CONCEPT OF OPERATIONS (CONOPS)

FOR

DUAL-FREQUENCY MULTI-CONSTELLATION (DFMC)

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

Prepared by the ICAO Navigation Systems Panel

Contents

1. Executive Summary

1.1 Current civil aviation use of GNSS is predominantly based on a single frequency of a single GNSS satellite constellation, namely the L1 frequency of the US Global Positioning System (GPS) constellation, which provides the foundation for the global implementation of PBN and automatic dependent surveillance (ADS). Within the Russian Federation, similar applications based on a single frequency of the GLONASS constellation are in operation. In addition to PBN and ADS, GNSS is also used in many other aircraft applications that require position or time information. They include aircraft systems (such as the ground proximity warning system) that have led to significant improvements in safety. Since the introduction of GNSS in aviation, there has been increased dependency on GNSS position and time, and it is expected that this trend will continue as new applications are introduced and the conventional navigation infrastructure is rationalized.

1.2 **Evolution towards DFMC GNSS.** The evolution of the various GNSS elements[1] towards DFMC will take place gradually. GNSS constellations offering dual-frequency signals will be introduced into service during the 2020s by the United States (GPS), the Russian Federation (GLONASS), Europe (Galileo) and China (BeiDou). A number of States and regions also plan to deploy DFMC satellite-based augmentation systems (SBAS). Ground-based augmentation systems (GBAS) already support single-frequency dual-constellation GNSS and it is expected that they will evolve to support DFMC. Even after the introduction of DFMC, current GNSS services and equipment will remain a solution for many aircraft and will be supported by the DFMC infrastructure in a backwards compatible way.

1.3 **Standardization**. ICAO SARPs for DFMC GNSS core constellations and augmentation system are currently under development. The avionics industry has launched standardization activities for DFMC GNSS avionics, initially using the L1 (1575.42 MHz) and L5 (1176.45 MHz) frequencies. DFMC GNSS avionics standards will be consistent with SARPs. Initial implementation and certification on commercial aircraft is expected to follow, at a pace that will depend on the costs and benefits for the initial capabilities. The timeline of ICAO and industry developments suggests that the initial operational introduction of DFMC GNSS would occur in the 2025 - 2028 timeframe. In the long term, it is expected that avionics standards will be available to enable the use of all DFMC GNSS elements and signals.

1.4 **Benefits**. DFMC GNSS can improve robustness and navigation performance. The use of dual frequencies will help mitigate vulnerabilities in respect of ionospheric disturbance and of radio frequency interference affecting a single frequency. The availability of multiple constellations will contribute to mitigate ionospheric scintillation and the risk of having insufficient satellites within a single constellation. These technical improvements will enable operational benefits in terms of safety and efficiency, such as improved operational reliability for CNS applications, increased deployment of 3D instrument approach operations worldwide in line with ICAO PBN Global goals, introduction of innovative operational concepts and applications, and continued rationalisation of conventional navigation aids. The value of these operational benefits will vary among different stakeholders. The actual achievement of the benefits will depend on

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[1] GNSS elements are defined in Annex 10, Volume I, Chapter 3, 3.7.2.2. They include GNSS core satellite constellations, augmentation systems and aircraft receivers.

GNSS service performance capabilities, the percentage of aircraft equipped with DFMC avionics, the number of GNSS elements in use, the ability of DFMC to support existing operational procedures, and its ease of integration within the existing ATM system.

1.5 **Long-term goal.** GNSS is a seamless, global system that broadcasts signals that can be received independent of airspace boundaries. In order to fully achieve the benefits associated with the seamless nature of GNSS, a desirable long term goal is that all States be able to accept for lateral navigation use[2] in their airspace all GNSS elements standardized by ICAO. Aircraft could then independently select suitable combinations of GNSS elements, subject only to compliance with the applicable SARPs and PBN navigation specifications, rather than dependent on airspace boundaries. This would increase availability and continuity of operations while limiting avionics complexity, and thus best meet aircraft operators' needs.

1.6 **Medium-term challenges** In practice, the process of acceptance of GNSS elements by States can be complex and run into hurdles that may affect the achievement of the long-term goal. In general, before acceptance for use in a State, several steps may need to be considered. They include the approval of the GNSS element for aviation use by the entity managing it, the airworthiness approval (avionics certification), the operational approval issued to the operator, and the acceptance of the use of the element for specific operations in an airspace. While the current processes addressing the first three steps provide a basis that can be directly applied to DFMC, experience has shown that institutional concerns and/or regulatory requirements may delay the acceptance of the use of GNSS elements in a given airspace, and/or lead to restrictions on their use.

1.7 **Way forward: ICAO actions.** In order to facilitate the progress towards the long-term goal against the challenges outlined above, there is a need for ICAO to develop guidance material specifically intended to assist States in minimizing regulatory and institutional hurdles to acceptance and use of current and future GNSS elements. This material would primarily be aimed to support the decision-making process of States considering the use of GNSS elements over which they do not have direct control. Additionally, there is a complementary need for ICAO to develop provisions intended for States and organizations that provide GNSS elements (e.g. core constellation providers), addressing publication of service performance standards, regular performance assessments, and notification of events that may affect the service. Such provisions, fully aligned with the Charter on the Rights and Obligations of States Relating to GNSS, would further guide on its implementation and facilitate the acceptance of GNSS elements by other States by making available information that would assist their decision-making process. These ICAO developments will have to be coordinated with recognized standard making organizations and other aviation stakeholders to ensure that all the dimensions of the challenges are fully addressed.

1.8 **Way forward: States' actions.** States should be aware of the long-term goal outlined above and should aim to achieve it to the extent possible. In particular, States should note that

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[2] GNSS is used for lateral navigation in PBN applications for oceanic, en-route, terminal area navigation, and for RNP AR, LNAV and BaroVNAV approaches. The GNSS elements used for approaches with vertical guidance based on GNSS and defined by a final approach segment data block will continue to be specified by States through the information contained in the data block.

restrictions on the use of GNSS elements may in some cases have a negative impact on safety by denying the associated safety benefits. Accordingly, they should avoid prohibiting the use of GNSS elements that are compliant with the applicable SARPs. States should also note that the introduction of mandates for equipage or use of specific GNSS elements in different States or regions could result in significant impact on users in terms of additional cockpit controls and procedures, crew training and maintenance support, and possibly raise human factors concerns. Accordingly, they should carefully consider and assess if mandates for equipage or use of any GNSS element are necessary or appropriate. More generally, States should recognize that lack of global uniformity in the acceptance of GNSS will increase equipment complexity and associated costs and will delay achievement of the potential benefits. States should also ensure that the ICAO provisions for publication in the aeronautical information publications (AIP) of information related to the use of GNSS elements are fully implemented.

1.9. Towards DFMC implementation: The realization of DFMC GNSS capability is a complex undertaking that is dependent on many individual Programmes and activities with cross dependencies. This CONOPS document includes a summary of the responsibilities of stakeholders, a list of proposed activities for NSP and a preliminary risk register.

2 Introduction

2.1 The use of GNSS within civil aviation has evolved rapidly and has enabled new navigation capabilities and operations in all phases of flight. In particular GNSS is an essential element of the ICAO Performance Based Navigation (PBN) Concept and, as the performance of GNSS and avionics capability has progressed, has allowed the evolution of new PBN Navigation specifications. This DFMC GNSS Concept of Operations (CONOPS) document is based on the experience gained with single-frequency GNSS and focuses on the evolution, to the introduction of the new GNSS technology in aviation.

2.2 ICAO SARPs for single-frequency (L1) GPS and GLONASS elements [3]and augmentations already exist, and the constellations have been in service for many years. SARPs for dual-frequency GPS and GLONASS need to be developed. Development of ICAO Standards for two additional dual-frequency GNSS constellations, BDS and Galileo, is in progress. These elements will be declared operational in the coming years. In the future, all of these dual-frequency GNSS constellations are expected to be offered to ICAO for use by international civil aviation. Evolutions of ABAS, GBAS and SBAS augmentations to accommodate these new constellations and signals are also being developed and corresponding SARPs are being prepared.

2.3 Understandably, States, and regions that have invested in the development of GNSS infrastructure wish to see those investments make a positive contribution to the benefit of national and international civil aviation operations. Once tangible operational benefits of DFMC GNSS is proven, individual airspace user including aircraft operators will consider equipping and using DFMC GNSS if specific operational benefits outweigh associated investment costs.

2.4 It has long been recognised that the inclusion of a second GNSS frequency band together with multiple GNSS constellations has the potential benefit of improving the robustness [4] of GNSS positioning by providing mitigations to GNSS vulnerabilities, such as improved ionospheric delay determination, radio frequency interference on a single frequency and improved satellite geometries, through the provision of additional ranging sources in different frequency bands.

2.5 The 12th Air Navigation Conference in 2012 made the following Recommendation:

Recommendation 6/6 – Use of multiple constellations

That States, when defining their air navigation strategic plans and introducing new operations:

a) take advantage of the improved robustness and availability made possible by the existence of multiple global navigation satellite system constellations and associated augmentation systems;

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[3] GNSS elements are defined in Annex 10, Volume I, Chapter 3, 3.7.2.2. They include GNSS core satellite constellations, augmentation systems and aircraft receivers.

[4] **Robustness** In the context of the CONOPS robustness refers to the ability to tolerate Ionospheric disturbances and RF Interference that might affect the operation of the GNSS receiver.

b) publish information specifying the global navigation satellite system elements that are approved for use in their airspace;

c) adopt a performance-based approach with regard to the use of global navigation satellite system (GNSS), and avoid prohibiting the use of GNSS elements that are compliant with applicable ICAO Standards and Recommended Practices;

d) carefully consider and assess if mandates for equipage or use of any particular global navigation satellite system core constellation or augmentation system are necessary or appropriate;

That aircraft operators:

e) consider equipage with GNSS receivers able to process more than one constellation in order to gain the benefits associated with the support of more demanding operations.

2.6 This CONOPS document has been prepared by the ICAO Navigation System Panel (NSP) in response to the Air Navigation Commission assignment to progress Recommendation 6/5 from the 12th Air Navigation Conference (a companion Recommendation to Recommendation 6/6, addressed to ICAO). An ICAO Secretariat Paper will be presented to the 13th ANC summarising the main aspects addressed in this CONOPS and proposing some recommendations for the way forward.

2.7 The NSP in isolation cannot define this concept of operations and this document is a vehicle to stimulate and facilitate discussions with other standardisation bodies such as other ICAO expert groups (e.g. Instrument Flight Procedures Panel (IFPP), Flight Operations Panel (FLTOPSP), PBN Study Group (PBNSG)), and external groups, RTCA, EUROCAE, the International SBAS and GBAS Working Groups, groups working on ARAIM, as well as other key stakeholders from the user community (States, ANSPs, avionics manufacturers, air traffic controllers, aircraft operators, airspace users,..). All of these parties will need to be involved, convinced and committed, in order to ensure that the DFMC GNSS CONOPS can be implemented.

2.8 This CONOPS addresses the combined use of multiple core constellations broadcasting signals in two frequency bands that are protected for aviation use. However, it does not preclude the implementation of solutions relying on the use of a single constellation broadcasting in two frequency bands or of a single-frequency signal from one or more core constellations.

2.9 Therefore this CONOPS aims at enabling a common framework for implementation among stakeholders to enable a safe and cost effective transition to DFMC GNSS considering technical, interoperability, operational, economic and institutional aspects.

