High Integrity Positioning: Lessons from the Aviation Industry

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Honeywell

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Introduction

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- Navigation positioning systems requirements:
  - Accuracy
  - Integrity
  - Continuity
  - Availability
- Difficult trade-offs when high integrity is required
  - Critical phases of flight
  - Dynamic positioning
- Integrated architectures offer advantages for safety
- INS/GNSS Hybrid integrated architecture (HIGH) is an example.

Accuracy

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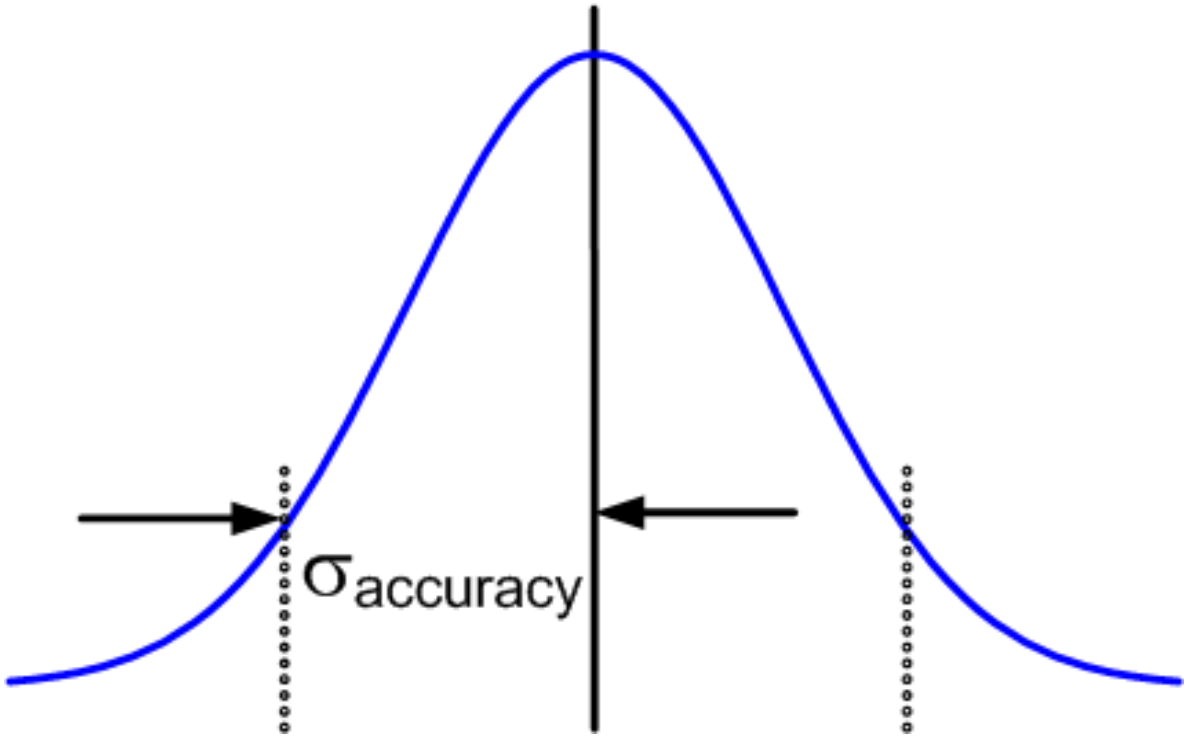
- Difference between measured and actual position
- Defined in a fault-free condition



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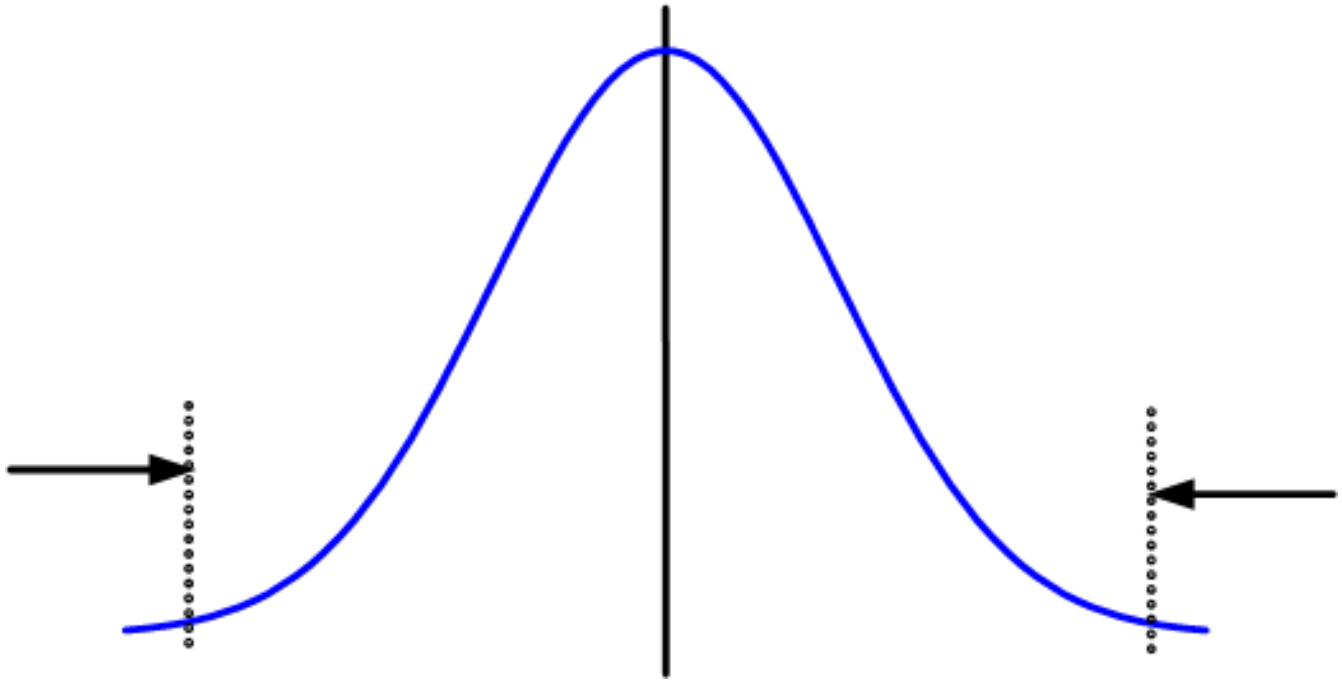

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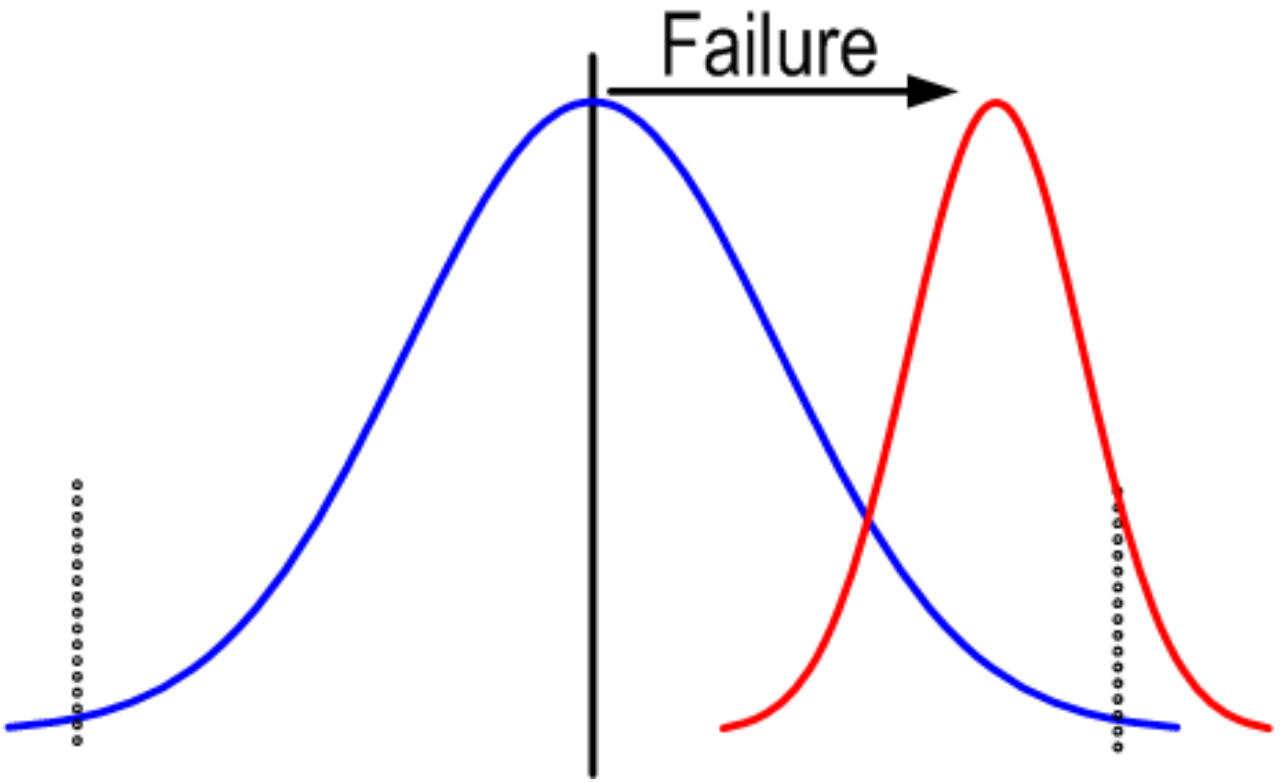

