

# **WG-4 Intent Subgroup Folder - March 2001**

## **TCP Concepts and Issues for ADS-B MASPS Revisions**

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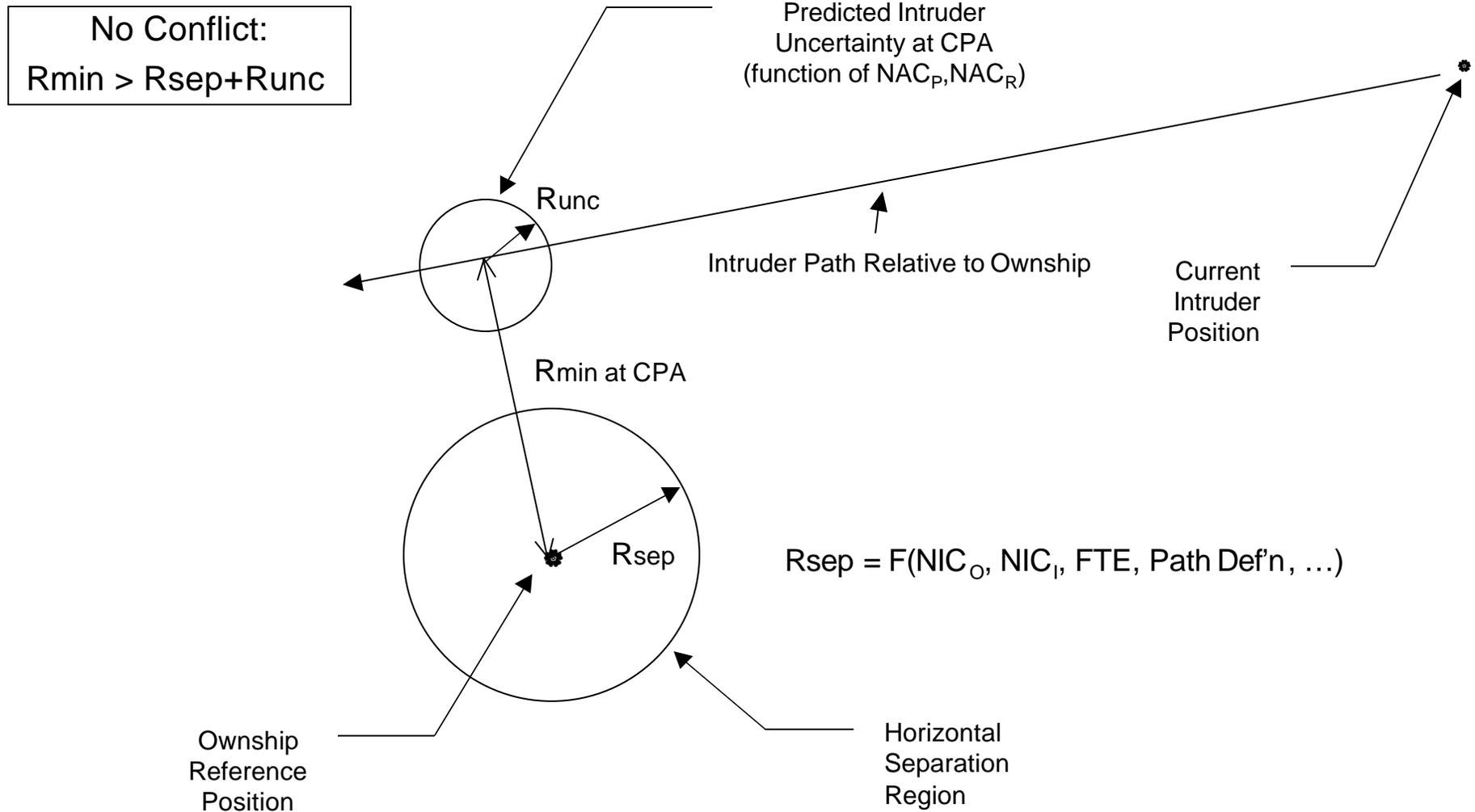
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- **Objective: Develop Intent Revisions Suitable for Applications under Study and Development:**
  - » **Airborne Separation Management (En-route)**
  - » **Airborne Collision Avoidance (En-route / Terminal)**
  - » **Precision RNP and FMS Procedures (Terminal)**
- **MASPS Intent Should Better Reflect today's Operational Capabilities - RNAV, FMS, Autopilot Systems**
- **Current MASPS Needs Revision to Reduce Ambiguities and Increase Integrity of Aircraft Trajectory Prediction**

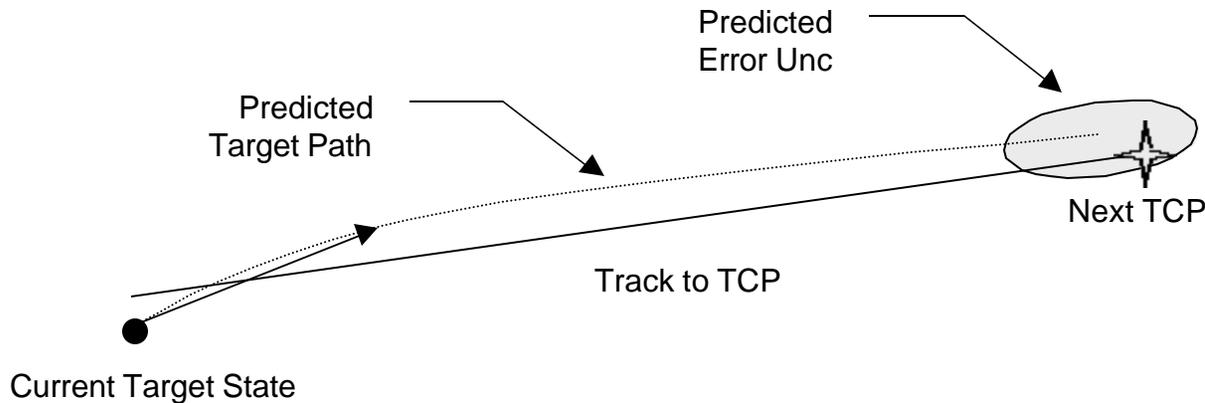
# Separation Assurance Concepts for Future ADS-B User Classes (DO242A, ...)

