Airborne Trajectory Management (ABTM):

A Blueprint for Greater Autonomy in Air Traffic Management

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Introduction

The aviation users of the National Airspace System (NAS) – the airlines, General Aviation (GA), the military and, most recently, operators of Unmanned Aircraft Systems (UAS) – are constrained in their operations by the design of the current paradigm for air traffic control (ATC). Some of these constraints include ATC preferred routes, departure fix restrictions and airspace ground delay programs. As a result, most flights cannot operate on their most efficient business trajectories and a great many flights are delayed even getting into the air, which imposes a significant challenge to maintaining efficient flight and network operations.

Rather than accepting ever more sophisticated scheduling solutions to accommodate the existing constraints in the airspace, a series of increasingly capable airborne technologies, integrated with planned improvements in the ground system through the Federal Aviation Administration (FAA) Next Generation Air Traffic Management System (NextGen) programs, could produce much greater operational flexibility for flight path optimization by the aviation system users. These capabilities, described in research coming out of NASA's Aeronautics Research Mission Directorate, can maintain or improve operational safety while taking advantage of air and ground NextGen technologies in novel ways. The underlying premise is that the nation's physical airspace is still abundant and underused, and that the delays and inefficient flight operations resulting from artificial structure in airspace use and procedural constraints on those operations may not be necessary for safe and efficient flight.

This article is not an indictment of today's NAS or the people who run it. Indeed, it is an exceptional achievement that Air Traffic Management (ATM) – the complex human/machine conglomeration of communications, navigation and surveillance equipment and the rules and procedures for controlling traffic in the airspace – has both the capacity and enables the degree of efficiency in air travel that it does. But it is also true that sixty years of the "radar religion" (i.e., reliance on radar-based command and control) has produced several generations of ATM system operators and researchers who believe that introducing automation within the existing functional structure of ATM is the only way to "modernize" the system. Even NextGen, which began as a proposal for "transformational" change in the way ATC is performed, has morphed over the last decade and a half to become just the inclusion of Global Positioning System (GPS) for navigation, Automatic Dependent Surveillance Broadcast (ADS-B) for surveillance, and Data Communications (Data Comm) for communications, while still operating in rigidly structured airspace with human controllers being responsible for separation and traffic flow management (TFM) within defined sectors of airspace, using the same horizontal separation standards that have been in use since raw primary radar was introduced in the 1950s.

No system as massive as the current NAS ATM can be replaced with a better system while simultaneously meeting the transportation and other aviation needs of the nation. A new generation of more flexible operations must emerge and yet coexist in harmony with the current operation (i.e., share the same airspace without segregation), thereby enabling a long-term transformation to take place in the way increasing numbers of flights are handled. Market forces will be the ultimate driver of this transformation, and investment realities mandate that real benefits must accrue to the first operators to adopt these new capabilities. In fact, the kinds of missions envisioned in the emerging world of UAS operations, unachievable under conventional ATM, demand that this transformation take place.

Airborne Trajectory Management (ABTM) is proposed as a series of transformational steps leading to vastly increased flexibility in flight operations and capacity in the airspace to accommodate many varied airspace uses while improving safety. As will be described, ABTM enables the gradual emergence of a new paradigm for user-based trajectory management in ATM that brings tangible benefits to equipped operators at every step while leveraging the air and ground investments of NextGen. There are five steps in this ABTM transformation.[1] NASA has extensively studied the first and last of these steps, and a roadmap of increasing capabilities and benefits is proposed for bridging between these operational concepts.

Step One - Traffic Aware Strategic Aircrew Requests (TASAR)

The roadmap begins with Traffic Aware Strategic Aircrew Requests (TASAR).[2] It is well known that today's ATC system permits greater flexibility in the choice of route and altitude for airborne aircraft than during the flight planning process. Flight plans must be filed to conform with established constraints in the airspace that are static, i.e., in place regardless of existing traffic. Once airborne, pilots routinely request shortcuts that are often accommodated by air traffic controllers who are doing their best to increase efficiency in the system, given the constraints of traffic flows and airspace structure to which they are required to adhere. Usually, this takes the form of a "direct to" clearance, eliminating a dogleg in the cleared route. But it is also true that "direct" is not the optimal path (i.e., shortest flight time or lowest fuel burn) unless the wind field is completely uniform, something that almost never occurs in nature. That is why modern flight planning systems seek the best wind route, optimizing the flight to minimize time, fuel burn, or a balanced combination of both. But flight planning systems must also modify the best wind route to conform to the constraints imposed by ATC, or else the filed flight plan won't be accepted into the FAA's EnRoute ATC Modernization (ERAM) computer. TASAR, depicted in Figure 1, goes a step beyond what can be accomplished pre-flight by the operator’s flight planning systems by providing the pilot a real-time flight optimizing tool in the cockpit.

