THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

AAE6102 – Satellite Communication and Naivgation

Aircraft Based Augmentation System

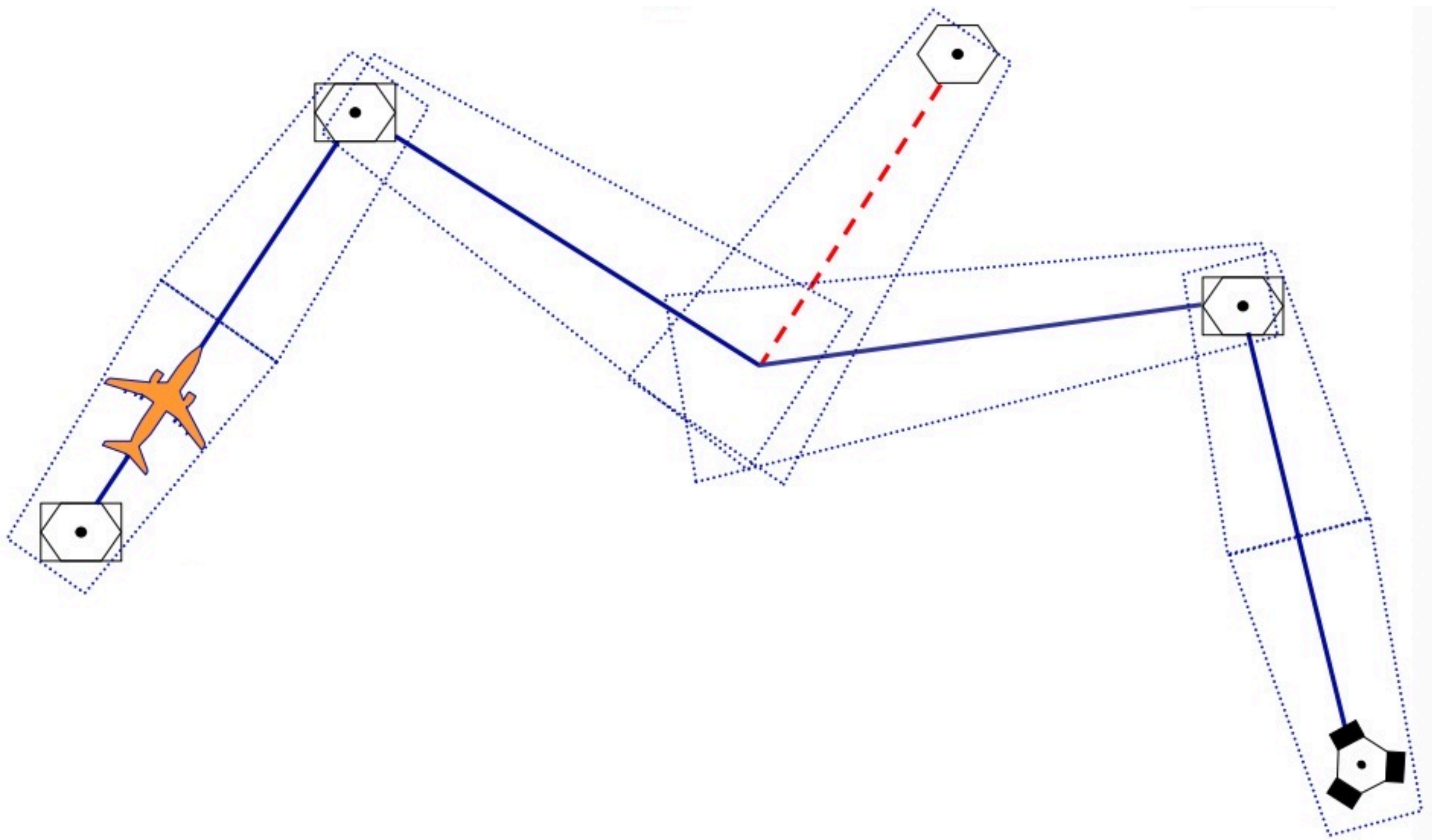
Dr. Yiping Jiang

Air Navigation

- There are essentially two kinds of markets and two regimes of operation to consider in the airborne area: GA and Air carrier industry. In the GA aircraft market, Loran-C navigators used to dominate, but penetration by GPS into this market is phenomenal, especially as GPS-aided approach capabilities become standard at most airfields.
- GPS now provides commercial and GA airborne systems with sufficient integrity to perform NPA. NPA is the most common type of instrument approach performed by GA pilots.

