



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Flight Management Computer Systems (FMCS)

Vertical Navigation (VNAV)

Sam Miller

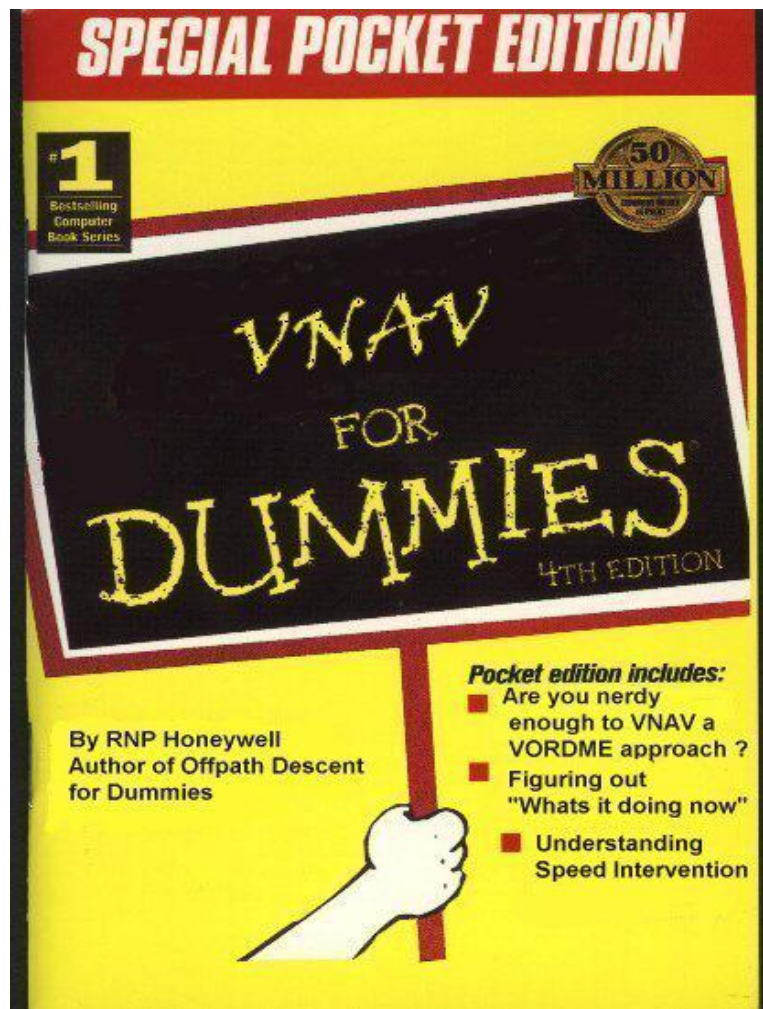
RNP/RNAV Standards and Procedures

February 2010



VNAV really is quite simple

(Except when it seems to have a mind of its own)



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Australia
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Introduction to VNAV

Overview

- **Brief History of VNAV**
- **VNAV Basics**
 - **Background**
 - **Flight Phases**
 - **Path construction**
 - **Path types**
 - **Influences on the path**
- **Benefits**
- **Summary**



Brief History of VNAV

- **Lateral Navigation (LNAV) and Vertical Navigation (VNAV) were first “fully integrated” on Boeing airplanes in the early '80s (757 / 767). Other airplane manufacturers and models followed shortly thereafter.**
- **The original intent of the FMS and its features was to offload routine tasks from the pilot and enhance fuel efficiencies for enroute navigation.**
- **No early vision existed into future operations such as RNAV / RNP / GPS / 4-D paths, etc.**
- **Note that not all FMS systems have an integrated VNAV capability. Modern FMSs in Air Transport airplanes, some regional's, and some Business and General Aviation are fully equipped. Others have limited or no VNAV capability.**



Brief History of VNAV

- **As the capabilities of LNAV and VNAV were better understood, each was increasingly used in terminal area operations.**
 - **Then they were applied to approach operations,**
 - **Then Area Navigation (RNAV) approach procedures,**
 - **Then Required Navigation Performance (RNP)**
- **Now, the FMS is the primary “on-board” tool for Performance-Based Navigation operations, which is the foundation for the US and European airspace modernization initiatives.**



