Viewing NAS Evolution from the Perspective of Required Changes to Aircraft Avionics

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I. Introduction

IT is widely agreed that there is a need to modernize the National Airspace System (NAS) to improve capacity and efficiency over the next 10 – 20 years. Many different parties (FAA, JPDO, PARC, RTCA etc.) have proposed strategies and timelines for achieving this modernization. The authors recognize that there are differing expectations associated with needed operational improvements specified in these plans and believe that there is value in determining a harmonized modernization solution that incorporates the desires of each of the parties, while minimizing the amount of modifications required to airborne and ground equipment.

In the past, the FAA has generally moved forward with modernization on a program-by-program basis. In general, most of the technological improvements have been ground based and the requirements for aircraft equipage have not been onerous. However, as NAS modernization continues, most future enhancements require not just new ground equipment, but improved avionics as well. With the aircraft becoming a much more significant part of NAS modernization, an asynchronous approach to issuing mandates or imposing operational restrictions may not be acceptable to the user community.

The first part of this paper presents the avionics needs that are based on the various proposed operational improvement strategies. The second part of this paper makes the case that the current way of scheduling operational improvements on an independent program-by-program basis may not be cost effective. Programs may have to be synchronized so that logical packages of avionics modifications are implemented, thus minimizing the number of avionics package changes to the aircraft.

II. Establishing the Need for Avionics Equipage

The authors first strove to establish a set of needs for avionics to accomplish NAS modernization. This was not a clear and simple task since the aviation community has not agreed upon which operational improvements are needed at various dates (except for a set established for the next 10 years in the FAA's Operational Evolution Plan), and thus they have not agreed upon the avionics equipage needs. Hence, the authors' first task was to postulate a set of avionics needs, which was accomplished by reviewing the multiple plans associated with modernization of the NAS. Some plans are sponsored by various organizations of the Federal Aviation Administration (FAA), others are written by the Joint Planning and Development Office (JPDO), while others come from the public via RTCA or the Performance-based Operations Aviation Rulemaking Committee (PARC). Each of these plans focuses on improving operational capability and providing Air Traffic Management Services in a more efficient and cost-effective manner. By reviewing these plans, the authors were able to deduce what avionics needs seem to be common and their associated time frames.

The need for avionics equipage varies by degrees. In some cases the aircraft will not be able to fly in controlled airspace without the prescribed capabilities, and for all practical purposes this is an absolute mandate. For example, if you don't have a 25 KHz radio you cannot fly in controlled airspace today. In other cases, the restriction is large but doesn't preclude aircraft from having access to some of the airspace or terminal areas. An excellent example is Domestic Reduced Vertical Separation Minima (DRVSM). This rulemaking did not require aircraft to equip, but those that did not are forced to fly at or below 29,000 feet, or above 41,000 feet. These altitude restrictions are extremely burdensome for most airline operators. Thus, flying in controlled airspace is not totally precluded, but failure to equip results in restricted operations (as compared to today's baseline). The third category is where the user gets additional benefits over and beyond today's baseline operation. For example, aircraft that have RNP 0.11 capability can follow approaches at some airports that are not available to other users under specific weather

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conditions. We call this an avionics capability that provides benefits and results in increased operations relative to today's baseline, but is not mandated.

The plans that were examined are:

[1]. *NAS Air-Ground Integration Program*, FAA, S Air-Ground Integration Program, July 1, 2005
[2]. *NGATS Operational Improvements Roadmap and Database v2,* JDPO, Program Management Division, 2006
[3]. *Operational Evolution Plan v8.0*, FAA, 2006
[4]. *Roadmap for Performance-Based Navigation: Evolution for Area Navigation (RNAV) and Required Navigation Performance (RNP), 2006-2025*, FAA, July 2006
[5]. *Roadmap for Data Link*, *present-2025*, PARC, draft, July 2006
[6]. *Navigation Evolution Roadmap v1* FAA, 2006 draft
[7]. *A*DS-B Implementation presented to JRC-2b, FAA, June 2006

Each plan contains its own groupings of time frames, such as near-term and mid-term, that are not necessarily consistent with the definition used in the other plans. Where there seemed to be a strong agreement among the different plans that an operational improvement is needed in the 2012-2020 time frame, the authors grouped these together as mid-term avionics needs. Where there were differences in timing, the avionics needs were allocated to the longer-term time frame (2020-2027). The results of our analysis are as follows:

