WG-4 Intent Subgroup Folder - January 2001
TCP Concepts and Issues for ADS-B MASPS Revisions

- **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**

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**

TCP and Current Intent Issues

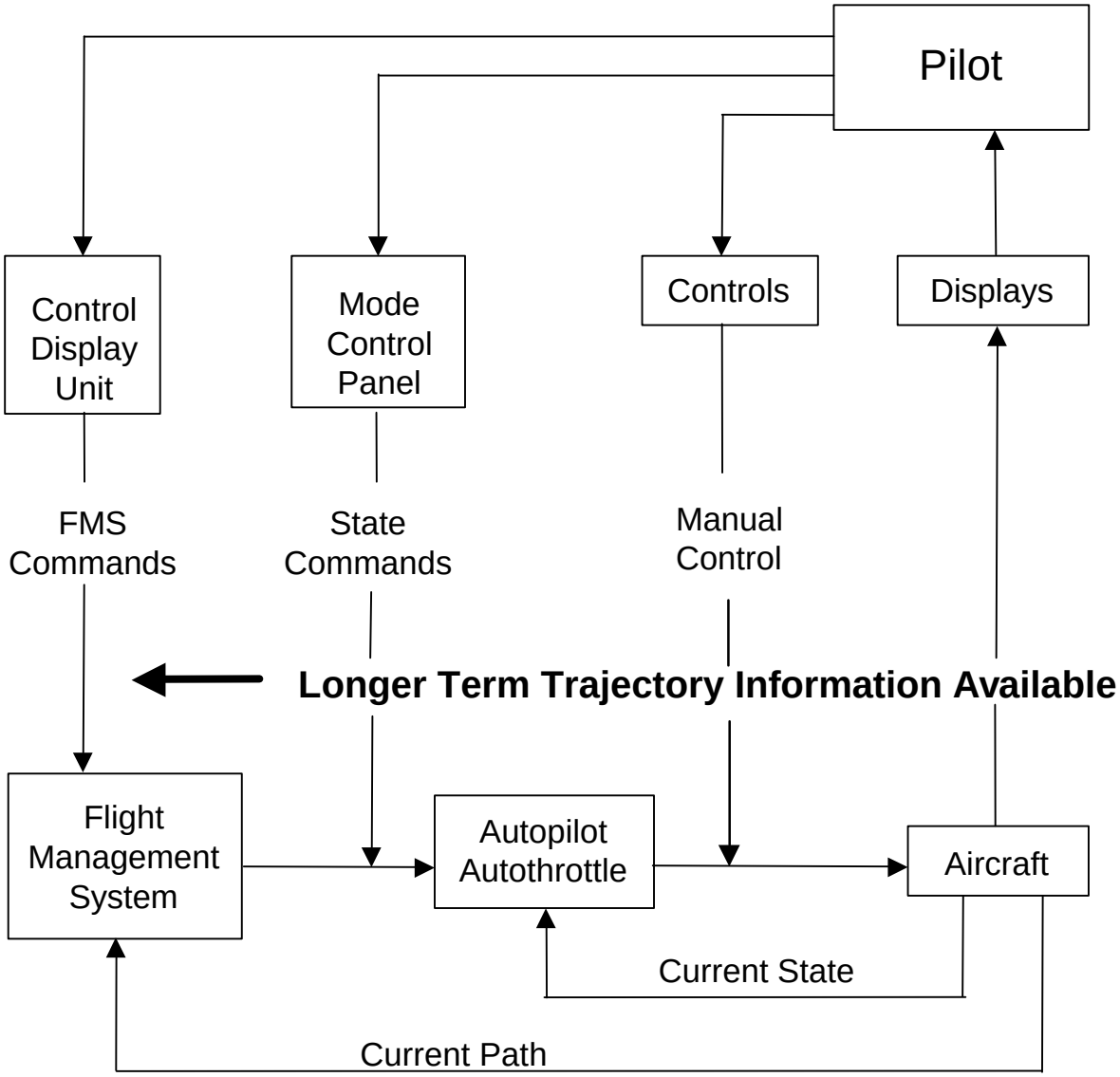
- **Scope Issues**
  - **Should MASPS include non TCP intent, e.g. Clearance Parameters?**
    - » *Selected Altitude & Heading (Recommend as Req't for Class A2, A3)*
    - » *Selected Airspeed, Selected Vertical rate / slope (Recommend as Desirable, but not Req'd for Class A2, A3)*
  - **How to Characterize Intent Validity ?**
    - » **Currently Active and Armed Flight Modes**
    - » **Guidance Validity bits for AP and FMS intent**
    - » **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*

Non-TCP Intent Information

- **Proposed non-TCP intent:**
  - Selected altitude and selected heading (recommended as minimum requirements for Classes A2, A3).
  - Selected airspeed and selected vertical speed (desirable, but not required for Classes A2, A3).

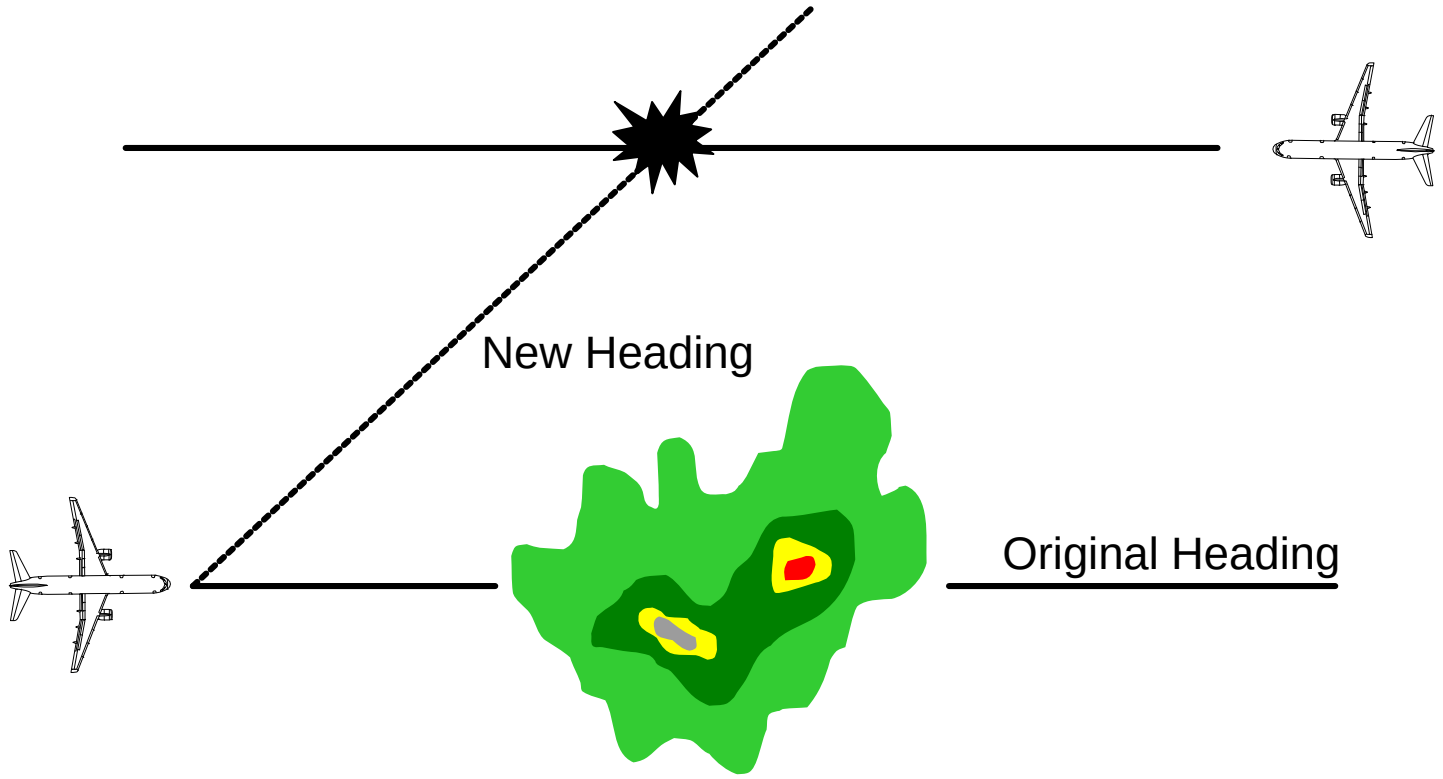
- **Benefits of Non-TCP intent:**
  - Provides information on intended trajectory for aircraft that are not broadcasting TCP's.
    - Non-FMS equipped aircraft.
    - Aircraft not operating in FMS mode (LNAV/VNAV).
  - Can affect FMS trajectory.
  - Can be used to verify understanding and compliance with ATC clearances.
    - Assigned heading.
    - Assigned altitude.

