Proposed ADS-B MASPS Revisions: Intent Information Broadcast
RTCA SC-186, WG-6
Version 2.3, October 2001

1. Executive Summary: Proposed Intent Changes for DO-242A

WG-6 of SC-186 is currently preparing Revision A changes to the ADS-B MASPS for balloting in the near future. One of the major changes proposed for Revision A is a significant restructuring and expansion of the Intent parameters for future ADS-B systems. This document summarizes the reasons for the proposed Intent changes and provides a detailed overview of the proposed changes to DO-242 (Ref. 1), for critical review and comment prior to SC-186 balloting and adoption of DO-242A.

There are three primary changes proposed for Intent broadcast with DO-242A ADS-B systems:

- Implementation of Target State Reports for broadcasting current flight segment target states, i.e. target altitude and target heading / track angle,
- Adoption of a broader definition of Trajectory Change Points (TCP's) which includes 2-D RNAV waypoints, 3-D and 4-D trajectory change points under DO-242, and level-off changes in vertical transitions,
- Implementation of Trajectory Change Reports for broadcasting successive flight segment parameters and trajectory change points. (Trajectory change 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 TCP's, and capability for transmitting up to four TCP's.)

Target state reports provide intent information on autopilot target states such as the current or next intended aircraft level-off altitude, i.e. target altitude, and information on directional intent expressed as a target heading angle relative to the air mass, or as a target track angle relative to an inertial or ground reference frame. These parameters reflect short term tactical intent and are typically input by the pilot, e.g. as selected altitude for limiting a descent or climb transition, or as selected heading or track when flying in a tactical, non-automated flight mode. Target altitude and target heading can also refer to the next intended targets flown by an autopilot in more automated modes such as RNAV and FMS modes, or as an input constraint to hold and maintain the current altitude or heading states.

The Trajectory Change Point definition in DO-242 was changed to accommodate a greater range of intent information, and to better reflect operational use and capabilities of existing and future aircraft avionics. The proposed Trajectory Change Reports allow for much greater flexibility in specifying intent information than the TCP's in DO-242, and provide a more comprehensive report structure for development and evolution of future ADS-B applications, e.g. trajectory conformance monitoring. Trajectory change reports include new parameters such as TCP Type to interpret the trajectory segment and change report data, and new parameters such as track-to-TCP, track-from-TCP, and turn radius as needed for trajectory segment predictions, e.g. for representing Fly-By turns consistent with FMS data outputs.

2. Introduction

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 lookahead 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 lookahead 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. ADS-B intent information is also proposed to enable advanced air-ground applications such as sequencing and merging of terminal area flow streams, and use of precision trajectory separation concepts for aircraft arrival and departure flows in congested airspace.

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 current ADS-B MASPS specify only a limited range of intent information, i.e. the use of 3-D and 4-D TCP's as endpoints of the current and next flight segment, respectively. Several reasons have been advanced for expanding the use of intent beyond that in the current MASPS:

(1) The current ADS-B TCP's need revision to reduce ambiguity in representing and predicting flight trajectories. One problem with the current MASPS is that TCP's alone do not adequately describe either the current intended trajectory segment, or the intended trajectory change at the endpoint TCP.

(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 lesser automated tactical modes, and to include a wide range of aircraft automation systems ranging from current 2-D RNAV systems to existing and future FMS based precision RNP RNAV systems.

(3) ADS-B systems need expansion to better reflect longer term intent, i.e. beyond that represented by next and next+1 TCP's. Some operational concepts advanced for ADS-B implementation could require trajectory prediction times in excess of ten minutes lookahead or longer. Moreover, trajectory changes may occur quite frequently in the

terminal area and more TCP's are required than in en-route applications for short term separation and flow planning. The proposed changes are also consistent with recently formulated Eurocontrol ADS-B requirements (Ref. 2).

The proposed ADS-B Intent revisions summarized in this document address the above issues. The proposal summarized here is based on inputs from several SC-186 groups and on inputs from European standards bodies, with substantial filtering and harmonization of inputs. The resulting proposal is intended to be a basis for current MASPS implementation, and to serve as an incremental basis for future development of ADS-B applications.

3. Scope of Revision A Intent Proposal

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. In this proposal we deal with this situation two ways: (1) allowing aircraft which output some intent information to communicate such intent when appropriate through the TSR and TCR report formats, and (2) providing intent provisioning in the report formats for future evolution and implementation of more comprehensive intent data. In short, Revision A provides an incremental approach to intent broadcasting, which allows for partial broadcasting of limited intent in Revision A, with 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 proposed Target State Reports allow for broadcast of next intended *Target* level-off 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, Revision A 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 TSR reporting, then it is allowed to broadcast such information with appropriate status indicators, even if the next intended level-off of the aircraft 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 target state report, to avoid interpreting Selected altitude as the probable next level-off state.

The Trajectory Change Reports proposed for Revision A consist of a number of horizontal and vertical flight segment and TCP 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 (Ref. 3). 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 9 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 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 TCP's 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 that are not currently available as inputs on a data bus or are not sufficiently developed are provisioned in the TSR and TCR reports, but are not fully implemented in Revision A. This includes TSR and TCR operational validity for intent reporting, altitude constraint parameters (AT and AT and Above/Below), and leg parameters such as turn radius which may not be available for some RNAV / LNAV systems. The validity data would provide guidance system status for TSR target values, and navigation system conformance for TCR reports and are considered essential for critical separation assurance applications. Current FMS / VNAV systems provide the ability to constrain vertical trajectories to meet altitude constraints at specified waypoints or fix locations. 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.

