GNSS height on Airbus A/C

Workshop ASE

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Agenda

1. In service experience: 5 A320 A/C flagged by Monitoring Agency
2. GNSS (Global Navigation Satellite System) height referential
3. GNSS height accuracy
4. GNSS height output through ADS-B
5. Conclusion

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In service experience: 5 A320 A/C flagged by Monitoring Agency

- A/C geometrical height transmitted as:
  - Either Height above Ellipsoid (HAE)
  - Or Height above mean sea level (MSL)
- ASE first computed for each assumption
- Statistical tests used to determine the correct height reference

- In case of unknown geoid reference (UNK – unable to determine), A/C still considered as monitored if range (of possible ASE) within +/-250ft

- Special consideration is given to any airframes with:
  - 'absolute ASE larger than 175 ft'
  - or 'absolute ASE plus one standard deviation larger than 200 ft'.

Type	Geoid	ASE	Range	Dev	Points	Days	Last Date
A320	UNK	NA	[48,200]	76	1012940	1138	2017-02-26
A320	MSL	87	[67,107]	20	1062292	983	2017-02-27
A320	MSL	59	[40,78]	19	1053910	931	2017-02-27
A320	MSL	50	[32,68]	18	1154476	974	2017-02-27
A320	MSL	85	[67,103]	18	1100097	964	2017-02-27
A320	UNK	NA	[36,187]	75	1130763	895	2017-02-27
A320	UNK	NA	[37,200]	81	1164868	907	2017-02-27
A320	UNK	**NA**	**[45,205]**	80	1175257	849	2017-02-27
A320	UNK	**NA**	**[54,212]**	79	1194955	836	2017-02-27
A320	MSL	62	[43,81]	19	950734	740	2017-02-27
A320	MSL	51	[34,68]	17	1320997	734	2017-02-27
A320	UNK	**NA**	**[51,203]**	76	985282	698	2017-02-27
A320	UNK	**NA**	**[57,215]**	79	907561	598	2017-02-27
A320	UNK	NA	[42,199]	78	549675	431	2017-02-27
A320	UNK	**NA**	**[46,204]**	79	537768	411	2017-02-27

- **5 A/C were unduly flagged due to incapacity to determine the correct GEO altitude reference**
  - ➢ Functional check of the ADM accuracy performed on 3 A/C out of 5 → NIL findings
  - ➢ Computation of ASE with correct hypothesis (HAE): no deviation compared to RVSM Altimetry System Error requirements

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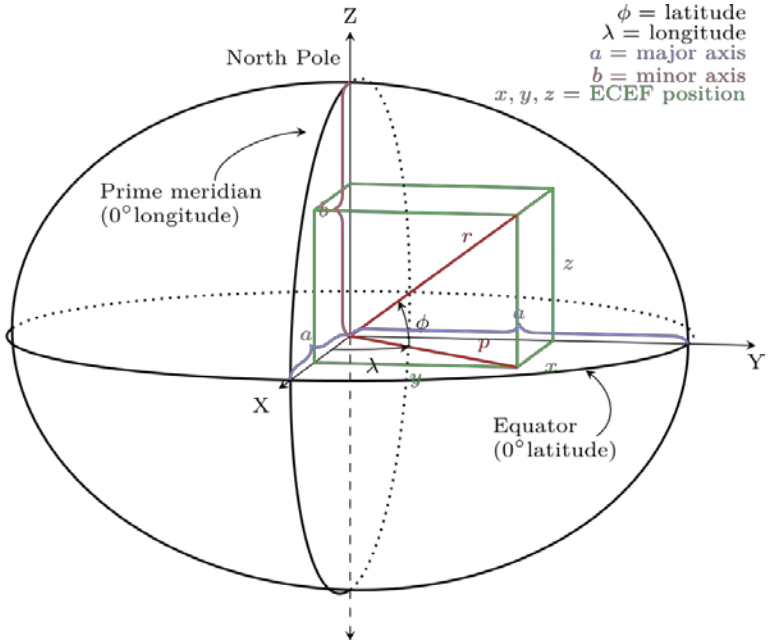
GNSS height - referential

