Developing an Onboard Traffic-Aware Flight Optimization Capability for Near-Term Low-Cost Implementation

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The concept of *Traffic Aware Strategic Aircrew Requests* (TASAR) combines Automatic Dependent Surveillance Broadcast (ADS-B) IN and airborne automation to enable user-optimal in-flight trajectory replanning and to increase the likelihood of Air Traffic Control (ATC) approval for the resulting trajectory change request. TASAR is designed as a near-term application to improve flight efficiency or other user-desired attributes of the flight while not impacting and potentially benefiting ATC. Previous work has indicated the potential for significant benefits for each TASAR-equipped aircraft. This paper will discuss the approach to minimizing TASAR's cost for implementation and accelerating readiness for near-term implementation.

I. Introduction

THE emergence of Automatic Dependent Surveillance Broadcast (ADS-B) and Portable Electronic Devices (PED) / Electronic Flight Bags (EFB) offers a rare opportunity to aircraft operators to significantly improve their flight operations in the near term. This opportunity is enabled by the ability of aircraft to receive the same high-quality traffic surveillance information viewed by Air Traffic Control (ATC) and, as conditions change during the flight, to compute re-optimized trajectories that are compatible with nearby traffic. Armed with this information, aircrews can more effectively work with air traffic controllers by making flight-optimizing trajectory-change requests that consider the proximity of other traffic (i.e., "traffic aware'), thereby proactively mitigating the controller's primary concern of traffic separation and enabling controllers to more frequently approve such requests. The result is a win-win situation for users and service providers: (1) users more often receive their desired trajectory improvements (whatever they may be), and (2) controllers can provide the desired service to users while saving workload associated with fewer problematic or non-approvable requests.

NASA is developing the concept of *Traffic Aware Strategic Aircrew Requests* (TASAR) as a near-term flight-deck application that leverages onboard computing and ADS-B IN traffic data and other data to provide user benefits.[1] NASA's work here is motivated by two primary objectives.

Objective 1: To reduce obstacles for users to achieve near-term direct benefits of ADS-B. The Federal Aviation Administration (FAA) is putting into place a surveillance infrastructure based on ADS-B OUT, and it has mandated that all aircraft in transponder airspace shall broadcast position data over ADS-B by the year 2020.[2] This new "satellite-based" surveillance infrastructure provides direct benefits to the FAA by reducing the cost of maintaining expensive radar systems and by providing more accurate surveillance data to air traffic controllers. User benefits of ADS-B OUT are less clear, however, and it is commonly accepted by users that ADS-B IN

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equipment is required to gain measurable benefits through specific applications of air-to-air surveillance. Several ADS-B IN applications are in various stages of definition, research, and development, and avionics products are already on the market providing limited ADS-B IN capabilities to customers. However, no single application has yet emerged to provide a dominating business case for widespread ADS-B IN equipage. NASA and other organizations are continuing to develop ADS-B IN applications with the hope that bundles of applications will provide sufficient incentive for accelerating ADS-B IN equipage and benefits, eventually leading to a profound total impact on airspace operations.

NASA is developing TASAR in order to provide a low-cost, low-risk avenue for the user community to realize early operational benefits of airborne surveillance without the obstacles that typically impede the pace of introducing new capabilities. TASAR requires no change to any aspect of the current ATC system. It leverages the existing flexibility for pilots to request trajectory changes in-flight, only it significantly improves this process. On the ground, it requires no new infrastructure, ATC procedures or tools, or FAA policy changes, all of which could otherwise significantly increase the time to initial implementation. On the aircraft, it requires only a computing platform with access to certain information and a simple display, with no impact to flight-critical systems. Later sections of the paper will discuss how certification and operational approval requirements have been minimized to enable users to implement TASAR with relative ease. Most importantly to users, TASAR is a “per-aircraft” application, meaning it does not depend on multiple aircraft to be TASAR-equipped for any single aircraft to benefit. Indeed, any application that provides full benefits to the first equipped aircraft on its first flight (and every flight thereafter) offers a significant incentive for users to be early adopters.

Objective 2: To accelerate the use of networked cockpit automation for trajectory management. For most users, flight optimization occurs in the flight planning and pre-departure clearance process well before the aircraft takes off. This process includes determining the optimal flight level based on aircraft performance, weight, and forecast winds, and it involves selecting a route consistent with forecast/observed weather and standard ATC filing requirements. Once the aircraft is airborne, further flight optimization (if any) falls to the dispatcher or the pilot. Of these two company representatives, the one most available to consider improvements to the flight is the pilot (whose attention is devoted to their flight). However, with few in-flight replanning tools available, the pilot is not always aware that optimization opportunities exist. The aircraft’s Flight Management System (FMS) can provide a recommended flight level change as fuel is slowly burned off, but they are not designed to recommend route changes due to updated wind or weather forecasts. It is up to the pilot to recognize potential flight improvements from experience, often without sufficient information, and to be motivated to make these requests.

Use of networked cockpit automation fits well with this need for better in-flight replanning. An onboard flight-optimization tool has a natural “home court” advantage. It has direct access to data and information from aircraft systems and sensors, and the pilot can keep the tool’s optimization objectives updated throughout the flight as conditions change. Broadband internet connectivity completes the picture by providing low-cost, real-time access to supplemental information on winds, weather, traffic, National Airspace System (NAS) status, and company/dispatch inputs. These factors combine to create an environment where any user (from large networked carriers to small operators) can do an effective job at optimizing each flight without additional resources devoted on the ground.

Achieving Objectives 1 and 2, while benefiting users today, should also create an environment in which future ADS-B IN applications will more quickly emerge. Some of these envisioned applications of airborne surveillance will provide users more autonomy in managing their flights and therefore are expected to provide significantly larger user benefits. In addition, with operational use of applications like TASAR, new innovative applications of airborne surveillance not previously envisioned are likely to emerge.

