18 AVIONICS

The most noticeable and rapid changes in aviation during the past 20 years have been in the avionics equipment available to all user classes, from small general aviation (GA) aircraft to large transport category aircraft. This will continue to be true in the future NAS because new capabilities and air traffic control (ATC) services will depend on avionics equipage. One factor the architecture reflects is the time required for the FAA to certify the new avionics envisioned for the future NAS.

The FAA is responsible for certifying new avionics to ensure the equipment meets acceptable performance and interoperability standards and operates safely. International agreements will be needed to enable worldwide manufacture and interoperability of avionics equipment. Another factor for the architecture is what, if any, changes in minimum avionics equipage requirements will be necessary for operating in the NAS and how to accommodate an aircraft fleet with mixed equipage levels.

Section 4, NAS Operations; Section 15, Navigation, Landing, and Lighting Systems; Section 16, Surveillance; and Section 17, Communications describe a variety of systems (or concepts that will lead to systems) for future NAS capabilities, some of which will require new avionics. New avionics may require new air traffic control procedures and/or aircraft operating procedures (14 CFR Part 91, 135, etc.) before the full benefits of the equipment can be realized.

Equipment (such as avionics) or modification to an aircraft must first be approved through the FAA's certification process. Although there are several ways to receive certification (such as Technical Standard Order Authorization, Supplemental Type Certificate, etc.), in general, each method leads to the same three required approvals: design approval, production approval, and installation approval. This is a very high-level representation of the comprehensive certification mechanism manufacturers must satisfy before installing products on an airplane.

Certification is not a standard process that occurs over a given period of time. Each product to be certified has a unique set of variables that affect the length of the certification process. The following time estimate for avionics certification is used for architecture planning purposes.

Industry collaboration to develop performance standards in a forum such as an RTCA Special Committee can take 2 to 3 years. Once a manufacturer applies for certification, FAA design and production approval can take up to 1 year, and installation approval can take another year. If rulemaking is necessary, it can take 3 to 4 years for a final rule to be issued. However, the rule development process can begin at any time (i.e., rulemaking is not tied to any manufacturer's product design, production, or installation approval). Architecture transition planning estimates account for aircraft equipment certification requirements and possible rulemaking actions (see Section 11, Regulation and Certification Activities Affected by New NAS Architecture Capabilities). RTCA has recently convened Task Force 4, an Industry/Government forum, to review FAA certification processes.

Traditionally, as the NAS evolved, questions about avionics equipage levels were addressed from the viewpoint of allowing user access to airspace while minimizing the equipage cost burdens consistent with safety. The architecture assumes the viewpoint that the benefits from new capabilities and services enabled by future avionics will provide the incentive for operators to equip. However, mixed avionics equipage levels will continue to be a fact of life in the future NAS.

The minimum equipage requirements/mixed equipage issue is complex due to diversity in operations (Part 91, 121, etc.), numerous aircraft types and performance levels, operational conditions (instrument or visual meteorological conditions), and the various airspace classes. Planning remains to be done on the mixed equipage issue to decide what, if any, new avionics minimum equipage requirements or changes in flight procedures will be needed. Therefore, the avionics architecture evolution steps, schedule charts, and cost charts described in this section *do not represent minimum equipage requirements for operating in the future NAS.*[1]

1. Terrain Alert and Warning System (TAWS) is an exception. See Step 1, cockpit displays page 18-4.

PART III

18.1 Avionics Architecture Evolution

The avionics architecture evolution steps estimate the time periods when avionics should be available to support the capabilities described in the communications, navigation, and surveillance sections.

18.1.1 Avionics Architecture Evolution—Step 1 (Current–1998)

Navigation

Aircraft avionics include a variety of navigation signal receivers such as very high frequency omnidirectional range (VOR), distance measuring equipment (DME), nondirectional beacon (NDB), tactical air navigation (TACAN), instrument landing systems (ILS), Long Range Navigation-C System (Loran-C), and the Global Positioning System (GPS) (either visual flight rules (VFR)-only or Technical Standing Order (TSO)-C-129-compliant). These receivers, which are built to international standards, are compatible with the NAS navigational aids infrastructure. Avionics receivers are usually installed in aircraft in various combinations to provide navigation, nonprecision, and precision instrument approach guidance to pilots, using signals from receivers displayed on various flight instruments and displays.