A. Mid-Term Avionics Needs

Table 1a. General Aviation Avionics Needs: Mid-Term

Aircraft Type	Avionics Needed	Operational Improvements	Time Frame
General Aviation: Non-FMS aircraft	WAAS Navigator	Glide slope, reduced minimums for landing, lower MEAs for some routes, permits the FAA to divest many VORs and ILS systems.	Now - 2020
	ADS-B out CDTI for ADS-B in	Permits weather and traffic to be broadcast to the cockpit, improves surveillance accuracy and coverage (greater coverage on the surface and remote areas), permits FAA to purchase fewer replacement secondary radars when current radars come to their end of life, limited air-to-air applications that permit one in and one out operations	Now - 2020

Table 1b. FMS Aircraft Needs: Mid-Term

Aircraft Type	Avionics Needed	Operational Improvements	Time Frame
Part 91/121/135 FMS aircraft	GPS or GPS/WAAS	Permits widespread RNAV and RNP operations in en route and terminal area.	Now - 2020
	Addressable data link (VDL-2 radios and CMU)	Permits the beginning of 4D trajectory-based ATM, enables improved controller productivity, reduces voice channel congestion, enables aircraft-specific traffic management initiatives.	2015 - 2020
	ADS-B out	Improves surveillance accuracy and coverage (greater coverage on the surface and remote areas), permits greater implementation of 3nmi separation standards, permits FAA to purchase fewer secondary radars when current radars come to their end of life.	2014 - 2020

B. Longer-Term Needs

Table 2a. General Aviation Avionics Needs: Longer-Term

Aircraft Type	Avionics Needs	Operational Improvements	Time Frame
General Aviation: Non-FMS aircraft	None Identified	None clearly identified for the longer-term that lead to additional avionics needs	

Table 2b. FMS Aircraft Needs: Longer-Term

Aircraft Type	Avionics Needs	Operational Improvements	Time Frame
Part 91/121/135 FMS aircraft	CDTI for ADS-B in	Permits super-density terminal operations and equivalent visual operations (EVO), improves controller productivity, permits improved safety by providing traffic awareness in the air and on the surface.	2020-2027
	Next Generation FMS	Permits super-density operations, improves controller productivity.	2020-2027
	Next Generation TCAS	Potentially needed because of the shift to super-density operations.	2020-2027
	RNP containment capability to 0.3 nm	Permits super-density operations, especially in the terminal area.	2020-2027
	Wake Vortex Sensors	Permits super-density operations and EVO	2020-2027
	Weather Sensors	Permits significantly improved weather forecasts by increasing the number of weather sensors feeding the forecasts.	2020-2027

The major difference between the reviewed plans is in the requirement for Cockpit Display of Traffic Information (CDTI) associated with ADS-B in for the FAR Part 121 and 135 aircraft. The JPDO's operational improvement (*NGATS Operational Improvements Roadmap and Database v2)* schedule has many ADS-B/CDTI applications in the mid-term, while the FAA plans do not include these applications until the longer-term. This is an important issue that the community needs to resolve since the major ADS-B benefits for the airlines and the commercial Part 135 aircraft operators will be from ADS-B/CDTI applications (many are air-to-air ADS-B applications), not ADS-B out. JPDO envisions that to address the efficiency and capacity concerns (especially in the terminal area) that ADS-B/CDTI applications must be implemented in the mid-term. However, a great deal of research and development is needed before these applications can be approved, so there is a great deal of uncertainty regarding their timing. For purposes of this paper, we assume that ADS-B/CDTI applications are available in the longer-term time frame, though limited use of these applications (e.g. merging and spacing) will occur earlier.

III. Scenarios for Evaluating Asynchronous and Synchronous Packaging of Avionics

An asynchronous packaging of avionics occurs when the avionics are needed to be installed to achieve an operational improvement once the FAA has completed its individual programs, without coordination of schedules with other programs. This is historically how modernization has been approached. Given the uncertainty of when individual programs will be completed, the authors presumed a likely schedule of future avionics needs in the asynchronous schedule. The dates given are defined as when the large majority of aircraft equip in order to take advantage of an operational improvement. In some cases there may be a mandate, but in other cases benefits may drive voluntary equipage.

A synchronous avionics packaging schedule results when all the programs and operational improvements mentioned above are coordinated, resulting in fewer but more extensive avionics modifications. This approach allows for installation of avionics during aircraft heavy maintenance visits, thus avoiding the potential for aircraft out-of-service costs due to frequent avionics modifications.

