National Aeronautics and Space Administration

Next Generation Air Transportation System (NGATS) Air Traffic Management (ATM)-Airspace Project

Reference Material

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1. Technical Plan

1.1 Relevance

As a cornerstone of the U.S. economy, aviation is a key catalyst for economic growth and has a profound influence on our quality of life. The Federal Aviation Administration (FAA) and industry forecast that air traffic operations are expected to increase 150 to 250 percent over the next two decades. Analysis of even the conservative growth estimate shows a significant lack of existing and planned capacity.[1] Coupling this with the proportional economic relationship between growth in the Nation's gross domestic product (GDP) and air travel require the Nation to invest in this critical infrastructure if we choose not to stagnate as a major world economy. In response to this crisis, the Commission on the Future of Aerospace in the United States has recommended the transformation of the U.S. air transportation system as a national priority. This recommendation was shortly followed by the 108th Congress and the President passing and signing into law the Vision 100 – Century of Aviation Reauthorization Act which led to the formation of the Interagency Joint Planning and Development Office (JPDO). The JPDO is charged with developing the vision for the 2025 Next Generation Air Transportation System (NGATS) and defining the research required to achieve that vision.[2] The NGATS vision calls for a system-wide transformation leading to a new set of capabilities that will allow the system to respond to future needs of the Nation's air transportation. The list includes communication and physical infrastructure, the acceleration of automation and procedural changes based on 4-dimensional (4D) trajectory analyses to substantially increase capacity with safety and efficiency of the National Airspace System (NAS), and dynamic reconfiguration of airspace to be scalable to geographic and temporal demand. A key element of the NGATS vision is the complete transformation to the concept of Trajectory-Based Operations in a Performance-Based environment. A key set of functions called the "Evaluator" concept, creates and evaluates proposed 4D aircraft trajectories and proposed trajectory updates with, weather, and other airspace resources and constraints ensuring compatibility and an efficient flow of traffic. Conceptual components of Trajectory-Based Operations (including the "Evaluator") operate over a wide range of time horizons that include airspace configuration, national traffic flow management, regional flow control, and traffic deconfliction. The primary focus of the NGATS ATM-Airspace project is to explore and develop integrated solutions providing research data to define and assess the allocation of ground and air automation concepts and technologies including the human roles necessary for the NGATS.

1.1.1 Current State of the Art and Value Added Contribution

Today's air transportation system in the U.S. is an extremely large, complex, and loosely integrated network of systems, procedures, and infrastructure with the primary goal to safely expedite the movement of people and goods. The National Airspace System (NAS), as it is known, services and encompasses a myriad of stakeholders, each having their own, and often conflicting, multi-objective goals and desired outcomes. These goals and objectives range from the air transport carriers desire to make a profit, the U.S. Government (through the FAA) requirement to ensure a safe and secure system, local governments (airports) desire to generate local economic activity and tax revenue, to the traveling public whom desire safe, inexpensive and expeditious trips including the leisure pilot's desire to fly freely. The primary daily control is executed through the actions of the "triad" of airline operations centers (dispatchers), aircraft operators (pilots) and the FAA (air traffic service provider). The process of control is primarily through the use of surveillance radars, voice radio systems and limited computer support systems coupled through numerous complex procedures. As an example, a nominal (air carrier) operation in today's system for a typical aircraft flying from Los Angeles to Chicago will start the process with the airline dispatcher scheduling and coordinating airline resources (e.g., pilots, planes, gates, etc.), then issuing a flight plan request to the FAA for service. The pilot will then execute this request through communication to tower air traffic controllers who will coordinate issuing a clearance to move from the aircraft's gate location. This is followed by the pilot interacting with numerous other controllers that control movement in specific areas on the ground or air with little regard for what is happening upstream. For this typical flight the pilot will communicate and receive clearances from 15 to 20 air traffic controllers from push back at the origin gate to docking at the destination. On a typical day with-in the NAS, 60,000 flights are flown. Couple this non-integrated distributed control paradigm with the cognitive human limitation that restricts the number of aircraft an individual air traffic controller can handle, and it is easy to understand how today's system has severe limitations on operational flexibility and overall capacity.

In the mid-1980s the concept of time-based management to integrate the distributed control paradigm of ATC was emerging from NASA fundamental research.[3] In the decade of the 1990s this research, built on the foundation of 4D trajectory prediction, was advanced to the development of laboratory prototype technologies that showed significant benefits for the NAS.[4] This led to a historic collaboration between NASA and the FAA, first to further detail the analytical benefits,[5,6] and then to validate the operational performance of the most mature trajectory-based technologies.[7,8] During the late 1990s and to the present, the FAA has made significant national investment to deploy these technologies through its Free Flight Program[9] as well as supporting directed research to enhance core NASA technologies.[10,11] The FAA controller workforce issues have limited some of the total national benefits,[12] but the associated operational fielding activities provided NASA with vast, unique experiences and skills. During the same period NASA began to explore advancements both in national traffic flow management[13,14] and the integration of flight deck into trajectory-based operations.[15,16,17] NASA also has made great strides in the systemic modeling of the NAS, including the analysis of benefits for revolutionary operational conceptual changes to the NAS.[18,19,20,21] This research is the springboard from which the NGATS ATM-Airspace project will make the technological enhancements for the NGATS to operate at the three times demand level.

1.1.2 Alignment with JPDO Vision

The JPDO outlined the needs of NGATS by specifying a vision and operating principles. Of major consideration in the principles is that the future Air Traffic Management (ATM) systems will consider user needs and performance capabilities, utilize trajectory-based operations, and optimally utilize human capabilities, automating, where appropriate, the functions performed by pilots and controllers. The NGATS vision calls for the human role within the system to move toward strategic decision making, and the tactical separation role moves towards full automation. The system will be designed to accommodate global use and environmental constraints. Embedded within these operating principles is a set of capabilities that are viewed as critical to success. These include: 1) Performance-based services, which will allow the NAS to respond to user investments that enable higher levels of performance; 2) Trajectory-based operations, which is the basis for changing the way traffic is managed in the system to achieve increases in capacity and efficiency; 3) Super-density operations, which maximizes the use of our limited runways at the busiest airports; 4) Weather assimilated into the decision making, allowing probabilistic planning over long time horizons; 5) Equivalent visual operations, which will allow the system to maintain visual flight rule capacities in instrument flight rule conditions; 6) Layered adaptive security, which assures our air transportation system is secure from terrorist activities without adding undue delay or hardship to the movement of passengers or cargo; 7) Broad-area precision navigation, which allows precise navigation anywhere in the airspace including precision landing at any airportal; and 8) Net-enabled information access, which will provide an affordable, reliable and secure means of enabling new applications dependent on information from multiple sources.

The JPDO NGATS FY08 Agency Budget Guidance calls for NASA research in many areas with the largest effort called for in the Aircraft Trajectory-Based Operations capability. It requests NASA research, working closely with the FAA, to develop methods and tools to inform design decisions on the allocation of NGATS functions between service provider and user and automation and human operators. NASA's interpretation of this guidance is to apply its capabilities and core competencies to develop methodologies and techniques to minimize or solve the demand/capacity imbalance problem in the NGATS future, building on the science of trajectory prediction. NASA proposed research for this critical need is described in the Dynamic Airspace Configuration (DAC) and Traffic Flow management (TFM) technical sub-sections. NASA also proposes research in the Separation Assurance (SA) and Airspace Super Density Operations (ASDO) technical sections where we will develop concepts and technologies that significantly increase the capacity of the NAS. This represents NASA's response to the overarching JPDO capacity requirements. Through analyses, prototyping, and the conduct of laboratory-based simulations and in special cases flight evaluations NASA with the JPDO, industry and academic partners will develop and provide design information to reduce the technical risk of a highly automated NGATS.

The Level chart, in Figure 1, shows the NGATS ATM-Airspace Project research and development activities in support of the JPDO's vision, NGATS concepts, and Internal Call for Proposal (ICP) technology development areas. The NGATS ATM-Airspace project includes research at all levels, with NASA sponsoring academic/industrial research partners concentrating on Level 1-2 areas and NASA with its JPDO contributing agencies and large "systems integrator" partners concentrating on the Level 3-4 areas. This way ARMD will ensure the in-

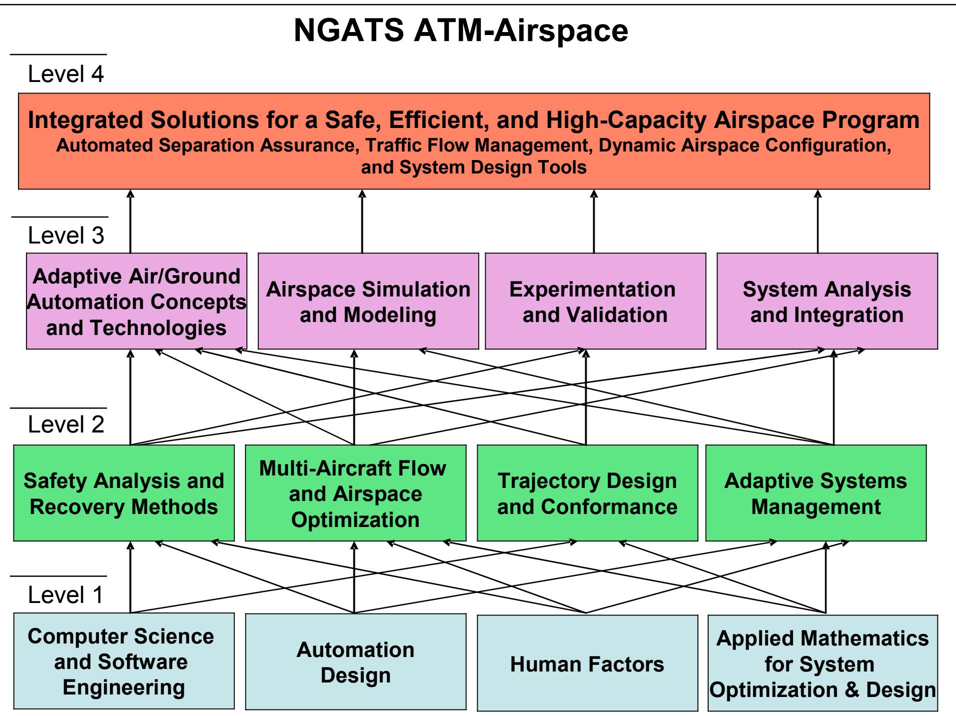

Figure 1. Level Chart

tellectual stewardship in these critical aviation science technical domains as well as developing research results and products to meet national needs as established by the JPDO vision. At level 1 are the foundational sciences necessary for the NGATS ATM-Airspace project, level 2 contains the critical disciplines, level 3 the inter-disciplinary activities and at level 4 the system design information necessary to enable the Next Generation Air Transportation System, desired by the JPDO.

The primary goal of the 10-year unconstrained product of the NGATS ATM-Airspace Project, as shown in the Level chart, is to develop integrated solutions for a safe, efficient and high-capacity airspace system. The NGATS ATM-Airspace project will draw on NASA's resident science core strengths at Levels 1, 2 and 3, as shown in Figure 1. The levels are a decomposition of the problem space, which map to the integrated solutions needed by the Aircraft Trajectory Based Operations for NGATS at the top and the sciences, disciplines and multi-disciplinary research at the lower levels. The technical approach will contain research and milestones at all of these levels with the majority at level 1 and 2. Each technical section has a unique focus but many areas are dependent upon the concurrent research in the other areas. The NGATS ATM-Airspace project is also based on the decomposition of the problem but along needed functions. The technical approach section of this reference material starts by describing the advancements necessary in trajectory prediction and analysis. Research in the Trajectory Prediction Synthesis and Uncertainty (TPSU) will be most directly used in the Separation Assurance (SA) and Airspace Super Density Operations (ASDO) technical areas to increase the capacity of the en-route, transition and terminal airspace. The TPSU will also provide basic trajectory predictions that will be advanced probabilistically for the needs of the Dynamic Airspace Configuration (DAC) to optimally move airspace capacity resources and Traffic Flow Management (TFM) to optimally modify airspace demand. The research in the Performance Based Services has a similar cross-cutting function as TPSU within the NGATS ATM-Airspace project by researching areas where new airborne capabilities can be utilized to aid DAC, TFM, SA and ASDO. Finally a holistic design view of the entire system is developed, analyzed and modeled to combine the overarching design attributes of NGATS in relationship to the functions NASA proposes to advance.

1.1.3 Justification for ARMD Investment

The operation of the NAS is an inherently governmental activity. NASA is the lead governmental agency to advance aviation related sciences and has, through numerous National Commissions and Policy Directives, been directed to conduct research to enhance the operations of the NAS. NASA and the FAA Administrators have entered into Memorandum of Understanding (MOUs), which charge NASA with conducting long-range ATM research. Through past and current contributions to the field, NASA has developed a uniquely skilled workforce, cutting edge research facilities and relevant products to advance the needs as identified by the JPDO. NASA's multi-disciplinary workforce has created revolutionary advancements to the state of the art. Some of NASA's better known products have either fully entered the NAS or have generated major innovations. These include, but are not limited to, the Center-TRACON Automation System, Traffic Management Advisor, Final Approach Spacing Tool, Direct-To, En Route and Descent Advisor, Future Airspace Concepts Evaluation Tool, Multi-Center Traffic Management Advisor, Surface Management System, Distributed Air-Ground Traffic Management concepts and technologies, and the Airspace Concept Evaluation System. There exists an impending national crisis to accommodate the future demand for air travel. It takes decades to make significant changes to the NAS, therefore it is vitally important for the ARMD to continue its ATM research and development in order to timely achieve the JPDO vision and meet national needs.

1.1.4 Coordination with the NGATS ATM-Airportal Project

Research and development activities described in this document must be tightly coupled with the work described in the response to the NGATS ATM-Airportal portion of the ICP. While it is acknowledged that the Airspace areas have unique constraints, the solution sets intended to address Airspace and Airportal issues are necessarily dependent upon one another to ensure systematic capacity improvements. Requirements, technologies, and procedures in the two environments must be exchanged and eventually integrated. For the purposes of this reference material, the functional division between Airportal and Airspace is the final approach fix (FAF) and the initial turn point on departures. Thus, functions, constraints, technologies, and procedures up to FAF are the focus of the NGATS ATM-Airspace Project, while optimizing surface operations, departure management, and wake vortex separation constraints are the focus of the Airportal Project. At the most basic level, the NGATS ATM-Airspace Project will deliver aircraft to the FAF within the constraints of the optimized surface operations and wake vortex limitations. The Airportal will deliver aircraft to the initial departure turn point considering the constraints of the receiving airspace system. The division represented in this and the Airportal reference material is intended to provide guidance for research, development, and resources.

The technical reason for the division is the recognition of the different degrees of freedom available to solve the capacity problem in Airspace and Airportal domains. It is clear that the surface movement is drastically different than movement throughout the airspace due to the severely restricted Airportal paths (taxiways, runways, ramps). But as aircraft get closer to the surface their paths also become very restricted due to the fact that they have to line up for landing on a specific runway at a specific aircraft energy state. Somewhere between 50 miles from the runway and the FAF is the area where the path constraints for landing will dominate the aircraft trajectory. Thus, this location was chosen to be the most logical demarcation.

1.2 Milestones and Metrics

Figure 2 shows the notional 10-year NGATS ATM-Airspace Project roadmap. At the end of five years, research results will provide information for design guidance and further research and development. During the ten-year plan validated algorithms and some prototype technologies that could accelerate the JPDO vision will be transitioned to the FAA and aviation industry for implementation. The details that are represented in the first 5 years are the concentration of this planning document. The five-year plan and associated milestones are detailed and provide the cost basis. The milestone listing provides an integrated numbering scheme, title, description where the title does not convey enough information, planned completion date, metrics, and precursor milestone dependencies. The milestones are ordered by level, technical area, and planned fiscal year for completion.