4. Short and Long-term Intent

Target State Reports (TSR's) 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 guidance and control of the aircraft. The primary elements of the TSR include the target altitude and target heading or track angle for the active flight segment. This information is called short-term intent. TSR's provide these intent elements even in cases where no TCP exists or TCP information is only partially available. Long-term intent includes information about TCP's and connecting flight segments and is provided in a series of Trajectory Change Reports (TCR's). Figure 1 shows the relationship between information provided in the TSR and TCR's for an aircraft flying a simple trajectory between RNAV waypoints. The target track to waypoint ABC and the target altitude for the active flight segment are provided in the TSR. Three TCR's 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 TSR and TCR's (if available) are described in the following sections.

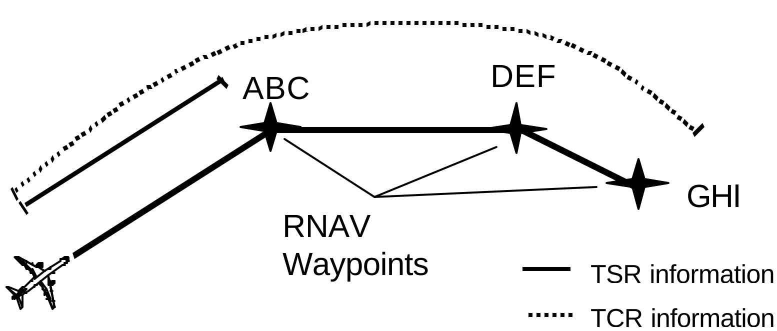


Figure 1: TSR and TCR Information

The amount of intent information available for data exchange depends in large part on the transmitting aircraft's current control state and equipment. The three primary control states, referred to here as manual (no flight director), target state, and flight plan 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 axis, respectively. This information is provided in the TSR. In the outermost loop corresponding to flight plan control, the aircraft has knowledge of multiple trajectory change points and connecting flight segments. TCR's provide this information. In the flight plan control state, the TSR provides target state information corresponding to the next TCP.

Most commercial aircraft have several flight modes corresponding to the target state and flight plan control states shown in Figure 2. Flight modes are normally selected through the Mode Control Panel or Flight Control Unit. They include choices such as hold current heading, hold current altitude, and maintain track between RNAV waypoints. The pilot can concurrently choose lateral and vertical flight modes that correspond to different control states, leading to different intent availability in the horizontal and vertical axes. Horizontal and vertical flight commands may be generated manually using a flight director display mode, rather than through direct autopilot commands. In this paper we do not distinguish between flight director and autopilot operation, since this information cannot be differentiated from ADS-B output reports.

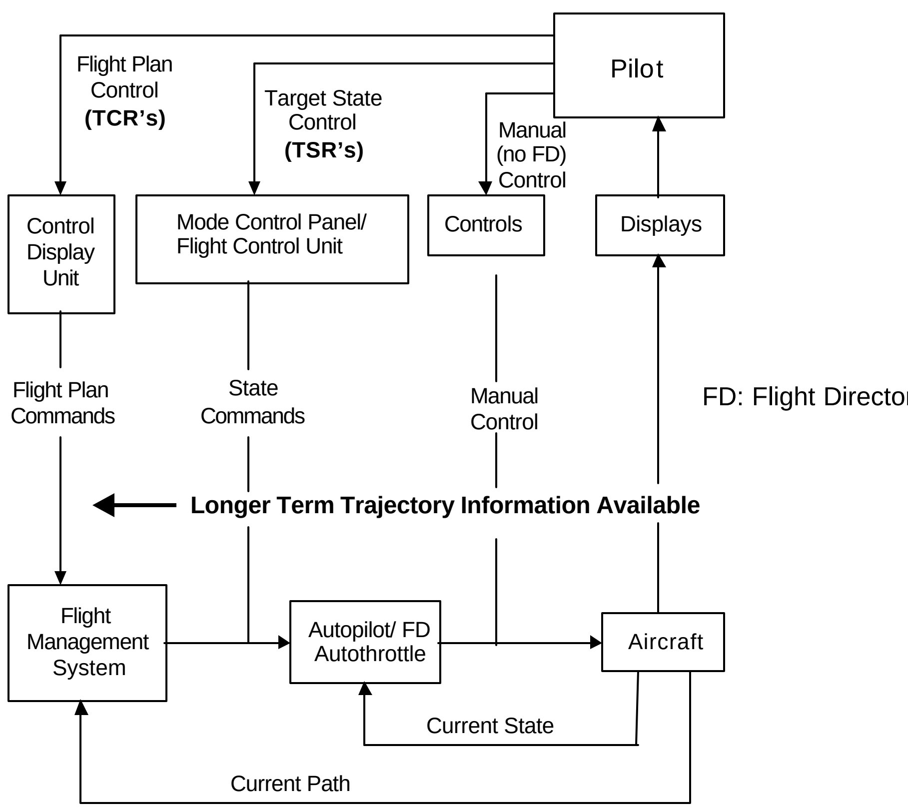


Figure 2: Aircraft Control States

Figure 2 shows typical equipment available on transport category aircraft that is capable of providing the associated information. Other flight hardware may also be able to generate this information. More sophisticated equipment is needed to transmit outer loop information, although inner loop information on current target states may be difficult to transmit for older analog aircraft. A Mode Control Panel (MCP) or Flight Control Unit (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 select a series of target states or flight segments through a keypad-based Control Display Unit (CDU). A pilot may program an entire route complete with multiple waypoints, speed, altitude, and time restrictions, and desired speeds along different flight segments. Because the FMS allows definition of consecutive flight segments, it is frequently used for long-term strategic flying.