User Classes	Functional Description	Separation Assurance Concept	Concept Enablers
<b>Class A1</b>	<ul style="list-style-type: none"> <li>• Broadcasts State Vector and Data Quality including Air Vector</li> </ul>	<ul style="list-style-type: none"> <li>• Tactical Sep. Assurance               <ul style="list-style-type: none"> <li>- State Vector Extrapolation</li> <li>- Air-Air CD&amp;R</li> <li>- Air-Grd CD&amp;R</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• State Vector Unc.- NAC</li> <li>• Position Integrity - NIC</li> </ul>
<b>Class A2</b>	<ul style="list-style-type: none"> <li>• A1 Plus Current Intent               <ul style="list-style-type: none"> <li>- Next TCP (4D)</li> <li>- Selected Alt./Heading</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Enhanced Tactical Separation               <ul style="list-style-type: none"> <li>- Enhanced Predict Integrity</li> <li>- Time Limit for State Extrapolation</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Next TCP</li> <li>• TCP Related Variables</li> <li>• MCP Selected Intent</li> <li>• FMI &amp; Guidance Validity</li> </ul>
<b>Class A3</b>	<ul style="list-style-type: none"> <li>• A2 Plus Remote TCP's</li> <li>• Horiz Route Containment</li> <li>• Vert Window Restrictions</li> </ul>	<ul style="list-style-type: none"> <li>• Procedural/Tactical Separation               <ul style="list-style-type: none"> <li>- 3D Airspace 'Tunnels'</li> <li>- Lateral/Vertical Tunnel Seg.</li> <li>- Time Based Longitudinal Separation</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Multiple TCPs</li> <li>• TCP Related Variables</li> <li>• RNP &amp; NAV Validity</li> <li>• Vertical Restrictions</li> </ul>
<b>Class A4</b>	<ul style="list-style-type: none"> <li>• A3 Plus Airspeed TCPs</li> </ul>	<ul style="list-style-type: none"> <li>• Procedural/ Enhanced Tactical Separation Assurance               <ul style="list-style-type: none"> <li>- Lateral/Vertical Tunnel Seg.</li> <li>- Enhanced Predict Integrity</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Wind State Prediction</li> <li>• Airspeed TCPs</li> <li>• Prediction Uncertainty</li> </ul>

# Horizontal Separation Assurance Concept - Class A1



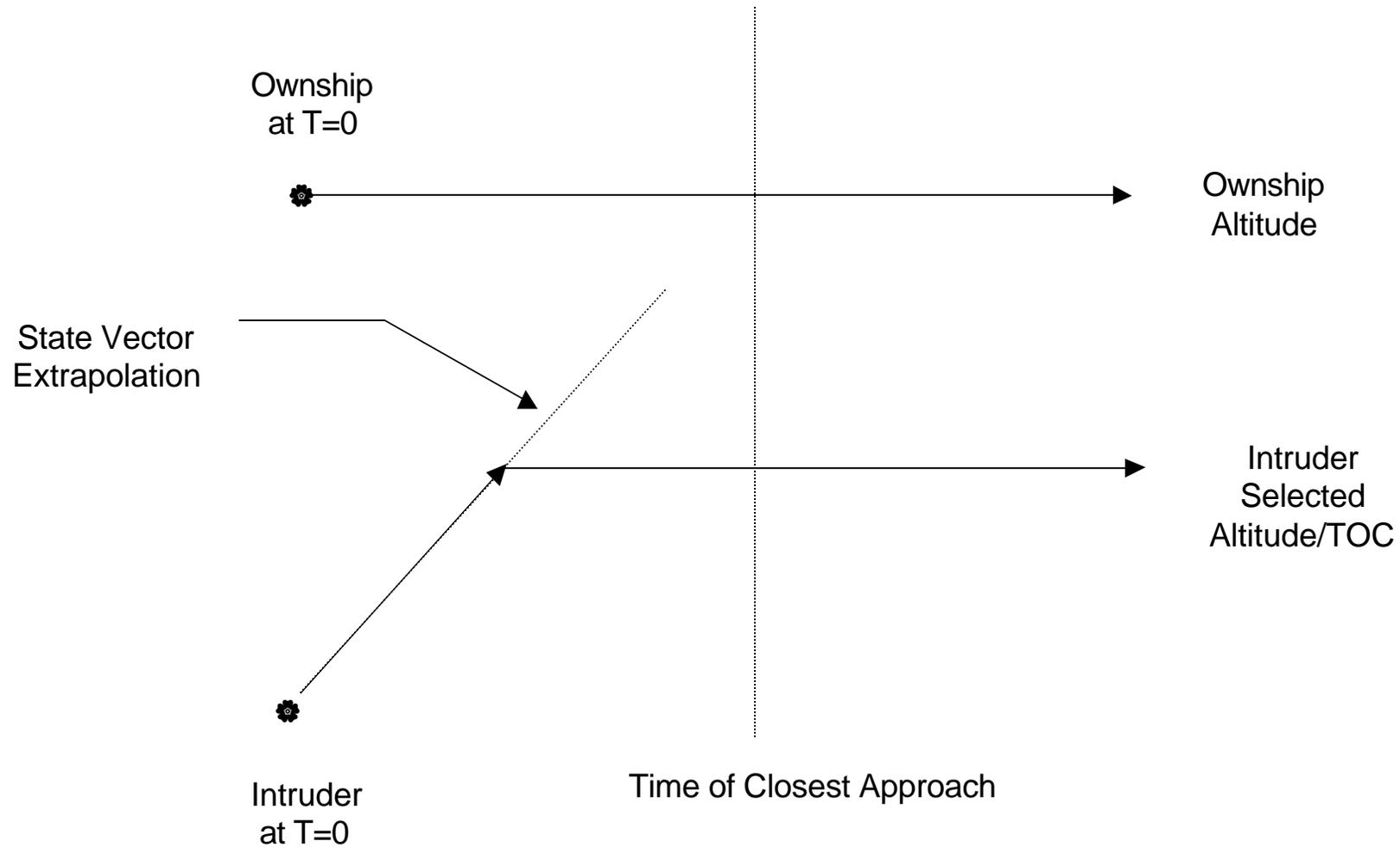
# Horizontal Separation Assurance Concept - Class A2



