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Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations

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Preface

This document is a description of the TASAR Concept of Operations. The document was prepared by Engility Corporation, 300 Concord Road, Billerica, MA under Contract No. NNL12AA06C with NASA Langley Research Center, Hampton, VA. The NASA Technical Monitor is David J. Wing.

Abstract

Aircrews submit trajectory change requests to air traffic control (ATC) to better achieve the operator's preferred business trajectory. Requests are currently made with limited information and are often denied because the change is not compatible with traffic. Also, request opportunities can be overlooked due to lack of automation that advises aircrews of trajectory changes that improve flight time, fuel burn, and other objectives. The Traffic Aware Strategic Aircrew Requests (TASAR) concept leverages Automatic Dependent Surveillance-Broadcast (ADS-B) surveillance information to advise the aircrew of beneficial trajectory changes that are probed for traffic compatibility prior to issuing the request to ATC. This document describes the features, benefits, and limitations of TASAR automation hosted on an Electronic Flight Bag. TASAR has two modes: (1) auto mode that continuously assesses opportunities for improving the performance of the flight and (2) manual mode that probes trajectory changes entered by aircrews for conflicts and performance objectives. The roles and procedures of the aircrew and ATC remain unchanged under TASAR.

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1. Introduction

The NASA Traffic Aware Strategic Aircrew Requests (TASAR) Concept of Operations (ConOps) offers onboard automation for the purpose of advising the pilot of traffic compatible trajectory changes that would be beneficial to the flight.[1] The TASAR onboard automation is expected to be hosted on a Class II Electronic Flight Bag (EFB) and leverages Automatic Dependent Surveillance Broadcast (ADS-B) surveillance information to increase the likelihood of Air Traffic Control (ATC) approval of pilot-initiated trajectory change requests, thereby increasing the portion of the flight flown on or near a desired business trajectory. All automation and pilot procedures are fully dedicated to a single aircraft, which allows tailoring of optimization criteria to the specific objectives of each flight and provides for timely responses to changing situations.

There is no change in separation responsibility under the TASAR concept. ATC has responsibility to separate Instrument Flight Rules (IFR) aircraft and maintains authority over the trajectories of all IFR aircraft in controlled airspace. IFR pilots are not permitted to make changes to their approved trajectory without first receiving approval from ATC.

1.1. Scope

This ConOps focuses on a range of capabilities for a near-term TASAR deployment within the current (2013) operating environment. The initial TASAR prototype deployment will, at a minimum, advise pilots of beneficial trajectory changes and leverage ADS-B surveillance information to increase the likelihood of ATC approval. Other capabilities described in this document, such as the potential future TASAR evolution paths in Section 5, may not be a part of the initial TASAR prototype deployment. This document also suggests how TASAR could evolve beyond a near-term deployment, but the near-term application remains the focus of this document.

1.2. Background

Referred to as *user requests*, trajectory change requests from aircrews may not be achieving their full potential to provide user benefits. Strategic traffic information is currently unavailable to most flight crews, so a trajectory change request has a reasonable chance of not being approvable by the controller because of resulting conflicts. The flight crew has access to tactical traffic information through the Traffic Alert and Collision Avoidance System (TCAS), but the time horizon of less than a minute to a few minutes is insufficient to check for conflicts. Also, probing for future conflicts to plan trajectory changes does not match the intended purpose of TCAS. Disapproved user requests are an operational detriment since they unproductively increase pilot and controller workload, contribute to radio frequency congestion, discourage further attempts by the pilot to optimize his flight, and do not produce a more desirable trajectory. In addition, conflict-free opportunities for improving the trajectory can remain undiscovered by pilots due to the lack of onboard traffic information and automation to compute more optimal trajectory changes that could be approved.

1.3. Problem Statement

Aircraft operating under IFR must fly trajectories approved by ATC. The approved trajectory often does not coincide with the aircraft operator's preferred business trajectory. Less-desired trajectories can be the result of previously assigned non-optimal routes, altitude and/or speed restrictions issued by ATC, and changing conditions or priorities during the flight. Some causes of in-flight priority changes are unanticipated weather (e.g., convective weather, turbulence, and icing), destination change, the need to make up time as a result of an earlier delay or reroute to avoid traffic or weather, the need to delay the arrival due to traffic congestion at the destination, and the need to increase altitude as fuel is burned to improve efficiency. As a result, pilots have a need or desire to change their trajectory while in flight. Requests for such changes today are often denied because of projected traffic conflicts that might result from their use.

1.4. Document Overview

This document is divided into the following sections:

- Section 1 introduces the TASAR concept
- Section 2 describes the roles and responsibilities of the controller, aircrew, and other actors within current operations
- Section 3 describes shortfalls of current user requests that the TASAR concept addresses as well as a short description of procedural changes under TASAR
- Section 4 provides a detailed description of the TASAR concept focusing on aircrew interaction with the onboard automation and the desired functions and behaviors of the onboard automation
- Section 5 describes potential TASAR future evolution paths
- Section 6 provides operational scenarios that show the interactions among the onboard automation, aircrew, controllers, and other actors

2. Current Operations

This section describes the current roles and responsibilities of the aircrew and controller when aircrews send requests to controllers. The lists in Sections 2.1 and 2.2 are not comprehensive and are presented for the purpose of describing in Section 4 how TASAR aids the aircrew and controller in performing their roles and responsibilities. No change in aircrew or controller roles and responsibilities are suggested under the TASAR ConOps.

2.1. Aircrew Roles and Responsibilities when Requesting a Trajectory Change

Today, when requesting a trajectory change, the aircrew has the following roles and responsibilities.

- Role of aircrew is to make trajectory change requests that meet their safety and efficiency objectives.
- Aircrew has responsibility for safety of flight and will not request a trajectory change that compromises safety. For example, the aircrew considers fuel reserves, convective weather, turbulence, and icing.
- Aircrew has responsibility to verify that the aircraft performance is sufficient to execute the change as requested. For example, the aircrew considers aircraft performance ceiling when making an altitude request.
- Aircrew has responsibility to verify that the aircraft equipment is sufficient to execute the requested operation, e.g., Reduced Vertical Separation Minima (RVSM).
- Aircrew has responsibility to generate requests that conform to operator policies and procedures.
- Aircrew has responsibility to coordinate with dispatcher and company operations as necessary.
- Aircrew has responsibility to limit requests so that the ATC voice communications frequency remains available for safety critical clearances.
- Aircrew has responsibility to execute approved requests.
- Aircrew has responsibility to execute or state inability to execute ATC amended requests.

2.2. Controller Roles and Responsibilities when Responding to an Aircrew Request

Today, when responding to an aircrew request, a controller has the following roles and responsibilities.

- Controller will consider and approve aircrew requests when practicable.
- Controller has responsibility to separate aircraft and will not approve a trajectory change request that violates minimum separation requirements.
- Controller has responsibility to reject aircrew requests that violate their standard operating procedures or do not conform to traffic management initiatives that are in place. However, certain restrictions and initiatives can be lifted after appropriate inter-sector coordination.
- Controller has responsibility to issue clearances and respond to aircrew requests in such a way that the voice communications frequency remains clear for safety critical clearances.
- Controller has responsibility to issue an approval, amendment, deferral, or denial in response to a request.

3. Justification and Description of Changes

There are no changes to the roles and responsibilities of the aircrew or controller under the TASAR concept. The pilot uses current procedures to request the trajectory change, including determining the appropriate time to make the request. The pilot is not obligated to make any request including requests provided by TASAR automation. All information from TASAR automation is advisory only. No reference to TASAR is required when a request to ATC is made since no special consideration is being requested.