More sophisticated aircraft are equipped with flight management systems that process information from the receivers to provide area navigation capability, although GPS is making area navigation more readily available to low-end users as well.

From an avionics-equipage perspective, there are few problems with the current navigational receivers other than the number that must be installed for navigation. Equipment is affordable, reliable, and internationally interoperable. In some terminal airspace, there is potential interference from frequency modulation (FM) broadcast signals with localizer signals. Additionally, ILS installation costs and problems in obtaining a suitable frequency limit the number of airports that can have precision approaches.

Surveillance

Most aircraft that use NAS and ATC services are equipped with highly reliable and affordable transponders. In general, aircraft are not permitted to fly above 10,000 feet or in certain terminal airspace unless they are transponder-equipped. When interrogated by a secondary surveillance radar (SSR), aircraft transponders reply with the aircraft's altitude and assigned identification code, which is then displayed on controller workstations. Transponders also respond to interrogations from airborne traffic alert and collision avoidance systems (TCAS). TCAS I includes a pilot display that identifies the location and relative altitude of nearby transponder-equipped aircraft. Aircraft equipped with TCAS II also provide pilots with a vertical resolution advisory to prevent mid-air collisions. Most domestic passenger-carrying airplanes with 10 to 30 passenger seats are required to have TCAS I; airplanes with more than 30 passenger seats must have TCAS II.

Communications

In the domestic environment, pilots and air traffic controllers use very high frequency (VHF) amplitude modulation (AM) radios for communicating and receiving air traffic control service information and in-flight weather information. Department of Defense (DOD) aircraft use both VHF and ultra high frequency (UHF) radios for air traffic control services. The FAA also uses the VHF spectrum to broadcast either recorded or automated weather observations of airfield conditions.

All aviation safety communications services for the U.S. oceanic regions use high frequency (HF) voice communications via a commercial service provider. The airlines also use ARINC's HF Data Link services or FANS-1/A-compliant equipment for data link services on transoceanic flights.

Some difficulties and limitations associated with communications in the NAS were identified in Section 17. Due to the growth in aviation activity, voice channel congestion is occurring. In some locations, the VHF spectrum is saturated to the point that no additional channels are available to expand existing ATC services or accommodate new services, such as the Automated Terminal Information Service (ATIS), or automated weather observations. Spectrum availability is one of the critical limiting factors to expanding NAS services and meeting growing demand.

Users, particularly the GA segment, have expressed a desire for a new universal data link communications capability to receive flight information services (FIS), such as updated weather forecasts, hazardous weather advisories, and/or graphical weather depictions in the cockpit. Commercially provided FIS services that include electronic messaging as well as weather information are becoming available for low-end GA users. Traffic Information Service (TIS) via Mode-S using the 1030/1090 MHz spectrum is addressed in Sections 16 and 17.

Cockpit Displays

Aircraft with electronic flight information systems (EFIS) can display a variety of information, such as navigation routes, onboard weather radar data, and TCAS information. EFIS displays are currently used to replace analog gauges with digital multifunction electronic displays; however, their functionality remains similar to that of the analog gauges they replace. Initial displays with limited multifunction capabilities are also available to low-end GA users.

One primary concern for all aircraft is the limited amount of panel space available for avionics and displays. This highlights the need for integrated avionics equipment and displays, which will take up less space than today's piecemeal, stand-alone systems. Integrated avionics suites are more prevalent on air carrier and high-end GA aircraft with EFIS displays and flight management systems. However, even these aircraft have problems resulting from add-on stand-alone equipment, and not all air carrier or corporate aircraft have EFIS displays or flight management systems.

