline in detail the steps taken by the leading cybersecurity providers to counter this threat. Much of this information simply is not available, certainly within the classified military arena.

We do however note that major military avionics providers typically include 10% to 40% of their annual R&D budget as 'classified' activity.

This classified activity will certainly include projects aimed at improving network centric arena activity including data and communications transmissions.

Encryption and jamming technologies are not new within the military arena and are now being adopted within the civil arena where the exposure has increased significantly in recent years.

A quick review of avionics software and hardware providers will show that they all offer full encryption services embedded within their range of avionics products that could be exposed to security threats.

Companies such as Honeywell, Thales, Collins Aerospace, BAE Systems, Raytheon Intelligence Systems, Ultra Electronics, Curtiss-Wright, Wind River, Lynx software Technologies all offer specific encryption services.

15. INTERNATIONAL ATC/INFRASTRUCTURE INITIATIVES

The previous section covered some of the key technology drivers which tends to be focussed upon product and software technology.

However, it can be argued that much of this technology is driven by the over-arching requirements to have an improved global air traffic infrastructure that addresses current and future needs from both a commercial and military perspective.

There are a number of industry bodies operating at national and international level (e.g., ICOA, IATA, FAA, CAA, EASA) that are supporting what are essentially global initiatives to create the future state in terms of air transport.

The international aviation community (both civil and military) is now facing important technological and operational challenges to allow a proper development and deployment of the CNS/ATM and Avionics (CNS+A) innovations announced by the US NextGen, the European SESAR (Single European Sky ATM Research) and other programmes such as CARATS (Collaborative Actions for Renovation of Air Traffic Systems) in Japan and OneSky in Australia.

It is these long-term initiatives such as FANS, NextGen (US) and SESAR (EU) that result in many of the mandatory changes in regulatory avionics requirements such as autonomous flight (ADS-B/A), Reduced Vertical Separation, Traffic Collision Avoidance and Precision Navigation performance.

Both NextGen and SESAR have been in operation for around a decade and will continue to operate through to 2030.

SESAR

The Single European Sky ATM Research (SESAR) programme is an EU-led modernisation programme of Air Traffic Management throughout Europe, from research through to deployment; currently being delivered by the National Air Traffic Control Service (NATS).

The key work packages within SESAR are as follows:

- AF1' or 'extended arrival management and integrated arrival management ('AMAN')/ departure management ('DMAN') in terminal areas' improves the precision of the approach trajectory and facilitates air traffic sequencing at an earlier stage and the optimum utilisation of runways by deploying specific ATM solutions.
- 'AF2'or 'airport integration and throughput' facilitates the provision of approach and aerodrome control services by improving runway safety and throughput, enhancing taxi integration and safety and reducing hazardous situations on the runway.
- 'AF3' or 'flexible airspace management and free route airspace' enables airspace users to fly as closely as possible to their preferred trajectory without being constrained by fixed airspace structures or fixed route networks. It allows operations that require segregation to take place safely and flexibly and with minimum impact on other airspace users.
- 'AF4' or 'network collaborative management' improves the European ATM network performance, notably capacity and flight efficiency. AF 4 contributes to the implementation of a collaborative network for planning and decision-making, which enables the implementation of flight- and flow-centric operations.
- 'AF5' or 'system wide information management (SWIM)' consists of standards and infrastructure enabling the development, implementation and evolution of services for information exchange between operational stakeholders delivered through an internet protocol.
- 'AF6' or 'initial trajectory information sharing' or 'i4D' improves the use of target times and trajectory information, including where available the use of on-board 4D trajectory data by the ground ATC system implying fewer tactical interventions and improved de-confliction situation.

It is clear that these work packages AF1 thru AF6 all have implications for avionics systems and will undoubtedly result in future regulatory mandates as to acceptable levels of avionic capabilities and performance.

This in turn will sustain a healthy retrofit and upgrade market for legacy fleets operating within EU airspace.

NextGen

The Next Generation Air Transportation System (NextGen) is the FAA-led modernisation of America's air transportation system to make flying even safer, more efficient, and more predictable. As part of NextGen, the U.S. Air Force awarded Lockheed Martin a modification worth up to $4.9 billion on the company's existing contract for the Next-Generation Overhead Persistent Reconnaissance (Next-Gen OPIR) satellite system for work associated with the manufacturing, assembly, integration, test, and delivery of three Next-Gen OPIR satellites and delivery of ground mission unique software and ground sensor processing software.

Via NextGen the FAA is creating new interconnected systems that fundamentally change and improve communications, navigation, and surveillance in the National Airspace System (NAS):

- Communications: In a modernised NAS, aircraft must be able to receive dynamic, complex instructions from ground systems that can identify where they need to be and at what time. Data Communications helps pilots and air traffic controllers to communicate more quickly, more easily, and with less risk of miscommunication than radio messages over busy frequencies.
- Navigation: The FAA has switched to a primarily satellite-enabled navigation system that is more precise than traditional ground-based navigation aids. Satellites enable the FAA to create optimal flight paths anywhere in the NAS for departure, cruising altitude, arrival, and landing operations. These precise, efficient procedures can reduce flying time, fuel use, and aircraft exhaust emissions while getting passengers to their destinations at more predictable times.
- Surveillance: The ongoing implementation of NextGen provides air traffic controllers with the exact location of aircraft and a clear vision of surrounding conditions, including weather patterns and aircraft.

The key NextGen Enabling Programs include the following:

- Data Communications (Data Comm)
- Performance Based Navigation (PBN)
- Automatic Dependent Surveillance-Broadcast (ADS-B) In and Out
- Decision Support System (DSS) Automation
- System Wide Information Management (SWIM)
- Weather
- Other Improvements
- Safety
- Environment and Energy

As with SESAR, we interpret many of the NextGen initiatives as requiring changes within avionics in order to deliver the operating efficiencies and new requirements.

NextGen is intended to meet the air transportation needs of the US in the 21st century – in particular, a significant growth in demand for air traffic services, possibly on the order of three times today's demand levels. Similar challenging objectives are set for the European SESAR program, which is also focusing on ATM fragmentation issues more severe in the European Air Space. With both R&D programs under way, it will be necessary to make clear how the enabling technologies will be deployed in the two continents in the near and mid-terms, and where the main synergies and differences lie between the European SESAR and US NextGen ATM programs. There are significant (technical, operational and legal) challenges for the NextGen and SESAR deployments, and to allow harmonisation and integration of the two programmes into the Global ATM Framework. Coordination is also fundamental between SEASAR/NextGen and other national/regional ATM modernisation initiatives (e.g., OneSky in Australia and CARATS in Japan).

In summary the key enabling technologies are listed as follows:

- Communications, Navigation and Surveillance Systems Performance Metrics
- Flow Management, Decentralisation and Collaborative Decision Making

- 4D Aircraft Trajectory Optimisation and Time-Based Operations
- Performance Based Navigation and Intent Based Operations
- Gate-to-Gate Optimisation Problems for SESAR/NextGen and CleanSky
- Dynamic Airspace Management (Time-Based and 4D)ATM Route Planning (ARP) and Flight Management Systems (FMS)
- HMI aspects of 4DT Management in Manned and Unmanned Aerial Vehicles

The increasing need to have military aircraft equipped to fly within civil airspace and growing demand for UAS/UAM vehicles provides an additional set of challenges for the ATM infrastructure.

Military aircraft and UAS are already equipped with ISR sensors (RADAR/LIDAR, SAR/ISAR, VIS/IR/EO sensors, laser rangefinders, etc.), SATCOM, GNSS, a variety of inertial sensors including platform/strap-down Inertial Navigation Systems (INS) and/or low cost MEMS, plus high throughput RF data links (for high data rate applications like free-stream video transmission) and conventional tactical data links for communications with legacy air, ground and see platforms in current network-centric scenarios. The concept of integrated multi-sensor navigation is no way limited in application to military avionic systems. There is a growing number of civil applications, where information from multiple sensors is combined to improve performance, provide redundancy management, increase robustness, or achieve graceful degradation when sensor failures (or outages) occur. Although the sensor integration possibilities are expanding the focus for military will be on integration of GNSS, INS and other sensors, such as RADAR, LIDAR and other Forward-Looking Sensors (FLS).

In military applications, further possibilities are also offered by Link 16 and other tactical data links. As the current standard for military anti-jam digital communications, Link 16 has been implemented in the JTIDS and MIDS/JTRS terminals. These systems provide Anti-Jam (AJ) communications using Frequency Hop and Pseudo Random Noise (PRN) spreading techniques. As a result, there are accurate time-of-arrival (TOA) measurements between the transmitting terminals. It is therefore important to develop an integrated navigation filter capability, which optimally integrates MIDS/JTRS data with other sensors (e.g., GNSS, INS, FLS), providing a robust navigation solution in GNSS-denied conditions.

UAS Developments

Research initiatives are underway in the US, Europe and Australia to assist the FAA, EUROCONTROL and CASA define safety thresholds and develop policies, procedures and systems that would make UAS unrestricted airspace access a reality. Before unrestricted UAS operations become possible, assurances must be made that they can operate safely. Developing a certifiable Sense and Avoid (SAA) capability for UAS is viewed as one of the most fundamental and yet most elusive tasks to be accomplished. For manned aircraft, one of the basic obligations of the pilot is to 'see-and-avoid other aircraft.' The see-and-avoid procedure has the advantage of not relying on any cooperative equipment in the threat aircraft. While see-and-avoid is subject to human limitations, it is proving difficult to develop a practical suite of sensors/systems that can provide anything nearly equivalent to human vision and associated decision making. SAA can be defined as the capability of a UAS to remain well clear from and avoid collisions with other airborne traffic. SAA provides the intended functions of self-separation and collision avoidance as a means of compliance with the regulatory requirements to 'see and avoid' compatible with expected behaviour of aircraft operating in the airspace system. From a conceptual point of view the SAA capability performs the following sub-functions:

- Detect – Determine presence of aircraft or other potential hazards
- Track – Estimates position and velocity of intruders based on surveillance reports
- Evaluate – Assess collision risk based on intruder and UA positions and velocities
- Prioritise – Determine which intruder tracks have met a collision risk threshold
- Declare – Decide that action is needed
- Determine Action – Decide on what action is required
- Command – Communicate determination action
- Execute – Respond to the commanded action

Counterpoint believes that the above initiatives will continue to be in force and supported over the next decade as the industry seeks to deal with many challenges including the need for improved operating efficiencies, management of congested airspace, commercial and military overlaps and the emergence of the UAS/UAM sector.

As has been the case in past decades the impact of these initiatives will be to both affect the design of future avionics architectures and to maintain a healthy retrofit and upgrade market.

16. AVIONICS WITHIN EMERGING MARKETS

In researching this report, we have identified a number of avionics suppliers located within emerging market countries such as China, India, Russia, Korea and Brazil. Equally many of the national bodies governing the development of aviation are actively supporting the industry in such areas as investment, education, and infrastructure.

Japan

With an established civil and military aviation history we have found little evidence of Avionic development within Japan. There are a number of large corporations that have developed positions within Aerospace e.g., Kawasaki, Mitsubishi, IHI corporation, Sumitomo. However, none of these have yet to successfully venture into Avionics.

This is all the more surprising when you consider Japan's significant technological capabilities within the broader electronics markets.

Equally Japan has sought to develop an indigenous airframe capability via Mitsubishi with its SpaceJet programme.

Unlike China, that effectively sought to leverage access to its indigenous Comac C919 programme by having western suppliers sign up to Joint Ventures within China, Japan has been comfortable sourcing all its SpaceJet avionics from western suppliers. The majority of the SpaceJet avionic suite is supplied by Collins based upon their integrated ProLine Fusion avionics.

However, as we compile this report in December 2020 Mitsubishi has announced that 95% of the workforce currently engaged in the SpaceJet project will be laid off or re-deployed. The press is speculating that this may be the final nail in the coffin for this programme given its troubled history regarding weight and performance.

Following the US decision not to allow export of F-22 fighters the Japanese elected to promote a new F-X fighter concept. This programme has yet to be formally launched. However, Japan has sought collaboration from both UK and US military contractors and will undoubtedly be reliant upon western contractors for avionic-related mission and sensor systems if and when the programme goes ahead.

Japan has held discussions with BAE Systems, Northrop Grumman, Lockheed Martin and L3 Harris corporation, we understand, in respect to its aspirations to develop (jointly) an indigenous military fighter platform.

Within the civil arena Japan has increased its participation in international joint development of civil aircraft and is a 35% partner in the production of the Boeing 787, and a 21% partner of the Boeing 777 and 777X jets. Japan is also a major components manufacturer for Airbus, supplying cargo doors, vertical stabiliser structure materials, titanium sheeting, carbon fibre and water tanks, etc.

Japanese aviation industry has certainly carved out a strong position as a strategic partner (structures) and systems provider. However, we remain somewhat surprised that there is not greater investment geared to developing indigenous supply of avionic equipment.

China

In 2015, the Chinese government released its 'Made in China 2025' strategic plan, through which it seeks to become a major manufacturer of high-end technology, including avionics and aerospace equipment. In

pursuit of this goal, Chinese state-owned companies leverage the country's highly desirable market to persuade foreign companies seeking market access to share technology.

The COMAC C919 programme was utilised very effectively to encourage western suppliers to form JVs with Chinese AVIC subsidiaries as a condition of being selected (not formally declared as such). This has resulted in a number of JVs within the avionics domain as follows:

- Aviage Systems is a 50/50 joint venture between GE Aviation and AVIC. Currently, it specialises in the supplies of the integrated modular avionics system to the C919. Specifically, GE will contribute its commercial Integrated Modular Avionics (IMA) technology to the joint venture. The JV will supply IMA technology, displays, onboard maintenance systems, flight recorders and flight management system for the C919.
- Rockwell Collins (now Collins Aerospace) and China Electronics Technology Avionics (CETCA) have established a joint venture to develop and manufacture the communication and navigation systems for the Commercial Aircraft Corporation of China (COMAC) C919 aircraft.
- Honeywell Aerospace is another major supplier of avionics to the C919. According to Honeywell's Asia Pacific aerospace division, the company has more than 12,000 employees in China right now. "We have 700 aerospace experts working across seven manufacturing plants, including two joint ventures for the C919," Kaul said. "These include supplying the aircraft's fly-by-wire system with HonFei Flight Controls and the supply of the braking system under a joint venture with Boyun Aviation Systems."
- Thales and China Electronics Technology Avionics Co., Ltd. (CETCA), have a Joint Venture Agreement that brings together world-class technology solutions companies dedicated to the new C919 aircraft. The Thales system will be a scalable platform offering services ranging from interactive audio capability through to full in-seat on-demand services, with an emphasis on minimising weight, cost and power consumption. Future evolution of the system will likely include wireless networks and connectivity

It is interesting to note that Honeywell has a total of 5 JVs in China within its aerospace division. However, it does not have a JV specifically covering its avionics supply for C919.

It is worth understanding some of the history behind China's plan for avionics within Aerospace.

For a long time, China's avionics systems suppliers targeted only the domestic military aircraft platforms. And unlike the aerostructure manufacturers of AVIC, these local avionics suppliers lack experience on western commercial programmes under the shadow of an embargo on sensitive components. Both the ARJ21 and MA series are equipped with avionics system from Collins Aerospace. Although a few local suppliers are involved in these programs, their work packages are on non-core components. C919 is the first platform that the local avionic suppliers are seriously involved in (largely via the Aviage JV with GE Aviation described within this report in suppliers' profiles).

AVIC's China Avionics Systems and CETC's CETCA are two major domestic suppliers, both are state owned/related. As a legacy of the frequent restructuring in the past decade, both companies now have yet to form a synchronised manufacture and internal supply chain within their subsidiaries, although both claim that they offer avionics products across the whole value chain. For example, both AVIC Chengdu CAIC Electronics and AVIC Taiyuan Aviation Instrument manufacture air data systems, both AVIC Lanzhou Flight Control and Beijing Qingyun Aviation Instrument manufacture autopilot systems, and both AVIC Taiyuan Aviation Instrument and Beijing Qingyun Aviation Instrument manufacture integrated display systems. This induced inter-subsidiary competition is making AVIC's avionics business fragmented.

Another factor that has caused this fragmentation of AVIC's avionics business is the design logic behind China's avionics systems. Unlike the western giants, AVIC's avionic systems' design are solely driven by the development of specific aircraft programs. The designed systems have almost no subcomponents that are compatible with any other platforms because the assigned subsidiaries that worked on these aircraft programs are often different and as a consequence of the forementioned inter-subsidiary competition it can be challenging for these subsidiaries to work together. Thus, the level of technical capability for the 18 avionics companies under AVIC varies as well.

According to the 'Made in China 2025' road map China's strategy on avionics is to focus on R&D in

- Integrated Core Processing (ICP) systems
- Integrated Navigation Systems (INS)
- Cockpit Displays
- Onboard Maintenance Systems (OMS)
- Communications, Navigation, Surveillance (CNS) equipment

China's avionics market (supplied by local suppliers) is growing at a CAGR of 6-7%, mainly driven by military programs: China aims to expand its military fleet by 2,876 more aircraft by 2029.

In 2019 (pre Covid-19) China's domestically produced avionics equipment was worth $542 million. Affected by the Covid-19 pandemic 2020's market shrank by 10% but will quickly return to pre Covid-19 level in 2021 and restore the growth in 2022. We predict that the growth rate between 2022 and 2026 will be at 6% (slightly above the 5% CAGR driven by the military fleet expansion) because China will be keen to take the opportunity to accelerate its military programs while western OEMs recovery slowly from the pandemic.

Beside the military applications, China has long history on manufacturing civil helicopters since 2007 compared with other civil aircraft types. And under the government's promise to open more air space for civil use it is believed that around 2027, there will be a boom in civil helicopter programs in China, boosting the growth on the domestic avionics market to 7%.

As discussed earlier, we believe China still has a long way to go to be able to supply to western programs, but strategic partnerships like JVs are currently the only way to gain access to Comac's programs. Technology knowhow is likely to be transferred to the local manufacturers.

AVIC China Avionics Systems, a subsidiary of AVIC, is China's largest avionics system supplier. Initially focused on military aircraft, the company is now expanding its offering to commercial aircraft by participating in the C919 program. Two subsidiaries of the China Avionics Systems are directly involved in the development of C919. AVIC Chengdu CAIC Electronics in involved in the development of Air Data Heater Controller. Shanghai Aviation Electronic developed and is now the manufacturer of the C919 control panel components, dimming control systems, and circuit breaker board. In addition, AVIC's other subsidiaries are also taking part of the C919 development via JVs with western avionics giants.

CETCA is the second largest, and the only other state-owned company, that supplies avionics in China. The company was established in 2009 for the purpose to support the C919 program. The company is involved in the design and development of avionics systems for the C919, C929, AG600, MA700, and ARJ21.

The table below shows a list of JVs in China.

JV	Year	Chinese company	Share %	Western company	Share %	Product/Service
Collins Aviation Maintenance Services Shanghai Ltd	1997	China Easter Airline	35	Collins Aerospace	65	Provide aftermarket services and support of avionics and in-flight entertainment equipment for Chinese airline customers.
AVIAGE Systems	2012	AVIC CAE	50	GE	50	Provide integrated avionics solutions across 3 packages to C919 including 5 sub-systems including: onboard maintenance system, Common computing resources, flight management system,

						remote data concentration, aircraft data network, digital information system, digital ecosystem and big data analytics, integrated display system, 3rd party hosted subsystems integration, tier-1 system integration services, and flight recording systems.
AVIC Leihua Rockwell Collins Avionics Company	2013	China Leihua Electronic Technology Research Institute (LETRI)	99	Collins Aerospace	1	Established to develop the ISS which combines weather detection, traffic alert and collision avoidance, Mode S surveillance and terrain awareness and warning functions into a single system.
Rockwell Collins CETC Avionics Co. Ltd. (RCCAC)	2014	China Electronics Technology Avionics Company (CETCA)	99	Collins Aerospace	1	Established for development of the communication and navigation avionics solutions, which included audio, radio tuning, HF, VHF, GPS, DME, Radio Altimeter, VOR/ILS and an optional Inmarsat SATCOM solution
HonFei Flight Technology Co. Ltd. (HonFei)	2017	AVIC Xi'an Flight Automatic Control Research Institute (AVIC FACRI)	50	Honeywell Aerospace	50	Develops and produces flight control systems for commercial aircraft, including the COMAC C919
Other strategic partnership	2014	AVIC Chengdu CAIC Electronics	N/A	Honeywell Aerospace	N/A	Supply ADIRS for C919 from design, manufacture to MRO

In recent years certain of these US based JVs have run into trouble owing to the onset of trade issues between China and US. Also, there are claims by the US that these JVs have exploited access to US derived IP which is now being utilised by Chinese companies.

Currently all the major western avionics suppliers, including Honeywell, Collins, Thales and GE Aviation benefit from the billions of dollars of avionic revenues generated to both supply and support the largely Airbus and Boeing dominated fleets in operation in China today.

The Comac C919, (together with the regional ARJ21, MA700 etc), is clearly a 'learning platform' for the Chinese Aviation industry and their aspirations to be self-sufficient in areas such as engines, avionics and systems will almost certainly result in there being Chinese competitors vying for contracts on any next generation platforms launching in a 2030+ timeframe.

Russia

There are a number of state-run institutions developing avionics capabilities that, over the years, have been encouraged to become independent commercial organisations, albeit with funding support from the state.

In 2017, the Russian government planned to invest up to 90 billion roubles ($1.5 billion) in the development of its domestic avionics industry in the coming several years. That is driven, in part, by the lack of cooperation between Russia and the U.S. in this field as a result of American sanctions following Moscow's 2014 annexation of Crimea from Ukraine. The design and production of the new systems and other Russian avionics are to take place at a new Radio Electronic Technologies' plant in the city of Kazan in southwest Russia, where a research and manufacturing cluster for avionics is to be established.

In the commercial aviation domain, Thales provides the full avionics suite to the Sukhoi Superjet100 (SSJ100) programme, where there is dependence upon western providers of avionics.

Russia has planned to replace MC-21 twin-jet airliner's avionics manufactured by America's Honeywell and Rockwell Collins, and France's Thales with indigenous airborne avionics before 2023. A draft tender was issued to look for potential Russian manufacturers. The deadline for the development, tests, and certification of the avionics is targeted to be completed by the end of 2023.

In the military field the Sukhoi Su-30MK, made by AVPK (a state-controlled joint venture of Sukhoi and four aircraft factories in east Russia), and MiG-31 MAPO (Moscow Aircraft Production Association) rely heavily on contracts from countries like China or India to support development of next-generation avionics.

Current Russian military programmes have been supported by a number of indigenous businesses including:

- Aerospace Equipment Corporation JSC (covered in the supplier profile section)
- Radio electronic Technologies (covered in the supplier profile section)
- CSRI Elektropribor JSC (state corporation not covered as navigation for land and space)

Arguably AEC is the most significant Russian Avionic supplier with a diverse range of capabilities as noted in this report.

It remains to be seen if Russia can create an internal capability in avionics, sufficient to meet both its military and civil needs, within its stated timeframe of 2025. A number of industry experts have suggested that the current available state funding is nowhere near adequate.

India

The Defense Avionics Research Establishment (DARE), established as an electrical avionics research centre in the 1950s, works on the development of electronic warfare systems and mission avionics for aircraft. It is one the two laboratories of DRDO that works on electronic warfare systems, along with Defence Electronics Research Laboratory. DARE developed the first mission computer for the Light Combat Aircraft (LCA) in 1991. The computer was responsible for managing the interaction between avionics, displays, sensors and weapon systems.

Insofar as avionics are concerned, HAL represents the only business within India that has proven avionics capabilities. HAL Korwa division or Avionics Division Korwa (see HAL Korwa in the supplier profile section of this report) was established in 1983, to take up the production of Display Attack Ranging and Inertial Navigation system for Jaguar International aircraft for the Indian Air Force, followed by manufacturing & supply of avionic systems for Russian MiG-27 & Su-30MKI aircraft.

The HAL Korwa Division is manufacturing & repairing various Avionics Systems fitted on MiG-27M Upgrade, Mirage-2000, LCA, Jaguar upgrade, AJT-HAWK aircraft. The division has also been engaged in the maintenance of UAVs Systems since 2001.

The other electronics business within India that services the military market sector is Bharat Electronics. We have not covered this business with a supplier profile as it tends to service land and marine but not avionics. However, in 2010, Boeing announced that it received the Data Link II communications technology for the Indian Navy's P-8I from Bharat Electronics Limited (BEL). Bharat delivered the Indian-designed

communications system that would enable the exchange of tactical data and messages between Indian Navy aircraft, ships and shore establishment.

In contrast to manufacturing, arguably India has established itself as an ideal 'centre of excellence' for the provision of Engineering services to western avionics businesses in recent years. This is especially the case where digital products are concerned that also require considerable amounts of software code.

Both aircraft OEMs and Tier 1 suppliers have established engineering design centres throughout India in support of the development of avionics related products.

Boeing, for example, is investing almost $100m developing a new facility in Bengaluru (next to the airport) where a new building will eventually house 3,000 employees. It will be Boeing's largest engineering and product development facility outside of Seattle, when completed.

Whilst the project has slowed due to the 737MAX issues and the pandemic it will be used to help develop secure communications standards and health management systems for next generation aircraft.

Honeywell, GE Aviation and Collins have all invested in developing engineering service centres within India in support of developing avionic equipment for the western markets.

Collins, for example, has an Engineering Design Centre located in Hyderabad which it established in 2008 and it is totally dedicated to the development of software.

Brazil

Brazil's aviation industry has enjoyed considerable success with the development of both civil and military platforms that they have been able to successfully export.

Following its founding in 1964 Embraer enjoyed early success with regional turboprop aircraft such as the Bandeirante and EMB 120 Brasilia whilst on the military side it developed the AMX fighter and Super Tucano military trainer.

Its successful foray into business jets followed with Legacy 650 and more recently the Phenom and Praetor families of aircraft.

Currently it produces the very successful range of E jets that lead the worldwide regional jet market.

It has also recently designed and developed the KC-390 military transport aircraft which is attracting export interest.

The success of Embraer has helped to spawn over 100 Aviation supplier businesses within Brazil for a range of equipment.

In terms of avionics supply, Embraer has largely relied upon western sources over the years with Honeywell, Collins and Thales all providing commercial avionics.

The recent C-390 Millennium military transport relies upon Collins for an avionic suite based upon its ProLine Fusion offering including the HUD. AEL Sistemas has developed some of the more sensitive avionic functions including the Mission Computers, Self-Protection Systems and Countermeasures SPS and DIRCM, respectively, the HUD (Head-Up Display) and EVS (Enhanced Vision System).

AEL Sistemas has been involved in the development of avionics for the A1 (Brazil and Italy), F5-M, the AMX fighter, A29 Super Tucano, T27 Tucano and C-390 Millennium transport aircraft.

We are not aware that AEL has established a significant presence in supply of avionics to commercial platforms.

17. RECENT DEVELOPMENTS/MAJOR CONTRACTS

Below is a tabulation of some of the recent avionic related contracts that have been secured by the avionic supply chain.

Customer/platform	Supplier/products
Aug 2020: Honeywell and Vertical Aerospace to collaborate on demonstrator UAM cockpit.	Honeywell and Vertical Aerospace have signed a letter of intent naming Honeywell as the supplier for flight deck technologies for its demonstrator aircraft program. The demonstrator program will help Vertical Aerospace understand flight characteristics, system requirements and the flight deck user interface to further the development of its urban air mobility (UAM) vehicle.
June 2020: Bell Textron selects GE Aviation for HUMS package on 360 Invictus helicopter.	GE Aviation was selected by Bell Textron Inc., a Textron Inc. (NYSE: TXT) company, to provide the Aircraft Health Awareness System as part of Team Invictus for the Bell 360 Invictus competitive prototype, a part of the U.S. Army's Future Attack Reconnaissance Aircraft (FARA) program.
Feb 2020: Russian VR Technologies selects Thales FlytX avionics for VRT500 helicopter.	Thales FlytX avionics suite selected by VR-Technologies, part of Russian Helicopters, for the future VRT500 light single-engine civil helicopter. The single-screen version of FlytX features a 15-inch touchscreen display to simplify the pilot's tasks
Nov 2019: Airbus selects Collins for CN 295 avionic suite	Airbus has picked the Collins Pro Line Fusion for the new Airbus C295 military transports. The flight deck includes SAR and tactical missions, including four pilot touchscreen displays, night-vision goggle capability, Head-Up Displays, an Enhanced Vision System (EVS) sensor, overlaid weather radar, an Integrated Terrain Awareness and Warning System for high-resolution 3D obstacle depiction, and Mission Flight Management Systems
Oct 2019: Hybrid Power and GE Aviation to provide complete computing platform for flight control for Hybrid powered UAV.	GE Aviation announced a teaming agreement with Hybrid Project to provide a vertical take-off and landing (VTOL) UAV. Commercial availability is targeted for Q1 2020.The agreement enables Hybrid Project's SuperVolo VTOL UAV with a full airborne computing hardware platform, flight and safety management. GE Aviation's computing platform enables flight control and airborne computing power while maintaining an independent safety controller. Auterion's Enterprise PX4 operating system resides on the vehicle, in the cloud, and the ground station.
Aug 2019: Utair selects GE Aviations QARs for Boeing fleet.	Utair has selected GE Aviation to supply wireless mini Quick Access Recorders (QAR) to assist Utair in meeting its flight data collection requirements from the State Civil Authority of Russia (SCAA). The miniQAR will be supplied from Avionica, a joint venture of GE Aviation. Deliveries are currently taking place across Utair's fleet of 45 Boeing 737 and 767 aircraft.
June 2019: USAF awards Harris L-3 contract to upgrade C130J avionics	USAF has awarded a $500million contract to the L-3 Platform Integration segment in Waco, Texas, on Tuesday for the C-130H Avionics Modernisation Program (AMP) Increment 2 project. L-3 engineers will upgrade the Air Force C-130H Combat Delivery (CD) fleet of 176 C-130H aircraft, which includes the C-130H1, C-130H2, C-130H2.5, C-130H3, and LC-130H variants of the C-130H four-engine turboprop utility and cargo aircraft.
June 2019: DGA and Airbus select Thales for H160M avionics	Airbus Helicopters and the French defence procurement agency (DGA) have selected the FlytX avionics suite for their future H160M Joint Light Helicopter. Using the latest display technologies to make flying easier,

Customer/platform	Supplier/products
	FlytX features a set of naturally intuitive, direct-interaction touchscreen interfaces.
Jan 2019: Lockheed Martin selects Collins for supersonic demonstrator avionics	Collins has been selected by Lockheed Martin to provide avionics for the new X-59 Quiet Supersonic Technology (QueSST) aircraft. The X-59 is being developed by Lockheed Martin for NASA to collect data that could make supersonic commercial travel over land possible through low sonic boom technology.

18. PROFITABILITY

We believe that the large aftermarket that characterises the avionics market generates higher margins than the OEM forward fit market. Whilst we are not able to always identify suppliers' profitability for avionics, all of the evidence suggests that aftermarket services can generate margins from the mid/high teens and upwards.

Garmin is a classic example of a manufacturer that has quickly established a credible track record within aerospace, offering a wide range of product and services whist reporting 20%+ operating profit margins.

We do note that the profitability for large US defence contractors can be typically fall within the 10% - 12% range which, we believe, is largely due to the US government/DoD 'open book' approach to defence contract pricing.

Below we show some suppliers' reported results, together with their commentary.

Reported results - Supplier profitability

Company	Counterpoint estimate of avionics %	2020 sales	2019 sales	2020 operating profit	2019 operating profit	2020 margin	2019 margin
Astronics - Aerospace	18%	$418.0m	€692.6m	($89.8m)	$16.7m	(21.5%)	2.4%
Collins Aerospace	18%	$19,288m	$26,028m	$1,466m	$4,100m	7.6%	15.8%
Garmin – Aviation segment	100%	$622.8m	$735.5m	$137.2m	$252.9m	22.0%	33.9%
Honeywell Aerospace	21%	$11,544m	$14,054m	$2,904m	$3,607m	25.1%	25.7%
Mercury Systems	62%	$796.6m	$654.7m	$91.1m	$76.6m	11.4%	11.7%
Thales	26%	€4,217m	€5,595m	(€76.2m)	€521m	(1.8%)	9.3%

- Astronics; 10K 2020; "Aerospace segment sales decreased by $274.6 million, or (39.7)%, to $418.0 million, when compared with the prior-year period. Sales were negatively affected by the grounding of the 737 MAX, overall lower build rates for commercial transport and general aviation aircraft and a weak commercial aircraft aftermarket as the airlines reduced spending and OEM's reduced production due to the global COVID-19 pandemic. Electrical Power & Motion sales decreased $159.0 million compared with the prior-year period. Additionally, Lighting & Safety sales decreased $66.5 million and Avionics sales decreased by $30.7 million. Aerospace operating loss for 2020 was $89.8 million compared with operating income of $16.7 million in the same period of 2019. Aerospace operating profit was impacted by impairment charges of $87.0 million, of which $86.3 million was related to goodwill. Restructuring-related severance charges of $5.3 million and leverage lost on reduced sales also significantly impacted operating results."
- Garmin commented in its 2020 10k: "Aviation revenue decreased 15% from the year ago period, due to fewer shipments to OEM customers and reduced contributions from ADS-B products."
- Honeywell commented: "Aerospace Net sales decreased due to lower sales volumes as the decline in global travel resulting from COVID-19 negatively impacted many of our customers, resulting in lower demand for our products from OEMs and reduced demand for our aftermarket products and services.
  - Commercial Aviation Original Equipment sales decreased 36% (decreased 35% organic) due to lower demand from air transport and regional and business aviation OEMs.

  - Commercial Aviation Aftermarket sales decreased 34% (decreased 34% organic) due to lower demand in air transport and regional and business aviation.
  - Defense and Space sales increased 9% (increased 10% organic) driven by growth in U.S. and international defence.
- Aerospace segment profit decreased due to lower sales volume and lower sales of higher margin products and services, partially offset by favourable pricing. Cost of products and services sold decreased due to lower sales volumes."
- Mercury commented in its 2020 annual report: "Total revenues increased $141.9 million, or 22%, to $796.6 million during fiscal 2020 compared to $654.7 million during fiscal 2019 including "acquired revenue" which represents net revenue from acquired businesses that have been part of Mercury for completion of four full quarters or less (and excludes any intercompany transactions). After the completion of four fiscal quarters, acquired businesses will be treated as organic for current and comparable historical periods. The increase in total revenue was primarily due to $91.4 million and $50.5 million of organic revenues and acquired revenues, respectively. These increases were driven by higher demand throughout all product groupings, especially integrated subsystems, across all end applications and, in particular, radar, within the airborne, naval and land platforms. The increase in total revenues is primarily attributed to higher revenues associated with the P-8, SEWIP and AIDEWS programs. Acquired revenue represents activity from the Germane, GECO, Athena, Syntonic and APC acquired businesses."
- Thales commented: "Sales in the Aerospace segment amounted to €4,217 million, down 24.6% from 2019 (-24.1% at constant scope and exchange rates). This drop reflects the collapse in civil aeronautics demand (by around 50% since Q2 2020) and the deferral of tenders in the space business due to the Covid19 crisis."

19. AVIONICS SUPPLIER PROFILES

19.1. AVIONICS SUPPLIER PROFILES – NORTH AMERICA

19.1.1. Aviation Communication & Surveillance Systems (ACSS)

Aviation Communication & Surveillance Systems (ACSS) is a joint venture 70% owned by L-3 and 30% owned by Thales. Established in 2001, it is a leader in safety avionics systems that increase safety, situational awareness and efficiency for aircraft operators in all phases of flight.

ACSS products include the TCAS 2000 and TCAS 1500 traffic alert and collision avoidance systems, a family of Mode S transponders, the T2CAS, a combined traffic and terrain collision avoidance system, and MASS, an enhanced TCAS system for military operations. More than 8,000 units of ACSS's TCAS products are operating in commercial, corporate and military aircraft.

ACSS has been supplying the commercial and military aviation markets with advanced safety, communication, surveillance and antenna products for nearly 20 years, with over 75,000 units fielded.

Financials

We estimate that ACSS generated $89m in revenues in 2019 and $62m in 2020.

We further estimate that ACSS revenues are split 50/50 between forward fit and upgrades/retrofit.

Operations and capabilities

Operations

The ACSS JV does not have dedicated facilities but relies upon Harris L3's facilities in the US and Thales facilities in France for design development and manufacture of its range of product offerings.

Capabilities

TCAS variants/MASS: During military formation flight, the Military Airborne Surveillance System (MASS) works with the Mode S-IFF (identification friend or foe) data link transponder to identify and distinguish between cooperative member and non-member aircraft. It supports unrestricted formation and rendezvous operations and can be installed on aircraft equipped with the ACSS TCAS 2000 and a Mode S-IFF transponder

with a simple software upgrade. The MASS complies with ATC guidelines to work in both military and civil airspace, providing TCAS/ACAS II operations during non-military flights.

The civil T3CAS is an integrated surveillance equipment certified on all Airbus A320 aircraft and long-range A330/A340 aircraft. This equipment is a single unit Traffic Collision Avoidance System (TCAS), a Terrain Avoidance Warning System (TAWS) and a Mode S transponder. The TAWS function features full Low RNP (Required Navigation Performance) 0.1NM (Nautical Miles) capability and unique performance-based algorithms that consider aircraft status (engines, weight, flaps/slats configuration, gears) and atmospheric conditions (temperature, pressure) for its Terrain Advisories (TA), hence improving the level of awareness and comfort of the flight crew.

The ACSS Mode S transponder boasts full ADS-B DO-260A certified capability, the latest definition of ADS-B OUT standard compliant with all the latest and upcoming mandates in the world (Canada, Australia, Singapore, Hong Kong). The Mode S transponder software is easily upgradeable to DO-260B for subsequent mandates in Europe (2015) and US (2020) to be compliant with NextGen and SESAR requirements.

Customers and contracts

Within ACSS Thales Avionics is the exclusive sales and support agent of ACSS products to Commercial Air Transport customers operating Airbus and Boeing aircraft.

Harris L3 is responsible for the military designated sales in the US and for export markets.

Customers include Airbus, Boeing, Commercial airlines, Airbus Helicopters, General Atomics, General Dynamics.

Platforms supported in the civil arena include the Boeing 777, 737, A320 and A330/340.

ACSS also supports rotorcraft and UAS/UAV platforms for customers such as Boeing, General Atomics, Airbus, Sikorsky and Bell.

Strategy

ACSS is focussed upon TCAS/TAWS, together with the necessary transponders, as part of its surveillance product offerings for both civil and military market sectors. In 20 years the business has built a market leadership position within this important growth area.

Recent Developments

Sept 2020: China Eastern Airlines have chosen to retrofit their 203 Boeing 737 aircraft with the Thales/ACSS NXT-800 DO-260B-compliant transponders to meet the requirements of the CAAC ADS-B Out mandate

June 2020: Airbus Helicopters has selected the Lynx® Multilink Surveillance System from ACSS for its H135 and H145 platforms. Under the agreement, ACSS will develop and supply a modified version of its Lynx NGT-9000R+ with integrated ADS-B, Traffic Collision Avoidance System (TCAS) specifically optimised for helicopters.

May 2020: SF Airlines, which operates China's largest cargo fleet, selected L3/Thales ACSS, as the exclusive avionics suppliers to retrofit its fleet with Automatic Dependent Surveillance Broadcast (ADS-B) Out-compliant airborne equipment. This selection is an active response to the Civil Aviation Administration of China (CAAC) promotion of ADS-B technology.

Sept 2019: General Atomics has awarded ACSS, a contract to supply an Airborne DAA Processor to be integrated into GA-ASI's Detect and Avoid System (DAAS). The DAA system is being developed for installation on several of GA-ASI's Remotely Piloted Aircraft (RPA) models. Under the contract, ACSS will supply approximately 200 DAA processor units over the next five years. The ACSS DAA processor consists of TCAS II, DAA and ADS-B functionality in a compact, lightweight MCU unit.

Apr 2019: ACSS has been awarded a contract by The Boeing Company to supply ADS-B surveillance, collision avoidance technology and flight data recorders for the MQ-25 unmanned aerial refuelling program.

Counterpoint comment

A very capable JV enjoying considerable success in terms of growth and market leadership. Thales and Harris L3 appear to be highly complementary, and it remains to be seen whether they can expand their product offering beyond surveillance.

19.1.2. Astronics Corporation

Astronics Corporation (NASDAQ: ATRO) serves the world's aerospace, defence, and other mission critical industries with proven, innovative technology solutions. They work with customers, integrating an array of power, connectivity, lighting, structure, interior, and test technologies to solve complex challenges. For 50 years they have delivered customer-focused solutions. Today global airframe manufacturers, airlines, military branches, completion centres, and Fortune 500 companies rely on the collaborative spirit and innovation of Astronics.

Astronics offers a breadth of technology solutions and services through 11 subsidiary business units and a number of product brands.

Astronics offers the market 6 product technology groups with avionics covering data loading/data recorders, avionics I/O and interface devices, Satcom, antennas and Enhanced Vision Systems (EVS).

Financials - Aerospace segment

FYE 31/12/20	2020	2019	2018
Sales $m	418.0	692.6	675.6
Operating Profit/Loss	(89.8)	16.7	69.8
Operating Margin	(21.5%)	2.4%	10.3%

In 2020 Astronics as a whole recorded $503m of revenues, compared to $773m in 2019.

Astronics commented: "Aerospace segment sales decreased by $274.6 million, or (39.7)%, to $418.0 million, when compared with the prior-year period. Sales were negatively affected by the grounding of the 737 MAX, overall lower build rates for commercial transport and general aviation aircraft and a weak commercial aircraft aftermarket as the airlines reduced spending and OEM's reduced production due to the global COVID-19 pandemic. Electrical Power & Motion sales decreased $159.0 million compared with the prior-year period. Additionally, Lighting & Safety sales decreased $66.5 million and Avionics sales decreased by $30.7 million. Aerospace operating loss for 2020 was $89.8 million compared with operating income of $16.7 million in the same period of 2019. Aerospace operating profit was impacted by impairment charges of $87.0 million, of which $86.3 million was related to goodwill. Restructuring-related severance charges of $5.3 million and leverage lost on reduced sales also significantly impacted operating results."

Avionics is one of 6 product areas within Aerospace, and its avionics sales were $106.8 in 2019 and $76.1 in 2020.

Operations and capabilities

Operations

Astronics has 11 subsidiary companies supporting its 6 product focussed offerings. Its facilities have a total of 1.2m ft²in terms of total space.

It designs and manufactures within the following facilities:

- Satcom/antennas/satellite business located in New Hampshire, US.
- Data/databus/connectivity business located in Everett, Washington State, USA.
- Enhanced Vision Systems (Astronics PECO) located in Oregon USA.

Capabilities

Astronics serves global customers with integrated hardware and software systems that deliver SATCOM, data, databus's, and avionic I/O connectivity.

Enhanced Vision Systems: Designed to enhance safety and situational awareness in flight Max-Viz dual sensor enhanced vision systems (EVS) utilises multi-spectral imagers include a long wave infrared sensor, a visible light + near infrared sensor, and patented blending and dynamic range management image processing to enable pilots to see clearly during day and night.

Data: "Silo" is an intuitive software tool that can enable Astronics I/O Computers to be used for turn-key data recording. Avionics I/O Computers are rugged, COTS devices that combine computing capabilities and multi-protocol databus interfaces in a small, lightweight package.

Antennas: AeroSat aircraft SATCOM antenna systems are available for OE or retrofit applications, these certified HTS-ready solutions have provided seamless inflight connectivity through millions of flight hours for more than a decade.

Avionics I/O computers: Rugged, conduction-cooled, COTS devices combine a powerful computer processor, multi-protocol databus interfaces (MIL-STD-1553, ARINC 429, ARINC 717, ARINC 708), Ethernet, USB, serial, discrete I/O, and other I/O in a small, lightweight package. They deliver outstanding performance on the ground and in the air and are routinely deployed on helicopter, fixed wing, ground mobile, and marine platforms.

Customer and contracts

Astronics customers include:

Airbus, American Airlines, Bell Helicopter, Boeing, Carson Helicopters, Cirrus Aircraft, Comlux, Dassault Aviation, Delta Air Lines, Embraer, General Dynamics, Gogo, Gulfstream, Honeywell, Hughes, Intel, L3 Technologies, Leonardo, Lockheed Martin, NASA Panasonic Avionics Raytheon Company, Rockwell Collins, Sikorsky, Textron, Thompson Aero Seating, United Airlines, U.S. Army/Navy/Air Force/Marines, Zodiac Aerospace

Collins has selected Astronics to provide its Ku-band tail-mounted satellite communications (SATCOM) antenna technology for the Collins Aerospace KuSAT-2000 solution.

We estimate that Astronics sells 40% of its products to the end users such as airlines, defence operators and business jet users as upgrades and retrofits.

Strategy

Astronics is focussed upon servicing Aerospace with both OE and retrofit products. It states its strategy is "to increase its value by developing technologies and capabilities, either organically or through acquisition, which will provide innovative solutions to its targeted markets."

Recent developments

October 2020: Astronics announced that the US and Canada approved the Max-Viz 1400 and 1200 Enhanced Vision Systems (EVS) for Airbus Helicopter's AS350 Écureuil. In cooperation with AVIO Astronics obtained the Supplemental Type Certificates for its Max-Viz 1400 and 1200 EVS from the U.S. FAA and the Transport Canada Civil Aviation (TCCA) for approved models which are the Airbus Écureuil AS350B, AS350B1, AS350B2, AS350B3, AS350BA, and AS350BD.

In the same month Astronics received an STC that covers EVS system for multiple Bell helicopter models, including 212, 412 and Bell 412EPI aircraft.

August 2020: Astronics announced a recent successful test flight employing its Ku-band tail-mounted antenna technology for the Collins Aerospace KuSAT-2000 SATCOM terminal for their LuxStream business jet connectivity solution. The KuSAT-2000 Tail-Mounted Antenna system demonstrated download speeds of up to 25 Mbps service in the United States and 15 Mbps globally utilising SES satellites.

Counterpoint comment

Astronics has grown successfully in recent years, however, much of this has come from its power products and lighting products. It is very much a niche player in avionics but it does have growth products in EVS, data and avionics I/O devices.

