

Summary of the Ninety-Ninth Meeting

Special Committee 159

**Minimum Operational Performance Standards for Airborne Navigation
Equipment Using the Global Positioning System (GPS)**

The ninety-ninth meeting of SC-159 was held October 27th, 2017 at RTCA Headquarters, 1150 18th Street NW, Suite 910, Washington, D.C. 20036. The attendees were the following:

Christopher Hegarty (Co-Chairman)	The MITRE Corporation
George Ligler (Co-Chairman)	Project Management Enterprises Inc.
Karan Hofmann (Program Director)	RTCA
Ken Alexander (DFO)	Federal Aviation Administration (FAA)
John Savoy (Secretary)	Honeywell International, Inc.
NAME	COMPANY
Michael Biggs	Federal Aviation Administration (FAA)
Rick Cassell	Systems Enginuity, Inc.
Barbara Clark	Federal Aviation Administration (FAA)
Yi Ding	Esterline CMC Electronics
Daniel Domey	Esterline CMC Electronics
Andrey Galyamov	NNC Consulting LLC
Adrian Hiliuta Esterline	CMC Electronics
Victor Iatsouk	Consultant
Barry Irwin	The MITRE Corporation
Andreas Lipp	EUROCONTROL
John Owen	Defence Science Technology Laboratory (DSTL)
Timothy Padden	U.S. Air Force
Patrick Reddan	ZETA Associates (Exempt, see note)
Zach Reynolds	L-3 Communications
Andrew Roy	Aviation Spectrum Resources, Inc.
Sergey Silin	ZAO "KB NAVIS"
Oleg Skubii	Research Design Lab NAVIS
Bob Stuckert	Federal Aviation Administration (FAA)
Dale Swanson	The MITRE Corporation
Monica Vafiades	U.S. Air Force
Joel Wichgers	Rockwell Collins, Inc.
Tin Ying	U.S. Air Force

The agenda for the meeting follows:

1. Introductory Remarks: DFO, RTCA and Co-Chairs
2. Approval of Summaries of Previous Meetings
 - a. Ninety-Eighth Meeting held May 11, 2017, RTCA Paper No. 277-17/SC159-1065.
3. Final Review and Comment (FRAC) activities
 - a. DO-235() Update
 - b. GNSS L1/L5 Antenna MOPS
4. Review Working Group (WG) Progress and Identify Issues for Resolution.
 - a. GPS/WAAS (WG-2)
 - b. GPS/GLONASS (WG-2A)
 - c. GPS/Inertial (WG-2C)
 - d. GPS/Precision Landing Guidance (WG- 4)
 - e. GPS/Interference (WG-6)
 - i. Discussion regarding taking draft DO-292 revision into Final Review and Comment (FRAC)
 - f. GPS/Antennas (WG-7)
5. Review of EUROCAE Activities and Discussion of Joint Activity with EUROCAE on a Dual-Frequency, Multi-Constellation GNSS Receiver MOPS
6. Update on ICAO/Navigation Systems Panel Dual Frequency/Multi Constellation Concept of Operations (CONOPS)
7. Discussion of Terms of Reference Updates
8. Action Item Review
9. Assignment/Review of Future Work
10. Other Business
11. Date and Place of Next Meeting
12. Adjourn

In accordance with the Federal Aviation Advisory Committee Act, Ken Alexander, Federal Aviation Administration (FAA), was the Designated Federal Official for this meeting.

Note that, with the agreement of the chairmen and other participants, the agenda was reordered to accommodate the availability of certain participants. The order in the minutes below reflects the actual sequence of topics.

Agenda Item 1. Chairman’s Introductory Remarks.

- Ken Alexander read a statement indicating that this Advisory Committee meeting is open to the public, that notice of the meeting was published in the Federal Register and that members of the public may present written or oral statements with the permission of the committee chairmen.
- Karan Hofmann, Program Director of RTCA, discussed RTCA’s proprietary references policy and committee participation membership policy.
- At the suggestion of Co-Chairman George Ligler, attendees introduced themselves.
- Unlike the 98th meeting, all attendees were present in person.