2.10 Ultimately, the uptake of GNSS future multi-constellation avionics will depend on the business case for an individual aircraft operator, as determined by the expected operational benefits and the associated costs and challenges to be met. Usage and equipage requirements for DFMC GNSS should be performance-based and driven by expected tangible operational improvements.

3 Goal and Scope of the Document

3.1 Goal

3.1.1 The goal of the DFMC GNSS CONOPS is to reach consensus between stakeholders on how new GNSS technology will be introduced in ATM in a safe and cost-efficient manner bringing operational benefits while addressing identified technical and institutional challenges and retaining backwards compatibility. A key principle of the new DFMC GNSS technology is that current safety levels be maintained.

3.2 Scope

3.2.1 In order to meet these goals the concept of operations will specifically address the following aspects:

- Define available and emergent GNSS systems and services; (section 4)
- Assessment of operational benefits; (section 5)
- Service provision and institutional frameworks and the approval by States for the use of GNSS elements in their airspace (section 6)
- Describe at high level the main avionics requirements and architectures for DFMC avionics.; (section 7)
- ATM applications and services with a current and/or future predicted dependency on airframe GNSS capability or capabilities; (section 8)
- A preliminary high-level implementation timeline covering GNSS systems developments, standardisation (MOPS and SARPs), receivers' certification and operational implementation in ATM and a high level assessment of key risks. (section 9)
- A summary of the roles and responsibilities of identified stakeholders; airspace users, constellation service providers, regulatory authorities, ANSPs, and States within the operational framework; (section 10)
- A list of outstanding activities for future work; (section 11)

3.2.2 An initial version of the document was distributed for consultation to other ICAO Panels, PBNSG, ICAO Regional Offices and external entities, including SBAS IWG and the International GBAS WG, recognized standards-making organizations (e.g. RTCA/Eurocae). The purpose of the consultation was to commence the coordination to harmonize the vision, concept, and goals of the various stakeholders with those of NSP. Comments received from the external review have been considered in the update of the CONOPS.

3.2.3 This CONOPS proposes developing provisions that once agreed by stakeholders, may be taken by other panels for inclusion in future SARPs and should be reflected in receiver MOPS.

3.2.4 The definition of contingency operations in the event of GNSS being unusable is a current issue that is not unique to the introduction of DFMC GNSS and is therefore considered to be outside the scope of this CONOPS document. Noting that the use of multiple constellations will improve the robustness of GNSS and therefore reduce the likelihood for contingency operations compared to current use based on GPS L1 only.

4 Future GNSS System overview

4.1 Interoperability

4.1.1 Maintaining interoperability between services and airborne equipment with DFMC GNSS presents some new and unique challenges which include: system complexity to manage new signals and GNSS elements, transition between States with different GNSS element approvals and augmentation systems which could augment different combinations of GNSS constellations or signals that may result in longer acquisition times. Interoperability is fundamental to maximizing the benefits offered by GNSS, and even more so as DFMC GNSS emerges. While not essential in every regard, it simplifies standards for acceptance, improves backward compatibility, and enhances the multi-purpose capabilities of equipment when able to leverage commonalities of signals, messages, and interpretation.

4.1.2 Coordinate Frame Aspects

4.1.2.1 GNSS elements each have a reference datum to which the respective measurements are referenced. These datums are very close but not identical. Errors due to differences in system reference datum will typically be small. Safety assessments need to determine if the errors are significant and conversion algorithms need to be developed to properly account for them if they are found to be significant.

4.1.2.2 ICAO has standardized on WGS-84 as the reference datum for all aeronautical information publication. Consequently, the output of the navigation sensor should be referenced to WGS-84 regardless of the GNSS elements used.

4.1.3 Timeframe aspects

Each of the four core constellations maintains it's own system time. Variations in system time from one core system to the next become significant when measurements from multiple systems are combined. Multi-constellation receivers need to account for the time offset between multiple constellations[5].

4.2 Core Constellations

The CONOPS does not set an upper limit on the number of core constellations that could be used by civil aviation in the long term. The CONOPS addresses the near to mid-term in which the GNSS system will make use of one or more of the four core constellations providing dual frequency global services for which SARPs either already exist or are under active development: GPS, GLONASS, Galileo, BDS. It is also expected that Japan will propose material to develop ICAO SARPs for QZSS.

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[5] While previous designs relied on a broadcast time offset, current technical assessment is that receivers should estimate the time bias for each constellation. This better addresses the variation in differential group delay introduced by the receiver

4.2.1 United States' Global Positioning System (GPS)

The GPS modernization program will introduce GPS III satellites and a new ground control segment. The GPS modernization program will provide three new civil signals with three of the four civil signals (L1 C/A, L1C and L5) being located within bands appropriate for aviation use. These signals were selected to be compatible and interoperable with other constellations' signals. L5 Full Operational Capability provided by 24 satellites is planned for 2025.

4.2.2 Russian Federation's GLObal NAvigation Satellite System (GLONASS)

GLONASS has 24 satellites and is fully operational for aviation use in the L1 frequency band using frequency division multiple access (FDMA). GLONASS will implement code division multiple access signals (CDMA) in the L3 band on all satellites by 2021. The further implementation of L1 CDMA signals is planned to be completed by 2028 and retain backward compatibility with the FDMA signals.

4.2.3 The European Union's Galileo

Galileo is currently deploying satellites to populate and validate the constellation. Galileo will provide E1 and E5 signals for aviation use and these signals are compatible and interoperable with GPS L1 C/A, L1C and L5. The Full Operational Capability of Galileo with 24 satellites is planned for 2020.

4.2.4 China's BDS

BDS is currently deploying satellites to populate and validate the constellation. BDS will provide B1I, B1C and B2a signals for aviation use and the B1C and B2a signals are compatible with L1C and L5. The space part of the BDS satellite constellation is composed of 24 MEO working satellites, 3 IGSO working satellites and 3 GEO working satellites, and deployed backup satellites according to the actual situation.

4.3 DFMC SBAS

4.3.1 The SARPs for single-frequency SBAS are published and four SBAS are operational, namely EGNOS, GAGAN, MSAS and WAAS. Other SBAS systems are being developed in a number of States such as SDCM by the Russian Federation, BDSBAS by China, KASS by South Korea and ASECNA SBAS (SBAS for Africa and Indian Ocean) by ASECNA States.

4.3.2 The ICAO NSP is developing draft SARPs for SBAS DFMC services. The draft SARPs propose that the SBAS L5 signal will provide the capability to support augmentation of core constellations dual frequency measurements.

4.3.3 SBAS service providers continue to expand SBAS services and improve the capabilities of existing systems. These improvements will increase SBAS service areas and provide mitigation against identified GNSS vulnerabilities, including RF interference, ionospheric disturbances and core constellation satellite failure, as described in the following paragraphs:

- WAAS modifications are being developed to provide a dual-frequency service. While doing so, improvements to integrity algorithms are being developed to improve availability and continuity. When a sufficient number of L1/L5-capable GPS satellites are operational, the dual-frequency service will be introduced using the L5 signal on WAAS GEOs, in addition to the single-frequency SBAS service using GEO L1 signals.

- The transition of the MSAS geostationary broadcast from MTSAT to QZSS geostationary satellites is in progress and the development is planned to provide satellite-based augmentation to future GNSS core constellations using the L5 augmentation signal from QZSS geostationary and non-geostationary satellites.

- An EGNOS upgrade (EGNOS V3) is under development that will augment Galileo E1 and E5a and GPS L1 and L5 signals. The dual-frequency augmentation of two core constellations will provide improved geometry and can be expected to provide lower protection levels and higher levels of continuity.

- The Russian Federation has made progress in the development of SDCM and in the future, SDCM is planned to be upgraded to provide dual-frequency augmentation of GPS and GLONASS satellites.

- The development of China's BDS Satellite-based Augmentation System (BDSBAS) is in progress and is planned to provide a dual-frequency service augmenting BDS and GPS and will consider augmenting GLONASS and Galileo in a later stage.

- India is developing a plan for GAGAN to augment GPS L1 and L5 signals in the 2025-28 timeframe. In the future, India may develop GAGAN to augment additional constellation based on the experience and benefits gained by other States.

- The development of the ASECNA SBAS is in progress and is planned to upgrade L1 initial services, to be provided from 2021/2022, to augment GPS and Galileo beyond 2028-2030.

4.3.4 It is expected that that SBAS systems providing a SBAS L1 service that will evolve to provide DFMC services, will continue to provide a SBAS L1 service to maintain backwards compatibility supporting SBAS L1 equipped users. SBAS systems not providing a SBAS L1 service may decide to provide only a DFMC service on the L5 frequency.

4.4 DFMC GBAS

4.4.1 The SARPs for single-frequency Category-I precision approach are published with many deployed systems. These SARPs already support dual-constellation systems providing augmentation for GPS and GLONASS. The SARPs Annex 10, Amendment 91 to support single-frequency operation for Category II/III operations based on GPS, have been adopted. The Russian Federation has deployed dual-constellation avionics and ground stations.

4.4.2 International development activities for DFMC GBAS are already in progress. The current baseline within the GBAS SARPs Working Group is that the DFMC GBAS will provide augmentation for one or two core constellations, although this may be revised as the ICAO NSP develop the DFMC GBAS SARPS.

4.5 DFMC ABAS: ARAIM

4.5.1 Receiver Autonomous Integrity Monitoring (RAIM) techniques have been widely use in aviation as ABAS augmentation to GNSS. Those techniques are currently based on a single failure hypothesis at any time of operation. In a multi-constellation environment, the availability of a large number of satellites allows for a relevant increase in the level of service. At the same time higher number of satellite in view will likely increase the probability of having multiple failure on satellites. Multiple failure or constellation failure probabilities cannot be neglected in multi-constellation GNSS operations.

4.5.2 Advanced RAIM (ARAIM) techniques are being developed as an ABAS augmentation for use under multi-constellation operations for which SARPs are being developed. ARAIM will allow increased service level globally and includes a monitoring capability of multiple faults up to constellation faults using information included in an integrity support message (ISM) and fault detection and exclusion capability when satellites faults occurred. The ISM is generated by an ISM Generator (ISMG) approved by the state's regulator of the ISMG. The ISM is associated to a specific core constellation. The ISM contents information on individual satellite failure probability, constellation failure probability, multipliers of the broadcasted sigma of the clock and ephemeris error for a satellite to be used for integrity or for continuity/accuracy, nominal bias, satellite mask for use in ARAIM, mechanism to trace the ISM generator and mechanism to trace the safety hazard of the ISM (i.e. for horizontal application only or for vertical guidance).

4.5.3 ARAIM takes benefits of the GNSS modernisation programs which include new frequencies and new constellations for future use in aviation. ARAIM has been developed to support en-route down to non-precision approach including RNP 0.1 NM capability. This initial capability is labelled Horizontal ARAIM (H-ARAIM) and is supposed to be part of the next generation of GNSS equipment being developed within EUROCAE/RTCA bodies. ARAIM also targets further service enhancements including global CAT-I precision approach in a next step, which requires further technical and safety analysis. This will be achieved through the Vertical ARAIM (V-ARAIM) and will be further consolidated based on the lesson learnt on H-ARAIM.

4.6 DFMC ABAS INS

4.6.1 The majority of commercial air transport aircraft with GNSS (GPS or GPS and GLONASS) capability currently combine GNSS and inertial measurements; however the GNSS and inertial integrations vary widely between manufacturers in their physical realizations, functional capabilities and technical performance.

