NEWLY ENACTED INTENT CHANGES TO ADS-B MASPS: EMPHASIS ON OPERATIONS, COMPATIBILITY, AND INTEGRITY

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Abstract

Significant changes to the intent reporting structure in the Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance Broadcast (ADS-B)[1] have recently been approved by RTCA Special Committee 186. The re-structured intent formats incorporate two major changes to the current MASPS (DO-242): addition of a Target State (TS) report that provides information on the horizontal and vertical targets for the current flight segment and replacement of the current Trajectory Change Point (TCP) and TCP+1 reports with Trajectory Change (TC) reports. TC reports include expanded information about TCPs and their connecting flight segments, in addition to making provisions for trajectory conformance elements. New intent elements are designed to accommodate a greater range of intent information, better reflect operational use and capabilities of existing and future aircraft avionics, and aid trajectory synthesis and conformance monitoring systems. These elements are expected to benefit near-term and future Air Traffic Management (ATM) applications, including separation assurance, local traffic flow management, and conformance monitoring. The current MASPS revision (DO-242A) implements those intent elements that are supported by current avionics standards and data buses. Additional elements are provisioned for inclusion in future MASPS revisions (beyond DO-242A) as avionics systems are evolved.

Introduction

Aircraft intent information refers to the intended future trajectory of an aircraft and is expected to offer significant benefits to many evolving Air Traffic Management (ATM) operations. Proposed air-air applications of intent information include in-trail spacing[2] and conflict detection, prevention, and resolution.[3,4] Intent information has been found to be beneficial in several experiments requiring pilots to maintain adequate separation from other aircraft.[5-7] Intent information is also expected to enable advanced air-ground applications such as sequencing and merging of terminal area flow streams,[8] use of precision trajectory separation concepts for aircraft arrival and departure flows in congested airspace,[9,10] flight plan consistency checking,[11] and conformance monitoring.[12-16]

One means by which aircraft can exchange intent information with each other and with ground systems is through Automatic Dependent Surveillance Broadcast (ADS-B). The original Minimum Aviation System Performance Standards (MASPS) for ADS-B (DO-242) establishes minimum information requirements and performance specifications for intent broadcast over ADS-B.[1] RTCA Special Committee 186 has recently completed a new revision to this document, to be published as DO-242A. Several changes to this document compared to the original MASPS should increase the operational utility of aircraft intent information. Intent elements supported by established avionics standards are introduced in DO-242A. Other elements are provisioned for possible incorporation into future MASPS revisions, as avionics systems are able to support them. The intent changes focus on establishing reporting structures that are more compatible with existing aircraft and avionics architectures, increasing confidence that an aircraft will follow its broadcast intent, and expanding the domain of potential ATM applications that can benefit from intent information.

ADS-B Architecture Changes Related to Intent Information

Information exchanged over ADS-B is assembled by the receiving aircraft or ground station into reports that are made available to user applications. Two major changes to the ADS-B reports that contain intent information include:

1. Addition of a Target State (TS) report that provides information on the horizontal and vertical targets for the current flight segment. The primary TS report elements include the target altitude and target heading or track. *Target altitude* is the aircraft's intended level-off altitude if in a climb or descent, or the aircraft's current intended altitude if it is being commanded to hold altitude. *Target heading* and *target track angle* are the aircraft's commanded lateral

direction and are used if the aircraft is being controlled to an air reference heading or ground reference track, respectively.

2. Replacement of the current Trajectory Change Point (TCP) and TCP+1 reports with Trajectory Change (TC) reports. A TC report describes one TCP and its preceding flight segment. For fly-by turns, it also provides information for the following flight segment. TC reports are designed to accommodate a greater range of intent information and to better reflect operational use and capabilities of existing and future aircraft avionics.

Figure 1 shows the relationship between information provided in TS and TC reports for an aircraft flying a simple trajectory between area navigation (RNAV) waypoints. The target track to waypoint ABC and the target altitude for the active flight segment are provided in the TS report. Three TC reports give information on waypoints ABC, DEF, and GHI. Note that this figure only represents one type of trajectory.