3.1. Capabilities

The TASAR concept provides additional onboard automation to aircrews with the following two functions that support aircrew requests:

1. Calculating changes from the current trajectory to better meet user objectives such as fuel burn, flight time, and ride quality.
2. Using ADS-B surveillance information to make trajectory change requests more acceptable to the controller by excluding those requests with conflicts at a short look-ahead time horizon that would be detected using the ADS-B information.

These two functions address the capability shortfalls listed in Table 3-1.

Table 3-1 List of Capability Shortfalls

Capability Category	Existing Capability	Future TASAR Capability	Capability Gap
Aircrew preferred trajectory selection	Post-departure trajectory changes depend on either (1) coordination with the flight dispatcher to take account of changing conditions or (2) experience, rules-of-thumb, or limited automation (e.g. computation of economy cruise speed) to make decisions independent of the flight dispatcher.	Onboard automation can re-compute optimal trajectory in response to changing traffic and weather conditions as well as be responsive to the aircraft state and changing priorities of the operator and aircrew.	Lack of automation for trajectory optimization on the flight deck.
	Aircrew manually enters winds into Flight Management System (FMS) at waypoints along trajectory.	TASAR onboard automation integrates dynamic winds, convective weather, and temperature information when developing trajectory changes that improve objectives. This functionality does not include sending wind information to the FMS.	Dynamic weather (winds, convective weather, temperature, turbulence) information is not integrated into onboard automation that computes trajectories.
Aircrew estimation of trajectory change acceptability to the controller	Aircrews use situational awareness obtained from voice frequencies as well as experience to estimate acceptability of a trajectory change to the controller.	Onboard trajectory planning automation considers ADS-B surveillance information in recommended trajectory changes.	Lack of automation that considers surrounding traffic information on the flight deck in the selection of trajectory change requests.
	Aircrew estimates whether trajectory change will occur in current sector or a downstream sector based on experience and rules-of-thumb.	Onboard automation uses knowledge of sector boundaries to determine if a trajectory change begins in the current sector or a downstream sector.	Lack of automation that integrates sector boundary information into aircrew trajectory change request decision-making.

3.2. TASAR Automation Hosting

The onboard automation is proposed to be hosted on a Class 2 EFB to permit read-only access to data from the aircraft's systems, such as the FMS and flight control interfaces. A Class 2 EFB is physically mounted in the cockpit convenient to the pilot and therefore more likely to be used and provide benefit.

3.3. Intended Users

TASAR is intended to be used by any FMS-equipped civil flight operation in the continental United States that files IFR with a flight planned cruising altitude at or above 10,000 ft Mean Sea Level (MSL). Federal Aviation Regulations restrict aircrews to performing only those duties required for the safe operation of the aircraft below 10,000 ft MSL excluding cruise below 10,000 ft MSL. This rule minimizes distractions to the flight crew during critical phases of flight that include taxi, takeoff, and landing. To be consistent across phases of flight, TASAR will become active when the aircraft is at or above 10,000 ft MSL and will deactivate after descending below 10,000 ft MSL.

The 10,000 ft MSL floor could be set as a configurable parameter for users planning to cruise below 10,000 ft MSL.

4. TASAR Concept of Operations

This section describes the aircrew interaction with the TASAR onboard automation and air traffic controllers. Section 6 expands on this section by presenting operational scenarios that describe the interactions. This section is organized as follows.

4.1. Assumptions and Constraints

The Federal Aviation Administration (FAA) has mandated that aircraft be equipped with ADS-B OUT by 2020 to operate in airspace that currently requires a transponder. If a sufficient percentage of aircraft are not equipped prior to the 2020 mandate (or have not enabled their ADS-B OUT systems), then the TASAR automation will still be able to offer optimized trajectory changes but will not be as effective in removing the potential for future conflicts. It is assumed that enough aircraft will be equipped prior to 2020 to provide sufficient traffic information for conflict probing or that sufficient supplemental traffic information is available from Traffic Information Services Broadcast (TIS-B) or other data sources.

The TASAR concept may also be constrained by the broadcast power of the ADS-B OUT antenna for aircraft sending ADS-B messages and the sensitivity of the ADS-B IN antenna for aircraft receiving ADS-B messages. The air-to-air broadcast and reception range could be as short as 20 nautical miles (nmi) if aircraft equip to the basic requirements of the 2020 ADS-B mandate. However, airlines and high-end general aviation operations that operate at higher altitudes are expected to equip their aircraft with extended ADS-B equipage to achieve a minimum of 60 nmi air-to-air range.

4.2. Primary Inputs from Aircrew

This section describes primary inputs that the aircrew will have the option of modifying during flight. Section 4.3 contains additional parameters that will not typically be modified by the aircrew during flight. The aircrew will be provided with default settings for all of the inputs included in this section.

(a) Mode of Operation

TASAR automation operates in two modes: (1) automated monitoring for opportunities (Auto mode) and (2) pilot initiated use (Manual mode). In Auto mode, the TASAR automation performs a continuous assessment of opportunities for improving the performance of the flight. In Manual mode, the pilot enters a desired trajectory change into the automation interface which is then probed for conflicts and performance objectives. Conflict probing for both Auto and Manual modes is intended to be consistent with controller conflict probing described in Section 4.6. The TASAR automation indicates if there are conflicts known to the automation in Manual mode and computes a conflict-free modification to the desired trajectory change.

An Auto mode or Manual mode request may be denied by ATC, but ATC could offer a modification that is conflict-free and ask the aircrew if the modified trajectory meets the objectives of the aircrew. The TASAR automation and the conflict probe used by ATC may have differing knowledge of future four-dimensional (4D) trajectories of surrounding traffic that could cause the TASAR automation to consider the trajectory proposed by ATC to contain a conflict. In this case, a Manual mode without conflict probing may have utility by evaluating the trajectory against the objective function and aircrew constraints (e.g., time constraints, reserve fuel) but not probe for conflicts.

The TASAR automation is in Auto mode by default and switches to Manual mode when requested by the aircrew or the automation senses the aircrew has entered a desired trajectory change into the FMS.

(a) Aircrew Request Complexity

The frequency of ATC issuance of clearances, the requests by other aircrews that are accepted or denied, the type of clearances issued by ATC, and the tone and urgency of the controller's voice can all give an indication of the workload the controller is currently experiencing and the acceptable complexity of an aircrew request. More complex requests could be available in low controller workload situations but could be unavailable in higher workload situations such as routing aircraft around severe weather. The aircrew could dynamically increase or decrease the complexity of the request in order to tailor the request to the situation.

Complexity would be defined by the number of entities in the request, with the lowest complexity requests being a simple "direct to" request or an altitude change. More complex requests would include adding one or more "off route" waypoints, as well as combining altitude and lateral (waypoint) requests. When generating a trajectory change, the TASAR automation will consider the pilot-selected request complexity as well as all levels below the selected request complexity. A default complexity setting will be provided.

(b) Optimization Objective

For operations in Auto mode, the aircrew selects the optimization objective, typically fuel burn, flight time, or a weighted combination of fuel burn and flight time. Passenger comfort and avoiding turbulence are also optimization considerations of the aircrew. However, due to the general lack of turbulence predictability, Auto mode may not have the required information to search for trajectories that minimize turbulence. Instead, the aircrew could use Manual mode to evaluate a pilot-specified candidate route or altitude that may avoid turbulence based on ride reports. Convective weather regions made known to the TASAR automation could be avoided by an additional buffer specified in the configuration settings in Section 4.3 in an attempt to minimize the hazards of convective weather.

Users may also desire to use TASAR automation to minimize overflight fees during international operations. Whereas initial TASAR deployment may be limited to operations in the continental United States, future TASAR deployments could include international operations with cost functions that minimize overflight fees.