Aircraft Control Modes



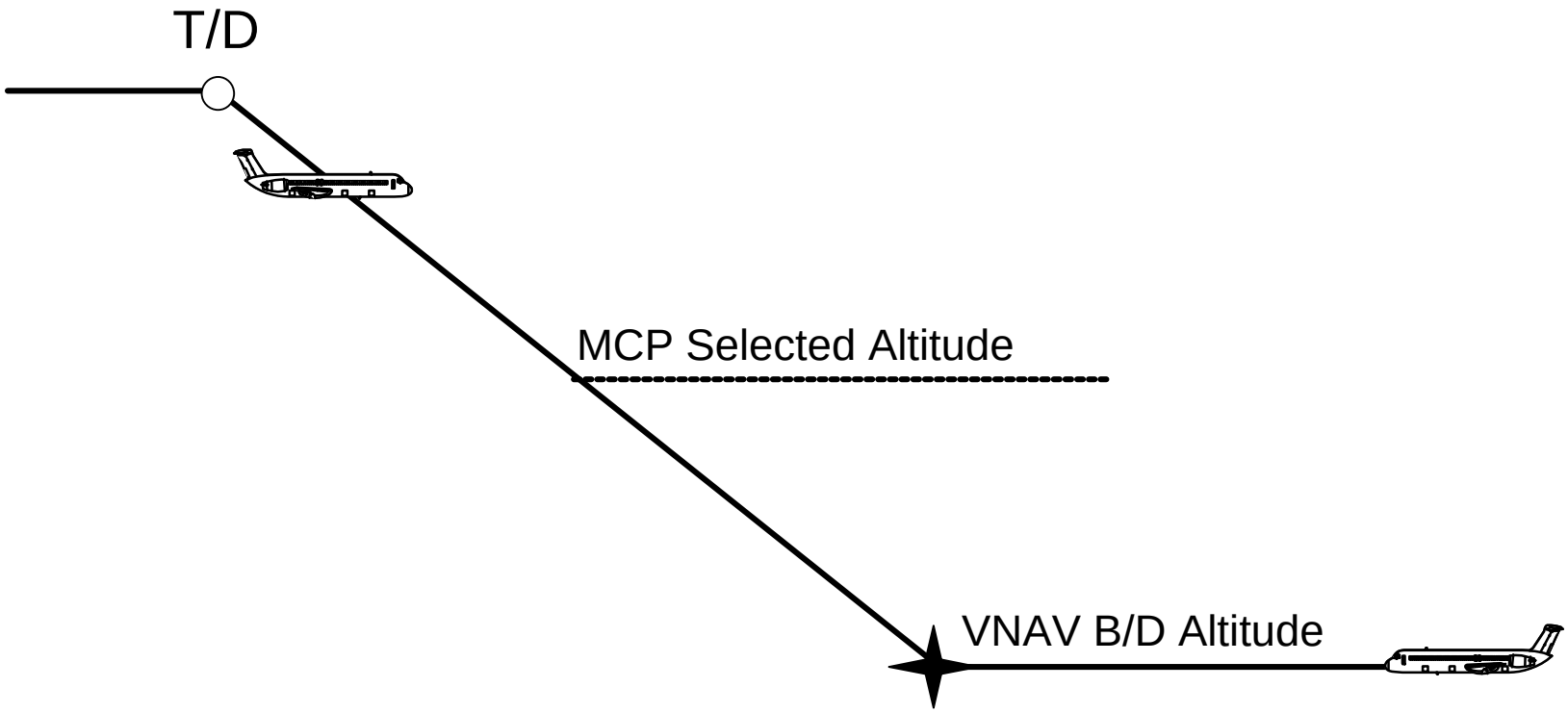
- **Pilot can operate aircraft in one of 3 control modes:**
  - Manual (no flight director).
  - State.
  - FMS.
- **Each successive outer loop provides more information about aircraft's long term trajectory.**
- **TCP's only available when aircraft operated in FMS control mode.**

Horizontal Example - Selected Heading



- Aircraft maneuvers around a thunderstorm.
- Selected heading provides advanced warning of impending conflict.

Vertical Example - Selected Altitude



- Aircraft in VNAV descent, MCP selected altitude causes level-off prior to reaching VNAV altitude target.
- Potential conflict with opposite direction traffic is avoided.

Flight Mode Indicators

- Flight Mode Indicators (FMI's) provide information on aircraft's active and armed horizontal and vertical modes.
- Used by receiving aircraft to determine which elements of intent information are relevant to aircraft's current flight path.
- Detailed construction of flight mode indicators under discussion by Intent Subgroup of WG4.
  - Horizontal: commanded heading/track vs. RNAV/LNAV.
  - Vertical - commanded MCP altitude vs. VNAV altitude target.
  - May also include speed FMI.

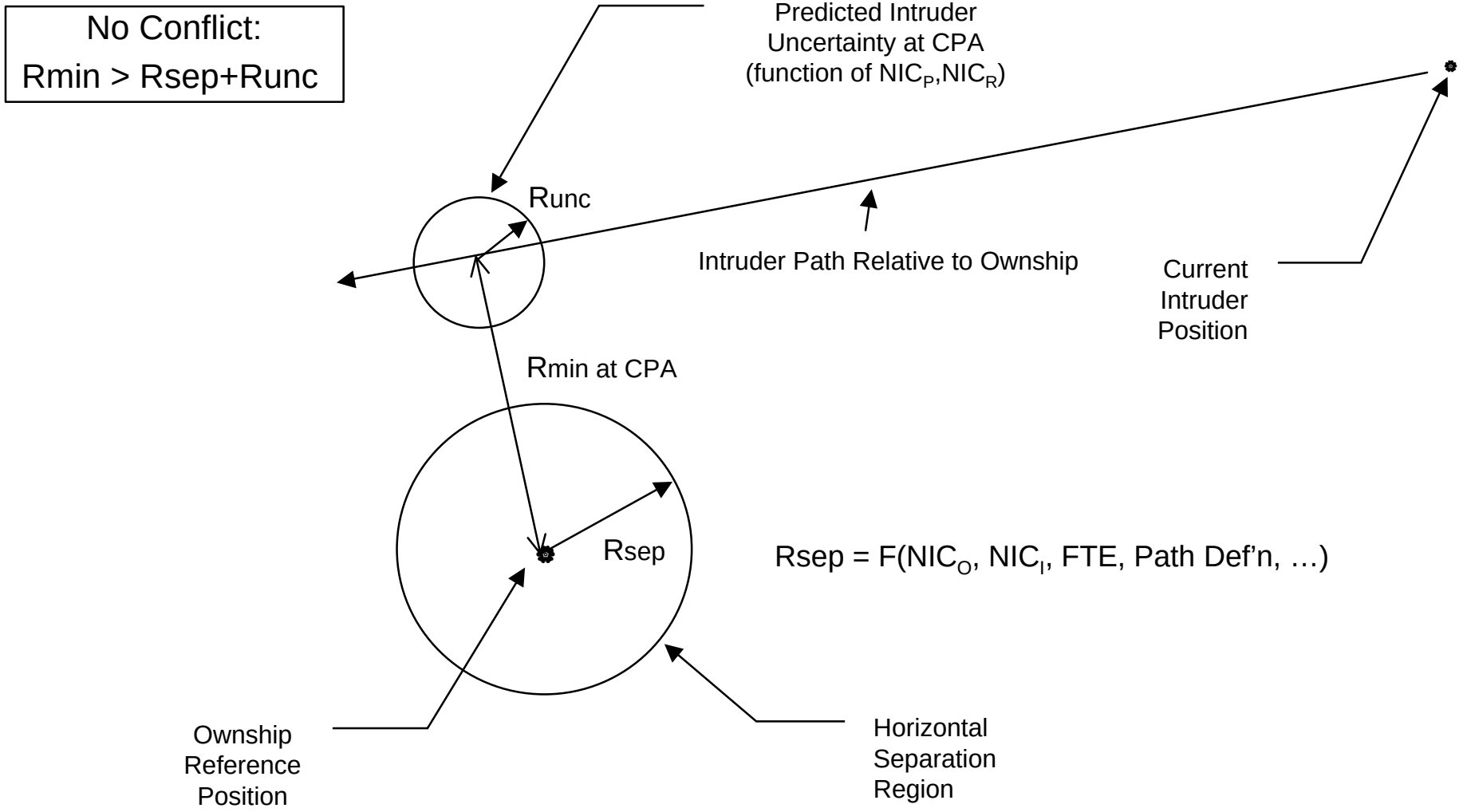
Intent Validity

- Used by receiving aircraft to help determine whether traffic aircraft is conforming to its broadcast intent.
- WG4 is considering 2 types of validity bits (both types have horizontal and vertical bits):
  - **Guidance.**
    - Based on flight director command error.
    - Indicates whether pilot is making control inputs toward commanded path.
  - **Navigation.**
    - Only available for RNAV, LNAV, VNAV modes.
    - Horizontal - indicates whether aircraft can meet required navigation performance.
    - Vertical - indicates whether aircraft can meet waypoint altitude constraints
    - Longitudinal / Time - may be developed as a future option