VNAV Basics

Background

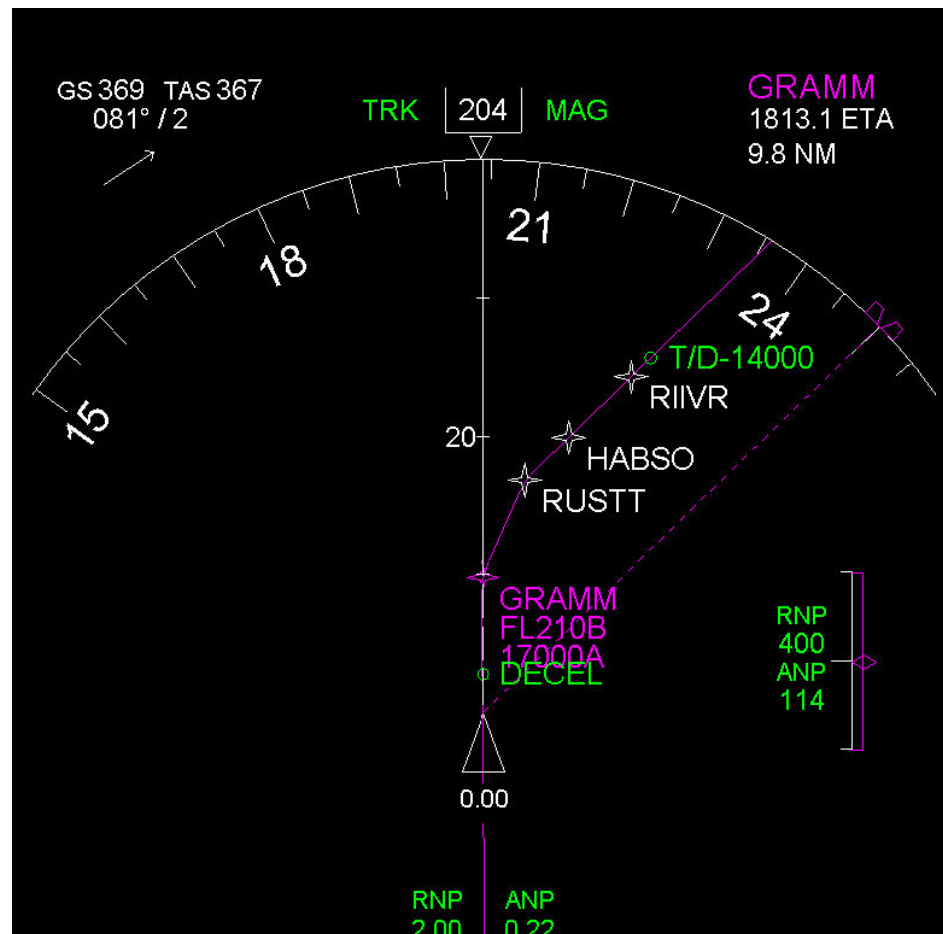
- **LNAV – Lateral Navigation**
 - Provides flight control steering (guidance commands) along the lateral flight planned path
- **VNAV – Vertical Navigation**
 - Provides flight control steering and thrust (guidance commands to flight control system and auto thrust) along the vertical path for Takeoff, Climb, Cruise, Descent, Approach and Missed Approach phases
 - Some less integrated VNAV systems “advise” the flight crew of the vertical path but have no autothrottle capability requiring the crew to manually maintain the descent path.



VNAV Basics

Background

- VNAV provides the vertical component of the flight plan along the lateral path.
- When not positioned on the LNAV path or purposely deviating from the path, VNAV is not intended to be used.





VNAV Basics

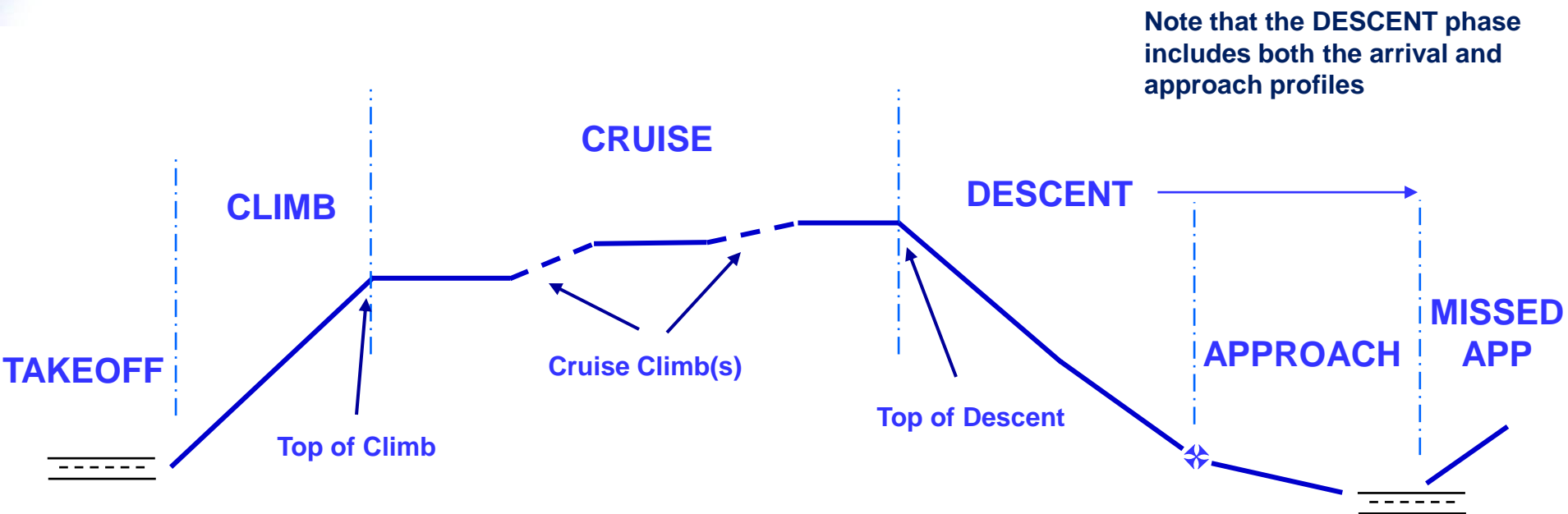
Background Specifics

- **VNAV is the vertical component of the navigation flight profile, i.e., the computed flight trajectory of the airplane in the vertical plane.**
- **The flight profile is 3-dimensional, potentially 4-D when a time requirement is added, and reflects all speed and altitude restrictions specified in the flight plan while also honoring airplane operating limits.**
- **VNAV computes guidance commands for the Autopilot or Flight Director and Autothrottle to follow the computed vertical profile.**
- **Bottom line: VNAV is designed to optimize the airplane's vertical performance capability and accuracy along the flight planned route.**



