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

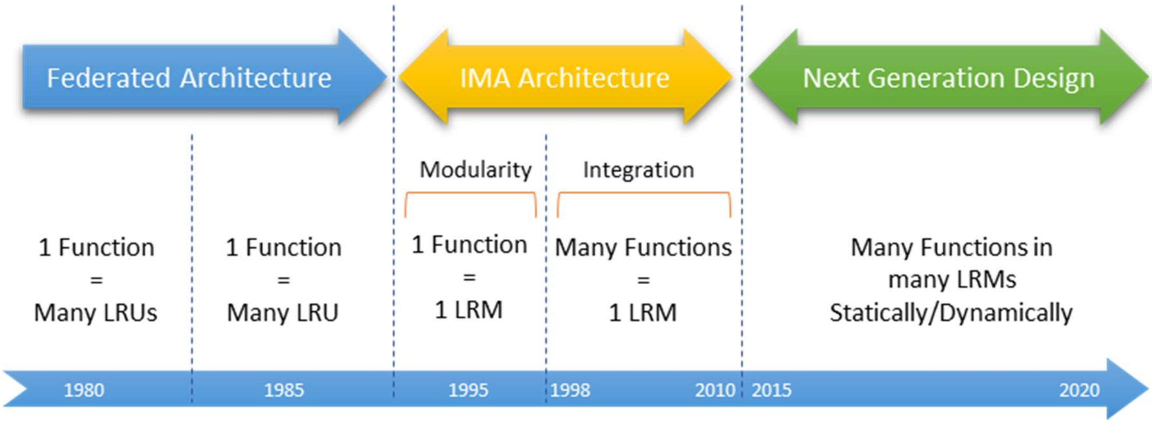
WAAS	Wide Area Augmentation System (method of differential GPS)
WRT	WXR Receiver/Transmitter
WX	Weather
WXR	Weather Radar System

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.

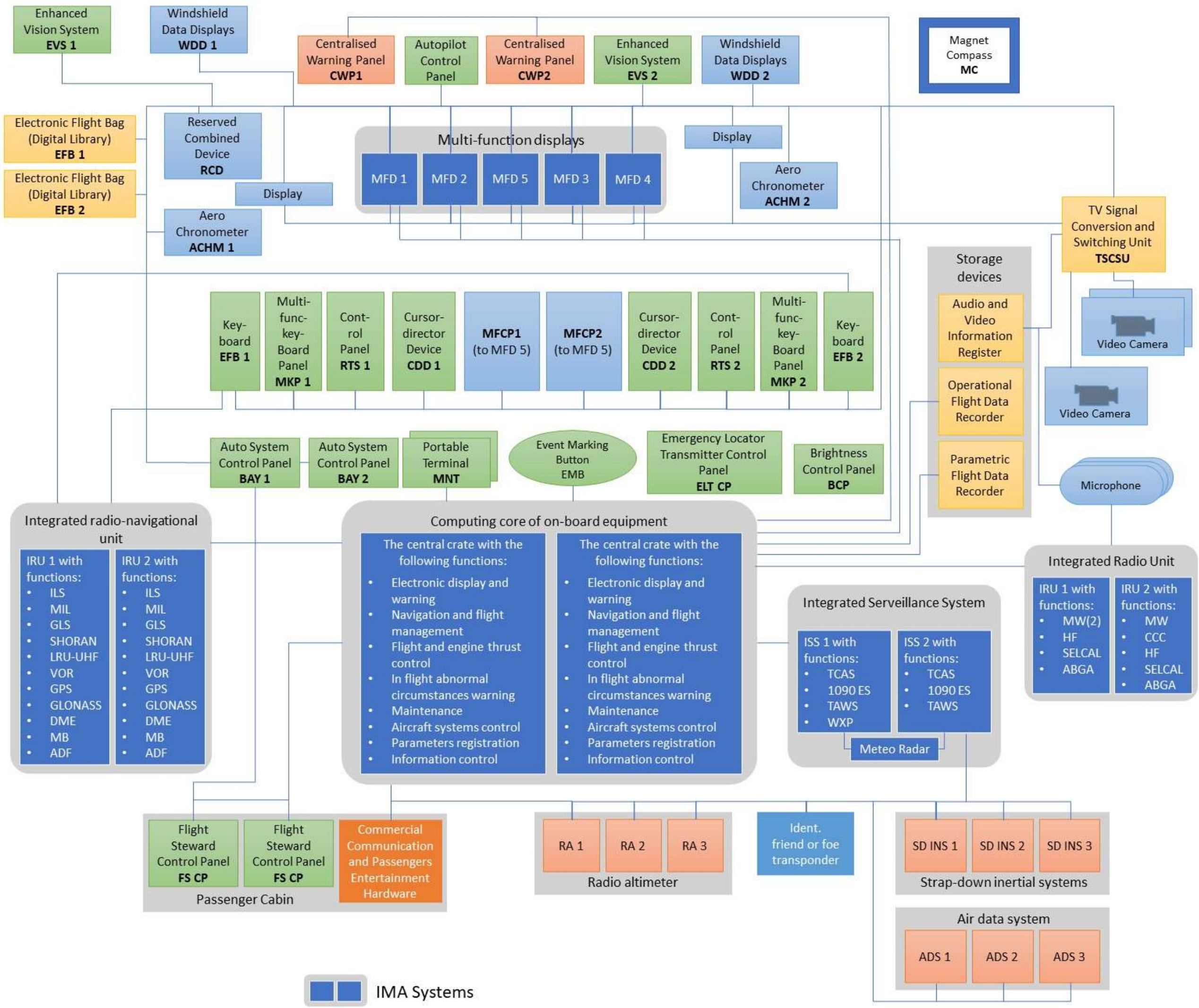
Both Honeywell and Raytheon (Collins Aerospace) will argue that their integrated cockpit offerings, as represented by Primus Epic/Apex and ProLine Fusion respectively, predate the adoption of IMA by OEM airframers.