This paper describes the approach to keeping costs as low as possible for operators to adopt TASAR and to accelerate readiness for implementation. The paper begins in Section II with a brief description of several parallel risk reduction activities underway to achieve these goals. Section III addresses the selection of an appropriate computing platform for the TASAR application. Section IV discusses safety implications for certification and operational approval. Section V addresses access to the required data during flight. Section VI provides a summary.

II. Risk Reduction

Adopting new technology or operational procedures is not a decision taken lightly by aircraft operators. Such investments often involve significant upfront expense and the assumption of certain risks of achieving a timely return on investment. NASA is pursuing several activities in parallel to reduce the risk to operators in adopting TASAR. Each is briefly discussed in this section. Additional detail on some elements is provided in references and the following sections of this paper.

A. Concept Documentation

To encourage a shared, detailed understanding of the TASAR concept and to facilitate communication among various parties involved in its implementation and approval, NASA produced a Concept of Operations document that spells out how TASAR is intended to work within the context of current-day operations.[3] The document describes the roles and responsibilities of the controller, aircrew, and other actors within current operations, the shortfalls of current user requests that the TASAR concept addresses, and a short description of procedural changes under TASAR. A detailed description of the TASAR concept focusing on aircrew interaction with the onboard automation and the desired functions/behaviors of the onboard automation is provided in the document and it describes the two primary modes of the technology: (1) auto mode that continuously assesses opportunities for improving the performance of the flight and (2) manual mode that probes pilot-entered trajectory changes for conflicts and performance objectives. The Concept of Operations document discusses the required inputs and expected outputs of the automation technology and gives operational scenarios that show the interactions among the onboard automation, aircrew, controllers, and other actors. The document also describes potential future evolution paths of TASAR.

B. Preliminary Benefits Assessment

To provide data for users to assess the merits of TASAR, NASA conducted an initial analysis of user benefits.[4] The simulation study showed that, on average, an aircraft employing TASAR reduced its travel time by about one to four minutes per operation and fuel burn by about 50 to 550 lbs. per operation, depending on the objective of the aircrew (e.g., time, fuel, weighted combination), class of airspace user, and aircraft type. The analysis presents results such that users could extract specific time and fuel savings based on city pairs similar to their own operation and optimization objectives and thus can estimate benefits specific to their business model. These results, presented in detail in Reference 4, support the formulation of an internal business case for TASAR.

C. Assessment of Requirements for Certification and Operational Approval

NASA conducted several analyses on the requirements to install, certify, and operate a TASAR system. First, an analysis of FAA regulations was conducted to determine the appropriate platform for the TASAR application and the certification and operational approval requirements for that installation. The analysis determined that a Class 2 Portable Electronic Device (PED) / Electronic Flight Bag (EFB) provides a reasonable balance between functionality and certification cost, given its read-only access to aircraft systems. The TASAR software application was determined to best fit the criteria of a Type B application, which does not require costly compliance to software development standards. Second, a hazards analysis was conducted and determined that TASAR would likely be assessed as having a "No Effect" or at most "Minor Effect" Failure Effects Classification. Following these analyses, a draft Project Specific Certification Plan was developed for TASAR and reviewed by Designated Engineering Representatives (DER). The DERs raised no concerns with the draft plan, and therefore applicants should anticipate no show-stopper issues in the certification and operational approval processes. Sections III and IV will discuss the PED/EFB platform and hazards analyses, respectively, in greater detail.

D. Development of TASAR Software Application

NASA is currently developing a high-fidelity prototype of the TASAR software application with the goal of making it available to users and technology providers. The NASA prototype is the "Traffic Aware Planner" (TAP) and runs on a commercial-off-the-shelf Class 2 EFB platform.[5] TAP's flight optimization and traffic conflict management algorithms were originally developed for advanced self-separation research, and these high-performance algorithms have been extensively tested and matured for over a decade. TAP continuously scans for time- and/or fuel-saving possibilities in three ways: lateral-only route changes, altitude changes, and combination lateral/altitude changes. TAP also supports manual mode in which the pilot enters a desired change, and the fuel/time impact and conflict prediction results are displayed. This mode will be useful for trajectory change requests sent by the aircraft's dispatcher and for "timing" the actual request for improved likelihood of ATC approval. Using a standard navigation database, TAP specifies solutions using published fixes to facilitate voice requests. The human-machine interface (HMI) is primarily textual with no display of traffic or own-ship position, thus minimizing issues for operational approval. Sample displays of the TAP application's "Auto" mode are shown in Figure 1.

For the future, TAP is readily upgradable to take full advantage of a Class 3 EFB environment, including loading solutions electronically to the FMS, full use of latitude/longitude waypoints (i.e., not just named fixes), and leveraging future data communications with ATC. Making the TAP software application available to the user community reduces development risk and delays, and it positions users to take immediate advantage of emerging

NextGen capabilities (e.g., ADS-B now, data communications in the coming years). Section V discusses considerations for integrating TAP in a live data environment.

Figure 1 Sample displays of TAP "auto" mode. TAP presents primarily textual information. The graphical display provides situation awareness of the proposed trajectory change and does not display traffic or own-ship position.

E. Pilot Assessment in Simulation and Flight

NASA is testing TAP functionality and usability with pilots in a high-fidelity human-in-the-loop (HITL) simulation and through in-flight assessments on a test aircraft. The HITL simulation experiment, conducted during the summer of 2013, involves 12 current airline pilots operating a full-mission Boeing 777 fixed-based simulator on a flight through airspace with simulated traffic, dynamic weather, and changing winds. Using the actual TAP-EFB integrated system, the study focuses on assessing HMI design and usability, while also validating that pilot workload would not be impacted by TAP during nominal and off-nominal conditions. Results will be published in a separate paper once data analysis is complete.