VNAV Basics

Flight Phases





VNAV Basics

Flight Phases

- **TAKEOFF**
 - **Speed-based climb (safety speed until acceleration height or flap retraction)**
- **CLIMB**
 - **Speed-based climb determined by most economical speed (ECON) or pilot selection (SElected SPD)**
- **CRUISE**
 - **3-D “Path-based” level segment determined by economics (speed and altitude) or pilot selection**
 - **Cruise-climb capability for a more efficient altitude**
 - **Cruise-descent capability should the pilot choose to change the cruise flight level or descend early**



VNAV Basics

Flight Phases

- **DESCENT**

- Path-based, idle or near-idle descent profile
- Descent phase begins at “top-of-descent” through approach to the beginning of the missed approach (typically the runway)
- Path is determined by airplane performance parameters, desired descent speed (ECON or SElected), winds, temperature, distance to airport, and intermediate altitude constraints
- In the event of adverse, unforecast winds / temperature, VNAV may sacrifice the path (shallow the flight path angle) to protect for a pending overspeed condition



VNAV Basics

Flight Phases

- **APPROACH**

- Path-based descent determined by the instrument approach procedure's vertical angle
- Approach is a unique segment and a “phase within the Descent phase”

- **MISSED APPROACH**

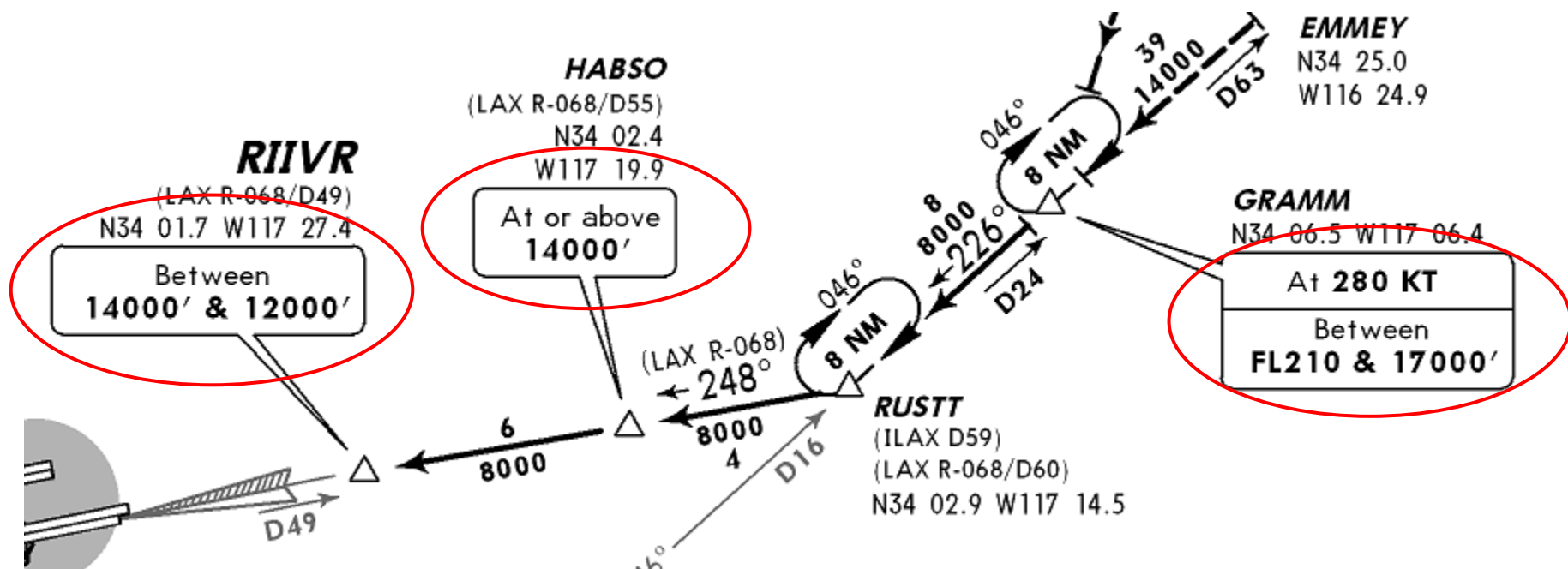
- Similar to the climb phase: speed-based climb to a pre-determined altitude and waypoint



VNAV Basics

Descent Path Construction - Background

- The vertical flight profile can be (and frequently is) affected by speed and altitude restrictions specified in the arrival procedure.










VNAV Basics

Descent Path Construction - Background

- The vertical flight profile reflects the speed and altitude restrictions specified in the flight plan.
- VNAV path segments are formed by altitude-constrained waypoints:

<u>Waypoint</u>	<u>Approach Chart Text</u>	<u>Engineering Symbol</u>
➤ “AT” altitude	<u>4400</u>	
➤ “AT or Above”	<u>4400</u>	
➤ “AT or Below”	<u>4400</u>	
➤ “Window”	<u>12000</u> <u>10000</u>	 