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

Both short and long-term intent information offer a potential benefit to airborne conflict management, separation assurance, surveillance, and conformance monitoring applications. Short-term intent is available in almost all flight modes, while 4D TCP's are only available when equipped aircraft are using sophisticated FMS and area navigation (RNAV) systems.

5. Target State Reports (TSR's)

Short-term intent parameters are assembled in the Target State Report, shown in Table 1. The principal elements of this report are the target altitude and target heading or track. These parameters represent the transmitting aircraft's vertical and horizontal target states and will also be included in the Trajectory Change Report if they are part of a TCP. The meaning of target altitude is dependent on the Vertical Automation Capability of the aircraft. If the aircraft is only capable of broadcasting autopilot targets, then <u>*target altitude*</u> is the autopilot Selected Altitude or Holding Altitude depending on the target source indicator. If the aircraft is capable of broadcasting autopilot and all FMS vertical targets, then <u>*target altitude*</u> 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 (Ref. 4). A partial FMS capability, where only certain FMS targets such as intended cruise altitude are available, is also supported.

Target heading is provided if the aircraft is actively being controlled to an air reference heading angle (such as a Heading Select or Heading Hold mode). Target track is used if the aircraft is controlled to a ground or inertial reference track angle, such as when flying between waypoints on a flight plan. A single bit specifies whether the aircraft is controlled to heading or track angle.

Horizontal automation capability is a single bit that specifies whether the aircraft only has horizontal autopilot capability, or also includes RNAV or FMS waypoint reporting.

Table 1: Target State Report

Element #	Contents	Anticipated Resolution or Number of Bits
1	Target Altitude[1]	100 ft[1]
2	Vertical Automation Capability	2 bits
3	Target Source Indicator (Vertical)	2 bits
4	Mode Indicator (Vertical)	1 bit
5	*Validity Bit (Vertical)	1 bit
6	Data Available (Vertical)	1 bit
7	Target Heading / Track	1 degree
8	Heading / Track Indicator	1 bit
9	Horizontal Automation Capability	1 bit
10	Target Source Indicator (Horizontal)	2 bits
11	Mode Indicator (Horizontal)	1 bit
12	*Validity Bit (Horizontal)	1 bit
13	Data Available (Horizontal)	1 bit

*Space reserved for future MASPS versions
[1]Target MSL altitude or flight level, consistent with local transition level.

Horizontal and vertical target source indicators describe the aircraft system providing the corresponding target state. Options include the FMS, 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 target source indicator should declare the target to be the former, e.g. MCP selected altitude rather than an FMS target altitude since MCP selected altitude has limiting authority over the FMS altitude.

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. These parameters are expected to increase integrity of predicted trajectory changes and to be useful for trajectory conformance monitoring.

Future space is reserved for horizontal and vertical validity bits. These bits would provide indications of pilot or autopilot conformance to target values. Guidance validity bits for vertical and horizontal target states are under consideration, but cannot be implemented in Revision A 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.

Horizontal and vertical data availability bits indicate that target heading/track and target altitude are being reported and data reports are filled with currently relevant information.

Consider the example shown in Figure 3. An aircraft climbs at constant vertical speed toward the MCP/FCU selected altitude of 8,000 ft while flying a constant 090 heading. TSR values are provided in Table 2. Both of the targets are resident in the MCP, as indicated by the target source indicators. The mode indicators show that the aircraft is maintaining the target heading and is acquiring, but has not yet captured, the target altitude. The target heading and target altitude are available and considered reliable, as provided by the availability indicators.

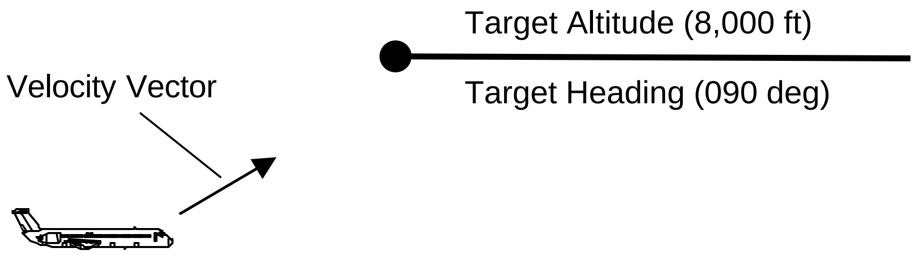


Figure 3: Constant Vertical Speed Climb at Constant Heading to MCP/FCU Selected Altitude

Table 2: Target State Report for Figure 3

Element #	Contents
1	8,000 ft
2	Vertical Autopilot Capability
3	MCP Selected
4	Acquiring
5	*
6	Available
7	090 deg
8	heading
9	MCP Selected
10	RNAV waypoint capability
11	Maintaining
12	*
13	Available

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). TSR 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. The aircraft is acquiring the horizontal target and maintaining the vertical target. Mode indicators show that horizontal and vertical target information is available.