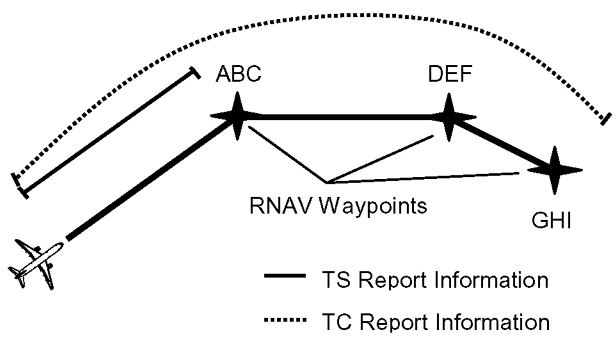

Figure 1. TS and TC Report Information

Tables 1 and 2 summarize the main differences in intent information content between the original ADS-B MASPS (DO-242) and the MASPS update (DO-242A). These elements are described in later sections. Note that these lists do not contain all of the TS and TC report elements. A more detailed description of all elements, as well as information related to the broadcast and management of intent reports is contained in a separate document.[17]

Table 1. DO-242 Intent Information (Primary Elements)

TCP and TCP+1
TCP Latitude
TCP Longitude
TCP Altitude
TCP Time to Go

Table 2a. DO-242A Target State Report (Primary Elements)

Target State Report
Target Heading or Target Track Angle
Horizontal Target Source Indicator
Horizontal Mode Indicator
Target Altitude
Target Altitude Capability
Vertical Target Source Indicator
Vertical Mode Indicator

Table 2b. DO-242A Trajectory Change Report (Primary Elements)

Trajectory Change Report
TC Latitude
TC Longitude
Horizontal TC Type
Track to TCP
Track from TCP
Turn Radius
Reserved for Horizontal Conformance
Horizontal Command/Planned Flag
TC Altitude
Vertical TC Type
Reserved for Altitude Constraint Type
Reserved for Able/Unable Altitude Constraint
Reserved for Vertical Conformance
Vertical Command/Planned Flag
Time to Go

Intent Availability Due to Control State

A 2000 FAA-Eurocontrol sponsored Technical Interchange Meeting (TIM) on intent information included a recommendation in its outbriefing to, "Study the relationships between aircraft control loops and intent parameters."[18] This recommendation is important, in part, because the amount of intent information available for data exchange depends strongly on the transmitting aircraft's current control state and equipment. These relationships were evaluated in several Boeing 777 simulator sessions and through a review of Airbus vertical flight modes.[19] The TS and TC reports are designed to take advantage of intent information available when aircraft are operated in either simple or complex control states.

The three primary control states, referred to here as manual (no flight director), target state, and trajectory are shown in Figure 2. With each additional outer loop, it is possible for an aircraft to communicate more information about future states and flight segments. While operating with target state control, a single set of commanded states is available. The TS report provides target altitude and target heading or track angle. Future MASPS revisions could incorporate target airspeed and target vertical speed, if deemed necessary to support ATM applications. In the outermost loop corresponding to trajectory control, the aircraft has knowledge of multiple trajectory change points and connecting flight segments. TC reports provide this information. In the trajectory control state, the TS report provides target state information corresponding to the current flight segment.

Most commercial aircraft have several flight modes corresponding to the target state and trajectory control states shown in Figure 2. Flight modes are normally selected through the Mode Control Panel (MCP) or Flight Control Unit (FCU). They include choices such as hold current heading, hold current altitude, and maintain track between RNAV waypoints. The pilot can concurrently choose lateral and vertical flight modes that correspond to different control states, leading to different intent availability in the horizontal and vertical axes. Horizontal and vertical guidance commands may be followed manually using a flight director display mode, rather than through direct autopilot commands. No distinction is made between flight director and autopilot operation, since this information cannot be differentiated from ADS-B output reports.

