



RNAV/RNP Operations & VNAV Approaches

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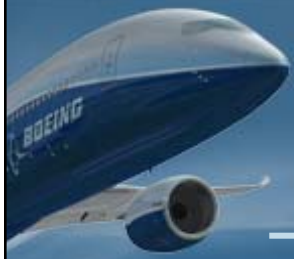
Discussion Objectives

- Discuss current RNAV status – US and Europe
- Provide safety-related background information
- Provide an understanding of basic RNP/ANP concepts and operations
- Provide an understanding of VNAV approach selection, execution and related topics



RNAV Use is Growing...

- We are now seeing a gradual transition from ground-based navigation aids to satellite based navigation
- More routes and procedures with no underlying navigation aids are being published
- RNAV capabilities are now being exploited further by US, European and other air traffic service providers
 - RNP operations
 - Increased traffic capacity en-route
 - SIDs, STARs and approaches
- Operators taking advantage of RNP operations
 - Improved airport access; lower minima
 - Increased safety; less reliance on VOR/ADF
 - Increased payloads from special procedures



RNP/RNAV = Higher Payload

Example:

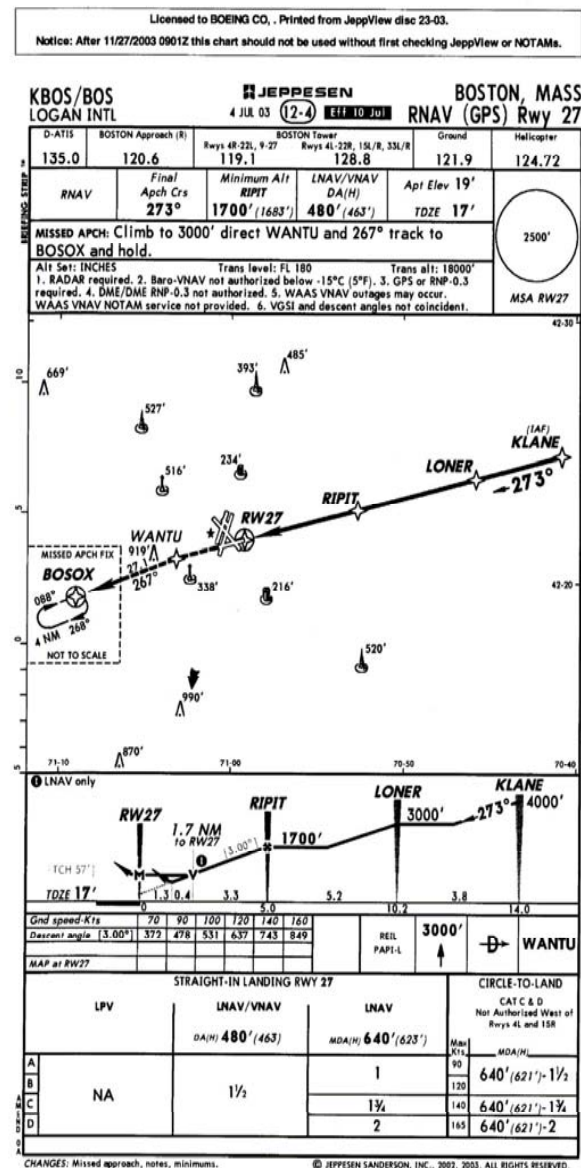
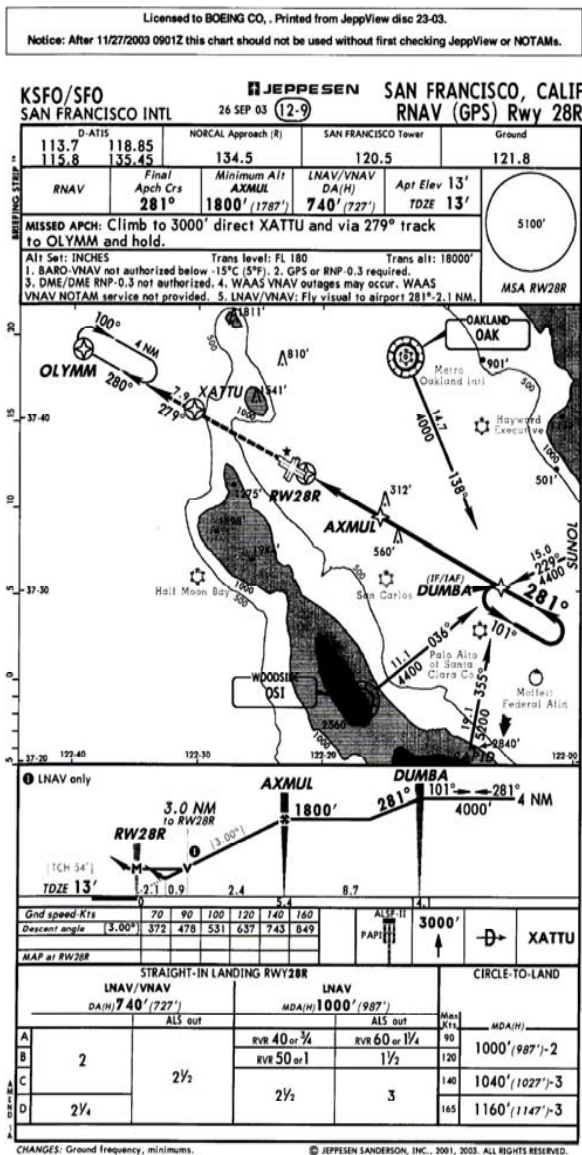
- Hong Kong (departing RW07)
- Weight limit governed by distant obstacle
- Engine-out SID developed with immediate turn after takeoff (RNP 0.15)
- Payload increased by several tonnes



Current US RNAV Status

- Use of RNAV widespread and growing
- Many RNAV and GPS approaches
- Lower VNAV minima available
- GPS approaches being re-designated as RNAV
- RNP 1.0 SIDs and STARs available and increasing in number
- Some special procedures developed (as low as RNP 0.11)

RNAV – VNAV examples





Current Euro-control RNAV Status

- BRNAV (RNP 5.0) established for airways
- PRNAV (RNP 1.0) is implemented for terminal operations (before FAF) – TGL 10 published.
- Requirements for Baro-VNAV and RNAV/RNP approaches being established – TGLs being drafted
- Some RNAV approaches available