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.

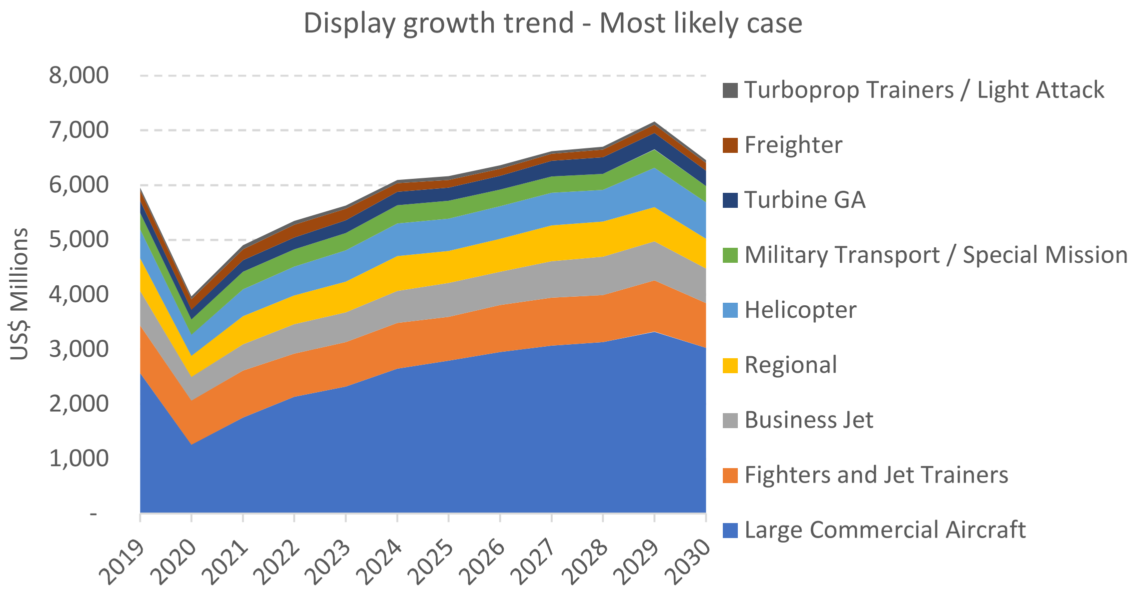
This expanded scope reflects the move in recent decades to specify and create multi role military platforms such as the A400M and KC-390.