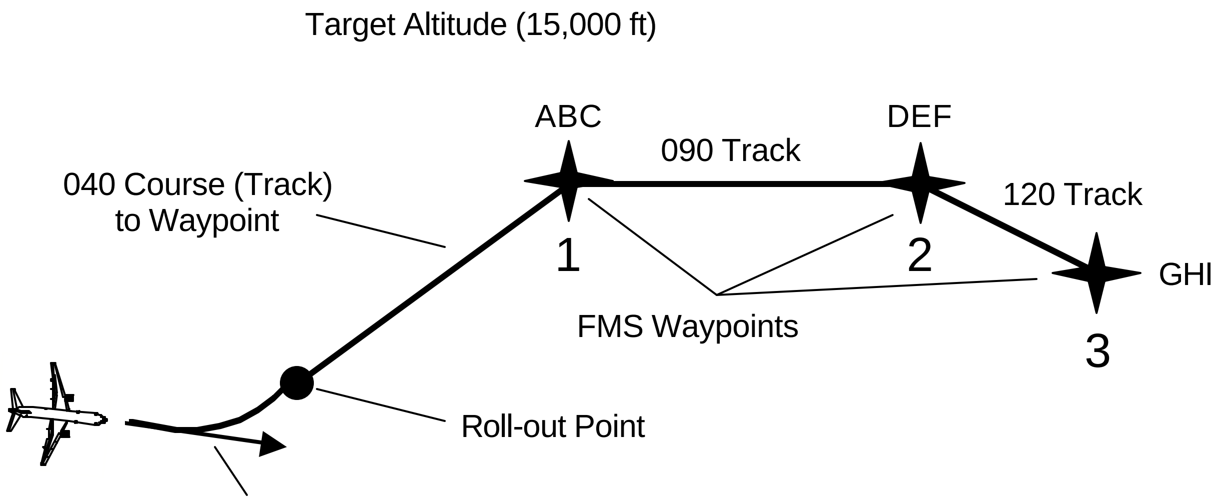


Figure 4: Intercept Course to FMS Flight Plan at Constant Altitude

Table 3: Target State Report for Figure 4

Element #	Contents
1	15,000 ft
2	Vertical Autopilot Capability
3	MCP selected altitude
4	Capture/Maintaining
5	*
6	Data Available
7	040 deg
8	track
9	FMS waypoint capability
10	FMS target
11	Acquiring
12	*
13	Data available

As described above, the target altitude and target heading/track provide horizontal and vertical target states for the active flight segment. Information subsets are allowed for aircraft incapable of providing these target states. MCP/FCU selected altitude and selected heading may be used in place of target altitude and target heading/track, respectively. Likewise, aircraft equipped with only an RNAV system may provide the RNAV track in place of the target heading.

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.

6. Trajectory Change Point (TCP) Definition

Further investigation into the many types of TCP's that can occur along an operational trajectory has led to a proposed TCP definition change for DO-242A. The current definition (DO-242, p. 39) only accommodates TCP's at a known 3D position in space. Although a 3D location is known for FMS waypoints, many flight segment changes do not occur at a known point. For example, an aircraft may be climbing in a constant vertical speed mode towards a target altitude (Figure 3). In this case, the aircraft may not take actual wind conditions into account when predicting the level-off location. Level-off prediction in a climb may also depend on changing aircraft performance. These uncertainties make it difficult to predict an accurate 3D intercept point. An analogous lateral situation may occur when an aircraft flies at constant heading to intercept a flight plan route. The intercept point is also dependent on wind parameters that may not be accurately known for intercept predictions. To account for these uncertainties, the following TCP definition is proposed: "A Trajectory Change Point may be described as a 3D location or interception of a 2D plane with the aircraft's velocity vector where the current aircraft trajectory is intended to change." Further details are provided in Appendix B.

Examples of TCP's 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 TCP types included in Revision A is provided in Section 9. Future revisions may add additional TCP types that meet this definition.

In addition to TCP's, points involving an altitude constraint (AT, AT or ABOVE, or AT or BELOW) are provisioned for future revisions into the Trajectory Change Report, even if they do 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.

7. Command and Planned Trajectories

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 5 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 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 bottom of descent. The programmed FMS path beyond the selected altitude represents a planned trajectory. Typically, selected altitude represents 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.

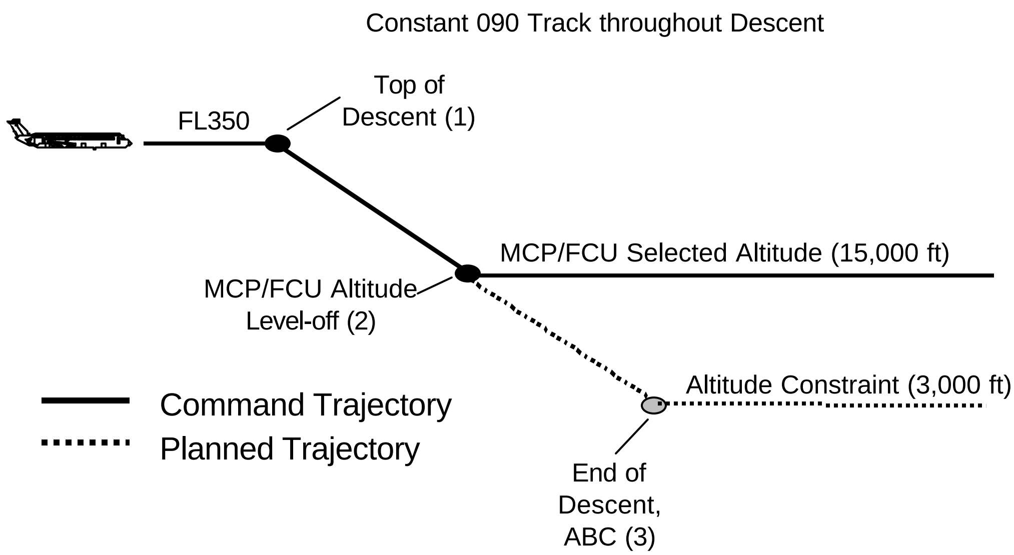


Figure 5: FMS Descent Showing Command and Planned Trajectories

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

Both the command and planned trajectories may provide useful information for separation assurance and flow management applications, respectively. In order to use this information effectively, the receiving system must be able to clearly delineate between the command and planned trajectories. This distinction is provided in the trajectory change report described below.