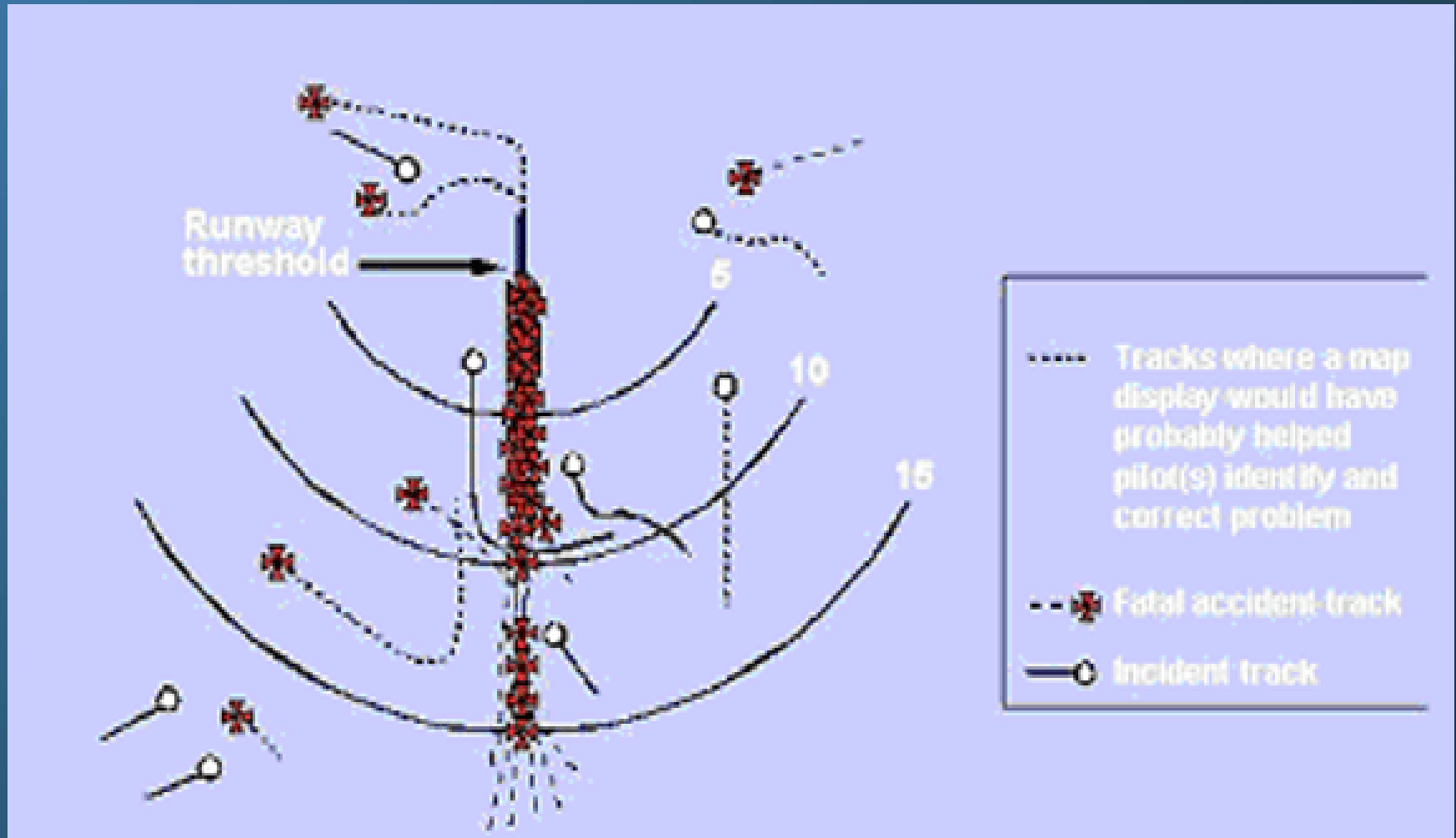


Safety History of Non-ILS Approaches Suggests RNAV/RNP

- 60% of CFIT accidents occur on NP approaches
- 47% occurred during step-down NP approaches
- Almost all accidents occurred in darkness or IMC
- 48% in mostly flat terrain
- Most common cause: descent below MDA

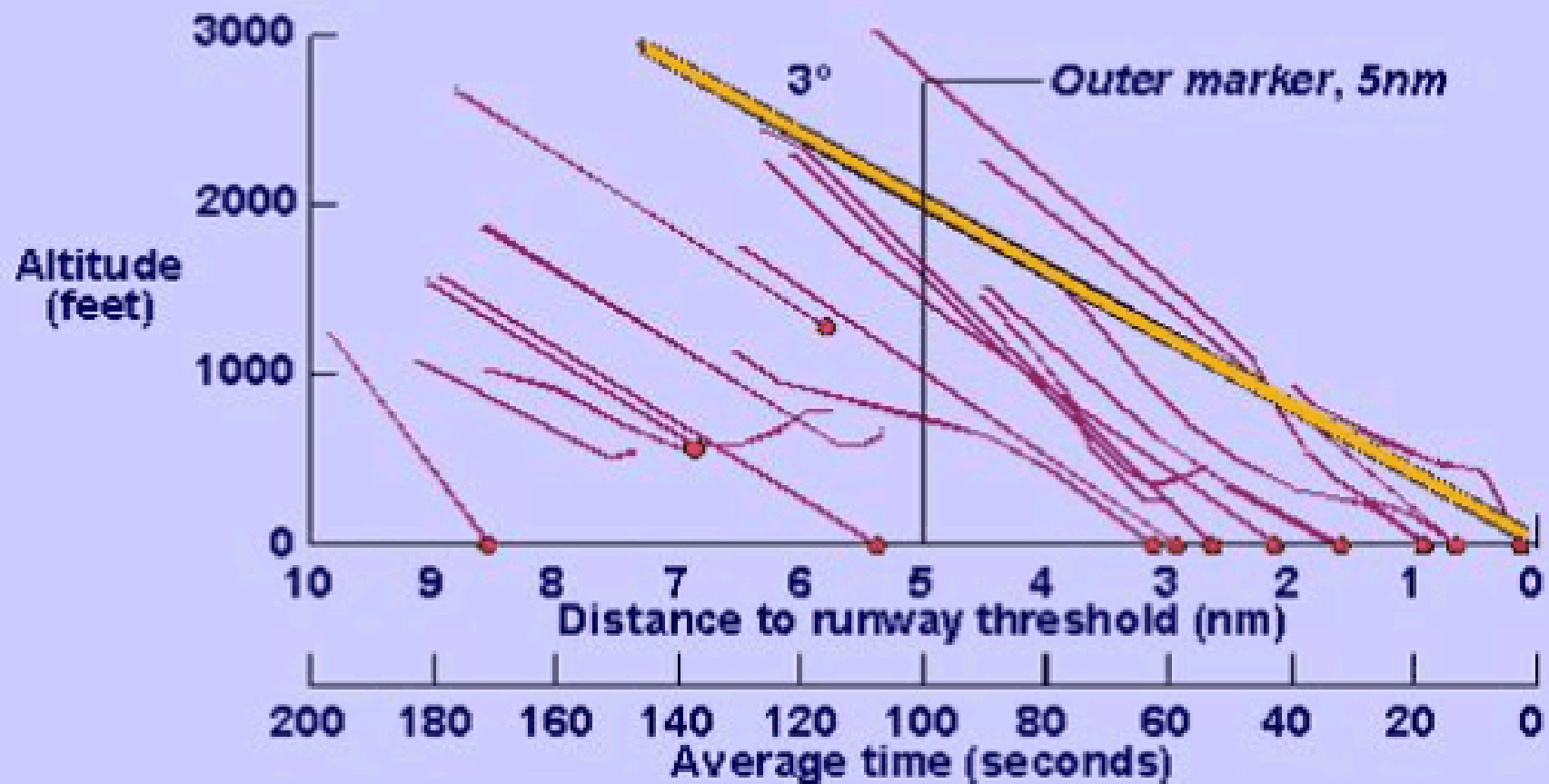


Map Location of Recent CFIT Accidents/Incidents





Vertical Profile of Recent CFIT Accidents/Incidents





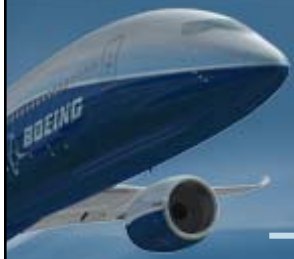
RNP/ANP Operations

- Definitions
- Why RNP?
- RNP vs ANP
- Airplane capability
- RNP/ANP displays and entries
- Crew Alerting summary



Definitions

- RNP – Required Navigation Performance.
 - Specified navigation accuracy for a route or departure/approach procedure in NM units
 - Enroute RNP's usually 2.0 or greater
 - Approach RNP's can be as low as 0.11
- ANP – Actual Navigation Performance
 - The FMC calculated certainty of the airplane's position in NM units
 - There is a 95% probability that the airplane is within the displayed ANP



Why RNP?

- Required Navigation Performance, or RNP, was developed as a method for certifying the navigation certainty for RNAV systems that can use multiple sensors for position updating
- RNP is used as a criteria for design of terminal area procedures and en-route segments
- RNP relates to obstacle clearance and/or traffic separation criteria