The in-flight assessment, scheduled for September 2013, will ensure that the TAP application works with real-world data and is usable by pilots in flight. The TAP-EFB integrated system will be installed in a Piaggio Avanti I aircraft equipped with ADS-B IN and broadband internet connectivity providing access to the latest wind forecasts. Flights will be operated under Instrument Flight Rules (IFR) in ATC-controlled airspace. A four-staged assessment will (1) verify operational data flow and proper processing of the information by TAP, (2) verify TAP's intended functionality, (3) gather data on pilot interactions with TAP in an operational environment, and (4) use TAP to support making actual trajectory change requests to ATC. Eight pilots will participate in the flight activity, and pilot workload and TAP usability assessments will be compared to HITL simulation results.

Reports from the HITL simulation and in-flight assessment will be made available to user applicants to serve as supplemental artifacts in the certification and operational approval process. These activities should help establish the maturity level of the TASAR concept and technology.

III. TASAR as a PED/EFB Application

At the core of the TASAR concept is an automation tool to be located onboard the aircraft as a flight-deck EFB application for ready access to the pilot. TAP is NASA's prototype of such a tool. The tool's primary purpose is to advise the pilot when an improvement to the aircraft's trajectory is available. The software would be installed on a computing platform that accesses the required data and provides the pilot ready access to its output, which are trajectory-change improvements that the pilot may request of ATC as part of a change request to the current clearance. Although one can envision an FMS upgraded with TASAR functionality, this approach does not lend itself to the low-cost, near-term solution envisioned to meet the objectives previously discussed. Rather, hosting the TASAR software as an EFB application on a PED better aligns with these near-term goals. Meanwhile, future FMS systems could be designed with similar functionality. This section of the paper will discuss issues associated with TASAR as a PED/EFB application.

A. EFB Class Selection

With the availability of low-cost commercial-of-the-shelf PEDs and their utility to provide increasingly more capable software applications to support flight operations, the FAA has developed and continues to update guidance information toward the proper use of EFB hardware including PEDs and their hosted software applications for flight deck use.[6] The FAA document defines the class of EFB platforms and associated installation (i.e., Classes 1, 2, and 3), and it defines the types of software application (i.e., Types A, B, and C) that may be hosted. As industry continues to push for increasing application capabilities being integrated and performed by EFBs, these guidelines continue to evolve in terms of the certification and operational approval requirements for the EFB's ability to interact with on-board avionics systems.

With the goal of developing a near-term application providing early benefits and at relatively low cost, NASA has developed TASAR with a read-only interface to on-board avionics systems to obtain the needed information to enable its in-flight trajectory replanning capability. Figure 2 provides a functional diagram of TASAR illustrating the high-level information flows, including the read-only interfaces to avionics, e.g., ADS-B IN, FMS.

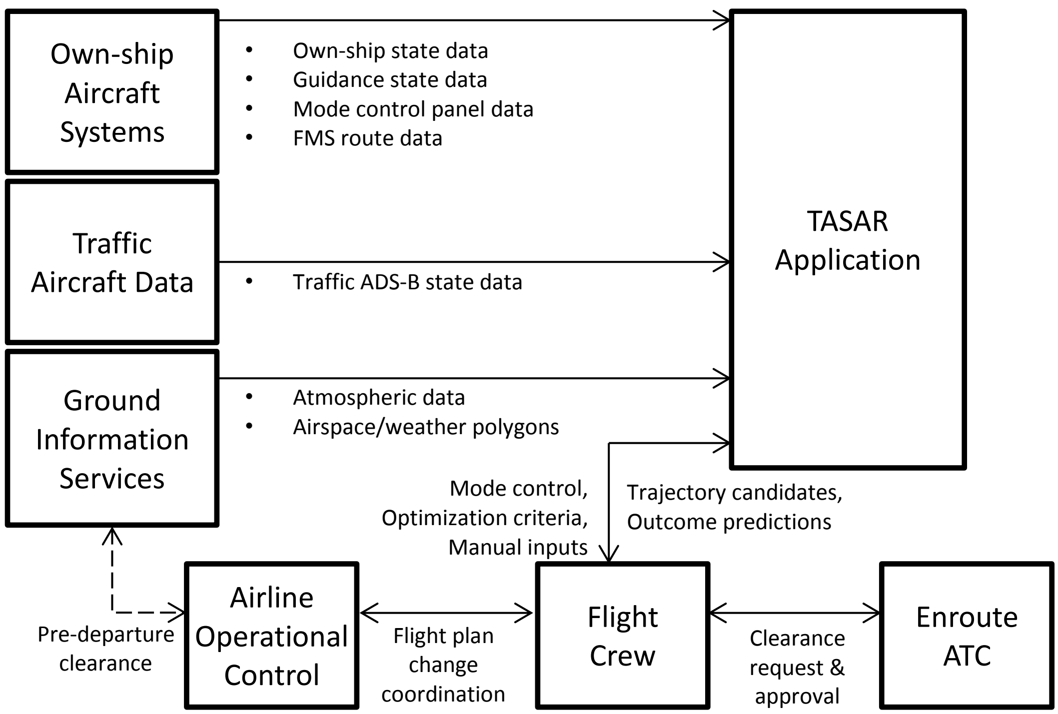

Figure 2 TASAR Functional Diagram

The type of EFB implementation that can be approved is dependent on the Failure Effects Classification of the application. To determine this classification, the intended function is reviewed and analyzed to determine potential operational hazards, failure modes, and safety implications. As will be described in the safety analysis of TASAR in detail in Section IV, TASAR is expected to easily meet a Failure Effects Classification of no greater than "Minor" and will most likely be "No Effect". Taking this classification into account, the three Classes of EFBs were assessed for their appropriateness to host the TASAR application.

Class 1 EFBs represent portable installations that do not interface to avionics, i.e., are not connected to aircraft systems for data or dedicated aircraft power. Class 1 EFBs represent the low-end of EFB capabilities in terms of cost and certification due to their isolation from avionics systems and being limited to hosting non-approved software limited to "Minor" Failure Effects Classification or lower. Class 1 EFBs are not appropriate for use for TASAR due to TASAR's requirement for access to avionics for flight data.

