HORIZONTAL ARAIM AVAILABILITY FOR CIVIL AVIATION OPERATIONS

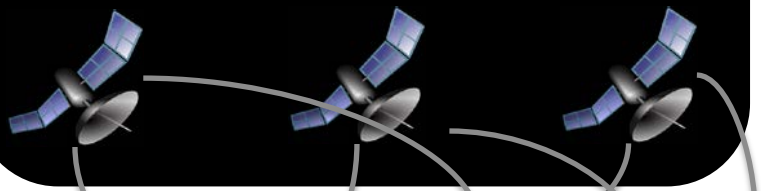
egis

April 7, 2017

INTRODUCTION

Space Segment

- Number of constellation
- Number of satellites
- Frequencies broadcasted



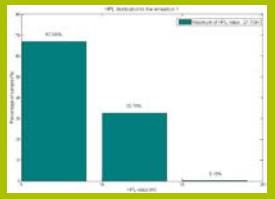
ISM configuration

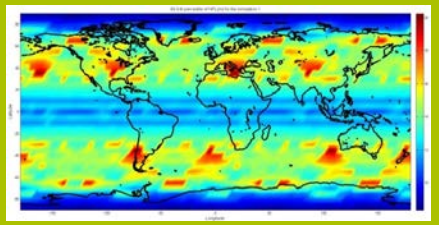
- URA
- Psat
- Pconst
- Bnom

- *This presentation shows the **ARAIM availability** results for civil aviation operations (**navigation and surveillance**) requiring **horizontal** GNSS positioning*
- *Results have been obtained with an ARAIM software simulation platform*

User segment

- User Grid
- Time setting
- User error models
- User ARAIM algorithm





CONTENT

1. **MISSION REQUIREMENTS & OPERATIONAL SCENARIOS**
2. SIMULATION RESULTS AND ANALYSIS
3. CONCLUSIONS

egis

H-ARAIM OPERATIONAL TARGETS IN NAVIGATION

Most stringent horizontal navigation application defined in the ICAO Performance Based Navigation (PBN) Manual[1] :

- RNP 0.1 (PBN navigation specification RNP AR APCH):
  - Required Total System Error (TSE) at ±0.1 NM (95%) for accuracy and ±0.2 NM for integrity
  - Allocation between Navigation System Error (NSE), Path Definition Error (PDE) and Flight Technical Error (FTE) is manufacturer/avionics-specific
  - Integrity alert requirement selected for the NSE: **0.1 NM**
  - H-ARAIM NSE **99.9% availability** performance characterized via **HPL**.

Current operation realized with ABAS RAIM equipment:

- Lateral Navigation (LNAV)

	Accuracy (m)	Alert Limit (m)	Integrity Risk
LNAV	220	556	10^{-7}/hour
RNP 0.1	92	184	10^{-7}/hour

H-ARAIM OPERATIONAL TARGETS IN SURVEILLANCE

Automatic Dependent Surveillance – Broadcast (ADS-B) applications uses GNSS positioning in ADS-B report

Two types of ADS-B mandates issued or under development

- ADS-B mandate targeting non-radar airspace with the objective to provide radar-like separation services (e.g. Australia, Canada, Singapore, Fiji, Vietnam, etc.).
- ADS-B mandate targeting ADS-B use in addition to radar based on RTCA DO-260[2]
  - *ADS-B mandate considered in Europe and in the United States*
  - *EU and US implementations considering different performance requirements for positioning information to be reported by the aircraft*

	Accuracy (m)	Alert Limit (m)	Integrity Risk
Europe	185	1111	10^{-7}/hour
United States	92	370	10^{-7}/hour

OPERATIONAL SCENARIOS: MODELS AND SETTINGS

Assumptions & Simulation configuration

- 5° mask angle and all in view
- 10 days of simulation sampled every 5 min
- 5°x5° user grid over latitudes [-90°; 90°]

Pseudorange measurement error model:

- $\sigma^2_{\mathrm{UERE}} = \sigma^2_{\mathrm{URA}} + \sigma^2_{\mathrm{iono}} + \sigma^2_{\mathrm{RX}} + \sigma^2_{\mathrm{MP}} + \sigma^2_{\mathrm{tropo}}$ plus nominal bias considered as described in [3]
  - Troposphere model of RTCA DO 229D[3]
  - Multipath and receiver noise based on SESAR 9.27 recommendations