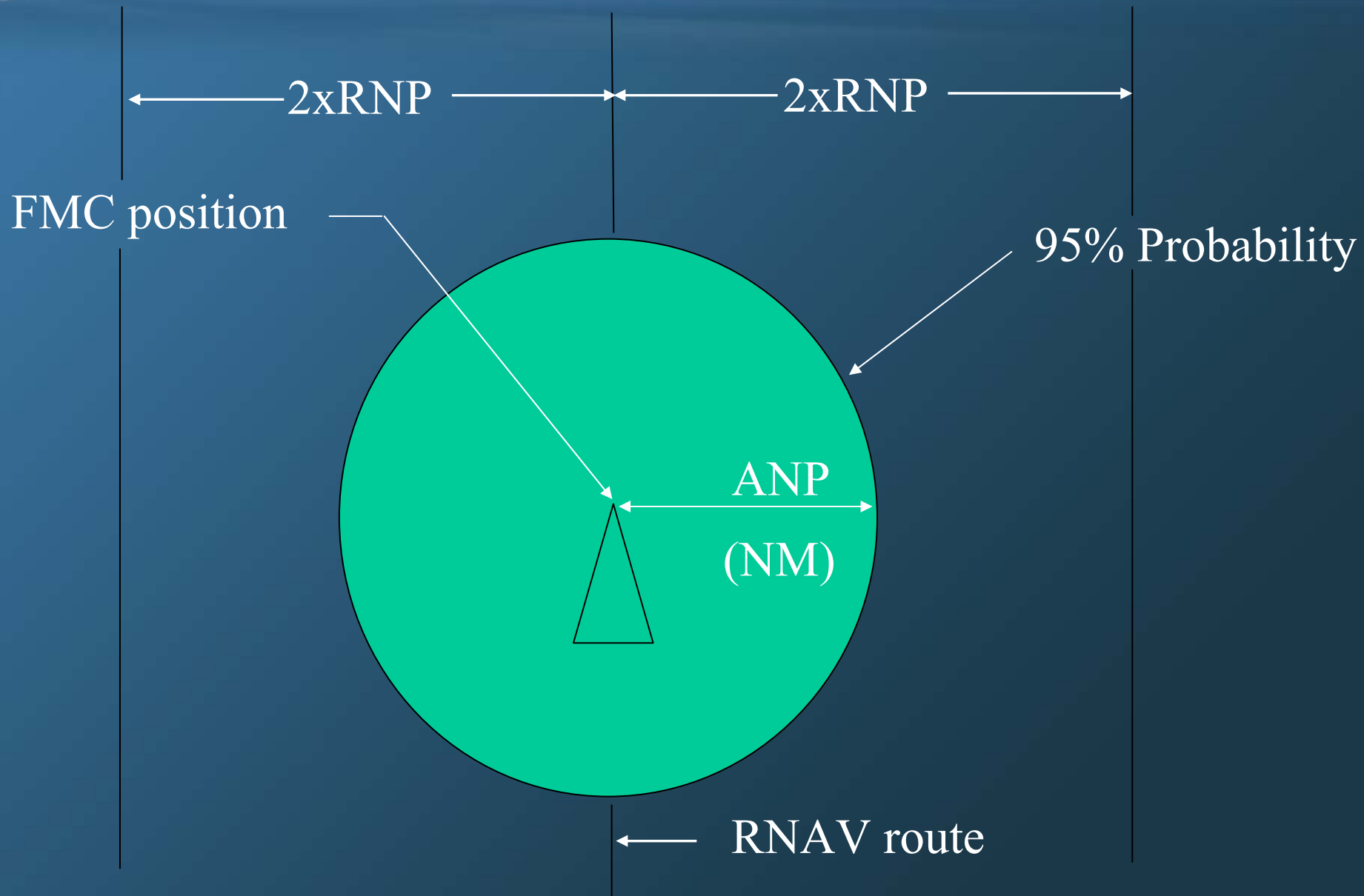


Factors Influencing ANP

- Method of FMC position updating (GPS, DME-DME, etc)
- GPS Receiver Autonomous Integrity Monitoring (RAIM) – only when using GPS updating
- If using navigation radio updating, geometry and proximity of stations to airplane position
- Time since last radio or GPS update (for the 737, without updating the ANP gradually increases)



ANP - a Measure of Position Certainty and Route Containment





What FMCs Have RNP Capability?

- | | |
|---------------------|-----------------------------|
| • 737-3/4/500 | FMC U7.1 or later |
| • 737-6/7/8/900/BBJ | All |
| • 747-400 | FANS (FMC Load 11 or later) |
| • 757/767 | Pegasus |
| • 777 | All |

[All FMCs that show RNP/ANP]

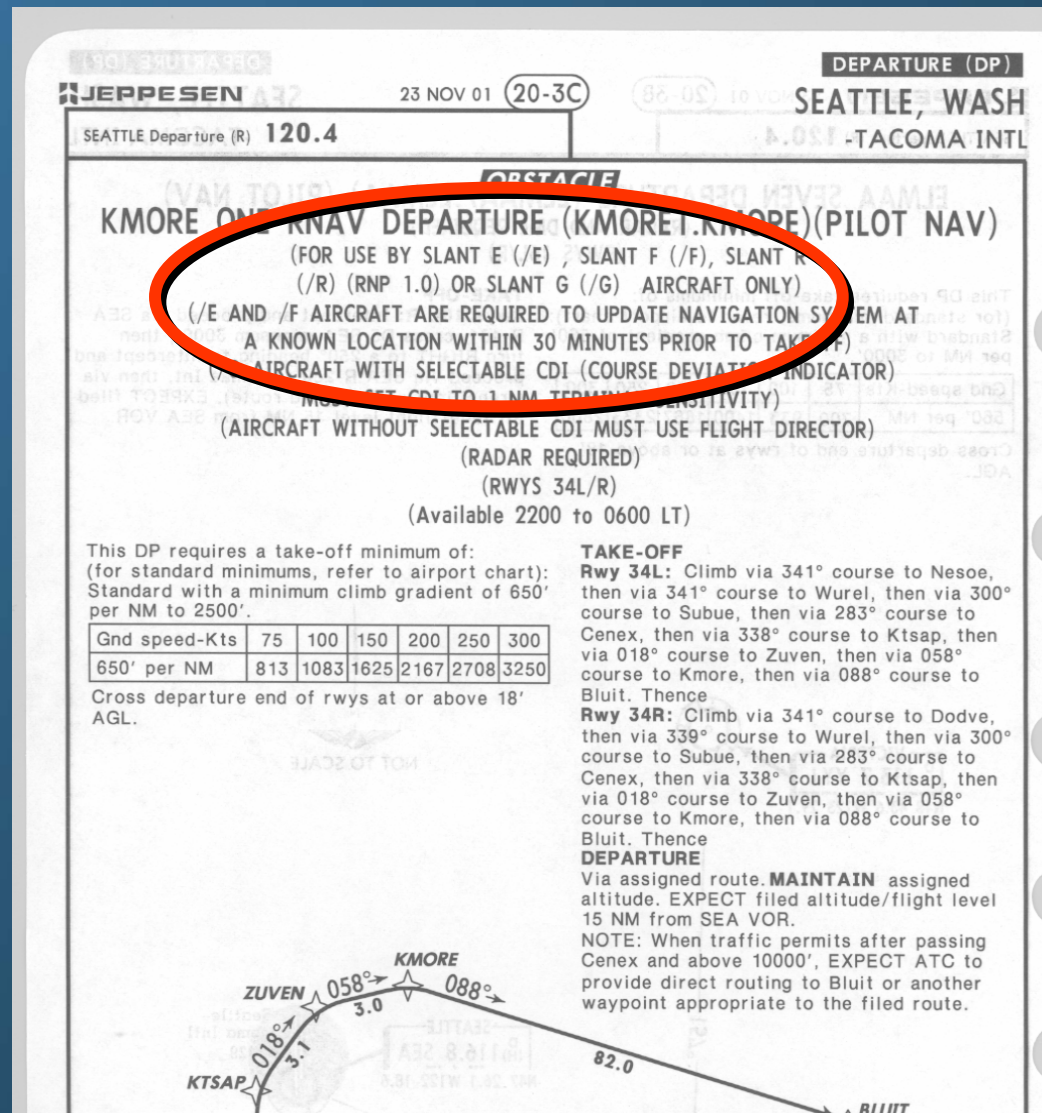


FMC-provided RNPs

- The FMC provides the RNP for the current route segment or terminal area procedure from the navigation data base if available
- If no RNP is available from the navigation data base, the FMC provides a default value according to the current phase of navigation:
 - Approach 0.5 or 0.3 NM
 - Terminal (below 15,000') 1.0 NM
 - En-route (domestic) 2.0 NM
 - Oceanic 12.0 NM
- The operator may select different default values
- If no RNP is specified for a route segment or terminal area procedure, the FMC default value is normally acceptable

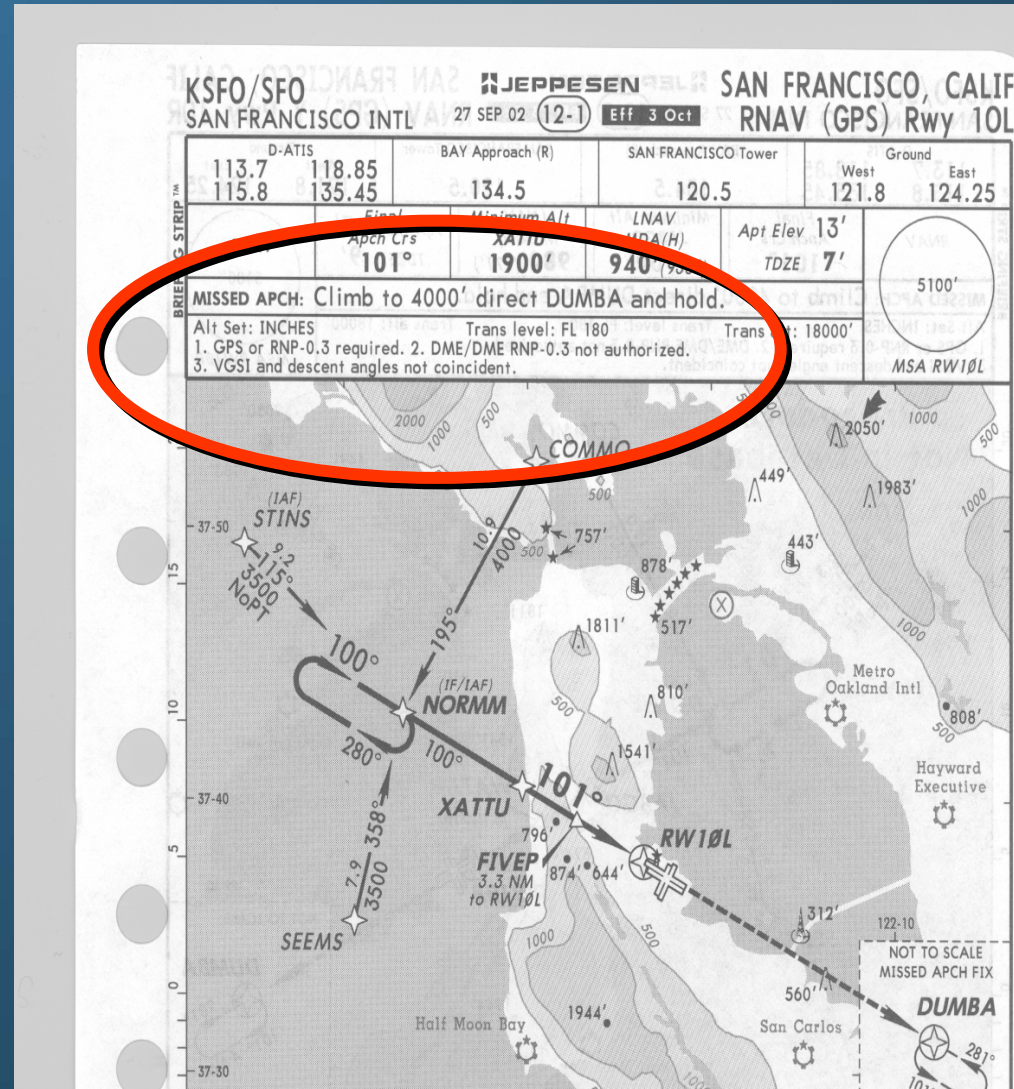


Procedure or Route-Specific RNP's are Indicated on Charts





Procedure or Route-Specific RNPs are Indicated on Charts





RNP for GPS Approaches

- GPS approaches can be flown with RNP-capable FMCs
- GPS updating may also be required
- RNP 0.3 must be used and is normally manually entered prior to commencing the approach
- Some operators have selected RNP 0.3 as the approach default value to eliminate the need to make this entry



