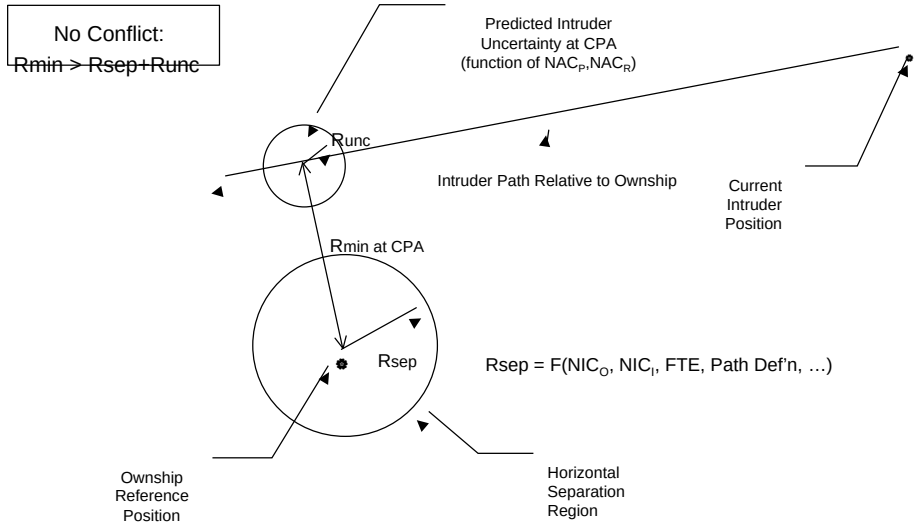
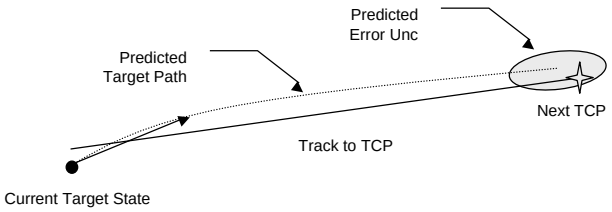
Separation Assurance Concepts for ADS-B User Classes

User Classes	Functional Description	Separation Assurance Concept	Concept Enablers
Class A1	• Broadcasts State Vector and Data Quality	• Tactical Sep. Assurance - State Vector Extrapolation - Air-Air CD&R - Air-Grd CD&R	• State Vector Unc.– NAC • Position Integrity - NIC
Class A2	• A1 Plus Current Intent - Next TCP (4D) - Selected Alt./ Heading	• Enhanced Tactical Separation - Enhanced Predict Integrity - Time Limit for State Extrapolation	• Next TCP • TCP Related Variables • MCP Selected Intent • FMI & Guidance Validity
Class A3	• A2 Plus Remote TCP's • Horiz Route Containment • Vert Window Restrictions	• Procedural/ Tactical Separation - 3D Airspace 'Tunnels' - Lateral/ Vertical Tunnel Seg. - Time Based Longitudinal Separation	• Multiple TCPs • TCP Related Variables • RNP & NAV Validity • Vertical Restrictions
Class A4	• A1 Plus Air Vector States • A3 Plus Airspeed TCPs	• Procedural/ Enhanced Tactical Separation Assurance - Lateral/ Vertical Tunnel Seg. - Enhanced Predict Integrity	• Wind State Prediction • Airspeed TCPs • Prediction Uncertainty

Horizontal Separation Assurance Concept - Class A1



Horizontal Separation Assurance Concept - Class A2



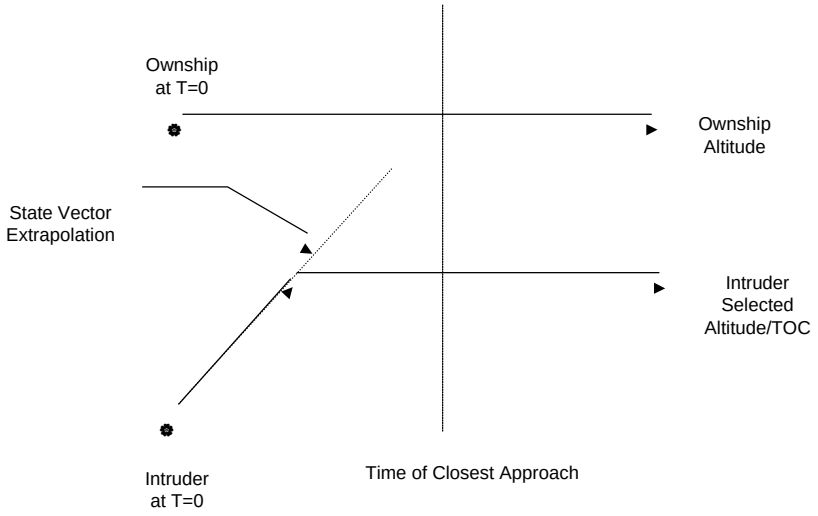
Enhanced Prediction Accuracy and Integrity:

(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.