8. Trajectory Change Reports (TCR's)

Trajectory change reports replace the TCP's defined in DO-242. They provide an expandable structure capable of describing TCP's, waypoint constraints, and the flight segments that connect them. 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 (Ref. 2).

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

Table 4: Trajectory Change Report

Element #	Contents	Anticipated Resolution or Number of bits
1	TCP Type (Horizontal)	4 bits
2	TCP Type (Vertical)	3 bits
3	Latitude	0.1 minute[1]
4	Longitude	0.1 minute[1]
5	Altitude[2]	25 ft / 100 ft
6	Time to Go (TTG)	1 second
7	*Altitude Constraint Type	2 bits
8	*Altitude Constraint Validity[3]	1 bit
9	Turn Radius	0.1 nmi[1]
10	Track to TCP	1 degree
11	Track from TCP	1 degree
12	*TCP Validity (Horizontal)[3]	1 bit
13	*TCP Validity (Vertical)[3]	1 bit
14	Command/Planned (Horizontal)	1 bit
15	Command/Planned (Vertical)	1 bit
16	Data Available (Horizontal)	1 bit
17	Data Available (Vertical)	1 bit
18	TCR sequence number (0, 1, 2, or 3)	2 bits
19 ??	*TCR synchronization code (0, 1, 2, or 3)*	*2 bits*

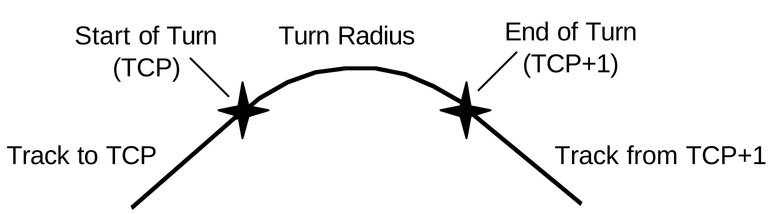
*Space reserved for future MASPS versions
[1]Required resolution for future precision approach / departure applications may be higher
[2]Altitude estimate, may not correspond to altitude constraint.
[3]Only applies to active flight segment.

The TCP type fields in elements 1 and 2 specify the flight segment and endpoint change type. Both a horizontal and a vertical TCP 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 TCP type fields specify the way that the data received is to be interpreted, e.g. which elements are required for constructing the flight segment and endpoint conditions. Example TCP types are fly-by waypoint, direct-to-fix, and RF leg (lateral cases) and top of climb, top of descent, and end of descent (vertical cases). Section 9 describes the TCP types included in Revision A. Other types, including waypoint constraints, may be added to future revisions.

The availability of TCR elements 3-6 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 TCP type. When using FMS lateral and vertical navigation, TCP's associated with waypoints can be estimated with high confidence. For TCP's 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 included. These predictions can vary greatly if they do not compensate for wind and aircraft performance.

Elements 7 and 8 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. Future DO-242 revisions may further expand TCR's to include speed and time constraints.

Figures 6 and 7 show the information needed for fixed radius and fly-by turns (Elements 9-11). 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 Revision A as a Direct-to transition to the specified endpoint. For other horizontal TCP's, only the track to the TCP (Element 9) is provided.



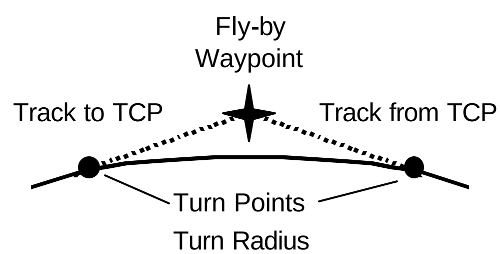


Figure 6: Fixed Radius or Fly-by Turn

Figure 7: Fly-by Turn

Space is reserved for horizontal and vertical validity bits (Elements 12-13). These bits 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 validity bits may broadcast the ability/inability of the aircraft to conform to the specified trajectory bounds. For non-RNP aircraft, other measures of conformance may be specified.

Elements 14-15 delimit whether the flight segment and TCP is part of the command or planned trajectory (see description in Section 7). Successive TCP's or altitude constraint points that are part of the command trajectory should be ordered as they are expected to occur, e.g. by TTG. In cases where time to go cannot be determined, points having an altitude closest to the aircraft's current altitude should be placed first. If there is space available for additional points, planned TCP's can be included, but they should be placed at the end of the TCP list.

Elements 16-17 assess the availability and currency of horizontal and vertical TCP data. The associated horizontal and vertical data fields should not be used if they are reported unavailable.

Element 18 provides the TCR sequence number for reconstructing the flight trajectory, i.e. TCP+0, TCP+1, TCP+2, TCP+3 have sequence number 0, 1, 2, and 3, respectively. *See section 10 for an explanation of the TCR synchronization code, element 19.*

Figures 4 and 5 are examples of horizontal and vertical FMS trajectories, respectively. The filled TCR elements corresponding to Figures 4 and 5 are given in Tables 5 and Table 6, respectively. Figure 4 shows an aircraft turning to join a 040 course to waypoint ABC, followed by two routing changes at DEF and GHI. The roll-out point is not considered to be a TCP, since the intended path is the 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 TCP's in this example are FMS waypoints. The aircraft is holding its selected 15,000 ft altitude, which is repeated for each TCP point. 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 TCR 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 TCR's to represent the intended path.