During Step 1, terrain awareness capability is available for air carriers and high-end GA aircraft through ground proximity warning systems (GPWS) that provide aural warnings when an aircraft is close to the ground. An enhanced terrain awareness warning system (i.e., the terrain alert and warning system (TAWS)) that provides more warning time than GPWS is becoming available. TAWS uses position data from a navigation system, such as a flight management system (FMS) or GPS, and input from a digital terrain data base to display surrounding terrain. The computer sends warning alerts to the plane's audio system and displays in the event of a potential collision with terrain. The TAWS computer can input display data to either the weather radar, EFIS, or some other display screen on which the surrounding terrain is shown with the threatening terrain highlighted.

Currently, some air carriers are voluntarily equipping with TAWS, and the FAA has released a notice of proposed rulemaking to mandate TAWS equipage. During Step 2, the FAA will mandate TAWS equipage to replace GPWS as the standard terrain warning system. TAWS will be required on all U.S.-registered turbine-powered airplanes with six or more passenger seats.

18.1.2 Avionics Architecture Evolution—Step 2 (1999–2003)

Safe Flight 21, a limited operational demonstration, will be a key step toward mitigating the scheduling and technological risks associated with NAS modernization. Safe Flight 21 is important to the avionics architecture evolution because the safety and efficiency benefits of modernization outlined in the overall architecture depend largely on avionics. The Safe Flight 21 program will test the avionics and ground infrastructure as a whole. Results from the Safe Flight 21 program will be used to refine the architecture, including avionics evolution. See Section 6, Free Flight Phase 1, Safe Flight 21, and Capstone, for a more complete discussion of the Safe Flight 21 program.

Navigation

In Step 2, GPS avionics capabilities will have at least three distinct levels of sophistication: (1) a GPS receiver for en route navigation and nonprecision approach capability; (2) a GPS Wide Area Augmentation System (WAAS) receiver with precision approach capability (Category (CAT I); and (3) a GPS Local Area Augmentation System (LAAS) receiver with CAT I/II/III precision approach capability. WAAS and LAAS are designed to provide a level of service equivalent to or better than ground-based systems. The architecture supports dual operations, from WAAS initial operating capability (IOC) until the ground-based navigation system phase-down is complete. This provides ample time for users to transition to GPS avionics and for the FAA to ensure that augmented GPS (WAAS/LAAS) operates as designed.

During this time frame, traditional ground-based navigation aids will continue to be available and studies will be completed to determine what, if any, ground-based navigation aids should be retained to supplement augmented GPS. If unforeseen problems arise, the architecture will be adjusted and phase-down of ground-based navigation aids will be appropriately modified. The FAA will not transition entirely away from ground-based navigation aids until it is certain that augmented GPS meets required performance. DOD will conduct an analysis to determine what GPS avionics capability is suited to its worldwide military mission, as well as to the NAS.

When purchasing equipment, all instrument flight rules (IFR) users will have to consider the cost of GPS navigation data base updates. IFR GPS navigation data bases must be updated every 28 days to match the cycle for chart and approach plate updates that reflect navigation/approach changes in the NAS. Currently, the cost to update low-end GA GPS navigation data bases is $500 to $700 per year.

Surveillance

Air-air automatic dependent surveillance broadcast (ADS-B), using GPS as the primary source of navigation data, will be available for pilot situational awareness. ADS reports will include aircraft identity, position, velocity vector, and other essential information. ADS-B-equipped aircraft within the proximity of another ADS-B-equipped aircraft can receive the broadcast, decode the position data, and display the received position on a cockpit display. Air-air ADS-B will require special avionics, GPS or FMS area navigation capability, and a cockpit display, including interfaces for the various components. Broader application for ATC surveillance will depend on creating an ADS ground infrastructure.

In Step 2, TCAS remains as an independent air-air collision avoidance system. ADS-B avionics will operate on a noninterference basis with TCAS-only-equipped aircraft. During this step, the existing equipage requirements for transponders and TCAS will remain in place and no change will be required for TCAS software, due to ADS-B. Also, Mode-3/C transponders will still be in use, operating seamlessly in the same system.

In the oceanic environment, the FAA will begin installing the necessary infrastructure to support automatic dependent surveillance addressable (ADS-A) operations. The main incentive for users to equip with ADS-A avionics will be access to selected oceanic tracks that permit more optimum flight profiles. Additionally, air-air ADS-B avionics will be used to support in-trail climbs/descents in the current oceanic track system.