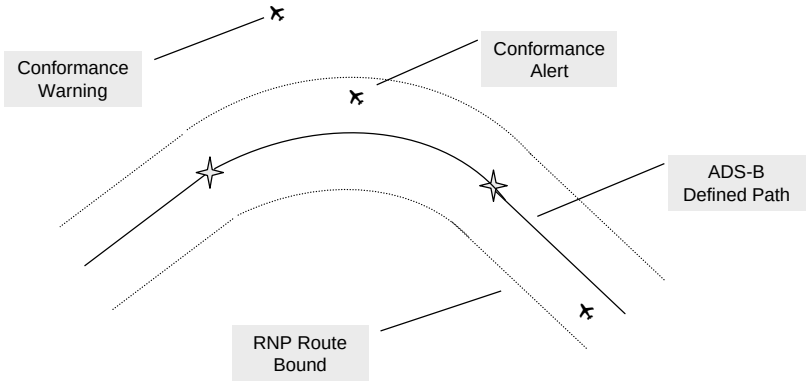
(2) Longitudinal Integrity: Enhanced prediction integrity obtained by validating target prediction at TCP lookahead time, i.e. integrity warning generated if next TCP falls outside predicted error uncertainty.

(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
(ADS-B User/Receive Side Integrity Monitoring)



Note: May require transmission of current RNP capability & validity

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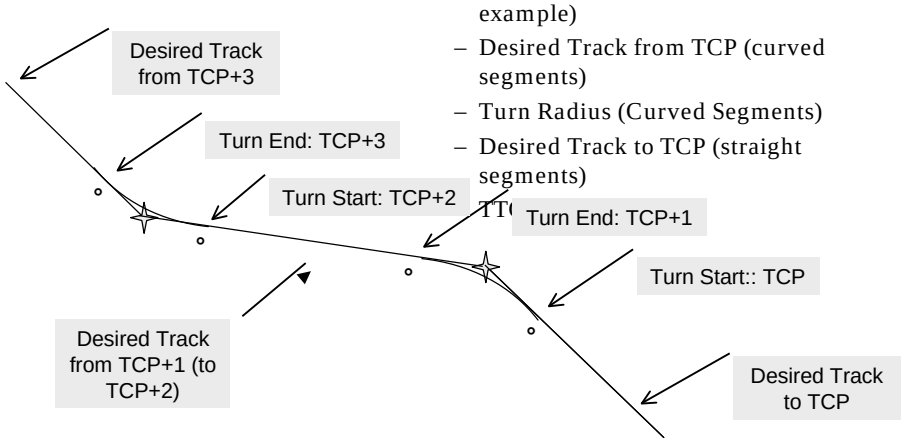
Turn Parameters for Fly-By S-Turn

- On-Condition Report for TCP's to Include:
  - TCP (Latitude, Longitude, Altitude)
  - TCP Indicator / Type (TF to turn example)
  - Desired Track from TCP (curved segments)
  - Turn Radius (Curved Segments)
  - Desired Track to TCP (straight segments)



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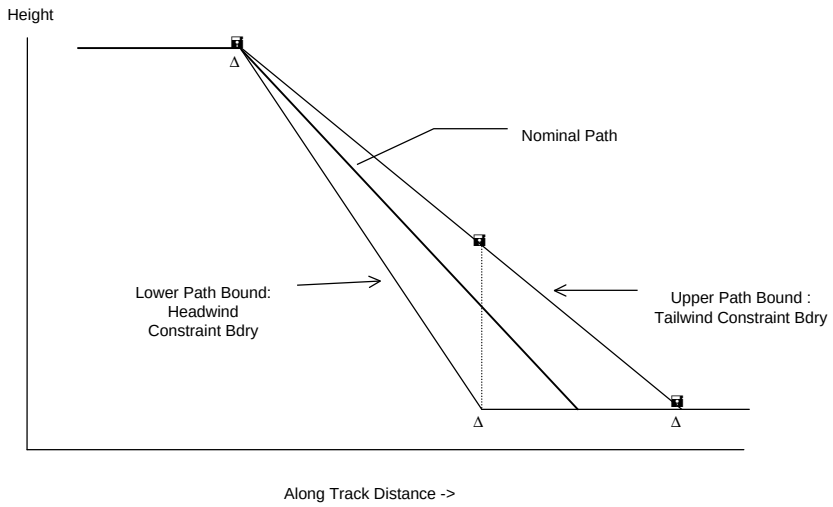
Descent Example with Descent Slope Bounds - Class A3



