Terminal Navigation Specifications

RNAV 2, RNAV 1 and Basic-RNP 1

What are terminal navigation specifications?

- Need help?

Overview

- Learning Objectives: At the end of this presentation, you should:
  - Understand the differences between RNAV 2, RNAV 1 and Basic-RNP 1
  - Understand the required (ground) navigation infrastructure and (airborne) navigation performance
  - Understand the flight crew operating procedures for RNAV 2, RNAV 1 and Basic-RNP 1
  - Know the aircraft and operator eligibility requirements for RNAV 2, RNAV 1 and Basic-RNP 1 approval
- Summary

Differences Between RNAV 2 and RNAV 1

- Accuracy (i.e., 2 versus 1)
- Performance Using GNSS
  - RNAV 2 intended for en route application
  - RNAV 2 allows use of simpler deviation displays
- Performance Using DME/DME/IRU
  - RNAV 2 allows longer IRU coasting time (and reduced DME infrastructure)

Overall, RNAV 2 and RNAV 1 have similar requirements and considerations. For brevity, the term “RNAV 1” will be used during this discussion and will encompass RNAV 2 and RNAV 1 operations.

Differences Between RNAV 1 and Basic-RNP 1

- RNAV 1
  - Primarily intended for use where radar surveillance is applied
    - For Instrument Departures, radar coverage expected prior to first RNAV course change
  - Accommodates a larger fleet of aircraft
    - Does not require on-board performance monitoring and alerting
    - Can be supported by GNSS, DME/DME or DME/DME/IRU
- Basic-RNP 1
  - Primarily intended for use where radar surveillance is not available
  - Requires on-board performance monitoring and alerting
  - Requires GNSS
  - Currently limited to use within 30 NM of departure or arrival airport

What is Basic about Basic-RNP 1?

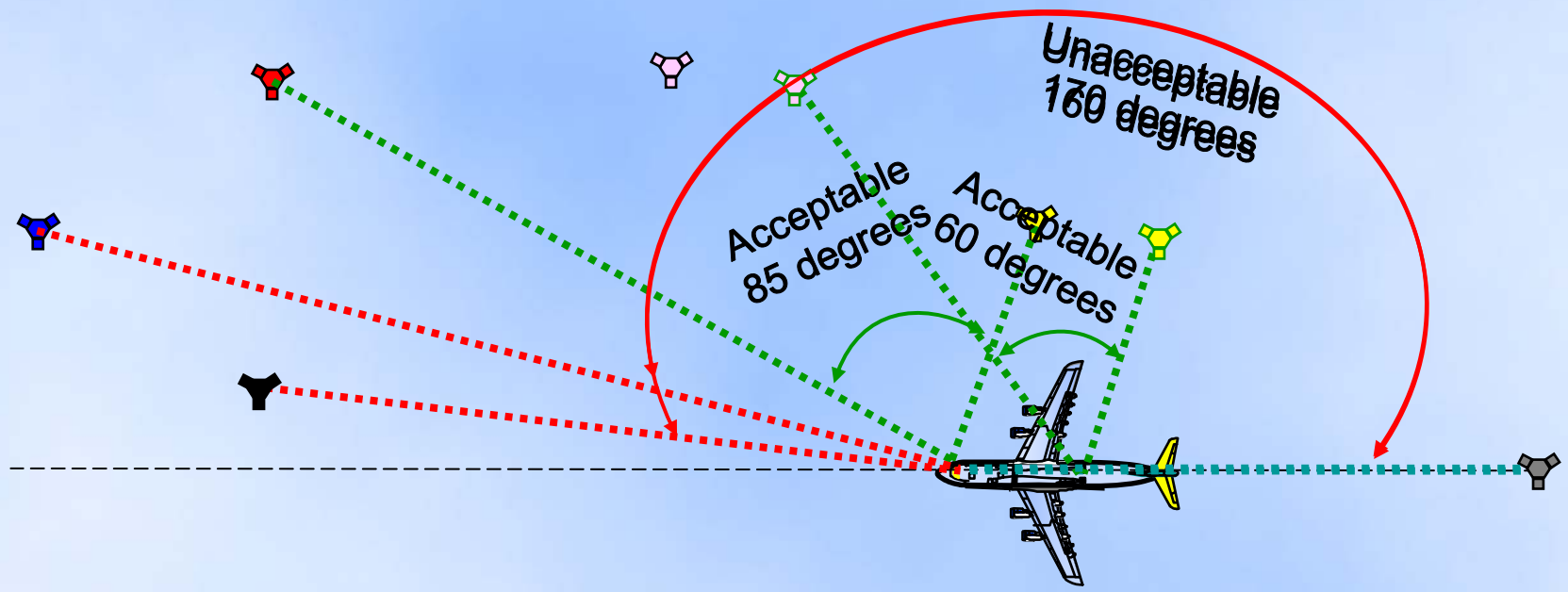
- RNP Study Group:
  - Recognized need for arrival and departure capability where radar does not exist
    - Typically accompanied by limited ground navaid infrastructure and light to moderate traffic density
  - Incorporated GNSS-based RNP operations
    - Minimal functional requirements to provide largest fleet equipage
  - Also recognized future need for new functional capabilities
    - Curved paths, vertical navigation, use outside of 30 NM from aerodrome, etc.
    - These capabilities will be addressed in future update to the PBN Manual