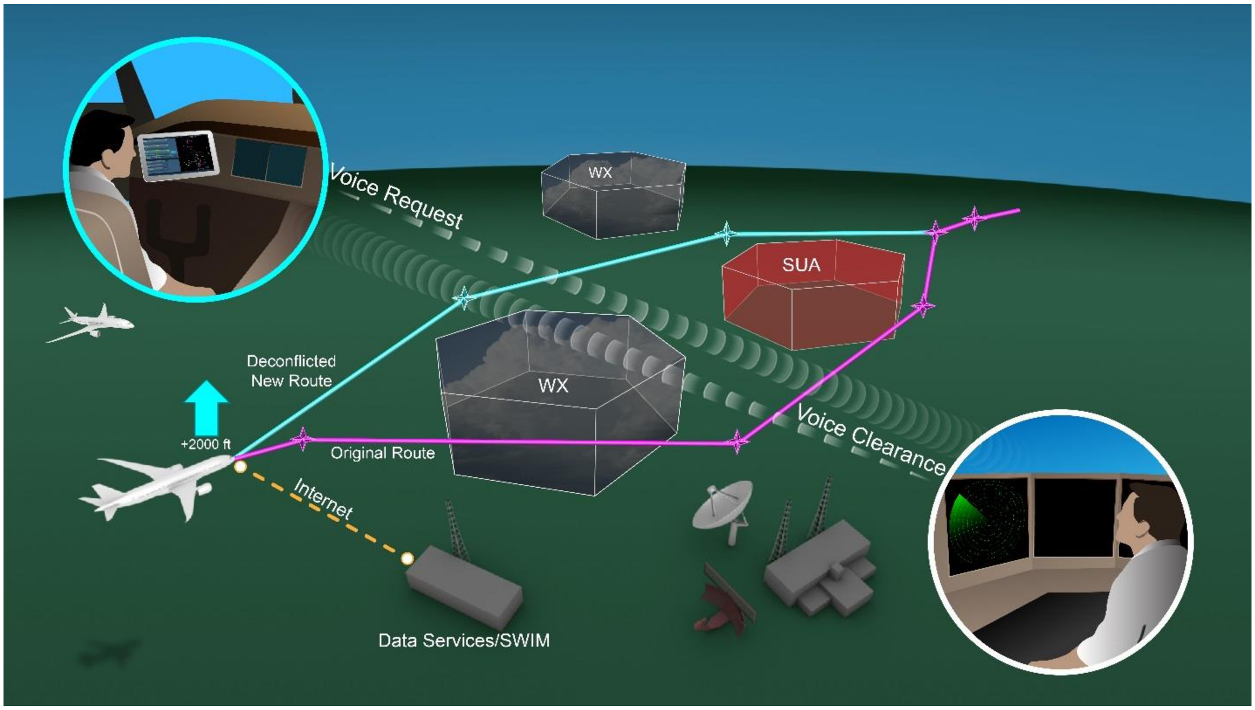

Figure 1 ABTM Roadmap Step 1 - TASAR

TASAR employs an EFB application with access to aircraft flight information from onboard avionics and airspace/environmental information on wind and weather forecasts, Special Use Airspace (SUA) activity, and other NAS constraints through the aircraft's broadband internet connection to a System Wide Information Management (SWIM) gateway or other third party service providers. This TASAR EFB application is exemplified by NASA's prototype Traffic Aware Planner (TAP) software application.[4] Using a sophisticated route optimization algorithm, TAP computes the best route and altitude from present position forward once each minute, using the most recent wind grid available, filtering out solutions that are conflicted by ADS-B IN traffic, active SUA, or hazardous weather, and presenting reroute solutions (lateral, vertical, and combination lateral/vertical) to the pilot. After review, the pilot may request the TAP-generated trajectory change from the controller, leveraging the greater rerouting flexibility while airborne to achieve significant operational benefits. Because the TAP solutions are already vetted for traffic, SUA, and weather, TASAR requests stand a better chance of being approved by ATC than a typically uninformed pilot request.