Agenda Item 2. Approval of Summaries of Previous Meetings.

- a. Ninety-Eighth Meeting held May 11, 2017, RTCA Paper No. 277-17/SC159- 1065.

Laurent Azoulai, noted that he had attended the 98th meeting, both as a representative of Airbus Industries and as co-chairman of working group 2.

Co-chairman, George Ligler reminded attendees to sign in.

The summary was then approved with this change.

Agenda Item 3. Final Review and Comment (FRAC) activities.

- a. DO-235() Update

Sai Kalyanaraman, chairman of WG-6, discussed some issues the group is having to close the GPS L1-CA link budget. The team is planning to perform some specific receiver testing to validate assumptions.

WG-6 did not expect to be able to resolve issues with intra-system GNSS noise in time to support a release in December of 2017.

Sai indicated that the team should have the final review and comment issues identified and could begin resolving them February. He did not expect to have all issues resolved by the upcoming March plenary meeting.

There was some general discussion about whether the work could be or needed to be completed by October 2018. The issue should be reviewed again at the March plenary meeting. It may be necessary to have a special plenary meeting to resolve/approve this update prior to October 2018.

- b. GNSS L1/L5 Antenna MOPS

Sai went on to discuss difficulties in the generation of multi-frequency antenna performance specifications. No GNSS antenna manufacturer had been supporting the development of these MOPS. As a result, it has been difficult to identify real, achievable performance parameters. Issues surrounding proprietary information were very difficult to overcome.

At the time of the meeting, there were multiple interference masks proposed for the L1 frequency based on two different proposed solution. Manufacturers would not commit to providing either mask, and this point of conflict is jeopardizing the ability of SC-159 to comply with the current Terms of Reference.

George Ligler proposed to hold a meeting with the antenna manufacturers in an effort to identify a process for resolving MOPS questions. Such a meeting would avoid any discussion of proprietary information and would focus on determining a process. An Action Item for this was created.

There was some discussion regarding the dependency of EUROCAE WG-62 on the antenna MOPS. EUROCAE WG-62 is dependent on the work of SC-159 WG-7 and this may force a resolution with issues.

Agenda Item 4b. Review GPS/GLONASS Working Group (WG-2A) Progress and Identify Issues for Resolution.

Working Group 2A has not met since the last plenary session and the working group chairman was not present.

Agenda Item 4c. Review GPS/Inertial Working Group (WG-2C) Progress and Identify Issues for Resolution.

Mats Brenner, chairman of WG-2C, presented the current status of that group.

- The working group was continuing to develop performance standards for GNSS-aided inertial systems. This included systems utilizing less accurate Attitude Heading Reference Systems (AHRS) or Micro-Electro-Mechanical systems (MEMS) sensors. Drafts of much of this work was completed prior to this plenary.
- The team had been working on new material concerning GPS Fault Modes, Ionospheric Storm Testing, the specific definition of HFOM, Tropospheric modeling, Ephemeris, RFI, and predictions for the capabilities of different equipment classes.
- Mats presented data that demonstrated the computational complexity of simulations that would need to be used to adequately show compliance. The team's estimates indicate that between 3 and 100 days of computer time would be necessary to execute these tests. It may be possible to significantly shorten this time using cloud-based computing or perhaps a modified ionospheric model.
- The working group has made several improvements in testing detection and exclusion of satellite failures during periods where the hybrid system is coasting with insufficient GNSS coverage. This includes focusing on HPL bounding during coasting and simplification of ionospheric bubble tests.
- The working group had spent some time discussing the current needs and objectives of WG-2C so that new team members could be made more aware of the efforts underway.
 - Basic RNP provides a reversion mode if performance cannot be met
 - RNP-AR has no reversion mode.
 - GPS vulnerabilities are becoming more and more apparent.
 - Integration provides greater availability of these functions
 - Lower-grade sensors normally used only for AHRS but combination with GNSS can provide positioning, velocity as well as AHRS.
 - The combination of GPS with AHRS is being built on existing standards and definitions. This has been causing communications issues.
 - Several manufacturers are beginning to spend money on blending GPS with lower quality sensors. If there are objections to using this equipment, the committee should identify that quickly and plan the work accordingly.
 - The FAA will discuss these communications issues internally and provide a response to WG-2C.
- WG-2C had discussed research from the Japan Aerospace Exploration Agency regarding ionospheric depletion bubbles. Their findings indicate that even the most simple system integrating GPS an inertial sensors would mitigate these issues.
- Mats indicated that he was seeking a co-chair to help with the leadership of the working group. He has had little success.