VNAV Basics

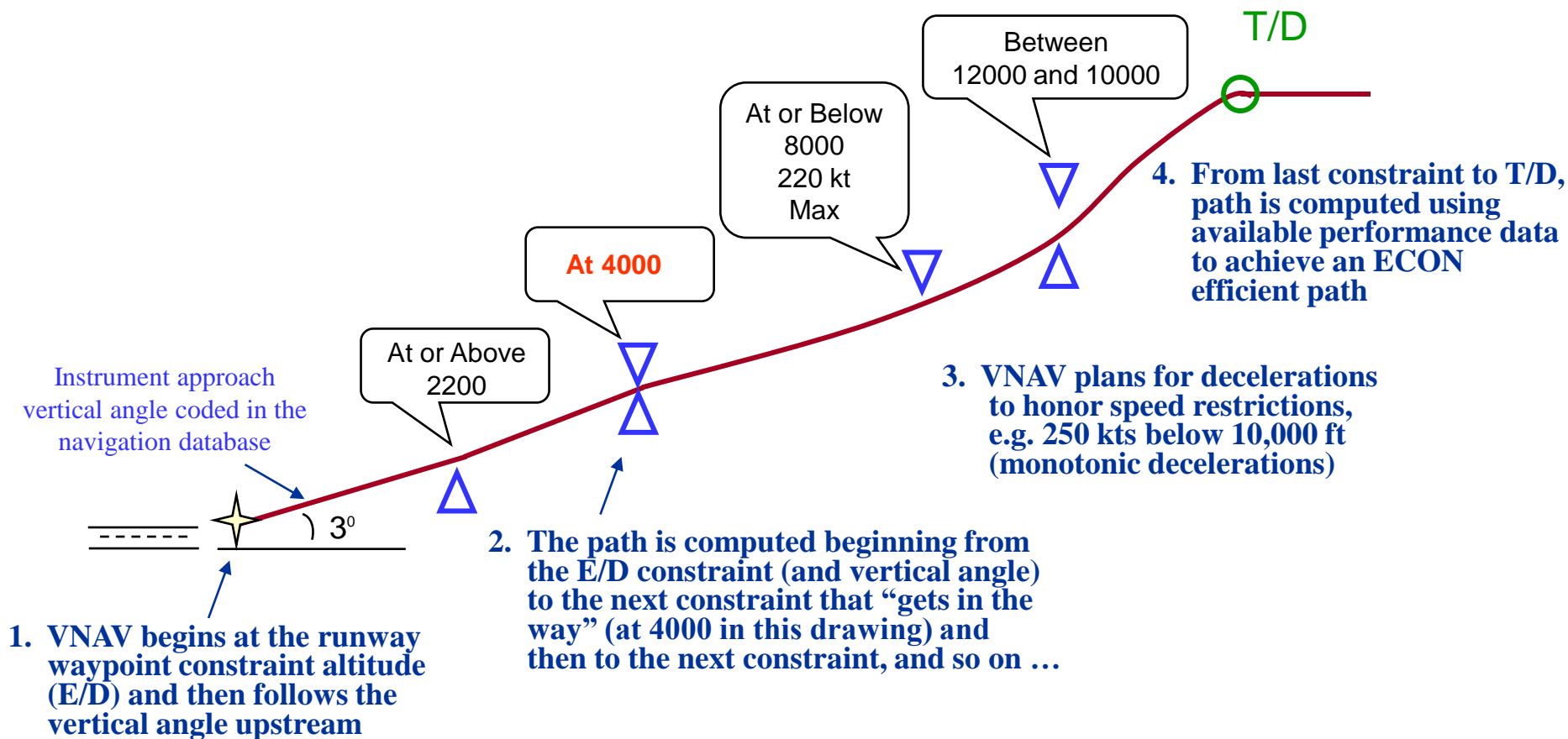
Descent Path Construction

- **The VNAV Descent Path is constructed upstream, beginning at the lowest waypoint constraint, up to the final cruise altitude.**
 - **The end-of-descent waypoint (“E/D”), generally the runway or missed approach point, is the anchor position of the vertical descent path.**
 - **Top-of-descent (“T/D”) is the end of the vertical descent path.**