Integrity

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- Provide timely warnings when the system should not be used for navigation
- Components:
  - System Estimated Error
  - Maximum Allowable Error (Alarm Limit)
  - Minimum Time to Alarm (TTA)
- Specified as the Probability of Hazardously Misleading Information (HMI)
  - P([Actual Error >= Estimated Error AND …
    Actual Error >= Alarm Limit]
    for greater than the TTA)
- Includes undetected failure scenarios

Integrity

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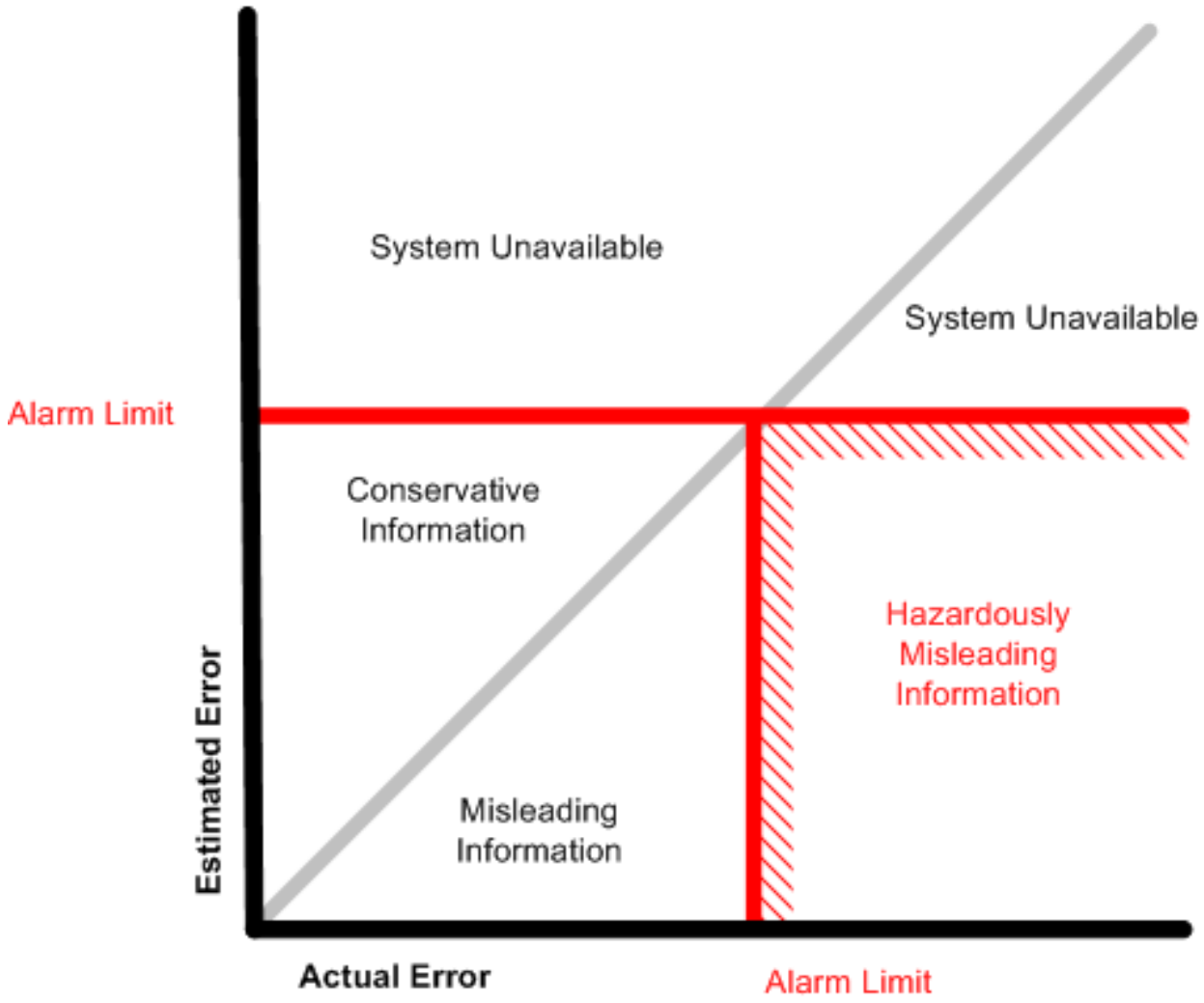

Integrity

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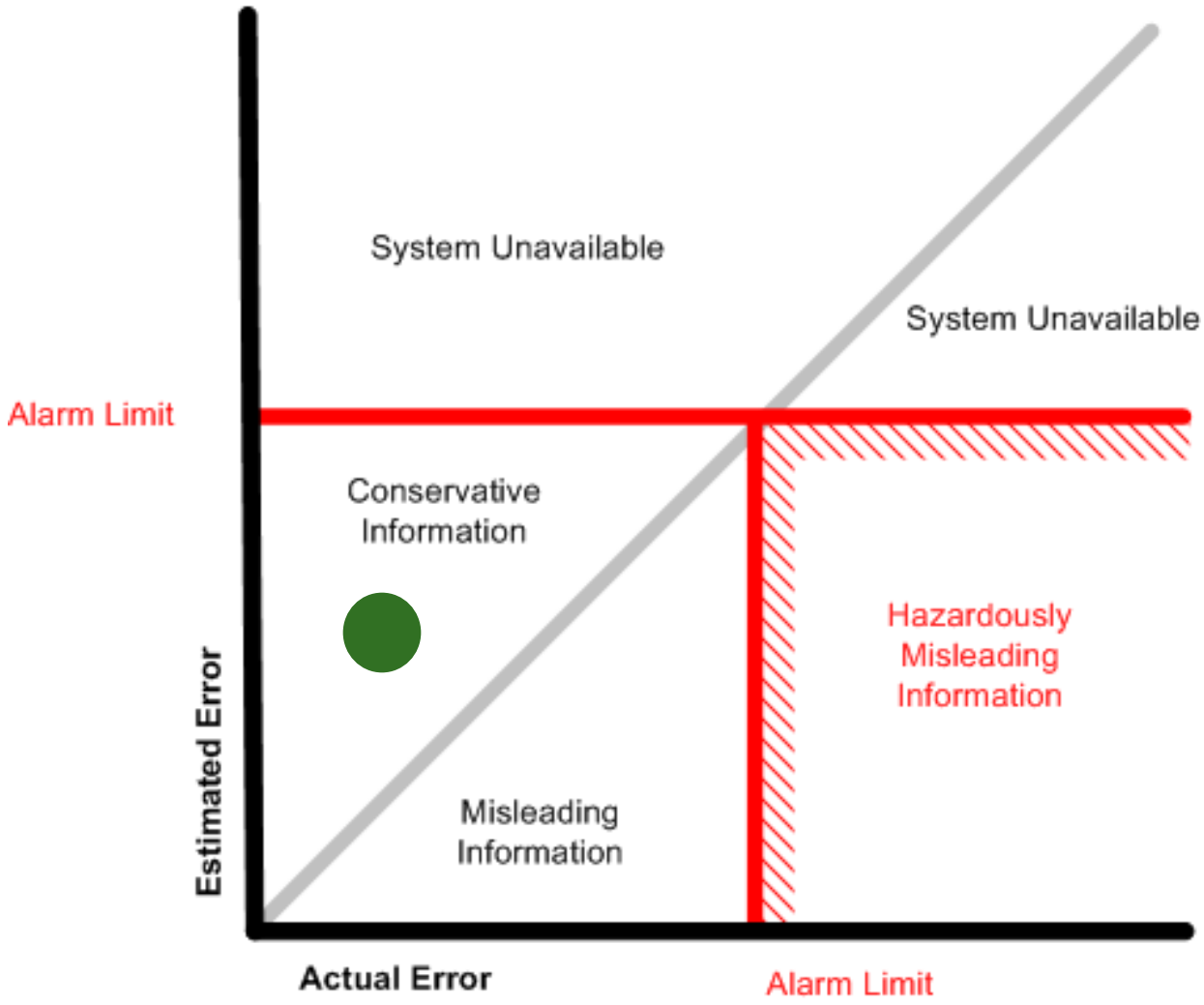

