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Development of Intent Information Changes to Revised Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (RTCA/DO-242A)

Richard Barhydt
Langley Research Center, Hampton, Virginia

Anthony W. Warren
Boeing Air Traffic Management, Seattle, Washington

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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Table of Contents

Abbreviations

AATT	Advanced Air Transportation Technologies
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
ARINC	Aeronautical Radio, Inc.
CAS	Calibrated Airspeed
CDU	Control Display Unit
CF	Course-to-Fix
DAG-TM	Distributed Air-Ground Traffic Management
DAP	Downlink of Airborne Parameters
DF	Direct-to-Fix
DO-242	Original ADS-B MASPS
DO-242A	ADS-B MASPS Revision A
E/D	End of Descent
FAA	Federal Aviation Administration
FCU	Flight Control Unit
FD	Flight Director
FL	Flight Level
FMS	Flight Management System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
LNAV	Lateral Navigation
MASPS	Minimum Aviation System Performance Standards
MCP	Mode Control Panel
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
RF	Radius-to-Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
TC	Trajectory Change
TCMI	Trajectory Change Management Indicator
TCP	Trajectory Change Point
TF	Track-to-Fix
TIM	Technical Interchange Meeting
TOC	Top-of-Climb
TOD	Top-of-Descent
TS	Target State
TTG	Time-to-Go
T_U	Update Interval
VFR	Visual Flight Rules
VNAV	Vertical Navigation

Abstract

RTCA Special Committee 186 has recently adopted a series of changes to the original Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance Broadcast (ADS-B).[1] The new document will be published as DO-242A. Major changes to the MASPS include a significant restructuring and expansion of the intent parameters for future ADS-B systems. ADS-B provides a means for aircraft to exchange information about their intended trajectories with each other and with ground systems. NASA and Boeing have played significant roles in recommending these changes and providing supporting analysis. The intent changes are anticipated to provide substantial benefits to several programs and operational concepts under development by the two organizations.

There are four primary changes in the specification of intent broadcast for DO-242A ADS-B systems:

- *Introduction of Target State (TS) reports for broadcasting current flight segment target states, including target altitude and target heading or track angle. These reports provide information about an aircraft's short-term intent.*

- *Adoption of a broader definition of Trajectory Change Points (TCPs) that includes 2-D Area Navigation (RNAV) waypoints, 3-D and 4-D trajectory change points under DO-242, and level-off changes in vertical transitions. The expanded definition accommodates uncertainties that can exist along an aircraft's trajectory.*

- *Introduction of Trajectory Change (TC) reports for broadcasting successive flight segment parameters and TCPs. (TC reports are the DO-242A equivalent of next TCP and TCP+1 reports in DO-242, but with an expanded report format for more generic TCPs, and capability for transmitting up to four TCPs.)*

- *Introduction of new transmission update rates and broadcast conditions for aircraft broadcasting TS and TC reports.*

These changes have been designed to better reflect the capabilities of existing and future aircraft avionics, while providing benefits to current and proposed applications. DO-242A implements intent information elements that can be supported by current avionics systems and data buses. Provisions are made for future incorporation of other intent elements, as needed to meet operational requirements. This document summarizes the reasons for the DO-242A intent changes and provides a detailed overview of current and future intended ADS-B MASPS changes related to aircraft intent.

1 Introduction

The revised Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance Broadcast (ADS-B) document (DO-242A) incorporates significant changes related to the exchange of aircraft intent information. Aircraft intent refers to information known about an aircraft's intended trajectory and is considered to be an enabling technology for the future National Airspace System.[2] ADS-B is a means by which aircraft can exchange intent with each other and with ground stations. As primary sponsors of the MASPS changes related to intent, NASA and Boeing have worked to ensure that the ADS-B MASPS is supportive of future intent applications under consideration by both organizations.

The reason for considering broadcast of intent information in ADS-B systems is to extend the domain of predictability of aircraft trajectories beyond short-term extrapolations using current aircraft position and velocity states. Most current ADS-B applications under development only require state vector data. However, future applications of ADS-B could require intent information to extend look-ahead time for trajectory predictions beyond the current flight segment, or as a means of enhancing integrity of extrapolated path predictions. Proposed air-air applications of intent information include airborne separation planning where more than a few minutes look-ahead time is desirable for conflict detection and conflict prevention, and conflict resolution, where broadcast of intended resolution maneuvers may be important for situation awareness of all nearby equipped aircraft.

As part of the Advanced Air Transportation Technologies (AATT) project, NASA is 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. Intent information is needed to support separation assurance applications and ensure situation awareness for all parties.

ADS-B intent information is also intended to enable advanced air-ground applications such as sequencing and merging of terminal area flow streams[4] and use of precision trajectory separation concepts for aircraft arrival and departure flows in congested airspace.[5-6] For these applications, aircraft intent exchange allows collaboration between air and ground personnel on detailed trajectory plans. Mutual understanding of aircraft intent should help ground controllers take advantage of precise navigation capabilities typical of advanced Flight Management Systems (FMS). System benefits would include more efficient airspace use and user-preferred routing.

The type of intent information considered for ADS-B broadcast is limited to generic trajectory segment information that does not require detailed knowledge of airplane avionics, e.g. the use of standard lateral leg types for horizontal flight segments, and the use of climb, cruise and descent flight segments with specified end-points for vertical flight transitions. The overall objective is to describe intended trajectory segments in a generic way, avoiding the use of airplane specific guidance implementations and control modes.

The original ADS-B MASPS specifies only a limited range of intent information, i.e. the use of 3-D and 4-D TCPs as endpoints of the current and next flight segment, respectively. Several reasons for expanding the use of intent beyond that in DO-242 and ways in which these issues are addressed include:

(1) The original ADS-B TCPs needed revision to reduce ambiguity in representing and predicting flight trajectories. One problem with DO-242 is that TCPs alone do not adequately describe either the current intended trajectory segment, or the intended trajectory change at the endpoint TCP. DO-242A replaces the old TCP and TCP+1 reports with a new Trajectory Change (TC) report. In addition to containing TCP-related information, the TC report provides information on connecting flight segments, conformance with the broadcast trajectory, and waypoint altitude constraints that may not involve a trajectory change.

(2) ADS-B intent should better reflect the operational capabilities of existing and future aircraft avionics systems, i.e. to represent autopilot target values when flying in less automated tactical modes, and to include a wide range of aircraft automation systems ranging from current 2-D Area Navigation (RNAV) systems to existing and future FMS-based precision Required Navigation Performance (RNP) RNAV systems. DO-242A incorporates a new Target State (TS) report that provides short-term tactical intent information from the onboard system actively supporting aircraft guidance. Primary elements of the TS report include the target altitude (next level-off altitude or commanded holding altitude) and target heading or track angle (depending on whether the aircraft is controlled to air-referenced heading or ground-referenced track angle).

(3) ADS-B systems will need expansion to better reflect longer-term intent, i.e. beyond that represented by next and next+1 TCPs. Some operational concepts envisioned for ADS-B could require trajectory prediction times in excess of ten minutes look-ahead or longer.[7] Moreover, trajectory changes may occur quite frequently in the terminal area and more TCPs are required than in en route applications for short-term separation and flow planning. These changes are also consistent with recently formulated Eurocontrol ADS-B requirements.[8] The TC report includes data management provisions to handle at least 4 TCPs.

The ADS-B intent revisions summarized in this document address the above issues. The resulting intent specifications are intended to be a basis for DO-242A implementation, and to serve as an incremental basis for future development of ADS-B applications.

2 Scope of DO-242A Intent Changes

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 those directly used to communicate to the pilot or to navigate, guide, or control an airplane. Changes to the ADS-B MASPS address this situation in two ways: (1) allowing aircraft which output some intent information to communicate such intent when appropriate through the TS report and TC report formats, and (2) providing intent provisioning in the report formats for future evolution and introduction of more comprehensive intent data. DO-242A provides an incremental approach to intent broadcasting by allowing for partial broadcast of limited intent while accommodating evolution to more comprehensive intent data on both an individual aircraft basis as avionics systems are upgraded, and with further intent evolution anticipated in future revisions to the ADS-B MASPS.

The newly introduced TS reports allow for broadcast of *Target Altitude*, and *Target Heading* or *Track* 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 allows for 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 TS reporting, then it is allowed to broadcast such information with appropriate status indicators, even if the aircraft's next intended level off altitude may be an unknown FMS target value. However, the fact that the aircraft is only capable of broadcasting selected altitude and autopilot modes is transmitted in the TS report, to avoid interpreting selected altitude as the probable next level-off state.

The TC reports introduced in DO-242A consist of a number of horizontal and vertical flight segment and TC types which are commonly used, have standard segment and TCP parameters, and are available as potential outputs on an ARINC data bus, e.g. the 702A trajectory bus.[9] 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. (See Section 8 for further explanation of these leg types.) Fly-over turns can also be modeled by appropriate use of the above leg types in conjunction with a DF or TF flight segment to model the turn transition to a specified end-fix. 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 2-D TCPs are also allowed, i.e. the vertical TCP components are marked as "not-available".

Some parameters and leg types that are important for intent broadcast and are not currently available as inputs on a data bus, or are not sufficiently developed, are provisioned in the TS report and TC reports, but are not fully implemented in DO-242A. Broadcast space is allocated for these elements, but manufacturers are not required to support them at this time. This provisioning should facilitate an easier path to implementation as future research demonstrates their utility in an operational environment. Examples of provisioned elements include operational intent validity (used for conformance monitoring), altitude constraint parameters ("At" and "At and Above/Below"), and leg parameters such as turn radius which may not be available for some RNAV / Lateral Navigation (LNAV) systems. The validity data would provide guidance system status for TS report target values, and navigation system conformance for TC reports and are considered essential for critical separation assurance applications. Current FMS / Vertical Navigation (VNAV) systems provide the ability to specify altitude constraints at specified waypoints or fix locations which may constrain the FMS planned vertical trajectory. Broadcasting of such constraints is important for predicting vertical trajectory level-offs and changes in vertical path to meet such constraints. However, these constraint points are not generally available from FMS systems, and are not available on an ARINC data bus today. Consequently, these parameters and leg types are to be provisioned for later version ADS-B MASPS adoption.

3 Short and Long-term Intent

Target State (TS) reports are implemented in DO-242A in order to provide information about the aircraft's active flight segment. The *active* flight segment refers to the current path and automation states being used for aircraft guidance and control. The primary elements of the TS report include the target altitude and target heading or track angle for the active flight segment. This information is called short-term intent. TS reports provide these intent elements even in cases where no TCP exists or TCP information is only partially available. Long-term intent includes information about TCPs and connecting flight segments, and is provided in a series of Trajectory Change (TC) reports. Both short and long-term intent are considered necessary for certain free flight operating environments.[2]

Figure 1 shows the relationship between information provided in TS reports and TC reports for an aircraft flying a simple trajectory between FMS/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. Other trajectory types and the information used to fill the TS report and TC reports (if available) are described in the following sections.

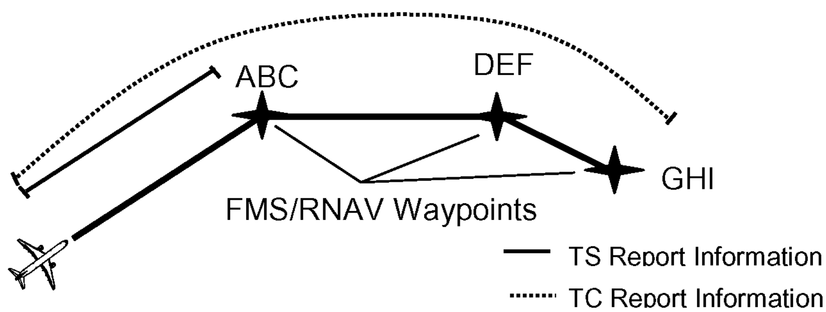

Figure 1. TS and TC Report Information

A 2000 FAA-Eurocontrol sponsored Technical Interchange Meeting (TIM) on intent information included a recommendation in its outbriefing to, "Study the relationship between aircraft control loops and intent parameters."[10] 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.[11] 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, one commanded state is available for the horizontal and vertical axes. The TS report provides these states in the form of target altitude and target heading or track angle. In the outermost loop corresponding to trajectory control, the aircraft has knowledge of multiple TCPs and connecting flight segments. TC reports provide this information. In the trajectory control state, the TS report provides target state information corresponding to the active 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 FMS/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 flight commands may be generated for manual flight 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.