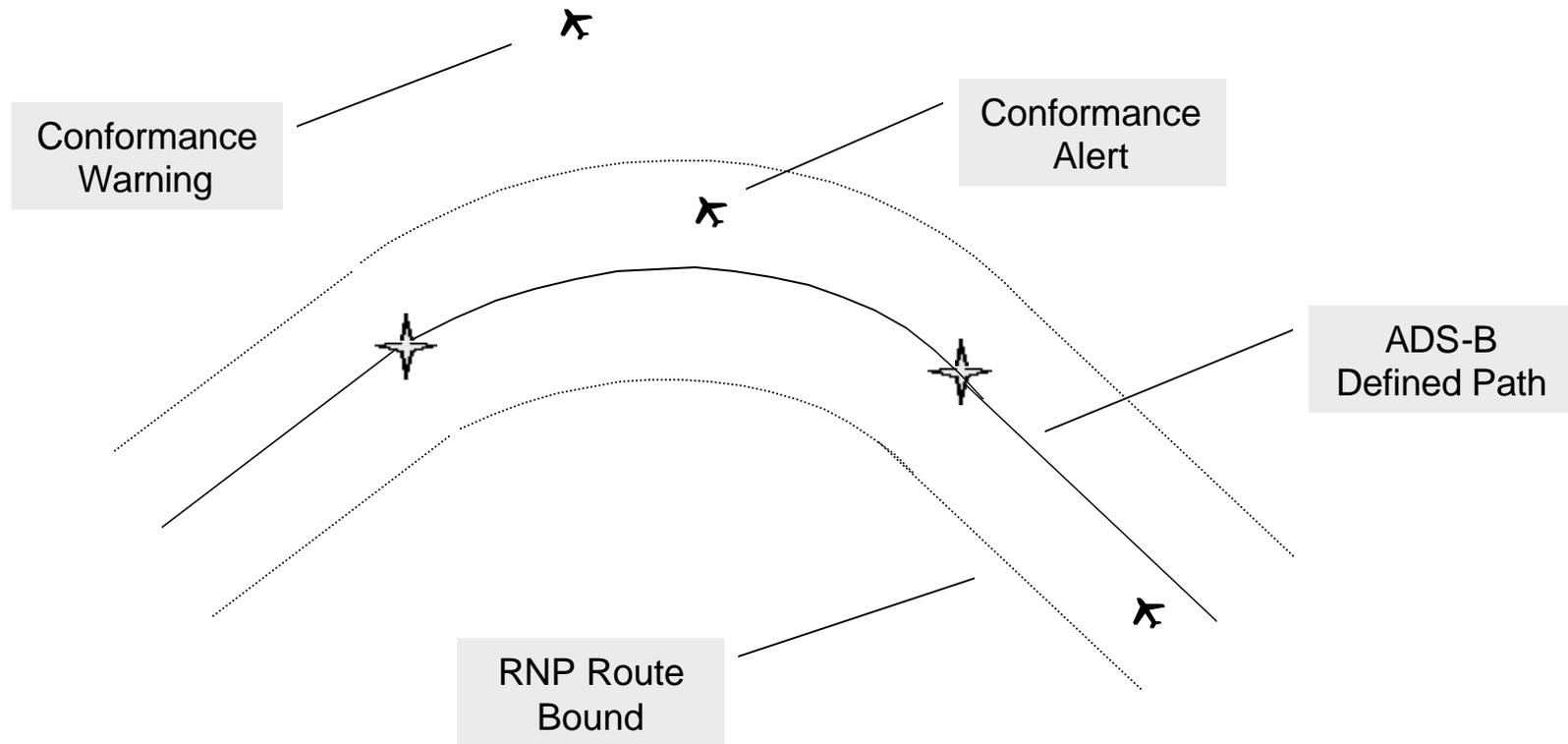
Enhanced Prediction Accuracy and Integrity:

- (1) Lateral Accuracy / Integrity: Target prediction may blend state vector and intent data, e.g. to reduce the lateral prediction error for long lookahead times.
- (2) Longitudinal Integrity: Enhanced prediction integrity obtained by validating target prediction at TCP lookahead time, i.e. integrity warning generated if next TCP falls outside predicted error uncertainty.
- (3) Lookahead Limiting: Limitation on Lookahead distance and time, i.e. do not extrapolate beyond TCP limits.