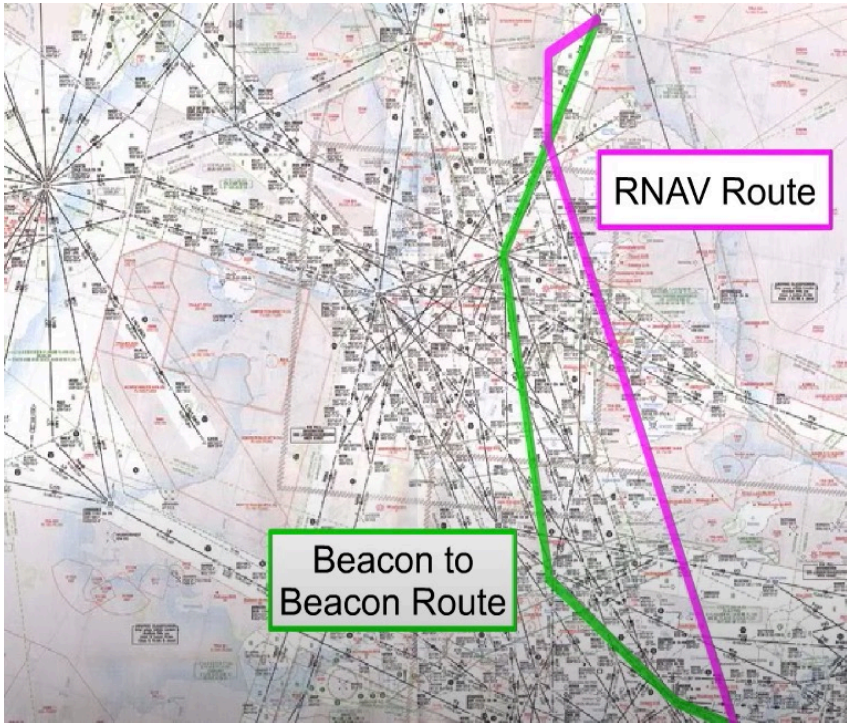
Conventional Navigation

- Air Navigation: History, VOR, ILS, DME, GNSS
- Conventional Navigation

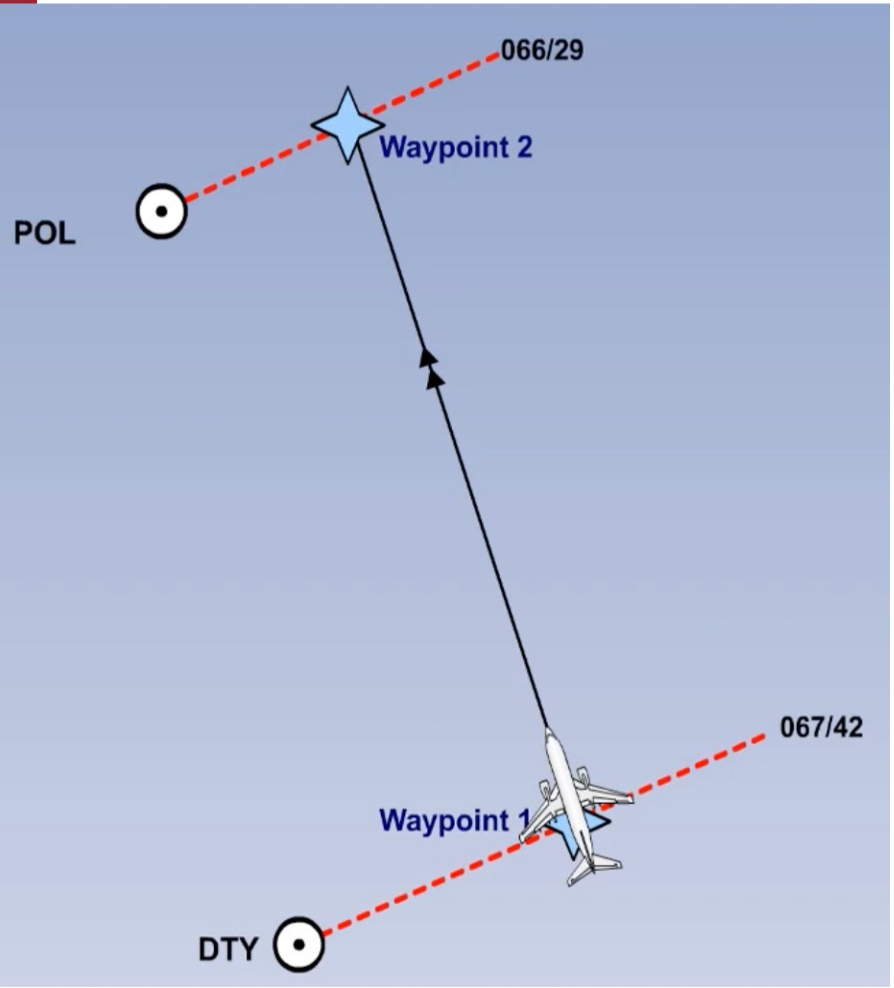


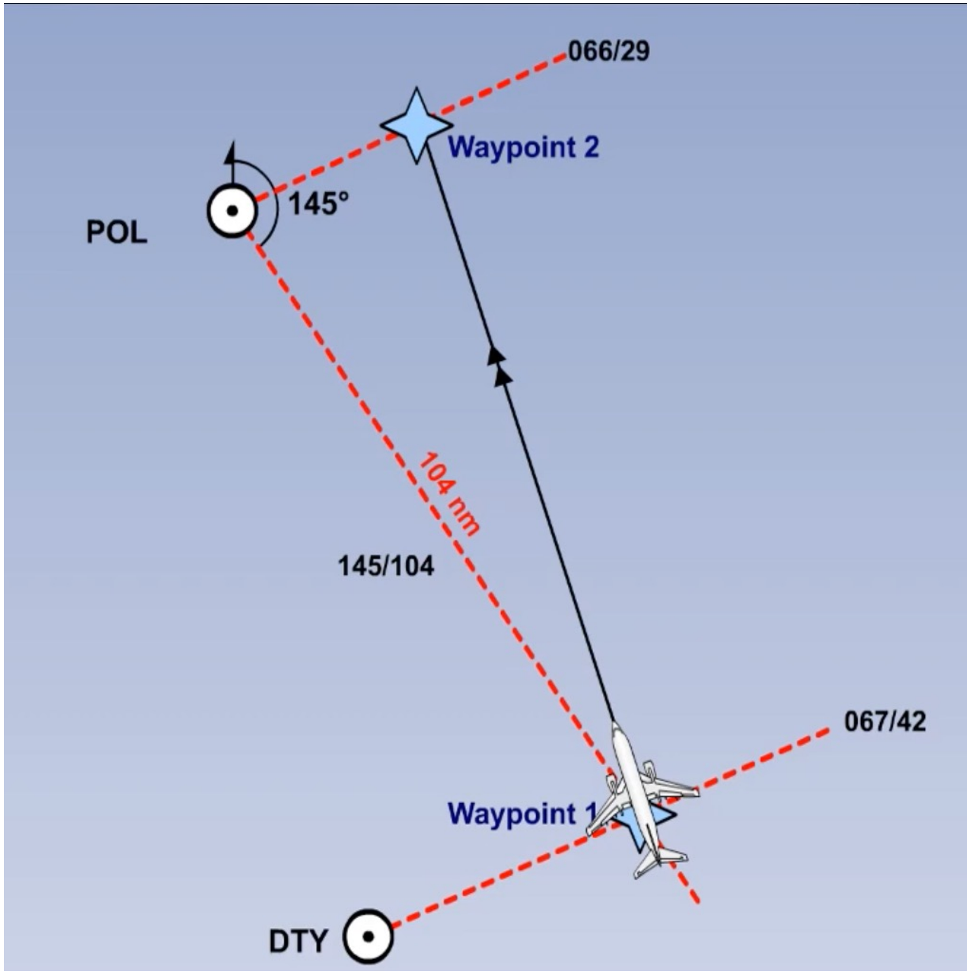
Area Navigation (RNAV)

- ICAO Annex 11: RNAV permits aicraft operations on any desired track within the coverage of station referenced navigation signals or within the limits of self-contained nav. systems
- No requirement to fly directly over ground based navigation aids.