More About RNP & ANP

- ANP does not relate to course tracking accuracy!
- When ANP exceeds RNP the airplane position accuracy is in question
- Smaller RNPs require more accurate FMC updating sources (DME-DME, GPS, etc)
- When ANP exceeds RNP, the airplane's actual navigation position does not meet the required accuracy and a crew alert is provided



Crew Alerting Occurs When ANP Exceeds RNP

- 757/67/77/47 – Caution level EICAS alert message during the approach phase, advisory level at other times
 - 777: NAV UNABLE RNP
 - 757/767: UNABLE RNP
 - 747-400: UNABLE RNP
- 737: UNABLE REQD NAV PERF-RNP displayed on Navigation Display during the approach phase, FMC scratchpad message at other times
- 737: Loss of GPS updating may not result in an RNP alert for some period of time since the ANP will change gradually.



Course Tracking Accuracy

- Observe the relationship of the airplane symbol and track line to the FMC course on the map display, and
- Observe the cross-track error on the FMC PROGRESS page 2
- Use of the autopilot in LNAV is normally the best method to ensure proper course tracking!



Response to an UNABLE RNP Alert

- Verify position using radar or other available nav aids
- If on an RNP route segment or RNP terminal area procedure:
 - Notify ATC immediately
 - Make an immediate missed approach if on an RNP approach
 - Request an amended (non-RNP) clearance
- If on the ground, a realignment is needed



VERIFY RNP FMC Message

- This message occurs to alert the crew that the manual RNP entry exceeds the default RNP or the RNP from the navigation data base, if available
- The crew must confirm the RNP entry
- If required, delete the manually entered RNP to use the FMC default value or the RNP from the navigation data base, if available



VNAV Approach Topics

- Types of approaches that are VNAV compatible
- Types of approaches that are not VNAV compatible
- Use of Decision Altitudes (DA(H)) versus Minimum Descent Altitudes (MDA(H))
- VNAV-related changes to charted approaches and navigation data bases
- FMC “on-approach” logic
- Flying the approach
- Other approach-related topics



Types of Approaches that are VNAV Compatible

- Non-ILS approach procedures such as RNAV, GPS, VOR, NDB, LOC, LOC-BC, SDF, etc. that have one or more of the following:
 - An appropriate path that has a missed approach point at or before the runway threshold
 - There is a glide path (GP) angle indicated on the chart and/or shown on the legs page
 - Approaches with a published VNAV DA(H)

Note: Many approaches are coded with a GP angle which the charted Jeppesen procedure does not show



On the LEGS Page, a VNAV-Compatible Path Will Have:

- An RWxx or MXxx waypoint at or before the approach end of the runway
 - The waypoint altitude constraint will result in approximately 50 feet threshold crossing height (TCH)
 - Examples (runway 12, TDZE at 1000' MSL)
 - RW12 170/1050
 - MA12 170/1190
- A “GP” angle shown on the LEGS page for the final approach segment