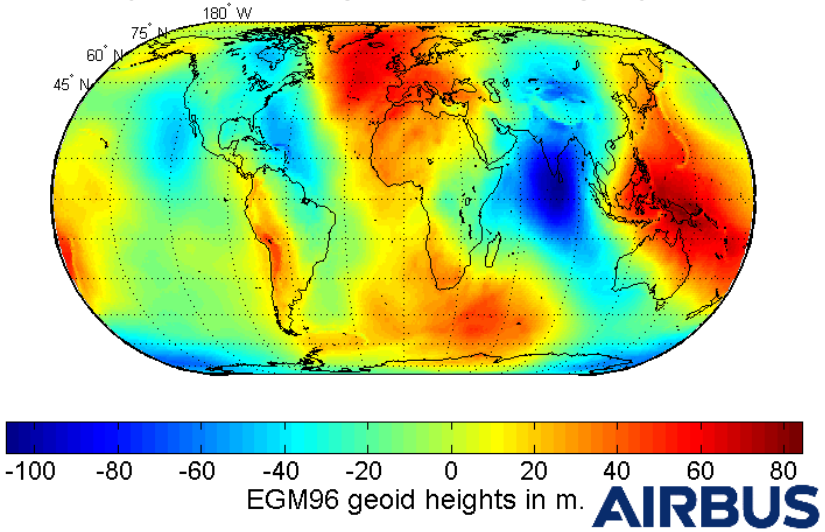
- Position solution computed in GNSS receiver is computed in the Earth-Centered Earth Fixes (ECEF) coordinate system



- Height above the ellispoidal (HAE) is obtained by converting the position (x,y,z) in ECEF to the position (Latitude, Longitude, Height) in WGS-84

- Height above the geoid in Mean Sea Level (MSL) is then computed by converting the height in WGS-84 using either:
  - NATO STANAG 4294 Navstar GPS System Characteristics Appendix 6 (geoid height for every 10° lat/long – used in legacy receivers)
  - EGM-96 used on modern receivers

The standard used to convert WGS-84 HAE to MSL geoid height is not the same on all GNSS receivers.



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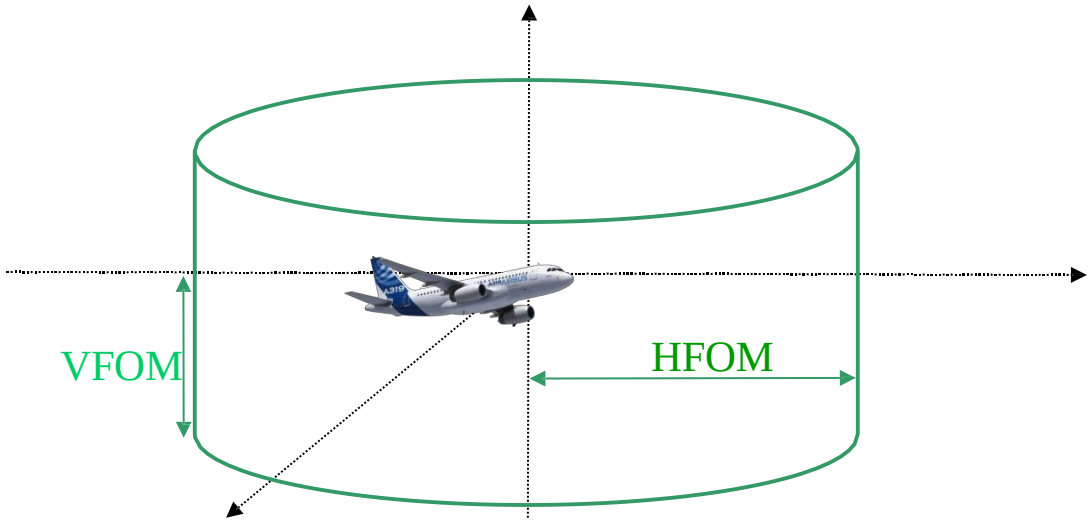
GNSS height – accuracy definition

- The VFOM (Vertical Figure Of Merit) is the half of the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, that describes the region assured to contain the indicated vertical position with at least a **95% probability** under **fault-free conditions** at the time of applicability



- **VFOM computation is not standardized and can be different from one receiver to an other**