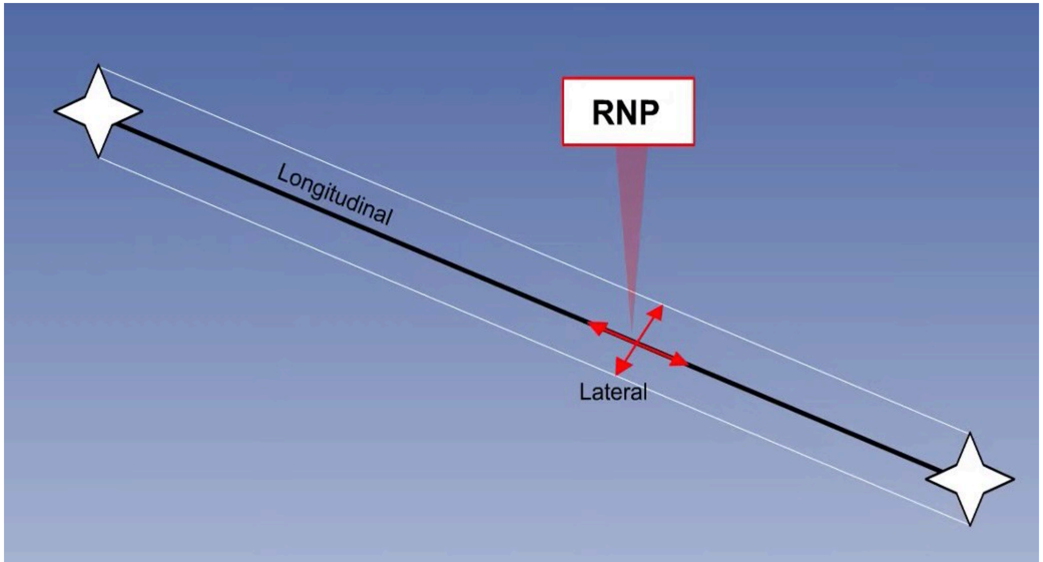
How does RNAV work?





Required Navigation Performance (RNP)

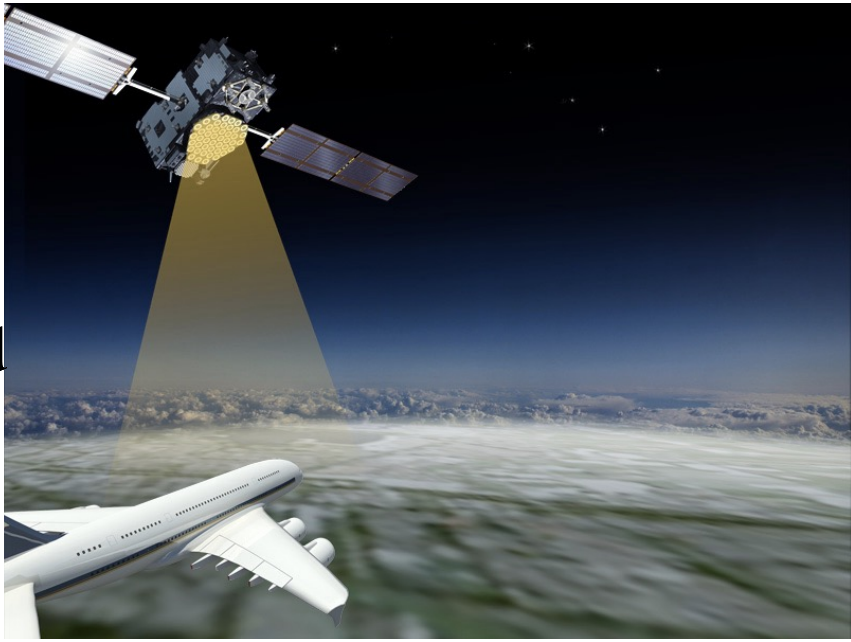
- A certain standard of accuracy must be met when RNAP is used, which is called RNP.
- E.g. if the standard of navigation accuracy is 1 nautical mile, then this standard has to be met 95% of the flying time in both latitude and longitude
- RNP can be specified for one or multiple routes, an area, a volumne of airspace



GNSS definition in ICAO Annex 10

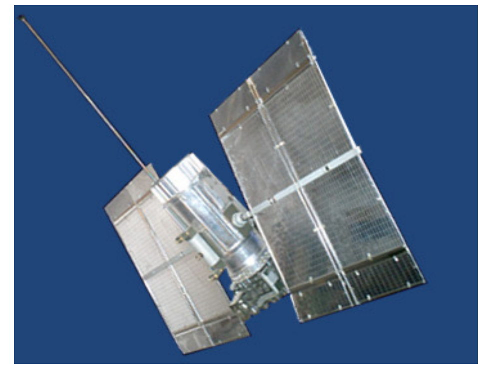
"A worldwide *position* and *time* determination system

that includes one or more satellite constellations, aircraft receivers and system *integrity monitoring*, augmented as necessary to support the required navigation performance for the intended operation."