A. Asynchronous Schedule

Aircraft Type	Avionics Needs	Time Frame
General Aviation: Non-FMS aircraft	WAAS Navigator	2012
	ADS-B out/ CDTI for ADS-B in	2019

Aircraft Type	Avionics Needs	Time Frame
Part 91/121/135 FMS aircraft	GPS or GPS/WAAS	2016
	Addressable data link (VDL-2 radios and CMU)	
	ADS-B out	2019
	CDTI and ADS-B in	2023
	Next Generation FMS	
	Next Generation TCAS	
	RNP containment capability to levels of .3 and below	
	Wake Vortex Sensors	2027
	Weather Sensors	

The rationale for assuming this schedule is that the FAA plans to begin their major divesture of VORs and ILSs in the 2010 to 2015 time frame (Navigation Evolution Roadmap, v1, FAA, 2006 draft). Thus, there will be considerable pressure for General Aviation aircraft to equip with a space-based navigation system somewhere in the middle of this period. The ADS-B out mandate is likely to be in the 2017-2020 period, so for purposes of this paper we have assumed 2019 as the mandated date.

If the FAA decides to invest in the data link infrastructure, it will likely do so in phase 3 of ERAM which is scheduled for completion in 2012. For the FAA to receive a return on its investment in controller productivity and improved traffic flow management, it would most likely want this capability installed in aircraft by 2016. References [1], [2] and [5] all call for addressable data link in this time frame. The RNP roadmap calls for mandating RNP-1 and RNAV in the 2016 time frame, thus requiring GPS[3] or GPS/WAAS for access to all OEP airports[4]. The rationale for the ADS-B out schedule is the same as presented above for GA. The avionics drops in 2023 and 2027 are relatively arbitrary but assume that the programs will not be synchronized enough to have a single drop. In fact, there could be more avionics package upgrades than presented in this paper if the programs are truly unsynchronized.

It can be seen that an asynchronous schedule would result in two major avionics modifications for General Aviation aircraft only 7 years apart. AOPA has repeatedly asked for 10 years for major modifications due mainly to the availability of avionics installers to service the 200,000+ aircraft. For the larger aircraft, four different modifications would be required, each only 3-4 years apart. Since most commercial aircraft are on 6-7 year heavy maintenance intervals, this may require the installation of avionics outside of the heavy maintenance visits.

B. Synchronous Schedule

A synchronous schedule coordinates the different avionics modification programs to reduce the number of installations, avoid aircraft out-of-service costs, and achieve synergy between related programs (such as having a GPS/WAAS position source available for both navigation and the ADS-B message).

[3] GPS is shorthand for the existing GPS system or any other space-based navigation system, such as Galileo, that has equivalent or better performance than the U.S. GPS system.

[4] There is no commitment by the FAA to provide adequate DME/DME coverage to meet the RNAV requirements at all OEP airports, so the authors assume that universal access to these airports would require GPS. However, this could change in the future with an update of FAA plans.

Aircraft Type	Avionics Required	Time Frame
General Aviation: Non-FMS aircraft	WAAS Navigator ADS-B out/ CDTI for ADS-B in	2016

Aircraft Type	Avionics Required	Time Frame
Part 91/121/135 FMS aircraft	GPS or GPS/WAAS Addressable data link (VDL-2 radios and CMS) ADS-B out	2018
	CDTI and ADS-B in Next Generation FMS Next Generation TCAS RNP containment capability to possibly .3 Wake Vortex Sensors Weather Sensors	2025

Synchronizing the avionics installations means that some programs must be accelerated while others are delayed. The main benefit of the schedule proposed above is that there is one less major installation for GA while other aircraft are spared two major modifications. The projected costs and benefits of such an approach must be adequately determined. The authors believe that the potential for savings is so great that this cost/benefit analysis should be conducted. The next section presents some high-level data to illustrate the need for a more in-depth analysis.

IV. Cost Differences

A. Analysis Methodology

This paper provides only a rough order of magnitude (ROM) estimate of the difference in costs between the synchronous approach postulated in this paper and one possible asynchronous approach. The difference in costs comes from three sources:

1. With more frequent avionics installations, the aircraft are out of service more often. This causes significant cost to the users because of either cancellation of flights, the requirement to have more aircraft on hand to compensate for the higher number of aircraft out of service, or loss of use of the aircraft.
2. Additional installations are almost always more expensive because the labor required for one larger installation is most likely to be less expensive than the labor for two or more smaller installations due to avoidance of repeated set-up and access time. Also, there will be a requirement for additional maintenance facilities when aircraft are modified out of their routine maintenance schedules.
3. In some cases the avionics cost of a single package system (where this is feasible) will be less than the cost of multiple smaller packages. This is illustrated with existing avionics where the Garmin 1000 (which includes VHF radios, Navigation systems, etc.) is less costly than if the systems were bought individually.