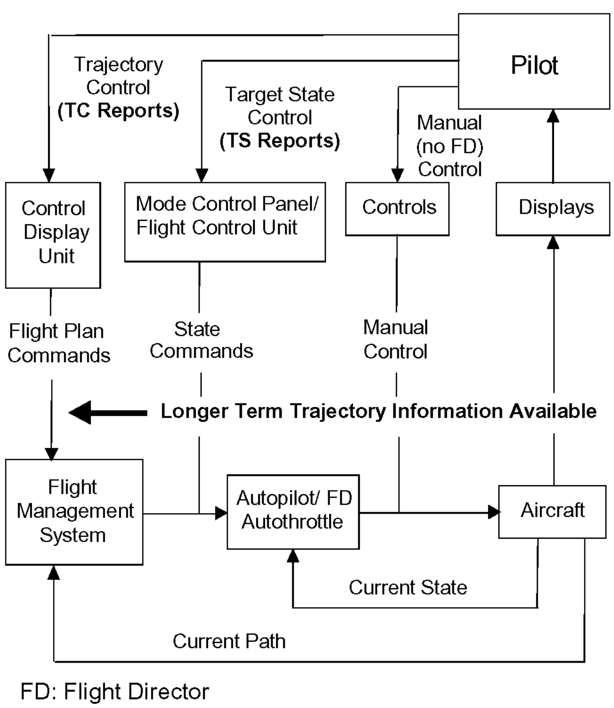

Figure 2. Aircraft Control States

Figure 2 shows typical equipment available on transport category aircraft that is capable of providing the associated information. Other flight hardware may also be able to generate this information. More sophisticated equipment is needed to transmit outer loop information, whereas inner loop information on current target states may be difficult to transmit for older analog aircraft. An MCP or FCU is the primary interface between the pilot and autopilot when not operating in Flight Management System (FMS) automated modes. These interfaces allow the pilot to select target states such as altitude, heading, vertical speed, and airspeed. Since only the next target state is allowed in each axis, pilots often use the MCP or FCU for short-term tactical flying. Conversely, the FMS allows the pilot to select a series of target states or flight segments through a keypad-based Control Display Unit (CDU). A pilot may program an entire route complete with multiple waypoints, speed, altitude, and time restrictions, and desired speeds along different flight segments. Because the FMS allows definition of consecutive flight segments, it is frequently used for long-term strategic flying.

Complex paths may be created when an aircraft's trajectory is generated with both MCP/FCU and FMS flight modes. Such a situation can occur when the lateral and vertical modes correspond to different control states or when an autopilot target value affects an FMS planned trajectory. The latter case is most common when the MCP/FCU selected altitude lies between the aircraft's current altitude and the programmed FMS altitude. In this case, the aircraft will level out at the selected value, i.e. selected altitude acts as a limit value on the planned climb or descent.[20]

Both single state (TS report) and multiple state (TC report) intent information offer a potential benefit to airborne conflict management, separation assurance, surveillance, and conformance monitoring applications. Single state intent is available in almost all flight modes, while 4D TCPs are only available when equipped aircraft are using sophisticated FMS and RNAV systems. The addition of TS reports enable the broadcast of intent information across a greater range of flight modes and control states.

Effects of Avionics System Evolution on Intent Broadcast

One of the challenges in developing and evolving intent information for ADS-B is that most current aircraft avionics, including many advanced digital FMS based systems, do not output much intent information on avionics buses for downstream use by avionics other than that directly used to communicate to the pilot or to navigate, guide, or control an airplane. DO-242A intent changes address this situation in two ways: (1) allowing aircraft which output some intent information to communicate such intent when appropriate through the TS and TC report formats, and (2) providing intent provisioning in the report formats for future evolution and implementation of more comprehensive intent data. These changes provide an incremental approach to intent broadcasting by allowing for partial broadcast of limited intent in DO-242A, while accommodating evolution to more comprehensive intent data as avionics systems are upgraded and intent structures refined in future ADS-B MASPS revisions.

The new TS report makes provisions for broadcast of target altitude and target heading or track angle data used for current path guidance. Since full implementation of target state data may depend on FMS or autopilot mode information not currently available on any avionics bus, DO-242A intent structures support partial implementations of target states based on information which is available for input to an ADS-B transmit system. For example, if only autopilot based selected altitude is available for target altitude reporting, then an aircraft is allowed to broadcast such information with appropriate status indicators, even if the next intended level-off altitude may be an unknown FMS target value. The fact that the aircraft can only broadcast selected altitude is transmitted through the target altitude capability element, to avoid having the receiving system interpret selected altitude as the probable next level-off state. Target source indicators in the TS report distinguish between the aircraft system (FMS, MCP/FCU or aircraft current state) driving the autopilot commanded states. Horizontal and vertical mode indicators determine whether the aircraft is acquiring or capturing/maintaining the corresponding target state.

Horizontal and vertical TC type fields included in the TC report specify the flight segment and endpoint change type. They are used to aid interpretation of the data elements used for synthesis of consecutive path segments. The TC report enacted in DO-242A makes provisions for TC types that have standard TCP and flight segment parameters and are available as potential outputs on an ARINC data bus, such as that defined by the 702A Characteristic.[20] The horizontal flight segment types include Course-to-Fix (CF), Track-to-Fix (TF), and Direct-to-Fix (DF) leg types, and Fly-By and Radius-to-Fix (RF) turn segments. Fly-over turns to a specified end fix can also be modeled by appropriate use of the above turn types in conjunction with a DF or TF flight segment. The vertical flight segments include initial climb to Top-of-Climb, flight at cruise altitude to Top-of-Descent, i.e. start of the descent phase, and some level-off transitions. In addition, target altitude as the intended end of a vertical transition is allowed as a TCP. RNAV systems that only output 2D TCPs and time to TCP are also allowed. The TC report structure can support additional TC types as avionics buses and aircraft systems are evolved and additional intent information becomes available for broadcast.