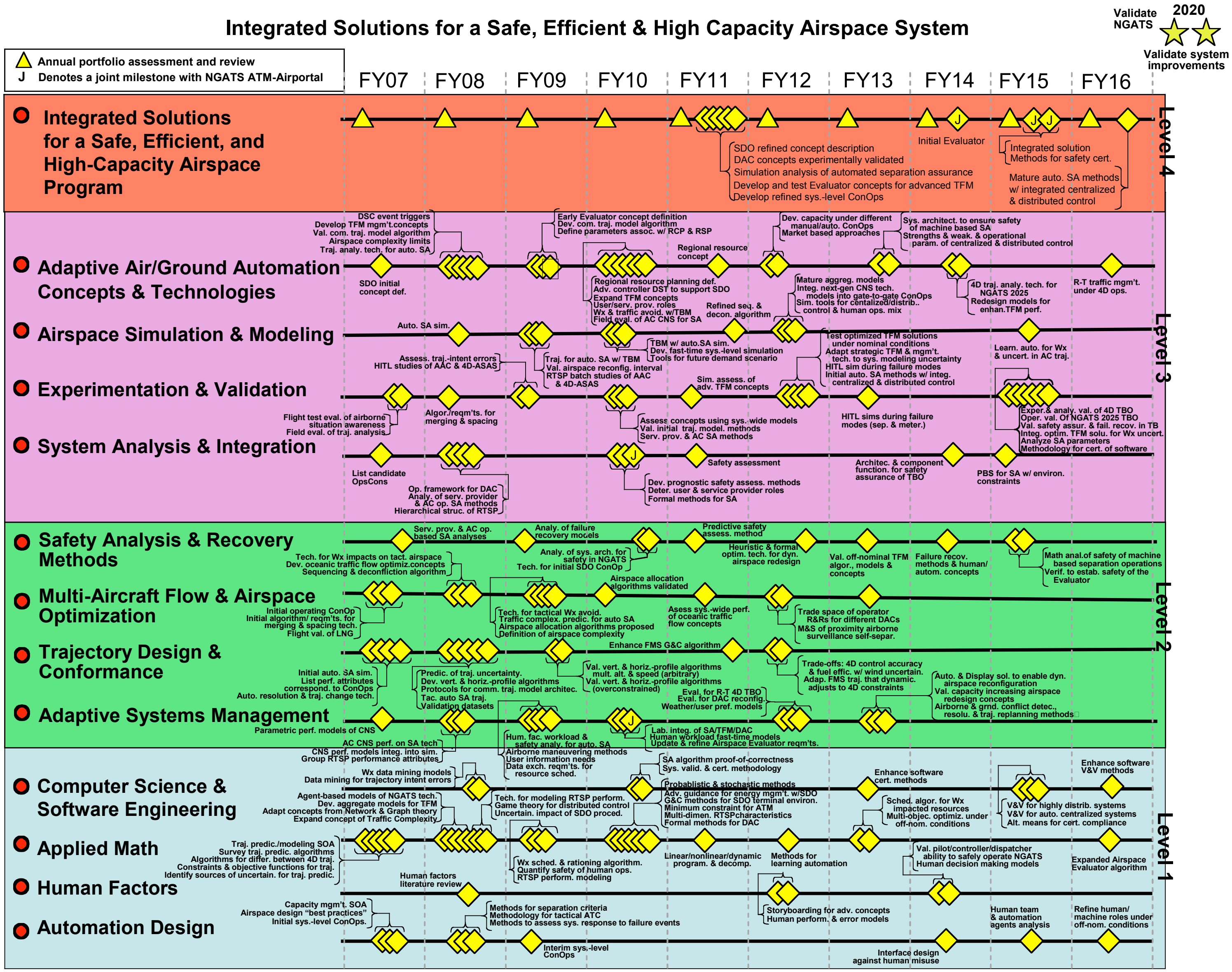

Figure 2. 10-Year Roadmap

Table 1. Milestone Numbering Scheme

Project	Level	Area	Description
AS	.4 .3 .2 .1	.1	Trajectory Prediction Synthesis and Uncertainty
		.2	Performance-Based Services
		.3	Dynamic Airspace Configuration
		.4	Traffic Flow Management
		.5	Separation Assurance
		.6	Super-Density Operations
		.7	System-Level Design, Analysis, and Simulation Tools

Table 2. Level 4 Milestones and Metrics

Number	Title	Description	Year	Metrics	Dependen-cies
AS.4.3.01	Dynamic airspace configuration concepts experimentally validated	The milestone will experimentally validate, via numerical simulations, the methodology and benefits of dynamically configuring airspace in response to projected aggregate demand. The output of this effort includes technical requirements and operational features such as the scope of reconfiguration, frequency of reconfiguration, and requirements such as advance notification for the airspace changes.	FY11	Frequency of airspace reconfiguration, extent of airspace reconfiguration, system stability measures, amendments and restrictions imposed on users, airspace complexity distribution	AS.3.3.01 AS.3.3.02 AS.3.3.03 AS.3.3.04
AS.4.4.01	Develop and test Evaluator concepts for advanced Traffic Flow Management to accommodate user preferences, reduce delays, and increase efficiency under all-weather conditions.	The purpose of this milestone is to develop and validate advanced algorithms and approaches to accommodate user preferences, reduce delays, and increase efficiency under nominal and off-nominal conditions. The TFM algorithms will include accommodation of 3x traffic demand under a variety of normal and severe weather conditions. The TFM algorithms will include both national and regional aspects to cover the appropriate planning horizons. The algorithms will address the appropriate balance between national and regional flow management for a set of traffic/weather scenarios, and will utilize a combination of deterministic and stochastic methods to increase the predictability of traffic, weather, and their interactions. The validation will include both objective and subjective data. Research will also be conducted to investigate the trade-offs service provider and aircraft operator control authority, e.g., gate-to-gate 4D contracts for “conventionally” equipped aircraft as well as point-type flow restrictions for 4D-ASAS equipped aircraft.	FY11	The specific metrics for this milestone include delays, throughput, fuel efficiency, flight duration, complexity distribution, workload, and user preference accommodation. The actual savings will be dependent on the concept of operations.	AS.3.4.01 AS.3.4.02 AS.3.4.03 AS.3.4.04 AS.3.4.05 AS.3.4.06
AS.4.5.01	Simulation analysis of service-provider-based automated separation assurance with complex traffic, metering, hazardous weather, and failure recovery.	The simulation incorporates results and lessons learned from prior technology, operating concept, and safety analysis milestones and focuses on safety in all traffic conditions including failure mode operations. The objective is to gather objective experimental data to establish the feasibility and safety of 4D trajectory based operations with service-provider-based automated separation assurance to achieve a substantial increase in capacity with safety and user preference.	FY11	Data to establish the safety, delay reduction, and user preference metrics of technology and operations as function of automation level, traffic complexity, and aircraft performance. Comparison of objective metrics with that of today’s operations.	AS.3.5.02 AS.3.5.03 AS.3.7.01 AS.3.5.04 AS.3.5.05 AS.3.5.06 AS.3.5.07 AS.3.5.08 AS.3.5.09 AS.3.1.03 AS.3.3.03 AS.3.4.03 AS.3.4.04 AS.3.4.05

Number	Title	Description	Year	Metrics	Dependen-cies
					AS.3.6.04
AS.4.6.01	ASDO refined concept definition	Refinement of initial concept considering lessons learned and more mature technologies and user feedback. Perform a detailed performance assessment using modeling, batch and HITL simulations. This milestone will be closely coordinated with the Airportal Project milestone L4.C.4.	FY11	Throughput/capacity at major airports and regional/reliever airports, noise and emissions impacts, delay reduction compared to no new technology/procedures and pilot and controller workload measurements.	AS.3.6.01 AS.3.6.02 AS.3.6.03 AS.3.6.04 AS.3.6.05 AS.3.6.06 AS.3.7.02
AS.4.7.01	Develop refined sys-tem-level concept of operations based on results of modeling, safety, cost-benefits, and human-in-the-loop simulations	The concept of operations will include both nominal and off-nominal conditions. The document will de-scribe concepts, technologies, information needs, functions, and roles and responsibilities. The concept of operations will also identify the rational for changes from the initial version and completeness and gaps in meeting the NGATS vision. Analyses performed using the NGATS system-level simulation from AS.3.7.02 will also guide development of the con-ops.	FY11	A refined concept of operations will be de-livered.	AS.3.7.02 AS.3.7.03 AS.1.7.04

Table 3. Level 3 Milestones and Metrics

Number	Title	Description	Year	Metrics	Dependen-cies
AS.3.1.01	Develop, validate, and document Common Trajectory Model algorithms and capabilities for NGATS applications within En-Route and transition airspace.		FY08	Trajectory accuracy, predictability	AS.1.1.02
AS.3.1.02	Common Trajectory Model algorithms validated terminal airspace, documenting accuracies and robustness.		FY09	Trajectory prediction accuracy, reliability	AS.3.1.01
AS.3.1.03	Comprehensive assessment of NGATS-relevant trajectory-intent errors.	Collection and analysis of a statistically significant set of airborne and ground-based intent information to determine the make up, frequency, and source of TP intent errors that NGATS must resolve to achieve targeted levels of system performance.	FY09	Trajectory prediction errors, intent errors	AS.3.1.02 AS.1.1.02
AS.3.1.04	Validation of initial trajectory modeling methods for representing NGATS-relevant (e.g., FAA) approach/departure procedures through terminal airspace accounting for specific runway, altitude and speed scheduling.		FY10	Trajectory prediction accuracy, reliability	AS.3.1.03
AS.3.2.01	Produce a list of candidate NGATS operational concepts.		FY07	NGATS vision mapping gaps	n/a
AS.3.2.02	Produce a detailed hierarchical structure of RTSP elements and advanced performance measures needed to support candidate NGATS operational concepts.	This architecture should enable operators to determine the level of service available for a given set of capabilities.	FY08	Organization of performance attributes to map with level of service	AS.3.2.01
AS.3.2.03	Working with industry and JPDO's Shared Situation Awareness IPT, define the parameters associated with RCP and RSP.	Refine initial RCP and RSP definitions as appropriate. (Milestone date contingent upon progress of government/industry committees.)	FY09	Definitions of RCP, RSP, RNP	AS.3.2.01 AS.3.2.02
AS.3.2.04	Parametric RTSP batch studies of AAC and 4D-ASAS concepts are completed under nominal and	Safety and efficiency metrics are recorded and results are used to make an initial determination of required performance capabilities needed to support the operational concepts.	FY09	Capacity, throughput, efficiency, safety, predictability	AS.3.2.01 AS.3.2.02 AS.3.2.03

Number	Title	Description	Year	Metrics	Dependen-cies
	failure mode conditions.				
AS.3.2.05	Human-in-the-loop studies of AAC and 4D-ASAS concepts are completed using minimum RTSP levels determined by previously performed batch studies.	Safety and efficiency metrics are recorded and an assessment of human impact on operational performance is made. Results are used to refine minimum RTSP levels for both concepts.	FY09	Capacity, throughput, efficiency, safety, predictability	AS.3.2.02
AS.3.3.01	Categorize events that trigger airspace reconfiguration	Develop a comprehensive set of scenarios under which airspace reconfiguration would be beneficial to NAS operations. Additionally, produce a catalog of the events that may trigger airspace reconfigurations, including an estimate of their characteristic parameters, the scope and likelihood of their occurrence, and their impact on NAS operations.	FY08	Number of scenarios documented, number of events catalogued	n/a
AS.3.3.02	Develop an operational framework for dynamic airspace configuration	Identify the fundamental structural elements of dynamically configured airspace. Specify how they combine to support various modes of operation. Examples include special airspace classes (tube networks connecting high-traffic airports[22]), airspace reserved for self-separating aircraft, and terminal airspace sectors utilized for both arrivals and departures.	FY08	Breadth and depth of taxonomy of the "building blocks" for airspace configuration and the "degrees of freedom" available to dynamically modify them.	AS.1.3.02 AS.3.3.01
AS.3.3.03	Airspace complexity limits for each class of airspace are analytically validated	In today's system the basic units of airspace are sectors, and the traffic level that can be safely handled by each sector is limited by controller workload. The NGATS features automated separation assurance and new roles/responsibilities for controllers. The output of this milestone is a set of guidelines for safe and efficient utilization of airspace. This effort will leverage prior work on dynamic density[23] to determine key parameters (e.g., geographic size/shape, traffic throughput) of airspace units under the DAC concept.	FY08	Binary: milestone completion status	AS.3.3.01 AS.3.3.02
AS.3.3.04	Validate by simulation that airspace could be reconfigured every four hours without adverse effects	This milestone will address operational constraints on the frequency of airspace reconfiguration. For example, while it might be beneficial to reconfigure airspace on an hourly cycle in response to a rapidly changing weather front, such rapid reconfigurations may cause transition problems arising from human factors issues such as cognitive adaptability. A preliminary step is to determine how often the airspace needs to be reconfigured (from a NAS performance perspective), based on the nature and time-scales of the events that trigger airspace reconfiguration. The output of this effort is an understanding of human operator issues and their impact on NAS efficiency in the context of DAC transitions.	FY09	Frequency of airspace reconfiguration, extent of airspace reconfiguration, system stability measures, amendments and restrictions imposed on users, airspace complexity distribution	AS.3.3.01 AS.3.3.02 AS.3.3.03
AS.3.4.01	Develop Traffic Flow Management concepts at the regional and national levels for different planning intervals to increase efficiency, reduce delays, and accommodate user preferences.	This milestone focuses on the development of advances TFM techniques that contribute to the goal of tripling NAS capacity by leveraging key features of the NGATS such as 4D trajectory-based operations, performance-based operations, automated separation assurance, and super-density operations. A key research challenge is to develop techniques that utilize both individual and aggregated 4D trajectories[13] to organize, schedule, and regulate traffic flow in accordance with calculated NAS capacity constraints. The spatial and temporal bounds of these constraints will be defined using advanced clustering leveraging prior work on gaggle density,[24] pattern recognition, dynamic density, and artificial intelligence techniques. The resulting TFM solution space will be analyzed to evaluate both service provider and aircraft operator control authority.	FY08	The output of this effort is an integrated set of advanced TFM concepts and the associated algorithms/models that will be integral to the development of the Evaluator.	n/a
AS.3.4.02	Early Evaluator concept definition and development, including initial concept of operation focused on national and regional TFM for increasing flow management	The purpose of this milestone is to define the relationships and operational transitions between TFM, dynamic airspace configuration, and separation assurance. As part of this activity, advanced techniques for assessing the impact of TFM initiatives[14] under both deterministic and stochastic scenarios will be developed. Candidate initiatives to be	FY09	The output of this effort will be a baseline Evaluator concept of operations that describes the composition and architecture of TFM functions as well as their	AS.3.4.01 AS.3.1.01

Number	Title	Description	Year	Metrics	Dependen-cies
	efficiency and accommodating user preferences.	examined as part of this effort include: rerouting and departure control at the national level; merging, spacing, and sequencing at the local level; and, sequencing and scheduling in multi-airport terminal areas. The benefits and utility of these TFM control strategies will also be assessed as part of this activity.		temporal and geographic scope.	
AS.3.4.03	Determine user and service provider roles to accommodate user preferences and increase efficiency.	The purpose of this milestone is to develop a methodology for incorporating user preferences into traffic flow management, building on prior work.[25] This activity involves determining appropriate roles and procedures that enable users and the air traffic service providers to collaboratively design efficient and equitable traffic management initiatives. Advanced tools and protocols will also be developed for formulating, evaluating, and implementing these collaboratively designed initiatives. An important component of these advanced capabilities will be sophisticated new algorithms that can allocate flights to capacity constrained NAS resources (e.g., airspace and runway) in a fair and equitable manner. The output of this activity will be algorithms, procedures, and protocols for fully integrating Collaborative Decision Making (CDM) into the TFM process.	FY10	The product of the milestone will identify the type of decisions that users and service providers should make to promote maximum efficiency, balance workload, and accommodate user preferences. The milestone report will also describe the information needs and exchanges to enable CDM to handle 3x capacity.	AS.3.4.01 AS.3.4.02
AS.3.4.04	Expand Traffic Flow Management concepts to address weather-modeling uncertainty to promote higher predictability and efficiency.	The purpose of the milestone is to develop probabilistic models to forecast demand and capacity of NAS resources (e.g., airspace and runways). The technical challenge is to develop modeling techniques that are robust to uncertainties such as weather conditions and substantial variations in user demand profiles. These stochastic forecasts are necessary for designing TFM control strategies (e.g., rerouting, departure delay, sequencing and scheduling) that will balance the forecasted supply/demand profiles in an equitable and optimal manner. A key component of this research activity will define weather forecast requirements for the aviation weather research community that will enhance the performance of both local and national level TFM.	FY10	The outputs of this activity are probabilistic models/algorithms, and weather product requirements, for improved predictions of NAS resource demand/supply under uncertainty.	AS.3.4.01 AS.3.4.02 AS.3.4.03
AS.3.4.05	Assess representative concepts for NGATS using system-wide models, and generate capacity, delay and predictability metrics.	The purpose of this milestone is to develop prototype tools to implement advanced TFM concepts utilizing 4D trajectories. This activity focuses on the implementation of various algorithms (e.g., probabilistic predictions of NAS resource demand/supply; regional metering and/or spacing; ground delay; customized rerouting incorporating user preferences) in a NAS simulation environment such as FACET.[26]	FY10	The output of this effort is a suite of advanced TFM tools integrated into a simulation test bed.	AS.3.4.04
AS.3.4.06	Simulation assessment of advanced TFM concepts.	The milestone will involve system-wide performance assessments of advanced TFM concepts for NGATS. The goal is to evaluate system-wide performance under various traffic and weather scenarios. This activity will require designing and performing numerical simulation studies, as well as higher fidelity HITL experiments to assess roles, responsibilities, procedures, displays, information needs, as well as accuracy and usefulness of algorithms. A key research challenge is to design performance metrics (e.g., capacity, delay, equitability, robustness) that will enable a system-level performance analysis using a RTSP approach.	FY11	The output of this effort will be a system-level simulation assessment of the feasibility and benefits of implementing advanced TFM techniques.	AS.3.4.05
AS.3.5.01	Flight test evaluation of an airborne situation awareness based application.	Through a series of flight trials in operationally relevant environments, assess the economic and operational feasibility of an airborne situation awareness based application known as ADS-B In-Trail Procedures. The flight trails will obtain operational data on the use of an airborne ADS-B application, preliminary system costs and benefits of an airborne ADS-B application and data on the use and role of airborne data for separation assurance. While these initial trials will not involve a delegation of separation responsibility to the cockpit they will investigate the roles and responsibilities of controller/pilot interactions when airborne data is included in the separation assurance process.	FY07	Metrics that will be obtained in these flight trials include fuel savings compared to normal operations, system effectiveness in a flight environment, and operational acceptance.	n/a