The development of the TASAR operational concept and the TAP software has taken place under NASA sponsorship for more than a decade and has been evaluated in simulations and flight tests by airline pilots and air traffic controllers. NASA has partnered with two airlines to conduct operational flight trials of TASAR beginning in the summer of 2017.

Step Two - Digital TASAR

Digital TASAR adds data communications to basic TASAR. TASAR's initial design accommodates the fact that requested changes in the flight trajectory can be cumbersome to describe in voice transmissions by constraining the number of requested new waypoints to no more than two, and these must be named waypoints. Similarly, no more than one altitude change is requested at a time. Procedurally, only one

TASAR request is made per control sector to keep the workload acceptable to both pilots and controllers. In Digital TASAR, depicted in Figure 2, Data Comm and the resultant graphic representation to ATC of the requested trajectory change mitigate these limitations of the voice request environment. Upgraded for Digital TASAR, the optimized solutions produced by the TAP software and their outcomes (i.e., fuel and/or time saved) will be loadable to the Flight Management System (FMS) and sent as a request to ERAM through the FAA's Data Comm Services with the push of a button, requiring neither voice requests nor manual keyboard entry. The request is then graphically displayed to the controller for consideration. Approval, amendment, or denial would also take place through the FAA's Data Comm Services.

Digital TASAR requests have higher value than basic TASAR because they are not constrained by the