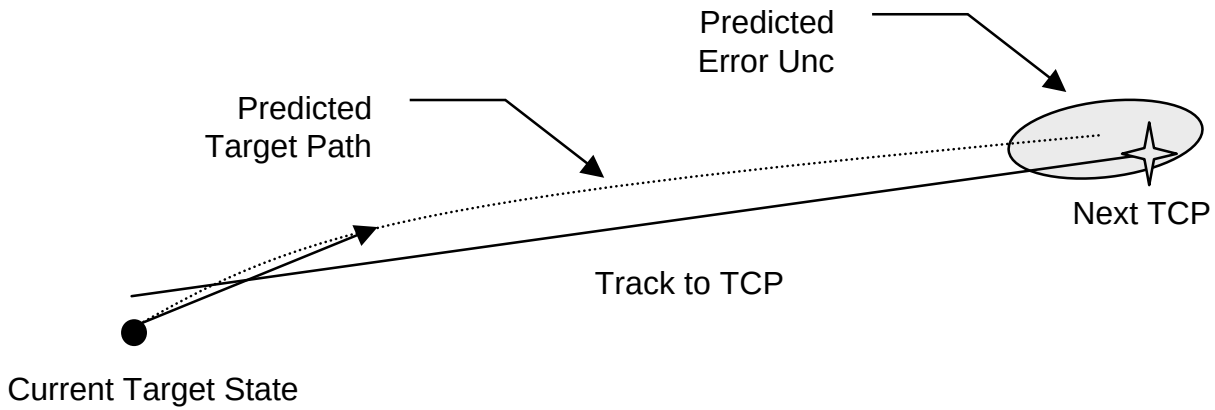
Separation Assurance Concepts for ADS-B User Classes

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



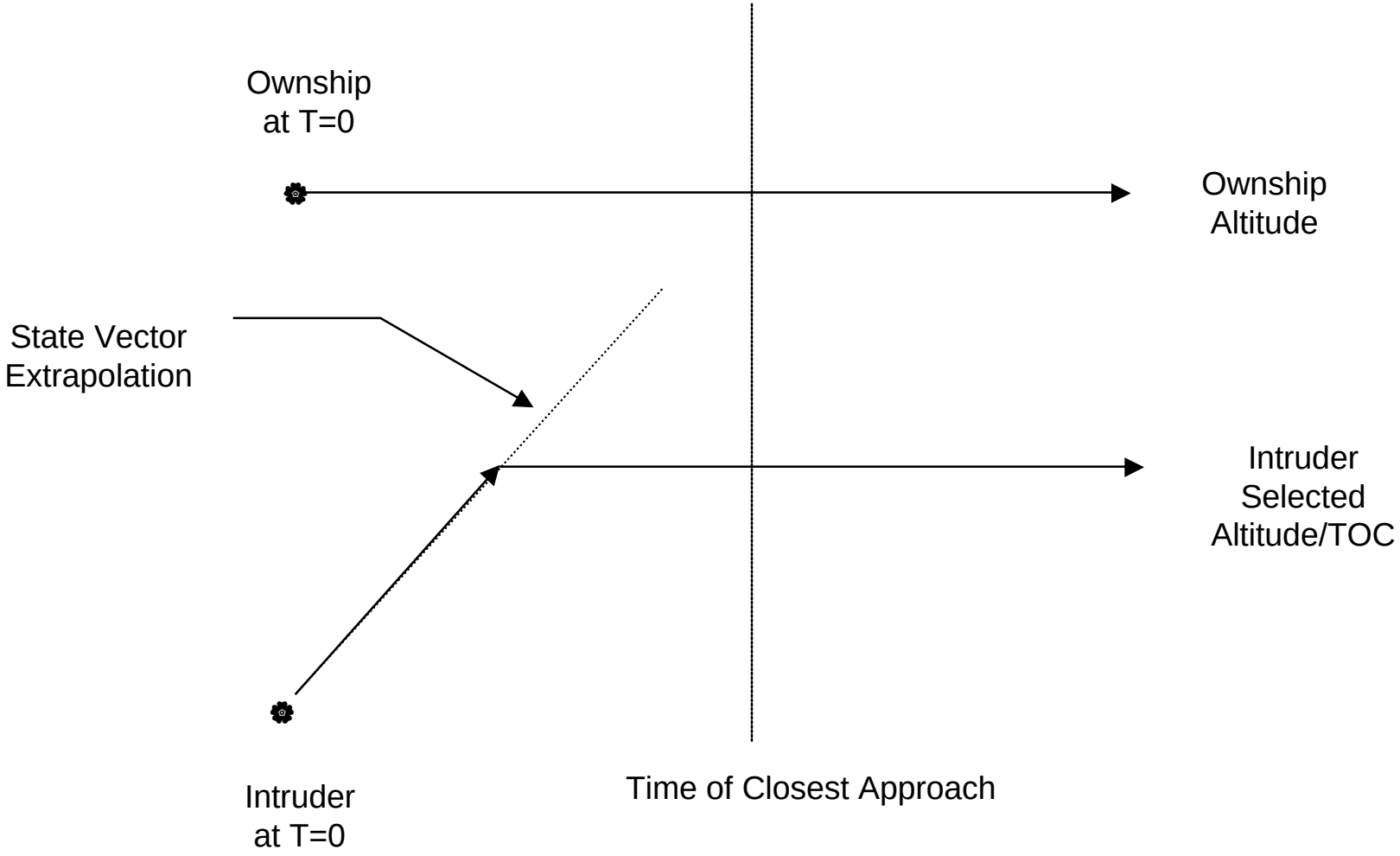
Enhanced Prediction Accuracy and Integrity:

(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.

