Assessing Benefits for Airborne Flight Planners as Part of the Future NAS

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Abstract

Current trends in traffic growth in the National Airspace System (NAS) show that traffic will eventually outgrow the capacity of the existing NAS infrastructure and management. Traffic growth is predicted to increase two percent annually, for the next 15 years, according to the Federal Aviation Administration (FAA). Limitations of the capabilities of aging equipment in the existing ground-based air traffic control (ATC) are proving to be insurmountable for this increase in traffic demand. As a result, a need exists to modernize the NAS, improve safety, return the maximum advantage to the NAS user, accomplish this in an affordable way for the service provider and the NAS user, while maintaining realistic schedules. A response to this issue is the concept of Free Flight. Free Flight will allow the pilot more flexibility, while enhancing safety and efficiency of the NAS. This change will affect the roles and responsibility distribution among Air Traffic Control (ATC) personnel and pilots including the capability for pilots to plan and execute new flight objectives for both path and time while airborne.

Implementing Free Flight will result in many changes in current NAS operations and structure. For the U.S. to modernize its aviation systems, new technologies need to be developed for all

phases of flight, from the airport surface to terminal and en route airspace. Flight deck technologies are also an important contributor to NAS modernization and Free Flight.

An activity was formed, within the National Aeronautics and Space Administration’s (NASA’s) Aviation System Capacity (ASC) program, with the intent of developing concepts to support NAS modernization. The goal of this activity, Advanced Air Transportation Technologies (AATT), is to develop and define concepts and decision support tools (DSTs) which could be used by the air traffic service providers, airline operations centers, and flight crews, to improve utilization of capacity, flexibility, efficiency, and predictability.

These DSTs are being defined and developed in accordance to the expectations of the NAS stakeholders and will be designed with the intent of evolving, as infrastructure enhancements and new technologies are implemented into the NAS. The introduction of these AATT tools with more advanced capabilities for the different Air Traffic Management (ATM) domains (Figure 1) will greatly support and complement the benefits of other technologies, current and in development.

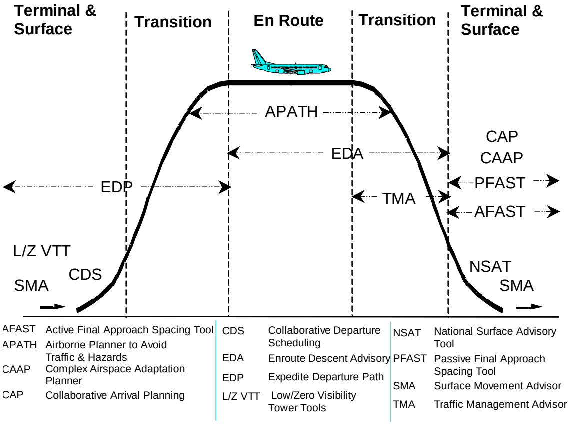

Figure 1 – AATT Tools

The Benefits and Safety Assessment sub-element of AATT is currently in the process of conducting benefits studies for each of the DSTs to define programmatic priorities, in terms of investment. The particular case study outlined in this paper is determining the preliminary operational concepts and benefits of the DST Airborne Planner to Avoid Traffic and Hazards (APATH), in its current state of definition. APATH is expected to provide the decision-making information for real-time route replanning in an integrated and prioritized manner. This will allow users to augment the benefits enabled by a future free flight environment, including potential optimal operations, as well as potential improvements in flexibility. Route flexibility will allow the user the ability to choose their own route and fly closer to their optimal flight paths, real-time.

In support of this and other studies, the National Airspace Resource Investment Model (NARIM) will be used. NARIM is a suite of tools, available to NASA and the FAA that, collectively, provides the capability of modeling and analyzing airspace concepts affiliated with the future advances to the NAS. NARIM is made up of three components: an operational component, an infrastructure component, and an investment component. These three elements provide NASA and the FAA multiple perspectives of the NAS. This in turn will have an impact on the cost/benefit to the users and service providers, the capability to model operational changes has to exist. Without the modeling capability, the impacts to the NAS can not be determined. NARIM provides the FAA and NASA with this capability.