Improved Path Integrity

In order to use intent information for traffic separation applications, the receiving aircraft or ground station must be able to assess the transmitting aircraft's ability to conform to its broadcast intent. Intent related changes to the ADS-B MASPS address this path integrity issue in three ways:

1. Clearly distinguishing between intent states that are actual targets for the autoflight system (command trajectory) and those that merely represent a pilot's plan or preference (planned trajectory).

2. Providing TC type fields that allow users to assess uncertainty in reported TCP locations and specify path characteristics for trajectory synthesis routines.

3. Establishing provisions for each aircraft to transmit its horizontal and vertical path conformance.

Command and Planned Trajectories

Each broadcast TC report has elements to indicate whether the horizontal or vertical TC components are part of the aircraft's command or planned trajectory, as defined below.

The *command* trajectory refers to the path the aircraft will fly if the pilot does not engage a new flight mode nor change the targets for the active or upcoming flight modes. The command trajectory may include multiple flight mode transitions. Changes to the command trajectory normally result from a pilot input. However, a non-programmed mode transition may also occur that causes the aircraft to leave the command trajectory, e.g. reversion to speed priority on descent if the intended vertical path results in an over-speed condition.

The *planned* trajectory includes intent information that is conditional upon the pilot engaging a new flight mode. Without pilot input, the aircraft will only fly toward the command trajectory targets.

Figure 3 illustrates the difference between the command and planned trajectories for a simple descent scenario. In this case, the aircraft is flying a lateral and vertical FMS path that includes a planned altitude level-off at the End of Descent (E/D). The MCP/FCU selected altitude lies between the aircraft's current altitude and the E/D. Assuming the pilot doesn't change the aircraft's flight mode or targets, the aircraft will fly on the FMS descent path until reaching the selected altitude and then level off. This path is the command trajectory. If the pilot resets the MCP target at or below the E/D altitude prior to reaching the selected altitude, the aircraft will continue to fly along the FMS descent path and will level out at the end of descent. The programmed FMS path beyond the selected altitude represents a planned trajectory. Typically, selected altitude indicates an ATC clearance altitude. In this case, the pilot may choose to fly directly to the end of descent as soon as a clearance to the planned altitude is received.

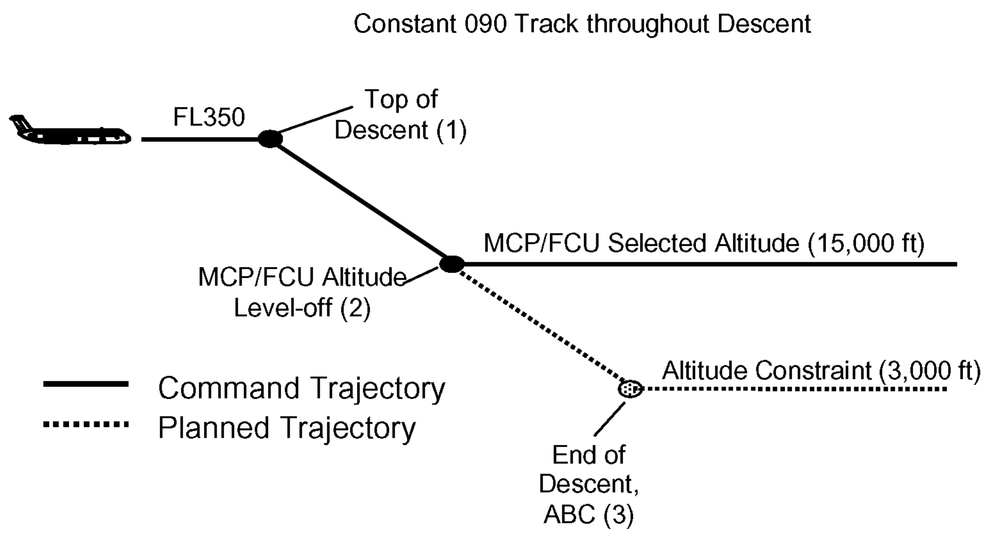

Figure 3. FMS Descent Showing Command and Planned Trajectories

These trajectory definitions are also expandable to aircraft sending intent information from non-FMS flight planning systems. For example, a LORAN or GPS navigation system on a general aviation airplane can be programmed to contain multiple waypoints. This path represents a planned lateral trajectory. It does not guarantee that the aircraft will fly that path, but represents information relevant to the pilot's long-term plan.