19.1.3. Boeing Jeppesen

Since 1934 when Captain E.B. Jeppesen began selling the world's first aviation navigation charts, the company that bears his name has evolved over 80 years.

In 2000 Boeing acquired the flight information service provider Jeppesen from Tribune Co. for $1.5 billion in cash. Jeppesen provides aviation maps and navigational data, pilot training, computerised flight planning, aviation software, aviation weather services and maintenance information to both airlines and flyers.

At the time of acquisition Jeppesen generated $235 million in revenues with 1,400 employees. Located in Denver, at offices in other U.S. locations, and in Germany, Australia, China, the United Kingdom. Jeppesen claims an 80 percent market share in aircraft navigational products, which amounts to nearly three-quarters of the company's business. The company also has a 25 percent market share in operations services, such as weather and maintenance information, an 80 percent share in pilot training services and a 30 percent share in trip planning.

Financials

There have been several new entrants to the navigation data service market since 2000, however, the addressable market has also grown significantly.

We believe therefore that Jeppesen is still the market leader for navigation data services and generated $400m of revenues in 2019 and $205m in 2020.

Operations and capabilities

Operations

Jeppesen has its operations located in Everett, Washington State, USA.

Capabilities

Jeppesen's services cover commercial, business jets, general aviation and government and military sectors.

They offer a range of product services comprising databases, training and simulation needs including the following:

- Aerospace solutions
- Crew solutions
- Data solutions
- Flight and Fuel data
- Flight and dispatch preparation
- Navigation
- Networks and operations

Each of these solutions is underpinned by a generic process that Jeppesen describe as Plan, Dispatch, Fly, Analyse and Control as an end-to-end process that provides feedback in a closed loop learning fashion.

Jeppesen claim to have more than 18,600 global airports in their records:

- 246 providers in 195 countries (in 24 languages and many different formats)
- Error-checking every chart with up to 16 data-verifying calculations
- Leading to 47,000 data changes per AIRAC cycle
- 2.6 million Jeppesen Aviation Data records to offer the market

Jeppesen offers the market a myriad of menu driven options via subscription services that includes terrain databases, airport layouts, route planning, flight simulation and training, fuel saving procedures, live weather data updates, playback for learning, en-route navigation changes.

Customer and contracts

We believe that Jeppesen has 1,000's of customers within bizjet, GA, rotorcraft, commercial and military sectors.

They also work closely with avionics providers. This includes Honeywell and they support the Honeywell Forge service support offering. They also work with Collins Aerospace, Garmin, Avidyne and other avionics providers to provide navigation database and other services.

They offer single operators of smaller GA/bizjet aircraft a range of subscription services for navigation devices.

These annual subscription charges vary from $400 for coverage in the US and Canada to $1,500 for a global set of data depending on menu options and the avionic equipment (e.g. Garmin, Avidyne, Universal Avionics etc).

Strategy

The cost of Navigation data has been steadily falling in recent years as more players enter the market. Jeppesen has increased its service offering beyond its traditional area of navigation we believe in part to maintain revenue growth.

Recent developments

August 2019: Jeppesen Tailored Charts for Avionics is being introduced initially with Honeywell Primus Epic INAV avionics systems for tailored chart customers operating Embraer E2 commercial aircraft. Regional airline Wideroe of Norway is the first operator to use the new tailored navigation service.

October 2017: Jeppesen announced its digital aeronautical charts and navigation data will be included with the iOS-based Honeywell GoDirect™ Flight Bag Pro electronic flight bag (EFB) application for business aviation operators. The Honeywell GoDirect Flight Bag Pro mobile app allows business aviation pilots to create flight plans, view weather conditions and access flight briefing information through a single user platform.

Counterpoint comment

Jeppesen is a clear market leader in terms of navigation database with a comprehensive range of service offerings and backed by Boeing. It has key alliances with Boeing Global Services, Honeywell, Collins and Garmin and should therefore continue to prosper.

19.1.4. CCX Technologies

CCX develop a wide range of cybersecurity and testing solutions for the aviation, and military and government markets. CCX has developed cybersecurity software and hardware platforms that help avionics manufacturers defend and protect an aircraft's onboard network.

Financials

We estimate that CCX generated $4m of avionics related revenues in 2019, and the same in 2020.

Operations and capabilities

Operations

CCX has a facility located in Ottawa, Canada. In 2020 CCX opened a service support office in New Jersey, USA.

Capabilities

CCX claim to have a unique approach with their cybersecurity solutions in that they operate over connections that are often bandwidth restricted and are installed right onboard the vehicle.

CCX offers its SystemX™ Cybersecurity Software Platform as an innovative system for monitoring onboard vehicular networks. It is available as SystemX™ Military & Government and SystemX™ Aviation. It's AP-250 Inline Cybersecurity Appliance, and AP-250 Inline Cybersecurity Development Kit are also intended for the onboard networks of aviation, and military and government vehicles.

The AP-150 Secure Networking Appliance (AP-150) is a flexible secure component used for a variety of onboard networking applications. It can be configured as a WAP, Server or Router, and customised to fit required applications. Powered by a SystemX™ Cybersecurity Software Platform, the AP-150 offers advanced data monitoring and firewall, plus IDS and IPS (Intrusion Detection and Prevention Systems) and secure boot.

It can be utilised on rotorcraft platforms in addition to fixed wing aircraft.

Customer and contracts

CCX does not identify its customers, some of whom may be classified, however, the products are targeted for communications networks in rotorcraft and military transport aircraft largely within the North American arena we believe.

Strategy

Developer of cybersecurity software and test devices for radio communications within sir, land and sea defence applications. They are expanding into the US market via their new facility in New Jersey, USA

Recent developments

None that we can see.

Counterpoint comment

CCX is a small business focused on providing radio comms cybersecurity protection which can be embedded in land, sea or air equipment. They have yet to establish a solid track record of deliveries within the avionics world.

19.1.5. Cobham

Cobham having been a pioneer of Aerial Refuelling in the 1930's operates today via 5 business sector units:

- Advanced Electronic Solutions
- Aviation Services Australia
- Aviation Services UK
- Communications and Connectivity
- Mission Systems (see note below)

Cobham Advanced Electronic Systems is the home to a number of avionic related capabilities including Electronic Warfare and Radar.

Cobham also has avionic related activity within its Communications and Connectivity division.

As we go to print Eaton has announced the acquisition of Cobham's Mission Division business for USD 2.83 Billion. The acquisition is anticipated to close within the second half of 2021. The purchase price represents approximately 14 times Cobham Mission System's 2020 EBITDA and 13 times its estimated 2021 EBITDA. There is very limited avionic capability within its mission systems division.

This follows on from the recent disposal of Cobham Antenna Systems to TransDigm Corporation for $965m which was announced in November 2020 and closed in January 2021.

Financials

In Cobham's Annual Report in 2019 (the latest available at the time of writing), we see the following revenues for 2019:

- Advanced Electronic Systems - £662.7m of revenues with operating profit of £31.6m - 4.8%
- Communications & Connectivity - £516.3m of revenues with operating profit of £66.9m - 13.0%

Out of a combined revenue £1,179m ($1,504m) within Cobham Advanced Electronic Systems and Cobham Communications & Connectivity we estimate that Cobham's avionics, sensors and antennas related business generated $309m of revenues in 2019, and $262m in 2020.

Operations and capabilities

Operations

Cobham Advanced Electronic Systems is headquartered at Arlington, VA, USA and has facilities in Colorado Springs, USA, Plainview NY, USA, San Diego, CA, USA and Exeter, NH, USA.

Cobham Communications and Connectivity has its airborne products located within its facility in Fullerton, CA, USA. It also has a regional support office in Dourdan, France.

Capabilities

Cobham Advanced Electronic Systems:

- Low-band Transmitters for Communications Countermeasures: The EA-18G Growler carries the CAES Integrated Antenna/Radome and Low-Band Transmitter, which is designed to protect strike aircraft, ships and ground troops by disrupting enemy radar and communications.
- Electronic Warfare Self Protection (EWSP) products and services offer a suite of countermeasure solutions to protect land, sea and air platforms from weapons fire. CAES EWSP products and services include an extensive suite of radar warning receivers (RWR) fitted to fixed- and rotary-wing aircraft.
- Electronic Surveillance products enable threat recognition, targeting and other tactical actions such as threat avoidance and homing. CAES products are also used for Signals Intelligence (SIGINT) to analyse intercepted frequencies and identify traits such as frequency, bandwidth, modulation and polarisation. CAES has developed and deployed electronic surveillance subsystems on multiple fixed- and rotary wing aircraft, attack-class submarines, missiles and ground vehicles.
- Provides data links and telemetry modules for use in UAV systems, missiles and munitions.
- Offers a variety of custom advanced electronics for transmit and receive functionality such as transmit/receive (T/R) modules, transmitters, receivers and AESA radars.

Cobham Communication and Connectivity:

- Has more than 60 years of experience in design, development and manufacturing of aircraft avionics systems including radio and audio control and management, technical standard ordered radio, tactical radio, and airborne server and router solutions.
- Provides Audio Management (DACS, AMS), Radio Management (RCU, RMP), Audio & Radio Management (RMS, ARCDU, RAIMS), Aircraft Passenger and Cargo Address System (PCAS) and a wide range of additional equipment, allowing enhanced audio services with warning generator, Satcom dialler, SELCAL, etc.
- Radio and Audio Integration Management System (RAIMS) has been designed for Long Range (LR) and Wide Body (WB) aircraft. It consists of two to three Radio Management Panels (RMP) associated with two Audio Management Units (AMU4032) integrating SELCAL and cockpit amplifier functions. This controller provides functionalities: radio communication management, audio management, Satcom dialling, and radio navigation frequency management.
- Has recently developed a Radio Management System (RMS) based on a mature MMI display. It consists of a colour display, left/right buttons for radio selections, bottom buttons for quick access menu, upper buttons for navigation menu and setup, toggle switch for emergency function, an upper-right knob for bright display adjustment and an inner/outer knob for frequency selections. It is compatible with most of radios using ARINC429, RS422, RS485 and MIL-STD-1553 interfaces.
- Offer Satcom services by enabling the 'office in the sky'. Passengers stay connected using social media, email, fax and voice calling whilst logistical, navigation and safety functionality supports cockpit communications and safe and efficient operations for aircraft and fleet operators. The AVIATOR portfolio of Swift Broadband and Classic H+ systems provides voice and data connectivity for both cockpit and cabin communications, ensuring that passengers, crew and operators experience fast and reliable connectivity at all times.
- Has a wide portfolio of antennas on offer for Airborne applications: Multiple antennas are supplied by Cobham Antennas for civil and military aircraft to meet VHF, UHF, L-band, Ku-band and Ka-band

applications. Also included are combination antennas that combine GPS or GPS WAAS and XM into a single radome.

Customer and contracts

72% of Cobham Communication and Connectivity's revenues are commercial and this includes radio, comms and GPS/Satcom/HF/VHF antennas.

84% of Cobham Advanced Electronic Systems' revenues are defence related with 60% in total generated within the US.

Key contracts are noted as follows:

- Radio and Radio Management on the T-6 and T-38 trainer programmes
- Communication/avionics on the NH-90 platform
- GA-7001 SATCOM high gain antenna sub-system has been selected by Emirates Airline for its Boeing 777 upgrade programme.
- China's Shenzhen Airlines is also using Cobham SB-S and Inmarsat's digital airline operations platform with
- Cobham's Light Cockpit Satcom (LCS) has been selected by Airbus as a line fit solution on its A320 and A330 families.
- Cobham's Nextgen terminal, AVIATOR S, becomes available as a line fit option on major OEM platforms including Boeing's 737MAX and 777X; and Airbus' A320, A330 and A350.
- Aviator 200S Satcom system approved and certified for the Boeing 777X and the Boeing 737MAX
- Radio Management System fitted to Airbus H145M military rotorcraft.
- Cobham to provide Future Air Navigation (FANS) 1/A compliant AVIATOR 700D systems for integration in the C-130J Super Hercules fleets as part of the Block 8.1 upgrade programme.
- Provides low-band transmitters (LBT) for the AN/ALQ-99 jammers on the EA-18G aircraft.
- Cobham has a contract to supply Electronic Warfare (EW) training pods for NATO, worth over £50 million, as part of the NATO Joint Electronic Warfare Core Staff (JEWCS) capability package.

Strategy

It is not clear at this time the extent to which Cobham's parent, Advent, will continue to dramatically re-shape the Cobham portfolio.

Recent developments

November 2020: Cobham Aerospace Connectivity has been selected by General Atomics Aeronautical Systems, Inc. (GA-ASI) and the U.S. Army to provide the anti-jam GPS systems for the MQ-1C ER Gray Eagle Extended Range (GE-ER) Unmanned Aircraft System (UAS) platform.

June 2020: Cobham Advanced Electronic Systems announced a capability to develop new millimetre wave (mmW) Active Electronically Scanned Arrays (AESA) for airborne early warning radar, intercept or acquisition control, ballistic missile warning and acquisition surveillance, mapping and missile tracking and guidance applications. Frequencies under development include Ka-Band and W-Band.

January 2019: Cobham and Boeing have signed a Technical Service Agreement (TSA) for the certification of the AVIATOR 200S system on the Boeing 777X and 737 MAX aircraft. The agreement provides a Boeing line fit option for Aviator 200S, which provides Inmarsat's new generation SwiftBroadband Safety (SB-S) service to airline customers worldwide.

April 2018: Lockheed Martin and Cobham are joining forces for the Next Generation Jammer Low Band competition to replace the U.S. Navy's ALQ-99 tactical jamming system currently on the E/A-18 Growler aircraft.

Counterpoint comment

Advent has disposed of several assets since acquiring Cobham and there may yet be other disposals. Cobham's avionics business is highly US-centric which is where the defence budget is greatest.

19.1.6. Collins Aerospace

Founded as a radio company in Cedar Rapids, Iowa, in 1933, Rockwell Collins left its mark on history, from establishing communications with Rear Admiral Richard Byrd at the South Pole to helping forge today's global positioning system. The company has become a leader in aviation and high integrity solutions, built on a legacy of quality, trust and customer service.

United Technologies Aerospace Systems (UTAS) was formed when UTC acquired Goodrich Corporation and merged the aerospace activities with Hamilton Sundstrand in 2012.

Rockwell Collins was acquired by UTC (UTAS parent) in 2019 and, when combined with UT Aerospace systems (UTAS), the combined entity became Collins Aerospace. Subsequently United Technologies formed a merger with Raytheon to create an aerospace business that now includes Collins Aerospace, Pratt & Whitney and Raytheon Intelligence and Space and Raytheon Missiles and Defense.

Raytheon today services 12 capability areas including avionics which is covered within this section of the report in respect to Collins Aerospace.

We cover the Raytheon Intelligence and Space division under a separate section.

Financials

FYE 31/12/20	2020	2019	2018	2017
Sales $m	19,288	26,028	16,634	14,691
Operating income $m	1,466	4,100	2,303	2,191
Return on sales %	7.6%	15.8%	13.8%	14.9%

In arriving at our estimate for Collins Aerospace's total avionic sales in 2019 of $5,097m we have added in avionic service sales from the IMS division and the contribution from UTAS (largely Air Data systems relating to Navigation) and deleted revenues associated with the non-airborne defence sector.

Total estimated revenues for Collins Aerospace's avionics business in 2019 was $4,824m, and $3,495m in 2020.

Collins Aerospace reports that OEM/Aftermarket is in the ratio of 60%/40% and that its civil/military split is the 75%/25% respectively.

Operations and capabilities

Operations

Collins Aerospace has circa 5,000,000 ft² of avionic related facilities within the US and around 1,000,000 ft² split between EU, Middle East and Asia.

A significant proportion of the design manufacture and test of avionics takes place in their Cedar Rapids, Iowa facility which extends to 2,900,000 ft².

Collins Aerospace also has facilities located in the Philippines (770,000 square feet), Winston-Salem, North Carolina (660,000 square feet), Melbourne, Florida (400,000 square feet), Annapolis, Maryland (370,000 square feet), Richardson, Texas (280,000 square feet), Everett, Washington (240,000 square feet), Heidelberg, Germany (240,000 square feet), Nogales, Mexico (230,000 square feet), Irvine, California (210,000 square feet) and Coralville, Iowa (200,000 square feet).

Further, it also has a global network of approved support centres that provide technical advice, spares, repairs, overhaul, exchange units/loaners and stockists who support a range of components.

Capabilities

Collins summarises its avionics capabilities as follows:

- Autopilot (including Flight Control System)
- Avionics Integration (harnesses, tray, connectors etc.)

- Computing & Networks (multi-core processing, mission computers, data transfer and storage, AfdX & Ethernet solutions)
- Displays & Controls (Head down displays, HUDs, CDU, Enhanced Vision Systems, Helmet Mounted Displays)
- Integrated Cockpit Solutions (CNS/ATM upgrades, Common Avionics Architecture System, Flight 2m Integrate Avionic System, Helisure Flight Situational Awareness)
- Weather Radar
- Software Applications (Hazard avoidance/re-router, Mission Flight Management Systems)
- Surveillance (TCAS, Reconnaissance, Mode S Transponders)

Collins has the following Joint Ventures which have been in place for a significant number of years:

- AVIC Leihua Rockwell Collins Avionics Company, a joint venture with China Leihua Electronic Technology Research Institute, a subsidiary of the Aviation Industry Corporation of China (AVIC), which provides integrated surveillance system products for the C919 aircraft in China
- Rockwell Collins CETC Avionics Co., Ltd. a joint venture with CETC Avionics Co., Ltd. to develop, produce and maintain communication and navigation products on Chinese commercial OEM platforms
- Data Link Solutions LLC (DLS): DLS is a joint venture with BAE Systems, plc for the joint pursuit of the worldwide military data link market
- ESA Vision Systems LLC (ESA): ESA is a joint venture with Elbit Systems, Ltd. for the joint pursuit of helmet-mounted cueing systems for the worldwide military fixed wing aircraft market.

In section 14 of this report, we reviewed the Collins Pro line Fusion product development together with its main platforms and customers. This section will therefore address all of the non-Proline Fusion capabilities.

ADS-B Autonomous flight: a range of solutions certified from the Textron King Air thru to the Boeing 787-8. A key product is their Multi Mode Receiver (MMR) for which Collins is a market leader. Many of these solutions have been designed to be retrofitted to existing in service aircraft.

Avionic installation and integration: it has a list comprising 100s of STC product solutions that fit most aircraft in active service today. Collins will undertake the necessary work to upgrade aircraft with the product, installation and certification required.

Communications: Collins provides a range of solutions including Data link services, SATCOM, voice and data and commercial aviation services. It provides Controller-Pilot Data Link Communications (CPDLC) and Automatic Dependent Surveillance-Contract (ADS-C) capabilities enhancing oceanic and remote flight operations and support compliance to airspace regulations and mandates. Collins Aerospace VHF, HF and SATCOM radios use the latest in software-defined radio technology. It provides global voice and data communications that enable customers to maximise flight and airline operations efficiency. It provides Communication Management Units such as the CMU-900 which is the newest ARINC 758 compatible Communications Management Unit and is designed to satisfy Data Link Communication needs into the future.

Head Up Displays (HUDs): HUDs offer benefits in day or night, allowing pilots to fly consistent approaches no matter what the conditions. With less go-arounds, diversions and cancellations because of low-visibility many of the world's airlines, business and regional operators, military tankers and transports, and NASA have acquired Collins Aerospace HUDs and Head-up Guidance Systems (HGS).

Flight Display solutions; Collins offers a wide range of display size and formats for integration within modern cockpits. Their AFD-2100 solution has the following features;

- 15.1 inches of useable display area
- Advanced Super View (ASV) technology, providing superb colour fidelity over a wide field of view
- Remote Light Sensor providing a consistent presentation by adjusting to ambient light changes
- True split screen capability
- Adaptable to evolving cockpit technology/applications such as:
  - Moving Map

- Real time weather
- Electronic Flight Bag applications
- Synthetic and Enhanced Vision
- CDTI applications

Navigation: offers a range of capabilities including GPS based guidance, landing systems and multi-mode receivers. Its Global Positioning System Landing System receiver, the GLU-925 offers Category I GLS, Category III ILS and Performance-Based Navigation RNAV/RNP operations. The system is standard equipment on the Airbus A350 and A380 and Boeing 747-8 as well as being certified for other Airbus and Boeing platforms. The Multi-Mode Receiver GLU-2100 is a fully digital, MMR with integrated instrument landing system (ILS), global positioning system (GPS), GPS landing system (GLS) and VHF omni-directional receiver (VOR). It also offers a full range of VOR, DME and ADF navigation products.

Surveillance: offers a range of products including transponders and weather radar, in order to provide traffic alerts, collision avoidance and weather conditions. The ISS-2100 configurable integrated surveillance system simplifies surveillance by joining several features – such as weather detection, traffic alert and collision avoidance, Mode S surveillance and terrain awareness and warning functions – into a single system.

Air Data Systems: offers a range of Air Data products that support navigation and standby instruments. These include pitot probes, pitot-static probes, multi-function probes with flow angle measurement, various flight test products and SmartProbe® air data systems.

Enhanced Vision Systems: EVS-3600 cuts through low-visibility conditions like smoke, smog, fog and darkness by displaying high-clarity visual references on HUDs, allowing pilots to see what's out there. This spectral coverage during critical phases of flight gives aircraft the ability to go more places more safely. The EVS uses short-wave infrared, long-wave infrared and a visible camera for the earliest possible detection of visual references.

ProLine 21 and Pro line Fusion: (see section 9 for Pro-Line description) both are options for OE forward fit and available as retrofit packages. However, ProLine Fusion aims to deliver the latest functionality in terms of surveillance and airspace modernisation.

The Pro Line 21 system is designed to be intuitive, so pilots quickly understand and act on the ever-changing mountain of data they are presented with. All flight data, including navigation, engine performance, and sensor readings are displayed on large, flat-panel LCD's. The Primary Flight Displays (PFD) complement the Multi-Functional Display (MFD). Real-time weather and terrain data ahead of the planned flight route can be accessed via the Broadcast Graphical Weather system. The Collins FMS-3000 is an integral part of the system, which provides cutting-edge flight planning, flight management, and multi-sensor navigation capabilities. Electronic charts are a feature: pilots can access airport approach plates, electronic checklists, and digital airport maps which display the real-time position of the jet. Another feature of the Pro Line 21 suite is the heads-up navigation Guidance System display. It that is designed to increase safety and precision in approaches, particularly during poor weather.

Collins Aerospace states that upgrading to Proline fusion offers the following benefits:

- ADS-B Out V2
- FANS 1/A
- RNP AR
- Graphical weather
- European ATN
- Multiscan weather

All of the above capabilities apply to both civil and military applications. Collins also has capabilities that are specific to the military sector as follows.

Reconnaissance pods: offers a SEEK EAGLE certified pod for F-16 and other fast-jet applications. With an integrated DB-110 sensor, this pod offers advantages over competing systems by relying on dual-environmental conditioning systems, to provide robust ground cooling and operations over a wide range of

altitudes. Full-size fore and aft data-link antennae enable maximum data-link range throughout a full 360° azimuth.

Mission computing: MC-4000 flight mission computers provide a combination of high-integrity, general purpose, multi-core processing resources, scalable I/O capabilities and high-integrity graphics generation. They also supply powerful, real-time video processing functionality based on a digital signal processing module.

Customer and contracts

A list of platforms and customers for Collins ProLine Fusion and ProLine 21 is contained within Section 14 of this report. However, Collins Pro Line 21 avionics have been fitted to various Cessna, Raytheon, Bombardier, Gulfstream, and Dassault platforms. The Pro Line 21 system is currently used in the CJ1+, CJ2+, CJ3, CJ4, Encore+, XLS+, the Premier 1A, both the Challenger 300 and Challenger 605, LearJet60XR, Gulfstream 150, Piaggio Avanti II, King Air B200 and 350, and Hawker 800XP, 850XP, 750, and 900XP. Dassault Collins dealers have retrofitted the line to the Falcon 20 and Falcon 50. Additional retrofits have taken place in the Challenger 601, Citation 550, Hawker 700 and 800, and the King Air 90, 200, 300 and 350.

Other applications include:

- A220: ProLine fusion avionics, Head Up display (option).
- A320; Radio Comms HFS-900 VHF system, SAT-2100 high speed data satellite comms, GLU 929 Multi-Mode Receiver, ADF, DME, VOR radio, Weather mapping radar WXR-2100.
- A330: VHF-900B VHF transceiver, TPR-901 transponder, SAT-609 SATCOM, WXR-2100 weather radar, Moving maps, Radio Altimeters, Multi-Mode Receiver GLU-920, ADF, DME, VOR equipment.
- A350: Avionics full duplex switched Ethernet, avionic communication management system, Information onboard management system, ADF, DME, VOR equipment
- A380: Radio comms equipment, VHF-920 digital radio, HFS-900 HF radio, inflight information system, avionics comms management system, ADFX Ethernet switch, ADF, DME, VOR navaids, Multi-Mode Receiver.
- A400M: Radio comms/management system, SATCOM, Full duplex Ethernet switch, DME,
- Airbus CN295: Radio comms equipment, ProLine fusion avionic suite.
- Boeing 737: Airborne Comms System, ICS-300 SATCOM (737MAX), Enhanced Vision Systems, Head up Guidance system, Radio Altimeters, MMRs, DME, ADF, VOR, TCAS.
- Boeing 747: Radio comms equipment, VHF-920 transceiver, SATCOM, Mode S transponder, Flight recorders, Autopilot, Data management unit, Weather mapping radar, WXR-2100 multiscan hazard detection, MMRs, ADF, DME.
- Boeing 767: FMS, Display systems (KC-46), EVS, Air Data Computers, HUD, MMRs, DME, ADF, VOR, Surveillance Air defence radar (KC-46), Tactical situation awareness (KC-46), CCIS systems, Link 16 and SATCOM (KC-46).
- Boeing 777: Avionics gateway secure server, Weather mapping radar, Multiscan threat weather tracking, Primary LCD display suite, EFIS, TCAS, mode S transponder, Head up displays, MMRs, DME, VOR, ADF navaids.
- Boeing 787: Radio comms management, core and common data network, flight deck display system and crew alert system, head up display system, integrated surveillance system, voice and data recorders.
- Comac ARJ21: ProLine 21 avionic suite, weather radar, AHRS.
- Comac C919: Weather mapping radar, Integrated surveillance system, TCAS, Mode S transponder, terrain warning system.
- F-15: Radio comms equipment, Tacan, HIS indicator, Helmet mounted displays, LCD display suite, ILS systems, Airborne GPS system, ADF, ILS receiver.
- F-18: Radio comms equipment, Helmet mounted displays.
- Embraer C-390: Radio comms equipment, HF-9000 HF radios, ProLine fusion avionics suite, ADF.
- Leonardo helicopters: EVS, TAWS (most models)

- Airbus helicopters: Radio comms equipment, Mode S transponder, VOR, DME, ADF (most models)
- F-35 lightning: Helmet mounted displays,
- C-130J: Head up displays

Strategy

Collins Aerospace has continued to build out its avionics capabilities and is adding significant digital, software and service offerings in support of its installed fleet. It is a market leader within Communications, MMRs, and Integrated avionics (ProLine Fusion). It is not yet a 'cockpit integrator' within large air transport in the same way that Honeywell, Thales and to some degree GE Aviation have become. However, under Raytheon's ownership this could change.

Recent developments

February 2021: U.S. Navy completed the successful first flight of the TCTS Inc. II Air Combat Training program on an operational F/A-18E/F Hornet. Developed and built by Collins Aerospace Systems and team-mate Leonardo DRS, TCTS Inc. II is a scalable and flexible open architecture system that enables highly secure air combat between Department of the Navy and Air Force aircraft, both 4th and 5th generation platforms.

December 2020: Collins Aerospace announced that its new Griffin™-2 visual display system (VDS) is set to launch with two undisclosed fast-jet programs in the Asia-Pacific region. The company has received orders for 20 systems over the next five years, and continued support through 2030.

September 2020: Collins Aerospace has been selected by Boeing to provide its proven NAV-4500 navigation receivers for the T-7A Red Hawk, the U.S. Air Force's (USAF) new advanced pilot training system in development by both Boeing and Saab.

June 2020: Collins Aerospace is helping the U.S. Navy and Marine Corps transition from analogue to digital night vision systems with their new Enhanced Visual Acuity (EVA) system. The system, recently selected for use by rotary-wing and tiltrotor aircrews, is the first to provide advanced digital night vision and display technology that increases flight safety and mission effectiveness for the war fighter.

Counterpoint comment

Collins Aerospace is a market leader in avionics with capabilities in many other airborne systems and equipment. It has traditionally been focussed upon the civil market but as part of Raytheon we believe that this may balance out in the coming years.

19.1.7. Curtiss-Wright

Curtiss-Wright Corporation had sales of $2.5 billion in 2019. It is a diversified, supplier of engineered products through three segments: Commercial/Industrial; Defense; and Power, which serve the defence, commercial aerospace, general industrial, and power generation markets.

Relevant products from Commercial/Industrial segment include sensor and data recording products contribute to flight operations that monitor and communicate vital data on conditions within and surrounding the aircraft. Curtiss-Wright is one of the leading manufacturers of 'black box' data recorders used on aircraft world-wide.

Relevant products from its Defense business segment include Avionics systems including air data systems, data acquisition, data concentrators, crash protected recorders, fire & ice detection and protection systems, flight testing and space data handling systems. These systems are supplied both to the commercial and defence aerospace markets.

Historical note: The Curtiss Aeroplane and Motor Company was the world's largest aircraft manufacturer in World War 1, producing 10,000 aircraft. The company acquired a public listing in 1916. Wright Aeronautical, which was set up to make aero-engines, was founded in 1919. The two companies merged in 1929. In WW2, it was the dominant producer of aero-engines (142,840 in total) and was also a producer of 29,269 aircraft (e.g. the P-40 War Hawk and Helldiver) but never succeeded in the post war years with a jet engine. In the 1960s, it started to diversify.

Financials

2020 sales were $2,391 million and of this defence aerospace was $463.8m, up from $416.8min 2019, and commercial aerospace was $325.5m, down from $433.0m in 2019, giving total aerospace sales of $789.4m in 2020, compared to $850m in 2019.

We estimate that sales of avionics products in 2019 were $240m of which $90m were navigation-related and $150m were data systems-related. In 2020, we estimate that sales of avionics products were $220m of which $80m were navigation-related and $140m were data systems-related.

Operations and technology

Locations

Curtiss-Wright Defense Solutions has the following facilities:

United States

- Curtiss-Wright Defense Solutions, Ashburn, Virginia
- Curtiss-Wright Defense Solutions, Santa Clarita, California
- Curtiss-Wright Defense Solutions, Portland, OR
- Curtiss-Wright Defense Solutions, Fairborn, Ohio
- Curtiss-Wright Defense Solutions, Salt Lake City, Utah
- Curtiss-Wright Peerless Instrument, Farmingdale, New York
- Curtiss-Wright Defense Solutions, Newton, PA
- Curtiss-Wright Defense Solutions, Tewksbury, MA

Canada

- Curtiss-Wright Defense Solutions, Ottawa

Ireland

- Curtiss-Wright Avionics & Electronics – Dublin, Ireland

United Kingdom

- Curtiss-Wright Defense Solutions, Letchworth Garden City
- Curtiss-Wright Defense Solutions, Cardiff
- Curtiss-Wright Avionics & Electronics - Christchurch,

Capabilities

Curtiss-Wright is one of the leading manufacturers of ‘black box’ data recorders used on aircraft world-wide.

On military aircraft, Curtiss-Wright technologies operate, monitor and control flight systems, weapons deployment, and data analysis for nearly every US fighter aircraft program, as well as unmanned aerial vehicles.

On military helicopters, Curtis Wright provides state-of-the-art electronics, including sensors and embedded computing products. In addition, its video management system maximises the effectiveness of airborne Intelligence, Surveillance and Reconnaissance missions by enabling multiple operators to view, control and record live video and mapping information in helicopters, such as the U.S. Army’s new Lakota light utility helicopter fleet. It maintains a presence on several US helicopter platforms, including the Black Hawk, Apache, Seahawk and Chinook.

In terms of specific capabilities, it provides:

- COTS (Commercial Off-the-shelf) Boards
  - Bus & Protocol Analysers
  - Direct Attached Storage

  - Graphics & Video Cards
  - I/O & Communication Cards
  - Networking (Switching and Routing) Cards
  - Processor Cards (Single Board Computers, FPGA Processors and Digital Signal Processors)
  - Radar Acquisition & Processing Cards
- Electronic Systems
  - Air Data Systems
  - Cockpit Voice & Flight Data Recorders
  - Data Concentrators
  - Data Recorders (Crash Protected, Rackmount, Rugged, Video, Quick Access and Application Specific)
  - Data Storage (Network Attached Storage and Storage Area Network Systems)
  - Radar Processing & Recording Systems
  - Rugged Switch/Router Systems and Physical Layer Switches
  - Rugged Mission Computers
  - Video Management and Display System
  - Program Specific Systems (Mission Management, Ammunition Handling, Flight Control, High Performance Embedded Computing, etc.)
- Aerospace Instrumentation
  - Antenna and Radio Frequency
  - Data Acquisition Systems
  - Ground Stations
  - High Speed Imaging & Video Systems
  - Network Switches for FTI
  - Quick Access Recorders
- Space Data Acquisition Systems
  - Data Acquisition Systems
  - Radiation Tolerant COTS Data Acquisition

Customers and contracts

Key programmes include:

- F-35 Lightning Joint Strike Fighter Program; Curtiss-Wright provides actuation equipment for the Ordnance Hoist System and Ordnance Quick Latch System as well as embedded computing and sensor electronics.
- Boeing P8-A Poseidon MMA; single board computer, data communication, sensors, and graphics and video products
- Global Hawk; flight control, sensors, mission operations and navigation are managed by Curtiss-Wright's Integrated mission and Sensor Management Systems.
- Triton (the U.S. Navy's version of the Global Hawk); Curtiss-Wright supplies the Advanced Mission Management System and the Integrated Mission Management Computer.
- Sikorsky CH-53K; data concentrator units for monitoring, processing data and controlling various subsystem components.

Strategy

Curtiss-Wright has been strategically active in both commercial and military avionics.

In commercial aerospace in 2019, Curtiss-Wright and Honeywell announced a partnership to develop a new way for airlines to monitor and analyse flight data. The companies signed an agreement to develop the next generation of mandate-compliant voice and data recorders, using real-time connectivity. This means the aircraft data can be used for more efficient operations, allowing for additional predictive maintenance and

real-time playback of data and voice communications. Along with added connectivity, these next-generation recorders provide an easy upgrade that saves installation time and lowers costs due to being form-fit replacements for Honeywell's HFR-5 series Cockpit Voice and Flight Data Recorders (FDRs).

In defence aerospace, in September 2020, it announced the acquisition of Pacific Star Communications, Inc. (PacStar®), which is a leading provider of secure tactical communications solutions for battlefield network management, including commercial off-the-shelf (COTS)-based rugged, small form factor communications systems, as part of its strategy to position itself to benefit from the US military's investment in integrated battlefield network management.

Recent developments

November 2020; Curtiss-Wright Corporation announced that it had completed the acquisition of Pacific Star Communications, Inc. (PacStar®) for $400 million in cash. PacStar is a leading provider of secure tactical communications solutions for battlefield network management, including commercial off-the-shelf (COTS)-based rugged, small form factor communications systems, and its proprietary "IQ-Core® Software" integrated network communications management software. "The acquisition establishes Curtiss-Wright as a critical supplier of advanced tactical and enterprise network communications solutions supporting a broad spectrum of high-priority U.S. military force modernisation programs. The combination of Curtiss-Wright's mission-critical mobile and secure COTS-based processing, data management and communications technologies with PacStar's highly complementary hardware and software solutions will enable the delivery of best-in-class platform network integration and tactical data link network management to the war fighter. In addition, it ensures that the Company is well-positioned to benefit from the military's continued investment in robust, secure and integrated battlefield network management". The business will operate within Curtiss-Wright's Defense segment. The acquisition supports Curtiss-Wright's financial objectives for long-term profitable growth and strong free cash flow generation. PacStar is expected to generate sales in excess of $120 million in 2020 and is expected to yield significant opportunities for revenue growth.

January 2021; Curtiss-Wright Corporation and Honeywell announced that their 25-hour Cockpit Voice Recorder (CVR) developed for the air transport market has received European Aviation Safety Agency (EASA) Technical Standard Order (TSO) certification. Based on Curtiss-Wright's compact, lightweight Fortress® CVR technology, the new Honeywell Connected Recorder-25 (HCR-25) surpasses the requirements of the upcoming 2021 EASA minimum 25-hour cockpit voice recording mandate for aircraft weighing over 27,000 kilograms. "The importance of reliable cockpit voice and flight data recorders cannot be overstated. That's why we are working alongside Curtiss-Wright to design and develop the next generation of recorders that leverages our full hardware and software expertise to meet the 25-hour requirement and identify the right information and make it available to accident investigation agencies when it's most needed," said Amanda King, vice president and general manager, Aerospace Connected Secure Solutions, Honeywell Connected Enterprise. "Both companies are pioneers and innovators of crash-protected recorders, providing flight recorders to the industry for over 60 years," said Lynn M. Bamford, President and CEO of Curtiss-Wright Corporation. "Working together, we will take flight recorder connectivity and performance to new heights, with extended operation and greater survivability."

Counterpoint comment

In avionics, Curtiss-Wright is positioned in a number of specialised niches where it provides key components that can be integrated into larger systems.

It clearly sees avionics, particularly military as a growth area for its business.

19.1.8. Ensco Inc.

ENSCO, Inc., and its wholly owned subsidiaries represent a $140 million international technology enterprise, headquartered in the Washington, D.C., area. For more than 50 years, the Ensco group of companies has been providing engineering, science and advanced technology solutions that guarantee mission success, safety and security to governments and private industries worldwide. Enco operates in the aerospace, avionics, national security, rail and cybersecurity sectors. Field offices and subsidiaries, representatives and partnerships are located throughout the United States and around the world.

Financials

Ensco generated $140m in 2019 with 630 employees.

We estimate the $25m was generated from avionics related revenues in 2019, falling to $20m in 2020.

Operations and technology

Location

Ensco Inc. is headquartered in Springfield, Virginia, USA.

Ensco Avionics, a wholly owned subsidiary of Ensco Inc., is based in Endicott, NY, USA.

Ensco has US office facilities in El Segundo, CA, Colorado Springs, CO, Cocoa Beach, FL and Melbourne, FL.

Capabilities

For more than 35 years, Ensco Avionics has developed sophisticated airborne systems for the aerospace industry to meet DO-178C/ED-12, DO-254/ED-80, DO-278A/ED-109, DO-326A, SEAL and military standards for manned and unmanned systems.

The focus of Ensco Avionics is on safety- and mission-critical software and programmable hardware engineering solutions, display application development, tailored synthetic vision applications, integration test solutions and the IData® Tool Suite.

The Ensco IData® Tool Suite is an innovative, advanced Human Machine Interface (HMI) software toolkit for creating and deploying embedded software display applications. IData offers advanced features with seamless integrations for 2D and 3D digital moving maps.

Customers and contracts

Ensco includes within its aerospace customers L3Harris, United Airlines, Alaska Aerospace Corporation.

Ensco Avionics' customers include Airbus, AVIC, BAE Systems, Boeing, Crane, Curtiss-Wright, Flight Safety, Gables Engineering Inc., GE Aviation, Gulfstream, Honeywell, ITT, Lockheed Martin, L-3 Communications, Moog, Northrop Grumman, Pilatus Aircraft, Pratt & Whitney, Raytheon, Rolls-Royce, Thales, Triumph Engine Control Systems, Triumph Thermal Systems, and Unison.

The majority of its avionics related services were provided in respect to the following products;

- Avionics Displays
- Custom Software Development for Avionics Systems
- Custom Displays for Human-Machine Interfaces for Cockpit Displays (Manned/Unmanned), Battle Management, C4ISR, and Ops Centres
- Testing, Verification and Validation of Avionics Components and Subsystems
- Engineering Services
- Synthetic Vision

Strategy

Creative thinking, innovation, and investment in high-technology research and development programs are the mainstay of our business.

Recent developments

August 2020: Ensco Avionics released IData® HMI Tool Suite Version 4.0 (IData 4.0). It is the latest advance in the tool suite that uniquely meets the industry's need to expedite the design, development and certification of embedded display applications and keep pace with rapidly emerging technologies, standards and certification requirements.

Counterpoint comment

Ensco has a large portfolio of avionic related blue chip customers that it serves. Its engineered/software services are highly specialised and we see that OEMs are outsourcing more of their bespoke software needs.

We believe therefore that Ensco should continue to thrive within this environment as software grows at above trend rates.

19.1.9. FLIR Systems, Inc

FLIR Systems I the Global Leader in the Design, Manufacture and Marketing of Thermal Imaging Infrared Cameras.

In Jan 2021 Teledyne Technologies announced that it will acquire thermal imaging camera supplier FLIR systems in a $8 billion cash-and-stock deal to increase its portfolio of imaging sensor technology.

The deal is expected to close mid-2021.

Financials

In 2020 FLIR had sales of $1,924 million.

Within its Defense Technologies division FLIR reported $767.6m of revenues in 2020, slightly down from $794.9m in 2019, generated from the following sub-sectors:

- Airborne systems
- Unmanned solutions
- Integrated systems
- Border surveillance
- Maritime systems
- Radiation and explosives detectors
- Chemical-biological threat detectors

We estimate that the Avionic related sensor sales, generated within the FLIR business, accounted for $60m in 2019 and $57m in 2020.

Operations and technology

Location

FLIR Systems, Inc. Corporate Headquarters is on Oregon, USA.

In addition FLIR has subsidiary companies FLIR Systems AB located in Taby Sweden; FLIR Systems West Malling, Kent, UK; FLIR Systems BV, Abu Dhabi: FLIR Systems Japan, Tokyo, Japan.

FLIR manufactures many of the critical components for its products, including but not limited to infrared detectors, pan-tilts, optics and coatings, laser sub-systems, and micro-coolers, and develop much of the software and middleware for its systems. This vertical integration minimises lead times, facilitates prompt delivery of its products, controls costs, and ensures that these components satisfy quality standards.

FLIR purchases other parts pre-assembled, including certain detectors, coolers and optics, circuit boards, cables, and wire harnesses.

These purchased and manufactured components are then assembled into finished systems and tested at one of its primary production facilities located in the United States, Sweden, Norway, Estonia, and Canada. Certain components and finished goods, including some of their visible-spectrum cameras, test and measurement products and maritime electronics, are produced by contract manufacturers.

Capabilities

FLIR's technology is almost entirely based upon infra-red. An infrared detector, which collects or absorbs infrared radiation and converts it into an electronic signal, is the primary component of thermal imaging systems. The two types of infrared detectors that FLIR manufacture are often referred to as "cooled" and "uncooled" detectors. Cooled detectors utilise a mechanical sterling cycle micro-cooler to reduce the operating temperature of the infrared sensor to approximately -200°C. These detectors offer very high sensitivity and spatial resolution for long-range applications or those applications requiring high measurement precision.

Cooled detectors, while more sensitive and thus able to see farther, result in a product that is more expensive, heavier, more complex, and uses more power than those using uncooled detectors. Uncooled detectors operate at room temperature and do not require a micro-cooler, resulting in products that are lighter, use less power and are less expensive to produce than those using cooled detectors.

Infrared imaging systems used for surveillance typically employ cooled infrared detector and numerous other imaging technologies to identify and track objects from long distances and at high resolution.

FLIR's Systems are often installed onto larger platforms and must be able to integrate with other systems such as aircraft avionics, radars, remote weapon systems, laser systems, command and control centres, and large, broad-based security networks.

FLIR offers several products that provide precise target location and designation capabilities in applications ranging from man-portable devices to high definition, multi-spectral, stabilised airborne laser designator systems.

FLIR are also active in the upgrade market. For example the 380X is a hardware, firmware, and software upgrade to support advanced image aiding features for our globally renowned Star SAFIRE 380 gimbal systems. Its impressive enhancements reduce operator workload and boost visibility for faster, smarter critical decision making.

Customers and contracts

A substantial portion of Government and Defense business unit consolidated revenue is derived from sales to United States and foreign government agencies, and FLIR's business will continue to be substantially dependent upon such sales.

Bell Helicopter has selected FLIR's BRITE Star II® airborne stabilised multi-sensor system as the Target Acquisition Sensor Suite (TASS) for the US Army's Armed Reconnaissance Helicopter (ARH-70A) Program.

Star Safire 380-HD has been selected by Bristow Helicopters for its fleet of AW189 and S-92 helicopters to be used in the UK's Search and Rescue (SAR) helicopter programme.

FLIR Systems selected by Sikorsky, with US Army concurrence, to supply the Talon for its HH-60M Black Hawk helicopters.

FLIR Systems Selected to Provide Thermal Imaging Systems for Air National Guard HC-130 Search and Rescue Aircraft.

FLIR generates revenues from the unmanned/autonomous defence sector with the following noted:

- $26m contract in Q3 for NBCRV Sensor Suite Upgrade program; augments $48m Army contract in 2019
- $32m Centaur UGVs award in Q4, resulting in $75m in orders year-to-date from Army, Air Force, Marine Corps and Navy
- ~$50m in awards year-to-date to deliver R80D SkyRaiders to U.S. federal government customers
- $14m award for lightweight vehicle surveillance from U.S. Customs and Border Protection

FLIR states that "These products and solutions are sold off-the-shelf or can be customised for specific applications and range in price from under $10,000 for certain hand-held and weapon mounted systems to over $1 million for our most advanced integrated sensing solutions platform."

Strategy

At FLIR we provide superpower vision, helping people around the world save lives, protect the environment, and enhance productivity. We're building more than innovative technologies; we're striving to build a more sustainable, more efficient, safer future.

Recent developments

Jan 2021: Teledyne Technologies announced that it will acquire thermal imaging camera supplier FLIR systems in a $8 billion cash-and-stock deal to increase its portfolio of imaging sensor technology. The deal is expected to close mid-2021. The combined entities will generate circa $3bn of digital imaging related revenues.