Class 3 EFBs are fully integrated, i.e., installed as part of the flight deck, and are part of the aircraft's Type Certificate (TC), allowing two-way communications of avionics data, e.g., flight plan information to and from the FMS. Class 3 EFBs are capable of integrating approved (i.e., certified) software applications. They are thus of considerably higher cost due to significant certification and operational approval costs associated with their intended use. While it is possible to integrate the TASAR application as a hosted application in a Class 3 EFB (using appropriate partitioning from approved applications already installed in the EFB), this does not represent the lower-cost approach envisioned for TASAR.

Similar to Class 1 EFBs, Class 2 EFBs also consist of portable commercial-of-the-shelf based computers and are considered to be PEDs. Class 2 EFB hardware does not require FAA design, production, or installation approval for the device and its internal components, and they are not considered to be part of aircraft type design, i.e., not in the aircraft TC or Supplemental Type Certificate (STC). Class 2 EFBs are typically mounted and must be capable of being easily removed from or attached to their mounts by flight crew personnel. Class 2 EFBs can be temporarily connected to an existing aircraft power supply for battery recharging. They may connect to aircraft power, data ports (wired or wireless), or installed antennas, provided those connections are installed in accordance with AC 20-173.[7] Based on the anticipated Failure Effects Classification of "Minor" or "No Effect" and the need for the TASAR application to have read-only access to avionics systems, a Class 2 EFB was considered the most appropriate EFB platform for TASAR. It should be noted in order to interface a commercial-of-the-shelf PED as a Class 2 EFB will require an appropriate Aircraft Interface Device (AID) to serve as an intermediary interface between the PED/EFB and the avionics systems, including aircraft power and antenna interfaces to commercially available communication data links.

The following high-level steps are required for installation and operational approval applicable to the TASAR Class 2 EFB:

1. Applicant must obtain approval via TC or STC for initial alterations related to (1) the mounting fixture installation, and (2) the installation of power and / or data connectivity.
2. Manufacturer, provider, or installer must assure via testing that the Class 2 EFB provides interference-free operation. If a data transmitter is used to transmit data to the Class 2 EFB, it must be tested to RTCA DO-160G, section 21, paragraph M.[8] This ensures that conduction or radiation of emissions do not result in interference.
3. Applicant must obtain TC, STC, or DER approval for installation of antennas that provide data to the EFB, e.g., weather data, airspace status information.

B. EFB Software Considerations

The FAA has designated EFB software into several categories: Types A, B, and C. Type A applications are those paper replacement applications primarily intended for use during flight planning, on the ground, or during noncritical phases of flight. Type B applications are intended for use during critical phases of flight or have software algorithms that must be tested for accuracy and reliability by applicant. Sample Type B applications are (1) display of aeronautical charts viewable electronically and allowing chart manipulation, (2) electronic checklists available in all phases of flight, (3) weight and balance calculations/algorithms, and (4) performance calculations. These must be tested and proven by the applicant. Type C software applications are found in avionics and include intended functions for communications, navigation, and surveillance that require FAA design, production, and installation approval. Neither Type A software nor Type B software requires compliance with RTCA/DO-178B[9], an important cost-saving factor. Type C applications do require such compliance and are typically not permitted on PED/EFBs as they are for airborne functions with a Failure Effects Classification considered to be a "Major" hazard or higher. Of the three software application types, the TASAR application is most closely associated with Type B.

While TASAR is currently neither a Type A nor Type B application (i.e., not on the FAA's approved list of applications[6]), it is closely aligned with Type B applications. For instance, TASAR: (1) is intended for use during flight planning (in case of TASAR, primarily during the en-route phase of flight), (2) includes variables in the information presented based on data-oriented software algorithms (in case of TASAR, using a variety of information sources for subsequent processing to determine trajectory-change candidates), and (3) will likely have a Failure Effects Classification of no more severe than "Minor".

While TASAR is similar to a Type B application, it is anticipated that it actually has a lesser threshold needed for approval compared to traditional Type B applications. With TASAR being an optional, supplemental, advisory support tool that the pilot or flight crew can use at their discretion (i.e., they can choose to ignore or disable at any time for any reason), it in essence represents a Type B "lite" application. Appropriate pilot training will further ensure that the pilot will not be distracted by TASAR during flight operations.

C. No Traffic Display

The TASAR concept is unique among existing and currently envisioned ADS-B IN applications in that it makes no use of a traffic display. In fact, because TASAR does not require flight crew awareness of traffic, the NASA TAP application was designed to specifically avoid displaying traffic data (including own-ship position) to the pilot. This approach reduces the certification and operational approval requirements that may be associated with such depictions and therefore reduces the cost of implementation. Sample displays of the TAP application's "Auto" mode, shown in Figure 1, show how most information is displayed in textual format. As shown in the figure, consideration is being given toward a simple graphical display of TAP trajectory recommendations in order to provide the pilot with greater situational awareness of these recommendations. An initial safety assessment suggests that such a display depiction would not adversely affect the safety case for TASAR and would actually serve to mitigate a TASAR processing failure by increasing the pilot's situational awareness and ability to detect such a failure. As noted, TAP does not depict own-ship position on the TASAR display, whether textually or graphically, which avoids a potential issue with regard to Failure Effects Classification of a Type C software application that displays own-ship on an airport map display.[6]

IV. Operational Safety Assessment

For TASAR to be a viable, near-term option for users, the concept must not only achieve a positive benefit-to-cost business case, but its design should have a relatively low threshold for achieving certification and operational approval from the FAA. The certification and operational approval of any new airborne equipment or capability will be subject to an FAA review of the operational hazards and safety of the application. To qualify as a Class 2 EFB application with Type B software, the airborne function must be determined to have a Failure Effects Classification of no greater than "Minor" effect due to potential hazards. Elements relevant to an operational safety analysis of TASAR were examined[10] using abbreviated application of established safety assessment methodologies.[11-14]

A. Intended Function

Key to the safety analysis is an understanding of the application's *intended function*. TASAR's intended function is to provide an advisory-only service to the pilot by identifying trajectory improvement opportunities over the current flight plan that have increased likelihood of ATC approval. Based on inputs provided by the pilot (in the form of flight optimization criteria and constraints), on-board avionics systems, and external data sources via ADS-B IN and airborne internet connectivity, the TASAR application computes available change request candidates that may improve flight time, fuel burn, or some other specified attribute. Change request candidates provided by TASAR are expected to have relatively high probability of ATC approval, as it anticipates ATC constraints such as traffic conflicts and airspace boundaries in the generation of optimization candidate solutions.