Dual constellation GPS + Galileo

- Nominal GPS configuration: 24 satellites, as in GPS SPS[7]
- Nominal Galileo configuration: 24 satellites[4]

Algorithm: Baseline ARAIM user algorithm (MHSS) [5]

Reference simulation settings

Parameters	Settings
Constellations	24 + 24
Signals	L1/E1 + L5/E5a
URA / URE [m]	1 / 0.5
SISA / SISE [m]	1,5 / 0,75
Bnom [m]	0,75
P_{satGAL} / P_{satGPS}	10^{-5} / 10^{-5}
$P_{constGAL}$ / $P_{constGPS}$	10^{-5} / 10^{-5}

Analysed scenarios :

- Impact of the probabilities of constellation and satellite fault
- Impact of the satellite clock and ephemeris residual error
- Impact of the constellation configuration

CONTENT

egis

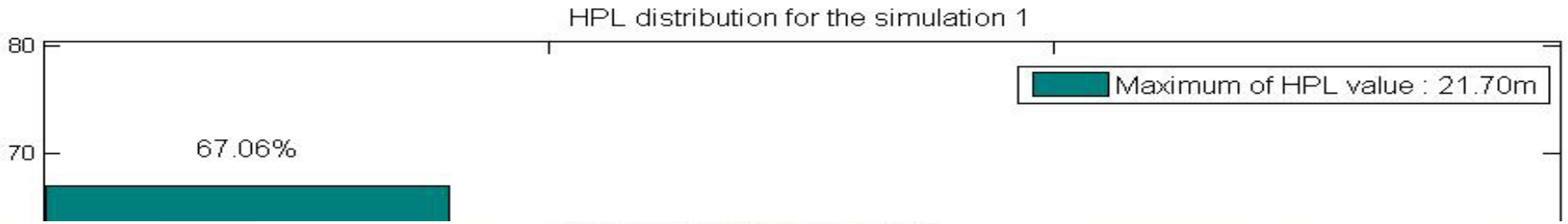
IMPACT OF P_{CONST} & P_{SAT}

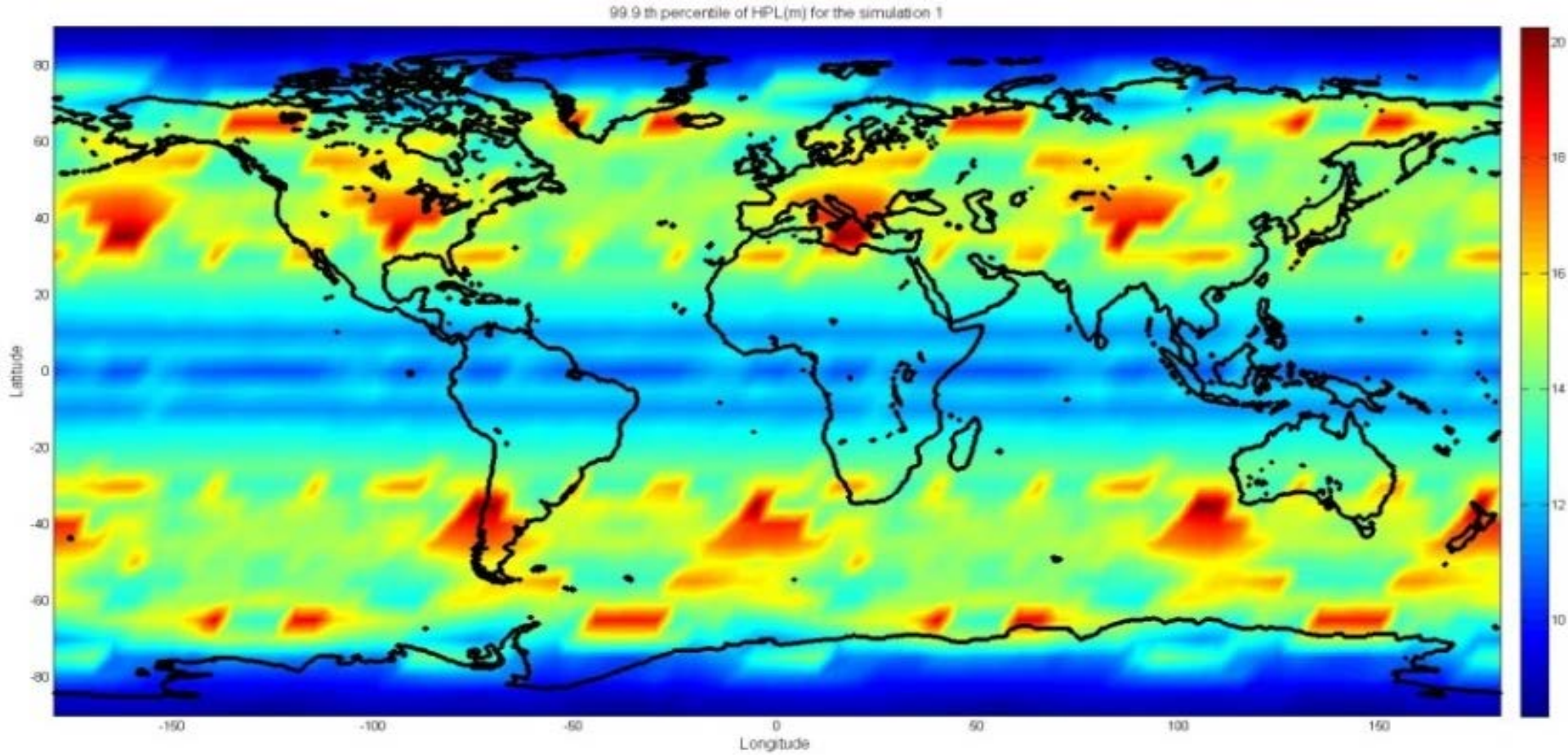
Operational Scenario	99.9 % HPL (m)	RNP 0.1 Availability	LNAV Availability	US ADS-B Availability	EU ADS-B Availability
Reference case	20.26	100%	100%	100%	100%
Degraded P_{const} effect	22.15	100%	100%	100%	100%
Degraded Galileo case	22.33	100%	100%	100%	100%
Realistic case	23.08	100%	100%	100%	100%