Number	Title	Description	Year	Metrics	Dependencies
AS.3.5.02	Field evaluation of trajectory analysis technology with aircraft CNS technology for time based metering.	En Route Descent Advisor (EDA) automation for conflict-free, time-based, arrival metering will be evaluated as a key component of the Boeing/NASA Tailored Arrivals (TA) concept. The field evaluation, involving trans-pacific arrivals into SFO, will integrate prototype EDA ground automation with aircraft CNS capabilities over Controller-Pilot Data-link Communications (CPDLC). The objectives of the experiment are: 1) measure the accuracy of EDA trajectory predictions in comparison with Flight Management System (FMS) predictions and actual track data; 2) measure the potential fuel savings and environmental benefits associated with the Continuous Descent Approach (CDA) procedures enabled by EDA/TA; and 3) study the integration of systems and procedures required to coordinate and execute trajectory-oriented arrival clearances across multiple airspace domains (i.e., oceanic, domestic en route, and TRACON)	FY07	Trajectory accuracy, fuel savings, noise footprint, workload, emissions	AS.2.5.02
AS.3.5.03	Trajectory analysis technology for automated separation assurance.	Laboratory analysis of 4D trajectory analysis methods, service-provider-based separation assurance algorithms, and prototype software for automated strategic and tactical separation assurance in en route and transition airspace under complex traffic conditions and in the presence of uncertainty and at 2-3x nominal traffic levels.	FY08	Trajectory efficiency comparable to or better than today's operations. Near zero losses of separation. Integrated and coordinated functionality for strategic and tactical resolutions. Integrated trajectory analysis for aircraft with mix of equipage. Trajectory analysis for limited failure modes. Results based on laboratory analysis of actual Center traffic data in en route and transition airspace. Metrics analyzed as a function of traffic density and complexity.	AS.2.5.02 AS.2.5.04 AS.2.1.03
AS.3.5.04	Service-provider-based automated separation assurance simulation.	Conduct human-in-the-loop simulations with air and ground operators focusing on service-provider-based automated strategic and tactical SA with expanded mixed equipage and failure recovery operations, refined aircraft CNS and failure mode models, and initial time-based metering technology and operations. Refine roles and responsibilities, human-machine interfaces, and SA technology. Document strengths and weaknesses of SA operating concepts and technology as a function of traffic density and complexity in the presence of uncertainty.	FY08	Objective experimental data to quantify human workload, safety, and trajectory efficiency as a function of human/machine operating concept during nominal and failure modes in en route & transition airspace. General consistency with laboratory derived metrics (e.g., AS.3.5.03) and understanding of inconsistencies. Subject matter expert feedback (FAA, airlines, controllers, pilots) on operating concepts.	AS.2.5.01 AS.2.5.02 AS.2.5.03 AS.2.5.04 AS.3.5.03
AS.3.5.05	Trajectory analysis for service-provider-based automated separation assurance with time-based metering.	Analysis and laboratory validation of trajectory analysis methods for the simultaneous solution of separation and time-based metering with user preferred trajectories for multi-aircraft converging flows under varied traffic density and complexity with failure modes and off-nominal conditions.	FY09	4D trajectory and SA automation achieves time-based metered arrival flows with overall delay and separation metrics comparable or better than that of today's operations while operating at increased traffic density with arrival stream densities comparable to that of today's operations in presence of uncertainty. Results based on laboratory analy-	AS.3.5.03 AS.3.5.04 AS.2.1.03 AS.2.1.05 AS.1.5.01

Number	Title	Description	Year	Metrics	Dependencies
				sis or actual Center traffic data in en route and transition airspace under a variety of traffic conditions.	
AS.3.5.06	Time-based metering with service-provider-based automated separation assurance simulation.	Expand human-in-the-loop simulation of service-provider-based automated SA to focus on controller/pilot roles & responsibilities for time-based metering with automated separation assurance under NGATS operations. Include expanded failure and recovery models and mixed equipage operations.	FY10	Understanding of human/machine allocation of functionality and service provider/aircraft operator allocation of operations and responsibility for heavy arrivals flows using time-based metering as a function of traffic density and complexity, in the presence of uncertainty, and with limited failure modes in arrival metering environment. Objective experimental data to quantify workload, safety, and trajectory efficiency during arrival flow management. Subject matter expert feedback (FAA, airlines, controllers, pilots) on operating concepts. Document strengths & weakness of concepts & technology as a function of traffic complexity.	AS.3.5.04 AS.3.5.05 AS.2.5.07 AS.2.5.09 AS.2.5.05 AS.2.5.06
AS.3.5.07	Technology for tactical weather and traffic complexity avoidance with time-based metering constraints.	Laboratory analysis of service-provider-based methods and algorithms for coordinated multi-aircraft weather re-routes with arrival metering constraints under 2-3x traffic density in the presence of uncertainty.	FY10	Tactical (5-20 min time horizon) rerouting for weather and traffic complexity avoidance results in factor of 2 improvement in tactical portion of a JPDO-derived overall NAS efficiency metric that accounts for delays, fuel-efficiency, and other factors as a function of overall weather and traffic density.	AS.3.5.06 AS.2.5.05 AS.2.5.06 AS.2.5.08 AS.2.3.01
AS.3.5.08	Safety assurance via light-weight formal methods and simulation.	Create software models of key SA components and drive them with safety-based scenarios to find system and algorithmic flaws before implementation.	FY10	Methods and scenarios developed and tested with SA technology and operating concepts that probe the possible safety envelope. System safety defined under wide range of scenarios and conditions.	AS.3.5.03 AS.3.5.05 AS.1.5.01
AS.3.5.09	Field evaluation of trajectory analysis technology with aircraft CNS technology for automated separation assurance.	Limited operational testing conducted to validate trajectory analysis and CNS technology assumptions that are critical to automated separation assurance through 4D trajectory based operations.	FY10	Operational data verifying trajectory analysis and CNS performance assumptions critical to SA technology and operations.	AS.3.5.02 AS.3.5.05 AS.3.5.06 AS.2.5.07
AS.3.6.01	ASDO initial concept definition	Develop an initial concept of operations to support ASDO that considers scheduling, separation and environmental constraints supplied by Airportal using multiple levels of aircraft performance. Perform modeling and batch simulations to quantify performance benefits. This milestone will be closely coordinated with the Airportal Project milestone	FY07	throughput/capacity at major airports and regional/reliever airports, noise and emissions impacts, delay reduction compared to no new technol-	n/a

Number	Title	Description	Year	Metrics	Dependen-cies
		L3.A.1.		ogy/procedures and pilot and controller workload measurement	
AS.3.6.02	Refine algorithms, procedures and information requirements for third phase of FAA's planned Merging and Spacing operations	Support FAA Merging and Spacing Working Group to develop and refine procedures and performance and operational requirements to enable airborne merging and spacing based on continuous descent approaches in higher density traffic to include merging multiple arrival routes in both en route and terminal airspace. Procedures and requirements will be validated using batch and HITL simulations.	FY08	Noise and fuel reduction, runway throughput, pilot workload. This activity should result in technology transfer of requirements to industry.	AS.2.6.01 AS.2.6.02
AS.3.6.03	Development of advanced controller decision support tools (DST) to support ASDO	Develop and test controller decision support tools that will enable the controller to manage and monitor traffic at all performance levels. Evaluation will include modeling and HITL simulation.	FY10	Throughput/capacity at major airports and regional/reliever airports, noise and emissions impacts, fuel use.	AS.3.6.01 AS.3.6.02 AS.2.6.03
AS.3.6.04	Regional Resource Planning Definition	Definition of method for improved utilization of ASDO resources. Defines process for determining airspace and airportal configurations to meet dynamic ASDO needs. Includes airportal configuration, levels of service (PBS), and ASDO airspace structure. Feeds refined ASDO Concept of operations. Will be coordinated with Airportal Project.	FY10	Review by JPDO, peer and user groups.	AS.2.6.07 AS.3.6.01 AS.3.6.02
AS.3.6.05	Refined Sequencing and Deconfliction Algorithm	Refined ASDO scheduler capability. Incorporates refined Concept of operations, refined performance models (requirements) based on HITL evaluation of roles/responsibilities, includes more mature ASDO technologies where available (e.g., CDA to CSPA utilizing performance required of ATM compatible FMS). Includes high-fidelity evaluation.	FY11	Throughput/capacity at major airports and regional/reliever airports, noise and emissions impacts, fuel use.	AS.3.6.03 AS.3.6.04 AS.1.6.02 AS.1.6.04
AS.3.6.06	Initial Regional Resource Utilization and Allocation Concept	Defines Regional Resource sharing concept for off-loading over-demand resources (runways, airports, routes, etc.) and recovery of assets (return to schedule). Feeds refined Concept of operations.	FY11	Review by JPDO, peer and user groups.	AS.3.6.05
AS.3.7.01	Conduct objective analysis of service provider and aircraft operator separation assurance methods.	Analyze central service provider- and aircraft operator-based separation assurance methods based on factors such as scalability, trajectory modeling requirements, surveillance performance, trajectory coordination, traffic density, traffic conditions (nominal, metering, severe weather, terminal), analytic or rule-based algorithms, error conditions, system architecture, failure modes, human cognition and workload, cost to equip, and safety. The analysis will consider en route and Super-Density operations in the presence of hazardous weather and under time-based metering conditions.	FY10	Stakeholder vetting and peer review	AS.1.7.04 AS.2.5.02
AS.3.7.02	Develop fast-time system-level simulation of NGATS technologies.	The fast-time system-level simulation of NGATS technologies will include the Agent-based models of ASDO, SA, TFM, and DAC technologies from AS.1.7.03. These models will be integrated together using the con-ops developed in AS.1.7.04 as a guide.	FY10	The system-level simulation includes models of ASDO, SA, TFM, and DAC technologies.	AS.1.7.03 AS.1.7.04
AS.3.7.03	Develop tools for generating future demand scenarios and analyzing NGATS data.	Future demand scenarios will be required for driving system-level analyses of NGATS technologies. Similarly tools will be needed to analyze NGATS data. NGATS data will be data outputs from system-level simulations and data collected from the NAS.	FY10	1x, 2x, and 3x demand scenarios can be generated. NGATS data analyses will generate metrics that answer critical NGATS questions.	AS.1.7.04
AS.3.7.04	Develop prognostic safety assessment methods for systems and operations	Research issue is to examine system and operational safety of advanced concepts and technologies. A primary research focus is to develop and apply prognostic safety methods and metrics. This milestone will be closely coordinated with the Airportal Project.	FY10	Independent peer review research results with ARMD AvSP and two external technical associations, including JPDO. System safety assessment methods to cover 85% of 2008 baseline safety case parameters. Operations safety assessment methods to provide quantitative methods for runway incursions, pilot/controller workload, taxi time	AS.1.7.01 AS.1.7.02

Number	Title	Description	Year	Metrics	Dependen-cies
				over active runways, and unacceptable wake encounters. Prognostic safety assessment method recognized by two regulator bodies as providing credible assessments.	
AS.3.7.05	Conduct initial safety assessments of proposed concepts, algorithms, and technologies to indicate the relative safety impacts with respect to the baseline system.	The safety assessments will span block-to-block operations (i.e. Airspace & Airportal), and clearly identify areas of safety concern within the proposed concepts. Results will provide valuable feedback to modify proposed system concepts.	FY11	Stakeholder vetted and peer reviewed by CAST.	AS.1.7.05 AS.2.7.02

Table 4. Level 2 Milestones and Metrics

Number	Title	Description	Year	Metrics	Dependen-cies
AS.2.1.01	Develop scripting language and protocols for a common-trajectory-model architecture (in collaboration with U.S. (FAA) and European trajectory-prediction research organizations (Eurocontrol)).		FY08	Trajectory modeling consistency for various concepts	AS.1.1.04
AS.2.1.02	Development of analysis tools and ensemble validation datasets (representing a statistically significant set of trajectory-prediction conditions envisioned under NGATS) from high-fidelity simulation, ATC radar and flight-plan data, field assessments, and flight-data recordings for use in trajectory prediction validation studies conducted by U.S. laboratories supporting NGATS.		FY08	Fidelity of scenarios, trajectory accuracy	AS.2.1.01
AS.2.1.03	Develop vertical and horizontal-profile algorithms to model complex combinations of trajectory constraints (stemming from NGATS 4D trajectory-based operations) involving multiple “simultaneous” constraints (e.g., path, speed, altitude, and/or time) for En route, Transition (to Terminal), and Terminal airspace. Validate algorithms for En route and Transition airspace.		FY08	Trajectory accuracy parameters	AS.2.1.02
AS.2.1.04	Survey and advance algorithms for predicting and describing propagation of trajectory uncertainty.		FY08	Algorithms account for effects of initial condition errors, aircraft dynamic model errors, and environmental variables.	AS.1.1.01 AS.2.1.01
AS.2.1.05	Validate vertical and horizontal-profile algorithms for trajectory smoothness and robustness		FY09	Trajectory prediction accuracy in 4 dimensions	AS.2.1.02 AS.2.1.03

Number	Title	Description	Year	Metrics	Dependen-cies
	criteria for over-constrained trajectory parameters in en route and transition airspace.				
AS.2.1.06	Develop and validate vertical and horizontal-profile algorithms for modeling multiple altitude and speed constraints of arbitrary order within en route and transition airspace.		FY09	Trajectory prediction accuracy in 4 dimensions	AS.2.1.02 AS.2.1.03
AS.2.2.01	Produce a comprehensive list of performance attributes corresponding to the list of candidate NGATS operational concepts.		FY07	Operational performance attributes such as capacity, throughput, delays, predictability, flexibility, user preference, safety, workload, efficiency	n/a
AS.2.2.02	Working with industry and the JPDO Shared Situation Awareness IPT, produce a set of parametric performance models of CNS systems..	These models should accept common operational conditions as input. They should represent state-of-the-art systems and be adjustable for expected performance ranges. They should be of sufficient fidelity to allow determination of concept performance at different levels of capability	FY07	Communication, navigation, and surveillance characteristics and operational parameters (e.g., delays, response time, navigation precision, bandwidth)	AS.2.2.02
AS.2.2.03	Group the performance attributes under RNP, RCP, RSP, or an advanced performance measure.		FY08	Grouping of performance attributes	AS.2.2.02
AS.2.2.04	CNS performance models are integrated into simulation systems and their performance is verified by actual operational data, where available.		FY08	CNS performance (accuracy, reliability)	AS.2.2.01 AS.2.2.02 AS.2.2.03
AS.2.3.01	Candidate airspace allocation algorithms proposed.	TFM and DAC are two degrees of freedom in accommodating users request to the fullest extent possible and the contours for this optimization will be established by the concept of operation. Given that the problem has to be solved iteratively due to the large size and different time scales involved in executing TFM and DAC, this research develops methods based on successive approximation and decomposition methods to develop the initial algorithms.	FY09	Number of candidate algorithms proposed	AS.1.3.01 AS.1.3.02 AS.1.3.03
AS.2.3.02	Candidate airspace allocation algorithms validated.	At least two candidate algorithms for airspace optimization are validated in a medium-fidelity simulation. In the simulation, airspace managers are assumed to be “generically qualified” to work any airspace sector.	FY10	Number of candidate algorithms assessed, number of candidate algorithms validated	AS.2.3.01
AS.2.4.01	Develop Oceanic Traffic Flow Optimization Concepts		FY08	Efficiency, throughput, delays, predictability	n/a
AS.2.4.02	An improved metric for airspace complexity is defined.	A metric is defined that aptly projects airspace complexity. The NGATS is expected to have a variety of airspace types with a variety of mechanisms for separation assurance: some human-based and others automation-based. Complexity is likely to be defined differently in each case. Regardless, the usefulness of the TFM and DAC functions are likely to hinge on the ability of this metric to accurately forecast airspace complexity.	FY09	Statistical correlation between metric and airspace complexity	AS.1.3.01 AS.1.4.04
AS.2.4.03	Assess System-Wide Performance of Oceanic Traffic Flow Optimization Concepts		FY10	Efficiency, throughput, delays, predictability	AS.2.4.01
AS.2.4.04	Update and refine Airspace Evaluator requirements for the Airspace functions of the Evaluator	Research to focus on enhancing Evaluator concept functionalities, strategic and tactical use, human / automation allocation and technology integration. This milestone will be closely coordinated with the Airportal Project.	FY11	Identify interface control requirements for 85% of predictive throughput functionality to FY10 L4 "initial Airportal Evaluator". Airportal Evaluator concept func-	AS.3.4.01 AS.3.4.02 AS.3.4.03

Number	Title	Description	Year	Metrics	Dependencies
				tionalities to demonstrate 20% improvement in strategic decision optimization vs. capacity and throughput at 4 major airports over a 30 day period. Validate surface optimization requirements using 2010 OEP capacity and 3X forecast domain in fast-time simulation.	
AS.2.5.01	Strategic automated resolution and trajectory change technology.	Laboratory analysis and results show that technology generates strategic (3-20 min) conflict resolutions and conflict-free trajectory changes for majority of traffic under varied traffic density and complexity conditions and in the presence of uncertainty. Service-provider-based algorithms are implemented.	FY07	95% of traffic conflicts are detected and resolved prior to the 3-5 min to loss of separation point with overall resolution delays and near-miss separation characteristics that are comparable or better than that of today's operations while operating under a significant increase in traffic density (e.g., 2-3x) and in the presence of uncertainty and under a variety of traffic conditions.	n/a
AS.2.5.02	Initial operating concept options description for service-provider-based SA approach	Document initial NGATS operating concept options for simulation analysis focusing on air and ground operator roles and responsibilities for a service-provider-based approach including SA functional allocation and human/automation functional allocation.	FY07	Description of a range of operating concepts (2 or 3) that will be evaluated in human-in-the-loop simulations. Operating concept descriptions include required technology, primary operator (controller/pilot) tasks, general user interface characteristics, examples of relevant operational traffic scenarios during nominal and failure modes.	n/a
AS.2.5.03	Initial service-provider-based automated separation assurance simulation.	Conduct human-in-the-loop simulation analysis of initial service-provider-based operating concept options with air and ground operators and limited mixed equipage and failure recovery operations. Use simple data-link, equipage, and failure mode models. Refine roles and responsibilities, human-machine interfaces, and SA technology. Document strengths and weaknesses of concept options and SA technology as a function of traffic density and complexity in the presence of uncertainty.	FY07	Provides opportunity for researchers and stakeholders (e.g., FAA, airlines, controllers, pilots) to gain initial insight and provide initial feedback by viewing operating concept with humans in the loop. Initial objective analysis of operating concept during nominal and failure recovery operations. Initial evaluation of methods for gathering and analyzing experimental data, including metrics collected in laboratory analysis, during human in the loop simulations.	n/a
AS.2.5.04	Tactical automated safety assurance trajectories.	Analysis to validate short-term trajectory modeling methods and algorithms for safety assurance in en route and transition airspace under varied 2-3x nominal traffic in the presence of uncertainty.	FY08	Tactical detection and resolution logic computes safe tactical trajectories and thereby prevents a loss of separation for the majority of those traffic conflicts (~95% of the 5% not solved strategically) that were not resolved by strategic automated resolution technology and thereby prevent loss of	AS.2.5.01 AS.1.5.02