GNSS Elements

Core Constellations

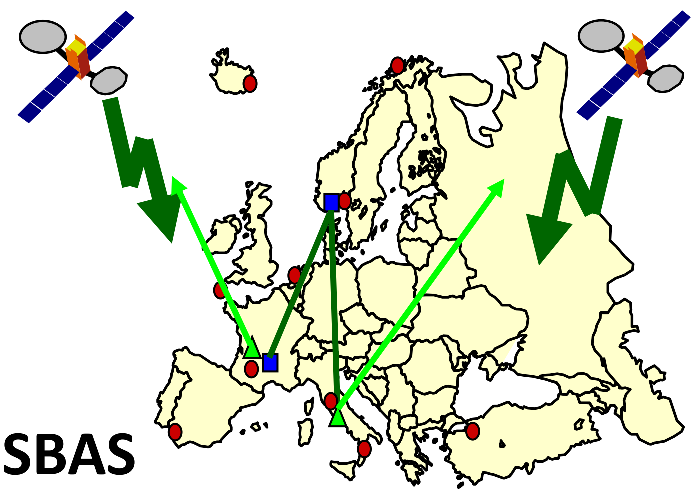


GPS

GLONASS

Augmentations

ABAS



SBAS

GBAS

Airport Approach with GNSS

- Airport approach warrants such a focused treatment because it is the most demanding phase of flight.
- The requirements associated with the underlying navigation system are quite extraordinary: navigation must be available greater than 99% of the time regardless of the weather; the navigation system must be especially reliable after an aircraft approach has commenced (the probability of a continuity break must be smaller than 8×10−6 per 15 seconds for the duration of the aircraft approach); and the navigation system must vigilantly protect against the possibility of misleading information (MI).

NPA to PA with GNSS

- Lower DAs demand more crew training and more sophisticated navigation equipment on the ground and in the air. However, a lower DA is certainly desirable during periods of inclement weather.
- Non-precision approach (lateral navigation (LNAV)) refers to approach procedures where the radio equipment gives lateral guidance only and the vertical information comes from barometric altimetry.
- Provision of worldwide vertically guided precision approach is the stated goal of the aviation community

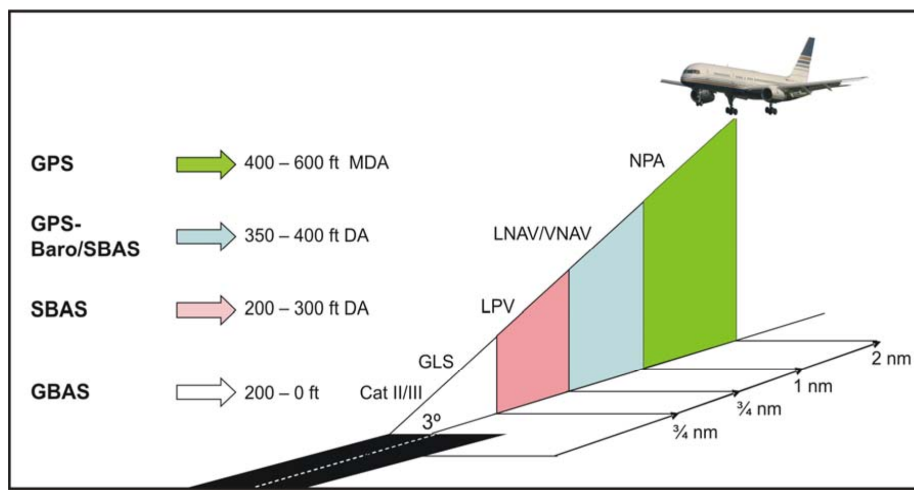


Figure 1 Approach Operational Minimums

integrity is of paramount importance for civil aviation.