(c) Threshold for Aircrew Notification

When operating in Auto mode, the automation will use a pilot-specified threshold for each objective (e.g., pound of fuel saved) for notifying the aircrew of an available trajectory change that sufficiently improves the objective. For weighted cost functions, each entity would have a settable threshold, rather than using a threshold for the entire weighted cost function. The aircrew may not have an intuitive feel for changes in the weighted cost function but will want to be notified if there has been a minimum improvement in either fuel or time.

(d) Desired Trajectory

Using Manual mode, the aircrew enters a desired trajectory change. This change could consist of a revised lateral path, an altitude change, or combination lateral/altitude change. For lateral path changes, the aircrew enters off-route named waypoints if desired and a reconnect point on the existing route, or the aircrew could enter just a downstream waypoint for a "direct to" request.

Aircraft generally need to be on an arrival route at some point prior to the destination airport. This procedure is specific to each destination airport, and generally larger airports require aircraft to be on the arrival route farther upstream of the airport. By default, the Auto mode will reconnect at or prior to the first fix on the arrival procedure on the originally filed route. If desired, or if the TASAR automation is unaware of the procedure, a pilot could specify a different waypoint to reconnect based on the pilot's experience. This parameter is only applicable to Auto mode, since the pilot specifies the named waypoint where the reconnect occurs in Manual mode.

4.3. Additional Input Parameters

The parameters described in this section could be included if research or operational use indicate their utility. They may be additional aircrew inputs or could be specified in pre-flight configurations to help define the behavior of the TASAR automation. Configuration parameters would not normally be updated by the aircrew since they are more general than a single flight and are intended to generally represent the policies and procedures of the operator.

(a) Time Constraint

The aircrew may be subject to arrival time constraints at the destination airport, and the primary optimization objective may be to minimize deviation from or not exceed a scheduled arrival time. Examples include block time for the aircrew, airport curfew, gate availability, and passenger connections. The TASAR automation could apply a high penalty to the objective function if these time constraints are not achieved.

Generally, the TASAR automation would not consider a time constraint by default. If the aircrew enters a time constraint, only solutions where the aircraft is projected to arrive at or before the time constraint would be presented to the aircrew, assuming the TASAR automation is able to find solutions that satisfy the time constraint. If the TASAR automation cannot find solutions that satisfy the time constraint, then trajectory changes would be presented that minimize deviation from the scheduled time.

(b) Reserve Fuel Constraint

The aircrew must ensure that certain constraints such as fuel reserves are not violated, since the violation of these constraints could impact flight safety. TASAR procedures will specify that the aircrew determines the acceptability of a request with respect to fuel reserves before making the request. The aircrew also coordinates with the dispatcher as required by standard operating procedures. TASAR automation is not intended to supplant existing systems and procedures for reserve fuel calculations or to display fuel reserve information.

(c) Traffic Separation Buffer

Whereas TASAR automation would apply standard separation criteria in its conflict probe of possibly trajectory changes, a configurable buffer could expand the conflict probe's parameters for preventing conflicts. The buffer parameter would account for: (1) separation margin for increased controller acceptability, (2) different ownship trajectory predictions between airborne and ground systems, (3) surrounding aircraft trajectory uncertainties, (4) atmospheric and wind modeling differences between the air and ground, and (5) differences between ADS-B and ground-based surveillance. The buffer would be a configuration parameter not adjusted by the aircrew in flight.

(d) Hazard Separation Distance

The configuration could specify minimum desired separations to hazardous convective weather and special activity airspace (SAA). The aircrew could also define the threshold for convective weather based on, for example, NEXRAD reflectivity.

(e) Optimization Update Rate for Auto Mode

An optimization update rate parameter would specify how often the TASAR automation computes trajectory changes while in Auto mode. Reoptimizing accounts for: (1) trajectory changes of other aircraft, (2) changing winds, convective weather, temperature, and other atmospheric conditions, (3) SAA activation schedule changes if available, and (4) aircraft weight changes due to burned fuel.

4.4. Automated Information Gathering

The TASAR automation would gather traffic and hazard information using automated retrieval with no required aircrew action other than possibly powering up the system.

(a) Airborne Surveillance through Various Sources

TASAR automation will have knowledge of other aircraft through air-to-air ADS-B, ADS-B Rebroadcast (ADS-R), and TIS-B. Aircraft ADS-B equipment will use either the 1090 Megahertz (MHz) (1090 MHz Extended Squitter – 1090ES) or the 978 MHz (Universal Access Transceiver – UAT) radio frequency. The 1090ES will be used in all airspace, while UAT will be used below 18,000 ft MSL to correspond with the ADS-B rule requirements. Class A airspace above 18,000 ft MSL will contain 1090ES aircraft only, while all other classes of airspace will contain a mixture of 1090ES and UAT aircraft. Depending on the ADS-B receiving capability of TASAR aircraft, surveillance information from some aircraft may not be received if they are on the opposing frequency and other ADS-R or TIS-B broadcast requirements are not met. TASAR aircraft equipped with multi-mode receivers would directly receive ADS-B messages from all 1090ES and UAT aircraft within range.

All ADS-B OUT equipped aircraft will broadcast state vector and mode status information, while aircraft equipped with ADS-B IN may also broadcast an air referenced velocity information. The state vector report includes the current latitude, longitude, geometric altitude, pressure altitude, north and east components of the horizontal velocity, and the vertical rate of the ADS-B target aircraft. The mode status report provides target aircraft characteristics such as broadcast capabilities and the quality of the broadcasted state vector data. The air referenced velocity report provides the airspeed and heading while airborne. Trajectory change reports that provide near-term 4D aircraft intent may not be broadcasted, depending on current FAA regulations .

(b) Surveillance through Airborne Internet

Aircraft equipped with airborne internet access could use surveillance data available over an airborne internet connection to overcome limitations caused by incomplete ADS-B equipage, ADS-B equipment range, and lack of planned future 4D trajectories in 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 National Airspace System (NAS) into a single source of surveillance data. The ASDI messages most relevant to TASAR automation are the radar track update (TZ), flight plan (FZ), and flight plan amendment (AF) messages. The TZ message contains the flight identifier, latitude, longitude, altitude, and groundspeed. The FZ message contains the flight identifier, aircraft type, airspeed (true or Mach), proposed departure time, requested altitude, route of flight, and estimated time of arrival. Flight plan amendments contain altitude and route updates.

Use of ASDI information by airborne systems has a number of limitations, including latency and quantity of data. Radar track data is updated at one minute intervals and could be delayed by five minutes or more before being downloaded from the internet, due to security requirements and other latency issues. Also, ASDI data is not filtered, so the aircraft could be sent a large volume of information with many flights that have no impact on the current trajectory of the aircraft. This issue could be mitigated by developing a separate system on the ground that filters data before sending to the aircraft. Airborne internet may have bandwidth limits to consider when the aircraft is downloading data. Also, ASDI messages are sent out continuously and flight plan and amendment information is only sent out once unless there is a change. Automation will not have access to these flight plans and amendments unless the automation is powered on and receiving data over the internet when the flight plans and amendments are sent.

(c) Hazard Information

Convective weather information would be available to the TASAR automation through onboard weather radar, airborne internet (if equipped), satellite weather, and Flight Information System Broadcast (FIS-B) (UAT or multi-mode ADS-B IN equipped aircraft only). Onboard weather radar is capable of detecting significant convection and lightning strikes at 200 nmi or more from the aircraft to provide an indication of the current weather in the forward direction of the aircraft. Satellite weather and FIS-B provide both provide NEXRAD reflectivity, which provides an indication of current weather conditions, and convective Significant Meteorological Information (SIGMETs), which provide forecasted convection.