# Target Vertical Prediction Integrity Example - Class A2

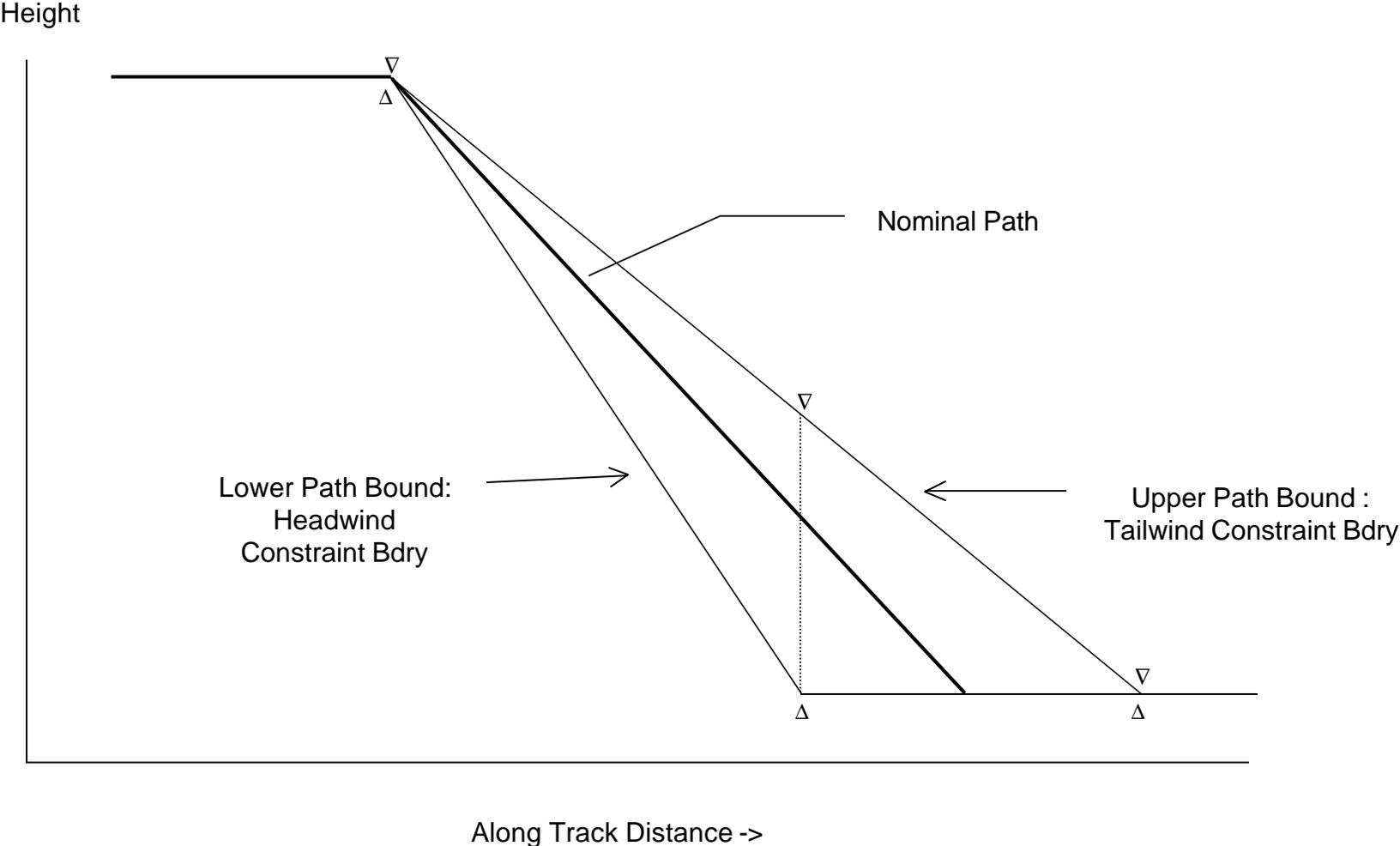


# Trajectory Conformance Monitoring Example (Class A3 User /Receive Side Integrity Monitoring)



**Note: May require transmission of current RNP capability & validity**

# Descent Example with Descent Slope Bounds - Class A3

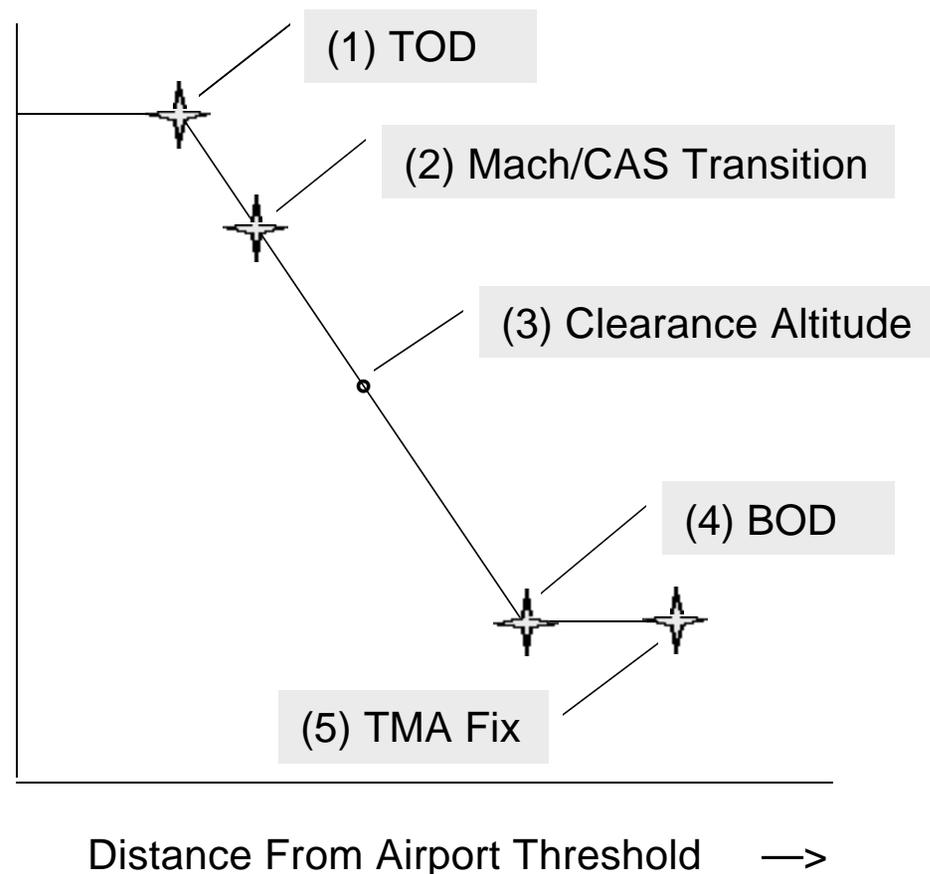


# Example of TCP Indicators - Descent from Cruise to TMA (Class A4)

## TCP/ Indicators for Descent Example

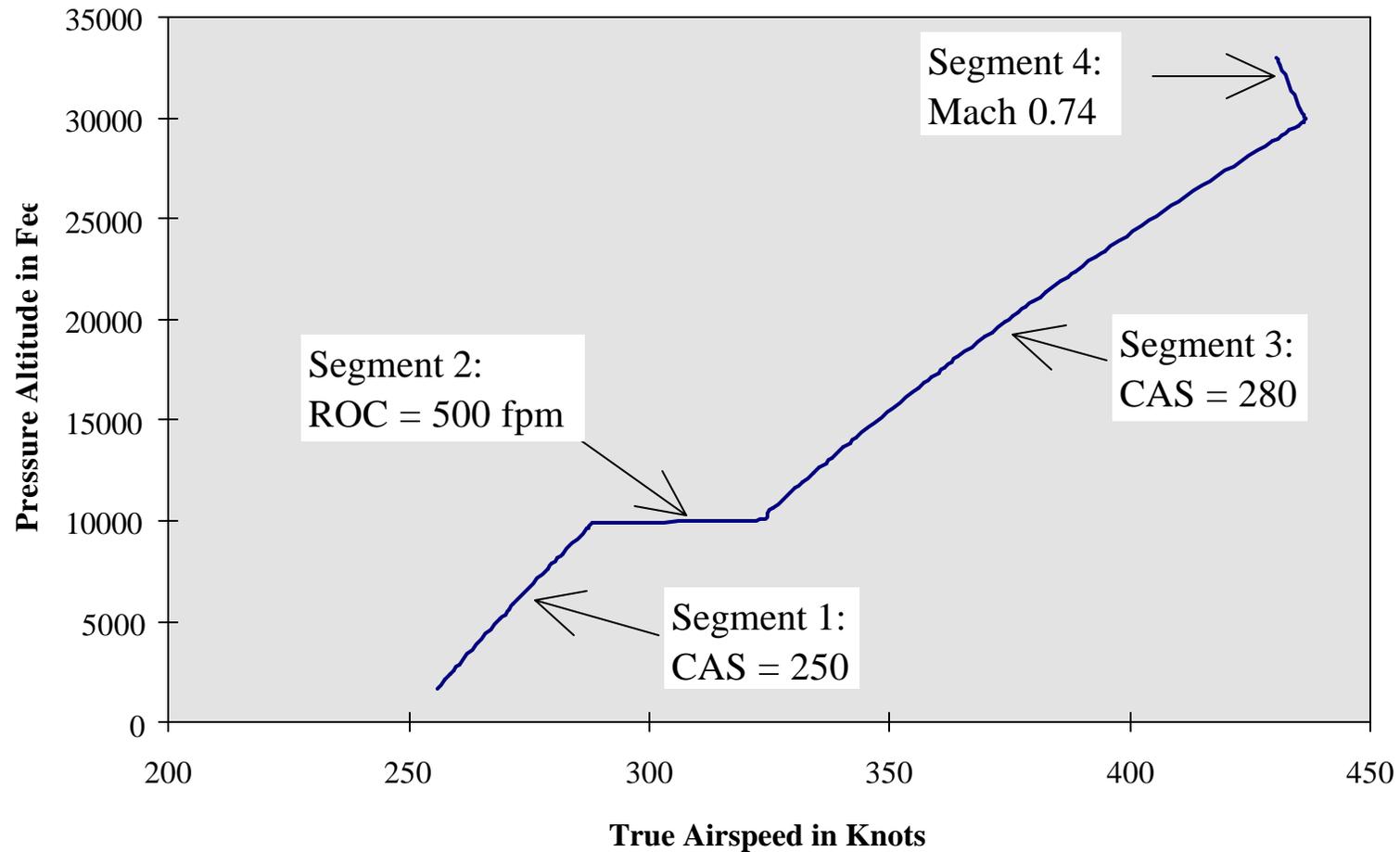
- 1 Horiz = Continue Course  
Vert = Initiate Descent (TOD)  
Speed = Continue (Mach)
- 2 Horiz = Continue Course  
Vert = Change Vertical Rate  
Speed = Change Airspeed
- 3 Selected Altitude (No TCP)
- 4 Horiz = Continue Course  
Vert = Level Off (Alt Restriction)  
Speed = Continue Airspeed
- 5 Horiz = Fly-By Segment  
Vert = Continue Level  
Speed = Speed Restriction

