

Predictive RAIM for RNAV 1 and RNAV 2 Operations Using TSO-C129 GPS

Presented to: ICAO SAM Implementation Group
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Date: 19 October 2009

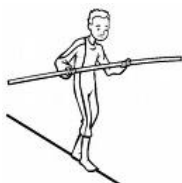


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Outline

- Recent questions
- What is RAIM?
- Why “predictions” *now*?
 - ✦ FAA Implementation
- Where does it apply?
- When are RAIM predictions required?
- How is compliance accomplished?



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Questions from past 6 months

- Why worry about working satellites?
- What about getting “fleet credit”?
- Why isn’t prior service history given more credit?
- Why can’t baro-aiding be used as a baseline?



Recently Submitted Questions

- **What is the difference between:**
 - ✦ **Global Navigation Satellite System (GNSS) monitoring status?** Addressed through published GPS Notices to Airmen (NOTAMS). **Who records?** US Coast Guard **Who gets data?** Requesting user **How is it used in flight operations?** RAIM calculation
 - ✦ **GPS data recording?** State requirement to record GPS data in case of incident/accident. How does US handle?
 - ✦ **Ground real-time monitoring status?** What is difference from GNSS monitoring?
 - ✦ **RAIM prediction monitoring?** Based on current GPS constellation status.



Recently Submitted Questions

- **Is RAIM prediction done for fault detection (FD), fault detection and exclusion (FDE), and Performance Navigation for the operation en route, terminal and non-precision approach (NPA)?**
 - ✦ Fault Detection only, but also includes option for baro-aiding
- **Is one RAIM prediction performed, or one for each case?**
 - ✦ U.S. Ops requirement for en route and terminal RAIM prediction. Non-precision approach (NPA) provided, but not required



Recently Submitted Questions

- **Who conducts the RAIM prediction, the Service Provider or the Operator? What type of consideration is necessary to analyze at this respect?**
 - ✦ In the US, the FAA established 6 means of compliance (discussed in briefing)
- **How will RAIM prediction consider solar phenomena? How will predictions be calculated?**
 - ✦ FAA's RAIM prediction does not focus on solar flare influence (discussed in briefing)



What is RAIM?

- Receiver Autonomous Integrity Monitoring
 - ✦ Means of providing GPS signal integrity monitoring
 - ✦ Need 5 satellites for fault detection (or 4 satellites and baro-aiding)
 - ✦ Need 6 satellites for fault detection and exclusion (or 5 satellites and baro aiding). (With only 5 satellite vehicles in view, GPS with FDE reverts to basic RAIM)
 - ✦ Receiver predicts NPA RAIM, but not en route or terminal
- TSO-C129() received “supplemental” approval
 - ✦ Supplemental limitation addressed four areas:
 - ✦ Limited availability of RAIM (geometry)
 - ✦ Equipment not required to provide satellite exclusion
 - ✦ Potential for interference to GPS
 - ✦ Inadequate capability to predict RAIM availability during flight planning
 - ✦ Certain TSO-C129 receivers are approved for oceanic operations



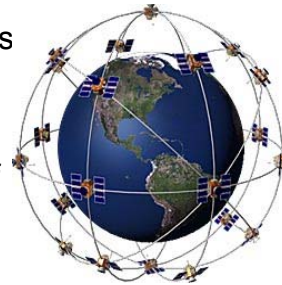
Predictive RAIM

- Challenges
 - ✦ No standardized method for RAIM prediction
 - ✦ Difficult to construct a baseline model when current equipage involves several variables
 - ✦ Proprietary receiver algorithm
 - ✦ Proprietary antenna design
 - ✦ May use lower mask angle ($< 5^\circ$)
 - ✦ Credit for baro-aiding should be given, if receiver and installation confirm this capability
- GPS frequently asked questions:
<http://pnt.gov/public/faq.shtml>



Why RAIM, it's never been a problem before...