Special activity airspace status is available through FIS-B and over the internet to aircraft equipped with airborne internet access. The TASAR automation will rely on published databases for terrain hazards since these hazards are not dynamic. Turbulence will not likely be considered by the TASAR automation initially. However, as the availability and quality of turbulence data improves, Auto mode functionality could be augmented to avoid current and forecasted turbulence.

(d) Wind Velocity and Temperature

The TASAR automation would gather wind velocity and temperature information and real-time updates from satellite weather, airborne internet (if equipped), or FIS-B to be used for trajectory optimization purposes. Updated wind field information in particular is key to effective trajectory optimization.

(e) ATC Procedures and Sector Boundaries

The TASAR automation may include a database of sector structure and letters of agreement between ATC facilities. However since they are not dynamic, updates will not be required during flight.

(f) Traffic Flow Management Initiatives

The FAA provides on-line tools to share reroute initiatives and active metering locations with airspace users. The websites do not provide flight-specific information, but it may be possible to determine if a flight will be impacted by the initiative. Aircraft equipped with onboard internet could have access to this information.

The TASAR onboard automation may also dynamically compute sector congestion to determine where traffic flow management initiatives may exist. The monitor alert parameter indicates to traffic managers when a sector may be approaching capacity and an initiative may be required. The monitor alert parameter may be dynamically modified based on weather conditions and complexity of traffic flows in the sector. If these modifications are not available outside of FAA facilities, the nominal monitor alert parameter value could be used by the TASAR automation to estimate sector congestion. Sector traffic counts (which may be incomplete before the ADS-B 2020 mandate) in nearby sectors could be dynamically constructed from airborne surveillance through ADS-B and TIS-B.

4.5. Dispatch Integration

TASAR automation may be integrated with Airline Operations Center (AOC) dispatch automation to help the aircrew make better requests and to keep dispatchers informed of aircrew actions. This section describes potential information sharing between the TASAR automation and dispatch which could be done over airborne broadband internet or another protocol.

(a) Updated ATC Information

Dispatch could have updated ATC traffic flow management (TFM) information that could influence which aircrew requests would be granted by ATC. For example, dispatch could be aware of a reroute initiative that has recently ended, and providing that information to the TASAR automation could result in the aircrew making a request that improves their objectives.

(b) Dispatch Directs Aircrew to make Trajectory Change Request

Dispatch may leverage fleet optimization and surveillance information functions on the ground to identify aircraft that could improve their trajectories or otherwise improve fleet operations. Once these aircraft are identified, dispatch could send messages to the aircrew or directly to TASAR automation indicating either a change in optimization objective or a specific trajectory change request to make to the controller. For the former, the aircrew updates the optimization objective in Auto mode, and the TASAR automation proceeds to seek trajectory changes for this new objective. For the latter, the aircrew would use Manual mode to probe the request for conflicts and other factors that influence acceptability of the request to the controller. In effect, the dispatcher is leveraging the onboard TASAR automation to "time" the desired request to ATC such that approval is more likely, thereby increasing the effectiveness of the dispatcher's flight optimization capabilities.

(c) Aircrew Request Coordination with Dispatch

Dispatch may wish to be informed of potential aircrew requests to (1) verify that a gate at the destination airport will be available if the aircraft arrives early, (2) check the impact on the fleet such as sequencing of flights at the arrival fix, or (3) verify that the requests improve the objectives of the operator based on the most up-to-date information onboard the aircraft (e.g., actual aircraft weight). Coordination with dispatch could be via automated downlink of the requested trajectory so that aircrews and dispatchers do not experience additional workload.

4.6. Probing for Trajectory Changes

This section describes the desired functions and behavior of TASAR automation when generating a more efficient trajectory.

(a) Degrees of Freedom for the Trajectory Change

The TASAR automation will search through the degrees of freedom listed in Table 4-1. The left column lists the objectives and constraints to be met by the trajectory change in the middle column. Examples of the trajectory change given in the right column of Table 4-1. Lateral and altitude trajectory changes need to be requested, while speed changes do not need to be requested (only reported if the speed change exceeds five percent of current airspeed or 10 knots, whichever is greater). However, if a controller issues a speed clearance, the aircrew must request deviations from the clearance.

Table 4-2 Trajectory Changes

Aircrew Objective(s) & Constraint(s)	Trajectory Change	Examples
Objectives: Minimum fuel and minimum time	Lateral route change to shorter wind optimal route. Will minimize fuel and time simultaneously.	Direct to downstream waypoint. Switch to alternative route. Sequence of waypoints. Request another arrival fix.
Constraint: Avoid hazards	Lateral route change that avoids convective weather and SAA by buffer specified by aircrew inputs. This is intended to be a more strategic change when conditions allow a route change as opposed to a heading change.	10 nmi parallel offset left of current track. Same examples as lateral route changes above.
Objectives: Minimum fuel *OR* minimum fuel and minimum time	Change altitude to reduce fuel burn but increase flight time (decrease groundspeed) OR change to altitude with sufficient tailwinds to reduce both fuel burn and flight time (increase groundspeed). Aircraft may have been at a less desired altitude due to optimal winds that have now shifted, altitude restrictions that have been lifted, or fuel weight that has been burned off during the flight.	Request FL330 when flying FL290.
Constraint: Avoid hazards	Climb to higher altitude to avoid convective weather or terrain. Icing hazards can also be avoided by selecting another altitude.	Request FL330 when flying FL290.
Objective: Minimum fuel	Increase or decrease airspeed closer to maximum-range cruise that minimizes fuel burn.	Request Mach 0.78 when flying Mach 0.80.
Objective: Minimum time	Increase airspeed above maximum-range cruise to make up time.	Request Mach 0.82 when flying Mach 0.78.
Constraint: Avoid hazards	Decrease airspeed to mitigate effect of turbulence.	Request decrease in speed from Mach 0.82 to Mach 0.80.

Shifting winds, fuel burned off during flight, changing aircrew priorities during flight, and previous assignment to a suboptimal trajectory will cause an aircrew to desire a lateral, altitude, speed, or combination of these as a trajectory change to be requested. Trajectory changes using lateral, altitude, speed, or a combination may also be used to avoid hazards and surrounding traffic. However, the primary consideration is to generate trajectories to meet the combined objectives of the aircrew.

(b) Conflict Probe

The TASAR automation considers the following information when probing candidate trajectories for conflicts with other aircraft or hazards. Both Auto and Manual modes would use the same conflict probe functionality.

- Ownship trajectory: Creates a four-dimensional trajectory from the TASAR-capable aircraft's state and intent. Flight mode segments are generated using the aircraft's flight plan, guidance modes, autoflight settings, and a performance model of the aircraft.
- Surrounding traffic trajectories: Creates a four-dimensional trajectory prediction for each known traffic aircraft. If the flight plan is not known for an aircraft, or the aircraft is not following their flight plan, the prediction is based on the aircraft following their current heading, speed, and vertical rate. If the flight plan is known for an aircraft, the prediction is based on following the sequence of waypoints using current speed or the best information available.
- Hazards: Static or dynamic regions of airspace that the aircraft must avoid or that the pilot prefers to avoid will be accounted for by the trajectory optimization function.
- Buffers around other aircraft and hazards: A conflict is indicated if the ownship (or its buffered location) is predicted to come within a specified lateral/vertical volume of any traffic aircraft (or its buffered location) or breach the boundary of any hazard area.
- The conflict probe would be configured to be consistent with current controller conflict probing look-ahead times. Generally, the onboard automation would probe approximately to a 10-minute look-ahead horizon. This shorter term probing is intended to improve acceptability to the current sector controller. Longer look-ahead horizons may reduce conflicts in the next sector but may also be succeptable to higher uncertainty from the longer-term trajectory predictions. If a conflict would be created in the next sector, the optimized trajectory change may be modified in order to prevent the conflict. The TASAR onboard automation may consider the tradeoff between the probability of a conflict and the impact on the preferred trajectory of the aircraft if the conflict occurs.