Altitude / Distance Profile for Descent Example



# Nominal Climb Transition for 737-400 Aircraft (Class A4 Speed / Altitude Transitions)

737-400 Standard Climb Profile - CAS = 250 / 280 / Mach 0.74



# TCP and Current Intent Issues

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- **Scope Issues**

- **Should MASPS include non TCP intent, e.g. Clearance Parameters?**

- » *Selected Altitude & Heading (Recommend as Req't for Class A2, A3)*
    - » *Selected Airspeed, Selected Vertical rate / slope (Recommend as Desirable, but not Req'd for Class A2, A3)*

- **How to Characterize Intent Validity ?**

- » **Currently Active and Armed Flight Modes**
    - » **Guidance Validity bits for AP and Flight Director**
    - » **Horizontal and Vertical RNP Capability and Nav Validity bits**

- **MASPS turn definitions may need additional TCP Related Parameters; i.e.**

- » **Desired track To TCP, Desired track From TCP, Turn Radius**

- **Does/Should TCP include airspeed changes ?**

- » *Recommended for future class A4 equipage*

- **Should MASPS delineate the TCP type and trajectory segment type, e.g. 1090 MOPS “leg-types” ?**

- » *Horizontal, Vertical TCP indicators Recommended for Class A2, A3*

# Recommended Non-TCP Intent Parameters

Non-TCP Intent	Justification Summary	Examples of Use
<ul style="list-style-type: none"> <li>Selected Altitude</li> </ul>	<ul style="list-style-type: none"> <li>Trajectory Prediction – (Need Level-off Altitude)</li> <li>Maneuver Coordination for ACM</li> <li>ATC Clearance Feedback</li> </ul>	<ul style="list-style-type: none"> <li>AP Command Mode Active (e.g. Altitude Hold)</li> <li>FMS Mode Active and MCP Altitude &gt; BOD MCP Altitude &lt; TOC</li> </ul>
<ul style="list-style-type: none"> <li>Selected Heading</li> </ul>	<ul style="list-style-type: none"> <li>Turn Rate Maneuver Observed (Need End-of-Turn Heading/ Trk)</li> <li>Maneuver Coordination for ACM</li> <li>ATC Clearance Feedback</li> </ul>	<ul style="list-style-type: none"> <li>AP Command Mode Active (e.g. Heading Hold)</li> <li>AP/ MCP initiated Turn</li> </ul>

Selected Altitude and Heading are Recommended to Increase Availability of Intent Information for Trajectory Predictions

# Flight Mode Indicator

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- Purpose - Identify currently active intent sources. Flight Mode Indicators (horizontal and vertical) proposed to identify whether TCP intent or AP selected intent is active.
- Proposed Horizontal Mode Indicators:
  - Selected Heading/Trk Modes
    - = 0 Selected Heading/Trk Inactive
    - = 1 Selected Heading currently active (MCP/AP)
    - = 2 Selected Track currently active (MCP/AP)
    - = 3 Heading Hold currently active (Ignores Selected)

## LNAV / RNAV Modes

- = 0 LNAV / TCP inactive
- = 1 LNAV / TCP armed (LNAV suspended)
- = 2 LNAV / TCP currently active\*

\* LNAV Mode = 2 only valid with Heading Mode = 0

# Flight Mode Indicator (Continued)

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- **Vertical Mode Indicators**

Selected Altitude Modes:

- » 0 = Inactive\*
- » 1 = Selected Altitude Capture†
- » 2 = Altitude Hold Capture† (Ignores Selected)

\*If the current flight segment is a climb or descent towards the selected altitude, then the altitude transition is limited by the selected value

VNAV Modes:

- » 0 = Inactive
- » 1 = VNAV/ TCP armed (for vertical transition)
- » 2 = VNAV altitude transition\*
- » 3 = VNAV Altitude Capture† (altitude Restriction)\*

†The Altitude Capture Modes Include Capture and Holding Functions

# Proposed Guidance Validity Bits\*

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- Horizontal Autopilot / Flight Director
  - 0: no active mode or command outside limits
  - 1: horizontal command signal within limits
- Vertical Autopilot / Flight Director
  - 0: no active mode or command outside limits
  - 1: vertical command signal within limits

\* Validity Bit is zero if no active MCP / FMS modes

# Trajectory Change Point (TCP) Basics

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- **Trajectory Change Point (TCP)**
  - Characteristics**
    - **Basic TCP consists of a fixed 2-D latitude & longitude and a Baro-Altitude/Flight Level**
    - **Estimated Time to TCP (TTG) is specified when available**
    - **Changes in routing (horizontal path) and vertical path are specified via TCP's:**
      - » **turn waypoints (fly-by, fly-over, radius-to-fix )**
      - » **level-off, begin climb/descent, change vertical rate/slope (?)**

# Proposed 1090 MOPS TCP “Leg Types”

ENCODING	MEANING
0000	No Specific Trajectory Change Point Description Information
0001	“Straight” (geodesic) Course to a “Fly By” Waypoint
0010	“Straight” (geodesic) Course to a “Fly Over” Waypoint
0011	“Straight” (geodesic) Course to a “Speed Change” Waypoint
0100	“Straight” (geodesic) Course to a “Vertical Speed Change “ Waypoint
0101	Arc Course to a “Fly By” Waypoint
0110	Arc Course to a “Fly Over” Waypoint
0111	Arc Course to a “Speed Change” Waypoint
1000	Arc Course to a “Vertical Speed Change” Waypoint
1001	Holding Pattern to a Holding Fix
1010	Course FROM the Waypoint, Termination Point Unknown
1011-1111	Reserved for future use

- Perceived Problems with Proposed TCP Leg Types:
  - Simultaneous Horizontal / Vertical / Airspeed Trajectory Changes
  - Leg Types do not Accommodate Path Restrictions, e.g. Altitude and Speed Restrictions
  - Need for both “Speed Change” and estimated time to TCP ?