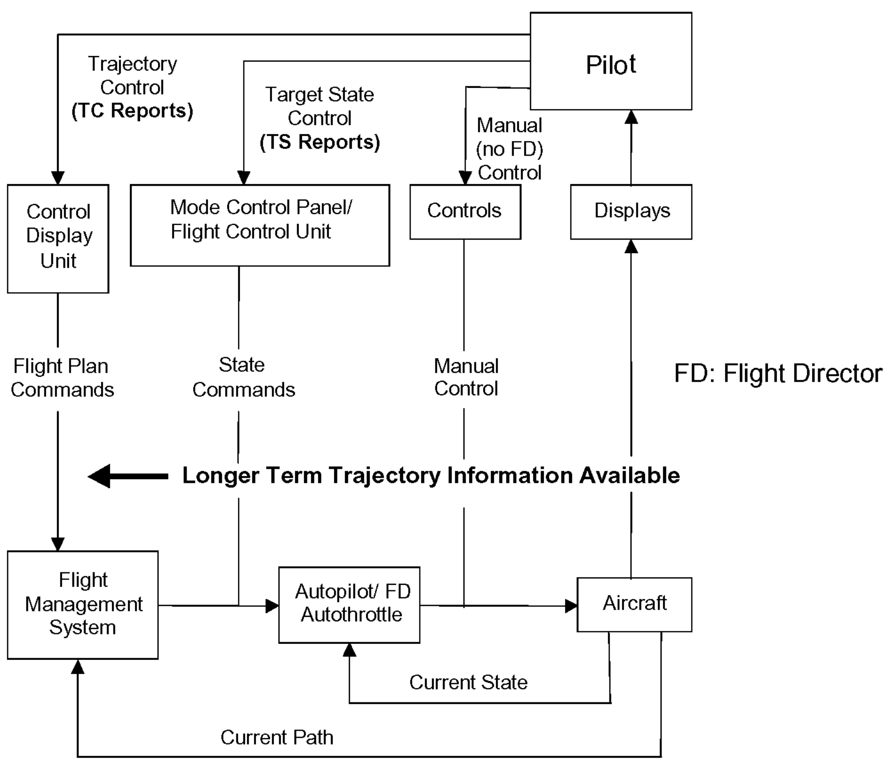

Figure 2. Aircraft Control States

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 intent, although 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 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 Flight Management System (FMS) allows the pilot to specify 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 specify desired speed and altitude appropriate to the current flight segment. 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 targets. Such a situation can occur when the lateral and vertical modes correspond to different control states, when FMS-based modes are armed prior to activation, 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, i.e. cruise altitude or altitude constraint. 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.

Both short (TS report) and long-term (TC report) intent information offer a potential benefit to airborne conflict management, separation assurance, surveillance, flight plan consistency, and conformance monitoring applications. Short-term 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 newly defined TS report enables aircraft with less complex automation systems and aircraft operating with target state control to exchange available intent with nearby aircraft and ground stations. This capability should help facilitate the NASA DAG-TM goal of providing benefits to National Airspace System users having a wide variety of aircraft equipage.[3]

4 Target State (TS) Reports

Short-term intent parameters are assembled in the TS report shown in Table 1. The first three elements of the TS report: *Participant Address*, *Address Qualifier* and *Time of Applicability* are common to all ADS-B reports. Each aircraft has a participant address that is unique from other air vehicles in the same operational domain. This address enables the receiving system to correlate messages received from transmitting air vehicles. The address qualifier denotes the type of address used to identify the transmitting air vehicle (24-bit ICAO address or other). Receiving systems update the time of applicability as new ADS-B messages are received. The time of applicability represents the time in which the reported values are valid.

The principal elements of the TS report are the *Target Altitude* and *Target Heading or Track Angle*. These parameters represent the transmitting aircraft's vertical and horizontal target states and will also be included in the TC report if they are part of a TCP. In order to provide a target state value, aircraft must be equipped with an autopilot or flight director that controls the axis consistent with the target value. The flight director must be on or the autopilot engaged while target state values are broadcast.

Target Heading is provided if the aircraft is actively being controlled to an air-referenced heading angle (such as when operating in a Heading Select or Heading Hold mode). *Target*

Track Angle is used if the aircraft is controlled to a ground or inertial-referenced track angle, such as when flying between waypoints on a flight plan. The *Target Heading/Track Indicator* specifies whether the aircraft is controlled to a heading or track angle. A bit is reserved for *Target Heading/Track Capability*. This field will indicate whether or not the transmitting aircraft has the capability to provide the horizontal guidance target. If implemented, it will allow aircraft unable to determine target heading or track angle as defined above to provide appropriate substitutes.

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. This definition is consistent with that adopted by the European Downlink of Airborne Parameters (DAP) program.[12] When determining target altitude, lower capability aircraft may not be able to consider all aircraft systems supporting vertical guidance. These aircraft may broadcast autopilot selected altitude or holding altitude as a substitute for target altitude. The *Target Altitude Capability* field indicates the transmitting aircraft's ability to determine target altitude. The *Target Altitude Capability* can be used by the receiving ADS-B sub-system to assess the target altitude integrity. Receiving systems should consider that the target altitude field, for aircraft having less than full target altitude capability, may not contain the target altitude as defined above.

Target Altitude Type indicates whether the target altitude is an MSL altitude or a flight level. It is assumed that the local transition level is known to the transmitting aircraft and that the target altitude is MSL or a flight level depending on whether the target altitude is below the transition altitude or not.

Horizontal and *Vertical Data Availability* status is combined with the respective *Horizontal* and *Vertical Target Source Indicators*. If these fields are non-zero, then target heading or track angle and target altitude are being reported and those reports are filled with currently relevant information. (Note: if TS report intent data is not received within a specified 'coast time', then those data fields not recently updated are marked 'not available').

The target source indicators specify the aircraft system providing the corresponding horizontal or vertical target state. Options include the FMS/RNAV, MCP or FCU selected values, or holding the aircraft's current state. In cases where the aircraft is acquiring a target altitude common to the MCP/FCU and FMS, the vertical target source indicator should declare the target to be the latter.

Table 1. Target State Report

	TS Report Element #	Contents
ID	1	Participant Address
	2	Address Qualifier
TOA	3	Time of Applicability
Horizontal Short Term Intent	4a	Horizontal Data Available and Horizontal Target Source Indicator
	4b	Target Heading or Track Angle
	4c	Target Heading/Track Indicator
	4d	(Reserved for Heading/Track Capability)
	4e	Horizontal Mode Indicator
	4f	(Reserved for Horizontal Conformance)
Vertical Short Term Intent	5a	Vertical Data Available and Vertical Target Source Indicator
	5b	Target Altitude
	5c	Target Altitude Type
	5d	Target Altitude Capability
	5e	Vertical Mode Indicator
	5f	(Reserved for Vertical Conformance)

Horizontal and *Vertical Mode Indicators* provide status information on whether the aircraft is acquiring (transitioning toward) the target state or is capturing or maintaining the target. (In the vertical plane, the FMS changes mode when 'capture' of a target altitude occurs. There may or may not be a subsequent guidance mode change when maintaining the target altitude.) These parameters are expected to increase integrity of predicted trajectory changes and to be useful for trajectory conformance monitoring.

Space is reserved for *Horizontal* and *Vertical Conformance* validity. These bits would provide indications of pilot or autopilot conformance to target values. Conformance to vertical and horizontal target states are under consideration, but cannot be implemented in DO-242A due to data source availability issues. These bits would determine whether the aircraft is being controlled in the direction of its flight director or autopilot command. In addition, several bits are reserved in the TS report for future growth.

Consider the example shown in Figure 3. An aircraft climbs at constant vertical speed toward the MCP selected altitude of 8,000 ft while flying a constant 090 heading. TS report values for intent elements 4 and 5, implemented in DO-242A, are provided in Table 2. Both of the targets are resident in the MCP, as indicated by the target source indicators. Non-zero values in these fields indicate that the target heading and target altitude are available and considered reliable. This aircraft has the capability to fully support target altitude, as defined above. The mode indicators show that the aircraft is maintaining the target heading and is acquiring, but has not yet captured, the target altitude.

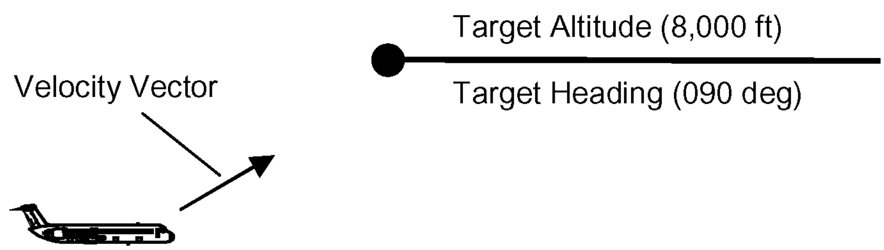

Figure 3. Constant Vertical Speed Climb at Constant Heading to MCP/FCU Selected Altitude

Table 2. Target State Report Elements for Figure 3

	TS Report Element #	Contents	Example Values
Horizontal Short Term Intent	4a	Horizontal Data Available and Horizontal Target Source Indicator	MCP Selected Heading
	4b	Target Heading or Track Angle	090 deg
	4c	Target Heading/Track Indicator	Target Heading
	4e	Horizontal Mode Indicator	Capturing/ Maintaining
Vertical Short Term Intent	5a	Vertical Data Available and Vertical Target Source Indicator	MCP Selected Altitude
	5b	Target Altitude	8,000 ft
	5c	Target Altitude Type	MSL
	5d	Target Altitude Capability	Full Capability
	5e	Vertical Mode Indicator	Acquiring

In another example, the aircraft in Figure 4 is turning to join a 040 course (track) to the ABC waypoint. It is holding its current altitude (15,000 ft). TS report values are provided in Table 3. The target source indicators show that the target track comes from the FMS, while the target altitude is the MCP selected altitude. Horizontal and vertical target states are available and considered reliable. As shown by the mode indicators, the aircraft is acquiring the horizontal target and maintaining the vertical target. Mode indicators show that horizontal and vertical target information is available.

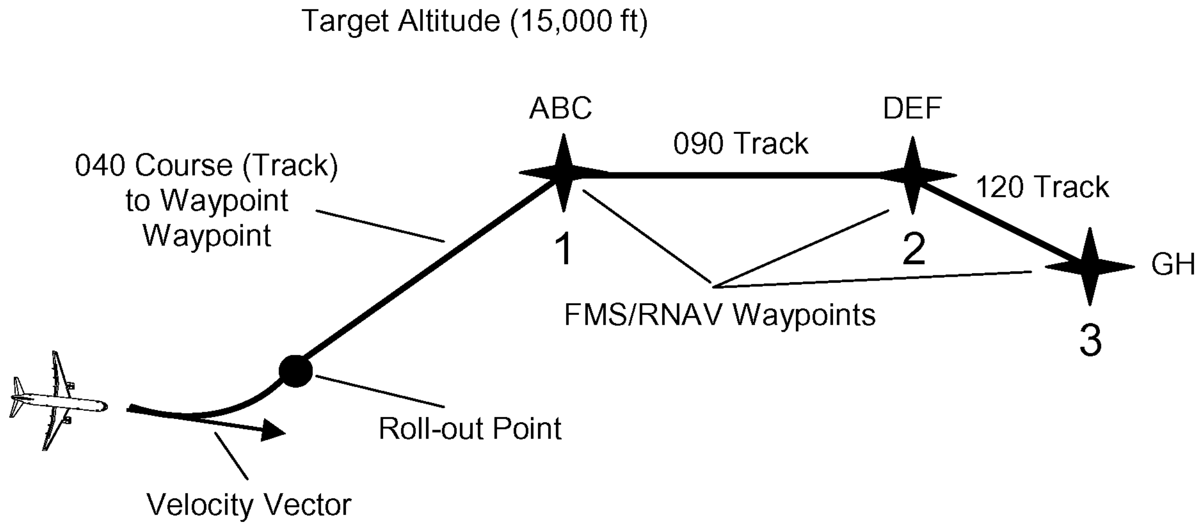

Figure 4. Intercept Course to FMS Flight Plan at Constant Altitude

Table 3. Target State Report Elements for Figure 4

	TS Report Element #	Contents	Example Values
Horizontal Short Term Intent	4a	Horizontal Data Available and Horizontal Target Source Indicator	FMS/RNAV
	4b	Target Heading or Track Angle	040 deg
	4c	Target Heading/Track Indicator	Target Track Angle
	4e	Horizontal Mode Indicator	Acquiring
Vertical Short Term Intent	5a	Vertical Data Available and Vertical Target Source Indicator	MCP Selected Altitude
	5b	Target Altitude	15,000 ft
	5c	Target Altitude Type	MSL
	5d	Target Altitude Capability	Full Capability
	5e	Vertical Mode Indicator	Capturing/ Maintaining

5 Trajectory Change Point (TCP) Definition

Further investigation into the many types of TCPs that can occur along an operational trajectory has led to a revised TCP definition for DO-242A. The new definition accommodates TCPs that do not occur at a known 3D position in space. Many flight segment changes occur when certain trajectory conditions are met, rather than at defined points in space. For example, an aircraft may be climbing in a constant vertical speed mode towards a target altitude (Figure 3). In this case, the condition for changing trajectory is based on capturing the target altitude and not on arrival at a defined point. The predicted location accuracy of these TC types may depend on unknown wind conditions and changing aircraft performance. An analogous lateral situation may occur when an aircraft flies at constant heading to intercept a flight plan route (see Figure 8). In this case, the first TCP occurs when intercepting the track to the next FMS/RNAV waypoint. The intercept location is also dependent on wind parameters that may not be accurately known.