(c) ATC Procedures

Letters of agreement between adjacent ATC facilities impose constraints that restrict the trajectory (speed, altitude, heading, or route) of aircraft when transitioning across facility boundaries in order to manage traffic flows. These agreements are not readily accessable to the user community but could be leveraged by TASAR automation if made available by database or other means. If these constraints are available, the Auto mode search could favor trajectory changes that are consistent with ATC letters of agreement. Similarly, Manual mode could inform the aircrew of any potential issues with known ATC constraints.

The following are possible TASAR considerations of ATC procedures involving facility letters of agreement:

- Controllers have less freedom to grant requests that violate letters of agreement than other restrictions. Auto mode may be configured so that generated requests attempt to avoid violating letters of agreement in most cases.
- Controllers are unlikely to grant requests during initial climb since these requests may conflict with arrival flows. However, when the aircraft reaches the high altitude structure, there is opportunity for granting requests, especially if the aircraft is far enough from the destination airport to not be impacted by metering restrictions. Auto mode could be configured so that requests are not generated below cruise altitudes.
- Requests for wrong altitude for direction cause additional workload for the controller to coordinate with the adjacent sector. Auto mode could be configured so that requests that involve wrong altitude for direction are not generated. Alternatively, the aircrew could be warned that requests for wrong altitude for direction are less likely to be granted.
- The distance upstream of the arrival fix where the aircraft merges into the arrival stream depends on the size of the airport. It is more acceptable to connect into the arrival route close to the arrival fix for small hub airports, while large hub airports generally require aircraft to be on the arrival route further out from the arrival airport. Auto mode requests could consider the first fix on the arrival procedure, as discussed in Section 4.2 (d), when generating lateral requests that reconnect to the arrival route.

- Controllers typically will not grant requests after initiating hand-off status with the next sector. The TASAR automation could consider sector boundary information and indicate to the aircrew when the aircraft is estimated to be within a threshold distance of the sector boundary and aircrew requests are less likely to be granted.
- Not all controller routine behaviors are included in facility standard operating procedures. Over time, sector controllers develop methods to cope with traffic. The TASAR automation is not intended to infer controller behavior in this case.

(d) Traffic Flow Management Initiatives

TFM initiatives including metering and reroutes may be considered by TASAR automation. Metering may include miles-in-trail (distance-based) or required time of arrival (time-based) metering. TASAR automation may inform the aircrew that the aircraft may be part of metering when approaching congestion and that there could be a reduced likelihood of the request being granted.

The TASAR onboard automation may also detect congested sectors as described in Section 4.4. Controllers will generally avoid sending traffic through an adjacent sector that is congested but may not be aware of congested sectors further away. If an aircrew request trajectory goes through an adjacent sector that it congested, it is likely to be rejected. However, if the aircrew request trajectory goes through another congested sector that is not adjacent to the current sector, then the request may be approved but the aircraft trajectory may be changed later to a less preferred trajectory to avoid the congested sector. Since the TASAR automation may not have the capability to accurately predict the trajectories of other aircraft to a longer time horizon, it is likely that TASAR automation would only consider congestion in the adjacent sector and possibly the sector beyond that during the Auto mode search. Manual mode may advise the aircrew if a trajectory change is projected to go through congested sectors. However, the ability to predict sector congestion depends on complete surveillance of the surrounding traffic. Predicting sector congestion may not be a useful function without means to receive data on all traffic regardless of ADS-B equipage.

An aircraft may also be part of a reroute initiative to avoid weather or mitigate more strategic sector congestion. In this case, the pilot will be aware if it is acceptable to make a request. Auto mode functionality will continue to search for trajectory improvements when the aircraft is part of a reroute initiative in order to provide the flexibility to the pilot to send a request if desired.

(e) Facilitating Voice Communications

Voice communication places practical restrictions on the complexity of aircrew requests. Section 4.2 proposed that the aircrew dynamically select a maximum complexity (i.e., number of elements in the request) depending on the situation. The default complexity is expected to be limited to two off-route waypoints. Combination altitude and lateral requests must be made simultaneously and may be limited to one off-route waypoint in addition to the requested altitude.

When generating waypoints, the TASAR automation restricts the trajectory to named waypoints to facilitate voice requests. These named waypoints will be considered along with other trajectory changes in the following order of preference from most preferred trajectory change to least preferred trajectory change: (1) named high altitude VORs (Very-high-frequency Omnidirectional Range) and fixes, (2) named low altitude VORs and fixes, (3) parallel offset from current track or airway, and (4) desired heading or range of headings.

Due to technical limitations, the controller workstation may not have all waypoints in a database readily available to the controller. If the waypoint is not in the database, the controller may need to manually enter the details of the waypoint which is a time consuming process. The TASAR automation will only develop lateral route requests that contain waypoints in the database. The database is center-specific, and so the TASAR automation would update available waypoints upon crossing a center boundary.

4.7. Displaying Trajectory Change to Aircrew

If the TASAR automation incorporates sector boundary information, only trajectory changes that begin in the current sector will be displayed to the aircrew, since controllers are primarily concerned with trajectory changes that occur in their sectors. Generally, trajectory change requests should not be made more than one or two minutes prior to the start of the trajectory change. Trajectory changes that occur downstream of the current sector would be presented to the aircrew when the aircraft enters the downstream sector where the proposed trajectory change will occur. The following subsections describe information that would be presented to the aircrew.

(a) Standby until Minimum Altitude

The TASAR automation displays a standby screen until the aircraft reaches an altitude at or above 10,000 ft MSL to correspond with the behavior described in Section 3.3.

(b) List of Trajectory Changes that Improve Objectives (Auto Mode)

A list of trajectory changes that improve the objectives of the aircrew and avoid hazards and traffic will be presented. Only those trajectory changes that are sufficiently free of conflicts and are determined to be otherwise acceptable to controllers will be presented to the aircrew. Once the aircrew makes the request to the controller, the aircrew has the option of freezing the requested trajectory change to prevent further updates.

(c) Modifications for Conflict-Free Pilot-Specified Preferred Trajectory (Manual Mode)

If the pilot enters a trajectory that does not avoid hazards or other traffic, then modifications to make the trajectory conflict free are presented at pilot request.

(d) Outcomes of Trajectory Change (Auto and Manual Modes)

The predicted change in fuel burn and flight time will be presented to the aircrew. The predicted distance to hazards and other traffic will not be presented to the aircrew since the trajectory changes presented will be at least the minimum required distance plus any buffers.

(e) Conformance with Standard Procedures and Letters of Agreement (Manual Mode)

If a trajectory change is not consistent with ATC standard procedures or violates a letter of agreement between facilities, the aircrew would be notified of the issue with the trajectory change entered by the aircrew. TASAR may also indicate if a request has a reduced likelihood of approval due to, for example, the aircraft being in handoff status to the next sector controller or the aircraft being too close to the destination airport.

(f) Traffic Management Initiatives (Manual Mode)

It may be desirable to inform the aircrew that the aircraft is part of a metering situation or reroute initiative, or that the trajectory change is projected to enter congested sectors.

(g) Time to Trajectory Change (Auto and Manual Modes)

The time to the location where the trajectory change should occur is presented to the aircrew. If not presented, the trajectory change is assumed to be immediate.

4.8. Aircrew Request Negotiation with Controller

The aircrew (not the TASAR automation) decides when a request is appropriate and makes a request to the controller. The response to controller approval, deferral, denial, or amendment is as follows.