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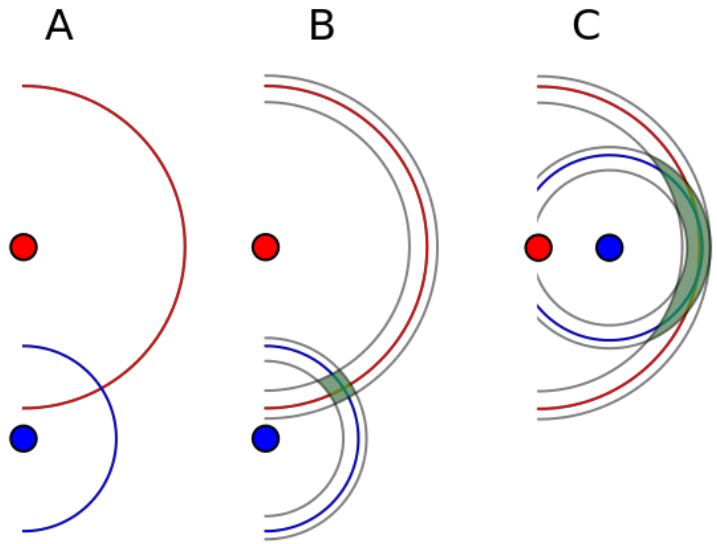
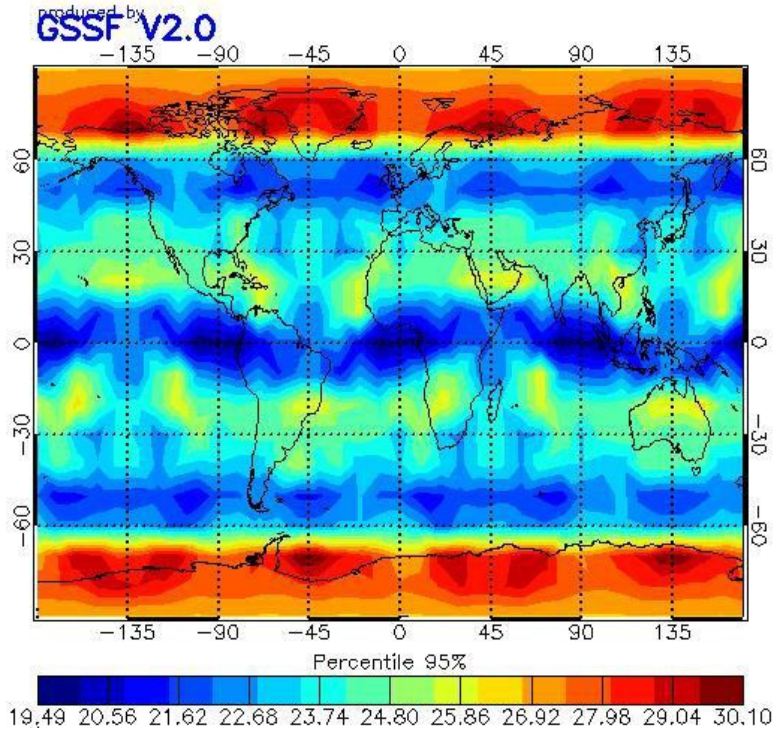
GNSS height – accuracy with the hands

- VFOM = 2*VDOP*UERE
  - VDOP is a geometry factor
  - DOP : Dilution Of Precision
  - UERE is the pseudorange error (User Equivalent Range Error)





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GPS height – Global average DOP values – Extracted from GPS SPS 2008

- Assumptions are **key**: 1 sideral day (23h56min), 5 minutes time steps, 4x4° Degree Global Grid, all in view solution, 5° Mak Angle, No aiding sensors, all 24 baseline satellites, no expanded slots