The following TCP definition has been adopted to accommodate prediction uncertainties: "A *trajectory change point (TCP)* is a point where an anticipated change in the aircraft's velocity vector will cause an intended change in trajectory." The change in trajectory may be either a change in path or a change in speed. Examples of TCPs under this definition include 2-D routing changes, the start and end points of a specified turn transition, FMS predicted Top of Climb and Top of Descent points, and target altitudes such as MCP selected altitude when currently in climb or descent transitions. A full list of TC types included in DO-242A is provided in Section 8. Future revisions may add additional TC types that meet this definition.

In addition to TCPs, points involving an altitude constraint (At, At or Above, or At or Below) are provisioned for future revisions into the TC report, 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.

6 Command and Planned Trajectories

A distinction is necessary between intent information that is actively used for aircraft guidance and control and other programmed targets residing within the automation system that are currently inactive. These types of intent are classified as the aircraft's command and planned trajectories, respectively. Command intent is considered most reliable for short-term trajectory predictions,[13] whereas planned intent may give valuable insights into a pilot's long-term strategic plan. NASA's AATT program is currently investigating various conflict alerting strategies that leverage both command and planned trajectory information.

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 5a 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 E/D. The programmed FMS path beyond the selected altitude represents a planned trajectory. In today's operational environment, selected altitude typically 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.

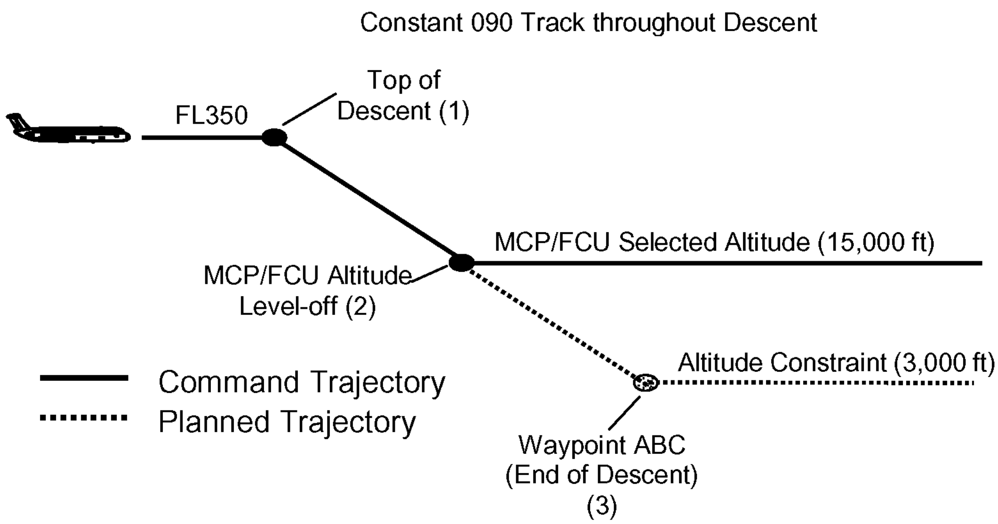

Figure 5a. FMS Descent with Intermediate MCP/FCU Selected Altitude

The command trajectory represents the active guidance targets used by the aircraft. It is therefore considered to be the most reliable source of trajectory intent.[13] Because the command trajectory normally conveys a higher level of path integrity, additional constraints are imposed on TCPs labeled as "command". The following conditions must be met for command TCPs:

1. The transmitting aircraft can determine that a TCP is part of the command trajectory, as defined above, and

2. The transmitting aircraft can determine that it is broadcasting all TCPs between the aircraft's current position and the corresponding TCP.

Unless the transmitting aircraft can meet these conditions, the command/planned flags in the TC report must be set to "planned". The determination of "command" versus "planned" must consider flight mode logic and targets resident in all auto-flight systems that support aircraft guidance. Command/planned status for the horizontal and vertical trajectories is considered independently (see Section 7).

Separation assurance applications will likely emphasize the command trajectory when predicting and resolving traffic conflicts. In some cases, the planned trajectory may be valuable for situation awareness when a change to the command trajectory is anticipated. This situation may be common in cases where the aircraft is flying a published arrival route. Consider the example shown in Figure 5b. The aircraft flies along a lateral and vertical FMS path containing a waypoint altitude constraint (XYZ) between the top and end of descent points. Following a common procedure, the flight crew sets the MCP Selected Altitude to the altitude constraint at XYZ (15,000 ft). Without further pilot input, the aircraft will remain level at 15,000 ft after passing XYZ. This path defines the command trajectory. In order to stay on the FMS descent path, the crew must reset the MCP selected altitude below 15,000 ft prior to reaching XYZ. If the crew intends to continue on the vertical FMS descent path, the command trajectory may not reflect the crew's long-term intentions. Separation assurance and flow management applications may benefit by considering both command and planned trajectory information.

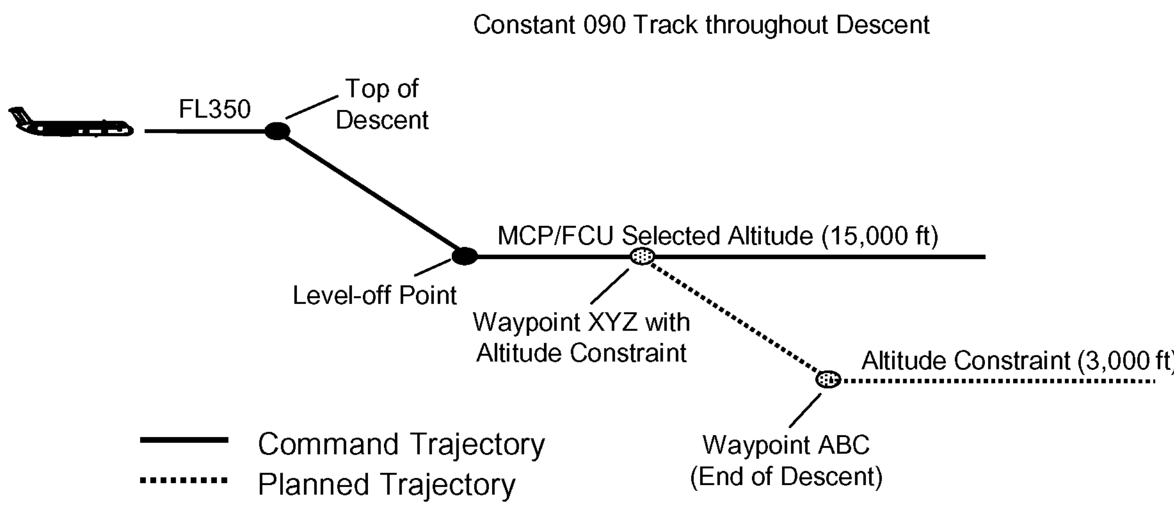

Figure 5b. FMS Descent with MCP/FCU Selected Altitude = FMS Target Altitude

The receiving system can use the horizontal and vertical command/planned flags in the TC report described below to determine whether a broadcast TCP is part of the aircraft's command or planned trajectory.

7 Trajectory Change (TC) Reports

Trajectory Change reports replace the TCPs defined in DO-242. They provide an expandable structure capable of describing TCPs, waypoint constraints, and the flight segments that connect them. One TC report is provided for each TCP or waypoint constraint. Many additional elements have been added to the DO-242 TCP report to facilitate path re-generation, data confidence assessment, and conformance monitoring. Some of the new parameters have been added to be consistent with ARINC trajectory bus specifications as reflected in Eurocontrol ADS Requirements.[8]

Table 4 shows the TC report structure. Not all elements are fully implemented in DO-242A, but are included to show planned expansion as data becomes available. TC report fields are filled based on information availability aboard the transmitting aircraft and the TC type.

Table 4. Trajectory Change Report

	TC Report Element #	Contents
ID	1	Participant Address
	2	Address Qualifier
TOA	3	Time of Applicability
TC Report #	4	TC Report Sequence Number
TC Report Version	5a	TC Report Cycle Number
	5b	(Reserved for TC Management Indicator)[1]
TTG	6	Time to Go (TTG)
Horizontal TC Report Information	7a	Horizontal Data Available and Horizontal TC Type
	7b	TC Latitude
	7c	TC Longitude
	7d	Turn Radius
	7e	Track to TCP
	7f	Track from TCP
	7g	(Reserved for Horizontal Conformance Flag)[1]
	7h	Horizontal Command/Planned Flag
Vertical TC Report Information	8a	Vertical Data Available and Vertical TC Type
	8b	TC Altitude[2]
	8c	TC Altitude Type
	8d	(Reserved for Altitude Constraint Type)[1]
	8e	(Reserved for Able/Unable Altitude Constraint)[1]
	8f	(Reserved for Vertical Conformance Flag)[1]
	8g	Vertical Command/Planned Flag

[1]Only applies to active flight segment.
[2]Altitude estimate or altitude target, e.g. cruise altitude.

The first three elements of the TC report: *Participant Address*, *Address Qualifier* and *Time of Applicability* are common to all ADS-B reports. Time of applicability and Time to Go (TTG) are updated each time a TC report is output. See Section 11 for a discussion of TC report "refreshment" when TC report intent information is not currently received.

The next three elements are parameters used for TC report maintenance and data refreshment, i.e. updating a TC report to the current time of applicability when no new data is received. *TC Report Sequence Number* is the current sequence of TCPs for reconstructing the flight trajectory, i.e. TCP+0, TCP+1, TCP+2, TCP+3, respectively. *TC Report Cycle Number* is a 2 bit code which increments whenever a major change in TC report intent occurs, such as sequencing the current TCP. See Section 11 for a detailed explanation of TC report cycle number and TC report updating and maintenance. Space is reserved for the *TC Management Indicator.* This field will specify how multiple TC reports are managed when there is a major change in intent. Management of multiple TC reports is described in Section 11, but is deferred for later MASPS revisions.

All TC reports should have a unique sequence number, a common time of applicability and a common TC report cycle number at each report time. Intent data not updated within the coast time specified in Section 10 are marked 'not available' and are not to be used until new intent data is received.

Time to Go (TTG) is a required element for all TC reports. It indicates the remaining time to the next TCP. TTG can be added to the time of applicability to determine the estimated time of arrival at the TCP.

Horizontal and *Vertical Data Availability* status is combined with the respective *Horizontal* and *Vertical TC Type* fields. If these fields are non-zero, then horizontal and vertical trajectory change information is being reported and those reports are filled with currently relevant information. (Note: if TC report intent data is not received within a specified 'coast time', then those data fields not recently updated are marked 'not available'). The associated horizontal and vertical data fields should not be used if they are reported unavailable.

The *TC Type* fields specify the flight segment and endpoint change type. Both a horizontal and a vertical TC type are included to aid interpretation of the data elements for constructing path segments. In addition, it is feasible to have both a routing change and a vertical change or constraint at the same waypoint. The TC type fields specify the way that the data received is to be interpreted, i.e. which elements are required for constructing the flight segment and endpoint conditions. Example TC types are fly-by waypoint, direct-to-fix, and RF leg (lateral cases) and top of climb, top of descent, and target altitude (vertical cases). Section 8 describes the TC types included in DO-242A. Other types, including waypoint constraints, may be added to future revisions.