(a) FMS Verification

Prior to issuing a TASAR request, the aircrew will use the FMS to verify that the TASAR request is flyable and will improve the objectives of the aircrew. Due to different aircraft performance models and atmospheric information between the TASAR automation and the FMS, it is possible that the TASAR automation may identify a trajectory change it estimates as beneficial while the FMS may indicate that executing the request would not be beneficial. If there is disagreement between the TASAR automation and the FMS, the FMS should be used as the authoritative source. Pilots may have the option to enter updated information into the FMS (e.g., winds) in order for the FMS to recognize that a TASAR generated request is beneficial.

(b) Confirm with Dispatch

Company policies regarding pilot/dispatcher coordination of flight plan changes are not altered by TASAR. Where required, this coordination could be automated through TASAR as described in Section 4.5.

(c) Approval

If the request is approved by ATC, the aircrew will execute the trajectory change. The TASAR automation will detect that the trajectory change has been executed and start computing trajectory changes relative to the executed trajectory change. The TASAR interface may provide means for the pilot to record the request was approved, deferred, denied, or amended.

(d) Deferral

If the controller defers the request, the TASAR automation continues to compute the optimization objective function without developing modifications to produce a trajectory free of conflicts. If the trajectory change is no longer optimal, the aircrew will use their best judgment to determine whether to cancel the request.

(e) Denial

The TASAR automation will not be updated in response to a controller denial of a request since the controller is unlikely to communicate why the request was denied. Instead, the potential requests presented to the aircrew will continue to be updated as the flight progresses.

(f) Amended Trajectory

Generally, a pilot will know if the ATC amendment is still advantageous and will be able to accept or reject the amendment without automation assistance. However, entering an ammended trajectory change offered by ATC into the TASAR automation using Manual Mode will be an option for the pilot to verify if the amended trajectory change is desired.

4.9. Benefits to be Realized

A preliminary fast-time simulation study showed that, on average, aircraft equipped with TASAR can reduce 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, class of airspace user, and aircraft type.2 Benefits are estimated to be higher at longer stage lengths since beneficial trajectory changes can be applied over a longer distance. The benefit mechanisms that elicit these benefits are discussed in this subsection.

A benefit mechanism is a causal linkage that converts a function into a benefit by applying the function to mitigate inefficiencies. Probing desired trajectory changes for possible separation violations with nearby traffic is one function for the benefit mechanism shown in Figure 4-1. This function is expected to mitigate the issue that aircrew requests are not always conflict free and are therefore sometimes denied. The other function shown in Figure 4-1 is the capability for TASAR-equipped aircraft to generate user-preferred trajectories, which mitigates the issue that the aircraft may not be following their preferred trajectory due to a previous inefficient trajectory assignment, a change in flight priorities, or a change in the environment (e.g., winds or weather).

The mechanisms shown between the first and second vertical dashed lines are enabled by these two functions and result in the four benefits shown between the second and third vertical lines in Figure 4-1.

The five benefits shown are: (1) aircrew better able to meet their objectives (delay, fuel costs, passenger comfort, etc.), (2) improved National Airspace System (NAS) performance, (3) reduced nuisance requests, and (4) reduced conflicts for controller to resolve. In order to quantify these benefits, four metrics are shown in boxes with dashed lines in Figure 1. These metrics are, respective to the four benefits: (1) aircrew utility, (2) NAS-wide delays, fuel burn, and congestion, (3) aircrew requests rejected by the controller, and (4) conflicts resolved by controller.

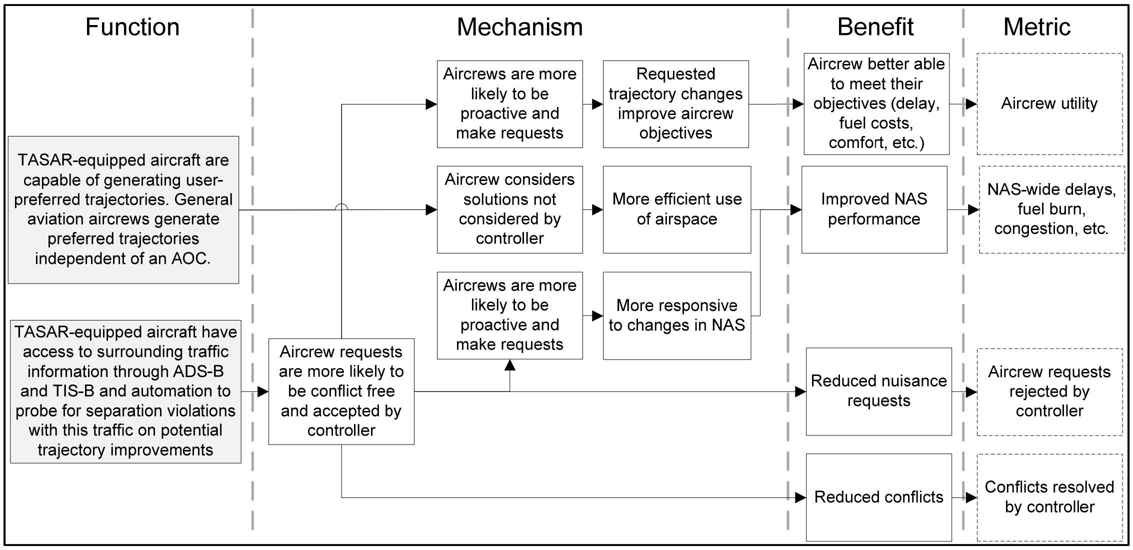

Figure 4-1 TASAR Benefit Mechanisms

Potential negative impacts of TASAR on the NAS are also considered, in addition to the benefits described in the previous subsection. Figure 4-2 shows potential impact mechanisms in a format similar to the benefit mechanisms shown in Figure 4-1. Four possible impacts are: (1) potential for increased controller workload if TASAR equipage grows too rapidly, (2) potential for increased user request denials if TASAR requests use insufficient margins of separation, (3) increase in conflicts to be resolved by the controller, and (4) potential for increase in airspace complexity. The expectation is that TASAR will reduce the conflicts for controllers to resolve, but there may be cases where TASAR resolves the immediate conflict but the resulting traffic situation may cause a controller downstream of the current sector to deal with more conflicts overall.