Integrity

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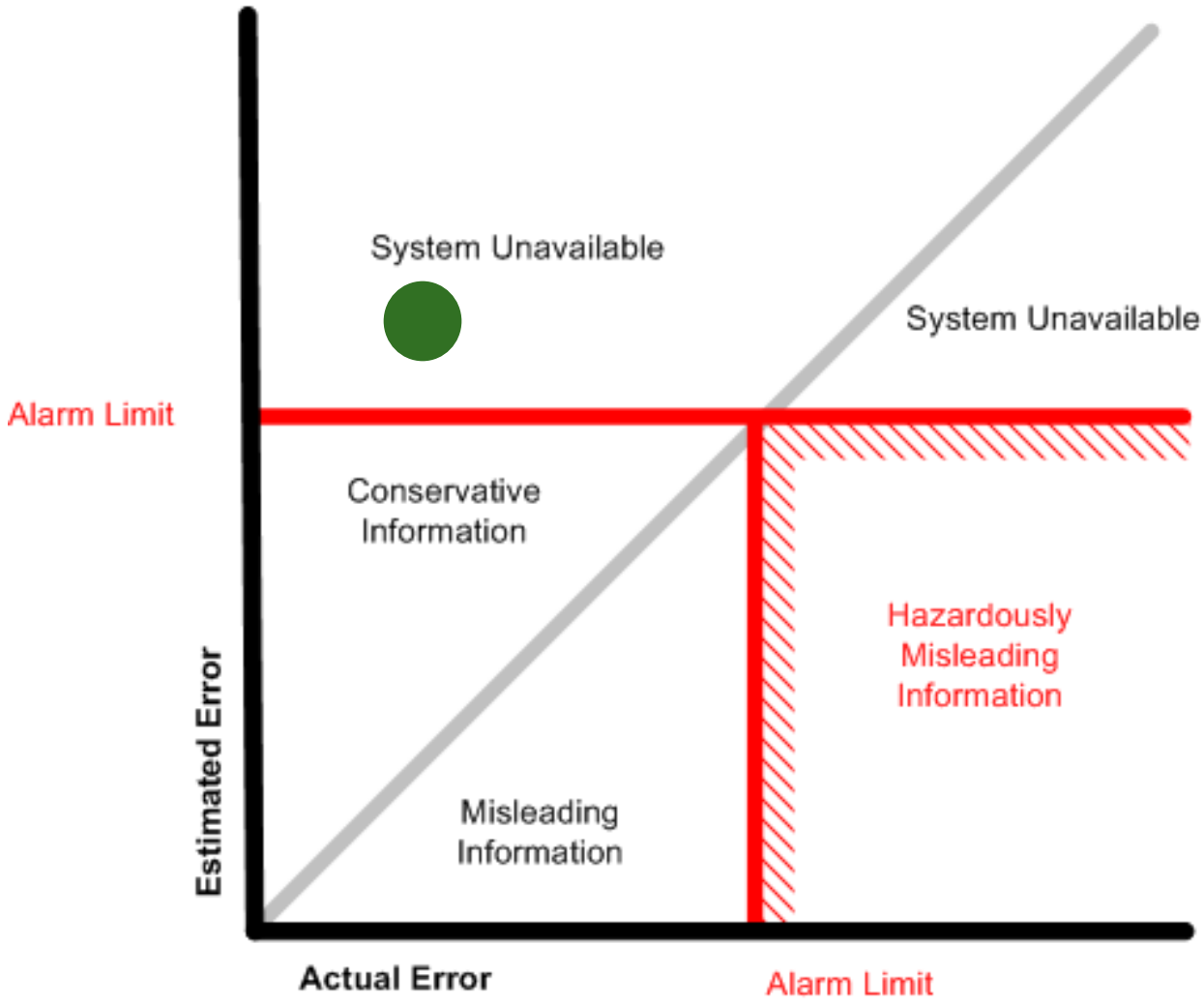

Integrity

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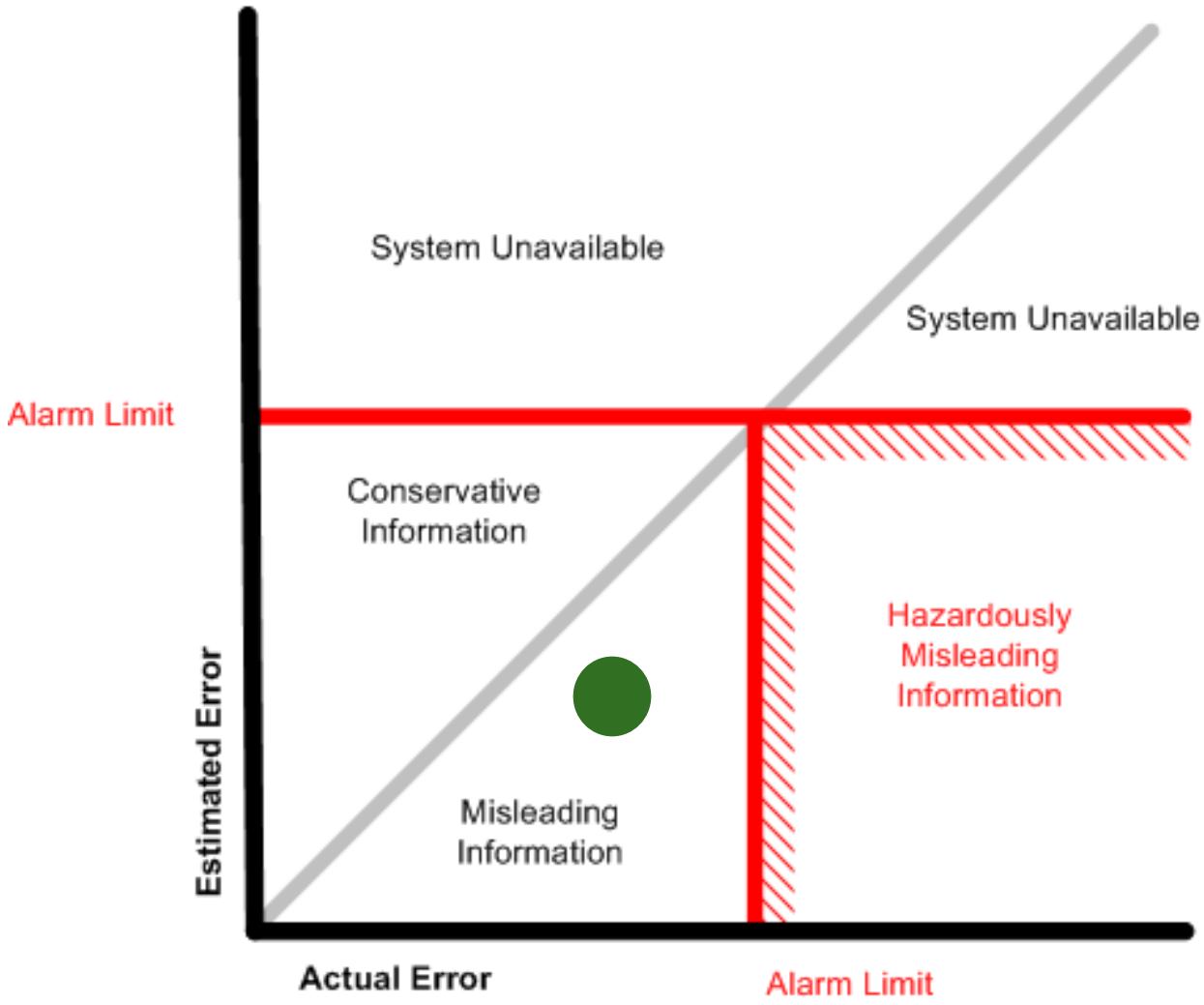