The availability of *TC Latitude* and *TC Longitude* data depends on the transmitting aircraft's operating mode and equipment capability. These elements are provided if they are associated with a known waypoint or can be estimated by the FMS. These elements will have varying accuracy depending on TC type. When using FMS lateral and vertical navigation, TCPs associated with waypoints can be estimated with high confidence. For TCPs which do not involve closed-loop control, such as top of climb, top of descent, or path intercepts, the latitude, longitude and time elements have higher uncertainty. Low integrity latitude/longitude predictions such as the "green arc" on Boeing aircraft that predicts altitude level-offs for MCP modes are not required, but TTG is required for any vertical TCP. These predictions can vary greatly if they do not compensate for wind and aircraft performance.

Figures 6 and 7 show the information needed for fixed radius and fly-by turns (Track *to TCP, Track from TCP,* and *Turn Radius).* Fixed radius turns include turn radius and start and end of turn points. Fly-by turns can also be described in this manner, however the alternate representation in Figure 7 is acceptable if the aircraft cannot provide start and end of turn points. In this case, the fly-by turn waypoint is provided, along with the track to and track from that point and the turn radius. Fly-over turns are represented in DO-242A as a Direct-to or Course-to transition to the specified endpoint. For other horizontal TCPs, only the track to the TCP is provided.

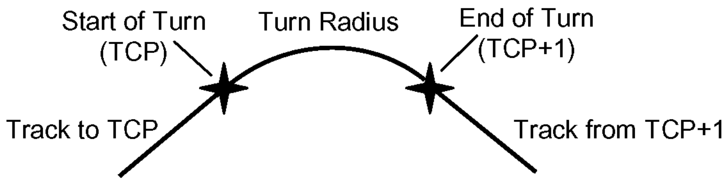

Figure 6. Fixed Radius or Fly-by Turn

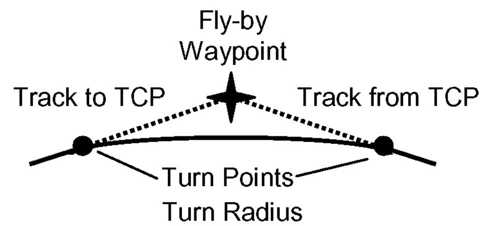

Figure 7. Fly-by Turn

Space is reserved for *Horizontal* and *Vertical Conformance* validity. These flags assess the conformance of the transmitting aircraft to its broadcast path. It is anticipated that future revisions may use horizontal and vertical RNP bounds to specify trajectory conformance. The conformance flags would broadcast the ability of the aircraft to conform to the specified trajectory bounds. For non-RNP aircraft, other measures of conformance may be specified.

The *Horizontal* and *Vertical Command/Planned Flags* delimit whether the flight segment and TCP is part of the command or planned trajectory (see description in Section 6). Successive TCPs or altitude constraint points that are part of the command trajectory should be ordered as they are expected to occur, i.e. by TTG. In cases where time to go cannot be determined, no TC report is generated. If there is space available for additional points, planned TCPs can be included, but they should be placed at the end of the TCP list.

TC altitude fields include *TC Altitude, TC Altitude Type, Reserved for Altitude Constraint Type,* and *Reserved for Able/Unable Altitude Constraint*. *TC Altitude* is the estimated or constraint altitude at the TCP, depending on vertical TC type. *TC Altitude Type* specifies whether the TCP altitude is referenced to MSL or Flight Level. The *Altitude Constraint Type* and *Able/Unable Altitude Constraint* are provisioned for future use. These elements can be used to indicate the type of altitude constraint ("At", "At or Above", "At or Below") and the transmitting aircraft's assessment of its ability to meet the altitude constraint. Altitude constraints may or may not be associated with a trajectory level off, since the aircraft may be able to comply with the constraint without changing its trajectory. In the case that "window" constraints are specified, i.e. both "At or Above" and "At or Below" altitudes are specified; only one window constraint is reported. (See Section 8.) Future DO-242 revisions may further expand TC reports to include speed and time constraints. NASA's AATT program is currently investigating autonomous flight operations in a constrained environment, such as those that may occur just outside a terminal area.[7] These restrictions could include combinations of speed, altitude, and time constraints. Note that the "able / unable" altitude constraint flag is different than the vertical conformance flag since the former applies at a single point and the latter to an entire vertical segment.

Figures 4 and 5 (5a and 5b) are examples of horizontal and vertical FMS trajectories, respectively. The filled TC report elements corresponding to Figures 4 and 5a are given in Tables 5 and 6, respectively. Note that DO-242A does not support multiple TC reports. Both of these examples show how the TC reports would be filled for fully equipped aircraft able to support each element implemented in DO-242A. It is expected that many current aircraft will not have these full capabilities, however these examples are provided in order to illustrate the application of a wide range of DO-242A data elements. Figure 8 shows a more complex trajectory involving MCP/FCU and FMS targets. Tables 7a and 7b offer a comparison of TC reports for Figure 8 provided by fully and partially equipped aircraft, respectfully.

Figure 4 shows an aircraft turning to join a 040 course to waypoint ABC, followed by two routing changes at DEF and GHI. The rollout point is not considered to be a TCP, since the intended path is a Course-to-ABC segment. After rolling out, it will join the FMS flight plan and fly to waypoints DEF and GHI. This example is flown at a constant altitude of 15,000 ft. All latitude and longitude fields are filled since all TCPs in this example are FMS waypoints. The aircraft is holding its selected 15,000 ft altitude, which is repeated for each TCP. The end of the CF segment is the start of the Fly-By Turn, which is represented implicitly by the ABC waypoint and Fly-By turn radius. (In effect, the Fly-By Turn TC report implicitly represents both the CF track-to ABC segment and the Fly-By Turn at ABC to the next TF segment.) The straight line and turn segments for the other Fly-By turns are similarly represented implicitly, reducing the number of TC reports to represent the intended path.

Table 5. Trajectory Change Report Elements for Figure 4

Element #	Contents	TC+0 Report Values (TCP 1)	TC+1 Report Values (TCP 2)	TC+2 Report Values (TCP 3)
4	TC Sequence Number	0	1	2
5a	TC Cycle Number	1	1	1
5b	(Reserved)	*	*	*
6	Time to Go (TTG)	TTG-ABC	TTG-DEF	TTG-GHI
7a	Data Available and TC Type (Horizontal)	CF and Fly-By	TF and Fly-By	TF and Fly-By
7b	TC Latitude	$\text{Latitude}_{\text{ABC}}$	$\text{Latitude}_{\text{DEF}}$	$\text{Latitude}_{\text{GHI}}$
7c	TC Longitude	$\text{Longitude}_{\text{ABC}}$	$\text{Longitude}_{\text{DEF}}$	$\text{Longitude}_{\text{GHI}}$
7d	Turn Radius	$\text{Radius}_{\text{ABC}}$	$\text{Radius}_{\text{DEF}}$	$\text{Radius}_{\text{GHI}}$
7e	Track to TCP	040 deg	090 deg	120 deg
7f	Track from TCP	90 deg	120 deg	Track from GHI
7g	(Reserved)	*	*	*
7h	Command/Planned - H	Command	Command	Command

8a	Data Available and TC Type (Vertical)	Target Altitude	Target Altitude	Target Altitude
8b	TC Altitude	15,000 ft	15,000 ft	15,000 ft
8c	TC Altitude Type	MSL	MSL	MSL
8d	(Reserved)	*	*	*
8e	(Reserved)	*	*	*
8f	(Reserved)	*	*	*
8g	Command/Planned - V	Command	Command	Command

* Reserved for Future MASPS Revisions

In Figure 5a, the aircraft is flying in cruise at FL350, approaching the top of descent. The FMS cruise altitude provides the vertical target source. It has a single FMS altitude constraint at End of Descent (cross ABC at 3,000 ft). The MCP altitude is set to an intermediate value of 15,000 ft. Since the aircraft is limited by MCP altitude, it will level off at 15,000 ft, given the current automation state. This path is the command trajectory. If the pilot resets the MCP altitude prior to reaching 15,000 ft, the aircraft will continue toward the End of Descent at ABC. ABC is included as a planned trajectory point. It has a known 3D location and the FMS time estimate may be provided.

Table 6. Trajectory Change Report Elements for Figure 5a

Element #	**Contents**	**TC+0 Report Values (TCP 1)**	**TC+1 Report Values (TCP 2)**	**TC+2 Report Values (TCP 3)**
4	TC Sequence Number	0	1	2
5a	TC Cycle Number	0	0	0
5b	(Reserved)	*	*	*
6	Time to Go (TTG)	TTG-TOD	TTG-MCP_ALT	TTG-ABC
7a	Data Available and TC Type (Horizontal)	Course-to-Fix	Course-to-Fix	Course-to-Fix
7b	TC Latitude	$\text{Latitude}_{\text{TOD}}$	Estimate	$\text{Latitude}_{\text{ABC}}$
7c	TC Longitude	$\text{Longitude}_{\text{TOD}}$	Estimate	$\text{Longitude}_{\text{ABC}}$
7d	Turn Radius	X	X	X
7e	Track to TCP	090	090	090
7f	Track from TCP	X	X	X
7g	(Reserved)	*	*	*
7h	Command/Planned - H	Command	Command	Command

8a	Data Available and TC Type (Vertical)	Top-of-Descent	Target Altitude	Target Altitude
8b	TC Altitude	350	15,000 ft	3,000 ft
8c	TC Altitude Type	Flight Level	MSL	MSL
8d	(Reserved)	*	*	*
8e	(Reserved)	*	*	*
8f	(Reserved)	*	*	*
8g	Command/Planned - V	Command	Command	Planned

*Reserved for Future MASPS Revisions
"Estimate": Element contents filled with FMS lat/long estimates, if available.

The TC report provides flexibility for accommodating different TC types and varying amounts of information available onboard the transmitting aircraft. The TC report structure shown in Table 6 represents full reporting capability. Many aircraft may not be equipped to support all of these data elements

The following conditions govern the determination of TC report broadcast for each TCP. These conditions can be applied independently to the horizontal and vertical axis parameters:

1. If the transmitting aircraft does not have an autopilot or flight director engaged, then no TC reports are generated. If the aircraft only supports a single axis autopilot or flight director, then the complementary axis data fields for TC reports are marked "unavailable".

2. A stable TTG must be obtained prior to generating intent messages for TC reporting. A TTG value is considered "stable" if the estimated TTG, based on past information, is consistent with the current TTG value, i.e. the difference between the estimated and current TTG value is less than some threshold value. Specific rules for TTG stability will be determined during TC report format validation testing.

Figure 8 and the associated tables (7a and 7b) show one application of these conditions and the command/planned logic described in Section 6. In this example, the aircraft flies a 030 heading to intercept a lateral FMS path (TCP #1) consisting of waypoints ABC (TCP #2) and DEF (TCP #4). The aircraft also climbs at constant vertical speed and levels off at FL210 (TCP #3). Tables 7a and 7b show TC reports for Figure 8 provided by a fully equipped aircraft (able to support all DO-242A elements) and one considered to represent an early (partially equipped) glass cockpit aircraft, respectfully.

The fully equipped aircraft (Table 7a) provides FMS estimates for the latitude and longitude at the intercept point and MCP level off. Altitude estimates are provided at waypoints ABC and DEF. Since heading legs are not supported in ARINC 702A, the track to path intercept must be estimated using the current track. The aircraft will join the planned path with a fly-by turn.