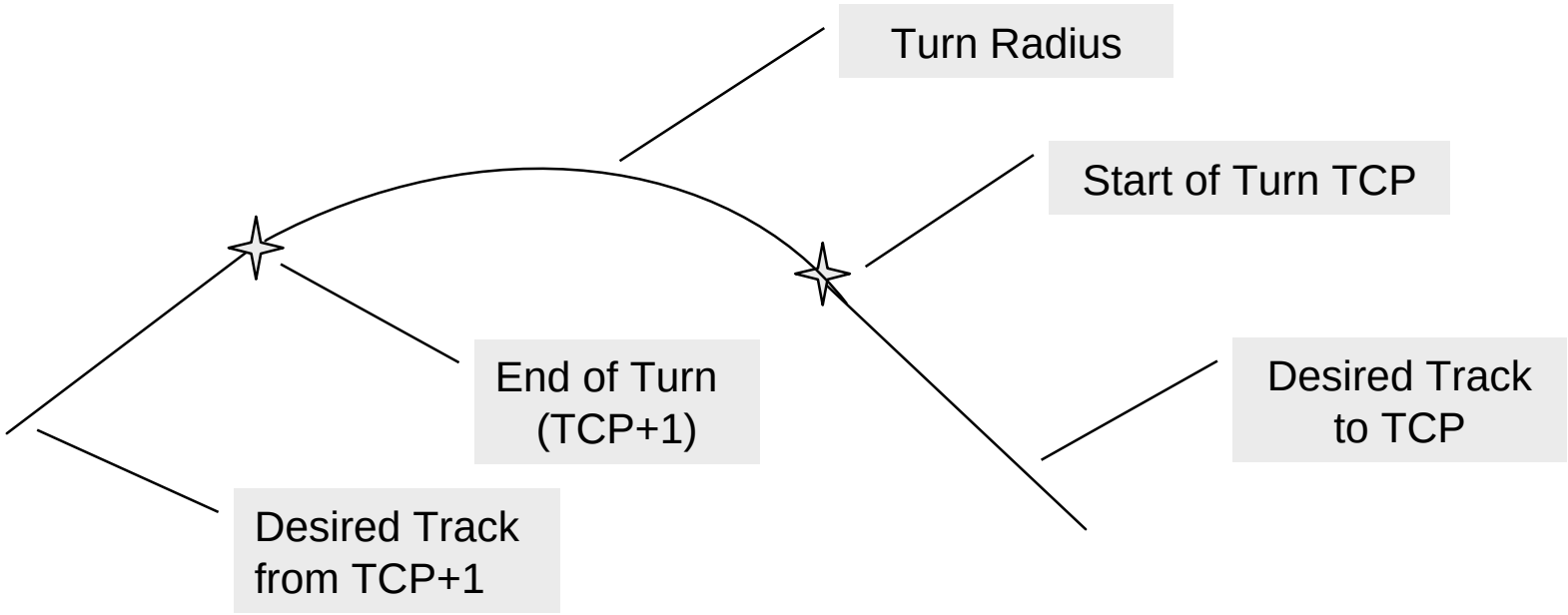
(3) Lookahead Limiting: Limitation on Lookahead distance and time, i.e. do not extrapolate beyond TCP limits.

Target Vertical Prediction Integrity Example - Class A2

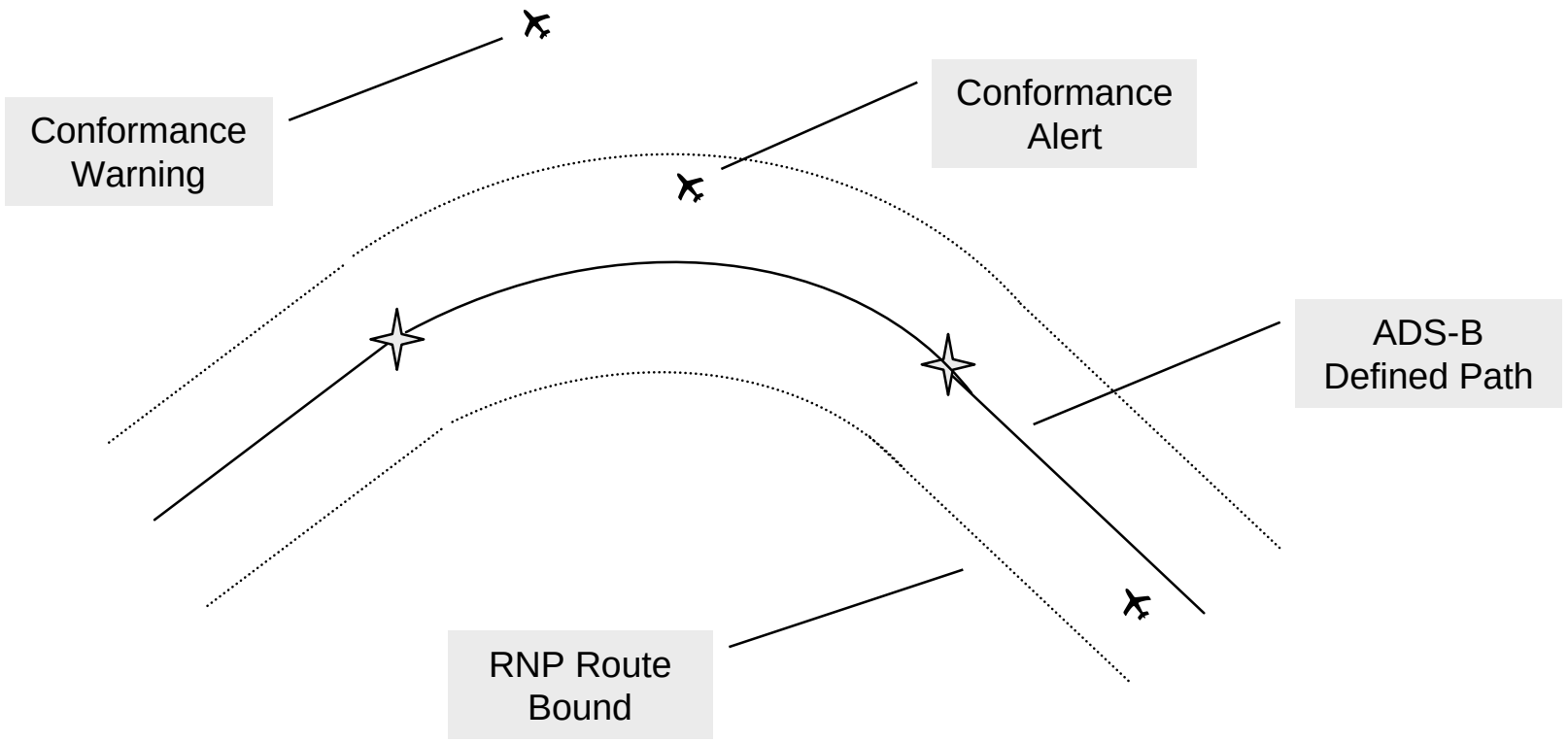


Preferred Turn Definition Method - Class A3

- Complete turn definition by using start-of-turn and end-of-turn TCP's and other parameters as needed: (Fly-by, Fly-over, Radius to Fix)
  - Turn Radius
  - Desired Track to TCP
  - Desired Track from TCP+1



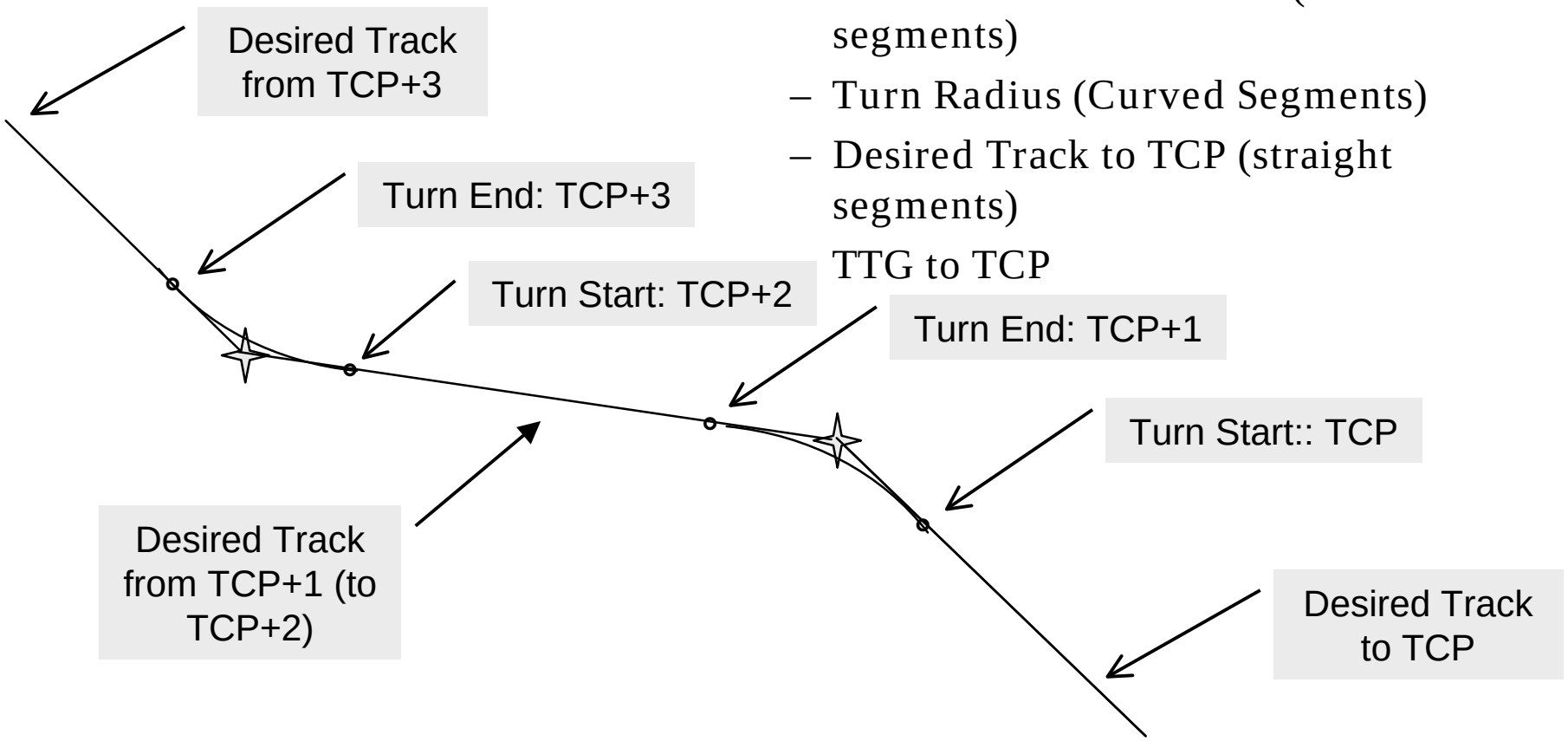
Trajectory Conformance Monitoring Example
(ADS-B User/Receive Side Integrity Monitoring)