Navigation Infrastructure: ANSP Considerations

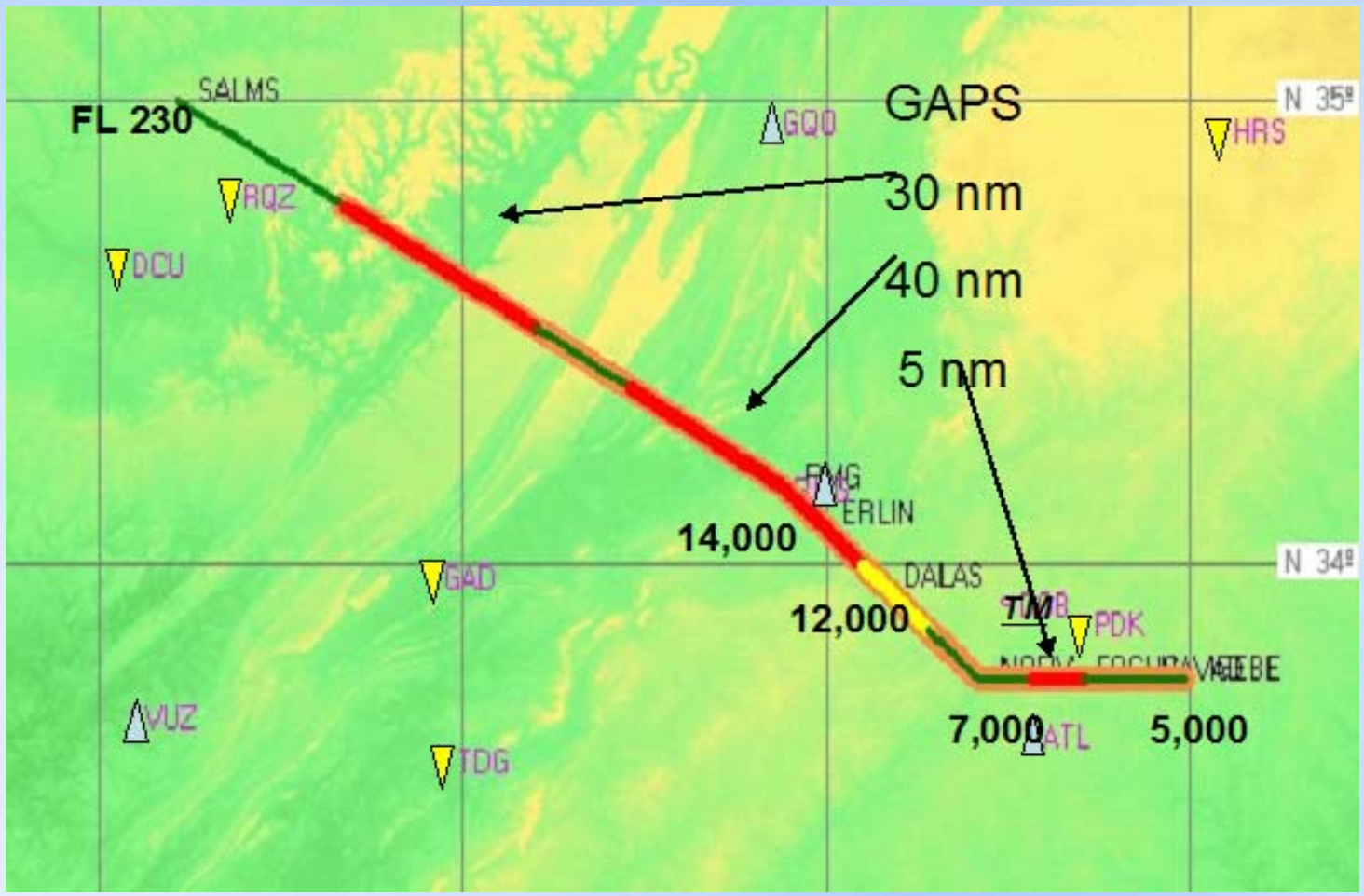
- Infrastructure:
  - Assess navigation performance with available infrastructure, including reversionary modes
- GNSS:
  - Ensure operators have means of predicting availability of fault-detection using ABAS (e.g. RAIM)
    - Predicted, continuous loss of ABAS fault detection of more than 5 minutes should be identified
- DME/DME or DME/DME/IRU (RNAV 1 only):
  - Use DME facilities in State AIP which comply with Annex 10 requirements
  - DME signals assumed to meet signal in space accuracy tolerances everywhere signals are received
  - DME signal used by aircraft in proper geometry

DME/DME (D/D) Include Angle

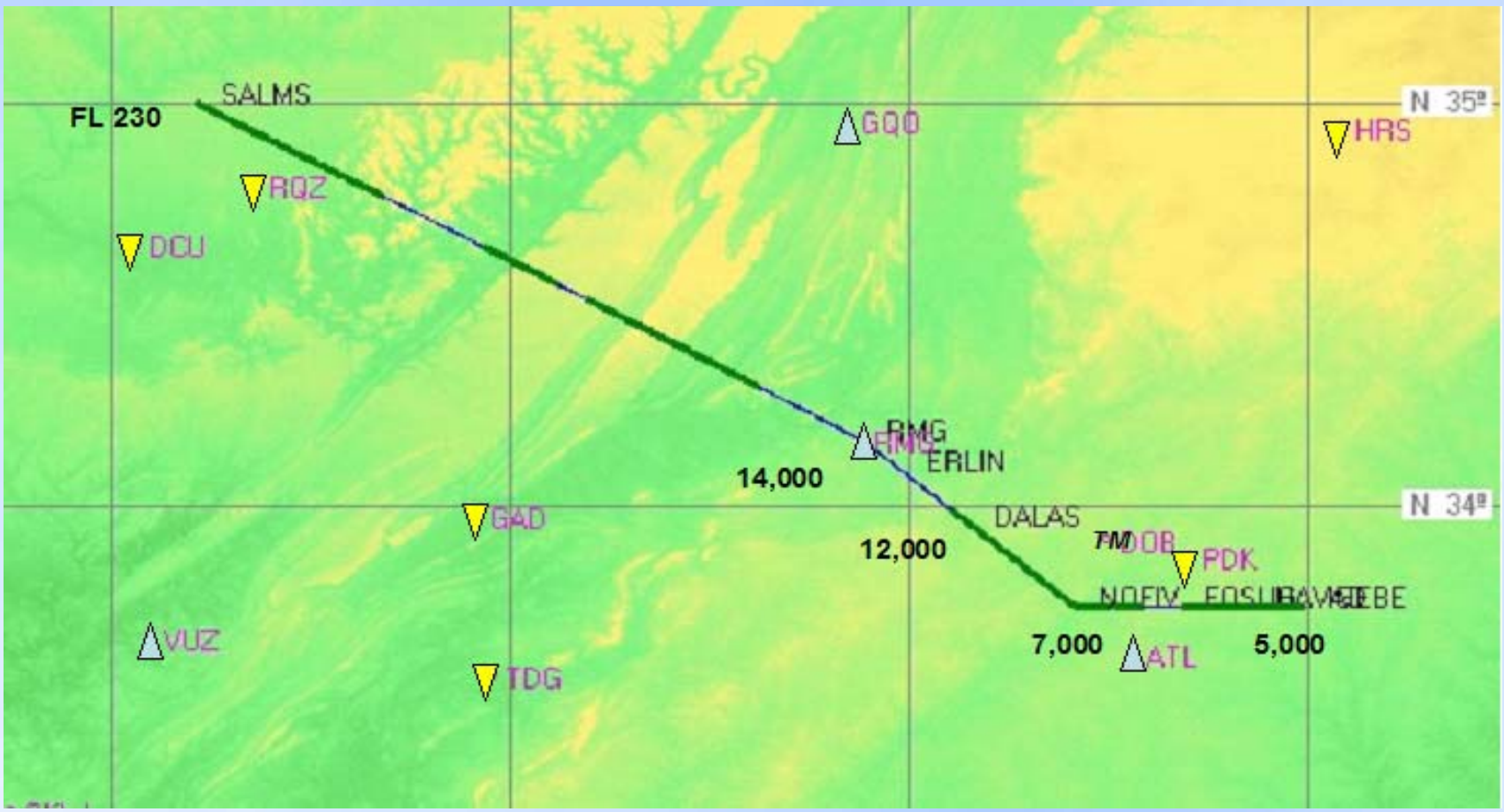
- DME/DME geometry solutions require two DMEs to be ≥ 30° and ≤ 150°