Number	Title	Description	Year	Metrics	Dependen-cies
				separation while operating under a significant increase in traffic density and in the presence of uncertainty and under a variety of traffic conditions.	
AS.2.5.05	Technology for determining weather impacts on tactical air-space operations.	Technology will be developed that can automatically determine if weather phenomena will impact normal airspace operations within the tactical time horizon.	FY08	More useful/accurate characteri-zation of weather impacts, ability to reduce lost usable airspace by 50% in some areas/conditions compared to today's operations.	AS.2.5.01 AS.2.5.02 AS.2.5.03
AS.2.5.06	Technology for weather related tactical advisories.	Improved automated tactical advisories would be created using better understanding of weather impact to airspace operations.	FY09	Recover 40% of lost capacity under certain conditions.	AS.2.5.05 AS.3.5.04
AS.2.5.07	Analysis of aircraft CNS perform-ance as it relates to separation assurance technology.	Laboratory analysis of the role of communication, navigation, and surveillance performance on strategic and tactical trajectory analysis methods. Should identify key CNS requirements needed to achieve service-provider-based automated SA with safety.	FY09	Description of what portion of separation assurance technology can be achieved with today's aircraft CNS performance capa-bilities, and what minimum delta aircraft CNS performance capa-bilities will be required to achieve mid-term and end-state SA tech-nology.	AS.2.5.01 AS.2.5.02 AS.2.5.03 AS.3.5.03 AS.3.5.04
AS.2.5.08	Traffic complexity prediction for automated separation assurance.		FY09	Ability to predict traffic conditions out to a 5-10 min time horizon where automated separation assurance logic would be forced into a tactical resolution mode, or would be unable to resolve a conflict without creating a secon-dary short term (0-5 min) conflict.	AS.2.5.01 AS.2.5.02 AS.3.5.03 AS.2.5.06 AS.1.5.01 AS.1.4.04
AS.2.5.09	Human workload, performance, and situation awareness analysis of higher levels of automation for service-provider-based separa-tion assurance.	Analysis of controller and pilot tasks, displays, and workload consid-erations as a function of level of automation for service-provider-based separation assurance and allocation of functions between controller, pilot and automation.	FY09	Workload, performance (re-sponse time and error), and situation awareness.	AS.1.5.04
AS.2.5.10	Analysis of failure and recovery modes associated with service-provider-based SA approach.	Identify failure and recovery modes for a service-provider-based SA approach as a function of technology, operating concept options, and architecture. Analysis includes both component failure and human failure, e.g., human error. Identify risk of separation loss and collision as a function of failure and recovery mode. Compare with today's operations.	FY09	Risk of failure, time to recovery, risk of collision in event of failure.	AS.3.5.03 AS.3.5.04 AS.1.5.03 AS.1.5.04
AS.2.5.11	Laboratory integration of service-provider-based separation assur-ance, traffic flow management, and dynamic airspace technol-ogy.		FY10	Ability to evaluate in the labora-tory the affects of TFM--generated trajectories on separa-tion assurance metrics and the effects of SA-generated trajecto-ries on TFM metrics in the pres-ence of uncertainty and with substantially higher traffic densi-ties.	AS.3.5.03 AS.2.3.02
AS.2.6.01	Flight validation of Low Noise Guidance (LNG)	The LNG algorithm developed under the NASA Quiet Aircraft Tech-nology (QAT) Program will be validated in flight onboard the NASA ARIES aircraft. The validation will consist of direct measurements of	FY07	Ground noise measurements, conformance to guidance, fuel burn.	n/a

Number	Title	Description	Year	Metrics	Dependencies
		aircraft trajectory and flight control as well as noise under the flight path while flying realistic operational scenarios under variable atmospheric conditions with both LNG and conventional aircraft guidance.			
AS.2.6.02	Support for initial algorithm, procedures and information requirements for merging and spacing technology	Support FAA Merging and Spacing Working Group to develop procedures and performance and operational requirements to enable airborne merging and spacing based on continuous descent approaches in low and medium density traffic. Analysis data collected from operational use to assess the impacts on fuel efficiency, noise reduction, flight times and aircraft spacing. Procedures and requirements will be tested and validated using batch and HITL simulations.	FY07	Noise and fuel reduction, runway throughput, pilot workload. This activity should result in technology transfer of requirements to industry.	n/a
AS.2.6.03	Initial Sequencing and Deconfliction Algorithm	Develop and test an initial ASDO scheduling capability that considers Airportal constraints, operational capabilities of a mixed fleet and the performance capabilities of the state of the art in FMS development. Testing will includes fast-time evaluation of algorithmic performance.	FY08	Throughput/capacity at major airports and regional/reliever airports, noise and emissions impacts, fuel use.	AS.1.6.01
AS.2.6.04	Develop method for airborne maneuvering within established limits to make gross corrections to inter-aircraft spacing.	Document methods and measured performance (relative sequence stability, repeatability across range of conditions, resulting spacing intervals).	FY09	Spacing minima, stability, efficiency	AS.2.6.02
AS.2.6.05	Identify user information and decision support needs for sequencing, merging and spacing.	Perform task analyses of advanced concepts in sequencing, merging and spacing at varying levels of automation and task delegation to identify the required information and decision support. Building on the CVSRF studies for AS.1.6.01 (and possibly 1.6.03), Evaluate proposed information requirements (content and timing) for execution of ASDO procedures. These analyses will help define the balance between user responsibility and automation for procedures proposed in the ASDO initial concept of operations. CVSRF analyses would support the definition of user informational requirements and decision support needs.	FY09	Type of information, frequency of update	AS.2.6.02 AS.2.6.03 AS.2.6.04
AS.2.6.06	Definition of data exchange requirements for Resource Scheduling Optimization	Definition of data content, quality and timeliness for coordinated optimization of surface and airspace resource utilization. Will deliver detailed and supported requirements for data content, quality and timeliness including effects of failure to meet these requirements.	FY09	Review by JPDO, peer and user groups.	AS.3.6.01
AS.2.6.07	Procedures and technologies for initial ASDO concept of operations	Develop prototype procedures, technologies and interfaces to support the ASDO initial concept definition. Testing and evaluation will include multiple batch and HITL simulations.	FY10	pilot and controller workload, percent of successful operations and successful identification of incompatible conditions that would prevent the operation, constraint-meeting performance, noise and emissions reduction, fuel burn, capacity increase.	AS.2.6.03 AS.2.6.05 AS.2.6.06
AS.2.6.08	Develop enhanced FMS guidance and control algorithms to enable ASDO	Algorithm design and development will be performed to support advanced flight guidance and control that will integrate low noise guidance (LNG), airborne precision spacing (APS) and required time of arrival (RTA) into an ATM-compatible prototype FMS for super density and equivalent visual operations. Testing and evaluation will involve several batch and HITL simulations as part of an iterative development and testing plan.	FY11	Adherence to RTA, pilot and controller workload, noise impact on ground, fuel efficiency, spacing precision, runway capacity/throughput.	AS.2.6.07 AS.1.6.03
AS.2.7.01	Develop method for modeling human workload in fast-time simulations, validate models against workload measurements.	Human workload is a critical limitation on current NAS operations. Under NGATS, automation will play a greater role, but humans will still play important roles in NAS operations. To effectively study the benefits/limitations of new NGATS concepts, human workload needs to be represented in the fast-time simulations that are used to model the NAS. Initially, workload for humans in current day operations must be modeled and those models validated against available real world data. This provides baseline workload models for comparison with models	FY10	Method reduces the uncertainty bounds by 50% for typical Air Midas analyses.	AS.1.7.04

Number	Title	Description	Year	Metrics	Dependencies
		representing future transitional states as the NAS migrates toward the NGATS concept of operations. As the role of humans in NGATS concepts becomes better defined, workload models for those roles will be updated.			
AS.2.7.02	Develop predictive, conceptual-level, safety assessment method for ill-defined complex interacting systems (including the NAS.)	The capability will be developed to assess safety contributions of technologies, and procedural or training changes at the conceptual level. The development of a credible risk based assessment methodology with uncertainty estimates will facilitate portfolio related decisions in addition to allowing high-level benefits analysis. The goal is to effectively combine a collection of safety assessments for components of the NAS. A particular challenge is to do this for future concepts that have ill-defined aspects relating to safety. Continuation of current development of the Diagnostic Safety Assessment Tool (DSAT) under the Aviation Safety Program will be required. A possible outcome may be a Safety component to the Required Total System Performance (RTSP) metric.	FY11	Stakeholder vetting and peer review by CAST.	AS.1.7.05

Table 5. Level 1 Milestones and Metrics

Number	Title	Description	Year	Metrics	Dependencies
AS.1.1.01	Survey and document the current SOA of trajectory prediction/modeling algorithms and software capabilities and the requirements envisioned for trajectory prediction to support NGATS automation systems.		FY07	Current SOA reported and documented.	n/a
AS.1.1.02	Survey and document the trajectory prediction/modeling algorithms and software capabilities (e.g., EDA, PARR, 4D-FMS) supporting the current state of the art (TMA, URET, FMS), and requirements envisioned for future TP capabilities to support NGATS-relevant trajectory prediction for the Evaluator and related automation.		FY07	Trajectory accuracy parameters	n/a
AS.1.1.03	Develop algorithms for measuring the difference between 4D trajectories		FY07	Algorithms developed with sufficient sensitivity to identify differences between actual vs. predicted trajectories, FMS vs. ground-tool trajectory predictions, and U.S. vs. European trajectory specifications.	n/a
AS.1.1.04	Identify and quantify a complete set of constraints and objective functions typically applied to trajectories to support ATM functions.		FY07	Constraints and objective functions documented from DAC, TFM, SA, and ASDO. Quantification includes typical values, bounds, or conformance precision, as appropriate to the ATM function.	n/a
AS.1.1.05	Identify and quantify sources of uncertainty for trajectory predic-		FY07	Characterization of trajectory prediction uncertainty includes	n/a

Number	Title	Description	Year	Metrics	Depend-encies
	tion.			sensitivities to wind prediction uncertainty, aircraft aero/engine performance variables, auto-flight mode, RNP, crew procedures, and flight segment type.	
AS.1.1.06	Develop data mining techniques for identifying trends in trajectory intent error.		FY08	Techniques validated to accurately identify trends in at least 80% of known trajectory intent errors from a current-day validation data set.	AS.1.1.05
AS.1.2.01	Identify suitable techniques for modeling RTSP performance characteristics.	These may include but not limited to statistical and analytical methods (e.g., queuing, game theory, network theory). The output of this effort is identification strengths and weakness of different modeling techniques.	FY08	The metrics include comprehensiveness and peer review acceptance.	n/a
AS.1.2.02	Synthesis of human factors and operational literature.	The focus is to identify limits of human performance in recognizing and accommodating/managing maximum number and types of aircraft performance characteristics on a sustainable basis.	FY08	The metrics are the comprehensiveness of human performance characteristics.	n/a
AS.1.2.03	Extensions of analytical and statistical techniques for modeling RTSP performance characteristics.		FY09	The metrics are the techniques explored are of sufficient maturity to construct parametric models for RTSP for use in modeling and simulation.	AS.1.2.01 AS.1.2.02
AS.1.2.04	Identify grouping techniques that will classify/represent the multi-dimensional nature of RTSP performance characteristics. Identify decision support and information presentation techniques applicable to grouping techniques.		FY10	The metrics are the grouping characteristics (robustness, consistency, sensitivity, and face validity)	AS.1.2.03
AS.1.3.01	The State of the Art is surveyed and documented.	The state of the art as it pertains to airspace capacity management (including airspace complexity metrics) is documented, based upon a survey of published research from NASA, FAA, and a minimum of two leading research firms and two leading European research organizations.	FY07	Breadth and depth of survey.	n/a
AS.1.3.02	The elements of airspace structure in the NAS are inventoried, and "best practices" in airspace design are documented. Adapt for NGATS.	The intent here is to capture the wealth of expertise in airspace design resident at the FAA, and to determine if and how it may be leveraged to guide the design of generic or standardized airspace for NGATS. Higher-level milestones should achieve a reduction in the time required for an ANSP employee to qualify ("check out") for a specialty. Clustering algorithms and aggregate models being developed in TFM will complement this milestone.	FY07	Breadth and depth of inventory.	n/a
AS.1.3.03	Utilize formal mathematical methodologies, such as genetic algorithms and neural networks, to develop dynamic airspace structures supporting both new and conventional classes of airspace.	Adopting a "clean slate" approach to airspace design, examine whether sectors or other regions of airspace can be constructed starting with a few basic units of airspace and optimizing the shape based on the composition of traffic and class of airspace.	FY10	Number and type of airspace units within the NAS	AS.1.3.01
AS.1.4.01	Develop empirical and data mining models for correlating weather and key metrics for NAS performance. The milestone will be evaluated in terms of improvements in estimating NAS	The performance of the National Airspace System is currently assessed in terms of factors like the number of arrivals and departures, delay per aircraft, and total system delay. The delay in the system is heavily influenced by convective weather. The NAS collects data about the traffic, thunderstorms and many types of delay statistics. The impact of weather – which is usually measured in terms of delays	FY08	This research should improve our ability to estimate aggregate delay based on predicted weather and expected traffic to within 10,000 minutes based on 2006 traffic levels.	n/a

Number	Title	Description	Year	Metrics	Depend-encies
	delay over current methods.	resulting from the application of traffic flow management initiatives in response to weather conditions, volume, equipment outages and runway conditions – is needed both for guiding flow control decisions during the day of operations, and for post operations analysis. There are some basic data retrieval systems such as POET based on commercially available database software. This research provides a method for estimating delay using the expected traffic demand and weather by adapting techniques of Statistical Decision Theory and the more recent developments in Data Mining as applied to information systems to discover structure/patterns from a mass of data and methods for rapid hypothesis testing.			
AS.1.4.02	Assess and develop aggregate models, such as network flow and linear time varying models, for traffic flow under nominal and off-nominal conditions.	Traditionally, models used in air traffic control and flow management are based on simulating the trajectories of individual aircraft. This approach results in models with a large number of states, which are intrinsically susceptible to errors and difficult for designing and implementing optimal strategies for traffic flow management. This research provides an innovative approach for the development of linear time variant dynamic traffic flow system models, based on historical data about the behavior of air traffic. The resulting low-order, linear, robust models are used both for the analysis and synthesis of traffic flow management techniques for current and future systems.	FY08	The aggregate models should demonstrate a 10 times reduction in the size of the models used for analysis.	n/a
AS.1.4.03	Characterize current and future ATM systems by adapting concepts from Network and Graph Theory	The evolution of ATM networks depends on traffic growth and advances in new classes of air vehicles. The air traffic and factors affecting it can be analyzed as different types of networks depending on the level of modeling: e.g., network of aircraft, network of sectors, network of centers, network of weather cells, and network of airports. This research adapts the advances in Network and Graph Theory to identify the stability, robustness and adaptability of current and evolving ATM systems.	FY08	The success of this milestone will be measured by its ability to characterize the new ATM network with a higher level of varying demand than today.	n/a
AS.1.4.04	Expand the concept of Traffic Complexity to controller, pilots and varying levels of automation	The design of TFM algorithms and methods use the safe separation of the resulting configuration as a limit to the traffic flow supported by a given region of airspace. Currently, this region of the airspace is defined by sector geometry, and the amount of traffic that can be supported by a sector depends on controller workload. Traffic Complexity is a measure of the controller's workload. As the concepts for separation assurance evolve from manual ground-based methods to highly automated ground-based and/or cockpit-based methods, the notion of traffic complexity needs to be expanded to meet these new situations. For cockpit-based separation, certain configurations of aircraft groups, i.e., gaggles, could potentially result in the failure of separation assurance functions and operations. A methodology is needed to define and predict the complexity of a traffic gaggle in the presence of uncertainty and as a function of the level of separation assurance automation and the operational concept.	FY08	The metric for this research is the increase in the ability to define traffic complexity from the current state of the art and expand it to pilots and varying levels of automation.	n/a
AS.1.4.05	Develop probabilistic and stochastic methods for flow management to address uncertainties in weather prediction. Metric used will be improvements over current deterministic methods.	Some significant sources of uncertainty in air traffic management are due to uncertain departure times, poor record keeping, and convective weather. Uncertainty plays a significant role in the management of traffic and may result in large delays in the system. The research in this area explores methods to model uncertainty and develop synthesis techniques to design a robust system. The methods to deal with uncertainty determines the best traffic flow management strategy by minimizing the expected value of the cost function and performs better than the deterministic versions in the long run. Another approach would be to minimize the worst effect due to the presence of the uncertainty such as minimizing the worst possible delay in the system.	FY10	The probabilistic methods should demonstrate a 10% improvement in the aggregate system delay or other appropriate system measures over deterministic methods.	AS.1.4.01 AS.1.4.02 AS.1.4.03 AS.1.4.04
AS.1.4.06	Develop linear/nonlinear/dynamic	TFM approaches using current and future traffic scenarios in the NAS	FY11	The decomposition methods are	AS.1.4.02