4.6.2 The benefits from the integration of additional GNSS elements into an existing ABAS (GPS/Inertial) system needs to be considered further by the industrial standardisation bodies to determine the optimum architectures.

4.6.3 It is not expected that any additional provisions will be required within SARPs to facilitate the integration of DFMC GNSS and inertial systems.

5 Operational Benefits of DFMC GNSS

This section presents an assessment of the technical benefits to improve performance and address the known GNSS vulnerabilities and the derived operational benefits that DFMC GNSS receivers that integrate augmentations (e.g. ARAIM, DFMC GBAS and DFMC SBAS), could bring with respect to current GNSS receivers.

5.1 Technical benefits.

5.1.1 DFMC GNSS integrating augmentations (e.g. ARAIM, DFMC GBAS and DFMC SBAS) can provide technical benefits in terms of improved performances (e.g. improved availability and continuity), larger SBAS service areas, capability to support CAT III operations based on GBAS at airports located in all latitudes and lower protection levels. These technical benefits are enabled mainly by the increased number of ranging sources and allocation of ionosphere delay mitigation to the airborne receiver. These technical capabilities would allow mitigating ionosphere gradient induced errors that is critical for approach operations.

5.1.2 Additionally, DFMC GNSS can improve robustness by mitigating identified GNSS vulnerabilities as described in the table below.

Vulnerability	**Mitigation**	**Method**
Vulnerability to ionospheric delay and delay variation caused by Space Weather.	Removal of large unpredictable ionosphere delay at expense of additional receiver noise and small residual ionosphere error	Requires avionics to process two frequencies from GNSS satellites.
Vulnerability to scintillation caused by Space Weather. (e.g. ionospheric irregularities)	Through increased numbers of GNSS satellites in view.	Requires avionics to process and use ranging signals from dual frequencies and various GNSS constellations.
Vulnerability to RF Interference in individual frequency bands.	Through avionics processing GNSS signals independently on different frequencies.	Requires avionics to independently process GNSS signals on different frequencies.
Vulnerability to core constellation fault.	Through increased numbers of GNSS constellations.	Requires avionics to process and use ranging signals from multiple GNSS constellations.
Poor dilution of precision due to poor geometry or terrain/obstacle screening.	Through increased numbers of navigation satellites in view.	Requires avionics to process and combine ranging signals from multiple GNSS constellations.

5.1.3 In addition to the mitigations that are derived from the availability of additional constellations and signals, it is also anticipated that the DFMC GNSS receivers and antennas will include superior technologies and algorithms that will improve the performance of the new receivers compared to the current generation, particularly with regards to radio frequency interference (RFI) .

5.2 Operational Benefits

5.2.1 The technical benefits described in the previous section enable the operational benefits are summarised in the table below.

5.2.2 This is a generic assessment of operational benefits that will be provided by DFMC to meet ATM demands with a 20 year time horizon.

	Benefit	Examples
1	**IMPROVED BUSINESS CONTINUITY** DFMC GNSS will improve availability and continuity of Positioning and Time distribution to increase the robustness of CNS and time systems and applications currently based on GPS L1. This will result in a risk reduction benefit in ATM systems and to every flight that improves the business continuity to airspace users.	• En-route/Terminal airspace (TMA): Reduced likelihood of reversion to DME/DME or INS that may impact capacity. • Final approach: Reduced missed approach rates for RNP APCH and RNP AR APCH and reduced likelihood to revert to conventional approaches. • Improved continuity in remote/oceanic/high latitude areas. • Improved continuity in areas with poor conventional navaid infrastructure. • DFMC will provide increased continuity of ADS-B surveillance that is of particular interest in non-radar airspace. • Reduced likelihood of a GNSS element failure affecting PBN and ADS-B applications simultaneously. • Support of reduced separations in Oceanic airspace assuming adequate communications capabilities. • Diversity of constellation and frequencies providing time reference for CNS/ATM airborne and ground systems and applications. The ability to use system time from multiple core constellations reduces the criticality of and dependence on GPS time by permitting comparison of time with independent sources.

2	**IMPROVED 3D APPROACHES** Vertical guidance worldwide[6] for all users to allow stabilized geometric approaches providing a reduction in CFIT accidents.	• Reduce the operational reliance and operational risk of incorrect QNH setting during in barometric VNAV approaches through the uses of SBAS, GBAS and VRAIM. This is of particular relevance for regions with limited QNH information availability. It is not intended to change from barometric altimetry (or radio altimeter) to provide an independent height reference for determination of Decision Height • Extension of SBAS APV I and CAT I service areas, particularly in equatorial regions. • Introduction of SBAS approaches with minima less than 200' and autoland (for autoland capable aircraft). • World wide availability of a robust CAT II/III service based on DFMC GBAS . • In the long term, worldwide CAT-I services based on vertical ARAIM.
3	**INNOVATION** In the long term, (2030+) DFMC is expected to enable new concepts and applications that in some cases cannot be imagined today. e.g. to support applications being researched within Next Gen, SESAR and CARATS. The CONOPS for the specific new applications is outside the scope of this CONOPS and will be prepared by others.	The benefits listed below identify some applications where improved performance may enable the support of innovative operational concepts/applications that may not be currently possible or considered: • Robust navigation and surveillance for all airspace users including Remotely Piloted Aircraft Systems (RPAS) and space planes. • The introduction of DFMC ABAS will enable to increase the percentage of the fleet with capability of geometric vertical navigation in TMAs that nowadays is limited to aircraft equipped with SBAS and/or GBAS. • In the future increased robustness may support future more demanding PBN specifications with very high availability. • New types of approach capabilities, such as CAT I / CAT II autoland or RNP AR APCH without the need for hybridization with inertial to sustain operational continuity. • Formation flying. • Support new ADS-B applications worldwide. e.g

[6] Approaches with Vertical Guidance (APV) was the subject of Assembly Resolution A37-11. DFMC is the enabling technology for GNSS CAT I to be available globally.

		- Traffic Situation Awareness with Alerting, - Detect and Avoid (DAA) for RPAS, - Enhanced airborne situation awareness for the airport Surface with Indications and Alerting (SURF-IA), - Paired Approach Blunder Detection.
4	**AIRBORNE EQUIPMENT** Rationalization of airborne equipment.	Potential for expanding equipment substitutions (e.g. authorizing substitution of DFMC GNSS receiver of ADF equipment)
5	**FLIGHT PLANNING** No need for RAIM prediction under certain conditions.	Removal of the need for operators to perform RAIM prediction. Due to increased numbers of satellites used for positioning, it is anticipated that it will be unnecessary to predict RAIM availability when positioning is determined combining ranging sources from multiple constellations assuming that at least 2 constellations will be accepted by States managing the airspace in which the flight operates. This needs further research to assess the potential limitation of this benefit when using Vertical ARAIM.

5.2.3 Different operational benefits can be obtained in terms of safety, increased accessibility, fuel savings, weight saving, delay reduction, training reduction, cost reduction, etc. However the realization of benefits depends on market segment (e.g. commercial air transport, general aviation, business jet and rotorcraft) considering the capabilities of aircraft and their operational conditions. The benefit related to the "improved business continuity" is more relevant to aircraft having GNSS as the only navigation system (e.g. some general aviation or regional aircraft) than to aircraft having also DME/DME and INS systems that already provide a robust navigation capability. On the other hand, for aircraft already equipped with SBAS, DME/DME and INS (e.g. A 350) the most promising benefits identified could be the extension of SBAS CAT I and APV I service areas, and the potential to have SBAS approaches with minima less than 200' and enabling CAT I autoland provided aircraft and crews support this capability.

5.2.4 Realizing operational benefits will be in proportion to GNSS service provider performance capabilities, percentage of aircraft equipage with proper technology, and publication of enabling aerospace procedures by states. To maximise the benefit, it is important to encourage all aircraft to have comparable capabilities as this increases the airspace efficiency. For approach operations it is easier to allow benefits to be obtained by individual aircraft in line with a 'Most Capable Best Served' approach that should reward early adopters.

5.2.5 Obtaining the identified benefits depends on State acceptance of DFMC elements in their airspace. In particular, if a State does not accept several GNSS elements in its airspace, the DFMC benefits will be significantly eroded.

6 Service provision aspects

6.1 Background

The Charter on the Rights and Obligations of States relating to GNSS Services (ICAO Assembly Resolution A32-19)[7] established high level principles applicable to DFMC GNSS. ICAO Assembly Resolution A39-11, Appendix F, "A Practical Way Forward on Legal and Institutional Aspects of Communications, Navigation, Surveillance/Air Traffic Management (CNS/ATM) Systems", reaffirmed that there is no need to amend the Chicago Convention for the implementation of CNS/ATM (including GNSS) and invited contracting States to also consider using regional organizations to address any legal or institutional issues that could inhibit implementation.

6.2 Roles and responsibilities of GNSS element providers

6.2.1 Core Constellation Service Providers and ISM generators for ARAIM

6.2.1.1 Signals from core constellations are always used in combination with ABAS, SBAS or GBAS to provide final navigation services to aviation users. Core constellation service providers do not establish bi-lateral contractual relations or agreements (e.g. service level agreements) with other States or SBAS or GBAS service providers, however they provide letters of commitment to ICAO to comply with respective SARPs that are adopted by the ICAO Council under the provisions of the ICAO Convention. ICAO accepted the offers made by the United States on GPS, and the Russian Federation on GLONASS. It is expected that a similar mechanism will be made for new elements and signals (e.g. GPS L5, GLONASS L3, Galileo and BDS). Core constellation service providers are expected to publish and comply with signal (or interface) specification and performance standards, to provide timely service status notifications that can be used to allow the preparation of NOTAMs and to publish periodic performance reports demonstrating compliance with respect to SARPs. These performance reports should be in line with GNSS monitoring provisions in the GNSS manual and may be used by States in support of the use of core constellations.

6.2.1.2 The Integrity data required to support ARAIM augmentation is still under development and is expected to be provided through an Integrity Support Message (ISM) generated by an ISM generator entity (ISMG) for a specific constellation. The ISM parameters are derived from the GNSS constellation performance commitment and measurements observed through a network of ground stations. It is expected that there will be a single ISMG per constellation who needs to be approved by the regulator in its country of origin in accordance to the ISM standards that are expected to be included in future ICAO SARPs contained in Annex 10. Proper mechanisms have to be set up between the ISMG entity and the dissemination channel of the ISM to ensure the data integrity. The dissemination scheme can be either through GNSS signals or through other means to be identified and is independent from the generation of the ISM content.

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[7] It is referred as "GNSS charter" in this CONOPS.

6.2.2 SBAS Service Providers

6.2.2.1 An SBAS service provider is responsible for offering services augmenting one or more core constellations according to SARPs. Letters of commitment will be sent to ICAO declaring compliance with SARPs. Different SBAS systems may augment different GNSS core constellations and frequencies. In some cases, when an SBAS service is provided to multiple States, Service Level Agreements may be put in place between States or between the SBAS service provider and ANSPs that define the responsibilities of the parties and the services that will be provided. SBAS Service Providers are expected to define their services and to ensure initial and continuing approval processes maintain compliance with the SARPs. SBAS service providers are expected to provide timely service notifications to allow the preparation of NOTAMs and to publish periodic performance reports demonstrating compliance with respect to SARPs.