Note: May require transmission of current RNP capability & validity

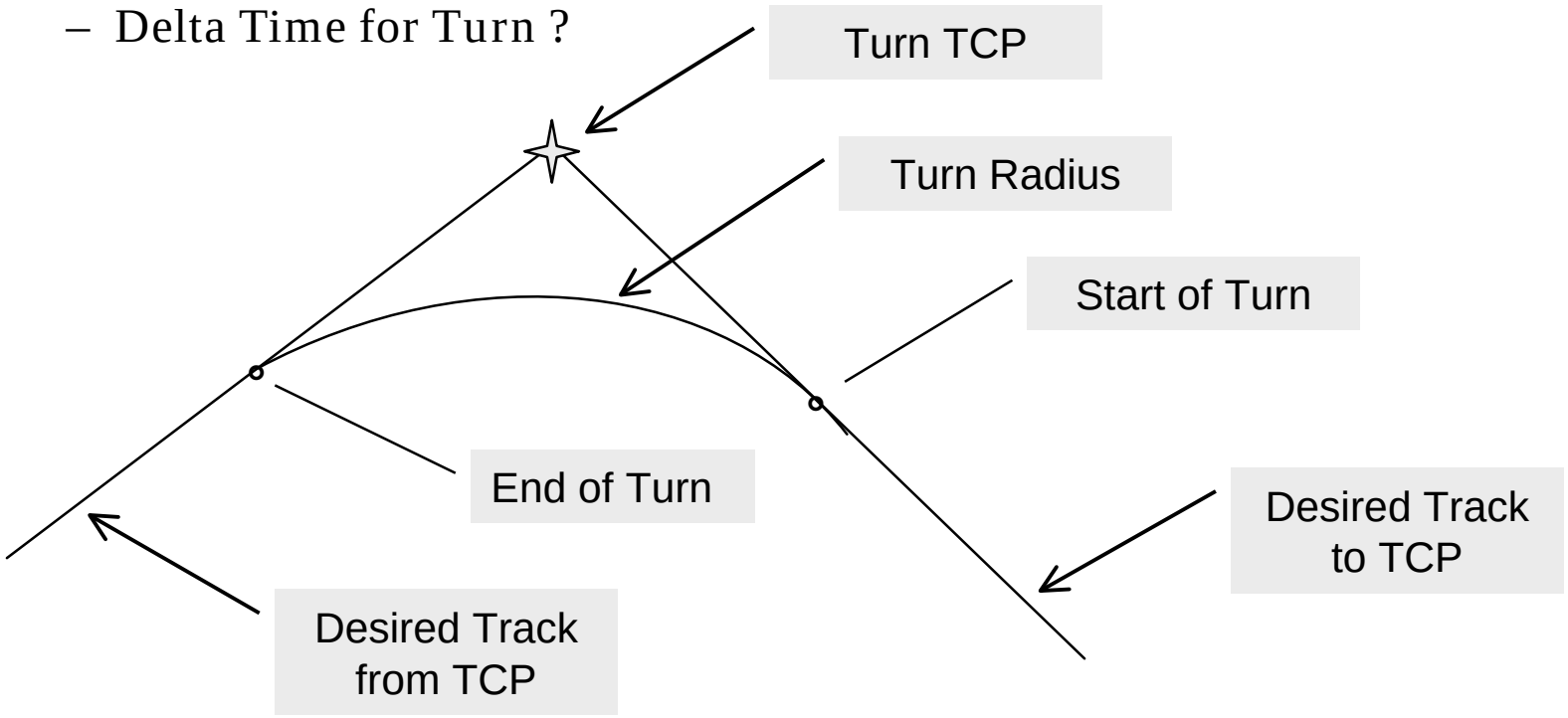
Turn Parameters for Fly-By S-Turn

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



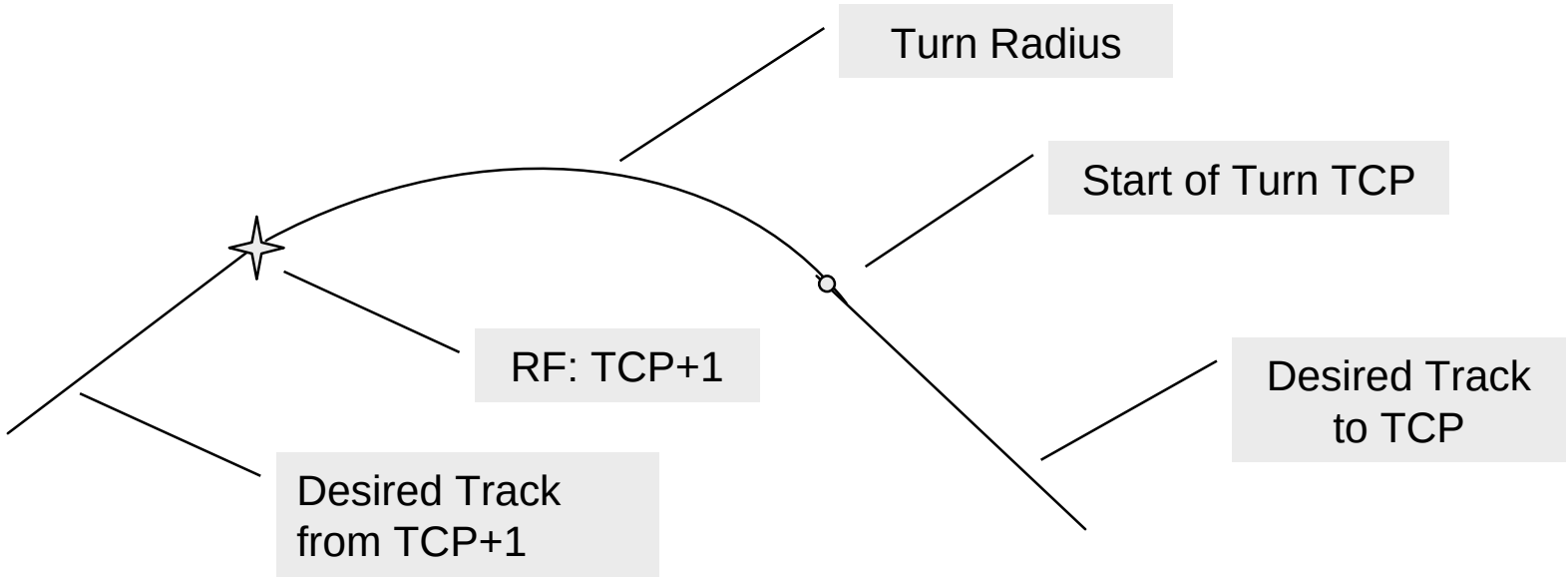
Alternative Fly-By Turn Definition Method - 11/00

- Complete turn definition by using turn corner TCP and other parameters as needed:
  - Turn Radius
  - Desired Track to TCP
  - Desired Track from TCP
  - Delta Time for Turn ?

