Joint Planning and Development Office

NextGen Avionics Roadmap

Version 2.0

September 30, 2011

Next Generation Air Transportation System
Joint Planning and Development Office

Revision History

Date	Document Version	Revision Description	Document Author/Reviser
July 12, 2011	2.0.0	Working Group Coordination Draft	JPDO Aircraft Working Group
August, 2011	2.0.1	JPDO Working Groups Peer Reviewed – Comments Adjudicated	JPDO Working Groups Reviewed
August, 2011	2.0.2	Peer Reviewed Adjudications Applied	JPDO Aircraft Working Group
September, 2011	2.0.3	JPDO Communications Technical Review	Concept Solutions
September, 2011	2.0.4	Technical Team Adjudications Applied	JPDO Aircraft Working Group Editorial Board

Contents

Table of Figures

List of Tables

Executive Summary

Avionics Roadmap, Version 2.0 provides Next Generation Air Transportation System (NextGen) planning organizations with a view of the far-term avionics-related capabilities required for operations envisaged for NextGen. It provides an aircraft perspective to allow the reader to understand the relationship between the various components of the National Airspace System (NAS), such as communication, navigation, surveillance, and related air traffic management systems and aircraft avionics systems. Aviation stakeholders will also benefit from reading this document because it provides a view of the aircraft-related capabilities required for late mid-term operations and the evolving far-term requirements of NextGen implementation.

The timeline for development of new avionics systems typically extends out 15-20 years from initial concept development to aircraft equipage. If this work is not started now, any future enhancements to the NAS would be delayed, thus further delaying the potential benefits of NextGen.

The Avionics Roadmap also recognizes that there will always be a state of transition as aircraft and related ground automation systems continue to evolve. At least 75 percent of the air carrier fleet in the year 2025 will have the same or similar avionics characteristics as glass cockpit aircraft introduced 30 years ago. Another consideration in the development of this Roadmap is the importance to the stakeholders of establishing a balance of capability between the ground and avionics systems.

The Roadmap makes the following assumptions regarding the state of the NAS in the far-term:

- The Air Navigation Service Provider (ANSP) automation system has the necessary decision support tools and communications capabilities to support Trajectory-based Operations (TBO).
- A net-centric communications structure is in place to allow all users and stakeholders of the NAS to access a common framework of information.
- The ANSP is providing TBO services for all Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) operations for aircraft transiting large terminal or metroplex areas.
- Automatic Dependent Surveillance Broadcast (ADS-B) is the primary means of surveillance in the NAS, and ADS-B In services are available for properly equipped and approved operators.
- Performance-based Navigation is applied in all four dimensions (lateral, longitudinal, vertical, and time) where needed to maximize safety and increase capacity and throughput.

The Roadmap also addresses far-term NextGen avionics characteristics in the following areas:

- Routes and Procedures
- Negotiated Trajectories
- Delegated Separation
- Low Visibility Arrival/Departures and Approaches
- Surface Operations
- Air Traffic Management (ATM) Efficiencies

Other topics include Airline Operations Centers/Flight Operations Centers (AOC/FOC), Safety Enhancements (Hazard Avoidance and Mitigation), Unmanned Aircraft Systems (UAS) and future work of the Joint Planning and Development Office (JPDO) Aircraft Working Group (WG). Key issues identified by the working group as critical to the evolution of NextGen are also discussed.

The Roadmap includes 10 appendices that address the following subjects: Trajectory Operations, Federal Aviation Administration (FAA)/JPDO Enterprise Architectures and FAA Aircraft Roadmap, Risk/Benefits Assessment, Department of Defense (DOD) Aircraft Operations, General Aviation (GA), Rotorcraft (Helicopter and Powered Lift), key policy issues, Trans-atmospheric (spacecraft transiting the NAS) Operations, Required Navigation Performance (RNP) and ADS-B, Safety Enhancements, and the International Civil Aviation Organization (ICAO) Aviation System Block Upgrade Concept.

While preparing the Roadmap, global harmonization issues were carefully considered but not specifically addressed. However, participation in the Aircraft WG did include active representation from Airbus and Thales, and has been reviewed by the JPDO Global Harmonization WG. The Aircraft WG recognized that the mid-term and far-term implementation timeframes are delayed. The WG chose, however, not to address this issue and focus instead on the Operational Improvements identified by the JPDO and the FAA, and how they relate to the required avionics characteristics needed for the far-term. Much of the work in this Roadmap is expected to be incorporated into the FAA's Enterprise Architecture.

Purpose and Background

The JPDO Aircraft Working Group has developed the Avionics Roadmap to provide other organizations involved in planning with a view of the far-term avionics-related capabilities required for the different types of operations envisioned for NextGen. It is intended to provide the organizations involved in NextGen planning with an aircraft-centric perspective to assist them in understanding the relationship between components of the NAS, such as communication, navigation and surveillance (CNS) and related ATM Systems, and the aircraft avionics systems. Aviation stakeholders will benefit from reading this document because it will provide them with a view of the aircraft-related capabilities required for the late mid-term period and evolving far-term requirements of NextGen implementation.

NextGen should be viewed as a "system of systems" with a balance of aircraft equipage and CNS/ATM infrastructure that provides the best performance/cost ratio to meet the intended functions and safety criteria. A balance between avionics equipage requirements and supporting ground systems is necessary to ensure that NextGen requirements are shared between users and service providers.

This document continues within the vision of NextGen and builds upon the previous version. It is intended to focus on characteristics of aircraft avionics, security, and interfaces needed to support the JPDO far-term NextGen vision. The document's principal focus is air carrier transport operations. However, it also supports a broad spectrum of the GA, military, UAS, and commercial space transportation users.

The vision of NextGen is to support the growing demand for air commerce. NextGen capabilities will improve the NAS infrastructure by increasing the efficiency and predictability of operations, supporting environmental goals of the U.S., and continuing to maintain the highest levels of safety. The Roadmap supports these objectives by identifying the necessary characteristics of advanced avionics systems needed to work within the scope of NextGen far-term capabilities. As NextGen continues to evolve, the mid-term stretches to 2025 and the definition of the far-term migrates beyond.

It should be noted that it is difficult to discuss absolute dates. In the U.S., NextGen outlines an approach to resolve safety, capacity, flexibility, and cost concerns as the airspace evolves. But economic, global, political, and policy issues guide the overall timing. It may be more appropriate to discuss necessary aircraft functions in the context of needed capabilities. For example, the original motivation for modernizing the airspace was a projection of a 300 percent growth in capacity by 2025. Considering the economic adjustments, 2025 is now considered to represent a 160 percent growth in capacity. This illustrates the difficulty in establishing hard timeline-driven decisions.

Additionally, it is also understood that adjustments to policies need significant time to coordinate them across the global community. It is necessary that decision makers act early to ensure that policies have been established to enable the future capability.

Figure 1 below illustrates the relationship between JPDO partner agencies required to achieve a common civil aviation system architecture that supports global harmonization. During the development of the Roadmap, global harmonization issues were carefully considered but not specifically addressed. However, Airbus and Thales were both active participants in developing the Roadmap and the document has been reviewed by the JPDO Global Harmonization WG. Other JPDO groups that include wide industry representation have provided additional input on global harmonization requirements.

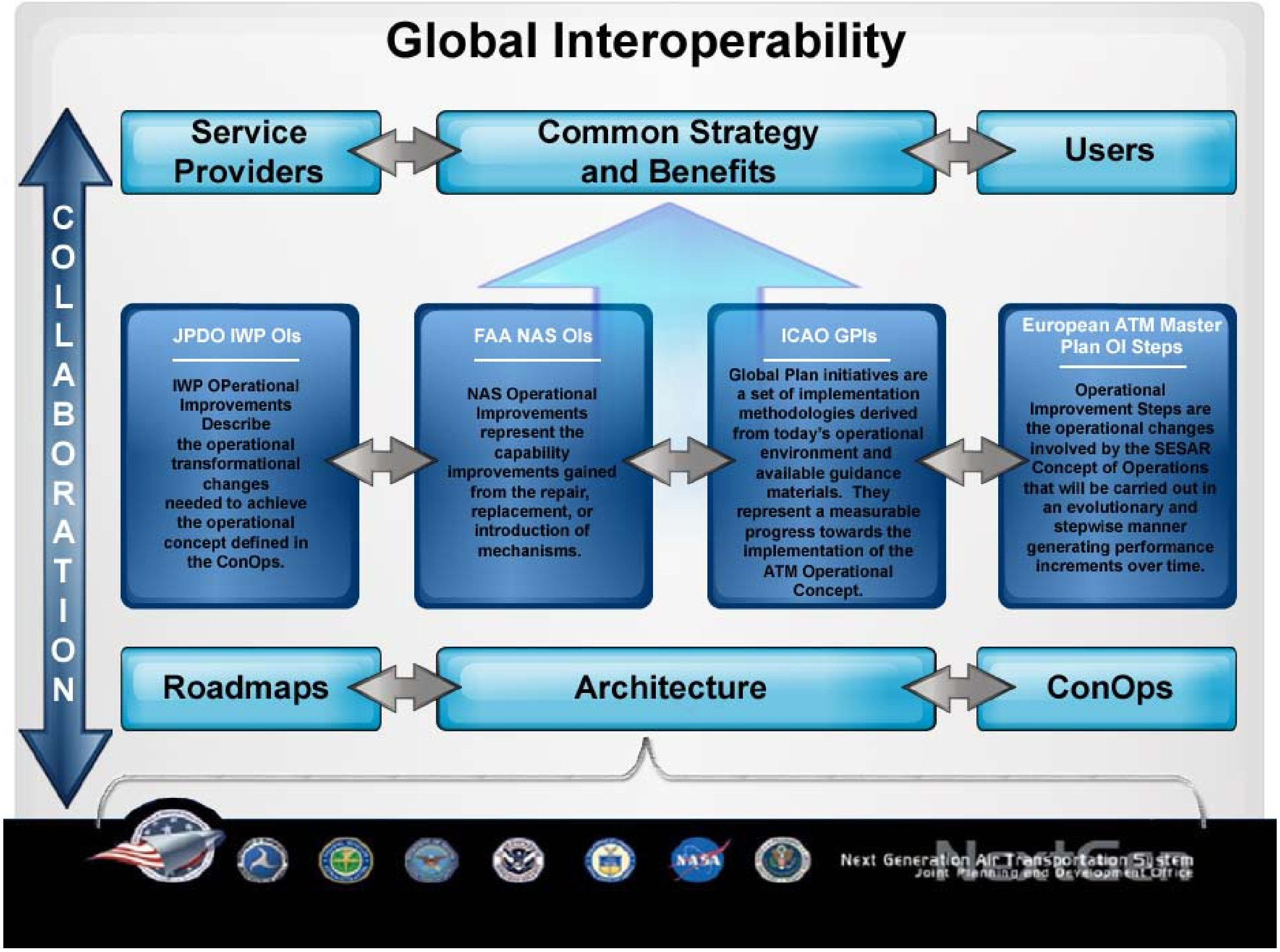


Figure 1 – Global Interoperability Vision

The Roadmap is also consistent with all existing JPDO and FAA NextGen planning documents. Since the publication of Avionics Roadmap v1.0, the FAA and the JPDO have split their areas of focus, with the FAA focusing in on the near-term and mid-term planning and the JPDO concentrating on the development of operational improvements that could be implemented in the far-term or have particular interest across multiple federal agencies. This division of labor is reflected in the FAA's NextGen Implementation Plan and NextGen Segment Implementation Plans, which spell out the implementation of improvements during the 2015-2018 timeframe. Alternatively, the JPDO's NextGen Concept of Operations and other core documents, including this Roadmap, describe the far-term vision for NextGen.

What the Roadmap Provides

The Roadmap provides the reader with an estimate of the required avionics capabilities that will be required for the future NAS. It makes the following assumptions regarding the state of the NAS in the far-term timeframe:

- The ANSP automation system has the necessary decision support tools and communications capabilities to support TBO.
- A net-centric communications structure is in place to allow all users and stakeholders of the NAS to access a common framework of information.
- The ANSP is providing TBO services for all IFR and VFR operations for aircraft transiting large terminal or metroplex areas.
- ADS-B is the primary means of surveillance in the NAS, and ADS-B In services are available for properly equipped and approved operators.
- Performance-based Navigation is applied in all four dimensions (lateral, longitudinal, vertical, and time) where needed to maximize safety and increase capacity and throughput.

Technical Challenges

The challenge from the aircraft perspective will be to make sure that the avionics capabilities match up with the capabilities of the ANSP services. This Roadmap considers the following in its evaluation: avionics systems that are in use at the end of the mid-term, and avionics research that is nearing maturity or has reached maturity at the end of the mid-term. Due to the relative uncertainty of a clear start time for the far-term, the Roadmap will not attempt to identify specific dates for the desired capabilities. It will work on the assumptions that the avionics will be available when the equipment has been certified and the ATM system can support them, as well as when the user communities choose to equip.

One of the more difficult challenges in avionics development is the lack of system requirements for the far-term and the need for standardized avionics characteristics. It typically takes 15-20 years to identify future characteristics, develop design standards, build, certify, and install aircraft equipment. Figure 2 provides examples that illustrate the point. It is imperative that a set of characteristics be identified that will provide a starting point based on the far-term concepts

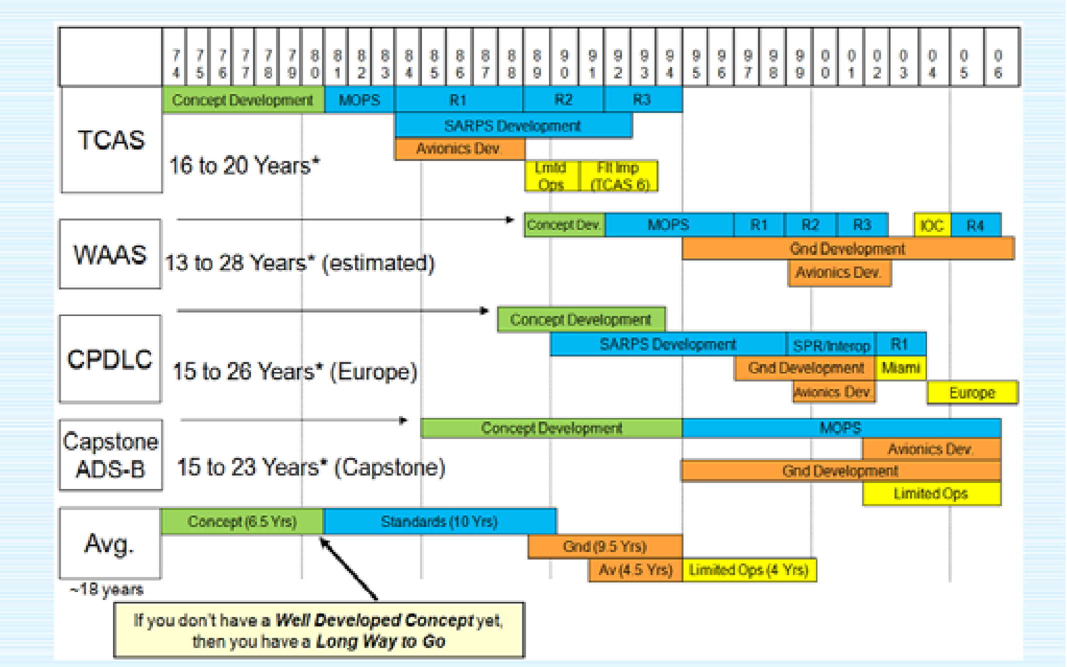


Figure 2 – Development Timelines for New Avionics

defined by the JPDO and the FAA. This Roadmap identifies those avionics characteristics that support operational improvements and enablers identified by the JPDO, its WGs, Study Teams, and the FAA.

Non-Technical Challenges

This Roadmap also considers non-technical issues that need to be resolved as enablers. Appendix 7 specifically deals with policies that need to be considered and resolved before a future operation can begin. These policies are not identified in each specific section of the Roadmap, as each policy may have multiple impacts in the proposed new capabilities. It should be clear, however, that each of the policy issues has significant impact on the ability to recognize the projected capability.

There will always be a continuing period of transition as aircraft systems and equipage evolve. The most difficult challenge for the aircraft side of NextGen is retrofitting legacy aircraft with new and evolving capabilities. At least 75 percent of the air carrier fleet in the year 2025 are currently flying in the NAS or in production. Essentially, these aircraft have the same avionics characteristics as glass cockpit aircraft introduced 30 years ago.

Aviation System Context

There are a number of concerns that must be addressed in the development of avionics to achieve the capabilities identified for NextGen. The basic issues are system oriented and involve increasing system capacity and efficiency while maintaining the highest level of safety, ensuring a positive cost/benefit ratio for NextGen stakeholders, and achieving the national environmental objectives. The aviation fleet operating in the U.S. is very diverse, including large air transport aircraft, military aircraft, light piston, turboprop, and jet powered business aircraft, tilt rotors, helicopters, airships, gliders, and UAS. This creates concerns in managing airspace where diverse aircraft operate in high density airspace due to the differing performance and avionics capabilities. Additional difficulties will arise as operators equip at different rates forcing the air traffic management system to control a mixed environment.

System Safety

As NextGen increases capacity and efficiency of the NAS, it is necessary to maintain and improve current safety levels. Integrating NextGen mid-term avionics systems with advanced ATM automation and decision-support tools will increase overall system safety in a variety of ways. Advanced display systems on the flight deck will enable increased situational awareness during surface movement and aid in preventing runway incursions. Wider use of RNP procedures, where advantageous, will allow greater throughput in terminal areas while insuring aircraft remain properly separated at minimum safe distances. New Ground-Based Augmentation System (GBAS) and Localizer Performance with Vertical Guidance (LPV) approach procedures will provide highly accurate vertical guidance – a significant safety enhancement over existing non-precision instrument approach procedures.

The use of ADS-B technology will provide air traffic managers with more accurate information regarding aircraft position and intent, allowing for safe separation at minimum acceptable distances. Far-term applications of ADS-B may also enable reductions in runway centerline separation for both dependent and independent closely spaced parallel operations between runways. It may also enable self and delegated separation to reduce controller workload, thus ensuring that safe separation is maintained. Other advances in future avionics systems may provide more accurate weather information, enabling flight crews and traffic managers to predict and depict hazardous weather conditions. This will allow the flight crew and the air traffic managers to better plan severe weather avoidance. As aircraft begin to carry additional external weather sensors, data is transmitted to the ground and then made available to other aircraft, Airline or Flight Operations Centers (AOC/FOC), and air traffic service providers. This shared situational awareness provides tactical and collaborative decision making.

System Capacity and Efficiency

The FAA estimates that by 2018, NextGen ATM improvements will reduce total delays, both in flight and on the ground, by approximately 35 percent. This reduction will provide $23 billion in cumulative benefits from 2010 through 2018 to aircraft operators, the public, and the FAA. It is also estimated that the U.S. will save about 1.4 billion gallons of aviation fuel during this period, cutting carbon dioxide emissions by 14 million tons.

Limited runway construction is projected during the mid-term time period and it is difficult to project increased runway availability beyond 2015 due to the limits of the FAA planning horizon for future runway development. Environmental concerns may impact airport expansion constraining future capacity. Thus, it will be increasingly important to use existing runways and air space to achieve the NextGen far-term objectives.

NextGen avionics, advancements in air traffic automation systems, and modifications to existing air traffic policies and procedures will be necessary to enable the projected growth. These advanced capabilities will allow improvements to the overall operation of the NAS and will assist in de-conflicting traffic flows in dense terminal areas. They will also aid in addressing the environmental concerns of the communities served by the airport while effectively accommodating growing traffic levels.

TBO has significant potential to increase system capacity and efficiency. TBO is a concept that engages the three main elements of flight operations: the Air Traffic Service Provider, the aircraft, and the operator's AOC/FOC function. TBO is based on the assumption that all three elements share the same information, and that flight planning and execution is a collaborative process in which the operator requests a route that meets its objectives and the ATM system can integrate the flight plan into the system. TBO involves a negotiation process that all parties must agree to, and includes a four dimensional (4D) flight path (i.e., lateral, longitudinal, vertical, and time). When the trajectory is agreed to, the plan is executed and monitored for conformance by all parties. TBO is based on advanced avionics, ATM decision-support tools, and data link communications.

Cost and Benefit Considerations

Costs to an aircraft operator are broken down into capital and operating costs. Capital costs reflect the expenses incurred when purchasing an aircraft or implementing major system upgrades. Operating costs reflect the costs of operating the aircraft, and include such factors as fuel, labor, depreciation, and maintenance.

When considering avionics purchases, a large part of the justification is dependent upon the benefits provided by the air traffic service provider that allow the avionics to be used to their full potential within realistic timeframes for return on investment (ROI). To ensure adequate equipage, manufacturers must be able to project sufficient demand and/or a mandate may be required.

The associated costs and benefits of avionics equipage are valued differently for GA than they are for commercial operations. Some GA operators may not be willing to invest in upgrades that constitute a significant percentage of the aircraft hull value and cannot be recovered in the resale marketplace. Others may choose to install all of the latest avionics capabilities, regardless of a quantifiable ROI. The cost/benefit case is an important factor that must be considered in the overall planning and implementation of NextGen and amplifies the importance of integrating the aircraft and Air Traffic Service Provider (ATSP) capabilities. Operating costs are greatly influenced by the efficiency of the NAS. Enhanced services can significantly improve the benefit ratio for both normal and non-normal operations (such as those affected by adverse weather conditions). Initially, TBO will enable commercial operators to have greater predictability for their operations, generally reducing flight times and, as a result, block times. Improved schedule reliability will result in lower costs and a better product for their customers. Non-commercial operators who equip appropriately will also benefit because it will improve access either to or through high-density terminal areas, resulting in reduced fuel requirements, emissions, and lower costs overall.

An important consideration in the cost/benefit ratio for most operators will be the issue of retrofit. The transition from mid-term to far-term NextGen capabilities will require the addition and/or software modification of avionics systems. Typically, a new aircraft purchased in the late mid-term or early far-term will be equipped with advanced NextGen avionics, so that the costs will be embedded in the total purchase price and the avionics will be integrated into the aircraft systems. Retrofitting older aircraft may require extensive modifications to the aircraft, resulting in significantly higher costs. It is worth pointing out that new generation (e.g., B787, A350, C-100) aircraft that are being delivered today, and perhaps into the far-term (2018 and beyond), are likely to require retrofit.

This emphasizes the importance of finalizing NextGen avionics requirements as soon as practical to allow the appropriate amount of time for development, certification, and implementation NextGen avionics must be developed within retrofitting constraints, including avionics weight, power consumption, antenna pace, antenna cable paths, panel space, conventional form factor, and software performance requirements. These are isues for many aircraft, and especially the legacy GA fleet. Size, weight, and power consumption will remain issues even for forward fit of new low-end GA aircraft. New technologies can be phased in gradually while maintaining infrastructure for the technologies they are replacing. It should also be remembered that both avionics and ATM system demands will continue to evolve past the present definition and expectations of far-term NextGen, so that even a fully NextGen-capable aircraft will become a legacy aircraft once future ATM system upgrade initiatives are undertaken. Incentives to equip should include commitments to provide continuing benefits from equipage over sufficient time in order for the operator to recoup the investment.

As noted in the two previous versions of the Avionics Roadmap, this document is aimed at bringing together many sources of information to enable a broader understanding of the capabilities that aircraft will need for far-term NextGen. In time, the implications of those capabilities (e.g., on cost, benefit, risk, availability, relationship to later changes, etc.) will need to be clearly understood, as all of these factors must be considered together to make the best decisions for NextGen. This contextual information is regarded as critical to enabling the overall dialogue, debate, and decisions needed for far-term NextGen.

NextGen Perspectives

The JPDO's *Targeted NextGen Capabilities for 2025* document is based on FAA-forecasted traffic levels and anticipated airline scheduling. The results present the top-level benefits in terms of increased throughput and reduced delay compared to the capabilities that will result from FAA's current NextGen Implementation Plan (NGIP) for 2018. Compared to the system described in the NGIP, in 2025, NextGen would reduce ATM-caused system wide delay by 46 million minutes, or nearly 60 percent, while accommodating 35 percent more flights.

This view of 2025 is also based on the premise that the FAA will be successful in their execution. The major improvement of 2025 NextGen upon the FAA's mid-term implementation is a more robust and dynamic flow management system coupled with the extensive deployment of ADS-B In, enabling fine tuning of flows close in to the terminal area to avoid weather conditions impacting flight. Although there will be no major changes in roles and responsibilities, the pilot and controller will have new tools at their disposal. Merging and spacing will still be a controller separation function, but the controller will be able to give the aircraft a new clearance, enabled by ADS-B In – instructing it to stay behind another aircraft by a certain distance or time, or to merge behind another aircraft. In today's system, aircraft have delegated responsibility in visual conditions. In 2025 NextGen, the same capability will be used. However, the pilot will be able to see the preceding aircraft using a Cockpit Display of Traffic Information (CDTI) rather than acquiring and tracking visually.

The meta-model below depicts NextGen strategic document relationships.

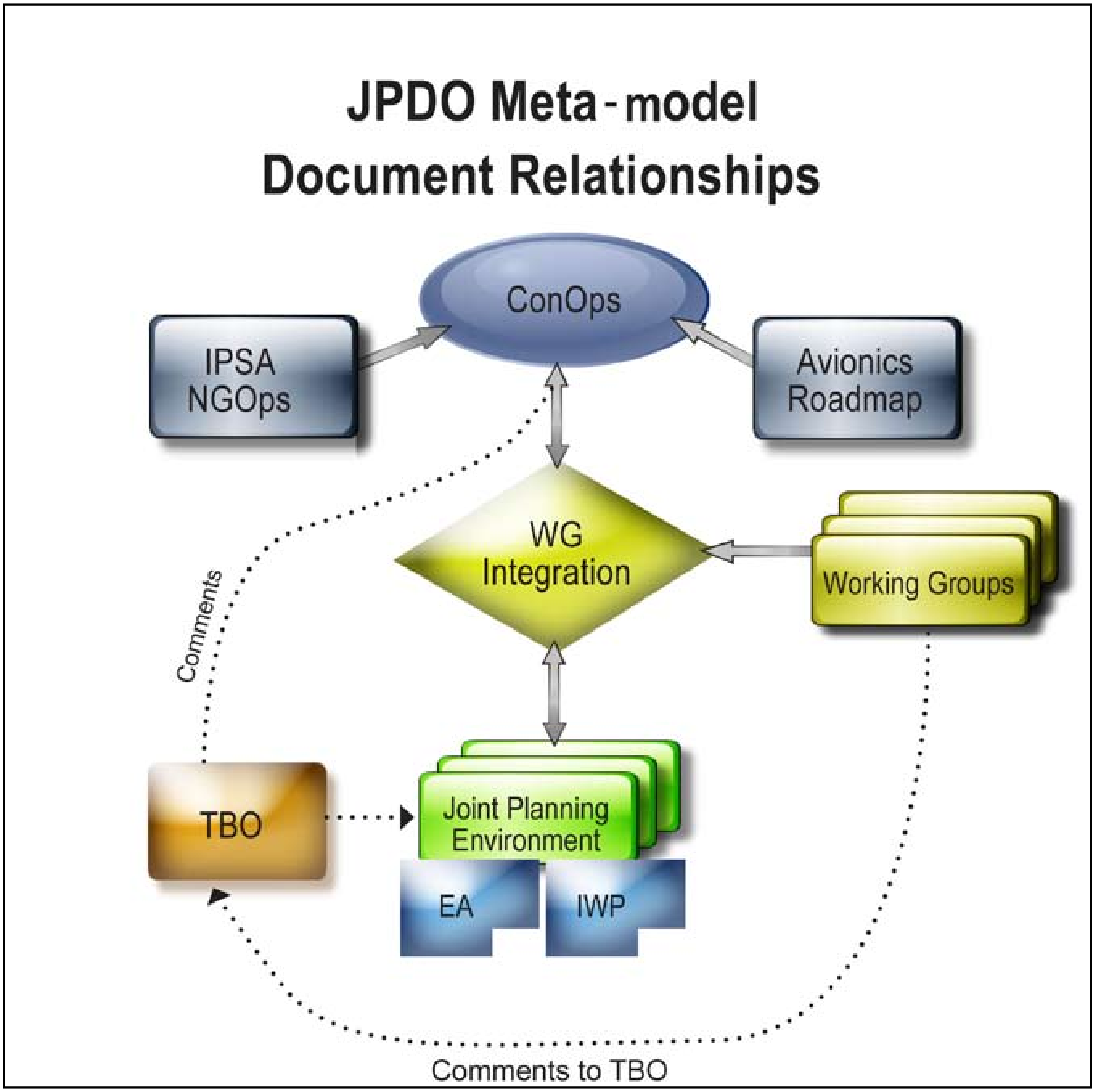
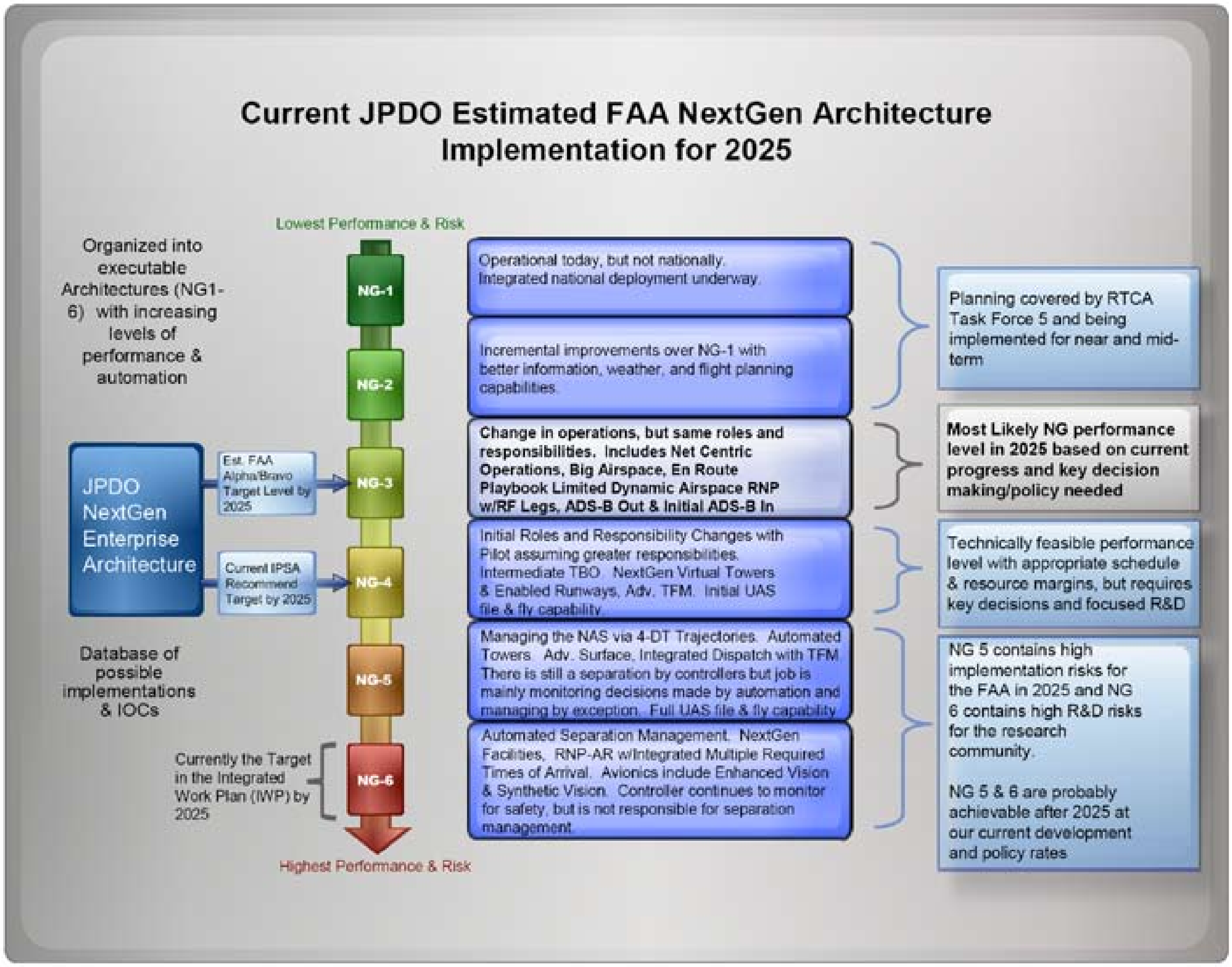


Figure 3 – JPDO Meta-Model Document Relationships

The targeted capabilities for NextGen in 2025 represent a JPDO assessment of technology developments that can be realistically implemented by that year.

The JPDO Interagency Portfolio and Systems Analysis (IPSA) Division has defined multiple NextGen Operational (NGOps) Levels, projecting relative performance and risk based on differing degrees of capability improvements, as shown in Figure 4. IPSA forecasts include the most likely performance NGOps level (i.e., NGOps 3-4), as well as other technically feasible performance levels attainable through the mid- to far-terms, based on critical decisions that need to be addressed in the near-term. Figures 5 through 9 depict the various programs and capabilities aligned with the various NGOps levels. Factors from the IPSA analysis were given significant consideration in the strategic planning and iterative updates of the Avionics Roadmap.



Current JPDO Estimated FAA NextGen Architecture Implementation for 2025

Lowest Performance & Risk

Organized into executable Architectures (NG1-6) with increasing levels of performance & automation

JPDO NextGen Enterprise Architecture

Est. FAA Alpha/Bravo Target Level by 2025

Current IPSA Recommend Target by 2025

Database of possible implementations & IOCs

Currently the Target in the Integrated Work Plan (IWP) by 2025

NG-1: Operational today, but not nationally. Integrated national deployment underway.

NG-2: Incremental improvements over NG-1 with better information, weather, and flight planning capabilities.

NG-3: **Change in operations, but same roles and responsibilities. Includes Net Centric Operations, Big Airspace, En Route Playbook Limited Dynamic Airspace RNP w/RF Legs, ADS-B Out & Initial ADS-B In**

NG-4: Initial Roles and Responsibility Changes with Pilot assuming greater responsibilities. Intermediate TBO. NextGen Virtual Towers & Enabled Runways, Adv. TFM. Initial UAS file & fly capability

NG-5: Managing the NAS via 4-DT Trajectories. Automated Towers. Adv. Surface, Integrated Dispatch with TFM. There is still a separation by controllers but job is mainly monitoring decisions made by automation and managing by exception. Full UAS file & fly capability

NG-6: Automated Separation Management. NextGen Facilities, RNP-AR w/Integrated Multiple Required Times of Arrival. Avionics include Enhanced Vision & Synthetic Vision. Controller continues to monitor for safety, but is not responsible for separation management.