# Uses of TCP Intent

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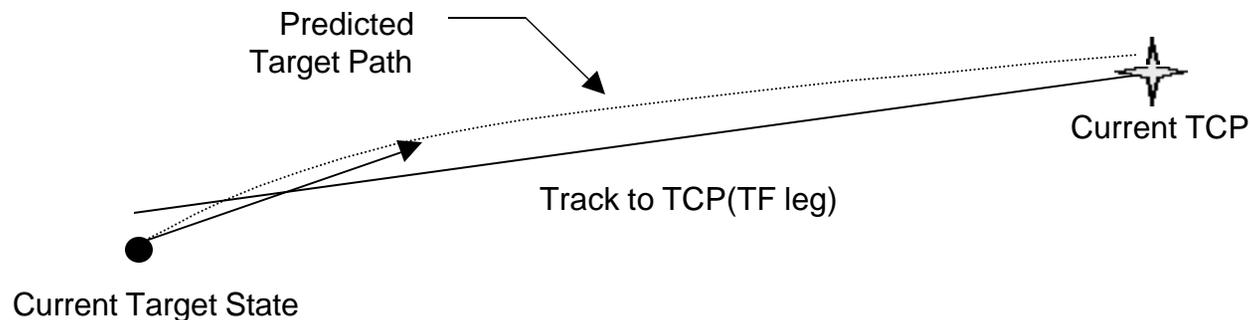
- Limiting Conditions for Current Flight Segment Extrapolation
  - distance, time, altitude limits for trajectory prediction
- Extension of Trajectory Definition Beyond Current Flight Segment
  - Anticipated Routing Changes including Turn Transitions
  - Anticipated Climb / Descent Changes
  - Anticipated Speed / Vertical Speed Changes (?)
- Ops Concepts: Flight Plan Deconfliction , 3-D Separation Tunnels
  - Deconfliction requires trajectory path definition and method to interpolate time of arrival at intermediate points
  - 3-D Trajectory Tunnels requires path definition and Integrity Volume for trajectory containment
- TCP Types Needed For Unambiguous Communication of Intended Trajectory Changes and Trajectory Path Definition

# Straight Line Segment Path Definition

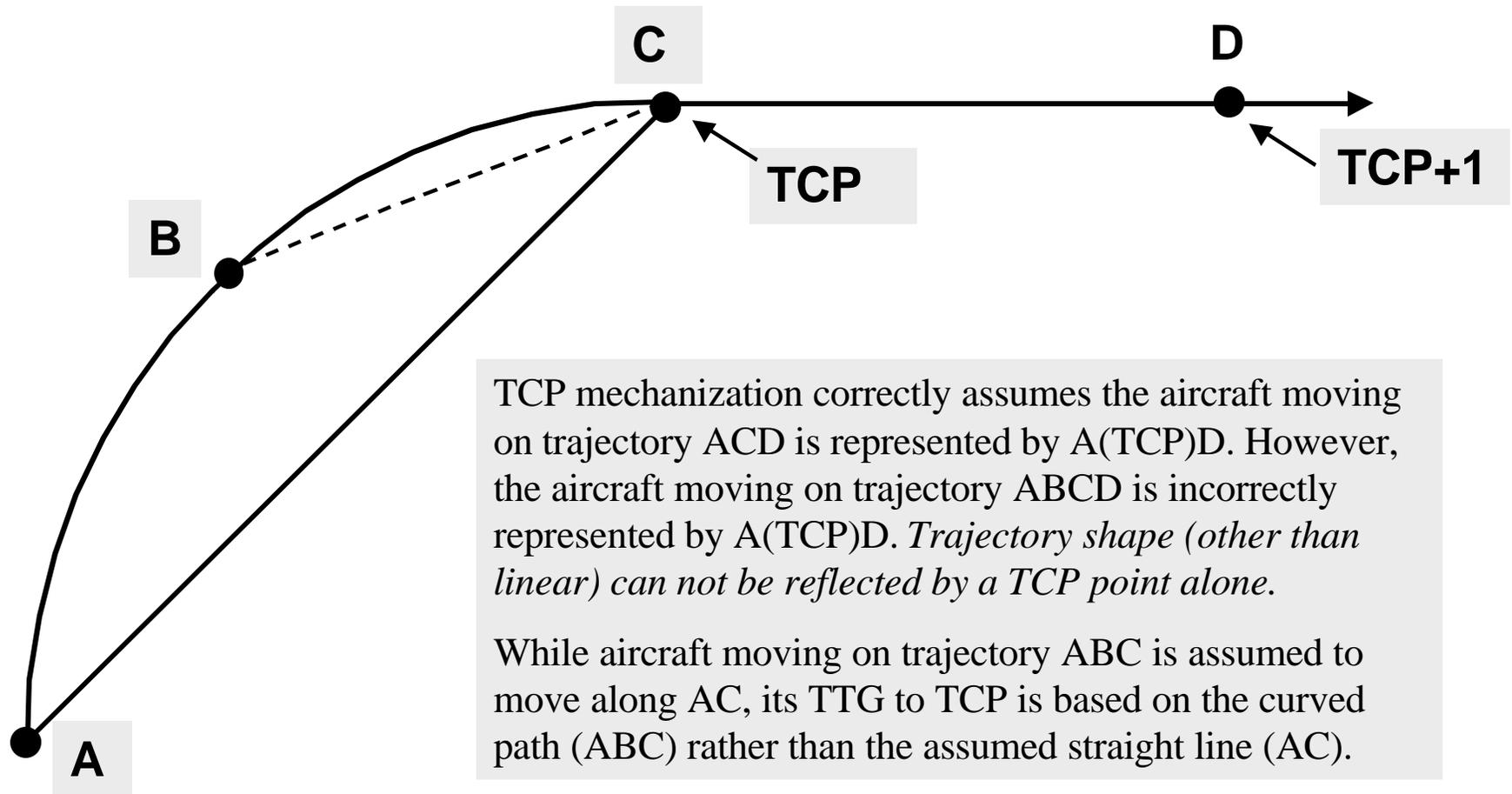
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- Segment End Conditions (time, distance, altitude) Defined by TCP
- Trajectory Change Defined by TCP Type, Track-to-TCP
  - TF leg: Path segment defined by current TCP and Track to TCP
  - DF leg: Track to TCP implicitly defined by straight line between Target position and current TCP
  - Track-to-TCP for subsequent TCPs need not be broadcast, i.e. may be computed from successor and previous TCPs.

