Air Traffic Management Capacity-Driven Operational Concept Through 2015

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Abstract

This paper describes an approach to developing an operational concept for the US National Airspace System. This approach carefully ties the system mission, the functions that the system must perform and the available resources, and presents a logical functional structure for the overall system that ties together functions, resources and subsystems. A key aspect of this approach is a careful flowdown of performance requirements or allocations from top-level system performance goals through the concept layers down to the technology level to ensure that design decisions will lead to a system that delivers the desired performance.

The papers illustrates this approach by defining an operational concept that is driven by system capacity as the primary performance goal, including a logical system transition path from the current system to a higher throughput system for 2015.

Introduction

This work was supported in part by NASA's Advanced Air Transportation Technologies program, under subcontract with the National Center of Excellence for Aviation Operations Research. The contract objective was to establish a probable baseline operational concept for 2015 and at least one feasible transition path to that future concept. In addition, this paper proposes a preliminary design process for the NAS that guides the system architecture design through a careful flowdown of performance requirements and operational and technology trades.

Preliminary Design for the NAS

Figure 1 illustrates an approach to a NAS preliminary design process to quantify long-range air transportation system needs, define operational concepts consistent with these needs, and translate these needs into subsystem technical requirements. The preliminary design will also provide tradeoff data relating performance levels, life cycle costs (for both the agency and the users), operational benefits, and technical and functional integration risks.

The process is driven by NAS top-level long-range performance objectives such as capacity, safety, affordability and environmental impact, obtained by combining market forecasts with public policy. The market forecast is then subjected to a mission analysis that takes into account airport infrastructure development and airline networking strategy to develop predictions of fleet mix, desired operator schedules and an associated predicted traffic demand load on system resources.

Along with the mission analysis, an evaluation of the current system operation and performance is done to provide a baseline against which future improvements can be designed and evaluated. The baseline incorporates the current operational concept and existing system architecture, for a set of operational scenarios that span a range of states sufficient to define normal, rare-normal and non-normal behavior to ensure a comprehensive architecture.

Using the traffic demand model and the current system baseline, an assessment is made of the performance shortfalls predicted through 2015, and this forms the basis for the synthesis of operational concepts that address the needed improvements. The new concepts take into account anticipated technology available in this time frame, along with the associated human performance characteristics.

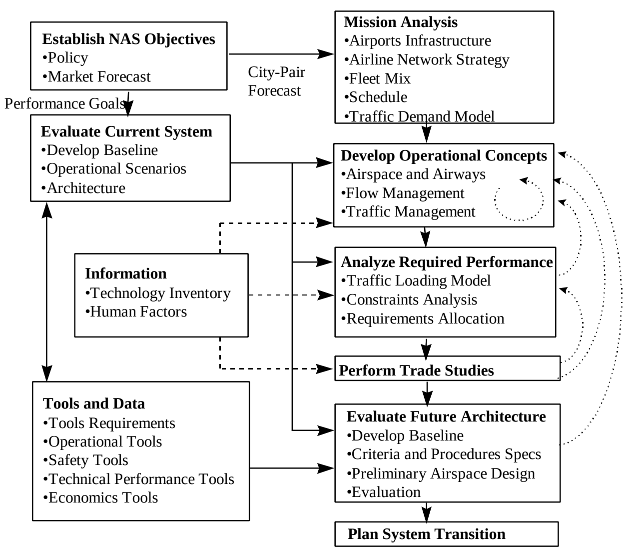

Figure 1. Preliminary Design Process for the NAS

The remainder of this paper discusses the development of operational concepts that are driven by performance goals with clear traceability of how performance is allocated to functions, operators and subsystems. The trade studies required to specify a sound and affordable architecture are described in more detail in [1].

Operational Concept Development

This section describes a framework for synthesizing air traffic management operational concepts, the basis of which was developed in [2]. A number of operational concepts have been developed for the NAS and other parts of the global aviation system [3-8] over the last 5 years, but it remains unclear how these concepts can be used to drive major architecture decisions and also ensure that system performance objectives are met.

Fundamentally, an operational concept answers the question "what must the system do, how well must it do this, and by whom is this done." This description captures function, performance levels and responsibility. Due to the size and complexity of a system such as the NAS, the number of functions, agents and subsystems involved leads to a large number of possible concept solutions. Considering all the possible solutions, the operational concept could be constructed using strategies such as:

1. Perform all functions desired by all stakeholders and implement all available technology.
2. Randomly search and evaluate all possible concept combinations to find the "best" solution.
3. Pick and insert changes in the current system based on technology opportunity and/or vocal stakeholder requests.
4. Redesign the operation to solve identified performance shortfalls in such a way that every design decision is guided by performance requirements.