Parameters	Settings
Constellation	24 + 24
Signals	L1/L5 and E1/E5a
URA / URE	1 / 0.5
SISA / SISE	1,5 / 0,75
Bnom	0,75
Scenarios description	Reference case • P_{satGAL} / P_{satGPS} : 10^{-5} • $P_{constGAL}$ / $P_{constGPS}$: 10^{-5} Degraded Pconst effect • P_{satGAL} / P_{satGPS} : 10^{-5} • $P_{constGAL}$ / $P_{constGPS}$: 10^{-4} Degraded Galileo case • $P_{constGPS}$ / P_{satGPS} : 10^{-5} • $P_{constGAL}$ / P_{satGAL} : 10^{-4} Realistic case • P_{satGAL} / P_{satGPS} : 10^{-5} • $P_{constGAL}$: 10^{-3} • $P_{constGPS}$: 10^{-8}

- *NSE requirement below 30m is sufficient to provide generous FTE budget margin for RNP 0.1 applications in a 24+24 constellation case*
- *100 % Availability reached in each scenario.*
  - Limited impact observed on the 99.9% HPL
  - Not a key parameter in H-ARAIM compared to LPV 200 ARAIM analysis
- *P_{const} at 10^{-3} and P_{sat} at 10^{-4} may be sufficient to sustain civil aviation needs for horizontal applications*

REFERENCE CASE DETAILS





IMPACT OF SATELLITE CLOCK & EPHEMERIS (URA/URE)

Operational Scenario	99.9 % HPL (m)	RNP 0.1 Availability	LNAV Availability	US ADS-B Availability	EU ADS-B Availability
Optimistic GPS and Galileo	20.26	100%	100%	100%	100%
Realistic GPS and Galileo	32.71	100%	100%	100%	100%
Worst case Galileo	33.41	100%	100%	100%	100%

- *Increased values for URA and SISA have a more significant impact on the results than low Psat/Pconst on the 99.9% HPL figure*
  - but not on the availability results
- *The worst case has been built upon the current GPS broadcasted URA value and the worst case SISA that could be encoded by Galileo*
  - Leads to increase of 13 meters on the 99.9 % HPL which still gives room for margin compared to the requirements for all horizontal applications