Communications

In collaboration with industry, the FAA will finalize standards for next-generation communications system (NEXCOM) VHF digital link (VDL-Mode-3) radios that have digital voice and data capability. VDL-Mode-2 digital data services through a commercial service provider will be available to properly equipped users during this time frame. The current VHF (and UHF for DOD) amplitude modulation system will remain in use for voice communications. FIS services will continue to be available through commercial service providers.

During Step 2, HF voice and data link will continue to be the primary communication links in the oceanic area. However, voice and data communications via geostationary (GEO) satellites will become more prevalent because satellite communications will be the primary link for ADS-A capabilities.

Cockpit Displays

New cockpit display avionics will provide information to the pilot in textual and graphical format including ATC clearances and messages, traffic information, moving maps, terrain displays, weather, aircraft and flight monitoring, and other information. These capabilities will offer improved flight safety, efficiency, and flexibility, particularly for GA users. A flight computer is usually required to process the information and drive the displays. Sophisticated transport aircraft and business jets will begin the transition to text and graphic displays using their EFIS systems and initial air-air ADS-B and VDL-2 data link capabilities.

The Safe Flight 21 program will provide the operational testing environment for developing integrated cockpit displays and multifunctional avionics, particularly for low-end GA. The results will be used by the FAA to create appropriate standards for cockpit displays in all user categories consistent with the concepts in the NAS architecture.

18.1.3 Avionics Architecture Evolution—Step 3 (2004–2007)

Navigation

The transition to GPS-based avionics for navigation will continue in Step 3. Traditional ground-based navigation systems will remain in service but will begin phase-down. The FAA projects that by the end of Step 3 or in early Step 4:

- GPS WAAS avionics will be installed in 65 percent of the GA fleet and 100 percent of the GA business and air taxi fleets.
- 100 percent of the air carrier, regional, and commuter fleets will equip with a GPS WAAS/LAAS receiver.

DOD avionics may be based on the precise positioning service (PPS) signal available only to the military and authorized users, rather than on WAAS. During Step 3, DOD will start to equip its fleet (approximately 16,000 aircraft) with GPS avionics suitable for the NAS.

Surveillance

During Step 3, the FAA will begin installing ADS ground stations in nonradar en route areas and at major airports to use ADS-B for air-ground and airport surface surveillance. Aircraft with ADS-B avionics will provide a periodic broadcast of the aircraft's position, velocity, altitude, identification, and other information. Mode-3/C transponders will still be compatible with the NAS radar surveillance infrastructure.

TCAS will be retained as an independent collision avoidance system and the equipage requirements for TCAS and transponders will remain in place. ADS-B will be complementary to TCAS, but will not require software changes or replacement of TCAS equipment. The proliferation of air-air surveillance systems will enable broader application of pilot self-separation procedures and rules.

In the oceanic environment ADS-A and air-air ADS-B avionics will be used, along with navigation, ATC communications, and automation improvements, to reduce aircraft separation.

Communications

The FAA will begin replacing approximately 40,000 VHF radios with new digital NEXCOM radios that have both digital voice and data capabilities. The radios will be able to emulate the existing analog system and can be designed so that selected modulation techniques are software programmable. A phased transition to NEXCOM avionics will begin during Step 3 to provide VDL-Mode-3 service to users in the super high and high en route sectors (above flight level (FL) 240).

The FAA is considering mandating NEXCOM equipage for operators in these en route sectors during Step 3 because the transition depends on all aircraft in the airspace being equipped with a suitable digital radio. DOD will be exempt from any NEXCOM mandates and will continue using UHF for voice communications. Other en route sectors and terminal areas will continue to use VHF analog voice communications or NEXCOM radios in analog emulation mode. Users will be motivated to equip with digital radios mainly because of the reduced operational constraints from frequency congestion.

Cockpit Displays

New multifunctional displays will continue entering service at all levels to integrate data and information from systems such as TIS, FIS, ADS-B, GPS, etc.

