Presented by

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GALILEO/GPS Combined receiver : Operational Use

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Scope

- Airbus is involved in several Research Projects focusing on Galileo :
  - Anastasia
  - GEM/GARMIS
- Airbus proposed during last EUROCAE WG-62 to study possible operational use of Galileo/GPS combined receiver and impact on current GNSS operations within A/C
- First, this WP propose to make a status on Galileo/GPS standardization
- Second of all, this WP also propose to review the various possible combinations of GPS/GALILEO receivers assessing pros and cons of each solution and impact on A/C navigation architecture
- The discussion and the conclusions of this WP may be used as inputs for ConOps update and Work Plan of EUROCAE WG-62

Standardization status

- Current ConOps included in interim Galileo MOPS
  - En route/Terminal Area/Non precision approach/Instrument approach with Vertical guidance
  - Cat I/II/III (thanks to Galileo local component or GPS/SBAS or GPS/GBAS)
  - Current roadmap described in Interim MOPS is to develop :
    - Galileo + GPS + SBAS MOPS Beta-2/Delta-2 jointly with RTCA directly from Galileo stand-alone MOPS

Standardization status

- Current status on standardization
  - Galileo only : interim MOPS : White Paper released
  - GPS/SBAS : DO229-D En route up to LPV (FRAC in Oct 06)

- Two alternatives :
  - Update ED72-A/DO208 : En route to NPA => DO208-A/ED-72B combined Galileo/GPS receiver (without SBAS).
  - Update DO229-D to incorporate GPS/Galileo + SBAS : EDXX/DOXYZ for Beta/Delta/Gamma receivers

Standardization status

- Current status on standardization (con't)
  - GBAS status
    - GPS/GBAS DO253-A RNAV to Cat I (DO253-B FRAC in Jan 07)
    - GPS/GRAS DOXYZ En route to APV-II (FRAC in Jan 07)
  - Two alternatives :
    - Update towards DO253-C when GBAS Cat II/III will come
    - Create a GALILEO/GBAS MOPS EDYY
  - Other MOPS of interest
    - RNP DO236-B RNP-RNAV performance : incorporate Galileo when DO236-C is open
    - DO228-A No room for E5B
    - ED-88-A : include Galileo for non interference between functions within MMR
    - A-SMGCS ? What and where can we cover these operations ?

Future operations with Galileo (and GPS)

- Galileo operational (FOC) for Air Transport not before 2012
- Future Applications/Operations identified (2020) :
  - Oceanic/En route/Non precision Approach
  - APV I-II or LPV
  - RNP-RNAV operations (RNP-10 to RNP-0.3)
  - Low RNP (RNP 0.1 and below in Terminal/Approach/Departures and Missed Approach)
  - 4D-RNAV
  - Cat I/II/III with GBAS
  - Maintain ILS Cat III capability
  - A-SMGCS operations
- All these operations are high demanding accuracy and integrity.
- Galileo and combined GPS/Galileo receivers shall support these operations.
- Continuity is often the weakness.
- Availability must not be forgotten.

Foreseen operational benefits of using Galileo

- What could bring Galileo (with or without GPS)
  - Reduction of multipath sensitivity
  - Higher accuracy
  - Propagate Geometric altitude use on–board A/C
  - Monitoring of Barometric altitude
  - GBAS Cat II/III (in addition with GPS)
  - Increase availability (e.g. Polar NAV)
  - Provide another mean to go from Mean based ops to Perf. Based ops
  - Alternate means to support equivalent operations to GPS.

Review of combinations of GPS/Galileo receiver

- Four candidates
  - Combination at Position level: GPS & Galileo operate separately
  - Combination at Pseudo-Range level: GPS & Galileo operate as a single integrated system
  - Use of “Basic” Galileo system + use of “Back-up” (GPS+SBAS) system
  - Use of one system only, Galileo or (GPS+SBAS)

- Specificities of each are reviewed
- Impact on integration with IRS (ABAS) is assessed

Combination #1-1

- **Combination at Position level: GPS & Galileo operate separately**
  - 2 different/independent navigation solutions :
    - Pseudo-ranges are measured separately by two receivers. Each GNSS receiver within the receiver (e.g. MMR) computes an independant position solution, associated protection levels and factors of merit.
    - Common sources of errors :
      - Propagation types of errors (iono , tropo, multipath) but not with the same magnitude. This depend on the frequencies used in Galileo and GPS receiver. First a nominal configuration with L1 + E5b Galileo receiver whereas GPS receiver will use only L1 and when GPS III appears, L5 frequency.
  - Integration with an IRS (ABAS)
    - Loosely coupled IRS/GNSS : Galileo and GPS separate receivers will either transmit two position solutions.
    - Tightly coupled IRS/GNSS : each receiver provides separate types of raw data to IRS => re-combination of Galileo and GPS solutions inside the filters within IRS : complex tuning of the hybrid filters due to the difference in terms of performance of each GNSS receiver pseudo-ranges.