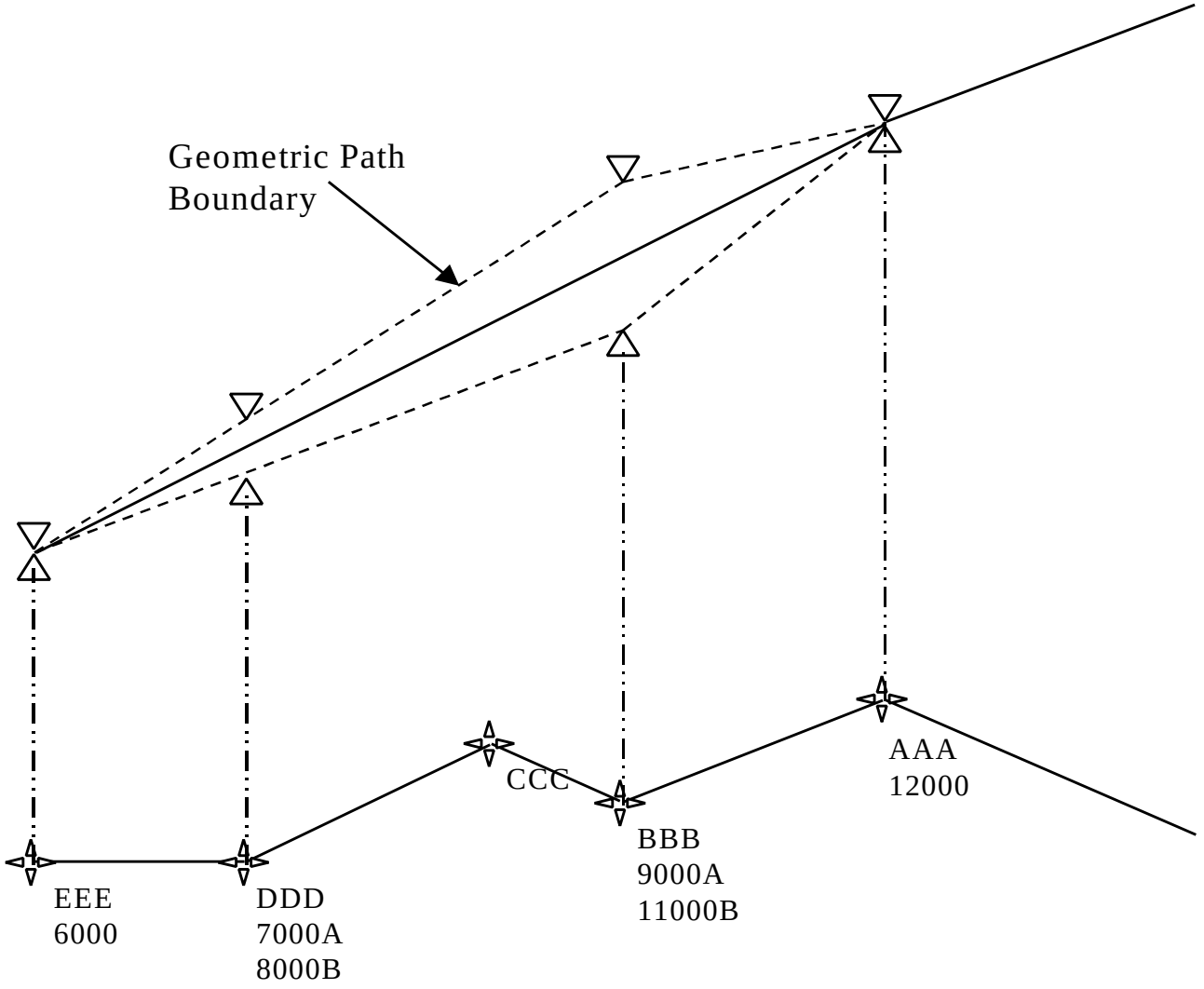


Radius to Fix (RF) Turn Definition - 11/00

- RF turn transition defined by TF leg to RF segment and RF turn to Termination Fix (TCP+1), and associated parameters:
  - Turn Radius
  - Desired Track to TCP
  - Desired Track from TCP+1
  - TCP Indicators (TF to RF Turn / RF Turn to TF)
  - TTG to Start and End of Turn