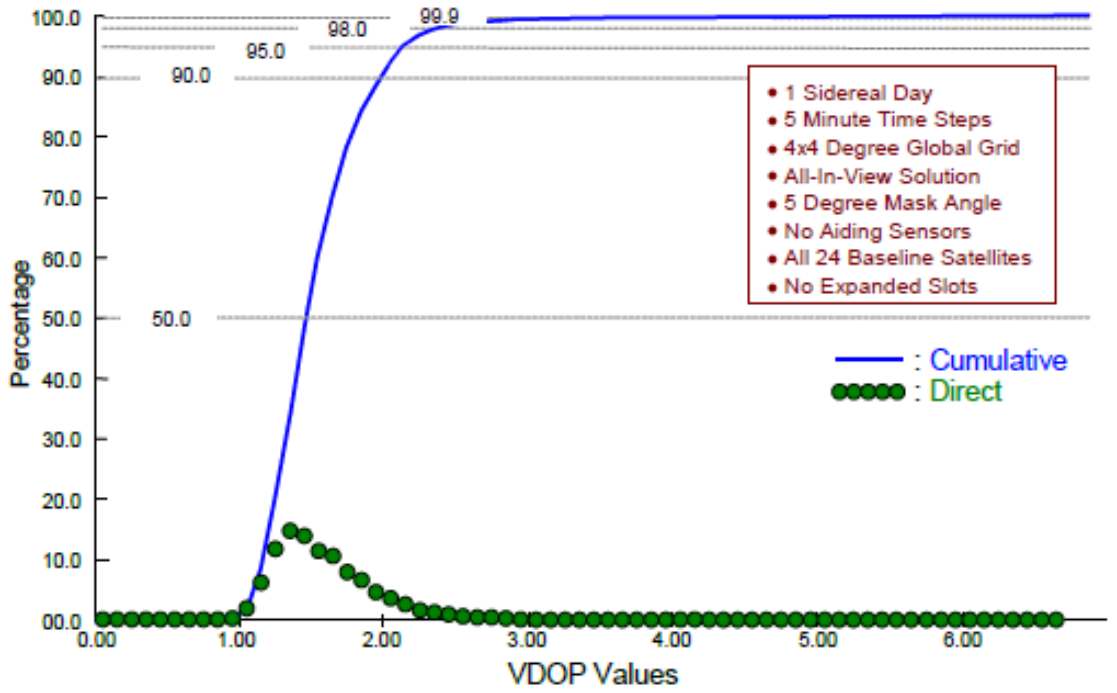

Figure B.3-2. VDOP Distribution Curves

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GPS height - Worst case DOP values – Extracted from GPS SPS 2008

Table B.3-1. DOP Distribution Tabular Results

Constellation Circumstance	"Worst Case" (Single Point) HDOP†	"Worst Case" (Single Point) VDOP†	"Global Avg." (Globe. Pop.) HDOP††	"Global Avg." (Globe. Pop.) VDOP††
99.9% Probability				
All 24 Satellites	~2.3	~4.4	~1.8	~3.5
1 Failed Satellite	>100	>100	~2.4	~4.9
2 Failed Satellites	*	*	~4.0	~7.9
98.0% Probability				
All 24 Satellites	~2.0	~3.4	~1.4	~2.4
1 Failed Satellite	~3.0	~6.0	~1.6	~2.8
2 Failed Satellites	~6.7	~14.1	~1.8	~3.3
90.0% Probability				
All 24 Satellites	~1.4	~2.5	~1.2	~2.0
1 Failed Satellite	~1.8	~3.0	~1.3	~2.2
2 Failed Satellites	~2.1	~4.4	~1.4	~2.3

* No Solution – with 2 satellites down the cumulative distribution never reaches 99.9% availability.
† Worst (highest value) satellite down or worst (highest value) pair of satellites down.
†† Average satellite down or average pair of satellites down.

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GPS height - Sigma UERE values - Extracted from GPS SPS 2008

- $UERE = \sqrt{URE^2 + UEE^2}$
  - URE is the User Range Error - pseudorange inaccuracy due to the Signal In Space
  - UEE is the User Equipment Error - pseudorange inaccuracy due to the receiver