Combination #1-2

- **Combination at Pseudo-Range level: GPS & Galileo operate as a single integrated system**
- Use of the best satellites at each instant (GPS or Galileo) → 1 single navigation solution
  - Pseudo-ranges from each satellite (either Galileo or GPS) are measured by this receiver.
    - Complexity is transfered at the receiver level : Processing the two constellations within the same receiver imply to receive signals that have different power levels from different carrier frequencies (L1, L5/E5a, E5b) and with different types of modulation.

Combination #1-2

- **Combination at Pseudo-Range level: GPS & Galileo operate as a single integrated system**
  - Complexity of the system
    - Integrity schemes used might be different according to constellation (GIC + RAIM FDE) or GIC + SBAS.
    - Time reference within the two constellations being different, an additional unknown variable has to be determined during solution computation or data is provided within Navigation message.
    - Different geodetic reference system (WGS84 for GPS and GTRF for Galileo), the difference being about 3 cm around the Globe.
    - Mask angle induced by Galileo satellites design will be physically 10° whereas GPS satellites can be tracked until 2°.
  - Integration with an IRS (ABAS)
    - Loosely coupled IRS/GNSS hybridization : Use of a unique position solution result of the combination of various pseudo-ranges
    - Tightly coupled hybridization : pseudo-ranges are filtered to be homogenous or raw with associated characteristics of Galileo or GPS estimated by the receiver to be taken into account in kalman filters within IRS.

Combination #3

- **Use of “Basic” Galileo system + use of “Back-up” (GPS+SBAS) system**
  - The choice for the Basic Mode or the Alternate/Degraded/Back-up mode will be done according to:
    - Best constellation geometry, Signal to noise ratio,
    - Location on the globe, Commercial or political reasons,
    - Jammed signal on one frequency not used by the other.
    - Certified means for a particular operation (opposite to performance based approach)

  ⇒Difficulty will be in selecting the best position solution if both systems will be usable.

  - Integration with an IRS (ABAS)
    - Position or pseudo-ranges from only one constellation selected will be transmitted to the IRS.
    - IRS will have to be able to switch from one constellation to the other when performance is degraded or when choice of constellation is modified, thus be able to adapt its filter to a specific constellation and the difference of errors characteristics.

Combination #4 : No combination

- **Use of one system only, Galileo or (GPS+SBAS)**
- Mono frequency
  - It is unlikely that this case will be used. It is only the today situation with GPS (L1). Introduction of Galileo will include at least two carrier frequencies (L1 and E5b).
- Dual frequency :
  - This is the simple case where only Galileo receiver is used or GPS when GPS III will come.
  - Would be driven by economical or political reasons.
- For market and rationality of the products, it is more likely that only combined GPS/Galileo receivers will be used.
- This case has only to be studied to cope with the case of one constellation being jammed or shut down => this comes back to combination #3

Use of Galileo in future operations (2020)

- **Oceanic/En route/Non precision approach**
- Single constellation/single frequency will be sufficient to support current operations already available with GPS
- Considering number of satellites and GPS/Galileo combination advantages

=> ABAS seems not needed except in case of total loss

=> Future GNSS receivers must increase transmission rate for navigation data (higher than 1Hz – 5 Hz should be sufficient).

Use of Galileo in future operations (2020)

- **RNP-RNAV / Low RNP**
- Depending on geographical environment and regulation basis, current navigation systems with L1 only GPS are sufficient to perform RNP and some low RNP approaches considering :
  - Performance is assessed at A/C level (impact of FTE)
  - ABAS is required to ensure sufficient continuity
- Additonal constellation/frequency could be used to increase performance thus simplify navigation architectures.
  - Mountainous areas, where masking and shadowing effects can be very effective, can imply a lack of GPS availability. In that case, hybridization with IRS is necessary to cope with GPS outages.
  - But, increase in terms of satellites in view with a high elevation could help to reach very low RNP thus enabling this operation without the help of ABAS.

  => Navigation architectures could be simplified considering hybridization is not standardized, proprietary and difficult to fine tune.

=> Consequence : Reduction of ABAS to perform low RNP would also imply that future GNSS receivers increase transmission rate for navigation data (higher than 1Hz – 5 Hz should be sufficient).