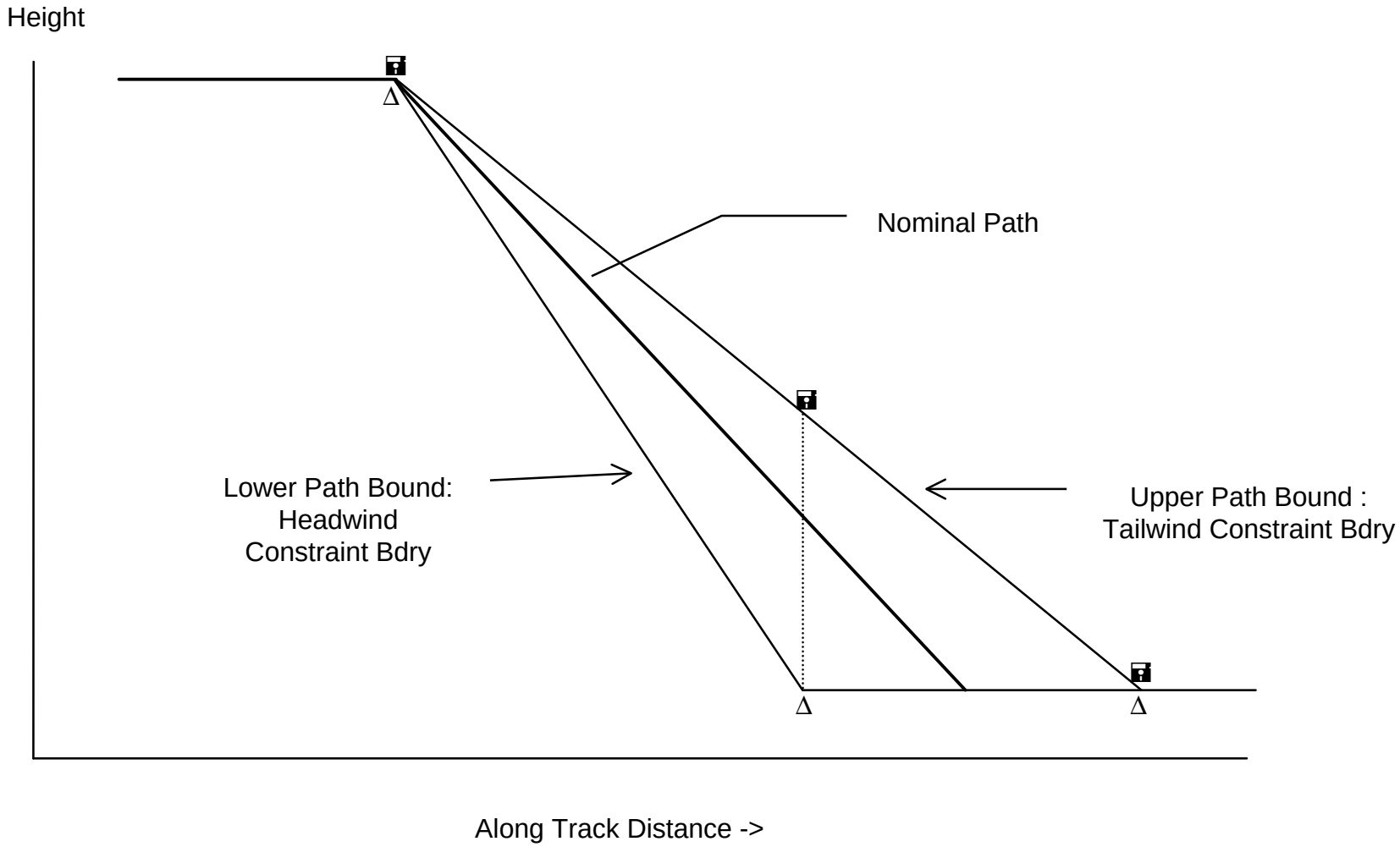


Descent Path Example with Vertical Window Constraints



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

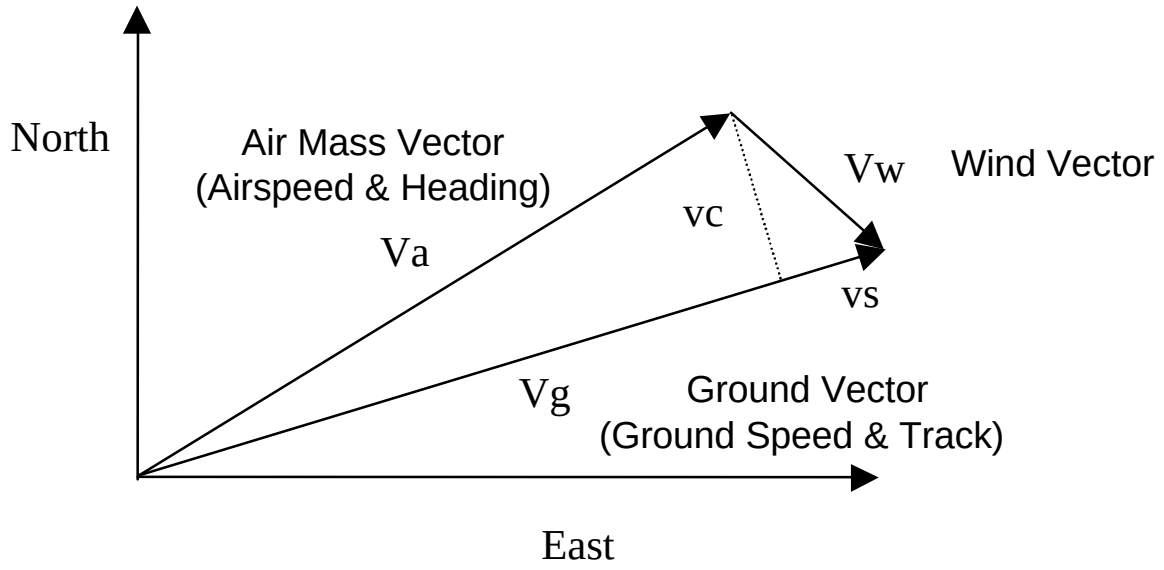
Descent Example with Descent Slope Bounds - Class A3



Class A3 Intent - Related Issues

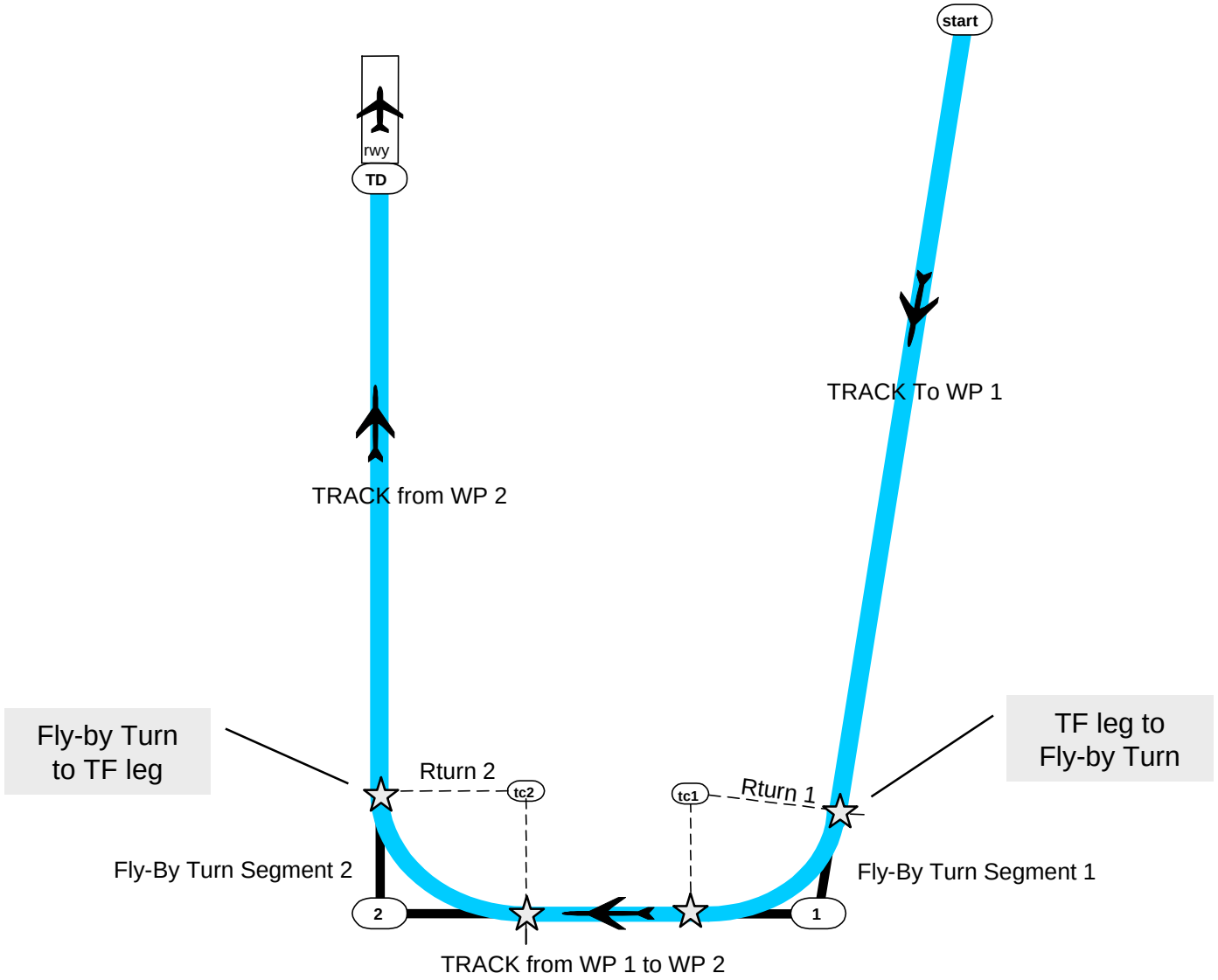
- Transmission of Horizontal and Vertical RNP Capability
  - Current RNP Capability and NAV Validity bit (Able / Unable to fly the horizontal path within the desired RNP limits)
  - Vertical 'Window' Constraint Limits & NAV Validity bit (Able / Unable to fly the vertical path within defined limits)
- Time Based / Procedural Separations at Remote Crossing Points
  - three-four minute separation reqt's between successive crossings
  - if airspace tunnels intersect (~ 20 to 30 nm crossing separations)
  - Enhanced longitudinal integrity needed for reduced separations, e.g. airspeed TCP's and wind vector synthesis along path
- Transmission of Air-Mass Velocity Vector
  - Highly desirable for estimating current wind vector
  - Useful for reconstructing ground velocity after turns for more accurate path prediction following a turn segment
  - Recommend as Desirable for Class A3 equipage

Use of Wind Triangle for Future Path Predictions



- Potential Use of Wind Triangle for Trajectory Predictions:
  - Given Air Vector and Ground Vector, Estimate Current Wind Vector
  - Given Wind Vector and Future Air Vector, Estimate Future Ground Vector
  - Given Wind Vector and Future Airspeed and Track, Estimate Future Ground Speed and Heading

Downwind to Final Approach Linked Turn Example



Proposed 1090 MOPS TCP "Leg Types"