18.1.4 Avionics Architecture Evolution—Step 4 (2008–2015)

Navigation

The architecture assumes that IFR users will complete their transition to GPS-based avionics during this time period. This will allow the FAA to complete the phase-down for traditional ground-based navigation systems, but some may remain in service if navigational system redundancy is warranted. GPS equipage will depend on user evaluation of operational need and any minimum equipage requirements the FAA may mandate. Those that fly VFR only will continue to do so and will either not have GPS at all or will equip with a noncertified VFR-only unit. Those that fly IFR down to CAT I precision approaches will equip with WAAS avionics or continue to use current TSO C-129 equipment and accept the nonprecision approach limitation. Those that currently fly to CAT II/III minimums will equip with LAAS.

Surveillance

Installation of ADS ground systems will be completed in the terminal and en route airspace, thus extending use of ADS-B for air-ground and airport surface surveillance. Aircraft equipped with TCAS and Mode-3/C transponders will still be compatible with the NAS infrastructure. ADS-B will be integrated with the future emergency locator transmitter (ELT) to provide discrete identification codes and GPS-based position information to enhance search and rescue operations.

TCAS will remain as an independent collision avoidance system, but the FAA may accept air-air ADS-B as an alternate means of complying with the collision avoidance mandate. The alternate compliance finding will depend on collecting data that prove air-air ADS-B is no less capable than TCAS. This data collection may be done during the Safe Flight 21 program. Additionally, implementing a TSO and changing existing regulations will have to be accomplished before air-air ADS-B can be substituted for TCAS.

Communications

As the transition to NEXCOM progresses, more ATC sectors will convert to digital communications, commensurate with user equipage. Flight information services such as weather information and notices to airmen (NOTAMs) will be available via the NEXCOM data link. During this step, the FAA is considering mandating NEXCOM radios at FL 240 and above as well as in selected high-density terminal airspace and some associated low-altitude en route sectors. Low-density terminal areas and en route sectors below FL 240 will continue using NEXCOM radios operated in analog emulation mode. DOD will be exempt from any mandated requirements and continue using UHF for air traffic services to allow more time to equip its significantly larger fleet.

Low and medium earth-orbiting (LEO/MEO) satellite systems will become available as an alternate means of ADS-A-compliant voice and data link communications for oceanic areas. Users will have a wider selection of avionics options because GEO and HF voice and data link systems will remain in use as well. Cost versus flexibility to fly optimum tracks and profiles will be a determining factor in how users choose to equip.

18.2 Human Factors

NAS modernization will invoke or accommodate significant changes on flight decks, such as using multifunction displays that present information on the location of proximate aircraft, weather, terrain, and other flight information. Human factors activities will be required in the development of avionics standards and installation, training, and maintenance guidelines. These include:

- Developing human factors requirements and standards for avionics certification
- Establishing human factors installation guidelines for retrofitting advanced avionics into older aircraft
- Developing, implementing, and assessing human factors training requirements for pilots, controllers, and maintenance technicians
- Standardizing avionics displays among different manufacturers.

18.3 Transition

Figure 18-1 shows the ground infrastructure transition to support avionics equipage and the anticipated transition for cockpit displays.

18.4 Costs

Table 18-1 shows estimated avionics equipment costs separated into four user-categories. The air carrier category represents major, national, and regional airlines flying all-jet fleets in Part 121 passenger or cargo revenue service. The mid-range category represents commuter, air taxi, and corporate GA flying turboprop, jet, or large multi-engine piston aircraft under Part 91, 121, or 135 regulations. The low-range category represents small single- or twin-engine piston aircraft operated under Part 91 regulations. The military category represents the full range of DOD aircraft from helicopters to cargo transports.

However, the lines between categories are often blurred because of aircraft type, performance, or operational use, and some aircraft or operations do not fit neatly into the defined categories. For instance, the New Piper Malibu, which is a singleengine piston aircraft, has the performance to be used in a Part 135 air taxi or small corporate aircraft operation. Similarly, one model of the Boeing 737, which normally fits the air carrier category, is being marketed as a corporate aircraft to compete against other high-end business jets with similar performance.