Number	Title	Description	Year	Metrics	Depend-encies
	programming and decomposition methods for advanced traffic flow management.	involves the computation of trajectories of all aircraft on a continental scale while satisfying the schedules of airlines and general aviation without exceeding the limitations imposed by airport constraints and en route airspace constraints due to weather and traffic. The problem is complex due to the large number of aircraft involved in the planning interval, number of decision-makers, and uncertainty of weather information. The optimization has to address equity issues and the robustness of solutions to changing conditions. A traditional approach to solving the non-linear stochastic optimization problem is to formulate it either as a Dynamic Programming problem or as a Multiple Integer Linear Programming problem. These methods have not been very successful in practice due to the curse of dimensionality and the sensitivity of the optimization to uncertainties in the problem. Current approaches to solving the problem in the NAS involve the use of heuristics. Any successful method to the TFM problem has to be executable in a timely manner, taking into account the co-ordination required to satisfy all decision-makers. The approach considered consists of decomposition methods resulting in a series of optimization problems, and a combination of the sub-optimization problems to present the total solution. The decomposition will be explored in three-domains: time, space (regions), and one based on procedures and functionality.		aimed at achieving a real-time planning capability (two minutes for a six-hour planning horizon) for NAS-level TFM problems.	AS.1.4.03 AS.1.4.04 AS.1.4.05
AS.1.5.01	Methods for establishing separation criteria for NGATS operations.		FY08	When methods derived from methods are applied to automated separation assurance technology metrics are comparable or better than that described under "Strategic automated resolution and trajectory change technology" milestone.	n/a
AS.1.5.02	Methodology for analysis of tactical ATC and airborne collision avoidance interaction.		FY08	Method developed and validated with actual air traffic data in the presence of uncertainties.	n/a
AS.1.5.03	Analytical methods to assess system response to failure events.		FY08	Method developed and validated with actual air traffic data in the presence of uncertainties.	n/a
AS.1.5.04	Methods for quantifying safety level of human operators in ATM system.		FY09	Method developed and validated in simulation in the presence of uncertainties.	AS.1.5.01 AS.1.5.02 AS.1.5.03
AS.1.5.05	Verification methodologies developed for analytic and rule-based heuristic approaches to SA algorithms and software.	Proof established for 100% separation assurance for arbitrary en-route unconstrained scenarios within a 95% threshold of a traffic complexity metric of 7 on the Dynamic Density scale.	FY10	False alerts, missed alerts, complexity, separation loss, potential	AS.1.5.04
AS.1.5.06	Formal proof of separation assurance for oceanic applications	Conduct a formal methods proof of SA for in-trail climbs and descents where aircraft motion is constrained to along-track and vertical flight changes.	FY07	Completeness	
AS.1.5.07	Recommended complexity metric	Identify recommended complexity metrics through extensive experimentation.	FY08	Number of machine operations	
AS.1.5.08	Mathematical safety proof for N independent aircraft	Develop mathematical proof of the safety property for N aircraft independently executing the CD&R algorithm	FY09	Number of axioms, number of lemmas	
AS.1.6.01	Characterize and quantify the uncertainty impact of ASDO procedures.	Identify and quantify significant sources of uncertainty impacting the prediction of 4D ASDO trajectories resulting from execution of enabling ASDO technologies. Document significant sources of uncertainty (characterize and quantify). CVSRF (and possibly ACSF) will be used to evaluate the variance in timing and accuracy of execution of ASDO proposed procedures. Continuous Descent Arrivals into terminal air-	FY08	Trajectory accuracy and uncertainty	AS.1.1.05

Number	Title	Description	Year	Metrics	Depend-encies
		space remove substantial controllability from air traffic, placing added significance on predictability to the controller and requiring better trajectory and procedural modeling for scheduling algorithms. A high-fidelity, motion-based flight deck simulator integrated in the context of air traffic operations (e.g., CVSRF operated with AOL through VAST-RT) provides the environment necessary to effectively evaluate the role of the aircraft operator in executing ASDO procedures.			
AS.1.6.02	Investigate scheduling and rationing algorithms for weather impacted NAS resources.	Evaluate scheduling and resource utilization options for limiting the impact of weather on ASDO operations in terms of capacity, safety and efficiency. Document proposed methods and estimated improvements in capacity, efficiency and safety impact.	FY09	Scheduling stability, prediction accuracy, capacity, fuel efficiency, safety	AS.1.6.01
AS.1.6.03	Develop advanced guidance methods for energy management for efficient ASDO operations.	Develop energy management methods for managing the tradeoff between required controllability (due to inherent uncertainty) and efficiency/noise impact. Energy management methods must be operationally feasible and allow for sufficient trajectory flexibility to manage inherent levels of uncertainty Document methods, fuel/emissions cost for controllability, noise cost for controllability. CVSRF (or ACSF) would be used to evaluate procedures for energy management in descent through ASDO airspace. Energy management of descent trajectories will be required to enable ASDO operations in mixed-equipage environments. Precise trajectories (e.g., RNAV, RNP, CDA) will require a high-level of controllability to integrate with lesser equipped aircraft without sacrificing throughput. A high-fidelity flight deck simulator would be used to evaluate methods for managing the required level of controllability within ASDO airspace. 'maybe' because this work would be limited to existing FMS capabilities (rather than implementation of a next-generation FMS).	FY10	Fuel efficiency, noise impact	AS.1.6.01
AS.1.6.04	Explore Innovative Guidance and Control Methods for the Super Density terminal environment	Investigate new methods for guidance and control of aircraft in the Super Density environment. Efforts may include exploration of methods for precision spacing and sequencing of groups of aircraft relative to one another and/or agent-based methods that achieve system-level performance objectives through distributed control and coordination. All methods should assess robustness to disturbances, as well as applicability in the safety-critical, highly constrained ASDO environment. Document proposed methods and their advantages/disadvantages for ASDO application.	FY10	Review of guidance and control methods, their strengths and weaknesses	n/a
AS.1.7.01	Develop initial system-level Con-Ops. Leverage JPDO NGATS Con-Ops, and expand development as required, to support Airspace Systems Program (Airspace & Airportal) research, and concept development.	The initial concept description will document current system configuration (baseline), against which, proposed concepts, technologies, functional allocation changes, roles and responsibilities between human and automation, information needs, and transition approaches from current state of the art to NGATS vision will be applied and evaluated.	FY07	Completeness by containing JPDO (stakeholder) and technologist views on separation assurance, demand/capacity imbalance and airspace modifications.	n/a
AS.1.7.02	Research game theoretic concerns with distributed control in safety critical scenarios.	A primary concern in distributed control mechanisms within the NGATS is safety and potential user abuse of the system. Game theory may be useful in determining likely behaviors and their safety effect. Game theory methods might be useful exploring the influence of user response on the operations themselves, particularly behaviors of maneuvering to gain position advantage in an unconstrained or delegated separation realm that may in turn compromise safety. Requiring rational behavior in the realm of safety is perhaps a risky proposition. The question then is how much prescription is necessary to limit safety-related choices in a manner to assure a safe result while still not over constraining the operations.	FY08	Publication on the applicability of Game Theory to ATM system design.	AS.1.7.01
AS.1.7.03	Develop individual agent-based		FY08	These models shall include at	AS.1.7.01

Number	Title	Description	Year	Metrics	Depend-encies
	models of NGATS technologies			least ASDO, TFM, SA, and DAC	
AS.1.7.04	Develop interim system-level concept of operations to accommodate 3x demand based on results of studies and identified gaps.	The interim concept of operations will document any modifications to the initial concept of operations based on results of analysis, prototypes, and simulations. It will also identify the changes and their rationale from the initial version. The concept of operations will also identify the gaps to achieving the NGATS vision.	FY09	Less than 50% change from initial version and stakeholder vetted.	AS.1.7.01
AS.1.7.05	Develop approach for System Validation and Certification methodology	Both traditional and advanced methods for software and algorithm validation, verification and certification will be required to enable eventual implementation of NGATS technologies. Compositional verification will address the validation and verification of interfaces among system components, for example, separation assurance and traffic flow management, to find anomalies at the system level and to assure that stated requirements are achieved. Adaptive system verification will be performed for the many adaptive algorithms that power the automation concepts, especially spacing and merging. Tools based upon techniques from Bayesian reasoning, advanced control theory, machine learning, and theory of complex systems will be extended and applied to those algorithms. Scenarios will be generated specifically to explore the safety envelope, robustness, and fault tolerance of the NGATS concepts. While NASA will not be responsible for system certification, NASA will maintain cognizance with current and evolving certification standards and work to assure that NGATS concepts are designed with certification in mind. These algorithm and software validations will be performed within individual technical areas however the unified methodology and process will be developed under the SDAST activity.	FY10	Results for AAC, ASAS, and TCAS algorithms.	AS.1.7.04
AS.1.7.06	Define minimal constraint/data for systemic control	The NGATS will have control components spanning long-term strategic, to near-term tactical timeframes. It is important to understand and model the hierarchical interactions between control entities in terms of how information and constraints are represented and utilized. For example, TFM deals with aggregated flows of aircraft and SA deals with very precise near-term trajectories of specific aircraft. TFM and SA will need to exchange constraints and state information, but they have fundamentally different types of control and representations of state. The goal is to develop a modeling approach to study the behavior and feasibility of different ways that control entities exchange such information.	FY10	Design constraint fields that span no more than 15% of the adjoining time horizons.	AS.1.7.04

1.3 Technical Approach

1.3.1 Trajectory Prediction Synthesis and Uncertainty

Transitioning Air Traffic Management (ATM) from airspace-based to trajectory-based operations represents a significant historic alignment of NAS users and Air Traffic Service Providers (ATSPs). Currently, user operations are trajectory-oriented. For example, pilots control their aircraft trajectories, and Airline Operational Control (AOC) centers manage city-pairs (i.e., trajectory-oriented). On the other hand, ATSPs are geographically and spatially oriented (i.e., airspace-oriented). This discrepancy of operations requires users to adjust their trajectories to accommodate the structure and capacity of a static nearly homogenous airspace. Transitioning ATM to Trajectory-Based Operations (TBO) will enable a more efficient ATM system that better accommodates user-preferred operations. The expected benefits are 1) more efficient use of airspace, 2) better accommodation of user preferences, 3) increased system capacity through a reduction in human operator workload, and 4) increased trajectory predictability, thus allowing precise use of all NAS capacity. Finally, TBO will provide the ability to make best use of deterministic and stochastic information over appropriate planning intervals.

The concept of four-dimensional (4D: position [latitude, longitude, altitude] and time) control has been a topic of research for the last 25 years. An early application of 4D-control was energy management guidance for fuel-efficient aircraft control.[27] A later application was coordination of multiple aircraft for precision Air Traffic Control (ATC). The use of 4D-trajectory-based tools has been applied operationally to aid air traffic controllers with traffic management,[7] efficient runway utilization,[8] and conflict detection.[28] A major challenge of using trajectory-based tools for ATM is the requirement to accommodate both airspace-based and trajectory-based operations. An initial effort to address this challenge was the conceptualization of the Advanced Airspace Concept (AAC),[29] which included identification and analysis of safety-critical technologies,[30] operational safety assessments,[31] and extensive fast-time analyses of the efficacy and robustness of core algorithms[32] for en-route and transition airspace. This concept relies on 4D trajectory accuracy and the ability to transmit trajectory adjustments via data link to the flight deck, generally directly into an aircraft's Flight Management System (FMS).

Research of how trajectory-based operations can be enabled through advanced flight deck technologies, known as 4D Airborne Separation Assistance System (4D-ASAS), also shows significant performance potential.[33] Studies of the procedures, supporting architectural configuration, enabling technologies, and decision-making interactions show conceptual feasibility.[16] Representative 4D-ASAS algorithms for distributed conflict resolution have been analytically modeled for correctness and safety. The concept relies on the ability to exchange trajectories and surveillance information among similarly equipped aircraft and to perform distributed conflict management and ATM constraint conformance.

JPDO-defined TBO is intended to serve two roles in the NGATS ATM-Airspace project. First, TBO provides a guiding philosophy for the system design of operational concepts and their associated ATM functions (e.g., TFM, separation assurance). By applying the principles of trajectory-based operations to these concepts and functions, the benefits described above can be more readily pursued. Second, TBO consists of research activities focused on advancing the state-of-the-art of trajectory modeling and prediction for the benefit of the various ATM functions. Using the basic principles of 4D trajectory modeling, one can theoretically predict future trajectories of aircraft within the NAS such that demand/capacity imbalances and aircraft separation conflicts can be detected. Advancements in trajectory prediction will enable ATM functions developed in the other technical areas such as Dynamic Airspace Configuration, Traffic Flow Management, Separation Assurance, and Airspace Super Density Operations to actively mitigate imbalances and resolve conflicts, while minimizing the impact to the users' preferred trajectories. Trajectory prediction always involves some degree of uncertainty,[34,35] which can vary dramatically depending on modeling assumptions. Operational concepts must account for uncertainty. The two principal areas of research proposed for TPSU are fundamental trajectory modeling and estimating and accommodating trajectory prediction uncertainty.

1.3.1.1 Fundamental Trajectory Modeling

The current state-of-the-art for 4D TBO is limited to specialized areas in air traffic control, namely time-based arrival metering (Traffic Management Advisor [TMA]), en-route conflict detection (User Request Evaluation Tool [URET]), and modern Flight Management Systems (FMS). Each of these systems uses a different approach to Trajectory Prediction (TP) and analysis. For example, FMS uses highly complex energy management algorithms; URET uses simple kinematics; and TMA uses a hybrid of both. Each approach is valid for its particular application. However, interoperability across systems and seamless trajectory control through all flight regimes will be required for the NGATS. The following are considerations that need to be addressed when generating 4D trajectories that support seamless TBO: 1) development and use of TP algorithms that are interoperable with aircraft FMS algorithms, 2) generation of suitable surrogates for aircraft without FMS technology, 3) ensuring stable interaction and interoperability between multiple legacy systems which utilize their own trajectory prediction capabilities, and 4) ensuring minimum life-cycle costs through use of an approach to 4D trajectory generation that is driven by maximum utilization of common TP capabilities. The FAA's current investment in trajectory-modeling for both the current system and NGATS has a large, recurring development and validation software maintenance cost. Thus, research of common and interoperable trajectory prediction algorithms for NGATS would provide long-term cost savings of software development and maintenance.

The trajectory prediction research will provide common trajectory prediction algorithms and components and trajectory modeling and synthesis technologies needed to support cutting edge research concepts.

1.3.1.1.1 Common Trajectory Prediction Technical Approach

Although trajectory prediction (TP) is the fundamental cornerstone of ATM automation (particularly for 4D-trajectory-based ATM operations), recent U.S. and European efforts have found that there are no clear, consistent, and cross-comparable sets of requirements for TP. This gap impedes identification of opportunities to develop and leverage common TP capabilities. The approach to addressing this gap is to first survey, building on current NASA/FAA/Eurocontrol research collaboration (Action Plan-16), the extent of the problem. This study includes reverse engineering the requirements and capabilities of current TP technologies and defining, to the extent possible, the additional requirements to support future automation required to achieve NGATS. Following a successful peer review of the results, the team will compile a set of trajectory situations that experts agree are representative of the toughest 5% of TP situations, i.e., the cases most critical to NGATS implementation. The team will formulate an agreed upon standard for a common script definition that will serve each need defined by the collective set of TP stakeholders. TP capabilities that lend themselves to common applications will be grouped into core sets of capabilities. Validation will be accomplished by applying the common capabilities to at least two different TP applications. The TP capabilities that will be selected for this effort will be limited to those which are likely to be usable by the community for future TPs (and backward compatible into legacy TPs) and are likely to achieve significant cost savings to NGATS.

Relevant work from within the U.S. and Europe will be leveraged to the maximum extent possible. This will be accomplished in the en-route/transition airspace, where the knowledge of TP is fairly mature, and in the terminal airspace, where knowledge of TP is not as mature. Particular attention will be given to the complexities associated with arrival/departure operations into/out of high-density airport/metroplexes, including operations referred to as Continuous Descent Approaches, Tailored Arrivals, and airport-centric arrival/departure operations.

This work has dependencies on the FAA, Eurocontrol, and the FMS manufacturers. In addition, the level one milestones associated with this work are candidates for NRAs.

1.3.1.1.2 Trajectory Advancements

The lack of common and adequate sets of TP validation data, tools, and methods prevents stakeholders from clearly and consistently analyzing, validating, and cross-comparing TPs. Facilities such as NTX and CVSRF will be used to collect TP validation data. Since the NGATS will be heavily dependent on accuracy and robustness of TPs, validation and design tools will provide an invaluable complement to the validation of specific “top-down” NGATS requirements. Collaboration among TP developers is the key to this approach. The NGATS community will define the common framework (set of tools, methodologies, and datasets). Results of prior work will be assembled and organized according to the common framework (to ensure utility to all contributors). Gaps will be identified and filled by dividing them up across the participants for completion. The results will then be peer reviewed and re-compiled for community use.

A critical part of TP is identifying the correct order in which to apply trajectory constraints. This order is highly variable (depending on aircraft physics, pilot, and atmospheric conditions) and cannot be determined a priori. Building a TP algorithm that supports re-ordering of constraints and describing constraints as functions of others is essential to achieving interoperability between TPs. An algorithm such as this is particularly needed for air and ground predictions of departure, en-route, and arrival transition segments.

The goal is to model variable-order climb/descent-profile constraints. The approach will use dynamic parameter adjustments to vary climb/acceleration energy (e.g., thrust management), flight-path angle, and ground track to satisfy constraints. Constraint sequence will be based on the physics of the aircraft type, flight procedures, and situation. Constraints that are physically over-constrained will be dynamically relaxed. Relevant work from within the U.S. and Europe will be surveyed and leveraged as appropriate. The research will also include the complementary issues of over-constrained trajectories and intent errors.

The metrics driving this work are TP accuracies. The TP accuracies envisioned for super-density NGATS operations are, using a 20-minute prediction horizon, of the orders of 1 nmi for lateral/horizontal, 500 ft for vertical, and 10 sec for longitude. The current state-of-the-art accuracies are approximately three times these values for a typical high-density airspace situation. Measurements of TP accuracies will be performed on a set of TP scenarios representing the most challenging situations envisioned to occur at least 1-5% of the time in future operations. The test set will be created from high-fidelity simulations and field trials and will be peer reviewed by a panel of subject matter experts from NASA, the FAA, and Eurocontrol.

This work has dependencies on the FAA, Eurocontrol, and the FMS manufacturers. In addition, the level one milestones associated with this work are candidates for NRAs.

1.3.1.2 Trajectory Prediction Uncertainty

Uncertainty of trajectory predictions stems from multiple sources. An automation system must have detailed knowledge of the aircraft's performance characteristics, procedures, and pilot intent to accurately predict a trajectory. Making assumptions, where such knowledge is lacking, results in uncertainty of the prediction. The best performance model for a given aircraft generally resides onboard a suitably equipped aircraft in the FMS and includes an airframe-specific lift/drag model, an engine model, and thrust-setting data. Predictions made for that aircraft by ground automation or other aircraft will generally be less accurate than FMS predictions, depending on the information available. In addition to model inaccuracies, environmental factors also generate uncertainty. Wind predicting models have resolution, currency, and accuracy limitations. Furthermore, the dynamic nature of convective weather systems generates real-time decision making that adds intent uncertainty. Procedural assumptions also come into play, such as crew-dependent procedures for softening the top-of-descent maneuver or approaching the runway. In addition, variances in RNP produce a component of trajectory prediction uncertainty. All of these sources of uncertainty can be mitigated to a degree, and yet some uncertainty will remain. Of research importance are estimating the prediction uncertainty and devising mechanisms by which this uncertainty can be accommodated in decision making, particularly in the area of conflict management. Insufficient accommodation can result in missed conflict alerts, which may eventually lead to short-notice urgent maneuvers or unnecessary loss of separation. The key need here is to dynamically predict uncertainty for use by stochastic-based automation in mitigating its impact.