Table A.4-2. L1 Single-Frequency C/A-Code UERE Budget

Segment	Error Source	UERE Contribution (95%) (meters)		
		Zero AOD	Max. AOD in Normal Operation	14.5 Day AOD
Space	Clock Stability	0.0	8.9	257
	Group Delay Stability	3.1	3.1	3.1
	Diff'l Group Delay Stability	0.0	0.0	0.0
	Satellite Acceleration Uncertainty	0.0	2.0	204
	Other Space Segment Errors	1.0	1.0	1.0
Control	Clock/Ephemeris Estimation	2.0	2.0	2.0
	Clock/Ephemeris Prediction	0.0	6.7	206
	Clock/Ephemeris Curve Fit	0.8	0.8	1.2
	Iono Delay Model Terms	9.8-19.6	9.8-19.6	9.8-19.6
	Group Delay Time Correction	4.5	4.5	4.5
	Other Control Segment Errors	1.0	1.0	1.0
User*	Ionospheric Delay Compensation	N/A	N/A	N/A
	Tropospheric Delay Compensation	3.9	3.9	3.9
	Receiver Noise and Resolution	2.9	2.9	2.9
	Multipath	2.4	2.4	2.4
	Other User Segment Errors	1.0	1.0	1.0
95% System UERE (SPS)		12.7-21.2	17.0-24.1	388
* For illustration only, actual SPS receiver performance varies significantly -- see Table B.2-1				

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GPS height – Selective Availability

- SA is a protection technique employed by DoD to deny full system accuracy. On May 1, 2000, President Clinton announced the discontinuance of SA effective midnight 1 May 2000. The effects of SA went to zero on 2 May 2000.

- SA aware receivers know that SA is OFF. SA not aware receivers don't know that SA is OFF.

- **SA not aware receivers consider an additional measurement error that can be estimated at 30m at 1sigma**

GPS height – VFOM values for SA AWARE and SA NOT AWARE

values	VFOM SA AWARE	VFOM SA NOT AWARE
OACI Annex10 amdt 86 – conservative values	73m – 240 ft	N/A
SPS average values (0 AOD)	68m (VDOP = 2 / UERE = 17m) – 223 ft	137,6m (VDOP = 2 / UERE = 34,4m) – 451 ft
SPS conservative values (Max AOD)	82,4m (VDOP = 2 / UERE = 20,5m) – 270 ft	144m (VDOP = 2 / UERE = 36m) – 473 ft

- VFOM values can be higher in degraded operational conditions:
  - Satellites masked
  - Multipath
  - Interference

GPS height accuracy is not constant and depends on various factors such as equipment, constellation and environment

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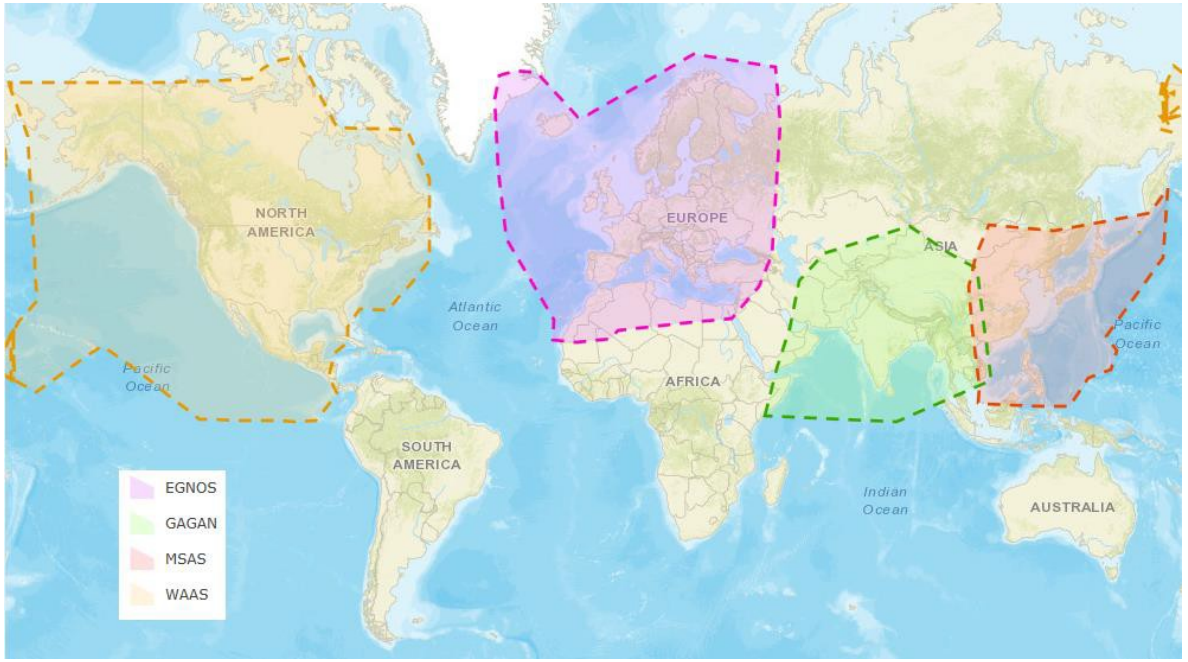
GNSS height – Satellite Based Augmentation Systems (SBAS)