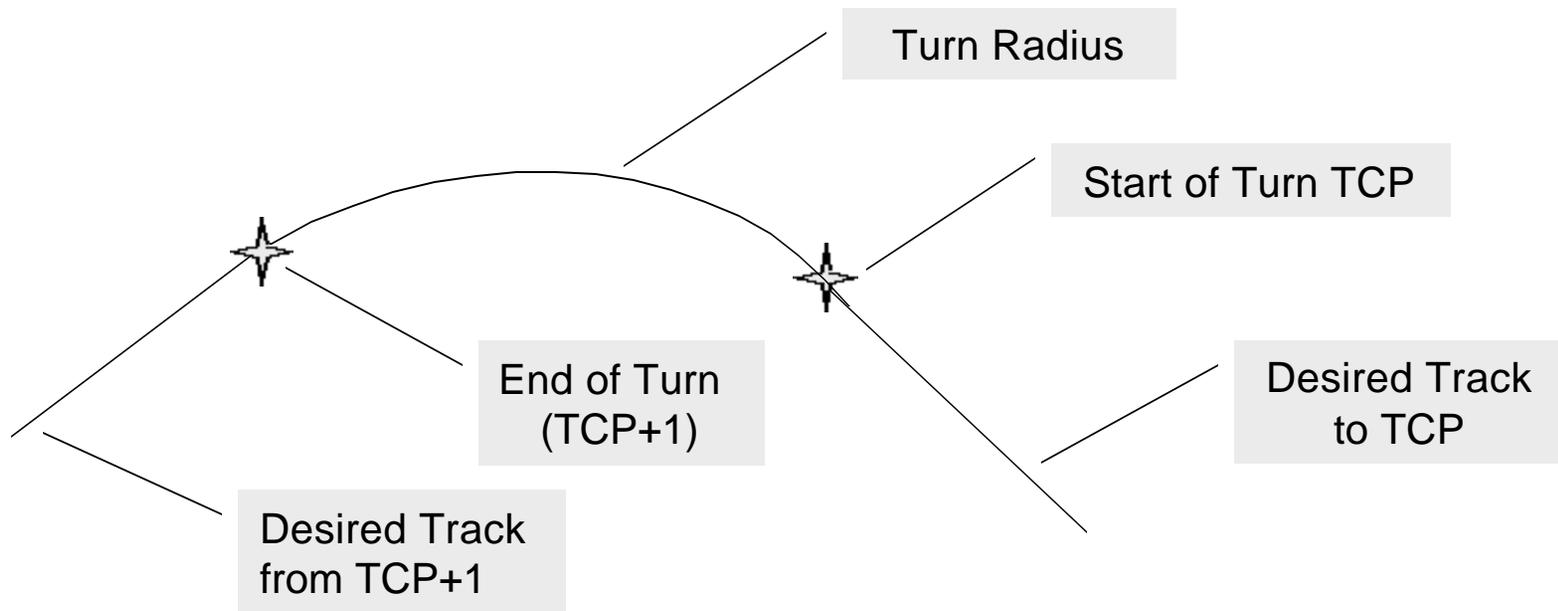


# Turn Ambiguity Example: (TCP as EOT point)



# Preferred Turn Definition - RF Method

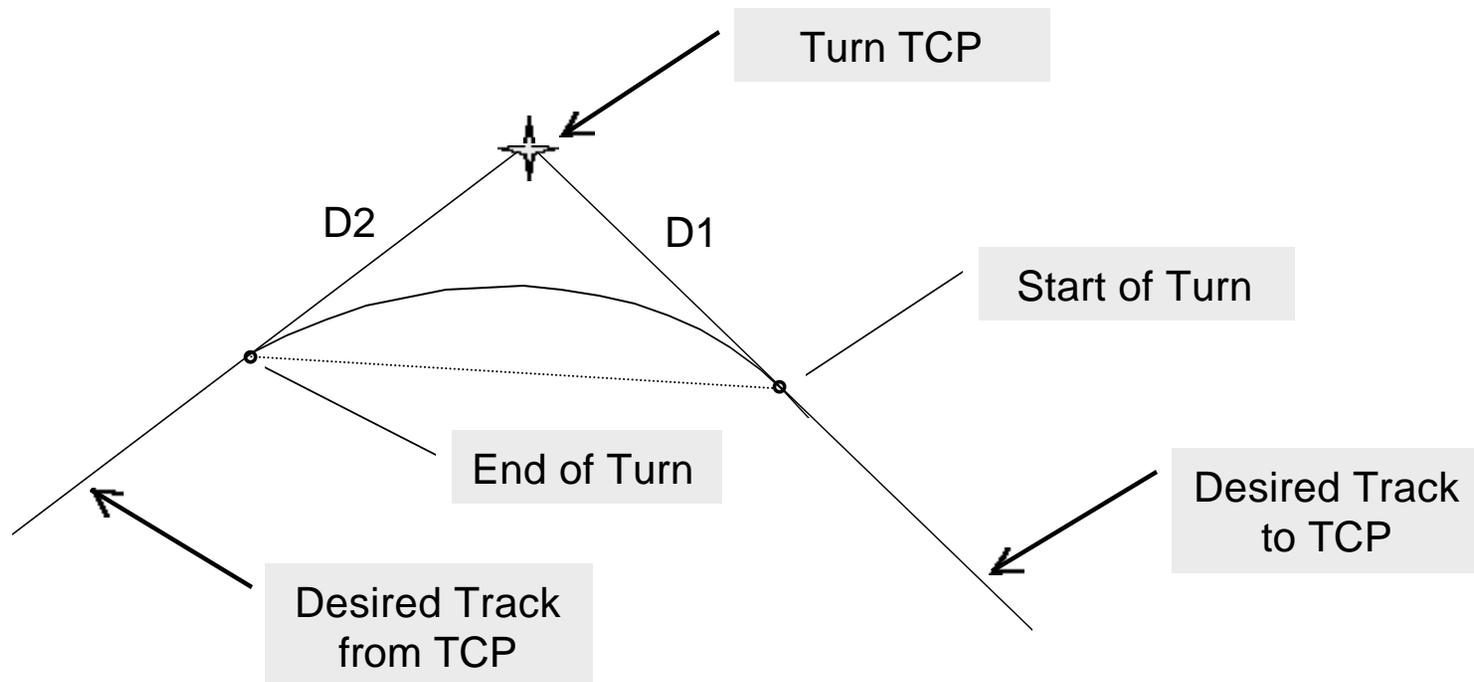
- Complete turn definition by using start-of-turn and end-of-turn TCP's and other parameters as needed: ( Fly-over, Radius to Fix)
  - End of Turn TCP
  - Turn Radius
  - Desired Track from End of Turn TCP



# Alternative Fly-By Turn Definition Method - 02/01

(Preferred over Earlier Method for Containment Integrity)