1.3.2 Performance-Based Services

A key NGATS capability is Performance-Based Services (PBS) that match Air Navigation Service Provider (ANSP) service levels to user performance capabilities across all flight domains and operational constraints. Defining multiple service levels will address a wide range of user needs while encouraging more private sector innovation and free market decision making. PBS allows users to select the performance level appropriate for their particular operation and surpasses the need to dictate specific equipment requirements. PBS is also a tool for controlling access to highly constrained resources and/or complex operating environments. Understanding and defining this performance framework, its associated levels of performance, and the commensurate levels of service, are critical steps toward reaching the NGATS vision.

PBS combines the fundamental building blocks of Required Navigation Performance (RNP), Required Communication Performance (RCP) and Required Surveillance Performance (RSP) into the aggregate multi-dimensional parameter of Required Total System Performance (RTSP). These three RTSP components are generally in the formative stages of definition with the following order of maturity: RNP (high), RCP (medium), and RSP (low). Research is needed to accelerate the completion of the definitions, to link them to the appropriate ANSP service levels, and to assess their impact on integrated system performance.

In addition, higher levels of user performance can also be achieved by integrating RTSP with onboard automation capabilities and procedures to produce integrated capabilities capable of off-loading some currently ground-based ATM functions. The application-specific functions that can be enabled individually or concurrently include time-of-arrival conformance, airborne spacing, and airborne separation. The first of these is critical for all aircraft participating in high-accuracy 4D-trajectory operations. The remaining two relate to an aircraft's ability to accomplish precise maneuvering relative to other traffic, either by delegation or by default. Predictable aircraft performance in these areas may be quite valuable to ATM beyond basic RNP, RCP, and RSP in supporting efficient use of NAS resources.

NASA research in PBS concepts will provide increased focus on an area that is foundational and critical to the NGATS vision and architecture. The work to quantify the performance levels achievable by aircraft must be conducted before system-level performance of integrated air/ground concepts can be measured. NASA will work with industry to produce definitions of RNP, RCP, and RSP that are capable of supporting proposed NGATS concepts. In addition, it will provide a framework to assess performance requirements for various proposed concepts of operation.

An initial representation of a potential PBS framework is provided in Figure 3. NGATS operational concepts drive a set of service levels and associated performance requirements. Core Communication, Navigation, and Surveillance (CNS) requirements are included at the baseline level and are represented by RNP, RCP, and RSP. All applications are expected to require some level of each RTSP component. Where needed, requirements in addition to RTSP are considered as part of a second tier. These advanced performance measures are also dependent upon a minimum level of RTSP.

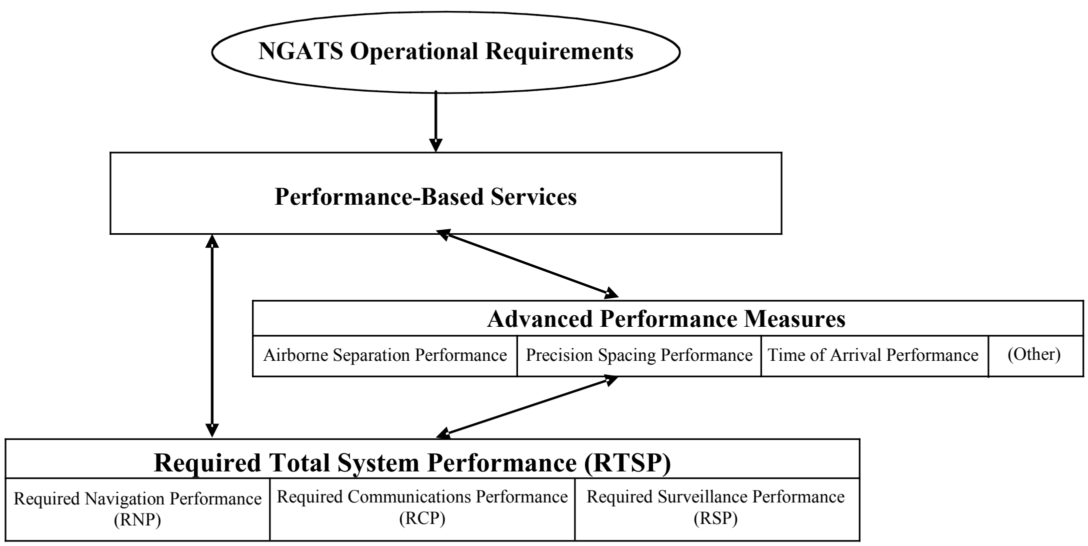

Figure 3. Performance-Based Services Hierarchy

1.3.2.1 RTSP and Advanced Performance Measures

Fundamental work on PBS has the goal of producing a classification of core and advanced capabilities needed to support proposed NGATS operational concepts. Beginning with a list of proposed applications, NASA conducts a requirements analysis to determine the capabilities needed to support them. These capabilities are initially captured in the form of functional attributes and are not assigned quantitative performance values. The requirements section of the Operational Services and Environment Description document format used by the RTCA/EuroCAE Requirements Focus Group is one example of the proper level of information for this assessment. Capabilities are grouped under either a core RTSP element (RNP, RCP, or RSP) or an advanced performance measure. The latter is used for applications that require avionics capabilities in addition to RTSP. The final outcome of this effort is the development of a hierarchical structure that includes core and advanced capabilities needed to support proposed NGATS operational concepts. NASA concepts such as AAC and 4D-ASAS are included in this assessment. Capabilities listed should allow performance studies to assign numerical levels to them. The architecture must enable operators to determine the types of capabilities needed to support a particular application. When performance studies are completed, operators will be able to determine specific quantifiable requirements for each required capability. The architecture must be expandable to allow additional applications.

In parallel, NASA representatives work with the appropriate government/industry committees (i.e., PARC, RTCA, ICAO) to determine a detailed set of attributes for RCP and RSP. This work is done in close cooperation with JPDO's Shared Situation Awareness IPT. NASA contributes technical expertise to ensure that definitions are supportive of proposed NGATS concepts. Initial RCP and RSP elements are revised as a result of these activities.

1.3.2.2 Application Specific Functions Enabled by RTSP

Partnerships with JPDO and industry are used to produce parametric models of state-of-the-art CNS systems. The models chosen for development are based on the information infrastructure being pursued by JPDO's Shared Situation Awareness IPT. They should be developed in a way that facilitates integration into NASA laboratories used to evaluate operational concepts. This development effort supports studies to determine the impact of CNS performance on proposed operational concepts. It does not aim to enhance the CNS capabilities. Such work is done outside of NASA.

The models should target the range of performance characteristics of candidate systems that may support proposed NGATS operational concepts. They should accept common system or operational parameters as input (such as traffic density, presence of secondary surveillance radar sites, transmitter strength, etc.) and produce the set of system performance values described above as output. These performance metrics were captured as functional attributes under the requirements assessment activity. Input parameters should be able to be adjusted to capture minimum requirement systems, state-of-the-art systems, and expected performance improvements over the course of the NGATS implementation period. The parameter range should also allow an increase sufficient to assess requirements when expected capabilities are insufficient to meet operational needs. Where appropriate, development should leverage existing models such as those for ADS-B and RNP currently residing within the Air Traffic Operations Simulation (ATOS).

The CNS models can be incorporated into NASA simulation facilities such as the Airspace Concept Evaluation System (ACES) and ATOS hosted by the Air Traffic Operations Laboratory (ATOL). Other laboratories may also be used. When possible, integrated model performance is validated using available operational data.

A series of batch studies is conducted to evaluate different proposed NGATS operational concepts under normal and failure mode conditions. These studies incorporate parametric adjustments of RTSP levels and produce a range of safety and efficiency metrics. Results are used to make an initial assessment of RTSP requirements needed to support the operational concepts. They may also be used to determine service levels based on aircraft and avionics capabilities. This connection will be done in coordination with the operational concept development.

1.3.2.3 Case Studies

As discussed in the Separation Assurance section (Section 1.3.5), several core aircraft capabilities are anticipated to be needed for either ground-based or airborne-based control strategies. These capabilities are likely to include a certain level of RNP and air/ground datalink. Under that section, work is outlined to determine the CNS requirements for a ground-based control strategy. CNS models and the proposed Performance-Based Services architecture developed under this section can be used to contribute to that work.

Several additional aircraft capabilities beyond basic CNS performance may enable the transfer of some traditionally ground-based ATM functions to participating aircraft. NASA's Distributed Air-Ground Traffic Management (DAG-TM) research developed a performance-based mode of operations that combines aircraft capabilities for 4D trajectory management and traffic-dependent maneuvering with ground-based capabilities for NAS resource management into a complementary air-ground architecture.[33] Using 4D-ASAS systems, supported functions include airborne-responsible roles in 4D time-of-arrival conformance, traffic separation, and precision spacing. Whereas these advanced airborne capabilities have been prototyped and tested in simulation under numerous conditions, the documented performance has been developed without consideration of RTSP levels. Research must now be performed to map the performance of these functions to RTSP and other advanced capabilities so that ATM-system-level performance achievable with 4D-ASAS capabilities can be determined.

The performance levels of RNP, RSP, and RCP will be parametrically implemented in simulation in ATOS. This facility is considered to be well-suited for this research, because it currently has several CNS models implemented and supports the advanced capabilities associated with 4D-ASAS. The laboratory architecture can also support the addition of other CNS models discussed above. A batch simulation will be conducted to map the RTSP performance inputs to the ATM functional outputs. A human-in-the-loop simulation will be conducted to assess the impact of human performance. By measuring the performance of these functions with respect to RNP, RSP, and RCP levels, relationships will be established in which the achievable performance of these advanced airborne ATM functions can be derived from the RTSP. The impact of this research activity will be to quantify the achievable performance of 4D-ASAS-enabled operations involving the execution by the aircraft of the specified ATM functions of time-of-arrival, separation, and spacing. The time-of-arrival and precision spacing performance results will support the Airportal Project in defining the expected delivery precision and rate of landing flights.

1.3.2.4 Partnership

NRAs will be used as a vehicle to take advantage of innovation outside NASA resources. The NRAs will cover the topics such as RTSP operational concepts, elements of RTSP and their characteristics, levels of RTSP and operational implications, and relationship between levels of RTSP and performance.

1.3.3 Dynamic Airspace Configuration

A part of ATM is the operational practice of predicting and mitigating air traffic demand/capacity mismatches. Under-capacity situations degrade system efficiency; over-capacity situations degrade system efficiency and system safety. ATM employs capacity and demand management techniques to balance capacity and demand. In the NGATS, demand management is allocated to the Traffic Flow Management function (ref. Section 1.3.4); one of the ways capacity management is allocated to the *Dynamic Airspace Configuration* function, discussed here.

1.3.3.1 Motivation

In today's air transportation system, the airspace is a rigidly structured network of navigation aids, airways, six classes of airspace divided into sectors, and special-use airspace. Airspace managers have little flexibility to reconfigure these airspace elements to meet variations in air traffic demand. The combining of two adjacent sectors is the only short-term technique available to alter the airspace structure. Managers may also open/close special-use airspace, but the status of such airspace is not well communicated to users, and capacity sometimes goes unused as a result.

Because today's air traffic managers have few degrees of freedom on the capacity management side of ATM, they largely rely on demand management techniques in order to balance capacity and demand. Users' requests are therefore subjugated to the relatively inflexible architecture of the NAS.

One of the operating principles behind the NGATS as articulated by the JPDO is: "It's about the users." Whereas today's system is characterized by limited user access to information about airspace status and the routine imposition on users of flow restrictions and/or route amendments, the NGATS is expected to improve customer service with open access to ATM information (such as airspace status) and fewer restrictions on and amendments of user requests. For example, the ANSP's first-order response to a projected overcapacity situation in the NGATS will be to proactively reconfigure the airspace and reposition its workforce to meet the needs of users, rather than requiring users to amend their trajectories or contracts to conform to the ANSP. Only after addressing the capacity side of the ATM equation should the ANSP move its focus to the demand side.

The mission of Dynamic Airspace Configuration research is to better serve users' needs by tailoring the availability and capacity of the airspace and promptly communicating its status to users.

1.3.3.2 Description of Capabilities and Operational Objectives

The NGATS airspace is expected to include new classes of airspace, such as Automated Airspace and Autonomous Self-Separating Airspace, and vestiges of some of today's classes of airspace may also persist. With this complex airspace environment as a backdrop, the JPDO has introduced the concept of a Dynamic Airspace Configuration capability to tailor the availability and capacity of the national airspace to projected aggregate demand.

The Dynamic Airspace Configuration function will provide the ANSP with a new degree of freedom to accommodate the airspace requests of users, balanced against needs of national interest (e.g., security). The primary input to the function will be regularly updated projections of aggregate demand. The DAC function then is expected to enable airspace managers to tailor the availability and structure of the airspace to those projections. To accomplish this, the DAC function is expected to include: (a) a capability to dynamically manage the allocation and deallocation of airspace for military and special uses; (b) a capability to temporarily instantiate high-density airspace corridors, low-density general-use zones, and/or any other class of airspace to best service aggregate user demand; (c) a capability to "flex" airspace boundaries to balance projected airspace complexity; and (d) a capability to temporarily restrict airspace access based upon performance standards to more equitably ration oversubscribed resources; among (e) other capabilities to be determined in the course of research. The primary output of the DAC function is a reconfigured airspace structure tuned to the extent feasible to accommodate aggregate user demand. Its operational concept will be guided by operational considerations in collaboration with JPDO, the FAA, and others.

This Dynamic Airspace Configuration capability is dependent upon two enablers:

- **A NAS infrastructure that supports flexible staffing of the national airspace.** By "flexible staffing," we refer to the notion that airspace sectors are designed to be "generic," such that an airspace manager would be qualified to manage any sector of a certain airspace class, regardless of its physical location. In order to maintain maximum flexibility in staffing the NGATS airspace, the design of the airspace will emphasize standardization. This is analogous to airframers' efforts to standardize cockpits for flexibility in crew scheduling. It also presumes the necessary infrastructure to enable all relevant sector information and communications to be provided at that airspace manager's position. The latter is not part of the proposed research; JPDO is expected to direct that research to the FAA.
- **A metric that aptly projects airspace complexity.** The NGATS is expected to have a variety of airspace types with a variety of mechanisms for separation assurance: some human-based, and others automation-based. Complexity is likely to be defined differently in either case. Regardless, the usefulness of the DAC function is likely to hinge on the ability of this metric to accurately forecast airspace complexity. This metric is expected to be the parameter by which the "goodness" of any given airspace configuration is judged. The Dynamic Airspace Configuration research plan does not attempt to develop this metric; the TFM research will address this need (ref. milestone AS.1.4.04).

The time horizon within which traffic managers could be expected to reconfigure airspace could range from the order of months to days to hours. For example, monthly allocation of airspace could be based on seasonal demand and weather trends; daily adjustments might be made to align with the jetstream; *n*-times-daily refinements of airspace characteristics such as RTSP requirements might be applied to best accommodate user demand once the final traffic projections (those with the least uncertainty) have come in.

Recognizing that Dynamic Airspace Configuration is a completely new operational paradigm for ATM, the discussion of capabilities and operational objectives is notional at this early stage. NASA expects to partner its research effort in this area with appropriate external contributors from the FAA ATO and other JPDO members (e.g., DoD, DHS)—as well as internal contributors researching the Traffic Flow Management function (i.e., the demand side of the ATM balance)—in order to develop a more complete understanding of all stakeholder objectives and a more rigorous operational concept. Forging this partnership is the first order of business for the DAC research initiative.

1.3.3.3 Approach

1.3.3.3.1 Discovery

The research effort will begin with a collaborative survey of the state of the art in terms of concepts and technologies supporting dynamic allocation of airspace and air traffic personnel to meet projected user demand. The survey will encompass efforts at NASA, FAA, other JPDO member agencies, and industry and the international research community. The survey will also serve to identify collaborators for the next step in the approach: concept development.

1.3.3.3.2 Concept Development

In concert with partners at JPDO, FAA ATO, etc., the research will develop candidate concepts of operation for the Dynamic Airspace Configuration function, including its relationship to Traffic Flow Management. The concepts will articulate how automation could assist the ANSP in identifying the most favorable airspace configuration(s) for a given demand projection. Areas of specific interest are expected to include those listed in 1.3.3.2 above.

1.3.3.3.3 Concept Assessment

The candidate concepts developed above will be brought for assessment and validation in a laboratory setting featuring a medium-fidelity airspace simulation. The Future ATM Concepts Evaluation Tool (FACET) is the most suitable simulation tool known to be available for this level of concept validation, and current plans rely on its use.

1.3.3.3.4 Technology Development

Once an acceptable concept has been identified, the research focus will shift to technology development. However, this is not anticipated to occur within the 5-year planning horizon of this reference material. Instead, technology development (i.e., prototype development and validation) is expected to commence in FY12, with milestones following along the FY12-16 roadmap.

1.3.3.3.5 Technology Incubator

Small-scale investments will be made to seed fundamental research into new technologies having large potential payoffs. Application of genetic algorithms to airspace allocation schemes are one possible area of investment. These investments are expected to be made through NRAs.

1.3.3.4 Partnerships & Dependencies

Each step in the approach outlined above will be a concerted effort involving the community of stakeholders. Initial efforts to scope and allocate the work will be coordinated with JPDO and are expected to involve significant input from the FAA. Through JPDO, representatives of DoD and DHS will have a role in addressing concepts for airspace availability and status. Internally, the DAC research will be coordinated with the NGATS ATM: Airportal project, particularly when developing the concept of use for dynamic configuration of the terminal airspace.