Table 18-1 provides a range estimate of nonrecurring costs for avionics equipment only. The table does not include items such as installation, or recurring costs for training or data base updates. The figures in the table are an average compiled from representatives of the avionics manufacturing industry and the military. For equipment, such as GPS/LAAS or ADS-B, the price range is an educated guess or cost goal because there are still too many unknowns relative to performance and certification requirements. For avionics such as EFIS displays or GPS-receiver autonomous integrity monitoring (RAIM), the costs are well known and the price range is based on the wide variety of choices and feature/capability options available.

Another factor that can affect the nonrecurring unit cost is the trend toward integrating avionics equipment rather than building individual, stand-alone boxes. The trend is particularly prevalent in the air carrier and mid-range categories but is also starting to affect the low-range category as well. One reason for the higher cost of air carrier and mid-range avionics is the higher reliability and performance standards the equipment must meet. For example, avionics on air carrier and high-end GA aircraft are typically built with more redundancy than equipment for low-end GA. The military has additional specifications that increase cost, such as resistance to electromagnetic pulse, ruggedizing equipment for high G loads, secure anti-jam system requirements, etc. Future architecture efforts must focus on what, if any, mandatory equipage requirements will be needed and by when.

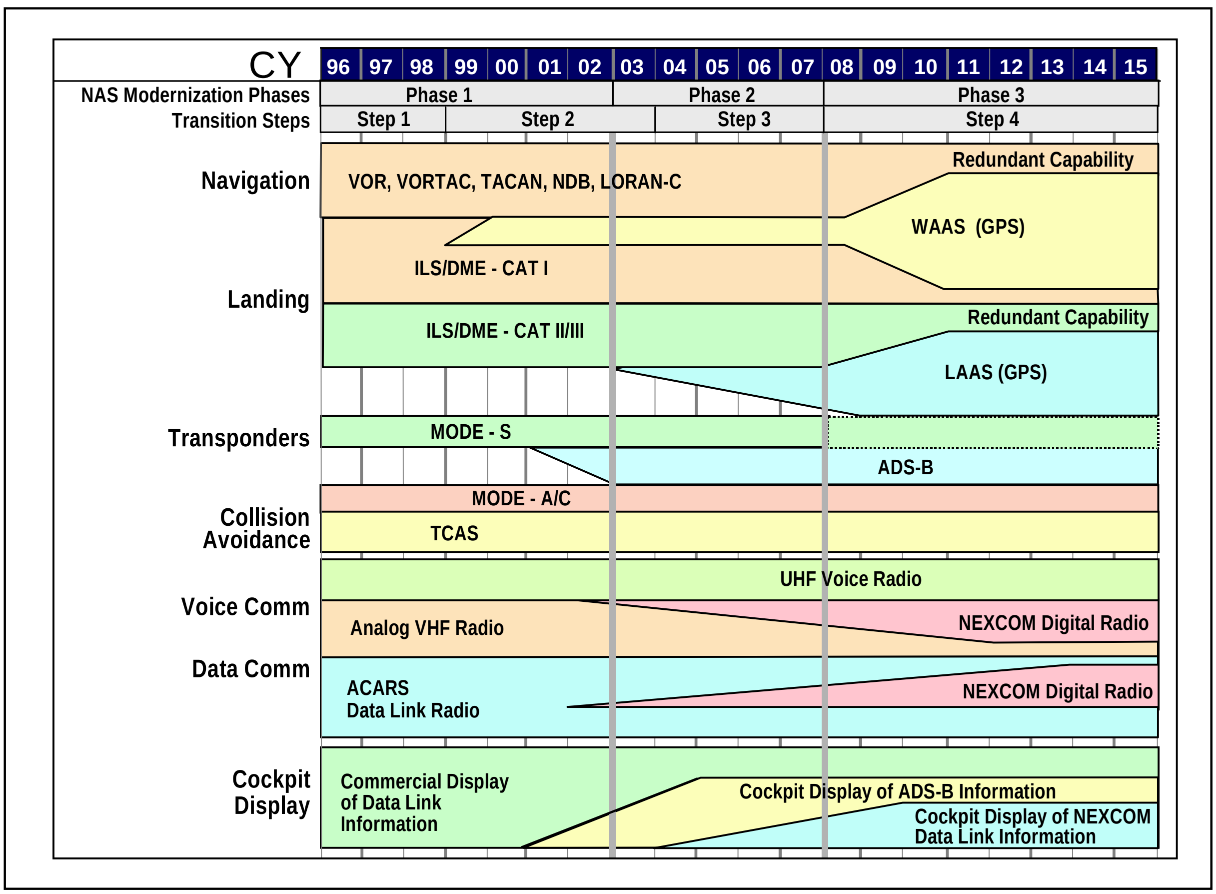

Figure 18-1. Ground Infrastructure Transition Supporting Avionics Equipage

Table 18-1. Estimated Avionics Costs (1998 Dollars)

Avionics	Air Carrier	Mid Range	Low Range	Military
Communication:				
Digital Radio (voice)	$10-20K	$10-20K	$4-5K	$60-80K[8]
CMU (data)	$25-45K[10]	$15-30K	$7-9K	$15-30K[12]
Cockpit Displays:				
TAWS	$47-50K[2]	$47-50K[1]	N/A[9]	$47-50K
EFIS	$200-229K	$40-229K[7]	N/A	$40-80K[13]
MFD	N/A	N/A	$10-12K[5]	N/A
FIS (Weather)			$6-8K[4]	N/A
Navigation:				
GPS-RAIM	N/A	$8-10K	$3.5-9K	$13-14K
GPS-WAAS	integ. with LAAS	$12-15K	$5-10K[3]	TBD
GPS-LAAS	$15-30K[11]	$15-30K[16]	N/A	TBD
Surveillance:				
ADS-A (Oceanic)	$700-775K[14]	$560-620K[15]	N/A	$800-1,000K[17]
ADS-B (Data Link)	$25-35K[20]	$25-35K	$5-7K[6]	$55-65K[18]
Mode-S	$20-30K[19]	$20-30K	$4.5-5.5K	$20-30K