Highest Performance & Risk

Planning covered by RTCA Task Force 5 and being implemented for near and mid-term

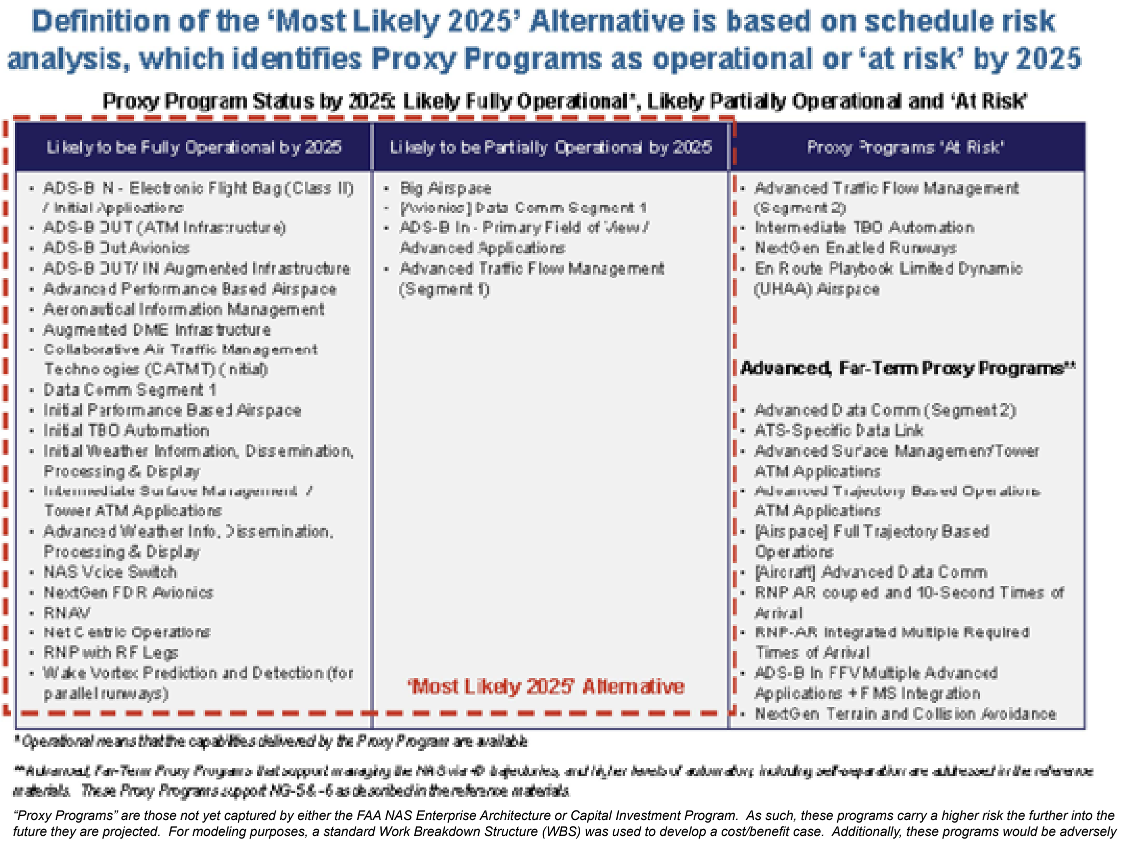
Most Likely NG performance level in 2025 based on current progress and key decision making/policy needed

Technically feasible performance level with appropriate schedule & resource margins, but requires key decisions and focused R&D

NG 5 contains high implementation risks for the FAA in 2025 and NG 6 contains high R&D risks for the research community.

NG 5 & 6 are probably achievable after 2025 at our current development and policy rates

Figure 4 – Current JPDO Estimated FAA NextGen Architecture Implementation for 2025



Definition of the 'Most Likely 2025' Alternative is based on schedule risk analysis, which identifies Proxy Programs as operational or 'at risk' by 2025

Proxy Program Status by 2025: Likely Fully Operational*, Likely Partially Operational and 'At Risk'

Likely to be Fully Operational by 2025

- ADS-B IN - Electronic Flight Bag (Class II) / Initial Applications
- ADS-B OUT (ATM Infrastructure)
- ADS-B Out Avionics
- ADS-B OUT/ IN Augmented Infrastructure
- Advanced Performance Based Airspace
- Aeronautical Information Management
- Augmented DME Infrastructure
- Collaborative Air Traffic Management Technologies (CATMT) (Initial)
- Data Comm Segment 1
- Initial Performance Based Airspace
- Initial TBO Automation
- Initial Weather Information, Dissemination, Processing & Display
- Intermediate Surface Management / Tower ATM Applications
- Advanced Weather Info, Dissemination, Processing & Display
- NAS Voice Switch
- NextGen FDR Avionics
- RNAV
- Net Centric Operations
- RNP with RF Legs
- Wake Vortex Prediction and Detection (for parallel runways)

Likely to be Partially Operational by 2025

- Big Airspace
- [Avionics] Data Comm Segment 1
- ADS-B In - Primary Field of View / Advanced Applications
- Advanced Traffic Flow Management (Segment 1)

'Most Likely 2025' Alternative

Proxy Programs 'At Risk'

- Advanced Traffic Flow Management (Segment 2)
- Intermediate TBO Automation
- NextGen Enabled Runways
- En Route Playbook Limited Dynamic (UHAA) Airspace

Advanced, Far-Term Proxy Programs**

- Advanced Data Comm (Segment 2)
- ATS-Specific Data Link
- Advanced Surface Management/Tower ATM Applications
- Advanced Trajectory Based Operations ATM Applications
- [Airspace] Full Trajectory Based Operations
- [Aircraft] Advanced Data Comm
- RNP AR coupled and 10-Second Times of Arrival
- RNP-AR Integrated Multiple Required Times of Arrival
- ADS-B In FFV Multiple Advanced Applications + FMS Integration
- NextGen Terrain and Collision Avoidance

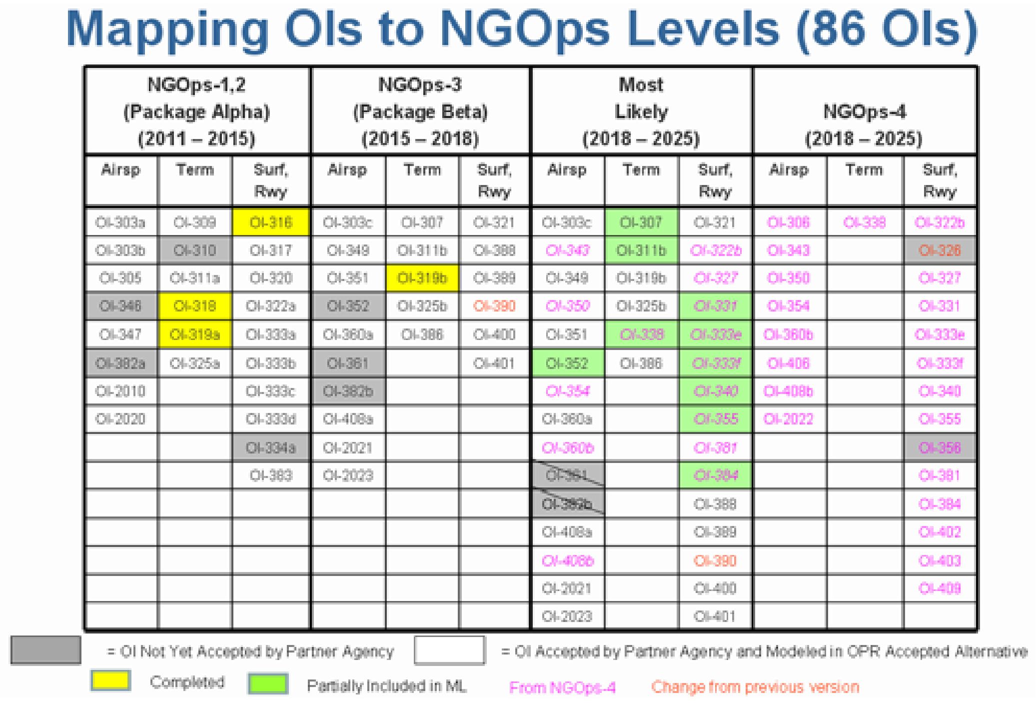
**Operational means that the capabilities delivered by the Proxy Program are available*

***Advanced, Far-Term Proxy Programs that support managing the NAS via 4D trajectories, and higher levels of automation, including self-separation are addressed in the reference materials. These Proxy Programs support NG-5 & -6 as described in the reference materials.*

"Proxy Programs" are those not yet captured by either the FAA NAS Enterprise Architecture or Capital Investment Program. As such, these programs carry a higher risk the further into the future they are projected. For modeling purposes, a standard Work Breakdown Structure (WBS) was used to develop a cost/benefit case. Additionally, these programs would be adversely affected by changes in schedules for those programs dependent on earlier programs.

Figure 5 – Definition of "Most Likely 2025"

Figure 7 – NGOps Program Alignment to Benefit Mechanism/Strategic Issues/Critical Decisions



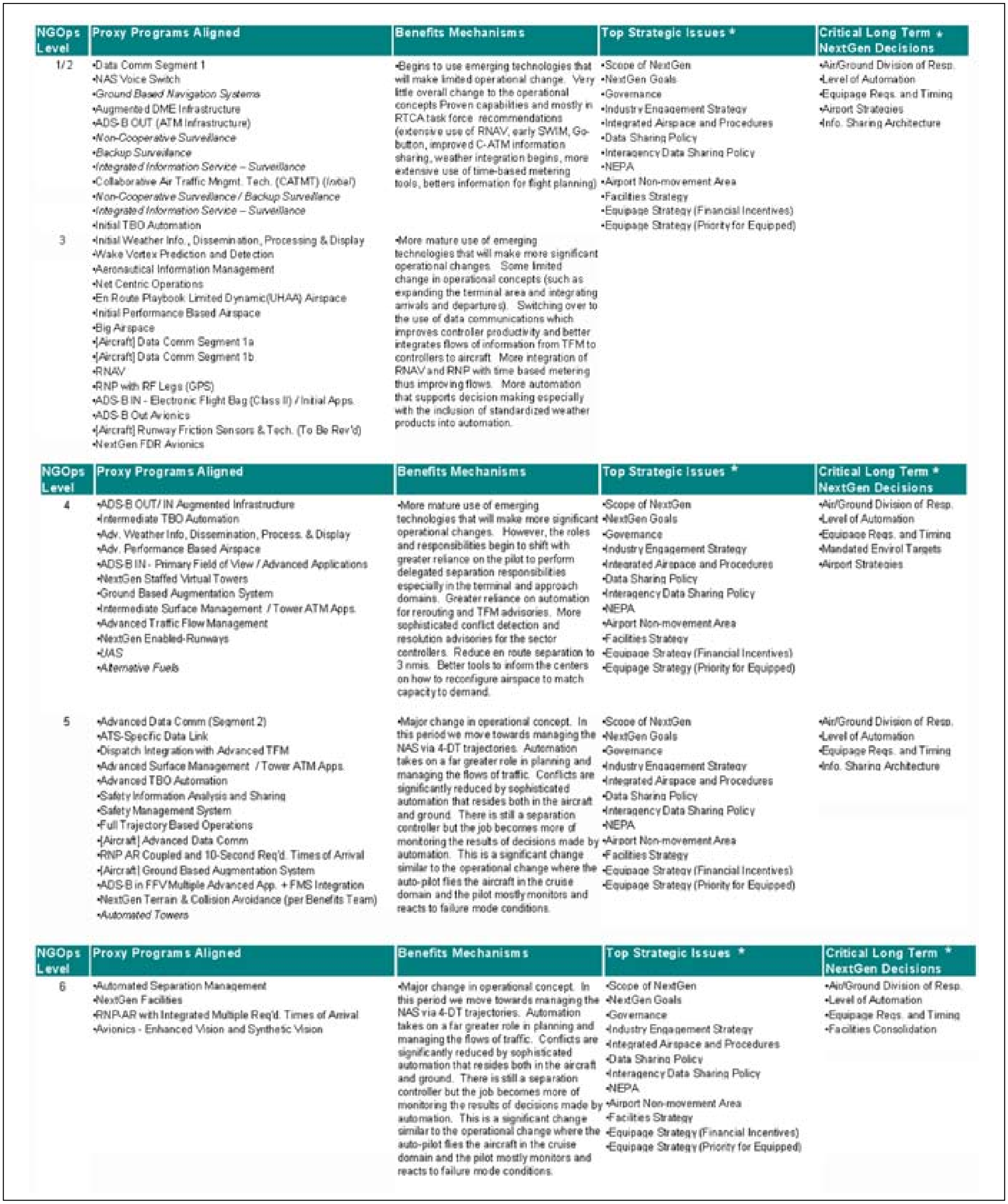
Mapping OIs to NGOps Levels (86 OIs)

NGOps-1,2 (Package Alpha) (2011 – 2015)			NGOps-3 (Package Beta) (2015 – 2018)			Most Likely (2018 – 2025)			NGOps-4 (2018 – 2025)		
Airsp	Term	Surf, Rwy	Airsp	Term	Surf, Rwy	Airsp	Term	Surf, Rwy	Airsp	Term	Surf, Rwy
OI-303a	OI-309	OI-316	OI-303c	OI-307	OI-321	OI-303c	OI-307	OI-321	OI-306	OI-338	OI-322b
OI-303b	OI-310	OI-317	OI-349	OI-311b	OI-388	OI-343	OI-311b	OI-322b	OI-343		OI-326
OI-305	OI-311a	OI-320	OI-351	OI-319b	OI-389	OI-349	OI-319b	OI-327	OI-350		OI-327
OI-346	OI-318	OI-322a	OI-352	OI-325b	OI-390	OI-350	OI-325b	OI-331	OI-354		OI-331
OI-347	OI-319a	OI-333a	OI-360a	OI-386	OI-400	OI-351	OI-338	OI-333e	OI-360b		OI-333e
OI-382a	OI-325a	OI-333b	OI-361		OI-401	OI-352	OI-386	OI-333f	OI-406		OI-333f
OI-2010		OI-333c	OI-382b			OI-354		OI-340	OI-408b		OI-340
OI-2020		OI-333d	OI-408a			OI-360a		OI-355	OI-2022		OI-355
		OI-334a	OI-2021			OI-360b		OI-381			OI-356
		OI-383	OI-2023			~~OI-361~~		OI-384			OI-381
						~~OI-382b~~		OI-388			OI-384
						OI-408a		OI-389			OI-402
						OI-408b		OI-390			OI-403
						OI-2021		OI-400			OI-409
						OI-2023		OI-401			

▨ = OI Not Yet Accepted by Partner Agency ☐ = OI Accepted by Partner Agency and Modeled in OPR Accepted Alternative

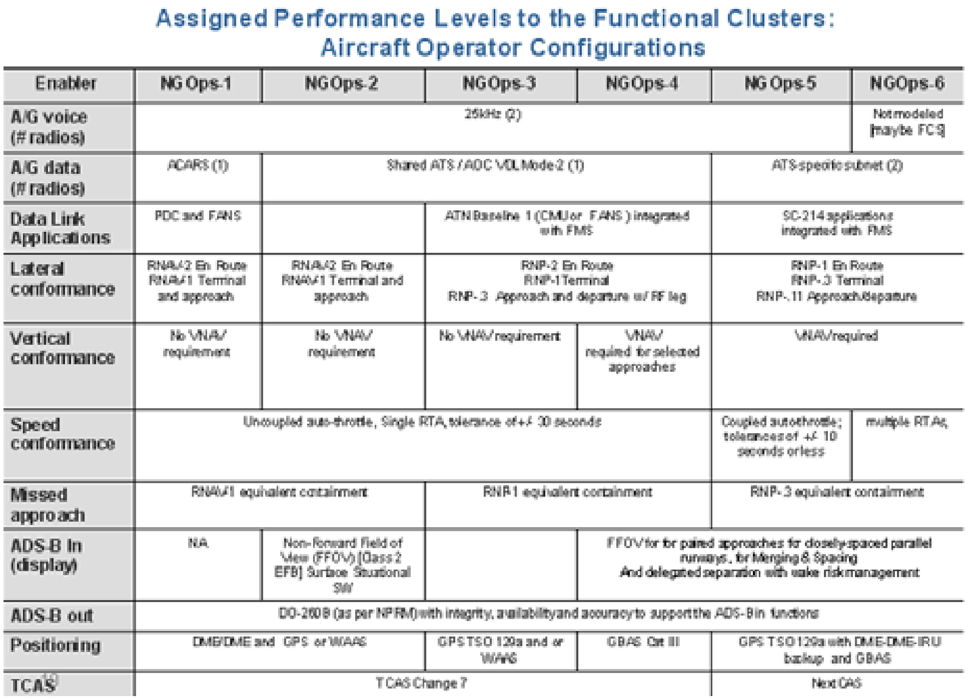
🟨 Completed 🟩 Partially Included in ML From NGOps-4 Change from previous version

Figure 6 – Mapping OIs to NGOps Levels



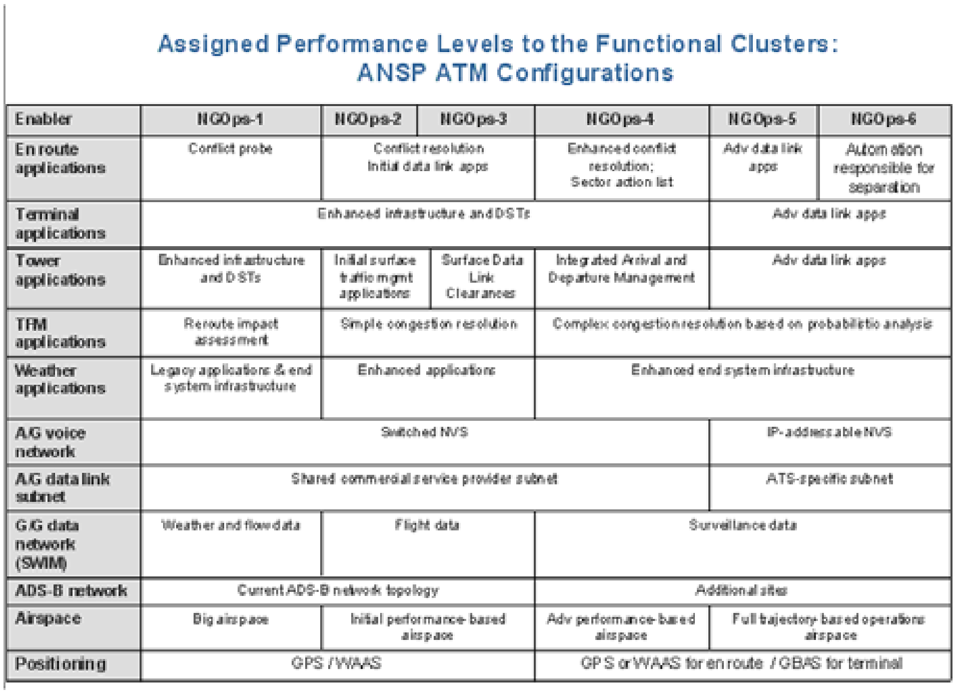
NGOps Level	Proxy Programs Aligned	Benefits Mechanisms	Top Strategic Issues *	Critical Long Term * NextGen Decisions
1/2	•Data Comm Segment 1 •NAS Voice Switch •*Ground Based Navigation Systems* •Augmented DME Infrastructure •ADS-B OUT (ATM Infrastructure) •*Non-Cooperative Surveillance* •*Backup Surveillance* •*Integrated Information Service – Surveillance* •Collaborative Air Traffic Mngmt. Tech. (CATMT) (*Initial*) •*Non-Cooperative Surveillance / Backup Surveillance* •*Integrated Information Service – Surveillance* •Initial TBO Automation	•Begins to use emerging technologies that will make limited operational change. Very little overall change to the operational concepts Proven capabilities and mostly in RTCA task force recommendations (extensive use of RNAV, early SWIM, Go-button, improved C-ATM information sharing, weather integration begins, more extensive use of time-based metering tools, betters information for flight planning)	•Scope of NextGen •NextGen Goals •Governance •Industry Engagement Strategy •Integrated Airspace and Procedures •Data Sharing Policy •Interagency Data Sharing Policy •NEPA •Airport Non-movement Area •Facilities Strategy •Equipage Strategy (Financial Incentives) •Equipage Strategy (Priority for Equipped)	•Air/Ground Division of Resp. •Level of Automation •Equipage Reqs. and Timing •Airport Strategies •Info. Sharing Architecture
3	•Initial Weather Info., Dissemination, Processing & Display •Wake Vortex Prediction and Detection •Aeronautical Information Management •Net Centric Operations •En Route Playbook Limited Dynamic(UHAA) Airspace •Initial Performance Based Airspace •Big Airspace •[Aircraft] Data Comm Segment 1a •[Aircraft] Data Comm Segment 1b •RNAV •RNP with RF Legs (GPS) •ADS-B IN - Electronic Flight Bag (Class II) / Initial Apps. •ADS-B Out Avionics •[Aircraft] Runway Friction Sensors & Tech. (To Be Rev'd) •NextGen FDR Avionics	•More mature use of emerging technologies that will make more significant operational changes. Some limited change in operational concepts (such as expanding the terminal area and integrating arrivals and departures). Switching over to the use of data communications which improves controller productivity and better integrates flows of information from TFM to controllers to aircraft. More integration of RNAV and RNP with time based metering thus improving flows. More automation that supports decision making especially with the inclusion of standardized weather products into automation.		
4	•ADS-B OUT/ IN Augmented Infrastructure •Intermediate TBO Automation •Adv. Weather Info, Dissemination, Process. & Display •Adv. Performance Based Airspace •ADS-B IN - Primary Field of View / Advanced Applications •NextGen Staffed Virtual Towers •Ground Based Augmentation System •Intermediate Surface Management / Tower ATM Apps. •Advanced Traffic Flow Management •NextGen Enabled-Runways •*UAS* •*Alternative Fuels*	•More mature use of emerging technologies that will make more significant operational changes. However, the roles and responsibilities begin to shift with greater reliance on the pilot to perform delegated separation responsibilities especially in the terminal and approach domains. Greater reliance on automation for rerouting and TFM advisories. More sophisticated conflict detection and resolution advisories for the sector controllers. Reduce en route separation to 3 nmis. Better tools to inform the centers on how to reconfigure airspace to match capacity to demand.	•Scope of NextGen •NextGen Goals •Governance •Industry Engagement Strategy •Integrated Airspace and Procedures •Data Sharing Policy •Interagency Data Sharing Policy •NEPA •Airport Non-movement Area •Facilities Strategy •Equipage Strategy (Financial Incentives) •Equipage Strategy (Priority for Equipped)	•Air/Ground Division of Resp. •Level of Automation •Equipage Reqs. and Timing •Mandated Envirol Targets •Airport Strategies
5	•Advanced Data Comm (Segment 2) •ATS-Specific Data Link •Dispatch Integration with Advanced TFM •Advanced Surface Management / Tower ATM Apps. •Advanced TBO Automation •Safety Information Analysis and Sharing •Safety Management System •Full Trajectory Based Operations •[Aircraft] Advanced Data Comm •RNP AR Coupled and 10-Second Req'd. Times of Arrival •[Aircraft] Ground Based Augmentation System •ADS-B in FFV Multiple Advanced App. + FMS Integration •NextGen Terrain & Collision Avoidance (per Benefits Team) •*Automated Towers*	•Major change in operational concept. In this period we move towards managing the NAS via 4-DT trajectories. Automation takes on a far greater role in planning and managing the flows of traffic. Conflicts are significantly reduced by sophisticated automation that resides both in the aircraft and ground. There is still a separation controller but the job becomes more of monitoring the results of decisions made by automation. This is a significant change similar to the operational change where the auto-pilot flies the aircraft in the cruise domain and the pilot mostly monitors and reacts to failure mode conditions.	•Scope of NextGen •NextGen Goals •Governance •Industry Engagement Strategy •Integrated Airspace and Procedures •Data Sharing Policy •Interagency Data Sharing Policy •NEPA •Airport Non-movement Area •Facilities Strategy •Equipage Strategy (Financial Incentives) •Equipage Strategy (Priority for Equipped)	•Air/Ground Division of Resp. •Level of Automation •Equipage Reqs. and Timing •Info. Sharing Architecture
6	•Automated Separation Management •NextGen Facilities •RNP-AR with Integrated Multiple Req'd. Times of Arrival •Avionics - Enhanced Vision and Synthetic Vision	•Major change in operational concept. In this period we move towards managing the NAS via 4-DT trajectories. Automation takes on a far greater role in planning and managing the flows of traffic. Conflicts are significantly reduced by sophisticated automation that resides both in the aircraft and ground. There is still a separation controller but the job becomes more of monitoring the results of decisions made by automation. This is a significant change similar to the operational change where the auto-pilot flies the aircraft in the cruise domain and the pilot mostly monitors and reacts to failure mode conditions.	•Scope of NextGen •NextGen Goals •Governance •Industry Engagement Strategy •Integrated Airspace and Procedures •Data Sharing Policy •Interagency Data Sharing Policy •NEPA •Airport Non-movement Area •Facilities Strategy •Equipage Strategy (Financial Incentives) •Equipage Strategy (Priority for Equipped)	•Air/Ground Division of Resp. •Level of Automation •Equipage Reqs. and Timing •Facilities Consolidation

Figure 8 – Assigned Performance Levels to Functional Clusters – Aircraft Operator Configurations



Assigned Performance Levels to the Functional Clusters:
Aircraft Operator Configurations

Enabler	NG Ops-1	NGOps-2	NGOps-3	NGOps-4	NG Ops-5	NGOps-6
A/G voice (# radios)	25kHz (2)					Not modeled [maybe FCS]
A/G data (# radios)	ACARS (1)	Shared ATS / AOC VDL Mode 2 (1)			ATS-specific subnet (2)	
Data Link Applications	PDC and FANS		ATN Baseline 1 (CMU or FANS) integrated with FMS		SC-214 applications integrated with FMS	
Lateral conformance	RNAV2 En Route RNAV1 Terminal and approach	RNAV2 En Route RNAV1 Terminal and approach	RNP-2 En Route RNP-1 Terminal RNP-.3 Approach and departure w/ RF leg		RNP-1 En Route RNP-.3 Terminal RNP-.11 Approach/departure	
Vertical conformance	No VNAV requirement	No VNAV requirement	No VNAV requirement	VNAV required for selected approaches	VNAV required	
Speed conformance	Uncoupled auto-throttle, Single RTA, tolerance of +/- 30 seconds				Coupled autothrottle; tolerances of +/- 10 seconds or less	multiple RTAs;
Missed approach	RNAV1 equivalent containment		RNP1 equivalent containment		RNP-.3 equivalent containment	
ADS-B In (display)	NA	Non-Forward Field of View (FFOV) [Class 2 EFB] Surface Situational SW		FFOV for for paired approaches for closely-spaced parallel runways, for Merging & Spacing And delegated separation with wake risk management		
ADS-B out	DO-260B (as per NPRM) with integrity, availability and accuracy to support the ADS-B in functions					
Positioning	DME/DME and GPS or WAAS		GPS TSO 129a and or WAAS	GBAS Cat III	GPS TSO 129a with DME-DME-IRU backup and GBAS	
TCAS	TCAS Change 7				Next CAS	



Assigned Performance Levels to the Functional Clusters:
ANSP ATM Configurations

Enabler	NGOps-1	NGOps-2	NGOps-3	NGOps-4	NGOps-5	NGOps-6
En route applications	Conflict probe	Conflict resolution Initial data link apps		Enhanced conflict resolution; Sector action list	Adv data link apps	Automation responsible for separation
Terminal applications	Enhanced infrastructure and DSTs				Adv data link apps	
Tower applications	Enhanced infrastructure and DSTs	Initial surface traffic mgmt applications	Surface Data Link Clearances	Integrated Arrival and Departure Management	Adv data link apps	
TFM applications	Reroute impact assessment	Simple congestion resolution		Complex congestion resolution based on probabilistic analysis		
Weather applications	Legacy applications & end system infrastructure	Enhanced applications		Enhanced end system infrastructure		
A/G voice network	Switched NVS				IP-addressable NVS	
A/G data link subnet	Shared commercial service provider subnet				ATS-specific subnet	
G/G data network (SWIM)	Weather and flow data	Flight data		Surveillance data		
ADS-B network	Current ADS-B network topology			Additional sites		
Airspace	Big airspace	Initial performance-based airspace		Adv performance-based airspace	Full trajectory-based operations airspace	
Positioning	GPS / WAAS			GPS or WAAS for en route / GBAS for terminal		

Figure 9 – Assigned Performance Levels to Functional Clusters – ANSP ATM Configurations

Key Issues

This section will present issues related to achieving NextGen from an avionics perspective, including policy, guidance, criteria, and implementation timelines. Timing is the cornerstone of implementation, as aircraft, ground/space systems infrastructure, and operational procedures all must be ready and available in order to become part of the NAS at the same time. Such coordination also enhances the business case for user equipage.

A significant issue from the near-term through the far-term is the availability, some would say guarantee, of budget appropriations to support implementation timelines. Budget decisions often result in schedule changes, impacting the ability of the community to achieve timely benefits. In the case of NextGen, a single change in schedule can impact the future of more than one program.

NextGen avionics issues converge into the following areas: CNS, including Global Navigation Satellite Systems (GNSS); Next Generation Traffic Collision Avoidance System (NextCAS) and ADS-B; and variations between NGOps levels. The criticality of solving these issues affects our ability to develop internationally harmonization standards. Budgetary limitations and potential schedule delays could affect our ability to champion international standards, leaving Original Equipment Manufacturers (OEM) facing the challenge of duplicative strategies and schedules, which need to be integrated into the JPDO's public documents. The JPDO's public documents provide a critical repository for alignment of stakeholder requirements.

Specific issues to be solved include:

- **NAS Sustainment and Back-up** – The future navigation infrastructure will be based primarily on GNSS. PNT services must account for a growth in traffic of somewhere between 1.5 and 2 times current levels at major airports (Top 30) – therefore affecting ~100 reliever airports to a lesser extent. The FAA is working to develop an alternative position navigation and timing strategy to act as a back-up system (e.g. DME/DME/IRU) that will support continued NAS operations.

  Since ADS-B is dependent on GNSS positioning for performance, any Position, Navigation and Timing (PNT) back-up must support the inherent performance requirements called out in the ADS-B specification. Alternative surveillance strategies under discussion include an alternate means to determine the aircraft's position; however, the need for back-up timing sources is closely tied to any alternative.

- **GNSS Risks** – Hazardously misleading information is a risk to GNSS users. Examples of these hazards include GNSS interference and spoofing. While spoofing (i.e., creating a controllable misreporting of position) is much less likely to occur than GNSS interference, the associated hazard is greater. Interference is easier to detect and, in many cases, can be mitigated by the aircraft (if properly equipped). Air carrier aircraft use multi-sensor systems and some of the newer systems equipped with closely coupled inertial multi-sensor systems may negate the impact of GNSS interference. In 2025, many of today's aircraft types will continue to operate in the NAS. To address these concerns and maximize the full benefits of NextGen, solutions may have to be incorporated into the Flight Management Systems.

- **Loss of GNSS Time Synchronization** - GNSS provides time synchronization for several critical services. Data link communication will be dependent on it. Many data networks synchronize their time using GNSS. Loss of this critical element will affect the System Wide Information Network (SWIM), net-centric communications and air-ground data link communications. Loss of these systems will have a severe impact on NextGen operations.

- **Aircraft Data Links** – While passengers will be able to have less fettered access to wireless information, these pathways cannot be used for flight related activities. The critical link is the certified pathway between aircraft systems and the protected ground infrastructure for CNS/ATM. There are concerns about the potential for dependence on a single link and that this could result in a loss of function. Highly reliable, persistent data link capabilities between the airplane and a flexible networking architecture that can route around failed network elements both in the air, on the ground, and due to disturbances or blockages of the radio frequency (RF) channels (e.g., interference) will be required. The aircraft is the pressure point at which original equipment manufacturers (OEM), industry, users, and services providers all converge. Due to the tightly integrated avionics structure, there are instances where avionics manufacturers are held at bay by specific aircraft strategies developed by the OEM.

Data Communications (Datacomm) continues to exist in limited capabilities until at least 2025. As a result, TBO will have to be pushed back due to this limitation. There are currently three spectrums available for datalink: High Frequency (HF), Very High Frequency (VHF), and Satellite Communications (SATCOM) (e.g., Inmarsat). Message timing uses GNSS as an initialization, but is internally generated.

One potential evolution of FANS could be seen as:

- FANS-1 and ATN CMU are mutually exclusive, i.e. only one can be installed/enabled
- FANS-2/B = FANS-1A+ and ATN B1 (LINK2000+)
- FANS-3/C = FANS-1A+ and ATN B3

It should be noted that the options above have implications on equipage and benefits. For instance, if operations are constrained by invoking the use of ATN B1, there is little to be gained by having more capable avionics, such as FMS with integrated datalink and ATN, and that such choices could impede the advancement of TBO. This potential evolution of FANS should be mapped to ATN Builds 1 through 2/3. The latest decision is to eliminate the current ATN B2 and replace it with ATN B3. The naming convention would remain ATN B1 and ATN B2. The need for a common lexicon of terms exists. In light of constant changes in programs, it is recommended that terms such as "FANS 1/A+" and "ATN Build X" be defined to eliminate confusion. Further, agreement on datalink evolution must be made immediately. It is important to address the issue* now so that solutions can be written into design requirements.

**This issue is being addressed by the JPDO's Safety, Aircraft, ANS WGs, and the NCO, and IPSA Divisions.*

- **ADS-B and NextCAS** – Analysis of the NextGen capability "Delegated Interval Management" by the Safety WG in 2010 indicated that ADS-B and Traffic Collision Avoidance System (TCAS) provide redundant outcomes of averting air plane pair collisions. NextGen Collision Avoidance System (NextCAS) requirements share the same 1090 MHz squitter frequency as ADS-B, thus causing potential saturation at inopportune moments. There is concern of not being able to share a common signal across these two systems. The intermingling of functions must be considered.

  Intermingling Functions – In order to maximize usefulness of NextCAS performance objectives, NextCAS requirements may include ADS-B functionality in their algorithms. Link congestion is a concern. If ADS-B provides misleading information, NextCAS functionality would be degraded, which could lead to a potentially catastrophic event. Closer coordination between the JPDO Safety and Aircraft WGs and RTCA SC 147 is required.

  This issue is being addressed by the JPDO's Safety, Aircraft, ANS WGs, and the Net-centric Operations and IPSA Divisions.