Strategy 1 is very costly and likely to be operationally infeasible, 2 will take too long to converge and 3 is not likely to deliver the needed long-term performance. This paper describes strategy 4, and postulates that it is feasible and likely to be the most effective method, as it produces a limited number of concept and architecture choices that can be traded against the overall performance objectives to find the best design.

Functions, Agents and Performance

Figure 2 illustrates today's air traffic management work system in terms of top-level functions and agents involved directly in the daily system operation. Not included in the figure are more strategic functions such as airspace management and airline scheduling, some of which may move into the daily operating realm in the future system. The functions can be further divided into subfunctions, and the agents can consist of individuals or teams, supported by technical subsystems, with the human and technology components combining to deliver the required functions with a certain level of performance.

The separation assurance and aircraft operation functions in Figure 2 are key in realising the fundamental capacity and safety objectives for the airspace. Nakamura and Schwab [9] proposed to tie the performance of the separation function and its subfunctions and systems to the separation service supported in a given airspace, through a set of Required Performance indices (illustrated in Figure 5). Key to the successful definition of system performance is that the rare- and non-normal performance will fundamentally drive system safety levels and therefore many of the critical architecture decisions. Thus, for communications, navigation and monitoring, the normal, rare-normal, and non-normal (both detected and undetected failure rates) must be specified, to insure a system design that will support the future mission capacity and safety levels. Additionally, in an environment such as today's radar-based ATC, it is necessary to include the overall impact of human performance, together with decision support and CNS elements, on the overall system performance.

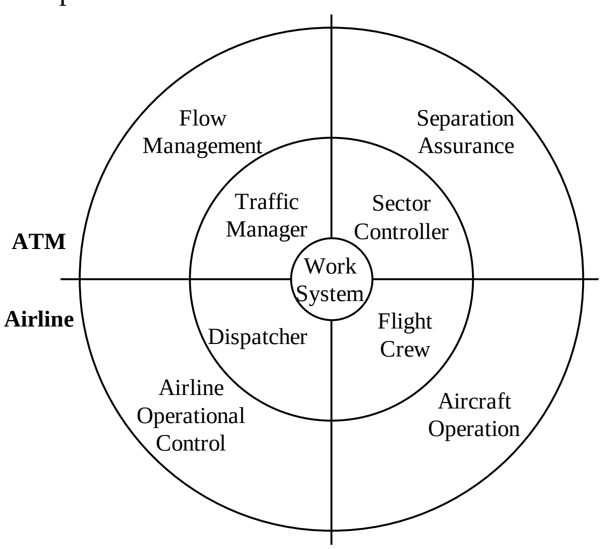

Figure 2. The ATM Work System

ATM System Functional Structure

The capacity of the air traffic management system is fundamentally bounded by the separation standards in effect for the airspace. System throughput is a measure of the realised flow through the system in a given time period, and is further constrained by the controller's ability to accommodate traffic demand in the face of operational uncertainty. Periods when demand exceeds capacity in parts of the system can overload the separation assurance agent and thus increase the collision risk, and it is important to include functions in the system that prevent such overload. In the NAS operation this is done through flow planning, where a planning horizon of 24 hours is appropriate given the daily traffic demand cycle.

The traffic flow planning function is complicated by the fact that the system is subject to a variety of sources of uncertainty. The three most important ones for the daily plan are:

- Weather prediction uncertainty, which affect primarily the arrival phase through airport arrival rates.
- Aircraft pushback readiness due to a variety of factors in aircraft turnaround at the gate, which affects primarily the departure phase.
- NAS equipment status, which can affect any phase of flight.

The uncertainty inherent in the daily flow plan often results in situations where the plan is out of phase with the unfolding situation, leading to possible overloads or wasted capacity. To deal with the uncertainty, the system could:

- Reduce the uncertainty level (difficult, but progress is being made)
- Provide plenty of room to safely absorb the uncertainty (procedural control, wasteful)
- Modify the plan dynamically to manage the situation as it unfolds

The last option, to modify the plan dynamically, is what the NAS is evolving toward in an effort to achieve an acceptable balance between throughput and safety. Thus the NAS includes several levels of planning:

- National and regional flow planning
- Facility-level flow planning
- Sector-level flow planning

Each level has a certain planning time horizon and range of possible planning actions. Figure 3 shows the overall functional structure of the air traffic management system in terms of functions directly affecting the process that links real-time traffic demand with actual flight through NAS airspace.