Integrity

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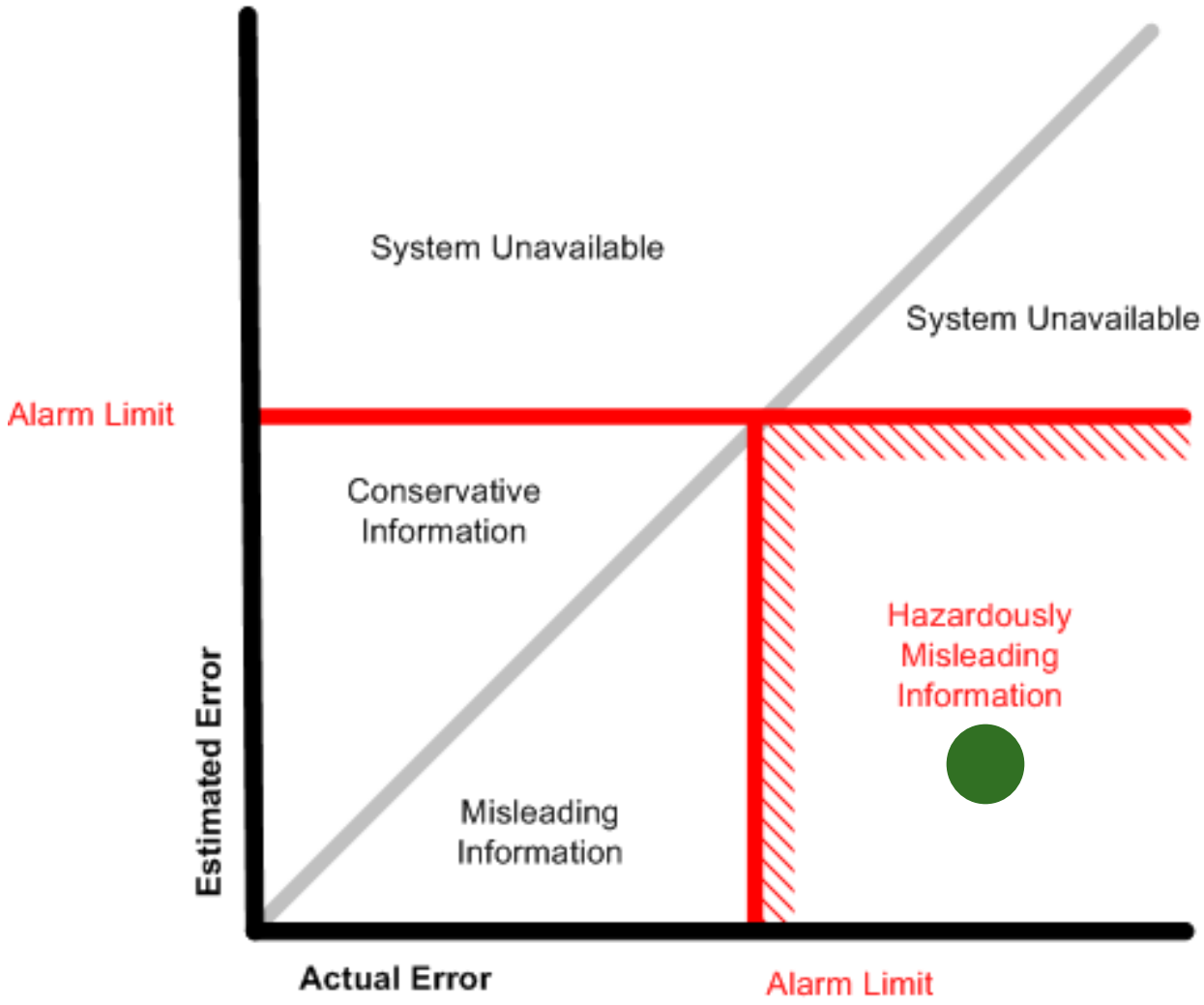

Horizontal Integrity Limit

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- The Horizontal Integrity Limit (HIL) is the region of protection at the required integrity, given an undetectable failure is present
- Guidance equipment can use the HIL output by the system and compare it to the Horizontal Alarm Limit (HAL) required by the operation
  - If the HIL < HAL then operation continues
  - If the HIL >= HAL then the operation aborts

Integrity User Interface

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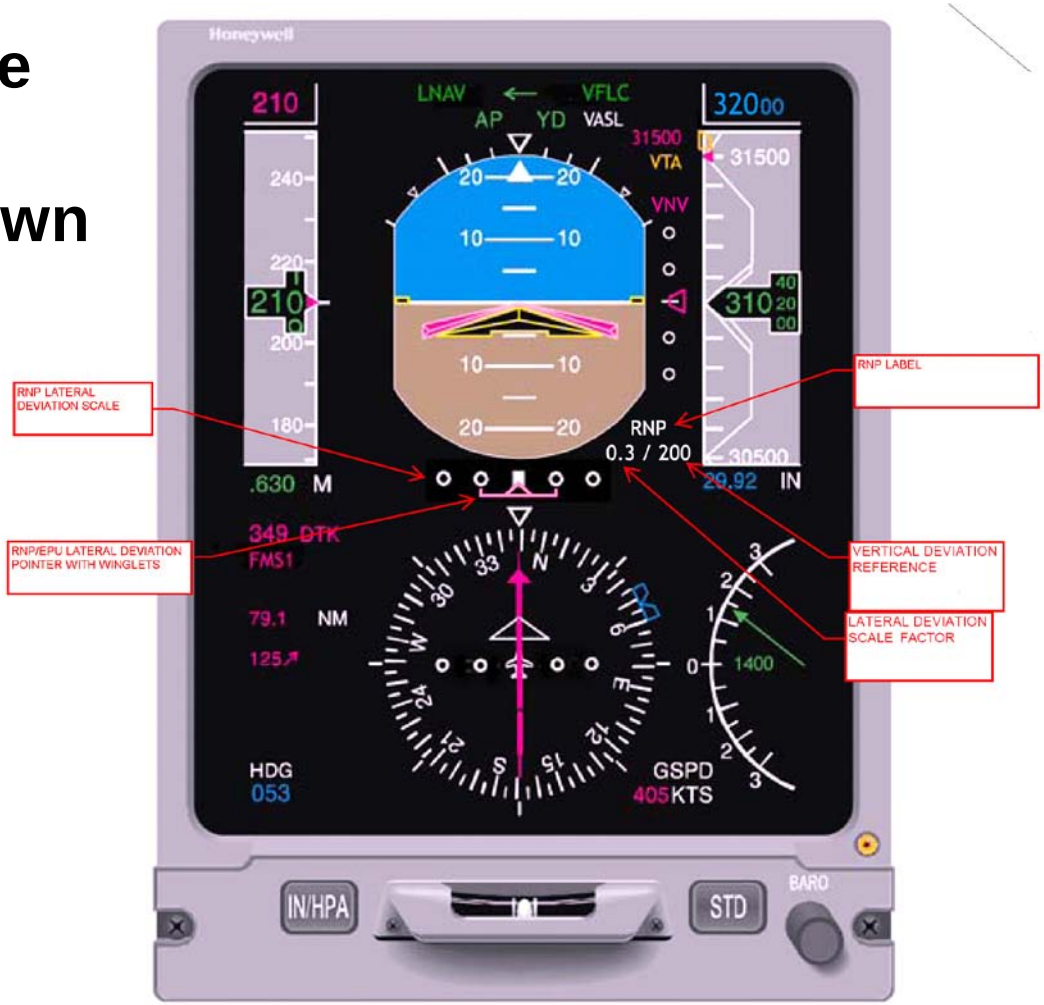
- Required operational integrity is known to the user (HAL)
- Current integrity is known by the system (HIL)
- A user interface communicates the integrity status

- Continue Operation

- Abort Operation



Continuity and Availability

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- **Continuity**
  - Probability that a valid navigation solution will be provided for the period of the operation
  - Aborting a high integrity operation has its own risks
- **Availability**
  - The percentage of time the system satisfies all of the accuracy, integrity, and continuity requirements at the start of the operation
  - Measure of the usability of the system as a whole

Aviation Requirements

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Performance Requirement	Oceanic	Domestic	Terminal	Approach	Cat III Landing
Risk Factor	Traffic	Traffic	Traffic/Terrain	Terrain	Terrain
Accuracy Horz/Vert	10 nm	2 nm	220 m	220m – 16m	6.2 m / 2.9-6.7 ft
Integrity – P(HMI)	10^{-7} / hr	10^{-7} / hr	10^{-7} / hr	$2x10^{-7}$ / approach	10^{-9} / approach
Horizontal Alert Limit	20 nm	4 nm	1 nm	0.3 nm – 40m	15.5 m/4.4m
Time To Alert	300 sec	15 sec	15 sec	10 – 6 sec	3.0 sec
Continuity	10-8/hr	10-8/hr	10-8/hr	1.8x10-6/ 15 sec	1.8x10-6/ 15 sec
Availability	0.99 – 0.99999 %	0.99 – 0.99999 %	0.99 – 0.99999 %	0.99 – 0.99999 %	0.99 – 0.99999 %

High Integrity Architectures

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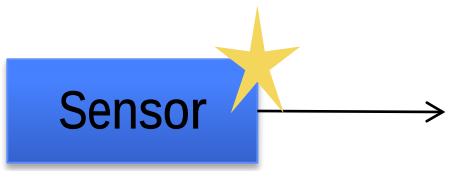
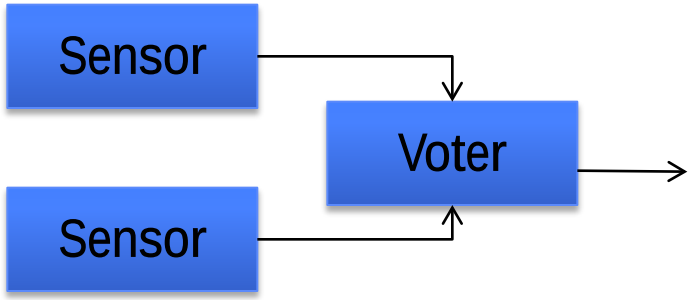
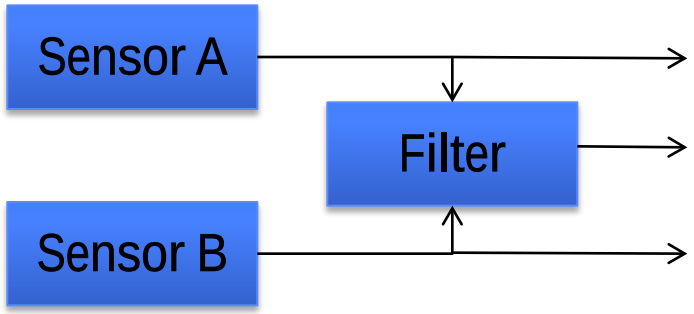
- **High Reliability**
  - Can be costly
  - May not be an option (GNSS)