Table 5: Trajectory Change Report for Figure 4

Element #	Contents	Contents	Contents
1	CF and Fly-By	TF and Fly-By	TF and Fly-By
2	Selected altitude	Selected altitude	Selected Altitude
3	Latitude_{ABC}	Latitude_{DEF}	Latitude_{GHI}
4	Longitude_{ABC}	Longitude_{DEF}	Longitude_{GHI}
5	15,000 ft	15,000 ft	15,000 ft
6	TTG-ABC	TTG-DEF	TTG-GHI
7	*	*	*
8	*	*	*
9	Radius_{ABC}	Radius_{DEF}	Radius_{GHI}
10	040 deg	090 deg	120 deg
11	90 deg	120 deg	Track from GHI
12	*	*	*
13	*	*	*
14	Command	Command	Command
15	Command	Command	Command
16	Data Available	Data Available	Data Available
17	Data Available	Data Available	Data Available
18	0	1	2
19	*1*	*1*	*1*

In Figure 5, the aircraft is flying in cruise at FL350, approaching the top of descent. The FMS cruise altitude is limiting and functions as the vertical target source. It has a single FMS altitude constraint at End of Descent (cross ABC at 3,000 ft). The MCP/FCU altitude is set to an intermediate value of 15,000 ft. Since the aircraft is limited by the MCP/FCU 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/FCU 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 for Figure 5

Element #	Contents (TCR)	Contents (TCR+1)	Contents (TCR+2)
1	Course-to-Fix	Course-to-Fix	Course-to-Fix
2	Top-of-Descent	Selected Altitude	End-of-Descent
3	Est	Est	Latitude_{ABC}
4	Est	Est	Longitude_{ABC}
5	FL350	15,000 ft	3,000 ft
6	TTG-TOD	TTG-MCP_ALT	TTG-ABC
7	*	*	*
8	*	*	*
9	X	X	X
10	Track to T/D	Track to ABC	Track to ABC
11	X	X	X
12	*	*	*
13	*	*	*
14	Command	Command	Command
15	Command	Command	Planned
16	Data Available	Data Available	Data Available
17	Data Available	Data Available	Data Available
18	0	1	2
19	*0*	*0*	*0*

"Est": Element contents filled with FMS lat/long estimates, if available.

The TCR report provides flexibility for accommodating different TCP types and varying amounts of information available onboard the transmitting aircraft. The TCR report structure shown in Table 4 represents full reporting capability. Many aircraft may not be equipped to support all of these data elements. One information subset that will be allowed in Revision A is the ability to provide only 2 dimensional waypoints. Many RNAV and GPS systems only allow lateral waypoints and have no associated altitude estimate. Further information subsets are under consideration. 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 and space is made available for these point types in Revision A.

9. Horizontal and Vertical TCP Types

A limited number of basic horizontal and vertical TCP types are accommodated in our proposal to enable representation of common trajectory flight segments for flight path prediction. It is expected that future revisions of the MASPS will accommodate additional TCP 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 TCP 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 TCP types such as Course-to-Fix, Track-to-Fix and Radius-to-Fix turns are needed to represent precision RNP trajectories. (In the future, intent integrity concepts may be introduced to monitor conformance to horizontal and vertical RNP bounds. This version of the MASPS simply introduces precision and non-precision TCP types.) The vertical TCP types include maintain or level at a Target Altitude (which may also be represented in the TSR report and may or may not include latitude and longitude estimates), and traditional Top-of-Climb, Top-of- Descent, and End-of-Descent TCP's. Altitude Constraints are also provisioned as a future TCP type.

Horizontal TCP Types:

- **Straight Line to Fix Lateral Transition**

The Straight Line 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 delimits the TCP endpoint. See Figure 8. This TCP 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 TCP type. Time-to-Go to TCP is also required in order to properly sequence this and other flight segments.

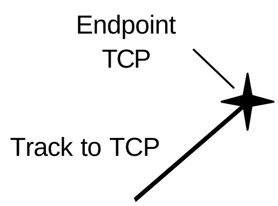


Figure 8: Straight Line to Fix Lateral Transition

- **Fly-By Turn Transition (Including CF or TF to Fly-By Turn segment)**

The Fly-By Turn TCR 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 9 shows the defining elements of a Fly-By turn, other than turn radius and turn center. Fly-By turns are considered non-precision trajectory 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 use of explicit TCP's 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.