Figure 3 illustrates the processes and information flow that make up the flight and traffic planning and separation assurance functions of the system. Figure 3 is only one of many possible cross sections through a very large and complex system and hides a considerable amount of detail, but is useful in tying the operational concept to system safety, capacity and affordability. It is also an idealised diagram of a system that is very adaptable due to the presence of human operators, and in which assignment of functions to agents is dynamic.

Figure 3 illustrates the path, starting at the left, from a desired flight schedule and a weather forecast, through filed flight plans, to real aircraft movement on the extreme right. Each block in the diagram indicates a function that is performed in the system today, and the arrows denote either real aircraft state, communication of a plan or intent, measurements or requests. The functions can be divided roughly into planning and execution, which overlap across the sector control functions.

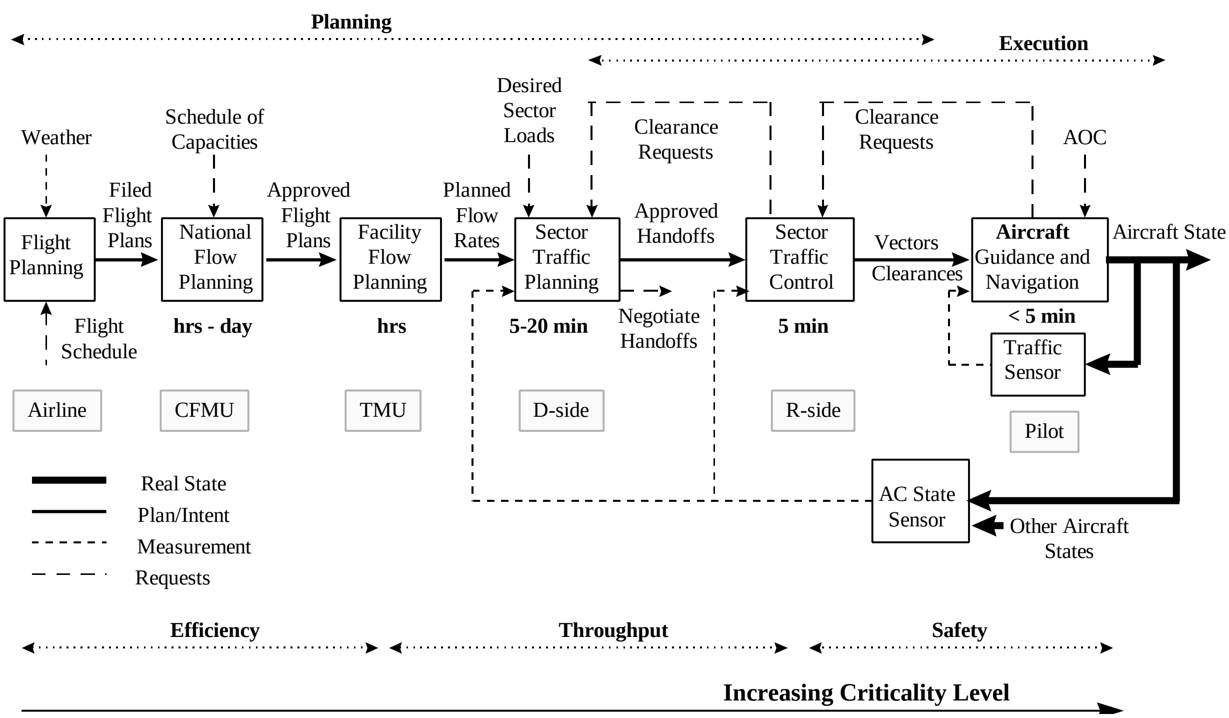

Figure 3. Air Traffic Management System Functional Structure

The diagram indicates the approximate planning time horizons for each function, ranging from a day for national flow planning to minutes or seconds for aircraft guidance and navigation. The actual time horizons employed by system operators vary greatly depending on the airspace and traffic levels, but the numbers in Figure 3 are reasonable for most components of the NAS.

An approximate analogy to the current assignment of functions to agents is shown in the figure through reference to the R-side (radar) and D-side (data) controllers, Traffic Flow Management (TMU) positions and Central Flow Management (CFMU).

The separation assurance function is here considered to be assigned to the sector controller team, using a radar display and flight plan information, with the aircraft crew as a collision avoidance backup, through visual observation of traffic and/or through use of the Traffic Alert and Collision Avoidance System (TCAS).

The criticality level of the system functions increases from left to right in the diagram. Criticality level is fundamental in all discussions about required performance to support a function, and for the level of attention to human factors that a function requires.

Figure 3 illustrates how uncertainty in planning is accommodated through several levels of re-planning in the system. Traffic situation data feedback to the planning levels is a weakness in the system today, and therefore there is not an ability to update the flow plan comprehensively across facilities or regions as situations change.