- Impact FD (or FDE, but no extra satellites)
 - ✦ Loss of availability
- Spoiled by success (~30 satellites):
 - ✦ Spare satellites improve availability of a particular "slot position", but not necessarily the geometry
 - ✦ Counting "operating" satellites does not guarantee proper geometry unless accounted in primary slot position
- RAIM prediction websites
 - ✦ <http://augur.ecacnav.com/augur/app/home>
 - ✦ <http://www.raimprediction.net>



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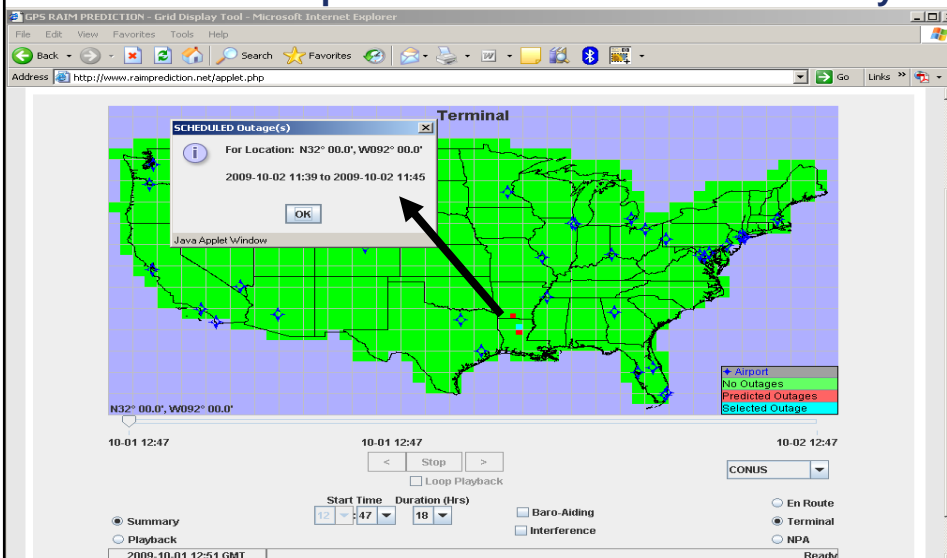
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...but there will be periods of forecast non-availability



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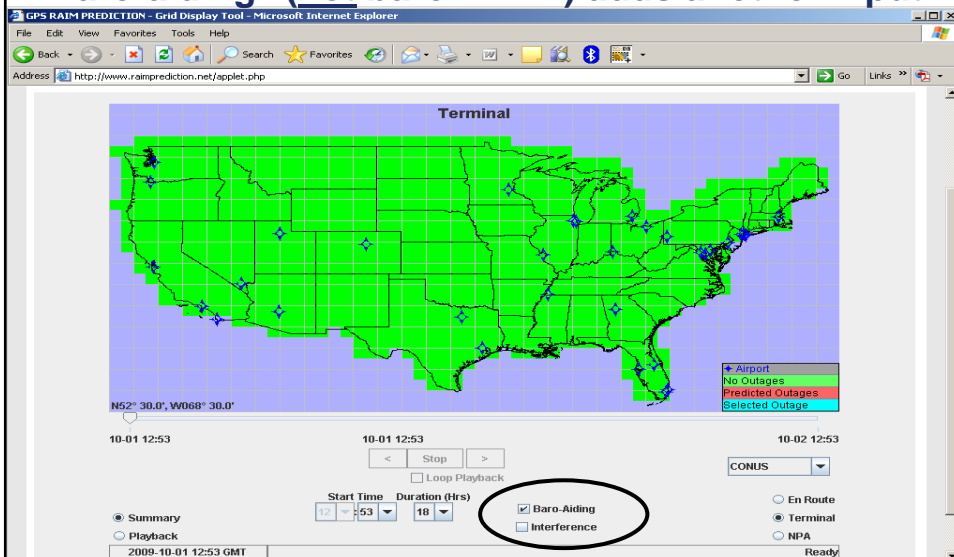
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“Baro-aiding” (not baro-VNAV) adds another input



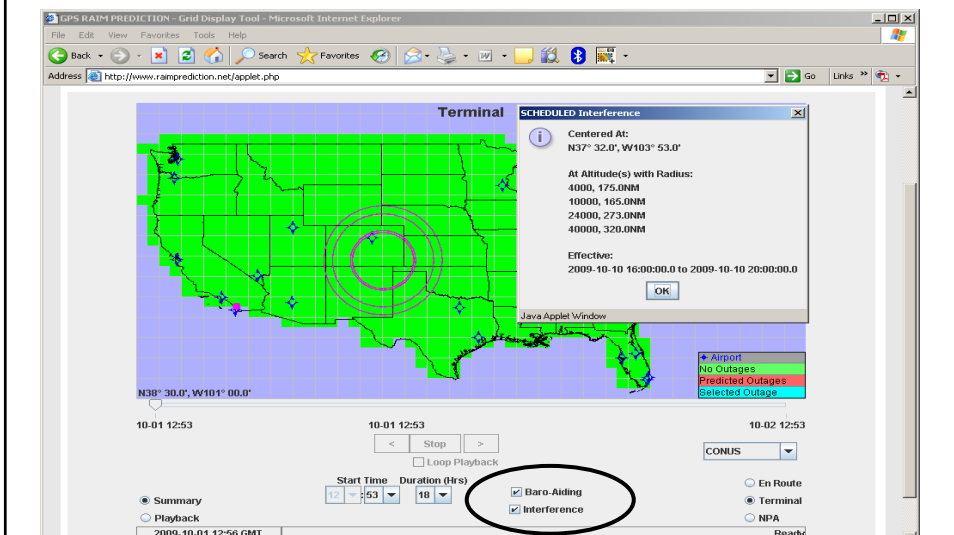
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Another feature: known interference testing