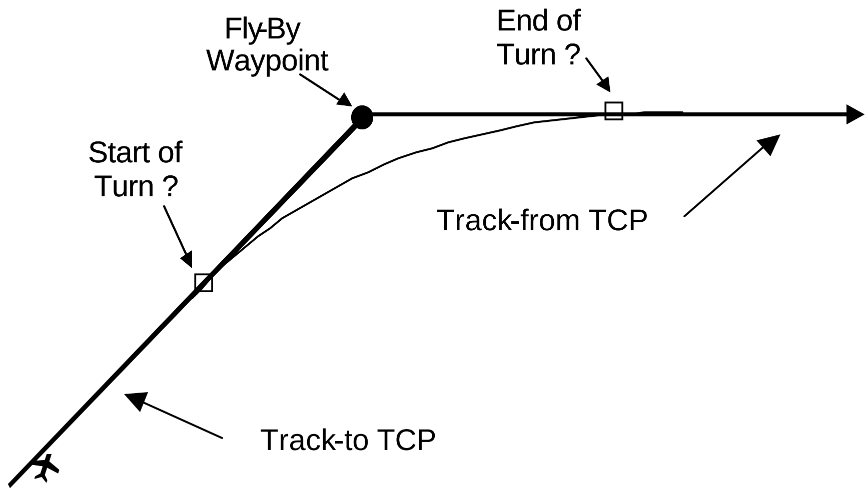
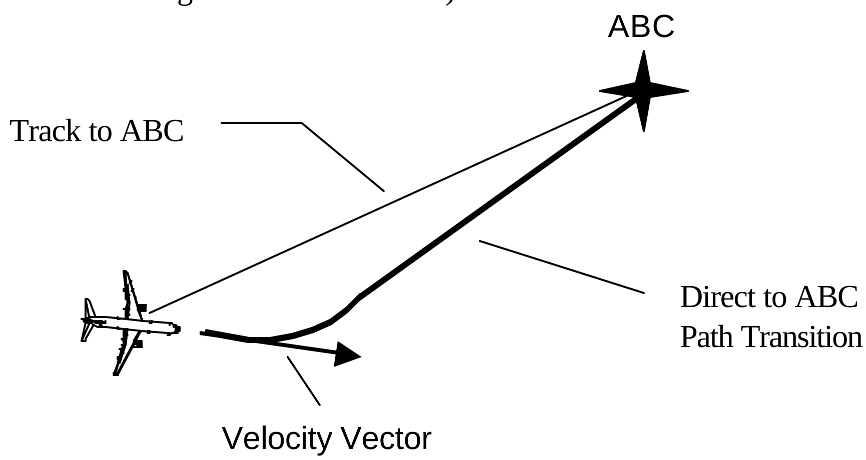


Figure 9: Fly-By Turn Transition with Turn Start and Turn Endpoints shown

- **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 10. 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 TCR 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 TCP's.)



- **Direct to Fly-By Lateral Transition**

The Direct-to Fly- Figure 10: Direct to ABC Lateral Transition Example transition. 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 track 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 track 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 11 shows a DF to Fly-By transition.

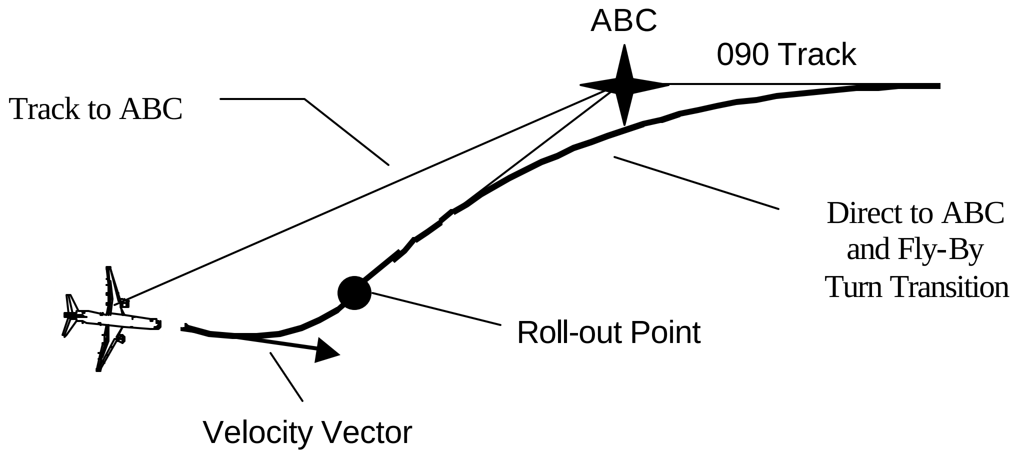


Figure 11: Direct to Fly-By Lateral Turn Transition

- **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 straight line 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. 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 straight line to fix entry and RF turn.

Vertical TCP Types:

- **Unknown Vertical TCP 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 TCP types below.

- **Target Altitude (no fixed endpoint)**

The vertical TCP types are either specific vertical transition types such as Top-of-Climb and Top-of-Descent with 3-D endpoints specified, or are simply level-off targets that end a vertical transition or denote the current maintaining altitude. 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 TCP's 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 TSR 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 TCP's are the Top-of-Descent point and the MCP selected altitude. (See Figure 5.) The only required TCP element for this type is the target altitude, although latitude, longitude and time-to-TCP are desirable whenever available. If no time-to-TCP is specified, then the order of TCP's is determined by altitude precedence, i.e. in the above example Top-of-Descent would be the current TCP and target altitude would be TCP+1.

- **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 TCR, the next TCR 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).

- **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 TCR after a TOD should contain a Target Altitude or End-of-Descent 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 TCP's also, e.g. 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. In the latter case, the level segment ends when the AT constraint is sequenced.)

- **End of Descent (EOD)**

End of Descent is typically the last altitude constraint or level-off altitude in the FMS flight plan. End of Descent is specified by latitude, longitude, level-off altitude and time-to-TCP estimates. Typically, an FMS aircraft is given clearance altitudes and vectored on entry to the terminal area, unless following a Standard Terminal Arrival Route (STAR). In the latter case, the EOD point is typically selected at or near the top of STAR point for continuous transition from terminal entry to final approach.

- **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 Revision A since current FMS buses do not provide such information to external data users. Representation of altitude constraints is considered essential for future implementations since 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 (Ref. 5). Altitude constraint TCP's will require specification of waypoint latitude and longitude, and 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 TCR representation of such constraints is currently under consideration, i.e. whether to include the estimated altitude at the constraint point, and how to accommodate window constraints consisting of a simultaneous At and Below constraint and an At and Above constraint at the constraint fix. Three bits are provisioned in Revision A to accommodate future expansion.

10. **Minimum Intent Report Requirements**

Equipage Class Requirements

In the current MASPS, Level A2 equipage was defined to support extended range ADS-B applications to 40 nm range and provides 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 provides 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.