This paper provides an overview of the envisioned APATH tool and ascertains benefits, as possible, related to the implementation of this tool into the current and future NAS. The benefits will be measured in terms of efficiency, environment, predictability, and flexibility.

Introduction

To increase the efficiency, flexibility, throughput, and predictability of the National Airspace System (NAS), Decision Support Tools (DSTs) are being developed in four areas: surface, terminal, enroute, and airborne. NASA Langley Research Center (LaRC) is leading the effort of developing the airborne DSTs. In support of this effort, benefit assessments and concept validation are necessary, incrementally, throughout the development process. These new DSTs must be developed and implemented in an enhanced NAS.

In the current NAS, several inefficiencies exist, that prohibit efficient implementation of this new technology. Among these inefficiencies are increased separation due to limitations of ground-based communications and surveillance systems and slow air/ground information transfer because only voice transmission is available.

The future concept of operation and the technologies and capabilities required to operate within this new environment are being designed to provide the users a more efficient system. This system is anticipated to reduce many inflexibilities that are found in today's ATC system, while still maintaining a safe environment.

Background

Three stakeholders exist in the current day operational NAS: the Flight Deck (FD), the Airline Operations Center (AOC), and Air Traffic Control (ATC) (see figure 2[1]**)**. The priorities and goals for each stakeholder vary greatly. The main focus of the FD is to maintain flight safety and quality, while optimizing the flight to increase user efficiency. The AOC's primary concern is maintaining schedule integrity, using national weather information and information on schedule impacts. The first priority of the ATC is to maintain safe airspace through separation assurance and traffic flow management, using information available on traffic congestion and system capacity. As a result, these stakeholders all have different perspectives stemming from the information available to them. A fully integrated system will provide the capability of sharing information, which is very advantageous in achieving benefits, such as efficiency and flexibility, and may be required to distribute responsibility for planning and hazard avoidance to the FD.

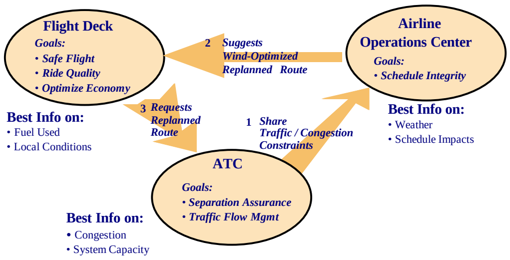

Figure 2 – NAS Stakeholders

Currently, during some route replanning scenarios, the FD and the AOC will negotiate a new route. The focus is on the goals of the AOC, and the AOC has the responsibility to ensure that the new route meets with the airline objectives. This new route will then be negotiated with ATC, with the ATC making the final decision regarding which route is to be flown, factoring in the issue of maintaining safety. The FD does not have a big influence on this process partly because it lacks the appropriate information, such as real-time weather and traffic, to make decisions in the replanning process. However, even if the information were available, the FD also currently lacks the ability to process the data to develop a modified flight plan. Distribution of information and increasing capabilities in the FD, as described herein, will require new technologies.

In the future, the NAS will include more advanced CNS/ATM systems that will provide users and service providers the ability to receive and process better information, and make free flight possible. These enhanced systems, such as Next-generation Communication (NEXCOM), conflict probe and Wide Area and Local Area Augmentation Systems (WAAS and LAAS), will provide for faster and more accurate communication, navigation, and surveillance capabilities and allows for the more efficient operations such as Reduced Vertical Separation Minima (RVSM), cruise climb, and more direct routing.

APATH Description

APATH is an airborne flight path planner that will be integrated into the Flight Management System (FMS), and other on-board systems, such as navigation and communication systems. It is anticipated that APATH will include capabilities to integrate real time data to support flight crew route replanning, using existing or new FD displays, crew input, and processing equipment. Equipping the aircraft with APATH may enable the flight crew become a more integral part of the replanning process, and may allow aircraft self-separation under some conditions.