6.2.3 GBAS Service Providers

6.2.3.1 A GBAS Service Provider offers services augmenting one or two core constellations according to SARPs. An ANSP operates a GBAS to support approach operations to a specific airport and/or provide lateral positioning service in the region around the GBAS ground station.

6.3 GNSS approvals[8]: current situation

6.3.1 As declared in the GNSS Charter, every State preserves its authority and responsibility to control operations of aircraft and to manage safety and apply regulations within its sovereign airspace. To use a particular GNSS element in a State different types of approvals have to be considered:

1. GNSS element technical approval. Before any GNSS element can be considered for aviation use, the system must be approved and the service must be offered[9] for aviation use. GNSS element approvals can be applied to core constellations and their signals (e.g. GPS L1 and L5), SBAS and GBAS systems. In some cases, SBAS and GBAS service providers are subject to regional/national certification processes. Currently GPS and GLONASS services are approved for multi-modal use by the US and Russian Federation respectively, whereas SBAS and GBAS are approved by regional or national aviation authorities (e.g. GAGAN was developed by the Airports Authority of India and was technically approved by its regulatory authority DGCA, GBAS stations are technically approved by the local aviation authority).

2. Airworthiness approval applicable to airborne equipment. This approval corresponds to the aircraft and associated GNSS/Navigation equipment based on provisions in ICAO Annex 8. The airworthiness approval must ensure that avionics are only using GNSS elements[10] that have been approved and are operational for aviation use. The airworthiness approval may be issued by a regional Regulator or the Regulator in the State of the aircraft manufacturer with possible

[8] The terms accept, approve, authorized and certified may have different meanings when used in different States and/or different contexts (e.g. GNSS service approvals, Airworthiness approval, Operational approval, GNSS elements approval in given airspace).
[9] Letters are sent by a State, or group of States operating SBAS or core constellations offering GNSS service to civil aviation.
[10] Examples: Using SBAS systems not broadcasting M Type 0, or having a PIN programming capability to enable using core constellation or signals (e.g. Galileo, GPS L5,..) when these elements will be approved, are SARPs compliant and offered for aviation operations.

participation from other State Regulators. FAA, EASA and CAAC also issue Technical Standing Orders (TSO/ETSO/CTSO) approvals for individual equipment items including GNSS avionics. Similar processes for national equivalents of TSOs are in place or planned to be progressively applied by regulators from other States.

3. Operational approval applicable to operators. Many State Regulators issue operational approvals to commercial operators registered in that State with approval applicable for both domestic and international operations based on provisions in ICAO Annex 6. Operators may also be subject to Operational approval by States where they are conducting operations. The Operational approvals contain specific authorizations, limitations and conditions that relate to specific phases of flight and are detailed in operations specifications.

4. GNSS elements acceptance in given airspace. States are responsible for accepting the use of GNSS elements in their airspace applicable to aeronautical flight procedures. State Regulators issue acceptances of navigation signals, required navigation specifications and individual Instrument Flight Procedures. These acceptances are promulgated in the State Aeronautical Information Publication (AIP) and are the basis of the procedures that are coded in aircraft navigation databases. Many States have not so far promulgated acceptances for all operational GNSS elements for all phases of flight and have not defined the conditions under which GNSS elements may be accepted for navigation in their airspaces.

Example: There is a WAAS system approval by the US /FAA that corresponds to the GNSS element technical approval (first bullet above). The use of WAAS is accepted by Canada for En route and LPV approaches, this corresponds to GNSS element acceptance in the Canadian airspace (forth bullet above). Airworthiness and Operational approvals (second and third bullets above) are granted by Transport Canada for aircraft and operators registered in Canada.

6.4 GNSS approvals: the long-term goal

6.4.1 GNSS, through its elements compliant with ICAO SARPS, is a seamless, global system that broadcasts signals that can be received by all airspace users irrespective of airspace boundaries. The GNSS Charter states that "*every State and aircraft of all States shall have access, on a non-discriminatory basis under uniform conditions, to the use of GNSS services, including regional augmentation systems for aeronautical use within the area of coverage of such systems*".

6.4.2 While some States' may require the use of a specific GNSS element, aircraft operators' needs are best achieved if aircraft can make a selection of combinations of GNSS element subject only to compliance with the applicable SARPs and PBN navigation specifications, rather than limited by State's airspace acceptances. This would enable DFMC GNSS avionics to achieve increased performance and robustness enabling identified operational benefits with reduced avionics complexity.

6.4.3 States have different regulatory requirements and institutional aspects that are considered in their approvals. However, they should give serious consideration to the fact that restrictions on the use of GNSS elements may in some cases have a negative impact on safety by denying the safety benefits that can be achieved through those GNSS elements. Accordingly, States should avoid prohibiting the use of GNSS elements that are compliant with the applicable SARPs. With regard to the introduction of mandates for specific GNSS elements in different States or regions, such mandates could result in significant costs for users in terms of additional cockpit controls and procedures, crew training and maintenance support, and possibly raise human factors concerns.

6.4.4 **The desirable long term goal is that all GNSS elements that are compliant with SARPS and have been accepted by ICAO[11] can be used in all States for lateral navigation[12] to facilitate interoperability, improve safety and increase effectiveness throughout the aviation community.** The GNSS elements used for approaches with vertical guidance based on GNSS that are defined by a final approach segment data block will continue to be specified by States through the information contained in the data block.

6.4.5 Current GNSS element technical approvals, airworthiness approvals and operational approvals provide a basis that can be applied to DFMC. However, in order to progress towards the long term goal defined above, States and regulatory authorities should further develop agreements on mutual recognition of these approvals in order to facilitate a seamless global use of GNSS.

6.4.6 Regarding the acceptance of GNSS elements in a given airspace the following lines of action have been identified to develop provisions to implement the GNSS Charter in order to progress towards achieving the long term goal defined above.

6.4.6.1 The GNSS Charter states that *"States and GNSS element service providers should co-operate to secure the highest practicable degree of uniformity in the provision and operation of GNSS services."* To implement this principle there is a need to harmonize the conditions and criteria to accept the use of all GNSS elements in all States. ICAO should develop comprehensive guidance material for States to facilitate the acceptance of current and future GNSS elements in their airspace addressing related aspects and identified issues and clarifying the meaning of related terms (e.g. approve, accept, certify and authorize). It is desirable that all States will ultimately publish the acceptance of GNSS elements in their Aeronautical Information Publication (AIP). The current GNSS provisions in Annex 15 and in PANS-AIM (Doc 10066) need to be adapted to DFMC GNSS and further guidance material is required. There is a need for ICAO Offices, Regional Aviation Safety Groups (RASGs) and Planning and Implementation Regional Groups (PIRGs) to play an active role in facilitating the implementation of the guidance material and promoting a coordinated approach on the acceptance of GNSS elements and promulgation in States AIPs within their regions to facilitate smooth transitions between neighboring States.

6.4.6.2 In current operations, the resolution of under-performances or anomalies of GNSS elements requires co-operation between element providers, States and industry. With increased complexities and numbers of GNSS elements and in the DFMC there is a need to develop these cooperative processes. These processes should involve GNSS element service providers, States,

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[11] ICAO acceptance to letters sent by States or group of States operating SBAS or core constellations offering GNSS service to civil aviation.

[12] GNSS is used for lateral navigation in PBN applications for Oceanic, En-route, terminal area and RNP AR, LNAV, LP and BaroVNAV approaches.

Regulators, ANSPs, industry and airspace users. Provisions in the GNSS manual on GNSS monitoring should be further developed to define actions/processes in case critical under-performances are detected. If it is determined that a certain GNSS element is not to be used in aviation this information should be notified globally (e.g. by means of ISM update for core constellations) in a coordinated way instead of having a limited number of States issuing a NOTAM on that element. New SARPs requiring GNSS element service providers to issue notifications (e.g. NANUs for GPS and NAGUs for GLONASS and Galileo and NUBUs for BDS) and to publish periodic performance reports. DFMC avionics should have the capability to deselect individual GNSS elements in the infrequent case of a contingency situation. Transparency from GNSS service providers is essential to build-up levels of trust from all States.

6.5 GNSS approvals: medium-term transition toward the long-term goal

6.5.1 In the medium-term, starting when DFMC operations are expected to be introduced in the 2025-2028 timeframe and until the long term goal is achieved, it is highly likely that States will approve the use of GNSS elements at different times and that the approval status of GNSS elements may vary significantly from one State to another. **The challenge facing ICAO, States, industry and other aviation stakeholders is to address State requirements for the use of specific GNSS elements while ensuring backwards compatibility for current equipment and limiting the complexity of DFMC avionics.** A solution to this challenge has not been agreed and there is a need to continue the discussion.

6.5.2 When facing this challenge there has been significant discussion on the impact of the different types of approvals on DFMC avionics and related backwards compatibility aspects. Different operational scenarios for airspace regarding the approval and use of DFMC GNSS elements according to the potential States' requirements (or not) on the matter:

- Airspace within which only specific GNSS elements are accepted for use for specific operations
- Airspace within which all GNSS elements are accepted for use for operations
- Airspace with no State declaration of GNSS element acceptance

To address these cases/scenarios, the following concept describes how DFMC GNSS elements should be used for a given airspace:

1) When only specific GNSS elements are accepted for use DFMC avionics should only use the GNSS elements that have been accepted by State managing airspace where the aircraft is flying.

2) When all GNSS elements are accepted for operations or there is no State declaration of GNSS element acceptance, DFMC avionics should select for lateral navigation the GNSS elements to be used subject to compliance with applicable SARPS, PBN navigation specifications and airworthiness approval requirements. This is the way current receivers are functioning today and should continue to function when the long term goal is achieved.

6.5.3 A comprehensive assessment of related technical, regulatory, economic and operational aspects to be considered along with some institutional aspects, exceed the sphere of competence of a technical panel like NSP. These possibilities for the concept implementation imply different levels of airborne avionics and operations complexity to select the appropriate set of GNSS elements but and also imply different levels of States' ability to control the use of GNSS elements in their airspace. The choice of the solution to be implemented will have an impact on the cost efficiency of DFMC avionics, and some industrial actors and operators could delay DFMC developments and adoption until the long term goal is achieved.

6.5.4 In order to reach an agreed way forward, interaction between industry and States is continuing through ICAO NSP, RTCA and EUROCAE. Appendix 2 includes preliminary functional requirements for avionics to respond to related to the State's airspace acceptance of GNSS elements and the preliminary industrial feedback on their impact on the DFMC avionics.

6.5.5 It has been suggested that the identification of the minimum State's requirements would reduce the complexity and cost of avionics and operations. As an example, if State requirements for acceptance are limited to SBAS, an implementation solution could be achieved through an additional SBAS L5 Message Type, or by DFMC avionics not using SBAS for lateral navigation, and using SBAS only for procedures controlled by the FAS datablock, avoiding the need for an FIR Database.

6.5.6 The example above illustrate that the plans, timeliness, conditions of States regarding acceptance of SBAS systems and core constellations signals, and the level of uniformity of approvals across States over time is a key aspect to be considered. However the fact that there is no established decision making process among States on this topic brings uncertainty and an associated risk that needs to be managed.

7 Industry perspective on DFMC GNSS Avionics

7.1 General

7.1.1 This section provides the avionics industry perspective about implementation and deployment of DFMC GNSS receivers into current and future aircraft in the regional, business, general aviation and air transport markets. It defines the scope of DFMC GNSS avionics, its major assumptions, feasibility and technical constraints when introducing Dual Frequency and Multi-constellation technologies, taking into account technical considerations, market needs & benefits, costs & complexity, performance and institutional requirements.