- **"See and Avoid" Technology Transition**
  The ability for aircraft flight crews to "see and avoid" other aircraft in the NAS is part of the regulations governing the general operation of aircraft in the NAS under Title 14 Code of Federal Regulations (14 CFR), Part 91, §91.113. Although the requirements stated in the regulations are described as "right of way" rules, the intent is to avoid collisions and remain "well clear" from other aircraft. While these operating regulations are specific, the concept of well-clear is non-specific in nature and allows for a pilot's subjective assessment when performing maneuvers for this purpose. This is problematic for designing an engineering solution to meet the see-and-avoid requirement. As a result, constructs are required to better describe the functions in terms that can be implemented in a

technical solution to meet the regulatory requirements. One such construct is the determination of when an action is needed to comply with those requirements. There are boundaries (or thresholds) that determine when action is needed to remain well-clear and avoid collisions with other aircraft. These thresholds are not fixed boundaries in space, but more dependent on time to closest point of approach (CPA), closure rate, maneuverability and other factors. These thresholds are unique for each aircraft being tracked in the vicinity of the UAS, and change over time as an encounter progresses.

Sense and Avoid equipment used as a decision-support tool - in lieu of "see and avoid" - to the Unmanned Aircraft Systems crew is expected to be subject to an airworthiness approval process. Additionally, this type of use may also be subject to specific operational approvals. The UAS crew is expected to be subject to an airworthiness approval process and its use may be subject to specific operational approvals. The Sense and Avoid system notionally consists of a surveillance sensor (or suite of sensors), trackers and/or surveillance data fusion logic, data communications architecture, threat detection and/or resolution computer logic, and (potentially) the display of traffic information and/or resolution guidance/advice. The system and its architectural components should be subjected to airworthiness evaluations to determine that the Sense and Avoid system meets its intended function and is developed to appropriate hardware and software design assurance levels.

The use of a Sense and Avoid system also requires consideration of the existing air traffic environments in which UAS might be operating. Although such a system should be designed to intervene when there is a potential loss of safe separation between aircraft, there are also cases where an air traffic service provider's strategy and intent would not be known by the Sense and Avoid system and conflicts between Air Traffic Control (ATC) and the Sense and Avoid system may arise. This could require components of the Sense and Avoid system (e.g. self-separation system) to be specifically authorized and delegated authority by the air traffic service provider in certain environments.

Central to the acceptance of a Sense and Avoid system is the safety of that system when introduced into the airspace. Safety and hazard assessment activities are proposed to be used to demonstrate that an acceptable level of risk for each safety hazard identified for the system is achieved. This is accomplished through a systematic approach of hazard identification, hazard/risk analysis, risk mitigation, and hazard/risk management. Various methods and tools for performing safety assessments are introduced with strengths, weaknesses, and applicability of those methods for demonstrating the safety of the different aspects of the Sense and Avoid system.

Sense and Avoid Conclusions:

- Sense and Avoid is the capability of a UAS to remain well clear and avoid collisions with other airborne traffic. Sense and Avoid is the combination of UAS Self-Separation (SS) plus Collision. Avoidance (CA) as a means of compliance with 14CFR Part 91, §91.111 and §91.113.
- The two functions of Sense and Avoid are SS and CA.
- The sub-functions are Detect, Track, Evaluate, Prioritize, Declare, Determine Action, Command, and Execute.
- UAS Self Separation is an essential component of the Sense and Avoid solution.
- SS could be the only function provided given that the safety analysis demonstrates that the Target Level of Safety (TLS) can be met with SS alone.
- Even if the CA system can meet the TLS, it cannot be the only function implemented in a Sense and Avoid system. CA alone will not satisfy the statutory requirement to remain well clear; so, even if CA met the safety target, a SS function still would be required.
- While receiving ATC separation services, ATC may delegate separation authority to the UAS to use SS.

  - UAS must possess the capability to avoid collisions and remain well clear of other aircraft by means of sensor systems and equipment specifically designed for this purpose.
  - All equipment used as part of the Sense and Avoid system, whether solely or partially used for that purpose, must be certified as airworthy (by applicable airworthiness authorities) to perform its Sense and Avoid intended function under foreseeable operating conditions.
  - The SS function must compute "well-clear" for each intruder in a Sense and Avoid system.
  - The Target Level of Safety (TLS) approach is the most desirable safety substantiation of a Sense and Avoid system.
  - Attempting to demonstrate an Equivalent Level of Safety (ELS) to manned aircraft for see and avoid is not an applicable means of compliance with the operational requirements of 14CFR Part 91, §91.111 and §91.113.

- **Security** – Existing FAA regulations and policy do not specifically address systems, networks, and data security requirements for aircraft systems. This could result in non-standardized agreements between the various applicants and the various regulatory agencies for developing an acceptable process and means of compliance for ensuring safe, secure, and efficient aircraft systems certification.

  National FAA regulations, policy, and guidance are needed to address the potential access to the systems, networks, and software components from unauthorized users which could result in corruption of aircraft systems (e.g., software applications, databases, configuration files, etc.) by worms, viruses, or other malicious entities.

  Until new regulations on security are published, some aircraft systems may require an FAA Special Condition on security for system and data networks protection from unauthorized external access. FAA Special Conditions are airplane model specific and are not general public rules. When required, an FAA Special Condition should be applied for each specific aircraft model type. These special conditions contain the additional safety standards that the Administrator considers necessary to establish a level of safety equivalent to that established by the existing airworthiness standards.

  When necessary, security is addressed in the specific Minimum Operational Performance (MOPS) requirements for a specific function or platform. For those systems not covered by a MOPS document, special conditions are established by the FAA. In support of the FAA Special Conditions, RTCA Special Committee (SC) SC-216 "Aeronautical Systems Security" is working jointly with the European Organisation for Civil Aviation Equipment (EUROCAE) to develop guidance material for identifying and mitigating aircraft system vulnerabilities. The scope of the RTCA/EUROCAE effort is to address security concerns for systems installed on a "non-interfering" basis. This system can include, but is not limited to, passenger communications systems, passenger entertainment systems, etc.

  It is expected that company networks used to provide passenger communications will also provide high capacity network access for non-safety applications such as SWIM and AOC/FOC air-to-ground information exchanges. As such, system security concerns will be included in the RTCA/EUROCAE deliberations.

- **SWIM** – SWIM is an advanced technology program designed to migrate the FAA's ground information technology (IT) systems into an integrated, service-oriented architecture (SOA) accessible to NAS users. SWIM enables the exchange of ATM data, such as weather information, airspace status (e.g., special use restrictions), airport status (e.g., Notice to Airmen or NOTAMs), and flight information. SWIM is intended to facilitate the addition of new ATM services and increase common situational awareness among NAS users (e.g., aircraft, operators, controllers, etc.). SWIM is a key enabler for the exchange of information among NAS users directly in support of the pre-negotiation/negotiation phases of TBO.

SWIM communication may originate or be routed to either the flight deck/cockpit or cabin. It is not intended for use with Datacomm clearance delivery. SWIM will provide access for both internal and external users of the SWIM virtual network. NAS architecture SWIM security requirements for both user domains (internal and external) are being developed and implemented.

It is important to recognize that the SWIM SOA environment affords "clients" (both air and ground) the ability to discover, retrieve, publish, and register contracts.

Figure 10 provides a notional architecture of the SOA environment wherein the SWIM clients are subjected to the SWIM service governance. An aircraft that is considered a SWIM SOA "client" must satisfy the entire airborne allocated SWIM services client qualification criteria. Airborne functional architecture allocations necessary to support airborne SWIM client services have not been formally identified and defined in airborne standards. This becomes important as airborne access to SWIM and an aircraft qualified as a SWIM client are differentiated.

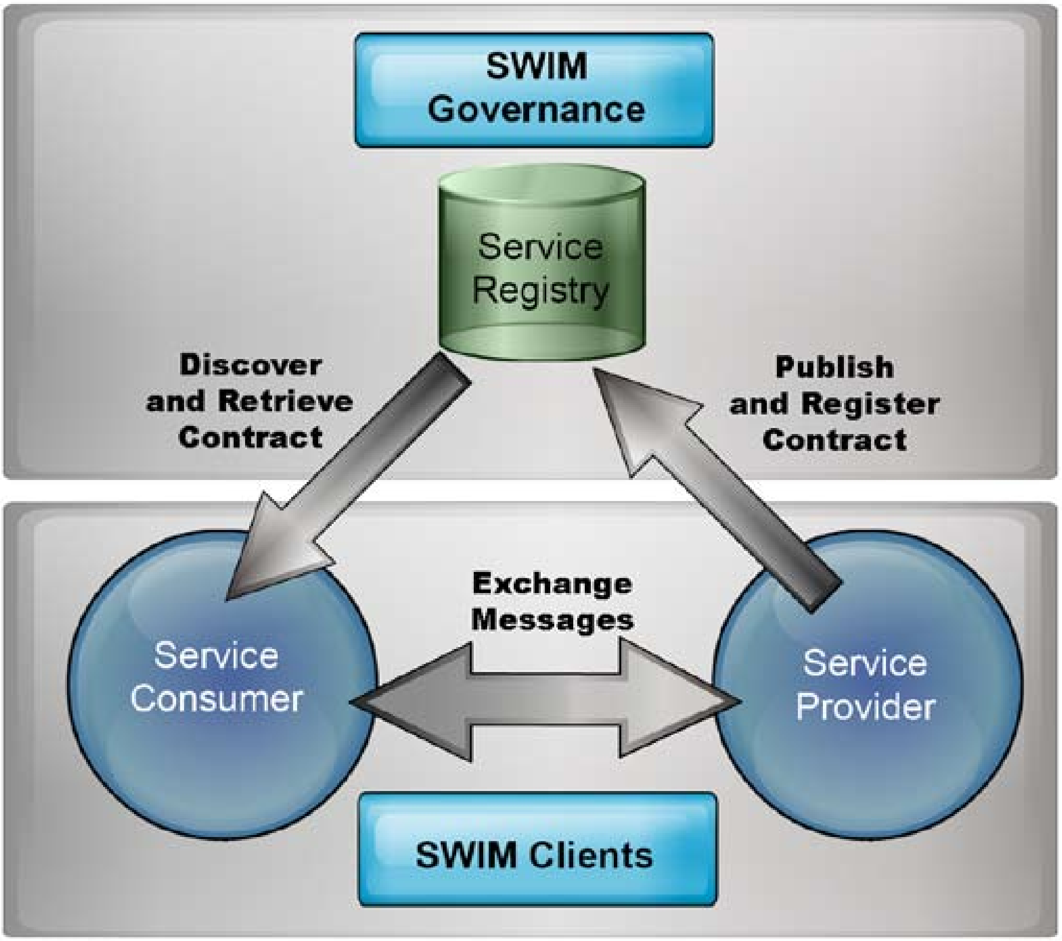


Figure 10 – SWIM SOA Environment

For NextGen, SWIM has been divided into three segments. Lifecycle implementation of each of these segments provides increasing functionality and information access. Initial segments accommodate aircraft using commercial air-to-ground communication provider networks (see Figure 11). These commercial provider networks include satellite-based services (e.g., Iridium or Inmarsat Swift Broadband), terrestrial-based services (e.g., AirCell or VHF Digital Link) and/or airport based services (e.g., Wi-Max IEEE 802.16g). This is commonly referred to as airborne access to SWIM (AAtS).

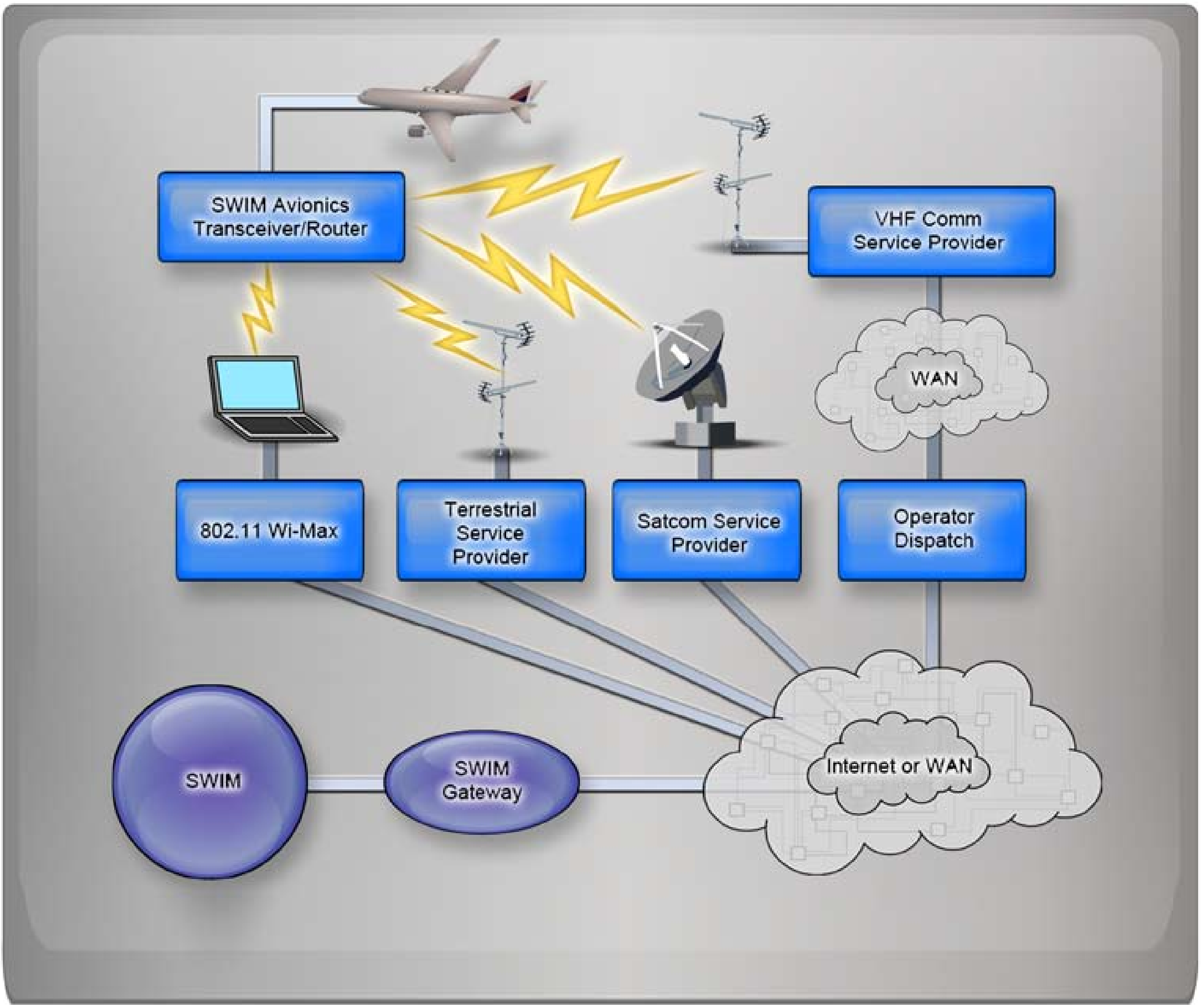


Figure 11 – Airborne SWIM Architecture

For AAtS operations, the aircraft is not uniquely equipped with SWIM airborne services, which are required for SOA environment access. AAtS operations allow for currently equipped aircraft to exchange data with a ground based SWIM client (NAS SWIM external user). An aircraft participating in AAtS is not considered a SWIM SOA client and thus does not have to be equipped with SWIM client qualification criteria.

For far-term segments, SWIM will support aircraft qualified as SWIM clients (NAS SWIM internal user). This will require the development of airborne standards to identify allocated requirements for participating aircraft. Aircraft qualified as SWIM clients must address the airborne allocation of security requirements.

Avionics-enabled NextGen Capabilities

The avionics-enabled improvements in this Roadmap are presented in six groups of related operational capabilities. This approach is intended to identify the type of aircraft operational capabilities that are considered necessary or advantageous for NextGen operations. The objective is to help operators identify the types of capabilities that will be available and are likely to be important to their far-term NextGen operations. This section also demonstrates the relationships between the capabilities and the specific changes reflected in other planning documents. The capabilities structure may be incorporated into other JPDO-developed planning documents when they are revised, and this may necessitate minor adjustments to the structure depicted in this Roadmap.

The six capabilities are structured in a building block fashion where they are progressively more encompassing and therefore enable more complex types of operations. The bullets below provide a high-level snapshot of how the capabilities were structured and relate to one another.

- **Published Routes and Procedures** – Predicated on improved operations associated with precision navigation capabilities based on RNAV and RNP.
- **Negotiated Trajectories** – Builds upon the capabilities of precision navigation by adding Datacomm capabilities to enable dynamic negotiation of preferred routes.
- **Delegated Separation** – Adds to the capability of negotiated trajectories through the availability of enhanced situational awareness (in the air and on the ground) to enable delegated separation practices to be expanded from use in visual conditions to use in non-visual conditions in controlled airspace.
- **Low Visibility/Ceiling Approach/Departure** – Recognizes that aircraft capability is available today to enable operations with weather constraints and with less dependence on costly ground infrastructure, allowing operations to more readily adapt to changing situations without reliance on existing or new ground infrastructure.
- **Surface Operations** – New avionics capabilities are more widely available early in the far-term, increasing safety of operations for approach/departure.
- **ATM Efficiencies** – Identifies capabilities that improve the ATM process, thereby reducing the FAA's costs of operations and/or enabling new services to be provided.

The six groups of capabilities outlined above are fully aligned with the FAA's NGIP, published in March 2011. This is critical because the Avionics Roadmap is aimed at addressing the overall evolution of aircraft capabilities and how they are enabled by certain avionics. To do this, there must be a clear understanding of what is in place today, what is committed, what is coming (per the NGIP), and what needs to be added in the far-term to fully use these broad capabilities. Additionally, to ensure greater standardization of navigation, it will be beneficial to review and, if necessary, modify current guidance material to address performance differences between different navigation systems and displays, such as:

- DO-236B (Minimum Aviation System Performance Standards for RNP for RNAV)
- DO-283A (Minimum Operational Performance Standards for RNP for RNAV)
- DO-257A (Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps)

Meta-model Overview

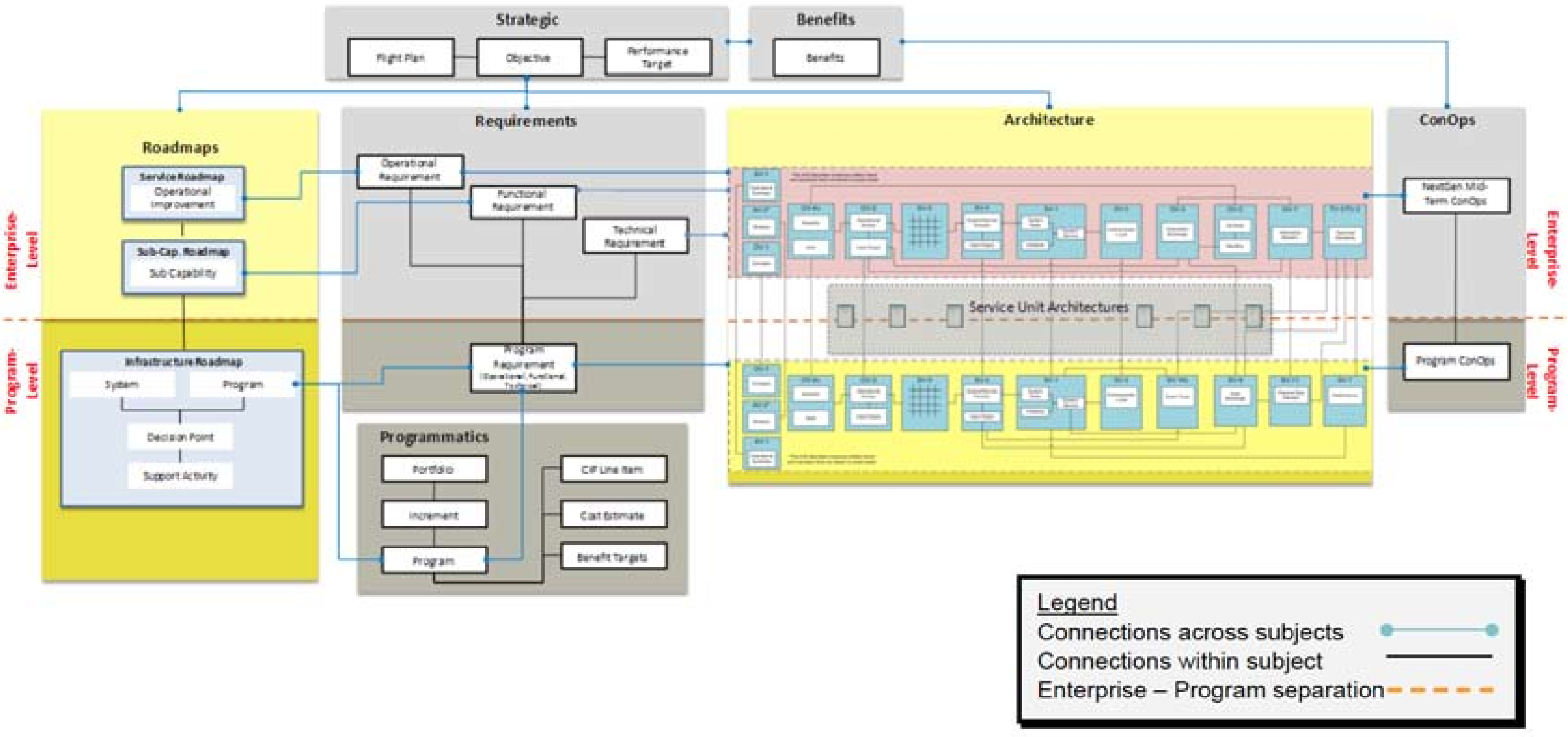
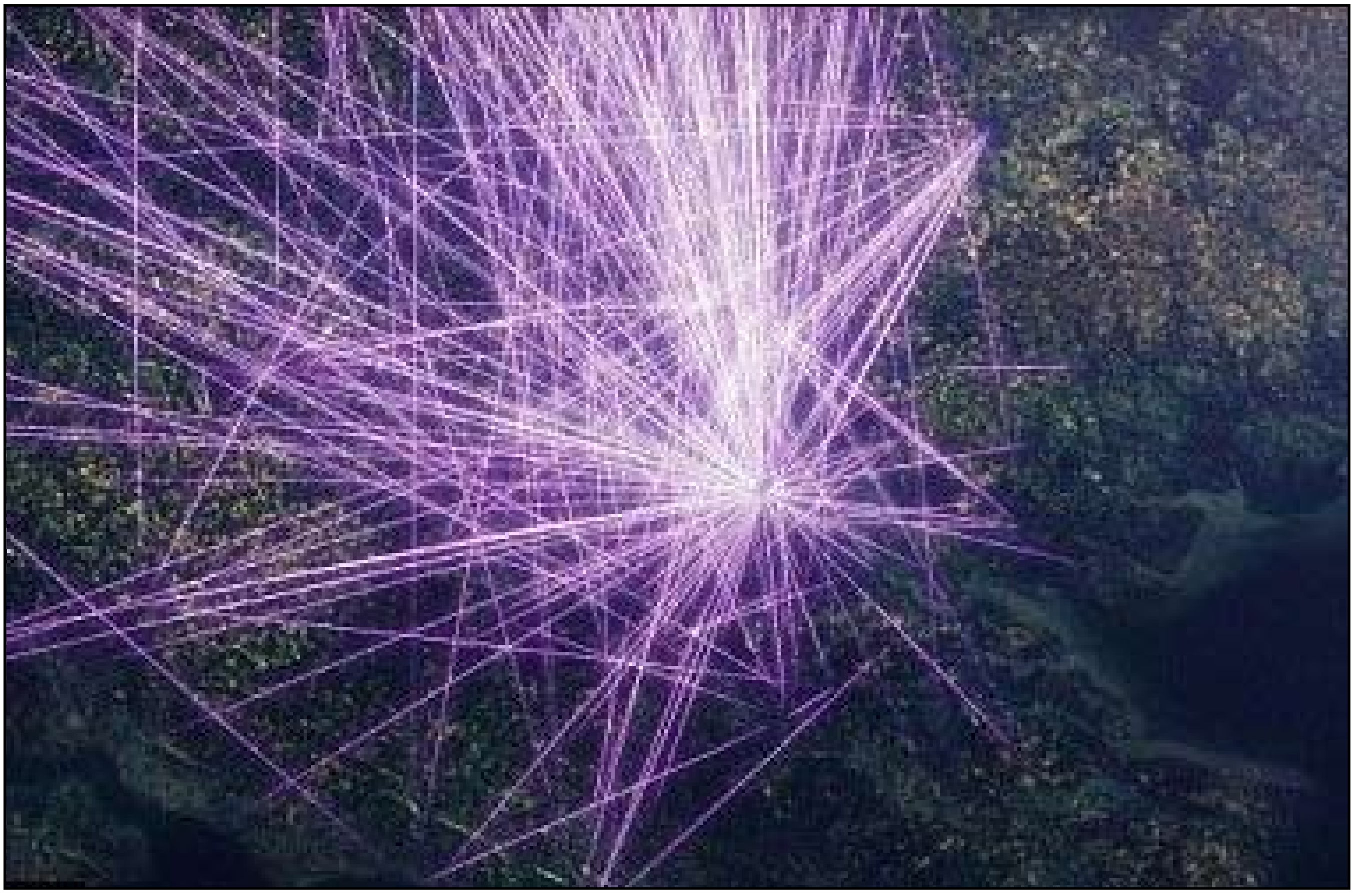


Figure 12 – FAA Modeled Relationships between Program and Enterprise Levels

The NAS Enterprise Architecture is a planning artifact for government agencies mandated by the Sarbanes-Oxley Act. It is used by the Office of Management and Budget (OMB), the Government Accountability Office (GAO), and the Office of the Inspector General (OIG) to surveil FAA acquisition planning and spending. It is also the FAA planning artifact that has the most detail accessible to the general public. Enterprise Architecture (including the Aircraft and other "linked" Roadmaps) are updated annually. Figure 12 shows the FAA's metamodel and the relationships between program and enterprise levels. These relationships cover roadmaps and strategic requirements, such as benefits, concepts of operations, and the respective architectures to support them.



Historical lead-in times for CNS initiatives (15 to 25 years) are dominated by the concept and standards phases of development that are typically performed in series. There should be a concerted effort to run these steps in parallel or to shorten them to some extent.

Policy decisions will need to be made to ensure that far-term capabilities are realized. These decisions will not necessarily dictate equipage strategies, but should focus on the requirements needed for avionics systems to meet the desired capabilities. Those strategies will likely vary between capabilities. Additionally, policies will need to achieve the desired balance between ground infrastructure and avionics equipage to balance the investment-sharing aspect of the NextGen transition. Research and development efforts will sometimes yield multiple solutions for achieving a capability and permit trade space between ground infrastructure and avionics equipage. In an effort to minimize their respective costs, the ANSP and operators will likely favor solutions that shift costs away from them.

Published Routes and Procedures

It is expected that during the far-term period, RNAV and RNP en route, terminal, and approach procedures (RNP, LPV, and GBAS) will predominate in the NAS. The capabilities presented below are fully aligned with the FAA Enterprise Architecture. Additional value from these procedures is expected to occur from the use of ADS-B technology that will enable reduced separation standards and delegated separation.

Negotiated Trajectories

By integrating the aircraft's navigation capability with data link, the precision and reliability of RNAV and RNP routes can be applied to dynamically defined routes. Data link will provide for dynamic exchanges between the aircraft, ANSP, and the operator AOC/FOC, resulting in more efficient trajectory negotiations and reductions in human error input.

Given the likely differences between aircraft capabilities (i.e., air transport, high-end business, military, and GA), it is expected that not all trajectories will be 4D or that their fidelity will vary. Other factors that will influence trajectory operations include vertical navigation capability, time of arrival control, and flight management systems.

The TBO framework will require that it can be used over a wide range of capability levels that will enable 4D trajectories for all flights operating under IFR or operating into high density or multiplex terminal environments. The TBO framework provided in Appendix 1 of this Roadmap reflects the most current JPDO perspective.

Delegated Separation

Three capability sub-groups have been identified for Delegated Separation that reflect different levels of avionics functionality and integration. In the first capability sub-group, ADS-B In and improved display capabilities will provide the flight deck with accurate position and trajectory data. Aircraft that are equipped to receive the ADS-B In broadcasts and have the associated displays, avionics, and crew training will be authorized to implement speed changes to achieve and maintain a controller-specified spacing value behind a preceding aircraft. In this sub-group, separation authority will remain the responsibility of the ANSP. Mixed equipage may be supported within a single arrival stream to achieve continuous descent arrivals. Operators not capable will be managed by the ANSP, provided they are ADS-B Out equipped.

In the second sub-group, ADS-B In, enhanced surveillance, and new procedures will enable the ANSP to delegate separation responsibility to the aircraft. Improved flight deck displays, avionics, and broadcast positional data will allow the flight crews of properly equipped and approved aircraft to manage their own separation when authorized by the ANSP.

In the last capability sub-group, ADS-B In, Performance-based Navigation, and advanced flight deck displays may support paired instrument approach operations between closely spaced runways. Advanced avionics using ADS-B In, flight deck displays, and on-board predictive wake vortex detection systems will enable aircraft to remain above or in front of the wake vortex of an aircraft on the parallel approach. This will allow reductions in lateral and longitudinal spacing. Achieving the minimum lateral and vertical spacing for these procedures will be determined by aircraft capability and safety risk models that evaluate the probability of a cross-track excursion. This will establish a business case and, if successful, encourage operators to equip and support environmental goals of reducing fuel burn, noise, and emissions while improving capacity and throughput.

Low Visibility/Ceiling Approach/Departure

In low-visibility/ceiling conditions, approach and departure procedures are constrained by the requirement to maintain strict IFR separation standards. This includes visibility, instrument landing system (ILS) runway protection areas, closely spaced parallel runways, runway turnoff alignment/location, and runway occupancy time. ILS is currently the predominant navigation aid to enable low- visibility/ceiling approaches. In the far-term, it is expected that the use of Local Area Augmentation Systems (LAAS), Wide Area Augmentation System (WAAS/LPV), and ADS-B In procedures will predominate and help alleviate current constraints.

Key avionics technologies that may improve airport accessibility include heads-up display (HUD), auto-approach/auto-land capabilities, enhanced flight vision systems (EFVS), synthetic vision systems (SVS), as well as the GBAS precision approach capability.

These new aircraft-based flight technologies will allow greater access and throughput at airports that would otherwise be unavailable due to insufficient ground infrastructure and other factors. By equipping aircraft with these avionics technologies, the operator will have greater flexibility and predictability of operations at a variety of airports with less dependence on existing ground infrastructure.

Avionics for Equivalent Visual Operations

The increased aircraft separation distance imposed by ATC during periods of decreased visibility represents an obstacle to increasing capacity of the NAS. For this reason, the introduction of avionics to support equivalent visual operations and synthetic vision systems is beneficial. In addition to providing improved pilot situational awareness in flight, such systems should also prove useful in avoiding runway incursions. Enhanced vision systems use image processing techniques to provide an improved look at the real world. Enhanced vision systems are essentially ready for introduction in the near-term and, in fact, some types of HUD with enhanced vision are already available. At the present time, enhanced vision systems allow descent below the 200 foot decision height. The aircraft can transition down to a 100 foot minimum, by which time ordinary visual identification of the runway must be made. However, the goal of future enhanced vision systems is to allow even lower minima, perhaps even to ground level.

Synthetic vision systems use computers to create a tactical view of runways and obstacles in a computer-generated pictorial display. The advantage of a computer-generated image is that processing of sensory image data is not necessarily required, but rather more reliance is placed upon ADS-B In, radar, altimeter, and terrain/obstacle data. The weakness of the approach is the accuracy of available data and the ability to detect small UAV and birds.

Enhanced vision systems use advanced imaging techniques to improve the image obtained from sensory information. These systems do not use computers to generate a synthetic view, but rather use signal processing to produce an image of improved visual clarity. For example, imagery taken at night from an aircraft camera can be processed to provide an almost daylight view if the red, green, and blue light spectrums are processed separately and suitably amplified and combined. Pattern recognition software can also be used to provide automatic detection of aviation safety hazards such as terrain, runway obstructions, or other nearby aircraft. Since such systems utilize cameras, computers, and cockpit displays, it is anticipated that enhanced vision systems and optics can be used to provide relatively low-cost tools to improve pilot situational awareness.

Another approach being investigated is the fusion of synthetic visual systems (SVS) and enhanced flight visual systems (EFVS). The motivation is that while a shortcoming of SVS is its reliance on terrain/obstacle data, EFVS has problems of its own, such as degradation in certain common atmospheric conditions (e.g., snow). If successfully fused without distracting or misleading visual artifacts, the combination of these systems promises the advantages of both while mitigating the shortcomings of each. Trials and studies are being conducted to determine what level of broad-based application/value exists and how it fits user needs.

Surface Operations

This section describes the surface operations and projected aircraft avionics requirements that are expected to exist in the NextGen far-term, at 2025 and beyond. It is based on the hypothesis that the responsibilities between aircraft crew, ramp controller, and ATC remains roughly the same as it does today for operations on the airport surface. After pushback and ramp area movement, ground ATC will define the taxi route that the aircraft should follow and will provide the aircraft with clearances along this path. Data link communication will be widely used to reduce voice communication and enable more complex clearances with less confusion in the prescribed taxi route. The crew will be responsible for their compliance and monitoring runway incursion potential.

On-board systems will include all or most/some of the following equipment:

- Moving Map Display
- ADS-B and/or TIS-B capability
- Heads Up Displays, Surface Guidance Systems, Enhanced/Synthetic Vision Systems
- Flight Management Systems
- Communication Management Units (CMU) for Datacomm with TBO standardization
- Braking Systems

Safety Enhancements, Hazard Avoidance, and Mitigation (SAFE 005)

Surface moving maps with overlaid "own ship" (SAFE 005) position information will improve flight crew situational awareness in ramp areas, taxiways, and runways, helping to reduce taxiway and runway incursions and confusion. Such moving maps may be presented on electronic flight bags (EFBs) or preferably on the navigation display, specifically when other surface applications are also made available (as described hereafter). Graphical qualities, modes, and ranges, as well as Human Machine Interface (e.g. interactive) depend on the specific installation. This capability may require augmented GNSS position information in conjunction with airport map databases. Some of the desired capabilities identified by SAFE 005 are listed below.