The DAC research is dependent on research being undertaken elsewhere within and beyond the Airspace Systems Program. Most significant is the dependence on TFM research (discussed in 1.3.3.2) to develop an apt metric for airspace complexity. But, the DAC research will also be steered to some extent by policy decisions via JPDO that determine what performance bases may be used to value airspace and discriminate among users. And, the relative success of research to automate separation assurance may alter significantly the stability of the airspace complexity metric, potentially impacting the frequency with which the airspace must be reconfigured.

1.3.4 Traffic Flow Management

The primary function of Traffic Flow Management (TFM) is to identify and resolve any imbalance(s) in the demand and supply of NAS resources such as airspace and runways. The approximate time horizon for TFM is from 20 minutes to 8 hours, which can be further broken out as Regional Flow Management (about 20 minutes to 2 hours) and National Flow Management (about 1 to 8 hours).

The goal of national flow management is to accommodate user-preferred gate-to-gate trajectories by managing and allocating NAS resources in situations where demand approaches or exceeds supply. The purpose of regional flow management is to provide a tactical control loop to adjust the strategic control solutions generated by national flow management from probabilistic demand/supply forecasts of NAS resources.

1.3.4.1 Technical Challenges in TFM

The TFM function in the NGATS has to be designed to deal with three times more traffic than today, and be able to handle a traffic mix consisting of airline operations, air taxi operations, general aviation, and unmanned air vehicles. The traffic demand in the future is expected to be less structured with a more significant variable component than today. A complicating feature is that the number of players generating the traffic demand may be more and varied in nature. Another significant variable in the design of the TFM function will be the interaction between the Separation Assurance and TFM functions. The separation assurance function determines the level of allowable traffic complexity in the design of traffic flows in different parts of the NAS.

Clearly, there is an interaction between the national flow management function and the dynamic airspace configuration function. As in the case of the airspace planner function, the planning time horizons for the national flow management function would include annual, seasonal, monthly, weekly, and daily. Each planning phase requires collaboration with the various users of the airspace. The types of functions performed during the annual to daily planning may have several things in common such as assignment of flights to specific routes, rerouting to avoid weather, and assignment of delays to individual flights. The long-term planning for this function relies heavily on historical data, forecasts of demand and the biggest source of disturbance to the system, the weather. As the actual date of flight approaches the historical data is replaced by actual weather forecasts, improved understanding of other airspace and airport constraints, and improved information on the status of planned flights received from the users through the collaborative decision making process.

In the NGATS, advanced TFM will be a key element of the Evaluator, enabled by 4D trajectory-based operations for optimal utilization of the prevailing airspace and air portal configuration. Predictability of demand for NAS resources would be significantly enhanced through the use of flight-specific 4D contracts consisting of a nominal 4D trajectory with conformance bounds that vary along the trajectory, i.e., tight bounds for short time horizons that may be gradually relaxed as the time horizon (and the associated uncertainty) increases. Many aircraft would have gate-to-gate 4D contracts, which may include estimates of gate identification, pushback time, take-off time, a complete 4D trajectory through the airspace, touchdown time, and gate arrival time. However, there may be some aircraft in the NGATS that are equipped to design, in real time, a 4D trajectory of their choice while separating themselves from other traffic – they are called “4D-ASAS” aircraft. An example TFM research topic is to determine if a 4D contract for such aircraft could consist of only a requirement to meet a RTA at a few points in space and/or a requirement to avoid a region of airspace during some time interval, while giving it the freedom to determine all other segments of its trajectory in real time.

On the supply side of the flow management equation, a major impediment to the accurate prediction of available/usable NAS resources is the weather (thunderstorms, fog, etc.). It is clear that the accuracy of weather prediction is inversely proportional to the prediction time horizon, and hence probabilistic forecasts of weather are desirable especially for longer planning time horizons (e.g., more than 2 hours). These weather forecasts will be utilized to generate probabilistic forecasts for the availability of NAS resources, thereby assimilating weather predictions into the decision-making process. Research in this area includes the determination of requirements for new aviation weather products and the effective utilization of weather products currently in the development pipeline – this will be done in coordination with the JPDO Weather IPT.

1.3.4.2 Technical Approach for TFM Research

The TFM effort is organized into the four focus areas outlined below, with appropriate base/fundamental research underlying each of these areas. The overall technical approach is a natural progression from concept development to building core capabilities (weather impact and collaborative decision making) to testing/evaluation.

1.3.4.2.1 Advanced TFM Concepts

This work focuses on the development of advanced TFM techniques that contribute to the goal of tripling NAS capacity by leveraging key features of the NGATS such as 4D trajectory-based operations, performance-based operations, automated separation assurance, and super-density operations. A key research challenge is to develop techniques that utilize both individual and aggregated 4D trajectories[13] to organize, schedule, and regulate traffic flow in accordance with calculated NAS capacity constraints. The spatial and temporal bounds of these constraints will be defined using advanced clustering leveraging prior work on gaggle density,[24] pattern recognition, dynamic density, and artificial intelligence techniques. The resulting TFM solution space will be analyzed to evaluate both service provider and aircraft operator control authority. The output of this effort is an integrated set of advanced TFM concepts and the associated algorithms/models that will be integral to the development of the Evaluator.

Another aspect of this work is to define the relationships and operational transitions between TFM, dynamic airspace configuration, and separation assurance. As part of this activity, advanced techniques for assessing the impact of TFM initiatives[14] under both deterministic and stochastic scenarios will be developed. Candidate initiatives to be examined as part of this effort include: rerouting and departure control at the national level; merging, spacing, and sequencing at the local level; and, sequencing and scheduling in multi-airport terminal areas. The benefits and utility of these TFM control strategies will also be assessed as part of this activity. The output of this effort will be a baseline Evaluator concept of operations that describes the composition and architecture of TFM functions as well as their temporal and geographic scope.

1.3.4.2.2 Collaborative Decision Making in TFM

The focus of this work is to develop a methodology for incorporating user preferences into traffic flow management, building on prior work.[25] This activity involves determining appropriate roles and procedures that enable users and the air traffic service providers to collaboratively design efficient and equitable traffic management initiatives. Advanced tools and protocols will also be developed for formulating, evaluating, and implementing these collaboratively designed initiatives. An important component of these advanced capabilities will be sophisticated new algorithms that can allocate flights to capacity constrained NAS resources (e.g., airspace and runway) in a fair and equitable manner. The output of this activity will be algorithms, procedures, and protocols for fully integrating Collaborative Decision Making (CDM) into the TFM process.

1.3.4.2.3 Weather Impact on TFM
The focus of the work is to develop probabilistic models to forecast demand and capacity of NAS resources (e.g., airspace and runways). The technical challenge is to develop modeling techniques that are robust to uncertainties such as weather conditions and substantial variations in user demand profiles. These stochastic forecasts are necessary for designing TFM control strategies (e.g., rerouting, departure delay, sequencing and scheduling) that will balance the forecasted supply/demand profiles in an equitable and optimal manner. A key component of this research activity will define weather forecast requirements for the aviation weather research community that will enhance the performance of both local and national level TFM. The outputs of this activity are probabilistic models/algorithms, and weather product requirements, for improved predictions of NAS resource demand/supply under uncertainty.

1.3.4.2.4 Simulation and Evaluation of TFM Concepts
The purpose of this activity is to develop prototype tools to implement advanced TFM concepts utilizing 4D trajectories. This activity focuses on the implementation of various algorithms (e.g., probabilistic predictions of NAS resource demand/supply; regional metering and/or spacing; ground delay; customized rerouting incorporating user preferences) in a NAS simulation environment such as FACET.[26] The output of this effort is a suite of advanced TFM tools integrated into a simulation test bed.

The activity will also conduct system-wide performance assessments of advanced TFM concepts for NGATS. The goal is to evaluate system-wide performance under various traffic and weather scenarios. This activity will require designing and performing numerical simulation studies, as well as higher fidelity HITL experiments to assess roles, responsibilities, procedures, displays, information needs, as well as accuracy and usefulness of algorithms. A key research challenge is to design performance metrics (e.g., capacity, delay, equitability, robustness) that will enable a system-level performance analysis using a RTSP approach. The output of this effort will be a system-level simulation assessment of the feasibility and benefits of implementing advanced TFM techniques.

1.3.4.3 Partnerships
NRAs will be utilized for fundamental research (Levels 1 and 2), e.g., new mathematical models of aggregate flows, dynamic density/complexity measures tailored for automated separation assurance, and techniques for data mining of large historical databases. Active participation in the FAA-Airlines Collaborative Decision Making (CDM) group will leverage their knowledge gained from field testing and evaluation of prototype technologies, e.g., Integrated Collaborative Rerouting (ICR), and Airspace Flow Program (AFP). Close coordination with JPDO will ensure that TFM research is aligned with the NGATS concept as it matures over time.

1.3.5 Separation Assurance
In today's operations air traffic controllers provide separation assurance (SA) by visual and cognitive analysis of a traffic display and issuing control clearances to pilots by voice communication. Decision support tools deployed in recent years provide trajectory-based advisory information to assist controllers with conflict detection and resolution, arrival metering, and other tasks.

DSTs have reduced delays, but are not expected to support a substantial increase in airspace capacity. And efforts to reduce airspace sector size have reached a point of diminishing returns. The human controller's cognitive ability to monitor a radar display and ensure separation for no more than about 15 aircraft (± 2 or 3 traffic complexity dependent) prevents a substantial increase in capacity.

A fundamental transformation of the way SA is provided is needed to achieve NGATS 2025 objectives. The JPDO envisions higher levels of automation and a more optimal allocation of SA functions between automation systems and human operators, and between central service providers and aircraft operators. The overarching research problem for SA is to identify trajectory-based technologies and human/machine operating concepts that could support a substantial increase in capacity (e.g., 2-3x) with safety under nominal and failure recovery operations, with airspace user preference and with favorable cost/benefit ratios.

The state of the art in ATM SA technology is reflected by recent DST deployments (TMA and URET, see Section 1.3.1.1) and a body of research (some cited here) covering 4D trajectory analysis, time-based metering and arrival flow management, traffic conflict detection and resolution,[34,36,37,38] and advanced concepts,[39]. Emerging aircraft performance capabilities are expected to play a key role in NGATS operations.

1.3.5.1 Technical Challenges in Separation Assurance

Key challenges for SA include the following: 1) Automated conflict detection and resolution algorithms, trajectory analysis methods, and system design characteristics are needed that together ensure safe and efficient resolution trajectories for very nearly 100% of conflict encounters under widely varying traffic conditions, uncertainties (e.g., surveillance, weather, pilot intent, failures), and increased traffic density; 2) Operating concepts and human/machine interface characteristics are needed to ensure controllers and pilots can maintain awareness of automatic SA functions, can simultaneously interact with semi-automatic SA functions, and can safely intervene in the event of unexpected conditions or component failures; 3) Identification and analysis of component (air/ground) failure and recovery modes to ensure timely failure detection and graceful recovery. This ensures that controllers and pilots are not exposed to sudden high workload, safety critical situations; and 4) The interaction of automated SA with hazardous weather and TFM automation is important given the increased capacity target and the uncertainty of hazardous weather and its impact on NAS operations.

1.3.5.2 Technical Approach for Separation Assurance Research

Separation assurance research is divided into 3 focus areas described below. The technical focus is on a service provider approach to automated SA. Many aspects of a service provider approach may be applicable to an aircraft operator-based SA approach. Several automation functions are comparable since both use trajectory-based automation to detect conflicts, provide efficient resolution trajectories, and analyze airspace user trajectory change requests. Testing is conducted using objective analytical metrics based on analysis of operational FAA traffic data and medium to high fidelity human-in-the-loop simulations. Operational experiments are conducted at points when operational data are needed to verify key outcomes or assumptions. Foundational research will address resolution algorithms for robust and efficient trajectory operations, interaction between resolution algorithms with overlapping time horizons, human situation awareness for automated ATM systems, and failure modes analysis.

1.3.5.2.1 Automated Separation Assurance Technology

The major challenge is to develop automatic conflict detection and resolution algorithms, trajectory analysis methods, and system architectural characteristics that together result in automated resolution trajectories that are safe, efficient (i.e., airspace user preferred), and robust under the huge variety of traffic conditions in the NAS. Achieving safe and efficient trajectory operations under complex interactions of climbing, level, descending, and merging aircraft, uncertainties such as wind, weather, and unforeseen events like deviating aircraft or data communication failures is a key research challenge. It is anticipated that for operational acceptance and interoperability with tactical safety assurance functions the automated resolution system must detect and resolve nearly all traffic conflicts 5-15 min prior to loss of separation depending on traffic conditions. Several automatic resolution approaches have been investigated in recent years including global trajectory optimization, closed-form analytical methods, and rule-based heuristic search methods. We focus on the latter since years of experience in trajectory analysis and conflict detection with operational Center/TRACON data suggest this approach is the most robust, expandable, and amenable to user preference given the complexities and uncertainties in the NAS. A common trajectory analysis methodology that serves airspace user, controller, and machine-generated trajectories is important to ensure coordination and consistency of trajectory analyses for varying levels SA automation, aircraft equipage, and failure modes. This will allow automatic SA functions and the human-driven SA functions to operate smoothly together.

An independent safety critical tactical (0-2 min to loss of separation) conflict detection and resolution function is envisioned as a backup should the primary trajectory server fail. The design of this function, its interaction with the primary trajectory server and the existing Traffic Collision Avoidance System (TCAS), and its ability to detect and resolve 100% of conflicts are key considerations.

When metering is required to balance traffic demand with limited capacity at choke points (runways and merge points) conflict resolution trajectories, or any trajectory change, must adhere to end-point constraints. This is an extremely challenging problem in dense traffic where the goal is to achieve fuel-efficient continuous descent trajectories for all aircraft in multiple arrivals streams descending to a fixed point through varying wind fields and crossing traffic. This work must consider interoperability and integration with Super Density Operations for consistency with possibly dynamic terminal entry (and exit) points with an aim towards continuous descent approach to landing.

Interaction between TFM and SA functions will influence the overall SA design. Weather modeling and avoidance at the tactical (0-30 min) level will have a strong interaction with SA since during hazardous weather many aircraft want to fly through limited and probabilistic openings in weather regions. Traffic complexity, traditionally determined by the number of aircraft in an airspace sector, becomes a function of the particular mix of closely spaced trajectories that could result in conditions where traffic conflicts might be un-resolvable should they occur.

Automated SA technology and operations will be assessed as function of emerging aircraft performance capabilities (e.g., FMS, RNP, datalink, GPS, ADS-B, CDTI) under varying traffic conditions, and mixed equipage operations.

1.3.5.2.2 Human/Automation Operating Concepts

Analyses of cognitive workload, situation awareness, and performance under varying service-provider-based concepts of operations and roles and responsibilities for NGATS will be conducted for controllers and pilots. Analyses assess safety, feasibility and benefits of operating concepts and displays from a human performance standpoint under nominal and failure recovery operations, with emphasis on coordination/teamwork between controllers, flight crews, and automation. The ability of humans to take over functions of automation, when needed, will be an important focus.

A series of human-in-the-loop simulations of increasing complexity and fidelity are needed to develop and validate human/machine operating concepts, human/automation allocation, and controller/pilot roles and responsibilities during nominal and failure recovery operations. Simulations include increasing levels of system safety and failure recovery modeling. The combination of technology, highly safety critical technology, and human/automation operations that ensures safety during failure modes is a central research issue.

1.3.5.2.3 System Safety and Failure Recovery Analysis

Identify component failure and recovery modes for automated SA methods including missed conflict alerts, datalink failure, primary trajectory server failure, false read-back (voice or datalink), human operator mistakes, and other factors. Analyze risk of failure, risk of collision if failure occurs, and technical/cost implications of reducing risk of failure. Analyze safety criticality level of various components in the automated SA system.

The Traffic Collision and Avoidance System installed on all air carriers provides an independent collision avoidance capability in the event separation standards are violated and a collision is possible. In a future system, with traffic operating under possibly reduced spacing, the likelihood of interactions between TCAS and automated SA functions will increase and as a minimum lead to increased nuisance and potentially problematic resolution advisories. Hybrid mathematical analysis or other advanced methods will be applied to assess the interaction between independent conflict resolution logics with overlapping time horizons.

Key components of the automated SA system will be modeled using automated software engineering tools and driven by safety-focused simulation scenarios to uncover conditions and other flaws that would not be found by traditional simulations. Such lightweight formal modeling and analyses will expose conceptual and implementation errors early in the design process.

1.3.6 Airspace Super-Density Operations

Airspace Super-Density Operations (ASDO) refers to highly efficient operations at the busiest airports and terminal airspace. The Separation Assurance research approach is aided by the extensive degrees-of-freedom (DOF) afforded aircraft in the cruise and transition airspace which could enable 2-3x capacity, how this drastic increase in traffic will be managed in the terminal domain is not as evident. The JPDO envisions a combination of new technologies enabling significant growth at large airports and increased operations at underutilized airports to absorb the expected increase. These operations need to be robust to the various business uses of the NAS including the hub-and-spoke (just-in-time) service that demands high capacity, tight scheduling, and predictable operations. This is to be done in the presence of the extreme challenge for the simultaneous satisfaction of precision sequencing, merging, spacing, and de-confliction requirements while using the airspace in an environmentally friendly fashion. This problem is well beyond the capability of any known approaches to multi-objective optimization. Coupling the problem with the wide breadth of aircraft performance contributing in a combinatorial fashion, severely limits the DOF of a possible solutions space.