7.1.2 As is already the case with current GNSS receivers, it is expected that DFMC GNSS receivers will not be universally applicable to all types of aircraft operations and many receivers will target specific aircraft user groups or regions.

7.2 Benefits driven development of avionics to market segments

7.2.1 The initial introduction of single frequency GNSS and its augmentations delivered quantified benefits that included availability and continuity increase, lower minima, accessibility to difficult areas, reduced airport fees, more direct routes, closer separations, noise and emissions reductions, increased deployment of 3-dimensional approaches worldwide (In line with ICAO PBN Global goals), introduction of innovative operational concepts and applications and the rationalisation of conventional navigation aids. The manner in which GNSS is implemented and used on current aircraft varies significantly in terms of integration with other aircraft systems and sensors, resulting in different levels of achieved performance and capability.

7.2.2 This DFMC GNSS CONOPS identifies the market expectations from receiver manufacturers and end-users, that requires consideration of the different needs of General, Business, Regional and Air Transport aircraft to deliver the relevant operational benefits identified in section 5. The value of these operational benefits would vary between different stakeholders. Realizing the benefits of DFMC will depend on GNSS service performance capabilities, the GNSS elements available in a given airspace, long term service commitments in ICAO SARPS and may vary with the percentage of aircraft equipped with DFMC avionics.

7.2.3 In order to be economically attractive to aircraft operators, it is essential that a new DFMC GNSS receiver is able to deliver incremental benefits through enhanced operational capability and robustness, where needed, compared with single constellation L1 implementations. Therefore, it is key that States and signal providers promote the deployment and utilization of DFMC GNSS, by providing operational benefits in quantitative terms.

7.2.4 The business cases for individual operators to implement DFMC GNSS may be quite different depending on the existing capability of their aircraft, the need to be in compliance with CNS mandates in regions where aircrafts operate, and the costs of acquisition that could be reduced thanks to the size of a fleet

7.2.5 In case benefits remain marginal for some categories of users, one of the challenges for the receiver designer is to develop a product that is as simple as possible and is able to achieve the required performance and robustness benefits for particular users in an affordable manner. States may have institutional concerns and regulatory requirements applicable to airspace and navigation service approvals that need to be managed. Any additional complexity induced by locally specific regulations, lack of bilateral agreements between States or regulators and service providers, and mandates driven by political considerations would cause additional costs and would significantly reduce DFMC benefits.

7.3 Key Technical choices

7.3.1 Standardisation activities are already in progress within RTCA and EUROCAE in line with the Terms of Reference (ToRs) of each group. RTCA and EUROCAE have shared their work programs and are investigating the possibility of a joint activity to develop an initial DFMC MOPS since their respective ToRs have the same objectives. However at this time, a joint MOPS activity has not been formalized due to differences in schedules and incomplete technical information from GNSS element providers for the new GNSS elements[13]. RTCA SC-159 and EUROCAE WG-62 are currently coordinating on DFMC (centered at L1 (1575.42 MHz) and L5 (1176.45 MHz)) GNSS signals with CDMA modulation with bandwidths up to +/- 12 MHz, antenna MOPS development and the GNSS Interference environment characterization[14] in support of DFMC receiver MOPS development. It is to be noted that the current RTCA SC-159 ToRs while embracing all core constellations, with multiple prerequisites before integrating them into a DFMC MOPS for operational use, only address the L1 and L5 frequencies defined above. In the long term, it is expected that avionics standards will be available to enable the use of all DFMC GNSS elements and signals.

7.3.2 In parallel to RTCA and EUROCAE activities there is already some work done to achieve the long term goal to use multiple GNSS elements. Informational appendix to RTCA DFMC antenna MOPS provide requirements to antenna able to use signals centered at L1 (1575.42 MHz), L1 (1601 MHz), L3 (1202.025 MHz) and L5 (1176.45 MHz). This information is based on antenna developed by Russian manufacturers for which ability to use GLONASS signals in DFMC receivers for the medium-term is critical.

7.3.3 DFMC GNSS receivers will rely on existing MOPS standards for GPS L1 with ABAS, SBAS, GBAS augmentations. In addition, they will process new signals and DFMC evolutions of augmentation systems to enable additional operational benefits.

7.3.4 The data processing tasks within a DFMC GNSS receiver will demand upgraded hardware processors and increased software complexity compared to a current receiver. These factors may result in increased costs associated with receiver design, test, manufacture and certification.

7.3.5 Although not specifically a requirement imposed by the introduction of new DFMC GNSS elements, it is anticipated that new avionics will reduce the impact of in-band and adjacent-band

[13] RTCA/EUROCAE have develops the so called GNSS table listing key technical parameters.
[14] Through updates to RTCA/DO-235B (L1) and RTCA/DO-292 (L5)

GNSS interference that may be present in the future operational environment, to the maximum extent practicable. Any measure to increase jamming or spoofing resilience should be assessed to minimize false alerts and loss of GNSS availability.

7.3.6 In order to provide the robustness to enable some of the operational benefits identified in section 5, the DFMC avionics should be tolerant to satellite, constellation and augmentation system errors, failures or alerts, and robustness to radio frequency interference on a single frequency to allow receivers to continue to provide the required performance in the nominal and degraded modes of operation. The loss of one constellation or augmentation system should not impact the capabilities of the remaining systems.

7.3.7 The ARAIM concept as defined in section 4.5 needs to be assessed by industry before being adopted and introduced in DFMC MOPS. Even if future DFMC receivers can address a wider scope of errors, GNSS elements presenting high probabilities of failures would significantly increase the complexity of the integrity mechanisms and limit the benefits of their use. In such cases, ARAIM and other ABAS solutions will be evaluated by industry to determine the preferred option.

7.3.8 It has been established that with the exception of V-ARAIM and other advanced capabilities, the benefits of simultaneously processing a third and fourth constellation are diminished, although the contribution of additional constellations may be different for alternative receiver architectures. It is therefore understood that receiver designers may limit the complexity of the receiver by restricting the number of constellations and signals that are required to be processed simultaneously to deliver the key benefits that are required by the airspace user customer.

7.4 DFMC GNSS and aircraft operators/crew

7.4.1 The introduction of DFMC GNSS capability on the aircraft should be as transparent as possible to the flight crew, thereby minimising training. In normal conditions (excluding some contingency or anomaly situations) the crew should not need to know the GNSS elements that are used by the GNSS receiver. In this respect, the level of pilot interaction with DFMC GNSS receivers should be similar to that of mono-constellation single-frequency receivers.

7.4.2 The need for user equipment to accommodate contingency situations that may require temporary suspension of use of certain GNSS elements is the subject of significant discussion. If manual deselection of a GNSS element is required, this is expected to be performed on the ground during maintenance or preflight activities. Deselection during the flight might increase the flight crew workload. The manual de-selection capability also introduces potential for human error, which is increased by infrequent operation of the de-selection activity. The need for de-selection of GNSS elements requires further industrial consideration.

7.4.3 A DFMC GNSS receiver that uses two or more constellations to provide a position solution will not require RAIM prediction to be included in the avionics, or undertaken as a flight planning activity. RAIM prediction would be required if a single constellation is likely to be used, which may happen for instance depending on the States acceptance of GNSS elements in their airspace.

8 Operational use of DFMC GNSS in aviation

8.1 High Level Objectives and Principles

8.1.1 DFMC GNSS avionics are expected to support the following main types of applications:

- DFMC GNSS avionics are expected to support all existing and future PBN navigation specifications
- Precision approach operations with SBAS and GBAS and V-ARAIM in the long term.
- Surveillance operations with ADS-B and ADS-C
- Specific functions within aircraft systems such as timing/synchronisation, terrain avoidance warning systems (TAWS) etc.
- Position determination in support of Autonomous Distress Tracking (ADT)

8.1.2 The introduction of DFMC GNSS capability is required to be as transparent as possible to the ATM operational environment and therefore should not increase ATC and crew workload. In this respect, the use of DFMC GNSS receivers for the applications above is required to be backwards compatible with the use of single-constellation single-frequency receivers.

8.1.3 In order to ensure backwards compatibility with existing systems and operations, the introduction of DFMC should not diminish operational capabilities achieved with single constellation L1 implementations.

8.2 Evolution of the ATM Operational Environment

8.2.1 Increased capacity and throughput is being demanded from the ATM operational environment through the implementation of concepts such as PBN, GBAS, datalink, 4-dimensional trajectory management and System Wide Information Management (SWIM) etc. These concepts will demand increased levels of automation within the ATM infrastructure, with many of these systems relying on position or time derived from GNSS. As the numbers of the more capable aircraft increase, evolution of operations and airspace may allow these aircraft to derive greater benefits. It should be noted that in the 2030 time frame, DFMC GNSS would expect to be more commonly equipped on the 'more capable aircraft'.

8.2.2 The evolution of the ATM operational environment may be foreseen to result in the resilience of the future ATM network becoming more tightly coupled to the availability, continuity and performance of GNSS. This increased dependency on GNSS position and time will result in the operational impact of GNSS failure significantly increasing over time. The increased robustness of DFMC will reduce the likelihood of such an event.

8.2.3 The majority of the issues to be addressed during the evolution of the ATM operational environment are related to the implementation of new operational concepts and procedures that are currently the subject of research, demonstrations or initial implementations and therefore are not dependent on all aircraft having DFMC GNSS avionics capabilities.

8.3 Navigation Applications supported by DFMC GNSS

8.3.1 Performance Based Navigation

8.3.1.1 DFMC GNSS will support all current PBN applications with greater robustness against vulnerabilities enabling the operational benefits as described in Section 5 of this CONOPS and is expected to be the enabling technology for global availability of CAT I operations based on GNSS.

8.3.1.2 Where the improved performances allow the development of innovative applications, assuming adequate COM and SUR capabilities, it is expected that new Navigation Specifications will be developed by the ICAO PBN SG and detailed in the PBN Manual.

8.3.1.3 The robustness offered by DFMC GNSS, will not fully eliminate all known vulnerabilities of current GNSS. As a result, in certain areas (e.g. airspace with high complexity and high traffic density) ANSPs may need to maintain a certain number of ground-based navigation aids to ensure reversionary capabilities are retained. In the future an Alternate Position Navigation and Time (APNT) capability based on new technologies may be developed to provide a contingent navigation and timing capability to GNSS supporting En-route through to non-precision approach operations.

8.3.2 Precision Approach Operations

8.3.2.1 SBAS and GBAS currently support Cat I type of operations. In the near future, GBAS will also support CAT II /III autoland operations in mid latitudes and it is expected that DFMC GBAS will enable to support robust CAT II/III operations in all latitudes.

8.3.2.2 SBAS DFMC R&D activities are being conducted in some States to identify if SBAS DFMC can also support Cat I autoland and operations with Decision Heights below 200 feet.

8.3.2.3 The extension of ARAIM capabilities to the vertical domain will enable GNSS DFMC services to achieve RNP APCH equivalents to CAT-I on a global basis in the medium to long term.

8.3.2.4 SBAS service providers offering L1 and DFMC services may declare different service areas for the same service performance level (e.g. APV I). There is a need to find an optimal implementation solution to maximize operational benefits that DFMC SBAS can bring while maintaining safety for SBAS L1 users.