- **Own Ship Surface Relative Position**
  This capability will aid flight crews by providing better situational awareness of their position relative to the locations of runways along their route of taxi, resulting in greatly reduced occurrences of taxiway and runway incursions and confusions. This is expected to be complemented by incorporating the following capabilities in the system:

- **Indication of Runway Identifier Toward Which the Aircraft is Approaching**
  This capability aids in positive runway identification to eliminate confusion as to the aircraft location with respect to active runways. This function may also be used to provide positive verification of the assigned departure or landing runway.

- **Approaching Runway Alerting Without Line-up Clearance**
  This capability alerts the flight crew when approaching the departure end of a runway and the aircraft has not yet received its line-up clearance, thus avoiding a possible runway incursion. This would occur when another aircraft is occupying the runway or is on final approach in close proximity to the threshold.

- **Final Approach Runway Occupancy Alerting (FAROA)**
  In this capability, an alert is provided to a landing aircraft on final approach when the runway is occupied by another aircraft or vehicle. While not a surface movement capability per se, it does provide situational awareness to an aircraft on final approach by providing it with information about aircraft on the runway or approaching the runway. This significantly reduces the potential for error, especially in low visibility conditions, for issuance of a landing clearance with another aircraft on or moving onto the landing runway.

- **Insufficient Runway Length and Alerting**
  This capability improves crew awareness of runway distance at the start of the takeoff roll and provides remaining runway distance during the landing roll. It will provide an alert when there is insufficient runway distance required to complete the takeoff or landing maneuver. During the landing maneuver, this aids the crew's decision process to determine if additional deceleration is necessary to stop within the remaining runway distance.

- **Runway Exit Indication**
  This capability provides situational awareness of the taxiway based on the known deceleration rate of the aircraft. This will allow the flight crew to optimize the deceleration rate of the aircraft and minimize time on the runway.

- **Situational Awareness**
  This capability uses a moving map display to show the locations of other aircraft/vehicles in proximity to own ship. This can be offered as retrofit packages to existing aircraft.

Capabilities for Improved Efficiency of Taxiing Operations

During periods of high traffic density and poor visibility, the following aircraft capabilities will allow for less dependence on costly ground infrastructure.

- **DataLink Clearances (DCL)**
  In the far-term, DCL will be pushed to the aircraft and may be available on the map display (if properly equipped). Additionally, taxi clearances may include a time element from first movement off the gate/parking spot to the end of the runway.

- **Braking Assistance**
  In the far-term, a brake monitoring system may provide automatic braking indications to the flight crew as to an assigned runway turnoff point. This system will help reduce brake wear and runway occupancy time.

The brake to vacate function will enable the pre-selection of both landing runway and exit point, using known airport data and the computation of landing performance. This may reduce runway occupancy time.

The human machine interface is addressed through visual and aural alerts to the flight crew. Aerodynamic braking will be used, preventing excessive wheel braking to meet the target runway exit. Less energy will be dissipated by the brakes, reducing brake wear.

From an operational perspective, brake to vacate will provide repeatable braking profiles which may lead to reduced runway occupancy. The objective is to prevent missed runway exits and reducing run way occupancy times. Benefits include increased capacity, increased safety, reduced environmental impact, extended brake life.

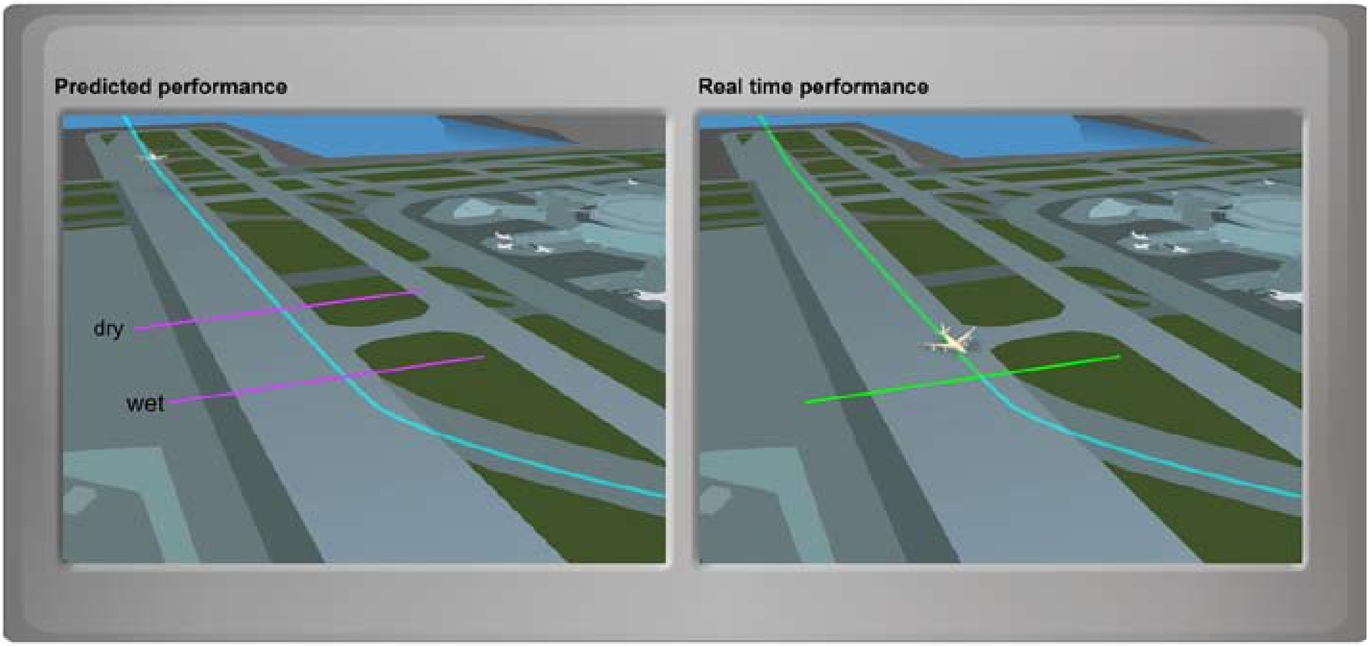


Figure 13 – Brake to Vacate Performance Comparison

Enablers for Improved Efficiency of Taxiing Capabilities

The following key enablers are required for implementing improved effiency of taxiing operations capabilities.

- **Airport Map Database**
  Existing Airport Moving Map Databases are suited for surface functionality including advisory and situational awareness capabilities. Database consistency, accuracy, and integrity issues must be addressed for future applications. In the far-term, map data that is essential to aircraft movement will be uplinked. Airport Moving Map Databases, which are currently a graphical depiction of the airport, may be complemented by data linking additional airport surface features.

- **Accurate Aircraft Position**
  Far-term surface functionalities will depend on use of a highly accurate GNSS-based position or systems providing equivalent performance.

- **ADS-B, TIS-B, and Multilateration**
  These are key enablers for all traffic-related surface functionalities. ADS-B In aircraft position on the airport surface will need to comply with the specific accuracy and integrity requirements for such surface functionalities.

ATM Efficiencies

Advanced aircraft avionics will enable improvements to the ATM process that can result in enhancements of services and reduced costs to the FAA. Key aircraft enablers, such as data communications and enhanced weather sensors, combined with ground-based decision-support tools will provide improvements in aircraft-to-ANSP information exchange, access, and throughput. These capabilities will provide direct and indirect benefits to the aircraft and greater overall NAS efficiency.

Airline/Flight Operations Centers (AOCs/FOCs)

AOCs/FOCs of the future will continue to reside with the individual operators, due to the dynamics of regulations and working relationships between the pilot, dispatcher, and controller. The advancement and use of constant AOC/FOC data communications, when paired with active flight following allows automation and dispatch resources to harness the maximum of FAA NextGen improvements. The outcome of the combined capabilities and improvements will result in more efficient NAS operations.

Reliable data and voice communication links will play a necessary role in supporting increased adoption of Operational Control Centers (OCC). A licensed dispatcher with aviation-specific knowledge and experience will provide pilots with timely critical weather information to assist with risk assessment, go/no-go decisions, and required monitor flight position. Additionally, as the TBO concept becomes the standard operating procedure, the OCC's role will grow in importance for negotiating 4D trajectories collaboratively with the ANSP.

The key enablers for information exchange between aircraft, ANSP, and AOC/FOC include:

- Data communications
- Development of the flight object and enhanced weather sensors
- Enhanced airborne and ground-based decision support tools
- Distribution of NOTAMS/TFRs/dynamic Special Activity Airspace (SAA)
  parameters to increase access and throughput

This solution set covers strategic and tactical flow management, including regulatory and critical interactions with operators (AOC/FOC) to mitigate situations when NAS demand cannot be accommodated. The Collaborative Air Traffic Management (CATM) solution set includes:

- Flow programs and collaboration on procedures that shift demand (e.g., routings, altitudes, and times)
- Foundational information elements for managing NAS flights (with stakeholders), allowing specific TBO objectives

Future AOC/FOC will require frequent performance analysis from each operator to meet dynamic requirements while working with limited internal resources (limited aircraft, man power, gate/ramp space, fuel, and ground equipment) and external restrictions (throughput constraints, staffing, equipment, and weather). Another vital part of meeting TBO objectives is the need for frequently updated real-time weather. This data is provided to the ANSP and AOCs/FOCs (and other NAS users). Pairing this data, AOC/FOC automation systems may adjust their daily schedule while ensuring the highest level of safety, throughput, and regulatory compliance. This shared information allows for maximum airspace efficiency while maintaining safety. Automation enhancements enable increased airspace flexibility and traffic volumes.

Advancements to flight planning systems will make the best use of all available airspace departing from conventional route structures by fully using NAS information through SWIM. The implementation of an open NAS structure will provide stakeholders with the potential to collaboratively mitigate delays while maintaining safety. Collaboration between flight crews, AOC/FOC, and ANSP utilizing data link communication and flight object automation advancements will aid in creating optimal flight trajectories. Prior ANSP-FOC coordination will facilitate a plan to mitigate any limitations in the NAS. Dynamic changes will be fully collaborated between ANSP, AOC/FOC, and the aircraft.

Far-term DataLink

En-route clearances and amendments will be transmitted simultaneously to AOC/FOC and flight crews. AOCs/FOCs will coordinate with the flight crew to jointly verify the revision. If the revision is acceptable to both the dispatcher and the flight crew, the flight crew then will advise ANSP and execute the revised clearance. Clearance amendments will have predefined limitations to ensure that Federal Aviation Regulations (FAR) requirements are met.

Safety Enhancements: Hazard Avoidance and Mitigation

Avionics will continue to play a paramount role in aircraft safety, using flight deck displays of the airport surface, other aircraft positions, and improved hazard information provided by ground systems and other aircraft. Near-term and mid-term safety enhancements are based on the awareness, avoidance, and mitigation of natural and man-made hazards, including terrain, obstacles, other aircraft (either on the airport surface or airborne), SAA, weather, and wake turbulence. Late mid-term and far-term safety enhancements will include avionic systems to prevent component failures and loss of control situations from occurring. These improvements will be based upon the introduction of integrated on-board avionic systems that can assess vehicle health and flight safety in real-time, enable effective mitigation, provide assistance or automatic recovery under off-nominal conditions, and offer effective situational awareness and decision support to the crew. The Avionics Roadmap recognizes that a safety assessment must be completed prior to the implementation of new technologies or capabilities. The JPDO Safety WG is currently developing and conducting a safety analysis of new systems envisioned for the far-term, consistent with the principles of Safety Management Systems (SMS).

Safety Enhancements

Safety enhancements are key to fully exploiting the potential of the other capabilities presented in the Roadmap. In other words, these capabilities and their corresponding enablers will allow a greater potential of the other five capability groups to be achieved. Safety enhancement capabilities also address areas of operation that are considered to have greater vulnerability from a safety standpoint due to higher traffic volumes and different operational procedures expected with NextGen.

Hazard Avoidance and Mitigation

Safety enhancements are based on the awareness, avoidance, and mitigation of natural and man-made hazards. Hazards include terrain, obstacles, other aircraft (either on the airport surface or airborne), SAA dynamic terminal airspace, weather, and wake turbulence. The aircraft continues to play a paramount role in aircraft safety, using flight deck displays of the airport surface, other aircraft positions, and improved hazard information provided by ground systems and other aircraft.

The table that follows summarizes the nine safety enhancements addressed in Section 8.3 of this document and in the preceding paragraphs. The “SAFE-xxx” designation is not a standard designation used in other JPDO or FAA documents. Its role here is to highlight capabilities that significantly enhance safety, either by being new initiatives or by expanding on existing safety practices to accommodate the greater demands made by densely populated NextGen airspace.

Table 1 – Safety Enhancement Capabilities and Key Enablers

Capability	Key Enablers
SAFE-001: Enhanced Low Altitude Operations – Leverage enhancements to Terrain Awareness and Warning System (TAWS) along with higher integrity and resolution terrain databases to reduce Controlled Flight into Terrain (CFIT) potential. ADS-B improves surveillance areas beyond today's radar footprint.	RNP (as required by specific procedure), Improved Terrain Database, TAWS Enhancements, ADS-B Out
SAFE-002: Weather Avoidance via Broadcast – Reduce impact of hazardous weather through broadcast of text and graphical weather information to aircraft.	Flight Information Services-Broadcast (FIS-B), Moving Map
SAFE-002: A Weather Avoidance via Datalink. Reduce impact of hazardous weather through data link of enhanced weather and turbulence forecasts to aircraft.	FIS-B, Moving Map, and for text only weather information: Initial Data Link (Future Air Navigation System (FANS) 1/A+, FANS 2/B, ATN Baseline 1 LINK Post Pioneer) For text and graphical weather information: Data Link (not supported by initial data link enablers)
SAFE-003: Obstacle Avoidance – CFIT is further reduced through availability of higher-frequency updates related to the position of temporary and permanent (fixed) man-made obstacles.	Improved Terrain Database, Improved Obstacle Database, Moving Map
SAFE-004: Airborne Collision Avoidance – Risk of airborne collisions is reduced through enhancements to Traffic Collision Avoidance System (TCAS) to reduce false alerts in complex maneuvers.	ADS-B In, Traffic Information Services-Broadcast (TIS-B), TCAS Enhancements
SAFE-005: Surface Collision Avoidance – Surface Moving Maps with own-ship and traffic are used to reduce runway incursions.	ADS-B In, TIS-B, Moving Map, Cockpit Display of Traffic Information (CDTI)
SAFE-005a: Surface Collision Avoidance with Alerting – Surface Moving Maps with own-ship, traffic, and alerting are used to reduce runway incursions.	ADS-B In, Moving Map, CDTI with Alerting (ground operations)
SAFE-006: Airspace Avoidance via Broadcast – Broadcast data link communication is used to provide pilots with updated information on Temporary Flight Restrictions (TFRs), improving pilot situational awareness.	FIS-B
SAFE-006a: Airspace Avoidance via Broadcast & Data Link – Data link communication is used to provide pilots with updated information on TFRs and SAA status, improving pilot situational awareness.	FIS-B, Initial Data Link (FANS 1/A+, FANS 2/B, Aeronautical Telecommunication Network (ATN) Baseline 1 LINK Post Pioneer)
SAFE-007: Wake Avoidance and Mitigation – Air/Ground Combination – Pilot situational awareness of wake vortices is improved through communication of ground-based wake detection and prediction information.	GNSS, ADS-B Out, Aircraft Characteristic Database, Aircraft Wake Database, Wake Transport Model, Wake Decay Model, Data Link (not supported by initial data link enablers)
SAFE-007a: Wake Avoidance and Mitigation – Aircraft-Based – Aircraft-based wake vortex sensors are leveraged to further improve detection and prediction, reducing wake hazards in high-density operations.	GNSS, Aircraft Characteristic Database, Aircraft Wake Database, Wake Transport Model, Wake Decay Model.

Table 1 – Safety Enhancement Capabilities and Key Enablers	
Capability	**Key Enablers**
SAFE-008: Equivalent Visual Operations – Aircraft-based use of visual and non-visual sensors, signal processing, and a terrain/obstacle database to provide daylight situational awareness in night/IFR conditions.	Enhanced Vision Systems (EVS); Synthetic Vision Systems (SVS); DSP (digital signal processing) for sensor fusion; Comprehensive terrain/obstacle data base; Improved sensors [Low-Level Light TV (LLLTV); FLIR; Millimeter-Wave Radar (MWR); Head-Up Displays (HUD).
SAFE-009: AOC/FOC – Dispatchers with aviation-specific knowledge and experience provide pilots with timely critical weather information, assist with risk assessment and go/no-go decisions, monitor flight position, and help negotiate 4D trajectories.	Data Link

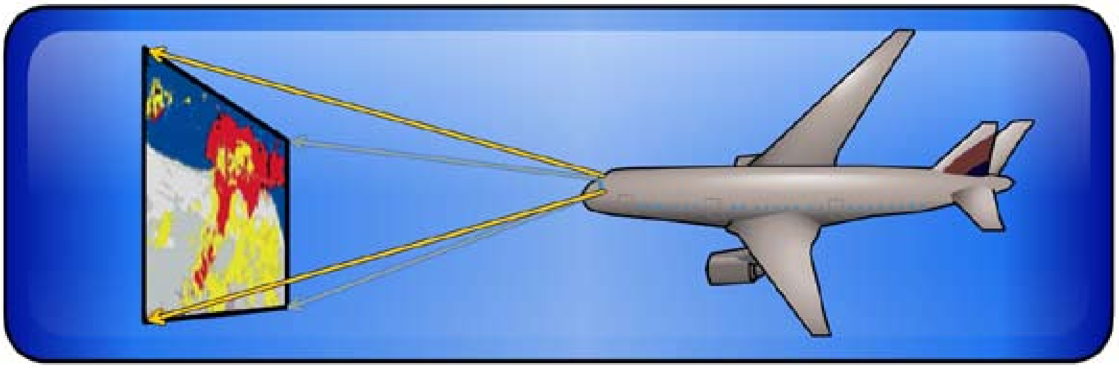
Avionics for Turbulence and Wake Detection

One way to achieve increases in capacity and safety is to incorporate avionics for the detection of wake-vortex and clear-air turbulence. The introduction of wake turbulence detection tools may allow aircraft to be more closely spaced during takeoffs and landings. Additional tools to detect clear-air turbulence and volcanic ash will also serve to increase safety. Clear-air turbulence is most commonly produced by high winds over mountainous regions. Although weather RADAR is currently used in inferring turbulence caused by convective weather, it works less efficiently in clear air conditions which are responsible for approximately 40 percent of turbulence-related passenger injuries.

Methods to detect turbulence and wake have been in development for the last decade. There have been airborne deployments of these systems for survey applications. The near-term requirements for NextGen are to develop and refine methods that provide accurate identification of turbulence hazards at sufficiently far distances to allow pilots time to implement mitigation strategies. At present, Light Detection and Ranging (LIDAR) and Forward-Looking Interferometer (FLI) technologies have demonstrated significant preliminary capability.

LIDAR systems are being developed to detect wake vortices, turbulence, and dry wind shear. LIDAR systems have been deployed on aircraft and satellites for survey and atmospheric research work. These systems use eye-safe lasers to detect rain, clouds, turbulence, and much smaller particles, such as chemical compounds, aerosols, and trace elements in the atmosphere. Eye safety is achieved by using 1550 nanometer wavelength light which is not focused by the eye, and hence can be used at higher power to enable detection at long distances. Systems using pulsed coherent LIDAR are currently being flight tested for clear air turbulence and for volcanic ash detection.

FLI technology uses a high spectral resolution interferometer and advanced imaging to provide high spatial resolution of clear air turbulence, wake vortices, wind shear, volcanic ash, and ice particles in the air and on runways. The National Oceanic and Atmospheric Administration (NOAA), private industry, and academia are currently engaged in developing and testing hardware prototypes for aircraft.



Unmanned Aircraft Systems (UAS)

Integrating UAS into the NAS is one of the critical issues between now and the mid-term vision of NextGen. The evolution of UAS rulemaking and strategic research and development began in June, 1981, when the FAA issued Advisory Circular 91-57 covering model aircraft issued which encouraged voluntary compliance with safety standards for model aircraft operations.

In February 2007, the FAA, through Federal Register Docket No FAA-2006-25714 issued the statement that UAS are aircraft. This was followed by interim operational approval guidance material; this eventually closed the door to the use of a Certificate of Waiver/Authorization (COA) for all but public UAS operations.

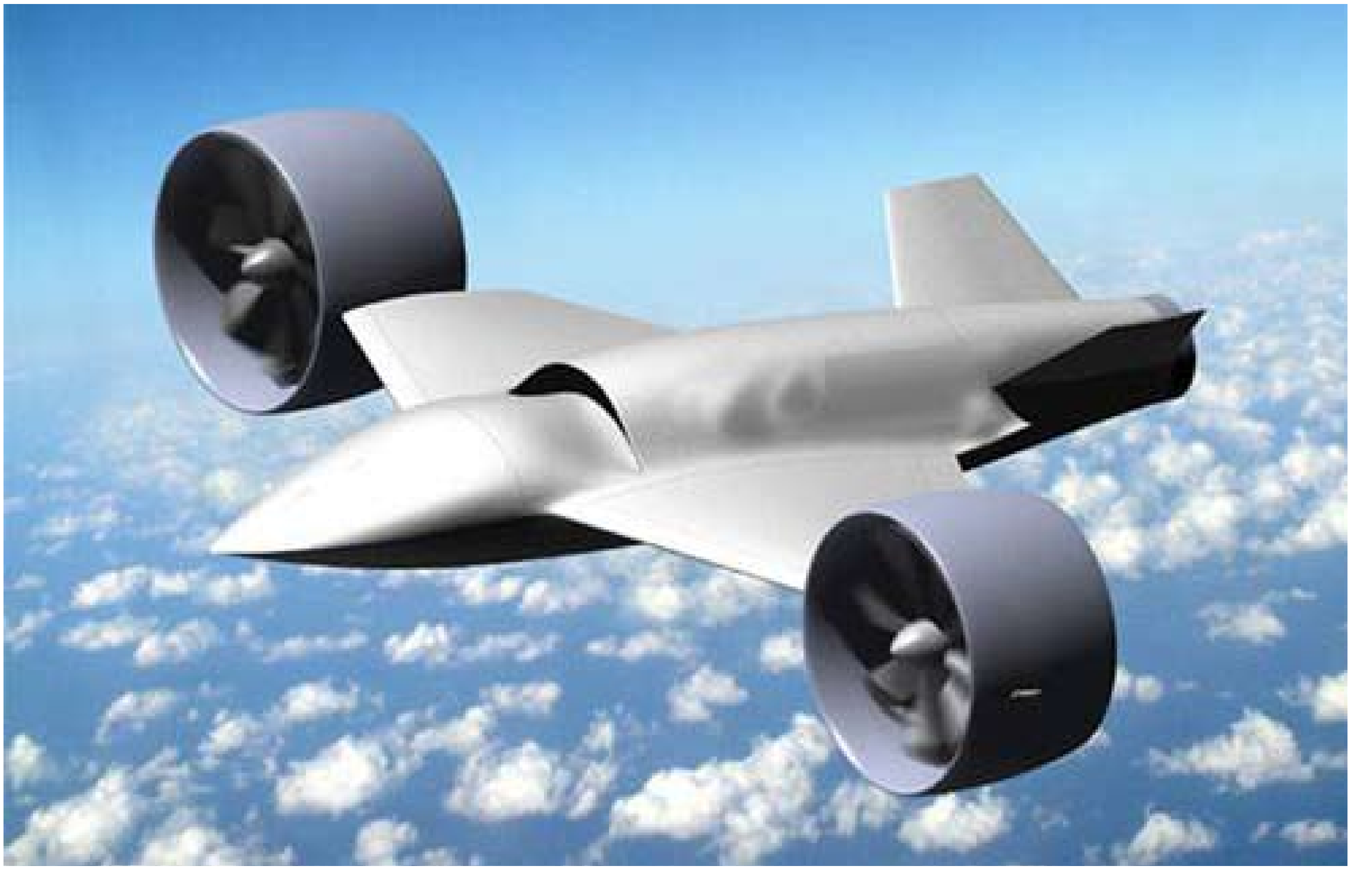
UAS in the NASEA and Beyond - Fostering Consensus and Developing a Strategic R&D Plan

In the 2010 NASEA, a high-level implementation plan for UAS would allow civil NAS operations by 2018; and a strategic Research and Development (R&D) plan is required. Research is needed to establish policy, regulation, and the UAS certification basis including:

- Establish end-to-end performance measures and thresholds for safe and efficient introduction of UAS into the NAS
- Pilot and crew roles, responsibilities, and certification requirements
- UAS control station minimum functions, human factors, and design standards
- UAS data link performance requirements
- UAS system safety and new applications of autonomy

UAS Issues

Current UAS access to the NAS is controlled differently for Public and Civil UAS operators. Public UAS activities require no FAA approval if operations are completely contained in active SAA (restricted and warning areas), however, current range rules apply. The private recreational use of model aircraft is still covered in FAA Advi-



sory Circular 91-57. The only means of UAS NAS access for civil operators is by obtaining a Special Airworthiness Certificate – Experimental Category as outlined in FAA Order 8130.34A Airworthiness Certification of UAS and Optionally Piloted Aircraft (Oct 2010). Commercial operations are not allowed under this certificate.

The Certificate of Waiver or COA process is only available to Public Use Aircraft. The host agency determines airworthiness.

One of the core issues in addressing UAS access to the NAS is categorizing UAS aircraft. From an avionics perspective, these categories will play an important role in understanding where the aircraft will operate, and thus the avionics requirements for the UAS. Assumptions will need to be made with regard to line of site versus beyond line of sight operations, mission roles, operating areas; and how UAS will transit to and from those operating areas.

UAS that operate exclusively within restricted airspace are exempt from meeting FAA regulations regarding aircraft certification requirements. However, as UAS operations expand outside these areas, either for mission purposes or transiting to and from restricted airspace, FAA regulatory guidance or military equivalency will apply to their operations. Avionics requirements, again, will depend on the degree of compliance necessary, as well as where they operate (from an airspace perspective).

The term UAS covers a broad range of aircraft including small UAS (sUAS) which Congress has categorized as those weighing less than 55 lbs (25 Kgs). The FAA expects to release a sUAS Rule for Public Comment in late 2011, with the rule taking effect in 2013. The expected benefits to the Notice of Proposed Rulemaking (NPRM) include:

- Reduction in the number of COA applications
- Ability to gather operational data for future actions
- Ability to enable routine operations
- Ability to enable subsequent 'waivers' or 'exceptions'
- Ability to assist manufacturers in developing 'mature' equipment leading toward certifiable standards
- Ability to allow recreational activities to continue

As of February 2011, the FAA has issued 83 SAC-EC Experimental Certificates (since 2005) and there are currently 18 active certificates for 17 aircraft types. These types include fixed wing, powered lift, airships and optionally-piloted aircraft. Further, there are 266 active COAs covering 85 proponents and 82 aircraft types.

In 2009, the FAA Unmanned Aircraft Program Office (UAPO) developed a high-level roadmap which was incorporated into the 2010 NASEA. Working together with the ATO, this roadmap is evolving into the near and mid-term implementation of UAS into the NAS.

The next version of the FAA's NASEA will provide more detail and support the ATO's envisioned Resource Management Plan and the NextGen Strategic R&D Plan called for in OMB pass back language.

Future Work of the Aircraft Working Group

Future activities for the JPDO Aircraft WG may include the following:

Non-avionics Issues

Operational profile changes may have broad implications on aircraft and engines continued airworthiness with respect to limits and safety margins as they relate to maintenance schedules. Operational safety is also an issue. For example, the transition to “continuous descent approaches” (or “optimized profile descents”) might pose potential risks with respect to susceptibility to engine core icing and/or cold dwell fatigue.

Aircraft/engine combination can have unique flight and performance characteristics that make them susceptible to conditions not seen in other similar designs. Therefore, it should not be assumed that aircraft can be flown and will perform in a generic manner. As the NAS changes to accommodate NextGen operations, risk assessments are needed to ensure that aircraft flight envelopes are not exceeded during expected “nominal” or “emergency” conditions. This means that automation regardless of source or configuration must be appropriate for the flight and performance characteristics of the aircraft. There should also be sufficient flexibility in NextGen operations to accommodate performance degradation that should be expected over time.

Avionics for On-Board Aircraft Systems Health Monitoring

Avionics for on-board vehicle health management are needed to provide automated detection, diagnosis, prognosis, and mitigation of adverse events during flight. Adverse events include those that arise from system, subsystem, or component faults or failures due to damage, degradation, or environmental hazards that occur during flight. Improved safety and reliability will be achieved by onboard systems capable of performing self-diagnostics and self-correcting anomalies that could otherwise go unattended until a critical failure occurs.

Advanced avionics will support prognostic health management and advanced processing and reasoning systems that can identify degradation and failures, and then transmit vehicle health status to ground-based maintenance systems. From a business point of view, such systems enable a better placement of people and aircraft in the right locations at the right time to enable cost-effective maintenance. It is difficult to position maintenance personnel at all airports. Therefore, there is a need to instrument the aircraft with sensors and systems onboard to predict when maintenance will be needed so that it can be performed at the economically best time and location.

Appendix 1: Trajectory Operations

Definition of Trajectory Operations

An aircraft trajectory is a representation of the planned or actual flown route in four dimensions (lateral, longitudinal, altitude, and time) with discrete points defined along that route. The granularity of the representation of the flight trajectory depends on the intended use of the information, and may not necessarily include all four dimensions. For example, some planning activities may require only a departure airport, departure time, destination airport, and arrival time (excluding any vertical dimension). Other uses, such as ensuring separation, may require a trajectory representation that includes a detailed 4D track projected into the future for some period of time.

Trajectory operations is an air traffic management concept where the integration of ground automation systems, aircraft systems, flight data exchange, flight scheduling, planning and decision-making results in an operating environment that supports and enables NextGen objectives, such as integrated flight planning, enhanced surface traffic management, streamlined departure/arrival management, and efficient cruise.

Trajectory operations aircraft operating in the NAS are managed through various views or representations of their 4DT. Every managed aircraft known to the system has a 4DT either submitted by the user, derived from a flight plan, or the type of operation (or a combination thereof). These trajectory representations contain detailed and useful information. The ability to adhere to them will become much more accurate as technological advances in aircraft avionics systems are realized. Aircraft with advanced avionics will be capable of flying precise trajectories in all four dimensions. Trajectory operations services are performance-based; meaning that the services available to an aircraft depend upon its level of avionics capability.

In its most basic form, trajectory operations may be a simple transformation of familiar procedures and operations to produce an aircraft flight path that is reliable, predictable, and repeatable. In more advanced forms, they could be characterized by higher levels of performance while allowing adaptability (for both air and ground applications) to satisfy an operational need.

Concept Overview

The fundamental requirement of NextGen is to safely accommodate significant increases in traffic in congested airspace, between heavily traveled city pairs and near the busiest airports. It is advantageous to the flow of traffic to manage all aircraft by trajectory, modifying trajectories when necessary. This can be done by setting constraints or flexibility (windows) and varying levels of performance to dynamically respond to changing situations and traffic density. For example, a dynamic adjustment to the performance level of one or more aircraft operating in close proximity may be employed in the use of closely spaced parallel runways based on lower Required Navigation Performance (RNP) values and vertical guidance. Another example is the use of lower RNP values for tighter in-trail spacing on a common track supported by Automatic Dependent Surveillance – Broadcast (ADS-B) technology. The transformation of the NAS to a trajectory-based system will enable increased throughput and a more efficient use of airspace. Airspace operations

are based upon trajectories and are inclusive of all aircraft, recognizing that aircraft have different capabilities. Thus, mixed capability trajectory operations form an inclusionary basis for air traffic management in the NAS. Note that various trajectory views may be formed to support flight crew, operator, and/or air navigation service provider (ANSP) decisions, and the system must be able to show how they can be manipulated (i.e., not locked into one "view").

Prior to departure, users share trajectory information with the ANSP and receive increased awareness of current and predicted NAS availability, including any constraint information. Throughout the day, relevant trajectory information is aggregated by ANSP automation to assess potential congestion problems and evaluate alternatives in collaboration with users. The agreed upon strategies are implemented through trajectory modifications. The resulting negotiated trajectory reflects user intent and provides a common basis for NAS access and knowledge of any system constraints. While flights are airborne, the ANSP uses appropriate trajectory views to manage separation with support from automation to detect and resolve problems (such as predicted conflicts). After flight completion, trajectories are used for post analysis and system monitoring performance by the ANSP and users.

The highlights of this trajectory-operations framework are summarized below:

- Mixed capability, trajectory-based operations form an inclusionary basis for air traffic management in the NAS. It is inclusionary because performance levels and functional capability requirements for specific times and routes are set by ATM, based on demand and user preferences. The system is able to handle aircraft with mixed capability levels everywhere. When performance requirements tighten, lower performers may have reduced access, but only at times of increased requirements.
- All aircraft have an associated 4DT view that is maintained by the ATM systems. Recognizing various levels of aircraft capability, these views can be: (a) generated on the aircraft and data-linked to ground systems (either to use as the full view of the aircraft's 4DT, or possibly to complete and improve the ground generated 4DT view); or (b) generated from the flight plan and turned into a 4DT view entirely by ground systems.
- The transition to 4DT begins with improvements to ATM systems that support the 4DT Concept of Operations, leveraging operations on published routes and procedures, and then taking advantage of the data communications capability in existing aircraft. ATM systems must accommodate a mix of aircraft capability in the same operational environment using the same automation capabilities.
- To the extent practical, a 4DT is negotiated and agreed to prior to departure. The accuracy and detail of the 4DT views increase as the time remaining until departure decreases and the uncertainty of the trajectory is reduced.
- Trajectories are modified by changing trajectory parameters in any dimension. They are constrained as necessary by changing or removing windows, or modifying performance requirements.
- ATM clearances that modify trajectories for managing the traffic may be delivered via voice or data communications, depending on aircraft capability and type operation. The performance level of each trajectory is known by the ground system and handled accordingly. Data allows the delivery of more complex clearances and revisions; voice communication provides an exception delivery mode and provides simpler services to unequipped aircraft.

The 4D Trajectory Defined

A 4D trajectory describes the path of the aircraft in four dimensions: lateral, longitudinal, vertical, and time. While the actual trajectory is only known after it is flown, there is always some uncertainty with respect to the aircraft's execution of the intended trajectory. The goal of trajectory operations is to manage uncertainty through various views that are used for flight planning, such as advisory services, airspace security, separation, and congestion management. To be effective, trajectory views in the various systems must be consistently maintained, so that all participants have an accurate representation at any point in time. This reflects the latest flight plan, aircraft information, performance requirements, constraints, or clearances that are relevant to the use of that trajectory.