To relate back to the system objectives, Figure 3 illustrates that safety is the primary responsibility of the aircraft, with separation assurance assistance from the sector controller. System throughput is delivered by the execution loop, with overload protection from the planning functions. Efficiency is worked primarily by the flow planning functions, through negotiations of flight plans, with assistance from the execution loop for in-flight rerouting.

Capacity, Safety and Separation Assurance

Figure 4 illustrates the separation assurance loop, with additional detail showing the primary sub-functions in the loop. The sector planning function's primary objective is to manage the number of potential conflict situations the sector controller may need to process. The set of flight plans inbound and inside the sector can be considered the primary data input to this function, along with the real-time traffic situation as it currently affects the sector controller's workload. The sector planner may also need to assist the controller with clearance requests from aircraft that he cannot immediately process. Thus, the sector planner function helps manage the sector controller workload, and is therefore the primary agent in managing exposure to collision risk.

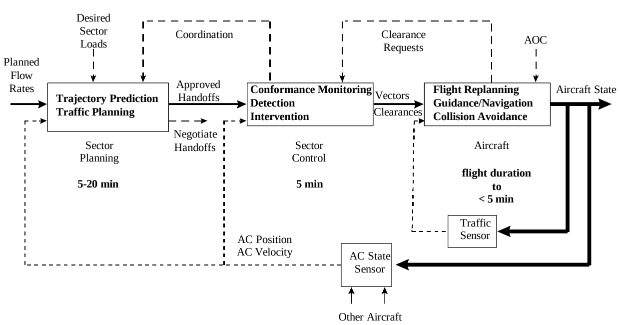

Figure 4. The Separation Assurance Loop

The sector controller in today's radar control operation is the only traffic management agent that communicates directly with the aircraft. The functions performed by the sector controller are conformance monitoring and short-term conflict detection and intervention, along with receiving, granting or rejecting route modification requests from the aircraft. Detection performance depends on the accuracy of the aircraft state sensor, the display resolution and update rate, and the controller's ability to predict the aircraft trajectory into the future. Intervention performance involves the decision to act on a potential conflict, and the communication of the action to the cockpit crew, which then must intervene and change the flight path. The sector controller is thus a critical element of detection and intervention, and today's system has very limited backup for failures in either the performance of the function or in the surveillance and communication systems the function relies on.

The cockpit crew is responsible for guidance and navigation according to an agreed upon flight plan, along with replanning for reasons of safety, efficiency or passenger comfort. The cockpit crew contributes to the performance of the intervention function through its response to ATC vectors. The crew also has a safety responsibility to monitor and avoid other aircraft in its immediate vicinity, either visually or through TCAS. This is currently a limited safety backup for the sector controller's separation assurance.

Figure 5 is a conceptual representation of effective traffic spacing, depicted as concentric rings or buffers with the innermost region (detection) representing the theoretical maximum capacity based on the separation standard. The separation standard in radar controlled airspace has been established primarily as a function of radar surveillance and display system performance. Traffic spacing in busy terminal areas is usually near the separation minimum, achieved by highly structured airspace design and high controller proficiency. Significant changes to one or more of the communication, surveillance, and controller/pilot intervention performance are necessary in order to reduce separations beyond the current minimum.

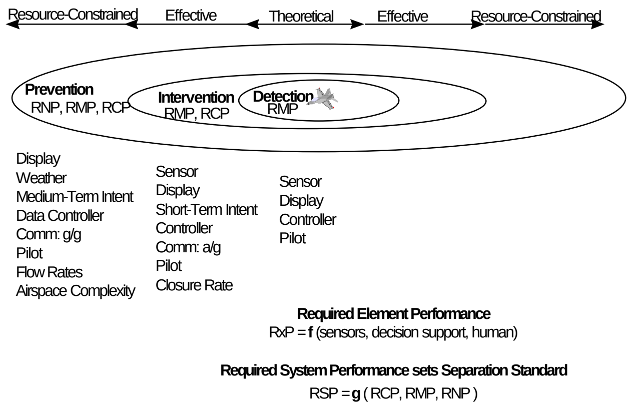

Figure 5. Traffic Spacing and Performance Factors

The middle separation ring (intervention) represents the additional separation required to determine that a conflict is imminent and intervene to resolve it. In a radar control environment this buffer is a function of the time from detection of intervention need, decision on resolution action, transmission of instruction to the pilot, and the pilot's response. The buffer size is also affected by traffic flow patterns (high closure rate encounters require larger control loop margins) and the speed and maneuverability of the aircraft. This buffer can potentially be reduced through the provision of better short-term aircraft intent data, data link communications, tools for conformance monitoring and short term conflict alerting.