Integrity in Civil Aviation

- With GNSS becoming a more important navigation infrastructure, unpredicted outage of GNSS services can cause undesired interruptions on aircraft operations.
- Navigation system integrity refers to the ability of the system to provide **timely warnings** to users when the system should not be used for navigation.
- There are three different integrity systems in civil aviation to provide integrity including aircraft based augmentation system (**ABAS**), ground based augmentation system (**GBAS**) and space based augmentation system (**SBAS**), depending on different locations to provide the correction and integrity information.

Integrity in Civil Aviation

- For aircraft navigation, **fault detection and isolation** is important. Faults that may cause misleading information (MI) must be detected and mitigated in real-time. The operation of GPS itself has been very reliable but faults that could cause MI have occurred. Some are man-made while others can be attributed to natural environmental effects.

Accuracy is related with user safety?

RAIM

- Receiver Autonomous Integrity Monitoring (RAIM) is one type of ABAS from 1980s, which is based on the **redundancy** satellite measurements and perform **consistency check** to detect faulty satellites.
- **Autonomous**: without reliant on any external ground monitoring facilities and conduct integrity monitoring within the user receiver itself
- Stand-alone positioning technique without any differential correction with GPS L1 signal
- Provide Enroute to NPA (Lateral navigation) services

Differences between ABAS, GBAS and SBAS?

RAIM

- RAIM monitors the satellite signals for the GPS receiver in the aircraft, that is able to detect faulty satellite and remove it from being used in positioning
- The airborne GPS unit without RAIM is usually used for VFR, since it is not able alert the pilot if insufficient quality satellite signals are received.
- Some IFR GPS receiver does not have RAIM, but requires alternative navigation methods, such as VOR, DME, ILS.
- If IFR GPS has RAIM, the alternative navigation sources are not necessary.
- Without RAIM, it is not possible to ensure the quality of the GPS solution.

RAIM

- ICAO Annex 10 and ICAO PBN manual require States and Air Navigation Service Providers (ANSPs) to provide timely warnings of GNSS RAIM outages.
  - RAIM prediction results are needed daily by pilots, flight dispatchers, air traffic controllers and airspace planners.
  - The use of appropriate RAIM prediction services is considered a necessary part of GNSS approvals.
  - RAIM prediction is required for en-route, terminal area, and approach operations.

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RAIM Prediction

RAIM Prediction Tool

Receiver Autonomous Integrity Monitoring (RAIM)
Service Availability Prediction Tool (SAPT)

Getting Started with RAIM

RAIM XML Service

Grid Display Tool

Airspace	Baro-Aiding	Outages
En Route	On	Click to View

RAIM Summary Pages

Phase-of-flight	With Baro-Aiding	Without Baro-Aiding
En Route		
Terminal		
NPA		
Click on an image to view		

https://sapt.faa.gov/default.php

RAIM Fault Detection and Identification (FDI)

Assuming only one satellite failed at the same time:

- 1. Does the failure exist?
- 2. If so, which is the failed satellite?

In case of supplemental navigation, question 1 is sufficient, since there is alternative navigation system to fall back if a failure is detected.

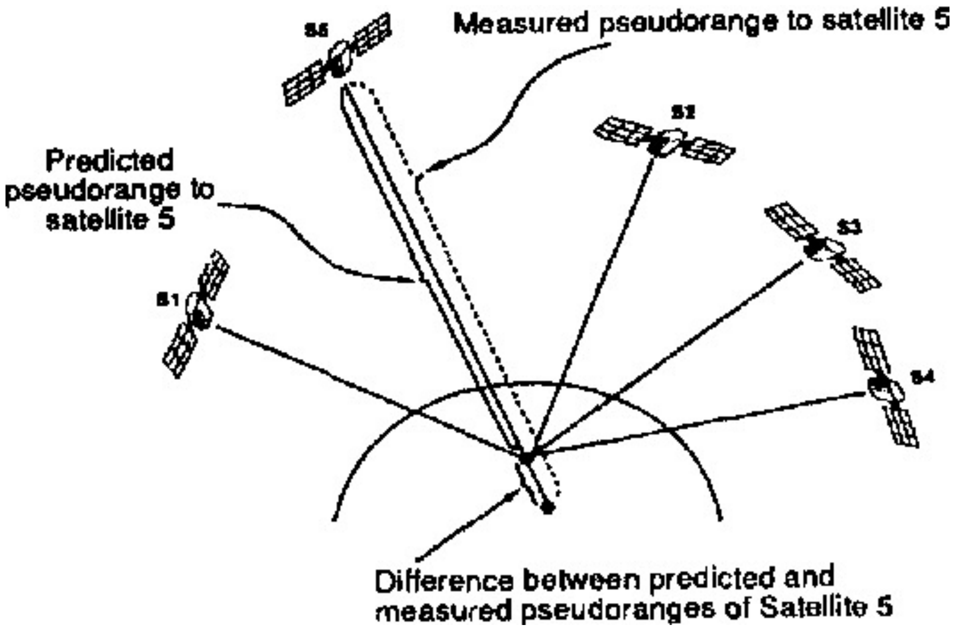
In case of sole-means navigation, both question 1 and 2 must be answered. The errant satellite must be identified and eliminated from the navigation solution, so that the aircraft can proceed safely with an uncontaminated GPS solution.