The level of detail in a trajectory view varies, depending on the aircraft's capability and type of operation. One fairly complete view of the intended trajectory might consist of: the desired trajectory parameters reflecting the operator's business objectives and ATM constraints, the actual trajectory (for the portion of the flight that has been completed), and performance requirements. Less complete views may be used for specific purposes, such as modifying a portion of the trajectory. It is critical that each trajectory view contain a minimum set of parameters that provide a description of the trajectory sufficient for the intended operation. Additional views are described below to clarify the trajectory concept.

Trajectory Objectives View (similar to the SESAR concept of "business trajectory"): Describes the operator's objectives for the flight. The operator may express these objectives in a general sense using FDO or by providing additional detail describing the objectives and how they intend to accomplish these. This is normally represented in the form of a UPT. The objective view must be modifiable and may be amended by the operator to conform to its business objectives. It provides an essential metric for performance measurement and acts as a reference for trajectory adjustments.

Intended Trajectory: Represents the 4D trajectory desired by the flight crew assuming there were no errors or uncertainty in executing the flight. There will be many limited views of the intended trajectory, depending upon the use of the information. These views must be consistent, accurately reflecting the underlying trajectory; however, their content may be different. A conventional flight plan (e.g., containing departure and arrival locations and times, route information, such as fixes, airways, jet routes, and arrival and departure routing) honoring all ANSP constraints is one representative of an intended trajectory. For equipped aircraft, the down-link of the FMS generated trajectory (containing the lateral, longitudinal, vertical, and time at various trajectory change points) is representative of an intended trajectory.

Actual Trajectory: The aircraft trajectory that is actually flown. The actual trajectory can differ from the intended trajectory. Possible causes can result from the following: input errors used to generate the intended trajectory (such as wind forecasts or engine/airframe modeling), errors in the control loop (e.g., estimated position of the aircraft), a lack of detail in the definition of the intended trajectory, and residual control error (i.e., flight technical error in the lateral and vertical dimensions). The actual trajectory exists behind the aircraft, up to the current aircraft position and velocity.

There are two general classes of trajectory attributes that may be used to define or manipulate a trajectory to satisfy the needs of operators, ANS, and the flight crew:

1. **Parameters** – Data that specify where the path must be at certain locations and times. If there is some flexibility in the allowed location of the path it may be defined by a window or an Area Navigation (RNAV) or RNP type. Parameters can be horizontal (to locate the path on the ground), vertical (to locate the path above the ground), or time-based (or speeds). Parameters can also be specified as windows (e.g., between altitude restrictions at a fix) or time windows, allowing flexibility in the path as defined and flown. Vertical windows in trajectory operations are an extension of current climb/descent operations where the vertical trajectory is unspecified.

2. **Required Performance** – Specifies how well the aircraft must perform within the trajectory parameters. The requirements can be expressed laterally (e.g., RNP), vertically (e.g., baro-error budgets) or in time (e.g., required/controlled time of arrival (CTA), ETAs, interval management). Each represents the allowable tolerance between the desired trajectory and the achieved trajectory. It is likely that in future trajectory operations, the RNP designation will include the lateral, vertical, and time-performance requirements. This performance requirement represents the total allowable system error between the actual and intended trajectory in all four dimensions.

Table 2 describes the key attributes that are used in current day operations as well as those needed for trajectory operations. While not exhaustive, it does include the major characteristics needed for trajectory operations. These parameters may be generated by the aircraft and down linked, generated by the air traffic management (ATM) system, or a combination thereof. Current data link systems do not allow certain elements of trajectories to be up- or down-linked. Capable Standards will need to be developed to enable these capabilities (e.g., RNP first segment, fixed radius transitions, and other elements not currently existing in aircraft).

Table 2 – Trajectory Characteristics Addressed in Current Operations

	Intended Trajectory	Window	Performance
Lateral (2D)	Current: Leg Types (Track-to-Fix, Radius-to-fix) Added: En-route Fixed Radius Transition (extend to variable radii)	Current: Fly-by turn transition area, holding patterns (ANS assumed windows) Added: ADS-B or offset passing	RNP/RNAV designation
Vertical	Current: Assigned altitudes, descent rates, flight path angle to any fix Added: Vertical change points not associated with a lateral fix (e.g., top of climb, top of descent, level changes, transition altitude, crossover altitude)	Current: Assigned altitudes (no flexibility), minimum en route altitude, at-or-above altitudes, at-or-below altitudes, altitude windows Added: Window along path connections	Implicit (i.e., not actively calculated and monitored); covered by certification and operational requirements for barometric altimetry [RVSM, AC20-129) (e.g., certification and operational requirements for barometric altimetry)
Time (along path)	Current: Speed assignment (no flexibility) Added: CTA, ETA, interval management	Current: Speed assignment (implicit tolerances), speed restrictions (at or below) Added: AT speed restriction, ETA window	Current: Implicit and variable Added: CTA performance, ETA performance (develop and standardize)

The aspects to trajectory management can all be realized by the initial definition or manipulation of the trajectory attributes described above. The following are examples:

- *Business Objectives* – The operator manipulates (or sets) some of the trajectory parameters by proposing routes, procedures, altitudes, speeds and/or times that satisfy the goals and economics of the flight.
- *Weather* – The operator, flight crew, or ANS may manipulate the trajectory parameters to relocate the trajectory to avoid weather, or to initially define a route that takes advantage of winds for better fuel use. This will be enhanced by the automatic translation of weather information Sinto aviation constraints.
- *Traffic Density or Demand* – ANS may dynamically set required performance for all, or some portion of the trajectory. Pre-defined procedures and routes may have set values for required performance, such as present day RNP routes and procedures.

Another aspect, achieved performance, is dependant on the data used to generate the trajectory (e.g., forecast weather, engine/airframe performance models and control systems implemented on the aircraft). Achieved performance can be measured independently or estimated by the aircraft and is used to assure compliance with the ANSP required performance. In a mixed equipage environment, knowing the performance levels available for use in a dynamic situation frees the ANSP from having to estimate aircraft performance.

A complete trajectory, as defined above, theoretically exists continuously in all four dimensions. However, for use in automation systems it can be represented by a view that contains the minimum set of parameters that allow its re-construction as a continuous path in time. This view is similar to the flight plan view, containing parameters such as: a sequence of coordinates to identify a series of fixes in the plan assigned altitudes or constraints, and estimated times of arrival at each. The required performance level in each dimension will be defined, allowing ATM trajectory and separation management to perform their functions.

The concept of windows describes an area of airspace that is reserved to accommodate performance variations. It may be defined in any or all of the four dimensions. Windows are used when there is a lack of required performance for a specific maneuver or due to a lack of standard design consistency across a large percentage of flight management computers. The use of a window allows airspace operations/procedures to be refined to a greater level than current procedures to provide some increased level of benefits to the users and the system overall. The following are examples of how a window may be applied in each dimension:

- *Lateral Fly-by Transitions* – Used when turns are based on a series of straight segments to allow for variability in Flight Management Computer turn performance. These typically result from variations in turn anticipation, speed and bank angles.
- *Vertical Windows* – Of particular value when computing optimum profile descents. The variability of aircraft speed, descent rate, and performance factors make vertical windows well suited for this application.
- *Time Windows* – Precise time control during the enroute and descent phases of flight is problematic given the variability in environmental conditions (e.g., wind, temp) Time windows may be applied to ensure de-confliction of crossing aircraft and maintaining longitudinal separation. The values vary as a function of the operation and the intended function (e.g., +/- 30 seconds for en route, +/- 5 seconds for terminal and approach).

As Flight Management Systems (FMS) continue to evolve and new performance standards are defined and implemented, the need for windows may diminish. However, this is not likely to happen in the current planning horizons for the far-term.

As these concepts are developed, separation becomes more strategic, using accurate and complete views of the intended trajectories to avoid conflicts between aircraft. Another important element of trajectory operations will be greater involvement of the users/operators. Operators will be able to input more parameters to better suit their business objectives, flight management and respond more quickly to changing weather and operational conditions. The control aspect of a negotiated trajectory results in a more accurate and complete view of the trajectory over a longer time horizon for aircraft that actively control to it. This will cover the entire flight from taxi-out to taxi-in. ANSP and users with greater flexibility to renegotiate flights that are affected by external conditions (e.g., weather, mechanical delays, passenger connections).

The flight object for trajectory operations must be defined in the near-term, as it can affect multiple aircraft and ANSP systems. Some key attributes that trajectory operations will include are performance, monitoring, and alerting in the lateral, vertical, and longitudinal (time) dimensions. While the windows concept will provide an increased level of benefits, new standards of performance for aircraft and new decision-support tools on the ground will need to be developed to fully exploit the benefits of trajectory operations.

While all aircraft trajectories are in fact continuous (e.g., from departure gate to arrival gate), the necessary view of the trajectory may only contain specific elements of the trajectory, with ground and airborne automation systems computing a continuous intended trajectory by using identical methods to fill the gaps, based on their respective views of the trajectory. While the actual trajectory is only defined behind the aircraft, the intended trajectory is only useful in front of the aircraft, and a trajectory clearance may only cover a portion of the remaining flight.

Intended Trajectories, ADS-B, Data Communications, and Open and Closed Trajectories

ADS-B provides current position and velocity vector data used by the ANSP for time-based flow management, ground-based conformance monitoring, conflict management, and conflict probe. In the mid-term, there will be some aircraft equipped with ADS-B In applications that make use of the position/velocity information of nearby aircraft on known flight paths. These ADS-B In applications will enable operations such as interval management, where individual aircraft maintain a controller-assigned interval with another specified aircraft to improve traffic flow efficiency. However, the ground automation will be the repository of the full 4DTs that are continually updated and used for conflict management, conflict probe, and flow management.

Data communications is the means by which strategic trajectory information from the aircraft is exchanged between equipped aircraft and ground automation systems. This is consistent with and a crucial component of the concept of closed trajectories. Data communications is the transport mechanism for aircraft trajectory information (i.e., trajectory views and attributes).

A "closed trajectory" means that the ANSP automation, controller, flight crew, and the aircraft automation all have a common, shared view of the aircraft's intended trajectory. Closed trajectories enable accurate evaluation of the paths of multiple aircraft at points ahead of the respective aircraft for the purpose of conflict detection and flow management. In an "open trajectory," the aircraft is no longer flying a shared view between the aircraft and ground automation. Examples of open trajectories include a vector or a descent based on pilot's discretion. There are specific operational situations where open trajectories will continue to be used, such as weather deviations, but as advancements in decision support tools and avionics evolve, they will be phased out.

Approaches to Along-Track Spacing

In the mid-term, along-track spacing will mainly be a function of time-based flow metering and ETA. Aircraft equipped with FANS-1/A capability may also use RTA. Early in the far-term period, greater use of time-based flow metering will be used as ground-based decision-support tools and improved weather information becomes available. The use of RTA will also increase as new aircraft enter the fleet and the benefits drive higher levels of retrofit. ADS-B will provide additional conformance monitoring capability.

Interval Management involves relative time (or distance) clearances – clearance to either maintain a time/distance interval along a common flight path, or cross a common flight path fix at a specified time/distance relative to another aircraft. The aircraft receives, via ADS-B In, position/velocity information about other aircraft and uses onboard avionics to establish and maintain a time/distance interval behind that aircraft per the ANSP clearance.

Trajectory Operations and Delegated Separation

Safe separation must be maintained during the execution phase of all trajectories. The responsibility for monitoring that separation can lie with the controller or the flight crew. Where separation is the responsibility of the controller, the separation is reflected in the trajectory clearance of the aircraft involved. Achieving optimal spacing may involve applying tight window constraints to the trajectories, and renegotiation of the trajectory as improved information becomes available (e.g., weather or the actual trajectories of aircraft).

Where separation responsibility is delegated to the flight crew, flexibility in the trajectory clearance may be needed to enable them to maintain the required separation without re-negotiating with the ANSP. While this may be construed as a window, it may also be a part of a trajectory clearance when aircraft are assigned to manage their own separation. The tradeoff between separation concepts needs to be further evaluated to determine the best allocation of requirements between the aircraft and ground systems.

Trajectory Operations and Optimized Profile Descents

Optimized profile descents (OPDs) can be accomplished on RNAV or RNP arrivals, with the aircraft optimizing the descent within the pre-published, or negotiated and agreed to vertical window. Early in the Far-term, time-based flow metering, ADS-B, and aircraft-based RTA will be used. As ground-based decision-support tools and avionics evolve and new standards for time management are developed, optimized profile descents will generate higher levels of benefits. In trajectory operations, if the ANSP has a more accurate view of the intended trajectory (at least vertical path and speed profile) from the aircraft, it can reduce the uncertainty in the vertical plane and along track paths and thus maintain higher levels of safety, efficiency and capacity.

Trajectory Operations and Information Exchange

To improve efficiency, it is critical to provide access to high-quality information during all phases of planning and execution including the negotiation phase. This includes constraints, such as forecasted and tactical weather (as translated into weather constraints), airspace, aircraft performance, traffic density, and environmental constraints. For the information exchange phase, there is a need for net-centric communications whereby all available data that affects the planning is available to all constituents. This data will be hosted in a way that can be accessed by any authorized user within the network.

To optimize the execution of the trajectory, information needs to be presented in a consistent way that is both timely and accurate. The information available will include airspace, traffic, terrain, weather, obstacles, and other system constraints and will be used by ANSP decision-support tools, operator flight/system operations control and aircraft systems during the trajectory planning and execution segments of trajectory operations.

Principle Elements of 4DT. The following illustration describes the elements that compose the concept of 4D trajectory operations

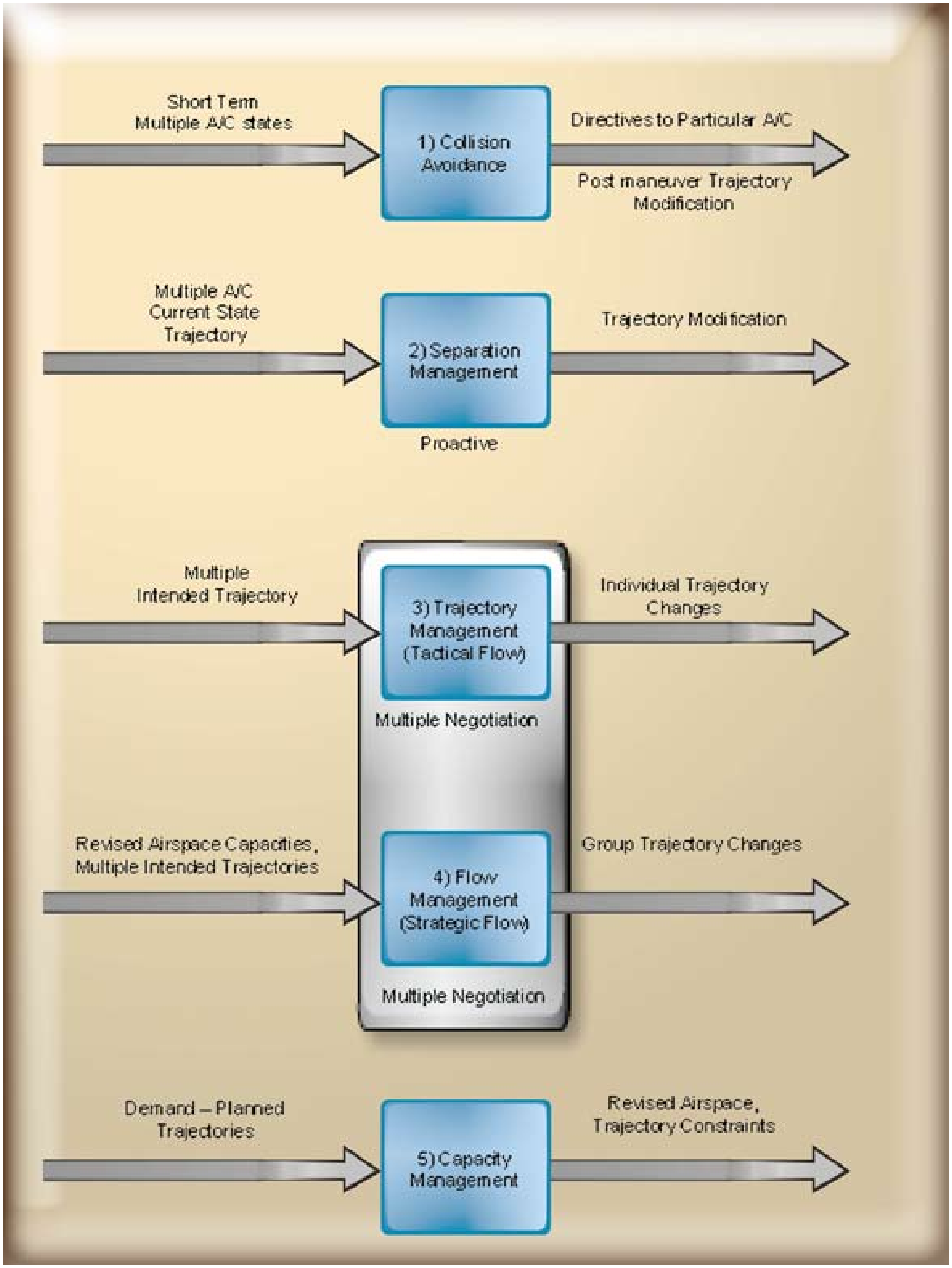


Figure 14 – Principle Elements of 4DT

Trajectory Management (Tactical Flow)

Trajectory management involves managing aircraft within a flow or that will enter a flow. Examples of trajectory management, or tactical flow, include the release of an aircraft for departure to fill an open position in a flow heading to another airport, or assigning an arrival time or spacing interval for merging to an active runway stream. Since planning across multiple aircraft and controllers is a difficult computation, several decision support tools are required to assist the traffic flow manager and controller in planning tactical flow. These tools provide the controller with the objective for each aircraft in terms of time (e.g., a release time for departure or an assigned crossing time for arrival merging). In the Far-term, trajectory management is supported by data exchange. The tactical flow objective for individual aircraft can be sent to the aircraft and the operator's system/flight control, where a trajectory change can be proposed that meets the desired objectives Near-term tactical-flow decisions remain the purview of controller and pilot, but as the planning horizon expands there are greater opportunities for the System Operations Center or Flight Operations Center (AOC/FOC) and Traffic Management Unit (TMU) to participate. This highlights the importance of establishing a collaborative decision-making process that ensures that the final trajectory is mutually acceptable to the participants.

Flow Management (Strategic Flow)

Flow management is an activity that manages the imbalance between demand and resource capacity. The cause of the imbalance can be somewhat static (e.g., scheduled runway closures or major sports event) or more dynamic (e.g., operator schedules, convective weather translated into a weather avoidance field or a NAS equipment outage). To this point, the discussion of uncertainty has been related to the accuracy of the forward projection of the trajectory and the accuracy by which the future state of the airspace, with respect to traffic is planned. In flow management, the uncertainty is not in the trajectories but the system. Trajectory-based flow management represents a fundamental shift in this concept.

In the current system, the situation is identified, capacities over a timeline are determined, and a scheme of rationing trajectories employed. Because the current NAS system is made up of individual decision sets, that are not well integrated, the approach to the resolution involves making a deterministic decision and executing an operator and ATC approved trajectory plan. This plan may involve a time-shift for trajectories, rerouting of trajectories, or cancellations.

In the mid-term, individual trajectories are tailored and exchanged across all decision loops. As conditions change, either as a preset option or a new proposal from the AOC/FOC, alternative trajectories can be evaluated from both a strategic and tactical flow perspective, adjusted and sent directly to the controller as data and a trial plan. The system will evaluate the proposed trajectory with respect to any separation issues and constraints. If none are found, it presents the trajectory to the controller who then in turn transmits it to the aircraft for execution.

Capacity Management

Capacity management involves the planning of resources to meet the expected "regular" demand. It adjusts for events such as runway availability and utilization, available instrument terminal approach procedures and the status of SAA. There are two functions in capacity management: design and administration.

The design function includes activities such as sectorization, route definition, and procedure design. Design is typically a longer duration activity. The design is based on historical and projected trajectories and based on expected schedules and traffic projections as in the case of a new runway.

Enhancements to the real-time administration of airspace allow more optimal use of airspace when available. Operators can file optional trajectories through SAA or subscribe to the real-time status so any change in that status can result in its use for more efficient operations.

Appendix 2: NAS Enterprise Architecture Aircraft Roadmap

The diagrams below represent draft FY11 NAS Enterprise Architecture Aircraft Roadmap activities that are expected to occur in the Far-term.

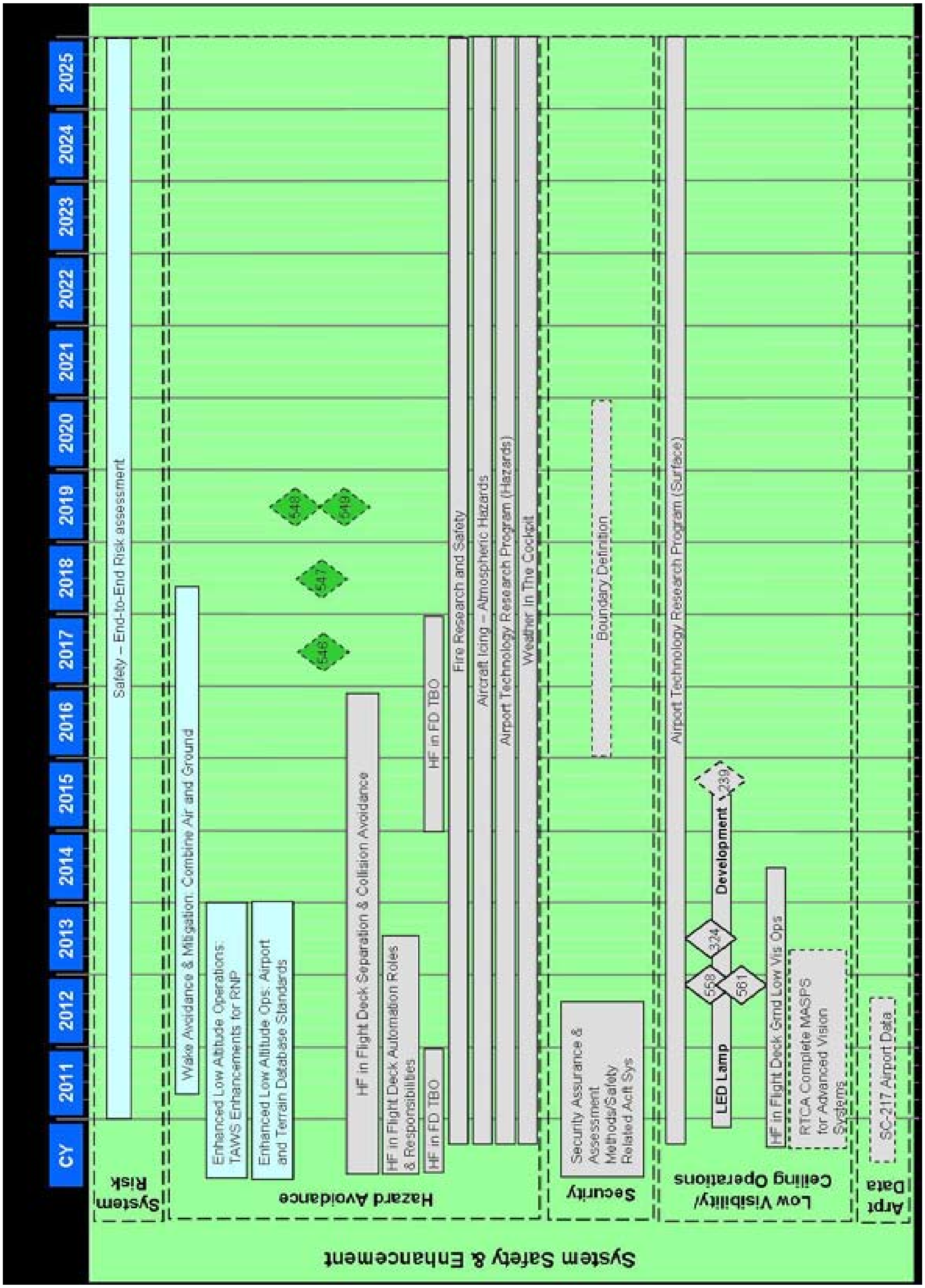
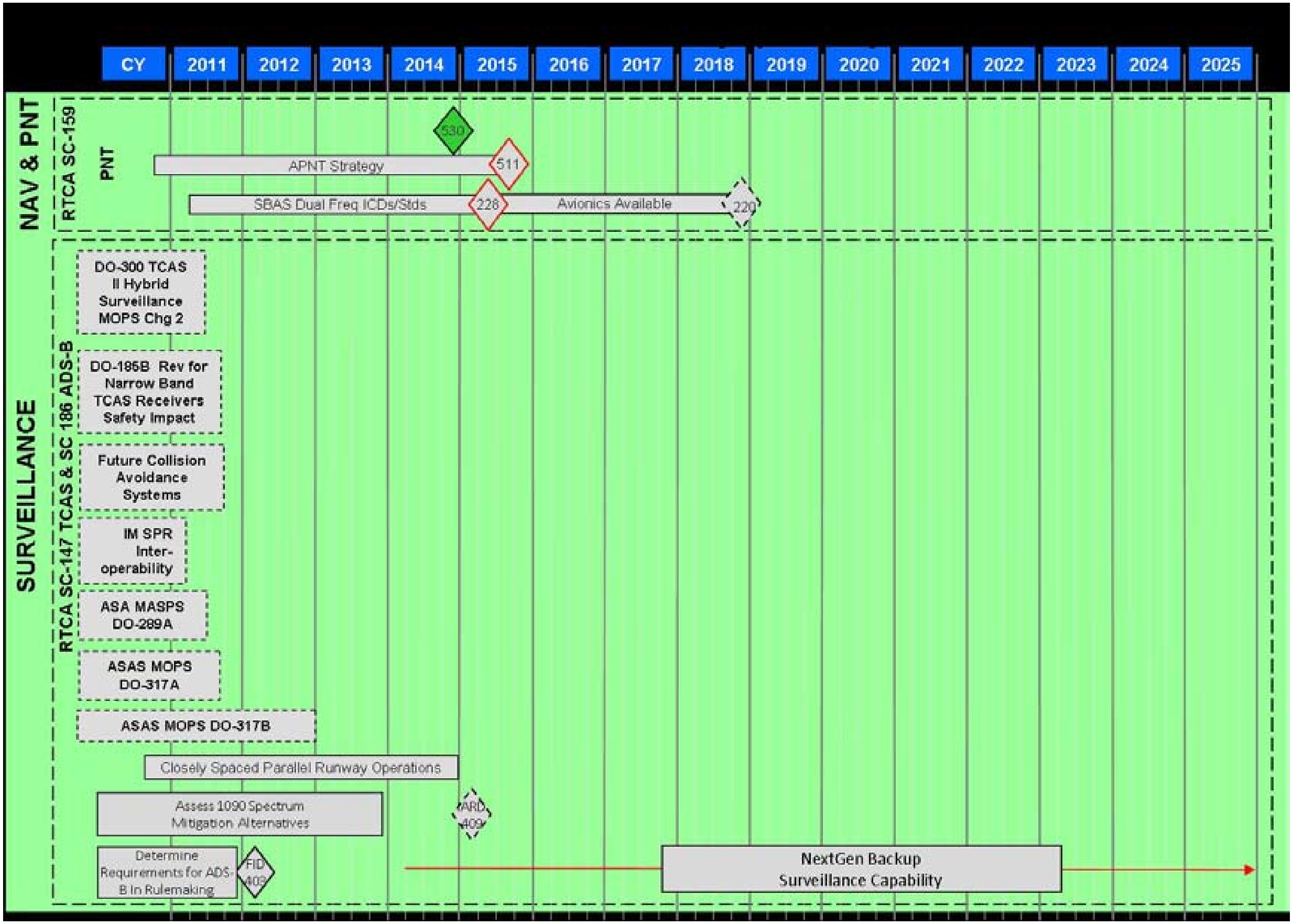


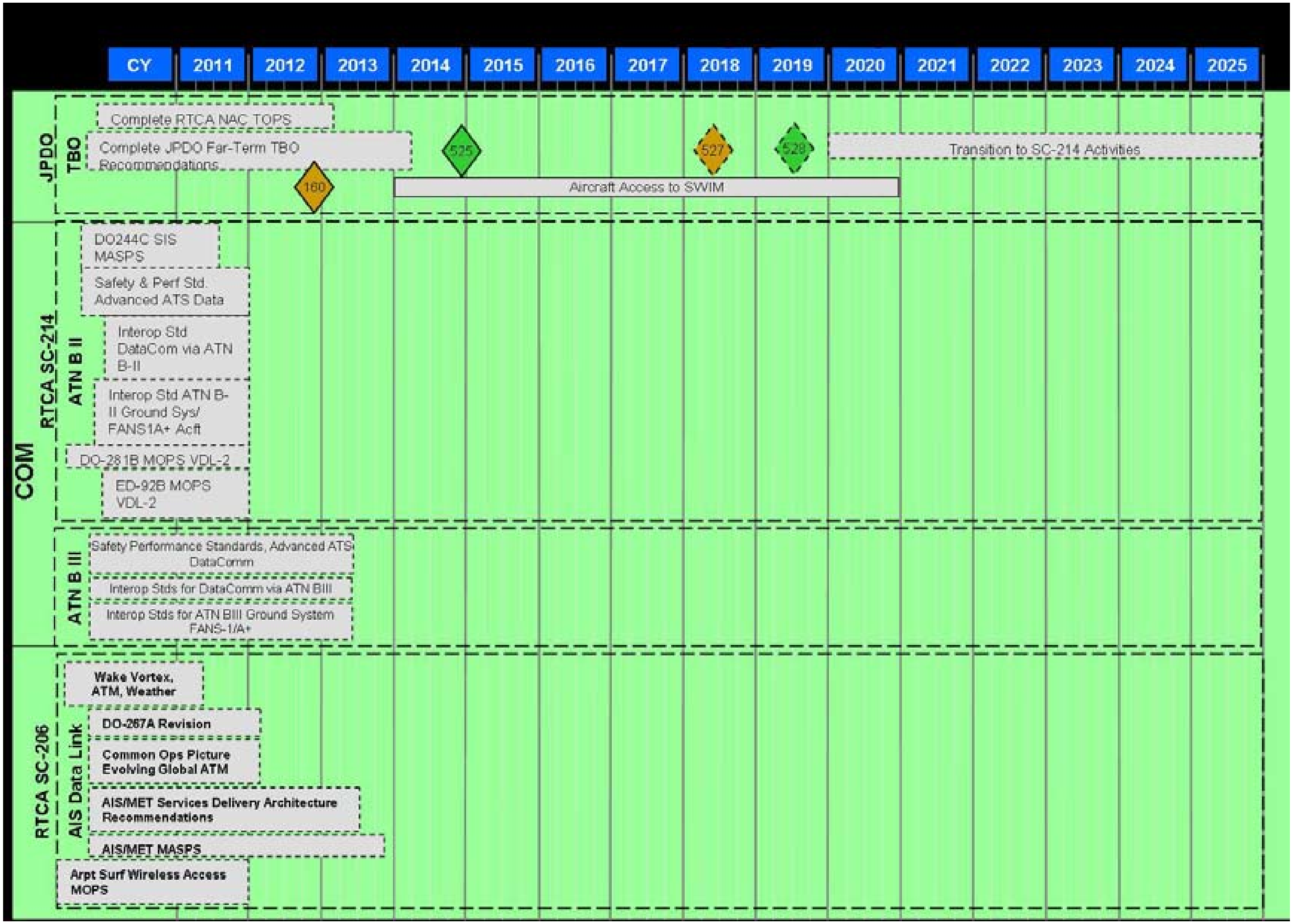
Figure 15 – NAS Enterprise Architecture Aircraft Roadmaps

Aircraft Roadmap 5 of 8

Aircraft Roadmap 6 of 8



Aircraft Roadmap 7of 8



Aircraft Roadmap 8 of 8

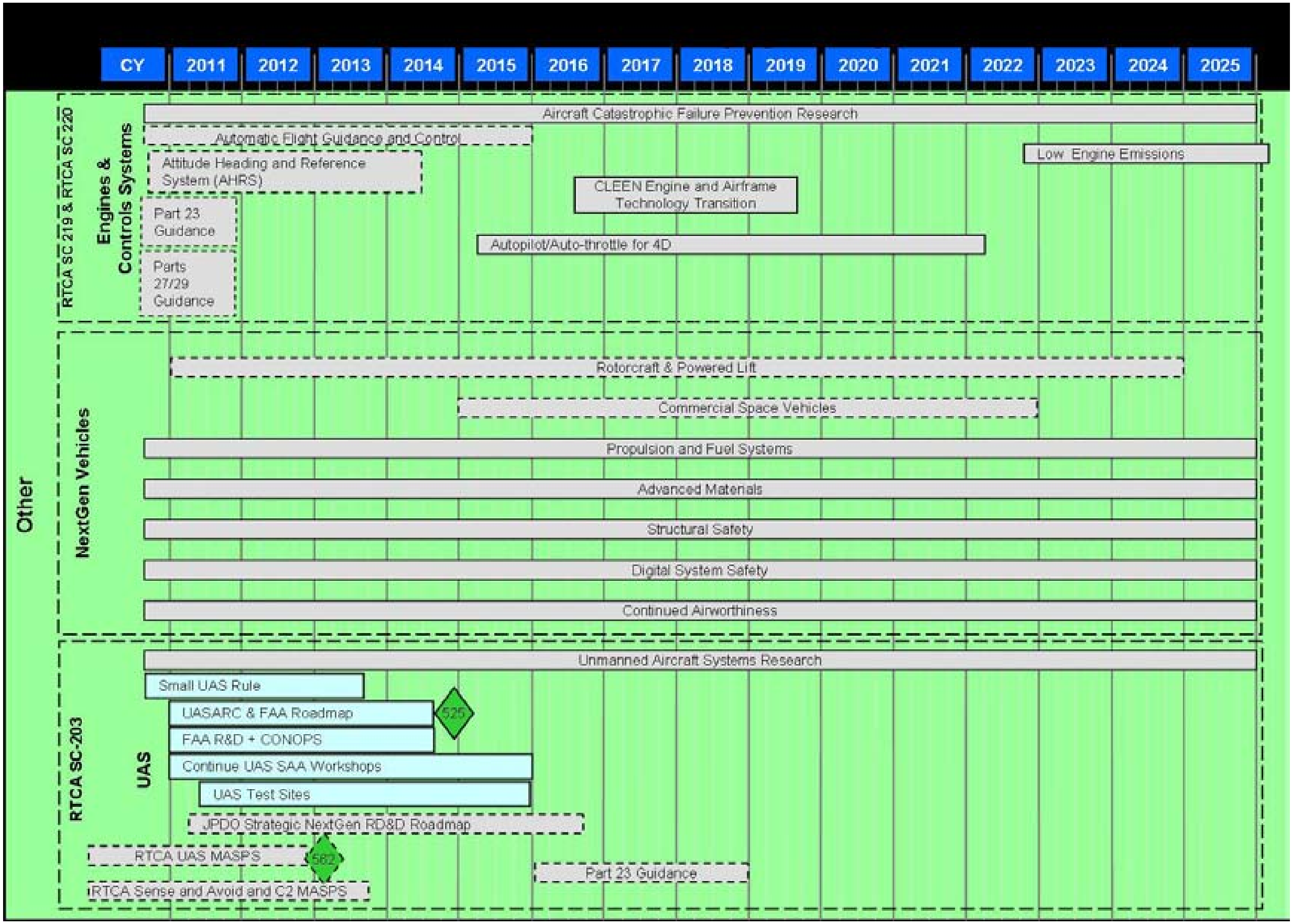


Table 3 –Far-term Operational Improvements					
Identifier	**OI Name**	**Description**	**Benefits**	**Earliest IOC**	**Latest IOC**
101103	Provide Interactive Flight Planning from Anywhere	Flight planning activities are accomplished from the flight deck as readily as any location. Airborne and ground automation provide the capability to exchange flight planning information and negotiate flight trajectory agreement amendments in near real-time. The key change is that the air navigation service provider's (ANSP) automation allows the user to enter the flight plan incrementally with feedback on conditions for each segment. Rather than testing full trajectories by submitting and waiting for full routes evaluations, the system will test each segment as entered and provide feedback. Through this process the user will work with the system to quickly reach a flight plan agreement. As before any subsequent change, constraint, preference, or intent triggers a full flight plan review with feedback to the filer. The filer can develop preferred trajectories that may include an identified constraint that the automation system maintains in case subsequent changes to conditions will allow its promotion to agreement. Automation thus maintains multiple flight plans for an individual flight.	Increased efficiency Increased accessibility Enhanced user-preferred trajectories	2015	2021
102117	Reduced Horizontal Separation Standards, En Route -3 Miles	The Air Navigation Service Provider (ANSP) provides reduced and more efficient separation between aircraft where the required performance criteria are met, regardless of location other than operations in oceanic airspace. Advances in Air Navigation Service Provider (ANSP) surveillance (e.g. ADS-B) and automation allow procedures with lower separation minimums to be used in larger areas of the airspace. This reduces the incidence of conflicts and increases the efficiency of the conflict resolution maneuvers.	Far-term	2018	2025