Example: Atlanta (USA) RNAV STAR
(Assessed for DME/DME Only)



Example: Atlanta (USA) RNAV STAR
(Assessed for DME/DME/IRU)



Other ANSP Considerations

- Communication and ATS Surveillance
- Obstacle Clearance: refer to PANS-OPS
- Additional considerations
- Publication (PBN Manual Vol II, part B or C, para 3.2.5)
- Controller training: Core training; nav spec specific
- Status monitoring: Monitor and maintain supporting infrastructure; notify users of changes (NOTAM)
- ATS System monitoring: Know why deviations occur

Navigation Performance*

RNAV 1

- GNSS
  - TSO-C129a
  - TSO-C145()
  - TSO-C146()
- DME/DME/IRU
- DME/DME

Basic-RNP 1

- GNSS
  - TSO-C129a
  - TSO-C145()
  - TSO-C146()

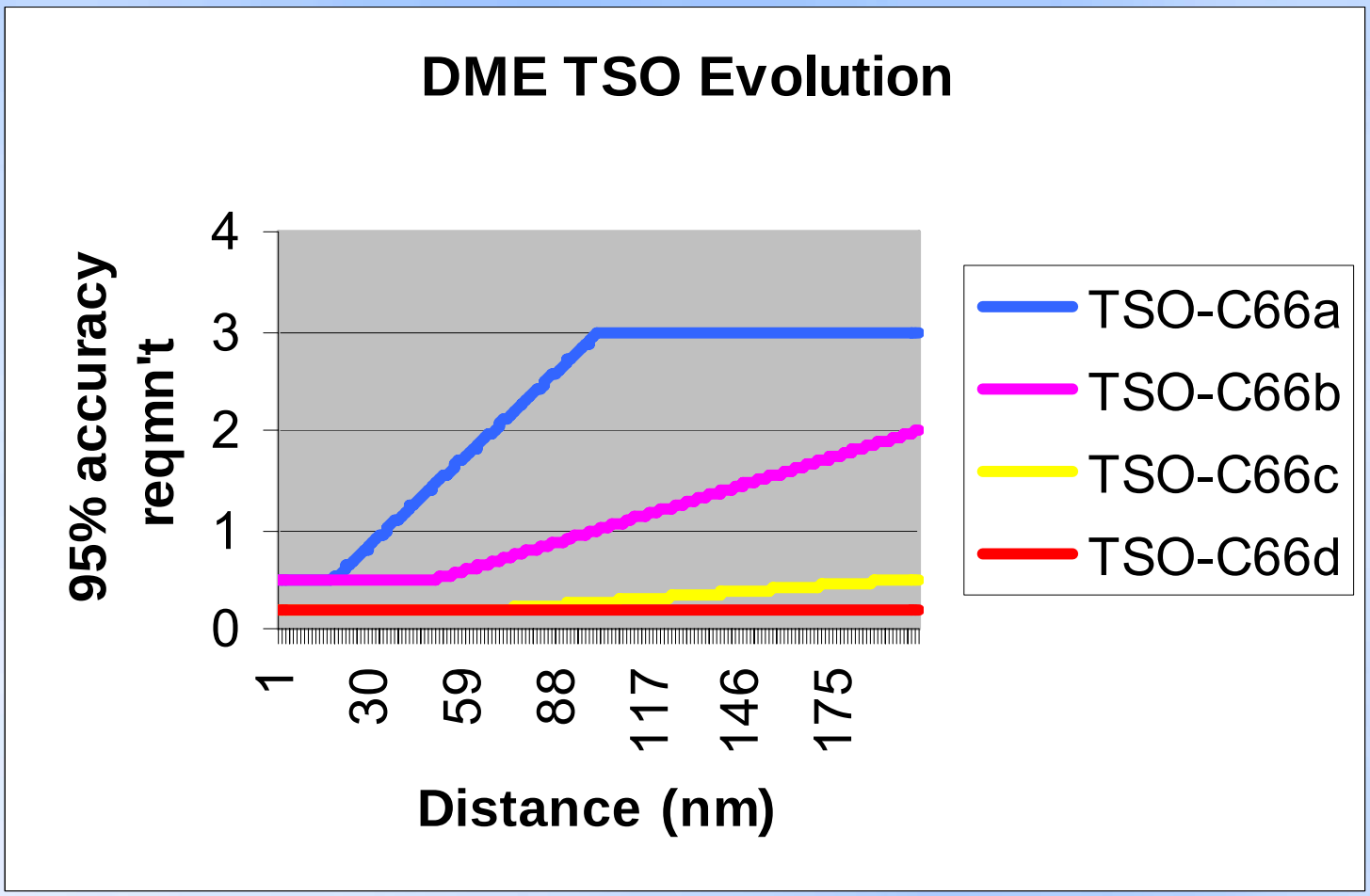
*Some systems may not qualify depending on functional capability (discussed later)

Navigation Performance

DME/DME System Criteria (RNAV 1 only)

- Accuracy based on TSO-C66c performance
- Navaid infrastructure must support RNAV system performance (ANSP considerations)
  - No requirement to use VOR, NDB, LOC, IRU or AHRS
  - Reasonableness checks verify valid DME measurements, and cannot assume DME signal remains valid, or extra DME signals are available
  - Aircraft required to comply with ANSP criteria:
    - Aircraft between 3-160 NM, below 40° above horizon (viewed from facility),
    - Include angle between 30°-150°,
    - Position estimation error accuracy from 0.56 NM to 1.2 NM

DME Receiver: Labeled Performance



Navigation Performance

DME/DME with Inertial Reference Unit (D/D/I) -- RNAV 1 only

- DME accuracy – same DME/DME criteria
- Inertial performance and limitations
  - Inertial system performance satisfies criteria of US 14 Code of Federal Regulations (CFR) Part 121, Appendix G
  - Automatic position updating capability from DME/DME is required
  - When infrastructure does not support DME/DME updating, impact of VOR radial accuracy when VOR is greater than 40 NM must not affect aircraft position accuracy
- Operational procedure (but related to aircraft): Ability to confirm aircraft system position, within 1,000 feet (0.17NM) of a known position, at the start of the takeoff roll.