Use of Galileo in future operations (2020)

- **APV-I-II / LPV**
  - Single system/constellation is sufficient (Galileo only or GPS + SBAS)
  - Dual frequency for Galileo only will be necessary for APV-II to get sufficient accuracy.
  - Integrity should be provided by Galileo GIC or GPS SBAS and (RAIM).
  - Use of RAIM only doesn't enable APV-II operations

=> No need to integrate with IRS thus that higher rate is needed at the output of the receiver for navigation data (higher than 1Hz – 5 Hz should be sufficient).

Use of Galileo in future operations (2020)

- **4D-RNAV**
  - Lack of requirement/Lack of standardisation material.
  - Need for a clear identification of requirements in terms of timing.
  - 4D-RNAV is RNP-RNAV + Vertical RNP + Timing
  - This should be worked within DO236-C activity
  - Roadmap for the requirements identification is not clear.

⇒Operational need is clear but how Galileo will facilitate 4D is not clear.

=> Propose to update the ConOps and identify in one of the future Galileo MOPS 4D-RNAV and the enablers (combinations)

Use of Galileo in future operations (2020)

- **CAT I with GNSS**
  - GBAS is necessary (if GNSS used).
  - Single system/constellation would be sufficient (Galileo or GPS) as it is today with GBAS cat I standard.
  - Single frequency is sufficient : it is the case today with GBAS cat I standard.
  - Integrity is provided by Ground Stations (Galileo GBAS or GPS GBAS)

⇒No need to integrate with IRS

⇒Galileo/GBAS MOPS only will be needed :

- For Galileo failure modes,
- When GPS is lost,
- For Market reasons if one state doesn't implement GPS GBAS.

Use of Galileo in future operations (2020)

- **CAT II/III with GNSS**
  - GBAS is necessary
  - Dual system/constellation should be necessary (Galileo + GPS) for GSL E and F
  - Dual frequency should be necessary for GSL E and F
  - Integrity is provided by Ground Stations (Galileo GBAS + GPS GBAS)
  - Integration with IRS could enable Cat II/III with GSL-D by improving continuity
  - GBAS ground station might not be dual constellation
  - Cat II/III capability has to be maintained in case one constellation/one frequency only is used.

=> Need to develop Galileo/GBAS only MOPS like for Cat I before developing Galileo/GPS GBAS MOPS

Use of Galileo in future operations (2020)

- **A-SMGCS**
- Difficulty to assess GPS/Galileo performance against A-SMGCS requirements whether Awareness or Guidance is considered.
  - Dual system/constellation might be necessary (Galileo+GPS)
  - Dual frequency should be necessary (high accuracy demanding ops)
  - Integrity should be provided by (Galileo GIC or GPS SBAS) and RAIM
  - Performance on velocity is required
  - Accuracy, Integrity & Availability performances could be insufficient with a Galileo/GPS system only.
    - Integration with an IRS could be necessary, to improve Accuracy, Integrity & Continuity performance depending on geographical environment
    - Additonal sensor might be needed to dead reckon in case of masking/shadowing or highmultipath effects.
      - GPS/Galileo itself should not bring direct benefit against multipath large errors.
- RTCA WG-5 performed some work to use GBAS as a possible candidate to enable A-SMGCS high demanding applications.
  - Conclusion was not positive for the highest demanding applications

=> Propose to update the ConOps and identify in one of the future Galileo MOPS A-SMGCS and the enablers (combinations)

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Additonal Functions/Operations to be considered

- Operations using or enabled by GPS on A/C
  - Initialization of ADIRU
  - Oceanic/En Route/Non Precision Approach
  - RNP 0.X Terminal Area and Approach
  - Cat I Precision approach with GBAS
  - Monitoring of A/C position

- Sub-functions of current GPS
  - Predictive RAIM : Predictive GIC ?
  - Altitude Aiding : to improve RAIM availability
  - Navigation accuracy and Integrity Monitoring
  - Deselection of GPS : Back to combination #3
  - Use of GPS data for Surveillance (EGPWS, TCAS) and Awareness (Airport Navigation)

=> Whenever possible, reassess these needs and reconduct when appropriate in Galileo MOPS

Conclusion

- Standardization process is long, must involve RTCA and is not always synchronized with availability of the signals
- Proposal to discuss WG-62 work plan according to inputs provided within this document
- Galileo can bring a lot of benefits but combination increase complexity.
  - Need to counterbalance complexity by improving GPS/Galileo receiver basic performance to avoid when possible need for ABAS.
- Some high demanding applications will require mutiple constellations/frequencies and ABAS :
  - A-SMGCS, Low RNP, GBAS Cat II/III
- Some GPS sub-fonctions have to be reconducted considering loss of GPS or Galileo in operations and facilitate introduction of the new constellation on A/C fleets.

Conclusion

- Feedback is expected from EUROCAE WG-62
- Request to have the inputs provided within this WP considered by EUROCAE WG-62 for future work.

- Questions ?