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Standard Positioning Service Performance Standard – Sept 2008

Operational Satellite. A satellite which is capable of transmitting, but is not necessarily currently transmitting, a trackable ranging signal. For the purposes of these performance standards, any satellite in the transmitted navigation message almanac is considered an operational satellite.

3.7.3 Operational Satellite Count Standards

The total number of operational satellites in the constellation shall be as specified in Table 3.7-3.

Table 3.7-3. Operational Satellite Count Standards

Operational Satellite Count Standard	Conditions and Constraints
<ul style="list-style-type: none"> • ≥ 0.95 Probability that the Constellation will Have at least 24 Operational Satellites Regardless of Whether Those Operational Satellites are Located in Slots or Not 	<ul style="list-style-type: none"> • Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operational satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in this SPS PS or not

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From GPS Program Update to 49th CGSIC, 21 Sep 09



GPS Constellation

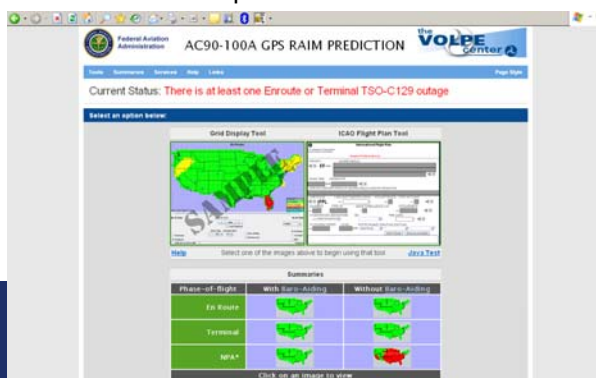
- **Very robust constellation**
 - 30 space vehicles currently set healthy
 - 11 GPS IIA
 - 12 GPS IIR
 - 7 GPS IIR-M
 - 1 GPS IIR-M waiting to be set healthy
 - 3 additional satellites in residual status
- **Global GPS civil service performance commitment met continuously since December 1993**



FAA Initial RAIM Prediction Requirements

- Demand for automated input/feedback
 - ✦ Initial meeting, 29 Oct 2007, with FAA (Air Traffic, Flight Standards, Certification) and industry (ALPA, AOPA, RAA, Boeing, USAF)
- Upgraded web page www.raimprediction.net
 - ✦ Baro-aiding, interference, and non-precision approach options
 - ✦ ICAO flight plan input for textual Pass/Fail
 - ✦ Flight planning vendor access is accomplished outside of website

Ken



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AC 90-100A Guidance (US En Route and Terminal RNAV)

- Guidance
 - ✦ AC 90-100A, para 10.a.(5): *IF using TSO-C129() to solely satisfy RNAV requirement, RAIM availability must be confirmed using current GPS satellite information*



Advisory Circular

Subject: U.S. Terminal and En Route
Area Navigation (RNAV) Operations

Date: 03/01/07
Initiated by: AFS-400

AC No: 90-100A

1. PURPOSE.

a. This advisory circular (AC) provides operational and airworthiness guidance for operation on U.S. Area Navigation (RNAV) routes, Instrument Departure Procedures (DPs), and Standard Terminal Arrivals (STARs). Operators and pilots should use the guidance in this AC to determine their eligibility for these U.S. RNAV routes and procedures. In lieu of following this guidance without deviation, operators may elect to follow an alternative method, provided the alternative method is found to be acceptable by the Federal Aviation Administration (FAA). For the purpose of this AC, "compliance" means meeting operational and functional performance criteria. Mandatory terms in this AC such as "must" are used only to ensure applicability of these particular methods of compliance when the acceptable means of compliance described are used. This AC does not change, add, or delete regulatory requirements or authorize deviations from regulatory requirements.