December 2020: FLIR Systems announced that it has acquired Altavian, Inc., a privately-held manufacturer of small unmanned aerial systems (sUAS) for defence and public safety customers. Altavian's airframes integrate multiple sensors, including FLIR thermal technology, to provide users with decision support and intelligence, surveillance, and reconnaissance (ISR) capability.

Counterpoint comment

A focused innovative business that serves a number of sectors including defence. As surveillance and EVS demands increase globally we believe that FLIR will continue to prosper. Equally, subject to approval, the acquisition by Teledyne could provide market and technology synergies.

19.1.10. Garmin

The Garmin aviation segment is a leading provider of solutions to aircraft manufacturers, existing aircraft owners and operators, as well as government/defence customers and serves a range of aircraft including business aviation, general aviation, experimental/light sport, helicopters, optionally piloted vehicles (OPV), unmanned aerial communication, flight control, hazard avoidance, weather radar, radar altimeter, datalink weather receivers and services, engine information systems, traffic collision avoidance systems, terrain awareness and warning systems (TAWS), controller-pilot data link (CPDLC), an expansive suite of automatic dependent surveillance broadcast (ADS-B) solutions, in-cockpit and cloud connectivity, wearables, portables, apps, training, simulation, flight planning/filing, premium trip services, aviation data services as well as other solutions that are known for innovation, reliability, and value.

Financials – Aviation segment

FYE 31/12/20	2020	2019	2018
Sales $m	622.8	735.5	603.5
Operating income $m	137.2	252.9	204.7
Return on sales %	22.0%	34.4%	33.9%

Garmin commented in its 2020 10k: "Aviation revenue decreased 15% from the year ago period, due to fewer shipments to OEM customers and reduced contributions from ADS-B products."

These are quite remarkable financials that underpin the value of investing heavily in R&D in order to generate the highest levels of sector operating income.

Garmin does not report a split between OEM and aftermarket services or retrofit and upgrade usage. This we believe is because it does not have the means to track end-use given the number of stockists and distributors.

We do however believe that retrofit and upgrade revenues account for 50% of total avionics revenues.

Operations and technology

Location

Garmin International, Inc. and Garmin USA, Inc. own and occupy facilities of approximately 1,990,000 ft² on approximately 107 acres in Olathe, Kansas, where the majority of product design and development work is conducted, the majority of aviation panel-mount products are manufactured, and products are warehoused, distributed, and supported for North, Central and South America.

Garmin International, Inc. leases 148,000 ft² of land at New Century Airport in Gardner, Kansas under a ground lease and occupies two aircraft hangars on this land, one of which is owned (47,000 ft²) and the other leased (53,000 ft²). Both properties serve as flight test and certification facilities that are used in development and certification of aviation products.

Capabilities

Integrated Flight Decks/Flight Displays: Garmin offers a range of integrated glass flight decks from the G1000® NXi for the general aviation and business aviation markets to the G5000® for business aviation, defence and commercial applications. Integrated capabilities include navigation, communication, flight instruments, weather, terrain, traffic, ADS-B, engine information on large high-resolution colour displays,

and automatic flight control systems. Head-up display technology virtually mirrors the primary flight display instruments allowing for increased aircraft capability in adverse weather conditions. Additional features include: Garmin's 3-D synthetic vision technology (SVT™), weather, Garmin's electronic stability and protection system (ESP™), electronic flight charts, touchscreen and voice controls, CPDLC, audio and visual feedback, and animation to help pilots know exactly how the system is responding to their input.

The helicopter offerings have been optimised for rotorcraft and offer features like helicopter synthetic vision technology (HSVT™), helicopter terrain awareness and warning system with voice call outs, radar altimeter display, helicopter-specific databases that include additional heliports and low-altitude obstacles, WireAware™ wire-strike avoidance technology, as well as high resolution terrain, tailored ADS-B traffic alerting, and the ability to display video from a forward looking infrared (FLIR) camera or other video sources.

Garmin also offers all-glass integrated flight decks to the retrofit market through G950® NXi, G1000® NXi, G3000® and G5000®. Additionally, Garmin offers electronic flight display solutions that provide essential information such as aircraft altitude, attitude and heading while also displaying data from other avionics such as weather, traffic and much more. These solutions include G3X Touch™, G500H TXi, G500 TXi, G600 TXi and G700 TXi.

Electronic Flight Instruments: To help aircraft owners with aging aircraft systems while provide modern flight display capability and preserve the integrity of their original aircraft panel, Garmin offers the G5 and GI 275 electronic flight instruments. These instruments are designed to replace existing mechanical attitude indicator, attitude directional indicator (ADI), course deviation indicator (CDI), horizontal situation indicator (HSI), engine indication system (EIS), and it can serve as a standby to a number of flight displays.

GPS/Navigation/Communication Solutions: Garmin serves the market with the GTN™ Xi series, a premium touchscreen GPS, VHF navigation and communication, and multi-function display (MFD). In addition to these core functions, this series of products combines a wealth of information for the pilot into a single display including flight planning, datalink weather, weather radar, traffic, terrain awareness and warning system (TAWS/HTAWS), charts, airport information, airspace boundaries, and much more. Additional capabilities provide advanced ADS-B "In" traffic display, including TerminalTraffic™ and patented TargetTrend™ technology as well as the ability to control the display with voice commands.

Services and Mobile Applications: Garmin Pilot™ is a premium, global app for iOS or Android mobile devices used for flight planning, filing a flight plan, in flight navigation, and automatic flight logging. It offers a comprehensive and simplified experience to access a wealth of information during any particular phase of the flight including weight and balance, performance, and trip calculations, checklists, airport information, weather, traffic, 3D Vision virtual perspective view of surrounding terrain, a digital document viewer, a scratch pad, geo-referenced sectional and approach charts, wireless database updating, ADS-B weather and traffic as well as SiriusXM radio and weather via subscription.

Garmin AUTOLAND: In the event of an emergency such as pilot incapacitation, the pilot or even a passenger on board can activate Autoland to land the aircraft with a simple press of a dedicated button. Autoland can also activate automatically if the system determines it's necessary. Once activated, the system immediately calculates a flight path to the most suitable airport and runway, while avoiding terrain and adverse weather, initiates an approach and automatically lands the aircraft.

Customers and contracts

Garmin is referred to in section 7 for its range of G1000/G3000/G5000 integrated cockpit avionic offerings together with many of its customer/platform contracts.

Garmin offers its products both as forward fit to OEMs and to end-users as retrofit/upgrades including airlines, bizjet operators, GA aircraft, and the rotorcraft market. These products include ADS-B, all glass LCD cockpits, GPS based navigation systems, FMS, auto-pilots and database services.

Garmin in referring to its Autoland device referred to "its aircraft manufacturing collaborators Piper, DAHER, and Cirrus, who shared the same vision to bring this life-saving technology to the industry."

We estimate that Garmin generates 55% of its revenues from OEM forward fit and 45% from upgrades, retrofit and services.

Strategy

For Garmin's aviation product lines, Garmin considers its principal competitors to be Aspen Avionics, Avidyne Corporation, CMC Electronics, Collins Aerospace, Dynon Avionics, Genesys Aerosystems, Honeywell Aerospace & Defense, Innovative Solutions and Support Inc., L-3 Avionics Systems, Safran SA, Thales, and Universal Avionics Systems Corporation.

Recent developments

February 2021: Kansas, US: Garmin® International, Inc. announced that its revolutionary Garmin Autoland system was honoured by FLYING Magazine with a 2021 Editors' Choice Award. Part of the Garmin Autonomi™ family of autonomous safety-enhancing technologies, Autoland is the world's first certified system of its kind with the ability to activate during an emergency situation to autonomously control and land an aircraft without human intervention.

Counterpoint comment

In a relatively short time, Garmin has become a highly tuned and diversified business. It has proved especially successful in business jet, rotorcraft, and GA markets, both for OE, and aftermarket transitioning to more modern and efficient avionic solutions. Many of its products have become the market benchmark.

19.1.11. GE Aviation

GE Aviation acquired Smiths Aerospace division in 2007 which provided it access to the avionics market in addition to power management and mechanical systems.

At the time of the acquisition Smiths generated $2,400m in aerospace with avionics estimated to have represented $1,000m+ of this total at that time.

GE Aviation's avionics portfolio today includes IMA, FMS, data recorders/data analytics, remote data concentrators, display products, mission and stores management. GE also provides a range of digital services including navigation databases (for FMS).

General Electric also has an avionic joint venture with Avic, China, (Aviage) which is reported on separately within this report.

Financials

FYE 31/12/20	2020	2019	2018	2017	2016
Sales $m	22,042	32,875	30,566	27,013	26,261
Segment profit $m	1,229	6,812	6,466	5,370	6,115
Return on sales %	5.6%	20.7%	21.2%	19.9%	23.3%

GE Aviation has secured significant shipset values on Boeing 777, 787, and 777X; Comac 919; and Lockheed Martin F-35 in recent years which have increased its revenue base in avionics.

We therefore estimate that its avionics business generated $1,214m revenues in 2019, and $830 in 2020.

Operations and technology

Location

GE has a number of avionics facilities. However, its two main bases for avionics are in Cheltenham, UK, and Grand Rapids, Michigan, USA.

It is supported from other facilities including Dayton, Ohio; Florham Park, NJ, USA (service & repairs), Clearwater, Florida, USA (service and repairs).

Capabilities

GE Aviation systems summarises its avionic capabilities as follows:

- Navigation and Guidance (Flight Management Systems)
- Controls and Interface (RIUs)
- Avionics Computing and Networking (IMA, Integrated Avionics computing, Vehicle management, mission and distributed computing products)
- Vehicle Health and Data Management (VDR, FDR, IDAR, High speed data transfer)
- Crew Information Systems (PFDs, SFDs,)
- Mission Systems (Stores management, refuelling management)
- Inertial Navigation Products (inertial Reference Units)
- AirXOS (Unmanned flight management - Flight Authorisation, Flight De-confliction, Dynamic Airspace Management, Remote ID, and Conformance Monitoring)
- Military and Advanced Programs (Cyber, High power processing, autonomy)
- Commercial Unmanned Systems (UAV, UAM, Autonomy, Ground links)
- Avionics Services

FMS: GE's FMS automates in-flight tasks, enabling the pilots to file a flight plan, then safely and efficiently fly an aircraft from its origin to its worldwide destination. Simultaneously, the GE FMS will account for traffic, weather, aircraft performance and required arrival time, while optimising performance. The FMS uses a variety of sensors to determine the aircraft's current position and sends guidance commands to the aircraft control systems, which guide the aircraft along the approved flight plan. GE's innovative solutions reduce pilot workload and fuel consumption through automation of aircraft performance calculations, which aid in evaluating flight plan changes.

FMS features include the following:

- C1 Flight Management Computer (FMC) upgrade improves performance by enabling the latest U-Series FMS software
- AOC/ATC datalink communication and flight planning
- Increased availability, with single FMC part number and consistent operations across fleets
- Advanced Airspace features: RNAV/RNP 0.1, PBN, RTA, FANS 1/A, Link 2000+, PBN (RNP 0.3), either FANS A/B/C, ATN BL1, ATN BL2
- Supports FANS datalink capabilities, with integrated FANS 1/A and ATN Baseline 1 capability

IMA computing solutions: GE's contribution to the Open Flight Deck project, which is looking at next generation flight deck technologies, has been informed by its leadership in open avionics systems on Boeing 787 and Gulfstream G500/G600. GE's open avionics vision - looking at how to embody these open approaches in other areas of avionics - has led to an open-architecture platform that incorporates the hardware, software development tools and infrastructure needed to support a range of applications. Through 'Open Flight Deck' the manufacturer can partner with a range of suppliers to develop applications.

Displays: GE Aviation has in the past supplied a range of LED displays mainly for the retrofit and upgrade market. It also has a solid state integrated standby indicator that combines heading, altitude and airspeed data. It also provides a DCDU display to the Airbus A320/A330 family, however, this is optional fit.

Remote Interface Units: The RIU-100 is a highly flexible and configurable Remote Interface Unit (RIU). RIU-100 offers a near "off-the-shelf" solution to a wide range of applications including:

- Distributed Input/Output (I/O)
- Centralised I/O
- Sub-system control (embedded or as standalone unit)

In a compact package the RIU-100 provides 100 interface channels combined with either a dual redundant MIL-STD-1553B Remote Terminal, or an ARINC 429 (2 Tx and 4 Rx channels) databus interface.

Voice and Data Recorders: The Voice and Data Recorder (VADR®) brings multiple high-speed databuses and analogue interfaces. The compact, lightweight, and affordable VADR® employs acquisition, recording, and memory protection technologies. The flexible VADR® is applicable to virtually any aircraft, and may be used as a data-only, voice only, or combined voice and data recorder to support:

- Regulatory compliance
- Aircraft maintenance
- Flight operations quality assurance
- Aircraft and component usage monitoring, limit exceedance monitoring

High speed Data Transfer: GE's (HSDTS) has been designed to handle the high volume of digital data on current and future airborne platforms, both manned and unmanned. It offers unparalleled data read/write speeds, the capability to host user developed applications and process data from its mass storage, interchangeable NVMe storage media, and user interchangeable capacity based on Commercial Off The Shelf (COTS) Solid State Drives (SSD). In addition, the HSDTS offers considerable I/O flexibility depending on user application. This high capacity, low SWaP data transfer system provides a single solution that is highly configurable for a variety of applications.

Mission computing: The GE Versatile Computing Platform (VCP) is a family of rugged embedded computers developed to satisfy a wide range of vehicle and mission computing applications. The VCP uses open architecture components and software to provide a flexible yet cost effective solution. The VCP provides standard digital avionics interfaces for vehicle or mission computer systems. The baseline VCP configuration contains a 6-slot 3U OpenVPX backplane, up to three 3U Single Board Computer (SBC) processor cards, up to eight I/O cards (3U and XMC), an Electro Magnetic Interference (EMI) filter assembly, and a power supply housed in a passive cooled chassis.

Inertial Reference Units: IRUs provide navigational grade 2-5 mils performance for platform navigation, system stabilisation, and pointing applications. This IRU is based on a proprietary inertial gyroscope technology that reduces size, weight, power, and cost (SWaP-C) when compared to units with similar performance. GE Aviation's IRUs are utilised on land, maritime, and airborne applications; with over 5,500 units fielded worldwide. This product family is scalable to customer's specific needs.

Customers and contracts

GE Aviation has the following avionics related contracts with the following customers:

- Airbus A320ceo/A320neo: FMS, DCDU (optional)
- Airbus A330/A330neo: FMS, DCDU (optional)
- Boeing 737: FMS, MCDU displays, air data computers, Auto/Pilot, data recorders, standby displays.
- Boeing 777X: Common Core Computing system, remote data concentrators.
- Boeing 787: Common Core Computing system, Remote Data Concentrators (Smiths also retained Wind River to assist with the development of the computing function)
- Gulfstream G500/G600: Data concentration and IMA computing platform for multiple avionics systems, advanced health and usage monitoring.
- Boeing Apache AH-64: pylon interface unit and maintenance data recorders
- Lockheed Martin F-35: Standby flight Displays.
- Eurofighter (Typhoon): Voice control system
- Boeing KC-$830m in 2020135: Integrated data acquisition recorder

Strategy

GE Aviation is focussed upon utilising its installed base, whether it be for engines or avionics, to provide digital service support solutions that add value to its customer base.

It understands how to add value throughout the life cycle of its products with support and service as reflected within its operating margins.

Recent developments

June 2019: GE Aviation has delivered the 20,000th flight management computer for military and commercial aircraft marking 35 years of continuously advancing the technology for flight crews. At the Paris Air Show, the company's new connected flight management system (FMS) is incorporated into their open systems demonstrator in the GE Aviation pavilion showing the potential of how additional efficiency gains can be provided to the airlines.

April 2019: GE Aviation introduced a new advanced avionics computer specifically built for military and commercial unmanned vehicles. This new computer provides an open architecture design that integrates vehicle management and advanced mission processing into a compact, lightweight design.

July 2018: Boeing has awarded GE Aviation a contract for avionics systems on the AH-64 Apache. The contract includes hardware delivery of the pylon interface unit, load maintenance panel and maintenance data recorders for the AH-64. Deliveries take place May 2018 through December 2022.

June 2018: Avionica and GE Aviation today announced that they have expanded their partnership by forming a joint venture through GE's acquisition of an ownership interest in Avionica. The JV allows the companies to accelerate edge processing and wireless connectivity to maximise the value of aircraft data. The terms of the deal were not disclosed.

Counterpoint comment

GE is a global player and this, in part, led to the Aviage JV with Avic. It is not clear how this JV is performing currently given the strained relationships between US/China and the concerns over exploitation of Intellectual Property.

GE has some strong capabilities in certain areas such as IMA/computing infrastructure, FMS and data, however, it does not offer the complete array of integrated avionics offered by other providers such as Collins, Honeywell and Garmin. It does not for example have a strong position with display products.

19.1.12. General Dynamics

General dynamics operates via four divisions as follows:

- Aerospace - (Gulfstream and Jet Aviation)
- Marine Systems - (NASSCO, Bath Iron Works, Electric boat)
- Combat Systems - (European Land Systems, Land Systems, Tactical and Ordnance)
- Technologies - (Mission Systems, Information Technology)

General Dynamics is not a major avionics provider, but it does have airborne mission systems capabilities within its Technologies division.

Financials

General Dynamics reports by segment and Technologies division revenues includes airborne mission, cyber, sensor and data products. In 2020, Technologies had sales of $12,648m compared to $13,359m in 2019

We therefore estimate that General Dynamics generated $305m of avionic related revenues in 2019, and $286

m in 2020.

Operations and technology

Location

General Dynamic's Mission Systems is headquartered in Fairfax Virginia, USA.

Other Mission Systems facilities are located as follows; Cullman, Alabama; Scottsdale, Arizona; San Jose, California; Orlando, Florida; Annapolis Junction, Maryland; Dedham, Pittsfield and Taunton, Massachusetts;

Bloomington, Minnesota; Florham Park, New Jersey; Catawba, Conover and Greensboro, North Carolina; Kilgore, Plano and Wortham, Texas; Fairfax and Marion, Virginia; Calgary, Halifax and Ottawa, Canada; Tallinn, Estonia; Oakdale and St. Leonards, United Kingdom.

General Dynamics has a subsidiary Mission systems business in Rome, Italy, however this does not include airborne equipment.

General Dynamics also has a Mission systems subsidiary located in Ottawa, Ontario, Canada that provides data Management Systems.

General Dynamics' Mission systems had a total of 8,100,000 ft² of facility space in 2019.

Capabilities

Stores Management: DSMS is a standards-based MIL-STD-1760 weapons control system that provides selection, arming, release and post launch control of modern precision guided weapons. DSMS is expandable – After DSMS is installed, new MILSTD-1760 stores can be integrated with software modification only and no additional hardware.

Identification Friend or Foe: The IFF crypto solutions developed are being integrated into the world's newest, most advanced military aircraft and aboard ships. They are also being incorporated into the upgrades of legacy IFF systems in operational aircraft.

ISR software: TAC-MAAS is advanced motion imagery Processing, Exploitation and Dissemination (PED) software, which delivers significant productivity and intelligence benefits for Intelligence Surveillance and Reconnaissance (ISR) operations. TAC-MAAS has an operationally proven track record and boasts demonstrated plug and play interoperability with STANAG 4609/NGA MISP compliant manned and unmanned ISR platforms. It has low training and operational support requirements delivering a cost-effective solution for leveraging intelligence from airborne sensor imagery.

Mission Computing: (AMC) is an integrated information processing system, providing complete hardware and software solutions. It is built on a well-defined open systems architecture allowing for rapid insertion of emerging technologies. General Dynamics supplies system design and integration services to ensure a precise fit to the requirements of each specific user platform. The AMC is a set of digital computer hardware and software that performs general purpose, I/O, video, voice, and graphics processing.

- Communication is over multiple buses, including 1553, Fibre Optic Fibre Channel, and Local PCI, and all modules integrate in an industry standard 6U VME backplane
- I/O configuration may be tailored with PMC mezzanine modules
- Design is scalable and expandable, with a clear and built-in path for technology upgrades and insertion
- Well-defined avionics Application Programming Interface (API) abstracts the application software from the underlying hardware, affording system evolution to ever increasing performance standards, while effectively managing obsolescence
- Ethernet interface supports software development and system maintenance.

Data Management Systems: The Data Management Systems (DMS) enables an aircraft to collect and present integrated tactical situational awareness data gathered by:

Multi-mode radars, electro-optic sensors, electronic support measure systems, acoustic processing systems, self–defence suites, magnetic anomaly detector systems, weapons/stores management suites, SATCOM systems, tactical datalinks, Automatic Identification Systems (AIS), Navigation and Flight Management Systems

SATCOM On-the-Move® antennas provide secure, beyond-line-of-sight communications for U.S. and coalition troops operating in remote locations. Designed for the rugged tactical environments, these antennas can be mounted on a fast moving vehicles, high speed boats, aircraft and UUVs. These antennas provide reliable X, Ku, or Ka Mil and commercial band satellite communications.

Customers and contracts

Specific contracts are as follows:

- General Dynamics Advanced Mission Computer (AMC) is the nerve centre of the U.S. Navy's F/A -18 Super Hornet and the U.S. Marine Corps' AV-8B Harrier.
- P3 Orion: Digital Stores Management System (DSMS) is a weapons control system enabling the launch and control of modern precision guided weapons.
- U.S. Navy's P-3C: Stores Management System.
- General Dynamics Canada Mission Systems is prime integrator of the mission sensors and systems for the CP-140 Aurora and the CH-148 Cyclone
- NATO AWACS Boeing EC-3: Data and mission computing console upgrade

Strategy

General Dynamics has strength in Mission Computing, Stores Management, IFF sensing and data management for military airborne applications. However, it is heavily dependent upon the F/A-18 programme along with AV8B which are both in mature life cycle mode of operation and support.

Recent developments

None that we can see.

Counterpoint comment

General Dynamics has strength in land, marine and space applications but has not secured any new airborne business in recent years (other than F/A-18 follow on contract awards and service support).

19.1.13. Genesys Aerosystems

Genesys designs and manufactures a full suite of electronic flight instrument systems and autopilot solutions specialising in fixed wing, rotorcraft, military and special mission aircraft fleet support with state-of-the-art avionics and product sustainment services.

During November 2020, Moog Inc announced that it has completed the acquisition of Genesys Aerosystems Group, for a purchase price of approximately $77.7 million. The purchase includes the operating subsidiaries S-Tec Corporation and Genesys Aerosystems, Inc.

Genesys Aerosystems brings together Chelton Flight Systems, Inc. and S-TEC Corporation, previously doing business as Cobham Avionics, and has 143 employees.

Financials

We estimate that Genesys generated a total of $42m in revenues in 2019.

We further estimate that the avionic related revenues accounted for $38m in 2019, and $30m in 2020.

Operations and technology

Location

Genesys has its main facility at Mineral Wells, Texas, USA.

It also has a facility at Anchorage, Alaska.

Capabilities

We note the following key developments in Genesys Aerosystems' history.

- Chelton Flight Systems, founded in 1997, developed the world's first FAA-certified 3D synthetic vision EFIS and GPS/WAAS navigator. Key technologies include synthetic vision with three dimensional highway-in-the-sky navigation, integrated flight management and hazard alerting, and ultracompact, highly ruggedised sensors. The company's uniquely customisable open-architecture systems dramatically reduce integration costs and schedules for both OEM and retrofit applications. Chelton Flight Systems products have been certified on over 700 different aircraft types.

- Genesys Aerosystems developed the world's first FAA-certified 3D Synthetic Vision flight display system and GPS-WAAS navigator. In addition, industry firsts like Highway-In-The-Sky navigation have helped it to grow to become a proven leader in integrated cockpit avionics systems for special-mission aircraft. Its display/EFIS products have been certified on over 700 different aircraft types in all four FAA regulatory classes: Part-23, Part-25, Part-27, and Part-29.
- S-TEC Corporation, founded in 1978, offers autopilots for aircraft and helicopters. From low cost analogue wing levellers to sophisticated, digital, three-axis systems with Flight Director and envelope protection, S-TEC has FAA certification for nearly 1,000 aircraft types and has delivered over 40,000 autopilot systems. The company's new HeliSAS brings digital, full-authority autopilot technology to the market in a package weighing an unprecedented 15 lbs. Available as a stability augmentation system only or with all autopilot modes, HeliSAS dramatically enhances safety for light single- and twin-engine helicopters.

Customers and contracts

Genesys lists its customers as follows:

- AgustaWestland
- Airbus Military
- Air Medical Group Holdings
- Bell Helicopter
- Carson Helicopters
- Embraer
- Grob Aircraft
- Sikorsky
- Textron AirLand

Strategy

Neither Genesys nor Moog has made specific comments regarding the future of Genesys within the Moog Aerospace division. Moog has stated that "We're excited to bring Genesys Aerosystems' products and people into Moog's Aircraft Controls Segment," said Mark Trabert, Moog Aircraft Controls Segment President. "Genesys adds to our product and capabilities portfolio. The product synergies and cultural alignment of our two organisations will enable future growth beyond our current core flight control business."

Recent developments

November 2020: Genesys Aerosystems announced today that the IDU-680 and IDU-450 EFIS displays with 8.0K software have earned Supplemental Type Certification on the Airbus AS350/355 helicopters. The Level A certified IDU-680 and IDU-450 EFIS utilise ADAHRS, and GPS SBAS data for precision aircraft operations, including RNP and LPV approaches. The large-format, 10.4 in or 26.4 cm screen diagonal, IDU-680 and smaller form, 6.4 in or 16.25 cm screen diagonal, IDU-450 can also integrate with select radios such as the Genesys Digital Radio (GDR), traffic systems, and datalink weather.

November 2020: Genesys Aerosystems, has received FAA Technical Standard Order (TSO) approval for the Genesys Digital Radio (GDR) product line. The GDR is a family of 11 remote-mounted, software-definable radios that feature combined VOR/localiser/glideslope, marker beacon, VHF communication with a frequency range of up to 118-156 MHz, and optional embedded UHF 225-400MHz capabilities.

Counterpoint comment

Moog appears to want to grow beyond its traditional areas of flight control and engine control and has targeted avionics/electronics which is arguably part of a more digital strategy.

19.1.14. Genova Technologies

Genova Technologies is third party software development company, which works across a number of diverse sectors. In aerospace, Genova Technologies is an engineering services company, providing outsourced avionics software development and verification.

Financials

Counterpoint estimates Genova's avionics-related sales were $10m in 2019, and $9m in 2020.

Operations and technology

Location

Genova's headquarters is in Cedar Rapids, IA.

Capabilities

Genova Technologies provides commercial and military avionics and aerospace manufacturers and federal government customers with solutions to meet mission-critical application development, web development, mobile technologies, information technology, and testing and validation needs.

It has expertise in the following stages of the software life cycle:

- System Validation
- Software Development
- Independent Software Verification
- Test Automation
- Software Tools Development and Qualification

Genova has over 20 years' experience with DO-178B/C and DO-254 processes.

Customers and contracts

Projects include a DARPA program to demonstrate a tactical airborne network. It also performs commercial aerospace work but in common with many such companies it does not generally reveal the identity of its clients.

Counterpoint comment

A relatively small player but clearly capable.

19.1.15. Green Hills Software

Green Hills Software was founded in 1982, is privately held, and has been profitable since its inception. Green Hills Software has averaged nearly 30% per year revenue growth and is now the world's largest independent real-time operating systems (RTOS+ company. Green Hills Software offers the safest and most secure RTOS and development tools for aerospace and defence. Its safety and security pedigree goes back to 1997 with the Boeing B1-B avionics upgrade and the Sikorsky Helicopter S-92 Avionics Management System from Rockwell Collins, which was later certified to DO-178 DAL A. Since then, Green Hills Software products have been deployed on almost every commercial and military aircraft. Its in-house group of certification experts has provided certification evidence for over 80 safety and security certifications across all the key processor architectures, reducing time, cost, and risk of certification.

Financials

We estimate that Green Hills generated $85m of revenues in 2020.

We further estimate that $15m of revenues were related to avionics product solutions, falling to $13m in 2020.

Operations and technology

Location

Green Hills Software is headquartered in Santa Barbara, CA, with European headquarters in the United Kingdom.

Capabilities

The INTEGRITY-178 tuMP real-time operating system (RTOS) provides benefits for safety and security-critical systems in aerospace and defence systems. For DO-178C airborne safety applications, INTEGRITY-178 tuMP is the only RTOS that supports multi-processing of ARINC 653 partitions across multicore cores in symmetric multi-processing (SMP) and bound multi-processing (BMP) mode. It is also the only RTOS to provide a general solution to multicore interference mitigation. Managing the shared resource contention that causes multicore interference can benefit all types of real-time systems by decreasing worst-case execution times.

For security-critical applications, INTEGRITY-178 is the only commercial operating system certified to Common Criteria EAL6+ and NSA High Robustness, and INTEGRITY-178 tuMP extends that pedigree to multicore processors. High robustness enables hosting multi-level security (MLS) applications, and INTEGRITY-178 tuMP is the only commercial RTOS capable of hosting cross-domain solutions (CDS). There is no reason to choose between safety and security when you can have the best of both in the same solution with the INTEGRITY-178 tuMP RTOS.

Avionic applications of these software solutions include the following:

- Flight Management Systems
- TCAS
- Mission computers
- Navigation, positioning
- Terrain Warning systems
- Weather radar systems
- Multi-function Displays
- ADIRUs
- Communication, Navigation, Intelligence (CNI)

Customers and contracts

Green Hills supported the Boeing B1-B avionics upgrade and the Sikorsky Helicopter S-92 Avionics Management System from Rockwell Collins.

They have also supported the following customer platforms:

- Boeing 787 Dreamliner
- Northrop Grumman UH-1Y
- Lockheed Martin F-22 Raptor
- Aselsan T-70 Blackhawk program
- Lockheed Martin C130J
- Northrop Grumman AH-1Z
- Saab Skeldar UAV
- Lockheed Martin F-35
- Airbus A380
- Rockwell Collins Avionics Management
- EADS mission Management Computer
- Lockheed Martin F-16 fighter

Strategy

Green Hills Software is a worldwide leader in embedded safety and security. It covers seven sectors including aerospace and develops industry standard products where criticality, security and reliability are key requirements.

Within aviation avionics it is clearly focussed upon supporting many lead OEM specifiers.

Recent Developments

November 2020: Green Hills Software announced that its INTEGRITY®-178 Time-Variant Unified Multi-Processing (tuMP™) RTOS was selected by the U.S. Army for the operating system upgrade to the Improved Data Modem (IDM-401) program. The IDM-401 is the common solution for digitising Army Aviation and is fielded on every modernised, rotary-wing Army aircraft, including the CH-47 Chinook, AH-64 Apache, and UH-60 Black Hawk.

February 2020: Green Hills Software announced that its INTEGRITY®-178 Time-Variant Unified Multi-Processing (tuMP™) RTOS running on a quad-core ARM® Cortex®-A53 CPU has been selected by Northrop Grumman Corporation for the F22 Embedded Global Positioning System (GPS)/Inertial Navigation System (INS)-Modernisation (EGI-M) program.

Counterpoint comment

Green Hill has a long list of blue-chip customers straddling several separate sectors. Clearly Green Hills is benefitting from its branded software products operating in RTOS which many OEMs do not wish to undertake in house.

We see a continuing trend to out-sourcing of high-end software from OEMs who find this more cost-effective than undertaking in-house bespoke development. We expect to see Green Hills continue to grow at above trend rates.

19.1.16. Honeywell

Honeywell Aerospace began in 1914. Over a century, through various acquisitions, mergers and name changes, Honeywell Aerospace combined legacy companies Sperry, Bendix, Garrett AiResearch, Pioneer, Lycoming, Grimes, King Radio and Allied Signal.

Honeywell Aerospace is a global supplier of products, software and services for aircraft. Products include aircraft propulsion engines, auxiliary power units, environmental control systems, integrated avionics, electric power systems, hardware for engine controls, flight safety, communications and navigation, satellite and space components, aircraft wheels and brakes, and thermal systems. Software includes engine controls, flight safety, communications, navigation, radar and surveillance systems, internet connectivity and aircraft instrumentation. Services are provided to customers for the repair, overhaul, retrofit and modification of propulsion engines, auxiliary power units, avionics and mechanical systems and aircraft wheels and brakes.

Honeywell Forge for aircraft connected solutions, software and data services designed to improve customers' efficiency and enable improved operations.

Honeywell's Aerospace division is comprised of the following businesses:

- Electronic Systems (35%)
- Engines and power Systems (32%)
- Mechanical Systems and Components (27%)
- Services and Connectivity (6%)

Honeywell's avionics products sits within its Electronic Systems (ES) division and it generates some avionic related revenues from Services and Connectivity.

Financials

FYE 31/12/20 $ millions	2020	2019	2018	2017	2016
Commercial Original equipment	1,932	2,997	2,833	2,475	2,525
Commercial Aftermarket	3,786	5,731	5,373	5,103	4,796
Defence and space	5,826	5,326	4,665	4,053	4,375
Transportation Systems		-	2,622	3,148	3,055
Total aerospace sales	11,544	14,054	15,493	14,779	14,751
Aerospace segment profit	2,904	3,607	3,503	3,288	2,991
Aerospace profit margin	25.1%	25.7%	22.6%	22.2%	20.3%

Honeywell commented: "Aerospace Net sales decreased due to lower sales volumes as the decline in global travel resulting from COVID-19 negatively impacted many of our customers, resulting in lower demand for our products from OEMs and reduced demand for our aftermarket products and services.

- Commercial Aviation Original Equipment sales decreased 36% (decreased 35% organic) due to lower demand from air transport and regional and business aviation OEMs.
- Commercial Aviation Aftermarket sales decreased 34% (decreased 34% organic) due to lower demand in air transport and regional and business aviation.
- Defense and Space sales increased 9% (increased 10% organic) driven by growth in U.S. and international defence.

Aerospace segment profit decreased due to lower sales volume and lower sales of higher margin products and services, partially offset by favourable pricing. Cost of products and services sold decreased due to lower sales volumes."

Honeywell's Electronic Systems division within Aerospace accounted for 35% of Aerospace revenues generating $4,919m in 2019, which breaks down as follows:

- International Defense sales 11% ($541m)
- Commercial OE sales 25% ($1,230m)
- Commercial aftermarket 29% ($1,426m)
- US defense 35% ($1,722m)

Honeywell's Service and Connectivity division generated $871m of revenues in 2019.

In arriving at an estimate for Honeywell's avionic revenues we believe that a significant proportion of its Electronic Systems sales are avionic-related (having made some reduction for satellite products) and that Service and Connectivity contributed via avionic related services.

We therefore estimate that in 2019 Honeywell generated revenues of $3,455m in respect to avionics product and services, falling to $2,365m in 2020.

Honeywell also reports that its OE/AM split is 60%/40%.

Operations and technology

Location

Honeywell Aerospace is headquartered in Phoenix Arizona, USA.

All of Honeywell's surveillance products including TCAS and Weather Radar are designed in their facility located in Phoenix, USA.

Honeywell also has an engineering software facility in Tempe Arizona that produces avionic software.

Their inertial measurement units are designed in Minneapolis, Minnesota, USA, however, in 2020 Honeywell announced that they would close this facility.

Honeywell has had a strong avionic engineering presence in Redmond, Washington but has reduced this facility from circa 1,000 engineers to around 350 in recent years.

Honeywell Avionics has a support centre in Westeville, Ohio, USA.

Capabilities

Honeywell summarises its avionics capabilities as follows:

- Cockpit displays, cockpit systems, flight management, flight control
- Navigation and sensors
- Radios
- Recorders and Transmitters
- Health and Usage monitoring systems
- Terrain and traffic awareness
- Weather radar

Honeywell Primus Epic Avionic suite: Primus Epic is built around field-removable modular avionic units (MAUs) which are the building blocks of the Primus Epic. Modules for computing, database storage, input/output, network communication, and power supply are plugged into a hardware cabinet called the modular avionics unit (MAU). Primus Epic applications will typically require between one and four MAUs, each with four to 24 module slots, connected by the latest version of Honeywell's ASCB databus which provides a throughput capacity of 20 megabits/s. Honeywell has developed its own software operating-system for the MAUs and "smart" liquid-crystal displays. The Digital Engine Operating System provides standard interfaces and services for all the resident functions and allows one function to be changed without affecting others. Software for multiple critical, essential and non-essential functions can be run on the same processor. The MAUs can be configured to perform many avionics functions within one box, including autoflight system, fault-warning computer, flight-management system, aircraft utility-systems control and another new feature, the integrated sensor suite. This is a complete primary-sensor system consisting of global-positioning and air-data modules, and a small inertial-measurement unit combining ring-laser and fibre-optic gyro technology in one sensor.

Combining computing and sensing functions has helped Honeywell to reduce acquisition cost by 30%, size and weight by 40% and application cost by 50%, while increasing maintainability by 60% and both dispatchability and reliability by 100%. In the Hawker Horizon, Honeywell reduced weight by some 45kg compared with its SPZ-8000 system in the Hawker 1000, eliminating 23 line-replaceable units and at least doubling system reliability.

Flight Management Systems: Next Generation Flight Management Systems (NGFMS) meets the needs of all aircraft sizes. The NGFMS is optimised for future Air Traffic Management (ATM) functionality and deliver improved fuel efficiency, reduced direct operating costs, reduced pilot workload and improved safety. With a redesigned architecture, the NGFMS software utilises a modular design that allows for aircraft specific adjustments in hardware, operating systems, Input/Output (IO) and other features. The system can run the same core functionality on multiple platforms with little modification from the core FMS functionality.

Primus Epic integrated cockpit: Honeywell is a leading provider of navigation, display systems, flight controls and flight management systems, developing a broad and scalable portfolio of hardware and software products that provide value for a wide range of aircraft configurations. Honeywell continues to develop advanced cockpit solutions, including the Primus Epic 2.0 and Epic 2.0+ integrated avionics systems, the latest evolution of the Primus cockpit family.

Air Data Inertial Reference Systems: Honeywell’s third-generation air data inertial reference system with digital gyros provides high system reliability and performance with reduced operation and maintenance in a 4 modular concept unit package. It is interchangeable with earlier 4 modular concept unit (MCU) air data inertial reference system (ADIRS) and 10 MCU ADIRS (with a tray adapter).

Enbedded GPS/INU navigation: Honeywell has produced and delivered more than 60,000 embedded global positioning system inertial navigation systems (EGI). Honeywell’s EGIs provide a robust civil certification to

DO-178 and DO-254, enabling much easier certification at the aircraft level for features such as automatic dependence surveillance-broadcast (ADS-B), required navigation performance (RNP) / area navigation (RNAV), wide area application services (WAAS).

Traffic Avoidance Systems: The SmartTraffic collision avoidance system (CAS) 100 system offers three models of commercial traffic alert and collision avoidance system (TCAS). The TPA-100 TCAS processor has sufficient processing capacity to incorporate future automatic dependent surveillance broadcast (ADS-B) IN functionality. Honeywell offers three versions of commercial TCAS within the TPA-100 TCAS processor family and they are available in both 6 modular concept unit (MCU) and 4 MCU ARINC form factors.

Enhanced Ground Proximity Warning Systems (EGPWS): The Honeywell EGPWS reduces the risk of controlled flight into terrain by providing flight crews with timely, accurate information about terrain and obstacles in the area. The system uses various aircraft inputs and an internal database to predict and warn flight crews of potential conflicts with obstacles or terrain. EGPWS software enhancements include SmartRunway and SmartLanding systems, developed to help flight crews avoid potential runway incursions and excursions.

Weather radar system IntuVue RDR-7000: Provides business aviation and helicopter pilots the information needed to make safer, faster and informed decisions before flying in bad weather and challenging environments. Engineered to provide far superior reliability, accuracy and durability than legacy magnetron-based radar systems, the RDR-7000 offers customers to remotely enable advanced software features.

JetWave™Honeywell's JetWaveTM system exclusively powers Inmarsat's GX Aviation global highspeed Ka-band service. Designed to deliver 'home equivalent' connectivity, Honeywell can help airlines provide a consistently outstanding passenger experience all over the world.

Honeywell Forge: Honeywell Forge for Airlines is the most advanced analytics platform that has been helping over 100 airlines identify, implement, and optimise dozens of initiatives to improve flight and maintenance operations. Currently, Honeywell Forge is being used to process data from more than 10,000 aircraft. Major airline groups like Lufthansa, IAG, Etihad, KLM, Japan Airlines are using the platform to improve operational efficiency.

Honeywell also provide a range of mission and vehicle management computers that are developed for numerous space applications (outside of the scope of this report).

Customers and contracts

Honeywell's Primus Epic family of avionic suites and their associated customers/platforms is covered in section 9 of this report.

- A320: FMS, Data management unit, air data inertial ref units, MMR.
- A330: Flight Management System, data management unit, air data inertial reference system, integrated multi-mode receiver.
- A350: Airborne Communication Unit, JetWave ka-band satellite connectivity.
- A380: FMS, Air Data inertial reference system.
- Boeing 737: Radio comms equipment, Airborne comms equipment, FMS, SATCOM systems, Flight data acquisition unit, Flight recorders, Cockpit voice recorder, Air data computers, HF data link, EFIS display system, Flat panel LCD displays (737-700.737-800,737-800.737-900), Multi-mode receiver, Terrain Awareness Warning system, EGPWS on BBJ variant.
- Boeing 747: FMS, Cockpit Control Systems, Cockpit indicators, Autopilot flight director, FANS system.
- Boeing 767: EFIS system, -700 display system, VOR, receivers.
- Boeing 777: SATCOM, Airplane Information Management (AIMs) system, Aircraft Environmental Surveillance System (AESS), flat panel LCD cockpit display system, MMR, high speed digital voice and data comms system.
- Boeing 787: FMS, Inertial navigation systems, autopilot, EGPWS, air data sensors, MMR.
- Airbus CN295: Flight recorders, Weather radar, IFF interrogators, FDR.

- Airbus H145M/EC145: Radar/radio altimeter, DME, VOR receivers, ILS.
- Boeing AH Apache: GPS/INS, SATCOM.
- Boeing F-15 Eagle: IFF transponder, Air data Computers, AHARS, Inertial Navigation Systems.
- Comac C919: Air data computers, Inertial reference systems
- Dassault 50EX: Laseref gryo inertial system, TAWS, EGPWS
- Dassault 7X/8X: Primus Epic (EASy flight deck), radio comms systems, JetWave-ka band satellite connectivity.
- Dassault 900LX: Primus Epic EASy flight deck, JetWave ka-band satellite connectivity.
- Embraer 170/190: Airborne comms system, ka-band satellite connectivity, Primus Epic avionic suite, DU-1310 Display unit, KDU-180 display unit, EGPWS, Integrated Navigation service. Next Gen FMS (option)
- Embraer E2 Gen jets: Primus Epic avionic suite, Next Gen FMS, SmartView Synthetic vision systems, DU-1310 Display units, MFCDU, Radar altimeter
- Gulfstream G280: Planeview flightdeck developed with Gulfstream.
- Gulfstream G500/550: Primus Epic avionic suite, EVS system, Weather mapping radar, LCD display suite, TCAS system, moving maps, ADS-B display capability.
- Gulfstream G600/650: Primus Epic avionic suite, EVS system, LCD display suite, TCAS, ADS-B display capability, 3D weather radar, EGPWS, NextGen FMS system.
- Gulfstream G700: Primus Epic based Symmetry avionic suite, NextGen FMS system, 3D Weather radar
- Leonardo AW139: Primus Epic avionic suite. EFIS displays.
- Lockheed Martin C-130J: Dual GPS/INS navigation system, military TCAS, Radio Altimeters, EGPWS, Weather radar system (option).
- Lockheed Martin F-35: Radar Altimeters
- Sikorsky UH-60 Black Hawk: Radar altimeter, Weather radar, GPS/INS navigation, Aspire 200 SwiftBroadband channels provide up to 650 Kbps per channel.

Strategy

Honeywell is a market leader in avionics with a complete range of offerings including key growth drivers such as integrated avionics, surveillance, autonomy and service offerings (i.e. Honeywell Forge).

As such it continues to invest in developing new technologies across a broad number of sectors (all of which requires heavy investment).

Aerospace has been the target of takeover on more than one occasion and Honeywell corporate has considered divesting its Aerospace division in recent past.

Recent developments

October 2020: Honeywell has acquired assets from Ballard Unmanned Systems who designs and produces industry-leading, stored-hydrogen proton exchange membrane fuel cell systems that power unmanned aerial systems (UAS), particularly those used for energy inspection, cargo delivery, and other commercial and defense applications where demand for UAS services are growing.

June 2020: Honeywell has launched its smallest, lightest satellite communications system yet, specifically designed for unmanned aerial vehicles. Weighing in at only one kilogram (2.2 pounds), the new system is 90% lighter than Honeywell's smallest connectivity system and will bring some of the same connectivity capabilities enjoyed by larger aircraft to smaller unmanned vehicles in the air or on land.

January 2020: Honeywell is providing airlines with Honeywell Forge software to help increase operational efficiencies and decrease costs associated with several factors, including unnecessary fuel burn. Fleets from GOL Airlines of Brazil and Sky Regional Airlines of Canada have joined a growing list of more than 10,000 aircraft worldwide harnessing the power of Honeywell Forge, with more than 3,000 using the Honeywell Forge Flight Efficiency module to make their airline more profitable.

June 2019: Honeywell's defense navigation team was awarded $99M by the U.S. Air Force to bring all active DOD aircraft up to new, M-Code standards as part of their 'EGI-M' initiative. M-code is designed to prevent

GPS jamming, an increasing problem surrounding the aerospace industry by using new, encrypted receivers like Honeywell's Embedded GPS inertial navigation system (EGI).

Counterpoint comment

Honeywell has been pushed down the league of large Aerospace corporations by acquisitive corporations such as Raytheon, Safran, Lockheed Martin and Harris. It needs to invest significant funds to maintain its broad portfolio of engines, APUs, Avionics, Flight Controls and Thermal/power management capabilities. We therefore consider it could be a strong candidate to be acquired or merged with other significant Aerospace providers in the coming years.

19.1.16.1. BendixKing

Vincent Bendix started the Bendix organisation with an idea for an automatic starter for automobiles in 1911. Bendix Corporation was renamed the Bendix Aviation Corporation in 1929 to signify a new direction for the company. Bendix formed its radio division in 1937 to make avionics and radio transmitters/receivers for aircraft.