System Performance

	RNAV 1	Basic-RNP 1
Accuracy	Lateral total system error ±1 NM (95%). Along track error ±1 NM (95%).	Same
Integrity	Malfunction of aircraft nav equipment - Major failure condition (10^{-5} / hour)	Same
Continuity	Loss of function – Minor failure condition if operator can revert to different nav system and proceed to suitable airport	Same
Signal-in-Space	If using GNSS, same as Basic-RNP 1 Not applicable for D/D RNAV or D/D/I RNAV	Aircraft GNSS equipment should alert if probability of SIS errors causing lateral position error > 2 NM exceeds 10^{-7} / hour

System Monitoring and Alerting

- Basic-RNP 1:
  - The RNP System, or the RNP System and pilot in combination, shall provide an alert if the accuracy requirement is not met, or if the probability that the lateral TSE exceeds 2 NM is greater than 10^{-5}
- RNAV 1:
  - No requirement

Navigation Performance: Functional Requirements
(RNAV 1 and Basic-RNP 1)

- Non-numeric lateral deviation display
  - CDI, (E)HSI, or map display with equivalent functionality
- Display functions
- Automatic leg sequencing
- Extraction of ATS routes from onboard navigation database

Functional Requirements
(RNAV 1 and Basic-RNP 1)

- Automatically execute leg transitions and maintain tracks
  - Initial Fix (IF), Course to Fix (CF), Direct to Fix (DF), Track to Fix (TF)
  - Direct-to leg can be manually initiated
    - Fix must load automatically
  - Heading path terminators (VA, VM, and VI) can be manually flown
  - Capability to automatically execute leg transitions consistent with CA and FM path transitions, or ability to select desired course to/from designated waypoint
  - Capability to load ATS route by route name
- Integrity annunciations
- Data base integrity
  - RTCA/DO-200A / EUROCAE ED76
  - Letter of Acceptance issued by appropriate regulatory Authority
  - Aircraft operators consider the need to conduct periodic checks of operational navigation data bases

Operating Procedures

Pre-flight Planning

- Flight plan suffixes
  - Recommend filing maximum transponder and navigation capability, based upon desired services or routing

- Navigation database (based on WGS-84)
  - Aeronautical Information Regulation and Control (AIRAC) cycle
  - Supplier holding an EASA or FAA Type 2 Letter of Acceptance (LOA) as described in AC 20-153
  - Stored data resolution sufficient for required track keeping accuracy
  - Database protected against pilot modification of stored data

Aircraft-Based Augmentation System (ABAS) Availability

- Notices to Airmen (NOTAMs)
- Prediction services (State or private)
- Guidance per operating authority
- Relevant to satellite constellation and avionics
- Assess for need to revert to alternative means of navigation

General Operating Procedures (1)

- Aircraft Flight Manual (AFM)
- Route checking
  - Navigation system waypoint sequence (textual and graphic)
  - Charts (paper or electronic)
  - Clearance
- Procedure retrieved by procedure name

General Operating Procedures (2)

- Use lateral deviation indicator, flight director, or autopilot in lateral navigation mode
- Maximum cross-track deviation limited to ½ times the navigation accuracy (e.g., 0.5 nm for RNAV 1) for normal operations on straight segments, 1 times the navigation accuracy (e.g., 1.0 nm for RNAV 1) during and after turns
- For RNP systems, ensure proper RNP (1.0) is displayed for Basic-RNP 1

Specific Standard Instrument Departure (SID) Requirements

- Important to verify proper runway selection, especially for parallel operations with multiple runway transitions
- Engagement altitude no later than 500 feet above airport elevation
- GNSS signal acquired before take-off roll (for operators of GNSS-equipped aircraft)
- For Basic-RNP 1, full scale sensitivity must be selected to not greater than 1 nm for SIDs extending more than 30 nm from the relevant airport (also applies to STARs)

Contingency Procedures

- Notify ATC of loss of navigation capability
- In event of lost communication; comply with specified, general or procedure-specific, guidance
- Where the contingency procedure requires reversion to a conventional arrival route, necessary preparation must be completed before commencing the RNAV route

Pilot Knowledge and Training

- RNAV and RNP procedure characteristics
- Waypoint types and path terminators
- Required navigation equipment
- System-specific information
- Operating procedures including how to perform specific actions
- Operator-recommended levels of automation
- Phraseology for applications
- Contingency procedures

Approval:
Migration path to RNAV 1 and RNAV 2

Table 3-1: Additional Requirements for obtaining an RNAV 1 and RNAV 2 approval from a TGL-10 approval

Operator has TGL-10	Needs to confirm these performance capabilities to ICAO RNAV 1 and RNAV 2	Note
If approval includes use of DME/VOR. (DME/VOR may only be used as the only positioning input where this is explicitly allowed.)	RNAV 1 does not accommodate any routes based on DME/VOR RNAV.	RNAV system performance must be based on GNSS, DME/DME, or DME/DME/IRU. However, DME/VOR inputs do not have to be inhibited or deselected.
If approval includes use of DME/DME	No action required if RNAV system performance meets specific navigation service criteria in this Chapter, 3.3.3.3.2 (DME/DME only) or 3.3.3.3.3 (DME/DME/IRU)	Operator can ask manufacturer or check FAA website for list of compliant systems - see Note below this table.
RNAV SID Specific Requirement with DME/DME Aircraft	RNAV guidance available no later than 500ft AFE on AC 90-100 Type B procedure	Operator should add these operational procedures.
If approval includes use of GNSS	No action required	

Note:
http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs410/policy_guidance/