The operational concept that APATH will function within is currently under study. One of the concepts under consideration is one in which a distributed, cooperative, air/ground free flight architecture exists. In this concept, the goal is to maximize user flexibility by using system participants as both information/data suppliers and users. The total NAS planning and decision-making process will be distributed through cooperating, intelligent, decision-aiding technologies. And, the concept will add an additional layer of redundancy to the NAS architecture. In this concept, the only restrictions to flight paths will be due to Traffic Flow Management issues and conflict avoidance. Equipage and certification of aircraft in order to

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[1] Courtesy of Honeywell Technology Center

operate at a level of independence, allowing for self-separation, is entirely voluntary. The authority for separation assurance will be delegated to the appropriately equipped aircraft. However, overall responsibility for safe operation of the NAS is that of the Service Provider. If necessary, the Service Provider may assume control by exception. This concept also assumes that aircraft not equipped with APATH will not be denied access to the system. This will be accomplished through design of procedures and ground based decision support automation that accommodates all equipage levels.

The role of APATH, in this concept, is to notify the flight crew when replanning of the aircraft's trajectory may be necessary and to assist the crew in the replanning process. APATH will generate flight path management advisories that incorporate crew preferences to the maximum extent possible. Through air/ground data link, APATH will also take AOC preferences into account. APATH is human-centered; it will be designed only to assist the flight crew in making trajectory replanning decisions.

As currently envisioned, operation of APATH will require transmission of aircraft position and intent information, providing a look-ahead capability, over a certain time range. Figure 3 illustrates the key components that currently make up APATH. This architecture is under investigation, but the fundamental components are expected to remain as shown.

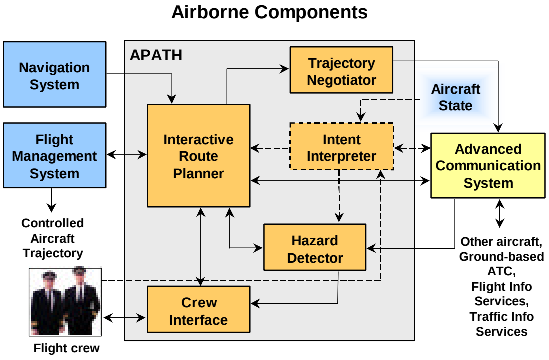

Figure 3 – APATH Components

A user interface will be utilized to display pertinent information and allow flight crew preferences to be entered into the DST. The flight deck will continuously broadcast its intent to other aircraft, ATC, and the AOC. If necessary, an APATH intent interpreter will continuously monitor the actions of all airspace participants within range, including its own flight crew, and develop predictions of future actions based on a shared model of intent. A hazard detector will use this information to predict potential threats, and a route planner will interact with the flight crew to improve flight efficiency or to meet crew specified objectives, such as schedule recovery. If another aircraft is involved in a conflict, then negotiations between the aircraft may be required.

Also, peripheral systems, providing communication of geographically and temporally dynamic information in flight, such as weather, Special-Use Airspace operations, terrain, etc., are needed by APATH to provide information on potential flight hazards to the flight crew. It is envisioned that, via datalink, APATH will be connected to the NAS Wide Information System, and will receive the latest information about infrastructure and airspace status, weather and traffic.

Although Figure 3 depicts the key components expected to make up APATH, required functions and architecture are still being investigated. Until the full operational concept is defined, the functionality of APATH can not be finalized.

As currently envisioned, APATH will enable the flight crew to have a greater decision making role in two areas: hazard avoidance and dynamic route planning.