B. Framing the Safety Case

A review of TASAR's inherent design characteristics can help to put the safety case in context. The TASAR system is *only* a supplemental, recommendation-generating system. It is not relied on for any critical functions supporting flight operations, and it should not be included on the aircraft's Minimum Equipment List. Its use is entirely optional, and it can be disabled or ignored without any adverse effects and for any reason, whether for a failure of the TASAR software or the EFB hardware, spurious or inconsistent trajectory-change recommendations, or if the aircrew finds it distracting. The TASAR concept makes no changes to pilot or controller responsibilities nor to their interchange on trajectory change requests, and so loss or failure of TASAR advisories have no effect on either the pilot or controller in performing their normal functions. These factors provide significant mitigations that greatly reduce the risks associated with failures of the TASAR system.

C. Operational Hazards and External Mitigation

An analysis identified potential sources for errors and misleading information stemming from information exchanges and TASAR automation processing actions. For example, own-ship or traffic information that are incorrect or incomplete could lead to TASAR change request candidates that have a conflict, but are presented as conflict free. In another example, incorrect information on winds or weather hazards could lead to TASAR change request candidates that lead into hazardous weather. A complete list of identified hazards is included in Reference 10. Any incorrect information provided to TASAR or errors/failures in TASAR automation processing could potentially result in misleading change request candidates being recommended to the pilot for consideration. Such misleading information may detract from the usability of TASAR to achieve operational benefits (i.e., time or fuel saved) and could result in additional workload from pilot troubleshooting. However, since the flight crew has no authority to deviate from their current ATC clearance, regardless of the information provided by TASAR, any occurrence of misleading information from TASAR will be non-hazardous in nature and is completely mitigated by the existing ATC clearance procedure.

Furthermore, the pilot has responsibility to evaluate TASAR-provided trajectory change request candidates before making a change request to ATC, providing cross-check opportunities to detect spurious or false trajectory change request candidates being offered by TASAR. In addition, certified aircraft systems (e.g., FMS, weather radar) serve as higher integrity information sources to check on acceptability and performance impacts of TASAR-recommended change requests. In the event of an undetected failure of the TASAR automation, inefficient routing is the only adverse outcome. Existing mitigation of any safety hazards is provided by ATC, as already is done for change requests today without TASAR, and by normal pilot procedures for safe operation of the aircraft (e.g., avoiding hazardous weather).

D. Internal Mitigations

The TASAR application itself can include additional inherent design factors that would further reduce the possibility of unintended adverse effects and are expected to enhance the usability of the application. For instance, the use of standard navigation databases and limits placed on the number of included waypoints would prevent lengthy, complex change requests that may lead to miscommunication or errors. Recommendations displayed using standard flight planning textual depictions would further facilitate expedited voice communications. TASAR applications may also include capabilities to assess sector complexity and own-ship's proximity to the sector boundary in order to only recommend change requests that have a high likelihood of being approved by ATC.

An important characteristic of TASAR is that there is no "recovery" time required for the flight crew associated with its discontinued use. In other words, in using TASAR, the pilot remains on an ATC-cleared trajectory at all times. In the event of a TASAR system fault, the pilot need only remain on the current clearance while disregarding the TASAR display. A simple reset of TASAR, or by simply choosing to ignore TASAR inputs (e.g., by not looking at the TASAR display) allows the pilot to continue to focus on flight operations (whether during normal operations or in the event of abnormal or emergency situations).

E. Probable Failure Effects Classification

Table 1 is derived from FAA Advisory Circular 25.1309-1A "System Design and Analysis"[13] and provides a mapping of the "Effects" due to failures and the allowable "Probability of Occurrence" that lead to the determination of the *Failure Effects Classification* of the planned application (i.e., TASAR). Based on the significant mitigation factors already identified above that are inherent to TASAR, the analysis concluded that TASAR can be safely developed and implemented with a "No Effect" or at most a "Minor Effect" designation. If needed, the latter designation would reflect any workload issues for the pilot or ATC due to inconsistent or erroneous change request recommendation(s). However, workload issues are not anticipated to be an issue for the pilot's use of TASAR, as the pilot can simply ignore TASAR for any reason. Through proper training in the use of TASAR, the pilot should not be distracted or be adversely influenced in using TASAR while conducting flight operations. From an ATC perspective, controllers will continue to conduct the change request process as in today's operation and are not expected to experience a workload issue due to TASAR.

Final determination of the Failure Effects Classification for TASAR will require a dialog between the applicant and FAA Certification and Operational Approval authorities using the results of the safety analysis, which will result in a final designation by the FAA.

Table 1 Acceptable Risk versus Potential Effects as defined for Civil Aviation.13 TASAR focus area is boxed.