8.4 DFMC GNSS and ATM

This section of the CONOPS describes the impact of introducing DFMC GNSS on ATM systems and procedures, in particular regarding the ANSPs responsibilities in terms of Air Traffic Control and Aeronautical Information Management.

NSP will coordinate with relevant ICAO Panels and groups (e.g. ATMOPS, ATMRPP, SASP, IFPP, PBNSG, etc) to develop provisions for ATM procedures and systems depending on the specific operational environment.

In the current performance based operational environment, ATC does not need to know the specific navigation equipment on an individual aircraft to meet the navigation specification. By extension of this performance based principle, as long as an aircraft is capable of meeting the required Navigation Specification for the airspace or a route ATC should not be required to know which aircraft have DFMC GNSS capability and these aircraft should not require additional ATC to pilot communications.

8.4.1 Mixed Fleet equipage

8.4.1.1 In most States it is not intended or anticipated that the carriage of DFMC GNSS avionics will be required. In the future environment, although receivers may meet a particular navigation specification, there will be differences in performance in respect of robustness between GNSS receivers from different manufacturers, receivers intended for different classes of aircraft, different numbers of constellations and frequencies processed and different augmentations. This mixed fleet equipage may possibly lead to a reduction of the potential benefits from DFMC GNSS as the ANSPs would not be in position to assume a particular implementation in the aircraft.

8.4.1.2 During some degraded conditions, aircraft equipped with DFMC GNSS capable receivers are expected to continue to use GNSS navigation while aircraft equipped with mono frequency mono constellation (e.g. GPS L1) receivers might revert to an alternate navigation system (e.g. DME/DME and/or INS). Aircraft equipped with DFMC GNSS receivers would be able to continue the intended operation during ionosphere events like bubbles and storms and might be able to continue en-route and terminal RNP operations during L1 interference conditions.

8.4.1.3 When aircraft with DFMC GNSS equipment enter into service, the existing airspace will have been designed for aircraft with single frequency avionics and this may limit the benefits to the more capable aircraft. As the proportion of DFMC equipped aircraft increase, operational and airspace evolutions will be necessary to consider how more capable aircraft may be provided with additional operational benefits. The integration of more capable aircraft particularly in terminal airspace, requires further consideration by the appropriate specialist groups.

8.4.1.4 As a result the challenge within the ATM operation does not result directly from the introduction of DFMC GNSS avionics, but in the ability to continue to accommodate aircraft with different capabilities and performance, including L1 single-frequency avionics for the foreseeable future.

8.4.2 Predictions of GNSS Outage/NOTAMS

8.4.2.1 In the current operational environment, a means of informing aircraft operators and ATC about GNSS outages caused by predictable events such as notified State testing affecting GNSS signals, or failure of GNSS elements is implemented in some States and Regions through GNSS NOTAMS or other means (e.g. RAIM prediction tools, AIP Supplements or AICs). These notification arrangements may lead ATC to apply capacity and flow restrictions in the affected sectors.

8.4.2.2 The increased robustness provided by DFMC systems will reduce the probability of GNSS outages for DFMC users. However there will be significant percentage GPS L1 users for the foreseeable future that continue to be informed based on current practices. The continued need for outage predictions and NOTAMs for specific operational environments should be reassessed in the future.

8.4.3 Flight Plan Systems.

8.4.3.1 It is known that the flight plan format introduced in 2012 does not support all of the navigation specifications contained within the latest version of the ICAO PBN Manual. There is no envisaged evolution of the current flight plan system. In accordance with SWIM principles, aircraft capability will be captured through the ICAO Flight & Flow Information for a Collaborative Environment (FF-ICE) initiative.

8.5 ICAO Standards and Guidance Updates

8.5.1 It is anticipated that a number of documents (e.g. ICAO PANS, and Manuals) supporting ATM operations that currently refer to GPS will need to be revised in the near future in order to encompass all GNSS elements. These activities may be significant in terms of ICAO Panel time and the scope of this task should be established and reflected in the Job Cards of the responsible Panels. This will allow DFMC documentation updates to be undertaken as part of the normal Panel and Study/ Working Group activities. Wherever possible, these documents should be updated to be applicable to all GNSS elements that are included in ICAO SARPs. (Noting that there are already plans to have provisions for DFMC GNSS in the PBN manual and PANS OPS.)

8.5.2 In particular, it is considered that amendment to ICAO Annex 15 and PANS-AIM (Doc 10066) including guidance material, may be required to accommodate the promulgation of the increased numbers of GNSS elements and signals in line with finally agreement by stakeholders on the airspace acceptances described in section 6. Eventually it could be necessary to define datasets to be used in electronic formats. (e.g. e-AIP)

8.5.3 Phraseology and ATC procedures published in ICAO Doc 4444 (PANS ATM) may need to be reviewed and updated further by relevant ICAO Panels to address issues relating to the introduction of DFMC.

8.5.4 It is also anticipated that there will be regional and national documentation that will require review and amendment when additional GNSS elements are approved for operational use.

9 Implementation Aspects

9.1 General

9.1.1 The realisation of DFMC GNSS capability is a complex undertaking that is dependent on many individual Programmes, projects and activities. These include the GNSS elements of core constellations, SBAS and GBAS systems together with supporting materials such as ICAO SARPs and receiver MOPS being available at particular points in time.

9.1.2 The dual-frequency GNSS core constellations are being technically coordinated, but are being implemented as independent Programmes by individual States, or groups of States to meet national and regional priorities and are not specifically designed to meet the needs of civil aviation.

9.1.3 The planned timescales in which the GNSS core constellations will be deployed and validated are known. However at the time of writing this CONOPS, the process and timescales for letters of commitment to ICAO for civil aviation use are not clearly defined.

9.1.4 Technical work on DFMC SBAS and GBAS augmentations is being progressed in a coordinated manner by the SBAS Interoperability Working Groups and the International GBAS Working Group. Technical studies on ARAIM are being undertaken by a specific US-Europe working group on the subject.

9.1.5 The Terms of reference of EUROCAE WG 62 and RTCA SC 159 indicate the planning to prepare and validate different modules of the MOPS including ARAIM, SBAS and GBAS augmentations. The validation of the standards and implementation of these augmentation systems is however dependent on the availability of the core constellation commitments relating to their use for civil aviation operation. It is to be expected that the transition from single-frequency to dual-frequency augmentation services will be phased over a significant period of time.

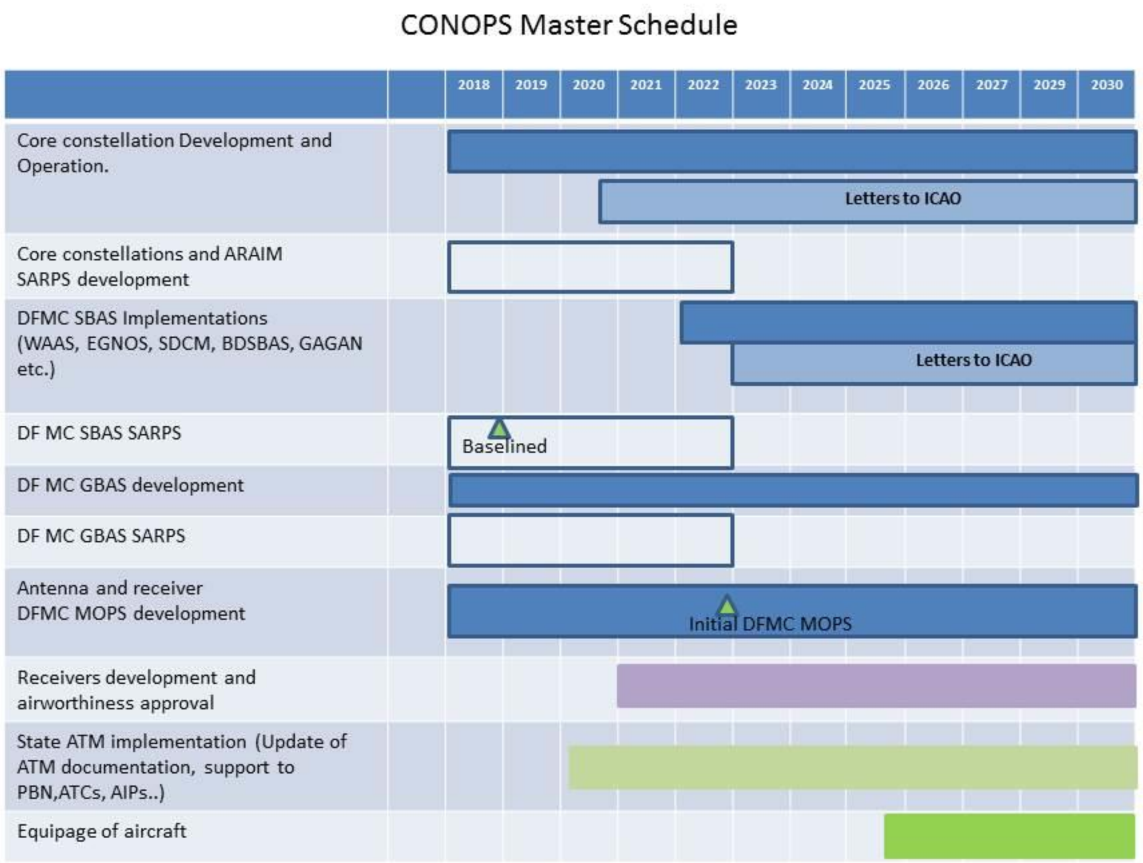
9.2 High Level Schedule

9.2.1 The figure below collates the available information on key milestones towards introducing DFMC GNSS for ATM operations. These milestones relate to the implementation of GNSS elements, preparation and validation of ICAO SARPs, preparation and validation of MOPS for avionics by EUROCAE and RTCA and operational implementation activities in ATM.

9.2.2 Stakeholders or the groups responsible for activities have their own detailed schedule (core constellations developments, NSP work programme for SARPs development, EUROCAE and RTCA ToR for developing MOPS, States and aircraft operators for operational implementation etc). This high-level schedule within the CONOPS does not intend to compile and update those detailed schedules but to provide an overarching timeline of all the activities related to the introduction of DFMC GNSS operations in ATM.

9.2.3 The high level schedule includes an indication of when GNSS element providers may offer their systems to ICAO for use by Civil Aviation.

9.2.4 In this version of the CONOPS, the timeline is preliminary and requires review and amendment. In particular, dates and deliverables provided in the ICAO NSP work plan for SARPs development should be reviewed and updated



Note 1: The timeline indicates that the introduction of DFMC GNSS operations could start in the 2025-2028 timeframe. Initial introduction of some DFMC GNSS capabilities may start at an earlier date.

Note 2: This high level schedule does not preclude the earlier introduction of single-frequency dual constellation operations such as GPS + GLONASS which are ready today in some States.

9.3 Implementation challenges

9.3.1 This section lists some of the implementation challenges identified in the document:

- The challenge facing ICAO, States, industry and other aviation stakeholders is to address State requirements for the use of specific GNSS elements while ensuring backwards compatibility for current equipment and limiting the complexity of DFMC avionics.
- Develop and implement provisions to enable getting to the long term goal.
- Standardize and develop cost-efficient DFMC GNSS avionics addressing technical and interoperability challenges at a reasonable level of complexity and costs.
- Address operational aspects (e.g. mixed fleet traffic) to make sure that the introduction of DFMC GNSS in the ATM system is as transparent as possible to ATC and pilots while enabling benefits for more capable aircraft.