VNAV Basics

Descent Path Construction

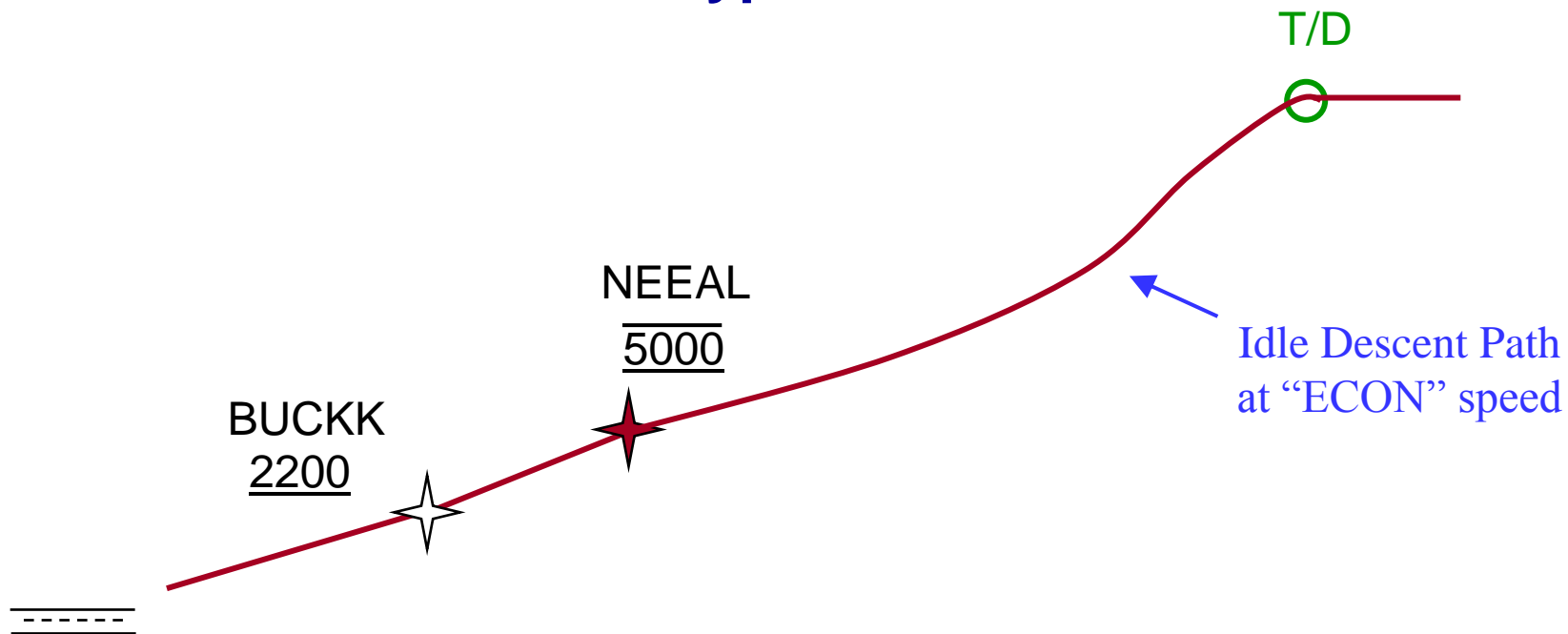




VNAV Basics

Descent Path Types

- **PERFORMANCE PATH** - computed descent path at idle (or near-idle) power from top-of-descent to the first constrained waypoint