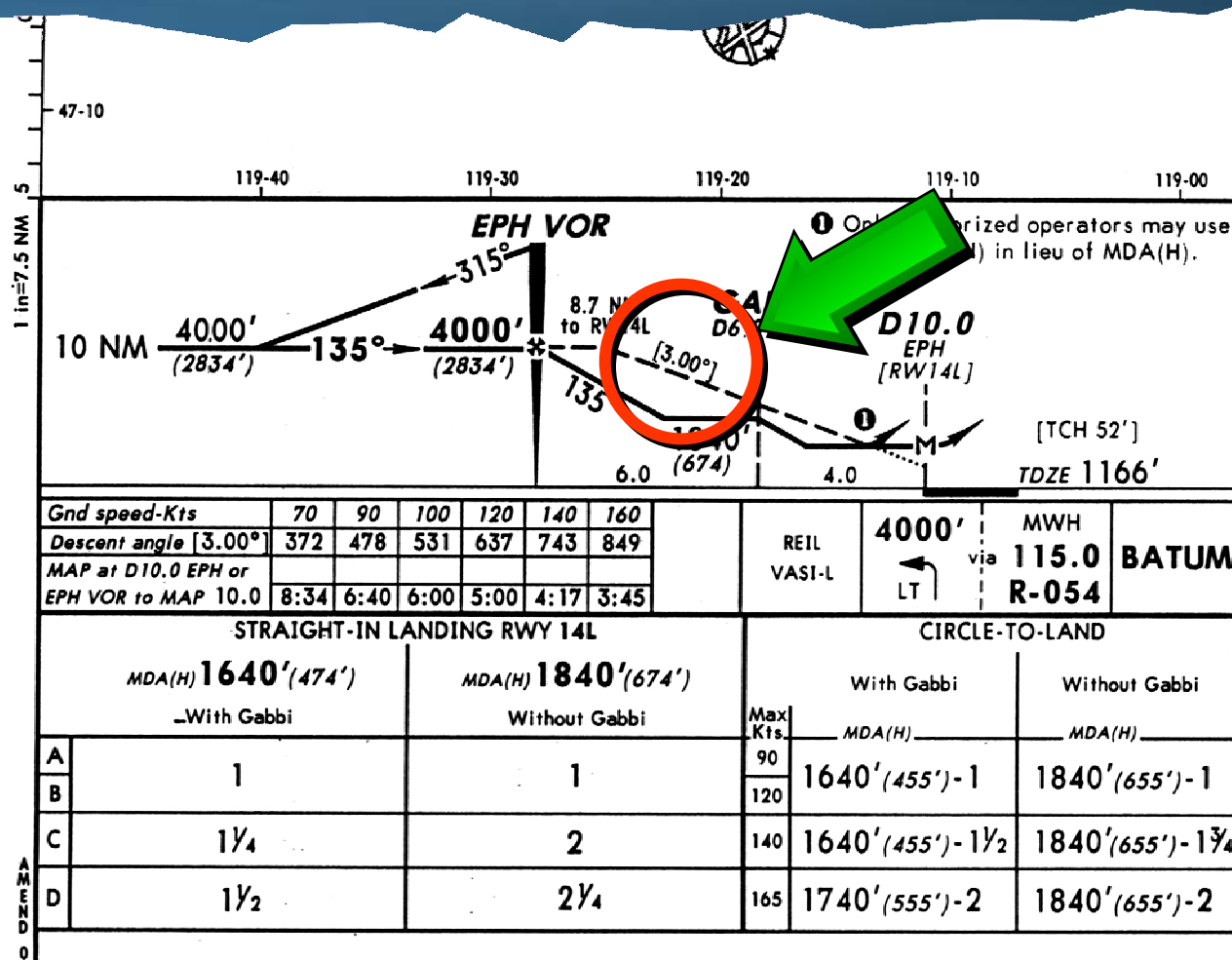


FMC Legs Page Shows Glide Path Angle

RTE 1 LEG		2 / 3
322°	7 NM	
PELLY	170	2800
322°	5 NM GP	3.00°
RW32R	155 /	0050



Approach Diagram Shows G.P. Angle and VNAV Compatibility

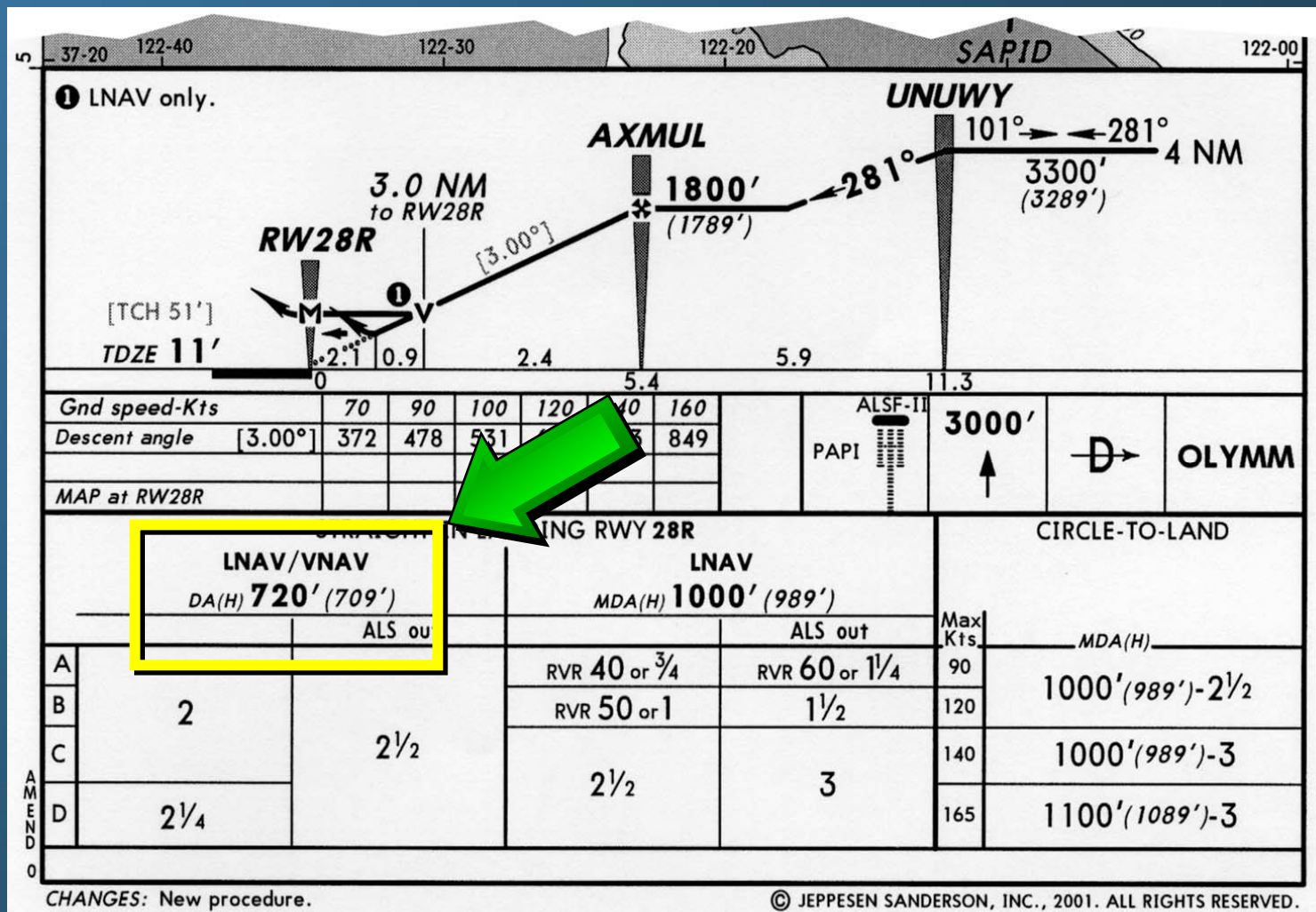


CHANGES: VNAV, new chart format.

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VNAV DA(H)s also show VNAV compatibility





Types of Approaches That Are Not VNAV-Compatible

- Approaches that do not have a GP angle, and
- There is no RWxx or MXxx waypoint with an appropriate path terminating at approximately 50' above the runway threshold, or
- The missed approach point is beyond the runway threshold



FAA AC 120-29A Contains Guidance on Use of VNAV

- VNAV approaches are considered as a “Category I Approach” with a decision altitude (DA(H))
- VOR, VOR/DME, NDB, LOC or LOC BC approaches may be flown with DA(H)s not less than 250 feet using VNAV, with appropriate operational approval and equipment
- A DA (QNH barometric altitude) is used
- Use of a published VNAV path, or GP angle, is required when a DA(H) is used



FAA HBAT 99-08 Permits Use of MDA(H)s as DA(H)s

- Eligible procedures include: VOR, VOR/DME, NDB, RNAV, GPS, LOC, LOC-BC, LDA and SDF
- When VNAV PTH is used, a slight momentary descent below the published DA(H) during the missed approach is acceptable
- RNP 0.3 capability or less is required
- Eligible procedures must have a visual segment obstacle assessment
- Without a published DA(H), the MDA(H) may be used as a DA(H) (with operational approval)



FAA Visual Segment Obstacle Assessment Complete for:

- ILS approaches with a published GP angle
- Runways with a VASI or PAPI
- RNAV approaches with a published VNAV DA (H)



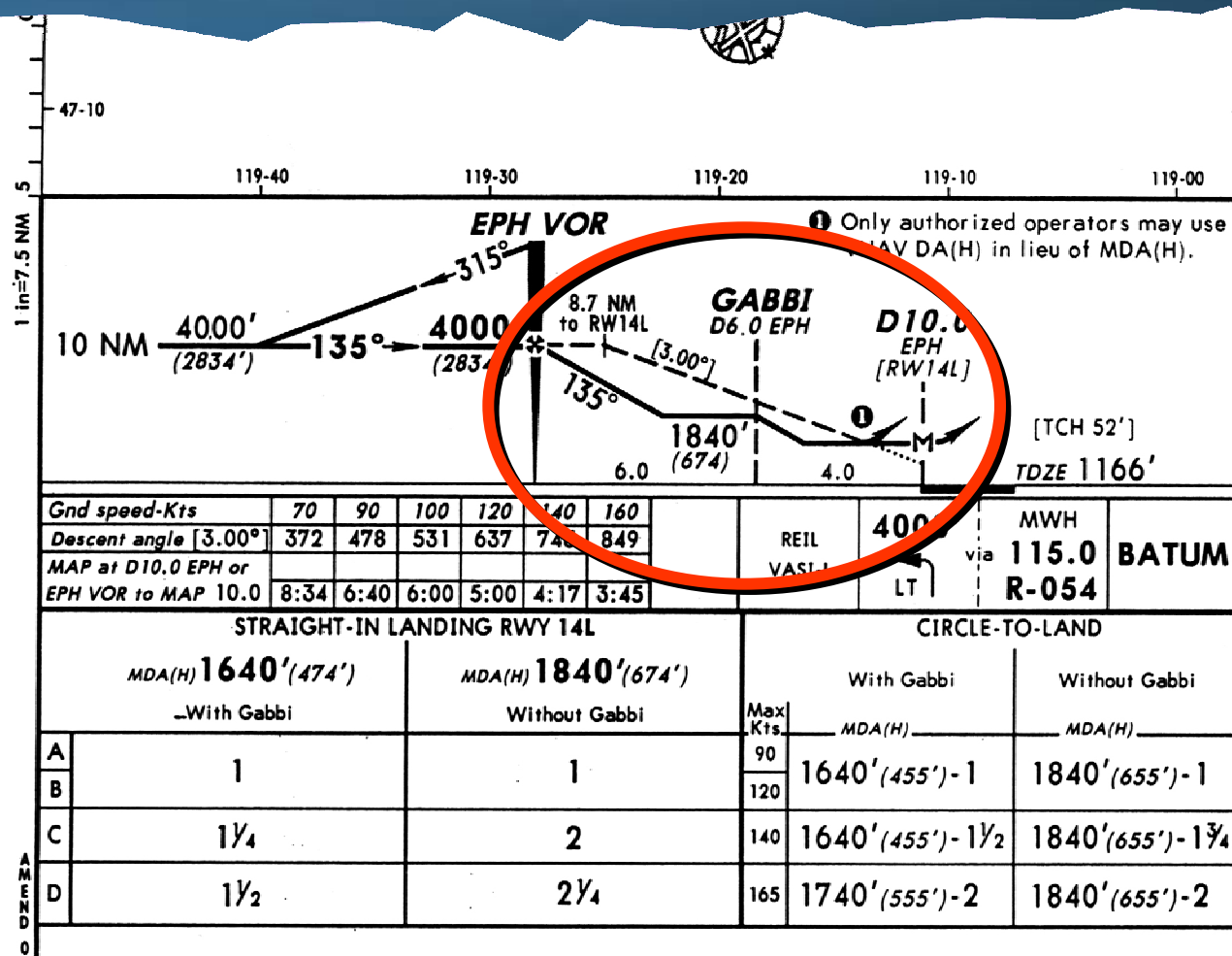
The GP Angle Provides Obstacle Clearance

- A published GP angle is evidence that:
 - the VNAV path will arrive at the published TCH, and
 - complies with underlying step-down altitudes
- The GP angle is constructed “backward” from the 50’ runway waypoint and normally intersects the FAF altitude constraint





The GP Angle Complies with the Step-down Altitudes



CHANGES: VNAV, new chart format.