9.4 Implementation risks

9.4.1 External Risks

The diverse manner in which the DFMC GNSS is being implemented results in a number of risks, many of which are beyond the management of the aviation community. If some of these external risks materialise, the aviation Programmes will be impacted and expected future benefits will be delayed.

It is therefore suggested that risks that are external to aviation should be subject to monitoring by the ICAO NSP. This could be achieved through the established Panel processes of Working and Information Papers presented by the States that are implementing GNSS element.

9.4.2 Aviation Risks

Risks that are under the control of aviation that may be associated with the timely availability of SARPs and MOPS for DFMC GNSS Elements, or for supporting ICAO documents, Annex 15, PANS-AIM (Doc 10066) and GNSS Manual, should be managed through the established ICAO processes such as the Panel work programme and job cards. Implementation progress should be regularly reviewed and the implementation risks should be managed in light of the progress made.

9.4.3 Top Aviation Identified Risks

The table below shows the identified the top risks. These risks should be periodically reviewed and reported in the NSP meeting reports.

ID	Hazard	Probability	Impact	Mitigation
1	If a significant number of States not accepting all GNSS elements, it will result in not achieving the long term goal defined in section 6 in a reasonable timeframe leading to erosion of operational benefits and undermining DFMC implementation.	**Medium to High**	**High**	• See proposed activities in section 11 (e.g. guidance material to facilitate acceptance of GNSS elements, management of underperformances, new responsibilities for GNSS elements service providers,..)
2	If iterations between stakeholders to find a solution for the medium term (see Appendix 2) do not converge, it will result in increased receiver complexity and cost leading to negative business cases undermining DFMC implementation.	**Medium**	**High**	• States to review their requirements. • Industry to continue engagement in discussions to address concerns from States.
3	If ICAO SARPs and related guidelines for GNSS elements are not available in a timely manner, it will result in delayed MOPS, GNSS elements and DFMC implementation.	**Medium**	**Medium**	• NSP members from GNSS element provider States to provide timely planning and technical material required for SARPs development and validation (including prototype development to validation some requirements). • NSP to update its work plan for each SARP based on the inputs from core constellation, SBAS and GBAS groups. • States and ICAO to make available sufficient resources to prepare the SARPs. • ICAO NSP to regularly review and maintain the work plan and relevant Job Cards
4	If MOPS for aircraft equipment are not available in a timely manner, it will result on certified avionics will not be available when planned, resulting in delayed implementation of DFMC GNSS capability and delayed benefits.	**Medium**	**Medium**	• GNSS element provider States to provide timely planning and technical material required for MOPS development. • RTCA and Eurocae members to make available sufficient resources to prepare MOPS.

5	In the event that a DFMC GNSS receiver cannot be realized at acceptable level of complexity and cost, there is a risk that design 'trade-offs' may reduce the effectiveness of mitigations to GNSS vulnerabilities, resulting in reduced benefits that impact the business case for the uptake of the new avionics.	**Medium**	**Medium**	• ICAO to engage with RTCA and Eurocae during the early design trade-off process to consider refinement of the CONOPS • ICCAIA to brief ICAO NSP on blocking or significant issues encountered during the development of prototype avionics.

10 Summary table of stakeholder's responsibilities

10.1 The Table below provides a summary of key stakeholder's responsibilities for the implementation of DFMC GNSS operations as described in this CONOPS document. Further detail on the responsibilities of ANSPs and State regulators is detailed at Appendix B of the ICAO GNSS Manual (ICAO Doc 9849) (to be updated to assist States with implementation of DFMC operations).

Stakeholder	Responsibility
ICAO	• Develop core constellation SARPs and guidance materials • Develop DFMC SBAS SARPs, guidance and training materials • Update DFMC GBAS SARPs, guidance and training materials • Develop SARPS and guidance material and training material related to ARAIM including ISM parameters • Update other ICAO documentation for DFMC GNSS • Process offers from service providers who offer GNSS Elements for use by the civil aviation community. • Inform ICAO Regional Coordination groups of DFMC GNSS developments.
Core constellation service providers	• Commission and maintain the core constellation in compliance with SARPs and Service definition documents. • Formally offer the core constellation to ICAO for global aeronautical uses. • Provide regular reports on achieved performance according to the performance parameters defined in the GNSS Manual. • Provide constellation and satellites status information in a timely manner (e.g. NANU/NAGU/NABUS) • Core constellation providers to continue to support UN ICG
SBAS service providers	• Commission and maintain the SBAS service in compliance with SARPs and service definition documents • Formally offer the SBAS to ICAO for use • Provide regular reports on achieved performance • SBAS providers to continue to support IWG
ISM generator	• Compute the ISM parameters values based on measurements according to the standardised models and practices. • Generate ISM in compliance with ICAO SARPS Annex 10
States and/or Regulatory Authorities	• Promulgate accepted GNSS elements within the State AIP. • Issue airworthiness approvals for DFMC receivers and installations.
Avionics Vendors	• Develop MOPS for DFMC GNSS receivers • Develop and certify avionics for DFMC GNSS for air transport, business and general aviation aircraft • Place avionics products on the market.

ANSPs	• Offer beneficial PBN operations that make use of DFMC GNSS with increased robustness • Deploy an appropriate PBN route network and publish approach, SIDs and STARs procedures that take advantage of the GNSS infrastructure • Commission and maintain GBAS services in compliance with SARPs.
Aircraft Operators	• To implement DFMC GNSS capabilities that are suitable for their operational and business requirements on their aircraft.

11 NSP Future Work

11.1 Pending ANC 13th conclusions and recommendations, this section include some proposed activities to be considered in the NSP work programme and job card update after CONOPS approval in April 2018.

1 There is a need to continue discussions and further iterations among stakeholders to agree a solution to the challenge for the medium term identified in section 6.

2 Evaluation and development of operational benefits for different market segments (e.g. commercial air transport including regional aviation, general aviation, business jet and rotorcraft) as well as other aviation stakeholders (ANSP, airlines, airports authorities).

3 Proceed with SARPS development for DFMC SBAS, DFMC GBAS and DFMC ABAS/ARAIM. There is a need to ensure a harmonized approach on the key assumptions considered in each augmentation at system and avionics levels and the underlying design logic of degraded and redundant modes among all augmentations.

4 There is a need to develop guidance material to facilitate acceptance of all GNSS elements by States addressing related issues such as DFMC service provision, regulatory compliance, spectrum protection, GNSS monitoring, legal aspects, legal recording,.. etc.

5 NSP needs to support the AIM Panel to update provisions in Annex 15 and PANS-AIM (Doc 10066) for DFMC GNSS.

6 Define necessary processes involving GNSS element service providers, States, Regulators, ANSPs, industry and airspace users to manage underperformances and anomalies in a DFMC context. Update GNSS monitoring provisions in the GNSS Manual to address for 4 core constellations and SBAS and provide guidance to States on what to do if the measured performance of a certain GNSS element is below the expected level.

7 Further develop provisions to GNSS service providers regarding publication of service performance standards and publication of regular performance assessment. Transparency from GNSS service providers is essential to build-up levels of trust from all States.

8 Continue discussions with other ICAO Panels and PBNSG related to operational introduction of DFMC in ATM. It is anticipated that a number of documents (e.g. ICAO PANS, GNSS manual, PBN manuals,..) supporting ATM operations that currently refer to GPS will need to be revised in the near future in order to encompass all GNSS elements.

9 Address in co-operation with other Panels and Groups, identified operational issues, such as the management of mixed mode fleets and new operational issues that probably will arise in the coming years. An example[15] is the management of SBAS L1 and DFMC SBAS equipped aircraft when the same SBAS service providers offers different services areas for the same service performance level.

10 Discuss applicability of GNSS elements approvals/acceptance's to CNS applications with relevant ICAO Panels.

11 Management of CONOPS risk register.

[15] See IP 1 from NSP 4.

Appendix 1: Acronyms

ABAS	Aircraft Based Augmentation System
ADS-B	Automatic Dependant Surveillance – Broadcast
ADS-C	Automatic Dependant Surveillance –Contract
ADT	Autonomous Distress Tracking
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
ANSP	Air Navigation Service Provider
APNT	Alternate Position Navigation and Time
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
ASECNA	Agency for Aerial Navigation Safety in Africa and Madagascar
ATC	Air Traffic Control
ATM	Air Traffic Management
BDSBAS	The BeiDou Satellite Based Augmentation System. The SBAS provided by China
CDMA	Code Division Multiple Access.
CNS	Communications Navigation and Surveillance.
DFMC	Dual-frequency, multi-constellation
EGNOS	European Geostationary Navigation Overlay Service. The SBAS Provided by the European Union
FDMA	Frequency Division Multiple Access
FF-ICE	Flight & Flow Information for a Collaborative Environment
GAGAN	GPS Aided GEO Augmented Navigation. The SBAS provided by India
GALILEO	GNSS core constellation owned by, and operated on behalf of the European Union
GBAS	Ground Based Augmentation System
GEO	Geostationary Earth Orbit
GLONASS	GNSS core constellation owned and operated by the Russian Federation
GNSS	Global Navigation Satellite System
GPS	NavStar Global Position System; GNSS core constellation owned and operated by the United States of America
INS	Inertial Navigation System
ISM	Integrity Support Message
KASS	Korean Augmentation Satellite System
LPV	Localiser Performance with Vertical guidance
MEO	Medium Earth Orbit
MOPS	Minimum Operational Performance Standard

PBN	Performance Based Navigation
PNT	Position, Navigation, Time
QZSS	Quasi-Zenith Satellite System. The Regional GNSS provided by Japan.
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP AR	RNP Authorisation Required
RNP APCH	RNP Approach
RPAS	Remotely Piloted Aircraft Systems
RTCA	US Aeronautical standardisation organisation
SBAS	Satellite Based Augmentation System
SDCM	System of Differential Correction Messages. The SBAS provided by the Russian Federation
SWIM	System Wide Information Management
TAWS	Terrain Awareness Warning System
TMA	Terminal Manoeuvring Area
ToRs	Terms Of Reference
UTC	Universal Time Co-ordinated
VDB	Very High Frequency Data Broadcast
WAAS	Wide Area Augmentation System. The SBAS provided by United States of America

Appendix 2: DFMC avionics use of GNSS elements

1. Introduction

1.1 The DFMC GNSS CONOPS highlights that the challenge for the medium term transition is to address State requirements for the use of specific GNSS elements while ensuring backwards compatibility for current equipment and limiting the complexity of DFMC avionics. A solution to this challenge has not been agreed yet, and interaction between industry and States is continuing through ICAO NSP, RTCA and EUROCAE. This appendix develops the current status of iterations between stakeholders and includes: guidance related to the States acceptance of GNSS elements (section 2), a set of preliminary functional requirements for DFMC for avionics (section 3) and the preliminary industrial feedback on the implementation impact (section 4).

2. Guidance to States on acceptance of GNSS elements for use in their airspace

2.1 This section has some guidance on how States could communicate the acceptance of GNSS elements in a DFMC operational environment in a given airspace for navigation purposes to be promulgated in the State Aeronautical Information Publication in accordance with Annex 15. The State acceptance for Navigation use may allow use for Communications and Surveillance applications.