Parameters	Settings
Constellation	24 + 24
Signals	L1/L5 and E1/E5a
Bnom	0,75
P_{satGAL} / P_{satGPS}	10^{-5} / 10^{-5}
$P_{constGAL}$ / $P_{constGPS}$	10^{-5} / 10^{-5}
Scenarios description	**Optimistic case** • URA = 1 m / URE = 0,5 m • SISA = 1,5 m / SISE = 0,75 m **Realistic case** • URA = 2,4 m / URE = 2 m • SISA = 3 m / SISE = 1,5 m **Worst Galileo case** • URA = 2,4 m / URE = 2 m • SISA = 6 m / SISE = 3 m

IMPACT OF CONSTELLATION CONFIGURATION

Operational Scenario	99.9 % HPL (m)	RNP 0.1 Availability	LNAV Availability	US ADS-B Availability	EU ADS-B Availability
24 GPS + 24 GAL	20.26	**100%**	**100%**	**100%**	**100%**
24 GPS + 18 GAL	1830	48.72%	57.50%	53.76%	60.76%
27 GPS + 24 GAL	669.3	98.97%	98.96%	98.63%	100%
27 GPS + 18 GAL	1830	48.72%	57.50%	53.76%	60.76%
23 GPS + 23 GAL with the DOP method	1033	**99.81%**	**99.85%**	**99.85%**	**99.96%**
23 GPS + 23 GAL removing PRNs 2	770.2	**99.85%**	**99.89%**	**99.85%**	**100%**

Parameters	Settings
Signals	L1/L5 and E1/E5a
URA / URE	1 / 0.5
SISA / SISE	1,5 / 0,75
Bnom	0,75
P_{satGAL} / P_{satGPS}	10^{-5} / 10^{-5}
$P_{constGAL}$ / $P_{constGPS}$	10^{-5} / 10^{-5}

- H-ARAIM availability is above 99.8% in GPS/GAL 23 satellites downgraded constellation situation
- Sensitivity of ARAIM to the constellation design and number of satellites
  - An increased number of satellites does not necessarily bring additional performance benefits
  - Algorithm is very sensitive to “partial / IOC” constellations with the failure probability model used

RESULTS: PARTIAL GALILEO CONSTELLATION SCENARIO (+ ROBUST GPS)

Operational Scenario	99.9 % HPL (m)	RNP 0.1 Availability	LNAV Availability	US ADS-B Availability	EU ADS-B Availability
Optimistic $P_{satGAL} = 10^{-5}$	26.87	**100%**	**100%**	**100%**	**100%**
Medium $P_{satGAL} = 10^{-4}$	27.44	**100%**	**100%**	**100%**	**100%**
Worst $P_{satGAL} = 10^{-3}$	27.48	**100%**	**100%**	**100%**	**100%**

Parameters	Settings
Constellations	**24 GPS + 18 GAL**
Signals	L1/L5 and E1/E5a
URA / URE	1 / 0.5
SISA / SISE	1,5 / 0,75
Bnom	0,75
P_{satGPS}	10^{-5}
$P_{constGAL}$ / $P_{constGPS}$	10^{-3} / 10^{-8}

- The targeted applications are available at 100%

- A nominal high performing constellation mixed with a constellation with a limited service record could bring operational benefits
  - Overcoming current ABAS/RAIM limitations of operations based GPS L1 signals only.

RESULTS: PARTIAL GPS CONSTELLATION SCENARIO

Operational Scenario	99.9 % HPL (m)	RNP 0.1 Availability	LNAV Availability	US ADS-B Availability	EU ADS-B Availability
Optimistic $P_{satGAL} = 10^{-5}$	Infinite	47.39%	56.65%	53.35%	63.42%
Medium $P_{satGAL} = 10^{-4}$	Infinite	47.35%	56.57%	52.83%	63%
Worst $P_{satGAL} = 10^{-3}$	Infinite	47.27%	56.49%	52.79%	62.86%

Parameters	Settings
Constellations	**18 GPS + 24 GAL**
Signals	L1/L5 and E1/E5a
URA / URE	1 / 0.5
SISA / SISE	1,5 / 0,75
Bnom	0,75
P_{satGPS}	10^{-5}
$P_{constGAL}$ / $P_{constGPS}$	10^{-3} / 10^{-8}

- A very **low level of availability** is obtained
  - Due to the fact that not enough satellites where available in some areas to monitor the Galileo constellation failure.
  - Same number of satellites as in previous results

- The constellation with the better failure probability needs to be well populated to sustain a user availability near 99%.
  - Additional simulations have indicated that a 99% availability target can be achieved with 21 GPS satellites.