NOTE: New applicants for a type certificate (TC) or supplemental type certificate (STC) should include a statement of compliance to this AC and qualification for U.S. RNAV routes and terminal procedures when the aircraft is found in compliance with this AC.

b. **Applicability of AC 90-100A.** AC 90-100A applies to operation on U.S. Area Navigation (RNAV) routes (Q-routes and T-routes), Departure Procedures (Obstacle Departure Procedures and Standard Instrument Departures), and Standard Terminal Arrivals (STARs). It does not apply to over water RNAV routes (ref 14 CFR 91.511, including the Q-routes in the Gulf of Mexico and the Atlantic routes) or Alaska VOR/DME RNAV routes ("JxxxxR"). It does not apply to off-route RNAV operations, Alaska GPS routes or Caribbean routes, or helicopter operations involving offshore or specific heliport procedures.

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Slide 15

Ken A10 Suggest reference somewhere in presentatio to Augur site since it covers CARSAM and states can accept predictions from that site if they choose to allow its use!

DOT/FAA Ken Alexander, 10/17/2009

RNAV system compliance

- AC 90-100A, US operational and ai

AC 90-100A and RNAV Substitution Compliance Table

Operational and al

THIS TABLE IS CURRENT AS OF 19 AUGUST 2009

DIRECTIONS

- 1 AC 90-100A RNAV 1 approval satisfies all AC 90-100 performance requirements and RNAV substitution requirements.
- 2 The navigation database should be obtained from a database supplier holding an FAA Letter of Acceptance (LOA) in accordance with AC 20-153. The operator's supplier (e.g., FMS manufacturer) must have a Type 2 LOA. Database LOA's are listed in the latter spreadsheets.
NOTE: A Type 2 LOA provides recognition of a data supplier's compliance with RTCA/DO-200A and the compatibility of their delivered data with particular avionics systems.
- 3 For approvals based solely on GPS, pseudorange step detection and healthword checking are required.
- 4 For approvals based on DME/DME/IRU, any Inertial Reference Unit/Inertial Reference System (IRU/IRS) may be used.
- 5 This compliance table does not change previous guidance to use GPS in lieu of ADF or DME for the following operations: Determine aircraft position over a DME fix; Fly a DME arc; Navigate to/from an NDB/compass locator; Determine aircraft position over an NDB/compass locator; Determine aircraft position over a fix defined by an NDB/compass locator bearing crossing a
- 6 APPROVED RNAV SYSTEMS FOR RNAV 1 PROCEDURES AND/OR RNAV 2 ROUTES. WHEN OPERATED IN ACCORDANCE WITH AC 90-100A, SYSTEMS LISTED IN THIS TABLE MEET THE PERFORMANCE REQUIREMENTS FOR RNAV 1 AND/OR RNAV 2 OPERATIONS UNLESS OTHERWISE STATED.

AC 90-100A RNAV 1 or 2 system approval based on:	Eligible to fly RNAV "Q" or "Tango" route	Eligible to fly RNAV SID/STAR/ODP	Eligible to use RNAV Substitution or RNAV Alternate means of navigation (US only) ³
GPS	YES ¹	YES ²	YES
DME/DME/IRU (no GPS)	YES ¹	YES ²	YES ⁴

<http://www.faa.gov/afs400/afs470/p>

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<http://www.faa.gov/afs400/afs470/p>

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RAIM Preflight Planning Procedures

- List of AC 90-100A Compliant equipment:

http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs470/media/AC90-100compliance.xls

- Operator ensures RAIM availability exists
- Predicted, continuous loss of RAIM > 5 minutes for any part of the intended flight:
 - ✦ Delay, cancel, or re-route where RAIM requirements can be met.
- For multi-sensor equipment with operating GPS and DME/DME/IRU positioning, a RAIM check is not required as long as critical DME's are functioning normally
 - ✦ (Critical DME discussion two slides away)

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Guidance



NOTICES TO AIRMEN

Domestic/International

September 24, 2009

Next Issue
October 22, 2009

Notices to Airmen

Operation on U.S. Area Navigation Routes, Standard
Terminal Arrivals, and Departure Procedures