Approval:
Migration path to RNAV 1 and RNAV 2

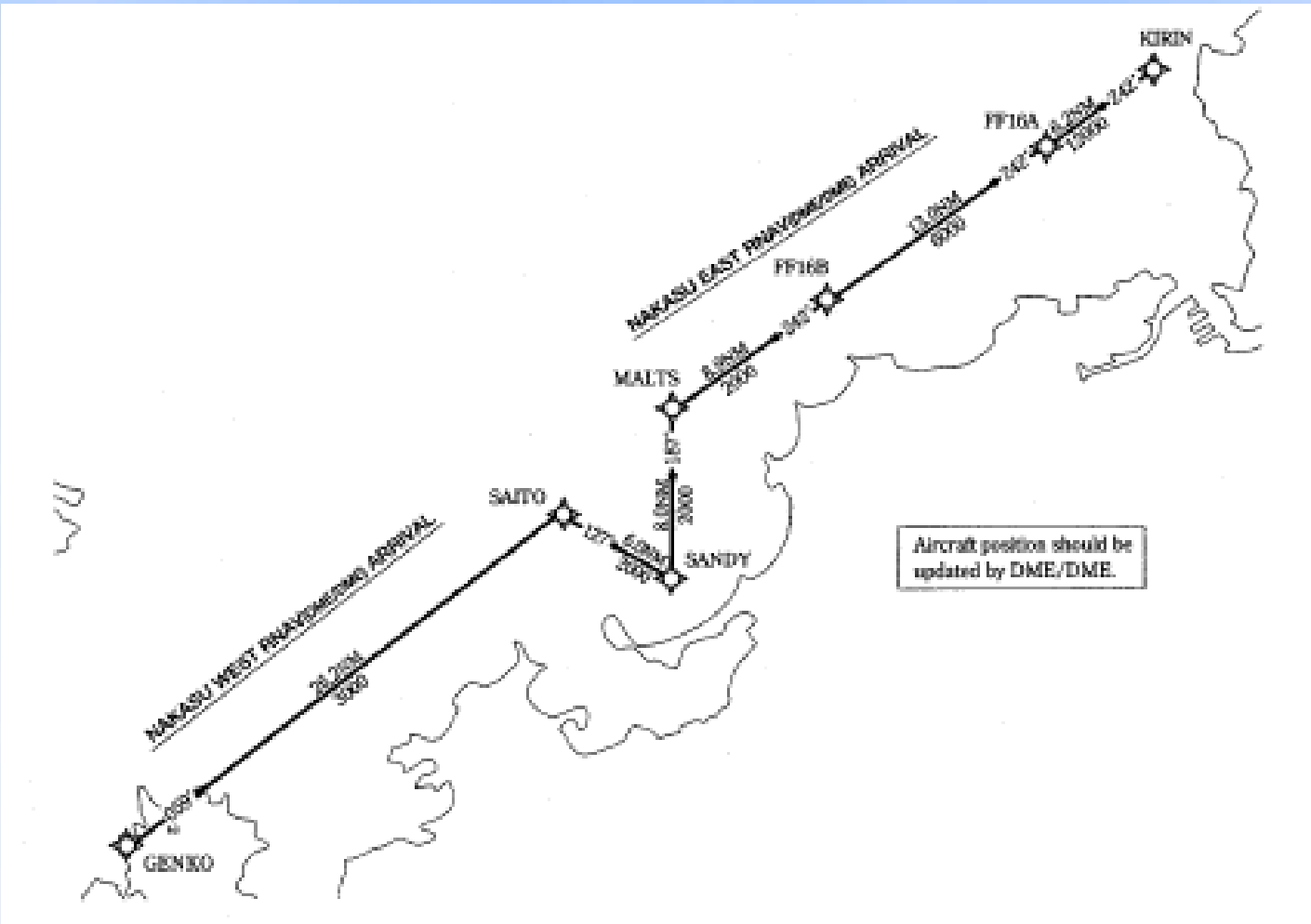
Table 3-2: Additional Requirements for obtaining RNAV 1 and RNAV 2 approval from an AC 90-100 approval

Operator has AC 90-100	*Needs to confirm these performance capabilities to ICAO RNAV 1/RNAV 2*	*Note*
If approval based on GNSS (TSO-C129)	GPS pseudorange step detector and GPS health word checking is required in accordance with TSO C129a/ETSO C129a.	Operator should check if pseudorange step detector and health word checking is supported by the installed GPS receiver or check if GPS receiver is approved in accordance with TSO C129a/ETSO C129a.
No navigation database updating process required under AC 90-100.	Data supplier and avionics data supplier must have letter of acceptance (LOA) in accordance with this chapter, paragraph 3.3.3.4.m.	Operator should ask data supplier for status for the RNAV equipment

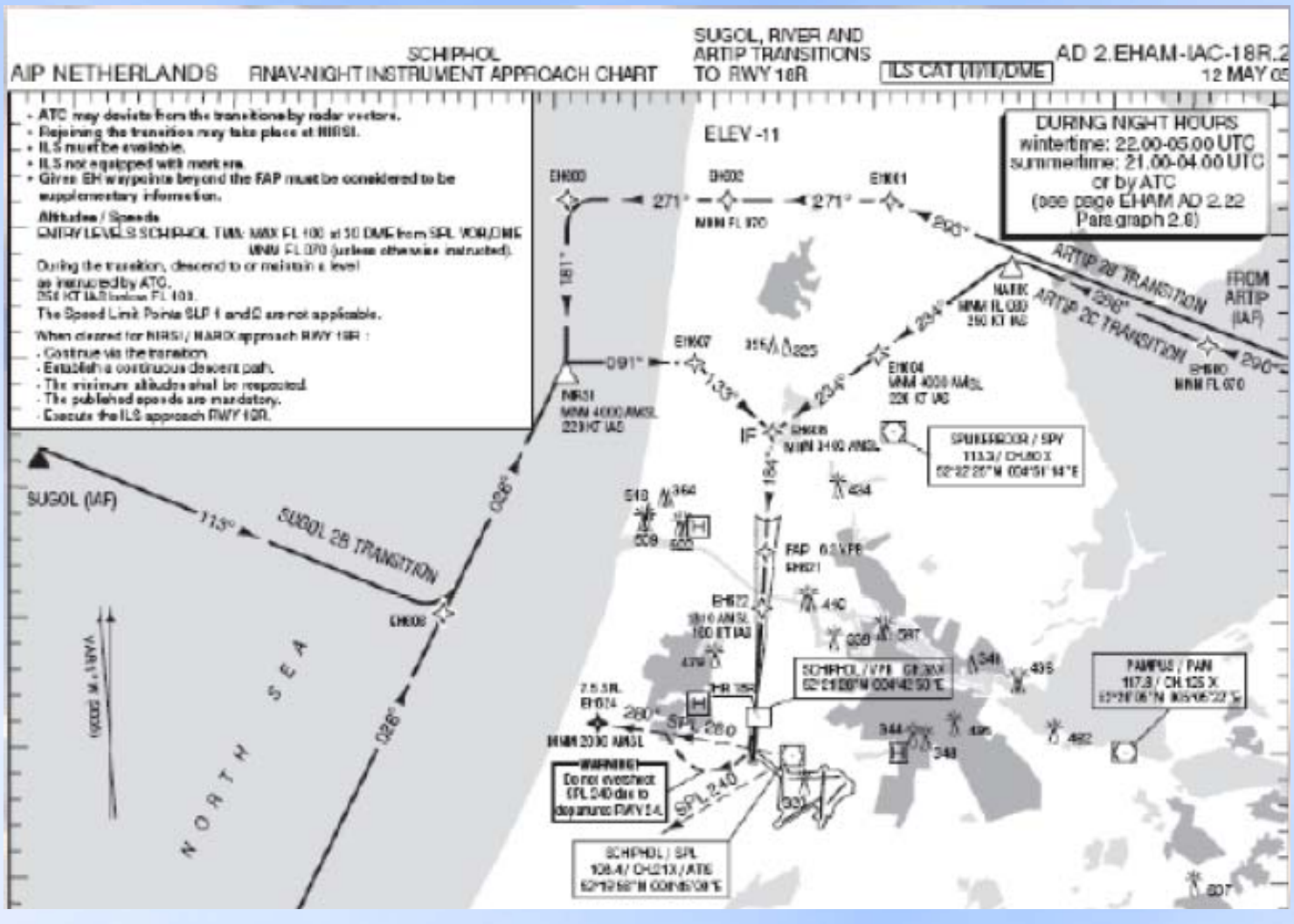
Current: If operator has AC 90-100A approval, then RNAV 1 compliant.