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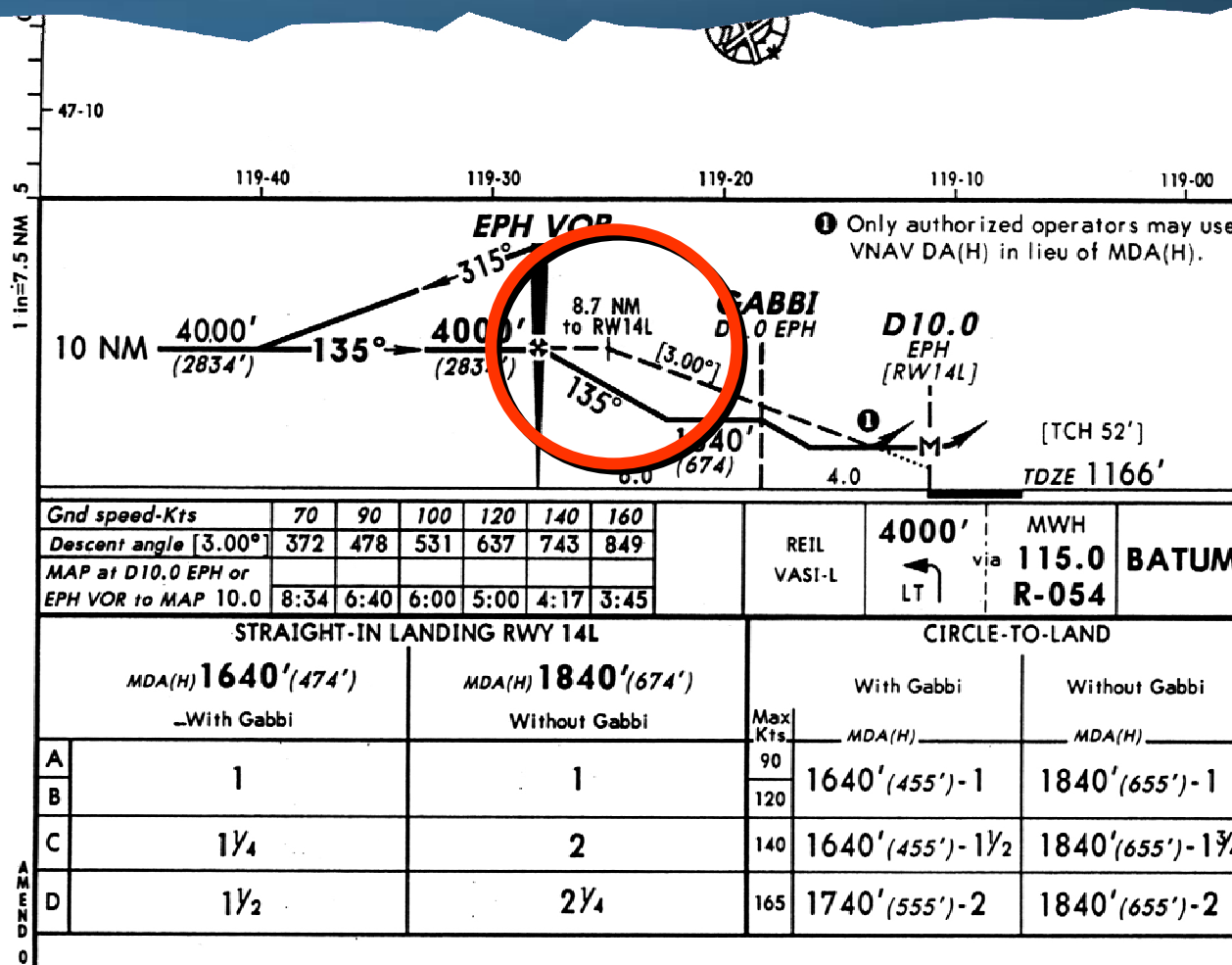


Most GP Angles Have a “Fly-off”

- If the distance from the FAF to the runway is greater than required for an immediate descent
- The “fly-off” may be indicated on the chart. Some FMCs (737 only) provide a “T/D” on the map display at the end of the “fly-off.”
- The FMC will command level flight in VNAV PTH until reaching the descent path



GP “Flyoff” Example



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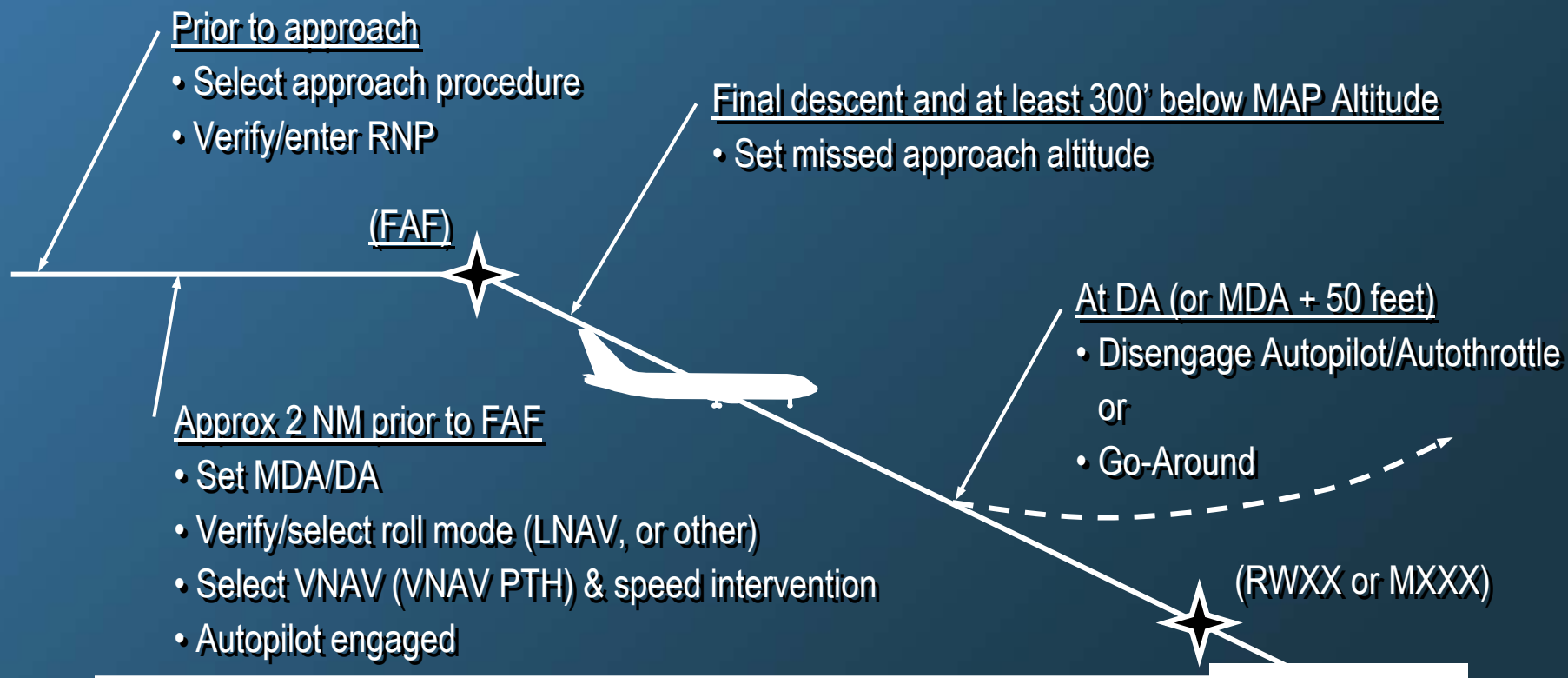
Non-ILS VNAV Path Availability: Total vs. % Flyable in VNAV

• Europe	1028/93%	• USA	4400/90%
• Africa	330/87%	• Canada	657/90%
• S. America	337/56%	• Asia/Pacific	639/90%
• Middle East	468/87%		

- Based on an informal navigation data base survey
- Jeppesen is in the process of recoding all non-ILS approaches