Ed King formed the King Radio Corporation and created the first low-cost, crystal controlled, 90 channel, VHF transceiver for smaller aircraft, dubbed the KY 90. King Radio released the KTR 900, the first all solid state transceiver, for airlines in 1966. King Radio released the KDF 800, the first digital automatic direction finder (ADF) for general aviation, in 1969. King Radio released the KX 175, the first low cost all solid state VHF navigation and communications unit with TSO design approval, in 1970.

In 1999, AlliedSignal merged with Honeywell and adopted the Honeywell name to take advantage of the company's universal recognition throughout the industries it serves, as well as in households around the world. Shortly after the merger was completed, Honeywell announced that due to pilot recognition and loyalty, it would retain the BendixKing brand for its general aviation avionics.

In 2011, BendixKing established its new headquarters in Albuquerque, New Mexico. The tradition of leadership and innovation continues with BendixKing.

Financials

Based upon historical reported revenues we estimate that BendixKing generated $25m in revenues in 2019, and $20m in 2020.

Operations and technology

Location

BendixKing has its main facilities in Albequerque, New Mexico, where it owns a 40,000 ft² facility and employs 140 personnel.

Capabilities

BendixKing designs, develops, sells, and supports a full suite of avionics, including integrated flight decks, navigators, audio panels, radios, transponders and ADS-B transceivers, autopilots, radar-based storm sensors, and in-flight and on-ground connectivity.

BendixKing avionics are offered on a variety of aircraft in the general aviation market, including single-engine and twin-engine piston and turboprop airplanes, business jets, helicopters, and military trainers.

Customers and contracts

BendixKing's products are found on aircraft manufactured by Cessna, Piper, Mooney, Beechcraft, Diamond, Cirrus, Pilatus, Hawker, Lear, Textron, Dassault and many others.

Their products are marketed, installed and supported by a globally distributed team of sales professionals and over 500 authorised dealers located throughout the North and South America, Europe, Middle East, Africa, Asia and the South Pacific.

Strategy

BendixKing offers lower cost products and it focus upon the lower priced tiers of the Aerospace & Defence sector should continue to serve it well.

Bendix King states that its strategy is focussed upon developing networked connectivity within all aircraft and is promoting subscription services via satellite accordingly.

Bendix King is offering its business commuters/operators satellite wi-fi connectivity for $39 per hour of $399 per month.

Recent developments

None that we can see.

Counterpoint comment

For many years BendixKing suffered neglect as a business brand where it was part of the much larger Honeywell Aerospace business. Much of its market share had been eaten away by the likes of Garmin, Universal Avionics, Astronics and others.

However the move to a low cost economy, and its independence as a brand, has allowed it to continue to service the GA, small bizjet and rotorcraft market sector.

We believe that Honeywell could dispose of BendixKing at some point as it does not appear to be a core part of their future and they are becoming stretched for investment over a wide range of systems.

19.1.17. Innovative Systems and Support

Innovative Solutions and Support, Inc. was incorporated in Pennsylvania on February 12th, 1988. The Company operates in one business segment as a systems integrator that designs, develops, manufactures, sells and services air data equipment, engine display systems, standby equipment, primary flight guidance, auto-throttles and cockpit display systems for retrofit applications and original equipment manufacturers ("OEMs"). The Company supplies integrated Flight Management Systems ("FMS"), Flat Panel Display Systems ("FPDS"), FPDS with Autothrottle, air data equipment, Integrated Standby Units ("ISU"), ISU with Autothrottle and advanced Global Positioning System ("GPS") receivers that enable reduced carbon footprint navigation.

Financials

We estimate that Innovative Solutions and Support generated revenues of $22m in respect to avionics products and services in 2019, and $16m in 2020.

Operations and technology

Location

In 2001, Innovative Solutions and Support purchased 7.5 acres of land in the Eagleview Corporate Park in Exton, Pennsylvania. The company constructed a 45,000 ft² design, manufacturing and office facility on this site. Land development approval allows for expansion of up to 20,400 ft². Such expansion would provide for a 65,400 ft² facility which the Company believes is adequate to meet the needs the foreseeable future.

The Company also occupies 8,358 ft² of office and warehouse space in Exton, Pennsylvania under a lease expiring in March 2021.

Capabilities

Flight Management Systems: The FMS offers full performance navigation and mission planning capabilities, storage for up to 128 Waypoints, storage for up to 100 Flight Plans, the ability to store a Global Nav Database on a 32 GB Solid State Drive, a common ARINC 424 Database, and integration with existing IRU/AHRS equipment. Flight crews will utilise the data in the navigation database to create, edit and modify flight plans. Navigation data includes airways, jet routes, SIDS, STARS, user stored routes and more. The FMS interfaces with the Innovative Solutions and Support's SBAS GPS receiver to provide a WAAS/Global Positioning System (GPS) based navigation solution. The GPS receiver is located remotely depending on space availability.

Auto-throttle: The Innovative Solutions and Support ThrustSense Autothrottle is the first ever full regime auto-throttle system to be certified for the King Air. ThrustSense allows the pilot to automatically control the power setting of the engines from take-off to landing phases of flight, including go-around. The autothrottle computed and controls power levels reducing pilot workload.

Displays: Innovative Solutions and Support offer a range of LCD display formats from 10 inch up to 20 inch. The displays typically have an 80-degree viewing angle, NVIS compliant display lighting, and a non-glare, anti-reflective display surface.

ADAHRS: Air Data, Attitude and Heading Reference System (ADAHRS) replaces DG/VG's, AHRS and air data computers in a single, compact, light-weight unit. Coupled with the Innovative Solutions and Support Beta-3 GPS Receiver it can provide INS grade performance to 25-foot 3D positional accuracy. The Innovative Solutions and Support ADAHRS outputs in Digital and Analog in format aircraft attitude, heading, altitude and air speed to interface with existing autopilot and display systems at a fraction of the cost of comparable AHRS alone.

Air Data Modules: The Innovative Solutions and Support Air Data Module (ADM), is a self-sensing, RVSM compliant, digital air data computer (DADC). The ADM inputs static (Ps) and pitot (Pt) pressures, total temperature (Tt), and installation configuration data. Air data is output on ARINC 429 and RS422 data formats. The ADM receives barometer setting number and Selected Altitude via ARINC 429 input. The ADM has an altitude range of -1000 to 53,000 feet (16,154 meters), an airspeed range of 40 to 400 knots, and a barometer setting range (via ARINC 429) of 22.00 to 31.00 in Hg (745 to 1050 hPa).

RNP Navigator: Innovative Solutions and Support designed its RNP/LPV Navigator to allow for RNP operations without having to modify the existing FMS in older aircraft. This saves many operators from performing costly FMS and MMR upgrades. The solution is easily integrated into our Flat Panel Display System or Integrated Navigation Standby Unit increasing operator flexibility while minimising aircraft downtime.

Integrated Standby Unit: The Innovative Solutions and Support Integrated Standby Unit (ISU) calculates, processes and displays altitude, attitude, airspeed, slip/skid, and navigation display information into a logical and concise single instrument display. The unit is designed to support Radio Management and Alternate navigation functionality. The ISU includes MEMS Gyro technology coupled with IS&S air data, RVSM and Flat Panel Display System (FPDS) product experience. The result is a highly reliable and accurate standby display system for retrofit and OEM applications.

Customers and contracts

The Company's revenue is concentrated with a limited number of customers. During fiscal year 2020 Innovative Solutions and Support derived 63% of revenue from the top five customers.

- Boeing 737NG Flight Deck Upgrade
- (K)DC-10 Cockpit/IP (aftermarket only)
- Boeing757/767 Cockpit/IP (757 aftermarket only)
- Cessna Citation AdViz Flat Panel Display
- Eclipse 500 Avio IFMS (aftermarket only)
- Eclipse 550 Vantage Cockpit/IP Flat Panel Display System (aftermarket only)
- Lockheed Martin C-130 EIDS and Cockpit/IP
- P-3 Cockpit/IP – (aftermarket only)
- McDonnell Douglas MD-80 (aftermarket only)
- Pilatus PC-12

Company's principal competitors include Honeywell, Collins Aerospace, L3Harris, GE Aviation, Thales and Garmin.

Strategy

Innovative Solutions and Support provides a number of avionics products for OEM and retrofit applications focussed mainly on the bizjet, GA and rotorcraft sectors.

Recent developments

October 2020: Textron announced it had achieved Type Certification by the Federal Aviation Administration (FAA) for its newest flagship twin turboprop Beechcraft King Air 360/360ER aircraft. The King Air 360 cockpit has the addition of the Innovative Solutions & Support ThrustSense Autothrottle.

Counterpoint comment

As a provider of discrete boxes Innovative Solutions and Support is exposed to both the integrators and low cost providers such as Garmin and Universal Avionics. Innovative Solutions and Support's limited size may make it difficult for them to grow in this challenging sector.

19.1.18. Jewell Instruments

Jewell Instruments is a world leader in the manufacture and distribution of acceleration and tilt sensors as well as electronic compasses, avionics components, solenoids and panel meters. It provides custom solutions for a diverse group of industries, including aerospace.

Financials

We estimate that Jewell Instruments generated $25m of revenues in 2019.

In terms of avionics instruments we further estimate that Jewell generated $4m of revenues in 2019, and $3m in 2020.

Operations and technology

Location

Jewell has two, fully modernised manufacturing facilities, one in Manchester, New Hampshire, and one in Barbados, West Indies. Both are fully capable of handling the most stringent manufacturing requirements while our Barbados facility also provides the extremely cost-competitive advantage of an offshore manufacturer.

60,000 ft² headquarters facility features R&D, engineering, and manufacturing personnel dedicated to Jewell's products and Partnership Manufacturing

The 20,000 ft² offshore manufacturing facility features a dedicated Jewell team experienced at providing low-cost, high-quality manufacturing.

Capabilities

Jewell Instruments is a leading provider of traditional electro-mechanical avionic meter mechanisms and instruments.

Applications include the following:

- Engine Monitoring
- Instrument Clusters
- Horizon Situation Indicators
- Attitude and Direction Indicators
- Fuel Gauges
- Oil Pressure and Temperature Gauges
- Turn, pitch, and bank indicators
- Flap indicators
- Autopilot displays
- Hover meters

Customers and contracts

Jewell does not list or identify its end customers, largely, we suspect, because it supplies to Tier2/3 suppliers and via distributors/stockists. It therefore may not always know on which platforms its products are installed.

These stand-alone discrete instruments and sensors are likely to be used for small business jets, GA, rotorcraft and UAV platforms.

Strategy

Jewell is largely a component provider offering older mechanical instruments in addition to solid state sensors. It operates in a niche market in terms of avionics with growing sales in other areas e.g. rail in China.

Recent developments

January 2020: Jewell Instruments acquired DGH Corporation (Hooksett, NH). Relocation to Jewell's headquarters in Manchester was due to occur within 90 days and management expected that the DGH operation would be fully integrated by the second quarter of 2020. DGH is an industry leading manufacturer of data acquisition hardware with over 30 years of experience in the process monitoring and control marketplace.

Counterpoint comment

A small independent niche provider of avionics components with limited exposure to aerospace.

19.1.19. Kontron Avionics

Kontron is a global leader in embedded computing technology (ECT). As a part of technology group S&T, Kontron offers a combined portfolio of secure hardware, middleware and services for Internet of Things (IoT) and Industry 4.0 applications. With its standard products and tailor-made solutions based on highly reliable state-of-the-art embedded technologies, Kontron provides secure and innovative applications for a variety of industries.

As a supplier of integrated hardware systems for the commercial aerospace industry, products include critical system components to enable in-flight broadband services including: Internet, VPN access, email, multimedia capabilities, video-on-demand, games and additional entertainment choices in a fully-integrated wireless cabin over a broadband air-to-ground or air-to-satellite link.

Kontron is therefore more of a cabin services provider with a suite of "office in the sky" products and services including PAX entertainment.

Its avionic family of products is largely related to mission computing.

Financials

We estimate that Kontron generated $15m of aerospace related revenues in 2019 of which $6m is related to avionic products, declining to $5m in 2020.

Operations and technology

Location

Kontron has its headquarters in San Diego, CA, USA. It also has offices located in Fremont, CA, USA and Montreal, Canada.

Globally, it has two support offices in Germany located in Augsburg and Ismaning.

Kontron has additional service support offices located in Taiwan, China, Malaysia and Saudi Arabia.

Capabilities

Kontron has 30+ years of experience building ultra-rugged computing platforms designed for commercial and defence applications and is uniquely positioned to address the needs of the In-flight Entertainment & Connectivity (IFEC) market.

Within avionics, Kontron offers a wide selection of military computing hardware solutions including application-ready COTS boards, integrated mission computers, and rugged enclosures. Kontron's high performance embedded computing (HPEC) systems provides advanced rugged architectures that balance processor power with I/O bandwidth to meet these needs. As the need for SOSA-aligned COTS platforms grows, Kontron's products, including the 3U StarVX and ApexVX based on Intel® Xeon-D and other next-generation processors, offer DSP performance and future proof APIs for sensor data processing applications.

Kontron's AF4783 MDOMAN has been designed in accordance with ARINC 791/792 and has the ability to support two different SATCOM modems without any compromise or feature limitations. The MODMAN also includes an Intel® Xeon® 6-Core processor, L2+ Managed Ethernet Switch, cellular modem, ARINC 429 and fixed/removable storage options. The dual integrated satellite modem approach eliminates the need for a second MODMAN to be installed onto the aircraft thus removing weight, cost and complexity while still allowing the aircraft the ability to utilise different satellite operators by selecting the appropriate modem during flight.

The Kontron ACE Flight™ 4600 is a complete, highly integrated application-ready platform that is specifically designed to meet advanced communication application requirements for Ethernet based network installations on both line fit and retrofit aircraft. Qualified to D0-160F and optimised for a full range of flight information systems, the enhanced Kontron ACE Flight 4600 line can build applications that include: crew and passenger web servers, flight maintenance or manifest servers, connectivity server, wireless content server and In-Flight Entertainment (IFE) servers.

The COBALT™ S1901 Mission Computing Platform features Intel high performance processor and is designed to meet the future needs of Defense computing platforms for AI, Deep Leaning and HPEC by providing multiple GPU or Accelerator card options. The compact S1901 is designed for various high speed I/O options such as 10GbE (copper, but fibre is an option), USB 2/3.0, ruggedised connectors for GPS and 1 PPS timing signals, and room for customisation options such as Camera Interfaces. Storage capacities are met using M.2 NVME slots, along with high capacity 2.5" SSD slots (fixed or removable). Standard options include Wi-Fi and/or LTE cellular modem, and MIL-STD-1553, CANBus, auxiliary cooling fan assembly, and a safety processor module for autonomous vehicle applications.

Customers and contracts

Kontron lists a number of key alliances/partnerships with the likes of Intel, Microsoft and Wind River. It also details the following applications/suppliers with its products:

- UAVs and the Rafale programme.
- It has worked with Qinetiq to host unmanned pilot control software on its computing platform for RAF trials.
- VX6090, a 6U VPX Dual 8-core Intel Xeon D processor has been certified by Thales for use in its radar systems.
- Sales direct to airlines for its range of Inflight entertainment/Wi-fi connectivity modules.
- Its Embedded Computing Technology (ECT) is used by Safran Electronics & Defense to supply COBALT mission computers for the Patroller Unmanned Aerial Vehicle (UAV).
- Supplies Collins Aerospace with the COBALT 904 media server that will host Collins new Stage™ content service, and it will also be integrated with its Venue™ cabin management and entertainment system. The system sells to bizjet and commercial airliners.

Strategy

Kontron states that its mission is to offer its customers a complete and integrated portfolio of hardware, software and services that unleash the full possibilities of their applications.

Recent developments

January 2021: S&T AG has acquired 100% of the Linz-based company HC Solutions GmbH (HCS) through its Kontron Technologies GmbH (KTEC). HC Solutions was founded in 1991 and is a software company that offers software development. They also implement software development projects for their customers and sell software licenses for the products they develop.

December 2020: Kontron, a leading global provider of IoT/Embedded Computing Technology, announced the addition of the ACE Flight™ 2780 Auxiliary Modem Unit to Kontron's best-in-class and highly reliable ACE Flight™ product line. The Auxiliary Modem Unit (AMU) is based on a new evolution of the ARINC 791 and 792 Ku/Ka Band Satellite Communication System standard, which is planned for approval in early 2021.

Counterpoint comment

Kontron is another embedded computing specialist that serves a number of sectors including aerospace and defence. It has carved itself a niche with IFE/Cabin related services – in particular I/O modems for Wi-fi, data and content downloaded via satellite services. Equally it has provided a standard family of military mission computing platforms that are suitable for many applications (especially UAV market).

19.1.20. L3 Harris

Harris was incorporated in Delaware in 1926 as the successor to three companies and subsequently listed on the New York Stock Exchange. In 2019 Harris and L3 entered into a merger agreement creating L3Harris Technologies, Inc. Harris today is a global aerospace and defense technology innovator, delivering end-to-end solutions for customers' mission-critical needs. They provide advanced defense and commercial technologies across air, land, sea, space and cyber domains. They support government and commercial customers in 130 countries, with its largest customers being agencies of the U.S. Government and their prime contractors. Harris's products, systems and services have defense and civil government applications, as well as commercial applications.

Harris has a JV with Thales France titled Aviation Communications and Surveillance Systems (ACSS) which is responsible for marketing a range of products including its autonomous solutions (ADS-B) products and a wide range of its data products. It is covered separately within this report under section 18.1.

L3Harris has capabilities within the following areas:

- Integrated Mission Systems, including multi-mission intelligence, surveillance and reconnaissance ("ISR") and communication systems; integrated electrical and electronic systems for maritime platforms; and advanced electro-optical and infrared ("EO/IR") solutions;
- Space and Airborne Systems, including space payloads, sensors and full-mission solutions; classified intelligence and cyber defense; avionics; and electronic warfare;
- Communication Systems, including tactical communications; broadband communications; integrated vision solutions; and public safety; and
- Aviation Systems, including defense aviation products; security, detection and other commercial aviation products; commercial and military pilot training; and mission networks for air traffic management ("ATM").

L3Harris employed circa 50,000 personnel at the end of 2019.

Financials

FYE 28/02/20 $ millions	2019	2018
Full Year Revenue	18,074	16,404
Integrated Mission Systems revenue	5,400	-
Space and Airborne Systems revenue	4,700	-
Communication Systems revenue	4,300	-
Aviation Systems revenue	3,900	-
EBIT	2,995	2,456
EBIT Margin	16.6%	15.0%

The percentage of Harris's revenue that was derived from sales to U.S. Government customers, including foreign military sales funded through the U.S. Government, whether directly or through prime contractors, was approximately 77%.

Company backlog was $20.6 billion at January 2020, of which $16.2 billion was funded backlog.

In 2019 L3Harris generated $18,400m of revenues across its 4 divisions, 3 of which contain avionic related products.

We estimate that L3Harris generated $1,274m of avionics-related revenues in 2019, and $1,150 in 2020.

Operations and technology

Location

L3Harris's principal executive offices are located at 1025 West NASA Boulevard, Melbourne, Florida, USA.

Many of its avionics products are designed and manufactured within its Melbourne, Florida facility.

Harris has a number of facilities both in the USA and the UK as follows:

Aviation Systems — Melbourne, Florida; Muskegon and Grand Rapids, Michigan; Torrance, Menlo Park and Anaheim, California; Arlington and Plano, Texas; Cincinnati, Ohio; Hauppauge, New York; Herndon, Virginia; Tewksbury, Massachusetts; and Phoenix, Arizona.

L3Harris has 15 locations within the UK (part of the L3 merger) but does not produce airborne equipment in the UK.

Capabilities

Displays: L3Harris' 10.4-inch Multi-Function Display – Technology Refresh (MFD-TR) is a next-generation display system providing a superior sunlight readable image area with exceptional bezel functionality in a physical format that can be applied to fixed-wing aircraft, rotorcraft, ground vehicles, and shipboard systems. The AH-64 6.25" x 6.25" Multi-Purpose Display (MPD) is a high-resolution display that provides both colour and monochrome video with colour symbology that supports flight, mission operations and situational awareness to the crew.

Of particular note is Harris's contract for the panoramic wide integrated LCD display for the F-35 upgraded cockpit due to enter service in 2022/23.

Harris also offers a range of integrated standby displays for secondary/back-up navigation.

Antennas: The 1501341 Series (Batwing) antenna design provides high performance satellite communications for satellite elevation intercept angles of +35° above the horizon through the aircraft zenith. This lightweight unit has been designed with performance parameters suitable for deployment in high performance, executive class aircraft, and helicopters. The antenna is constructed of a foam filled fiberglass housing which contains all component parts including the required phasing coupler.

Intelligence, Surveillance, Reconnaissance: Scalable Open Architecture Reconnaissance (SOAR™), the ground-breaking new ISR solution from L3Harris and General Atomics Aeronautical Systems, Inc., integrates industry-leading, full-band signals intelligence (SIGINT) capability with a medium-altitude, long-endurance Predator B wing-mounted pod to offer unparalleled options for war-fighters in the ISR domain.

Electronic Warfare Systems: In partnership with Lockheed Martin and the U.S. Air Force, L3Harris is developing the new AN/ALQ-254(V)1 Viper Shield to provide U.S. allies with cutting-edge countermeasures against sophisticated, ever-changing threats. This advanced electronic warfare system will provide a virtual electronic shield around the aircraft, enabling war-fighters to complete missions safely in increasingly complex battlespace scenarios. Its modern, all-digital architecture using commercial-off-the-shelf (COTS) technology enables enhanced system performance, a smaller form factor, reduced weight and easier future upgrades.

Cockpit Voice and Data recorders: L3Harris has been providing voice and flight data recorder solutions for nearly 60 years. The L3Harris recorders support air transport, regional, military and business aviation platforms. Specialised recorders are available for helicopters and general aviation. With 100% data retrieval rate, L3Harris has a global footprint providing highly reliable and innovative products.

Data storage: Series 4 Data Transfer System (DTS) provides a compact, self-contained system to store and retrieve data from removable 2.5-inch flash disks over either a USB or SATA interface. It is designed to meet MIL-STD-810 and RTCA DO-160 environments and provides up to a maximum capacity of 8TB of storage.

Tactical Air Navigation: TACAN+, provides efficiency, reduces costs and offers flexibility to pilots on various helicopter and military aircraft platforms. It is the only TACAN able to run four TACAN/DME ground stations simultaneously, and two in bearing, with a tracking velocity at 1800 knots. It also provides optimised Air-to-Air ranging performance for multi-aircraft scenarios with a software-controlled dual antenna switching and configuration and enables interface flexibility with A429 input and output ports for communication.

Electronic Warfare: Harris offers advanced integrated defense electronic warfare systems ("AIDEWS") that provide integrated and podded self-protection and jamming. It also provides integrated defensive electronic countermeasures ("IDECM") system for the F/A-18;

Customers and contracts

L3Harris notes that its principal competitors include BAE Systems, Boeing, General Dynamics, Lockheed Martin, Northrop Grumman, Raytheon (Collins Aerospace), and Thales.

For the F-35 Lightning II Joint Strike Fighter ("F-35") and F/A-18E/F Super Hornet ("F/ A-18") aircraft, Harris provide high-speed fibre optic networking and switching, image processing, digital map software and other electronic components, including a multi-function Advanced Data Link communication subsystem primarily intended for stealth platform air-to-air communications. Other specific products and programmes include:

- F/A-18: Integrated Defensive Electronic Countermeasures (IDEC)
- F-16: Advanced Integrated Defensive Electronic Warfare Suite (AIDEW).
- B-52: Self-protection, countermeasures system
- MH-47: Self-protection, countermeasures system
- CV-22: Self-protection, countermeasures system
- MH-60: Self-protection, countermeasures system
- B-1B: Countermeasures systems
- C130 variants: ALQ-172 self-protection integrated RF subsystem has successfully defended B-52 bombers and Special Operation C-130 Combat Talons and Gunships against RF threats in combat missions.
- Electronic Warfare: Harris supplies electronic warfare systems (IDECM) for F/A-18 and B-52 aircraft
- Mission Avionics and Electronic Warfare: long-term avionics platforms, including the F-35, F/A-18, F-16, CV-22 and B-52.

L3Harris derives an unknown percentage of its revenues from classified programmes.

Strategy

L3Harris provides insight via its annual report and investor presentations as to its strategy which is focussed on increased penetration of DoD budget pools, seeking adjacencies to its existing capabilities and realising synergies from its merger between L3 and Harris.

We also note that L3Harris has strengthened its focus upon the commercial sector in recent years.

L3Harris also refers to disposals that may account for 10% of its existing portfolio in non-core areas.

Recent developments

December 2020: L3Harris is debuting its Hydra Common Control Head and Weaver software suite – two products that simplify mission management for military operators. The remote capability and compact design of the Hydra Common Control Head brings mission system operation from the aircraft fuselage into a small, cockpit-mounted device. It allows the operator to simultaneously control up to 15 radios, sensors and radars, while its open architecture framework can be reconfigured for changing equipment requirements. The hardware is compatible with most mission systems, including L3Harris's RF-300A and RF-7850A/M airborne radios.

December 2020: The U.S. Navy has awarded L3Harris a five-year, $496 million contract to deliver prototype tactical jamming pods designed to extend U.S. Air superiority. The Next Generation Jammer Low Band (NGJ-LB) is a high-powered, high-capacity airborne electronic warfare (EW) system. L3Harris's single-pod solution enables extended stand-off jamming capability, covers a broad spectrum and processes an increased

number of threats. The system operates seamlessly with joint and allied forces and provides growth capacity for emerging threats.

January 2018: The U.S. Air Force has selected Harris to provide engineering support services for the electronic warfare (EW) systems onboard the international variant of the F-16. Harris will provide software updates and engineering support for its AN/ALQ-211(V)4/8/9 Advanced Integrated Defensive Electronic Warfare Suite (AIDEWS) systems that protect the fleets of F-16s from eight other countries against evolving electronic threats.

Counterpoint comment

L3Harris has a very strong presence within the US military market as well as in Canada, Italy and UK mainly for security and ATC infrastructure. It's JV with Thales appears to be successful in focussing upon surveillance products that are often mandated generating strong retrofit sales potential. L3Harris has also applied more focus to commercial aerospace where it has a small presence currently but it is now a focus area for growth.

19.1.21. Lockheed Martin

Lockheed Martin is a Maryland, US based corporation formed in 1995 by combining the businesses of Lockheed Corporation and Martin Marietta Corporation.

It has four strategic business areas today including the following:

- Lockheed Martin Aeronautics platforms:
  - F-35 Lightning II Joint Strike Fighter
  - C-130 Hercules - international tactical airlifter
  - F-16 Fighting Falcon - low-cost, combat-proven, international multi-role fighter
  - F-22 Raptor - air dominance and multi-mission fifth generation stealth fighter.
- Missile and fire Control (MFC)
- Rotary and Mission Systems (RMS)
- Space

Lockheed Martin has the following capabilities within its MFC and RMS divisions:

- MFC has avionic related product capabilities including F-35 Electro-optical targeting system, Fire control, electro-optics, radar for warning/targeting, Lantirn sensor pod including NAV and IRST sensors.
- Within RMS has Electronic Warfare systems for Apache and Blackhawk, Radar warning.

Financials

In 2020 Lockheed Martin Corporation generated $65.4bn of revenues across its four business divisions.

- MFC business segment generated net sales of $11.3 billion, which represented 17% of its total consolidated net sales.
- RMS business segment generated net sales of $16.0 billion, which represented 25% of its total consolidated net sales.

We have estimated that Lockheed Martin generated $625m from avionics-related product sales in 2019, and $590m in 2020.

Products represented 84% of sales with Services accounting for 16% of sales. However, we understand that the product sales include retrofit sales.

Operations and technology

Location

Lockheed Martin has its main manufacturing facilities within the MFC and RMS divisions located as follows:

Missiles and Fire Control - Camden, Arkansas; Ocala and Orlando, Florida; Lexington, Kentucky; and Grand Prairie, Texas.

- MFC has its largest facility in Orlando which is also an R&D centre where it employs in excess of 8,000 people.
- Lexington Kentucky is a major MFC facility with 3,000+ employees.
- The Santa Barbara facility supports the design and manufacture of electro-optical products.

Rotary and Mission Systems - RMS employs approximately 34,000 people in the U.S., Canada, Mexico, Taiwan, Japan, United Kingdom, Germany, Poland, the Netherlands, New Zealand and Australia.

Capabilities

Missiles and Fire Control – Provides air and missile defense systems; tactical missiles and air-to-ground precision strike weapon systems; logistics; fire control systems; mission operations support.

- The Electro-Optical Targeting System (EOTS) for the F-35 Lightning II is an affordable, high-performance, lightweight, multi-function system that provides precision air-to-air and air-to-surface targeting capability in a compact package.
  - 1,149 produced to date.
- The Distributed Aperture System (DAS) Window Panel set for the F-35 Lightning II consists of six low-observable, infrared transparent windows for Electro-Optical (EO) DAS sensors that provide threat detection and 360-degree situational awareness to the pilot.
  - 7,104 produced to date.
- As a passive, long-range sensor system, IRST21 uses infrared search and track technology to detect and track airborne threats with weapon-quality accuracy, increasing pilot reaction time and improving survivability in radar-denied environments.
  - First operational flight on F-16 – July 2020
  - Competitively selected for F-15 program of record – August 2017
  - Block II contract awarded by U.S. Navy; the next generation of IRST21 technology – July 2017
  - First fielded on F-18 – March 2019
  - First flight on F-15 – July 2016
  - First flight on F-16 – June 2015
- A proven electro-optical targeting system, Sniper ATP is housed in a single, lightweight pod. Sniper ATP handles the most challenging precision targeting and intelligence, surveillance and reconnaissance (ISR) air-to-air and air-to-ground missions.
  - Operational across 15 aircraft platforms among 27+ domestic and international customers
  - Laser designator with aircrew selectable tactical and eye-safe wavelengths
  - Laser Lead Guidance (LLG) against moving targets

Rotary and Mission Systems: Lockheed Martin provides design, manufacture, service and support for a variety of military and commercial helicopters; ship and submarine mission and combat systems; mission systems and sensors for rotary and fixed-wing aircraft; sea and land-based missile defense systems; radar systems.

Electronic Warfare:

- Lockheed Martin has fielded more than 3,000 airborne electronic warfare systems over the last 45 years, including electronic support measure (ESM), electronic attack (EA), radar warning receiver (RWR), electronic intelligence, communications intelligence, and anti-jam GPS products.
- Lockheed Martin provides the AN/ALQ-210 for the U.S. Navy and international MH-60R and the AN/ALQ-217 on the U.S. Navy's E-2C/D aircraft. Lockheed Martin has recently upgraded the ALQ-217 with a digital receiver and enhanced capabilities. Lockheed Martin has modernised the targeting ESM system on the U.S. Army and international Apache AH-64D/E aircraft with the digital receiver based Modernised Radar Frequency Interferometer (MRFI). Lockheed Martin extends this digital receiver product line with its newest system, the APR-52 Digital RWR, on the USAF Combat Rescue Helicopter.

Anti-jamming systems: GSTAR is a fully digital system providing protection against adversarial jammers for all types of platforms. The beam-steering capability allows the platform to survive the harshest of contested environments. GSTAR can be configured as a nulling only solution for compatibility with existing GPS Receivers with the inherent growth to beam-steering without replacement of the GSTAR or the antenna.

Radar/Advanced Early Warning: Lockheed Martin's radar and electro-optical/infrared sensor systems provide advanced precision targeting, navigation, threat detection and next generation intelligence, surveillance and reconnaissance capabilities. From the Navy's Advanced Hawkeye system on the E-2D aircraft to the unmanned airborne Legion Pod's infrared search and track (IRST) system provides passive, high-fidelity detection and tracking of air-to-air targets in radar-denied environments.

Auto GCAS: Lockheed Martin Skunk Works - The Auto GCAS, developed jointly by Lockheed Martin Skunk Works®, the Air Force Research Laboratory and the National Aeronautics and Space Administration (NASA), is designed to reduce incidents of what is known as controlled flight into terrain, or CFIT. According to U.S. Air Force statistics, CFIT incidents account for 26 percent of aircraft losses and a staggering 75 percent of all F-16 pilot fatalities.

- The Auto GCAS capability is currently operating on more than 600 U.S. Air Force F-16 Block 40/50 aircraft worldwide
- Lockheed Martin and the F-35 Joint Program Office (JPO) completed F-35 Auto GCAS integration and flight testing in 2018 and began fielding this proven life-saving technology in 2019.

Displays: The TADS Electronic Display and Control (TEDAC) is the modernised replacement for the Optical Relay Tube (ORT) located in the co-pilot/gunner (CPG) crew station of the AH-64 Apache Helicopter. The TEDAC presents the CPG with high resolution sensor video from the Modernised Target Acquisition and Designation Sight (M-TADS). TEDAC replaces the ORT's small CRT display and direct view optics with a large 5" x 5" flat-panel cockpit display that utilises active matrix liquid crystal display (AMLCD) technology.

Customers and contracts

Specific avionics applications are listed below:

- F-35: Electro-optical targeting system and Distributed Aperture Radar system
- The AN/APR-48B Modernised Radar Frequency Interferometer (MRFI) is installed on the AH-64E Apache Guardian helicopter.
- The AN/ALQ-217 ESM system functions as the highly sophisticated ears of advanced tactical aircraft and is currently installed on the U.S. and international E-2C and E-2D Advanced Hawkeye and P-3C type aircraft.
- The multi-mission AN/ALQ-210 Electronic Support Measures (ESM) and concurrent RWR system is fitted to the MH-60R rotorcraft.
- AH-64: TADS AMLCD display system for target acquisition and designation.
- F-16: Auto – GCAS system
- E-2D Advanced Hawkeye early warning radar system.
- F-15/F-16/F/A-18: IRST 21 infrared search and track systems.
- Unmanned Air Systems: PODs for reconnaissance, search and tracking.
- Apache AH-64: Electronic Warfare suite
- Sikorsky Blackhawk: Electronic Warfare suite

Strategy

Lockheed Martin invests in advanced software and digital technologies required for next generation platforms. It clearly has an advantage as an OEM constructor of the F-35, C130J and Sikorsky platforms which arguably provides it with additional insight and access.

Its strategy is to continue to develop high end sensitive electronic capabilities for multinational platforms that are operating around the world.

Recent developments

June 2020: The US Army took a big step to rebuilding its electronic warfare capabilities, awarding Lockheed Martin a contract for $74.85 million to develop, build, and test operational EW pods. The Lockheed Martin Silent Crow pod is now the leading contender for the flying flagship of the Army's rebuilt electronic warfare force.

October 2019: Lockheed Martin will provide the U.S. Army and foreign military customers additional electronic warfare systems that enable faster detection and identification of threats. The Modernised Radar Frequency Interferometer system identifies intelligence, surveillance and reconnaissance (ISR) emitters and allows the pilot to detect and engage a threat long before the aircraft becomes vulnerable, increasing aircraft survivability and lethality.

October 2019: Lockheed Martin received a $25 million initial contract award for engineering and manufacturing development (EMD) for the GPS Spatial Temporal Anti-Jam Receiver (GSTAR) system that will be integrated into the F-35 as part of its modernisation phase. The GSTAR system will replace the current Antenna Electronics Unit (AEU) and will provide enhanced capabilities including the next-generation, anti-jam solution.

June 2019: In 2019, Lockheed Martin finalised a $34 billion agreement with the F-35 Joint Program Office for the production and delivery of 478 F-35s over three contract lots.

July 2019: Lockheed Martin announced work with the U.S. Air Force as it began integrating the Automatic Ground Collision Avoidance System (Auto-GCAS) into its F-35 fleet.

April 2019: In response to significant and increasing demand for the F-16 – the world's most advanced fourth-generation fighter – the company reshaped its operations and officially began F-16 production in Greenville, South Carolina.

Counterpoint comment

Lockheed Martin is both an OEM constructor and a provider of avionic/electronic warfare systems. It sits within the top league of defense contractors within the US. We believe that it will remain at the forefront of US defense contractors necessary to be able to compete with Boeing and other defense contractors.

19.1.22. Lynx Software Technologies

Founded in 1988, Lynx Software Technologies is a software company that specialises in secure virtualisation and open and reliable real-time operating system.

Systems deployed in high-threat environments such as fighter jets, unmanned aerial vehicles (UAVs), stealth ocean vessels, military transport vehicles, and helicopters—all of them examples of systems running on Lynx software—require the highest levels of security, safety, and reliability.

Financials

We estimate that Lynx generated $35m of revenues in 2019 of which $15m were related to aerospace avionics, falling to $13m in 2020.

Operations and technology

Location

Lynx has its headquarters and main office location at Lynx Software Technologies, San José, CA, United States.

It also has subsidiary offices located in France and the UK.

Capabilities

LYNX MOSA.ic for Avionics is a set of Lynx software packages, 3rd party technologies, and associated tools which Lynx has proven to reliably work together for rapidly building robust avionics systems. Specifically, LYNX MOSA.ic for Avionics includes the following:

- LynxOS-178® (Safety RTOS)

- Buildroot (Linux)
- LynxSecure (Separation kernel)
- Lynx Simple Applications (bare-metal apps)
- Certification evidence
- Tools

LYNX MOSA.ic embodies the integrated business and technical DoD implementation strategy of the Modular Open Systems Approach (MOSA) defined in Title 10 U.S.Code § 2446a.—Requirement for modular open system approach in major defense acquisition programs. It enables system developers to build systems compositionally using open standards, relying heavily on the reuse of well-tested and certified components.

LynxOS-178 (safety RTOS) is a native POSIX®, hard real-time partitioning operating system developed and certified to FAA DO-178B/C DAL A safety standards. It has been awarded a Reusable Software Component (RSC) certificate from the FAA for re-usability in DO-178B/C certification projects. LynxOS-178 is the primary host for real-time POSIX and FACE™ applications within the LYNX MOSA.ic™ development and integration framework. LynxOS-178 native POSIX implementation satisfies the PSE 53/54 profiles for both dedicated and multi-purpose real-time as well as FACE applications.

LynxSecure is a separation kernel which provides isolated environments in which multiple safety critical and general purpose operating systems can perform simultaneously without compromising safety, security, reliability or data integrity. LynxSecure offers both time-space partitioning and was designed from the ground up to be small, real-time, and safety and security certifiable.

The LynxSecure product would typically be utilised in IMA or common computing resources in order to allow for partitioning of utility/avionic functions with mixed levels of criticality.

Customers and contracts

Lynx lists the following major positions:

- F-35 Joint Strike Fighter's (JSF) Mission System (TR3)
- F-35 Joint Strike Fighter's (JSF) Cockpit Display System
- General Atomics Gray Eagle Extended Range (GE-ER) UAV
- General Dynamics Integrated Computer System
- Boeing/Insitu ScanEagle
- NASA's SLR2000 Satellite Laser Ranging System
- All-Purpose Remote Transport System (ARTS)
- C3I Upgrade for Flyvefisken Class Ships (Royal Danish Navy)
- Bombardier Challenger 300 Flight Display
- Sikorsky UH-60 Blackhawk Helicopter
- NASA's AVIRIS (Airborne Visible/Infrared Imaging Spectrum)
- Lockheed Martin P-3 Orion Surveillance Aircraft
- Galileo Satellite Navigation System
- Collins CAAS "Glass Cockpit"
  - Little Bird (AH-6, MH-6)
  - Chinook (MH-47D, MH-47E)
  - Blackhawk (MH-60K, MH-60L, MH-60L-IDAP)
  - KC-135 Stratotanker
- Future Combat Systems (FCS)
- Medium Extended Air Defense System (MEADS)
- AFIRS Program (Automated Flight Information Reporting System)

- Software-Defined Radios (SDRs) from ITT Corporation

Strategy

Lynx states that its strategy revolves around helping customers build Mission Critical Edge platforms for avionics, unmanned aerial systems, satellites and for industrial applications.

Recent developments

January 2021: Lynx Software Technologies announced that its LYNX MOSA.ic™ product has been selected as the winner of the "IoT Security Platform of the Year" award in the 5th annual IoT Breakthrough Awards program conducted by IoT Breakthrough, a leading market intelligence organisation that recognises the top companies, technologies and products in the global Internet-of-Things (IoT) market.

August 2020: Lynx Software Technologies announced that General Atomics Aeronautical Systems, Inc. has adopted the LYNX MOSA.ic™ software framework for the Gray Eagle Extended Range (GE-ER) Unmanned Aircraft System (UAS). An early goal of the software modernisation sought to integrate a new and advanced video codec implemented on the Zynq UltraScale+ adaptable multiprocessor system on chip (MPSoC) from Xilinx, Inc. The modularity of LYNX MOSA.ic enabled the team to achieve an efficient and robust solution in a mixed criticality environment including both Linux and a deterministic real-time operating system.

Counterpoint comment

Lynx has established itself as a technology "enabling" company that helps avionics suppliers with both bespoke and off the shelf software solutions.

19.1.23. Mannarino Systems & Software Inc.

Founded in 1999 by John Mannarino, Mannarino Systems & Software Inc.is a privately held corporation.

Mannarino provides safety-critical systems, software, and airborne electronic hardware engineering services to the aerospace, defense, space, simulation, power generation and rail industries. Mannarino is highly specialised in the design, verification and validation of critical systems and software, including Full Authority Digital Engine Controls (FADEC), avionics, Health and Usage Monitoring Systems (HUMS), Ground Support Equipment (GSE) software, aerial refuelling systems, Unmanned Aerial Vehicles (UAV) and industrial engine controls.

Financials

We estimate that Mannarino generated $6m of avionic related revenues in 2019, falling to $5m in 2020.

Operations and technology

Location

Mannarino is located in Montreal (Quebec) Canada, the third largest aerospace hub in the world, as well as a gateway to European and US markets.

Capabilities

Mannarino is a Design Approval Organisation (DAO) for Airborne Software (RTCA/DO-178B/C) and Airborne Electronic Hardware (AEH) (RTCA/DO-254), authorised by the National Aircraft Certification Branch of Transport Canada Civil Aviation (TCCA).

M-RTOS is a modular, flexible and affordable operating system for a wide range of aerospace applications, from Commercial Off-The-Shelf (COTS) electronic hardware to federated LRU (Line-Replaceable Unit) aircraft systems, to IMA (Integrated Modular Avionics) platforms. M-RTOS was developed to minimise memory and timing usage and outperform the competition on key benchmarks. M-RTOS guarantees robust spatial and temporal partitioning and can run on microprocessors incorporating memory protection. The M-RTOS integrated development environment, Mannarino Workbench, is an Eclipse-based tool suite that employs a modern web-based help system and a role-based approach structured to easily accommodate concurrent collaborative development with large, distributed teams.

Mannarino lists its fields of expertise, in terms of successful software applications, to include Avionics, Aerial Refuelling, Health and Usage monitoring and Gas turbine Engine Control.

Customers and contracts

Mannarino has a long affiliation with Lockheed Martin Aerospace, where investment agreements were signed between the two companies as part of the Canadian Government Industrial Regional Benefits & Industrial Technological Benefits (IRB/ITB) requirements in exchange for the Canadian Government's acquisition of military equipment from foreign companies abroad.

Strategy

Mannarino states that its mission is to provide safety-critical systems, software, and airborne electronic hardware engineering services to the aerospace, defense, space, simulation, power generation and rail industries.

Mannarino is currently a member of the following organisations:

- Aerospace Industries Association of Canada (AIAC)
- American Helicopter Society (AHS)
- American Society of Mechanical Engineers (ASME)
- Association of Unmanned Vehicle Systems International (AUVSI)
- Canadian Association of Defense and Security Industries (CADSI)
- Helicopter Association International (HAI)
- National Business Aviation Association (NBAA)
- Unmanned Systems Canada (USC)

Recent developments

January 2021: Mannarino Systems announced that its recently launched real-time operating system, M-RTOS will achieve FAA approval on a Part 23 program within 18-24 months.

Counterpoint comment

Mannarino is a provider of RTOS software systems that enable avionics providers who are comfortable out-sourcing key elements of their computing platform software needs.

19.1.24. Mercury Systems

Mercury was founded in 1981 and is currently listed on the NASDAQ stock exchange.

Mercury is a market leader in secure mission-critical technologies for the aerospace and defense industries. Its innovative solutions power more than 300 critical aerospace and defense programs.

Since 2015, Mercury has added substantial capabilities to its technology portfolio including:

- embedded security, with the acquisitions of Lewis Innovative Technologies Inc., custom microelectronics, RF and microwave solutions, and embedded security, with the carve-out acquisition from Microsemi Corporation, The Athena Group, Inc., Delta Microwave, LLC, and Syntonic Microwave LLC;
- mission computing, safety-critical avionics and platform management, and large area display technology with the CES Creative Electronic Systems, S.A. , Richland Technologies, L.L.C., GECO Avionics, LLC, and American Panel Corporation acquisitions;
- rugged servers, computers and storage systems with the acquisitions of Themis Computer and Germane Systems, LC.

Headquartered in Andover, MA, and with manufacturing and design facilities around the world, Mercury specialises in engineering, adapting and manufacturing new electronic and software solutions to meet the industry's current and emerging high-tech needs.

Mercury provides leading-edge sensor and processing technologies tailored for mission-critical applications. Their products include secure embedded processing modules and subsystems, mission computers, secure and rugged rack-mount servers, safety-critical avionics, RF components, multi-function assemblies, subsystems and trusted custom microelectronics.

Mercury offers a COTS-model approach to subsystem design and pre-integration that helps defense applications keep pace with the AI evolution by leveraging the best-in-class commercial technologies, engineering and commercial R&D investment.

Financials

FYE 03/07/20	2019/2020	2018/2019
Sales $m	796.6	654.7
Operating income $m	91.1	76.6
Return on sales %	11.4%	11.7%

Mercury commented in its 2020 annual report: "Total revenues increased $141.9 million, or 22%, to $796.6 million during fiscal 2020 compared to $654.7 million during fiscal 2019 including "acquired revenue" which represents net revenue from acquired businesses that have been part of Mercury for completion of four full quarters or less (and excludes any intercompany transactions). After the completion of four fiscal quarters, acquired businesses will be treated as organic for current and comparable historical periods. The increase in total revenue was primarily due to $91.4 million and $50.5 million of organic revenues and acquired revenues, respectively. These increases were driven by higher demand throughout all product groupings, especially integrated subsystems, across all end applications and, in particular, radar, within the airborne, naval and land platforms. The increase in total revenues is primarily attributed to higher revenues associated with the P-8, SEWIP and AIDEWS programs. Acquired revenue represents activity from the Germane, GECO, Athena, Syntonic and APC acquired businesses."