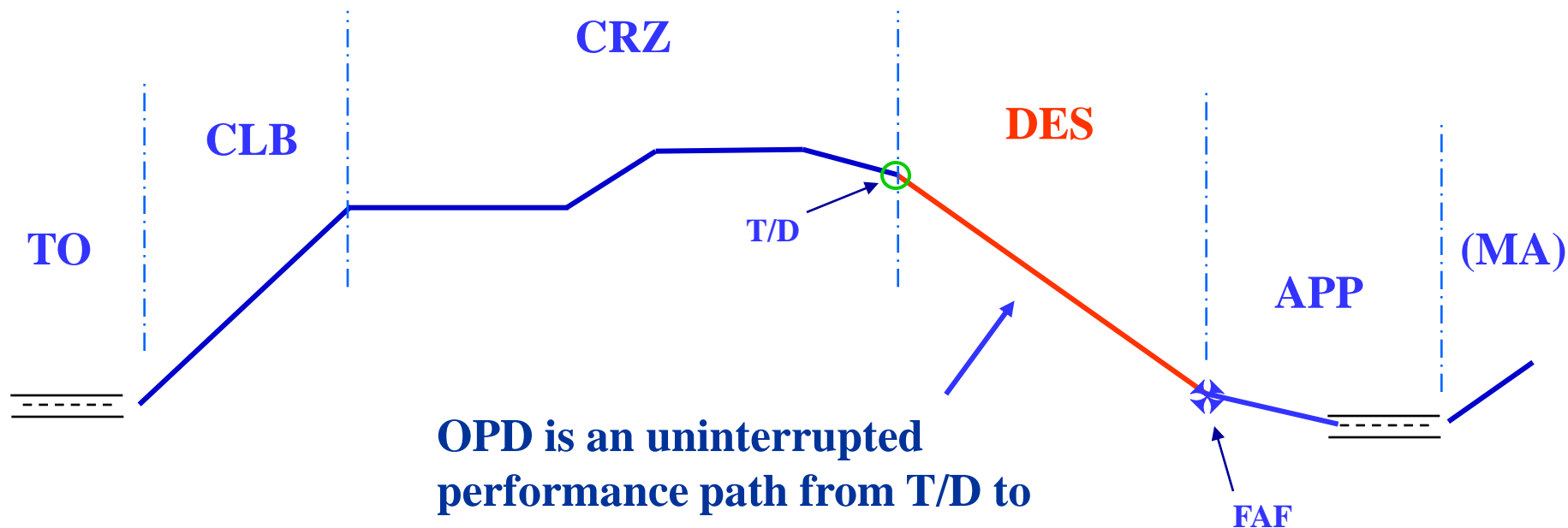




VNAV Basics

Descent Path Types

Optimized Profile Descent - An Ideal Performance Path



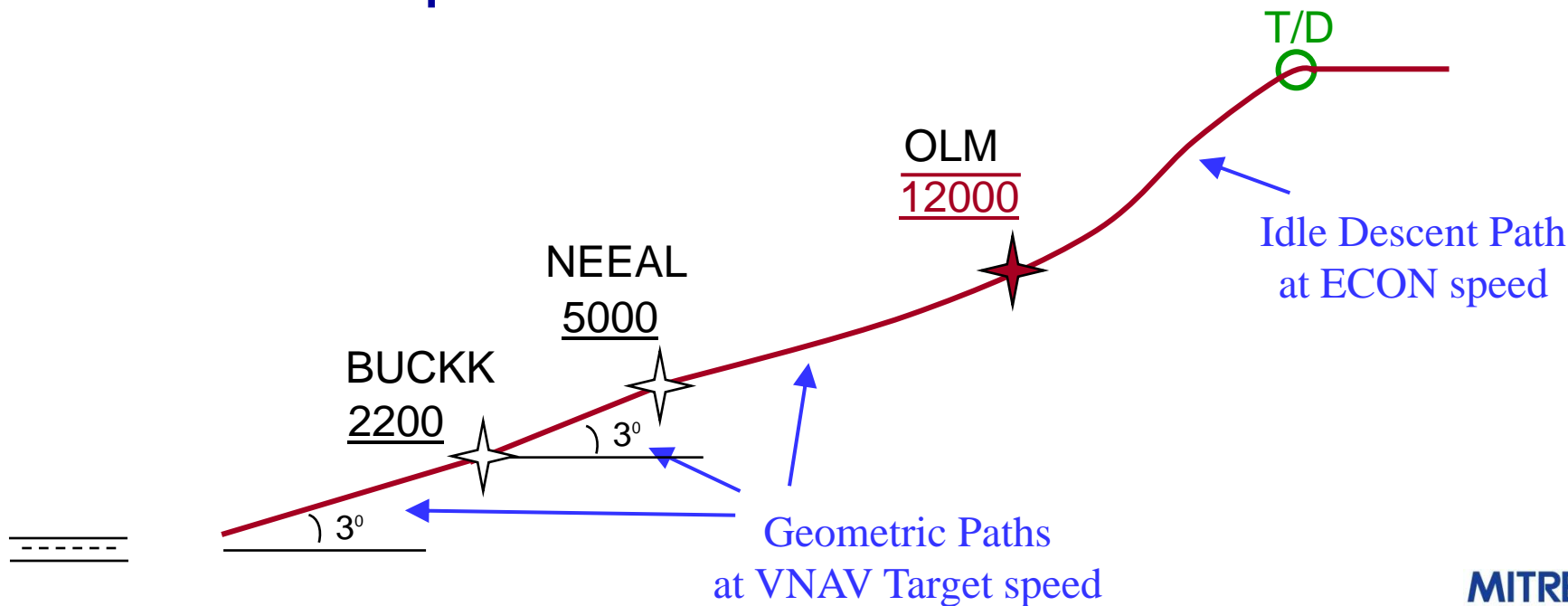
OPD is an uninterrupted performance path from T/D to the Final Approach Fix (nominally)



VNAV Basics

Descent Path Types

- **GEOMETRIC PATH** - computed 3-D “point-to-point” descent path between two constrained waypoints or when tracking a prescribed vertical angle
 - The geometric path is a shallower descent and typically a non-idle path





VNAV Basics

Influences on Path Construction

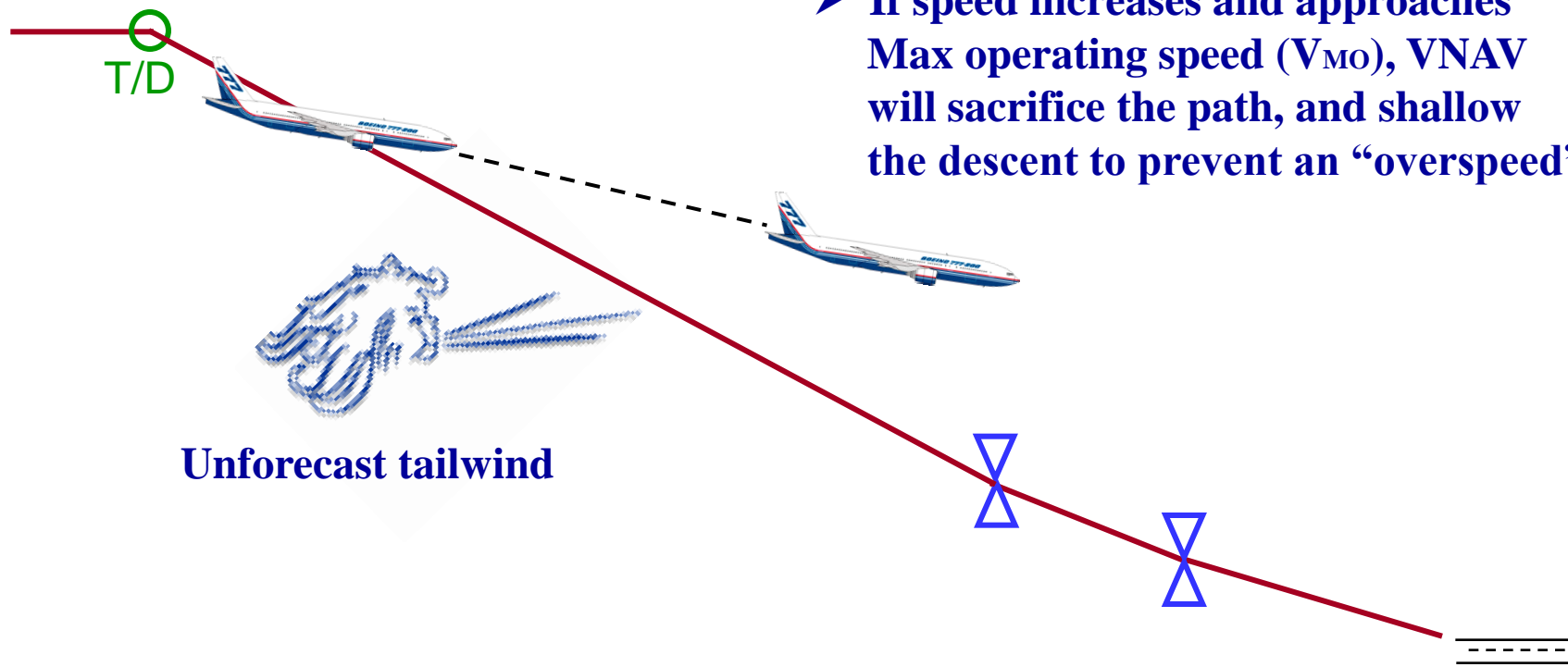
- **Computation of the path is influenced by several factors**
 - **Airplane type and performance**
 - Some (not all) FMCs contain airplane performance data
 - **Gross weight (and other airplane specific data)**
 - **Accuracy of forecast wind inputs**
 - **Anti-icing (creates a higher idle thrust)**
 - **Actual weather**
 - Winds
 - Temperature