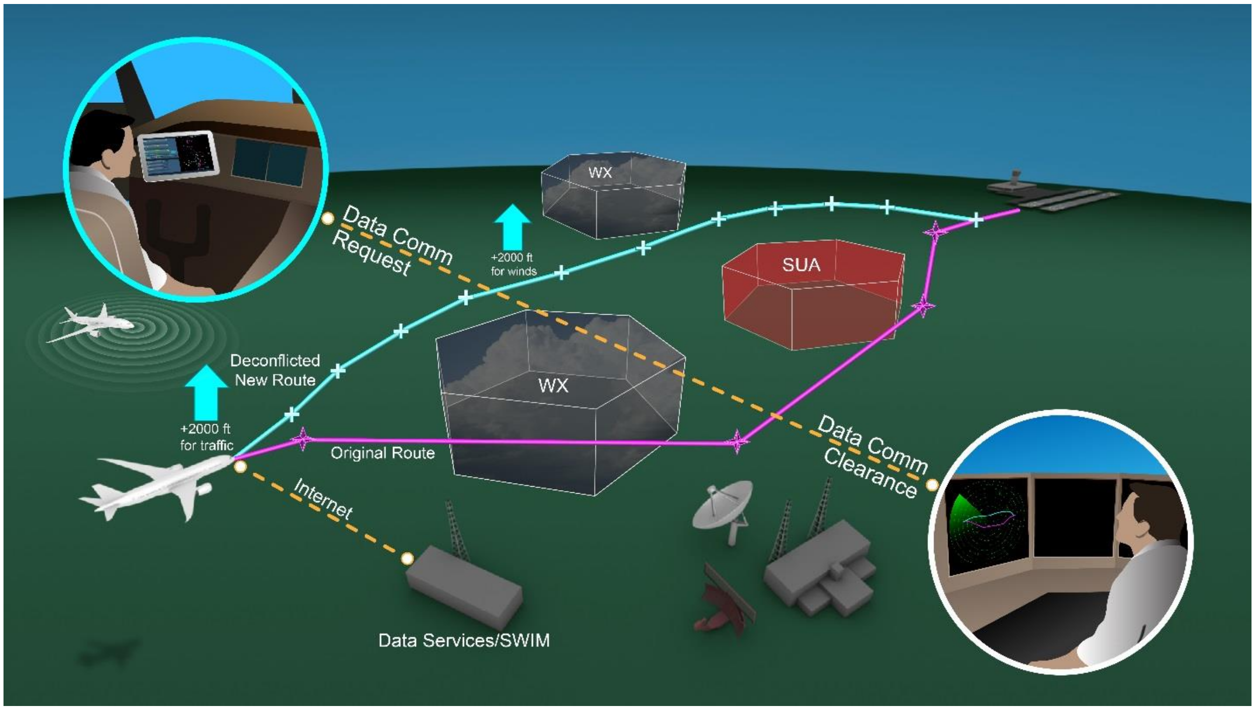

Figure 2 ABTM Roadmap Step 2 - Digital TASAR

voice request and approval limitations, enabling more complex optimized trajectory change requests. However, they are actually simpler for the pilots and controllers to use because they are graphically portrayed and digitally shared without voice reference to individual waypoint names. Because the trajectory change *request* is not safety critical, unlike the amended clearance, a pre-Data Comm Full Services (circa 2022) method for down-linking the request can be considered. For example, oceanic aircraft have used the Future Air Navigation System (FANS) 1 system for decades for handling alpha numeric requests and re-clearances. On the aircraft, this will require a TAP connection to the data communications system with attendant certification considerations. Airborne internet access to ERAM through a gateway like the Leidos flight plan forwarding system provides another method for making Digital TASAR requests. Digital TASAR will also simplify coordination with the airlines' flight dispatch function, allowing dispatchers to provide real-time adjustments to the optimization objective used by TAP to reflect total airline network optimization considerations, such as passenger connections, aircraft scheduling, and maintenance routing.

Step Three - 4D TASAR

4D TASAR adds the fourth dimension of time and/or speed management to the TAP optimization algorithms and enables integrating the solutions with such systems as the airborne Flight Deck Interval Management (FIM) application and the ground-based Time Based Flow Management (TBFM) automation for arrivals to capacity constrained airports. This provides an additional opportunity to save time and fuel beyond the lateral and vertical trajectory optimizations made using a constant cruise Mach number. It enables dynamic control of the Cost Index by the airline and also permits the flight to be inserted in the correct sequence in the arrival flow without being placed in a physical line of Miles-in Trail traffic, a process that prevents every aircraft in the "conga line" from optimizing their speed.