Operation on U.S. Area Navigation (RNAV) Routes, Standard Terminal Arrivals, and Departure Procedures

http://www.faa.gov/airports_airtraffic/air_traffic/publications/notices/

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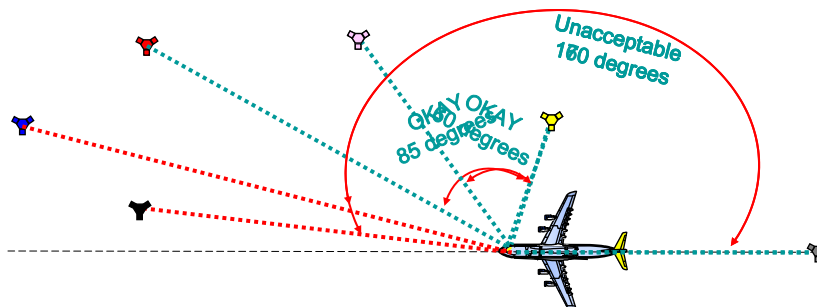


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Multi-sensor aircraft using DME/DME/IRU RNAV: Critical DME

- DME/DME geometry solutions require the two DMEs to be ≥ 30 and ≤ 150 degrees. Position estimation accuracy better or equal to 0.56 NM



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Critical DME

- If required for DME/DME/IRU performance, listed on RNAV 1 procedures
 - ✦ By design, Q routes will not have critical DME's
- Geometry and SSV can result in several critical DME's
- Unofficial list of critical DME's recently developed
- Performance assumptions:

Flight Type: Arrival/Approach
 Aircraft Category: Cat D
 Climb Gradient: *None assigned*
 Ground Speeds:

Table:

200.0 Kts up to 11000.0 Ft.
 240.0 Kts up to 18000.0 Ft.
 260.0 Kts up to 24000.0 Ft.
 340.0 Kts up to 99900.0 Ft.

Wind Settings: *None assigned*
 Descent During a Turn: Allowed

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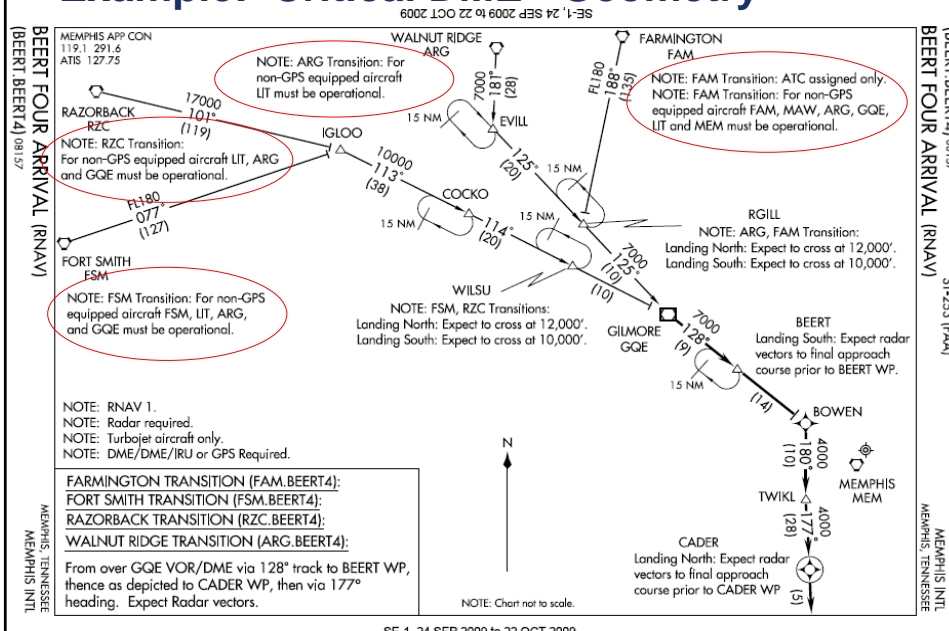
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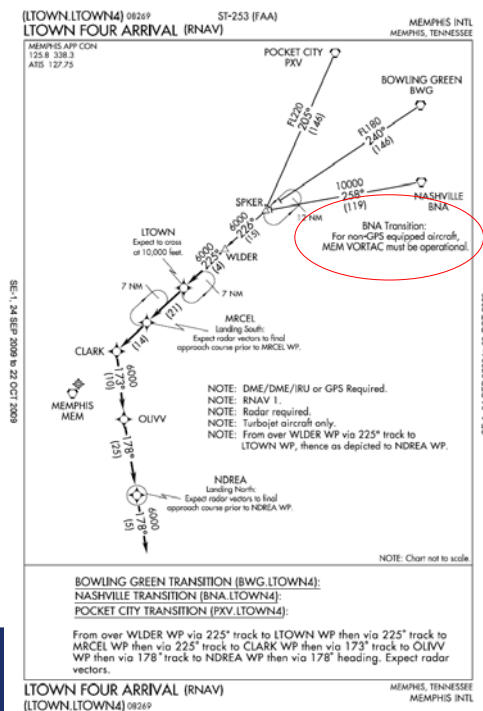
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Example: Critical DME - Geometry