Both the command and planned trajectories may provide useful information for separation assurance and flow management applications. The command trajectory, however, is considered to represent the aircraft's current intent and therefore has broadcast priority over planned TCPs. This strategy was also explicitly expressed at the 2000 Intent TIM.[21] The TC report structure enables the receiving system to clearly distinguish between the command and planned trajectories.

TCP Position Uncertainty

TC type fields allow the receiving system to assess the flight segment "leg" type and accuracy of reported TC latitude, longitude, and altitude values. Many change points can occur along an operational trajectory that do not occur at known 3D positions. For example, an aircraft may be climbing in a constant vertical speed mode towards a target altitude (see Figure 4). In this case, the aircraft may not take actual wind conditions into account when predicting the level-off location. Level-off prediction in a climb may also depend on changing aircraft performance. These uncertainties make it difficult to predict an accurate 3D level-off point.

Figure 5 illustrates other TC types having uncertain 3D locations. In this example, the aircraft is flying at constant heading to intercept a flight plan route, while climbing to a new altitude. The flight plan intercept point (TCP #1) is dependent on wind parameters that may not be accurately known for intercept predictions. Waypoint ABC (TCP #2) has a defined 2D lateral position, however the crossing altitude isn't precisely defined, due to wind and aircraft performance. These uncertainties also exist for the level-off point (TCP #3). Only Waypoint DEF (TCP #4) has a precise 3D location. TC type fields may enable the receiving air or ground system to establish a lower conformance expectation for a transmitting aircraft that has less certain TCPs along its flight path.[22]

To account for TCP position uncertainties, a new TCP definition is established for DO-242A: "A Trajectory Change Point may be described as a point where an anticipated change in the aircraft's velocity vector will cause an intended change in trajectory." This definition replaces that currently used in DO-242 (p. 39). The older definition only recognizes TCPs that have a well-defined 3D location. Under DO-242A, aircraft would not be required to report predicted TC position and altitude information if those data are unknown. This allowance makes provisions for avionics systems that are unable to provide conditional waypoint predictions, such as path intercepts and anticipated level-off points.

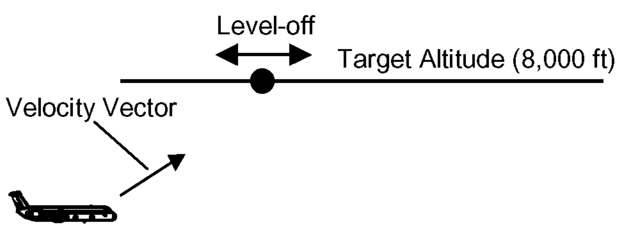

Figure 4. Climb at Constant Vertical Speed to MCP/FCU Selected Altitude

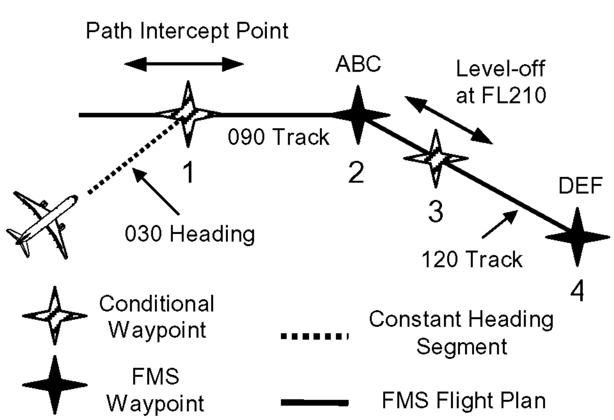

Figure 5. Constant Vertical Speed Climb and Constant Heading to Intercept FMS Flight Plan

Path Conformance Information

In addition to TCPs, points involving an altitude constraint (At, At or Above, or At or Below) are provisioned for future MASPS revisions even if they may not involve a trajectory change. These points influence trajectory predictions even if no level-off occurs at the altitude constraint, and provide value for conformance monitoring applications. They also form the basis for implementing vertical RNP using altitude "window" constraints in future RNP systems.[10] An altitude constraint "able/unable" element provides the own aircraft's assessment of its ability to meet the next altitude constraint.