- Complete turn definition by using Fly-By TCP and other parameters:
  - TF Segment to Fly-by Turn
    - Desired Track to TCP
    - Turn Anticipation Distance (D1)
    - Time to Start of Turn
  - Fly-by Turn Segment
    - Desired Track from TCP
    - Turn Exit Distance (D2)
    - Time to End of Turn
    - Turn Radius



# Potential Horizontal TCP Types

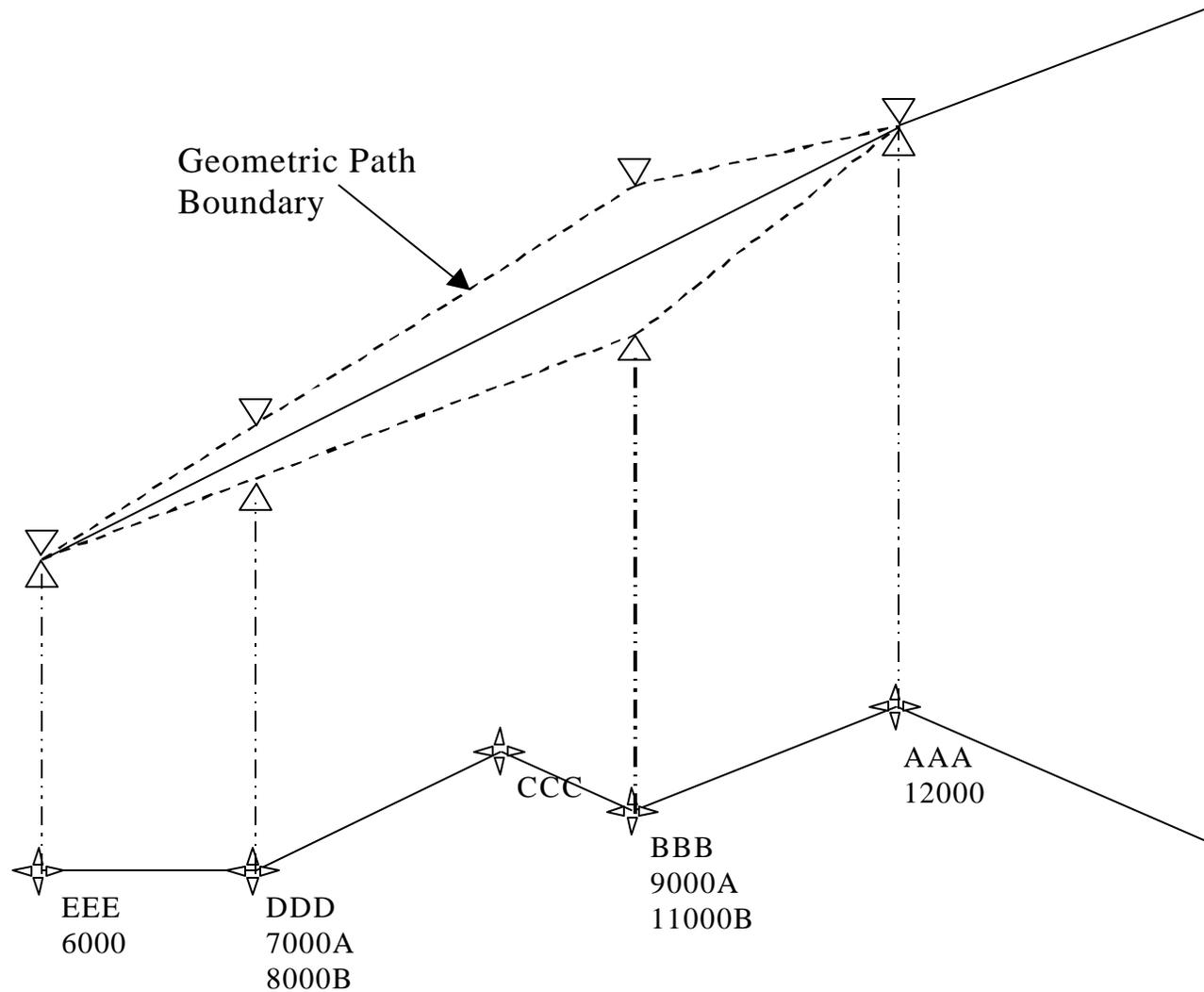
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- **Horizontal TCP Indicators / Types** *(Recommended)*
  - Straight Line (TF/DF leg) to a Fly-by Turn (A3 only)
    - Parameters: Track-to-TCP, Turn Anticipation
  - Straight Line (TF/DF leg) to a Fly-over, RF Turn (A2, A3)
    - Parameters: Track-to-TCP
  - Straight Line (TF/DF leg) (continue previous course)
    - Parameters: Track-to-TCP
  - Turn segment for a Fly-by Turn
    - Parameters: Track-from-TCP, Turn Exit Distance, Turn Radius
  - Turn segment for a RF Turn
    - Parameters: Track-from-TCP, Turn Radius

(Note: Parameters are required for ADS-B Report, but may not require message transmission in some cases.)

# Descent Path Example with Vertical Window Constraints



- **Example shows two “Window Constraints” and two “AT” Constraints**

# Potential Vertical and Speed TCP Indicator Types

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- Vertical TCP Indicators (*Recommended*)
  - Level-off (BOD, TOC)
  - Initiate Climb/Descent (BOC, TOD)
  - Continue vertical path( climb, descend, level)
  - change vertical rate/slope (*desirable but not required*) ?
  - Altitude restriction (at or above / at or below/ both)
- Airspeed TCP Indicators (*Not Recommended for DO242A*)
  - Continue Airspeed / Mach
  - Change Airspeed at TCP
  - Speed Restriction at TCP

# MASPS Intent - Summary of Proposed Changes

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- 1 **Incorporate AP / MCP Selected Intent Parameters:**
  - **Selected Altitude, Heading/Trk Min Req't for Classes A2, A3**
  - **Use Mode Indicators to Clarify Active AP/FMS Modes (H /V)**
  - **Broadcast Horizontal and Vertical Guidance Validity Bits \*\***
  
- 2 **Augment TCP Reporting:**
  - **TCP Indicator Type**
  - **Segment Data (Desired Track to/ from TCP, Turn Radius)**
  - **Additional TCP's and TCP Req'ts\*\***
  
- 3 **Broadcast RNP Capability & Nav Validity Bits (Class A3)**
  - **Horizontal RNP containment and Vertical Window Restrictions\*\***
  
- 4 **Incorporate Desirable ADS-B Parameters (Not Min Req't)**
  - **Reusable Message Slots or Lower Rate Updates:**
    - **Air Reference Vector (Airspeed, Mag/True Heading) (SV)**
    - **Selected Airspeed, Vertical Rate/ Slope (MS)**
    - **Airspeed TCP/ Restriction (OC)\*\***

\*\* Future Plans or Defer to Later MASPS Revisions ?