We estimate that Mercury generated $455m of avionic related revenues in 2019 and $488m in 2020.

Operations and technology

Location

Mercury has the following facilities operating as centres of excellence;

- Phoenix, Arizona AMC manufactures our custom microelectronics products in an AS9100 quality system-certified facility. The Phoenix, Arizona facility also contains our USMO, which is an IPC1791 and DMEA-certified trusted manufacturing facility and is primarily focused on advanced secure system-on-chip design, assembly, packaging, and test.
- Oxnard, California facility manufactures radio frequency and microwave products in an AS9100 quality system-certified facility.
- Cypress, California, West Lafayette, Indiana, Huntsville, Alabama and Mesa, Arizona facilities are AS9100 quality systems-certified facilities as well.
- Fremont, California and Alpharetta, Georgia facilities are ISO 9001:2015 quality systems-certified. Our Chantilly, Virginia facility is an AS9100 quality systems-certified facility.
- Andover, Massachusetts and Hudson, New Hampshire facilities design and assemble our processing products and are AS9100 quality systems-certified facilities. The Andover, Massachusetts facility is also a DMEA-certified trusted design facility and is primarily focused on advanced security features for the processing product line.
- Mercury's European operations, based in the UK and Switzerland, provides electronic design and manufacturing, maintenance and support services and is AS9001 and EASA Part 145 quality systems-certified. Its Silchester, England facility provides engineering, development and integration services and is AS9100 quality systems-certified.

As at July 2020, Mercury employed a total of 1,947 people. It has 141 employees located in Europe, six located in Canada, one located in Japan, and 1,799 located in the United States.

Capabilities

Mercury lists its offering under 3 generic headings which are:

- Electronic components

- Modules, subassemblies
- Integrated sub-systems

These categories apply themselves in end applications such as displays, EO-IR, avionic computing, mission computing, electronic warfare and sensor processing.

These end applications are utilised in aerospace and defense sectors including airborne platforms, missiles and naval ships.

Mercury are primarily used in both commercial aerospace applications, such as communications and ground radar air traffic control, as well as advanced defense and intelligence applications, including space-time adaptive processing, synthetic aperture radar, airborne early warning, command, control, communication and information systems, mission planning, image intelligence and signal intelligence systems. Their products transform the massive streams of digital data created in these applications into usable information in real time.

Historically, defense electronics providers have utilised closed architectures to meet the Department of Defense (DoD) emphasis on application-specific solutions with unique reliability, performance, space and security requirements. Mercury's open and modular design approach is particularly beneficial for Artificial Intelligence because it supports the rapid modernisation of mission-critical systems and accelerates AI electronics deployment through design flexibility and reduced complexity.

Mercury's open-architecture solutions span military and commercial aviation, navigation, unmanned aerial vehicles, missiles and helicopters. Their secure airborne capabilities include mission computing, safety-critical avionics, displays, processing, RF and radar. Mercury tailors the latest technology for rugged, secure, Size, Weight and Power (SWaP)-optimised airborne solutions.

Modules and Subassemblies. Modules and subassemblies include combinations of multiple functional technology elements and/or components that work together to perform multiple functions but are typically resident on or within a single board or housing. Modules and subassemblies may in turn be combined to form an integrated subsystem. Examples of modules and subassemblies include embedded processing modules, embedded processing boards, switch fabric boards, digital receiver boards, graphics and video processing and Ethernet and input/output boards, multi-chip modules, integrated radio frequency and microwave multi-function assemblies, tuners, and transceivers.

Integrated Subsystems. Integrated subsystems include multiple modules and/or subassemblies combined with a backplane or similar functional element and software to enable a solution. These are typically but not always integrated within a chassis and with cooling, power and are also often combined with additional technologies for interaction with other parts of a complete system or platform. Integrated subsystems also include spare and replacement modules and subassemblies sold as part of the same program for use in or with its integrated subsystems.

Customers and contracts

Given the product categories noted within the section above Mercury operates at a number of levels within the supply chain supplying components, embedded modules and integrated sub-systems.

Mercury lists its key customers as follows:

Mercury has successfully penetrated strategic programs including Aegis, Patriot, Surface Electronic Warfare Improvement Program ("SEWIP"), Gorgon Stare, Predator, F-35, Reaper, F-16 SABR, E2-D Hawkeye, Paveway, Filthy Buzzard, PGK, P-8, Advanced Integrated Defensive Electronic Warfare Suite ("AIDEWS"), Common Display System ("CDS") and WIN-T.

F-35: Mercury are providing the signal-processing systems for the Integrated Core Processing (ICP) system, F-35's central computer, which supports all of the embedded computing elements for several different aircraft subsystems, including digital signal processing (DSP) for the sensors and cockpit displays

Specific customers listed include the following:

- Airbus

- BAE Systems
- Boeing
- General Atomics
- L3 Harris
- Leonardo
- Lockheed Martin
- Northrop Grumman
- Raytheon Technologies
- SAIC
- Sierra Nevada
- Thales

Mercury derives sales from avionic upgrade programmes including the F-15 and F-16.

Strategy

Mercury's overarching strategy is to provide all types of processing subsystems requiring trusted, secure mission related computing.

Mercury has a long history of driving modular open systems architectures and has remained committed to creating, advancing, and adopting open standards for all our products, from its smallest components and connectors to the largest, high-performance, integrated multi-computer systems.

Mercury has a strong merger and acquisition culture and track record with the following deals concluded in recent years:

- 2017: Delta Microwave EW, Space for $ 41m
- 2017: RTL Platform/Mission for $6m
- 2018: Themis C2I, Comm's $180m
- 2018: Germane Systems C2I, Acoustics for $45m
- 2019: GECO Platform/Mission for $37m
- 2019: Athena Security for $46m
- 2019: Syntonic Microwave Electronic Warfare (not disclosed)

Recent developments

November 2019: Mercury Systems, Inc. announced that its high-performance signal processing and RF solutions were selected by Raytheon for its advanced Lower Tier Air and Missile Defense Sensor (LTAMDS) program, the Army's next-generation missile defense radar. LTAMDS is a new radar that will ultimately replace the U.S. Army's current Patriot radars and will operate on the Army's Integrated Air and Missile Defense network.

April 2019: Mercury Systems, Inc. announced that it will offer an Intel® Select Solution for Hardened Security with Lockheed Martin. Designed to help defense and aerospace customers secure mission-critical data, the solution will provide hardened, full stack security that delivers best-in-class performance which sets new standards of affordability for secure and rugged tactical edge computing.

Counterpoint comment

Mercury is one of the larger hardware computer peripheral providers that offers a wide range of components through to embedded systems.

19.1.25. Moog - Avionic Instruments

Moog Avionic Instruments designs and manufactures aircraft navigation, engine instrumentation, and custom military display systems.

With over 35 years of experience in cockpit displays, avionics and instrumentation. Moog has in-house engineering capabilities for design, manufacture and test of a full range of products. Moog services the fixed wing and rotary wing communities in both the military marketplace and commercial aviation.

Moog also has a separate business area, Advanced Avionics Systems, which provides designs specifically for spacecraft and payload applications.

Further, Moog has another business area, Navigation and Surveillance Systems (NaSS), which provides navigation services for land and sea-based application.

In December 2020 Moog acquired Genesys Aerosystems which is reported separately in this report.

Financials

We estimate that Moog's avionic-related business generated $25m of revenues in 2019, and $20m in 2020.

Operations and technology

Location

Moog's main avionic instrument facility is located in Virginia, USA.

Capabilities

Moog offers the following family of avionic products:

- Navigational Instruments
- Engine Indicators
- Signal Data Converters
- Spares and Service

In terms of Navigation Indicators Moog offers Horizontal Situation Indicators, Digital Bearing Distance Indicators and Radio Magnetic Indicators

Customers and contracts

Moog lists its main customers within its Airframe Controls segment as follows:

Aircraft Controls: Boeing, Airbus, Lockheed Martin, Collins Aerospace, Northrup Grumman, Japan Aerospace, General Dynamics, Honeywell, Bombardier, BAE Systems Aerospace and the U.S. Government.

Specific avionics applications include:

- KAI T-50: Flight instruments
- Bell 407: Flight instruments

Moog is certified to repair and maintain instruments and accessories. These components have been manufactured under the names of:

- Moog Components Group
- Northrop Grumman
- Litton
- Aeronetics
- Edison

Strategy

Moog does not appear to have invested within its Avionics Product range which is largely a legacy portfolio of products. Clearly with the recent acquisition of Genesys it has acquired a business that includes defense electronic capability.

Recent developments

None that we can see.

Counterpoint comment

Moog has not been a strong player in avionics (other than space/satellites) and the investment in Genesys represents a key move. Genesys may have been acquired to strengthen Moog's existing space business although Moog has stated that it will help to build out beyond its existing flight control business.

19.1.26. Northrop Grumman

From 2020, Northrop has organised itself into four operating divisions:

- Aeronautics Systems
- Defense Systems
- Mission Systems
- Space Systems

Within its Aeronautics systems division Northrop produces a number of manned and unmanned platforms including B-2 Spirit strategic bomber, the E-8C Joint STARS surveillance aircraft, the RQ-4 Global Hawk, and the T-38 Talon supersonic trainer, the RQ-5 Hunter unmanned air vehicle, the BQM-74 Chukar, RQ-4 Global Hawk-based MQ-4C Triton, MQ-8 Fire Scout, Grumman C-2 Greyhound, Grumman E-2 Hawkeye, and the EA-6B Prowler.

Northrop also provides major components and assemblies for different aircraft such as F/A-18E/F Super Hornet, EA-18G Growler, and the Lockheed Martin F-35 Lightning II.

Within Mission Systems Northrop provides tactical aircraft sensors include the AN/APG-68 radar, the AN/APG-80 AESA radar, and the AN/APG-83 AESA radar upgrade for the F-16 Fighting Falcon, the AN/APG-77 AESA radar for the F-22 Raptor, and the AN/APG-81 AESA radar for the F-35 Lightning II, and the AN/AAQ-37 electro-optical Distributed Aperture System (DAS) for the F-35, and the APQ-164 Passive Electronically Scanned Array (PESA) radar for the B-1 Lancer.

Northrop also maintains the AWACS aerial surveillance systems for the U.S., the United Kingdom, NATO, Japan, and others. Northrop Grumman is the prime contractor for the development and integration of the Air Force's $2-billion Multi-Platform Radar Technology Insertion Program.

The majority of its avionic related capabilities resides within both Aerospace and Mission systems as described below.

Financials

FYE 31/12/20 $ millions	2020	2019	2018
Full Year Revenue	36,799	33,841	30,095
Aerospace Systems revenue	12,169	11,116	10,293
Defense Systems revenue	7,543	7,495	6,621
Mission Systems revenue	10,080	9,410	8,949
Space Systems revenue	8,744	7,425	5,845
Operating Income	4,065	3,969	3,780
Operating Margin	11.0%	11.7%	12.6%

The avionic, sensors and electronic warfare capabilities for airborne systems reside within both its Defense and Mission systems divisions.

We estimate that Northrop generated $1,187m in airborne avionics and sensors in 2019 and $1,225m in 2020.

Operations and technology

Location

Northrop has its headquarters for its major divisions in US locations as follows:

- Aerospace Systems, headquartered in Redondo Beach, California, USA
- Northrop Grumman Mission Systems, headquartered in Linthicum, Maryland, USA
  - Mission systems has one of its main facilities in Arlington, North Virginia, USA
- The Defense Systems is headquartered in McNair, Virginia, USA
  - Its radar business is located in its San Diego, USA facility.
  - Defense systems has its main facility located in Minneapolis, Minnesota, USA.

Capabilities

Northrop splits its capabilities into 4 distinct segments as follows;

- Airborne sensors and network (40%)
- Cyber and Intelligent systems (17%)
- Maritime land systems and sensors (22%)
- Navigation, targeting and survivability (21%)

In terms of the operating divisions, identified above, Northrop's Airborne Systems includes the following:

Manned Aircraft: Designs, develops, manufactures and integrates strategic long range strike aircraft systems, tactical fighter aircraft and airborne battle management systems. Key programs: – Long range strike – B-21 Raider, B-2 Spirit – Tactical fighters – F-35 Lightning II, F/A-18 Super Hornet – Airborne battle management – E-2D Advanced Hawkeye, E-8C JSTARS

Autonomous Systems: Designs, develops, manufactures, integrates and sustains autonomous aircraft systems for strategic and tactical ISR missions. Key Programs: – Strategic ISR platforms - RQ-4 Global Hawk, MQ-4C Triton, NATO Alliance Ground Surveillance – Tactical ISR – MQ-8 Fire Scout, Firebird

Northrop's Mission and Defense Systems includes the following capabilities:

Radars: The SABR APG-83 is an Active Electronically Scanned Array (AESA) fire control radar. Building on Northrop Grumman's 40-year legacy producing radars for the F-16, it integrates within the F-16's current structural, power and cooling constraints without Group A aircraft modification. The capabilities of this advanced AESA are derived from Northrop Grumman's family of highly successful 5th generation fighter AESA radars, the F-22's APG-77 and F-35's APG-81.

Northrop is a world leader in airborne fire control radars and the sole supplier for both USAF 5th generation fighter platforms; the F-22 Raptor and the F-35 Lightning II. Northrop Grumman is unmatched as the largest producer of airborne fire control Electronically Scanned Arrays (ESAs).

Integrated Avionics: Northrop provides the Integrated Avionics Suite for the UH-60V, which modernises the U.S. Army's UH-60L Black Hawk helicopters with a digital, open architecture integrated glass cockpit, including an integrated computational system, visual display system and Control Display Units. This replaces the analogue gauges in UH-60L helicopters with an integrated system that provides one of the most advanced avionics systems in the U.S. Army.

Airborne Sensors & Networks: Fire control, surveillance and early warning and control radar systems; electronic attack and electronic support systems; software defined radios and network gateways, communications and counter-communications systems; and multi-sensor processing.

Key programs: Airborne Early Warning & Control and air-to-ground sensors – Battlefield Airborne Communications Node (BACN) – F-35 fire control radar, Distributed Aperture System (DAS), and Communications, Navigation and Identification (CNI) integrated avionics system – Scalable Agile Beam Radar (SABR) for F-16 – Restricted programs

Navigation, Targeting & Survivability: Competencies include EO/IR and RF self-protection; targeting and surveillance systems; digitised cockpits; and inertial navigation systems.

Key programs: – LITENING Advanced Targeting Pod – Large Aircraft and Common Infrared Countermeasures (LAIRCM, DoN LAIRCM, CIRCM) systems – APR-39 DV(2) and EV(2) Radar Warning Receiver programs – Embedded Global Positioning System (GPS)/Inertial Navigation Systems-Modernisation (EGI-M) program – UH-60V Black Hawk integrated mission equipment package – Restricted programs

Airborne Electronic Warfare: Northrop Grumman has provided Airborne Electronic Warfare solutions for more than 55 years.

Northrop provides the electronic warfare suite for its F-16 fighter aircraft fleet. The system provides full-spectrum radar warning, threat identification and advanced countermeasure capabilities. It also has proven pulse-to-pulse operability with the F-16's newly acquired AN/APG-83 Scalable Agile Beam Radar (SABR), also built by Northrop Grumman.

Northrop builds, maintains and upgrades electronic sensing systems for the Northrop Grumman EA-6B Prowler and Boeing EA-18G Growler electronic combat aircraft. They also provide radar warning receivers and electronic support measures for platforms such as the Boeing P-8A Poseidon.

Northrop Grumman has been selected to provide the B-kit for the AC/MC-130J RFCM Program. The AN/ALQ-131(V) Electronic Countermeasures (ECM) pod and the AN/APR-39D(V)2 Radar Warning Receiver/Electronic Warfare Management System maximise survivability by improving aircrew situational awareness via interactive management of all onboard sensors and countermeasures.

Customers and contracts

Northrop generates 85% of its revenues within the US and 15% from International/FMS sales. Within each of its operating divisions classified or restricted programs account for between 19% and 38% of its sector revenues.

Most of Northrop's key platforms and associated products are identified above under "technologies and capabilities".

A number of Northrop's key avionic supply contracts are identified as follows;

- Northrop provides Lockheed Martin with the AN/APG-81 fire control radar for the F-35 Lightning II. The Northrop AN/APG-81 active electronically scanned array is the cornerstone of the F-35's advanced sensor suite, providing unparalleled battlespace situational awareness that translates into platform lethality, effectiveness and survivability.
- Northrop provides the Integrated Avionics Suite for the UH-60V, which modernises the U.S. Army's UH-60L Black Hawk helicopters with a digital, open architecture integrated glass cockpit, including an integrated computational system, visual display system and Control Display Units.
- Northrop's approach for the design and implementation of the UH-60V integrated mission equipment package is based on experience with similar upgrades for the U.S. Marine Corps AH-1Z and UH-1Y helicopters, U.S. Navy E-2D Advanced Hawkeye, and the Royal Jordanian Air Force AH-1 programs.
- Northrop Grumman supplies the Navigation System for Embraer's New KC-390 Military Aircraft which includes the hybrid global positioning system (GPS) and inertial reference system for the KC-390 medium-lift military transport aircraft
- Northrop provides the AEA suite for the EA-18G Growler which allows the fighter to disrupt, deceive and deny a broad range of military electronic systems; it features wing tip pods and gun bay pallets, in addition to antennas and receivers.
- Northrop provides the B-kit for the AC/MC-130J RFCM Program. The B-kit includes the apertures, amplifiers and electronics including radio frequency countermeasures suite.
- Northrop's equipped Triton (based upon Global Hawk) has Multi-Function Active Sensor radar, Electro-Optic Infrared, Electronic Support Measures and Automatic Identification System have a 360-degree field of view radar.

- Global Hawk utilises Northrop's near-real-time, high-resolution imagery of large areas of land in all types of weather – day or night. The EQ-4B Global Hawk carries Northrop's Battlefield Airborne Communications Node (BACN) payload providing life-saving support to war fighters.
- The capabilities of the advanced AESA are derived from Northrop Grumman's family of highly successful 5th generation fighter AESA radars, the F-22's APG-77 and F-35's APG-81.

Northrop offers the market a range of retrofits upgrades including AESA radars, electronic warfare suites and electronic countermeasures.

Strategy

Northrop is both a provider of manned and unmanned autonomous airborne platforms and a provider of the high value electronics avionics, sensors and military systems embedded within these platforms.

As such it arguably has an advantage over the Tier1 suppliers in terms of access to customers, funding, R&D and the agencies that influence DoD budgets etc.

Recent developments

January 2021: Northrop will provide new computers and displays for the U.S. Navy E-3D Hawkeye carrier-based radar surveillance aircraft under terms of a $13.1 million order. Naval Air Systems Command are asking the Northrop Grumman Aeronautics Systems segment in Melbourne, Fla., to provide 39 avionics flight mission computers, 10 control display units, and one environmental stress screening station for the E-2D aircraft.

July 2020: Northrop has been selected to provide the prime mission equipment for the Sierra Nevada Corporation-led AC/MC-130J Radio Frequency Countermeasure (RFCM) program. Northrop Grumman's RFCM system utilises the latest in antenna, amplifier and electronics technology. This technology provides superior situational awareness and better enables aircraft survivability in operationally relevant environments.

January 2020: Northrop has received a contract from Lockheed Martin to enable new functionality to protect the 5th Generation F-35 Lightning II multi-role fighter. As part of a collaborative arrangement between Northrop, BAE Systems and Lockheed Martin, the three companies will integrate Northrop's AN/ASQ-242 Integrated Communications, Navigation and Identification (ICNI) and BAE Systems' AN/ASQ-239 Electronic Warfare/Countermeasures (EW/CM) system for optimal operational utility.

Counterpoint comment

Northrop is a market leader within the US defense sector and has a global presence necessary to support both foreign military sales and to exploit non-US defense budgets.

It has a very strong presence in Unmanned Airborne Systems which we see as a significant growth sector.

19.1.27. Performance Software

Performance is a software and engineering services firm that provides innovative, turnkey solutions for safety-critical projects serving clients in the avionics, aerospace/defense, healthcare, and energy markets.

Performance specialises in developing real-time embedded avionics systems and full lifecycle software solutions certifiable to DO-178B and DO-178C levels A through D.

Financials

We estimate that Performance generated $43m of revenues in 2020 with avionics representing $16m, down from $18m in 2019.

Operations and technology

Location

Performance has its headquarters located in Phoenix, Arizona, USA.

It also operates additional support offices in Seattle, Clearwater, Grand Rapids, Waukesha, and New Orleans.

Capabilities

Performance delivers software solutions for the following Aerospace & Defence related systems:

- Cabin systems
- Engine control systems (FADEC)
- Flight deck display systems
- Geospatial information systems (GIS)
- Onboard maintenance systems (OMS)
- Electrical power systems
- Flight Control systems
- Flight Management Systems
- Navigation and guidance systems

In terms of Avionics, Performance has the following product offerings:

- Precision Navigation & Mapping™ provides customisable, photo-realistic experiences with the highest precision. Increased pilot situational awareness; improve safety margins and enhance operational efficiency. With a worldwide database of airports accommodating general aviation through wide-body air transport.
- Performance JETS is a cloud-based systems and software development platform for the rapid deployment of avionics products. By using an FAA approved virtual platform it realise the benefit of unlimited access to hardware and accelerates time to market by finding bugs sooner, efficiently developing software, and running tests.
- Performance GPU is a customised OpenGL software–rendering library for embedded applications designed for commercial displays and military displays. It provides a means to render graphics through software rather than dedicated hardware, eliminating the need for hardware GPUs altogether by removing hardware from the graphics-processing equation.
- The Performance DataLoader™ suite of components are ARINC 615A and ARINC 665 compliant and were developed with modularity, reliability, fast loading speed and customisation in mind. These onboard data loaders allow for fast implementation of new software developments.

Customers and contracts

Performance does not specifically identify its customers although it does have Boeing supplier approvals and within its case studies it does refer to large global OEM avionic providers (e.g. for FMS support).

In 2014 Performance signed a long-term contract with Rockwell Collins to provide its Airport database software as part of Collins ProLine Fusion avionic suite. Performance also has FAA approval for airport database mapping products.

Performance was awarded two supplier accolades from Collins in 2010 so we believe that it has a long standing relationship with Collins.

Strategy

Performance states that it is a software and engineering services firm that provides innovative, turnkey solutions for safety-critical projects. We serve clients in the avionics, aerospace/defense, healthcare, and energy markets whose missions require meticulous attention to detail.

Recent developments

None that we can see.

Counterpoint comment

Performance is focussed on the aerospace and defense sector and has been supporting OEMs/Tier1s with its software and data services for many years.

19.1.28. Raytheon Intelligence and Space

Raytheon Technologies, recently formed via its merger with UTC, includes 4 business units including:

- Pratt & Whitney
- Collins Aerospace
- Raytheon Intelligence and Space
- Raytheon Missiles and Defense

Collins Aerospace is reported separately within this report.

Raytheon Intelligence and Space is headquartered in Dulles, Virginia. The business specialises in intelligence, surveillance and reconnaissance and space systems. This includes cybersecurity solutions, weather and environmental solutions and information-based solutions for homeland security. The company also provides training, logistics, engineering, product support, and operational support services and solutions for mission support, homeland security, space, civil aviation, counter-proliferation and counter-terrorism markets.

Raytheon occupies 500 facilities spread across 40 countries. It employs approximately 35,700 personnel.

Financials

In 2020 Raytheon Intelligence and Space generated $10,841m of revenues.

We estimate that its airborne avionic related products including sensors generated revenues of $1,806m in 2019 and $1,871m in 2020.

Operations and technology

Location

Raytheon Intelligence and Space is headquartered in Dulles, Virginia

It has a number of facilities located throughout the US as follows;

Fullerton, CA; Aurora, CO; Indialantic, FL; Orlando, FL; Palm Bay, FL; Indianapolis, IN; Louisville, KY; Billerica, MA; Burlington, MA; Marlboro, MA; Annapolis Junction, MD; Troy, MI; State College, PA; El Paso, TX; Richardson, TX; Dulles, VA; Herndon, VA; Newport News, VA; Springfield, VA; and Calgary, Canada.

It operates from a total of 5,258,700 ft² of facility space of which 92% is located in the US.

It has a significant presence in Australia with a HQ in Canberra and supported by 20 regional office facilities.

In terms of other overseas facilities these are located in UK, Germany, Poland and Saudi Arabia, however, these facilities typically support land, maritime and infrastructure projects and do not supply airborne equipment.

Capabilities

Raytheon's key technologies and capabilities include the following:

- AESA Radar
- Electronic Warfare
- Multi-Spectral Targeting Systems
- Joint Precision Approach and Landing
- Protected Satellite Communications
- GPS antennas and Receivers

AESA Radar

The APG-82(V) optimises the F-15Es multirole mission capability. In addition to its extended range and improved multi-target track and precision engagement capabilities, the APG-82(V) offers improvement in system reliability over the legacy F-15E APG-70 radar.

Raytheon's APG-79 AESA radar design, now extended to the APG-82(V) is combat-proven on fielded F/A-18s, and it's being adapted now to modernise the Strike Eagle.

The ALR-69A, the world's first all-digital radar warning receiver, alerts pilots to threats in dense signal environments. The system is being tested on the F-16 Fighting Falcon and is installed on the C-130H Hercules and KC-46A Pegasus.

Mission Computing

Raytheon provides a Modular Mission Computer (MMC) for the mid-life update for the F-16. The MMC delivers enhanced computing power to the aircraft's avionics and weapon systems. As a member of Lockheed Martin's F-16 team, Raytheon developed a single high-performance system to replace the fighter jet's three original computers. The MMC's advanced features — and potential for expansion — enable the F-16 to meet present and future mission challenges. For pilots, the MMC significantly improves situational awareness, air-to-air capabilities, targeting accuracy and information. Equipped with this powerful computer, the F-16 can take greater advantage of such growth technologies as helmet-mounted cueing systems, advanced weapons loads, reconnaissance pods and forward-looking infrared targeting and navigation systems.

Electronic Warfare

Raytheon's Next Generation Jammer Mid-Band is an advanced electronic attack system that denies, disrupts and degrades enemy technology, including communication tools and air-defense systems. Built with a combination of agile, active electronically scanned arrays and an all-digital back end, it gives E/A-18 Growler pilots an edge in the hotly contested electromagnetic spectrum.

In 2018 the U.S. Air Force awarded a contract for Raytheon's AN/ALR-69A(V, the world's first all-digital radar warning receiver. The contract calls for the rapid procurement of 779 units or more for the USAF fleet of tactical air and large body aircraft.

Multi Spectral Targeting System

Raytheon's Multi-Spectral Targeting System (MTS) combines electro-optical/ infrared (EO/IR), laser designation, and laser illumination capabilities in a single sensor package. To date, Raytheon has delivered more than 3,000 MTS sensors to U.S. and international armed forces and successfully integrated 44 variants of the system on more than 20 rotary-wing, Unmanned Aerial System, and fixed-wing platforms – including the MH-60 Blackhawk, the C-130 Hercules, the MQ-9C Reaper, the MQ-1 Predator, and the MQ-1C Gray Eagle.

Joint Precision Approach and Landing

Joint Precision Approach and Landing System, or JPALS, is a software-based, high-integrity differential GPS navigation and precision approach landing system that guides aircraft onto carriers and amphibious assault ships in all weather and surface conditions. It uses an anti-jam encrypted datalink to communicate between the aircraft and an array of GPS sensors, antennas and shipboard equipment.

In 2018, U.S. Marine Corps F-35Bs deployed aboard the USS Wasp using JPALS to guide them onto the deck. JPALS is also installed on the USAF land-based F-35A and USN/USMC carrier-based F-35C.

Protected Satellite Systems

Raytheon is a provider of protected Advanced Extra High Frequency terminals in production for the Army, Navy and Air Force. With more than 500 systems in the field, our terminals currently support the legacy Milstar satellites and are ready to operate with the newest AEHF satellites.

GPS antennas and receivers

The MAGR2K brings M-Code GPS capability to maritime and avionics platforms, including the F/A-18, MV-22, CV-22 and MH-53E. The MAGR2K enhances GPS acquisition and performance and provides all-in-view GPS satellite tracking and GPS integrity. The open architecture and modular design allows for easy upgrades. Raytheon has delivered over 3,000 units to 20 different platforms to the U.S. Air Force, Navy and international partners.

Customers and contracts

Raytheon provides avionic solutions for the following applications:

- F-15: APG-82 AESA radar systems, AN/APG-63 and AN/APG-70 are a family of all-weather multimode radar systems (earlier versions of APG-82).
- F-16: Radar Warning receiver, Modular Mission Computer
- F/A-18: APG-82C radar systems, MAGR2K GPS receivers, AN/ASQ-228 Advanced Targeting Forward-looking Infrared (ATFLIR) pod, AN/ALR-67(V)3 Radar Warning Receiver (RWR), Miniature Airborne Global Positioning System Receiver (MAGR-2000)
- F-22: design, develop and manufacture of the projector for BAE Systems' Digital Light Engine head-up display
- MV-22: MAGR2K GPS receivers
- CV-22: MAGGR2K GPS receivers
- MH-53: MAGGR2K GPS receivers
- F-35: JPALS precision landing system, Distributed Aperture System
- MH-60 Blackhawk: Multi-Spectral Targeting System
- C-130J: Multi-Spectral Targeting System, Radar warning receiver, MXF-626K VHF Communications Systems, APX-119 identification friend or foe (IFF) transponders
- MQ-9: Multi-Spectral Targeting System
- MQ-1: Multi Spectral Targeting System
- E/A-18 Growler: Next Gen Jammer System

Strategy

Raytheon is a US military defense contractor primarily with extensive capabilities in emergent technologies such as digital, cyber, AI and electronic warfare. It provides forward fit and retrofit solutions in addition to expanding its service support contract capabilities.

It’s strategy, in part, is to exploit these capabilities with its recent acquisition of Collins Aerospace via synergies and cost savings.

Recent developments

December 2020: U.S. Special Operations Command (SOCOM) has selected Raytheon to provide open-systems aircraft mission processor avionics to replace outdated equipment aboard Special Operations AC- and MC-130J aircraft. The MC-130J Commando II aircraft has avionics similar to the AC-130J, and has a combat systems operator and auxiliary flight deck stations; 13 colour multifunctional liquid crystal displays; head-up displays; integrated navigation systems; improved fuel, environmental, and ice-protection systems; enhanced cargo-handling system; infrared sensors; satellite communications for voice and data; increased DC electrical output; and provisions for the Large Aircraft Infrared Counter-Measure system (LAIRCM).

August 2020: Raytheon has developed the Next Generation Jammer Mid-Band which flew on an E/A-18G Growler – its first flight test on the aircraft. The U.S. Navy's NGJ-MB is an advanced electronic attack system that denies, disrupts and degrades enemy technology, including communication tools and air-defense systems.

February 2020: Raytheon is harnessing technologies from the F-15’s APG-63(v)3 and APG-82 active electronically scanned array radars, along with the APG-79 from the Super Hornet and Growler, for the B-52 Radar Modernisation Program.

June 2019: Raytheon, which has increasingly focused on its growing cyber and network business, has won contracts to find and fix cyber vulnerabilities in the Air Force’s F-15 fighter and C-130 transport fleets. Those are the company’s latest deals in what is a business worth at least hundreds of millions of dollars in the last 18 months.

Counterpoint comment

With Collins' focus primarily on the civil sector and Raytheon's focus on the defense sector the bringing together of these two entities appears to make a lot of sense.

The primes naturally are quite wary of entities this size with control over engine technology in the mix as well.

Raytheon Technologies does not build airframe platforms so it can focus its efforts on becoming the world number 1 systems integrator.

19.1.29. Sierra Nevada Corporation

Founded in 1963 and acquired by its current private owners in 1994 Sierra Nevada Corporation has grown to be a $1.9Bn revenue business in 2019 employing 5,000+ personnel in facilities around the world.

Sierra Nevada Corporation is a leading supplier of space systems to Space Systems, Commercial Solutions, and National Security and Defense, and has participated in more than 450 missions to space, including Mars.

It has pursued growth via acquisitions with the following noted in recent years:

2003: Acquisition of San Francisco-based military computer designer Inter-4, 2004: Acquisition of California-based, WaveBand Corporation, 2004: Acquisition of Aviation Resources Delaware, Inc. 2008: Acquisition of MicroSat Systems, Inc. of Littleton, Colorado, 2008: Acquisition of SpaceDev, Inc. added tremendous space heritage with products that had flown on more than 300 spacecraft over 20 years, 2012: Acquisition of 3S Engineering LLC (a wholly-owned subsidiary of SNC), 2014: Acquisition of Orbital Technologies Corporation (ORBITEC) of Madison, Wisconsin, 2015: Acquisition of 328 Support Services GmbH allowed for global expansion of Sierra Nevada Corporation's modern commercial aircraft technologies, 2015: Acquisition of Kutta Technologies Inc. and Kutta Radios Inc. expanded communications and visualisation capabilities in the areas of command-control-communications software applications and rugged, survivable communications systems.

Today Sierra Nevada Corporation operates through its 3 divisions of space, national security and defense and commercial solutions.

Sierra Nevada Corporation has developed the DreamChaser spaceplane which is a multi-mission space utility vehicle designed to transport crew and cargo to low-Earth orbit (LEO) destinations such as the International Space Station.

Within its portfolio of capabilities Sierra Nevada Corporation provides avionic related offerings including C4ISR products and services and Enhanced Vision Systems for fixed and rotary wing platforms.

Financials

Sierra Nevada Corporation generated $1,990m of revenues in 2019.

Based upon its commercial avionics operations we estimate that Sierra Nevada Corporation generated $125m of revenues in 2019, falling to $100m in 2020.

Operations and technology

Location

Sierra Nevada Corporation has its headquarters in Nevada, USA.

It also has offices throughout the USA located in Huntsville AL, Phoenix AZ, Folson CA, Fremont CA, Los Gatos, CA, Englewood, CO, Duke field FL, Jacksonville FL, Wichita KS, Hagerstown MD, Omaha NB, Greenville TX, Houston TX, Salt Lake city UT, Hendon VA.

Outside of the US Sierra Nevada Corporation has offices in London UK, Ankara Turkey and Oberpffafenhoffen Germany.

328 Support Services GmbH, Germany, is a subsidiary of Sierra Nevada Corporation, USA. Employing over 170 aviation experts it supports more than 180 aircraft globally. Through its EASA Part 21J Design Organisation (Category 1A) as well as its Part 21G Production Organisation (C1, C2 and D1 rating) and Part

145 Maintenance Organisation, 328SSG provides the aero industry with design, certification, production and maintenance services. This includes base and line aircraft maintenance, avionics installation, exterior painting, Part-M services, refurbishment, training services (part 147), STC design activities and bespoke VIP interiors including avionic & IFE upgrades. 328SSG is based at Oberpfaffenhofen Airport, near Munich.

Capabilities

Sierra Nevada Corporation provides Command, Control, Computers, Communications and Intelligence, Surveillance and Reconnaissance (C4ISR). Sierra Nevada Corporation has more than five decades of experience with Signals Intelligence (SIGINT), wideband digital electronic intelligence (ELINT), electronic support measures (ESM) and systems wide-area motion imagery (WAMI) C4ISR technology enables customers to turn sensor outputs into tangible knowledge, bringing solutions to the table and allowing efficient, effective decision-making.

Sierra Nevada Corporation has installed end-to-end C4ISR capabilities on 200+ types of manned and unmanned aircraft for both commercial and government customers.

Sierra Nevada Corporation has developed Enhanced Visual Systems (EVS) for use in degraded environments. Sierra Nevada Corporation uses a multi-sensor suite fused in real-time with terrain, imagery and obstacle data that is then integrated with symbology and command guidance to restore the visual cues for all modes of flight, in both natural and degraded visibility. Sierra Nevada Corporation's primary sensor is a 94 GHz millimetre wave radar, which was specifically designed and optimised for improving vision in aircraft.

The Mission Solutions and Technologies (MST) business area provides affordable, turn-key command/control, communications, integrated ISR, force protection and security solutions worldwide. The MST team has a long legacy of supporting the Department of Defense, Department of Homeland Security, commercial and international customers with years of experience in platform operations, engineering and full lifecycle management across domains – air, land, sea, space and cyber.

Sierra Nevada Corporation also has a variety of STC's from Wi-Fi activation installations to avionics cockpit retrofit programmes.

Sierra Nevada Corporation has developed the Scorpion multi mission aircraft, based upon a turbo-prop airframe, which contains the following avionic mission related equipment:

- Retractable 15 inch, high-definition, electro-optical/infrared sensor in a nose extension modification that records, stores and transmits full-motion video
- Multi-mode surveillance radar with high-resolution
- Communications network with line-of-sight (LOS) and beyond-line-of-sight (BLOS) capability with secure voice and data features
- Two mission management workstations allows for simultaneous multi-sensor usage

Customers and contracts

Sierra Nevada Corporation has installed a range of C4ISR systems solutions on the following platforms:

PZL M-28, Boeing CV/MV-22, Embraer A-29 Super Tucano, Dornier D-328, Pilatus PC-12, King Air (SNC Scorpion® aircraft), Cessna Caravan, Cessna Sovereign, Cessna Citation, AH-64, De Havilland DHC-6 Twin Otter, De Havilland DHC-7, Merlin/C-26, Bombardier Dash 8, C-130, Gulfstream 3, UH-60, SH60.

Sierra Nevada Corporation has numerous STCs for Cessna aircraft and the Twin "Shrike" Commander 500-S.

Sierra Nevada Corporation has Type Certificate for the D328 jet & turboprop (EASA TC A.096; FAA TC No. A45NM; & FAA TC No. A55NM), as well as IP for the Dornier 428 & other assets.

200 Supplemental Type Certificates (STCs) & complete design & build-and-certify solutions for both helicopters and large aircraft types for an extensive customers list such as Airbus, Lufthansa & Turkish Technic

Sierra Nevada Corporation has FAA Parts Manufacturer Approval (PMA) and Four FAA Part 145 Certified Repair Stations.

Strategy

Sierra Nevada Corporation states that its mission is to Dream, Innovate, Inspire and Empower the next generation to transform humanity through technology and imagination.

Recent developments

February 2021: Autonomous developments. Sierra Nevada Corporation's obstacle avoidance system is based on Degraded Visual Environment (DVE) Solutions technology, currently in use by the U.S. military. DVE enhances visibility and situational awareness in the dark, inclement weather and low-visibility conditions, enabling them to detect and avoid stationary and moving obstacles in the path through the travel to and from any destination.

September 2020: Sierra Nevada Corporation was awarded a second $47m contract for two additional Multi-Role Enforcement Aircraft (MEA) by U.S. Customs and Border Protection (CBP), bringing total MEA aircraft orders to four in 2020. Sierra Nevada Corporation has been the prime systems engineer and integrator for the MEA fleet since 2009.

Counterpoint comment

Sierra Nevada Corporation is a successful privately owned business that can develop complete airframes in addition to providing avionics and electronic systems and as such it is somewhat unique. It is focused upon space and national security within the US with some overseas exposure.

19.1.30. Teledyne Technologies

Teledyne Technologies had sales of $3.1 billion in 2021.

It has four divisions as follows:

- Instrumentation: Test and measurement, monitoring and control instrumentation, and power and communications connectivity devices for marine, environmental, electronics and other applications
- Digital Imaging: High performance sensors, cameras and systems within the visible, infrared, ultraviolet and X-ray spectra, used in industrial, government and medical applications
- Aerospace and Defense Electronics: Sophisticated electronic components, subsystems and communications products, including defense electronics, commercial avionics and harsh environment interconnects
- Engineered Systems: Innovative systems engineering, manufacturing and specialised products for government, space, energy and industrial customers

The third of these includes its avionics business.

Financials - Aerospace and Defense Electronics

FYE 31/12/20	2020	2019	2018
Sales $m	589.4	690.1	640.2
Operating income $m	80.8	143.4	131.8
Return on sales %	13.7%	20.8%	20.6%

Teledyne commented in its 2020 10K: "Our Aerospace and Defense Electronics segment net sales for 2020 decreased 14.6%, compared with 2019. Operating income for 2020 decreased 43.7%, compared with 2019. The 2020 net sales decrease reflected $94.8 million of lower sales of aerospace electronics and lower sales of $5.9 million of defense electronics. The continued weakness in the commercial aerospace industry, due to COVID-19, has negatively affected sales of aerospace electronics. The decrease in operating income in 2020 primarily reflected the impact of lower sales and $18.3 million of higher severance, facility consolidation expense and certain unfavourable changes in contract cost estimates. Cost of sales for 2020 decreased by $19.6 million, compared with 2019, and reflected the impact of lower net sales. Cost of sales as a percentage of net sales for 2020 increased to 67.0% from 60.1% in 2019 and reflected the impact of higher severance, facility consolidation expense and certain unfavourable changes in contract cost estimates. Selling, general and administrative expenses, including research and development expense, decreased to $113.5 million in 2020, from $132.0 million in 2019 and reflected the impact of lower net sales, partially offset by higher

severance and facility consolidation expense. The selling, general and administrative expense percentage was 19.3% in 2020 compared to 19.1% in 2019."

We estimate that Teledyne Aerospace and Defense Electronics generated $112m of revenues for avionic equipment in 2019, falling to $85m in 2020.

Operations and technology

Location

Teledyne Aerospace and Defense Electronics is headquartered in Southern California, with locations in the US and the UK, and sales offices in Toulouse, France; Tokyo, Japan; Kuala Lumpur, Malaysia; Dubai, United Arab Emirates; Beijing, China; and Singapore.

Its US facilities are located in Thousand Oaks, CA and Minneapolis, MN.

Teledyne Aerospace and Defense Electronics has a support and service facility located in Toulouse, France.

Within the UK Teledyne Aerospace and Defense Electronics has a data products business located in Heathrow and a facility located in Glasgow.

Within Asia Teledyne Aerospace and Defense Electronics has offices in Selangor, Malaysia: Beijing, China and Singapore.

Capabilities

Teledyne's GroundLink® Comm+ system provides airlines with a data infrastructure backbone that supports numerous applications, seamlessly connecting aircraft equipment with back office systems. The newest solution enabled by the GroundLink system is Groundlink® Data Link. This application is designed to provide the ACARS system (CMU, CMF or ATSU) with cellular connectivity via the GroundLink Comm+ unit to send and receive AOC and AAC messages when the aircraft is on the ground. In-flight ACARS over IP is also available for aircraft equipped with broadband.

Electronic Flight Bags: Teledyne Controls provides for enhancing EFB systems functionality by adding off-board communication, access to aircraft parameters and data management capability via its new GroundLink® AID+ system. This solution extends all AID functions to Wi-Fi enabled EFB systems and other crew devices through a cockpit wireless network available in all flight phases. The AID+ system permits wireless tablet based EFBs (such as iPads) or traditional Ethernet connected Class1/2 EFBs to be integrated with the aircraft regardless of EFB form factor, operating systems or whether they connect with the aircraft as a wired or wireless EFB system.

Software uploads: Teledyne Controls' GroundLink Dataloading allows airlines to efficiently transfer Software Parts (SPs) and navigation databases to their aircraft, instantaneously and reliably, with the press of a button. This integrated system enables airlines to transition from manual SP distribution based on floppy disks, CDs and paper-based methods, to a paperless and automatic distribution process.

Data acquisition: Teledyne Controls' enhanced Digital Flight Data Acquisition Unit (DFDAU) is an integrated system that combines the functions of Mandatory Data Acquisition and Recording with a sophisticated Aircraft Condition Monitoring System (ACMS). This comprehensive system provides aircraft operators with a standardised hardware and software solution for high-power data acquisition, management and recording in an internal PCMCIA recorder.

In 2011 Teledyne Controls and Thales signed a reseller agreement, whereby Thales will provide Teledyne's Wireless GroundLink Quick Access Recorder (WQAR) to existing EQAR (Extended storage Quick Access Recorder) customers.

Teledyne also offers low cost ACARS via mobile telephony (5G). The newest solution is enabled by the Groundlink® Data Link. This application is designed to provide the ACARS system (CMU, CMF or ATSU) with cellular connectivity via the GroundLink Comm+ unit to send and receive AOC and AAC messages when the aircraft is on the ground. In-flight ACARS over IP is also available for aircraft equipped with broadband.

Customers and contracts

Teledyne provides Digital Data Acquisition and Transfer Units to most civil platforms including Airbus, Boeing, Comac C919, Embraer 170/190 and Sukhoi SSJ 100 aircraft.

Teledyne Controls is a major provider of Electronic Flight Bags to all Airbus and Boeing modern platforms.

Selected by 90 operators worldwide, Teledyne's WQAR has been certificated on numerous aircraft types. It is available factory fit from Boeing on the 777 and 737NG aircraft; Airbus on the A320 family, A330, A340 and A380 aircraft types and Embraer on the E190/195 family.

The Royal Air Force (RAF) has selected AirFASE® - a leading flight data analysis (FDA) tool to monitor and measure the safety and operational performance of its current and future fleet of 22 Airbus A400M Atlas aircraft.

GroundLink® Aircraft Interface Device (AID) from Teledyne Controls has been certified and is fully operational for use across Austrian Airlines' entire fleet of Airbus, Boeing and Embraer aircraft.

Strategy

Teledyne built its name on intelligent solutions that collect, manage and deliver aircraft data more efficiently. Its innovative technology and collaborative customer relationships have revolutionised the way aircraft operators access, manage and utilise their data, helping them achieve higher goals in safety, performance and efficiency.

The FLIR acquisition is a major strategic move for Teledyne. The rationale for the acquisition of FLIR by Teledyne is stated as being entirely complementary in that they both serve different sectors with differing technologies. FLIR has significant exposure to Aerospace and Land systems whilst Teledyne is exposed to Space and Subsea sectors. Equally FLIR's technology is almost entirely based upon infra-red whilst Teledyne utilises microwave, radio, gamma rays, X-rays and ultra-violet light spectrums for its applications.