The outermost ring (prevention) is adjusted by the sector traffic planning function to limit tactical controller workload by preventing too many potential traffic conflicts from developing simultaneously in the sector. As workload increases, the planning controller adopts strategies to prevent the possibility of conflicts. These strategies include level-offs, holding and re-routing of aircraft away from dense airspace. These strategies must take into account the uncertainty in medium-term (20-30 minute) trajectory prediction The overall effect is to reduce system throughput and to increase aircraft time and fuel in the system. This buffer can potentially be reduced through air to ground sharing of medium-term intent data through data link, along with automation aids for conflict probing, conflict resolution and terminal area sequencing and spacing.

In a procedural environment, the separation minima are dictated by conflict prevention, with essentially no ability to detect and intervene due to poor performance of the communications and monitoring functions (third party voice position reports and clearances). This necessitates a large prevention buffer (and very low throughput), based purely on navigation performance, to make the likelihood of the need for intervention acceptably small.

Potential improvements in airspace throughput should be proposed in light of a model such as Figure 5. Specific tools and improvements to CNS/ATM can be targeted to specific factors that influence the size of the individual separation rings. In general, the performance levels required for change increase towards the center of the rings. The inner circles are probably more difficult to affect and thus involve a higher implementation risk. The FANS 1/A CNS/ATM enhancement primarily addresses the outer ring, as it was targeted at procedurally controlled airspace. Radar control airspace has a much smaller prevention buffer and significant airspace improvements may eventually demand that the intervention and/or detection buffers be addressed there.

Figure 5 illustrates how prevention, intervention and detection combine in an overall separation assurance function, and lists the performance factors involved in each component. Nakamura and Schwab [9] propose a framework where the performance of each of these fundamental factors is combined in an overall Required System Performance parameter, which is then directly related to a minimum allowable separation between aircraft. The navigation function performance has been formalised through the definition of Required Navigation Performance, as described in [10]. RNP includes a definition of accuracy, integrity and availability levels, which are functions of navigation sensors and their sources, cockpit-crew interface design and pilot performance. To compose an overall performance index (RSP) for the separation assurance function, consideration must be given to Required Communication Performance (RCP) and Required Monitoring Performance (RMP), along with possibly a metric relating to the performance of the traffic planning function.

Capacity Driven Operational Concept

The sequence of transition steps presented here defines one of many possible paths that the system operational concept and architecture could follow through the year 2015. This particular path is constructed with the objective of achieving long-term capacity increases, using the author's best judgement of what system enhancement steps could be taken during this period with available and emerging CNS/ATM technologies. This transition path, and most of the individual steps within it, have not been validated, and thus the system capacity impact cannot be quantified. The selected technologies will need to be subjected to requirements validation and system tradeoffs. This transition path, however, is a reasonable baseline from which to initiate the trades that must be performed as part of the preliminary design process illustrated in Figure 1.

NAS Flow Management

Figure 6 shows the proposed concept transition path for national and local traffic flow management. The diagram shows two parallel paths, one starting at the national level and the other starting at the airport level. The two paths merge in the third transition step into a coordinated traffic flow management system.

National Level. Improved Traffic Flow Management

This step involves real-time information exchange between NAS users and central flow management, focused primarily on automatic schedule updates from the airlines and timely notification to airlines of flow management actions.

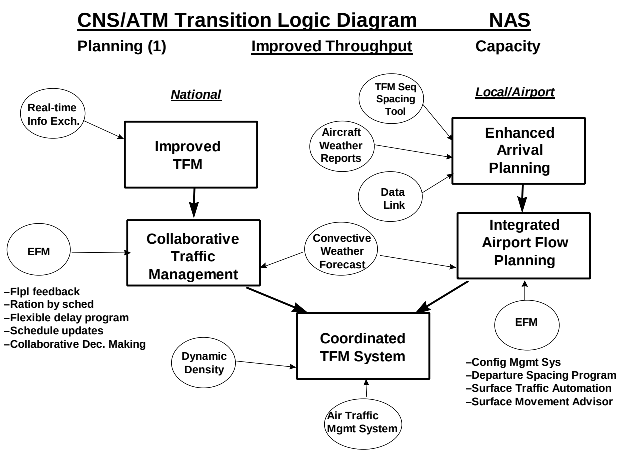

Figure 6. CNS/ATM Transition Logic for Flow Management

National Level. Collaborative Traffic Management

This operational enhancement includes a collection of changes in flow management aimed at giving users more flexibility in deciding how delay is allocated across their operation. Delay will be allocated to operators according to their published schedule, and the operator in turn allocates the delay to their individual flights. Where arrival airport capacity is the constraint, emphasis will be on arrival airport resource management and away from departure gate-hold times. This will allow operators to minimize the overall cost impact of delay on their operation by prioritizing flights according to issues such as passenger and baggage connections.