Current RNAV Implementations

RNAV(DME/DME) Arrival -- Japan



P-RNAV night routes into Schiphol



US RNAV departures at Atlanta (USA)

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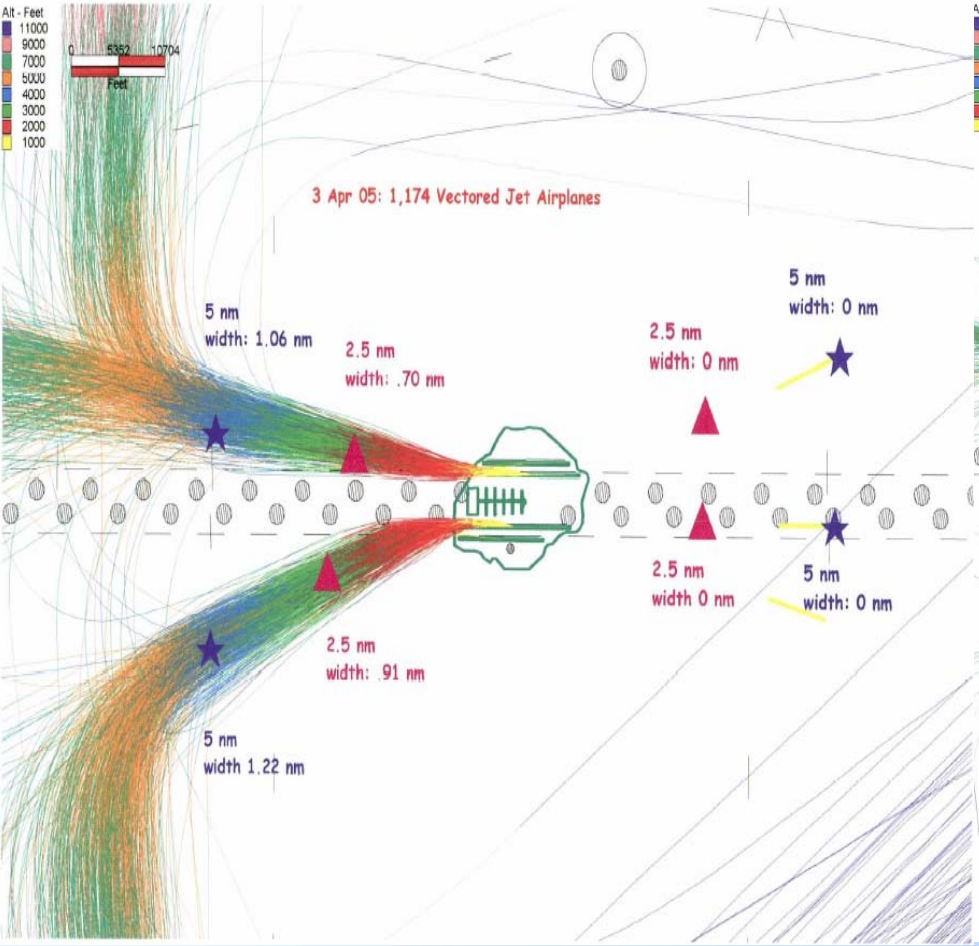

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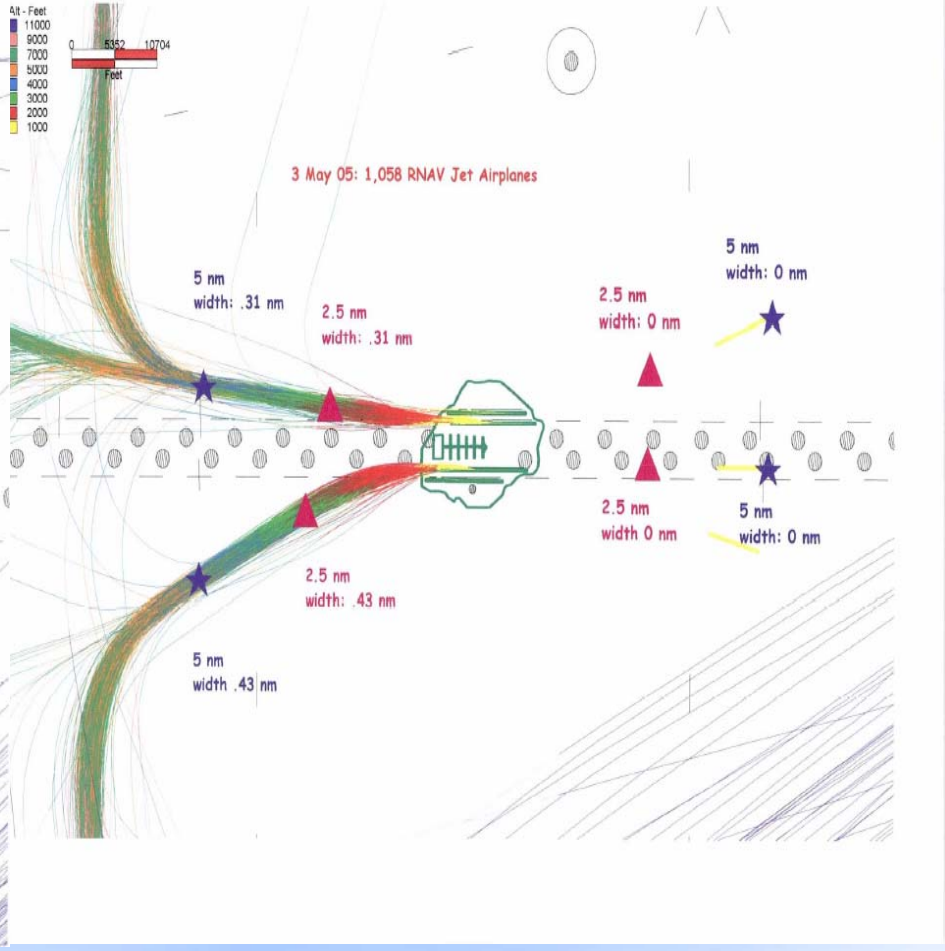
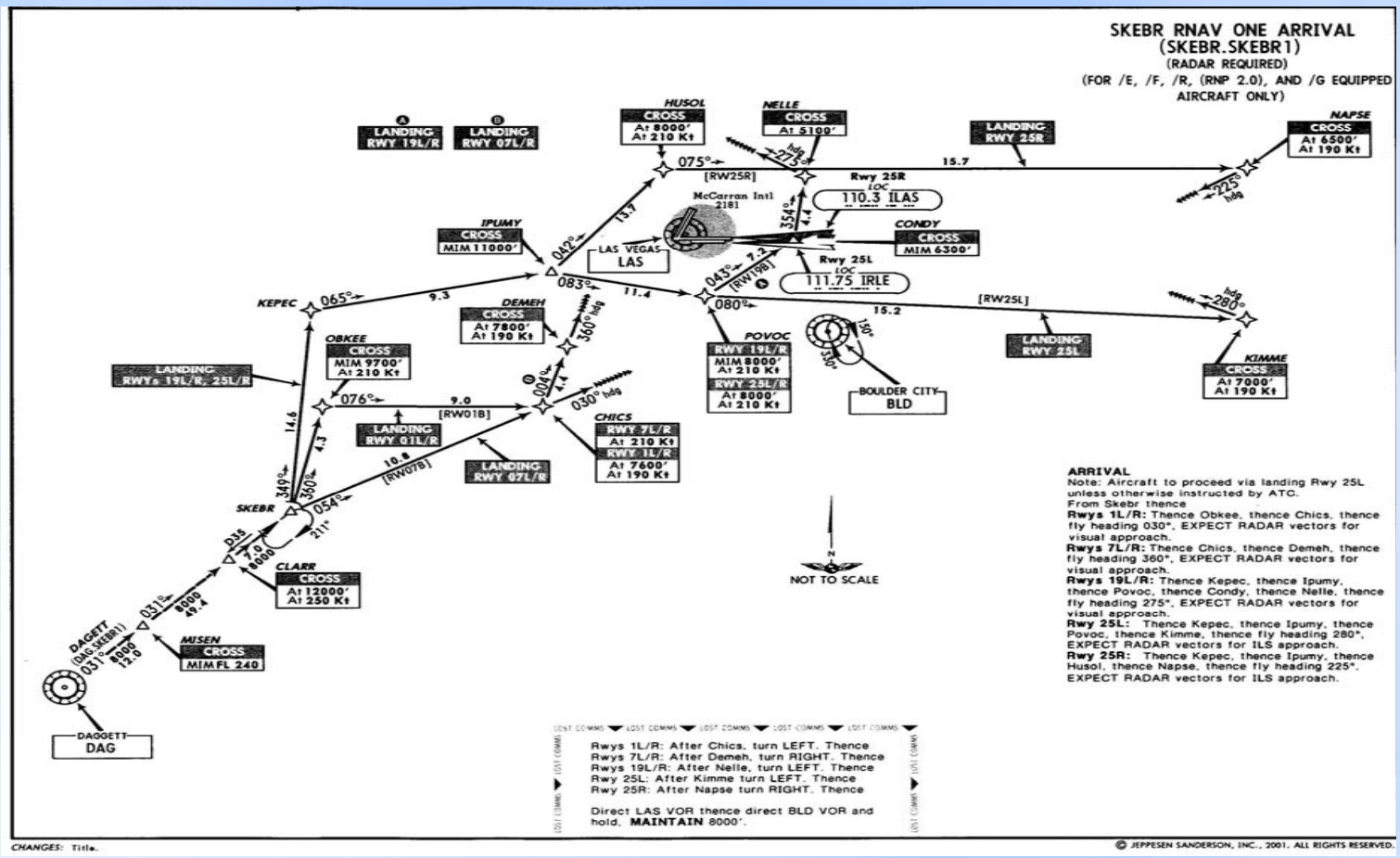