Hazard Avoidance

Hazard Avoidance is safety related, and allows the FD to identify a hazard and maneuver around that hazard in flight. Safety is a high priority, but APATH tactical hazard avoidance is not designed to replace alerting systems such as the Traffic Alert and Collision Avoidance System (TCAS). The primary purpose of APATH is to provide capability for flight crews to assume responsibility for traffic separation. This should increase the flight crew's ability to manage their flight paths according to their own objectives. The general look-ahead time for Hazard Avoidance will depend on the distributed air/ground concept selected, but is expected to be in the range of 6 to 15 minutes. Below 6 minutes, ground-based controllers are expected to intervene if a conflict is predicted, and above 15 minutes, conflict prediction accuracy and local traffic management constraints will reduce the effectiveness of the hazard avoidance planner.

Dynamic Route Planning

Dynamic Route Planning can be broken into two areas: 1) Look-ahead time of approximately 15-30 minutes (combining Hazard Avoidance with Local Flow Management), and 2) Look-ahead time of approximately 30+ minutes (Strategic Replanning). For the purposes of this study, the aforementioned look-ahead times were combined into one, for Dynamic Route Planning (DRP), with a range of 30 minutes on. DRP allows the flight crew to obtain information on particular events that are happening upstream, and replan their path accordingly. However, in the circumstances that involve DRP, the route is planned with the long-term goals of the flight and airline in mind. These circumstances may include, but are not limited to, traffic congestion, avoiding known weather hazards along the route, and changes of status in either airspace or infrastructure. Hazards and airspace constraints that APATH will be designed to consider in its planning, and their associated look ahead horizons, are depicted in Figure 4.

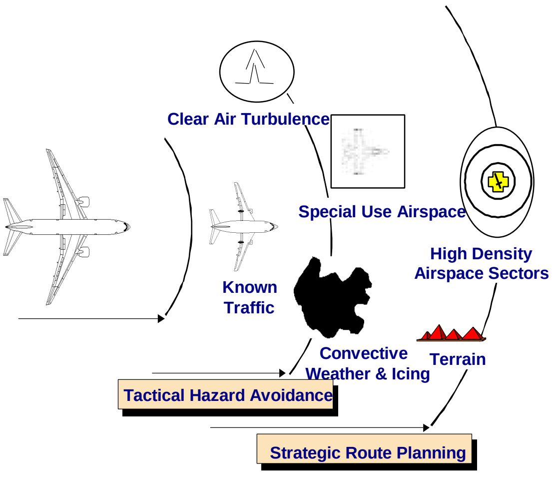

Figure 4 – Hazards and Constraints Considered by APATH

CASE STUDY:

This section profiles a scenario modeled in this task, to give the reader a clearer understanding of what was accomplished in this analysis. The objective of the analysis is to identify at a high level the potential pool of benefits and APATH's contribution to these benefits. In this particular effort, the focus of the analysis was traffic in the Continental United States (CONUS). Assumptions in this study included: 100% of aircraft will be APATH equipped, and, in the future scenarios, systems needed to achieve Free Flight in different domain (en route, surface, and terminal) will be fully deployed and will reach their full capabilities as currently planned. Several metrics were defined and investigated in this study. Quantifiable metrics include efficiency and environmental. Qualitative metrics include flexibility, predictability, productivity, and safety.

Eventually, the metrics that are being investigated will be studied at a higher fidelity. Subsequently, benefits will then be able to be directly and primarily associated with certain technologies. As APATH is currently envisioned, the benefits that are expected to apply to APATH, and that are anticipated to be independent of the operational concept, but are not exclusive to APATH are: efficiency, environmental, and predictability. For example, ground-based concepts can potentially claim these same benefits. Also, several benefits may be very exclusive of APATH, and have to be investigated, further, in order to provide a basis to support increasing technologies in the FD. These benefits are thought to be flexibility, productivity, and safety.

Efficiency

As an en route planner, residing in the flight deck, APATH develops and recommends a revision to the flight plan, en route, in response to new information. The focus is to provide the revised flight plan to flight deck to help the flight meet its schedule, as fuel-efficiently as possible, by avoiding hazards and disruptions, and returning to original flight path (hazard avoidance). In addition to avoiding hazards, it is predicted that APATH can also develop revised flight plans, en route, to take advantage of information that affects long-term planning, like favorable weather conditions (i.e. winds) to optimize the flight (dynamic route planning). This increase in efficiency can be measured by comparing the current NAS operations with the future, Free Flight operations and then assessing the contribution of APATH.