- **Redundant**
  - Cost for duplicated function
  - Increased continuity/avail
  - Voter adds new failure modes



- **Integrated**
  - Fuse complementary safety properties
  - Increase continuity/avail
  - Can be complex



High Integrity IRU/GNSS Architecture

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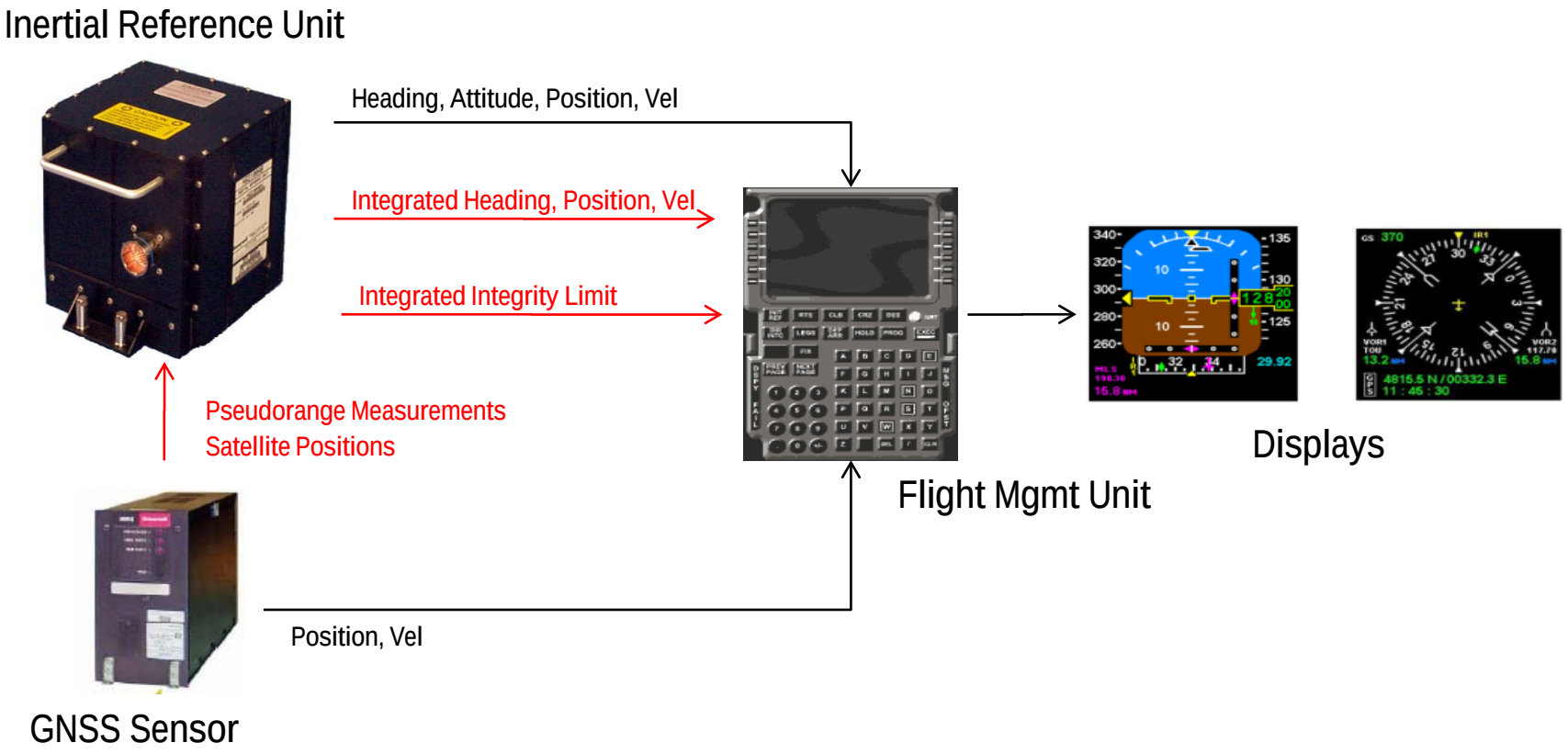

- **By sending GNSS data to the IRU it is possible to form:**
  - **an integrated navigation solution, and**
  - **integrated integrity**

Integration Method (HIGH)

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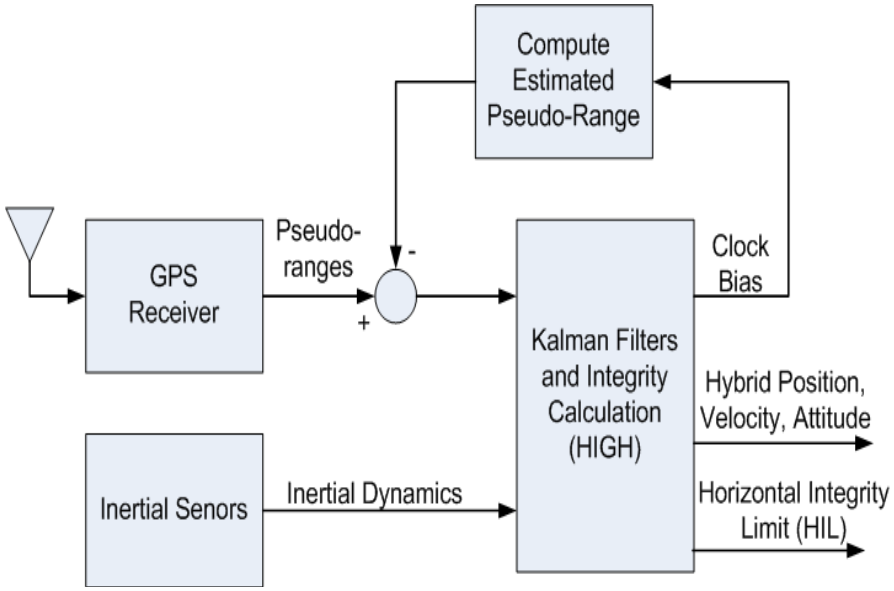
- **Kalman Filters**
  - Used for years
  - Sensors with complementary properties
- **Advantages**
  - Fused accuracy
  - Fused bandwidth
  - Fused integrity
- **Honeywell INS/GPS Hybrid (HIGH)**
  - Uses multiple Kalman filters
  - Examines separation between filter solutions



Impact of Satellite Errors on Hybrid Systems

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- **Kalman filters within a hybrid system can be corrupted by satellite errors.**
  - **Typically Ramps or Steps in Pseudo-Range**
- **Once a Kalman filter has been affected by a satellite error, the impact of the error cannot be removed**
  - **This has a major impact on integrity.**
- **Advantage of using solution separation as an integrity scheme is that there is always a fault-free solution**

HIGH Allows Operations Even After a Satellite Failure

Solution Separation Method Description

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- **HIGH Step II Maintains a Bank of Kalman Filters**

Main Filter	(uses N satellites)
Sub-Filters	(use N-1 satellites)
Sub-Sub-Filters	(use N-2 satellites)