- SBAS provides augmentation to GPS data, enabling to get height with a better accuracy and integrity:
  - For WAAS and EGNOS which enable LPV 200 operations, vertical accuracy of 4 to 6m (13 to 20 ft) can be expected

- SBAS service provider cover North America (WAAS), Europe (EGNOS), India (GAGAN) and Japan (MSAS). By 2020 Russia (SDCM) shall be covered.



Height computed in SBAS mode will reduce errors wrt GPS mode

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GNSS height - ADS-B OUT with mode S transponders

- ADS-B: Automatic transmission of surveillance data from A/C to ATC and from A/C to A/C
- MODE S: When a Secondary Surveillance Radar interrogates mode S transponder they reply with a large set of surveillance data (e.g. flight number, 24-bit adress, speeds, heading…)
- ADS-B OUT: Capability to broadcast surveillance data. This capability is part of mode S transponders

- Among data broadcasted in flight on Airbus A/C are:
  - Barometric altitude relative to a standard pressure of 1013.25 millibars
  - Difference between barometric altitude and GNSS height (HAE WGS-84). GNSS altitude (MSL) may be used.
  - The resolution is 12,5 feet

- A350 and A380 A/C always broadcast GNSS height HAE

- A320 and A330 family A/C in DO-260B or DO-260A* broadcast GNSS height HAE
  - * If HAE is unavailable then MSL is output for DO-260A A/C on A320/A330

- A320 and A330 family A/C in DO-260 broadcast GNSS height MSL

GNSS height type is frozen for a given A/C

DO-260 version can be determined using ADS-B data

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GNSS height - ADS-B OUT with mode S transponders - Accuracy

- Accuracy of the GNSS height can be estimated using the following parameters depending on the DO-260 version of the transponder:

DO-260

Table 2-67: NUC$_P$ Coding Requirements

Coding	Horizontal Protection Level (10^{-5})	Horizontal Error (95%)	Vertical Error (95%)	Comment	Corresponding TYPE Code (from Table 2-11)
0	No Integrity	Unknown	Unknown	No Integrity	0
1	< 20 NM	< 10 NM	Baro Alt	RNP - 10	17
2	< 10 NM	< 5 NM	Baro Alt	RNP - 5	16
3	< 2 NM	< 1 NM	Baro Alt	RNP - 1	15
4	< 1 NM	< 0.5 NM	Baro Alt	RNP - 0.5	14
5	< 0.5 NM	< 0.25 NM	Baro Alt	e.g. NPA, DME - DME	13
6	< 0.2 NM	< 0.1 NM	Baro Alt	e.g. GPS - SPS	12
7	< 0.1 NM	< 0.05 NM	Baro Alt	e.g. GNSS (No SA)	11
8	TBD	< 10 m	< 15 m	e.g. SBAS	21
9	TBD	< 3 m	< 4 m	e.g. GBAS	20
10 - 15	TBD	TBD	TBD	future expansion	TBD