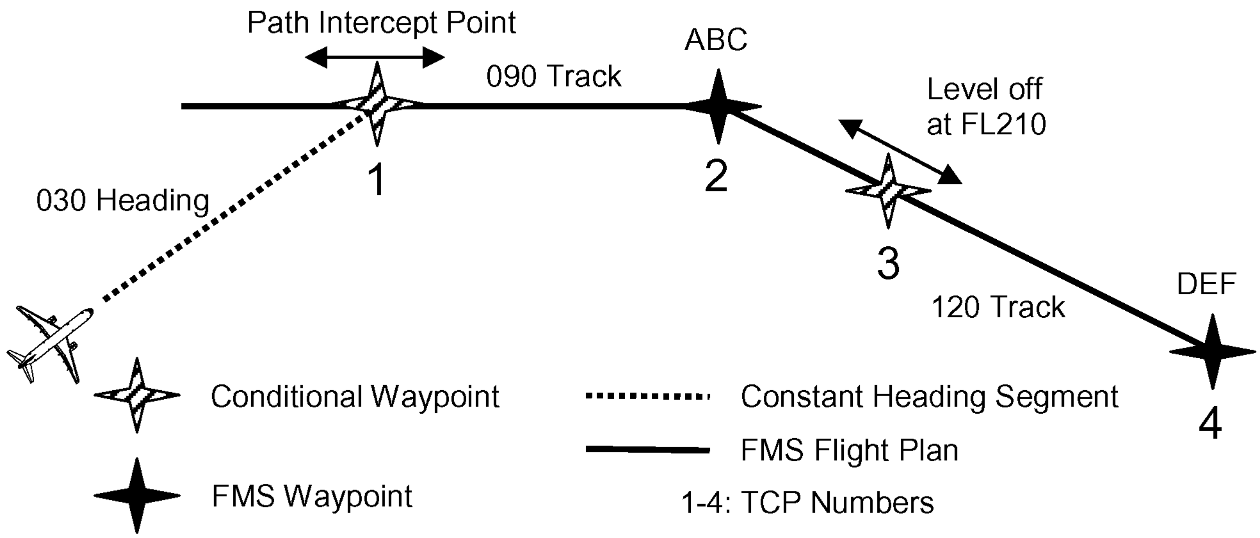

Figure 8. Constant Vertical Speed Climb and Constant Heading to Intercept an FMS Flight Plan

Table 7a. Trajectory Change Report Elements for Figure 8 (Fully Equipped Aircraft)

#	Contents	TC+0 Report Values (TCP 1)	TC+1 Report Values (TCP 2)	TC+2 Report Values (TCP 3)	TC+3 Report Values (TCP 4)
4	TC Sequence Number	0	1	2	3
5a	TC Cycle Number	0	0	0	0
5b	(Reserved)	*	*	*	*
6	Time to Go (TTG)	TTG-Intercept	TTG-ABC	TTG-MCP_ALT	TTG-DEF
7a	Data Available and TC Type (Horiz)	Fly-by	TF and Fly-by	Course to Fix	TF and Fly-by
7b	TC Latitude	Estimate	$\text{Latitude}_{\text{ABC}}$	Estimate	$\text{Latitude}_{\text{DEF}}$
7c	TC Longitude	Estimate	$\text{Longitude}_{\text{ABC}}$	Estimate	$\text{Longitude}_{\text{DEF}}$
7d	Turn Radius	Intercept Radius	$\text{Radius}_{\text{ABC}}$	X	$\text{Radius}_{\text{DEF}}$
7e	Track to TCP	Current Track	090	120	120
7f	Track from TCP	090	120	X	Track from DEF
7g	(Reserved)	*	*	*	*
7h	Command/Planned (Horizontal)	Command	Command	Command	Command
8a	Data Available and TC Type (Vertical)	Estimate	Estimate	Target Altitude	Target Altitude
8b	TC Altitude	Estimate	Estimate	210	210
8c	TC Altitude Type	MSL	Flight Level	Flight Level	Flight Level
8d	(Reserved)	*	*	*	*
8e	(Reserved)	*	*	*	*
8f	(Reserved)	*	*	*	*
8g	Command/Planned (Vertical)	Command	Command	Command	Command

*Reserved for Future MASPS Revisions
"Estimate": Element contents filled with FMS lat/long estimates, if available.

The partially equipped aircraft flying the Figure 8 trajectory (Table 7b) has an MCP and FMS. The FMS cannot predict the location of the path intercept and does not provide lateral position for the MCP level off. Target altitude in this case represents the selected altitude provided by the TS report. Since the FMS does not support path intercepts, no TC report is provided for TCP #1 (a blank column is provided for clarity). The possibility of an intermediate horizontal TCP requires all successive horizontal TCPs to be labeled as "planned". All vertical TCPs are "planned" because the aircraft cannot fully determine next target altitude. For instance, it has no means to determine if an intermediate level off (such as an altitude constraint) will occur between the aircraft's current position and the MCP level off at FL210. (Note: TTG to MCP level off can be estimated from estimated altitude at ABC, TTG to ABC, and climb rate, if no FMS avionics bus gives a time estimate to MCP level off.)

Table 7b. Trajectory Change Report Elements for Figure 8 (Partially Equipped Aircraft)

#	Contents	No Report for Intercept Point	TC+0 Report Values (TCP 2)	TC+1 Report Values (TCP 3)	TC+2 Report Values (TCP 4)
4	TC Sequence Number		0	1	2
5a	TC Cycle Number		0	0	0
5b	(Reserved)		*	*	*
6	Time to Go (TTG)		TTG-ABC	TTG - MCP_ALT	TTG-DEF
7a	Data Available and TC Type (Horiz)		TF and Fly-by	Not Available	TF and Fly-by
7b	TC Latitude		$\text{Latitude}_{\text{ABC}}$	X	$\text{Latitude}_{\text{DEF}}$
7c	TC Longitude		$\text{Longitude}_{\text{ABC}}$	X	$\text{Longitude}_{\text{DEF}}$
7d	Turn Radius		$\text{Radius}_{\text{ABC}}$	X	$\text{Radius}_{\text{DEF}}$
7e	Track to TCP		090	X	120
7f	Track from TCP		120	X	Track from DEF
7g	(Reserved)		*	*	*
7h	Command/Planned (Horizontal)		Planned	X	Planned
8a	Data Available and TC Type (Vertical)		Estimate	Target Altitude	Target Altitude
8b	TC Altitude		Estimate	210	210
8c	TC Altitude Type		Flight Level	Flight Level	Flight Level
8d	(Reserved)		*	*	*
8e	(Reserved)		*	*	*
8f	(Reserved)		*	*	*
8g	Command/Planned (Vertical)		Planned	Planned	Planned

*Reserved for Future MASPS Revisions
"Estimate": Element contents filled with FMS lat/long estimates, if available.
"X": Information not available.

The TC report format provides a flexible structure for accommodating aircraft with widely varying navigation and automatic flight equipage. In addition to the partially equipped FMS aircraft represented in Figure 7b, numerous other variations are possible. For example, many RNAV and GPS systems only allow lateral waypoints and have no associated altitude estimate. Capability is also provisioned in the TC report for handling additional TC types in future MASPS revisions. As discussed above, future DO-242 revisions may include the capability to report waypoint constraints. Altitude constraints are likely to benefit a number of applications,[4-5,7] and space is allocated for these point types in DO-242A.

8 Horizontal and Vertical TC Types

A limited number of basic horizontal and vertical TC types are accommodated in DO-242A of the MASPS to enable representation of common trajectory flight segments for flight path prediction. It is expected that future revisions of the MASPS will accommodate additional TC types, depending on evolution of airplane avionics and on application needs, e.g. additional lateral types such as hold patterns and additional vertical types such as waypoint altitude constraints. Some of the TC types such as Direct-to-Fix transitions and Fly-by-Turns are needed to represent non-precision trajectories where the inertial path over the earth is not entirely predictable. Other TC types such as Course-to-Fix, Track-to-Fix and Radius-to-Fix turns are needed to represent precision RNP flight legs. (In the future, intent integrity concepts may be introduced to monitor conformance to horizontal and vertical RNP bounds.[6] This version of the MASPS simply uses precision and non-precision TC types.) The vertical TC types include maintain or level at a Target Altitude (which may also be represented in the TS report), and traditional Top-of-Climb and Top-of-Descent trajectory changes. Estimated altitudes are provided when transitioning towards a target altitude at a lateral trajectory change. Altitude constraints are also provisioned as a future TC type.

8.1 Horizontal TC Types

8.1.1 Geodesic Path (Straight Course) to Fix Lateral Transition

The Geodesic Path to Fix transition includes both Course to Fix (CF) and Track to Fix (TF) leg types. The lateral path is defined by a course or track angle to a 2-dimensional waypoint that defines the endpoint TCP (see Figure 9). This TC type is typically followed by a routing change, i.e. a Direct to Fix (DF) transition or a Radius to Fix (RF) turn. The case where a CF or TF leg ends with a Fly-By Turn is a separate case since more parameters are needed to represent Fly-By turn cases. From the viewpoint of the transmitting aircraft, CF and TF leg types are somewhat different since the latter represents a transition between a "from" waypoint toward the "to" waypoint / TCP point. However, from the receiving system viewpoint there is no difference between a CF and a TF leg ending at a TCP, since the "from" waypoint is only implicitly represented by the Track to TCP. Thus, both cases are combined into a single TC type. Time-to-Go to TCP is also required in order to properly sequence this and other flight segments.

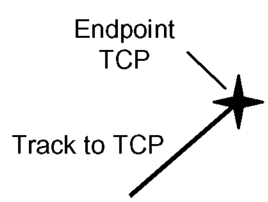

Figure 9. Geodesic Path to Fix Lateral Transition

8.1.2 Fly-By Turn Transition (Including CF or TF to Fly-By Turn Segment)

The Fly-By Turn TC report implicitly represents two flight segments, i.e. a straight segment such as a Course-to-Fix directed toward the fly-by waypoint, and the actual fly-by turn transition to the track-from course. Figure 10 shows the defining elements of a fly-by turn, other than turn radius and turn center. Fly-by turns are considered non-precision leg types since the start-of-turn point and end-of-turn points constructed using turn radius are rough estimates of turn behavior, i.e. the actual path over earth can be substantially different due to winds and flight technical error. However, fly-by turns save message bandwidth compared to the use of explicit TCPs for start and end of turn segment. Required elements include the fly-by latitude, longitude and time-to-TCP (time to fly-by point sequencing), and track-to TCP, turn radius, and track-from TCP. Turn direction (one bit indicator) is also available for some systems and may be desirable for ADS-B transmission, but is not required for path reconstruction. Since end-of-turn is implicit, the TC report is sequenced when the track angle state captures the track-from TCP.

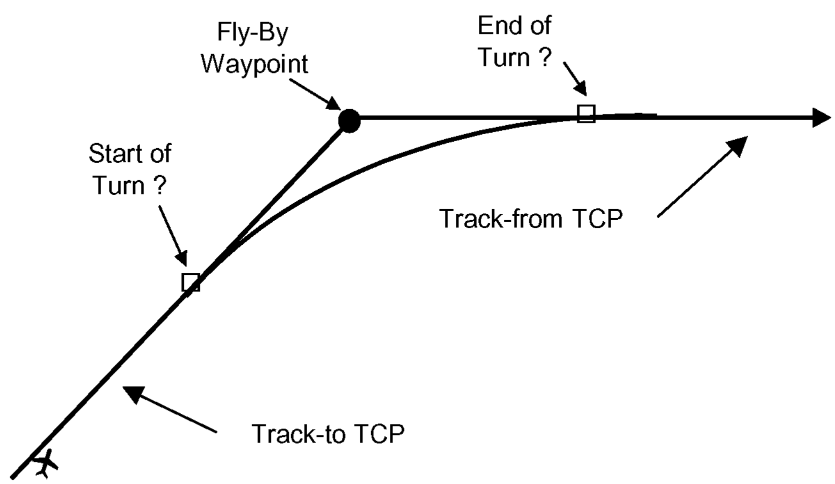

Figure 10. Fly-By Turn Transition Showing Turn Start and Turn Endpoints

8.1.3 Direct-to Fix Lateral Transition

The Direct to Fix (DF) transition is defined implicitly as a path from the current horizontal position and velocity to the specified endpoint TCP. The transition typically consists of an initial turn transition to orient the velocity vector in the direction of the endpoint TCP, and a straight-line segment proceeding directly toward the specified endpoint (see Figure 11). The Direct-to Fix can be used as a means of specifying a fly-over turn toward the next waypoint, and is considered a non-precision trajectory type since DF segments are typically not repeatable or well defined in terms of turn behavior. Mandatory elements for the Direct-to-Fix TC report include the endpoint latitude, longitude and estimated time-to TCP, and a track-to TCP which can be computed from the latest reported position state vector as the direction from the aircraft position to the TCP (assuming that DF is the active flight segment). The track-to TCP will change dynamically in the turn transition phase until the aircraft velocity vector is aligned toward the endpoint TCP, and then remains relatively constant after the turn segment is completed. (Note: the DF transition is backwards compatible with the original DO-242 TCPs.)