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102136	Reduced Oceanic Separation and Enhanced Procedures	Availability of user preferred oceanic profiles is increased through reduction of aircraft to aircraft longitudinal, lateral, and horizontal spacing between aircraft that meet required total system performance capabilities including, enhanced communication, surveillance, and flight deck avionics. Longitudinal and lateral spacing between aircraft conducting oceanic pair-wise altitude change maneuvers (in-trail climbs and descents), is reduced to 10 miles, with ground-based separation responsibility. Horizontal spacing between aircraft conducting oceanic pair-wise co-altitude maneuvers, such as passing a similar-speed aircraft, is reduced to below 30 miles, with ground-based separation responsibility. Communications between aircraft, and between the aircraft and the air navigation service provider (ANSP), enable real-time control instructions by the ANSP and aircraft-to-aircraft delegation of separation authority. Accurate and immediate feedback of routing or altitude changes provides immediate acknowledgement for separation assurance, trajectory changes, and deviations around air traffic or weather. This may be implemented using either 1) Automatic Dependent Surveillance-Contract (ADS-C) and satellite-based communication, or 2) Automatic Dependent Surveillance-Broadcast (ADS-B), on-board displays and algorithms, and satellite-based communications.	Far-term	2019	2025
102142	Efficient Metroplex Merging and Spacing	Air navigation service provider (ANSP) automation and decision support tools incorporate aircraft wake characteristics and forecast wake transport conditions. Spacing buffers between streams approaching and departing multiple metroplex runways are reduced to allow efficient airborne merging and spacing, increasing greater traffic throughput and reduced ANSP workload in terminal areas. Arrival and departure flows are planned and executed based on a comprehensive view of real time airport operations. Automation provides optimal departure staging and arrival sequencing based on aircraft wake, wake conditions and airborne performance characteristics. Data communications provides required navigation performance routes to the flight deck. This OI includes development of ANSP capability and procedures and requires an Implementation Decision to determine what complex airborne merging and spacing operations will be required for effective use of high-density metroplex airspace, such as crossing streams, merging and diverging streams, etc.	Far-term	2020	2024

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102143	Delegated Responsibility for Horizontal Separation (Lateral and Longitudinal)	Enhanced surveillance and new procedures enable the ANSP to delegate some responsibility for maintaining aircraft-to-aircraft separation to flight crews. Improved display avionics and broadcast positional data provide detailed traffic situational awareness to the flight deck. When authorized by the controller, pilots will implement delegated separation between equipped aircraft using established procedures to achieve more consistent and predictable aircraft spacing. This spacing will more accurately apply existing separation standards, in various meteorological conditions, while at the same time reducing controller workload. Broadcast surveillance sources and improved avionics capabilities provide ANSP and the flight deck with accurate position and trajectory data and therefore increased situational awareness. Aircraft that are equipped to receive the broadcasts and have the associated displays, avionics, and crew training will perform delegated separation when authorized by the controller. During specific meteorological conditions and/or air traffic procedures, delegated separation operations include the transfer of separation authority for a specific maneuver to achieve improved NAS capacity and flight efficiency. For example, during Instrument Meteorological Conditions (IMC), the additional situational awareness on the flight deck provided by displays of proximate traffic enable aircraft to accept some separation responsibility without adding a separation buffer to the 3 NM separation standard. During certain marginal conditions in the terminal area, this procedure enables aircraft to continue with the Visual Meteorological Conditions separation instead of decreasing capacity by switching to much lower capacity IFR operations. Under this procedure, aircraft that have established initial visual contact can continue a visual approach while traversing a light cloud layer, using the onboard traffic display briefly to augment situational awareness until visual contact is reestablished. Aircraft performing delegated separation procedures are paired and separate themselves from one another by maintaining a given time or distance from a designated aircraft using cockpit-based tools. The use of this procedure will replace some of the ATC vectoring and speed instructions made necessary by existing surveillance. For aircraft not delegated separation authority, ANSP automation will still support separation.	Far-term	2015	2022

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102145	Single Runway Arrival Wake Mitigation	Single Runway Arrival Wake Mitigation will provide increased arrival capacity to single runways by reducing longitudinal wake separation standards for IFR operations under certain crosswind conditions. Weather sensors and products will be used to monitor crosswind conditions, and air traffic automation systems will be used to indicate to controllers when they can safely reduce wake separation standards, increasing arrival capacity.	Far-term	2020	2023
102146	Flexible Routing	Leveraging enhanced flight capabilities based on Required Navigation Performance, flight operators can operate along preferred and dynamic flight trajectories based on an optimized and economical route for a specific flight, accommodating user preferred flight trajectories. Aircraft may execute a desired route using existing, fixed waypoints or other route coordinates, which may have some flexibility in time and space dimensions "window." Aircraft may coordinate a route change with ANSP at any time through data or voice communications (air-ground data exchange); however, minor changes of the route within the tolerances of the "window" are allowed and do not require coordination with the ANSP. ANSP uses ground-based decision support tools to maintain separation responsibility for aircraft. The result of this OI optimizes available airspace, allowing flight operators more flexible routings to reduce block time and fuel burn. ANSP may require flight operators to fly within designated route structures for congestion management, as needed. Increased system precision and enhanced automation supports the efficient use of flight levels so that aircraft can more closely fly routes that maximize the airlines' goals of fuel efficiency, aircraft operations, and schedule. Aircraft provide state and intent data that will lead to fewer predicted problems, and as a result, fewer diversions from the preferred routing. Reduced separation standards will also result in increased capacity within flow constrained airspace, allowing more aircraft to fly through those areas, rather than being rerouted or delayed to avoid them.	Far-term	2019	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102147	Self-Separation Airspace - Oceanic	Oceanic user efficiency and Air Navigation Service Provider (ANSP) productivity are improved through self-separation operations in designated oceanic airspace for capable aircraft. Aircraft fly preferred optimum profiles without coordination with ANSP. Aircraft-to-aircraft separation is delegated to the flight deck in designated airspace for capable aircraft with Automatic Dependent Surveillance-Broadcast (ADS-B) and onboard conflict detection and alerting. The separation minima are reduced to a level that maintains appropriate margins of safety. Prior to an established point or designated timeframe, aircraft coordinate with ANSP to receive a clearance to exit self-separation airspace.	Far-term	2022	2025
102148	Self-Separation Airspace Operations	In self-separation airspace, capable aircraft, equipped with Automatic Dependent Surveillance-Broadcast (ADS- B) and onboard conflict detection and alerting, are responsible for separating themselves from one another, and the Air Navigation Service Provider (ANSP) provides no separation services, enabling preferred operator routing with increased ANSP productivity. Research will determine whether the ANSP will provide any traffic flow management services within self-separation airspace. Aircraft must meet equipage requirements to enter self-separation airspace, including transmission of trajectory intent information through cooperative surveillance. Transition into self-separation airspace includes an explicit hand-off and acceptance of separation responsibility by the aircraft. Transition into ANSP-managed airspace is facilitated through assigned waypoints with Controlled Time of Arrivals (CTAs), allowing the ANSP to sequence and schedule entry into congested airspace, and self-separating aircraft are responsible for meeting assigned CTAs. Self-separating aircraft execute standardized algorithms to detect and provide resolutions to conflicts. Right-of-way rules determine which aircraft should maneuver to maintain separation when a conflict is predicted. Contingency procedures ensure safe separation in the event of failures.	Far-term	2022	2025

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102149	Delegated Separation - Complex Procedures	In Air Navigation Service Provider (ANSP)-managed airspace, the ANSP delegates separation responsibilities to capable aircraft to improve operator routing, enhance operational efficiency, or increase ANSP productivity. This Operational Improvement involves more complex delegated separation responsibilities than those performed using a cockpit display to cross, merge, or pass another aircraft. Using advanced airborne technologies with conflict detection and alerting, aircraft in ANSP-managed En Route and transition airspace are delegated separation responsibilities to perform more complex operations, possibly maintaining separation from more than one other aircraft. The feasibility of using advanced airborne conflict detection and alerting technologies to perform complex procedures under delegated separation responsibility will be determined based on an evaluation of previous delegated separation Operational Improvements. This Operational Improvement involves more complex delegated separation responsibilities than those performed using a cockpit display to cross, merge, or pass another aircraft. Using advanced airborne technologies with conflict detection and alerting, aircraft in ANSP-managed En Route and transition airspace are delegated separation responsibilities to perform more complex operations, possibly maintaining separation from more than one other aircraft. The feasibility of using advanced airborne conflict detection and alerting technologies to perform complex procedures under delegated separation responsibility will be determined based on an evaluation of previous delegated separation Operational Improvements.	Far-term	2025	2030

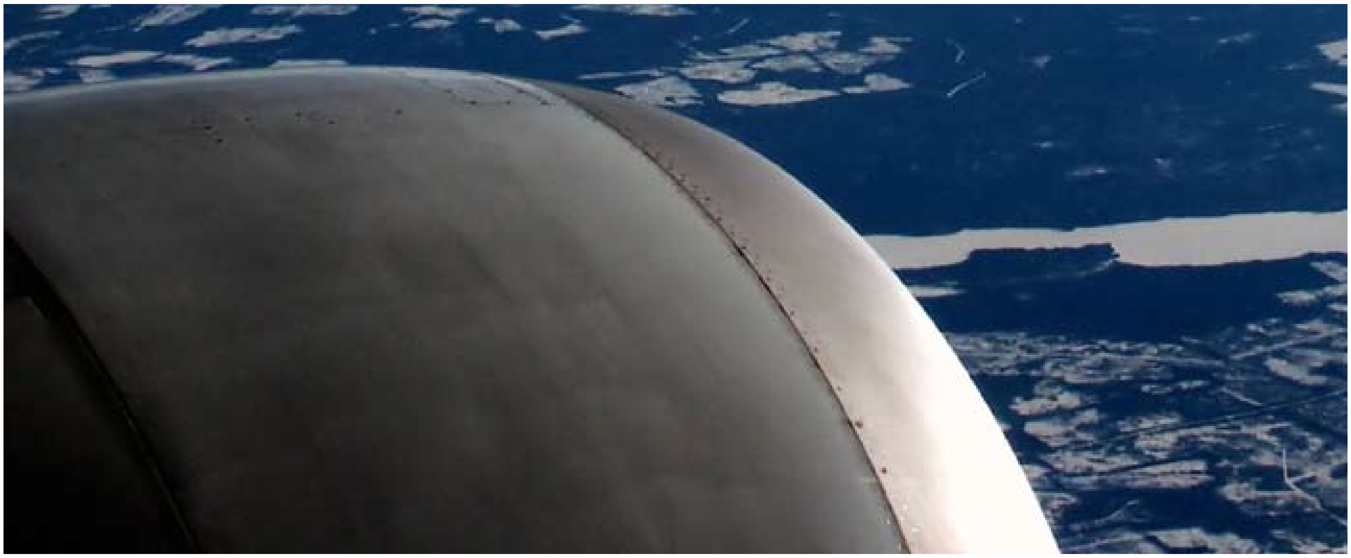


Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
102150	Reduce Separation - High Density Terminal Less Than 3-miles	Metroplex airspace capacity is increased through implementing separation procedures for conducting separation with less than 3-miles between arrival and departure routes in a high density environment. This Operational Improvement increases metroplex airspace capacity and supports super density airport operations. Enhanced surveillance and data processing provides faster update rates to allow reduced separation. Arrival/departure routes with lower Required Navigation Performance (RNP) values (e.g., RNP<1 nm) are defined with less than 3 miles lateral separation between routes, subject to wake vortex constraints, enabling the use of more routes in a given airspace. This may require airborne lateral separation between routes. Enhanced Required Surveillance Performance (RSP) is required, allowing more precise location so that separation can be further reduced. The specific level of RSP will determine to what degree separation can be less that 3 miles. This requires a Policy Decision to determine what RNP values to require based on performance benefit versus equipage requirements and operational considerations. Expected use: high density terminal and transition airspace.	Far-term	2025	2030
102151	Single Runway Departure Wake Mitigation	Single Runway Departure Wake Mitigation will provide increased departure capacity from single runways by reducing longitudinal wake separation standards under certain crosswind conditions. Airport weather sensors and products will be used to monitor crosswind conditions, and air traffic automation systems will be used to indicate to controllers when they can safely reduce wake separation standards, increasing departure capacity.	Far-term	2018	2021
102152	Dynamic, Pairwise Wake Turbulence Separation	Wake turbulence separation applications for departure, arrival, and en route operations are integrated into air traffic automation to provide dynamic, pairwise, lateral, longitudinal, and vertical separation requirements for trajectory management based on aircraft and weather conditions, in real time.	Far-term	2024	2027
102153	Limited Simultaneous Runway Occupancy	Runway capacity is increased through the allowance of more than one aircraft on the runway, at a given time, for specific situations. The expected use is to relax some of the present procedures/rules, thereby allowing an aircraft to land while another aircraft is in the process of exiting the runway onto a taxiway, or allowing an aircraft to enter the runway while another aircraft is in the process of departing from that runway.	Far-term	2020	2023

Table 3 –Far-term Operational Improvements					
Identifier	**OI Name**	**Description**	**Benefits**	**Earliest IOC**	**Latest IOC**
102153	Limited Simultaneous Runway Occupancy	This OI is not intended to permit simultaneous aircraft operations on the runway, but rather to permit an aircraft to start or end a maneuver while another aircraft is completing a maneuver; only one aircraft may be conducting an actual operation, take off or landing, while the other aircraft is either exiting the runway or getting in position to perform an operation. This OI may require ADS-B in/out for surveillance and pilot situational awareness, such as cockpit display (CDTI), augmented with GPS sensors (WAAS or LAAS) for accurate position, depending on the specific situation and conditions at that time.	Far-term	2020	2023
102409	Provide Surface Situation to Pilots, Service Providers and Vehicle Operators for Near-Zero-Visibility Surface Operations	Aircraft and surface vehicle positions are displayed to aircraft, vehicle operators, and air navigation service providers (ANSP) to provide situational awareness in restricted visibility conditions, increasing efficiency of surface movement. Surface movement is guided by technology such as moving map displays, enhanced vision sensors, synthetic vision systems, Ground Support Equipment and a Cooperative Surveillance System. Aircraft and surface vehicle position will be sensed and communicated utilizing systems such as Cockpit Display of Traffic Information (CDTI) and Automatic Dependent Surveillance-Broadcast (ADS-B). Efficient management of surface movement requires cooperative surveillance (i.e., ADS-B out) for all aircraft and ground vehicles present.	Far-term	2015	2025
103121	Full Improved Weather Information and Dissemination	This improvement provides the full capability that supports the NextGen concept of operations to assimilate digital weather information into decision-making for all areas of operations. The net-centric access of weather observations, analyses, forecasts (including probability), and climatology via a robust 4D Weather Data Cube and a de-conflicted 4-D Weather Single Authoritative Source (4-D Wx SAS) becomes complete. Requisite weather information is 'pushed' to ANSPs, flight operations, and aircrews if a change in weather may potentially impact operations (based on user-defined weather thresholds of interest). All weather information is provided at the appropriate aviation decision-maker tailored resolution, update frequency, geographic scale, etc. crucial to NextGen operations. Improved accuracy of forecast information and universal access to the 4-D Wx SAS enables integration of weather and its uncertainty into user and ANSP decision support tools, which supports risk management.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
103121	Full Improved Weather Information and Dissemination	Today, the NAS is unable to provide a common weather picture for universal use. When aviation decision makers use weather information that is inconsistent in source, derivation and content, collaborative decision making is virtually impossible. Given a common weather picture, aviation operations that can be affected by weather are made more consistent with respect to potential system and individual flight operation impacts. The resolution of these impacts can be formulated more effectively and decision making becomes more seamless over operational times, boundaries, and activities. NextGen's mid-term implementation of the 4-D Wx SAS begins to rectify these inefficiencies. In the Far-term, the 4-D Wx SAS matures, meeting all NextGen operational decision-making performance requirements for accuracy, latency, availability, etc. Also, the mechanism involved in determining the SAS, from available weather sources, becomes dynamic, highly automated, and more effectively provides the 'best' source of weather information to stakeholders to support operational decision making. The 4-D Wx SAS also meets the needs of stakeholders for tailored weather information directly applicable to all manner of NextGen era decisions. Stakeholders can pull tailored weather information or it can be proactively updated ("pushed") based on user requests. Safety, efficiency, and capacity are enhanced by providing decision makers and decision support tools with tailored weather information such as: timing of a wind shift to more effectively support airport runway reconfiguration; flight impacting weather along a 4DT; high-resolution terminal area wind forecasts to support arrival/departure operations; or timely hazardous weather information from a lead aircraft that is provided to following aircraft. Combined with universal (net-centric) access, the 4-D Wx SAS provides a common weather picture to all stakeholders and decision support tools (DSTs). This common weather picture facilitates effective collaborative decision making, supports traffic flow management by trajectory, and allows users to duplicate and better understand tactical ANSP recommendations.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
103122	Full Improved Weather Sensor Network	New ground, airborne (including UAS), and space-based (e.g., satellite) sensors, when combined with additional mid-term sensors, provides a complementary network of weather sensors that enhances early detection capability and increases forecast accuracy for three - seven day forecasts. Integration of the enhanced sensor data into weather forecasts, ANSP decision support tools, and user flight-optimization tools provides NAS stakeholders with extended look-ahead capabilities for weather avoidance trajectories through risk mitigation. The increased information allows the more accurate initiation of forecast models so they can better depict the beginning of a weather event. The increased 3-7 day forecast accuracy will greatly increase the strategic planning efforts of the ANSP and the operators. New global forecasts will support improved flight planning and operations for international arrival and departures. Additional in-situ information will enhance remote virtual tower operation. The sensor network will be incrementally improved and right-sized to ensure information sufficiency, reliability, and availability while reducing life-cycle costs. Additional satellite sensors with enhanced detection technologies combined with tailored atmospheric focus, better defines the atmosphere by actively transmitting aviation-relevant weather observations to ground-based systems. These are further incorporated with ground- and airborne-based weather sensor information into the 4D Weather Data Cube and the 4-D Weather Single Authoritative Source (4-D Wx SAS). As an example, new satellite-based sensors and emerging ground-based capabilities will provide enhanced atmospheric observations to support emergingFar-term Operational Improvements such as self-separation in en-route airspace and other 4DT trajectory-based NextGen operations in Super Density airspace.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements					
Identifier	**OI Name**	**Description**	**Benefits**	**Earliest IOC**	**Latest IOC**
103122	Full Improved Weather Sensor Network	The expansion of airborne sensors to additional aircraft types, the fielding of new technology sensors, and new technology UAS sensors provide enhanced atmospheric information by actively collecting and transmitting essential weather observations regarding moisture, temperature, turbulence, icing, and winds. These sensors improve atmospheric sampling, from the atmospheric boundary layer up through maximum flight levels, which further improves aviation weather forecast model output at lower flights levels and extends the reliability of longer term forecasts. Once in the 4-D Weather Data Cube, this information is disseminated to ANSPs, users, and their automation systems, providing reliable, timely and consistent weather information enabling them to mitigate the impacts of weather on operations through common situational awareness provided via the 4-D Wx SAS. The addition of new technology ground-based sensors as well as quality controlled, non-Federal ground-based surface observing sensors enhances weather information for operations. Cost savings in this timeframe are realized by right-sizing the entire suite of sensors. This is accomplished by comparing operationally required information (resolution, reliability, availability, etc.) with sensor capability, density, and duplication. Additional cost savings are realized by providing necessary connectivity and automation to control and configure the sensor network to optimize meeting changing needs of ANSP and user requirements.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
103123	Full Integration of Weather Information into NAS Automation and Decision Making	Further advances in weather information content/dissemination and a NAS-wide increase in the direct integration of weather into decision support tools will enable users and service providers to more precisely identify specific weather impacts on operations (e.g., trajectory management and impacts on specific airframes, arrival/departure planning) to ensure continued safe and efficient flight. NAS automation tools directly utilize weather information (including uncertainty), demand information, and other capacity constraints to analyze the integrated information picture. The results of this analysis allows users and service providers to select from among proposed, automation-developed mitigation strategies to balance demand to available capacity, both strategically and tactically. These strategies will minimize weather-induced changes to user-preferred flight plans (e.g., fewer flights rerouted) as the weather-impacted airspace will be more precisely defined in both extent and timing, based on enhanced weather observations and forecasts, including probabilities. Both the user and the Air Navigation Service Provider (ANSP) will have these automation systems, which will be linked and share a single source for weather information, to enable automated negotiation of the proposed strategies, unique to the weather and traffic situation. The availability of enhanced weather information, integrated with automated decision support tools, will be increasingly extended to the cockpit to ensure safety, and maintain flight efficiency.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements					
Identifier	**OI Name**	**Description**	**Benefits**	**Earliest IOC**	**Latest IOC**
103123	Full Integration of Weather Information into NAS Automation and Decision Making	Because of the profound impact of adverse weather on the safety, efficiency, and capacity of the NAS, improving ATM decision making, when weather impacts operations, remains a key NextGen objective for the long-term. Mid-term advances will put into place many of the initial building blocks needed to accomplish this objective. The 4-D Weather Data Cube (and 4-D Weather Single Authoritative Source (4-D Wx SAS)) provides a consistent, de-conflicted common weather picture (e.g., observations, forecasts, and climatology, from the surface to the top of the NAS) that will provide ANSPs and users with a common view of the weather situation. In addition, initial versions of decision support tools that integrate weather information into their decision analyses will be deployed. In this timeframe, the full 4-D Wx SAS extends the observation and forecast information that was made available in the initial version of the 4-D Wx SAS. It will continue to provide a consistent, seamless common weather picture of information, but the observation and forecast information will be: more precise; more rapidly updated; of higher resolution; and directly useable by automation without human intervention. In addition, probabilistic weather forecasts quantify risks that potentially impact weather will occur. As a result, a more exact assessment (in terms of volumetric extent, timing, and severity) of the weather-impacted airspace is derived to inform development of strategic and tactical mitigation actions that minimize impacts on user flight plans.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
103123	Full Integration of Weather Information into NAS Automation and Decision Making	The use of a new generation of weather-integrated decision support tools will become more prominent in helping users and ANSPs respond to identified weather impacts. The customized weather information, provided by the enhanced 4-D WX SAS, will be integrated into these advanced tactical and strategic decision support tools developed under the TBO, CATM, Flexible Terminal, and High Density Airport solution sets. These tools will assess the operational impact of weather on flights/trajectories (including estimation of aircraft-specific weather hazard levels), and provide candidate actions to the ANSP and user that mitigate the impacts of weather on traffic flow and safety. The improved observation and forecast information will enable those developed actions to be less disruptive to the NAS. For example, probabilistic weather forecasts will enable transition from today's overly conservative flow planning to a paradigm of risk-based traffic management initiative (TMI) development where strategies are incremental and affect fewer flights. The automation integration will be extended to include direct integration of ANSP decision support capabilities with those of users to, for example, negotiate trajectory changes. Over time, the combination of trusted weather information and weather-integrated decision support tools will reduce the occurrence where human decision makers must evaluate and decide what to do; the decision makers will trust the solutions proposed by the automation, and execute them. Direct information dissemination by 4-D WX SAS will also provide proactive updates ("push") to requestors as the weather situation changes. Because of the increased use of air/ground data communications, delivery of safety-critical weather information directly to the flight crew will be increased. Pilots will integrate weather information into their flight deck support tools to identify and avoid hazardous weather along their flight path, while preserving flight efficiency where possible. The combination of consistent weather information and decision support tools that utilize it will enable more effective and timely decision making by both ANSPs and users, for meeting capacity, efficiency, and safety objectives.	Far-term	2018	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
104105	Automated Support for Trajectory Negotiation	Trajectory management is enhanced by automated assistance to negotiate pilot trajectory change requests with properly equipped aircraft operators. Four-Dimensional Trajectories (4DTs) are negotiated between the pilot/aircraft operator and the air navigation service provider (ANSP), using ground-based automation to provide trial planning using intent data in en route trajectory-based operations. A trajectory change can be requested by an Unmanned Aircraft System (UAS) operator, Flight Operations Center (FOC) personnel or flight deck. The trajectory change would then be relayed to the pilot/aircraft operator over a safety critical link. The aircraft operator must acknowledge receipt and acceptance of the negotiated trajectory change. Decision support tools identify complexity and density conditions and provide alternatives to the ANSP. These alternatives include proposed trajectories, or intent data, that are exchanged with the operator via data communications, allowing solutions that are not subject to constraints imposed by voice. This will enable higher density of operations thus higher capacity as well as decrease human errors in trajectory negotiation and data entry.	Far-term	2018	2025
104121	Automated Negotiation/Separation Management	Trajectory management is enhanced by separation management automation that negotiates with properly equipped aircraft and adjusts individual aircraft Four-Dimensional Trajectories (4DTs) to provide efficient trajectories, manage complexity, and ensure separation assurance. Negotiating with aircraft and adjusting individual 4DT trajectories synchronizes or restricts access to airspace, tactically resolves conflicts among aircraft, and avoids weather, special use airspace, terrain, or other hazards. The ANSP Separation Management function is fully automated and manages separation by negotiating conflict-driven updates to the 4DT agreements with the aircraft. This evolution, required to maximize capacity and en route throughput, allows flexibility for higher density of operations thus higher capacity, as well as a decrease in human errors in trajectory negotiation and data entry. This Operational Improvement requires a Policy/Implementation Decision to determine appropriate roles/responsibilities allocated between humans/automation and air/ground.	Far-term	2023	2030

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
104125	Integrated Arrival/Departure and Surface Traffic Management for Metroplex	Metroplex traffic flow is more efficiently managed through arrival/departure and surface scheduling automation, integrated with all available constraint information, including weather impacts, optimizing traffic throughput by eliminating potential gaps in unused capacity, thereby increasing regional/metroplex capacity. Adjustments to the integrated airspace RNP routings are dynamically designed, validated by automated tools, and uplinked via data communications to participating aircraft to meet changing weather conditions and/or congestion. Metroplex trajectory management assigns each arriving aircraft to an appropriate runway, arrival stream, and place in sequence. Departing aircraft are assigned an appropriate runway and a departure time based on efficient merging and spacing with aircraft departing other metroplex terminals, as well as those already in overhead streams. Surface scheduling automation integrates arriving and departing aircraft and provides runway and taxi movement to optimize all surface movement. Data communications enables the Air Navigation Service Provider (ANSP) to maximize access for all traffic, while adhering to the principle of giving advantage to those aircraft with advanced capabilities	Far-term	2020	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
104126	Trajectory-Based Management - Gate-To-Gate	All aircraft operating in high density airspace are managed by Four Dimensional Trajectory (4DT) in En Route climb, cruise, descent, and airport surface phases of flight to dramatically reduce the uncertainty of an aircraft's future flight path in terms of predicted spatial position (latitude, longitude, and altitude) and times along points in its path. Integrating separation assurance and traffic management time constraints (e.g., runway times of arrival, gate times of arrival), this end state of 4DTbased capability calculates and negotiates 4DTs, allows tactical adjustment of individual aircraft trajectories within a flow, resolves conflicts, and performs conformance monitoring by Air Navigation Service Providers (ANSPs) to more efficiently manage complexity, ensure separation assurance, and enhance capacity and throughput of high density airspace to accommodate increased levels of demand. This will be enabled by the trajectory exchange through data communications, as well as many new surface automation and 3D (x, y, and time) trajectory operations. In trajectory-based airspace, user preferences are accommodated to the greatest extent possible, and trajectories are constrained only to the extent required to accommodate demand or other national concerns, such as security or safety. Performance-based services are conducted for differing types of operations based on anticipated traffic characteristics. The ANSP role evolves into managing trajectory-based airspace by maintaining largely conflict-free, user-preferred flows. This evolution allows the flexibility required to maximize capacity and en route throughput.	Far-term	2025	2030
104127	Automated Support for Conflict Resolution	ANSPs, supported by automation, remain responsible for separation management. Conflict resolution is enhanced by automated assistance to probe pilot trajectory change requests with properly equipped aircraft operators to resolve conflicts. Decision support tools identify conflicts and provide alternatives to the Air Navigation Service Provider to resolve the conditions. These alternatives include proposed trajectories, or intent data, that are exchanged with the operator via data communications, allowing solutions that are not subject to constraints imposed by voice. Ground-based automation provides trial planning using intent data, and conflict detection and resolution to probe Four-Dimensional Trajectories (4DTs) in en route trajectory-based operations. The conflict resolution (trajectory change) would then be relayed to the pilot/aircraft operator. The aircraft operator must acknowledge receipt and acceptance of the trajectory change.	Far-term	2018	2025

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
104206	Full Surface Traffic Management with Conformance Monitoring	Efficiency and safety of surface traffic management is increased, with corresponding reduction in environmental impacts, through the use of improved surveillance, automation, on-board displays, and data link of taxi instructions. Equipped aircraft and ground vehicles provide surface traffic information in real-time to all parties of interest. A comprehensive view of aggregate traffic flows enables ANSP to project demand; predict, plan, and manage surface movements; and balance runway assignments, facilitating more efficient surface movement and arrival and departure flows. Automation monitors conformance (position and path) of surface operations and updates the estimated departure clearance times. Surface optimization automation includes activities such as runway snow removal, aircraft de-icing, and runway configuration	Far-term	2018	2024
105207	Full Collaborative Decision Making	Timely, effective, and informed decision-making based on shared situational awareness is achieved through advanced communication and information sharing systems. Stakeholder decisions are supported through access to an information exchange environment and a transformed collaborative decision making process that allows wide access to information by all parties (whether airborne or on the ground), while recognizing privacy and security constraints. Decision-makers request information when needed, publish information as appropriate, and use subscription services to automatically receive desired information through the net-centric infrastructure service. Net-centricity ensure a robust, globally interconnected network environment in which information is shared in a timely and consistent manner among users, applications, and platforms during all phases of aviation transportation efforts. This information environment enables more timely access to information and increased situational awareness while providing consistency of information among decision-makers. A mixture of near-real-time and post-ops analysis from both the air navigation service provider and aircraft operators is shared.	Far-term	2017	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
105207	Full Collaborative Decision Making	With nearly instant feedback on the system-wide implications of their plans, decision-making can be allocated to the person in the best position to make safety and efficiency call, including an increased level of decision-making by the flight crew and flight operations centers. Decision-makers have access to options analysis DST which performs fast-time simulations to assess the NAS wide implications of any proposed changes in trajectory on other flight operations. Decision-makers have more information about relevant issues, decisions are made more quickly, required lead times for implementation are reduced, responses are more specific, and solutions are more flexible to change. To ensure locally developed solutions do not conflict, decision-makers are guided by NAS-wide objectives and test solutions to identify interference and conflicts with other initiatives.	Far-term	2017	2023
108105	Flow Corridors - Level 1 Static	High density En Route static flow corridors accommodate aircraft that are capable of self-separation, equipped with Automatic Dependent Surveillance-Broadcast (ADS- B) and onboard conflict detection and alerting, traveling on similar routes, achieving high traffic throughput by minimizing complexity and crossing traffic. When there are large numbers of suitably equipped aircraft traveling in the same direction on similar routes, the Air Navigation Service Provider (ANSP) may implement flow corridors, which consist of long tubes or "bundles" of parallel lanes. Aircraft within the corridors are responsible for separation from other aircraft (that is, the corridors are self-separation airspace), and use onboard separation capabilities for entering and exiting the corridors, as well as for overtaking, all of which are accomplished with well-defined procedures to ensure safety. Flow corridors efficiently handle very high traffic densities, increasing throughput and increasing the airspace available to other traffic. Flow corridors are procedurally separated from other traffic not in the corridor. Procedures exist to allow aircraft to safely exit the corridor in the event of a declared emergency.	Far-term	2020	2024
108106	Flow Corridors - Level 2 Dynamic	High density En Route dynamic flow corridors accommodate aircraft that are capable of self-separation , equipped with Automatic Dependent Surveillance-Broadcast (ADS- B) and onboard conflict detection and alerting, traveling on similar wind-efficient routes or through airspace restricted by convective weather cells, Special Use Airspace (SUA), or overall congestion.	Far-term	2025	2030