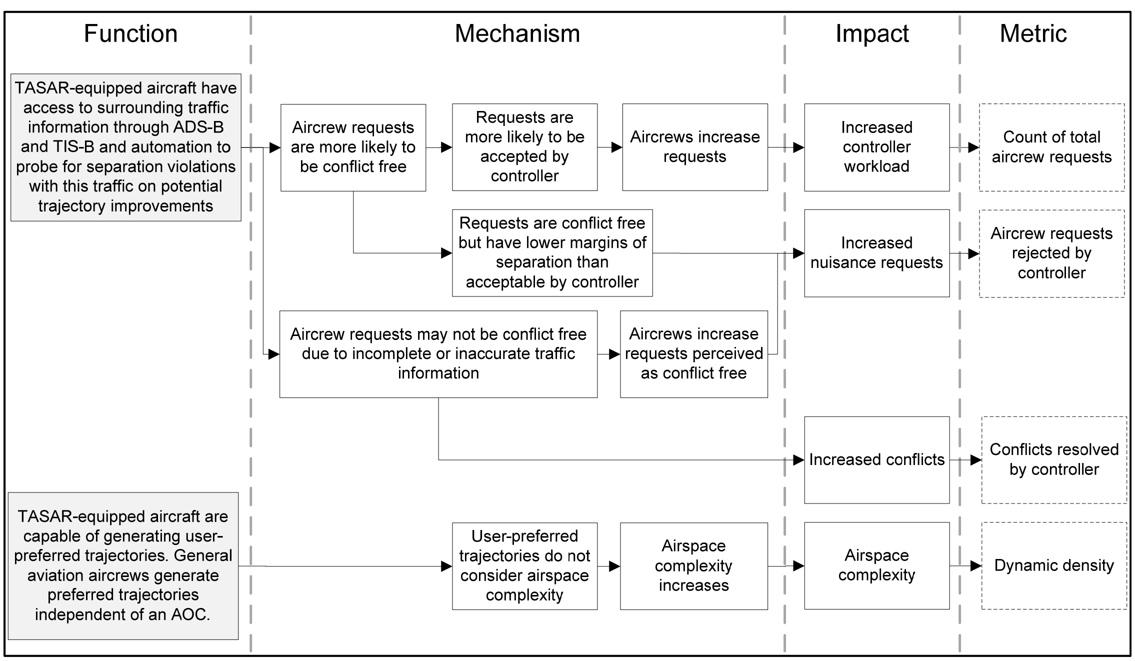

Figure 4-2 Mechanisms for Potential Negative Effects of TASAR

TASAR may provide two important benefits in meeting the challenge of airspace system modernization. (1) Its near-term operational use will provide a better technical understanding of ADS-B surveillance and its use by onboard automation, leading to the development of advanced concepts that involve a high degree of aircraft and flight crew autonomy. The development of TASAR should also provide a better understanding of the data and computational needs of the aircrew when planning their trajectory to meet their objectives. (2) Perhaps more importantly, TASAR may provide a user incentive for equipping aircraft with ADS-B, thereby accelerating equipage in advance of the 2020 ADS-B Out equipage mandate. Given the 2020 mandate, it is assumed that aircraft will equip with ADS-B Out when equipping with ADS-B In to obtain the TASAR single aircraft benefits.

5. Potential Evolution Paths for TASAR

TASAR will need to evolve to be consistent with future NAS operations and to take advantage of the Next Generation Air Transportation System (NextGen) operational improvements. Operational improvements that are presented in this section were obtained from the National Airspace System Enterprise Architecture (NAS EA) website (https://nasea.faa.gov/).

5.1. 4DT Negotiation via DataComm

Initially, TASAR requests will be limited to named waypoints over voice communications. The introduction of data communications (DataComm) will allow for more complex TASAR requests, such as waypoints defined by latitude and longitude, to allow the aircraft to more closely follow the preferred trajectory of the operator.

DataComm will eventually be used in NextGen to transition from routes defined by named waypoints to four-dimensional trajectories (4DTs) defined by three-dimensional spatial locations and time. TASAR algorithms would generate modifications to 4DTs including new fix time objectives in their definition to facilitate trajectory negotiation.

5.2. Flight Deck Planning with ANSP Feedback

One of the NextGen operational improvements is intended to allow flight crews to do trial planning from the flight deck. This trial planning will be enabled by aircraft access to system-wide information management (SWIM) and air navigation service provider (ANSP) ground automation tools that provide feedback on constraints impacting the trajectory. TASAR could be used as the automation function on the flight deck that generates optimized trajectories which are then sent over SWIM or direct downlink to be probed by ground automation. The TASAR automation algorithms would then need to revise the optimized trajectory based on feedback received from the ground automation tools.

5.3. Enhanced Flight Plan with Alternative Trajectories and Preferences

Under NextGen, it is expected that the flight plan will contain information regarding user preferences, such as ranked alternative trajectories. These preferences will be used by the ANSP to generate traffic management initiatives that better meet the preferences of the airspace users. One potential role for TASAR automation could be to continually evaluate these alternative trajectories to search for the most optimal alternative. If better alternatives are found, the flight deck planning with ANSP feedback function described in Section 5.2 could be used to evaluate the alternatives.

5.4. Types of Trajectory Constraints

Time-based metering, point-in-space metering, and 4DTs are all part of a NextGen shift by the ANSP to generate traffic management initiatives with flight-specific trajectories. TASAR automation will need to account for these types of constraints when generating more optimal trajectories, as well as other NextGen initiatives such as delegated separation and performance-based access to airspace and routes.

6. Operational Scenarios

This section describes sample scenarios corresponding to the two TASAR modes: Auto mode and Manual mode. Each of these scenarios define a range of aircrew objectives, the preconditions that cause the aircraft to be on a less desired trajectory, the post conditions after the request is granted, and the steps in the scenario.

6.1. Sequence for Automated Monitoring for Opportunities (Auto Mode)

Aircrew objectives:

1) Minimize flight time, OR
2) Minimize fuel burn, OR
3) Minimize weighted combination of flight time and fuel burn

Precondition alternatives that cause the aircraft to be on a less desired trajectory:

i. Planned route is not wind optimal post-departure, or winds shift during flight, or aircraft changes lateral route to cause another altitude to be wind optimal.
ii. Aircraft is part of a reroute initiative to avoid convective weather or mitigate congestion, and aircraft are not shifted back to user-preferred routes after the initiative has ended. Or aircraft is part of an altitude capping or tunneling initiative and aircraft is not returned to user preferred altitude after initiative has ended.
iii. Convective weather impacts aircraft en route. This is intended to be a more strategic change when conditions allow a route change as opposed to a series of ad hoc heading changes. Or convective weather is projected to impact current trajectory and aircraft is capable of climbing over convective weather by required buffer.
iv. Convective weather shifts allowing a more preferred tactical trajectory change.
v. Change in activation schedule of SAA while aircraft is airborne.
vi. Aircraft is at a lower altitude than desired to minimize fuel burn. Aircraft burns off weight during flight to allow climbing to a higher, more fuel efficient altitude.
vii. Aircraft is destined for a smaller airport (e.g., TEB) but is caught in an arrival stream of a larger airport (e.g., JFK) causing the aircraft to be flying slower than desired. Higher altitude is desired to bypass larger airport arrival stream.

Post conditions after request approved:

1) Aircraft following approved, more optimized trajectory
2) Utility of operator increased

Main Scenario:

1. Flight crew receives initial flight plan from dispatcher.
2. Flight crew receives initial business objectives for the TASAR automation from dispatcher if dispatcher provides business objectives. Otherwise, the flight crew will select a default configuration for the TASAR automation in step 7.
3. Flight crew enters flight plan into FMS.
4. Aircraft departs and is flying IFR cruise in en route airspace.
5. Onboard TASAR automation becomes active once the aircraft is above 10,000 ft MSL.
6. TASAR automation receives current flight plan from FMS.
7. Flight crew enters initial objectives into TASAR automation or uses a default TASAR automation configuration.
8. TASAR automation is in Auto mode by default.
9. TASAR automation receives updates (if any exist) from flight operational control or internet source (if equipped).
10. Flight crew receives updated objectives from dispatcher (if objectives have changed).

11. Flight crew enters updated objectives into TASAR automation (if objectives have changed).
12. TASAR automation receives updated position/state of aircraft equipped with ADS-B Out as well as aircraft not equipped with ADS-B Out from TIS-B.
13. TASAR automation receives updated weather, winds, and atmospheric information from satellite weather, FIS-B, or internet depending on aircraft equipage.
14. TASAR automation receives updated SAA activation schedule from FIS-B or internet depending on aircraft equipage.
15. Preconditions i to vi
16. TASAR automation identifies aircraft is not following preferred business trajectory to meet flight objectives.
17. TASAR automation creates a 4D trajectory prediction for the ownship as well as all aircraft known through ADS-B.
18. TASAR automation identifies conflict-free (to a time horizon) lateral, altitude, or combination lateral and altitude trajectory change that improves objective.
19. TASAR automation indicates to flight crew that threshold for making request is exceeded.
20. TASAR automation indicates attributes of the trajectory change to the flight crew.
21. TASAR automation indicates to the flight crew the estimated time to when the trajectory change will occur.
22. Flight crew selects trajectory change which freezes the TASAR automation from further updates.
23. Flight crew verifies with FMS that request will improve objectives.
24. Flight crew verifies that request will not result in a violation of required fuel reserves.
25. Flight crew makes request to controller.
26. Controller approves request if acceptable.
27. If controller approves the request, the flight crew executes the approved request in the FMS and TASAR automation receives the updated trajectory from the FMS.
28. TASAR automation continues searching for trajectories in Auto mode.