Probability (Quantitative) [Not to Exceed]	1	10^{-3}	10^{-5}	10^{-7}	10^{-9}
Probability Descriptive	N/A	Probable	Improbable		Extremely Improbable
Failure Condition Hazard Severity Classification	None	Minor	Major	Hazardous/ Severe Major	Catastrophic
Effects on Aircraft and Occupants	• No Safety Effect	• Does not significantly reduce airplane safety (slight increase in safety margins) • Crew actions well within capabilities (slight increase in crew workload) • Some inconvenience to occupants	• Reduce capability of airplane or crew to cope with adverse operating conditions • Significant reduction in safety margins • Significant increase in crew workload Severe Cases: • Large reduction in safety margins • Higher workload or physical distress on crew – can't be relied upon to perform tasks accurately • Adverse effects on occupants		• Conditions which prevent continued safe flight and landing
System Design Assurance Level (DAL)	E	D	C	B	A

V. Accessing Required Data

A technical challenge facing TASAR is the application's access to the data required to perform its intended function, advising aircrews of traffic compatible trajectory changes that improve operator objectives including fuel burn and flight time. An analysis was conducted for the NASA prototype application, TAP, regarding its access to the required data. At its core, the TAP application provides a route-replanning capability that optimizes the aircraft's future trajectory based on fuel and/or time. This route-replanning capability requires the TAP application to know a wide variety of information regarding the own-ship aircraft, including its current state (e.g., position, altitude, speed, weight), guidance modes (lateral, vertical, speed), guidance settings (e.g., FMS active route), and performance limits (e.g., maximum cruise altitude). To perform fuel burn and flight time optimization during route-replanning, the TAP application also needs to have a model of atmospheric conditions (winds, temperature, and pressure aloft). The TAP application integrates its route-replanning capability with a conflict probe to assess the compatibility of a proposed route change with traffic aircraft and airspace constraints (e.g., convective weather, Special Activity Airspace (SAA)). This conflict probe requires knowledge of traffic aircraft states, airspace geometries, SAA activation schedules, convective weather, and other airspace restrictions and hazards to determine if an auto-generated or pilot-input trajectory change request would be unacceptable to a controller.

As a cockpit-based system, the TAP application's primary sources for its required data are the avionics systems onboard the own-ship aircraft. Avionics data are shared among the aircraft's various avionics systems via a data bus that follows the ARINC 429 specification. Class 2 EFB applications can indirectly access this data bus via a certified aircraft interface device (AID). An AID reads ARINC 429 data from the data bus and provides this data to EFB applications following the Simple Text Avionics Protocol (STAP) defined in ARINC Specification 834.

A secondary source of data for the TAP application is via the aircraft's broadband internet capability. The TAP application only uses secondary sources, such as broadband internet, if the required data are not available from the primary avionics systems sources. As can be imagined, access to the internet from the cockpit allows access to a wide range of additional data sources.

In preparation for TASAR in-flight assessments, the TAP application has been integrated with the systems onboard a Piaggio Avanti I aircraft equipped with ADS-B IN and broadband internet connectivity. The Piaggio is a general aviation aircraft, and as such, outputs from its avionics systems follow the General Aviation Manufacturers Association (GAMA) General Aviation ARINC 429 subset. The challenges experienced in gaining access to TAP-required data onboard the Piaggio illustrate several challenges expected when integrating the TAP application with a wider range of aircraft types in the future. The Boeing 737NG series and Airbus 320 are the primary aircraft types serving the United States (US) domestic airlines, and therefore considerations for adapting TAP to these aircraft were taken into account in this analysis. The following subsection presents a discussion of the own-ship avionics as the primary data source. The subsequent subsection discusses broadband internet as a secondary data source.

A. Own-ship Avionics as the Primary Data Source

For an application on the EFB to receive data via an AID, the ARINC 429 outputs of various avionics systems need to be assigned to the input ports of the AID. For the Piaggio, the following avionics outputs were made available and are used by the TAP application:

- Flight Management System (FMS)
- Inertial Reference Unit (IRU)
- Global Positioning System (GPS)
- Air Data Computer (ADC)
- ADS-B Receiver
- Electronic Flight Instrument System (EFIS)

Own-ship State Data

Own-ship state data are provided to TAP by the FMS, ADC, and IRU systems; Universal Time Coordinated (UTC) data are provided by the GPS; guidance mode information is provided by the EFIS; FMS active route data are provided by the FMS; and traffic state data are provided by the ADS-B receiver.

Not all of the required own-ship state data are available from the AID. For example, the aircraft's current gross weight is required but unavailable in the GAMA ARINC 429 subset. Gross weight is used by TAP to accurately predict the aircraft's future trajectory, especially in climb and descent phases of flight. Though the TAP application can still advise aircrews of traffic compatible route changes by using default or aircrew-specified weight values, this situation does highlight a challenge for the TAP application. Manual crew inputs to the TAP user interface can be used to enter information, but this may detract from TASAR's usability. To minimize crew workload, the TASAR concept has a design goal to receive as much information as possible through direct interfaces with the aircraft systems. Because avionics systems are not required to provide all of the data included in the ARINC 429 specification, some level of customization of the TAP application for a specific aircraft platform is to be expected. Systems may also provide data in a format outside of the ARINC 429 specification. For example, the GAMA ARINC 429 subset conflicts with ARINC 429 in that the 075 label used for Gross Weight from the FMS in ARINC 429 is used for active route data from the FMS in the GAMA subset. The current TAP application is being architected to make customization as straight forward as possible for new aircraft platforms.