Lessons Learned (1)

- Coordination with stakeholders is critical to success
  - Manufacturers
  - Operators
  - Air Traffic Control
  - Other user groups
- TSO marking does not guarantee required functionality
  - Advisory material (e.g., AC/AMC) defines full installation criteria
- Ensure procedure coding is useable by desired population

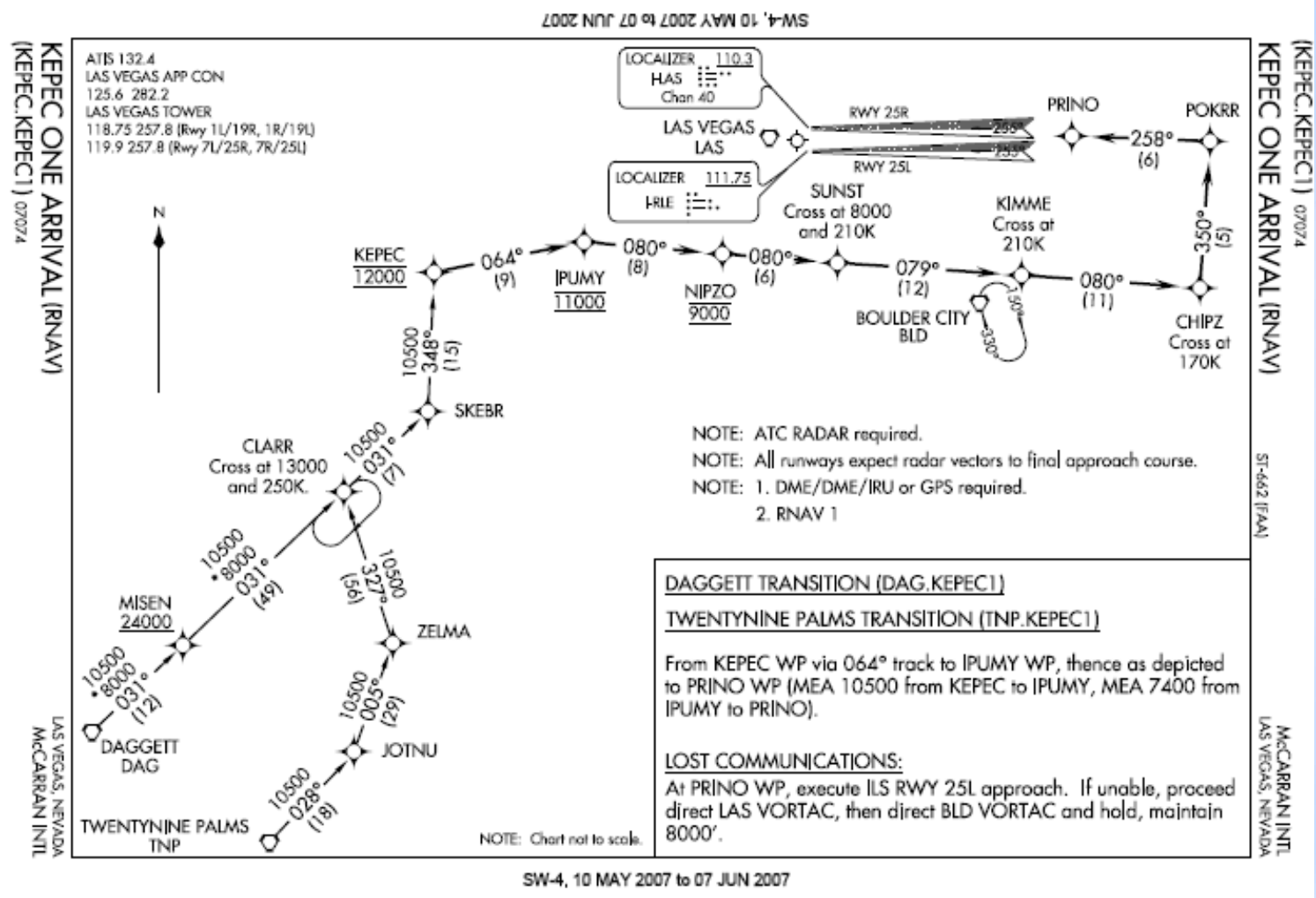
Lessons Learned (2)