Recent developments

Jan 2021: Teledyne Technologies announced that it will acquire thermal imaging camera supplier FLIR systems in a $8 billion cash-and-stock deal to increase its portfolio of imaging sensor technology. The deal is expected to close mid-2021. The combined entities will generate circa $3bn of digital imaging related revenues.

March 2020: Teledyne launched the Loadstar® Server Enterprise 3 (LSE 3), a new software configuration management and distribution tool that eliminates the inefficient and costly use of floppy disks and other physical media to load essential software and data to the aircraft – a practice that potentially costs airlines millions of dollars each year in unnecessary labour and can leave aircraft stranded on the ground.

November 2019: The Royal Air Force (RAF) has selected AirFASE® - a leading flight data analysis (FDA) tool from Teledyne Controls - to monitor and measure the safety and operational performance of its current and future fleet of 22 Airbus A400M Atlas aircraft.

June 2018: Teledyne Controls has announced a partnership with the Chinese aircraft manufacturer COMAC to build a Real Time Monitoring System (RTMS) for ARJ21 aircraft.

May 2017: Jeppesen has teamed with Teledyne Controls to integrate Jeppesen FliteDeck Pro with Teledyne's GroundLink Comm+ system with Aircraft Interface Device (AID) functionality, known as GroundLink AID+.

Counterpoint comment

Teledyne Controls provides onboard data loading, storage and transmission products which it then supports with data analytics, data uploads and general support services. Like many avionics providers its business model is delivering value thru the service and support associated with its installed hardware base.

19.1.31. TransDigm

TransDigm Group Inc. is a leading global producer, designer and supplier of highly engineered aerospace components, systems and subsystems for use on nearly all commercial and military aircraft in service today.

Transdigm operates via a Private Equity-like Capital Structure and Culture.

TransDigm Group is comprised of 50 independent companies. Each TransDigm company operates its local business autonomously and realises its own company-specific market strategy.

Heavily invested within the US, TransDigm has approximately 60 manufacturing locations in the U.S. and employs about 8,000 people.

In 2020 TransDigm reported revenues of $5,103m with associated EBITDA of $2,419m (46%).

Financials – Power & Control

FYE 31/12/20	2020	2019
Sales $m	2,695	2,736
EBITDA $m	1,345	1,395
Return on sales %	49.9%	51.0%

TransDigm commented in its 202 10K: "Organic sales for the Power & Control segment decreased $237 million, a decrease of 8.7%, for the fiscal year ended September 30, 2020 compared to the fiscal year ended September 30, 2019. The organic sales decrease resulted primarily from decreases in commercial aftermarket sales ($157 million, a decrease of 21.0%) and commercial OEM sales ($145 million, a decrease of 23.0%); partially offset by an increase in defense sales ($59 million, an increase of 4.6%). The decreases in organic commercial OEM and aftermarket sales are attributable to the COVID-19 pandemic. The decrease in organic commercial OEM sales is also attributable to the Boeing 737 MAX production slowdown. Partially offsetting the decrease in organic sales is an increase in acquisition sales of $196 million, an increase of 7.2%, as a result of the Esterline acquisition."

The Power & Control division has three businesses that operate within the Avionics sector and these are described as follows.

19.1.31.1. Aerosonic

Founded in 1953, Aerosonic LLC located in Clearwater, Florida, designs and manufactures highly engineered air data sensors for military and commercial aerospace applications. They have experience with air data products and have been producing them for over 85 years.

Financials

Aerosonic employs 150 personnel within its Clearwater facility.

Aerosonic are reported as having generated $31m of revenues in 2019 and Counterpoint estimates that $25m were associated with Avionics products and $20m in 2020.

Operations and technology

Location

Aerosonic operates from a wholly owned facility located in Clearwater, Florida.

Capabilities

Aerosonic lists its product capabilities as including the following:

- Pitot and Pitot-static probes
- Air data computers
- Angle-of-attack sensors
- Stall warning systems
- Multi-function probes
- Static ports
- Electronic standby instruments
- Mechanical cockpit instruments

- Air data test booms

Aerosonic's air data computers compute a variety of functions such as Static Pressure, Total Pressure, Calibrated Airspeed, Mach, SAT, TAS, Altitude Rate, Airspeed Rate, and Pressure Ratio – any air data function can be added. In some unique applications, equivalent airspeed is calculated instead of calibrated airspeed.

The Angle of Attack (AoA) Probe provides AoA or Sideslip (SS) by sensing the direction of local airflow. It is mounted on the fuselage with the sensing probe extending through the aircraft fuselage. The sensing probe is continually driven to null pressure differential between the upper and lower slots in its forward surface.

Pitot probes: Aerosonic has an extensive portfolio of pitot probes including pitot, pitot static and pitot/angle-of-attack probes designed and in service, meeting the requirements of virtually any type of aerospace application. Probes may be configured as standalone with pneumatic outputs to the Air Data Computer, or they may integrate the computing function and eliminate the pneumatic connection.

Digital Standby Instruments. Aerosonic, provides the next generation of stand-by indicators. Digital accuracy and reliability that will track with the primary flight display and reduce life-cycle costs.

Aerosonic is also a FAR 25 approved repair and overhaul facility.

Customers and contracts

Aerosonic lists 10 distributors that stock and supply its products located in the US, Far East and Europe.

At the time that Transdigm acquired the business Aerosonic's primary customers were recorded as the U.S. government and Boeing.

Aerosonic avionics equipment is listed in the Technical Orders and can be found on a majority of military aircraft including C-130, F-16, T-50, CN-235/C-295, UH-60 and many more.

In 2010 Aerosonic received an order from KAI to provide air data test equipment to provide in-country support of components used on Korean T-50s.

In 2011 Aerosonic said it received a contract from the U.S. Defense Logistics Agency to supply AAU/32A encoding altimeters used on Army OH-58 and UH-60 helicopters.

Strategy

To promote excellence in air data products and services within the aerospace and defense markets.

Recent developments

Jan 2020: Aerosonic entered an agreement with AllClear to support its products in the aftermarket. "We are very pleased to announce this partnership with AllClear. We believe this agreement will greatly increase Aerosonic's ability to support our F-16 and T-50 international customers".

Counterpoint comment

A focussed niche business with an established customer base largely in the US.

19.1.31.2. CMC Electronics

The company was founded in 1903 as Canadian Wireless Telegraph Company of Canada by Guglielmo Marconi. In 1925 the company was renamed Canadian Marconi Company. In 1948 English Electric purchased the UK based Marconi Company and in 1953 acquired 50.6% of Canadian Marconi Company.

It was also owned by BAE Systems before passing thru ONCAP and was then acquired by Esterline in 2007.

Esterline/CMC was acquired by Transdigm group in 2018.

CMC Electronics has an international reputation for the design and manufacture of customised cockpit systems integration, avionics and display solutions for the military and commercial aviation markets.

Based in Montreal Canada since 1903, CMC Electronics also has facilities in Ottawa, Ontario and Chicago, Illinois, serving its customers worldwide.

Financials

Transdigm do not report subsidiary sales, however, at the time of the acquisition of Esterline in 2018 CMC Electronics reported sales of $861m.

This includes simulator, medical and gaming revenues which we estimate accounts for at least 50% of sales.

CMC Electronics revenues are estimated as having been $359m in 2019 and $266m in 2020.

Operations and technology

Location

CMC Electronics operates out of its headquarters located in Montreal where it owns a 272,000 ft² facility.

It also has facilities in St Laurent, Ottawa and Sugar Grove, Illinois.

Capabilities

Avionics computers; The PU-3000 series of Avionics Computers is the fourth generation of Avionics Computers from CMC. These computers include a high-performance multi-core processing capability, an array of graphics performance options (from Quad Head Graphics Processing Units to software based rendering engines).

The FV-4000 is an open architecture avionics computer offering flexible power and advanced technology in a low-cost airborne processing and display generation system.

LCD Displays: The CMA-6800 LCD display is a form, fit and function replacement upgrade solution for the Honeywell ED-800 CRT units on selected regional, corporate and helicopter aircraft. These include: ATR 42/72 series 200/300/500, Bombardier Aerospace Dash8 Series 100/200/300, Fokker 50, Jetstream 41, Hawker 800/1000, Challenger 601, CL-415, Cessna 650, Falcon 900, Gulfstream III and Sikorsky S-76A/B/C.

The latest display development, the MFD 3068, is an ARINC 653-based display platform is based on Green Hills' Integrity 178 tuMP Real Time Operating System (RTOS) and MOSArtTM (Modular Open System Architecture) middleware.

Integrated military cockpits: The Cockpit 4000 is a fully integrated avionics suite that provides a glass cockpit enabling air forces to download their training onto less expensive Basic and Advanced trainer aircraft. System capabilities include primary flight display, integrated communications/ navigation management, steer-point navigation, tactical situation display, engine indication and caution advisory, stores management, no-drop bombing scoring system, and a virtual Multi Mode Radar and Radar Warning Receiver (RWR) training system.

Integrated Avionics Computer: The CMA-5000 supports Multi-Function Displays (MFD), Head-Up Display (HUD) systems and mission functions on modern aircraft. A rugged platform with powerful processing capabilities, the system is designed to satisfy civil certification requirements for avionics systems.

FMS systems: The CMA-9000 is a compact flight management system designed for modern digital cockpits in fixed and rotary wing aircraft. It is intended for civil and military transport as well as helicopter FMS applications. It is the next generation FMS derived from the successful CMA-900 FMS/GPS and the CMA-3000 helicopter FMS. The CMA-9000 conforms to the ARINC-739 MCDU standard making suitable as display and control unit for other systems such as ACARS, ACMS, SATCOM. Moreover, it has the capability to act as Radio Management Unit.

Electronic Flight Bags: CMC's Crew Information System addresses requirements for information sharing associated with cockpit, cabin and aircraft maintenance systems. In conjunction with CMC's new PilotView® Aircraft Information Server, this product line delivers an integrated aircraft information management server that enables a wide range of cockpit and situational awareness applications.

CMC also provides both civil and military applications with a range of navigation and GPS sensors and receivers in support of the product lines noted above.

Customers and contracts

CMC lists its retrofit and upgrade displays/FMS sales on platforms including ATR 42/72 series 200/300/500, Bombardier Aerospace Dash8 Series 100/200/300, Fokker 50, Jetstream 41, Hawker 800/1000, Challenger 601, CL-415, Cessna 650, Falcon 900, Gulfstream III and Sikorky S-76A/B/C.

With more than 3,000 PilotView units delivered to Business Jet, Commercial Airline Operators and Aircraft OEMs, CMC's Electronic Flight Bag is designed with the cockpit in mind (certified for 777 amongst others).

CMC lists the following platforms that are OEM certified for its EFB products;

ATR 42 / 72, 737NG, Global XRS / 5000, Bombardier CRJ700 / 900 / 1000, Dassault F2000 / 900 / 7X, Legacy Embraer 600/650, Embraer E170/165/190

CMC also list a number of STC certified Pilotview EFB platforms including A330/340, 747-800, EMB 135J, 757, Falcon 2000/2000EX, 737-700 BBJ, Challenger 604/605, Global Express 5000, Gulfstream 100/150/GIV/GV.

Strategy

CMC Electronics has achieved an international reputation for innovation and excellence in the design and manufacture of cutting-edge cockpit systems integration, avionics and display solutions for the military and commercial aviation markets.

Recent developments

Mar 2019: CMC announced that RUAG Aviation and the Swiss Air Force have selected its CMA-9000 Flight Management System (FMS) and CMA-5024 GPS Landing System for the modernisation of Swiss Air Force's Cougar helicopters. The modernisation of the Swiss Cougar helicopters further broadens the use of CMC's navigation solutions by the Swiss Air Force, who also operates 15 Super Puma transport helicopters and 20 EC135/635 helicopters, all equipped with CMC's CMA-9000 and CMA-5024.

Counterpoint comment

CMC is a stand-alone business within the TransDigm portfolio and it has benefitted from its focus upon the retrofit/upgrade market sector. It may struggle to continue to find success in the OEM market given the more integrated approach being adopted and the requirement for significant investment.

We also see the Covid pandemic as reducing the number of older legacy aircraft in service which may reduce part of CMC's retrofit market.

19.1.31.3. ScioTeq

Barco Avionics displays (Belgium) was acquired by Esterline in 2015 for $200m and at the time it generated $200m of revenues and employed 600 personnel.

It was subsequently renamed as ScioTeq and then in 2018 TransDigm acquired the business as part of its acquisition of Esterline.

Today ScioTeq offers products which include video displays, smart displays, mission computers, software platforms, and radar displays, are used in the air, on the ground, and at sea, providing mission critical information.

It operates via three business sectors as follows:

- Avionics
- Air Traffic Control,
- Defense & Security

Financials

In 2019 it was reported that ScioTeq employed 322 personnel and generated $105m of revenues.

We estimate that ScioTeq's revenues generated from sales of Avionics was $40m in 2019 and $33m in 2020.

Operations and technology

Location

ScioTeq's main facility is located in Kortrijk, Belgium where it has 130,000 ft² of facility space. It also has support services facilities in Toulouse France, Israel and Singapore.

ScioTeq also has a subsidiary located in Duluth, Georgia, US.

Capabilities

ScioTeq has been serving the Avionics market for 35 years, and is present on more than 150 aircraft types, both civil and military platforms, both fixed wing and rotor wing. ScioTeq's visualisation technology allows it to provide aircraft manufacturers and system integrators the best image quality in a scalable manner, supported by an open system solution (MOSArtTM).

Smart displays: Smart display products combine optical quality with a high-performance multi-core processing capability graphics performance and a set of interfacing options. Equipped with the ARINC 653 compliant MOSArt™ platform services, these displays are capable of hosting multiple, high-demanding software applications developed to varying Design Assurance Levels, up to and including DAL A.

Multi-function displays: Modular design allows customers to simultaneously host combinations of software applications that can be customer proprietary, ScioTeq proprietary, such as Primary Flight Display (PFD), Navigation Display (ND), Synthetic Vision System, etc., and from 3rd parties.

Control and Display Management: These are offered as a complete product family, including the civil CDMS-3739 (ARINC 739), the military-oriented CDMS-3753 (combo ARINC-429 and MIL-STD-1553), and the versatile CDMS-370x, which hosts ScioTeq's unique MOSArtTM platform. This MOSArtTM-equipped version allows customers to develop or integrate their own application (e.g. FMS or mission solution) on the flexible CDMS-3000 platform.

Mission Computers: Mission computers include a high-performance multi-core processing capability. Modular by design, these provide an array of graphics performance options (from Quad Head Graphics Processing Units to software based rendering engines), and a vast set of interfacing options.

Customers and contracts

ScioTeq lists the following platforms as having its commercial avionics installed on the following platforms;

PC-12, PC-24, L600, L650, G-IV, G-V, Citation X, GEX, L45, Tu-204, Tu-214, Be-200, An-124, Il96, Il114, A380, ATR42, ATR72, DHC-6, C-919.

Scio-Teq lists its military platforms supported as follows:

F-16, C-130, C-5, A400M, A330MRTT, C-27J, F-35, Mirage 3, Mirage 5, PC-21, KT-1C, E-2D, P-3, P-8, C-160, C295.

Supporting air forces from multiple countries, including US Airforce, Royal Air Force, French Airforce, German Airforce, Spanish Airforce.

ScioTeq has been active in the upgrade market for many years with display upgrades including EC105, Super Puma, RC-135 Rivet trainer, P-3C, Beriev Be-200.

ScioTeq were also selected by Honeywell to provide a dedicated interface display as part of Primus Epic which was used to upgrade PC12, Y12 and Twin Otter aircraft amongst others.

Strategy

ScioTeq enables its customers to make real-time decisions by providing advanced visualisation solutions with the features and capabilities needed to ensure success. Its products are used in the air, on the ground, and at sea, providing mission critical information to customers on some of the most advanced platforms on earth.

Recent developments

October 2020: Hexagon Geospatial, of Leuven, Belgium – a specialist in software tools for visualising location intelligence – and ScioTeq in Kortrijk – a provider of advanced visualisation solutions – have been selected by

General Atomics to support development of the MQ-9B SkyGuardian. Hexagon will develop additional enhancements to the auto-routing capability currently in development. ScioTeq is the current GA-ASI advanced displays supplier and will be awarded a project to study the feasibility of a vision-based navigation capability for UAS.

Counterpoint comment

ScioTeq is similar to its sister company CMC in that it has a strong focus on upgrade and retrofits, however, we question how sustainable this is if OEM sales are not forthcoming.

We also see the Covid pandemic as reducing the number of older legacy aircraft in service which may reduce ScioTeq's traditional market.

19.1.32. Wind River

Wind River was founded in 1981 as a software company providing industrial customers with critical application software solutions.

It was subject to an IPO in 1993, acquired by Intel in 2009 and then acquired by its current private equity investor TPG in 2018.

For nearly 40 years, Wind River has helped the world's leading technology companies with generation of the safest, most secure devices in the world. And in a new era of autonomy and connectivity, Wind River continues to lead the way. Wind River's software runs the "can't fail" computing systems of modern infrastructure, including mission-critical aircraft, rail, automobiles, medical devices, manufacturing plants, and communications networks.

Wind River's technology is in more than 2 billion devices throughout the world and is backed by a global service support infrastructure.

Wind River supports a number of sectors including the following with key customers identified:

- Aerospace and defense: Airbus Group, BAE Systems, Boeing, Lockheed Martin, Northrop Grumman, GE, Honeywell
- Automotive: BMW, Fiat, Ford, General Motors, Honda, Johnson Controls, Valeo Group
- Industrial and medical: ABB, KUKA, Mitsubishi, Rockwell Automation, Schneider Electric, Siemens, Toshiba
- Medical: GE Healthcare, Olympus, Stryker, Varian
- Networking: ARRIS, Avaya, Ciena, Ericsson, Tellabs

Financials

Intel recorded a reduction in revenues of circa $330m (annualised) when it disposed of Wind River in 2018.

We therefore estimate that in 2019 Wind River generated $365m of revenues across its 6 operating sectors including Aerospace and Defense.

We further estimate that Wind River generated $35m of revenues for avionics related software sales in 2019, and $28m in 2020.

Operations and technology

Location

Wind River has its corporate headquarters in CA, USA however it is supported by a global network of distributors and service centres throughout the Americas, EU and Asia.

Wind River also generates revenues from licensing of software and has specific facilities in the US, EU, Middle East and Asia that service this product offering.

Capabilities

Wind River is a market leader in offering a number of embedded software products as follows:

- Total IoT and embedded OS

- Commercial embedded Linux
- RTOS on a global basis

Wind River supports a range of workflows for a digital world, providing customers with open source offerings, an RTOS, or a combination. This flexibility allows companies to deliver products that leverage the latest community-driven innovations while meeting the safety, security and reliability requirements for mission-critical avionics applications.

VxWorks Real Time operating System (RTOS) has been utilised by many avionics manufacturers that need to operate multiple applications utilising shared resources in real time. These applications are hosted using VxWorks such that the criticality of each is recognised and managed in real time accordingly.

VxWorks is suited to IMA or shared computing resource platforms being adopted by military and civil avionics specifiers.

Wind River® Linux enables customers to build and deploy robust, reliable, and secure Linux-based edge devices and systems without the risk and development effort associated with in-house efforts.

In terms of avionics Linux provides an industry standard upgrade path at lower cost than many in-house bespoke solutions. The benefits of Linux include keeping code base up to date, track and fix defects, apply security patches, customise your runtime to adhere to strict market specifications and certifications, facilitate IP and export compliance, and significantly reduce costs.

Customers and contracts

Within Aerospace Wind River lists its customers as including the following:

Airbus Group, BAE Systems, Boeing, Lockheed Martin, Northrop Grumman, GE, Honeywell and Collins Aerospace.

We also note the following in recent years:

- March 2019. Teledyne e2v, Wind River and CoreAVI announced today that they will provide key technologies for BAE Systems' new mission computer. The solution includes Wind River VxWorks® real time operating system running on Teledyne e2v Qormino® Common Computer Platform, and CoreAVI supplying its temperature-screened AMD Embedded Radeon™ E8860 GPUs as well as its safety critical ArgusCore SC1™ OpenGL®1.0.1 graphics drivers.
- Leonardo Helicopters turned to Wind River for its industry-leading VxWorks 653 product, a commercial off-the-shelf (COTS) platform for delivering safety-critical, integrated modular avionics (IMA) applications.
- Wind River's secure software has served as a key technology for the Mars Science Laboratory rover Curiosity, Northrop Grumman X-47B, unmanned aircraft, CIRA's FTB-1 reusable unmanned spacecraft, and the nEUROn Unmanned Combat Air Vehicle demonstrator, among others.

Strategy

Wind River is accelerating digital transformation of critical infrastructure by delivering the technology and expertise that enable the deployment of safe, secure, and reliable IoT systems. It is a global leader in delivering software for intelligent connected systems, and offers a comprehensive, edge-to-cloud software portfolio designed to address the challenges and opportunities critical infrastructure companies face when evolving and modernising their systems as they work to realise the full potential of IoT.

Recent developments

July 2020: Wind River upholds its long-standing ranking as the technology leader in the real-time operating system (RTOS) and commercial Linux categories with its flagship VxWorks® and Wind River Linux, according to VDC Research. The company has also surpassed Microsoft as the overall commercial leader in the edge compute OS market.

Counterpoint comment

Wind River has a long track record of providing software support to avionics designers and has worked directly with many blue chip customers within the Aerospace & Defence sector. We believe it to be one of the leading software houses in developing next gen open architectures for avionics computing solutions.

19.2. AVIONICS SUPPLIER PROFILES – EUROPE

19.2.1. BAE Systems

BAE Systems is a UK based defense contractor that generated $26Bn of revenues in 2019. It operates through several divisions including air (52%), land (15%), Maritime (26%), and Cyber (5%).

The US represents 42% of total group revenues and BAE has many facilities in the US where it designs and manufactures many of its defense related avionics and sensors products.

BAES is both a military OEM airframer, building platforms such as the Hawk trainer and the Eurofighter Typhoon, and a provider of electronic systems including Flight Controls, Engine FADECs and Electronic Warfare.

In 2000 BAE Systems acquired Lockheed Martin's Aerospace Electronic Systems which provided the basis for Electronic Systems today.

In 2013 BAES disposed of its UK based commercial Avionics operations businesses to Finmeccanica Group (now Leonardo).

BAES's Electronics division is headquartered in Nashua New Hampshire, USA.

The Electronics Division operates via 5 business units as follows:

- Electronic Combat Solutions (ECS)
- Survivability, Sensing and Target solutions (SST)
- C4ISR systems
- Control & Avionic Solutions (incl. Flight Controls)
- Power and Propulsion Solutions (incl. FADECS)

This report covers ECS, SST and C4ISR where BAE provide airborne EW, ECM and sensor systems.

Financials

Electronic Systems	2020	2019
Sales £ms	4,557	4,439
Underlying EBITA[1] £ms	684	687
EBITA margin	15.0%	15.5%

In 2020 BAE Systems reported revenues of £20,862m of which £5,848m was generated within its Electronics Systems division.

BAE Systems commented: "Sales in our Electronic Systems defence business grew by 12%, with almost half of that growth coming from our acquisitions. Our commercial operations were impacted by COVID-19, though overall segment sales growth was around 3%. Underlying EBITA was in line with the prior year, although return on sales was lower reflecting the fall in higher margin commercial revenues. The sector continued to deliver high cash conversion levels. Order backlog benefited from orders for F-35 electronic warfare systems, the Precision Strike business and the C4ISR programmes".

80% of Electronics Systems revenues are generated from airborne applications with the balance split between maritime and land-based operations.

We estimate that BAE generated $883m of revenues associated with its airborne electronic warfare, countermeasures and sensors products in 2019 and $832m in 2020.

Operations and capabilities

Operations

BAE Inc. is a subsidiary of BAE Systems plc located in the US. Headquartered in Falls Church, Virginia, BAE Systems, Inc. employs approximately 35,100 across its major operations in the United States, United Kingdom, Sweden, and Israel,

BAE Inc has its Electronics Systems headquarters in Nashua, NH, USA where it develops much of its Electronic Warfare capabilities including DEWS electronic warfare and countermeasures as fitted to F15 and F35 platforms.

BAE Systems has design development and support for its Electronics Systems division in New Jersey, Texas, Virginia and Georgia.

BAE's Electronics Systems employs 16,600 personnel throughout the US, UK and Europe.

Capabilities

BAE Systems' digital electronic warfare system geolocates potential threats by detecting adversary radars at significant ranges, allowing the aircraft to limit its own radar emissions, enabling it to better conceal its location when operating in hostile territory. Data collected by the system helps identify, monitor, analyse, and rapidly respond to threats by providing the pilot with maximum situational awareness. Advanced avionics and sensors provide a complete view of the battlespace, enabling pilot to take appropriate action and ensure mission success.

Key features of BAE's electronic warfare capabilities include:

- integrated radar warning, targeting support, and countermeasures in one system
- Reduced long-term lifecycle costs to keep the aircraft fielded now and in the future
- Enhanced situational awareness through all-aspect, broadband radar warning and geolocation capabilities
- Always-on multispectral, radio frequency (RF) and infrared (IR) countermeasures enable rapid response for complete pilot protection
- A 360º view of the battlespace, promoting mission success even in signal dense environments.

Survivability, Targeting & Sensing Solutions exploits the electro-optical and infrared spectrum to provide leading threat warning and infrared countermeasures systems, precision guidance and seeker solutions, advanced targeting solutions, head-up displays and state-of-the-art tactical imaging systems.

C4ISR Systems: BAE addresses the market for actionable intelligence through innovative technical solutions for airborne persistent surveillance, identification systems, signals intelligence, underwater and surface warfare solutions, and space resiliency products.

Tactical networks – defending Mission Computers: BAE develops cyber defense systems that protect wireless tactical networks against zero–day attacks. Leveraging expertise in autonomic defense and wireless networking, BAE's cyber defense system combines monitoring, decision, and response technologies to automatically detect and contain any attack, known or unknown, and preserve critical mission capabilities.

Next Gen electronic warfare systems: With more than 60 years of experience BAE's electronic warfare systems have flown on over 120 platforms and operate on 80% of U.S. military fixed-wing aircraft, over 95% of U.S. Army rotary-wing aircraft, and those of U.S. allies. BAE Systems is the sole electronic warfare provider for 5th generation F35 aircraft.

Electronic Combat Solutions. Provides capabilities in advanced electronic warfare solutions for airborne applications, including electronic support, electronic attack, and electronic protection technologies.

- Electronic Protect (EP): BAE supplies the Directional Infrared Countermeasures (DIRCM) category, with a laser-based Advanced Threat Infrared Countermeasures (ATIRCM) system that protects fixed-wing and rotary aircraft from missile attacks under a more comprehensive range of mission situations.
- Electronic Support (ES) follows operational directives to rapidly detect, intercept, identify, and track electromagnetic energy sources to recognise threats, collect targeting and signals intelligence data, and

inform future operational planning. ES threat detection is often considered Electronic Warfare's intelligence, surveillance, & reconnaissance (ISR) mission, which also includes geolocation and direction-finding capabilities.

- Electronic Attack (EA) is the use of electromagnetic or directed energy weapons to assault enemy forces' electronic infrastructure with the intent to degrade or eliminate their combat capabilities. This includes threat analysis and response, as well as countermeasures such as signal jamming, electromagnetic deception (spoofing), lasers, radio frequency (RF) weapons, or any combination of the above electronic warfare tools to achieve threat neutralisation.

Customer and contracts

BAE systems provides the electronic warfare suite for the F-35 lightning fighter platform and has delivered 500 systems to date. BAE supplies the following key avionic/sensor suites for the F-35:

- Management computer technology which is currently undergoing an upgrade development programme with Lockheed Martin.
- Active inceptor system
- Electronic warfare system (classified)

BAE supplies the F-22 Raptor programme with its AN/ALR-94 EW suite which provides advanced self-protection to detect and defeat surface and airborne threats with cutting-edge offensive and defensive technologies that combine robust situational awareness, precision targeting support, and robust threat countermeasures

BAE provides the AESA Radar system for the Eurofighter Typhoon – with the contract being upgraded and extended in 2020.

Via a contract with Boeing, BAE systems provides the USAF with its Eagle Passive Active Warning Survivability System for the F-15 fighter aircraft. The EPAWS provides advanced aircraft protection and has completed successful F-15 aircraft flight tests.

BAE also has a contract to digitally upgrade its ALR-56 Radar Warning Receiver system, enhancing the capability of technology on F-15 jets.

Via a contract with Boeing and Warner Robins Air Logistics Complex, totalling more than $1bn (£0.8bn), BAE is responsible for the installation of the Digital Electronic Warfare System (DEWS) on new and existing F-15 aircraft. BAE are also executing a contract worth in excess of $300m (£227m) to provide DEWS to support the sale of new F-15 aircraft to another international customer.

BAE states that due to the sensitive nature of electronic combat systems and technology, approximately one quarter of its Electronic Systems' revenues are driven by its work on classified programmes.

Strategy

BAE systems is a market leader in EW and is already developing 6th generation EW technology for upgrades to the F-35 and next generation platforms. It also has extensive capabilities within Mission Computing, Radars, ECM and related sensor technologies.

It plans to continue to invest in Electronic Systems as a key part of its overall portfolio.

Recent developments

January 2021: The U.S. Navy announced it has awarded contracts of $81.3 million to BAE Systems and $64.1 million to Lockheed Martin for F-35 electronic warfare system upgrades. BAE Systems received a contract modification to produce 1,512 radio frequency countermeasures for Lot 12 of F-35 Joint Strike Fighter aircraft in use by the U.S. Navy, non-U.S. Department of Defense participants and Foreign Military Sales customers.

December 2020: Boeing are moving to production of electronic warfare avionics for the USAF F-15 jet fighter fleet that will help protect the combat aircraft from radar-guided missiles. BAE's supply of EPAWSS will be part of the avionics suite of the next-generation F-15EX, which is based on the F-15 Advanced Eagle that Boeing is building for the air forces of Qatar and Saudi Arabia, which has a digital electronic warfare suite, an

infrared search and track (IRST) system, and the Raytheon APG-63 active electronically scanned array (AESA) radar.

November 2020: BAE Systems has been awarded contracts from the U.S. Army to develop key technologies for the Advanced Teaming Demonstration Program (A-Team). BAE Systems was the only company awarded contracts for three of the program's four focus areas, designed to advance manned and unmanned teaming (MUM-T) capabilities that are expected to be critical components in the U.S. Army's Future Vertical Lift (FVL) program. BAE Systems was selected to deliver a highly automated system to provide situational awareness, information processing, resource management, and decision making that is beyond human capabilities.

Counterpoint comment

BAE has been very successful at growing its revenue base in the US (42% in 2019) where a significant proportion of the market exists. The fact that the US DoD relay upon a UK company to provide some of the most sensitive systems on the F-35 is proof of its leadership position within military systems.

19.2.2. Diehl Aerospace

Diehl Aerospace, a joint venture between Diehl (51%) and Thales (49%), is primarily an avionics company. It is part of Diehl Aviation (known as Diehl AeroSystems until 2018), which is one of five corporate divisions in the Diehl Group, a German family-run enterprise with business fields in several industries and a workforce of more than 15,889 employees worldwide. All aviation activities within the Group are consolidated under Diehl Aviation.

Diehl Aerospace was founded in 2006 as result of the merger of Diehl Avionik Systeme GmbH and Diehl Luftfahrt Electronik.

Financials

Diehl Aviation had sales of €1,488m in 2019 and 5,690 employees.

Diehl Aerospace had sales of €270m and 1,300 employees in 2015, the latest year for which separate financials are available publicly.

Counterpoint estimates that avionics sales were $250m in 2019 and $165m in 2020.

Operations and technology

Location

The headquarters of the company are in Überlingen, Germany.

It has a fully owned subsidiary in Singapore, Diehl Aerospace Pte. Ltd. The Singaporean company was set up in joint cooperation of both shareholders of its parent organisations, Diehl and Thales.

Diehl Aviation has Customer Support Centres in Sterrett (Alabama), Seattle, Charleston in addition to other CSCs in Toulouse (France), Dubai and Singapore.

Capabilities

Diehl Aerospace designs and manufactures avionics systems in the following areas:

- Cabin and Utility Control Systems including:
  - Doors and Slides Management System (DSMS) to electronically control and centrally monitor the passenger and freight doors as well as the relevant emergency hatches and slides.
  - Cabin lighting control systems
  - Cabin security systems
- Cockpit and Display Systems including:
  - Multifunction Displays for all Airbus aircraft types. The latest A350 XWB Display System allows the presentation of flight and navigation parameters as well as the communication between the crew and the various software applications.
  - Symbol Generators: The Diehl Aerospace Centre of Excellence for symbol generation develops state-of-the-art technologies for graphic generation and processing.

- Flight control:
  - Flight Control Unit (FCU); an intelligent interface between the pilot, autopilot, and electronic display system in the cockpit. The FCU is an equipment that contains controls and displays required for: Auto-Flight System, Primary Flight Display configuration including baro setting. Navigation Display (ND-CP) configuration including: Range and Type of display, Weather information display, Terrain information display, Traffic information display. The FCU is installed in the glareshield of the Cockpit.
  - Actuator Control Electronic (ACE) for Honeywell Flight Control Electronic (FCE) of the Boeing 787. The ACE is connected to flight control actuators, associated sensors and acquires signals from the flight control internal and external sensors. The ACE is designed as self-checking pair and provides the highest data integrity to the flight control application hosted in the Flight Control Modules of the Honeywell FCE.
- High lift control systems
  - Slat Flap Control Computer (SFCC) controls and monitors the slats and flaps. This is realised by activation, control and monitoring of the actuators which move the slats and flaps. Each SFCC comprises of one slat and one flap channel.
- Integrated Modular Avionics
  - Core Processing Input/Output Module: The CPIOM is a high performance computer which provides processing capability to host multiple segregated applications on one computer. A standard ARINC 653 application programme interface enables clear independence of the application towards the computing device. The flexible core software is fully configurable by the seamless Tool Suite. The CPIOM is connected to the Avionic Full Duplex Switched Ethernet (AFDX) aircraft bus using Diehl Aerospace's AFDX End System.
  - The RDC consists of a high performance I/O computing intelligence including a core software. The interfaces (i.e. inputs, outputs and digital buses) are members of a standardised interface catalogue. Depending on the specific position in the aircraft the RDC selects different pre-defined configurations and adopts the functions accordingly.
  - AFDX End Systems: The AFDX communication data bus network is a worldwide standard defined in the ARINC 664 documentation. Most of the avionics computers today use this standard for intercommunication. An Avionics Full Duplex Switched Ethernet (AFDX) End System is available in PMC standard format that can easily be integrated to connect each computer to that network. The AFDX End System is available also to operate under harsh environmental conditions.
- APU control unit
  - Versatile Electronic Control Box: The abbreviation VECB denotes a universal engine control computer system for auxiliary power units. It controls and monitors the auxiliary power units in the aircraft. The VECB is a versatile system, meaning that the same unit can control different types of single engine families without substantial modifications.

The Diehl Aerospace Centre of Excellence for symbol generation develops state-of-the-art technologies for graphic generation and processing.

Customers and contracts

- A330; slat flap control computer and command sensor unit
- A380; display systems for the Cockpit and Display System (CDS) and the Onboard Airport Navigation System (OANS), Doors and Slides Management System (DSMS) (now aftermarket only)
- A320 family; Diehl Aerospace produces the Display Management Computer (DMC) of the A320 Cockpit Display System. The DMC is a data concentrator, that collects all data from sensors and external sources, consolidates it and sends it to the cockpit displays.
- A350XWB; Diehl Aerospace in cooperation with Thales provides Multifunction Displays for all Airbus aircraft types and develops the Display System for the A350 XWB. The Display System allows the presentation of flight and navigation parameters as well as the communication between the crew and the various software applications. The work share of Diehl Aerospace consists of a metal housing with integrated ventilators for the cooling in the case of an emergency, of a Power Supply-I/O Board including an attached AFDX Module and a graphics processor board.

- Eurofighter Typhoon; Landing Gear Computer, which controls and monitors the landing gear.
- Boeing 787; actuator control electronics. Since 2004 Diehl Aerospace, in cooperation with Honeywell, has developed components for the Flight Control Electronics (FCE) package for the Boeing 787. The FCE package consists of Flight Control Modules (FCMs), Actuator Control Electronics (ACEs), Power Conditioning Modules (PCMs), a Mode Control Panel (MCP), and Rate, Acceleration and Pressure Sensors. The FCE package integrates fly-by-wire primary flight control, high-lift control, autoflight, and processing of air data/inertial data for use by other airplane systems.
- NH90; display systems for the Helmet-Mounted Sight Display (HMSD) and Operator Control Panel (OCP)
- Airbus Helicopters Tiger; display systems for the Helmet-Mounted Sight Display (HMSD) and Operator Control Panel (OCP)

Strategy

In November 2020 Diehl Aviation announced the steps it would be taking to align itself for the post Covid-19 market environment: "In response to the crisis in aviation triggered by the corona virus, Diehl Aviation is commencing implementation of a future-oriented project with the objective of providing the division by the end of 2022 with an economically sustainable and future-oriented cost structure, through restructuring and an innovation campaign. Since the spring of 2020, the aviation industry has suffered a slump in demand by about half due to the fall-out from the corona pandemic. Airlines and aircraft manufacturers assume that it will take years to get to back to pre-crisis levels. Specifically, Diehl Aviation expects that the business volume in 2022 will be slightly more than half of 2019 sales levels. In its concept for the future, the company plans to retain all of its sites in Germany and to employ around 4,000 people worldwide and 3,000 people in Germany. Following a peak in employment in 2019 with around 6,000 employees and steps to improve flexibility already implemented since then, this corresponds to a reduction of up to 1,400 jobs in Germany by 2022. This will affect all divisions, sites and companies, albeit to varying degrees and to a different extent. These measures will enable Diehl Aviation to reverse the trend by 2022 and to return to profitability by 2023.

Moreover, Diehl Aviation will develop new products and get involved in new projects. Among other things, these include product innovations for touchless cabin functions in commercial aircraft, entering the Urban Air Mobility (UAM) market segment as well as taking part in the multi-national military Future Combat Air System (FCAS) project and also the development of sustainable lightweight materials as well as systems for flying with zero emissions".

Recent developments

July 2020; Diehl Aerospace announced that having been involved in the two-year concept phase (Joint Concept Study) for the development of the European FCAS (Future Combat Air System), it was now moving into the demonstration phase. The aim of the project initiated by Germany and France – which Spain has since joined as a further partner - is to develop a New Generation Weapon System (NGWS) by 2040.

May 2020; Diehl Aerospace, a unit of the leading aerospace supplier Diehl Aviation, has signed a contract with Volocopter for the development and production of Flight Control Computers (FCC). Volocopter is the manufacturer of the first fully electric air taxi in certification to transport passengers safely and quietly within cities. Under this agreement, Diehl Aerospace will supply the FCCs including the primary and backup control computers for Volocopter's "eVTOL" (electrical vertical take-off and landing) aircraft named VoloCity, currently under development.

November 2019; After initiating its presence in Charleston, South Carolina, in early 2018, Diehl Aviation is expanding its range of services at the site.

Counterpoint comment

Diehl Aerospace is a niche avionics supplier but has a strong position on Airbus programmes and is also an important military supplier on German programmes.

19.2.3. Hensoldt

Hensoldt is a publicly owned German military sensor manufacturer, albeit with a significant German Government shareholding.

The company originated from the electronics business unit of the defence division of the Airbus Group. At the end of February 2017, Airbus sold this business to KKR, a prominent US private equity company, for €1.1 billion, and at this point the business was renamed Hensoldt. Since then, Hensoldt has acquired the German company Euroavionics and British radar specialist Kelvin Hughes as well as the start-up PentaTec. Most recently, Hensoldt acquired the French-based company Nexeya and IE Asia-Pacific and Tellumat in South Africa.

In September 2002, there was an IPO, and the company was listed on the Frankfurt Stock Exchange.

In December 2020, the German Federal Government announced its decision to acquire 25.1% of Hensoldt's shares from KKR, leaving KKR with approximately 43% of Hensoldt's shares upon closing of the transaction.

Hensoldt's business is divided into two segments: Sensors and Optronics. Sensors comprises three divisions: Radar, IFF & COMMS, Spectrum Dominance & Airborne Solutions and Customer Services. The Optronics division's Airborne Solutions unit includes Hensoldt's avionics activities.

Financials

Hensoldt has over 5,400 employees and had revenues of €1,207m in 2020 and €1,114.2 million in 2019. Of this we estimate that $165m was avionics in 2019 and $151m in 2020.

Operations and technology

Location

Hensoldt is headquartered in Germany, and has a large presence in Europe, with a global footprint. It has sales offices in 19 defence markets globally. its major production facilities in Germany are in Ulm, Oberkochen, and Pforzheim (formerly EuroAvionics GmbH). It has a production site in Massy, France and Enfield, United Kingdom, as well as another two in Irene and Pretoria, South Africa.

Capabilities

Hensoldt's Airborne Solutions range from Avionics components and systems to complex Integrated Airborne Mission Systems, as well as Unmanned Solutions.

In avionics it offers the following:

- Airborne Computing
  - Single & Multi Core Processing computers
  - Various accessories for small, medium and large sized computers
  - Flexible control options (control unit, keyboard, touchscreen, line select keys joystick)
  - RTCA/DO qualified systems
  - Compact Certified Airborne Computer for civil and military applications
  - Flight Control Computer
  - Customisable Mission Computing
- Flight and Mission Data Recording & Management
  - Lightweight Crash Recorder (LCR) models
  - Fixed Crash Recorder (FCR) models
  - Deployable Crash Recorder (DCR) models
  - Solid State Data Carrier and Data Transfer Unit (SSDC + DTU) - a transfer solution for mission and maintenance data
- Connectivity
  - Cyber Security Solutions

  - Flying Firewall and Connectivity systems
  - Data exchange capabilities between ground and air
  - Individual and mission-optimised system configurations
- Mission Management/Pilot Assistance
  - Situational Awareness and Mission Management Systems
  - State of the Art maps
  - Fully certified computers
  - Vector Overlay Generator
- Video Management
  - Powerful mission systems for camera operations
  - Video Distribution Units
  - Video Configurations options
  - Video and Audio Recorder
  - State-of-the-art features for any airborne sensing platform
- Unmanned Systems
  - UAV/OPV systems
  - Manned-Unmanned Teaming solutions
  - Autonomous flight control
  - Systems for harshest environment conditions
  - Various payloads and sensors
- Mission Planning Support
  - Weight & Balance solutions for Windows PC, Laptop and iPad
  - Mission Planning Tools
  - Using/preparation of confidential maps and databases
  - Mission network through multiple communication methods
  - Simulation software for training purposes
  - Ground-based and modular mission management system
  - Fleet Management System
  - Sensor control software solution
- Data Analysis and Evaluation
  - Planning for optimum aircraft availability
  - State Data Carrier Adapter - Inferface device for read- out SSDC
  - Enhanced Handheld Computer - recorder models for large aircraft
  - Read-out Station for crash recorder products
- Cloud Solutions
  - OPTARION ® OptaCloud: Multi-Mission Planning in a safety and security cloud-based environment.
- Active Sensing
  - SferiSense500: Obstacle warning system based on very advanced laser detection and ranging technology.

Customers and contracts

Hensoldt's revenues are split geographically as follows:

- Germany 43%
- Rest of Europe 23%
- Rest of the World 33%

Over 30 years it has more than 6,500 delivered Airborne Computers operated on all major fixed-wing and helicopter civil and military platforms.

Significant contracts include:

- Eurofighter; Hensoldt (Germany) and Indra (Spain) are developing the Eurofighter Common Radar System (ECRS) MK 1 radar that will be delivered to Eurofighter partner Airbus Defence & Space for installation in German and Spanish Eurofighter combat aircraft.

Strategy

"We strive to become Europe's leading, platform-independent provider of defence and security sensor solutions with global reach."

- Provide integrated customer solutions building beyond component and sub-system heritage
- Champion core markets and increasingly access adjacent markets including civil applications
- Strive to develop cutting edge new solutions and to exploit new technology trends
- Strengthen international and export reach building on strong European developed capabilities

Recent developments

January 2021; Hensoldt has acquired the Austrian company SAIL LABS, a leading provider of AI-based Open-Source Intelligence (OSINT) solutions. With this step, HENSOLDT completes its sensor portfolio with intelligent solutions for the digital space and thus takes a further step towards becoming one of the leading data analysis houses in the security and defence sector in Germany.

November 2020; Hensoldt and its subsidiary Euroavionics in Pforzheim have entered into a close cooperation with SPAES GmbH & Co.KG from Karlsruhe. The company is an equipment and engineering service provider for aircraft, especially helicopters and jets. With the new distribution partnership with SPAES, Hensoldt takes a further step to expand its network in the civil avionics market.

Counterpoint comment

A highly capable supplier. The core busines is sensors it is a significant avionics supplier particularly in military but also in commercial markets.

19.2.4. Leonardo

Leonardo can trace its history back to the 1860's, however, its modern development commenced in 1948 when following the war, a number of industrial businesses including helicopters, structures, defense electronics came together. Agusta formed a JV with Westland in the 1960s and this eventually became the helicopter business of today. Various subsidiaries of Ferranti, Marconi and Racal formed the Selex ES electronics business which today is Leonardo Defense Electronics.

Leonardo also has a major subsidiary, Leonardo DRS, which has a number of facilities in the US (see below).

Leonardo had sales of €13.4 billion of in 2020 via the following operating divisions:

- Helicopters - €3,972m
- Defense Electronics & Security - €6,525m
- Aeronautics - $3,393m
- Other - €407m

Leonardo had 49,882 employees in 2020.

The majority of Leonardo's avionic products today sits within its electronics business unit and its Leonardo DRS business in the US.

The Defense and Electronics security business division breaks down further, including Leonardo's shareholding, into the following:

- Electronics Division (100%)
- Cyber Security Division (100%)

- Leonardo DRS (100%)
- MBDA (25%)
- Vitrociset (100%)
- Elettronica (33%)

The following part of this company profile refers to both the electronics division and Leonardo DRS.