Own-ship Active Route Data

The receipt of active route data from the FMS also provides a significant general challenge for the TAP application. For late model B737 and A320 aircraft, FMS intent information is provided to the aircraft's data bus using the ARINC Characteristic 702A-1 standard. TAP requires own-ship active route information, including lateral, altitude and speed constraints, to generate effective route changes and to accurately predict the flight time and fuel burn for these changes in support of its route replanning capability. Unfortunately, the current specifications for active routes under ARINC 429 are focused either on providing 4-dimensional (4D) predictions of the aircraft path based on the active route (702A-1) or on providing primarily lateral route information for cockpit displays (GAMA General Aviation Subset). Hence, required route constraint data may be unavailable from these systems. For example, neither 702A-1 nor GAMA provides the current cruise altitude for the active route. These limitations have the potential to impact TASAR concept feasibility, so they were investigated as part of the application design. An analysis of the TAP trajectory generation (TG) function and currently available data from aircraft systems found that there is enough information for TAP to predict own-ship trajectories without additional pilot inputs. To do this, a few default values based on rational assumptions are used. Providing correct data will result in more accurate trajectory predictions. For instance, if the aircraft is near top-of-descent, the pilot may need to enter additional information such as altitude constraints in descent to increase trajectory prediction accuracy. Additional approaches to calculating approximations to unavailable active route data are also under investigation. For example, a good approximation for most level-flight cruise situations is to assume that the current own-ship altitude is the cruise altitude. In another example, whereas trajectory change point identifier information is not provided by the 702A-1 standard, latitude and longitude information can be used to identify waypoint names from a database.

Further investigations may find that improved trajectory predictions are not necessary. Because TAP advisories are based on trajectory changes rather than absolute values, a portion of the trajectory prediction errors, and hence the optimization parameter (e.g., time, fuel) estimate errors, are removed. The TG function used in the initial TAP application is of the same level of sophistication as an FMS TG function. Further research may find that a lower level of sophistication is fully acceptable for the TASAR concept. For the above reasons, the risk in concept feasibility due to limitations in obtaining own-ship data from current aircraft systems is believed to be manageable. Over time, new standards may allow a more complete set of internal FMS data to be available to the aircraft data bus. This will further improve the accuracy of TAP optimization values.

Atmospheric Data

Wind, pressure, and temperature at the aircraft's current position and altitude are available to the aircraft's avionics systems, but they are inadequate for TAP route-replanning. The TAP application needs atmospheric data for a broad geographic scope covering all alternative routes that the TAP application will consider. TAP has the capability to utilize 4D gridded wind and temperature fields if such data can be provided. Currently, the only avionics system that has atmospheric data beyond the aircraft's current position is the FMS, but even if these data were readily available through the aircraft data bus (it is not for the Piaggio), the atmospheric modeling data within the FMS is limited. For example, for the Boeing 737 FMS, climb and descent winds are entered for only three altitudes and are not related to a specific lateral location.[15] For the cruise portion of the flight, a single wind value can be entered for each lateral waypoint in the active route, or alternatively, a single average wind value for the entire cruise phase can be entered. Temperature data are similarly limited. Since atmospheric modeling has a significant impact on the performance of the route-replanning capability, alternative atmospheric data available from secondary data sources that cover a broader geographic scope (see next subsection) is likely to be preferable.

Traffic and Airspace Hazard Data

Hazard information is a key element of the TASAR concept, and current avionics can support the identification of traffic and airspace hazards. For traffic aircraft, the data received from the ADS-B receiver via the AID follow the ARINC Characteristic 735B and are sufficient to define the current state of 128 traffic aircraft within ADS-B range. Traffic data for display systems is available to TAP in the Display Traffic Information Files (DTIF) format. Though TAP can handle and would benefit from additional ADS-B reports regarding the intent of the traffic aircraft (ADS-B target state or trajectory change reports, as defined in the Minimum Aviation System Performance Standards), there is currently no ARINC specification for these additional ADS-B reports. For special use and other restricted airspace, the airspace boundaries are available to TAP via its internal database, which conforms to the ARINC 424 Specification. What is not available to TAP from the database or other avionics systems is the schedule for when the airspace is available. This information could be entered manually by the user, but alternative sources (see next subsection) are preferred. For convective weather hazards, one desired source for these data is the onboard weather radar. Unfortunately, these data are not readily available to the Piaggio's AID. Even if onboard weather radar data is available on other aircraft platforms, it is expected that more strategic convective weather data sources (see next subsection) would still be desired in addition to the onboard weather radar to enable assessing route change compatibility with potential convective weather hazards at larger distances than can be supported solely by onboard weather radar data.

B. Broadband Internet as a Secondary Data Source

TASAR automation can leverage onboard broadband internet to provide supplemental traffic state and intent data, atmospheric conditions, airspace restrictions, and any other data source available over the internet. Internet data sources could have higher resolution, broader geographic scope, and longer forecast horizons than other potential data sources such as Flight Information Service-Broadcast (FIS-B), ADS-B, Traffic Information Service-Broadcast (TIS-B), satellite weather service, or onboard weather radar. Broadband internet is currently available to aircraft through a cell-tower based service and a satellite-based service that are available throughout the continental US where the initial deployment of TASAR is targeted. Maximum bandwidth can vary depending on the characteristics of the broadband system and the size and power characteristics of the on-board antenna. On the Piaggio aircraft, a low-gain satellite broadband antenna (11 in., 1.5 lbs.) was installed to accommodate size and placement restrictions. The maximum bandwidth of this low-gain antenna is 200 kbps, which is approximately 1/15th of the current typical maximum bandwidth of cell-tower based internet on commercial aircraft (3 Mbps). Broadband may be provided to the TAP EFB platform via an Ethernet or wired connection using standard internet protocols.

Traffic Data

ADS-B IN is envisioned to be the primary source of traffic state data for computing traffic-compatible trajectory changes. However, not all aircraft will (1) be equipped with ADS-B OUT prior to the 2020 ADS-B mandate, (2) broadcast ADS-B on a channel (1090 MHz Extended Squitter or 978 MHz Universal Access Transceiver) that can be received by the own-ship ADS-B IN system, or (3) be within ADS-B reception range of the own-ship. This would cause TASAR to have incomplete surveillance when exclusively leveraging ADS-B. Although complete surveillance is not required for users to benefit from TASAR[4], the closer the TASAR automation and ATC's view of the traffic situation are to each other, the more requests will likely be traffic compatible and approved. TIS-B broadcasts surveillance data to equipped aircraft and can be used to provide more complete traffic surveillance of target aircraft that are not equipped with ADS-B OUT. However, TIS-B provides limited traffic information and is best suited as a complementary data source. For example, TIS-B is filtered so that aircraft not equipped with ADS-B OUT beyond 15 nmi of the own-ship or above or below the own-ship by more than 3,000 ft will not be broadcasted through TIS-B. Another limitation is that TIS-B has a service ceiling so that the own-ship will not receive any traffic information at some point at or above 24,000 ft.