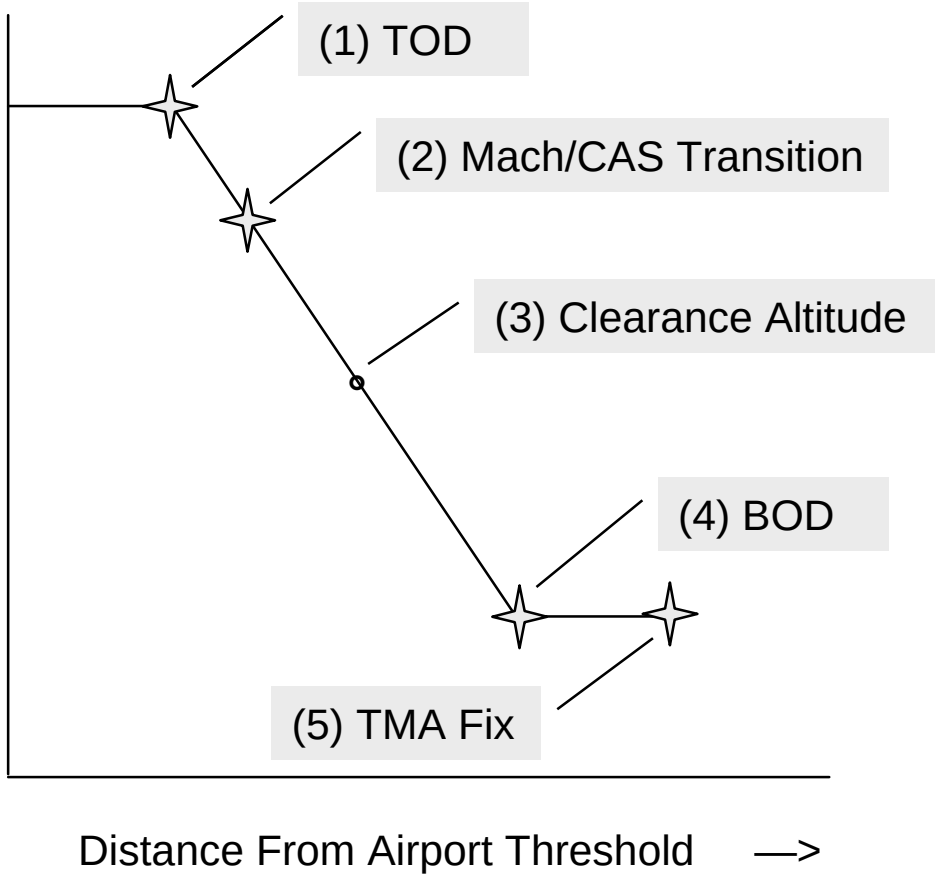
ENCODING	MEANING
0000	No Specific Trajectory Change Point Description Information
0001	"Straight" (geodesic) Course to a "Fly By" Waypoint
0010	"Straight" (geodesic) Course to a "Fly Over" Waypoint
0011	"Straight" (geodesic) Course to a "Speed Change" Waypoint
0100	"Straight" (geodesic) Course to a "Vertical 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
- Recommend: Separate Horizontal / Vertical TCP Indicators

Example of TCP Indicators - Descent from Cruise to TMA

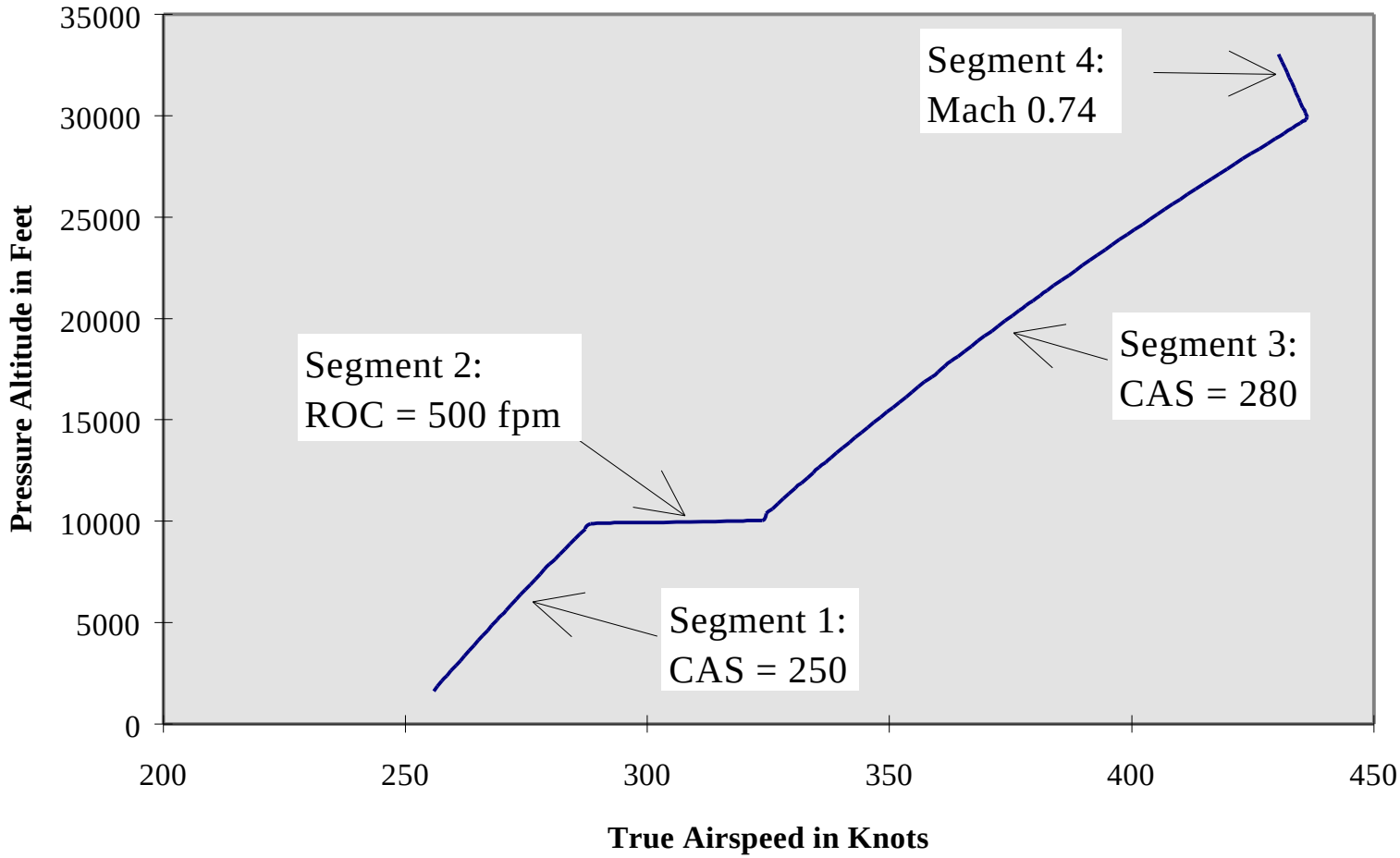
- TCP / Indicators for Descent Example
  1. Horiz = Continue Course
     Vert = Initiate Descent (TOD)
     Speed = Continue (Mach)
  2. Horiz = Continue Course
     Vert = Change Vertical Rate
     Speed = Change Airspeed
  3. Selected Altitude (No TCP)
  4. Horiz = Continue Course
     Vert = Level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

Altitude / Distance Profile for Descent Example



Nominal Climb Transition for 737-400 Aircraft

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



Potential Horizontal TCP Indicator Types

- **Horizontal TCP Indicators / Leg-Types** *(Recommended)*
  - Turn waypoint segment to a TF Leg (curved path)
    - » Valid for Fly-by, Fly-over and Radius-to-Fix turns
  - Straight Line (TF leg) to a Turn (Fly-by, Fly-over, RF)
  - Straight Line (DF leg) to a Turn (Fly-by, Fly-over, RF)
  - Straight Line Segment (continue established course)
  - Holding Pattern to a Holding Fix
  - Others ...

Potential Vertical and Speed TCP Indicator Types

- Vertical TCP Indicators *(Recommended)*
  - Level-off (BOD, TOC)
  - Initiate Climb / Descent (BOC, TOD)
  - Continue vertical path(climb, descent, level)
  - change vertical rate / slope *(desirable but not required) ?*
  - Altitude restriction (at or above / at or below / both)
  - Others …

- Airspeed TCP Indicators *(Desirable but not required for A3) ?*
  - Continue Airspeed / Mach
  - Change Airspeed at TCP
  - Speed Restriction at TCP

TCP Requirements Issues

- RNP Containment Bounds Min Req't or Desirable for Class A3?
- Horiz & Vertical TCP's Min Req't for A2, A3; Airspeed TCP's Desirable for Class A3?
- TCP Broadcast Conditions:
  - Limit of Four TCP's ? *(Two Turns or One Turn & Climb/Descent)*
  - Broadcast Req'ts for Next and remote TCP's, e.g. time / distance limits *(Broadcast TCP's For up to 10 ? min lookahead)*
  - Reception Req'ts for Next and remote TCP's, e.g. update rates *(Next TCP <=10 sec updates ; remote TCP's - 20 sec updates ?)*

MASPS Intent - Summary of Currently Proposed Changes

1. **Incorporate AP / MCP Selected Intent Parameters:**
   - **Selected Altitude, Heading/Trk Min Req't for Classes A2, A3**
   - **Use FMI Indicator 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 <u>Desirable</u> ADS-B Parameters (Not Min Req't for A3)**
   - **Reusable Message Slots Available Per ADS-B Report Type:**
     - **Current Airspeed, Mag/True Heading (SV)**
     - **Selected Airspeed, Vertical Rate/ Slope (MS)**
     - **Airspeed TCP, Time/Speed Restrictions (OC)**