HIGH Implementation of Solution Separation

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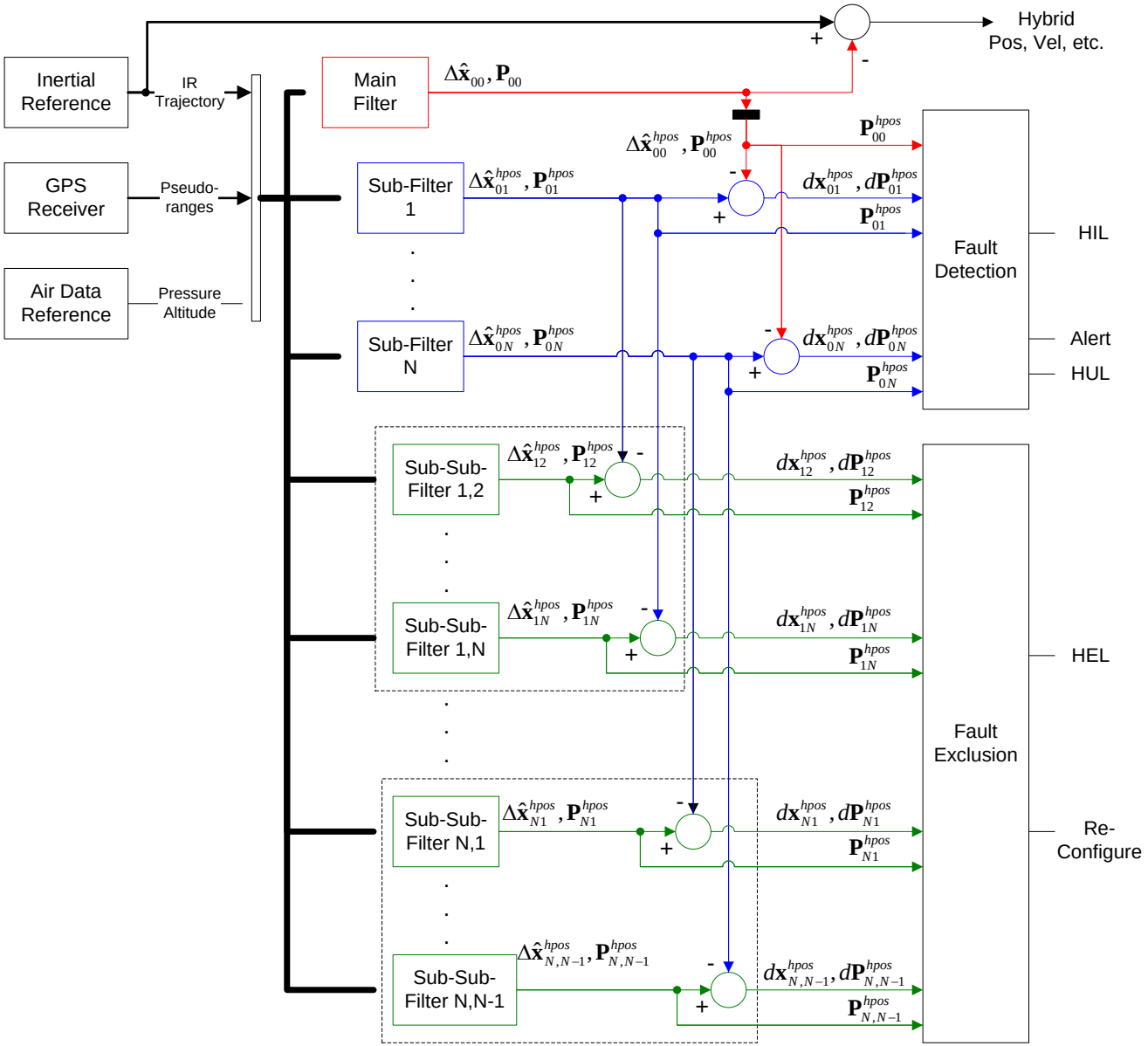

Calculation of Horizontal Integrity Limit

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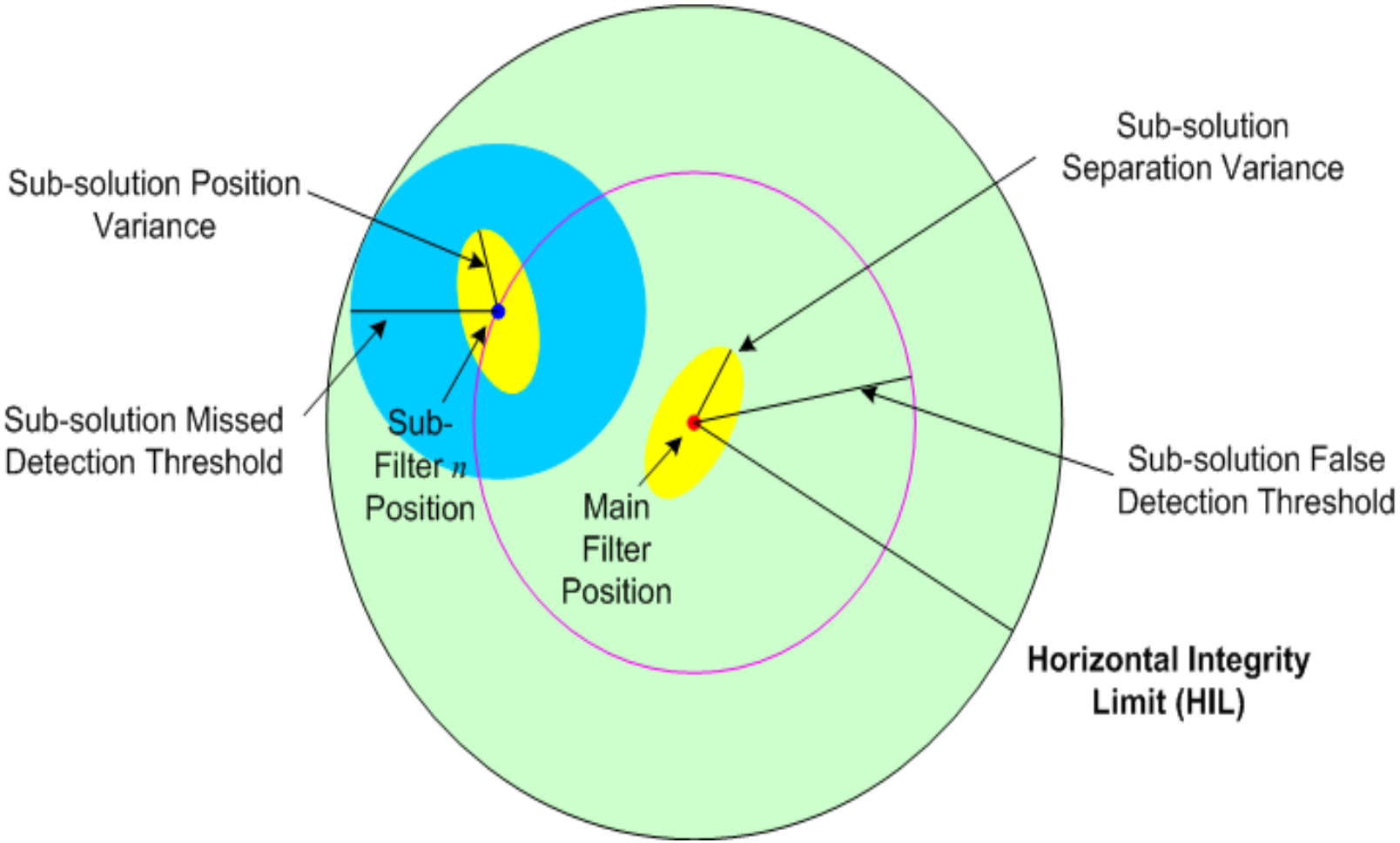

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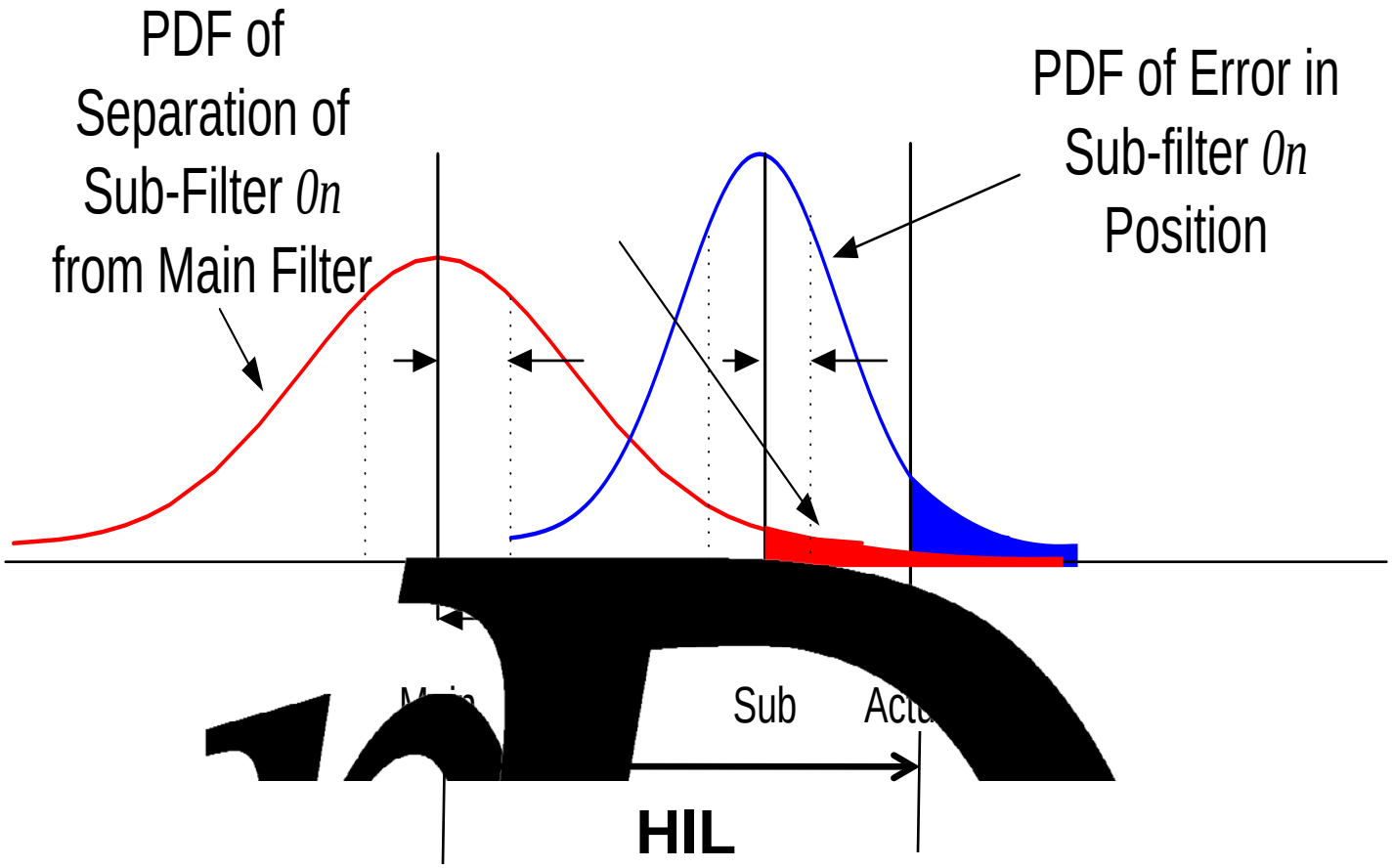