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
108106	Flow Corridors - Level 2 Dynamic	Dynamic high density flow corridors are defined daily and shifted throughout the flight day to avoid severe weather regions and airspace restrictions (e.g., SUA) or take advantage of favorable winds. Dynamic corridor entry and exit points are also defined. This extends static flow corridor technology via dynamic airspace design capabilities to provide more En Route capacity to trajectory-based aircraft when the available airspace is restricted. Real-time information on corridor location, and logistics and procedures for dynamically relocating a corridor while it is in effect must be developed. If corridor use is to be widespread, techniques for merging, diverging, and crossing corridors may also be required.	Far-term	2025	2030
108213	Dynamic Airspace Performance Designation	Airspace allocation is flexible allowing dynamic access requirements to airspace based on the type of operations to be flown within a given airspace. Flying within certain airspace is based on aircraft performance requirements, to accommodate increasing demand or minimize impacts of adverse weather or other system constraints. A dynamic change in airspace access is executed by providing real-time airspace performance designation information and requirements to airspace users, whether preflight or during airborne operations. Temporary Flight Restrictions and Special Use Airspace use is factored into the dynamic airspace performance designation process. A change to airspace performance designation may be routine or made dynamically in response to forecast demand. This requires development of rules and operational procedures, including established look-ahead times, for defining airspace performance designation and the type of operations permitted within a given airspace, as well as those allowed in preconfigured airspace designations. Flight planning and airborne aircraft may be affected by airspace designation. This OI does not preclude the use of predefined airspace structures or airspace performance designation such as those that may be used/required on a frequent basis, such as identified choke-points or areas of known high density, requiring designated performance capabilities.	Far-term	2019	2023

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
109317	Operational Security Capability with Dynamic Flight Risk Assessment for Improved Security Airspace Planning and Manageme	Security Restricted Airspace (SRA), represented by volumetric expressions, is defined and managed by the Air Navigation Service Provider (ANSP) or its designee using an integrated airspace planning, configuration, and distribution capability to establish time-dependent and risk-based security restriction parameters. Through inter-agency net-enabled infrastructure (NEI) and Air Ground data communication capability, the ANSP Security personnel receive automated updates of in-flight dynamic security-relevant information and associated flight risk profile updates provided by the Security Service Provider (SSP). Built upon the foundation of the National Airspace System's (NAS) mid-term operational security capabilities, NAS security airspaces will be adjusted/updated/coordinated/implemented dynamically that their access restrictions and flights' allowable proximity to them will be variable based on the flight risk profile and its current trajectories. Such a security airspace management framework incorporating the flight risk profile (examples of consideration: air vehicle type, origin/destination, trajectory compliance behavior, communication status, security certificate status, Law Enforcement personnel presence, passenger of interest, aircraft security measures on board, etc.). Changes in flight-specific Security Airspace restrictions are coordinated automatically with SSP, Defense Service Provider (DSP), Flight Operations Center (FOC) and NAS facilities through the NextGen NEI while the notification to the cockpit is through Air/Ground data communication. Such automated capabilities provide stakeholders with timely airspace security restrictions information; consequently, reduce the likelihood of unintentional airspace violations and subsequent deployment of interdiction assets by the DSP.	Far-term	2025	2025
109320	NextGen EMS Framework Implementation Phase III	Expand NextGen EMS to a broader set of stakeholder organizations and FAA, including environmental goals, targets, and performance evaluation, pilot activities and communications programs. It will include multiple increments delivered over time.	Far-term	2019	2025
109323	Increased Use of Commercial Aviation Alternative Fuels - Phase III	Expand ASTM International approval of "drop-in" alternative fuels to increase available alternative fuel supply for commercial use. Explore non "drop-in" alternative fuels, their supply and infrastructure requirements. It will include multiple increments delivered over time.	Far-term	2019	2025

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
109324	Implement NextGen Environmental Engine and Aircraft Technologies - Phase III	Support certification and commercialization of aircraft technologies for enhanced environmental and energy efficiency improvements demonstrated during Phase II. Explore and demonstrate additional aircraft materials and fuel-flexible jet engines technologies. It will include multiple increments delivered over time.	Far-term	2019	2025
109325	Environmentally & Energy Favorable Air Traffic Management Concepts and Gate-to-Gate Operational Procedures - Phase III	Explore, develop, demonstrate, evaluate and support the implementation and deployment of Air Traffic Management and gate-to-gate operational changes to the NAS that have the potential to reduce the environmental impacts of aviation support mobility growth by increasing the capacity and throughput of the NAS. It will include multiple increments delivered over time.	Far-term	2019	2025
109404	Automated Virtual Towers	Throughput at low- to moderate-demand airports (when tower is non-operational) and non-towered airports is increased through the use of automated tower services. The automation provides a variety of services from sequencing and basic airport information to limited separation management. IFR throughput (in both IMC and VMC) is increased through utilization of both ground and air surveillance systems and by exploiting available aircraft capabilities. Airport complexity and demand as well as customers' needs and capabilities are carefully determined, then appropriate levels of automation and modes of communication are installed to maximize capacity while still meeting cost/benefit and safety analyses. An automated voice interface ensures that minimally equipped aircraft receive service.	Far-term	2020	2023
109405	Business Continuity Services	The NextGen net-centric and geo-independent system architecture will allow improved ATM business continuity services throughout the NAS in the event of a facility shutdown or incapacity. Implementing NextGen business continuity will improve service by reducing the number of aircraft delays in the event of a long-term facility outage.	Far-term	2018	2025

Table 3 –Far-term Operational Improvements

Identifier	OI Name	Description	Benefits	Earliest IOC	Latest IOC
109405	Business Continuity Services	In the event of a long-term facility outage due to man-made or natural causes, critical ATM services will be divested from an affected facility and reconstituted at accommodating facilities. Homeland Security Presidential Directive-7 (HSPD-7) establishes a national policy for Federal departments and agencies to identify and prioritize critical infrastructure and to protect them from terrorist attacks. This operational improvement leverages the HSPD-7 policy to provide business continuity services for critical ATM services affected by terrorist and other man-made causes and natural disasters. All components of critical ATM services will be addressed, including automation, surveillance, weather, and voice and data communications. Accounting for necessary physical space for systems and equipment in facility planning and planning for a trained contingent of personnel efficiently mitigates the effects on ATM services. In the event of a long-term facility outage due to man-made or natural causes, critical ATM services will be divested from an affected facility and reconstituted at accommodating facilities. Homeland Security Presidential Directive-7 (HSPD-7) establishes a national policy for Federal departments and agencies to identify and prioritize critical infrastructure and to protect them from terrorist attacks. This operational improvement leverages the HSPD-7 policy to provide business continuity services for critical ATM services affected by terrorist and other man-made causes and natural disasters. All components of critical ATM services will be addressed, including automation, surveillance, weather, and voice and data communications. Accounting for necessary physical space for systems and equipment in facility planning and planning for a trained contingent of personnel efficiently mitigates the effects on ATM services. Business continuity services will restore up to 100% of critical services in as little as one week. This will greatly mitigate the economic impact of long-term facility outages and resultant loss of ATM services on our nation's economy.	Far-term	2018	2025

Appendix 3: Risk and Benefits Assessments

To understand the benefits and risks associated with various levels of performance and technology options for the 2025 NextGen system, the JPDO has evaluated system alternatives representing seven levels of technological capability and complexity. The analysis to date indicates that the targeted capabilities described, achieve an appropriate balance of performance, cost, and risks.

The targeted benefits accrue from a variety of operational improvements enabled by the deployment of RNAV/RNP navigation systems, ADS-B In, Data Comm, ATM automation, improved weather information, net-centric operations, and other features. These will enable the following:

- Closely spaced parallel runways with separations down to 700 feet under Instrument IFR
- Merging and spacing tools that improve the predictability of traffic flow
- Improved traffic flow management and reduced separation standards to improve the use of airspace
- Trajectory planning and flexible routing that reduce the likelihood of weather-induced delay
- Enhanced situational awareness for pilots that improves knowledge of their location on the airport surface and runway incursion alerting

A major effect of these improvements is to increase throughput and reduce delay, fuel burn, and emissions – or to achieve some combinations of these. Other effects include enhanced safety and reduced variability in system performance. The extent to which the 2025 system will affect throughput and delay will depend, in part, on how users will employ its capabilities.

The JPDO's analysis (currently under review) illustrates the benefits of advanced technologies embodied in NextGen Far-term based on FAA-forecasted traffic levels and anticipated airline scheduling. The results present the top-level benefits in terms of increased throughput and reduced delay compared to the capabilities that will result from FAA's current NGIP. Compared to the NGIP, in the far-term, NextGen may reduce ATM-caused system delays by nearly 60 percent, while accommodating slightly more flights (3.5 percent), or the improved capabilities could be used for greater increases in capacity, but with less dramatic delay reductions. By the Far-term the FAA estimates at least 1.4 billion gallons of aviation fuel will be saved and carbon dioxide emissions will be cut by 14 million tons.

In light of problems faced by past development of complex air traffic management (ATM) systems, the risk of cost overruns is a major consideration for NextGen planning. The JPDO reviewed previous advanced technology efforts to indicate the potential development and implementation risks for NextGen. The JPDO has also conducted an initial risk assessment of the NextGen enterprise, based on in-house assessments of hazards, probabilities of occurrence, and expected impacts. The assessment identified eight significant challenges as the top risks. In addition, the study identified several lesser risks as warranting significant attention.

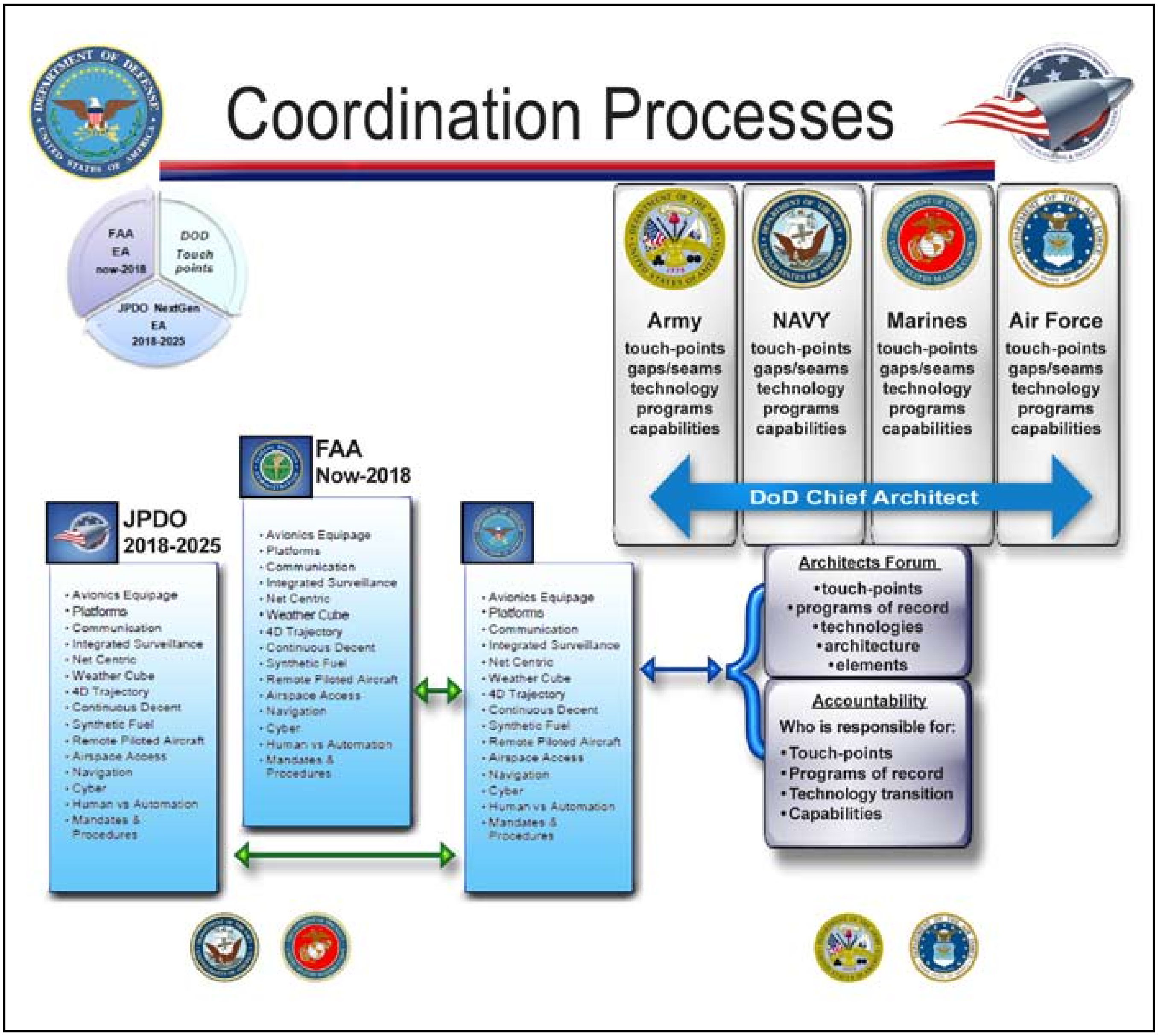
With several topics identified as significantly high risks, NextGen development must be supported with a strong risk management program, including periodic assessments, validation of requirements, and risk abatement activities, such as early technology demonstrations and maintenance of alternate paths. Additionally, stable and continuous funding streams are essential to timely NextGen implementation and a management structure with clear responsibilities and strong decision-making authority.

Appendix 4: Department of Defense (DOD)

Military aircraft represent an extremely broad range of users and capabilities and, therefore, have a very wide scope of operational needs going from point-to-point in visual meteorological conditions operations outside of high-density airspace to instrument meteorological conditions through high-density airspace.

Different segments of the military aviation community will require different levels of access to airspace, based on aircraft performance, desired operational capacity, and safety enhancements. For example, some DOD aircraft are derivatives of civil aircraft and have space, weight, and the capacity to accommodate civil avionics. Other DOD aircraft have a vastly different capacity than civil aircraft and have limited capability to add additional equipment. These include most tactical jets and helicopters. For this reason, tactical aircraft program managers are more constrained from adding new non-tactical capabilities to their aircraft and if compelled to equip, often choose to modify military avionics to add civil capabilities rather than to add additional avionics to their aircraft. Developing modifications for these military avionics may take additional time in comparison to the use of commercial-off-the-shelf (COTS) avionics.

DOD Systems Program Offices (SPOs) and Platform Program Management (PM) offices will have to make decisions to equip for NextGen functionalities based on funds availability, mission objectives, cost to equip, and expected benefits. Note that even after an equipage decision is made, the funding process is lengthy, taking on the order of three to five years to obtain funds to begin the process of equipping. A very rough estimate of the time to implement a new NextGen functionality for the entire DOD fleet is 10 or more years from the time it is mandated. Optional civil requirements will not normally be implemented fleet wide by DOD as funding is based on firm requirements.



Coordination Processes

FAA
EA
now-2018

DOD
Touch
points

JPDO NextGen
EA
2018-2025

Army
touch-points
gaps/seams
technology
programs
capabilities

NAVY
touch-points
gaps/seams
technology
programs
capabilities

Marines
touch-points
gaps/seams
technology
programs
capabilities

Air Force
touch-points
gaps/seams
technology
programs
capabilities

DoD Chief Architect

JPDO
2018-2025

- Avionics Equipage
- Platforms
- Communication
- Integrated Surveillance
- Net Centric
- Weather Cube
- 4D Trajectory
- Continuous Decent
- Synthetic Fuel
- Remote Piloted Aircraft
- Airspace Access
- Navigation
- Cyber
- Human vs Automation
- Mandates & Procedures

FAA
Now-2018

- Avionics Equipage
- Platforms
- Communication
- Integrated Surveillance
- Net Centric
- Weather Cube
- 4D Trajectory
- Continuous Decent
- Synthetic Fuel
- Remote Piloted Aircraft
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- Human vs Automation
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- Avionics Equipage
- Platforms
- Communication
- Integrated Surveillance
- Net Centric
- Weather Cube
- 4D Trajectory
- Continuous Decent
- Synthetic Fuel
- Remote Piloted Aircraft
- Airspace Access
- Navigation
- Cyber
- Human vs Automation
- Mandates & Procedures

Architects Forum

- touch-points
- programs of record
- technologies
- architecture
- elements

Accountability

Who is responsible for:

- Touch-points
- Programs of record
- Technology transition
- Capabilities

Figure 16 – DOD Coordination Process

Typical examples of different types of military operations are rotorcraft and fixed wing operational and training flights from U.S. military bases through civil airspace:

- To restricted or special use areas or other military bases and return
- To due regard oceanic operations possibly in restricted or special use areas and return
- To other U.S. or foreign military bases
- DOD is the largest operator of UAS in the NAS

Appendix 5: General Aviation

General Aviation (GA) represents a broad level of users and capabilities and will therefore have a wide range of operational needs, including:

- Basic point-to-point operations in visual conditions outside of high-density airspace
- Operations into and through high-density airspace in instrument conditions
- Satellite and primary airports in large metroplexes

The purpose of this Appendix is to characterize the wide range of desired capabilities for GA. GA aircraft will have a spectrum of options to meet the requirements for these capabilities.

Operators will have to make equipment decisions based on their mission objectives, equipage costs, benefits, mandates, and other supporting aircraft system capabilities. Different segments of the aviation community will desire different levels of access to airspace based on aircraft performance, desired operational capacity, and safety enhancements. As with current policies, airport and airspace access in NextGen will be performance driven.

Operators that only access class G airspace (or its equivalent under VFR) will require no new equipment. Operators that desire access to class A, B, C, or Mode-C veil airspace under VFR will require ADS-B Out if not operating under a waiver. Aircraft operated in these areas under IFR will need navigation capability commensurate with the operational procedure they intend to conduct. The following are some examples:

- Basic area navigation capability to access airspace under Instrument Flight Rules (IFR) where Very High Frequency (VHF) Omnidirectional Radio Range (VOR) or Non-Directional Beacon (NDB) radio navigation aids are no longer available
- More precise area navigation (e.g., RNP 1.0 or 0.3) to utilize new transition routes through terminal airspace (both IFR and VFR)
- Operators desiring access to hub airports in these areas may be required to have additional equipment and training depending on the operations being conducted (e.g. RNP navigation systems and ADS-B In for closely-spaced parallel approaches and collision and conflict avoidance)
- Participation on airspace or paths that operate in 4DT may need Data Comm to participate. Policy and human factors evaluations will need to be conducted to make sure that a single pilot can effectively communicate in a fully deployed 4DT environment. Procedures and training need to support single pilot operation in the Far-term.

New equipage will permit operators to access new capabilities that improve the speed, efficiency, flexibility, safety and ease of their flight. For instance, VFR operators transiting class B or C airspace will have the same options that they have today without new equipage. However, operators that equip with area navigation systems with appropriate performance may have access to a wider variety of routes and altitudes to transition such airspace. The continued maintenance of traditional VFR corridors and the implementation of new transition routes are made possible by aircraft operating at the primary airport utilizing Optimal Profile Descent (OPD) arrivals and continuous climb departures, thereby freeing up the surrounding low altitude airspace.

Additionally, only the minimum equipage necessary to conduct an operation will be required based on pilot qualifications. For example, if a pilot-aircraft combination can meet an RTA tolerance with manual flight, then they can participate in associated 4DT operations without auto-throttle equipage. Other pilot-aircraft combinations may need decision aids to assist the pilot in meeting the same RTA tolerance, while others may opt for automation such as Flight Management System (FMS) type coupling between navigation and aircraft control.

Scheduled air transport operators and GA operators may meet the same performance requirements in given airspace in different ways. The table below shows key contrast between these two operator communities. The avionics architectures vary considerably between air transport and GA and will probably continue to vary. Air transport will continue along a highly integrated FMS-centric path while most of GA, especially piston, follows a modular path more easily tailored to GA's very diverse missions, business cases, and upgrade paths. GA and air transport will differ in the choice of systems, as well as architecture. For example, GA has already embraced Wide Area Augmentation System (WAAS) for precision approaches, which provide high benefits at relatively low cost for most GA airports and operators.

Table 4 – Comparison of General Aviation and Air Transport (assuming VFR operations are unchanged)

Characteristic	General Aviation	Scheduled Air Transport
Schedule	On-Demand	On-Schedule
Mission Type	Passenger and cargo plus training, recre¬ation, aerial services, etc.	Passenger and cargo
Destinations	Destinations vary widely (over 5,000 public-use U.S. airports) and include off-airport operations. Small percentage of OEP operations.	Specific destinations with a minimum level of infrastructure and security (about 400 U.S. air¬ports). Large percentage of OEP operations.
Altitudes	Large percentage of missions are complete¬ly below 18,000 feet	Few missions are completely below 18,000 feet, although all have some portion (takeoff and landing) below 18,000 feet.
Aircraft Type	Diverse family of aircraft, including no en¬gine, piston, turbo-prop, jet, and single and multi-engine	Predominately jet and multi-engine
Fleet Size	Small and single-aircraft "fleets"	Large Fleets
Crew Size	Frequently Single-Pilot	Multi-Pilot Crew
Type of Operations	High percentage of VFR missions (under 18000 feet)	Always IFR
Operations Support	No Flight Operations Center/Dispatcher support; relies on Flight Service Stations	Extensive FOC/Dispatcher Support
Training	Starts pilots from zero time; mostly done in low-performance piston aircraft in small schools; often informal	Builds on general aviation or military training; Extensive use of sophisticated simulators and formal curricula
Flight Plan	Large percentage of operations performed without a formal flight plan	All operations performed on a formal flight plan
ANSP Workload	Majority of VFR operations have low or no ANSP involvement	All operations have ANSP involvement

NextGen policy must allow multiple paths to evolve into NextGen performance solutions. The benefits of traffic, weather, and ATC services will motivate owners to equip with ADS-B In, as well as ADS-B Out. Looking further ahead, segments of GA will be early adopters of emerging capabilities and will embrace capabilities that improve the levels of safety, efficiency, flexibility and convenience while enhancing operational benefits. One example of these benefits is using ADS-B to provide managed separation in uncontrolled airspace to increase traffic flow while providing enhanced situational awareness. Within the GA community, flights can originate or end at remote locations, and for a variety of purposes. NextGen airspace design and equipage requirements must consider diverse operations, including:

- Flights from small airports to other small airports or metroplex airports, or through metroplex airspace
- Air ambulance, firefighting, and police patrol
- Helicopter transport or cargo operations
- Crop dusting
- Gliders, airship, and hot air balloons for entertainment or surveillance
- Sightseeing
- IFR and VFR training

Appendix 6: Rotorcraft Operations

Introduction

In this appendix, the term Rotorcraft applies to both helicopters and powered-lift aircraft. Rotorcraft and powered-lift operations in NextGen will span a range of operations, from day VFR to complex, precise operations in highly congested airspace under IFR. Aircraft equipment requirements will parallel and build upon solutions for conventional fixed-wing operations. In areas where GNSS signals, surveillance, and voice/data communications are not available due to line of sight limitations, solutions need to be developed to allow rotorcraft to depart and establish communication and navigation capabilities. Rotorcraft and Civil Tilt Rotors (CTRs) must be afforded a means to take advantage of their uniquely slow speed and highly maneuverable flight characteristics to safely provide commercially viable services. If NextGen is to deliver on its promise of enhanced safety and efficiency, Rotorcraft and CTRs must be afforded a means to take advantage of their uniquely slow speed and highly maneuverable flight characteristics to safely provide commercially viable services.

Rotorcraft and Powered-Lift Operations

Rotorcraft employ the full range of flight operations seen by fixed wing aircraft today, but have unique attributes owing to a capacity for low airspeeds and heightened maneuverability. Typical operations run the gamut from day-VFR to IFR, often using high-end FMS coupled to autopilots. A substantial part of current commercial helicopter operations employ day-VFR for diverse reasons such as sightseeing, pipeline, and powerline inspection, and aerial crane operations. Rotorcraft will have special avionics requirements in addition to those used by fixed-wing aircraft in the NextGen environment. Special capabilities include powerline detection, enhanced terrain warning systems, hemispheric enhanced vision, and special displays to take advantage of the enhanced maneuverability. NextGen must continue to support these and related objectives.

Table 5 – Rotorcraft and Powered Lift Operations and Capabilities

Operations	Capabilities
Low Vis Ops (e.g., Transmission line avoidance)	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution); Vertical Nav solution with SVS/EFVS systems tailored to rotorcraft requirements, visual/synthetic sensors – RF energy, etc.
Point In Space	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution)
Steep approach angle	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution); Vertical Nav solution with SVS/EFVS systems tailored to rotorcraft requirements
Pursuit Operations	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution) Vertical Nav solution with SVS/EFVS systems tailored to rotorcraft requirements
Pipeline & Transmission Inspection	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution); Vertical Nav solution with SVS/EFVS systems tailored to rotorcraft requirements
Aerial Crane Operations	Coupled FMS/SVS, enhanced nav and database, enhanced cockpit display (resolution); Vertical Nav solution with SVS/EFVS systems tailored to rotorcraft requirements

Similar to many corporate fixed-wing aircraft, a number of helicopters have been equipped with high-end FMSs coupled to flight directors (autopilot functions). A good example of these aircraft is the S-76C++. Other examples include the Sikorsky S-92 and Bell 412. As with the fixed-wing world, these aircraft have more capability installed in their FMS than is generally used in the current NAS, a point emphasized in discussions during a March 2004 NASA/FAA/Industry workshop on use of precision flight path guidance. That workshop found the development of a helicopter IFR procedure for the 30th Street Heliport on the west side of Manhattan Island, while technically feasible using existing GNSS avionics, was impossible to develop based on current airspace rules and procedures. Eliminating the impediments cited by the 2004 workshop underpin some equipment requirements for advanced operations planned for NextGen.

Civil tiltrotor transport (CTR) operations are expected to be part of the future NextGen landscape, thanks, at least in part, to a notional NASA aircraft design that resolves many of the underlying safety and technical issues with counter-rotating prop-rotors (e.g., no torque effects with power changes) and a cross-shafted, four engine design (e.g., minimal pilot task-loading upon engine failure). CTRs have commonality with both Rotorcraft and fixed-wing aircraft. CTRs can serve as a useful example of advanced rotorcraft operations, just as the spectrum of rotorcraft operations provide ample examples of CTR operations. Future civil Rotorcraft and CTR operations are anticipated to benefit from the unique speed and maneuverability capabilities inherent in rotary-wing operation, in concert with advances in avionics and airspace management rules. This accords well with the NextGen concept of operations in which user decisions on equipage and flight operations capability foster several levels of user capability.

Improving Airspace Efficiency

Being runway-independent aircraft, helicopters and tiltrotor hold the potential for alleviating excess demand at busy airports by freeing up landing slots on primary runways. The primary challenge for its accomplishment is to identify new, alternate landing areas that do not infringe on primary airspace, yet are sufficiently co-located. Meeting this challenge will require precision guidance for highly congested airspace.

Rotorcraft and CTR operations will feature flight paths and procedures independent of conventional fixed-wing operations, an operating concept termed "Simultaneous Non-Interfering/Runway Independent Aircraft" (SNI/RIA). These operations are expected to invoke tighter flight-path performance standards for maneuvering around fixed-wing operating corridors and flight obstructions, both of which are necessary for operations into and out of vertiports/heliports located away from the primary runways at hub airports or at independent facilities (e.g., hospitals or potential industrial park and downtown commercial facilities). This capability will rely on GNSS technologies combined with advanced displays that improve situational awareness and enable the pilot to maintain the tight trajectories anticipated.

Simultaneous Non-Interfering/Runway Independent Aircraft Operations

The SNI/RIA Concept of Operations represents what is likely the most demanding operation to be supported by advanced Rotorcraft and CTRs. Airspace studies envision advanced Rotorcraft and CTRs separated from conventional fixed-wing traffic while both are operating at comparable speeds (e.g. 250 knots when operating below 10,000 feet). The advanced Rotorcraft and CTRs use their inherent, excellent low-speed operating characteristics to fly paths with tighter turning radii than is possible with fixed-wing aircraft, and to fly potentially steeper final approaches (nominal six degrees for helicopters and up to nine degrees for powered-lift aircraft) to clear obstructions. The low-speed operating characteristics can lead to vertical landings, making for minimal Touchdown and Lift-Off Surface (TLOF) size.

The base assumption of current advanced rotorcraft and other airspace studies specifies RNP 0.3 navigation capability. Whether still tighter flight path capability will be required for SNI operations at congested hub airports remains a subject for study. The FAA has provided guidelines for the construction of procedures in an RNP environment. These procedures, however, fail to address the design of close-in decelerating approaches containing aggressive turns, the kinds of approach necessary for maneuvering around obstructions and restricted airspace. The design of flight paths in support of SNI/RIA is an ongoing research topic. If, as expected, tighter and more complex flight paths prove necessary, tighter tracking performance should be achievable, as already demonstrated in a 2004 NASA flight test that was reported in RTCA documents.

Community noise reduction represents another feature expected of advanced Rotorcraft and CTR operations in NextGen. Rotorcraft noise abatement procedures and new rotor designs address a different operating issue than conventional fixed-wing aircraft. Much of conventional fixed-wing aircraft noise abatement centers on take-off as high thrust requirements for acceleration to flight speed and climb dominate noise generation. Conversely, rotor physics leads to most high-noise operation occurring with positive rotor angle of attack, conditions that occur during deceleration and descent. Rotorcraft and CTR noise abatement solutions are expected to come from both rotor design for source noise reduction and from flight operation design. Noise abatement operations (e.g., flaps and nacelle angle for powered-lift aircraft) will tightly control aircraft operating state (e.g., speed, descent rate, and aircraft configuration), as well as flight path. Noise abatement flight paths on approach to landing might be quite different than conventional fixed-wing airplane paths. NASA is conducting a three year CTR study with an estimated conclusion date at the end of calendar year 2011.

Equipment Requirements for NextGen Rotorcraft and CTR Operations

Most Rotorcraft and CTR operations in NextGen will be supported by NextGen avionics developed for conventional fixed-wing aircraft but tailored to specific rotorcraft capabilities. Examples of this would include the current practice of designing avionics to accommodate lower altitudes and more severe vibration and RF noise intensities. Additional design differences such as control laws and information displays will become necessary as NextGen implements new, more complex procedures in the Far-term.

Guidance based on advanced airspeed measurement systems, GNSS, and inertial reference for position, speed and acceleration in the low-speed operating regime, remains a topic for ongoing development. At issue is use of the lowest speeds advanced Rotorcraft and CTRs are capable of in an instrument flight setting. The long-term goal is rotorcraft equipped for safe operation under all meteorological and environmental conditions, just as easily and safely as accomplished today in visual conditions.

While employing GNSS as the position source for low altitude navigation, rotorcraft may encounter obstructions which can reduce viewable satellites below levels needed for continued safe navigation to ensure accuracy and integrity. Satellite constellations other than GNSS targeted for initial operating capability at the end of the next decade, however, will more than double the number of available satellites and mitigate the impact of obstructed satellites in some instances. This will require upgraded GNSS capability for aviation purposes. “Pseudolites”, or ground-based versions of GNSS satellites that transmit similar ranging signals, are another possible mitigation. The civilian GBAS and DOD Joint Precision Approach and Landing System (JPALS) perform the same function and encompass an airport or vertiport. Another solution might be higher accuracy, reduced drift, inertial navigation systems.

The advent of new technologies when coupled with GNSS accuracy will enable pilots to follow flight paths with greater accuracy. For example, NASA research has addressed this concern by demonstrating the use of a pursuit guidance cockpit display to manually fly a rotorcraft or Short Take-off and Landing (STOL) aircraft through a complex, multi-segment, decelerating approach trajectory. In the display a “leader” aircraft is symbolically displayed on the screen together with the flight path vector of the vehicle (see Figure 17). The pilot, by providing flight control inputs that places the flight path vector on the leader symbol, causes the vehicle to con-

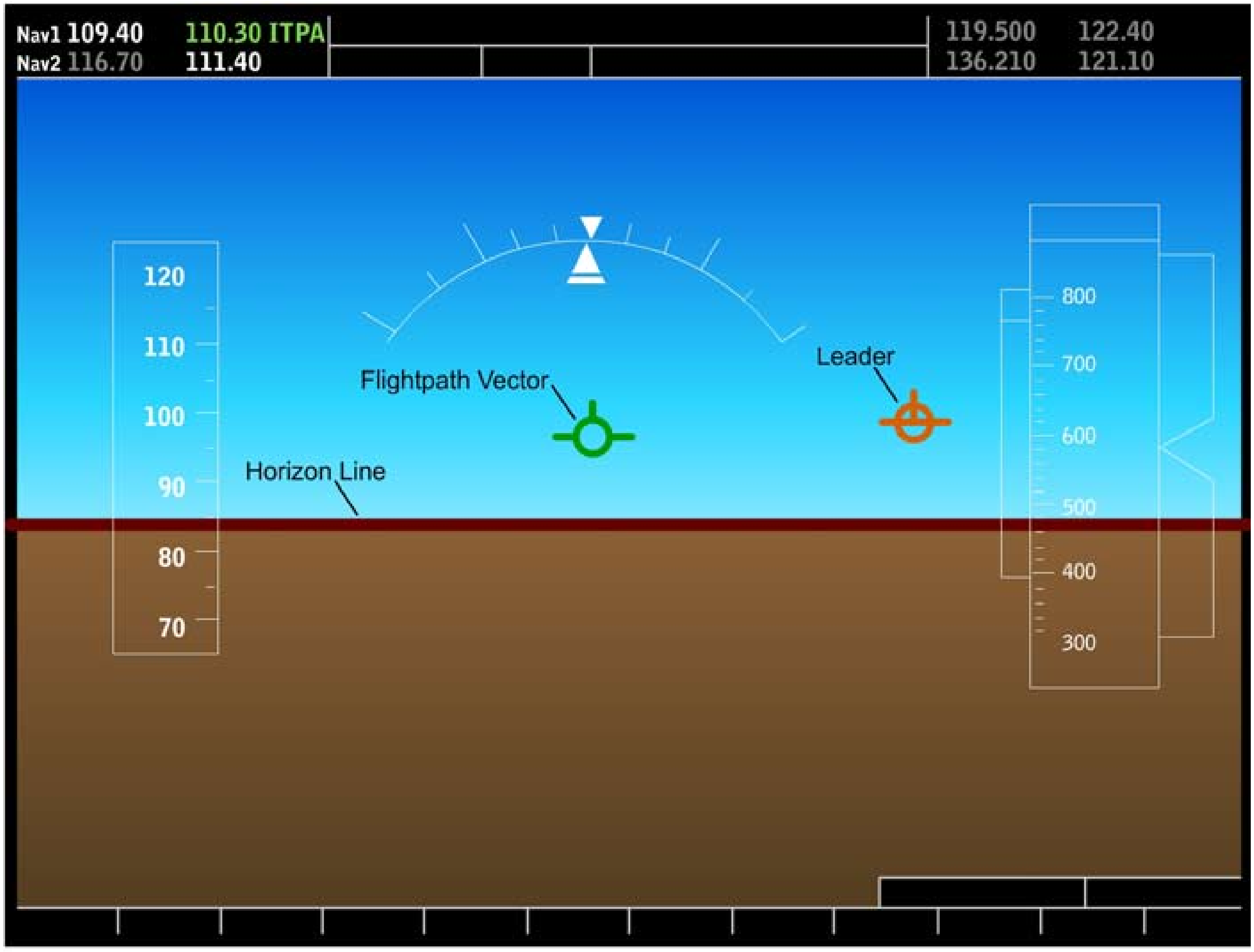

Figure 17 – Pursuit Guidance Display Concept

verge on the required trajectory. Flight evaluations of the pursuit guidance display establish that RNP boundaries equal to or less than 0.1 are achievable.