Agenda Item 4a. Review GPS/WAAS Working Group (WG-2) Progress and Identify Issues for Resolution.

Laurent Azoulai, co-chairman for working group 2, discussed the progress made during the week.

- Working groups 2 and 4 met throughout the week to make common progress on the new dual frequency, multi-constellation MOPS. There were themes for the joint meetings.
 - SBAS and core constellation program status
 - DF/MC SBAS MOPS work plan
 - Discussion of EUROCAE WG-62 DF/MC SBAS MOPS requirements
 - ICAO DF/MC concept of operations
- Jason Burns had provided an update on the WAAS program status
 - The revised Federal Radionavigation Plan was released in August 2017. The FRP provides a commitment to maintain the characteristics of GPS signals that enable codeless and semi-codeless access until at least two years after there are 24 operational satellites broadcasting L5. This is currently planned for 2024.
 - There was some effort under way to replace obsolete hardware, including the integration of two new geostationary satellites.
 - At the time of the meeting, there were 4,422 LPV/LP procedures published.
- There was a briefing on the status of EGNOS as well.
 - There were improvements made to both the EGNOS ground segment and space segment.
 - There was some degradation in the availability of LPV200 but the results remain acceptable.
 - LPV continues to gain acceptance in Europe with 257 LPV approaches in operations and 493 LPV procedures planned by 2020.
 - EGNOS V3 updates are planned for 2023 that will include updates of obsolete equipment. This will still only augment L1-CA signals.
 - EGNOS V3.2 is planned for 2024/2025 to support DFMC features. This is tentative as no contract had been signed at the time of the meeting.
 - GSA has been supporting the development of commercial equipment by providing funding for the development of Advanced Multi-Constellation Receiver Autonomous Integrity Algorithms.
- There was a briefing on the status of MSAS by Masashi Giho.
 - Laurent highlighted the fact that by 2023, MSAS will support single frequency, L1 LPV with MSAS V3.
 - Starting in 2017 MSAS V4 will begin working on validation of DFMC SBAS supporting ALL GNSS constellations.
- Lockheed Martin/ GMV had provided a briefing regarding an Australian SBAS test bed.
- Ignacio Alcantrarilla Medina had presented Galileo program status
 - The target has been to have 30 Galileo satellites on orbit by 2020.
 - Laurent showed us data on Galileo performance metrics. There was an outlier but as a whole, the data indicates that the performance commitments should be met.
 - The European Commission is considering regulatory mandates for the use of Galileo and EGNOS in European Airspace.
 - The EU through GSA is supporting the development of DFMC GNSS by funding the development of prototype user equipment.