Airport Level. Enhanced Arrival Planning

This enhancement step provides improved terminal area arrival flow planning, including arrival runway load balancing, enhanced arrival sequencing and improved arrival flow re-planning, given a perturbation such as runway change or convective weather.

Airport Level. Integrated Airport Flow Planning

This enhancement step involves a group of airport traffic planning initiatives aimed at integrating arrival and departure traffic, along with surface movements, into a coordinated plan. This will include optimal airport balancing of arrival and departure resources and the need for automation to support airport configuration management.

Coordinated Traffic Flow Management System

In this step flow planning at the national, regional and local level are brought together in a coordinated system. The function allocation strategy to achieve this step, and the technologies required are to be determined; the relevant issues are discussed in [2].

NAS En Route and Outer Terminal Area

Figure 7 shows the proposed concept transition path to achieve increased capacity in the en route and TMA Arrival/Departure operating phases. The sequence of operational improvement steps represented by the boxes, from top to bottom, address a reduction in effective traffic spacing starting with airway spacing criteria, through reduction of prevention and intervention buffers, to the eventual reduction in the separation standard.

Reduced Lateral Spacing For More Arrival And Departure Transition Routes

This enables closely spaced standard arrival and departure routes to fit additional traffic streams within terminal area corridors. This will help avoid congestion over entry points into terminal areas and reduce the need for in-trail traffic that backs up into en route airspace. This enhancement will be most beneficial in terminal areas where airspace is constrained due to proximate airports, special use airspace, or severe weather activity.

Airspace design criteria have to be changed to enable this operational enhancement. Those criteria are likely to be predicated on a level of navigation performance in the range of RNP 1 to RNP 0.3, along with the corresponding surveillance and monitoring performance.

<u>Reduced Prevention Buffer</u>

The prevention buffer is the outermost separation ring discussed in Figure 5, added to reduce the number of potential conflict situations in the sector. This is the role of the sector planning function in Figure 4, and thus the enhancements proposed here relate to the performance of medium-term trajectory prediction and traffic planning functions. Improvements in both the horizontal and vertical dimensions are included in this step, where the benefits of improved vertical accuracy may be greater but will require more technology investment.

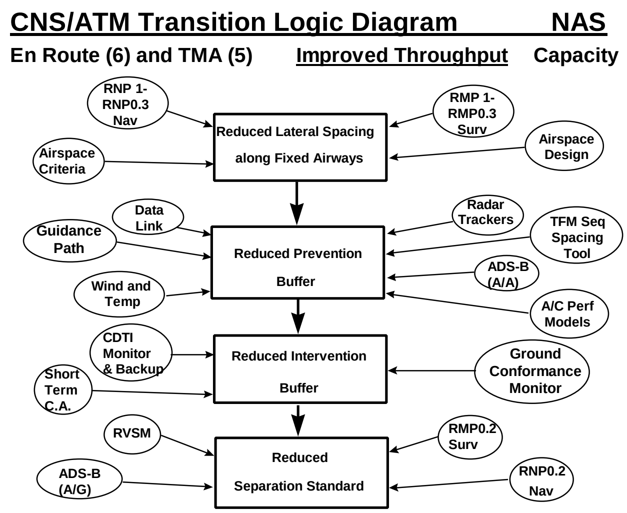

Figure 7. CNS/ATM Transitions for En Route and Terminal Area

An improvement in medium term trajectory prediction will be needed to reduce the uncertainty that the controller has today when predicting conflicts. This improvement will be enabled by tracker enhancements that provide higher accuracy and lower latency, better wind and temperature information, and a medium term conflict probe. The terminal area will benefit from automation for more accurate sequencing and spacing of climbing and descending traffic, which will require accurate aircraft performance models. Data link may be required to exchange weather information, aircraft performance parameters, and trajectory definition .

In addition to the above factors, a higher probability that the aircraft will follow its intended path may be required, and this may involve 4D terminal area navigation capability. Depending on the level of criticality of the function, there may be a requirement for cockpit traffic situation awareness to provide redundancy of function.

<u>Reduced Intervention Buffer</u>

To reduce the intervention buffer it is postulated that data link may improve the delivery time and integrity of communications from controller to pilot. A ground-based conformance monitor is assumed that alerts the controller to aircraft deviations from intended trajectory, and a short term conflict alert function is also assumed. Criticality level is expected to be high, which may require an independent airborne monitoring function.