The cost to users is quite varied for taking an aircraft out of service. This paper will use the costs shown in Table 3.

Table 3. Cost Factors Associated with Additional Avionics Installations

Type	Cost Per Flight For An Aircraft Not In Service	Average Flights/Day	Cost /Day For An Aircraft Not In Service	Extra Labor Costs For Multiple Installations	Extra Costs Because of Non-Consolidated Avionics
Part 121 Large	-	-	$100,000[5]	$1500/day[6]	None
Part 121 Regional	-	-	50,000[7]	$ 1500/day	None
Part 135 (air taxi)	$2174[8]	4	$8696	$1500/day	$10,000[9]
GA Business	$920[10]	1	$920	$1500/day	$10,000
GA Personal			$20[11]	$1000/day[12]	Combined WAAS/ADS-B $4000[13]

These numbers were obtained from multiple references (see footnotes) and some were developed as engineering judgment by the authors, however they are very simplistic factors and further efforts will be needed to determine exactly what would be required to perform multiple avionics installations. For example, if an installation can be performed during multiple segmented C checks during overnight maintenance visits, then the extra installations would not incur out-of-service costs. Conversely, if the installation takes several days, thus extending a scheduled check, the costs would be significant.

B. Initial Results

Our rough order-of-magnitude estimate of the impact of having an asynchronous schedule ranges from under a billion dollars to as high as six billion dollars. This comes from multiplying the number of aircraft expected to be retrofitted by the factors presented in Table 3 and comparing the synchronous to the asynchronous schedule. Why is the estimate so uncertain? The answer is that a large cost associated with having an asynchronous schedule would be incurred by the regional and major airlines if the installation would require that the aircraft be taken out of service other than when a heavy maintenance visit (D-Check) occurs. It is not clear from the magnitude of the avionics changes if these additional avionics installations could occur during multiple overnight maintenance visits or C-checks without the aircraft incurring additional out-of-service time. The uncertainty is also associated with how many days the aircraft would have to be taken out of service.

V. Conclusions

It is clear that airlines will strenuously resist taking aircraft out of service just for an avionics upgrade. Thus, planners of the NAS modernization should be very conscious of the impacts of their plans on avionics installation requirements to insure that either the schedules of operational improvements are synchronized or that the additional costs of an asynchronous schedule are not onerous to the users.

This is not a theoretical argument. The concept of aligning the implementation dates of various programs has precedence within the FAA. During meetings of the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC), the FAA received input from industry regarding the need for alignment of proposed tasks associated with the aircraft electrical wiring interconnect systems (EWIS) with the previously accepted new tasks to improve

[5] Discussions with 2 major air carriers
[6] Authors' estimate of what the labor costs would be based on labor rates for maintenance personnel
[7] Authors' estimate that cost for regionals would be about half that of the larger air carriers
[8] FAA Benefits Assessment of the Wide Area Augmentation System (WAAS) Program, May 28, 2004, p. 18
[9] Authors' estimate based on historical cost reductions associated with avionics consolidation
[10] FAA, Benefits Assessment of the Wide Area Augmentation System (WAAS) Program, May 28, 2004, p. 18 (used their air taxi number of $2174 for air taxi and their GA number for business GA since it seemed unreasonable to assign a cost of $920 for personal travel)
[11] Based on our estimate of daily ownership cost of a personal aircraft.
[12] Based on costs with current WAAS and ADS-B equipage installation
[13] Based on authors estimated from discussion with vendors on what a cost savings may be by consolidating ADS-B-out avionics and WAAS into a single avionics package for general aviation aircraft.

fuel tank system safety. The FAA recognized the need to align these two programs in the Notice of Proposed Rulemaking (NPRM) that addressed EWIS issues and was published in the *Federal Register* on October 6, 2005, page 58508. The NPRM stated "The intent of this proposal is to help ensure the continued safety of commercial airplanes by improving the design, installation, and maintenance of their electrical wiring systems as well as by aligning those requirements as closely as possible with the requirements for fuel tank system safety." The alignment of these requirements enables the airlines to perform EWIS and fuel tank tasks during the same maintenance visit, thus reducing their costs while still achieving the desired safety benefits. In response to user concerns these rules were coordinated.

The purpose of this paper is to provide enough analysis to determine if this is an issue that merits further investigation, not to provide a definitive analysis. The authors conclude that further analysis is merited. As the aviation community moves forward with Air Traffic Management modernization, the impact on the users must be evaluated and individual program schedules may have to be adjusted to provide a synchronous avionics evolution strategy.

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