Financials

The Electronics and Defense security division of Leonardo reported €6,525m (including Leonardo DRS) of revenues in 2020.

We estimate that Leonardo's airborne avionics and sensor sales in 2019 were $306m and $289m in 2020.

Operations and technology

Location

Headquarters of the Leonardo Group is in Rome. Within Italy, Leonardo has over 31,000 employees and 70 facilities, 38 of which are manufacturing plants, where it designs, develops, and make helicopters, aircraft, avionics systems, land and naval systems, cyber and security solutions, space systems.

Leonardo employs over 7,300 people across 9 sites in the UK, where it designs and builds new-generation helicopters, advanced avionics systems, land and naval optronics and communications.

Leonardo also has facilities in Poland with PZL-Swidnik S.A., a company with over 2,800 people that develops and manufactures helicopters.

Within the Leonardo DRS (US based subsidiary) business there are a number of facilities located in the US as follows:

- Leonardo DRS has its headquarters in 2345 Crystal Drive, Suite 1000, Arlington, Virginia, USA.
- Airborne and Intelligence systems located in Melbourne, FL. Leonardo DRS' Airborne & Intelligence Systems line of business provides ISR components, sensors and integrated systems spanning the EO/IR, SIGINT, MASINT, and Communications domains.
- Airborne and Intelligence systems located in Germantown, MD. This facility designs and manufactures high-performance RF tuners, receivers and exciter technologies, as well as SIGINT products emphasising small size, light weight and minimised power consumption.
- Airborne and Intelligence systems located in Fort Walton Beach, FL 32548. The line of business occupies a campus in Fort Walton Beach, Florida that is home to the Advanced Programs Support (APS), Air Combat (AC), and Mission Systems (MS) product lines.
- Electro-optical and infra-red systems has a facility located at in Cypress, CA. The Leonardo DRS Electro-Optical and Infrared Systems line of business in Cypress, CA conceptualises, develops, produces and sustains sensors and systems in the visible through long wave IR spectrum.
- Electro-optical and infra-red systems located at in Melbourne, FL. Leonardo DRS Electro-Optical Infrared Systems provides innovative, world-class military thermal imaging systems.

Capabilities

Leonardo's electronics division provides airborne, land and naval applications from advanced components to fully integrated ISR, C4I, ISTAR solutions; combat and mission management systems, tactical unmanned systems, radar, communications, electronic warfare, optronics, infrared search and track, artillery, underwater systems, air and maritime traffic management, automation systems and space payloads and equipment.

Key capabilities are described as follows:

Aircraft Monitoring Unit: In order to meet current and expected future avionics recording requirements, the AMU acquires and processes a diverse mix of signals and supports several digital I/O formats including MIL-

STD-1553B, ARINC-429, ARINC-717 and high-speed RS-22. The AMU can also output data to multiple recording devices for dual-combined recorder installations.

Station Keeping Equipment: With the help of the AN/APN-243, aircraft can operate within a 10 nm radius of a selected participating master system on the same frequency, allowing for close contact between aircraft. The system is also designed for easy, accessible upgrade, with reduced weight, size and cost.

Aircraft Mission Recorder: The solid-state recorder (USSR) is a reliable, ruggedised, next generation net-centric data storage device, combining the functionality of a multi-channel video/audio/1553 recorder, mission data server and adjunct. It replaces legacy single-channel 8mm tape-based recorders as well as less capable, standalone solid-state recorders (SSRs) in fixed or rotary winged, manned or unmanned aircraft.

Altitude Hold and Hover Stabilisation: In brownout or whiteout conditions, over-water hovers and tight landing zones (LZ), the AHHS system provides hands-free cyclic and collective control for cruise, low-altitude hover operations, precision hover and drift control, automatic descend to the ground, and automatic go-around. Giving pilots confidence, safety and more precise control in otherwise blinding and debilitating conditions.

Modernised TADS/PNVS Receiver for the Apache: Leonardo DRS provides the integrated forward looking infrared (FLIR) receivers for both the Modernised Target Acquisition Designation Sight (M-TADS) and the Modernised Pilot Night Vision Sensor (M-PNVS) for Lockheed Martin's Arrowhead® — Apache's advanced electro-optical fire control system, which is used for target acquisition/designation and safe flight in day, night and adverse weather conditions.

Ruggedised Laser System: Solaris™ is a lightweight, high-power military ruggedised laser system for aircraft survivability applications. Solaris™ has been adopted as the laser source for Northrop Grumman's Common Infrared Countermeasures (CIRCM) solution, their 5th generation infrared countermeasure (IRCM) technology for warfighter protection. Solaris provides fast, simultaneous breaklock jamming with high power in multiple colours to defeat current and future threats.

Radar systems: Leonardo is a leader in Airborne Radars for both surveillance and fire control applications. Its portfolio extends from value-driven mechanically scanned radars to the latest software-based AESA technology.

Electro-optical Infra-red: SkyWard has been designed and developed to satisfy the more demanding requirements of 5th generation fighter aircraft with an embedded solution. A pod configuration is also available to allow easy installation on existing platforms. It comprises two Line Replaceable Units (LRU) - a Sensor Head Unit (SHU) and a Processor Unit (PU).

Airborne Gateway Processor: The AGP is an Aircraft Survivability Equipment (ASE) controller contained within a single, flight qualified, Line Replaceable Unit. It integrates federated ASE sensors and countermeasures to provide a combined threat picture and prioritised tactical response per the user-programmed Pre-Flight Message (PFM). The AGP is installed by Boeing as aircraft 'A'-Kit on all new and remanufactured AH-64D/E Apache Longbow Helicopters.

Mission computing:

- SP2305 is an airborne Link 11 system providing modem and network control functions to operate in a tactical digital information link. It employs networked communication techniques and a standard message format for the exchange of information between airborne, land and shipboard tactical data systems using either HF or UHF equipment.
- The Cockpit Mission Display Processor (CMDP) is a high safety avionics computer platform with a powerful embedded graphics capability. It is configured using the base of the standard hardware and layered software modules, that make the CMDP certifiable according to DO178B and DO254 level B (optionally level A) and suitable as a main cockpit mission computer.

Customers and contracts

The Commercial element of Leonardo's business provides Electronic Controls, Display Solutions and Lighting Systems for commercial and military. aircraft, in support of many of the most advanced fixed and rotary

wing programs, including the Lockheed Martin Joint Strike Fighter (JSF/F-35) and Airbus A320, A400M and A350XWB.

Specific contracts are listed below:

- Saab Gripen C/D: Skyward-G IRST (Infrared Search & Track) passive sensor and IFF (Identification Friend-or-Foe) system
- F-35: Targeting system laser
- Osprey radar has been selected for platforms ranging from the US Navy's MQ-8C Fire Scout unmanned helicopter to the Leonardo AW101 helicopter. It is the only radar of its type currently available to offer full spherical coverage with no moving parts.
- NH90: IFF Interrogator.
- AH-64: Airborne Gateway Processor for Aircraft Survivability Equipment.
- AH-64 UK fleet: Defensive Aids System (DAS)
- Typhoon: Praetorian Defensive Aids Sub-System (DASS), Captor-E Radar sub-system
- Schiebel UAS: AESA Radar system
- Royal Canadian Air Force's (RCAF's) CP-140 ISR/ASW aircraft: 'Miysis' Directed InfraRed CounterMeasure (DIRCM) system
- Saab Global Eye Swingrole Surveillance system: AESA Radar system
- General Atomics MQ-9B: electronic warfare suite.

The UK Dragonfire consortium – led by MBDA and comprising Leonardo, QinetiQ, Arke, BAE Systems, Marshall and GKN – has brought together the relevant UK industry expertise to develop a Laser Directed Energy Weapon (LDEW) Capability Demonstrator Programme (CDP) on behalf of the UK Ministry of Defence, under contract to the Defence Science and Technology Laboratory.

Strategy

Leonardo's strategy comprises the following key steps;

- Strengthen our core
- Keep strong focus on our core to fuel growth
- Delivering the significant Backlog
- Exploiting full potential of product Portfolio (platforms + sensors & systems)
- Grow Customer Support & Training
- Capturing growing demand for Cyber Defence

Transform to Growth

- Adding new capabilities
- Leveraging these capabilities in a more integrated way across businesses
- Evolving to meet changing market and customer needs
- Master the new, accelerating innovation

Identify, develop, leverage, scale new technologies "transversal" across the Group

- Fully digitalised in engineering, products and offering
- Drive innovation leveraging our 10,000 engineers talent pool

Recent developments

June 2020: Leonardo DRS announced that it has received a contract from the U.S. Naval Air Systems Command to provide engineering design and test hardware for AN/AAQ-45 Distributed Aperture Infrared Countermeasure (DAIRCM) advanced aircraft protection systems. The mixed cost-plus-incentive-fee and firm-fixed-price, contract is worth $120 million.

February 2019: Leonardo has signed a contract worth approximately €180m to provide new electronic warfare training equipment for the NATO Joint Electronic Warfare Core Staff (JEWCS). Leonardo was selected in an international competition and will incorporate technology from partners Cobham and Elettronica Group.

Counterpoint comment

Leonardo has good access to the EU market, the US market via Leonardo DRS and it also enjoys significant foreign military sales. Interestingly, its own internal market for electronics, i.e. its family of helicopters, is run at arms-length and avionics are competitively sourced.

We believe that Leonardo is well positioned to continue to grow within the defence sector.

19.2.5. Meggitt

Meggitt plc is a publicly listed UK company with sales of £1,684 million in 2020. It focuses on components and sub-systems operating in harsh environments with high technology content and significant aftermarket. It primarily operates in the aerospace and defence markets, with some interests in the energy market. It now reports four segments:

- Airframe systems
- Engine systems
- Energy and equipment
- Services and support

Meggitt Avionics is part of Meggitt Sensing Systems, one of the world's leading providers of high-performance sensing, monitoring, power and motion systems. The division's capabilities include air data systems and flight displays; ignition systems; motion and position sensors; power generation and conversion; as well as sensing and machinery monitoring.

Meggitt Avionics' roots go back to 1852, when they were originally known as Negretti and Zambra, suppliers of barometric pressure instruments.

Meggitt Avionics today supplies ADAHRS, Displays, Air Data Computers, Oxygen systems and sensors.

Financials

The Airframes division, in which Meggitt Avionics sits, generated sales £793.1m in 2020.

We estimate that Meggitt Avionics generated $52m in avionic related revenues in 2019 and $36m in 2020.

Operations and technology

Location

Meggitt's avionics business is located in Fareham, UK with its own dedicated facility comprising 60,000 ft².

Capabilities

Key product offerings include the following:

- ADAHRU: An integrated air data and attitude/heading reference unit. Combines both measurement systems into a single line replaceable unit.
- Air Data Unit (ADU) is a stand-alone solid-state device that measures pitot and static pressures
- Secondary flight display instrument for commercial, military and rotary wing platforms. Provides attitude, altitude and airspeed with a single 3ATI display unit
- Electromechanical Indicators: Meggitt provides a range of 2,3 and 4 ATI instruments that show attitude, altitude, airspeed, engine parameters and other key performance indicators.

Meggitt Avionics also supplies Oxygen systems for pilots and crew, however, this product is not within the scope of this report.

Meggitt offers a repair and overhaul service for its range of products also from within its site in Fareham, UK.

Customers and contracts

Meggitt works with the major aircraft OEMs and its systems are used on many large commercial aircraft programmes including: A380, 777X and MA700 as well as business jets and trainers including the HondaJet, Cessna Citations, Dassault Falcons and Pilatus PCs.

Meggitt also has a significant presence within the Rotorcraft sector working with all the major helicopter OEMs with systems on civil and military helicopter programmes, including: AH-64 Apache, AW109, AW139, AW189, AW101, AW129, CH-47 Chinook, H130 and Korea's Light Armed Helicopter.

Meggitt supplies its integrated secondary flight display unit to Leonardo Helicopters, HondaJet, Bombardier Learjet, Textron Aviation business jets, Boeing Apache.

Meggitt supplies the following customers with its Air Data Unit (ADU); BAE / Hawk variants, Pilatus, Textron Aviation business jets, Dassault.

Strategy

Meggitt Avionics is a relatively small niche provider of stand-alone avionics products which are utilised in smaller airframes. However, there is some exposure to these stand-alone boxes becoming integrated within packaged avionic solutions.

It is not clear what the strategy is for investment and development of any new offerings by Meggitt Avionics.

Recent developments

January 2021: The US Navy contracted Meggitt to provide liquid cooling for avionics thermal management aboard P-8A maritime patrol jet. Meggitt's liquid palletised system provides essential cooling to mission-critical equipment and sensors aboard the Navy P-8A maritime patrol aircraft.

Counterpoint comment

Meggitt Avionics does not appear to be a core part of Meggitt's offerings, and we therefore believe that it may be a candidate for disposal at some time in the future.

19.2.6. Rohde & Schwarz

The company was founded more than 85 years ago by university friends Dr. Lothar Rohde and Dr. Hermann Schwarz.

The Munich based technology group develops, produces and sells a wide range of electronic capital goods for industry and government customers with a focus on solutions that contribute to a safer and connected world.

Rohde & Schwarz has an extensive sales and service network and is present in more than 70 countries, primarily with its own subsidiaries. Exports account for approximately 85 percent of revenue. The company is headquartered in Munich, Germany, and has strong regional hubs in Asia and the USA.

It operates through 4 distinct business areas including:

- Test and measurement
- Broadcast and media
- Aerospace, defense and security
- Network and cybersecurity

Rohde & Schwarz meets the high requirements of the aerospace and defense industry (Aerospace & Defence) with its high-end systems for use in radar and satellite technology, avionics, navigation and military communications. The company is also participating in urban air mobility (UAM) initiatives and provides businesses with all the T&M equipment they need.

Financials

Rohde & Schwartz had net revenues of €2.58 billion in the 2019/2020 fiscal year (July to June) and we estimate that $75m was related to avionics products in 2019 and $70m in 2020.

Operations and technology

Location

Central R&D is based at company headquarters in Munich. Rohde & Schwartz's other R&D centres are located throughout Germany as well as in the USA, Singapore, China, Korea, Denmark, France, Great Britain, Romania and Switzerland.

Capabilities

Rohde & Schwartz offer a wide range of ground-based communication systems for ATC providers that link to airborne traffic. Their equipment is installed at over 200 ATC centres throughout the world.

Rohde & Schwartz have a number of distinct technologies that are applied to airborne platforms as follows;

- Electronic protective measures: (EPM) protect radio links from electronic countermeasures (ECM) such as jamming. These methods ensure a jam-free radio link. To protect radio links from tapping and spoofing; the information being transmitted can be encrypted via embedded encryption or additional external encryption devices.
- Legacy radios: The Airborne Voice/Data Radio R&S®XK516 is designed for use in commercial aircraft. The system provides conventional voice and high-speed air-to ground, ground-to-air, and air-to-air data communication over long distances.
- Encrypted data: SOVERON® WAVE also offer a strong encryption concept for exchanging voice and data messages. The waveforms are adapted to environmental conditions at all times and help ensure continuously stable communications. The waveforms provide high data rate transmissions within self-administered ad hoc networks. The waveform suite provides the best options for transmitting secure high data rates without satellites in a jammed environment in various ground, air and combined ground-air-ground scenarios.
- Voice/data radio comms: The R&S®XK516 airborne voice/data radio is designed for use in commercial aircraft. The system provides conventional voice air-to-ground, ground-to-air, and air-to-air data communications over long distances. It is suitable for aircraft operational communications (AOC), airline administrative communications (AAC) as well as air traffic communications (ATC).
- Radio antennas: Rohde & Schwartz offer a range of HF/VHF radio antennas both for ground and airborne use by airframe constructors.
- Digital receivers: Rohde & Schwartz offer a wide range of digital receivers for both ground, handheld and airborne use by airframe constructors.
- Drone defense: Rohde & Schwartz ®ARDRONIS detects commercial drone activity, it automatically classifies the type of drone signal, determines the direction of the drone and its pilot, and disrupts the radio control link to prevent the drone from reaching its target. The majority of commercial remote controlled drones are controlled (uplink) via frequency hopping spread spectrum (FHSS), a modern frequency agile waveform. Another major family of drones is controlled (uplink) via WLAN. Signals transmitted from the drones (downlink) are typically FHSS, wideband or WLAN signals.
- Rohde & Schwartz ®M3AR multiband VHF/UHF software defined radios are designed for line-of-sight communications in avionics. The compact and lightweight transceivers make them suitable for operation in all types of aircraft, including unmanned aerial vehicles (UAV). More than 8,000 delivered units. Successfully integrated in many aircraft platforms

Longevity is a fundamental quality feature of Rohde & Schwarz products. However, the high pace of innovation in modern communications technology means that products have to be regularly adapted to new technological developments. Rohde & Schwarz supports customers by offering comprehensive services throughout all phases of the product lifecycle.

Customers and contracts

Rohde & Schwarz does not list its customers for Aerospace however it does refer to both Airbus and Boeing in respect to its legacy radio comms products. Some specific application provisions are listed below:

- Typhoon: Secure radio communications.

- Embraer E99 early warning aircraft: Secure communications suite

Strategy

Rohde & Schwarz invest heavily in R&D and are clearly developing a range of technologies including digitisation, cybersecurity, software-based communications and 5G infrastructure. It is not clear how focused they are on airborne Aerospace and Defense applications (see comment below).

Recent developments

January 2021: Rohde & Schwarz was selected by the Brazilian Air Force (FAB) to equip its modernised Embraer E-99M aerial early warning and surveillance aircraft with modern and secure communications. FAB is modernising five aircraft, each E 99M equipped with highly secure software defined radios and waveforms of the SOVERON family, widely used in the country.

Counterpoint comment

Rohde & Schwarz appear to be strong within test and measurement, the role out of 5G infrastructure, broadcast and media and Air Traffic Control. Their presence is also well established in land, sea and handheld applications. It is therefore not clear how important the airborne equipment sector is to Rohde & Schwarz who continue to support their legacy installed base. They do invest in digital/software technologies but they are not a market leader in airborne radio/comms.

19.2.7. Saab

When Saab was founded in 1937, its primary aim was to provide military aircraft for Sweden.

Saab today is headquartered in Stockholm, Sweden and serves the global market of governments, authorities and corporations with products, services and solutions ranging from military defence to civil security.

Its main aircraft products include the Gripen fighter platform and the recently awarded Boeing/Saab T-X trainer for the USAF.

Within its Air division Saab also offers command and control, electronic warfare, surveillance, communication systems in addition to its main fighter platforms noted above.

Saab's 2020 sales divide as follows:

- Aeronautics (fighter platforms) - 20%
- Dynamics (weapons, missiles) - 19%
- Surveillance (avionics, EW, Radar) - 21%
- Support and services (some avionic product integration) - 18%
- Industrial products - 13%
- Kockums (submarine systems) - 8%

Saab's avionics products and services are largely located within its Surveillance division and Support services division.

Financials

In 2020 Saab generated SEK35,431m in revenues with 17,500 employees.

We estimate that Saab generated $339m of avionics related revenues in 2019 and 3317m in 2020.

Operations and technology

Location

Saab has its main design and manufacturing plants located in Gothenburg, Järfälla, Linköping, Luleå and Arboga, Sweden.

A significant element of Saab's Avionic products are produced within its Huskvarna facility also located in Sweden.

Saab's Surveillance products are manufactured within a number of its plants including Gothenberg, Jarfalla, and Karlskrona.

Saab has a Surveillance facility located in Halden, Norway and a subsidiary business (Saab Grintek Defense) located in Cape Town, South Africa.

Capabilities

Electronic warfare: Saab's Arexis expands the concept of the platform protection, to provide not only survivability, but to enable offensive operations within hostile air defense systems. The Arexis pod enables protection and offensive capabilities to a full fleet. Arexis's deploys Artificial Intelligence (AI) therefore requiring a minimum of attention from the aircrew. The Arexis air-launched decoy can deceive a wide range of threats. The controls in the Arexis Air-Launched Decoy (ALD) together with its network connectivity will detect and suppress the threats, keeping other high-value assets safe.

Surveillance: Based on the Global 6000/6500 aircraft family from Bombardier, GlobalEye combines Saab's Erieye Extended Range radar with an advanced suit of sensors and a multi-domain Command and Control (C2) system. GlobalEye combines complex systems integration, radar, command, control and communication systems into one powerful solution. GlobalEye operating at 35,000ft can detect low-level threats (at 200ft) at distances exceeding 458 km (247 nautical miles). The numbers for ground based radars (2,800ft) are 152 km (82 nautical miles).

Communication systems: The TactiCall Voice Communication Solution provides Ground/Air & Ground/Ground communication capabilities for Air Control Centres such as Air Operational Centres (AOC), Combined Air Operational Centres (CAOC), Control & Reporting Centres (CRC), Ground Entry Points (GEP), Tactical Command Post (TCP) and Last minute briefing Systems. A conversation with a fighter aircraft can start as non-secure and during the conversation be switched to a national or NATO secret conversation "Go Secure – by a single touch". Air Operational modes on radio-based communication are supported in this way.

Command and Control: Saab's Airborne Command and Control (C2) offer is a non-flight-critical C2 and mission management solution for Airborne Early Warning (AEW), Maritime Patrol Aircraft (MPA), Maritime Surveillance Aircrafts (MSA) and Signal Intelligence Aircrafts (SIGINT) as well as rotary wing platforms. The solution supports, Core mission management functionality (route planning, sensor control, local situation picture), Air, sea and ground surveillance (target detection, identification and classification), Search and rescue coordination (SAR reporting, cooperation unit handling and search area management), Weapon management (threat evaluation and weapon allocation, vectoring, mission assign), ISR (capture EOS, image optimisation), ELINT/COMINT (identification and classification).

Customers and contracts

Specific applications are listed below:

- Gripen: Safety critical avionics core computers, enhanced PS-05/A radar with ECM defense modes using active Electronically Scanned Radar (AESA) system, Infrared Search and Track (IRST) system, the newly integrated Electronic Warfare (EW) system, missile approach warning systems.
- Pilatus PC-21: Mission and Graphics computers
- GlobalEye Bombardier 6000 MPA AEW: ERIEYE ER radar, IFF, ADS-B, Maritime Patrol Radar, Satcom, Self-Protection System, Datalinks.
- Saab 2000 AEW/MPA: Erieye AESA radar, IFF/SSR, comms voice and data, Self-Protection System (SPS)
- NH90: Mission Tactical Computer, Core Management Computer
- A400M: High-Lift Control and Monitoring System
- UAV (fixed- and rotary wing) – Mission and Communication Computer

Its Aviation Communication system is integrated on the GlobalEye AEW&C and the ATR72-600 MPA

Strategy

Saab states that the key drivers for its business are as follows:

- Strong focus on international expansion in strategic markets through a globalised approach and industrial partnerships to accelerate growth in an ethical and responsible way
- Faster innovation through investments in technology and R&D within our core competence areas to further contribute to our defence and security capabilities and product portfolio
- Continuous cost efficiency in every part of the business, optimisation of the product portfolio and increased automation and digitisation

Recent developments

September 2020: The first Brazilian Gripen E, designated by Brazilian Air Force (FAB) as F-39 Gripen, concluded its first flight in Brazil. The aircraft flew from the airport in Navegantes to Embraer´s facility in Gavião Peixoto.

August 2020: Saab's offering to Finland for the HX fighter procurement includes both the fighter jet Gripen E/F and the GlobalEye Airborne Early Warning and Control System.

Counterpoint comment

Saab is one of the smaller national defense contractors, however, its recent contract award with Boeing to supply the TX trainer aircraft for the USAF is a big win.

In terms of defense avionics and electronics it has exposure to the Gripen and various maritime patrol and early warning platforms. It has enjoyed some success with foreign military sales of Gripen but less so with stand-alone avionics products.

19.2.8. Safran

Whilst Safran is best known for its aero-engine business, and its associated CFM JV with GE Aviation, it has also enjoyed strong growth in recent years supported via a number of major acquisitions as follows:

- TI/Dowty Landing Gear
- Goodrich Electrical Power business
- Zodiac Aerospace
- Electro-Mechanical Systems (THSA business from Collins Aerospace)

Safran today operates through a number of divisions with Avionics and related sensors forming part of the Safran Aircraft Equipment, Defense and Aerosystems division.

Safran has leadership positions in optronics, avionics, electronics and critical software for both civil and military markets. Safran is the No. 1 company in Europe and No. 3 worldwide for inertial navigation systems (INS) used in air, land and naval applications. It is also the world leader in helicopter flight controls and the European leader in optronics and tactical UAV systems. Operating across the globe through the Safran international network, Safran Aircraft Equipment, Defense and Aerosystems and its subsidiaries employ 8,161 people in Europe, Africa, Asia-Pacific, North America and South America.

Safran has been operating within Avionics for 50 years offering a broad range of applications:

- Commercial aircraft: onboard information, maintenance aid, landing aid, engine control.
- Civil helicopters: inertial navigation, flight control suites, autopilots, observation systems.
- Commercial aircraft and civil helicopters: inertial navigation, data processing and transmission, flight control, autopilots, flight data recorders, aircraft situation tracking systems.
- UAVs: optical sensors for surveillance and targeting

Financials

Safran had €16,498 of revenues in 2020.

Safran Aircraft Equipment, Defense and Aerosystems had revenues €6,893 m in 2020.

We estimate that the airborne avionics related revenues accounted for $189m in 2019 and $130m in 2020.

Operations and technology

Location

Safran Electronics & Defense has much of its design and manufacturing facilities within France. It has major facilities located at Plaisir, Montreuil, Massy all located on the outskirts of Paris.

Safran Electronics & Defense Canada Inc. has full systems, hardware and software engineering capabilities, however, most of these capabilities are related to engine control electronics.

Safran Electronics & Defense has an Optronics and Navigation system facility in Bedford, New Hampshire, USA.

It has data systems business (part of Zodiac) located at Les Utils, south of Paris and Norcross, Atlanta, USA

Safran Electronics & Defense has a manufacturing facility for Avionics products located in Costa Mesa, USA.

Safran Electronics & Defense Brazil designs flight control systems such as the APIRS attitude and heading reference system and observation and fire control systems for helicopters, ships and armoured vehicles.

Safran Electronics & Defense has a low-cost manufacturing site located in Mexicali, Mexico.

Capabilities

Safran Electronics & Defense has developed a number of avionics and sensor related technologies and capabilities including the following:

Navigation: Safran Electronics & Defense offers a wide range of navigation systems based on proven sensors. SEDs new SkyNaute family covers requirements for all types of airborne platforms – long range, single aisle and regional airplanes, helicopters and drones. SkyNaute family adopts hybrid inertial/satnav systems like ADIRU (Air Data Inertial Reference Unit) or attitude and heading reference systems like APIRS (Aircraft Piloting Inertial Reference System).

Safran Electronics & Defense also offers navigation systems including:

- Hybrid navigation systems, combining inertial and satellite sensors, plus air data management:
  - ARINC 738 / D0 229C / ARINC 429 / ADIRU with optical (GLR) or vibrating (GRH) gyroscope.
- AHRS: Attitude and Heading Reference System:
  - APIRS (Aircraft Piloting Inertial Reference System) with fibre optical gyroscope (FOG).

Helicopter Navigation: Based on Safran Electronics & Defense HRG (hemispherical resonator gyroscopes) and accelerometers proven technologies (used in land and space navigation solutions), Safran Electronics & Defense's new integrated SkyNaute navigation brings:

- High performance Inertial & Piloting data
- Protection levels for RNP/RNP-AR operations
- 100% RNP 0.1, even in coasting > 10 min
- Fly-by-Wire, SVS (Synthetic Vision System) & HUD (Head-Up Display) architecture ready solution

Inertial reference units: Safran Electronics & Defense's FMU series of Inertial Measurement Units (IMU) are equipped with Fibre Optic Gyro (FOG) technology and servo-looped MEMS accelerometers.

FMUs, as well as their packaged versions, are proven solutions for civil and industrial applications such as hybrid GNSS-inertial navigation systems, which require high reliability, excellent signal stability and very low noise.

These devices are used in a range of civil/mil helicopter and airborne military applications.

Euroflir: Euroflir is a range of electro-optical gyro-stabilised observation systems for helicopters, aircraft and UAVs. The Euroflir EOS are equipped with latest-generation thermal cameras, HD day cameras and laser sensors, allowing them to carry out numerous military and security missions in optimal conditions. This

includes theatre surveillance, SAR and CSAR, coastal patrols and homeland or maritime surveillance. The combat proven Euroflir™ 410 is already used on Patroller UAV.

Information/data systems: Safran Electronics & Defense, with expertise in flight data management systems and aeronautical maintenance support, offers a full, integrated range of equipment for the acquisition, management, recording and analysis of information.

- Safran Electronics & Defense's aircraft information systems (AIS) like that developed for the Airbus A380, provides access to multiple data: flight logs, onboard electronic documentation, navigation diagrams, performance calculations, etc.
- Safran Electronics & Defense's aircraft condition monitoring system (ACMS) records and analyses the flight data and information from aircraft equipment. The data can be used to monitor the condition of the systems, optimise preventive maintenance and aircraft lifetime
- Safran Electronics & Defense has developed a high-performance solution for operators and airlines: the analysis ground station (AGS). This system analyses flight data from each aircraft to optimise their fleet management and reduce maintenance costs.

Airborne optronics: As a specialist in gyro-stabilised optronics for helicopters, Safran Electronics & Defense offers high-performance equipment for search, location, identification and target designation including the following:

- Euroflir gyro-stabilised electro-optic pods, equipped with latest-generation thermal cameras, HD daytime cameras, multi-spectral spotting scope and laser sensors allow for all types of security operations: land or sea surveillance, patrols, rescue, weapons guidance, etc.
- The firing sights for helicopters developed by Safran Electronics & Defense are compatible with a wide variety of weapons used on the new generation of aircraft.
- The wide-angle sensors and enhanced vision systems (EVS) used in the Safran Electronics & Defense optronics solutions satisfy requirements to improve flight safety for aircraft: anti-collision, flying in poor-visibility conditions both day and night.

Safran Electronics & Defense also offers the industry flight services via its Cassiopee brand. Cassiopée is a twofold offer that combines flight data management software packages and analysis solutions for all types of airplanes and helicopters. Its services enable fuel consumption reduction, maintenance costs optimisation and flight safety enhancement.

Customers and contracts

- A320: Flight Data Management System
- A330: Data loading system
- A350: Aircraft Condition Monitoring System
- WEFA – Aircraft condition monitoring system: Together, the contracts awarded cover more than 1,000 airliners of various types: Airbus A320ceo, A320neo, Boeing 737, ATR 42 and ATR 72.
- GADIRS (GPS Air Data & Inertial Reference System) is a hybrid triplex navigation system selected by Airbus for the A400M
- Inertial Navigation System for the Rafale fighter.
- Data loading systems: Airbus to modernise all data loading systems for the avionics suites on its A320 family of commercial jets (A319, A320, A321) with SED data loading systems.
- The long-range electro-optical system EuroflirTM 350, GPS Inertial navigation system and Autopilot equip the Airbus H225M helicopter. The combat-proven Euroflir™ 350 is already used on many French Army and other nations' rotary-wings (H125M Fennec, AS350 Ecureuil, AS532 Cougar, H225M Caracal, etc.) EuroFlir 410 is used on the NATO Helicopter Management Agency's (NAHEMA) NH90 helicopters and the French navy's AS565 Panthers.
- The Sigma 95L Inertial Navigation System (INS) is used for NH Industries' NH90 helicopter program.

- SED has delivered its 10,000th APIRS™ inertial reference system, which will be fitted to an ATR 72-600 regional turboprop.
- Safran Electronics & Defense is very active in China in the optronics and navigation sectors through its two subsidiaries Reosc and Colibrys.
- Safran's Cassiopée Flight Data Monitoring solution. Starting in December 2020, this service will initially be available to all ARes II-equipped Cessna Citation CJ4 jets.
- HAL and SED have announced the signing of three new contracts, at the Aero India 2019 Airshow, for Safran-designed autopilots for various helicopters manufactured by HAL.

Strategy

Safran Electronics & Defense states that its "primary areas of focus are multispectral optronics, image processing, new-generation tactical drones, vibrating gyros and MEMS (micro-electromechanical systems), applied to next-generation navigation systems for both military and civil applications".

It is also focused upon generating IP and has 2,100 patents filed round the world.

Recent developments

November 2020: Safran Electronics & Defense has won a contract from China Southern Airlines Company Limited to deploy Cassiopée Alpha, its new all-in-one flight data processing and analysis solution, for the airline's entire fleet of more than 600 aircraft.

October 2020: Safran Electronics & Defense has won a contract from Airbus Helicopters to supply new-generation Euroflir™410 observation systems for ten NH90-TTH Caiman helicopters deployed by French Special Forces. These new Standard 2 helicopters will allow French forces to handle the full range of utility missions.

October 2019: Safran Electronics & Defense announced the start of construction work on its future studies and research centre in Valence. Focusing exclusively on Research & Development (R&D), the centre will concentrate its work on developing more electric aircraft and new technologies for highly integrated electronics.

June 2019: Safran Electronics & Defense, Hensoldt Optronics and Mades today signed collaboration agreements on the Euroflir™ 610, a high-performance multispectral electro-optical targeting and observation system proposed for the European MALE RPAS (Medium Altitude Long Endurance - Remotely Piloted Aircraft System).

Counterpoint comment

Safran Electronics & Defense is an amalgamation of a large number of businesses spread throughout many sites and facilities and appears to be largely as a result of mergers and acquisitions. It has two main capabilities in inertial navigation and electro-optics. Recent moves into data and services (via its Cassiopee brand).

We do not see Safran Electronics & Defense as being a strong contender within next generation integrated avionics but it is a very capable provider of a range of discrete products and services.

19.2.9. Tecnobit

In 1976, Tecnobit was created in Madrid and was moved to Valdepenas in 1981.

In 1983 Tecnobit obtained the first contract with the Ministry of Defense for the development of an encrypted communications system and, since then, it has been considered a national strategic company.

In 2008 Groupe Oesia acquired 100% of Tecnobit.

Today, Tecnobit is the engineering company of the Oesía Group having grown consistently for 40 years. Its constant innovative effort has made it a clear international benchmark in the Avionics fields of Communications, Security and Defense. It supplies Aerospace & Defence OEMs with the most advanced developments in Avionics, Optronics, Secure and Tactical Communications, Simulation and Inhibitors.

Financials

In 2019 Oesia Group had revenues of approximately $114m covering 24 subsidiaries.

Tecnobit, as a major subsidiary in Avionics, Optronics and C4ISR capabilities generated $57m (50% of Group revenues).

We estimate that Tecnobit's avionics related revenues were $30m in 2019 after deductions for land and naval equipment, and $28m in 2020.

Operations and technology

Location

Tecnobit's international operations centres are the corporate headquarters in Rivas (Madrid) and the main operating plant in Valdepeñas (Ciudad Real).

Capabilities

Tecnobit has equipment developed for the Eurofighter, both on board and in support of the operation. These teams use either Tecnobits own developments such as WHCU -Windscreen Heater Control Unit- , GLU -Ground Loading and Data Exchange Unit or are developed jointly in European consortia. These joint efforts include equipment such as FLIR / IRST -Forward Looking Infrared / Infrared Search and Track , BSD -Bulk Storage Device- , ADT -Air Data Transducer.

The MIC equipment is an evolution of the Tecnobit tactical data link equipment for use in Airbus A400M aircraft and Airbus A330 MRTT. It is a device of low weight and high processing capacity, designed to handle all the Link 16 information received from the MIDS (Multifunctional Information Distribution System) for subsequent communication with the on-board mission computer.

Tecnobit offers extensive experience in developing optronics products and systems, including thermal cameras and infrared applications and solutions.

In the Command and Control area, Tecnobit has a position in several technologies such as Tactical Communications, Communications Security, FFT & BMS ("Friendly Force Tracking" & "Battle Management Systems") and in Maintenance Services.

Customers and contracts

Tecnobit has designed solutions for major European programmes including Eurofighter and A400M, where they participate as Main Contractor and presence with other key companies such as BAE Systems, Airbus Military, Cassidian, Selex Galileo or Thales.

Tecnobit is provider of the audio management system (AMS) for the A400M. This is one of the most advanced in the market owing to the number of integrated communication systems.

The A400M Audio Management System constitutes a platform where it is possible to separate the so-called "clear audio" (for unclassified audio communications) and "secure audio" (classified audio communications). All the interfaces in the system are made through fibre optic lines, which minimises crosstalk between audio channels (crosstalk, EMI / EMC) and compromised emissions.

Tecnobit has developed the mission control consoles for the MH60R maritime patrol helicopter.

Tecnobit are under contract to provide maintenance of the displays of the F/A-18 fighter-bomber of the Spanish Air Force.

The MHSD and MUFC are the two cockpit displays of the F/A-18 that were designed for the half-life adaptation (MLU) in order to increase the tactical capabilities. Tecnobit manufactured under license from Kaiser Electronics (Collins) 82 pairs of displays for the entire aircraft fleet between 2005 and 2009.

The Mission Interface Computer is tactical data link for use in Airbus A400M and Airbus A330 MRTT. It is a device designed to handle all the Link 16 information received from the MIDS (Multifunctional Information Distribution System) for subsequent communication with the on-board mission computer.

Strategy

Oesia, the parent of Tecnobit, states that Tecnobit is the engineering company of the Oesía Group. Its constant innovative effort has made it a clear international benchmark in Communications, Security and Defense.

Recent developments

January 2020: Tecnobit expanded the family of SDR radios with the TGOR-AR , the aeroportable Software Defined Radio (SDR) with a 1/2 ATR form factor , designed for installation on aerial platforms, including RPAS, which, with its Cognitive Radio and Dynamic Spectrum Assignment capabilities, adapts to interference and spectral gaps.

Counterpoint comment

A European defense contractor with exposure to defense programmes working in collaboration with other EU defense contractors. It has had some success attracting work via Lockheed Martin and Collins Aerospace but we suspect that this may be offset derived work (and therefore limited).

19.2.10. Thales

Thales, formerly Thomson-CSF, was founded in 1968 through the merger of the professional electronics businesses of Thomson-Brandt with Compagnie Générale de Télégraphie Sans Fil (CSF).

The group was renamed Thales in 2000 and it is still partially owned by the French government.

Thales Group had sales of €17.0 billion in 2020 and had 80,702 personnel operating in 68 countries.

Thales Group today operates across four distinct sectors which generated the following revenues in 2020:

- Aerospace - €4,217.0m
- Transport - €1,617.9m
- Defence & Security - €8,048.8m
- Digital Identity & Security - €2,991.8m

Thales Aerospace division supports space in addition to providing aerospace customers with flight deck avionics, navigation, air traffic control systems (ground based), InFlyt (IFE) equipment and services, electrical power systems and connectivity solutions.

Thales claims that it is Number 3 in the world for avionics and Number 1 in Europe.

Financials - Aerospace

FYE 31/12/20	2020	2019
Sales €m	4,217.0	5,595.1
EBIT €m	(76.2)	520.8
Return on sales %	1.8%	9.3%

Thales commented: “Sales in the Aerospace segment amounted to €4,217 million, down 24.6% from 2019 (-24.1% at constant scope and exchange rates). This drop reflects the collapse in civil aeronautics demand (by around 50% since Q2 2020) and the deferral of tenders in the space business due to the Covid19 crisis.”

Based upon Thales position in flight decks, navigation and connectivity, operating in both the civil and military sectors, we estimate that Thales generated avionics related revenues of $1,830m in 2019 and $1,230m in 2020.

Operations and technology

Location

Thales has its main avionics facility in Meudon, just south of Paris.

Thales has subsidiary avionics operations in locations in France including Chatellerault, Vendome, Bordeaux, Vitrolles (Marseille) and Toulouse.

Thales Avionics Services Worldwide (ASW) Americas, based in Piscataway N.J. provides repair, retrofit and spare support for flight avionics equipment.

Thales has a significant presence in China with 3 JVs however these cover ATM, inflight entertainment and connectivity services. Thales sells avionics direct to Chinese Airlines but does not manufacture locally.

Thales has 9 sites in the UK, but these do not typically provide avionics solutions.

Capabilities

Thales summarises its avionics capabilities as follows:

- Flight deck systems, (FlytX large tactile displays)
- Flight Management Systems (FMS, PureFlyt leader in FMS)
- Thales Synthetic Vision System (3D representation on PFDs)
- Thales Remote Electronic Unit (REU)
- Autopilot, Thales autopilot main key features
  - Certified with TSO/ETSO, DAL A
  - Precision Approach modes up to ILS CATIIIB and including steep approach
  - Non-Precision Approach modes: LNAV, LNAV/VNAV, RNP-AR 0.3, LPV, GLS
  - Protection: flight envelope, Alpha floor, speed protection, windshear escape guidance, TCAS/TAWS AP coupling, sensor single source
  - Auto throttle / Auto thrust (Thrust Quadrant Assembly included)
  - Military modes including terrain following.
- Integrated Modular Avionics (IMA), cockpit displays and computing platforms
- Eyes-up solutions from head-up displays to helmets and head-worn displays.
  - “Designed by pilots for pilots, TopMax is a lightweight full-color Head-Worn Display System (HWDS) for business jets, commercial aviation, and cargo operators.”
  - TopOwl is Thales helicopter pilot head-up display helmet
- InFlyt Experience IFE
- Connected Aerospace. Connectivity is helping to enable the proliferation of artificial intelligence, big data, cloud, mobility and social media components. These are key aspects of digital transformation with a cohesive portfolio in avionics, mission management systems, air traffic management and cybersecurity, Thales is well-equipped to achieve the digital transformation and deliver connectivity to the aviation ecosystem in a secure and seamless way.

The following capabilities are largely within the civil aircraft sectors.

Thales FlytX flight deck: FlytX achieves a 30 to 40% reduction in size, weight and power consumption compared to legacy avionics. This decrease is the result of the IMA's strong integration of avionics applications such as FMS (Flight Management System), HTAWS (Helicopter Terrain Awareness and Warning System) and RMS (Radio Management System) inside the display. There is no more need for specific hardware and the number of LRUs (Line Replaceable Units) has been dramatically reduced.

The FlytX solution has been developed to be integrated to the connected aircraft environment. It can securely link avionics systems with operation centres, other service providers, and the open world (third-party mission applications) making the cockpit more mission-oriented and flexible. FlytX can display and interact securely with a connected tablet (e.g. Electronic Flight Bag) thanks to a Cyber-by-design architecture

which guarantees a strict separation between critical flight information and data coming from open-world sources (autonomous IT bubble).

PureFlyt FMS: Thales has developed an entirely connected FMS, designed to offer safety, security, and fuel and operations efficiency. The FMS is able to draw on both onboard and open-world data, such as weather information. By combining the integrity of the FMS and the agility and power of Electronic Flight Bag flight functionalities, aircraft trajectory can be permanently controlled, adapted and enhanced, resulting in optimised flight, decreased fuel consumption and improved passenger comfort. Cyber-secure by design, PureFlyt has also been designed to be future proof, accommodating the implementation of concepts such as the Initial 4D (I4D) trajectory management methods currently being researched by SESAR (Single European Sky ATM Research) in the EU and NextGen in the US.

HUD Systems: Resulting from Thales' decades-long experience in military Helmet Mounted Display Systems (HMDS) and civilian Head-Up Display (HUD), TopMax provides additional operational credits in order to reduce take-off and landing minima. The product includes augmented reality and intuitive off-axis symbology features that strongly enhance situational awareness and safety.

The TopMax HUD operational capabilities largely exceed existing HUD solutions because of:

- 360° full color vision capability
- Unlimited Synthetic Vision System (SVS)
- Off-axis symbology including cross wind, synthetic runway and extended centreline
- 3D traffic display

Auto-Pilot: Thales has decades of experience both within civil fixed wing and rotorcraft applications for Auto-Pilot systems. Solutions includes single equipment and end-to-end autopilot system as well as software solution which can be installed on existing computing device. Autopilot software applications that implement several functions: stabilisation and control, guidance modes, auto throttle via the following:

- Control panels
- Auto throttle assembly
- Actuators
- Probes and sensors
- Computing device.

Navigation systems: The transition of current Air Traffic Management (ATM) to performance-based ATM systems has demonstrated the fundamental need for aircraft to have reliable and accurate navigation systems.

Thales designs all of the critical technologies across the navigation chain, from Air Data to high accuracy inertial systems. Thales designs and manufactures its own sensors for all these equipment types in France.

In addition to having a strong navigation presence on many civil platforms Thales has developed specific navigation solutions for mission based military platforms featuring the following capabilities:

- Operational mission success through state-of-the-art performance: accuracy, jamming resistance and integrity
- NATO operability: standardised user equipment and interfaces as well as specific concept of operation (e.g. NAVWAR)
- Compliance with civil air traffic regulation (CNS/ATM)
- Specific military environment: dynamic range, EMC, vibration
- Independence in operational capability
- Growth potential: low-cost inertial solutions through MEMS technology and GNSS evolutions (GPS M-Code, Galileo PRS, anti-jamming)

Thales Connected Aircraft: As connectivity becomes more prevalent across aviation ecosystem it is helping to enable the proliferation of artificial intelligence, big data, cloud, mobility and social media components.

These are key aspects of digital transformation which Thales is leveraging for customers. With a cohesive portfolio in avionics, mission management systems, air traffic management and cybersecurity, Thales is positioned to achieve the digital transformation.

Service and Support: Thales has a global network of support and service centres that provides spares, repairs, and upgrades to airlines and end-users.

In addition to this Thales has a service support partner in Avio that offers a range of digital/software support services as follows:

- AvioCabin: fast, native and user-friendly application which will make cabin operations run like clockwork.
- AvioConnect : a secure communication application that improves the communication between different stakeholders around the aircraft to decrease turnaround times and make workflows more efficient.
- AvioTech: enables pilots, mechanics, MCC and cabin crew to review the status of the aircraft, report defects, review open and deferred defects.
- AvioCyber : AvioCyber security services allows to grow awareness on security matters and to build preventive and corrective actions to secure your airline operations.
- AvioIntegrations: Dedicated group of highly experienced software developers focusing entirely on the agile systems integration of your back-end systems with the AvioSuite.
- AvioData: AvioData provides efficient, reliable and qualitative data deliveries to your avionics and your AvioBook. AvioData also provides a business intelligence solution turning Airline operational data into enhanced and synthetic views leading to better operational awareness and optimisation.