<u>Reduced Separation Standards</u>

This refers to both vertical and horizontal separation. Reduced Vertical Separation Minima (RVSM) in domestic airspace would likely be predicated on vertical path following performance similar to what is required in the North Atlantic. Horizontal separation is likely to require improvements in the surveillance sensors both for en route and terminal areas, and better navigation performance. The detailed requirements will have to be worked out, starting with the development of a risk evaluation methodology to determine the influence of technology and human factors on collision risk in positively controlled airspace.

NAS Approach/Departure Transition

Figure 8 shows the proposed concept transition path for increased capacity in the Arrival and Departure transition phases. The sequence of operational improvement steps represented by the boxes, from top to bottom, address a reduction in effective traffic spacing starting with route spacing, intervention buffers, through reduction in the basic separation standard.

<u>Reduced Lateral Spacing For More Arrival And Departure Transitions</u>

This enables closely spaced arrival and departure routes to fit additional traffic streams within terminal area corridors. Airspace design criteria have to be changed to enable this operational enhancement. They are likely to assume RNP 0.3 along with corresponding surveillance performance.

<u>Reduced Separation Buffer (Ground Vectoring)</u>

This enhancement involves more accurate timing of aircraft delivery to the final approach fix through more effective ATC vectors. The improvement will be enabled by better trackers for trajectory prediction, automation for accurate traffic sequencing and spacing, and support to generate accurate ATC vectors for final approach spacing.

<u>Reduced Separation Buffer (Aircraft Guidance)</u>

The component of the spacing buffer at the final approach fix that is contributed by the aircraft guidance and navigation performance will be improved in this step. This will involve the use of required time of arrival functionality, and data link to deliver clearances with accurate timing information. Short term conflict alert functionality may be needed to improve conformance monitoring.

<u>Reduced Horizontal Separation Standard</u>

In this operating phase it is normally spacing on final approach that determines the separations applied. As seen in Figure 9 the concept includes a plan to reduce spacing on final approach, and thus the approach transition phase may need corresponding separation reductions. The improvement and enablers would be analogous to the last box in Figure 7.

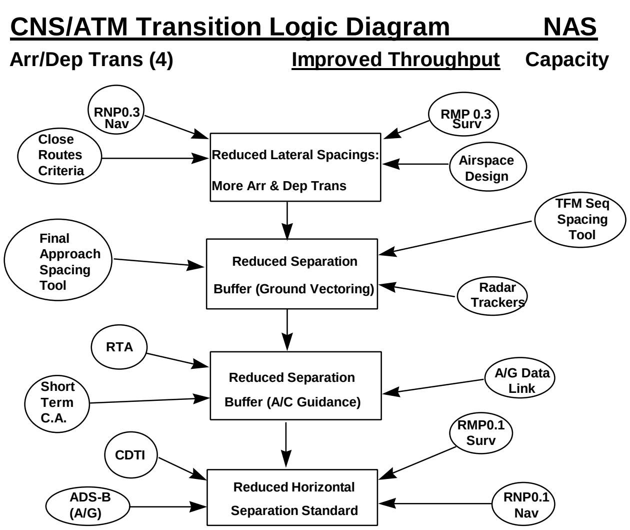

Figure 8. Transition Logic for Arrival Transitions

NAS Final Approach

Figure 9 shows the proposed concept transition path to achieve increased capacity in the Final Approach and Initial Departure operating phases. The chart shows two independent enhancement paths, the one on the right centered on additional runways, the one on the left centered on increased runway utilization.

<u>Additional Available Runways</u>

This improvement involves new runways being built, and existing runways being made more available through development of instrument approaches. FAA's Airport Improvement Program is the enabler for new runway construction, which also may rely on new approach and procedure design to address airport noise concerns. FMS capabilities can be utilized to reduce both the spread and the severity of noise impact, through tailored approach and departure procedures.

Instrument approaches to a larger number of runways in the CONUS will be enabled by differential GPS down to CAT III minima.

<u>Increased Runway Utilization, Current Technology</u>

This improvement step involves the installation of existing technology where needed to increase throughput of closely spaced parallel and converging runways in IMC. To fully take advantage of the Precision Runway Monitor and Converging Runway Display Aid technologies it may be necessary to include arrival and departure sequencing and spacing automation.