Exercise

- 1. Develop your own method to detect if or not there is fault
- 2. Develop your own method to identify the faulty satellite
- 3. With your method, what is the minimum satellites to perform fault detection? what is the minimum satellites to perform fault isolation?

RAIM FDI

- In a typical RAIM implementation the avionics use all satellites in view to form a position and time estimate for the aircraft.
- The receiver projects this position estimate back onto the line-of-sight vectors to the individual satellites. The differences between the projections and the original pseudorange measurements are residuals, which are used to assess the likelihood of any underlying measurement fault.
- How about in position domain?



How to bound different errors? E.g. multipath, noise, troposphere, ionosphere…

RAIM Protection Level

- RAIM computes real-time error-bounds. These bounds are called protection levels (PLs) that must overbound the true position error under all conditions and in real-time

- The receiver uses the current PL to determine whether a particular operation is safe. If the protection level is smaller than the alert limit (AL) required for a particular operation, then the pilot may fly that procedure.

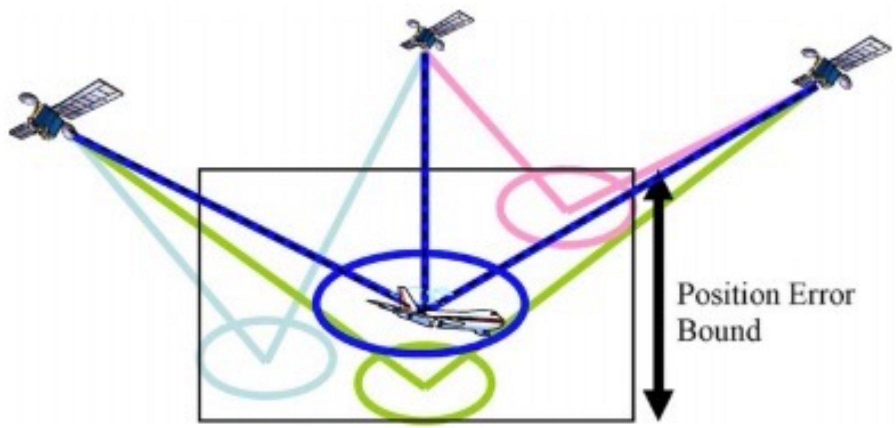
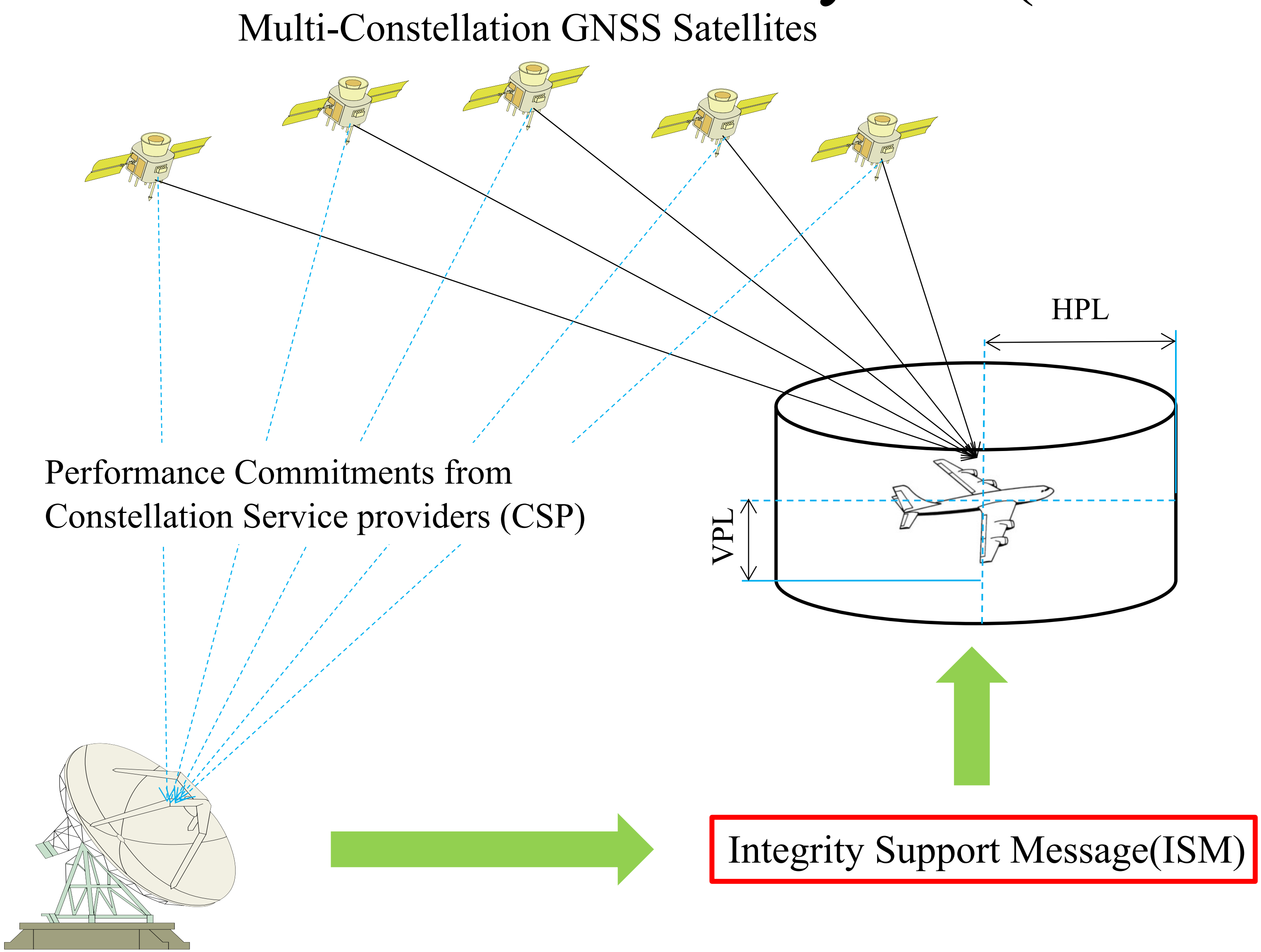


Fig. 4. *Although it can be formulated in several ways, the basic idea of the receiver autonomous integrity monitoring (RAIM) is to compare the all-in-view solution (in blue) to the subset solutions. The subsets that need to be considered depend on the assumed prior probabilities of fault.*

Why PL is dependent on satellite geometry?

Future Development: Advanced RAIM System(ARAIM)



ARAIM Basics

- Purpose: 1) Satisfy en route, terminal, and precision approach operations as low as 200'AGL at 99.0% availability or better and be capable of providing **LPV-200** performance worldwide; 2) Enables a reasonable path to an autoland capability with 10^{-9} integrity worldwide.
- The ARAIM integrity architecture is an extension and refinement of existing RAIM algorithms. ARAIM would improve on today's RAIM because the large ionospheric errors affecting range measurements would be removed using **dual-frequency measurement** diversity.
- ARAIM places the greatest integrity burden on the aircraft and the smallest burden on the GNSS constellation and the external monitors.

ARAIM Basics

- ARAIM is not autonomous. External monitoring must exist for all the same faults. The external monitoring will guarantee failure probabilities for the individual satellites are as expected and provide the associated user range accuracies.
- This information need only be updated approximately every hour so the time-to-alert requirement is satisfied by the fault detection algorithm on the aircraft. The external monitors simply need to ensure that faulted satellites do not stay in the mix for a long time. As such, ARAIM is the least demanding with respect to the bandwidth and latency of the integrity broadcast mechanism to the user.