- Stefan Wallner described to the working group details on the Galileo Open Service Safety-of-Life work plan.
 - The Safety-of-Life work plan objectives include
 - Establishing justification of the use of the Galileo Open Service in safety-of-life applications
 - Providing standardization of algorithms such as dual-frequency/multi-constellation SBAS and H-ARAIM
 - Design and development of EGNOS V3 and its safety cases
 - Assessment of the current Galileo OS capabilities suitability for safety-of-life applications
 - Stefan provided an organizational overview of the entities responsible for carrying out the work plan including ESA, EC and GSA.
 - Laurent indicated that one outcome of the work plan would be completion of the GNSS worksheet that SC-159 considers to be a prerequisite for development of a MOPS containing Galileo functionality.
 - Laurent also noted that the current assessment for the probability of failure of a Galileo satellite (P_{sat}) does not appear to be comparable to the current GPS performance, but that the goal continues to be equivalent or better performance.
- J.P. Fernow presented to the working group a means to reduce the HFOM and VFOM values transmitted by the next generation of GNS receivers.
 - J.P. described how the potentially inflated HFOM and VFOM values transmitted by the current generation of equipment results in ADS-B transponders transmitting large values for NAC_P and this, in turn, limits the usefulness of the ADS-B signal for some applications.
 - J.P. provided several means of reducing figures of merit.
 - There was a recommendation for the minimum acceptable level of figure-of-merit performance.
 - The global, daily average availability of the condition $HFOM < 8.5 \text{ m}$ should be at least 99% for the 24-satellite GPS constellation with no outages and all $URA \geq 2 \text{ m}$
 - There is no plan to re-open DO-229 or DO-316 at this time but working group members are encouraged to evaluate the impact making such a change on their equipment.
- John Savoy asked the working group to consider whether DO-229E adequately addresses how equipment should handle satellites for which an SBAS provider has broadcast a “Do Not Use” UDREI.
 - There is not a complete consensus within the working group and no changes are proposed at this time.
- Laurent Azoulai et al provided a briefing regarding the current activities of the ICAO Navigation Systems Panel.
 - China and Korea have informed the NSP about plans for a new operational SBAS. PRN codes for those systems were identified in the SARPS.
 - The US GPS Directorate presented an amended policy to manage the assignment of SBAS GEO satellite codes.

- The NSP made some progress on SBAS link authentication as well as dual-frequency, multiple constellation SBAS.
- The concept of operations document for dual-frequency, multi-constellation SBAS is also progressing, however the issue of the selection of GNSS elements in certain geographical regions remains contentious.
 - There was considerable discussion regarding performance-based functionality vs. States' AIP publications with no resolution.
- Mikaël Mabillean presented the progress on the development of the concept of operation for ARAIM.
 - The ARAIM is intended to support enroute navigation, high-availability non-precision approaches and high availability of the surveillance function.
 - A draft of the document was provided for comment.
 - One issue of significant import is the distribution of integrity service information. Two options are being considered: the use of an on-board database and the transmission of an integrity service message by GNSS service providers.
- Ken Ashton and Laurent Azoulai led a review of the dual-frequency multi-constellation concept of operations.
 - There were three sections that need significant work.
 - Section 5 detailing the benefits of dual-frequency multi-constellation operations;
 - Section 6 detailing the objectives for avionics; and
 - Section 7 detailing the GNS elements to be processed.
 - A drafting group was formed to provide inputs to the document.
- Barbara Clark led a discussion concerning TSO considerations for MOPS development.
 - The FAA will structure the TSO in a manner dependent on the structure of the MOPS and the characteristics supported by the equipment.
 - Complexity of the receiver and the resulting complexity of the receiver qualification should be monitored.
- J.P. Fernow led a discussion on the jitter of velocity transmitted by the GNS receivers and how it impacts ADS-B.
 - Fluctuations of vertical velocity transmitted by certain receiver equipment have been observed.
 - MITRE is investigating the source of these fluctuations and may propose additional MOPS requirements.
- Jed Dennis discussed a paper identifying dual-frequency multi-constellation SBAS concepts. The paper discusses the key concepts that differentiate the DFMC SBAS from the L1 SBAS service. Feedback to the ICAO Navigation Systems Panel was to be provided by the CONOPS authoring group.
- Barbara Clark reviewed material presented to the ICAO Navigation Systems Panel regarding GNSS interference and its effects on the pilots and crew. This reinforces the need to address interference mitigation in future MOPS work.
- Laurent Azoulai presented the International Air Transport Association's perspective on dual-frequency multi-constellation GNSS.
 - IATA was particularly concerned that future MOPS should reduce the reliance on any single GNSS element.