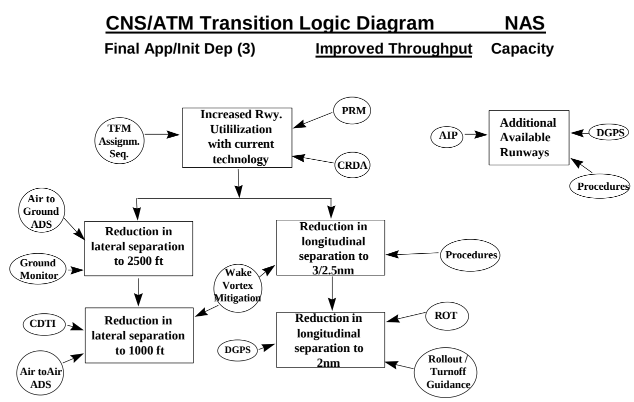

Figure 9. Final Approach and Initial Departure

<u>Reduction in Lateral Separation to 2500 ft</u>

This reduces further the minimum lateral separation between parallel runways for independent operations. To assist with blunder detection, ADS event-based position reporting and improved monitoring on the ground will be needed. Precision missed approach guidance may be needed.

<u>Reduction in Lateral Separation to 1000 ft</u>

The reduction below 2500 ft between independent parallel runways in IMC is currently being discussed in the context of airborne separation assurance through CDTI. Wake vortex is an issue here. This is an ambitious step, and the exact requirements will have to be worked out carefully.

Reduction in Longitudinal Separation to 3 or 2.5 nm

In IMC, the longitudinal separation on final approach is currently set by wake vortex considerations, and therefore this enhancement step must address wake detection and avoidance, through wake prediction/detection technology and new procedures.

Reduction in Longitudinal Separation to 2 nm

Further reduction in longitudinal spacing on final approach would address runway occupancy and the need to ensure rapid braking and turnoff performance of the aircraft. In low visibility this may require improved rollout and turnoff guidance, perhaps based on differential GPS. Included here might be the possibility of allowing two aircraft on the runway at the same time, assuming the required braking performance to stop short.

NAS Surface

The proposed concept transition path to achieve increased capacity on the airport surface is described in [2], with two independent enhancement paths, one centered on low visibility operations, the other on good VMC.

Efficiency in Low Density En Route Airspace

The affordability objective can be further addressed through accommodation of user preferences in airspace where capacity is not constrained. This consideration could be added to the set of transitions presented in this paper, along with the required enhancements in airspace management, including dynamic airspace allocation and resectorization. Whether the performance gain is sufficient to justify the cost must be evaluated along with other proposed improvement, along with the operational and technical feasibility.

Conclusions

This paper presents an operational concept for the NAS in 2015, assuming that increased system capacity is the primary modernization driver. The concept is presented in the form of a transition path from today's operation to 2015, describing a series of operational improvement steps along with suggested technology enablers. The concept is presented in the context of an overall NAS preliminary design process that emphasizes system performance and trade studies to arrive at a high performance architecture. Key to the successful application of the process is a careful flowdown of performance requirements from the overall mission to functions, operators and systems, which guides the system design to deliver the desired performance outcome.

Acknowledgments

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References

1. Schwab, Robert W., Haraldsdottir, Aslaug and Warren, Anthony W., "A Requirements-Based CNS/ATM Architecture," SAE/AIAA World Aviation Congress, Anaheim, CA, September 1998.
2. Boeing Commercial Airplane Group, *Air Traffic Management Concept Baseline Definition*, NEXTOR Report # RR-97-3, Oct. 31, 1997. On the World Wide Web at http://www.boeing.com/ commercial/caft/reference/documents/newdocs.htm
3. U.S. Federal Aviation Administration, *Air Traffic Services Concept of Operations for the National Airspace System in 2005*, Washington DC, September 30, 1997.
4. RTCA, Inc., *A Joint Government-Industry Operational Concept for the Evolution of Free Flight*, Washington DC, August 1997.
5. Eurocontrol, *EATMS Operational Concept Document (OCD)*, Brussels, Belgium, January 1997.
6. RTCA, Inc., *Operational Concept for Air Traffic Management (ATM) - Aeronautical Operational Control (AOC) Ground-Ground Information Exchange*, Washington DC, April 29, 1997.

7. RTCA, Inc., *Final Report of RTCA Task Force 3, Free Flight Implementation*, Washington DC, October 26, 1995.

8. U.S. Federal Aviation Administration, *Flight Management System - Air Traffic Management Next Generation (FANG) Operational Concept*, Washington DC, July 1997.

9. Nakamura, D.A. and Schwab, R.W., *Development of Minimum Aviation System Performance Standards for RNP for Area Navigation*, Boeing Commercial Airplane Group, Working Paper for ICAO Working Group A: Review of General Concept of Separation Panel, Montreal, 1996.

10. RTCA, Inc., *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*, Document DO-236, Washington DC, January 27, 1997.