The first step was to analyze operations on a given day, assuming current NAS operations. Trajectory files for a day in 1996 and 2015 were used in this study. Fuel burn and elapsed time were calculated for all of the 1996 trajectories on this day, under the given day's current operations. The next step was to analyze operations for the 1996-day assuming Free Flight operations. The end state environment that was assumed in these scenarios is cruise climb. Fuel burn and elapsed time was calculated for all of the trajectories on this day, under Free Flight operations. The comparison of the current day operations to the Free Flight operations, using the same traffic set, gives the Free Flight benefit in 1996. The same calculation and comparison were done for the baseline and Free Flight scenarios in 2015. The result is the total benefit of Free Flight attributed to all planned CNS/ATM tools and automations.

The given 1996 day was an average day in the NAS, and was a relatively good weather day. Therefore, there were not a significant amount of delays on that day. Most of APATH's benefits are realized when delays occur due to avoidance of severe weather, turbulence, active SUAs, and traffic congestion. Therefore, to more accurately reflect APATH's tactical hazard avoidance capability, as well as the dynamic route planning benefit, more delays were required to more accurately calculate the benefits that APATH may ultimately provide.

To model and analyze APATH benefits in a bad weather day, a few selective flights were modeled with hazard weather, and estimates of the average duration of the deviation caused by the severe weather were made. This subset of flights was analyzed to determine the fuel burned and elapsed time during irregular operations, assuming current operations. The trajectories for this subset of flights were run through the Optimized Trajectory Generator (OPGEN) to simulate Free Flight operations for this day in 1996. The fuel burned and elapsed time will be calculated for the Free Flight operations. After looking at this subset, fuel burned and elapsed time for the entire NAS will be interpolated from this (by accounting for airport traffic, time of day, etc).

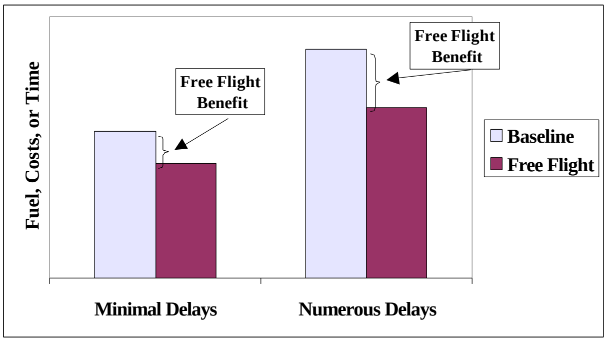

Figure 5 – Fuel, Cost, and Time for Baseline and Free Flight Operations

Figure 5 is an illustration of how the fuel burn and time savings benefits are envisioned to look like in 1996 and for the "high delay" that will be created.

Additionally, some delays cannot be reduced en route due to reduced capacity at the arrival airport. Several baseline days were analyzed to determine the airports with reduced acceptance rates due to severe weather or other hazards. Then, specific flights that are arriving during the time that the airport is operating at reduced capacity were extracted. Regardless of the technologies available, weather (or other factors) may force certain events to occur, like a ground hold at the arrival airport, restricting access to that airport during a certain period. Therefore, the estimated time of arrival (ETA) for a flight may be changed, due to this ground hold, because of the saturation at the arrival airport. To determine how APATH technology may impact this scenario, trajectories indicative to the envisioned APATH were modeled. Given that the arrival time has been constrained, and a delay has been imposed, APATH can then be used to reduce the operating cost, in this scenario, in terms of fuel burn, consequently reducing the cost of the initial delay.