Within the Defense and Security division of Thales there are a number of discrete mission and sensor related capabilities that are largely found on fighters, air transport and rotorcraft platforms.

These include the following capabilities:

- Electronic warfare systems
- Fire-control radars
- Mission computers
- Optronics

Specific examples of these capabilities are noted as follows:

Rafale scanned array EASA radar: The AESA RBE2 is the very high performance radar designed for the omni-role Rafale fighter. It has been designed in close collaboration with Dassault Aviation and DGA -French defense procurement agency- to meet expectations of Air Forces by combining advanced fire control radar detection and target tracking needs thanks to innovative technologies.

ECM: Protection of the Rafale is entrusted to the SPECTRA (Self-Protection Equipment to Counter Threats for Rafale Aircraft), a multi-spectral integrated defensive aids suite that has been developed by Thales in partnership with MBDA. SPECTRA works across the electromagnetic, laser and infrared domains, employing smart data fusion from multi-spectral sensors to provide identification, location, jamming and decoying against a wide range of threats.

Rotorcraft protection: Capitalising on this unrivalled experience in Radar Warning Receivers, Thales has developed the CATS family which provides a cost-effective solution for equipment of a wide range of helicopters. These include the following capabilities:

- hostile environment situation awareness
- helicopter self-protection and awareness both combined in a single equipment.

CORAC 2016: Thales is working on the Extended Modular Avionics (EMA) concept alongside Airbus, Airbus Helicopters, Dassault Aviation, Sagem and about 30 other partners who are all supporting research into onboard computer platforms as part of a project led CORAC. This R&D project aims to prepare the groundwork for second-generation IMA and covers all aspects of onboard electronics, including flight control

and aircraft functions, operator services and passenger services. It is expected to deliver tangible results for commercial airliners, business jets and helicopters in service in 2020-2030.

Customers and contracts

For its range of commercial avionics and military mission product offerings the following programmes are supported:

In the civil transport:

- Airbus A320 family, A380, A350 XWB
- ATR-600
- Boeing 787
- Bombardier Global Business jets, CRJ700/900/1000
- Dassault Falcon 6X
- Gulfstream G500, G600, G650
- Sukhoi SSJ-100

In the military domain:

- Airbus A400M
- Dassault Mirage 2000, Rafale
- Embraer C-390
- Eurofighter Typhoon

In the helicopter sector:

- Airbus Helicopter Tigre, H Force
- Boeing Chinook
- Leonardo A109, Wildcat
- NH Industries NH90
- Sikorsky Blackhawk, S76D

Thales began developing inertial navigation systems over 30 years ago, and numerous platforms rely on them today, from the Mirage 2000 and MiG-29 fighters to the C-130 military transport, Tiger helicopter and Ariane 5 rocket. More recently, these systems have also been selected for the Airbus A350 XWB, ATR 72-600 and Embraer KC-390.

Strategy

Thales's strategy has been to create a small structure capable of exploring and disseminating to the rest of the group what works: the Digital Factory. The Thales Digital Factory responds to a fundamental trend: to offer a superior service by relying on more connected, smarter, more collaborative technological systems, capable of partial autonomy. For Thales, the goal is nothing less than to become an essential digital platform within the global ecosystem of large civilian or military infrastructure projects where security is essential. And this does not matter what changes are taking place in geopolitical plate tectonics.

Recent developments

October 2020: Following successful rollout across Europe, Thales in the UK, Nokia and SkyFive are launching a new 4G LTE Air to Ground (A2G) solution to a global market. Delivering a fibre-like connectivity experience, A2G significantly improves the inflight access to web, streaming and on-line games to passengers. In addition to improved passenger experiences, aircraft operators will benefit from significantly shortened installation times, minimising the time aircraft are out of operation.

September 2020: An industrial consortium made up of FCMS, Indra and Thales has been selected to develop a suite of sensors for the European Future Combat Air System (FCAS). Germany, Spain and France selected the consortium. The countries are the three main stakeholders of the Next Generation Weapon System

(NGWS) / FCAS programme. French Armament General Directorate (DGA) signed the contract with Indra on behalf of the three countries.

February 2020: The FAA has awarded Leidos and Thales a contract to supply up to 142 secondary surveillance radars for the Mode S Beacon Replacement System (MSBRS) contract. Leidos and Thales will deliver a FAA-compliant solution to enhance surveillance radar performance and sustainability.

Counterpoint comment

We believe that Thales claim to be number 3 in avionics is probably accurate. They do not yet have the global infrastructure to match Collins or Honeywell, however, they do have capabilities that are complementary to avionics with IFE, ATM and connectivity.

19.2.11. Ultra Electronics

Ultra Electronics was formed in the late 1980s out of a management buy-out from the former Dowty Group.

Following its establishment and flotation on the UK stock exchange it pursued M&A activity with many small acquisitions largely located in the US.

Ultra primarily supports the defense and security sectors but does have some airborne mission related capabilities.

Within its Intelligence and Communications division Ultra offers avionics related products including communications for ADS-B and link 16 in military applications. It also provides a range of secure datalink options for communication and data transmittal.

Financials

Ultra reported revenues of £859.8m in 2020.

Its 2020 revenues were segmented as follows:

- Maritime - £391.8m
- Intelligence & Communications - £241.0m
- Critical Detection & Control $227.0m

Counterpoint estimates that its avionics-related sales accounted for $38m in 2019 and .

Operations and technology

Location

Ultra's main Intelligence and Communications facilities are located in Greenford (London), Aberdeen, Farnborough, Gloucester, Tring and Southampton in the UK.

In the US Ultra has I&C facilities in Annapolis, MD; Austin, Texas; Germantown, MD; San Diego, CA; Lancaster, PA; Whippany, NJ; Woburn, MA; Tampa, FL.

Ultra's radar avionics products are produced in their Lancaster PA facility in the US.

Ultra I&C also has facilities in Canada and Australia but they do not supply airborne products.

Capabilities

Advanced Tactical Airborne Systems: ATAS includes the maturity and adaptability of its certified tactical data link gateway software only distribution coupled with a flight-qualified COTS enclosure or coupled with existing platform equipment. The ATAS interfaces to the most common MIDS, JTIDS, JTRS, SATCOM, and small form factor airborne-capable Link 16 terminals for MIL-STD-3011A/C, Satellite TADIL J, MTC, CoT. The ATAS provides interfaces for Link 11, VMF, CMF, SADL connectivity with coalition forces.

IFF: With an emphasis on positive identification of airborne, sea-going and land-based vehicles, and the size reduction of these vehicles, its customers need small form factor IFF solutions. This is particularly true in military theatres, with an increasing requirement to identify an object prior to engagement to reduce fratricide. Compatibility with legacy IFF systems (Modes 1,2,3A/C,S) is required, but US and foreign militaries are moving toward Mode 5, which requires data encryption.

Radar Altimeter: Ultra provides advanced radar altimeter solutions capable of high accuracy altitude measurements in adverse conditions. Its radar altimeters are used in UAVs, space launch applications, autonomous targets and towed targets. The linear FM (Chirped) Radar Altimeter product line uses modular construction and advanced digital signal processing (DSP) techniques to provide a small volume, low power consumption, high performance RALT.

The Precision Strike Sensor Core (PSSC) provides the path to jam resistant, radar-based target detection, identification, designation and terminal guidance for conventional and precision munitions. PSSC was purpose built for use with the guided 105mm to enable first shot accuracy for AC-130 gunships.

Advanced Comms Pods: Designed for quick integration onto airborne payloads or wing stations via the REAP Pod, REAP provides full spectrum communication range extension, voice repeater and relay functions. Certified to TRL level 8 by the US Air Force, Ultra have provided advanced communication payloads for over 10 years.

Data Acquisition Units: The Ultra PCM890 System is the next generation of the highly successful PCM880 series of data acquisition systems. The PCM890 is used for instrumenting missiles, airborne vehicles, and other platforms requiring a small volume ruggedised PCM encoder.

Typical communications needs are delivered as follows:

- Enhanced communications to cooperate with state, local and federal agencies – Integrates MANET, Civilian P-25 and military radios for seamless relay and bridging.
- ADS-B – Transmits aircraft position without impact to the existing onboard IFF transceivers.
- Link 16 – Transmits ownership J2.2 direct PPLI on LOS Link 16 allowing all network participants real-time situational awareness of the Remotely Piloted Aircraft (RPA). Transmits J12.6 Target Sorting on the "Fighter to Fighter" NPG with decreased latency allowing time sensitive targeting.

Customers and contracts

79% of Ultra's I&C sales are to customer located in the US.

Ultra lists its major customers as General Dynamics, Raytheon, Thales, USAF, USN and US Army.

It provides a range of Radio Frequency products to Raytheon, Hensoldt, Boeing, Lockheed Martin and General Atomics.

A specific contract is:

- AC130: Precision Strike Sensor Core (PSSC)

Strategy

Ultra is in the process of creating a more integrated and collaborative business necessary to become "one" Ultra. Having acquired many, at times disparate, businesses over the years it has recently disposed of some non-core businesses.

Recent developments

None that we can see.

Counterpoint comment

Ultra enjoys a strong presence within its maritime/naval and land defense business areas but less so in airborne defense. It does however have a significant presence in the US and supports a range of major US defense contractors.

19.3. AVIONICS SUPPLIER PROFILES – REST OF THE WORLD

19.3.1. AEL Sistemas (Elbit)

AEL is a jointly held Brazilian company with 75% owned by Elbit Israel and 25% by Embraer.

It is located in Porto Alegre and is dedicated to the design, development, manufacture, maintenance and logistical support of military and space electronic systems, for applications in aerial, sea and land platforms.

Operating within defense technology since 2001, AEL participates in strategic projects of the Brazilian Armed Forces such as Gripen NG, KC-390, Guarani and SISFRON - Integrated Border Monitoring System.

Financials

In 2019 AEL reported $31m of revenues.

We estimate that AEL generated $16m of revenues in 2019 based upon its core avionics offering of mission computers, navigation and terrain avoidance products, and $14m in 2020.

Operations and capabilities

Operations

AEL has its main facilities in Porto Alegre located in the south of Brazil. it employed 230 personnel at the facility.

Capabilities

AEL has developed the following:

- Terrain Following relief-based guidance system that allows low-altitude tactical flights to safely follow the contour of the terrain. The development of the system was supported by FINEP and hundreds of real flight hours have already been carried out in simulated environments.
- Inertial Navigation System that will allow Brazilian independence in inertial navigation systems. EGI (Embedded GPS / INS) provides a navigation solution for aircraft according to the SNU-84 standard, including position, speed, acceleration and attitude, among other parameters.
- Wide array display (WAD) for the Saab Gripen platform. This prototype unit was first delivered in 2017 and is still under evaluation we believe.
- Mission Computing: The X-86 is an embedded computer module, standard VPX, applied as a mission computer of the aircraft KC-390. With hardware, software and mechanic projects developed by AEL Sistemas.

Customer and contracts

AEL Sistemas is the main provider of the avionics suite of the A-29 Super Tucano, F-5M, A-1M and C / P-95M Bandeirante aircraft for the FAB and AF-1 for the Brazilian Navy. AEL also supplies electronic equipment for the T-27 Tucano training aircraft and the Brazilian Air Force (FAB) AMX subsonic fighter. The company currently provides advanced mission electronic systems for the KC-390 and Gripen NG programs.

AEL participates in the modernisation program of the C-95, P-95 and SC-95, aircraft widely used for cargo transportation, passengers, patrol and aerial surveillance. Using state-of-the-art technology, AEL developed, integrated, certified and installed the avionics display system.

Strategy

AEL appears to be a funded centre for the development of avionics technologies necessary to support indigenous Brazilian programmes.

Recent developments

May 2018: AEL Sistemas announces the delivery to Saab of the ‘Model C’ prototype of the Wide Area Display (WAD) widescreen display for the Brazilian Gripen E/F, a state-of-the-art equipment that meets the requirements of the Brazilian Air Force´s F-X2 program with Saab.

Counterpoint comment

We are not aware of any export sales to date and AEL is reliant upon indigenous military programmes. It is therefore a niche provider of avionics technologies dependent upon Brazilian military budgets.

19.3.2. Aerospace Equipment Corporation JSC

Joint Stock Company Corporation Aerospace Equipment was founded in Russia in1998. JSC was established within the framework of the Federal Target Program for Restructuring and Conversion of the Defense Industry. The controlling shareholder of JSC "KAO" is currently the Joint Stock Company "Concern Radio Electronic Technologies", which unites more than 95 enterprises and organisations of the radio electronic industry.

Aerospace Equipment Corporation JSC specialises in the supply and servicing/maintaining of air flight simulators, instrumentation and onboard equipment. It is one of the biggest Russian companies in the area of airborne avionics for military and civil aviation, air defense systems, missile systems, ground motor vehicles and other high-tech branches of industry. As a corporation it has a variety of capabilities and provides many services including support of the entire lifecycle of its products.

It manufactures a wide array of products including:

- airborne data acquisition recorders
- sighting equipment
- navigation and weapon-aiming systems
- airborne radar stations
- single display indication systems
- automatic control systems
- actuators and sensors for the manned aircraft and unmanned aerial vehicles
- IFF transponders

Financials

Today Joint Stock Company "Corporation" Aerospace Equipment "is:

- One of the largest Russian suppliers of aviation instruments, onboard equipment and flight simulators to the domestic and foreign markets.
- An efficiently managed association with total sales of 6 billion roubles.
- A company that invests in promising developments and technologies that will provide competitive advantages for manufactured equipment in the future.

6 billion roubles of revenues translates into $78m generated within the AEC JSC Corporation.

We estimate that $45m of this relates to navigation, displays, target acquisition, radar and data recorders for civil and military use.

We are not aware that these revenues are generated via sales outside of Russia other than via Russian platforms sold for export.

Operations and capabilities

Operations

AEC JSC is headquartered in 198095 Saint-Petersburg ul.Marshala Govorova 40/11-407, St. Petersburg, Russia.

The business also has a subsidiary plant in Moscow and offices in New Delhi, India.

Capabilities

AEC JSC does not report extensively on its technologies and capabilities, however, the following is noted:

- JSC Moscow Radio Plant “Temp” has been specialising in the production of navigation devices operating on domestic and foreign systems and radio beacons.
- JSC Almetyevsk plant "Radiopribor". The plant specialises in the production of antenna-feeder systems.

- Izmeritel plant: Serial manufacturer of sighting and navigation systems, unified indication and target designation systems, emergency registration of flight information, etc.

Customer and contracts

We believe that AEC JSC has supplied a number of indigenous Russian platforms including Mig 29, Mig 31, Su 27, Su 30 and Antonov transport aircraft.

Strategy

The Russian government has been pushing for their state funded companies to adopt a more commercial approach and develop products that can be sold into the western world.

They specifically wish to replace Western suppliers for avionics on the current Sukhoi S100 Superjet.

Recent developments

None that we can see.

Counterpoint comment

AEC has yet to develop an export market although it does have co-operative agreements in place with HAL India. It is questionable the degree to which it can export sensitive military avionics or develop commercial products that can compete with the Western world.

19.3.3. Aviage Systems

Aviage Systems is a 50/50 joint venture between General Electric Company (GE) and Aviation Industry Corporation of China (AVIC) founded in 2012.

It was partly set up to allow access to the Comac 919 platform via a JV arrangement with Avic and GE agreeing to co-develop avionic solutions within their purpose built Shanghai facility.

Financials

We estimate that the JV, based largely upon supply to the current C919 programme, generated $25m of revenues in 2019, with similar sales in 2020.

Operations and capabilities

Operations

Aviage has its headquarters in Zizhu Hi-Tech Park, Shanghai, China with a 36,000m² office to support the growing engineering and manufacturing needs, including world-class R&D, Integration & test lab facilities.

It also has sales and engineering support centres in Phoenix, USA and Toulouse, France.

Capabilities

Aviage was set up between GE Aviation and AVIC initially to support the Comac C919 programme with contracts to develop 5 main sub-systems including the IMA computing platforms, utility systems integration, FMS, display suite, flight recorder system, remote data concentrators, aircraft data network and in-flight connectivity (ICP).

In addition, Aviage offers the following capabilities to OEMs and Airlines:

- The Aviage High Integrity Computing Platform (HICP) solution provides a scalable open architecture platform that translates to reduced operational cost through simplified maintainability and service ability, and fuel consumption savings which come from low system power requirements and lower total system installation weight.
- Data concentration solutions provide configurable, flexible remote interfacing products for distributed Input/Output (I/O) and sensor management to actuation control.

Aviages Digital Solutions (DS) subsidiary business includes the following capabilities:

- Digital Information System (DIS) provides innovative solutions to improve airline on board operation environment. By offering reliable connectivity and hosting on-board applications, DIS helps to elevate airline operation efficiency.
- Data Analytics Solution offers local platform architecture design and consulting service. It provides analytics on airline operation and system performance based on advanced machine learning and AI technology.
- Cybersecurity offers security lab setup, testing for avionics products, network filtering, access control and web application firewall.

Aviage also operates a CCAR-145 maintenance organisation certificate issued by CAAC, which has the capability of testing, repairing, modifying and overhauling the accessories of the airborne products. This facility is co-located alongside the main operations in Shanghai.

Customer and contracts

Aviage's main customer contract is with Comac for the C919 aircraft for the products outlined above.

The Comac C919 flew in 2017 and is preparing for certification and EIS currently scheduled for 2021 with China Eastern Airlines' subsidiary OTT Airlines.

Aviage is well positioned to support this aircraft, which has over 540 firm orders from Chinese airlines, and it will undoubtedly be part of any future wide body or NextGen developments within China. The C919 has yet to achieve certification outside of China but there are close ties within Asian and African markets.

Aviage since 2020 has been supporting Chinese airlines, such as 787 operators, with MRO support.

Strategy

Aviage is building capability within avionics as noted by the move to expand into data recorders contained in "recent developments" below.

Recent developments

June 2020: Aviage and Shenzhen Donica Electronic Technology Co. have signed an exclusive cooperation agreement, and jointly launched the first QACVR (Quick Access to Cockpit Voice Recorder) for Boeing 787. In future Aviage Systems and Donica will work together to develop the global QACVR market.

March 2020: Aviage has recently signed a 3-year avionics MRO service contract with Hainan Airlines, providing inspection, repair and overhaul service of Boeing 787 IMA components. The deal represents the first collaboration between Aviage Systems and Hainan Airlines.

March 2020: Aviage and SATPRO have recently signed a partnership agreement to jointly launch the first HTS (High Throughput Satellite) Ku SATCOM system designed and manufactured in China. In the five year agreement, both will be exclusive partners to develop the Asia Pacific and India connectivity markets for narrow-body aircraft.

Counterpoint comment

We see China as patient and collectively it will take the time necessary to achieve its five year plan of developing the necessary indigenous capabilities. Aviage should benefit in the long-term from its position in China.

Meanwhile Aviage will build its avionic knowledge rapidly via its repair and MRO business.

19.3.4. Bharat Electronics

Founded in 1954 Bharat Electronics Limited (BEL) is an Indian state-owned aerospace and defence company with a number of factories and regional offices in India. It is owned by the Indian Government and primarily manufactures advanced electronic products for the Indian Armed Forces.

BEL today has nine major facilities in India covering a wide range of defense and non-defense sub-sectors including electronic warfare, communications and avionics.

BEL primarily services the Indian Defense Forces with a range of products that includes Electronic Warfare, Communications, Avionics, Electro-Optics and Radars.

Financials

BEL reported that it exported $49m worth of product in 2019 the majority of which was defense related.

BEL benefits from "offset" sales with certain countries which provided the following sales in 2019:

- Data Link II for the Boeing Company, USA.
- IFF – Interrogator for the Boeing Company, USA.
- Radar Finger Printing Systems for the Boeing Company, USA.
- EoS CoMPASS for Elop, Israel

We estimate that BEL generated $18m in revenues for defense related avionics and sensors in 2019, and $16m in 2020.

Operations and capabilities

Operations

BEL has two main facilities supporting its Electronic Warfare design and manufacture and these are located in Bangalore and Hyderabad.

Capabilities

Electronic Surveillance Module: The lightweight ESM system is meant for fitment on small helicopters. This ESM system provides reconnaissance of ground based, airborne, ship-borne and subsurface Radars. The system intercepts, detects, identifies and displays various parameters of the intercepted radar signals. It provides threat warning from a large built-in radar library and accord threat prioritisation. BEL also has an ESM solution for large Air Transport aircraft.

Radar Warning Receiver (RWR): Designed for fitment on fighter aircrafts and helicopters. It intercepts, detects and identifies all types of ground and airborne emitters (Pulse, CW, ICW, Pulse Doppler, Pulse agile, Frequency agile) and presents them on the Cockpit Display Unit with the help of alphanumeric/special colour symbols and audio tones.

Electronic Warfare suite: BEL does not describe this capability for fighter aircraft in detail but it does list the following key parameters:

- Unified [Warning & Jamming]
- Radar Warning: 1 - 18 GHz; Digital Receiver based
- Wide Band Receiver with 100% by HPOI Receiver
- Selectable Narrow Band Receiver options
- Dynamic Range:65 dB
- DOA Accuracy: Coarse & Fine DF modes
- Jamming: 6-18 GHz, DFRM based jamming
- Active Phased Array (APA) steering with narrow beams for accurate/pin point threat jamming
- APA based with Solid State TR Modules
- Various mutually exclusive ECM technique generations & Multiple Threat handling.

Displays: The Multifunction keyboard display (used on the Light Combat Aircraft) is a combined control and display unit comprising alphanumeric keyboard and an LCD dot matrix display. It is used for data entry and management of the various aircraft systems. MFK also performs the Data loading, Selection and Display of relevant page information.

BEL offers a range of small discrete displays that are utilised on e.g. Light Combat Aircraft.

Electro-optic devices: The EOIR payload is a day and night surveillance system that includes a Daylight colour Camera, 3rd generation 3-5 µm thermal imager, Eye-Safe Laser Rangefinder (ELRF) , Automatic video tracker,

Grip and display, Video data recorder as well as command and control capabilities. It is distinguished by a wide variety of interfaces, enabling integration with various systems, such as Computer and GPS.

Customer and contracts

We believe that much of the $49m of export sales noted under "financial" is related to land and coastal defense products.

BEL, within its annual report notes its strategic partnership with Global players like LIG NEX1 (Korea), Lockheed Martin (USA), Elbit (Israel) in the international segment.

Strategy

It appears that BEL is engaged in R&D work associated with Electronic Systems, however, it has not exported these for airborne applications nor been that successful in supporting India's indigenous airborne platforms.

Recent developments

None that we can see.

Counterpoint comment

BEL is largely a state run organisation covering a diverse range of market sectors and products. We do not see it becoming a major player in defense electronics other than for indigenous development work.

19.3.5. Elbit Systems

Elbit Systems was founded in 1966 by Elron Electronic Industries which combined Elbit's existing expertise within the Israel Ministry of Defense-Research Institute.

Elbit Systems is an international defense electronics company including Elbit Systems and its subsidiaries. It operates in the areas of aerospace, land and naval systems, command, control, communications, computers, intelligence surveillance and reconnaissance (C4ISR), unmanned aircraft systems (UAS), advanced electro-optics, electro-optic space systems, electronic warfare suites, signal intelligence (SIGINT) systems, data links and communications systems and radios.

Elbit's military fixed-wing aircraft and helicopter systems and products include a broad range of avionic systems, such as integrated flight deck systems, mission management computers, displays, digital maps and digital recorders. The portfolio also includes airborne electro-optic systems such as head-up displays, airborne intelligence gathering systems, precision guidance systems, aircraft structural components, nanosatellites and a range of aircraft tactical, virtual, appended and embedded trainers and simulators.

In March 2018, Elbit Systems and Universal Avionics announced that Elbit "is in the process of completing the acquisition of the privately owned Universal Avionics Systems Corporation [UASC] through an asset acquisition agreement."

Universal Avionics Inc. is run as an entirely separate subsidiary of Elbit and it is therefore covered separately within this report.

Elbit Systems of America also has a 50% interest in a joint venture with Collins Aerospace, a unit of United Technologies Corp., which is engaged in the area of helmet mounted display systems for fixed-wing military and para-military aircraft.

Elbit design and supply integrated UAS platforms for a range of applications. These include a variety of UAS platforms, including the Hermes™ 900, 450 and 90 family and Skylark™ families of UAS. It provides the majority of avionic and sensor suites integrated within these platforms.

Financials

Elbit generated $4,503m revenues in 2019 across the group.

We estimate that the avionics and sensors related revenues accounted for $519m in 2019, and $485m in 2020.

Operations and technology

Location

Facilities owned or leased by the company:

Ownership	Israel	USA	Other Countries
Owned	2,771,000 ft²	1,050,000 ft²	1,078,000 ft²
Leased	6,559,000 ft²	784,000 ft²	568,000 ft²

Elbit Systems of America, LLC (Elbit Systems of America) and its subsidiaries provide products and systems solutions focusing on U.S. military, homeland security, medical instrumentation and commercial aviation customers. They have operational facilities in Fort Worth, Texas; San Antonio, Texas; Merrimack, New Hampshire; Talladega, Alabama; Roanoke, Virginia; and Boca Raton, Florida.

The Roanoke, Virginia facility includes the activities of Elbit Systems of America - Night Vision, which was acquired by Elbit Systems of America in September 2019.

C4I and Cyber - Headquartered in Netanya, Israel, Elbit Systems C4I and Cyber Ltd. (C4I and Cyber) is engaged in the worldwide market for C4ISR systems, cyber intelligence solutions, homeland security solutions, data links and radio communication systems and equipment.

Elisra - Based in Holon, Israel, Elbit Systems EW and SIGINT – Elisra Ltd. (Elisra) provides a wide range of electronic warfare (EW) systems, signal intelligence (SIGINT) systems and C4ISR technological solutions for the worldwide market.

Elop - Based in Rehovot, Israel, Elbit Systems Electro-Optics Elop Ltd. (Elop) designs, engineers, manufactures and supports a wide range of electro-optic systems and products mainly for defense, space and homeland security applications for customers worldwide.

Capabilities

Elbit's portfolio of electro-optic systems and products includes forward looking infrared (FLIR) systems for night observation, laser range-finders and laser radars, stabilised payloads and electro-optic-based ISR systems. Elbit supplies direct infrared countermeasure (DIRCM) systems for the protection of aircraft to payloads for space, airborne, naval and land-based missions, to head up displays (HUD) and advanced target acquisition systems (TAS), as well as laser, thermal imaging (TI) systems, HLS solutions, ground integrated sights and I2 night vision systems for intelligence, surveillance and reconnaissance (ISR).

Elbit produces C4ISR capabilities for land, airborne and naval and cyber intelligence systems providing networked combat solutions. Elbit provides a wide range of advance communications and network solutions for land, navy and air force applications, supporting a full range of military video, data and voice network needs.

Military and helicopter systems: Elbit provide systems and products, including helmet mounted displays, mission computers, cockpit management systems, helmet mounted sights and smart munitions kits. The range has been broadened to include advanced laser designators, range finders, optronic payloads and airborne reconnaissance systems.

Helmet mounted systems: Elbit's Helmet Mounted Systems (HMS) enable pilots to view flight data, sensor and 3D location-based information within direct line-of-sight (LOS). The HMS allows the pilot to slave the aircraft's sensors to its avionics systems and missiles simply by looking at the target. Suitable for both day and night operation, the HMS can be supplied as part of upgrade programs or on a stand-alone basis.

Family of Starlite data communications are noted as follows:

- Starlite SR: An advanced, short-range digital data-link system, Starlite SR is designed for small manned and unmanned platforms. The lightweight system is suitable for mini-UAVs, loitering munitions, VTOL applications, handheld transceivers, and other small tactical platforms.
- Starlite MR: An advanced digital data-link solution for mid-range manned and unmanned aerial, naval and land platforms including medium UAVs, USVs, UGVs, loitering munitions and mission helicopters. The

lightweight, compact system has an operational range of up to 150km. Starlite MR complies with leading international aviation regulations and standards.

- Starlite ER: An advanced, extended-range, line-of-sight digital wireless communication system for manned and unmanned aerial, naval and land platforms. Starlite ER is designed for long-range vehicles including MALE UAVs, USVs, mission helicopters and aircraft. The flexible, lightweight, and compact system has an operational range of up to 250km.

Customers and contracts

Elbit supports a number of significant platforms including F-16, F-18, F-15, F-35, V-22, T-7A, C-17, AH-64 and UH-60.

Specific contracts include:

- F-35: Elbit provides the laser designator to Raytheon for the Multi Spectral Targeting System (MSTS)
- F-35: Integrated Helmet display system in partnership with Collins Aerospace.
- KC-390: Electronic Warfare suite.
- F-16: Infra-red missile warning system.
- C-130/AC-130 Common Lightweight Digital Rangefinder (CLDR).
- F-18: Large Area Displays, JHMCS Helmet display.
- F-15: Large Area Displays.
- Gripen: electronic warfare suite
- Hermes UAS: Laser G MIST™, WAPS SkEye, 20/MX15 Wescam marker/designator, Radar Maritime MPR and Radar GMTI / SAR: Radar, COMINT, ELINT.
- Skylark UAS: stabilised dual EO/IR payload

Strategy

Elbit states that its vision is “to be a world leading source of innovative, technology-based systems for diverse defense and civilian applications.”

Recent developments

September 2019: Elbit Systems of America completed the acquisition of the night vision business of L3Harris Technologies (the Night Vision Business) for a purchase price of approximately $351.5 million. Located in Roanoke, Virginia, the Night Vision Business is engaged in the development, production and supply of night vision technology for the U.S. and allied military and security forces and for the U.S. federal homeland security market.

Counterpoint comment

Elbit has established itself in the US market via the acquisition of Universal Avionics and L3Harris’s night vision business. It also has a strong presence in the UAV/UAS sector which reflects Israel’s strong presence in this market sector.

It’s strength in the civil market is reflected within the lower value GA, bizjet, rotorcraft sectors serviced by Universal Avionics.

19.3.5.1. Universal Avionics

Universal Avionics is a wholly owned subsidiary of Elbit Systems located in Israel.

Universal Avionics was founded in 1980 when Hubert L. Naimer, formulated the details of a "Master Navigation System", which led to the development of the world's first Flight Management System (FMS).

Today Universal Avionics is a leading manufacturer of innovative avionics systems offered as retrofit and forward-fit solutions for the largest diversification of aircraft types in the industry. Markets served include Business, Special Missions, Government / Military, Airline (regional / commercial), Helicopter and OEM.

Universal Avionics lists its primary products as including Enhanced Flight Vision Systems, Flight Management Systems (FMS), Primary Flight and Multi-Function Displays, Data Link / Communications Management Unit (CU) Systems, Cockpit Voice & Data Recorders.

Financials

In 2019 we estimate that Universal Avionics employed ~450 personnel and generated $87m in revenues across its range of avionics products, falling to $70m in 2020.

Operations and technology

Location

Universal Avionics' main facility is located in Tuscon Arizona and it has support facilities in Toulouse and Singapore.

Universal Avionics conducts all of its design, test and manufacture within its Tuscon facility.

Universal Avionics also has engineering facilities located both in Georgia and Washington.

Capabilities

FMS: The UNS-1Lw features a standard set of I/O capabilities for interface with essential components of the flight deck. The system is comprised of a 4- or 5-inch Flat Panel Control Display Unit (FPCDU) along with a remotely mounted Navigation Computer Unit (NCU). The NCU is contained in a 2-MCU LRU which includes an internal GPS/SBAS receiver.

Platform for NextGen and SESAR: Universal Avionics' SBAS-capable FMS features a precise, internal SBAS Global Positioning System (GPS) receiver that improves accuracy and integrity of GPS-derived position information. The Receiver Autonomous Integrity Monitor (RAIM) prediction requirements in US airspace are thereby removed and navigation capabilities for all classes of aircraft in all phases of flight are increased. The embedded SBAS GPS receiver provides ILS-like guidance down to near CAT I ILS minimums. In addition, the SBAS-FMS meets stringent internal monitoring requirements to provide guidance to any of the Minimum Descent Altitude (MDA) levels for Area Navigation (RNAV) (GPS) approach guidance.

Flight Decks: Universal Avionics specialises in flight deck upgrades, providing flexible options for over 50 aircraft types ranging from the Pilatus PC-12 to the Boeing 747. Customised from an SBAS-capable FMS upgrade to one, two, three or a full suite of Advanced Flight Displays configured in Primary Flight Display (PFD), Navigation Display (ND) and Multi-Function Display (MFD) formats for the utmost in flexibility.

Integrated flight deck display suite: The InSight Display System is designed as an integrated flight deck solution, featuring embedded synthetic vision with advanced mapping capability, electronic charts, and radio control. As an integrated solution, InSight retains the ability to interface with a large number of federated components such as attitude/heading sensors, air data computers, radars, traffic systems, radios, and autopilots. InSight translates into lower operating and maintenance costs while providing enhanced safety, situational awareness, and functionality for pilots.

Enhanced Vision Systems: ClearVision is a complete Enhanced Flight Vision System (EFVS) solution providing head-up capability combined with enhanced vision (EVS) and synthetic 3D terrain display (SVS). It features a large field-of-view, with the brightest and highest resolution HUD for commercial aircraft in the market.

Database services; Navigation Database subscription service is offered to provide current, accurate navigation information for operators of Universal Avionics's Flight Management System. Subscriptions are available in worldwide and regional coverage areas to meet the requirements of flight operations. A special helicopter database is also available for rotorcraft operators.

Software: Universal Flight planning allows for the user to perform offline GPS FDE predictions for remote/oceanic operations (including Minimum Navigation Performance Specifications (MNPS) airspace), making it possible to obtain approval for remote/oceanic operations using GPS as a primary means of navigation. The program uses a GPS almanac text file in the YUMA format obtained from the U.S. Coast Guard GPS website.

Universal Avionics offers repair and overhaul services together with loaners and exchange units from its FAA/EASA approved repair centre in Tuscon Arizona.

Universal Avionics also offers an integration service for flight deck retrofits and upgrades, however, these services are offered via 3rd party specialists located throughout the US and EU.

Customers and contracts

- Airbus CN235 (airtech) military – Universal Avionics FMS and multi-mission FMS
- ASI Aviation F 406 – EFIS display suite.
- Cessna Citation – UNS-IEspw Flight Management System
- Dornier 228 – Flight Management Systems, EFI-890R display suite
- Gulfstream G550 – Flight Recorders, solid state cockpit voice and flight data recorders.
- Gulfstream G650 – Flight Recorders, solid state cockpit voice and flight data recorders.
- LET 410 – EFIS – 890R dual display
- MD900 Explorer – EFIS, IFR capable integrated flight deck, Next Gen flight deck.
- Shaanxi Y-8 – UNS-1K Flight Management System
- TAI Hurkus – EFI 890R display and radio control unit
- XAC MA600 – UNS-1M nav system EFIS display suite.

Strategy

Universal Avionics does not appear to state its strategy per se, however, they believe every operator should have the benefit of advanced technologies in their aircraft, for the freedom to fly in airspace around the world efficiently and safely.

Recent developments

January 2021: Universal Avionics introduced its latest InSight Integrated Flight Deck solution with Authorised Dealer, Redimec S.R.L.'s installation on a Hawker 800XP. The InSight Display System was selected for a more modern, reliable flight deck solution to address high failure rates and climbing repair costs associated with existing equipment. The aircraft upgrade is now complete with a fully integrated display system capable of LPV, CPDLC and ADS-B Out.

January 2021: Aerion has selected the Universal Avionics ClearVision Enhanced Flight Vision System (EFVS) for the AS2 supersonic aircraft currently under development, comprising the complete Head-Up Display and EFVS solution featuring the SkyLens Head-Wearable Display (HWD) with its proven unlimited Field of Regard.

December 2020: Universal Avionics announces the successful first flight of its Gulfstream G-III aircraft, featuring the latest in interactive Human Machine Interface (HMI) technologies for enhanced head-up / head-down coordination.

January 2020: Universal Avionics and MD Helicopters announce a strategic partnership to integrate Universal Avionics' advanced InSight Display System as the full-digital flight deck solution for MD Helicopters' MD 900/902 Explorer. MDHI will integrate the InSight Display System into the production and retrofit of the twin-engine helicopters.

April 2018: Elbit Systems Ltd. announced today that it completed the acquisition of the assets and operations of the privately-owned U.S. Universal Avionics Systems Corporation for a purchase price of approximately $120 million.

Counterpoint comment

Universal Avionics sees itself as a provider of hardware solutions, however, it is supported by integrators, STC certification processes, database service provision, training and repair stations. Universal Avionics has a significant proportion of its sales generated from retrofit/upgrade sales and we have yet to see the effect of the pandemic on legacy platforms, some of which may not return to service.

19.3.6. Hindustan Aeronautics

Hindustan Aeronautics Limited (HAL) develops a range of defense platforms for use by the Indian Defense ministries in addition to export sales to foreign military operators.

These include the Hawk (under licence from BAE), Light Combat Aircraft, SU-30 Mk1, Intermediate Jet Trainer (IJT)/HJT-36, Light Combat Helicopter, Light Utility Helicopter.

Much of the avionics required for these platforms are sourced from HAL's two avionic subsidiaries located in Korwa and Hyderabad.

Avionics Division Korwa was established in the year 1983, to take up the production of Display Attack Ranging and Inertial Navigation system for Jaguar International aircraft for Indian Air Force followed by manufacturing & supply of avionic systems for Russian origin MiG-27 & Su-30MKI aircraft. Division at present is manufacturing & repairing various Avionics Systems fitted on MiG-27M Upgrade, Mirage-2000, LCA, Jaguar upgrade, AJT-HAWK aircraft. Division is also engaged in the maintenance of UAVs Systems since 2001 onwards.

Avionics Division, Hyderabad was established in the year 1966 for manufacture of MiG 21 Avionics equipment. Co-located Design Division, Strategic Electronics Research and Design Centre (SLRDC) has indigenously developed more than 40 types of Avionics systems for LCA, ALH, IJT, SU-30 MKI , HTT-40, Jaguar Darin II & III, LCH,LUH and Hawk trainer Aircraft. SLRDC provides Design, Development and Engineering support to several Avionic products which are manufactured for fitment in a number of fixed and rotary wing Aircraft like MiG 21, Jaguar, MiG 27, MiG 29, Cheetah, Chetak, ALH, Su-30 MKI, Hawk, Do-228, LCA. HAL is involved in the manufacture and repair & overhaul of a wide range of avionics equipment, including airborne radars, communication, navigation equipment and on-board computers fitted on fixed and rotary wing platforms of Russian, Western and Indian origin. In addition to catering the requirement of Defence services, Division also supplies avionics equipment to Civil and Export customers.

Financials

We estimate that HAL generated $50m in avionic related sales in 2019 from its two subsidiaries located in Korwa and Hyderabad, and $42m in 2020.

Operations and technology

Location

HAL's avionics capabilities are located in its Korwa, India facility where design and manufacturing takes place under one roof.

HAL also has avionics capabilities within its Hyderabad facility. All avionic related design and manufacturing processes are contained within this facility.

Printed circuit board (PCB) work is outsourced from both facilities.

Capabilities

Within the Hyderabad facility HAL provides the following:

- Radar Control System (RLSU - 30MK) which has Passive Electronic Scanned Array sensor for Su-30 MKI aircraft.
- Identification of Friend or Foe (IFF) & variants with advanced technology
- Omni Range/Instrument Landing System (VOR/ILS)
- Tactical Air Navigation (TACAN)
- Solid State Digital Video Recording System (SSDVRS)
- Very High Frequency (VHF) Radio set & Data Link
- Ultra-High Frequency (UHF) Stand by Radio set
- Mission Computer (MC)
- Display processors (DP)

- Open Architecture Computer (OAC)
- Open System Architecture Mission Computer (OSAMC)

Within the Korwa facility HAL offers the following avionics capabilities:

- Inertial Navigation System (INS): The inertial navigation and attack system uses an inertial platform with a compactly packed fast computer for generating in-flight navigation and weapon aiming parameters.
- Weapon Control System (HUDWAC): Preparation of aircraft armament to combat applications which provided guided tracking of weapons until hitting the target Microprocessor based head-up Display & Sighting System.
- Combined Map and Electronic Display (COMED): The head down display is a cockpit mounted navigational aid with multifunction facilities. It displays the ground map as stored in a filmstrip superimposed with symbols generated in a CRT.
- Flight Data Recorder (FDR): The Flight Data Recorder is installed in the aircraft to monitor, process and record signals from avionics systems and sensors for subsequent analysis on the ground.
- Inertial Navigation and Global Positioning System (INGPS): An inertial system with an embedded GPS receiver that provides aircraft peripheral equipment with all necessary inertial inputs.
- Multi-Functional Display (MFD) : A small LCD screen used to display information to the pilot in numerous configurable ways. It is available in different size and nature.

HAL is party to a number of Joint Ventures with the following of note:

- Samtel (India) HAL display JV: Design, Development and Manufacture of various types of display systems for Airborne, Military and ground applications for sale in India and International markets.
- BAE/HAL software JV: Design, Develop & Market Computer Software, Firmware Programs and provide software solutions & service to the customer

Customers and contracts

HAL lists its export customers as including Airbus, Boeing, GE Aviation, Honeywell, Moog and a number of Air Forces around the world.

It has provided avionics for LCA, ALH, IJT, SU-30 MKI, HTT-40, Jaguar Darin II & III, LCH, LUH and Hawk trainer Aircraft.

Further services include Design, Development and Engineering support to several Avionic products which are manufactured for fitment in a number of fixed and rotary wing Aircraft like MiG 21, Jaguar, MiG 27, MiG 29, Cheetah, Chetak, ALH, Su-30 MKI, Hawk, Do-228, LCA.

HAL states that more than 500 HUDs have been supplied for various Indian platform such as Su-30MKI, Jaguar and MiG-27M upgrades.

Strategy

HAL has been focused upon increasing it export sales for a number of years. It has had some success with exporting avionics. However, this is often as part of a platform sale. India has a reputation for engineering and software capabilities, and this may provide it with a stronger growth path than with product offerings.

Recent Developments

February 2021: HAL entered into an agreement with Elbit Systems Electro Optics Elop Ltd., Israel for supply of Digital Overhead Head Up Display Systems (DOHS) during the recently concluded Aero India-2021. The Digital Overhead HUDs will be initially manufactured in existing facility of HAL's Division at Korwa. A dedicated facility will be augmented progressively in proportion of manufacturing volume.

Counterpoint comment

HAL has invested R&D in avionics but has enjoyed limited success with commercial export sales. We see its strength in developing affordable platforms for many nations that have limited defense budgets.

19.3.7. Radio Electronic Technologies

Part of the state controlled ROSTEC corporation KRET sits alongside United Engines, Russian Helicopters and United Aircraft Company as part of the Aviation Group sector.

Joint-stock company Concern Radio-Electronic Technologies (KRET) was registered on February 19, 2009 in Russia.

The Concern is the leading Russian designer and manufacturer of on-board radio electronic equipment for all types of aircraft (over 80% of the market) and state identification systems (over 90% of the market). The company's products are sold in more than 30 countries.

KRET JSC incorporates over 60 enterprises engaged in the design and manufacturing of on-board radio-electronic equipment systems; radio-electronic warfare and reconnaissance devices; systems and devices for state recognition; medical equipment and hardware.

KRET currently manufactures a broad range of products designed for the following industries:

- Radio electronics
- Aerospace
- Industrial manufacturing
- Healthcare.

KRET's primary business is the manufacturing of on-board radio-electronic equipment for military and civilian aircraft.

Financials

ROSTEC reported $2,600m of revenues in 2019 covering Aviation, Health, Energy, Automotive and Industrial sectors.

We estimate that KRET represents around $1,200m of total revenues with the airborne Avionics and Electronics businesses generating $80m in 2019.

Operations and technology

Location

KRET has 60 subsidiary facilities distributed throughout Russia.

KRET’s headquarters are located in Moscow.

Capabilities

KRET provides a range of Avionic capabilities including E and ECM for Russia’s indigenous military aircraft.

KRET’s EW systems are primarily installed on X-101 and X-102 cruise missiles carried by Russian Tu-95, Tu-160 and Tu-22M3 strategic bombers.

Russia’s MiG-35 multirole fighter jets are equipped with the latest platform-less inertial navigation system provided by KRET. The MiG-29K/KUB fighters are now being equipped with the LINS-100RS inertial system, while the MIG-35s will receive the BINS-SP2, which is absolutely quiet, solid and user-friendly. The system is designed to determine the location of the object, provide complex processing and deliver navigation and flight information. It is also able to determine the coordinates and parameters of an object in complete autonomous mode.

Customers and contracts

Some specific application contributions are listed below:

- KRET has designed the electronics for some of Russia's most advanced military aircraft, including Su-57, Su-35S, Ka-52 Alligator, Mi-171A2, Yak-130, MiG-29K/KUB, IL-476, and Tu-204SM, as well as for the Soyuz TMA manned spacecraft.
- KRET provides the KBO-17 Avionics suite which includes the Electronic flight Instrument System on the Mil MI17/171 platform.

- KRET also provides the Automatic Flight Control System for the Su-57 fighter platform.

Strategy

The large Russian aerospace companies have been encouraged by the state to develop commercial solutions that can be marketed to the West, however, the level of funding required and the time necessary is often debated.

In 2014 KRET, as part of Rostec, signed an agreement to establish a Helicopter Avionics Integration Centre (HAIC) to help boost the competitiveness of Russia's helicopter industry on the global market.

Recent developments

September 2018: Russia's Concern Radio-Electronic Technologies is ready to re-equip the fleet of Russian Il-20 reconnaissance planes with advanced electronic warfare devices following the recent Il-20 tragedy in Syria.

Sept 2018: The Radio-Electronic Technologies Concern, part of the Russian State Corporation Rostec, and the Indian company Space Era Materials and Processes have concluded an agreement on the participation of the Russian side in establishing a service centre for military aviation in India. The agreement will allow the Russian side to participate in competitions held by the Indian government to provide after-sales service of military hardware supplied by Russia, and also to take part in creating a service centre for Russian-made aircraft and helicopters.

Counterpoint comment

We are not aware that KRET has penetrated western markets with avionics for helicopters or military platforms. We therefore believe it remains an indigenous supplier to Russia's military market.

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