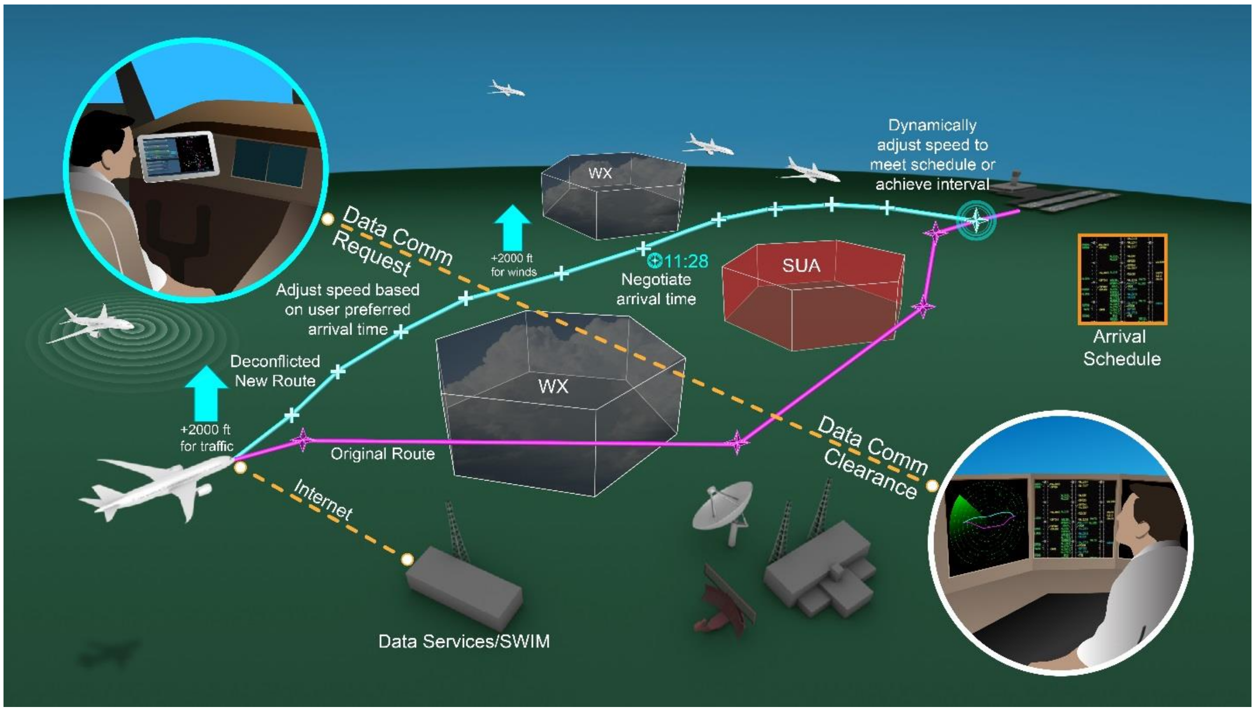

Figure 3 ABTM Roadmap Step 3- 4D TASAR

The coordination of 4D TASAR (depicted in Figure 3) with the FAA's TBFM automation further reduces the chance for rejection of the trajectory optimization requests and strengthens the business case for using integrated avionics in the aircraft. In fact, the opportunity for full flight path optimization may provide a sufficient business case for upgrading aircraft for both FIM and Data Comm, including the higher level of certification required in this equipment. But the integration of the 4D tool with TBFM is only relevant at the largest airports where excess traffic demand presents a continuing operational constraint. For some airline flights, most GA flights, and nearly all UAS operations, major airport congestion is not an issue because they do not typically use these airports. For these users, the enhanced optimization capability provided by 4D TASAR can provide additional fuel and time savings, unimpeded by destination airport constraints.

Step Four - Strategic ABTM

In Strategic ABTM, depicted in Figure 4, trajectory changes will purposefully begin in the next sector (beyond the current sector) and will ensure no new conflicts are created in that sector (similar to a controller's responsibility when handing off aircraft). Such requests will be submitted to receive expedited (eventually automatic) approval from ATC without impacting the air traffic controller of the aircraft's current sector. When sent via Data Comm to the ERAM computer, the Strategic ATBM trajectory changes will automatically update the flight plan while simultaneously becoming the active route in the FMS on the aircraft. These changes (starting in the next sector) will not impact the controller in the active sector since they begin beyond his area of consideration and thus will not change the locus of responsibility for separation. ATC interventions for Strategic ABTM flights will be rare because the trajectory changes will be de-conflicted and preserve the essential constraints dictated by airspace use and TFM. While pilot assessment and approval is still required before sending Strategic ABTM solutions to ERAM, these TAP solutions will have become the primary mode of trajectory management in the cockpit. These iterated solutions will contain the latest in airline fleet and network optimization objectives, wind optimization, weather, traffic and airspace hazard avoidance.

During the years of experience gained in operating the previous versions of TASAR, the traffic de-confliction algorithm in TAP will have been refined and shown to provide reliably de-conflicted,