Environmental

After the efficiency benefits have been determined, then the environmental benefits were calculated using the fuel savings. The analysis used engine-specific emission indices provided by engine manufacturers (documented by ICAO) (ICAO, 1996) and indices developed by Boeing (Baughcum, 1996). These indices are not only engine-specific, but also specific to the aircraft's phase of flight. Emissions were calculated using the following formula provided by ICAO and the FAA's Office of Environmental and Energy (AEE) (Anderson, 1997).

*Emissions (lbs.) = Fuel Burn (1000 lbs.) * Emission Index (lbs. emission/1000 lbs. fuel)*

Emission savings were calculated for nitrogen oxides (NOx), hydrocarbons (HC) and carbon monoxide (CO). This relates directly to one of the NASA Enabling Technology Goals: Environmental Compatibility. Part of this particular goal’s focus is to reduce emissions of future aircraft by a factor of three within 10 years, and a factor of five within 20 years. So, the potential preliminary environmental benefits of APATH are in line with the current thrust of NASA’s research and technology.

Predictability

The use of APATH may improve the consistency of execution of schedule. This is achieved by including the capability in the flight deck to manage speed profiles and constraints over longer distances, consequently improving the ability of the system to deliver aircraft efficiently to the transition and arrival. The ability to support more effective sequencing and spacing aircraft will maximize peak throughput at a lower variance. This increased predictability will allow the users to tighten their schedule times, resulting in reduced Airline Direct Operating Cost (ADOC).

Flexibility

One of the constraints on flexibility in the NAS is the increased level of uncertainty and potential workload associated with allowing more user preferred routings and user enroute flight requests. At a minimum, since APATH will potentially include traffic and other constraints in the planning function and better situational awareness in the cockpit, the service provider will be more confident in the request's feasibility. This will reduce the likelihood that the service provider will reject the request or that a subsequent controller will find it necessary to re-impose restrictions. Flexibility may also be improved by enabling users to combine the best information from each flight deck, such as individual aircraft performance parameters, with aircraft or airline objectives, to generate user-optimized replanned flight paths.

This increased flexibility will allow airlines to maintain their fleet schedule and aircraft placement. For example, if a flight is canceled, then that aircraft will not be in the position for the next leg of the flight or subsequent flights. If the airline cannot easily replace the aircraft required for subsequent flights, then a ripple effect of cancellations and delays will occur. Although flexibility is one of APATH's main benefits, it is not quantified at this time.

Productivity

In the current paradigm of ground based control, the possibility exists there is an upper limit to the amount of airspace operations that can be handled, no matter how good the ground-based decision automation tools are in the future. The issue will continue to be workload of the human controller, who needs to devise and execute a plan for managing all aircraft assigned to the sector. Because APATH may enable the cockpit to take a proactive approach in flight replanning, this could potentially reduce the workload of the controller. However, a more detailed analysis is needed to help understand and quantify the workload/productivity of the controller and the pilot. A separate task is needed to address the roles and responsibilities of the current controller/flight deck and how these roles and responsibilities may be distributed in the future.

Safety

In this analysis, safety is discussed qualitatively. Adding redundancy to the ATC system by increasing flight deck capability and increasing situational awareness of the pilots may improve safety. However, more detailed human in the loop analysis is needed to quantify such benefits.

Conclusions

APATH is still in the early development stages. This analysis is a preliminary study on the possible benefits of the functionality of APATH, as it is currently envisioned.

This study analyzes the potential consequence of traffic growth and changes in the NAS operations to the current airspace structure, and the potential benefits that APATH may provide. As a result of more direct, optimized routes, flights will tend to spend less time in the air and follow trajectories that could potentially increase the task load of sector controllers. Understanding the changes and the demand of the NAS could assist in the restructuring of the airspace and enhancement of the AATT tools to support more efficient operations and balance controller task load.

Other factors need to be investigated in follow-on studies. These include, but are not limited to, capacity, access and operational scalability. Understanding how APATH affects these metrics can possibly provide justification for redistributing some of the workload to the FD, through new and improved airborne technologies.

The analysis and results are available upon request.