**Introduction**

- GPS is an important component of today’s aviation navigation infrastructure
  - Its role will continue to increase over the coming years
- Future GNSS constellations will also become important to contributors
- However, their incorporation must be done with great care as the integrity requirements for aircraft guidance are very stringent
  - Less than $10^{-7}$ probability of misleading information
  - International standards define different types of GNSS augmentations to achieve this level of integrity
Integrity Monitoring

• Space-based and ground-based augmentation systems provide independent monitoring of the GPS signals through calibrated ground monitors
  – Requires ground monitoring network communication channel to aircraft

• Receiver Autonomous Integrity Monitoring (RAIM) compares redundant satellite measurements against each other to determine identify and eliminate large faults
  – Requires a larger number of ranging measurements
• Key Feature:
  – Integrity Determination by the User with RAIM
• Key Enabler
  – Requires Redundant Ranging Sources
• Key Benefit
  – Provides horizontal guidance for aircraft
• Key Challenge
  – Accuracy & Availability
• GNSS vertical accuracy is worse than horizontal
• Aviation requirements are more strict in the vertical
  – Vertical maneuvers bring the aircraft closer to the ground
• Therefore, it is much harder for GNSS to meet aviation vertical guidance requirements
• But, absolute vertical guidance from GNSS offers a strong safety benefit
  – Enables smooth, continuous precision approach paths
• Want to provide vertical and horizontal guidance
Two Civil Frequencies

- The ionosphere creates the largest source of uncertainty affecting today’s use of GPS for aviation
- When GPS L5 becomes widely available it will become possible to directly remove the ionospheric influence
  - May allow RAIM to support vertical navigation
- Unfortunately, the two frequency combination increases the effects of other noise sources
- It is desirable to reduce these noise terms and/or add more satellites to offset this increase
Future Considerations

Galileo (EU)

COMPASS

GLONASS

GPS
Interoperability of Integrity

• Interoperability should be a goal not just for GNSS signals, but for integrity provision as well
  – Augmentation systems already internationally coordinated

• Open service signals should target performance comparable to or better than GPS L1 signals today

• Different providers may make different design choices and different assurances
  – However, it is important to establish a common understanding of how RAIM depends on GNSS performance and how signals from different services could be combined to improve RAIM
  – Cooperation and transparency are essential
Benefits of Multi-Constellation RAIM

- Combining signals from multiple constellations can provide significantly greater availability and higher performance levels than can be achieved individually.

- Potential to provide a safety of life service without requiring the GNSS service provider to certify each system to $10^{-7}$ integrity levels.

- Creates a truly international solution:
  - All service providers contribute
  - Not necessarily dependent on any single entity
  - Coverage is global and seamless
Requirements on New Signals and Constellations

- Assure good nominal signal accuracy
  - On order 1 m ranging accuracy
- Perform a fault modes and effects analysis
  - Understand and make transparent potential faults and their effects
- Assure low fault rates
  - Of order $10^{-5}$/SV/Hour
- Assure good continuity of signals
  - Less than $10^{-5}$/hour probability of unexpected outages
- Assure good availability of signals
Summary

• RAIM allows for worldwide aviation navigation without requiring additional ground infrastructure

• Additional GNSS constellations can significantly improve performance and availability

• New GNSS constellations should assure that their open service signals support RAIM

• International cooperation and coordination will be essential to achieving this goal