Precondition i (Shifting winds):

TASAR automation identifies that winds have shifted and preferred lateral trajectory or preferred altitude may have changed.

Precondition ii (Restriction no longer needed):

Dispatch notifies flight crew or flight crew determines from voice communications with ANSP that route or altitude restrictions are no longer needed.

Precondition iii (Shifting convective weather):

TASAR automation monitors for growth, decay, or shifting of convective weather to alter a strategic route or recommend an altitude change.

Precondition iv (Shifting convective weather):

TASAR automation monitors for growth, decay, or shifting of convective weather to allow a tactical heading change.

Precondition v (Activation/schedule change for SAA):

TASAR automation identifies available SAA airspace that was previously unavailable due to a change in SAA activation schedule

Precondition vi (Change in aircraft ceiling):

Aircraft burns off sufficient fuel to allow aircraft to climb to a more advantageous altitude.

Precondition vii (Aircraft caught in slower arrival stream):

Airspace above aircraft clear enough to allow climb to another altitude and airspeed increase.

6.2. Sequence for Pilot Initiated Use with Conflict Probing (Manual Mode)

Aircrew objectives:

1) Minimize flight time, OR
2) Minimize fuel burn, OR
3) Minimize weighted combination of flight time and fuel burn, OR
4) Minimize turbulence or weather avoidance

Preconditions that cause the aircraft to be on a less desired trajectory:

- i to vii. Same as Auto mode.
- viii. Icing impacts aircraft during flight.
- ix. Aircraft is diverted to alternate airport.
- x. Aircraft is delayed en route and needs to make up time.
- xi. Aircraft is impacted by turbulence.
- xii. Conditions at destination airport require diverting to an alternate airport or, for business operators, onboard passengers request a change in destination.

Postconditions after request approved:

1) Aircraft following approved, more optimized trajectory
2) Utility of operator increased
3) Better ride for passengers

Main Scenario:

1. Steps 1 to 14 from Auto mode steps in Section 6.1.
2. Preconditions i to xii
3. Aircrew enters desired lateral, altitude, or speed trajectory change into FMS or onboard TASAR automation.
4. If trajectory change is entered into FMS, TASAR senses the trajectory change.
5. TASAR automation creates a 4D trajectory prediction for the ownship as well as all aircraft known through ADS-B.
6. TASAR automation probes for conflicts. TASAR automation develops conflict-free (to a time horizon) modification if necessary.
7. TASAR automation checks for violations of standard procedures or letters of agreement. TASAR automation notifies flight crew of any violations.
8. TASAR automation indicates attributes of the trajectory change to the flight crew.
9. TASAR automation indicates to the flight crew the estimated time to when the trajectory change will occur.
10. Flight crew verifies with FMS that request will improve objectives.
11. Flight crew verifies that request will not result in a violation of required fuel reserves.
12. Flight crew makes request to controller.
13. Controller approves request if acceptable.
14. If controller approves the request, the flight crew executes the approved request in the FMS and TASAR automation receives the updated trajectory from the FMS.
15. TASAR automation continues searching for trajectories in Auto mode.

Precondition xii (Diverting to alternate airport):

1. Aircrew selects option from TASAR automation to search for alternative destination airports.
2. TASAR automation develops list of alternative airports that are reachable.
3. Aircrew selects desired alternative airport.
4. TASAR automation displays lateral trajectory to destination airport.

7. Definitions

1090 MHz Extended Squitter (1090 ES): Extended Squitter Automatic Dependent Surveillance-Broadcast equipment operating on the 1090 Megahertz radio frequency.

Automatic Dependent Surveillance-Broadcast (ADS-B): A surveillance service using the automatic transmission of an aircraft's or surface vehicle's position and other state information. The source of ADS-B information is derived from the aircraft's navigation system (e.g., Global Navigation Satellite System receiver, Flight Management Computer, etc.). Other aircraft may receive this information and compare it to their own position to accurately determine relative position. Ground systems may also use ADS-B information to augment or replace less accurate radar-based surveillance information, or to provide cost effective surveillance coverage in non-radar airspace.

ADS-B Report: An ADS-B Report contains the information elements assembled using messages received from a transmitting participant. These information elements are available for use by applications external to the ADS-B system.

ADS-B Message: An ADS-B Message is a block of formatted data that conveys the information elements used in the development of ADS-B Reports. Message contents and formats are specific to the ADS-B data link.

Airline Operations Center (AOC): Centralized organization staffed by certified flight dispatchers responsible for the planning and conducts of airline flight operations.

Air Traffic Control (ATC): Service by ground-based controllers to separate traffic, organize traffic flow, and provide information and other support to the pilot when the controller is able.

Electronic Flight Bag (EFB): Computing platform on the flight deck designed to reduce paper-based reference material and to automate calculations.

Flight Management System (FMS): Automation to help flight crew guide aircraft along flight plan.

Instrument Flight Rules (IFR): Flight crew operates aircraft solely by reference to instruments.

Mean Sea Level (MSL): Mean height of the surface of the ocean.

Reduced Vertical Separation Minima (RVSM): 1,000 ft minimum vertical separation between flight level 290 and Flight Level 410.

Traffic Aware Strategic Aircrew Requests (TASAR): Onboard automation leveraging ADS-B surveillance information for the purpose of advising the pilot of traffic compatible trajectory changes that would be beneficial to the flight.

Traffic Alert and Collision Avoidance System (TCAS): Alerts pilots of increased collision risk and, under certain conditions, recommends maneuver to reduce risk of collision.

Traffic Flow Management (TFM): Planning and execution of plans by ATC to maintain demand for airspace and airport resources below capacity through use of flow controls such as ground stops, ground delays, metering, and rerouting.

Traffic Information Service Broadcast (TIS-B): Uplink of surveillance information (ground radar or aircraft targets on another ADS-B frequency) on ADS-B data link to supplement air-to-air ADS-B surveillance.

Universal Access Transceiver (UAT): Universal Access Transceiver Automatic Dependent Surveillance **–** Broadcast equipment operating on the 978 Megahertz radio frequency.

8. References

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[2]Henderson, J., Wing, D.J., and Idris, H., “Preliminary Benefits Assessment of Traffic Aware Strategic Aircrew Requests (TASAR)”, AIAA-2012-5684, *AIAA 12th Aircraft Technology, Integration, and Operations Conference (ATIO)*, Indianapolis, IN, September 2012.

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14. ABSTRACT

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Aircrews submit trajectory change requests to air traffic control (ATC) to better achieve the operator's preferred business trajectory. Requests are currently made with limited information and are often denied because the change is not compatible with traffic. Also, request opportunities can be overlooked due to lack of automation that advises aircrews of trajectory changes that improve flight time, fuel burn, and other objectives. The Traffic Aware Strategic Aircrew Requests (TASAR) concept leverages Automatic Dependent Surveillance-Broadcast (ADS-B) surveillance information to advise the aircrew of beneficial trajectory changes that are probed for traffic compatibility prior to issuing the request to ATC. This document describes the features, benefits, and limitations of TASAR automation hosted on an Electronic Flight Bag. TASAR has two modes: (1) auto mode that continuously assesses opportunities for improving the performance of the flight and (2) manual mode that probes trajectory changes entered by aircrews for conflicts and performance objectives. The roles and procedures of the aircrew and ATC remain unchanged under TASAR.

15. SUBJECT TERMS

ADS-B; Air traffic control; Electronic flight bag; Route optimization; TASAR

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