	GNSS element acceptance by States	**RATIONALE / COMMENT**
	CORE CONSTELLATIONS and ABAS	
G#1	Core constellations are GNSS elements. States should publish the acceptance status of the core constellations: GPS, GLONASS, Galileo and BDS when augmented by ABAS.	Signals from GNSS constellations are always used in conjunction with an augmentation system for navigation.
G#2	The State acceptance of a core constellation consists of individual acceptance of the signals provided by that system that are standardized within ICAO SARPs for aeronautical use.	A separate acceptance is expected for each signal. Many States have approved the use of GPS L1 C/A and/or GLONASS L1 and in the future are expected to approve the use of the second frequencies L5, L3 etc. when the necessary technical evidence has been obtained. The core constellation operational Status messages are not unique to aviation and do not necessarily indicate that the satellite meets all of the provisions within the SARPs. Therefore some States may require the

		capability to delay the acceptance of GPS L5 while still accepting GPS L1.
G#3	States should publish the acceptance status of the ISM for V-ARAIM.	Note: The provision of the ISM for V-ARAIM will be linked to the provision of a final version of the ARAIM concept of operation (including both H and V-ARAIM). This may be reviewed as the concept matures.
	SBAS	
G#4	SBAS systems are GNSS elements. States should publish the acceptance status for individual SBAS systems whose service areas overlap with their airspace.	
G#5	The State acceptance of an SBAS system implies the acceptance of all SBAS signals of this particular system (i.e. SBAS L1 and SBAS L5) that are standardized within ICAO SARPs for aeronautical use.	This accounts for the fact that each SBAS signal can be declared unusable for aviation use. An SBAS system can broadcast messages type 0 on L1 and L5 independently).
G#6	The acceptance status of an SBAS system applies to all SBAS functions (e.g. ranging, integrity and correction functions) of that system.	The rationale for a single acceptance is to simplify the implementation through reduced numbers of State acceptance. Note: This does not relate to non-standardised messages (e.g. data included in MT63.)
G#7	When a State accepts an SBAS the acceptance includes the use of core constellation satellites when augmented by that SBAS in line with the SARPs, even if the core constellations are not accepted for the use with ABAS.	Example: A State accepting SDCM is accepting the use of GPS and GLONASS signals when augmented by SDCM. This acceptance is independent of the acceptance of GPS and GLONASS when augmented by ABAS that is subject of a separate acceptance (see G#1).

	GBAS	
G#8	GBAS is a GNSS element that is a national system not subject to different approvals by multiple States.	GBAS supports State approved approach procedures to a particular airport within that state. When a GBAS station provides a service to several States, bilateral arrangements may be needed. The approval of a GBAS augmenting some constellations does not imply the acceptance of those constellations when augmented by ABAS that is subject of a separate acceptance (see G#1).
	AIRSPACE	
G#9	If there is no information in the AIP on the State acceptance status for any GNSS element within a given airspace, it is considered that all GNSS elements are available for lateral navigation[16].	This relates to GNSS elements that are SARPs compliant and have been accepted by ICAO. The use of these GNSS elements is in line with the interpretation that ANC 12 Recommendation 'States adopt a performance based approach.' means that all elements should be accepted for use. This is consistent with current practice of aircraft using GPS in States that have not approved the use of GNSS in an advisory capacity, providing the navigation facilities approved by the State are monitored.
G#10	A GNSS element should have the same acceptance status in all contiguous FIRs managed by a State.	Note 1: In the case of international airspace that may be managed by a group of States, the acceptance will be determined through existing regional arrangements Note 2: Non-contiguous FIRs can have different acceptance status (e.g. French overseas FIRs may have different acceptance statement than the French metropolitan FIRs).
G#11	A State's acceptance of a GNSS element applies to all phases of flight where routes or procedures permit the use of GNSS for lateral navigation.	Note: The rationale for a single approval is to simplify the implementation by reducing the number of approval steps. Specific provisions exist for States to approve the GNSS elements that can be used for critical operations, (e.g.

[16] GNSS is used for lateral navigation in PBN applications for Oceanic, En-route, terminal area and RNP AR, LNAV, LP and BaroVNAV approaches.

		FAS data block for geometric vertically guided approach operations).

3. Preliminary Functional Requirement for avionics implementation.

3. 1 For the medium term transition until States will accept all GNSS elements for lateral navigation, DFMC GNSS avionics would need to be capable of delivering navigation services that only use GNSS elements that are accepted in the airspace where the aircraft is flying. Not all of the accepted elements/signals need to be used necessarily.

3.2 The table below identifies Preliminary Functional requirements that would need to be implemented within the aircraft DFMC avionics. These requirements are not applicable to single constellation single frequency receivers.

	Preliminary Functional Requirement for Avionics Implementation	**RATIONALE / COMMENT**
PFR # 1	For navigation applications, avionics should only use GNSS elements that are accepted by States for Navigation purposes.	For clarity, avionics are required to use for navigation any single, or a combination, of the accepted GNSS elements. **Note:** Where a State has not promulgated the acceptance of any GNSS element, the provision of G#9 considers all elements to be available for use.
PFR # 2	To accommodate contingency situations, aircraft equipment should include functions to disable specific GNSS element.	This preliminary functional requirement is to address an exceptional event and does not necessarily imply an implementation through action by the flight crew. This PFR may be needed in any case irrespectively of the agreed implementation solution.
PFR # 3	Any technical implementation of the preliminary functional requirements should have expansion capacity to accommodate new GNSS elements and new States in the acceptance process.	Decision on provisioning should be made based on manufacturer benefits and cost feasibility. Expansion can be estimated based on the systems known to be operational or planned to be operational during the life cycle of equipment under development.

4. Preliminary industrial feedback on the DFMC avionics implementation impact.

This section provides some preliminary considerations and recommendations related to the impact of the preliminary functional requirements described in the sections above on MOPS standards and DFMC avionics design, manufacture and certification. The text is based on the inputs received from some industrial partners participating to RTCA and EUROCAE.

4.1 General considerations

4.1.1 It is likely that not all States will accept GNSS elements simply by not indicating their acceptance status in their AIPs. Management of GNSS element acceptance or absence of acceptance would require knowing, from a reliable and up-to-date source, GNSS acceptance status per State and defining a default mode when GNSS acceptance is unknown. A preliminary proposal to manage this situation is presented as G#9.

4.1.2 Navigation using GNSS for lateral navigation is possible without the need for any airspace acceptance, except when system to be used is specified in the FAS datablock.

4.1.3 There will be for many years mixed fleets with legacy aircraft only equipped with GPS L1 or GLONASS L1 receivers, SBAS L1, and some aircraft equipped with DFMC GNSS receivers. Consequently, States should not revoke already accepted use of GPS L1, GLONASS L1 or SBAS L1 signals upon DFMC GNSS becoming operational. Any revocation of an acceptance of a GNSS element could lead to a degradation of safety margins and loss of benefits brought by safety nets that are using GNSS as well as an unnecessary reversion to conventional navigation. Accordingly, legacy receivers being able and allowed to continue use GPS L1 C/A, SBAS L1 or GLONASS L1, as long as it remains compliant with ICAO SARPS and independently from any GNSS acceptance status in AIP, it is recommended by industry that DFMC avionics keep the possibility to use the same legacy signals under conditions to be defined by Industry and States, to cope for instance with emergency situations, to avoid discrimination on DFMC avionics and to encourage adoption of DFMC GNSS.

4.1.4 Requirement to use multiple core constellations to perform any operation should be avoided. This means that the use of multiple core constellations in parallel should not be required unless it brings an incremental benefit or robustness compared to existing use of GPS L1 C/A, SBAS L1 or GLONASS L1. Multiple charting for LPV operations to select different SBAS or combination of GNSS elements should be avoided.

4.1.5 Approval of GNSS elements for Navigation should be valid for Surveillance and Communication applications to avoid any additional complexity and costs to manage differently GNSS elements between the three types of utilization.

4.2 Considerations on SBAS acceptance

4.2.1 SBAS, compliant with the SARPs, have overlapped coverage areas (geo footprint) and ICAO SARPS Amendment 91 ensure that integrity is met within their coverage areas. This makes SBAS a truly global system beyond airspace boundaries, usable by receiver anytime anywhere as long as ICAO SARPs are met. There is no technical/operational/safety reason for States not accepting the use of all SBAS systems compliant with Amendment 91. As a consequence, there should not be any restriction on those grounds to use SBAS beyond airspace boundaries, thus there should be no need to deselect one SBAS and select another one for lateral navigation. In case the use of SBAS service is predicated upon the certification of the service provider, there should be bilateral agreements to ensure any SBAS signal can be used across airspace boundaries. In specific cases, FAS Data Block is used to require the use of a particular SBAS for approach operations.

4.3 Implementation impact of a FIR Database

4.3.1 Implementing the Preliminary functional requirements would require the avionics to check in real-time the acceptance or the health status of GNSS elements using an external source of information including:

- GNSS elements with separate acceptance for each signal frequency (L1 or L5)
- A signal-in-space failing to meet ICAO SARPS requirements
- Aircraft is located in certain airspace (e.g. FIRs with restricted or mandated use of particular GNSS element).

4.3.2 One solution envisaged is to install an on-board database which would require regular updates within existing database update cycles (e.g. AIRAC cycle), without changes being applied between these cycles to answer a timely issue with a GNSS element. There are many drawbacks of adding such a feature within the avionics:

- It would add an additional cost and complexity induced by the management of multiple conditions applying to GNSS elements to compute a navigation solution. The above listed conditions would result in an exponential number of combinations to be managed in a timely manner as soon as one variable changes its state.
- Defining GNSS acceptance status using FIRs for instance requires having a reliable unique source without any dispute on FIRs boundaries. FIRs may cover multiple countries and terminal areas around an airport that can be shared by multiple convergent FIRs. Switching between FIRs to enable/disable a GNSS element may cause unexpected operational effects such as position jumps, loss of continuity, crew workload. Navigation close to multiple FIR boundaries can be difficult in particular when FIRs boundaries are not defined by straight lines and a single boundary may be crossed a number of times in succession.
- It leads to operational costs linked to maintenance and update of the database content and associated to costs to the data provider for the database
- It would increase crew workload and add risk upon management of GNSS elements acceptance such as procedure with lack of training to select/deselect, risk of wrongly selecting or deselecting a GNSS element.

4.3.3 From the above, GNSS avionics should not have to manage changes of the GNSS acceptance status in a given airspace during a flight. All States should accept the use of GNSS element compliant with ICAO SARPS for lateral navigation to achieve the long term goal. Non-compliances with SARPS should be notified preferably within the signal. Therefore, selection/deselection in real time of a GNSS element based on their acceptance status in a FIR should not be required.

4.3.4 ICAO SARPS and RTCA/EUROCAE MOPS constitute a binding contract between the receiver and the signal-in-space that must be respected to ensure safety of operations and interoperability. There is no mechanism, such as integrity monitoring, which can protect the receiver from unknown and unexpected failure mode, resulting in performance non-compliant with the ICAO SARPS. Indeed, GNSS elements service providers are responsible for their signal, spectrum filling and protection, and compliance to the SARPS. It would be desirable that signal providers have the means to monitor and disable the use of any GNSS element, under their responsibility, by aviation users in case ICAO SARPS are not met. Such mechanisms can include but are not limited to, inflating URA for GPS (or SISA for Galileo), activating MT0 for SBAS or provide information in ISM directly broadcast by the GNSS element itself.

4.3.5 Revocation of the acceptance in case of non-compliance with critical SARPS requirements (e.g. integrity) should be applicable to all States and should be implemented on ground during maintenance or preflight activities through actions such as pin-programming, OPC modification or any configuration management action.