CONTENT

1. MISSION REQUIREMENTS & OPERATIONAL SCENARIOS
2. SIMULATION RESULTS AND ANALYSIS
3. **CONCLUSIONS**

egis

SUMMARY & CONCLUSIONS

- *H-ARAIM concept:*
  - Designed to operate in a multi-frequency multi-constellation environment
    - » Some input parameters are updated via the ISM
  - Provides robust navigation and surveillance service availability
    - » Overcomes operation limitations of current GPS L1 + RAIM
- *H-ARAIM performance for the targeted civil aviation operations (DFMC scenario)*
  - **100% availability in a GPS 24 + Galileo 24** configuration
    - » Even with large failure probabilities for one of the constellations (P_{const} =10^{-3} and P_{sat} =10^{-4}) and average values for the second one (P_{const} =P_{sat} =10^{-5})
    - » Even for high URA/URE values
  - **100% availability with a partial Galileo constellation (GPS 24 + Galileo 18)** if strong commitment on failure probabilities for GPS (**$P_{const\ GPS}$ =10^{-8}**)
    - » Even with high failure probabilities for Galileo ($P_{const\ Galileo}$ =10^{-3} and $P_{sat\ Galileo}$ =10^{-3})
    - » However, significant availability degradation observed with a partial constellation if the failure probabilities of the second constellation are not sufficiently low (ex.: P_{const} =10^{-5})

SUMMARY & CONCLUSIONS

- Conclusions:
  - There is a reduced need to qualify a Constellation Service Provider with a very low P_{const} for H-ARAIM as long as it is used in a dual-constellation configuration with a robust second constellation with low P_{const} (10^{-8})
  - Some values of P_{sat} and P_{const} combined with a low number of visible satellites from one of the constellations have a significant impact on the final user performance, **but not all combinations**.
  - The **number of satellites** of a constellation and their slot alignment within the orbit shall be carefully monitored, specially if the other constellation has not very low P_{const}

- Note: The presented results are part of SESAR Project 9.29, Multi-constellation GNSS Receiver. The presentation does not contain official EUROCONTROL or SESAR Policies.

ACRONYMS

Acronym	Description	Acronym	Description
AAIM	Airborne Autonomous Integrity Monitoring	ISM	Integrity Support Message
ABAS	Airborne Based Augmentation System	LNAV	Lateral Navigation
APV	Approach with Vertical Guidance	LPV	Localizer Performance with Vertical Guidance
ARAIM	Advanced RAIM	NPA	Non Precision Approach
CSP	Constellation Service Provider	PBN	Performance Based Navigation
DFMC	Dual Frequency Multi Constellation	RAIM	Receiver Autonomous Integrity Monitoring
FOC	Final Operational Capability	RNP	Required Navigation Performance
GBAS	Ground Based Augmentation System	SARPS	Standard and Recommendation Practices
GNSS	Global Navigation Satellite System	SBAS	Satellite Based Augmentation System
HPL	Horizontal Protection Level	SISA	Signal In Space Accuracy
ICAO	International Civil Aviation Organisation	SV	Satellite Vehicle
ICD	Interface Control Document	URA	User Range Accuracy
IOC	Initial Operational Capability	VPL	Vertical Protection Level

REFERENCE

1. “Performance Based Navigation Manual”, ICAO, doc 9613 Vol II
2. B. Roturier, M. Mabilleau, “Analysis of SBAS and RAIM performance versus ADS-B mandates”, ICAO NSP WG1 &WG2 5th meeting, Sept/Oct 2014.
3. RTCA, “Minimum Operational Performance Standards for Satellite Based Augmentation System Receiver”, DO 229 D, December 2006
4. European Commission, “Galileo Program Status Update”, EUROCAE WG62 39th meeting, June 2015
5. EU-U.S. Cooperation on Satellite Navigation Working Group C-ARAIM Technical Subgroup “Milestone II report”, February 2015.

THANK YOU!

CONTACT

Daniel Salos

System Definition & Performance

Navigation Services

daniel.salos@egis.fr

Mikael Mabilleau

System Definition & Performance

Navigation Services Manager

mikael.mabilleau@egis.fr

www.egis-group.com

egis

Caisse des Dépôts GROUP