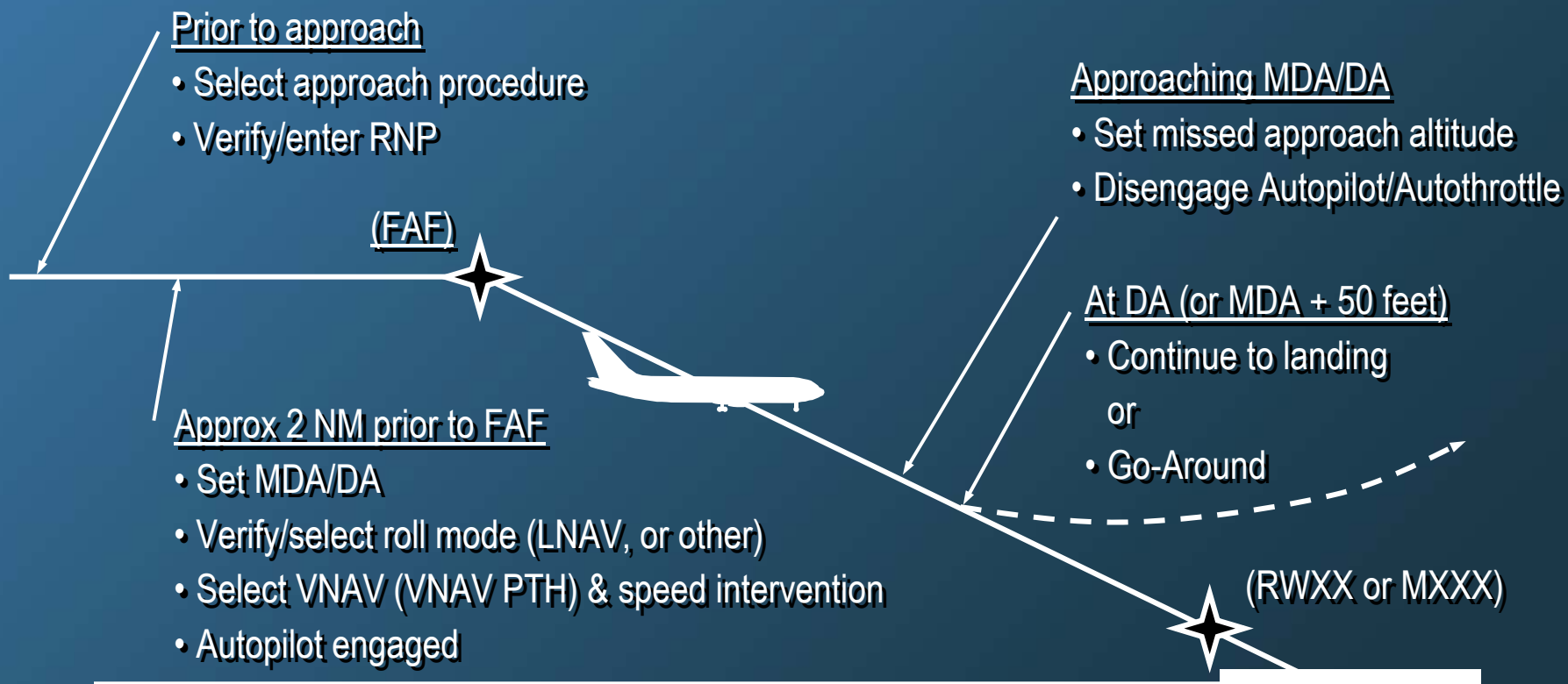


Typical VNAV Approach Procedure (except 737-3/4/500)





Typical VNAV Approach Procedure (737-3/4/500, U7.1 or later)





Recommended Procedure if Use of DA(H) Not Approved

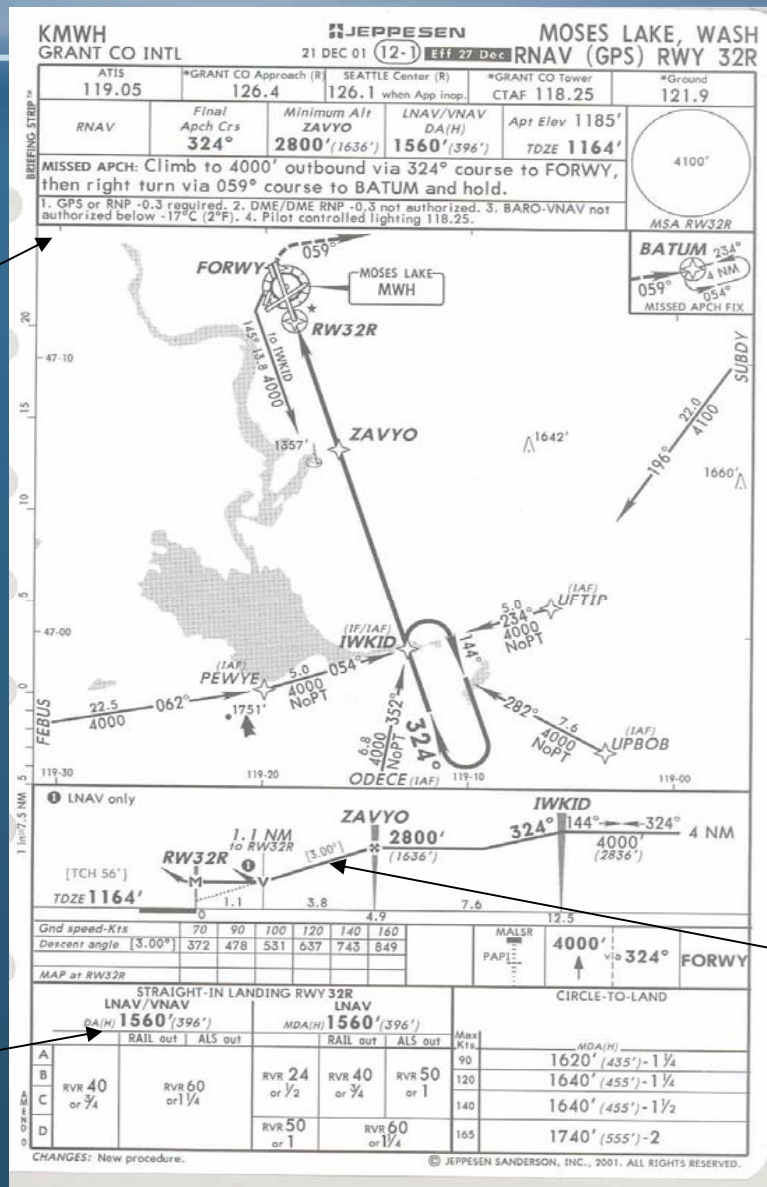
- Set MDA(H) + 50' using the minimums selector
- Use the same procedure as previously discussed
- Initiate the missed approach at MDA(H) + 50' if adequate visual reference is not established



Approach Example

RNP &
other info

VNAV
minimums



GP angle



Autopilot Use

- Autopilot use is recommended on VNAV approaches
- Experience has shown autopilot use on non-ILS approaches to be beneficial
- Better vertical and lateral path tracking
- Lower workload
- Less possibility of below path excursions



AFDS Mode Reversions from VNAV PTH (747-400/757/767/777)

- The 747-400, 757/767 and 777 AFDS, once in VNAV PTH and on approach, will not revert to any other mode automatically except to climb above the path in VNAV SPD if the placard speed is approached
- VNAV PTH mode must be exited by another mode selection or via go-around initiation
- With the AFDS engaged, the airplane will stay on path



AFDS Mode Reversions from VNAV PTH (737)

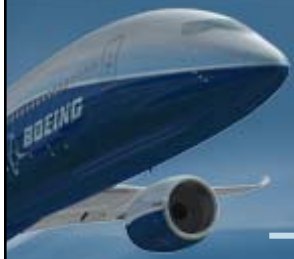
- The 737NG AFDS, once in VNAV PTH and on approach, will not revert to any other mode with landing flaps selected
- VNAV PTH mode must be exited by another mode selection or via go-around initiation
- With the AFDS engaged, the airplane will stay on path

Note: Earlier NG FCCs and all 737-3/4/500 FCCs permit the AFDS to automatically revert to LVL CHG if a significant under-speed occurs (alpha mode).