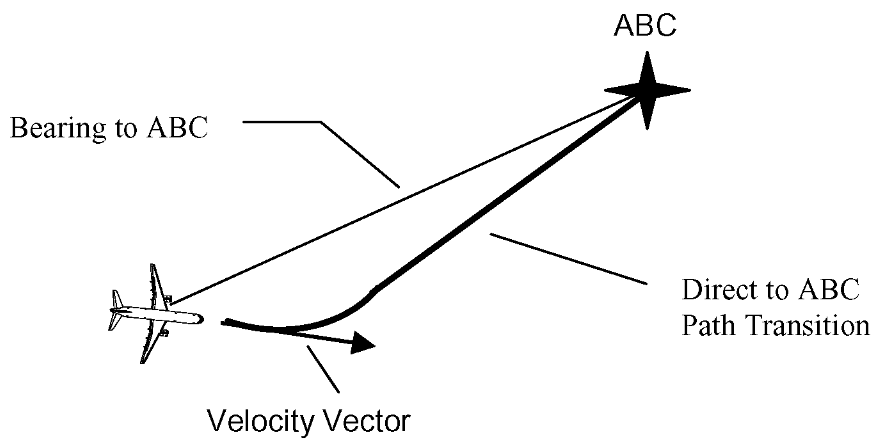

Figure 11. Direct to ABC Lateral Transition Example

8.1.4 Direct to Fly-By Turn Transition

The Direct-to Fly-By is a combination of a Direct-to segment followed by a Fly-By turn. The information conveyed is very similar to the Fly-By turn transition, except for the meaning of the track-to Fly-By component, i.e. latitude, longitude, and TTG to the fly-by waypoint are required as well as track-to, track-from and turn radius components. If the DF to Fly-By is the active flight segment, then track-to may be computed as the inertial bearing angle from the current aircraft position to the fly-by waypoint. If the DF to Fly-By is preceded by an earlier TCP, then the track-to is computed as the bearing angle from the preceding TCP to the fly-by waypoint. However, the trajectory reconstruction process is inherently different for a DF to Fly-By compared to a TF to Fly-By transition, since the DF transition typically includes a turn segment to align the velocity vector toward the fly-by TCP, whereas the TF to Fly-By assumes a straight-line trajectory from the previous waypoint or TCP. Figure 12 shows a DF to Fly-By transition.

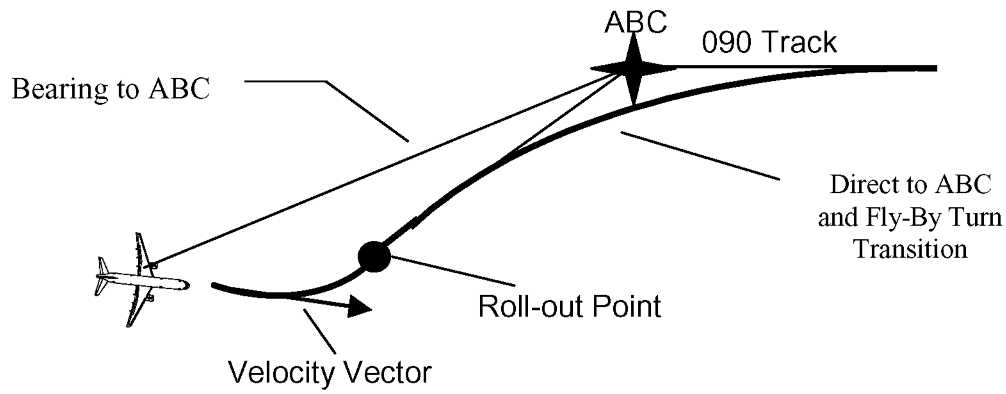

Figure 12. Direct to Fly-By Lateral Turn Transition

8.1.5 Radius to Fix Turn Transition

The Radius to Fix (RF) turn transition describes a constant radial turn over the earth, beginning at a turn start point that is the previous TCP and ending at the endpoint fix. Typically, RF turns are used to describe precision trajectories consisting of CF or TF to fix geodesic path segments and RF turn segments. Mandatory elements include the endpoint TCP latitude, longitude and time-to-TCP, the turn radius, and the track-from TCP. Turn direction can be transmitted also, but is not a required element. The turn center-point is constructed by first generating a line perpendicular to the track-from direction at the fix endpoint. The turn center-point is placed along this line segment at a distance equal to the turn radius from the endpoint fix. Care must be taken to achieve continuity of position and velocity when transitioning from the previous TCP to an RF turn segment. RF turns are considered a basic navigation leg type for implementing precision RNP routings. Figure 6 shows a geodesic path to fix entry and RF turn sequence.

8.2 Vertical TC Types

8.2.1 Unknown Altitude Type

This type is to preserve backwards compatibility with the original MASPS, i.e. a 3-D TCP is specified where the altitude value is an FMS estimate and may or may not represent one of the specified vertical TC types below.

8.2.2 Target Altitude

The Target Altitude TC type applies to level-off targets that end a vertical transition or denote the current maintaining altitude. This type contrasts with specific vertical transition types, such as Top-of-Descent and altitude constraints that specify defined 3-D endpoints. Some aircraft may be able to estimate the aircraft's horizontal position at the Target Altitude trajectory change. Target altitude can be either an autopilot selected or an FMS target value such as selected cruise altitude. It is considered a TCP and separately reported and sequenced with other TCPs, if the command trajectory has a climb or descent transition that ends by leveling off at the target altitude. A target altitude TCP can be different than the target altitude in the TS report. For example, if the aircraft is maintaining cruise altitude prior to Top-of-Descent and the MCP selected altitude is set to an intermediate altitude, then the active target altitude is the selected cruise altitude, and the next two vertical TCPs are the Top-of-Descent point and the MCP selected altitude (see Figure 5a.). The only required TCP elements for this type are time to target altitude, target altitude, and altitude type, although latitude and longitude are desirable whenever available.

8.2.3 Top of Climb (TOC)

Top of Climb is the TCP endpoint of the climb phase of flight, i.e. Top-of-Climb designates the point where the aircraft levels off at a desired cruise altitude. Top-of-Climb is specified by latitude, longitude, and time-to-TCP estimates, as well as the selected cruise altitude. Note, after a TOC TCP, the next TC report contains a vertical TCP with either a target altitude (which can be the current cruise altitude or an intended step change altitude) or the Top-of-Descent (see below).

8.2.4 Top of Descent (TOD)

Top of Descent is the planned endpoint of the cruise phase of flight, i.e. Top-of-Descent designates the point where the aircraft is scheduled to begin descent from cruise altitude. Top-of-Descent is specified by latitude, longitude, and time-to-TCP estimates, as well as the selected cruise altitude. The next TC report after a TOD should contain a Target Altitude or Altitude Constraint vertical TCP with altitude value less than the cruise altitude at TOD. (Note: ideally all points where a vertical transition from level flight begins should be delimited as TCPs also, such as start-of-climb from an intermediate flight level. However, the pilot may simply use the autopilot interface with a new selected altitude and manual engagement to start such flight segments, or alternately may use an "At" constraint at a waypoint with FMS engagement of the next vertical transition segment to achieve the same purpose.)

8.2.5 Estimated Altitude

If the aircraft is in climb or descent mode transitioning towards the next level-off altitude when a lateral waypoint or TCP is sequenced, the altitude value is typically estimated by the FMS, i.e. if the aircraft is not maintaining a target altitude or subject to an altitude constraint at the waypoint, then the altitude value provided by the FMS is an estimated altitude.

8.2.6 Altitude Constraints (At, At and Above, At and Below)

Altitude constraints are often used in the climb and descent phase of flight to maintain separation of departure, arrival, and over-flight traffic patterns in congested airspace. Altitude constraints are provisioned in DO-242A, because current FMS buses may not provide such information to external data users. Representation of altitude constraints is considered essential for future versions of this MASPS (after Revision A), because vertical path intent is not complete until such intent data is available. Moreover, altitude constraints are the basis for implementing vertical RNP using altitude "window" constraints in future RNP systems.[6] Altitude constraint

TCPs will require specification of waypoint latitude and longitude, time-to TCP, the actual altitude constraint value, and the type of constraint, i.e. At, At and Above, or At and Below. The exact representation of such constraints is currently under consideration, i.e. how to accommodate window constraints consisting of a simultaneous At and Below and an At and Above constraint at the constraint fix. Three bits are provisioned in DO-242A to accommodate future expansion.

9 Equipage Class Requirements

In the original MASPS, Level A0 and Level A1 equipage provides basic state vector broadcast capability for VFR and IFR users, respectively. In addition, Level A2 equipage was defined to support extended range ADS-B applications to at least 40 NM range and provide at least a single TCP broadcast in order to assure the validity of trajectory predictions for several minutes look ahead. Level A3 equipage was similarly defined to support extended range applications such as flight path de-confliction out to 90 NM range and provide at least two TCP broadcasts to assure continuity of trajectory predictions near the first TCP, and to achieve at least five minutes trajectory look ahead time.[1]

DO-242A equipage classes retain the concept and overall capability of Level A2 and Level A3 equipage, but revise the definitions of these equipage classes to better reflect horizontal and vertical autopilot and RNAV capability. A minimum Level A2 ADS-B system will have the ability to broadcast TS reports for target altitude and target heading, and at least one TC report. The reason for requiring target altitude is to assure that a Level A2 system has some intent capability in both horizontal and vertical axes, i.e. to support extended range predictions in both horizontal and vertical dimensions. A minimum Level A3 ADS-B system will have Level A2 capability and the capability to broadcast multiple (up to four) TC reports. The reason for allowing up to four TC reports, as compared with two TCPs in DO-242, is that there are several conditions where two TCPs are insufficient to predict ahead five minutes or to 90 NM range. Specifically, routing changes are quite frequent in the terminal area transitioning towards final approach or on initial departure after take-off. Under these conditions, additional TCPs may be needed to achieve desired look-ahead time for terminal area planning applications. Other potential applications that could require more TCPs include air-ground planning applications for en route traffic flow management[14-16] and transition between free flight air-air operations and ATC managed traffic.[7]

10 Minimum Intent Acquisition Range and Reporting Requirements

10.1 Transmission Update and Acquisition Range Requirements

DO-242 requirements on update rate for TCPs are partly implicit and are not directly related to the functional requirements for applications, i.e. "The rate shall be sufficient to ensure continuous positive assessment by the receiving aircraft at least 2 minutes prior to reaching the closest point of approach for class A2 equipage (5 minutes… for class A3)".[1] In addition, TCP update rates as a function of range are specified in Table 3-4 as equal to the coast interval for state vector reports, with 95% confidence of reception.[1] Moreover, most TCP intent data is static or slowly changing until the time to TCP is imminent or the TCP point is sequenced.

The update requirements for TS and TC reports are specified, as in DO-242, as a function of range and in terms of the update interval T_U for 95% reception probability of a single TS or TC report. Table 8 summarizes the new DO-242A minimum requirements for update interval as a function of range. TC reporting requirements are not implemented in DO-242A, but proposed values are specified in an appendix. It is recommended that TS and TC information be updated more frequently if there has been a recent major change in intent or a newly initiated intent broadcast, e.g. the recommended update interval T_U for TS and TC reporting at 40 NM range after an intent change is 12 seconds compared to 18 seconds below.

Table 8. ADS-B Update Requirements for Intent Reporting
(Minimum 95% Update Interval Requirements in Seconds)

Report Type	**R ≤ 20 NM**	**R = 40 NM**	**R = 50 NM**	**R = 90 NM**	**R = 120 NM**	**Notes**
Equipage Class	A2 Required	A2 Required	A2 Desired	A3 Required	A3 Desired	(1)
TS Report	12	18	23			(2)
TC Report (Proposed)	12	18	23	41	54	(2)

<u>Notes for Table 8</u>:

1. *For a Level A2 system, 40 NM acquisition range reception is required, 50 NM is desired. For a Level A3 system, 90 NM acquisition range reception in the forward direction is required, 120 NM acquisition range reception forward is desired.*

2. *Formula for update interval (T_U) is T_U = max (12, 0.45*Range). This formula allows for up to a 15% loss in range to update intent reports, with 95% confidence.*

3. *Table 8 is based on an air-air en route scenario between two aircraft closing at 1200 knots, which is considered a worst case for deriving range requirements for ADS-B conflict alerting.*

4. *The coast interval for report validity is two times the update interval T_U at the last reported range for that ADS-B participant. If no new intent data is received within the coast interval, the associated data are considered invalid.*

10.2 TS and TC Report Broadcast Conditions

TS reports should be broadcast whenever the ADS-B participant is a Level A2 or A3 system, the flight director or autopilot is engaged consistent with the axis of the target states being broadcast and when either of the following conditions apply:

1. Target altitude or an acceptable substitute for target altitude is available from the aircraft automation system, or

2. Target heading or target track is available from the aircraft automation system.

The following conditions govern the determination of TC report broadcast status for each TCP. These conditions can be applied independently to the horizontal and vertical axis parameters:

1. If the transmitting aircraft does not have an autopilot or flight director engaged, then no TC reports are generated. If the aircraft only supports a single axis autopilot or flight director, then the complementary axis data fields for TC reports are marked "unavailable".