1.3.6.1 Technical Challenges in ASDO

Capacity at the busiest airports plays a key role in determining the efficiency and robustness of the NAS and ultimately the attainable growth in air traffic. Significant growth at the busiest airports as well as regional and smaller airports is needed to achieve the capacity goals of the NGATS. However, even small increases in demand at the busiest airports can lead to significant delays in the current system requiring FAA slot controls to ensure safety and robustness of the current NAS network. Furthermore, increased capacity in the current architecture is a long, arduous process that is not scalable (realized capacity increase falls short of anticipated). A new operational paradigm in the terminal area is needed to support the demand projected by the NGATS. To achieve the required increase in terminal area capacity, the following four technical challenges must be addressed:

1) Enabling precision trajectories in dense terminal airspace. In high-density terminal airspace, aircraft operations are tightly coupled to the schedule, (especially for arrivals). Tactical decisions, including separation services, have a direct, and often detrimental, effect on capacity. For example, TCAS false alerts near final approach lead to unwarranted resolution maneuvers and gaps on final approach, resulting in lost capacity. Thus limiting the effectiveness of this critical safety technology. Achieving levels of throughput approaching theoretical capacity requires control authority to minimize the effect of inherent uncertainty in operations. Current use of precision procedures in terminal airspace is limited to either areas of the airspace where little control authority is needed (ILS once established on final approach), or lacks precision in the vertical and temporal domains (e.g. terminal RNAV procedures). ASDO must enable precise, highly efficient trajectories while incorporating technologies to significantly increase capacity.

2) Defining regional airspace resource optimization processes. Managing traffic flows into and out of multiple airports in close proximity to large airports presents a significant challenge for ASDO. During peak demand periods, maximizing capacity for the busiest airports may outweigh access for less capable aircraft. However, it is essential to enable increased operations at smaller airports in the same region to offload some of the demand on the busiest airport(s) where practical (e.g. air taxi operations). The processes to enable simultaneous precision and non-precision operations in terminal airspace must be defined to maximize regional terminal airspace capacity while minimizing access restrictions. Current practice for managing regional airspace is limited to static airspace design, airport configuration management, limited inter-airport departure coordination, and inter-facility voice coordination of airport configuration changes. ASDO must address demand in the regional context in an effort to increase capacity and robustness of high-density terminal operations.

3) Achieving robustness to varied and chaotic weather conditions. Weather-related delays account for the majority of total air traffic system delays. While some weather phenomena will necessarily restrict capacity for safety of flight, technologies are being developed to mitigate a large percentage of weather-related delays. How ASDO employs these technologies is central to achieving system-level robustness to varied weather conditions. Present terminal area operations are largely reactive to weather phenomena and mostly rely on national traffic flow management (TFM) to limit demand when weather forecasts indicate reduced capacity is likely. ASDO must proactively address uncertain weather forecasts and chaotic weather phenomena to take advantage of improved aircraft capabilities and provide airspace flexibility.

4) Satisfying environmental considerations while enabling NGATS traffic density. Environmental considerations (i.e., noise and emissions) have significantly extended and even prevented the construction of new runways. Increasing terminal airspace capacity with current operational procedures will magnify environmental impacts substantially at the nation's busiest airports. The integration of technologies that reduce aircraft spacing with technologies that enable the ensemble of aircraft specific performance to simultaneously and safely conduct low-noise, highly efficient trajectories is fundamental to realizing NGATS capacity goals. Further, new operational procedures are required to support the use of these technologies. If the NGATS is to support projected air traffic demand, every aspect of ASDO must minimize environmental impact to the extent practical.

1.3.6.2 Technical Approach for ASDO Research

The ASDO technical approach will follow a concurrent iterative concept development path rooted in improvements in understanding the 4 fundamental challenges noted above.

Concept of Operations Development: This effort will begin by conducting a literature survey to determine the state of the art in proposed methods for managing terminal airspace, and expand on current understanding to enable SDO. Rapid prototyping and fast-time simulation will be employed to assess and iteratively refine the concept of operations based on improved understanding of the fundamental challenges and development of enabling technologies to address those challenges. In coordination with the Airportal project and the JPDO, this effort will determine the initial allocation of roles and responsibilities for the aircraft operator and the ANSP, and for the human and automation in terminal airspace operations. It will further provide guidance to the JPDO on the designation of ASDO airspace and required capabilities.

Sequencing and Deconfliction Technologies Development: This work advances sequencing and deconfliction methods beyond the current practices of modified first-come-first-served scheduling and tactical separation service. Foundational research in this area will lead to an understanding of the inherent uncertainty associated with execution of precision trajectories in ASDO airspace, as well as improvements in multi-objective constraint optimization for air traffic systems. Further development of these technologies through fast-time simulation will determine the control authority necessary to achieve the prescribed capacity goal, and potentially enable resource utilization schemes that enhance robustness to varied and chaotic weather.

Precision Spacing and Merging Technologies Development: This research element addresses the need to reduce the level of uncertainty inherent to aircraft operations in ASDO airspace and enable many aspects of the Equivalent Visual Operations capabilities of NGATS. Fundamental challenges to execution of precise trajectories in dense terminal airspace include extending traditional concepts and theories for precision guidance and energy management to dependent, multiple aircraft scenarios, as well as human factors considerations for procedures and interfaces in nominal, off-nominal and failure modes. Addressing these challenges require rapid prototype analyses of proposed tools and interfaces, and part-task, as well as full mission simulation. This effort will result in procedures and technologies for airborne precision merging and spacing extended to meet multiple constraints and environmental considerations.

Regional ASDO Resource Optimization: The final focus area will work closely with the NGATS ATM-Airportal Project to define methods for regional resource optimization that enhance regional ASDO capacity and robustness of that capacity to a variety of disturbances. Efforts will further be coordinated with the JPDO, incorporating anticipated PBS concepts towards defining terminal area airspace designations and their associated capability requirements. Foundational research in this area includes developing methods for managing precision and non-precision operations in the same airspace.

1.3.7 System-Level Design, Analysis, and Simulation Tools

This cross-cutting technical element will focus on the system-level design, analysis and system simulation requirements providing overarching views of the Airspace project's technology and concept research thrusts. The National Airspace System (NAS) with its highly varied multi-stakeholder multi-objective interaction has evolved over the decades in response to perceptions of need and assumed response to the technological advancements. The effects of the advancements are often not observable once completed, thus leaves the stakeholder community unsatisfied with the response to their needs. This is due to the fact that NAS is a complex system with emergent behavior not directly linked to any single event or technology. Also, the design processes used today for technology and procedure insertion into the NAS is at the component level using prototyping and iterative human-in-the-loop simulation. There is limited if any system design constraints at the system level that effect the design or even provide feedback to the detailed sub-system (component) design.

Design, analysis, and simulation are closely tied, interactive activities. Each one is dependent on and supportive of the next. System design is the process of designing a system that encompasses all of the relevant technologies and concepts emanating from the other technical areas. System analysis consists of a suite of studies that are posed to answer key questions coming from system design. The answers to these questions will guide design decisions and influence the final design of the system. System simulation is the process of integrating models of the technologies flowing out of the other NGATS technical areas, including the Airportal project, into a common simulation platform, where possible, or used in combination to view many design and stakeholder aspects. These foundational design tools will simulate the NGATS system in aggregation and provide detailed views of the Airspace project technical components. The close interaction between the System-Level Design, Analysis and Simulation Tools (SLDAST) task researchers, working at the system level, and other Airspace project task researchers (including Airportal), working at the component level, is imperative to provide an integrated system view of the Airspace technologies and concepts.

The SLDAST activities will be coordinated primarily with JPDO's Evaluation and Analysis Division and Enterprise Architecture Division where the JPDO concentration will be on short-term biannual performance assessment for Congress and Office of Management and Budget as well as the architectures and analyses beyond NASA's scope (e.g. security, NGATS system cost (physical and information infrastructure), system benefits…) which will be leveraged to emulate system views and requirements beyond the projects research thrusts. Information flowing from the JPDO Portfolio Management Division, Agile Air Traffic System Integrated Product Team (IPT), Weather IPT, Safety IPT, Shared Situation Awareness IPT, and global harmonization IPT in the form of the stakeholder Operational Concepts will be used to help SLDAST focus on detailed representations of Airspace project technologies and concepts within that broad context. It is anticipated that the JPDO will be able to utilize some of the SLDAST designs, analyses and tools for their high-level, short-term NGATS analyses. The following sub-sections describe major technical activities and approach.

1.3.7.1 System-Level Design

System-level design includes relevant technologies and concepts that enable the system and subsystems to function. A detailed, baseline, block-to-block system-level design is necessary as the foundation for the technical work associated with the NGATS ATM-Airspace project. It will act as the system blueprint from which system changes will be proposed, analyzed, and book kept over the life of this project. The system-level design will also identify key performance metrics and their interrelationships including but not limited to capacity, efficiency, predictability, system interoperability, implementation risk, throughput, workload, safety, and environmental considerations (e.g., noise, emissions). System-level design elements will be iteratively modified based on stakeholder needs, requirements analysis, performance needs, functional decomposition, trade-off studies, cost-benefit assessments, safety assessments, fast-time modeling, human-in-the-loop simulations, and other assessments. A key challenge of the design research is the functional allocation and roles/responsibilities between human and automation, air and ground systems, along differing time horizons and under all foreseeable situations including high density, severe weather, novel, rare, and automation degraded situations. Transition considerations among different modes of operations will also be explicitly identified. Using the system blueprint and integrated system models and performance metrics different postulations of the system challenges will be defined and iterated based on both the technology view of the Airspace research thrusts and the stakeholder view of the JPDO operational concepts.

1.3.7.2 System-Level Analysis

A series of fast-time modeling and simulations, and human-in-the-loop simulation studies will be performed to examine the system-level performance metrics and sensitivity of proposed technologies. The development of a battery of nominal and off-nominal traffic and weather scenarios as well as analyzable questions emanating from the key design challenges will be defined and validated and used as part of the blueprint testing of operational concept and technologies. These scenarios will include differing traffic demand levels (up to 3x), equipage, weather, roles and responsibilities, and operational paradigms (e.g., different balance of service provider and user control). The system-level analysis will use the suite of models produced in system-level simulation to characterize and assess the concept for resulting system-level performance impacts. System level performance sensitivities to alternate system-level designs, along with first order dependencies between interacting subsystem elements, will be generated.

1.3.7.3 System-Level Simulation Tools

Design tools that simulate the NGATS system will be required to perform the studies listed in the system-level analysis section. Rapid and reliable development and modeling of integrated operational and technical innovations within context of the NGATS environment will be developed from system agent based simulations to user gaming as potentially represented by game theory approaches. The system simulation will include models of the relevant technologies and concepts being developed in the other technical areas of the NGATS ATM-Airspace Project, most importantly ASDO, SA, TFM, and DAC. This simulation will then be able to show how all these technologies function together to produce the NGATS. The development of the NGATS system simulation will build upon the Airspace Concept Evaluation System (ACES) and other emerging design tools including but not limited to generating future demand scenarios and analyzing data from simulations and the real NAS.

Appendix A. Acronyms and Abbreviations

3D	Three-Dimensional (Latitude, Longitude, and Altitude)
4D	Four-Dimensional (Latitude, Longitude, Altitude, and Time)
AAC	Advanced Airspace Concept
AATS	Agile Air Traffic System
AATT	Advanced Air Transportation Technologies
AC	Aircraft
ACES	Airspace Concept Evaluation System
ACSF	Advanced Concepts Flight Simulator
ADS-B	Automatic Dependent Surveillance - Broadcast
AFP	Airspace Flow Program
AIAA	American Institute of Aeronautics and Astronautics
AILS	Airborne Information for Lateral Spacing
ANSP	Air Navigation Service Provider
AOC	Airline Operational Control
AOL	Airline Operations Laboratory
AOP	Autonomous Operations Planner
APS	Airborne Precision Spacing
ARC	Ames Research Center
ARIES	Airborne Research Integrated Experiments System
ARMD	Aeronautics Research Mission Directorate
AS	Airspace
AsA	Airservices Australia
ASAS	Airborne Separation Assistance System
ASDO	Airspace Super-Density Operations
AST	Advanced Subsonic Technology
ATA	Air Transport Association
ATC	Air Traffic Control
ATL	Hartsfield International Airport
ATM	Air Traffic Management
ATO	Air Traffic Organization
ATOL	Air Traffic Operations Laboratory
ATOS	Airspace and Traffic Operations Simulation
ATS	Air Transportation System
AWRP	Aviation Weather Research Program
B.E.	Bachelor of Engineering
B.S.	Bachelor of Science
BCA	Boeing Commercial Aircraft
BOS	Logan International Airport
CAASD	Center for Advanced Aviation System Development (MITRE Corporation)
CAST	Commercial Aviation Safety Team
CD&R	Conflict Detection and Resolution
CDA	Constant Descent Advisor
CDM	Collaborative Decision Making
CDPM	Center Deputy Project Manager

CDTI	Cockpit Display of Traffic Information
CE	Concept Element
CFD	Computational Fluid Dynamics
CIWS	Corridor Integrated Weather System
CMF	Cockpit Motion Facility
CNS	Communication, Navigation, and Surveillance
CPDLC	Controller Pilot Data Link Communications
CRD	Concepts and Requirements Definition
CSPA	Closely-Spaced Parallel Approaches
CTAS	Center-TRACON Automation System
CVSRF	Crew Vehicle System Research Facility
D2	Direct-To Decision Support Tool
DA	Dynamic Airspace
DAC	Dynamic Airspace Configuration
DAG	Distributed Air/Ground
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DHS	Department of Homeland Security
DLT	Development Liaison Team
DOT	Department of Transportation
DPM	Deputy Project Manager
DSAT	Diagnostic Safety Assessment Tool
DST	Decision Support Tool
EAD	Evaluations and Analysis Division
EAS	Efficient Aircraft Spacing
EDA	En Route Descent Advisor
EDX	En Route Data Exchange
EFB	Electronic Flight Bag
EFPM	Efficient Flight Path Management
ERAM	En Route Automation Modernization
ETMS	Enhanced Traffic Management System
EuroCAE	European Organization for Civil Aviation Equipment
EVO	Equivalent Visual Operations
FAA	Federal Aviation Administration
FACET	Future ATM Concept Evaluation Tool
FAF	Final Approach Fix
FDDRL	Flight Deck Display Research Laboratory
FDRS	Flight Deck Research Station
FE	Flight Explorer
FFRDC	Federally Funded Research and Development Center
FMC	Flight Management Computer
FMS	Flight Management System
FTE	Full-Time Equivalent
FY	Fiscal Year
GATI	Global Air Traffic Interoperability Project
GDP	Gross Domestic Product

GFD	Generic Flight Deck
GPS	Global Positioning System
HITL	Human-in-the-Loop
HUD	Heads-Up Display
ICAO	International Civil Aviation Organization
ICP	Internal Call for Proposals
ICR	Integrated Collaborative Rerouting
IEEE	Institute of Electrical & Electronics Engineers
IFD	Integration Flight Deck
INS	Inertial Navigation System
IPT	Integrated Product Team
ISAT	Inter-center Systems Analysis Team
ITP	In-Trail Procedures
ITWS	Integrated Terminal Weather System
JFK	John F. Kennedy International Airport
JPDO	Joint Planning and Development Office
K	Thousands
L1	Level 1
L2	Level 2
L3	Level 3
L4	Level 4
LaRC	Langley Research Center
LAX	Los Angeles International Airport
LED	Logic Evolved Decision
LGA	Laguardia Airport
LMI	Logistics Management Institute
LNG	Low Noise Guidance
M	Millions
M.S.	Master of Science
MCP	Mode Control Panel
MIT	Massachusetts Institute of Technology
MITLL	MIT Lincoln Laboratories
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NGATS	Next Generation Air Transportation System
NOAA	National Oceanic and Atmospheric Administration
NRA	NASA Research Announcement
NTX	North Texas Research Facility
OEP	Operational Evolution Plan
OGA	Other Government Agencies
OMB	Office of Management and Budget
OpsCon	Operations Concept
ORD	O’Hare International Airport

PARC	Performance-Based Operations Aviation Rulemaking Committee
PARR	Problem Analysis and Resolution Ranking
PBO	Performance-Based Operations
PBS	Performance-Based Services
PDM	Proposal Development Manager
pFAST	Passive Final Approach Spacing Tool
Ph.D.	Doctor of Philosophy
PI	Principal Investigator
PM	Project Manager
PM	Project Management
PMC	Program Management Council
POC	Point-of-Contact
QAT	Quiet Aircraft Technology
R&D	Research and Development
R&R	Roles and Responsibilities
RCP	Required Communication Performance
RFD	Research Flight Deck
RFG	Requirements Focus Group
RFI	Request for Information
RIOP	Research Investment Opportunity Paper
RNAV	Area Navigation
RNP	Required Navigation Performance
RSA	Research and Systems Analysis
RSP	Required Surveillance Performance
RTA	Required Time of Arrival
RTCA	RTCA, Inc. (formerly Radio Technical Committee on Aviation)
RTSP	Required Total System Performance
SA	Separation Assurance
SATNAV	Satellite Navigation
SDAST	System-Level Design, Analysis, and Simulation Tool
SDF	Louisville-Standiford Airport
SDO	Super-Density Operations
SEA	Seattle Tacoma International Airport
SFO	San Francisco International Airport
SMD	Science Mission Directorate
SMS	Surface Management System
SWEPT	System-Wide Evaluation and Planning Tool
SWIM	System-Wide Information Management
TA	Tailored Arrival
TAP	Terminal Area Productivity
TBD	To Be Determined
TBO	Trajectory-Based Operations
TCAS	Traffic Collision Avoidance System
TFM	Traffic Flow Management
TFM-M	TFM Modernization
TIM	Technical Interchange Meeting

TM	Technical Memorandum
TM	Traffic Management
TMA	Traffic Management Advisor
TP	Trajectory Prediction
TPSU	Trajectory Prediction Synthesis and Uncertainty
TRACON	Terminal Radar Approach Control
TRF	Transport Research Facilities
TSAFE	Tactical Separation Assisted Flight Environment
UAL	United Airlines
UARC	University Affiliated Research Center
UAV	Unmanned Aerial Vehicle
UPS	United Postal Service
URET	User Request and Evaluation Tool
V&V	Verification and Validation
VAMS	Virtual Airspace Modeling and Simulation Project
VAST-RT	Virtual Airspace Simulation Technologies – Real-Time
VCSPA	Very Closely Spaced Parallel Approaches
WBS	Work Breakdown Structure
Wx	Weather
WYE	Work Year Equivalent

Appendix B. References

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