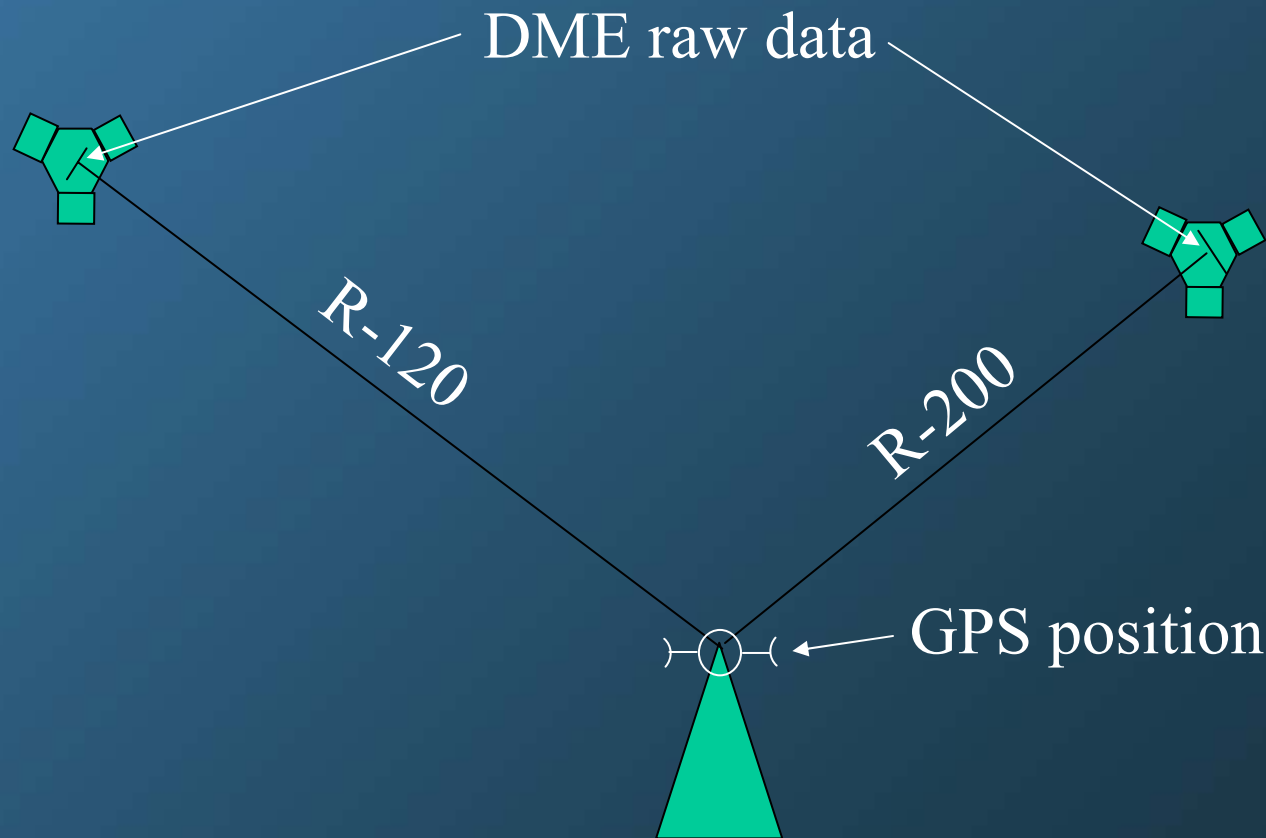


Raw Data Monitoring

- For all types of approaches that are based on ground navigation aids raw data should be monitored if available
- A raw data check prior to final approach may be accomplished by:
 - Using the POS function on the 737NG, 747-400, 767-400 and 777
 - Using the VOR/ADF function on the 737-3/4/500
- The 757/767 still require a VOR deviation display for VOR approaches on final approach



POS Function – FMC Position is Verified if Raw Data Matches Map





“On-Approach” Logic

- Criteria met for all airplanes using the published Boeing VNAV procedure
- Raises the alerting level to Caution for UNABLE RNP
- Causes the RNP to change to approach RNP if not manually entered
- Permits selection of the missed approach altitude and continued descent in VNAV PTH (except 737 classic)
- Speed intervention is enabled in VNAV PTH mode
- For VOR approaches, the FMC auto-tunes the VOR and automatically inserts the final approach course on the NAV RAD page and on the navigation display



Waypoint Modifications for VNAV Approaches

- Approach waypoints should normally be used “as is” from the navigation data base
- Use of a VNAV DA(H) requires use of a GP angle
- A straight-in intercept course to the FAF is permissible for radar vectored approaches
- Appropriate cold temperature corrections to waypoint altitude constraints are permissible
- Do not add or delete waypoints in the final approach segment!



Pilot-Constructed Approaches

- Navigation data base selection is required for RNAV and GPS approaches
- Approaches from the navigation data base are preferred for other types of approaches
- If no navigation data base approach is available and time permits, a manually constructed approach may be flown using LNAV provided:
 - Navigation data base waypoints and the RW waypoint are used
 - VOR, DME or other raw data is used as the primary navigation reference for the approach



Pilot-constructed approaches, cont.

- VNAV (using speed intervention) would be available only if using an overlay approach such as an ILS when flying an NDB approach and the waypoint altitude constraints were modified to comply with the approach to be flown
- Manually constructed waypoints are not compatible with on-approach logic
- Automatic procedure tuning will not occur for pilot-constructed approaches (747-400, 767-400 and 777 only)



Operations in Non-WGS-84 Airspace

- SIDs, STARs and enroute navigation are OK with GPS updating active
- GPS need not be turned off if “appropriate procedures are used”
- RNAV approaches may be flown with GPS active only if appropriately verified in the non-WGS-84 environment
- VOR or ADF approaches may be flown using LNAV with GPS active if raw data monitoring is used throughout the approach

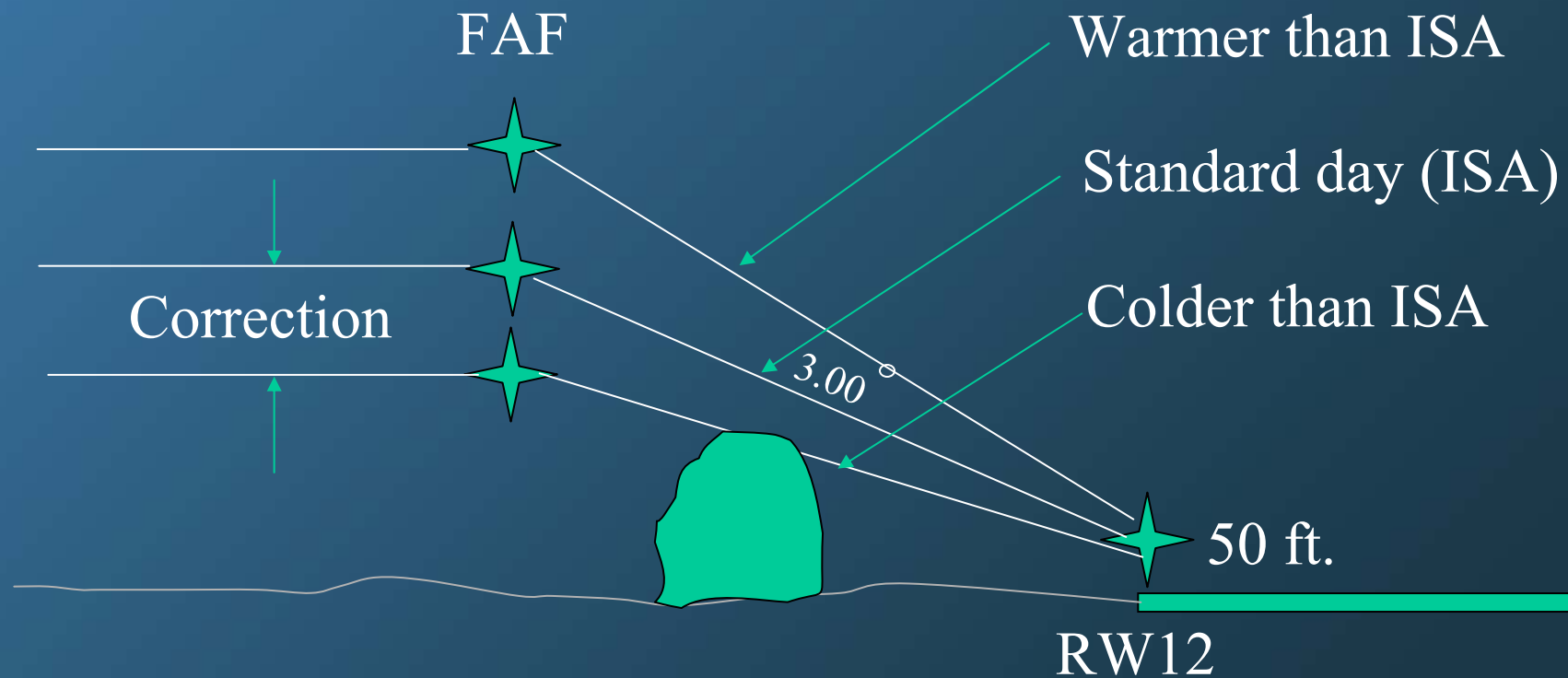


Cold and Warm Temperature Considerations

- The VNAV path coincides with the published angle only when the temperature is ISA (standard). It will be:
 - Steeper in warmer temperatures
 - Shallower in colder temperatures
- Some approaches have a published minimum temperature
- In extreme cold temperatures, when appropriate, the pilot should consider adding a cold temperature altitude correction to the FAF and approach transition waypoint constraints to correct the path
- The altimeter error will be greater near the FAF and smaller near the runway



The VNAV Path Is Affected By Temperature





System failures

- With dual navigation systems most single navigation system failures will not result in an UNABLE RNP alert or otherwise prevent an approach from being flown
- Loss of a single FMC or GPS receiver will not affect ANP
- If operating with a single updating sensor (such as GPS or DME if GPS is not being used) or a single FMC there must be a non-FMC means of navigation available for the approach and missed approach:
 - Radar vectors, or
 - VOR, or
 - NDB, etc.



RNAV with Non-GPS Airplanes

- Without GPS updating the FMC meets accuracy requirements for en-route and terminal area navigation (RNP 2.0 and 1.0) assuming DME-DME updating is active
- The 777/747/757/767 (both GPS failed) satisfies RNP 10 assuming max time from last DME update less than 6 hours
- For approaches, including RNAV, RNP 0.5 capability exists but DME-DME updating must be confirmed by the crew prior to starting the approach
- RNP display capability is not required provided approach RNP is 0.5 or greater
- GPS approaches at US airports require GPS updating to be active (D-D updating not allowed for RNP 0.3)



Summary

- RNAV/RNP operations can be a significant operational advantage to most airlines
 - Increased payload by creative procedure design
 - More reliable airport access thru lower minima
 - Possibility to eliminate 'problem' approaches
- LNAV/VNAV PTH operations are becoming the best way to conduct non-ILS operations
 - Better control of lateral and vertical path
 - Lower minima
 - Lower workload; easier to fly & stabilize