2. A stable TTG must be obtained prior to generating intent messages for TC reporting. A TTG value is considered "stable" if the estimated TTG based on past information is consistent with the current TTG value, i.e. the difference between the estimated and current TTG value is less than some threshold value. (Specific rules for TTG stability will be determined during TC report format validation testing.)

Given that the above conditions are satisfied, an A2 level system should, as a minimum, broadcast TC+0 reports whenever the ADS-B participant is within 4 minutes TTG to the next trajectory change point, or as needed to meet the acquisition range requirements for A2 equipage as specified in Table 8. Similarly, an A3 level system should, as a minimum, broadcast TC reports whenever the ADS-B participant is within 8 minutes TTG to the affected trajectory change point, or as needed to meet the acquisition range requirements for A3 equipage as specified in Table 8. (In other words, an A3 system should broadcast all TCPs within 8 minutes TTG to the extent that is feasible for that participant.) These broadcasts should continue until the current flight segment is sequenced or a major change in intent occurs which requires reinitiating TC report intent broadcasts.

In addition to the above conditions for intent broadcasting, it is important for level A3 systems to achieve continuity of intent as active flight segments are sequenced. This may be achieved with minimum additional broadcast of TC reports by adhering to a maximum of one TC report with TTG greater than 8 minutes. If the TTG to TC+0 report is greater than 8 minutes, then only TC+0 reports should be provided. In the event that TTG to the first TCP (TCP+0) is less than 3 minutes, then it is desirable to broadcast a TC+1 report for intent continuity, even if the TTG to TCP+1 exceeds 8 minutes. The overall objective is to achieve at least 3 minutes TTG continuity of intent when feasible, and to prevent indiscriminant broadcast of TC reports that are not operationally relevant.

11 Trajectory Change Report Management

11.1 TC Report Synchronization and Refresh

It is assumed that ADS-B systems will require multiple messages to construct a complete TC report sequence when outputting multiple TC reports. It then becomes necessary to ascertain that whenever a TCP is sequenced or intent information is changed, that the TC reports are appropriately synchronized and that all TC reports are currently valid and have the correct TC sequence number. In order to achieve proper synchronization, all broadcast messages related to TC report intent need to contain some mechanism for validating TC report messages that originated together as a coherent group of sequenced TCP data, and for rejecting old TC report data that originated prior to the latest changes in intent information.

The means adopted of achieving TC report synchronization for DO-242A is to report a two-bit TC cycle number for all TC report related messages. All TC reports which are output at a common time of applicability should be checked to assure that the cycle number for the underlying messages is current and common to all TC reports, i.e. any intent data which contains an old cycle number should be purged and not reported with current TC report data. In the case where the change consists of sequencing (passing through) the TCP+0 point, a TC Management Indicator is provided in the TC+0 report to signal that the data in the TC+1 report, TC+2 report, and TC+3 report can be reused by decrementing the TC sequence number and updating the common time of applicability, i.e. TC+1 report becomes TC+0 report, etc. The TC cycle number is also updated in each refreshed report, so that the re-sequencing process is not repeated until a new TC cycle number is reported.

The TC cycle number should be incremented each time a major change in intent is detected by the ADS-B transmitting subsystem, i.e. the TC cycle number would cycle from 0 to 1 to 2 to 3 to 0 again as the transmitted intent sequence or intent data is changed. Simple changes in estimated values such as estimated altitude at a waypoint are not considered major changes in intent, nor would addition of a TC report with sequence number higher than those currently being reported. Major changes of intent typically would result in TC report re-sequencing or would involve changes in TC type associated with a pilot input, e.g. a “direct to” clearance that bypasses one or more current trajectory change points. The message synchronization process must assure that only currently valid TC report data is being reported and that each TC report at a common report time has a unique sequence number.

TTG is originally computed from ETA or estimated time of arrival at a waypoint as the time difference between the ETA point and the estimated time of applicability for ADS-B broadcasting. When TCP message data with TTG is received, coast time is set to zero, and TTG is referenced relative to the report time of applicability. If no further messages for that TCP are received at the next report time, then coast time is incremented and TTG is decremented by delta time of applicability, i.e. the report time, coast time and TTG are all updated relative to the current time of applicability. This process of TC data ‘refreshment’ continues until an updated TCP message with TTG is received, the coast time exceeds the coast interval threshold for data renewal causing the TC report data to be marked “not available”, or the TC report is sequenced.

11.2 TC Report Management for Future Level A3 Systems

Report management for Level A3 ADS-B systems may be accomplished by means of the TC cycle number and the TC management indicator. A change in the TC cycle number means that a major change in intent has occurred which will require a reissue of one or more TC reports, or a re-sequencing of previously issued TC reports. The TC management indicator provides information for the ADS-B report assembly function as to what actions need to be done for each previously managed TC report, i.e. whether to maintain and refresh that report, whether to re-sequence that report, or whether to mark that report as unavailable until a new TC report replaces the currently invalid intent data. This section describes report management for multiple TC reports as currently envisioned for future versions of the ADS-B MASPS.

The TC Management Indicator (TCMI) is a 3-bit field communicated in messages supporting a TC+0 report and indicates the disposition of all current TC reports when an incremented TC cycle number is detected in any such report. The currently defined values of the TC management indicator are shown in Table 9. The indicator values 0 to 2 are required for any Level A3 system, whereas the values 3 to 5 provide optional capability to minimize the rebroadcast of current TC reports upon detection of a major change in intent. Additional capabilities may be desired for standardization in future MASPS, e.g. a special value could be used to convey a "Direct to" re-sequencing of TC reports which bypasses one or more of the current TC reports.

Table 9. Trajectory Change Management Indicator (TCMI) Values

TC Management Indicator	**TC Report Management Functions Following Receipt of an Updated TC Cycle Number**
0	Maintain and refresh all currently valid TC reports.
1	Forward sequence all current TC reports (TC+1 $\rightarrow$ TC+0, etc.).
2	Mark all currently received TC reports invalid.
3	Maintain current TC+0 report; Mark all subsequent TC+n reports invalid
4	Mark current TC+0 report invalid; Maintain all subsequent TC+n reports.
5	Backward sequence all current TC reports (TC+0 $\rightarrow$ TC+1, etc.).
6,7	Reserved for future indicator definition.

Upon determination of a newly issued TC cycle number, the report assembly function should perform all sequencing and updating of current TC reports, as indicated by the TC management indicator. A TCMI value of <u>zero</u> indicates that all TC reports that are valid should be updated with TC cycle number, and have times updated to the current time of applicability. Normally, the TCMI will have a non-zero value to indicate additional actions to be performed on current TC reports. After the report assembly has performed the actions signaled by the TCMI on all updated TC reports, the TC management indicator should be reset to zero in TC+0 to indicate completion of those tasks. Once the TCMI is set to zero, any TC report data obtained during the current data broadcast can be used to update current TC reports or to initiate new TC reports.
A TCMI value of <u>one</u> indicates that the currently active flight segment reported by TC+0 has been sequenced. This value is required in order to maintain continuity of intent after the current flight segment is sequenced. The sequencing logic is: (1) if there is no currently valid TC+1 report, and the TC+0 report has a horizontal TC type which indicates a valid track from TCP, then the current TC+0 report may be maintained after TC report updating for a time interval not

to exceed 2 minutes beyond the time of TCP sequencing. Otherwise, the current TC+0 report is marked as invalid; (2) if there is a currently valid TC+1 report, then the element values for TC+1 are reinitiated as the new TC+0 report with appropriate report data refreshment. Similarly, any subsequent TC+n reports are resequenced as TC reports with sequence number n-1. The current TC report with largest valid sequence number is then marked invalid since its values are contained in a resequenced TC report.

A TCMI value of <u>two</u> indicates that all current TC reports are to be marked as invalid. This value can be used to signal ADS-B applications that TC intent is no longer available, or as a precursor to reissue of new TC intent after a major change in ADS-B participant intent. Upon receipt of a TCMI value of two, the report assembly function should set the horizontal and vertical data available fields of each TC report to 'data unavailable' so that ADS-B applications will no longer use any previously received TC intent data.

A TCMI value of <u>three</u> indicates a major change in intent in one or more TC reports with sequence number greater than zero. In this case, the TC+0 report is updated and refreshed as indicated above, except that the track-from TCP value may have changed. If the effect of the intent change invalidates the current track-from TCP in TC+0, then the ADS-B transmit subsystem should send the updated value of track-from TCP for TC+0 report updating. All subsequent TC+n reports should then be marked invalid as described above for a TCMI value of two.

A TCMI value of <u>four</u> indicates a major change in TC+0 reporting with subsequent TC+n reports still valid, i.e. this value indicates that new intent messages are forthcoming or have just been received that contain major intent changes for the active flight segment. Upon receiving a TCMI value of four, the current TC+0 report should be marked as invalid and all subsequent TC+n reports updated and refreshed as described above, except that there could be a change in the track-to TCP value for the TC+1 report. If the effect of the intent change invalidates the current track-to TCP in TC+1, then the ADS-B transmit subsystem should send the updated value of track-to TCP for TC+1 report updating.

A TCMI value of <u>five</u> indicates that a new TCP has been inserted prior to the current TC+0 report, i.e. the active flight segment has been changed to insert a horizontal routing change or a vertical constraint prior to the currently active TCP. Figure 13 shows an example scenario where a new TCP has been inserted in order to change path length and time of arrival at subsequent TCP points. Upon receiving a TCMI value of five, the current TC+n reports are given incremented n+1 sequence numbers (limited to a maximum value of four), and updated with incremented TC cycle numbers and times as described above. The current TC+0 report field is then marked as invalid until newly issued TC+0 report data are received. If the effect of the intent change invalidates the current track-to TCP in TC+0, then the ADS-B transmit subsystem should send the updated value of track-to TCP for updated TC+1 reporting.

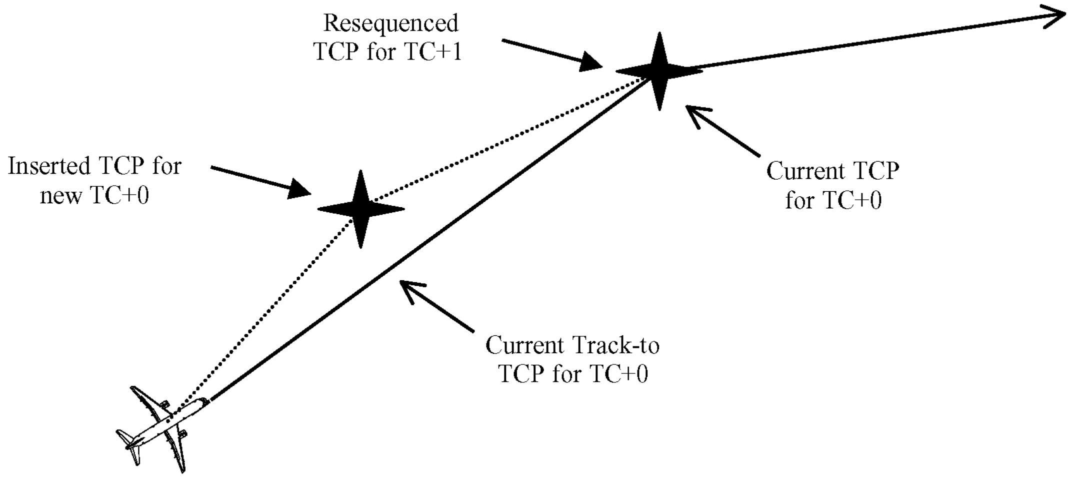

Figure 13. Example Scenario for TCMI Intent Resequencing

12 Conclusions and Future Plans for Intent Consideration

12.1 TS and TC Report Format Validation

Although considerable effort was expended in developing and evolving the TS and TC report formats for ADS-B intent broadcast in DO-242A, this work did not include simulation or detailed analysis of newly introduced ADS-B intent formats. Future simulation and flight test studies of proposed operational concepts using intent broadcast are needed to validate the formats and intent structure developed to date, and to further evolve ADS-B intent standards for future revisions of the ADS-B MASPS. This work needs to be coordinated with the operational groups developing intent-based operational concepts in order to further mature the use of airborne intent for surveillance and separation assurance applications. TS and TC report elements implemented in DO-242A can either be supported by current avionics or may be substituted with commonly available information. Additional coordination is needed with avionics manufacturers to ensure that all TS and TC report elements, including those provisioned for later MASPS versions, can be fully supported and are available for information exchange over standard data buses.