- IATA was also concerned that every effort should be made to discourage the discrimination against any GNSS element that complies with the ICAO requirements.
- IATA would encourage the use of performance-based selection of GNSS elements and ask that states refrain from using mandates to force particular equipment.
- John Studenny presented a notional proposal for the structure and content of a dual-frequency MOPS. The proposal differs greatly from the existing DO-229 and from the EUROCAE WG-62 draft, but spurred much good discussion.
- Denis Bouvet provided an overview of the EUROCAE WG-62 draft dual-frequency, multi-constellation MOPS.
 - The draft follows the structure of DO-229
 - Several departures from DO-229 were also discussed including specification of smoothing filters, measurement accuracy requirements and the allocation of probability of false alarm in the SBAS L5 integrity mode.
- Ed Williams led a discussion on the impact of liability on the use of GNSS elements. In particular, a given a state may wish to preclude the use of its GNSS elements by other states to limit the liability.
 - Ed proposed to limit the use of GNSS elements based on flight information regions. This would be mechanized using an on-board database.
 - In general, working group 2 was not in favor of using additional databases and preferred a performance-based approach.
- Working groups 2 and 4 met jointly to discuss the development of the dual-frequency, multi-constellation MOPS.
 - The two working groups believe that a joint effort is required to develop the MOPS.
 - Dual-frequency, multi-constellation MOPS development can begin with just a single additional constellation.
 - It may not be necessary for all of the data in the “GNSS Table”, discussed in previous SC-159 plenary, to be completed for work to begin.
 - RTCA and EUROCAE should work together to develop a joint document to facilitate international certification.
 - The two committees believed that the dates defined in the SC-159 Terms of Reference appear challenging.

Agenda Item 4d. Review GPS/Precision Landing Guidance (WG-4) Progress and Identify Issues for Resolution

Matt Harris, co-chairman for working group 4, discussed the progress made by that group.

- Both DO-246E and DO-253D were published in the summer of 2017.
- Following the discussions with working group 2 previously discussed, working group 4 focused on VDB VHF compatibility.
 - The group discussed the fact that the current DO-253 receiver requirements do not adequately address the amount of interference to the VDB that can be generated by localizer or VOR transmitters. This is exacerbated by siting and operational constraints. The goal is to support most ILS and VOR installations without undue VDB siting restrictions by taking advantage of achievable receiver performance.

- The working group reviewed material developed by ICAO NSP/4 and the Spectrum Group. With this material, the working group
 - Agreed on the form of new VDB receiver adjacent channel interference requirements
 - Agreed on related test conditions for the adjacent channel interference requirements
 - Agreed on a concept for higher message failure rate for GAST C when overflying ILS or VOR.
- Working group 4 planned to continue ad hoc meetings in an effort to refine the MOPS requirements addressing adjacent channel interference, draft guidance to be placed in the SARPS and to refine SARPS requirements review during the working session.
- A joint meeting with the ICAO Spectrum Working Group was planned to review the validated MOPS changes and SARPS change proposals.
- It was proposed for the FAA to include the new requirements in the TSO so that the DO-253 can be updated at a later, more convenient time.
- The working group also addressed other ICD and Mops issues
 - Bruce Johnson asked the group to consider clarifying the time to reflect changes in type 2 message data in GBAS airborne receiver outputs
 - Barbara Clark described a potential problem with DO-253D DSIGMA requirements.
- The working group had little time to discuss the status of other GBAS working groups but noted the following.
 - The MOPS was updated to support GBAS Approach Service Type D and the RTCA PMC approved and published the document in July 2017.
 - The ICAO SARPS have been updated and the State letter review process was completed during the summer of 2017. Annex 10 Amendment 91 is expected to become applicable in the latter part of 2018.
 - The working group expects that TSO-C161 and TSO-C162 will be updated in first part of 2018.

Agenda Item 4e. Review GPS/Interference (WG-6) Progress and Identify Issues for Resolution

Sai Kalyanaraman, discussed the Working Group progress in the development of DO-235C.

- Several updates were made to the DO-235C link budgets. The Galileo E1 Open Service budget closes
- There were some potential issues in the L5 band remaining to be discussed including L-band Digital Aeronautical Communications System and Airborne TACAN stations.
- The link budget for GPS L1 C/A did not appear to close. Further investigation is required.
- The draft DO-253C was available for comment. The working group will meet approximately every two weeks to resolve open issues. The plan is to have the document available for Final Review and Comment by February 2018.