Trajectory Change Point (TCP) Basics

- **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

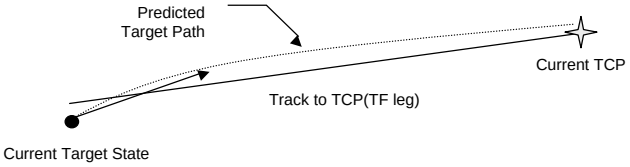
- Perceived Problems with Proposed TCP Leg Types:
  - Simultaneous Horizontal / Vertical / Airspeed Trajectory Changes
  - Leg Types do not Accommodate Path Restrictions, e.g. Altitude and Speed Restrictions
  - Need for both "Speed Change" and estimated time to TCP ?

Uses of TCP Intent

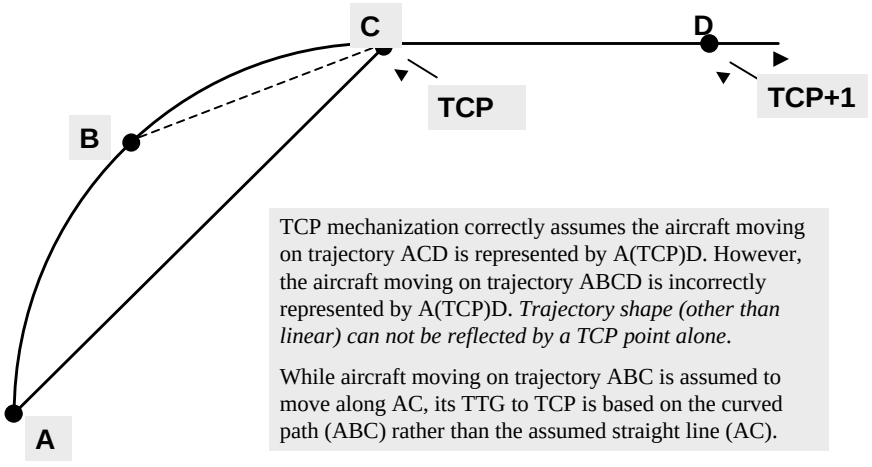
- Limiting Conditions for Current Flight Segment Extrapolation
  - distance, time, altitude limits for trajectory prediction
- Extension of Trajectory Definition Beyond Current Flight Segment
  - Anticipated Routing Changes including Turn Transitions
  - Anticipated Climb / Descent Changes
  - Anticipated 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

- 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)

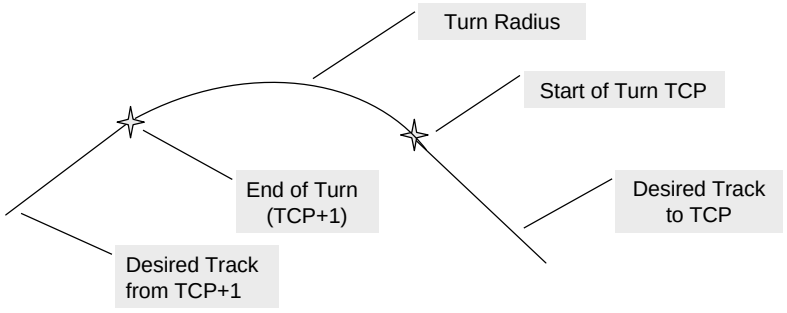


TCP mechanization correctly assumes the aircraft moving on trajectory ACD is represented by A(TCP)D. However, the aircraft moving on trajectory ABCD is incorrectly represented by A(TCP)D. *Trajectory shape (other than linear) can not be reflected by a TCP point alone*.

While aircraft moving on trajectory ABC is assumed to move along AC, its TTG to TCP is based on the curved path (ABC) rather than the assumed straight line (AC).