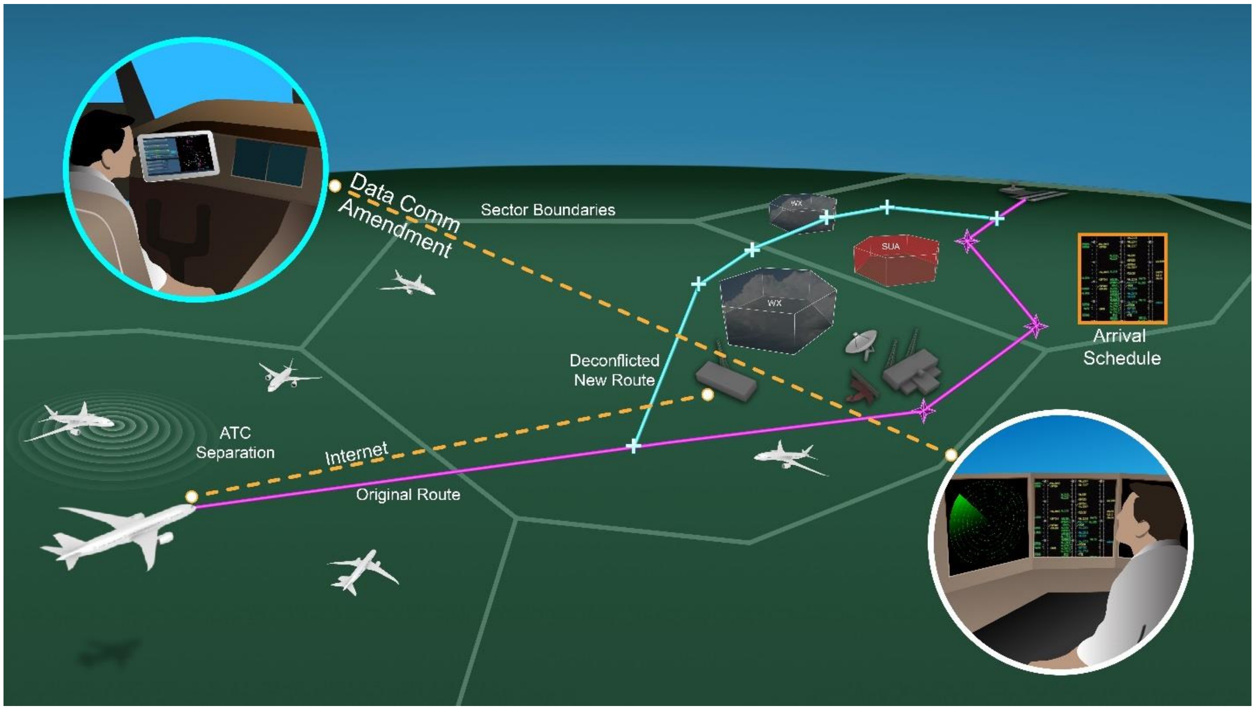

Figure 4 ABTM Roadmap Step 4 - Strategic ABTM

optimized solutions. This extensive dataset will provide the foundation for the final step of ABTM wherein the separation function can be provided by the onboard trajectory management system. Traffic de-confliction is part of the legacy of TAP because it is software initially created for NASA's extensive research in airborne self-separation. The predecessor tool, NASA's Autonomous Operations Planner (AOP), Error! Reference source not found. has both a strategic (longer range) and a tactical component with interfaces to the aircraft's FMS and tactical flight controls. AOP is able to leverage "intent" information from other traffic that may be obtained in the future through SWIM, ADS-B IN, or other means. Validating AOP's traffic separation algorithms embedded in TAP through years of operational use in the non-safety-critical TASAR and Strategic ABTM application of "user requests" will result in a robust and highly reliable trajectory planner that will have proven its integrity through a formal safety assessment process for the final step in the roadmap: Full ABTM.

Step Five - Full ABTM

Full ABTM, depicted in Figure 5, adds tactical separation assurance capability to the Strategic ABTM capability (i.e. downstream sector modifications to the route) such that autonomous trajectory changes can safely begin in the current sector rather than be delayed to the next sector. NASA has invested significant time and resources investigating this operation under the concept of "Autonomous Flight Rules" (AFR)[3] and determining the required functionality of onboard ABTM automation through development of the prototype "Autonomous Operations Planner" (AOP).**Error! Reference source not found.** The ultimate objective of AFR and AOP is to enable operators to self-manage their trajectories in the NAS alongside conventionally managed traffic, preserving safety and fairness in the use of NAS resources but