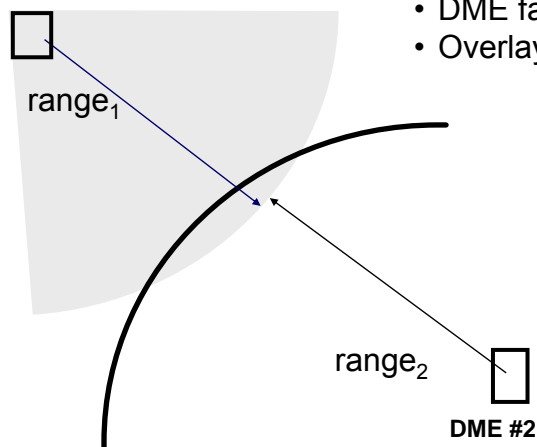


Example: Critical DME



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Procedure design considerations



- DME facilities in view
- Overlay of RNAV routes

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Comply with any one of the following methods:

- **Monitor the status of each satellite in its plane/slot position**
 - ✦ Account for the latest GPS constellation status (e.g., NOTAMs or NANUs),
 - ✦ Compute RAIM availability using model-specific RAIM prediction software.
- **Use the FAA RAIM prediction website: www.raimprediction.net.**
- **Contact a Flight Service Station to obtain non-precision approach RAIM.**
- **Use a third party interface, incorporating FAA/VOLPE RAIM prediction data without altering performance values, to predict RAIM outages for the aircraft's predicted flight path and times.**
- **Use the receiver's installed RAIM prediction capability to provide non-precision approach RAIM, accounting for the latest GPS constellation status (e.g., NOTAMs or NANUs).**
 - ✦ Since receiver only required to predict NPA RAIM, will need to check airports spaced at intervals not to exceed 60 NM along the RNAV 1 procedure's flight track. "Terminal" or "Approach" RAIM must be available at the ETA over each airport checked.
- **Operators not using model-specific software or FAA/VOLPE RAIM data will need FAA operational approval.**

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RNP – *performance based*

- Aircraft "system" performance
 - ✦ Horizontal alert limit may not depend on manufacturer implementation in meeting same RNP level
- "Business as usual" is changing
 - ✦ Ground infrastructure: nav aids, surveillance
 - ✦ Aircraft capability: New RNP procedures = greater capability, capacity, and fuel savings
 - ✦ AC 90-105 captures this *transition*

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Future Volpe work

- O&M to continue current effort
- Continued prediction performance comparison against avionics manufacturer prediction
- Upgrades to support interoperable system with international prediction systems (e.g., AUGUR)
- Upgrades to support increased coverage volume beyond continental US, Alaska, and Hawaii
- Algorithm and web service support for TSO-C196 receiver



Summary

- RAIM
 - ✦ Spoiled by success, let's not become complacent
- What, Why, Where, When, and How
 - ✦ Geometry more important than satellite count
 - ✦ Enforcement began 28 Sept 2009

NOTE: Until September 27, 2009, a RAIM prediction does not need to be done for any RNAV route conducted where ATC provides radar monitoring or RNAV departure/arrival procedure that has an associated "RADAR REQUIRED" note charted. On September 28, 2009, operators filing RNAV 2 routes (Q and T), RNAV 1 STARs, and RNAV 1 DP's will need to perform a RAIM prediction as part of their preflight planning.
(Performance Based Flight Systems Branch, 7/22/09)

- Future work



Thank you

Questions?



Backup: Ionospheric Storm

- **Initial burst of noise (not predictable)**
 - ✦ Small and brief
 - ✦ Worst case = loss of low elevation satellites, similar to banking. No effect on operations.
- **Ionospheric scintillation (not predictable)**
 - ✦ Rapid fluctuations; GPS signal can split and cancel itself
 - ✦ Satellites in different parts of sky. Typically impact one signal at a time. Degradation in RAIM availability
- **Ionospheric delay (not predictable)**
 - ✦ Negligible with respect to non precision approach (NPA) or RNP 0.1. For LPV, corrected by WAAS (not a problem).
 - ✦ Can disrupt LPV (~ 8 hours). Reason LPV not used for alternate capability