Traffic data available over the internet can be used to overcome incomplete ADS-B OUT equipage, ADS-B and TIS-B reception range, and lack of intent (planned trajectories) in the ADS-B reports. The Aircraft Situation Display to Industry (ASDI) is one source of surveillance data that the FAA provides to subscribers to increase situational awareness. ASDI combines radar, ADS-B, and flight plan information from across the NAS into a single source of surveillance data. ASDI provides position and planned route data to subscribers, which are generally flight operators with dispatching responsibilities. The following four limitations would need to be addressed before TASAR uses ASDI data, possibly by the flight operator providing a ground system that filters and processes ASDI data before being sent via broadband to TASAR. (1) A security audit of each TASAR instance would need to be performed if receiving data directly from the FAA as well as providing a static internet protocol (IP) address for each TASAR instance. The security audit and static IP would not be required if a flight operator rebroadcast their existing ASDI feed to the aircraft. (2) ASDI could consume a significant portion of bandwidth for low-gain antenna systems such as that used by the Piaggio. This issue could be mitigated if a flight operator leveraged a ground system to filter ASDI data by geographic scope, remove data fields that TASAR does not require, and compress the ASDI data before being sent to TASAR. (3) Flight plans and amendments are only broadcast once (unless modified) so the receiving system must be continuously online to receive all ASDI messages. Otherwise, only a subset of flight plan and amendment messages will be available to TASAR. A ground system that maintains a list of flight plans and amendments for airborne flights could be used to overcome this limitation. (4) ASDI provides information at a slower update rate (one update per minute) as compared to TIS-B (at least five updates received per minute) and ADS-B (at least ten updates per minute). Additionally, ASDI data could be delayed up to five minutes. This data latency and slower updates may need compensation by TASAR algorithms.

Weather Data

Broadband internet could be used as a source of convective weather for TASAR if FIS-B, satellite weather, and/or onboard weather radar data are not available to the TASAR automation. FIS-B may not be available above a 24,000 ft service ceiling or may not provide the right data source that has a suitable resolution for route-replanning while also being suitably broad in geographic scope. Satellite weather provides convective weather in a proprietary format that would need to be made available to TASAR application developers. Onboard weather radar data are sent directly to a display in the Piaggio and are not available to TASAR as discussed in the previous subsection. If these data sources are unavailable or unsuitable, then broadband internet could be used to access a source of convective weather over the internet (e.g., National Convective Weather Forecast) that is suitably broad in geographic scope to cover the range of alternative trajectories considered by TAP. Initial feedback from subject matter experts suggest that TAP may need to incorporate user control of the severity threshold for convective weather that TAP should avoid when developing alternative trajectories.

Atmospheric Data

Winds and temperature aloft for a range of altitudes and a broad geographic scope covering all alternative waypoints considered by TAP are needed to evaluate trajectories against operator objectives including fuel burn and flight time. FIS-B and satellite weather provide this information, but with limitations similar to that described above for convective weather. Rapid Refresh (RAP)[16-18] is one source of winds and temperature data in gridded binary (GRIB) format that covers the continental US at a range of altitudes. A course RAP grid resolution (e.g., 40 km) can be selected to minimize bandwidth with finer resolutions (e.g., 13 km) available if bandwidth permits.

Airspace Data

SAA activation schedules, Notice to Airmen (NOTAM), temporary flight restrictions (TFRs), pilot reports (PIREPS), and other similar data sources can be used by TASAR automation to identify regions of airspace unavailable for trajectory planning. These data are all available over broadband from FAA websites and other sources. FIS-B and satellite weather, if available, could also be a source of this information.

VI. Conclusion

NASA's research and development activities to date on the TASAR concept have focused on proof-of-concept and risk reduction for potential users. A design goal for the TASAR concept and its enabling flight deck technology has been to provide direct user benefits at low cost, for near-term implementation, and with low operational approval risk. NASA has assessed potential benefits, investigated implementation with currently operating aircraft and currently-available data sources, and determined the likelihood of technical certification and operational approval.

TASAR has been found to provide user benefits only with an EFB equipment investment. Users opting to leverage ADS-B IN equipment and additional data sources (e.g., satellite weather, broadband internet) can expect an increase in user benefits. TASAR also leverages the aircrew workforce, whose workload en route is typically low, and thus requires no additional ground personnel or extra workload on the dispatcher.

NASA has developed a prototype software application for TASAR called the "Traffic Aware Planner" (TAP) with the intent of making it available to users and technology providers. An analysis of TAP compatibility with operational flight deck systems has determined that the minimum required data for the TAP algorithms are accessible from standard ARINC 429 data for late-model transport and business aircraft. Additional data that will provide increased user benefits may become available through broadband internet sources in the near future.

An analysis of FAA regulatory material confirmed that a Class 2 PED/EFB provides a well-suited, low-cost platform for TASAR, and that the software falls below the criticality level of most Type B applications. An analysis of hazards and safety requirements determined that TASAR would likely receive a Failure Effects Classification of "no effect" or at most "minor effect." A draft Project Specific Certification Plan was developed and reviewed by Designated Engineering Representatives with no concerns raised.

Finally, during the summer of 2013, TAP is being tested by airline pilots in high-fidelity simulation and in a flight test aircraft operating in ATC-controlled airspace using real-world data flows. The concept, development, analyses, and test results are being documented and will be made available as artifacts to support initial applicants in the FAA approval process.

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