- **Another way to think of HIL is the position bound at the time of detection**

Integrity Coasting Performance During Nominal Test

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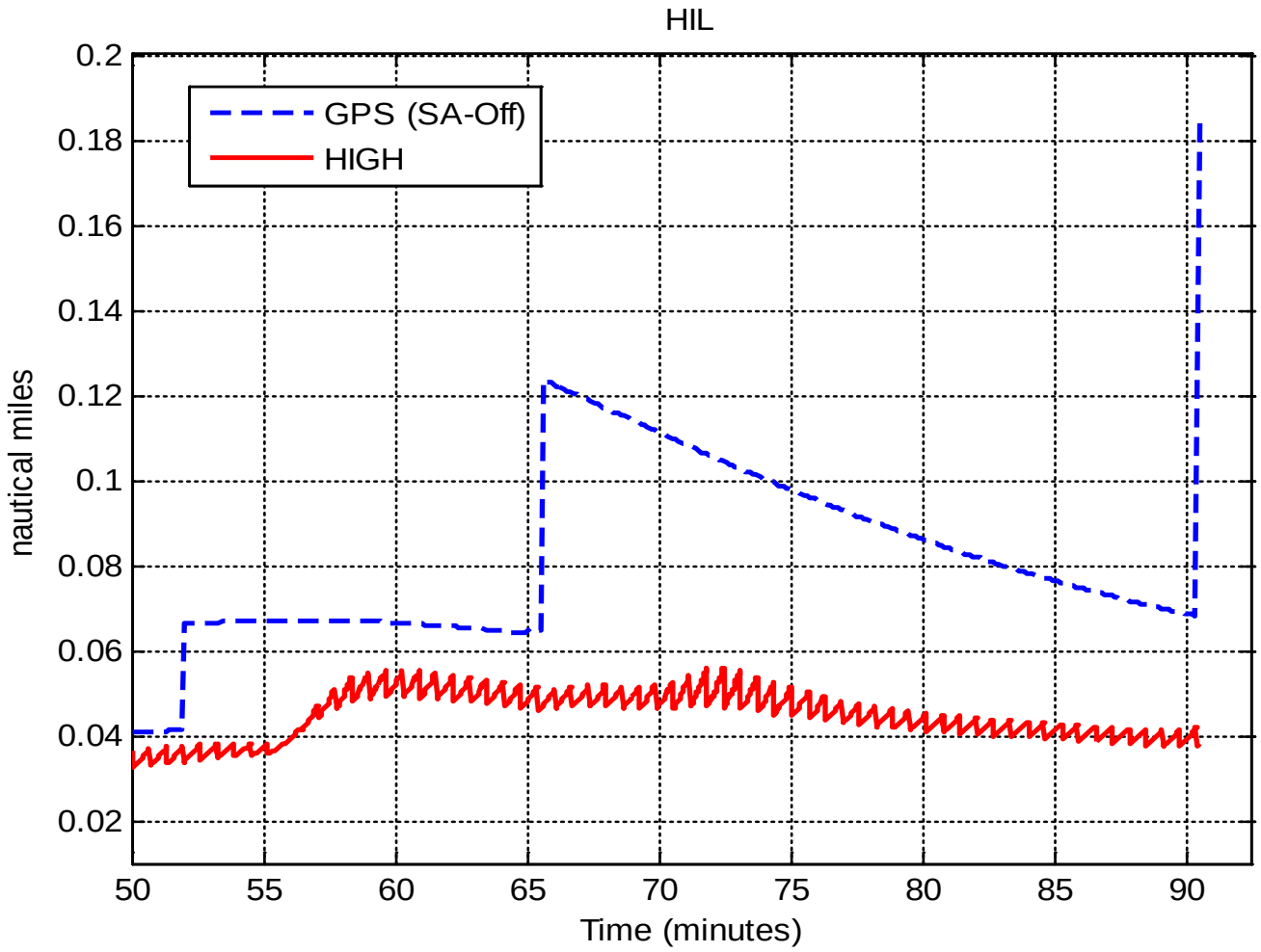

HIGH Less Sensitive to Satellite Geometry and Masking

Integrity Coasting Performance During Flight Test

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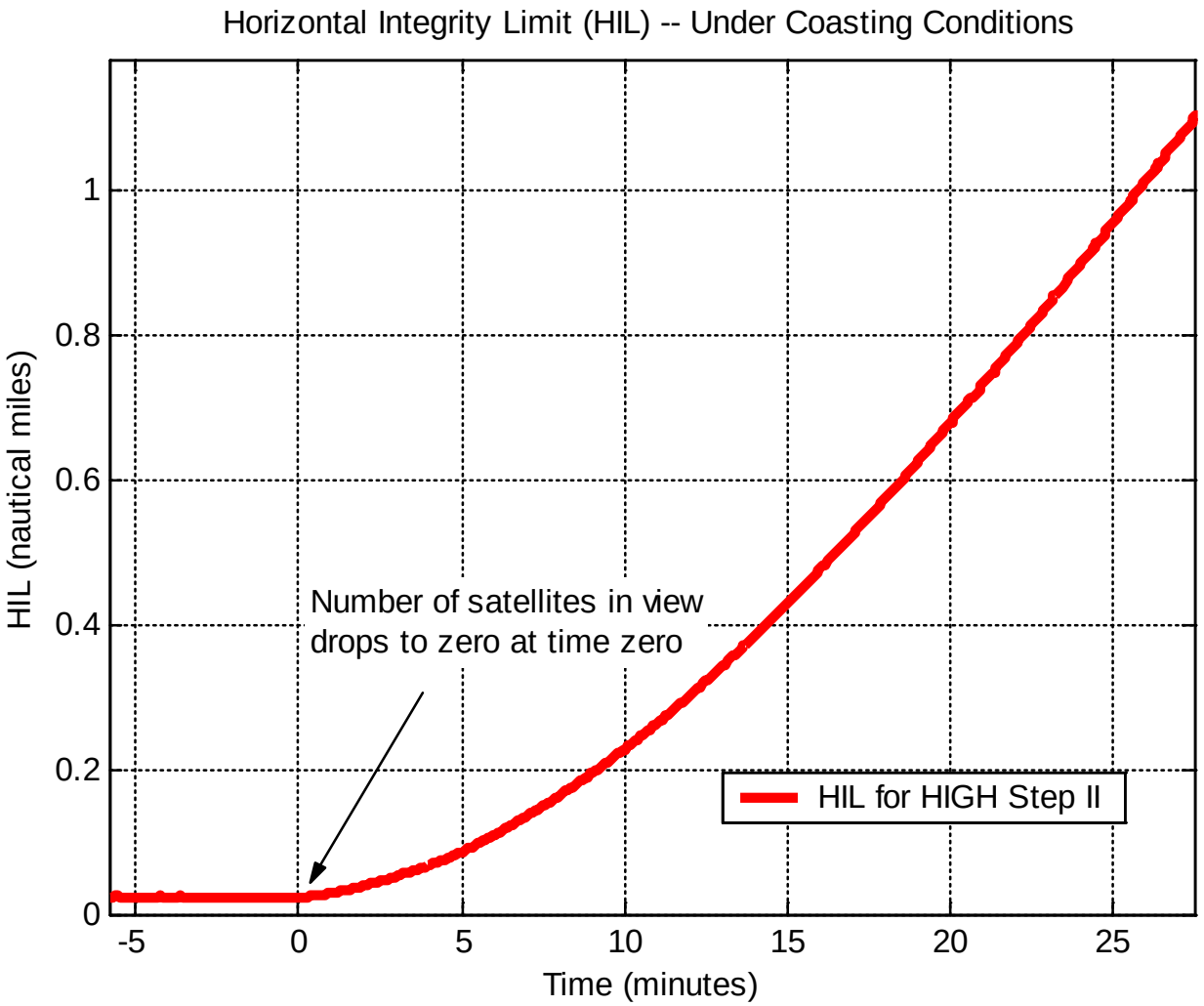