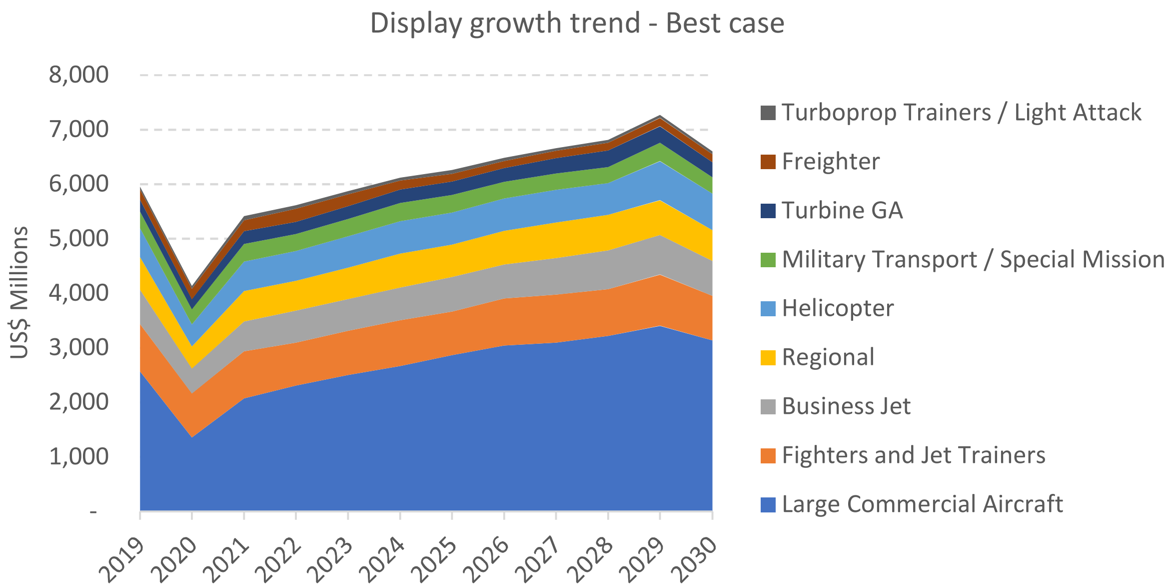
When describing military fighters e.g., F-35, we noted interoperability as being a key requirement. These fighter role aircraft often need to be supported in the overall networked war theatre by long range early warning aircraft and refuelling tankers etc.

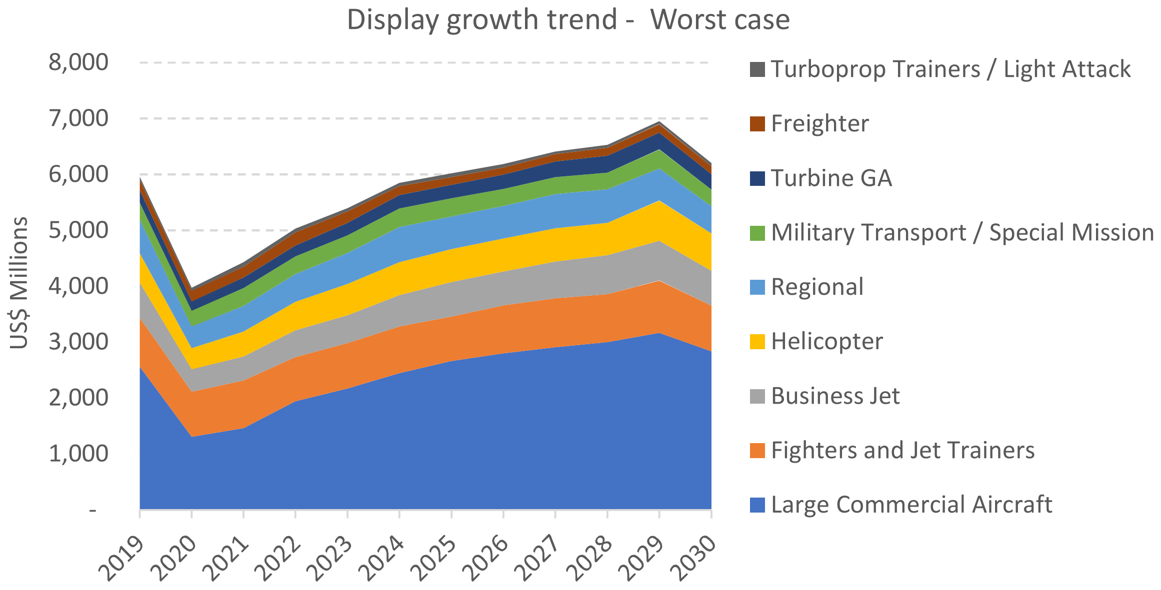
Many of the large military transport aircraft have to meet the relevant civil authorities' requirements (e.g. FAA, CAA, EASA) if they are to be permitted to operate within civil arenas (which covers most of the globe). Airbus as constructor for the A400M was therefore a natural choice (notwithstanding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

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**






Display growth trend - Worst case
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
-
US$ Millions
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Turboprop Trainers / Light Attack
Freighter
Turbine GA
Military Transport / Special Mission
Regional
Helicopter
Business Jet
Fighters and Jet Trainers
Large Commercial Aircraft

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.

11.12. 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.

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)

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).

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 ft^{2}in 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

<u>Operations</u>

Jeppesen has its operations located in Everett, Washington State, USA.

<u>Capabilities</u>

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.