VNAV Basics

Influences on Path Maintenance

- **Should an unforecast tailwind occur:**
 - **VNAV will attempt to maintain path**
 - **If speed increases and approaches Max operating speed (V_{MO}), VNAV will sacrifice the path, and shallow the descent to prevent an “overspeed”**

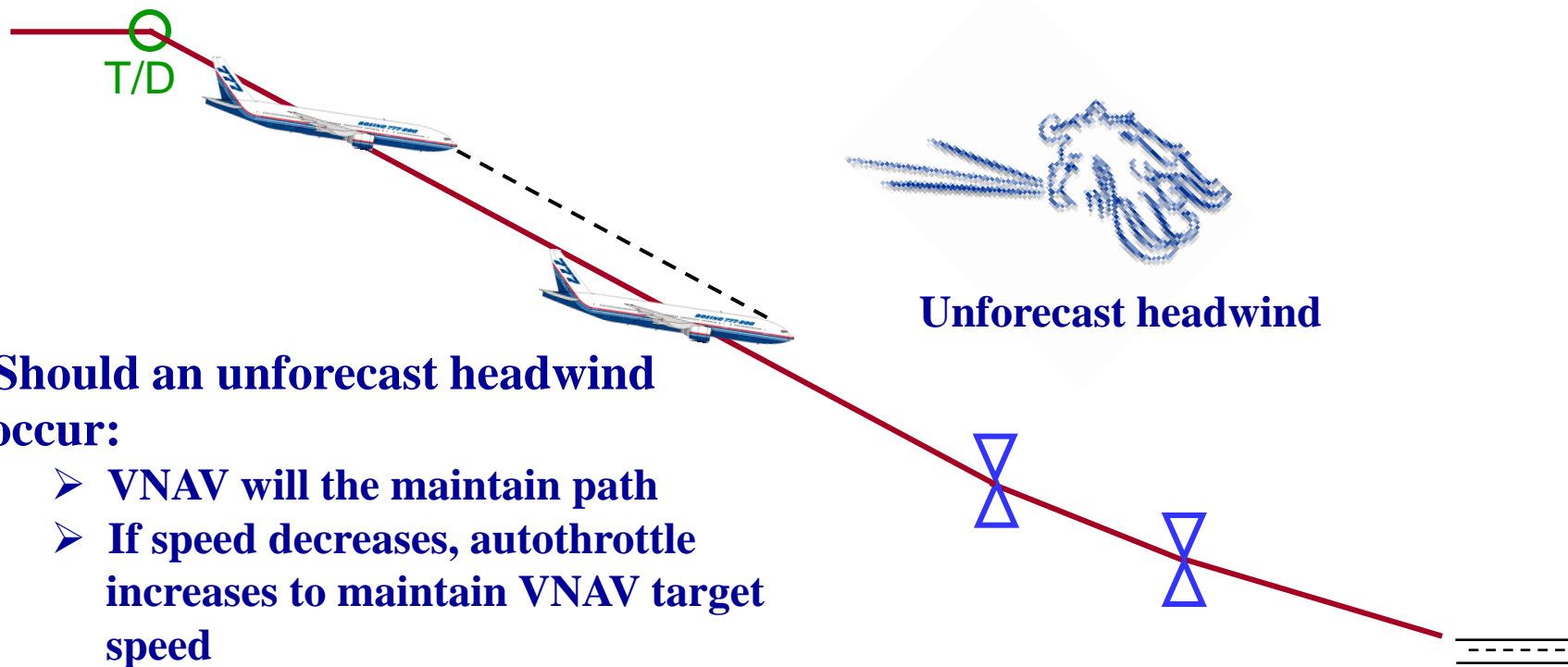


Unforecast tailwind



VNAV Basics

Influences on Path Maintenance



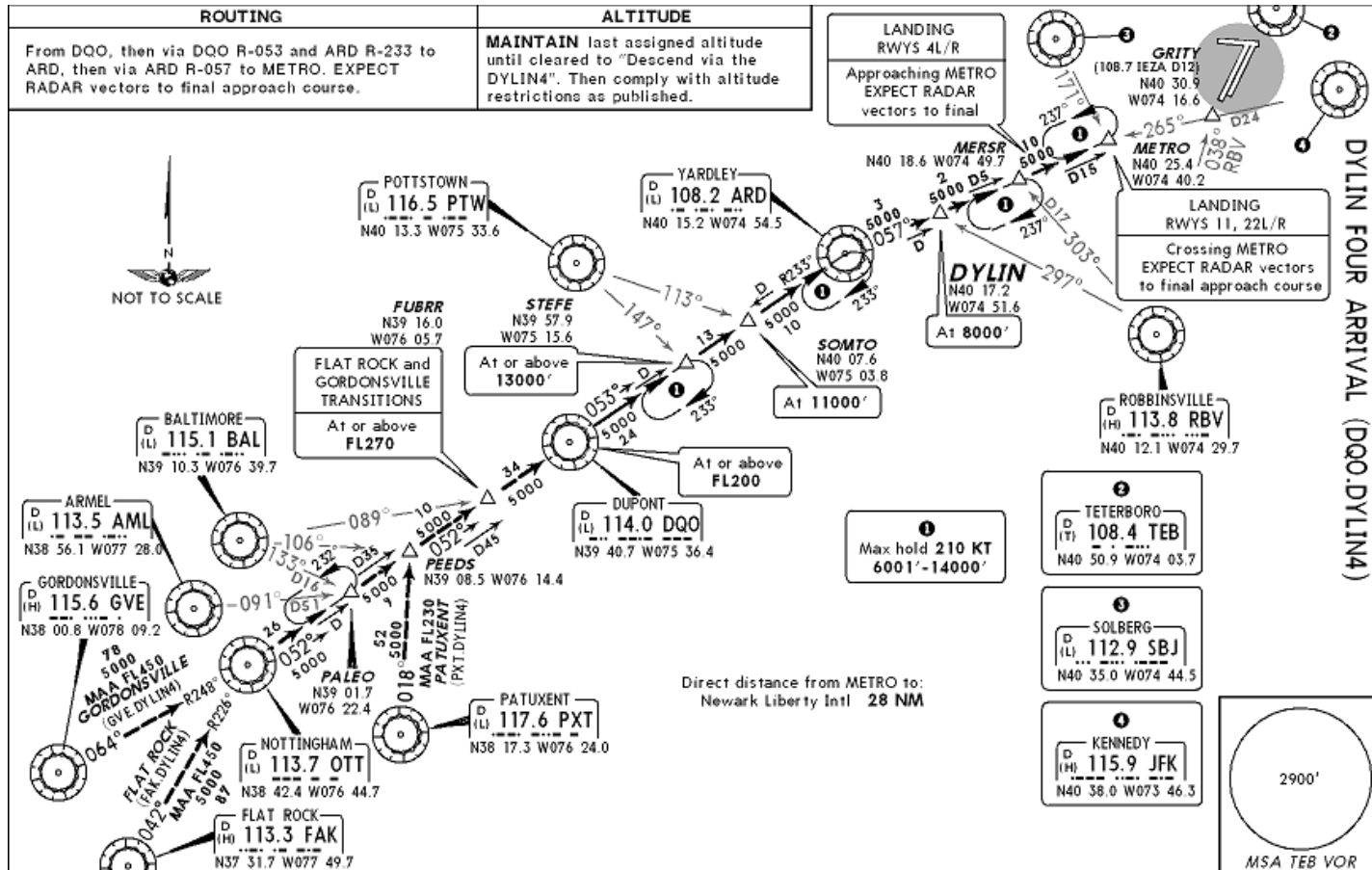
- **Should an unforecast headwind occur:**
 - **VNAV will the maintain path**
 - **If speed decreases, autothrottle increases to maintain VNAV target speed**



VNAV

Benefits

- LNAV and VNAV reduce the workload on such as these:

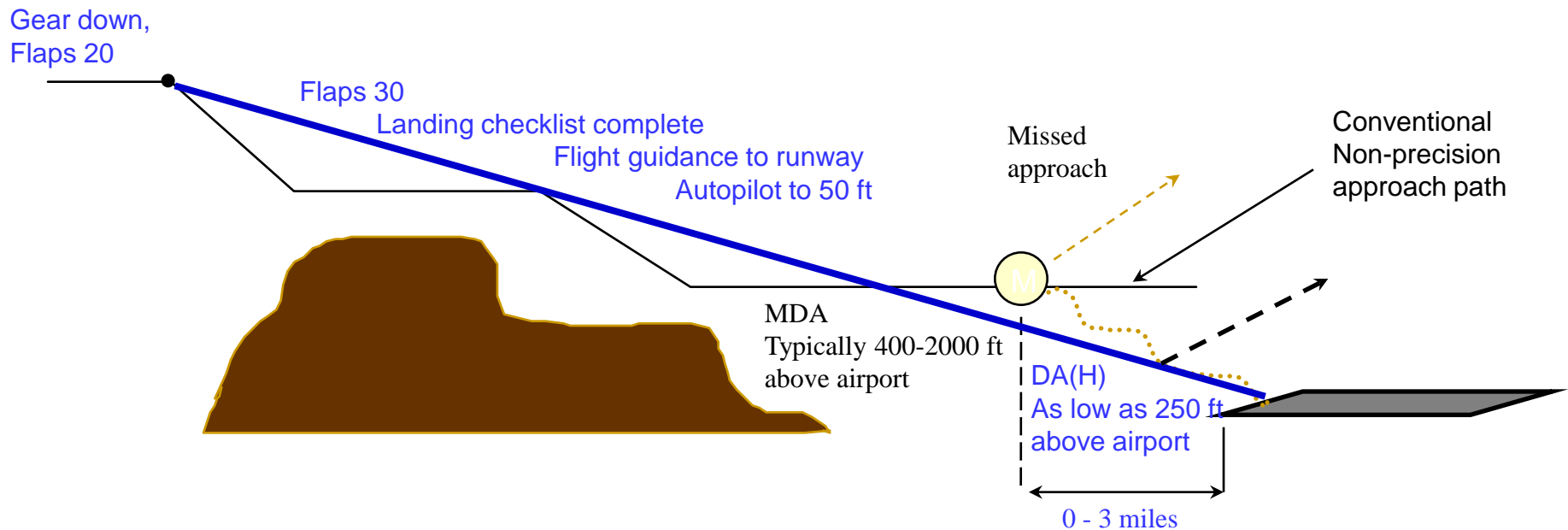




VNAV

Benefits

- A Stabilized VNAV final approach path enhances safety as compared to the “dive ‘n drive” method





VNAV BASICS

Summary

- **The VNAV path is computed based upon airplane performance characteristics, and speed or altitude constraints along the LNAV path.**
- **The descent path can be either “performance” or “geometric.”**
 - **The geometric path is typically a shallower descent and a non-idle path. VNAV will manage energy to comply with speed restrictions.**
- **Numerous factors influence path computation, winds for example.**
- **Given good input data (wind, temp, e.g.), VNAV will provide an efficient descent path.**



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