Horizontal and vertical mode indicators in the TS report provide status information on whether the aircraft is acquiring (transitioning toward) the target state or is capturing or maintaining the target. These parameters are expected to provide verification of predicted trajectory changes and to be useful for trajectory conformance monitoring.

Space in the TC report is reserved for each aircraft to assess its horizontal and vertical path conformance. It is anticipated that future ATM applications may use horizontal and vertical RNP bounds to specify trajectory conformance.[10] The conformance elements indicate whether the aircraft is within the specified trajectory bounds. For non-RNP aircraft, other measures of conformance may be specified.

Support for Near-term and Future ATM Applications

Many current and evolving ATM applications related to separation assurance, traffic flow management, and conformance monitoring could potentially benefit from the newly enacted intent information. The TS and TC report intent structures provide more detailed path prediction and conformance monitoring information, while accounting for limitations due to avionics architecture and aircraft control states.

Altitude clearance verification is a potential near-term use for the enhanced intent information. Several European agencies are investigating the use of selected and target altitude information under the Downlink of Airborne Parameters (DAP) program.[16] The aircraft's selected altitude, dialed into the MCP or FCU, is considered to most closely represent the ATC clearance altitude.[16] Controllers can compare the clearance altitude with that selected by the pilot to help ensure that aircraft do not fly through their assigned altitudes.[12,15,16] The selected altitude is currently available on ARINC 429 avionics buses.[20] Selected altitude does not account for intermediate level-offs that may occur when the aircraft is being controlled by the FMS. The ADS-B definition of target altitude closely matches that used by Eurocontrol.[16,23] Target altitude is presumed to be advantageous in reducing false alarms generated by vertical conflict detection algorithms. Without intermediate level-off information, these algorithms may assume that an aircraft will maintain its present vertical path. The TS report can support either selected or target altitude, however most aircraft will need additional processing in order to generate target altitude. Airbus has proposed target altitude logic for advanced FMS aircraft that considers flight modes and various autoflight system targets.[19] The target altitude capability element provided in the TS report indicates whether the aircraft is broadcasting selected or target altitude.

Comparison of clearance and programmed trajectories can also be extended to longer-term intent. Intent information shared between the aircraft and ground controllers is anticipated to enhance situation awareness for all participants.[11-13] However, reliability and integrity of broadcast intent data needs to be demonstrated before such information can be used for traffic management applications. Controllers will then have higher confidence that air crews have correctly programmed assigned routes and altitudes and are able to comply with those clearances.

Aircraft intent is an enabling technology for several new ATM concepts. NASA is currently investigating a free flight concept known as Distributed Air Ground Traffic Management (DAG-TM).[3] In this environment, air crews would work collaboratively with air traffic service providers to resolve airspace and traffic conflicts and enable user-preferred routing. Effective conflict probes will be critical to achieving these goals. Enhanced path definition elements, such as target altitude and TC type, provided in the TS and TC reports should enable these probes to work effectively when aircraft are operating in diverse flight modes. The conformance monitoring parameters provisioned in the TC report should provide adequate path integrity for enabling new ATM concepts, while preserving or enhancing today's safety margins.

TC report enhancements may also benefit ground tools such as the Center TRACON Automation System (CTAS). CTAS uses aircraft trajectory predictions to help controllers with sequencing and merging operations in busy terminal airspace. In the future, CTAS may use broadcasts of on-board trajectory information to refine predictions made by ground-based trajectory generators. Anticipated improvements in path accuracy derived from broadcast intent should allow more efficient airspace management and increase the likelihood that pilots will be able to fly user-preferred trajectories.[8]

Conflict probes used by ground stations currently have difficulty predicting vertical conflicts, due to significant vertical path uncertainty.[9] The addition of TC type information provided in the TC report should allow trajectory generators to better recognize and account for inherent uncertainties, such as wind and aircraft performance, that exist at some TCPs. New TC report parameters enabling own-aircraft assessment of altitude constraint compliance and path conformance status should also help.

Conclusions

Newly enacted changes to ADS-B intent reporting enable progressive implementation of aircraft intent broadcast, beginning with those elements supported by current avionics. The new framework establishes standards for trajectory reporting and synthesis that will enable effective use of intent information for surveillance applications. Support for many of the longer-term ATM applications is currently restricted by information available on avionics buses. However, new sources of intent information may become available.[24] Near-term applications such as RNP navigation should drive the development of these data sources. The intent framework established by the new TS and TC reports enables these data to be incorporated as avionics systems are evolved and as needed to meet surveillance application requirements.

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