HIGH Provides Integrity Even After GNSS Loss

Fault Detection and Exclusion

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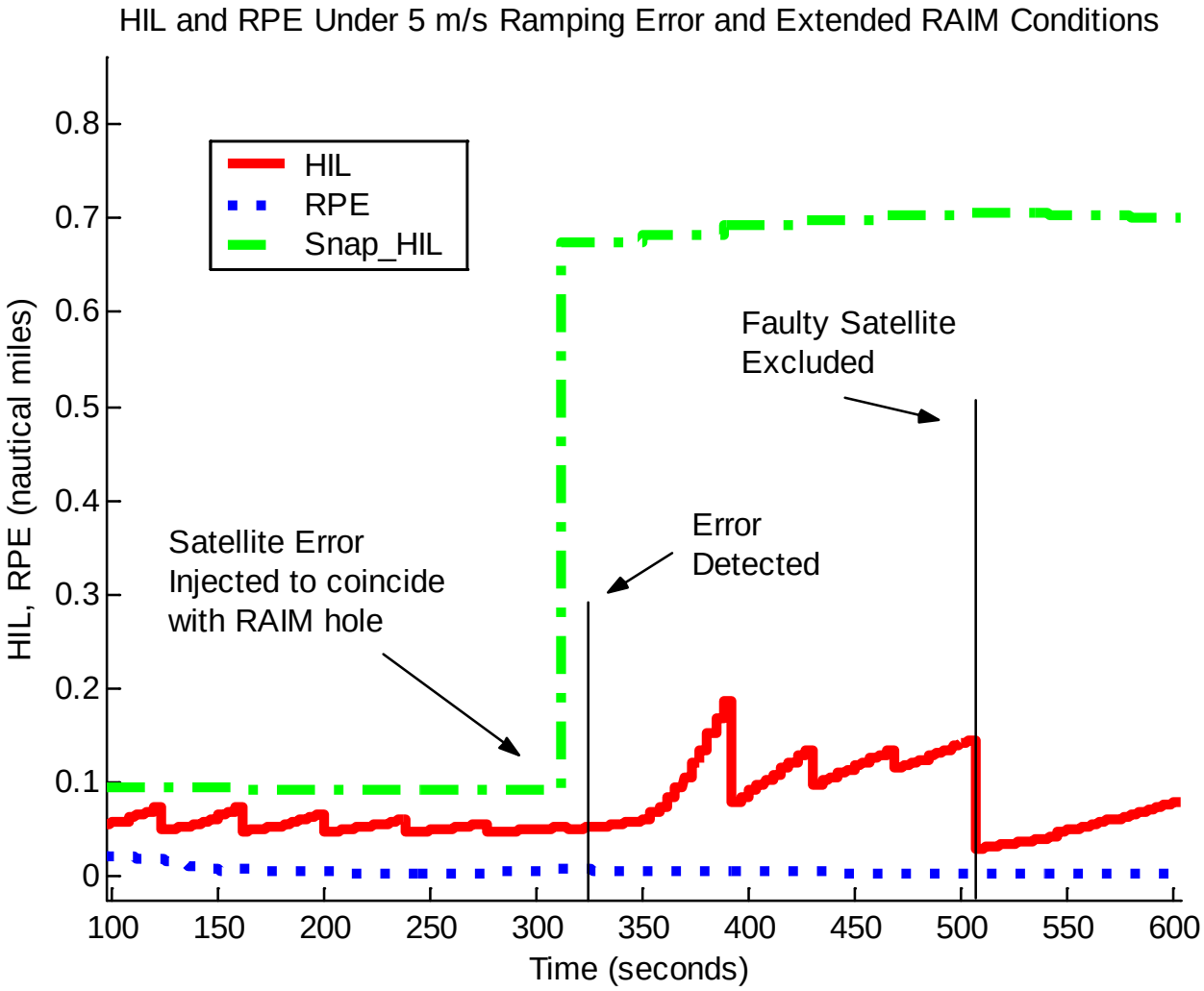

HIGH Provides Fault Detection/Exclusion in Poor Geometry

Time Slice for HIGH Availability

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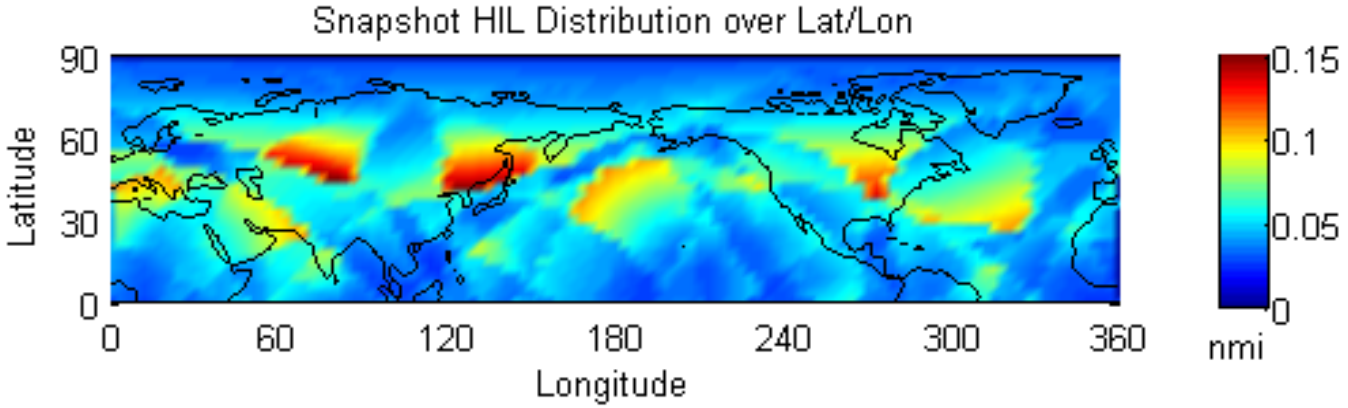

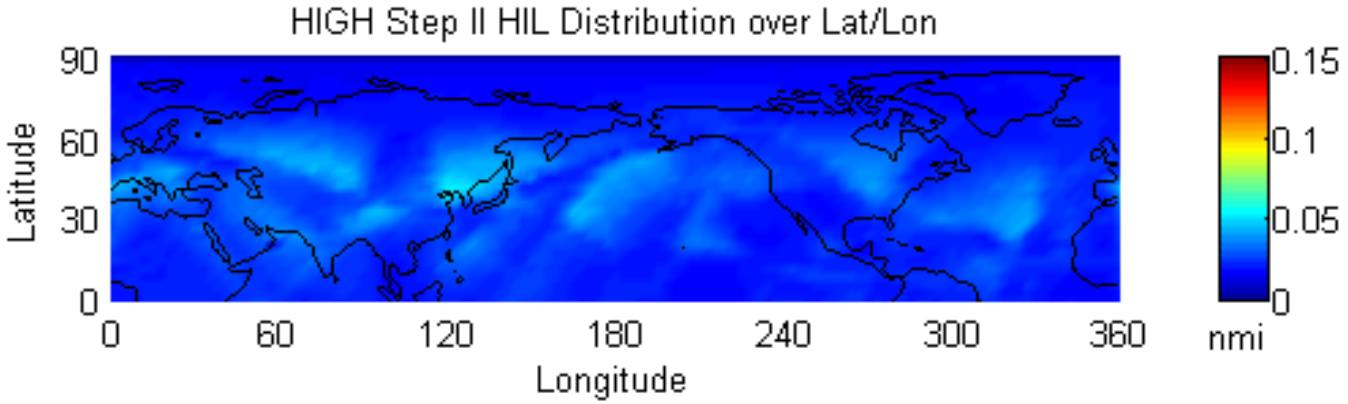

HIGH Improves Availability

Conclusion

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- Accuracy, integrity, continuity and availability are common needs in any form of safety critical navigation
- IRU/GNSS integration with solution separation provides advantages:
  - Lower integrity limits under both nominal and adverse geometries
  - Higher availability
  - Operations even after a satellite failure
  - Integrity even after satellite dropouts
  - Fault detection and exclusion even in poor geometry

Thank You!

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