DO-260A

Table 2-71: Navigation Accuracy Category for Position (NAC$_P$) Encoding

Coding (Binary)	Coding (Decimal)	95% Horizontal and Vertical Accuracy Bounds (EPU and VEPU)	Comment	Notes
0000	0	EPU ≥ 18.52 km (10 NM)	Unknown accuracy	1
0001	1	EPU < 18.53 km (10 NM)	RNP-10 accuracy	1, 3
0010	2	EPU < 7.408 km (4 NM)	RNP-4 accuracy	1, 3
0011	3	EPU < 3.704 km (2 NM)	RNP-2 accuracy	1, 3
0100	4	EPU < 1852 m (1 NM)	RNP-1 accuracy	1, 3
0101	5	EPU < 926 m (0.5 NM)	RNP-0.5 accuracy	1, 3
0110	6	EPU < 555.6 m (0.3 NM)	RNP-0.3 accuracy	1, 3
0111	7	EPU < 185.2 m (0.1 NM)	RNP-0.1 accuracy	1, 3
1000	8	EPU < 92.6 m (0.05 NM)	e.g., GPS (with SA on)	1
1001	9	EPU < 30 m and VEPU < 45 m	e.g., GPS (SA off)	1, 2, 4
1010	10	EPU < 10 m and VEPU < 15 m	e.g., WAAS	1, 2, 4
1011	11	EPU < 3 m and VEPU < 4 m	e.g., LAAS	1, 2, 4
1100 - 1111	12 - 15	Reserved		

DO-260B

Table 2-71: Encoding of the Geometric Vertical Accuracy (GVA) Subfield in Aircraft Operational Status Messages

GVA Encoding (decimal)	Meaning (meters)
0	Unknown or > 150 meters
1	≤ 150 meters
2	≤ 45 meters
3	Reserved

Only position with NUCp of 8 or more or NACp of 9 or more GVA of 2 or more may be used

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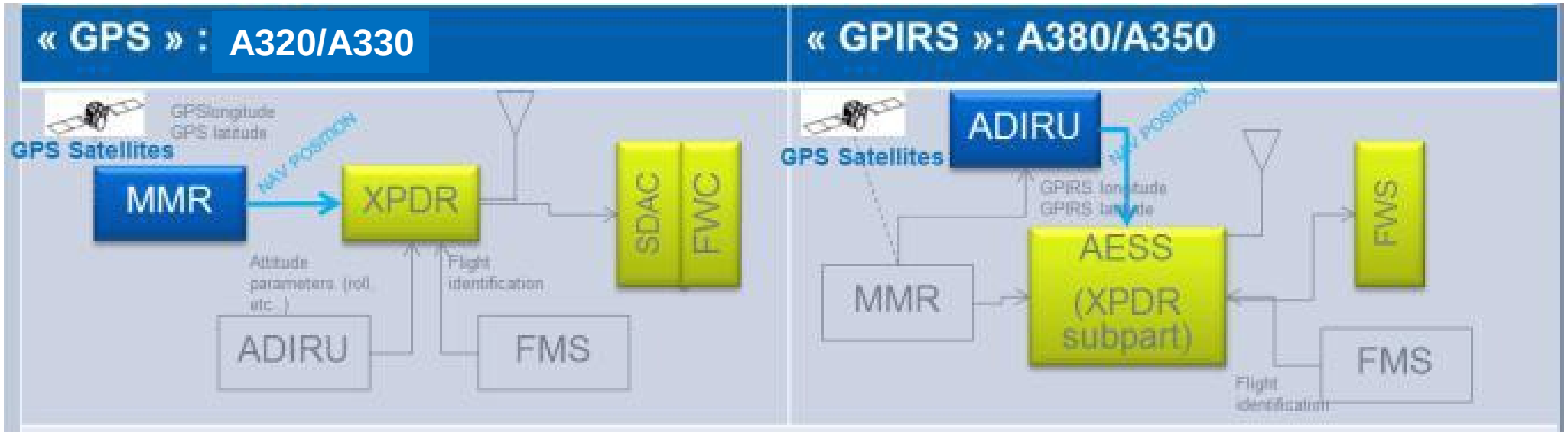
GNSS height - ADS-B OUT with mode S transponders – Airbus architecture



Source of NAV position for ADS-B depends of A/C type

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Conclusion

- Current usage of GNSS height broadcasted by ADS-B for ASE monitoring can lead to false alerts (on Region Monitoring Agencies side) in case the GNSS height referential is unknown

- GNSS height type (WGS-84 or MSL) referential can be determined using A/C type and its DO-260 version

- All sources of errors of the GNSS height should be considered when performing ASE monitoring:
  - Errors due the equipment, GPS constellation and environment
  - Conversion errors from WGS-84 to MSL
  - Resolution of data broadcasted by ADS-B

- GNSS height (WGS-84 or MSL) can be used considering the broadcasted accuracy of the position

- GNSS Height computed in SBAS mode will reduce errors wrt GPS mode

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Thank you

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