12.2 Intended Airspeed Reporting

DO-242A of the MASPS limits intent reporting to horizontal and vertical target states and trajectory change points. Other types of intent, such as target airspeed and target vertical rate, were not considered for TS reporting in DO-242A, since there seems to be less agreement as to the importance and operational utility of such data. There are some applications such as in-trail approach monitoring where intended airspeed may be extremely valuable for intent reporting, e.g. to cue the trailing aircraft that the lead aircraft is decelerating to a target airspeed value. Similarly, several recent studies have shown the value of reporting aircraft minimum approach speed (VREF) to properly space aircraft on final approach prior to deceleration to landing speed.[17-18] Commanded airspeed changes were not included in DO-242A TC reports, since gross changes in airspeed are accommodated by including Time-to-TCP as a report element. However, potentially useful intent parameters such as target airspeed and airspeed TCPs will be reexamined for introduction in future MASPS revisions.

12.3 Additional TC Leg Transition Types

The TC leg types that were considered for DO-242A are limited to basic leg types for horizontal and vertical transitions. There are other leg types that are potentially available from FMS systems, e.g. procedure holds, Mach/CAS cross-over speeds on climb and descent, planned changes in vertical rate or flight path angle, longitudinal deceleration prior to meter fix entry, etc. One potential leg type is an "Interpolated Track to Fix" type that would be similar to a Track to Fix type, except that the ADS-B transmit subsystem could potentially interpolate additional TCP points in order to assure that a TCP is available for broadcast within operationally relevant time limits for TCP broadcast. Expansion of TCP leg types will be re-examined for future MASPS use based on operational value and future development of separation assurance operational concepts.

12.4 RNP based Intent Integrity Monitoring

The extent to which intent data can be used for critical separation assurance applications will depend on the integrity of such data, i.e. the reliability of trajectory path following and staying within specified bounds of the intended path. The RNP RNAV MASPS[6] specify integrity containment bounds for path following which can serve as a basis for intent integrity metrics for ADS-B reporting, provided such aircraft are RNP qualified. In future versions of the ADS-B MASPS, it is expected that RNP metrics and altitude "windows" may be used to express aircraft capability to stay close to the broadcast path, and to fly within specified trajectory bounds. This version of the MASPS did not include RNP integrity metrics since operational concepts for trajectory based separation assurance are not considered sufficiently mature and only limited operational experience is available to assess the value of RNP systems. The material below summarizes the overall concept of RNP containment integrity and conformance monitoring.

In the horizontal plane, RNP accuracy and integrity bounds are used to describe the expected lateral path deviation and the allowable lateral path deviation for path conformance. For example, an RNP-1 RNAV system is certified to stay within 1 NM of the intended lateral routing at least 95 % of the time, including turn maneuver periods. The RNP integrity bound for conformance monitoring is twice the accuracy value, i.e. a conformance warning is generated by the RNAV system if the aircraft deviates from the intended lateral path by more than 2 NM. If TC intent data is to be used for critical separation assurance applications, such as detecting and resolving flight path conflicts, then it may be necessary to expand TC report data to incorporate lateral RNP RNAV capability and a lateral RNP conformance flag (element 7g of Table 4) for assessing the integrity of horizontal TC report data. The transmitted conformance flag would indicate that the aircraft was capable of detecting a loss of RNP containment, and that the current lateral path deviation was within allowable limits for lateral path conformance. Since the broadcasted intent data could potentially result in misleading predictions of the future intended aircraft path, conformance monitoring on the ADS-B receive side may be necessary as well. Figure 14 illustrates the concept for user conformance monitoring of lateral path predictions for a horizontal turn maneuver. In this example, the aircraft is moving along an intended path toward the left side TCP Start-of-Turn point to the right side TCP End-of-Turn TCP point. As the aircraft approaches the RNP route bound, a conformance alert is generated, cautioning the data user of a potential integrity error in the broadcast path. When the aircraft flies outside the intended RNP containment region a conformance warning is generated, indicating an intent integrity error.

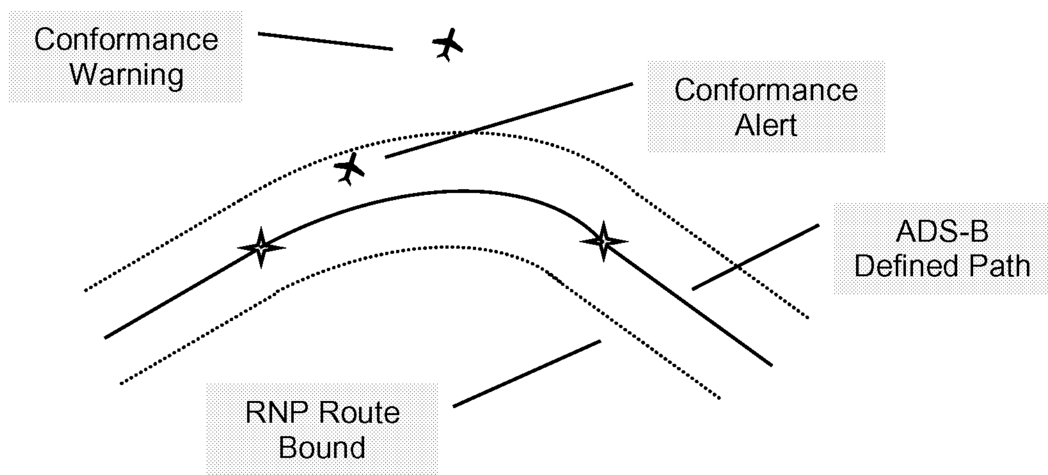

Figure 14. RNP Lateral Conformance Monitoring For Intent Validation

In the vertical plane, RNP integrity is specified as the allowable vertical containment at specified waypoints (ref. RNP MASPS), using either "window" altitude constraints or an "At" constraint at each vertical TCP. This is shown for a descent example in Figure 15. The airplane would be expected to stay within the vertical bounds better than 99% of the time (using thrust or drag energy management if necessary), and to broadcast an alert message if unable to comply with the specified vertical tolerances. The vertical RNP concept is more restrictive than existing altitude constraints and will need operational validation before implementing in future ADS-B MASPS. It is expected that two quantities would need to be added to TC reports for implementation, i.e. the delta height between upper and lower constraints, and a vertical conformance flag (element 8f of Table 4).

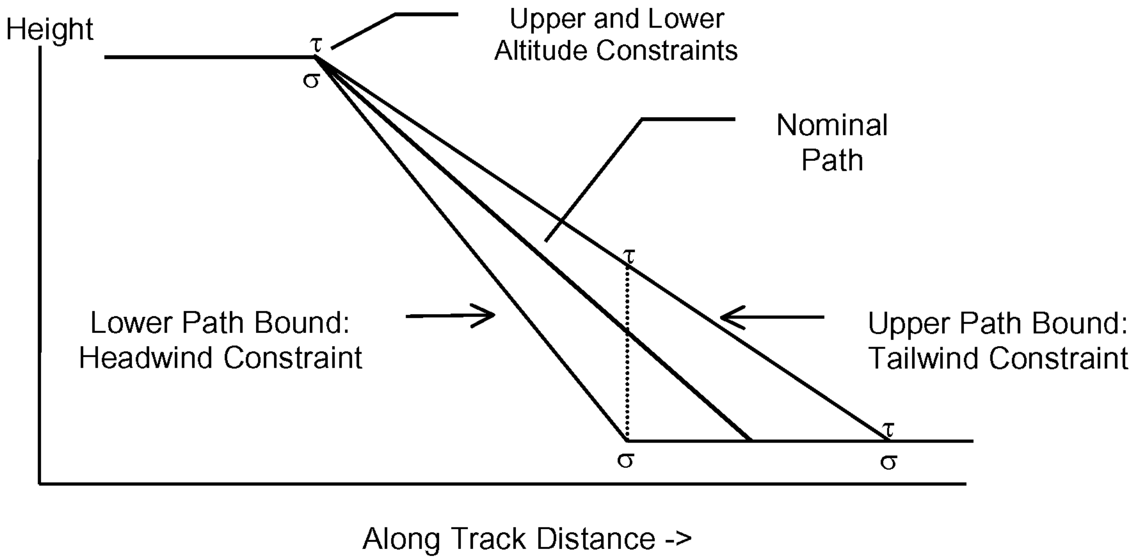

Figure 15. Vertical Path Conformance Region for Descent Example

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Glossary of Trajectory / Intent Terms

Active Trajectory. The *active* trajectory or flight segment refers to the current path and automation states being used for guidance and control of the aircraft.
Command Trajectory. The *command* trajectory refers to the path an aircraft will fly if the pilot does not engage a new flight mode nor change parameters for active or future flight segments.
Non-Precision Trajectory. A *non-precision* trajectory refers to an aircraft path with no specific containment bounds between the intended path or flight parameters and the actual path flown. Typically, transitions to an intended trajectory such as Direct To segments are non-precision, whereas aircraft flying RNP path segments with known lateral and vertical containment are precision trajectories. (A trajectory can also be a precision flight path in the horizontal and non-precision in the vertical plane.)
Planned Trajectory. 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. If the aircraft system is unable to determine whether a trajectory segment is planned or command, then the default type is a planned trajectory.
Selected Altitude. *Selected Altitude* is an altitude value which is dialed in an autopilot interface such as a Mode Control Panel to specify a desired limit value for climb or descent segments, or to specify a desired target altitude to maintain for level flight segments.
Selected Heading / Track. *Selected Heading* is a desired air reference heading value that is dialed into an autopilot interface such as a Mode Control Panel to specify a target value to transition towards and maintain for constant heading angle flight. *Selected Track* is similar to selected heading except that the directional reference is inertial track angle rather than heading.
Short Term Intent. *Short Term (TS report) Intent* refers to the intended path and intended flight parameters on the currently active flight segment. Short-term intent can refer to either autopilot or FMS/ RNAV parameters associated with the current flight segment.
Target Altitude. Ideally, *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. However, since many aircraft only have limited ability to communicate target altitude, it is acceptable to broadcast alternatives to target altitude based on aircraft capability.
Target Heading / Track. *Target Heading / Track* is the heading or track angle target used by the aircraft guidance system to acquire or maintain the lateral path. The actual value used depends on the active guidance source, i.e. allowed values include Selected Heading / Track for direct autopilot specification, Heading/ Track Hold for autopilot maintenance of the current heading or track angle, and FMS / RNAV specified track angle to the next lateral waypoint.
Time of Applicability. *Time of Applicability* is defined in the DO-242 MASPS as the time of report validity. Since Time to Go (TTG) is defined as the "estimated remaining flight time to the TCP point", we here interpret time of applicability for TC reports as the current time for newly received report data. TTG then represents time to TCP relative to current time of applicability.
Trajectory Change Point. A *Trajectory Change Point* is a point where an anticipated change in the aircraft's velocity vector will cause an intended change in trajectory. The change in trajectory may be either a change in path or a change in speed.

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13. ABSTRACT *(Maximum 200 words)*

RTCA Special Committee 186 has recently adopted a series of changes to the original Minimum Aviation System Performance Standards (MASPS) for Automatic Dependent Surveillance Broadcast (ADS-B). The new document will be published as DO-242A. Major changes to the MASPS include a significant restructuring and expansion of the intent parameters for future ADS-B systems. ADS-B provides a means for aircraft to exchange information about their intended trajectories with each other and with ground systems. NASA and Boeing have played significant roles in recommending these changes and providing supporting analysis. The intent changes are anticipated to provide substantial benefits to several programs and operational concepts under development by the two organizations. Major changes include the addition of Target State reports and the replacement of Trajectory Change Point reports with Trajectory Change reports. These changes have been designed to better reflect the capabilities of existing and future aircraft avionics, while providing benefits to current and proposed applications. DO-242A implements intent information elements that can be supported by current avionics systems and data buses. Provisions are made for future incorporation of other intent elements, as needed to meet operational requirements. This document summarizes the reasons for the DO-242A intent changes and provides a detailed overview of current and future intended ADS-B MASPS changes related to aircraft intent.

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