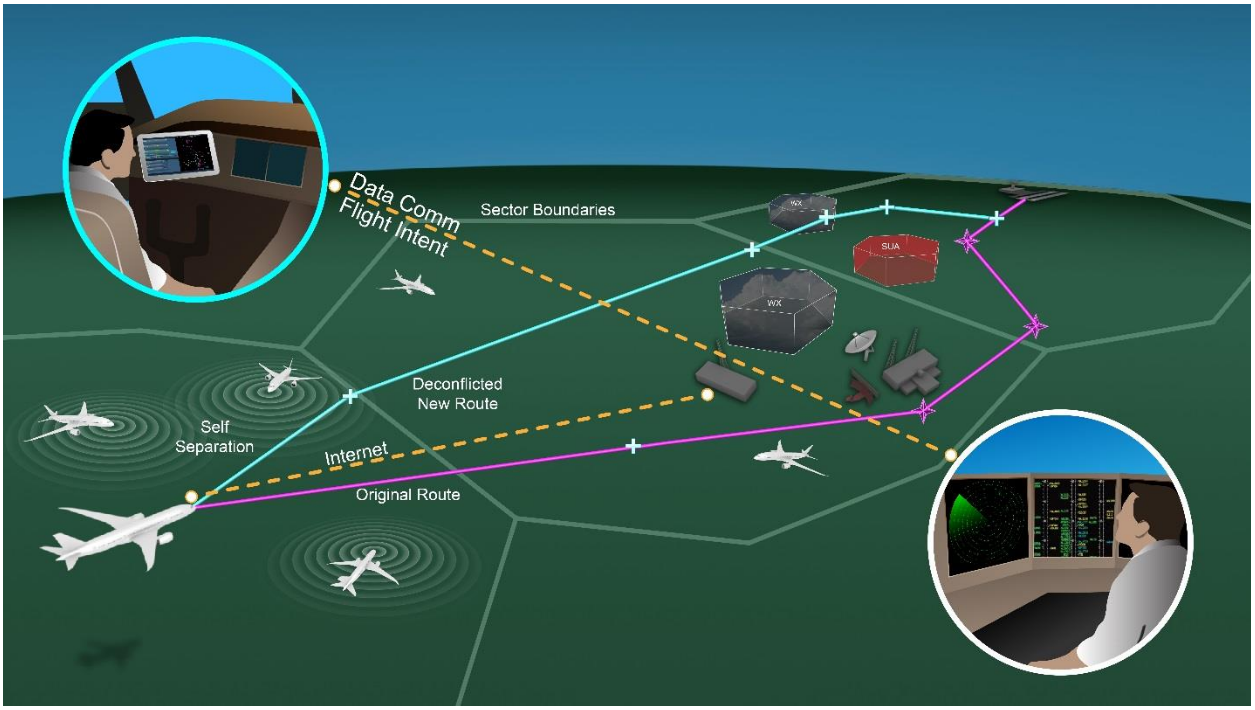

Figure 5 ABTM Roadmap Step 5 - Full ABTM.

bypassing constraints.

AFR combines the flexibility of Visual Flight Rules (VFR) with the safety of Instrument Flight Rules (IFR). With the help of sensors and computational hardware, pilot displays provide full-time guidance along a continuously updated, wind-optimized trajectory, safely avoiding other traffic, active SUAs and weather hazards. AFR flights will participate in destination airport TBFM, but will employ optimized insertion into the traffic flow close to the landing runway. The benefits of flying the best wind route are very large and may be mostly achieved in earlier stages of ABTM, but these benefits are small in comparison to the delays resulting from TFM constraints in all its forms. In Full ABTM, the TAP system will be certified for the separation function. This equipment certification along with pilot training and operational approval will permit AFR operations for flights in the NAS at all altitudes and in all but active SUA airspace.

Achieving the approvals for AFR in FAR Part 121 operations may be time consuming but potentially accelerated by supporting experience gained using the concept first in Part 91 GA operations and in low altitude UAS operations. These flights also provide a logical environment to prove out reduced horizontal separation standards made possible using high update rate ADS-B IN that provides precise target positioning and short term intent. Reduced horizontal separation standards should be based, like collision avoidance systems, on the time to the closest approach and a minimal fixed protection area. Reducing the size of protected airspace in safe, legal separation would dramatically reduce the number of conflicts experienced in a given traffic density and the extent of the required resolution maneuvers.

The Way Forward

The FAA's NextGen programs are creating some essential technologies to modernize the way air traffic is managed. Augmented GPS for positioning, timing, and navigation in all phases of flight have made area navigation by all airspace users a reality. Instrument approaches may now be made to nearly every runway without expensive ground-based transmitters. Data communications is only just beginning to be realized, but it holds the promise of freeing aviation from the limitations of voice and extensive manual entry of flight information. The sharing of system status and weather data through SWIM is also in its infancy but can be used to help ensure safety by providing information at the right time and in all the right places. ADS-B provides the information needed to perform reliable traffic de-confliction and, ultimately, separation services on board the aircraft while sharing intent with all other NAS systems. But the lack of change in the control paradigms themselves has led to continued constraints imposed on IFR operations as a way of life, much to the frustration of system users. ABTM offers a way to overcome most of these constraints on properly equipped flights without impacting other traffic or conventional air traffic services.

In keeping with incremental improvements to TASAR capability and their resulting operating benefits to the first adopters, Step 1 is relatively simple, requiring only modest changes on the aircraft and no changes to ground systems or to pilot/controller procedures. It is essentially a tool used during the enroute cruise phase of flight. Step 2 increases the benefits to the first adopter by enabling longer and more complex trajectory changes for the entire flight outside the terminal airspace. The following steps continue to add benefit using logical extensions of NextGen and NASA developed tools. Though the greatest benefits to users will be achieved in the final step, Full ABTM, stopping at any step still adds value for the operator.

Most importantly, ABTM introduces these capabilities in a way that benefits the first adopter and every succeeding operator that chooses to equip. There is no requirement for a "critical mass" of users to equip or for ground systems to be modified, other than those changes currently planned for NextGen, to realize the benefits. Continued public/private partnering to refine and prove the benefits and safety of these new ABTM capabilities can ensure the initially envisioned transformation of ATM actually takes place.

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