Our proposal for Revision A equipage classes is to retain the concept and overall capability of Level 2 and Level 3 equipage, but to revise the definitions to better reflect horizontal and vertical autopilot and RNAV capability. A minimum Level A2 ADS-B system would have the ability to broadcast target altitude and target heading, and at least one TCR 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 would have Level A2 capability and the capability to broadcast at least four TCR reports. The reason for requiring four TCR reports as compared with two TCP's in the current MASPS is that there are several conditions where two TCP's is not sufficient 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 TCP's are needed to achieve desired look ahead time for terminal area planning applications. Other potential applications that could require more TCP's include air-ground planning applications for en-route traffic flow management, and transition between free flight air-air operations and ATC managed traffic.

Transmission Update Requirements

Current requirements on update rate for TCP's are 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)". Moreover, most TCP intent data is static or slowly changing until the time to TCP is imminent or the TCP point is sequenced. It was concluded after review of the current MASPS, that more direct requirements on required update rate are needed for TSR and TCR reports, and TCR data should be updated less frequently for TCP's that have large TTG values.

The proposed update requirements would broadcast TCR reports at a high rate when TTG to TCP is less than a threshold value, i.e. when less than 2.5 minutes TTG, and at a much lower rate when TTG to TCP is larger than the threshold value. TSR reports would also be broadcast at the higher rate. (The 2.5 minute threshold is based on a nominal time budget for a flight plan deconfliction application where sufficient look ahead time is needed to detect and resolve a predicted air-air conflict.) In addition, major changes in TCR intent (to be signaled in the Mode Status report) may require prompt updating of all affected TCR's.

The high rate update requirement is for the broadcast rate to be sufficient to achieve a 95% reception probability of a TCR or TSR report within a 10 second period. (This requirement is consistent with the current MASPS requirement that "… the report assembly function shall provide update when received or indicate "no data available" if none is received in the preceding 10 second period.") The low rate broadcast requirement is to receive at least one broadcast TCR report with 99% reception probability between 5 minutes TTG and 2.5 minutes TTG to TCP. (For example, this requirement may be achieved with a low rate broadcast of 30 seconds per transmission and a reception probability of at least 70% per broadcast.) The proposed rate requirements emphasize the importance of TCR information within 2.5 minutes TTG and de-emphasize the relative value of remote TCR information with TTG greater than 5 minutes.

In addition to the above rate requirements, Revision A would limit the conditions when a TCR report needs to be broadcast. A TCR report for any TCP other than the active TCP would not be required if TTG to that TCP exceeds TBD minutes. (Suggested TBD value = 20 minutes). For example, if TTG to the next trajectory waypoint is 26 minutes, then no TCR reports beyond the next waypoint (TCP+0) are required. This limitation would prevent indiscriminate broadcast of TCR reports that are not operationally relevant.

TCR Report Synchronization

It is assumed that most ADS-B systems will require multiple messages to construct a complete TCR report sequence when broadcasting multiple TCP's. It then becomes necessary to ascertain that whenever a TCP is sequenced or intent information is changed, that the TCR's are appropriately synchronized and that all TCR's reported are currently valid and have the correct TCR sequence number. In order to achieve proper synchronization, it is recommended that all broadcast messages related to TCR intent contain some mechanism for validating TCR messages that originated together as a coherent group of sequenced TCP data, and for rejecting old TCR data that originated prior to the latest change in intent information. One means of achieving this objective is to broadcast a two bit (or larger) synchronization code for all TCR related messages, including Mode Status reports of a change in TCP data. All TCR reports which are output at a common time of applicability would be checked to assure that the synchronization code for the underlying messages was current and common to all TCR reports, i.e. any intent data which contains an old synchronization code would be purged and not reported with current TCR data. The synchronization code would be incremented each time a change in intent is detected by the ADS-B transmitting subsystem, e.g. the synchronization code could cycle from 0 to 1 to 2 to 3 to 0 again as the transmitted intent sequence or intent data is changed. The message synchronization process must assure that only currently valid TCR data is being reported and that each TCR report at a common report time has a unique sequence number.

11. References

(1) Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B), RTCA DO-242, Washington D.C., 1998.

(2) "Automatic Dependent Surveillance Requirements," Eurocontrol SUR/ET3/STO6.3220/001, June 2001.

(3) ARINC Characteristic 702A-1, "Advanced Flight Management Computer System", Jan. 2000.

(4) Barber, S. and Ponnau, M., "Review of Register 4,0," Surveillance and Conflict Resolution Systems Panel (SCRSP) Surveillance Systems WG/B, Rio de Janeiro, Apr. 2001.

(5) Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, RTCA Document DO-236A, SC-181, Sept. 2000.

12. Glossary of Trajectory / Intent Terms

Appendix A: Future Plans for Intent Consideration

Intended Airspeed Reporting

Revision A 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 Revision A 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, 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. Airspeed changes were not included in the proposed TCR reports, since gross changes in airspeed are accommodated by including Time-to-TCP as a report element. However, potentially important variables such as intended airspeed and the potential use of airspeed TCP's will be reexamined in future MASPS.

Additional TCP Leg Transition Types

The TCP leg types that were considered for Revision A were 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. Expansion of TCP leg types will be reexamined for future MASPS use based on operational value and future development of separation assurance operational concepts.

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 in following and staying within specified bounds of the intended path. The RNP RNAV MASPS (Ref. 5) specify accuracy and integrity bounds for path following which can serve as a basis for intent accuracy and integrity metrics for ADS-B reporting, provided such aircraft are RNP qualified. In the future 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 "tubes". 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.

More to follow

Appendix B: Trajectory Change Point Description and Examples