Research has shown that cockpit display of both traffic and wake information can provide benefits for rotorcraft and powered-lift aircraft, just as with closely-spaced parallel approaches (CSPA) for fixed-wing aircraft. As with precision guidance, the idea is to use cockpit displays to indicate not only the pursuit-guidance trajectory, but also to depict wake of trailed aircraft. Refining wake prediction algorithms for helicopters and powered-lift aircraft is the subject of ongoing research.

The need for surveillance, position accuracy assurance, and communications on the part of the airspace manager was cited during a 2004 NASA Rotorcraft Precision Flight Path Guidance Workshop. Rotorcraft take-off and landing operations away from conventional airport infrastructure likely will encounter line-of-sight obstruction, which block radio signals to and from the conventional communication and radar surveillance infrastructure. Some variation of the pseudolite transceiver idea may provide part of the solution. High-density operations at hub airports likely will require a similar solution to that already employed for closely-spaced parallel runways: precision approach radar surveillance. Note, however, that the line-of-sight surveillance and communication issue remains for the full spectrum of rotorcraft operations, and requires an airspace management solution beyond individual aircraft equipage. The current deployment of ADS-B may correct this problem since relatively low cost ADS-B transceivers can be placed to support SNI/RIA operations.

With regard to the particular characteristics of large powered-lift aircraft, NASA research has shown in simulation that these aircraft will prove unflyable with the control laws used in the current generation of V-22 Osprey. The large distance between the pilot and vehicle Center of Gravity (CG), in combination with cross-coupling of pitch and roll inputs, requires that the FMS incorporates a controller to help the pilot fly the aircraft. This is especially important to enable the maneuvering of large powered-lift aircraft in an urban heliport environment. The flight controller of the FMS will need to offer control laws for fly-by-wire systems that account for the latencies and large CG/pilot offsets.

In using ADS-B, the relevant Technical Standard Orders (TSOs) allow rotorcraft to always transmit airborne messages, even if on the ground. However, the ADS-B Out final rule (published 28 May 2010), which becomes effective on 1 January 2020, qualifies the TSOs by stipulating instead that rotorcraft must transmit airborne and grounds messages when airborne or on the ground, respectively, just as with fixed-wing aircraft. Unlike many fixed-wing aircraft, however, most helicopters lack a Weight-on-Wheels sensor. This, combined with horizontal and vertical speed capability largely independent of aircraft height above ground level (AGL), makes determination of Rotorcraft air/ground status a challenge. An additional sensor may be necessary, and a possible candidate is a radar altimeter. Use of a radar altimeter is already a requirement for certain rotorcraft operations (e.g., over water), but use is also being encouraged to reduce CFIT accidents . The above ground level (AGL) data from the radar altimeter, however, will need a hardware communication path into the ADS-B Out transmitter, and the transmitter will need software that reads and interprets AGL input to make an air/ground determination. An existing ADS-B Out transmitter may require an update or replacement if an interface to a radar altimeter proves necessary.

Data and voice communication, along with surveillance requirements for Rotorcraft will largely follow similar requirements for conventional fixed-wing aircraft. The key exception is where direct, line-of-sight communication is obstructed, as noted above for GNSS signal loss and airspace management position surveillance. Additional transceivers (ADS-B) co-located on cell phone towers, or use of commercial cell phone technology if able to meet safety and security requirements, may solve the line-of-sight problem.

Appendix 7: Key Policy Issues Associated with the Roadmap

Many of the same policy issues identified in the previous JPDO Avionics Roadmap continue to impact far-term implementation. A number of those issues (e.g., equipage, roles and responsibilities, lack of an identified alternative PNT approach) should be at least partially resolved by the time far-term applications are implemented. Far-term NextGen operations will increase the reliance on new sensors, automation, and decision support tools. These tools will allow the human role to evolve from carrying out repetitive tactical tasks to managing decision support tools, thereby providing improvements in achieving a flight's intended objectives. Consequently, the roles and responsibilities of pilots, controllers, and dispatchers will evolve further.

The increasing dependence on technology will impede NextGen implementation and lead to more stringent performance requirements and increased avionics costs. Striving for an accident-free NAS does not translate to zero risk, and failure-free technology is not realistic or affordable. Performance requirements must be combined and balanced with risk mitigations to achieve safety goals. Additionally, technology elements should be constructed as part of an overall system and be spread between aircraft and ground capabilities to reduce risk, manage cost, and minimize the impacts of failures through overlapping and interrelated capabilities.

Keys policy decisions in the following areas are required to achieve JPDO's NextGen goals. These areas include but are not limited to the following:

Balance of Human vs. Automation

The aviation community has made significant strides in adopting aircraft automation. NextGen will require another evolution in decision support tools and automation to support operations like merging, final approach spacing, CSPO, surface situational awareness, runway incursion alerting, and reduced landing minimums (enabled by enhanced vision systems). While these associated automation tools will provide users with greater situational awareness, they also increase the risk for data overload and distraction of the flight crews, controllers, and dispatchers. Finding the right balance between human involvement and automation represents one of the great challenges of NextGen. This balance includes safety, performance, and cost considerations.

Safety Requirements (Certification)

Certification levels need to be assigned early in the process for new avionics systems. There are significant cost and schedule risks to all stakeholders if they are not properly assigned. In addition, existing equipment should not have to be re-certified nor operational procedures currently approved/modified for the same operation. Assignment of design assurance levels will need to consider all applications of any enabling technology within all operational improvements. An example of this is new avionics characteristics as they relate to the hazard of misleading information. This could be a major risk for en route navigation, but hazardous if considered for approach indication and alerting. This example highlights the need to consider aircraft and infrastructure components as part of the system.

Equipage Incentives

US fleet, including commercial, military, and general aviation aircraft is diverse and equipping it will always present technical, logistic, and economic challenges. Incentives should be benefits driven or use economic incentives where insufficient benefits exist. Additionally, early adopters need to be "grandfathered in" or compensated for upgrades that cannot be incentivized by operational benefits. Policies for providing operational priority to early adopters are one way to provide a return on investment and incentivize equipage. These policies should leverage new operational capabilities enabled by new equipage whenever possible and be supported by formal FAA institutional performance goals.

When operational incentives are not possible, policy may include prioritization policies that are indirectly related to equipage. However, efforts to implement operational benefits/incentives should be exhausted before resorting to non-performance-based incentives. Some policy precedents may already be in place and provide the necessary policy foundation by the time the Far-term time frame arrives. Policy decisions may also be needed to sunset legacy technology and equipage when it hinders NextGen progress or is no longer economically viable.

A reduction in avionics costs and development time could be achieved by establishing a more cooperative non-adversarial process between the FAA and avionics manufacturers. One step would be to streamline the fragmented and non uniform approach to the current costly and extended process for avionics certification/TSO process.

Appendix 8: Trans-atmospheric Operations

Trans-Atmospheric Vehicles (TAVs) are those that divide their flight time between the NAS and the region above the NAS, including suborbital and orbital realms. Today TAV flights are rare, especially when compared to the numerous conventional commercial and military flight operations. NextGen's Far-term, however, is expected to see growth that approaches what can be described as routine, affordable commercial space transportation. Conventional operations in the NAS will need to accommodate this growth. Provisions for the unique high-speed, up-and-back flight operations of TAVs will need to be made.

Many NextGen airspace improvements will lend themselves equally to TAV operations. The planned distributed network-centric air traffic management (ATM) architecture will not only tie together TAVs with spaceports, user facilities, control centers, and range assets, but will interface with the planning, schedule, coordination, decision-making functions and weather data of the NAS. Just like the current concept of operations, TAV departures and arrivals will require a carefully controlled, perhaps even segregated, airspace – a "space transition corridor" between the ground and regions above NAS. The jurisdiction and authority that guarantees vehicle separation will be shared between ATC, below FL600, and Space Traffic Management above the NAS and up to low earth orbit (LEO) and beyond. In addition, 4D trajectory-based operations will prove beneficial to TAV operations, so NextGen improvements aimed at their establishment for conventional aircraft will eventually need to incorporate TAV operations as well.

Technology improvements in conventional avionics will surely migrate to TAV vehicles. The TAV flight envelope with its high altitudes and high speeds, however, makes unique demands on these avionics and so will require that additional measures be taken by the avionics manufacturers. For example, GNSS navigation will require equipment that continues to output at speeds well above 1,000 knots. FMS will need to be quicker and more responsive to meet the demands of a vehicle travelling at more than 2,000 knots. More generally, best practices used for space applications, including radiation-hardening, mechanical robustness, and weight reduction, will be needed to ensure the reliability and utility of TAV avionics.

Trans-atmospheric Vehicles

Development of the NextGen ATM undertaken in the near-term must account for expected changes that impact ATM in the Far-term. Though a rarity today, vehicles that bridge the divide between conventional atmospheric ones and sub-orbital/orbital ones are expected to be flying on a near-regular basis come the Far-term. These aircraft fall into one of two categories: Expendable Launch Vehicles (ELVs), intended to reach the upper atmosphere or space using propulsion from one or more expendable boosters, or Horizontally-launched Trans-Atmospheric Vehicles (TAVs) launched from the ground or after being ferried to high altitude by a conventional aircraft (i.e., "mothership").

The Space Shuttle exemplifies an ELV. Once spent, the booster separates from its payload (the manned crew vehicle), and the former plummets into the ocean. This type of system, however, can just as easily be unmanned. A case in point is the SpaceX cargo version of the reusable Dragon spacecraft, being developed under NASA's COTS program. The ELV in this case is the Falcon 9 booster. Re-supply of the International Space Station (ISS) will likely be via freight-carrying, unmanned ELVs now that the Space Shuttle fleet has been retired.

The TAV, despite a development history dating back to early NASA and Air Force Research Laboratory (AFRL) efforts, remains a commercial and military development item (though perhaps not for long). Rather than just orbiting a payload, its mission is to achieve sub-orbit or orbit, generally followed by a return to earth in a controlled manner. A current operational example – somewhat of an ELV/TAV hybrid – is Orbital Science's 3-stage Pegasus, launched from beneath a Lockheed L-1011 (a Reusable Launch Vehicle, or RLV) at 40,000 feet over the ocean. The Pegasus boosters are expendable (ELVs), however, the upper stage unmanned payload is on a one-way trip not intended for a return to earth.

Another TAV example, and one without ELV components - is illustrated by Virgin Galactic's initiative to commence commercial sub-orbital flights as early as fourth quarter 2011. A mothership (RLV), VMS Eve, will ferry the reusable VSS Enterprise, a manned spaceship the size of a Falcon 900 jet, to 50,000 feet. Once there, the Enterprise is dropped, its internal hybrid rocket engine fired, and a velocity of 2,500 miles per hour will be reached in a few seconds, carrying the TAV to an altitude of 70 miles. Following re-entry, the tail structure of Enterprise is "unfeathered" at 70,000 feet and it glides back to the spaceport runway.

In coming to grips with trans-atmospheric operations, it makes little difference whether the vehicle involved is an ELV or TAV. The specifics of launch, cruise, and recovery may differ, but the overall interaction and concerns with other aircraft are similar. For example, the mothership carrying a TAV payload can be treated as a conventional aircraft subject to a typical safety analysis, but once the TAV separates from the mothership it becomes an ATM anomaly, traveling at supersonic speeds of 2,500 mph while transiting Class A airspace. Separation standards for sub-sonic aircraft break down when having to account for an aircraft flying 5x faster than most aircraft around it, though short exposure times – a result of high velocity – help mitigate risk.

Commercial operations are expected to be in accordance with scheduled launch manifests and have preplanned flight profiles. Military operations will likely require more manifest flexibility (e.g., launch-on-alert) and flight profile flexibility. Also, whereas commercial systems could operate out of one or possibly two launch sites, military systems are expected to operate from disbursed launch locations. Either a commercial or military operation could be remotely-piloted or autonomous, in which case the same ATM considerations (e.g., sense-and-avoid) that apply to conventional aircraft operations would also apply to trans-atmospheric ones.

Regulatory Framework for TAV Operations

The regulatory approach today is for all trans-atmospheric flights infringing on the NAS to comply with CFR rules (Title 14, Vol. 4, Chap. III, Parts 400-1199 - "Commercial Space Transportation") and Federal Register amendments produced by the FAA Office of Commercial Space Transportation. In essence, for trans-atmospheric operations exclusion regions extending from the ground/ocean to 100,000 feet are calculated prior to dispatch and defined around launch site, landing site, and any impact sites in the case of ELV components. Ample notice must be provided to aircraft and ships so they can steer clear of the designated regions. So, maintaining separation today is accomplished via pre-departure planning and creation of segregated airspace. This same approach may be sufficient over the course of NextGen implementation in the immediate future; however, it cannot be taken for granted in the Far-term. Further analysis and speculation are needed.

NextGen Benefits for TAV Operations

To see how a commercial trans-atmospheric enterprise might benefit from NextGen, consider a system similar to the Eve/Enterprise configuration mentioned previously. The mothership departs and returns to its spaceport, which initially resembles a small private airport with no conflicting traffic. With passenger/astronaut ticket prices at their current level ($200,000), this spaceport model is unlikely to change. By the Far-term, however, ticket prices are expected to drop, which will stimulate demand and airborne traffic.

During much of its travels, the TAV will be under ATC jurisdiction. At some point, however, it leaves the NAS domain and transitions to the jurisdiction of a future entity charged with space traffic management. Coordination among these entities, along with the TAV itself and user control and support staff, will be necessary and enabled by advances in net-centric communication.

A mothership like Eve has a range of 2,000 NM with a potential need to fly en route through unsegregated airspace, ending with a drop/launch of its TAV payload at a specific time and location for trans-atmospheric flight along a particular trajectory. So, while potentially competing for air space with other aviation users, the RLV/TAV will seek to arrive at a particular location at a particular altitude at a particular time (especially if rendezvous with an existing orbital entity is a mission objective vs. a simple "there & back"). By its very nature, a 4D trajectory is defined and so would benefit from a number of NextGen Operational Improvements (OIs):

- OI-0311: Increased capacity and efficiency using RNAV and RNP
- OI-0318: Arrival time-based metering – controller advisories
- OI-0325: Time-based metering using RNAV and RNP route assignments
- OI-0337: Flow corridors - Level 1 static
- OI-0368: Flow corridors - Level 2 dynamic

Once the TAV is launched, its extreme dynamics remove it from simple NextGen analysis, so restricting it to segregated airspace, as is done today, is the likeliest scenario. Longer term, however, it – and even its mothership – would benefit from Far-term OIs that deal with special cases:

- OI-0346: Improved management of airspace for special use

- OI-0365: Advanced management of airspace for special use
- OI-0366: Dynamic airspace performance designation

Many other NextGen OIs also benefit TAV operators, just as they benefit operators of conventional aircraft. A mothership returning to its spaceport is subject to the vagaries of weather just like other aircraft, so would gain operational efficiency from OIs that provide network access to weather data:

- OI-2010: Net-enabled common weather information infrastructure
- OI-2020: Net-enabled common weather information - Level 1 initial capability
- OI-2021: Net-enabled common weather information - Level 2 adaptive control/enhanced forecast
- OI-2022: Net-enabled common weather information - Level 3 full NextGen

Other NextGen concerns possibly apply to TAVs even more than to conventional aircraft. National security and environment are two examples, stemming from the nature of a TAV's exotic fuel mixture and possibility for sensitive payloads, coupled with the TAV's inherent kinetic energy/speed:

- OI-4600: Reduced threat of aircraft and UAS destruction or used as a weapon

Trans-atmospheric Vehicle (TAV) Avionics

The avionics needed to support adoption of NextGen benefits in TAV motherships is identical to those for conventional aircraft. For example, a mothership will benefit from automated flight planning and control, so an FMS is likely to be a key avionics component of the flight deck. For the TAV itself, it too will benefit from an FMS. More generally, though the categories of TAV equipage are not that different from those of other aircraft, certain attributes of that equipage must satisfy its unique flight envelope.

As an example, a standard commercial GNSS is manufactured to enter Dead Reckoning Mode at speeds above 1,000 kts or altitudes above 60,000 feet mean sea level (MSL). These restrictions are engineered into the GNSS to comply with the Department of Commerce, Bureau of Export Administration's "Commodity Control List" that permits unencumbered GNSS shipments under General Destination (G-Dest) export rules only if so limited. Any TAV necessarily violates both the speed and altitude limitations, so GNSS – and likely other avionics equipage – for TAVs will need non-typical software to support NextGen GNSS-based initiatives (e.g., RNAV and RNP) requiring precise satellite-based positioning.

Environmental stresses on TAV equipage will be more severe owing to high altitudes and rapid accelerations. The former makes demands on radiation-hardening and protection against decompression. The latter makes demands on mechanical robustness (e.g., vibration, shock, crash safety, etc.). Avionics manufacturers wishing to provide equipage for TAVs will need to adopt many "best practices" already applied in the space industry.

Because of the fuel penalties associated with accelerating a mass to high speeds and lifting it to high altitudes, the weight of avionics – like everything else on board the TAV – will need to be kept to a minimum. Conventional avionics enclosures, connectors, and wiring – even assembly techniques – will need to be examined in the context of weight-reduction, similar to exercises already conducted by manufacturers wishing to sell avionics and sensors to the small and mid-size Unmanned Aerial Vechicles (UAV) markets. Wider use of composite materials and less use of aircraft aluminum is expected.

Understandably many conventional NextGen operational improvements are based on further development and implementation of a distributed network-centric architecture. The TAV avionics suite will require communication equipment that can leverage this planned architecture. Spaceflight operations will need to access a network-centric communications capability that enables coordination and control of space transportation assets and activities throughout the United States – and ultimately around the world – using a variety of operation/mission control centers and user facilities that carry out data storage and manipulation for reasons such as vehicle health and payload analysis.

Appendix 9: RNP and ADS-B

RNAV is a method of navigation that permits aircraft operations on any desired flight path. RNP is a statement of navigation performance necessary for operations within a defined airspace. RNP avionics provide on-board integrity monitoring and alerting.

ADS-B provides a surveillance technique in which aircraft automatically provide, via a data link, data derived from on-board navigation and position-fixing systems, including aircraft identification, four dimensional position, and additional data as appropriate. ADS-B In will provide significantly improved situational awareness for flight crews and may also enable delegated and self separation capabilities. RNP, Data Comm, and ADS-B form the core elements ofFar-term Operational Improvements (OIs).

NextGen far-term capabilities may provide additional benefits, such as use of aircraft intent transmitted via ADS-B to enhance airborne collision avoidance systems. Operational Improvements from increased RNP use may include flow corridors and reductions to separation minima. The core elements of the Far-term will enable 4D trajectory operations as well as enhanced merging and spacing in congested airspace near airports and metroplexes.

RNAV and NextGen Navigation

RNAV is a key element of NextGen navigation and largely attributable to the ubiquity of aviation-certified Global Navigation Satellite Systems (GNSS). No longer limited by ground-based navigation aids (e.g., VOR, NDB, TACAN), operators are free to seek optimal routings between origin and destination. This freedom permits greater flexibility. The result: more aircraft can take advantage of a given quantity of airspace without compromising safety and airspace efficiency. This added capacity is essential to the ongoing expansion of the world economy and material well-being since global progress goes hand-in-hand with higher demand for passenger and cargo air traffic.

Role of RNP in Airspace Capacity

RNP differs from RNAV in that it includes onboard integrity monitoring and alerting. This feedback of position information with high accuracy and low latency reduces error margins necessary for safe aircraft operations in areas of reduced separation and obstacle clearance. The result is that air navigation service providers (ANSPs) may be able to design routes, Standard Instrument Departures (SIDs) and Standard Terminal Arrivals Standard Terminal Arrival Routes (STARs), and approaches that allow reductions in aircraft spacing and obstruction clearance. RNP values that are expected to be utilized in NextGen airspace have been defined by the International ICAO and include the following values: RNP-4, RNP-1, RNP 0.3, and RNP-0.1.

The number of RNP-certified aircraft will expand into the Far-term and will be significant in determining the utilization of these procedures. In the Far-term, new avionics capabilities evolve that will further enhance the availability and use of RNP procedures.

Certain limitations of existing FMS will need to be overcome to realize the full potential of RNP. Harmonized standards across FMS systems will be required to ensure that all FMS perform certain functions in the same manner (e.g., turn performance, vertical navigation, time of arrival control, etc.). Current FMS have varying degrees of turn performance that while not significant, if standardized will provide greater turn consistency. A significant benefit may be achieved through the development of vertical navigation standards for both geometric and performance-based vertical navigation. Development of these standards has not yet started so it's likely that full integration into the air carrier fleet will not occur until well into the Far-term. The aircraft working group strongly recommends initiation of this activity as soon as possible.

Role of ADS-B in Airspace Efficiency

ADS-B Out will become the primary surveillance system in the Far-term with radar serving as the backup system. ADS-B services will provide more accurate position and intent information that may support reduced separation standards and support 4D trajectory-based operations. In the Far-term, ADS-B In services may enable additional capabilities as Surface Movement, Indicating and Alerting on the flight deck, and In-Trail Climb Procedures. It will also be a core element of 4D trajectory-based operations. Other applications of ADS-B In may include: closely space parallel approaches with delegated separation, en route delegated separation, and self separation.

ADS-B and RNP: Technology Enablers (ENs) and Operational Improvements (OIs)

In the Far-term, ADS-B Out avionics enhance airborne collision avoidance (EN-0222: Airborne Collision Avoidance – Level 4). TCAS is an airborne surveillance system that warns flight crews of potential collisions. Trajectory-based TCAS, will leverage lateral and vertical navigation intent data from ADS-B to determine if aircraft trajectories create a collision threat in a way that reduced false alerts while not increasing nuisance alerts compared to existing TCAS.

ADS-B may support cockpit display of airport taxiways, runways, ramps, and surface structures while depicting the aircraft's position overlaid by taxi route clearance (EN-0226: Surface Moving Map - Level 2). Key to this enabling capability is that all aircraft and surface vehicles are equipped with ADS-B Out. Aircraft displaying surface movement on a map display may need ADS-B In, as well as application software for alerting the crew when a potential collision threat arises. Typical threats include aircraft on short final or about to taxi onto a runway. Taxiing threats would include aircraft approaching each other head-to-head or converging.

ADS-B In will play an important role in self-separation, in which the flight crew has responsibility for maintaining safe separation distances even in airspace nominally under radar surveillance, captured in the following far-term OIs:

- OI-0359 Self-Separation Airspace - Oceanic
- OI-0362 Self-Separation Airspace Operations
- OI-0363 Delegated Separation - Complex Procedures

RNP capability enables a flight crew to maintain a desired flight path with high accuracy, enabling reduced separation without compromising safety, captured in the following OIs:

- OI-0343 Reduced Horizontal Separation Standards, En Route - 3 Miles
- OI-0348 Reduced Separation - High Density Terminal, Less Than 3 Miles
- OI-0354 Reduced Oceanic Separation and Enhanced Procedures

Flow corridors will require adherence to corridor containment constraints if multiple flow corridors are to be supported in limited airspace. RNP provides the necessary position monitoring and crew alerting of excessive deviation to achieve this objective. Related far-term OIs include the following:

- OI-0357 Flow Corridors - Level 1 Static
- OI-0368 Flow Corridors - Level 2 Dynamic
- OI-0350 Flexible Routing

Combining the accuracy of RNP with 4D flight paths allows greater traffic densities in congested airspace. This is notably so on and near airports and metroplexes where numerous aircraft are competing for the same terminal airspace during approach and departure operations. Related far-term OIs include the following:

- OI-0339 Integrated Arrival/Departure and Surface Traffic Management for Metroplex
- OI-0338 Efficient Metroplex Merging and Spacing

Appendix 10: International Civil Aviation Organization (ICAO) Aviation System Block Upgrade

The Aviation System Global Block Upgrade (ASBU) initiative was launched as an outcome of the 37th ICAO General Assembly to facilitate the interoperability, harmonization, and modernization of air transportation worldwide. ASBU is seen as a method for ICAO to assist its Member States in developing a programmatic, collaborative approach for a harmonized set of air traffic management (ATM) solutions to meet aviation's global needs for interoperable airspace.

The specific elements of the Block Upgrades are being defined by a team subject matter experts from the FAA, JPDO, Single European Sky ATM Research Joint Undertaking (SESAR JU), EUROCONTROL, International Air Transport Association (IATA), International Federation of Air Line Pilots' Associations (IFALPA), International Federation of Air Traffic Controllers' Associations (IFATCA), Civil Air Navigation Services Organisation (CANSO), Airports Council International (ACI), International Business Aviation Council (IBAC), International Council of Aircraft Owner and Pilot Association (IAOPA), RTCA and the European Organisation for Civil Aviation Equipment (EUROCAE). Additional expertise and perspectives are provided by industry through the International Coordinating Council of Aerospace Industries Associations (ICCAIA) and the JPDO's NextGen Institute.

Modules consider a broad number of the factors including:

- Goals and plans in the ICAO Global ATM Concept and Global Air Navigation Plan
- Existing detailed plans for NextGen, SESAR, Collaborative Actions for Renovation of Air Traffic Systems (CARATS), others, and experience
- The criticality of global interoperability and harmonization in ATM modernization
- Current knowledge on the feasibility of the modules
- The need for balance, clear rationale and measurable value in implementation
- The notion of building upon existing advanced but underutilized capabilities
- Recognition of the risk element in implementation and risk identification considerations
- Challenges in moving forward

What is an Aviation System Block Upgrade (ASBU)?

An ASBU consists of a series of modules containing well-defined ATM improvements that can be implemented globally from a defined point in time to enhance the performance of the ATM system. A module can be the grouping of communications, navigation, and surveillance components on the aircraft, and a communication system and ground components of air traffic control (ATC) automation, or decision support tool for controllers, etc.

Each module can be tailored to meet the needs of a state or region and will offer performance benefits, supported by procedures, technology, regulation/standards as necessary, and a business case.
The following Blocks have been defined:

- Block 0: Available to be deployed globally from 2013
- Block 1: Available to be deployed globally from 2018
- Block 2: Available to be deployed globally from 2023
- Block 3: Available to be deployed globally from 2028 and beyond

The dates refer to the availability or ability to use associated performance improvements in an operational manner and generate operational benefits. For Block 0, no new airborne technologies are required, although modules may imply the deployment of existing technologies to a larger aircraft population depending on chosen modules respectively paired with tied benefits.

Risks, Challenges, and Next Steps

All programs face risks and require appropriate mitigation strategies. The most significant risk in global airspace modernization is related to the timing and mix of technical, institutional, and infrastructure requirements. ASBUs are an attempt to mitigate the risks anticipated in establishing a globally harmonized airspace.

As airspace is "right sized" to a state's unique needs and a business case is developed that supports measureable and tangible operational benefits, there are a set of risks that exist independent of the specific solution chosen, including the following:

- Non-homogeneous deployment across the ICAO Regions
- Lack of synchronization of air and ground deployments
- Future investment in the existing ATM programs by key stakeholders will not be secured
- Delays in standards development and approvals
- AIM is not implemented in a global interoperable way
- SWIM not implemented in correct form

ICAO is working on the deployment of ASBUs to resolve many of these risks. The timing and sizing of the ABSUs are, in part, an effort to allow for development of mature standards, integrated air and ground solutions, and establishment of positive business cases. Capabilities that lack specific maturity in content or described benefit are purposefully placed in the later Block Upgrades.

Establishing a roadmap for implementation will allow for discussion and resolution of open issues associated with the specific risks that may be attributed to ASBU. For standards-setting organizations (e.g., ICAO, RTCA, Eurocae, SAE), the ASBU could become the basis for harmonization and delivery of globally harmonized, interoperable standards. This would assist in reducing the complexities and challenges of providing a global foundation of standards and equipage leading to achieving the goal of harmonized global airspace modernization.

The global mapping of ICAO's ASBU and various roadmaps constituting a revamped Global Air Navigation Plan are expected to be the main topic for discussion at ICAO's 12th Air Navigation Conference in November 2012.

Participants of the Aircraft Working Group

Participants of the Aircraft Working Group	
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Acronym List

4D ASAS	4D Airborne Separation Assurance Systems
AC	Advisory Circular
ACAMS	Aircraft Condition Analysis and Management System
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AIAA	American Institute of Aeronautics and Astronautics, Inc.
ALPA	Airline Pilots Association
ANP	Air Navigation Plan
ANS	Air Navigation System
ANSP	Air Navigation Service Provider
AOA	Aircraft Operation Area
AOA	ATN Over ACARS
AOC	Airline Operations Center
AOPA	Aircraft Owners and Pilots Association
ARINC	Aeronautical Radio Incorporated
ARM	Avionics Roadmap
ASDE-X	Airport Surface Detection Equipment, Model X
AT	Air Traffic
ATC	Air Traffic Control
ATIO	Aviation Technology, Integration and Operations
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATO	Air Traffic Organization
AWG	Aircraft Working Group
CAASD	Center for Advanced Aviation System Development
CAST	Commercial Aviation Safety Team
CATM	Collaborative Air Traffic Management
CAVS	CDTI Assisted Visual Separation
CDA	Continuous Descent Arrival
CDROM	Compact Disc Read-only Memory
CDTI	Cockpit Display of Traffic Information
CEFR	CDTI Enhanced Flight Rules
CFIT	Controlled Flight into Terrain
CFR	Code of Federal Regulations
CM	Configuration Management
CMU	Communications Management Unit
CNS	Communication Navigation and Surveillance
COI	Community of Interest
CONOPS	Concept of Operations

CPDLC	Controller Pilot Data Link Communications
CSPO	Closely-Spaced Parallel Operations
CSS	Cooperative Surveillance System
CTA	Controlled Time of Arrival
DS	Delegated Separation
D-TAXI	Digital Taxi Clearance
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instrument Systems
EFVS	Enhanced Flight Vision Systems
EN	Enabler
ERAU	Embry-Riddle Aeronautical University
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FCM	Flow Contingency Management
FDMS	Flight Deck-Based Merging and Spacing
FIS-B	Flight Information Service-Broadcast
FL	Flight Level
FMC	Flight Management Computers
FMS	Flight Management Systems
FOC	Flight Operations Center
FAROA	Final Approach Runway Occupancy Alerting
FMC	Flight Management Computers
FY	Fiscal Year
GA	General Aviation
GBAS	Ground Based Augmentation System
GLONASS	Global Navigation Satellite System (Russia)
GLS	GNSS Landing Systems
GNSS	Global Navigation Satellite System
GOMEX	Gulf of Mexico
GPS	Global Positioning System
GRAS	Ground-based Regional Augmentation System
GSE	Ground Support Equipment
HMI	Human-Machine Interface
HUD	Head Up Display
IA	Initial Approach
ICAO	International Civil Aviation Organization
ID	Identification
IFR	Instrument Flight Rules
IIFD	Integrated Intelligent Flight Deck
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions

IPSA	Interagency Portfolio and System Analysis
IRAC	Intelligent Resilient Aircraft Control
IVHM	Integrated Vehicle Health Management
IWP	Integrated Work Plan
JIMDAT	Joint Implementation Measurement Data Analysis Team
JPDO	Joint Planning and Development Office
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical Guidance
LSA	Light-sport aircraft
LTA	Lighter than air
LV	Low Visibility
MDCRS	Meteorological Data Collection and Reporting System
MEA	Minimum En Route (IFR) Altitude
MEM	Memphis
MFD	Multifunction Display
MMC	Marginal Meteorological Conditions
MT	Mid-Term
MVA	Minimum Vectoring Altitude
NARP	National Aviation Research Plan
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASEA	National Airspace Enterprise Architecture
NextGen	Next Generation
NGIP	NextGen Implementation Plan
NOTAM	Notice to Airmen
NPRM	Notice of Proposed Rulemaking
NT	Negotiated Trajectory
OC	Operational Capability
OE	Operational Errors
OEP	Operational Evolution Partnership
OI	Operational Improvements
PANS	Procedures for Air Navigation Services
PARC	Performance-based Aviation Rulemaking Committee
PBN	Performance-based Navigation
PFD	Primary Flight Display
PRP	Published Routes and Procedures
RAA	Regional Airline Association
RAAS	Runway Awareness and Advisory System
RAMP	Ramp Manager
RBA	Risk Benefit Analysis
R&D	Research and Development
RF	Radius to Fix

RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SAA	Special Activity Airspace
SAFE	Safety Enhancement/Hazard Avoidance & Mitigation
SATCOM	Satellite Communications
SBAS	Space Based Augmentation System
SBS	Surveillance and Broadcast Services
SESAR	Single European Sky ATM Research Programme
SEVEN	System Enhancement for Versatile Electronic Negotiation
SID	Standard Instrument Departure
SM	Separation Management
SOC	Systems Operations Center
STAR	Standard Terminal Arrival Routes
SVS	Synthetic Vision Systems
SWIM	System-Wide Information Management
TAA-Piston	Technically-Advanced piston GA Aircraft
TAWS	Terrain awareness and warning system
TBD	To Be Determined
TBO	Trajectory-based Operations
TOPs	Trajectory Operations
TCAS	Traffic Alert Collision and Avoidance System
TFR	Temporary Flight Restrictions
TIS-B	Traffic Information Service - Broadcast
TMU	Traffic Management Unit
TSO	Technical Standard Order
UAPO	Unmanned Aircraft Systems Program Office
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
US	United States
VDL-2	VHF Digital Link Mode 2
VDR	VHF Digital Radio
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
WAAS	Wide Area Augmentation System