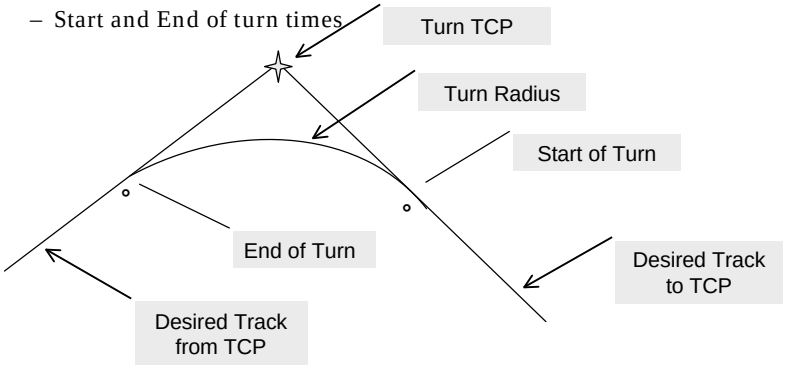
Preferred Turn Definition - RF Method

- 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



Proposed Fly-By Turn Definition - 11/00

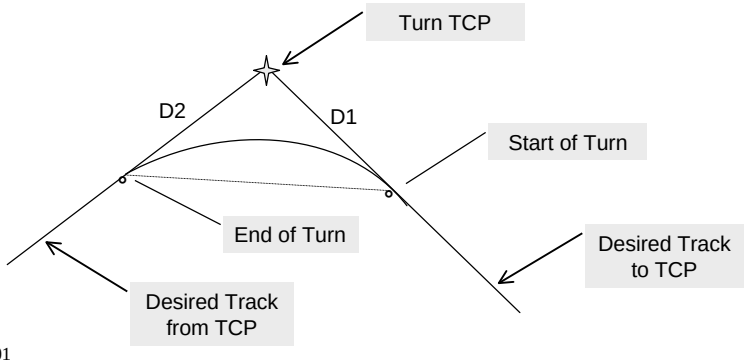
- Complete turn definition by using turn corner TCP and other parameters as needed:
  - Turn Radius
  - Desired Track to TCP
  - Desired Track from TCP
  - Start and End of turn times



Alternative Fly-By Turn Definition Method - 02/01

(Preferred over Earlier Method for Containment Integrity)

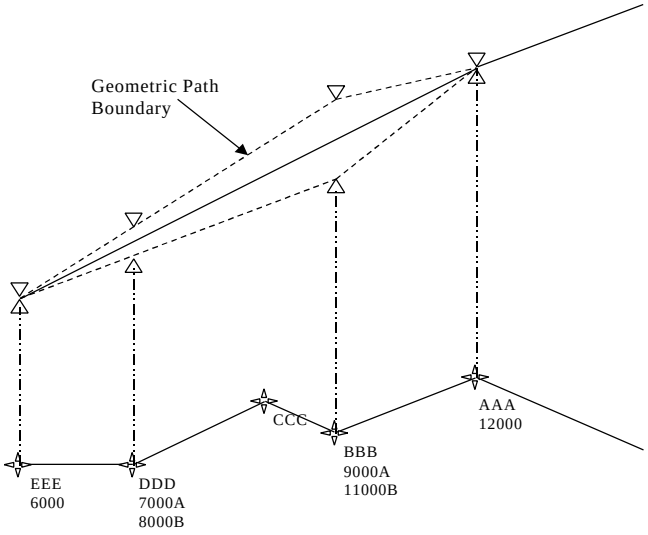
- Complete turn definition by using Fly-By TCP and other parameters:
  - TF Segment to Fly-by Turn
    - Desired Track to TCP
    - Turn Anticipation Distance (D1)
    - Time to Start of Turn
  - Fly-by Turn Segment
    - Desired Track from TCP
    - Turn Exit Distance (D2)
    - Time to End of Turn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



Potential Horizontal TCP Types

- **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
  - Holding Pattern to a Holding Fix ?
  - Others … ??

Descent Path Example with Vertical Window Constraints



- **Example shows two "Window Constraints" and two "AT" Constraints**

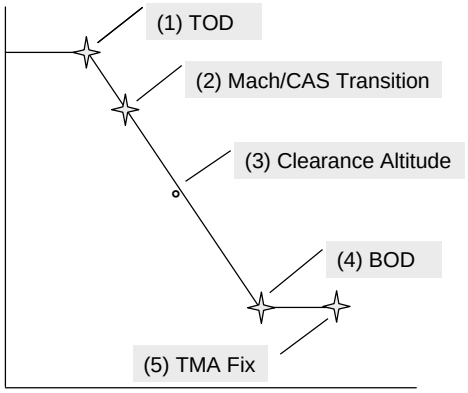
Potential Vertical and Speed TCP Indicator Types

- 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

Example of TCP Indicators - Descent from Cruise to TMA

- 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 (BOD)
     Speed = Continue Airspeed
  5. Horiz = Fly-By Segment
     Vert = Continue Level
     Speed = Speed Restriction

Altitude / Distance Profile for Descent Example



Distance From Airport Threshold —>

Nominal Climb Transition for 737-400 Aircraft

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