Procedure Complexity



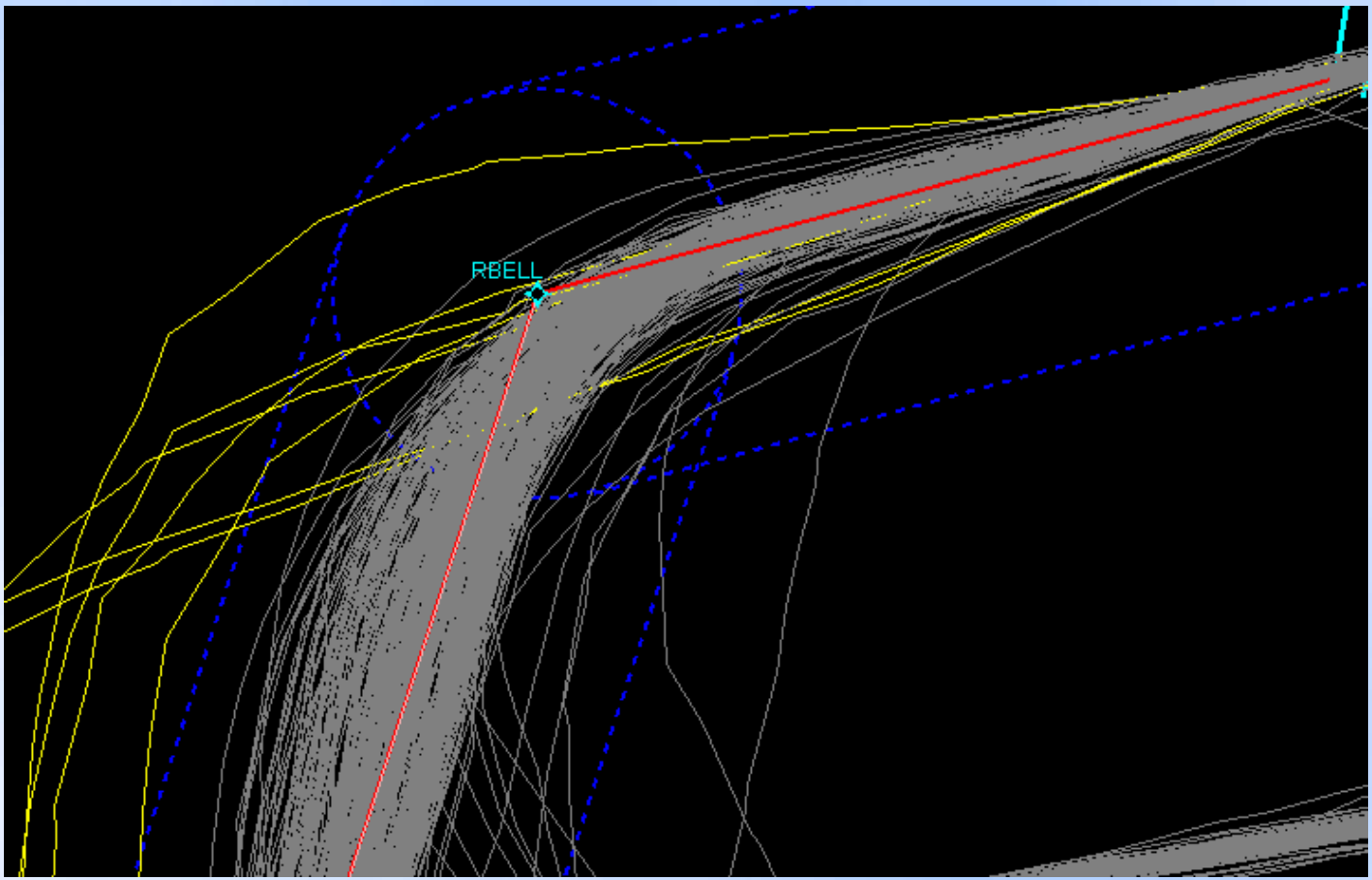
Lessons Learned (3)

Reduced Chart Clutter



Lessons Learned (4)

Turn Anticipation- variable for ambient conditions, altitude, angle of turn, phase of flight, avionics, and aircraft



Lessons Learned (5)

- Use of simulator and flight trials
  - Highly encouraged
  - Use to identify any changes necessary prior to public implementation
- Public implementation
  - Delay initial procedure implementation following database and chart release
  - Be ready for path deviations
  - Conformance and overall operator participation will improve over time

Lessons Learned (6)

- Controller expectations for flight path conformance must be realistic
  - Should allow for normal variations
  - Not be limited to depictions of the nominal path, flyability or simulation results alone
- Provide controllers with clear guidance on the interpretation of chart narratives, altitude, and speed information

Hypothetical Exercise

- User equipage:
  - 50% of aircraft can perform DME/DME/IRU
  - 50% of aircraft are equipped with approved GPS
- Navigation infrastructure:
  - DME/DME coverage is not continuous
  - GPS is available with no known interference
- Radar coverage:
  - Not available 24 hours/day, 7 days/week
- Communication
  - Direct pilot controller communication is available (24/7)
- What Terminal Navigation Specification would you use?
- Coordination should occur with which organizations?

Summary

- RNAV 1 and Basic-RNP 1 differences:
  - RNAV 1 routes primarily developed for RNAV operations in a radar environment
  - May be used in non-radar environment if State assures system safety
  - Basic-RNP 1 intended for similar operations outside radar coverage (ATS surveillance limited or not available)
- Required navigation infrastructure and performance:
  - RNAV 1 uses DME/DME,DME/DME/IRU, or GNSS
  - Basic-RNP 1 primarily designed for GNSS
  - Functional performance requirements just as important as accuracy
- Flight crew operating procedures include certain requirements for RNAV system engagement as well as adherence to track
- Aircraft and operator eligibility requirements are listed in PBN Manual
  - PBN Manual provides standardized guidance, but not a stand-alone certification document
- Coordination among Operator, Regulator, and ANSP is crucial for success

Bearing in mind the target audience in ICAO Regions

Feedback and Questions