Agenda Item 4e. Review GPS/Antennas (WG-7) Progress and Identify Issues for Resolution

Sai Kalyanaraman, discussed the Working Group progress in the development of a dual frequency antenna MOPS.

- Working Group 7 has been working jointly with EUROCAE to develop a dual-frequency antenna MOPS.
- As discussed previously, feedback was needed from antenna manufacturers to ensure the antenna can be realized at a reasonable cost.
- A draft version of the MOPS was made available and antenna manufacturers we asked to provide feedback.

Agenda Item 5. Review of EUROCAE Activities and Discussion of Joint Activity with EUROCAE on a Dual-Frequency, Multi-Constellation GNSS Receiver MOPS

Pierre Durel presented an overview of the activities of EUROCAE WG-62 during their 43rd meeting.

- WG-62 has made the following recent progress in the development of their GPS/Galileo/SBAS MOPS
 - The working group reviewed draft version 0.4.
 - The group received a briefing from Stanford University regarding actions assigned to the IWG during the MOPS review.
 - The working group determined that there is a need for the ICAO dual-frequency, multi-constellation, SBAS SARPs to be aligned with the MOPS developed by WG-62.
- The WG-62 Galileo ad hoc session has been working on the Galileo OS MOPS document as well as on the NeQuick ionospheric model.
- The WG-62 multi-frequency, multi-constellation ad hoc session discussed a variety of topics including concept of operations document, miscalculation of tropospheric delays, modeling of ionosphere-free residuals, the probability of GPS constellation failure and the behavior of signals impacted by ionospheric scintillation.

Laurent Azoulai discussed the progress made by WG-28

- A proposed draft of ED-114A, change 1 has been completed and entered the Final Review and Comment process. The proposed changes included corrections to some formula, as well as updates to the continuity and integrity risk diagrams to use consistent units.
- A draft of ED-114B had been started. This revision was intended to support GAST-D approach. Issues related to adjacent channel interference were not resolved. Work at RTCA regarding adjacent channel interference must be completed before this effort can be completed.

Agenda Item 6. Update on ICAO/Navigation Systems Panel Dual Frequency/Multi Constellation Concept of Operations (CONOPS)

Laurent Azoulai noted that this material was largely addressed during the Working Group 2 briefing discussed above. He went on to ask for volunteers for an ad hoc authoring group to provide feedback to the ICAO NSP for the CONOPS.

Agenda Item 7. Discussion of Terms of Reference Updates

The assembled team discussed several modifications to the terms of reference for SC-159. The version of the terms of reference document to be updated was available on the RTCA workspace.

- The leadership team planned to meet with EUROCAE to coordinate when work products can be completed.
- The team will update the dates in the terms of reference document based on discussions that were held during the 99th meeting.
- The working group agreed that it was too early to update DO-253 but that modifications for the VDB adjacent channel interference would be necessary by March 2019. The team further agreed that a change 1 to DO-253 would be more appropriate than a new revision.
- The working group also determined that DO-246 should be recognized as a work product of SC-159.

Agenda Items 8 and 9. Action Item Review and Assignment/Review of Future Work

The SC-159 leadership team planned to meet in November to identify changes to the due dates of the various work products identified in the SC-159 terms of reference.

If needed, George Ligler will coordinate with Sai Kalyanaraman to set up a meeting with various GNSS antenna manufactures. This meeting will address a process for finding data that can be used to define the antenna MOPS.

Barbara Clark will work with the FAA team-members to provide clarification to WG-2C of the issues raised by the FAA during the working group meeting and provide a response by November 17.

Agenda Item 10. Other Business

There was no further discussion and the meeting concluded.

Agenda Item 11. Date and Place of Next Meeting

The 100th meeting of RTCA SC-159 was planned take place the week of March 12th, 2018. Working groups 2, 2C, 4, 6 and 7 plan to meet throughout the week beginning on Monday with the plenary session on Friday morning.

-S-
John Savoy
Secretary

CERTIFIED as a true and accurate summary of the meeting.

-S-
Christopher Hegarty
Co-chairman

-S-
George Ligler
Co-chairman