1. Non-EFIS-equipped aircraft may have less capable system with regionalized data base and no reactive windshear costing between $15 and 20K.
2. For digital or analog data bus, includes reactive windshear. Requires EFIS display.
3. Additional costs may be incurred for annunciator lights or new course deviation indicator.
4. Includes dedicated display. Service available on laptop computer provided by operator for 1.5 to 2.0K.
5. Excluding equipment that provides information to display.
6. Includes basic Mode-S with ADS- B card and receiving/processing TIS information (no display). Predicts transponder cost decrease due to integrated functions and increased user equipage.
7. Price depends on how sophisticated/how many display tubes the EFIS has, i.e., a one-tube basic system versus a five- or six-tube high-end system.
8. Includes military-unique requirements such as secure communications capability.
9 Certified TAWS probably will not be available for small aircraft. However, noncertified TAWS-like capability will be available as part of MFD software packages.
10. Cost is dependent on several factors, such as range of features selected.
11. Cost presented here is an estimate for an integrated WAAS/LAAS receiver.
12. FAA will continue to support the UHF infrastructure for DOD use.
13. Costs vary depending on aircraft type and features selected.
14. Data from Industry Customization Working Group using B767 example. ADS-A is not sold as stand-alone equipment; it is part of FANS package, including display, FMC, CMU, etc., and hardware/software upgrades. Low figure is for FANS-1/A package without CPDLC capabilitiy and excluding GPS. High figure includes CPDLC capability. Add $260K for CNS/ATM-1-compliant package.
15. Industry Customization Working Group estimates that mid-range costs are approximately 15 to 20 percent less than air carrier costs. Add $220K for CNS/ATM-1-compliant package.
16. Cost for integrated WAAS/LAAS system similar to air carrier.
17. Complete FANS-1/A, CNS/ATM-1-compliant package, including displays, hardware, software, and military-unique requirements.
18. Includes TCAS II equipment with provisions for ADS-B add-on and military-unique requirements.
19. Airlines are required to have two transponders.
20. Mode-S with ADS-B card. Non-EFIS-equipped aircraft will also require a dedicated display costing approcimately $20K.

18.5 Watch Items

- Establish minimum equipage requirements with appropriate user input
- Review and implement RTCA Task Force 4 recommendations on certification.