APPENDIX D

OVERVIEW OF BENEFITS AND ISSUES RELATING TO THE FUTURE COMBINATIONS OF INDEPENDENT SATELLITE NAVIGATION SYSTEMS AND THEIR AUGMENTATIONS

1. INTRODUCTION

1.1 The International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) have been developed for both Global Positioning System (GPS) and GLObal NAvigation Satellite System (GLONASS) for L1 signals and for aircraft-based (ABAS), satellite-based (SBAS) and ground-based (GBAS) augmentations systems.

1.2 In the future, GPS will be enhanced by providing additional signals and will possibly include a worldwide integrity function. GLONASS-M satellites with improved characteristics will be added to the constellation and subsequently new generation GLONASS-K satellites will be launched. A new constellation called Galileo is also being developed by Europe and will provide three signals and a worldwide integrity function.

1.3 A number of benefits for the civil aviation users can be expected from the use of these additional signals and constellations. The existing systems can be combined to improve robustness and therefore increase the ability to meet performance requirements in the presence of interference or system failures. In addition, increased performance can be obtained in nominal conditions when using combination of signals from independent systems. This means that, for some regions, the use of combined constellation is likely to offer navigation service levels that previously required the use of augmentation systems. Finally, the availability of multiple constellations could alleviate institutional concerns about relying on a single service provider.

1.4 The introduction of these new elements also raises some technical, economical and institutional issues that need to be addressed in order to take full credit of the opportunities offered.

2. OPPORTUNITIES FROM NEW SIGNALS AND CONSTELLATIONS

2.1 Implementation time frames

2.1.1 As of September 2003, the estimates of service delivery for the various constellations and new signals are as follow:

a) GPS/L1: available;

b) GPS/L5: Initial operational capability - 2012, Full operational capability - 2015;

c) GLONASS/L1: available (number of operational satellites is limited);

d) GLONASS/L3: planned availability from 2008;

e) Galileo/L1: planned availability from 2008 ;

f) Galileo/E5a: planned availability from 2008; and

g) Galileo/E5b: planned availability from 2008.

2.1.2 For any new signal/constellation, an additional time period of one to two years would probably be needed for the purpose of validation/certification by civil aviation authorities before approving signals use for safety-of-life applications. This implies that the operational use of new signals and combined constellations service could start in the 2010 time frame.

2.1.3 ICAO planning for GNSS standardization involves development and validation of SARPs for the above-mentioned elements of GNSS as the development of these elements progresses.

2.2 Technical and operational opportunities

2.2.1 Assessment of GNSS vulnerability and mitigation methods (AN-Conf/11-WP/17 refers) indicates that there is inherent merit in making satellite navigation as robust as possible against interference. In this respect, each of the new GNSS signals will be more resistant to interference than GPS/L1 due to higher power and wider bandwidth, resulting in better interference rejection capability. Moreover, all signals intended for safety-of-life applications will benefit from the protection provided through International Telecommunication Union (ITU) allocation within the aeronautical radionavigation service (ARNS) bands.

2.2.2 Frequency diversification is also a very effective mitigation against unintentional interference, since it is highly unlikely that such an interference source would simultaneously affect more than one frequency. Indications have been received that all core constellations (GPS, GLONASS and Galileo) will provide services on multiple frequencies, and any combination of two of these constellations make available at least one non-common frequency.

2.2.3 Atmospheric effects will also be mitigated in a very effective way when a combination of constellations is used. The impact of signal loss which exists today in equatorial regions and at a lesser extent at high latitudes under severe ionospheric scintillation conditions will be significantly mitigated when more satellites are in view. This could be achieved by combining at user level the different measurements from different constellations.

2.2.4 With single frequency satellites, GBAS and SBAS must correct for errors induced by the ionosphere. Multiple frequencies from each satellite support this error correction in the receiver. When combining constellations, availability and continuity of service limitations currently related to the events such as ionospheric scintillation, system maintenance, space segment failures or terrain/building masking (e.g. for GNSS-based surface operations) will be alleviated due to the larger number of satellites in view.

2.2.5 In areas where integrity data is not provided (by SBAS or future core constellations), performance improvement may be obtained by combining measurements from multiple constellations with ABAS, albeit with less robustness. This will obviate the need for SBAS deployment in some instances and simplify SBAS architecture in other cases.

2.2.6 Some States are already considering potential benefits of increasing GNSS robustness through frequency diversity with a single constellation. Combining the different signals of at least two of these constellations at user level would further enhance the robustness, improve performance and also seriously mitigate the institutional concerns issued from the use of a single constellation.

2.3 Institutional opportunities

2.3.1 There are non-technical reasons for the use of multiple constellations . These reasons can include institutional concerns about the control and maintainability of a single constellation, the threat of service denial, and the possibility of a major failure in a core constellation. The availability of multiple, independent constellations from independent service providers will in particular allow that:

a) satellite navigation services can continue to provide their nominal performance despite a lack of funding resources to maintain a specific constellation, technical difficulties with operation of the constellation, launch failures, or destruction resulting from emergency situations;

b) navigation service can be maintained on a worldwide basis, even if the performance of a single constellation is degraded or denied in the whole coverage area during a national emergency situation, as recognized by the Convention on International Civil Aviation (Article 89 refers). In this case an independently managed second constellation could continue to provide service; and

c) navigation service can be maintained even in the case of signal interruption or major modification of one satellite constellation, a mid-term service interruption of one constellation or the decision of one satellite constellation provider to discontinue provision of the service.

3. CHALLENGES ASSOCIATED WITH THE INTRODUCTION OF ADDITIONAL INDEPENDENT CONSTELLATIONS AND AUGMENTATIONS

3.1 Complexity related to using multiple combinations of elements

3.1.1 The introduction of independent constellations and augmentation system elements introduces technical complexity. This must be managed properly in both the technical and operational domains to ensure that aircraft operators obtain the benefits described above and that these benefits exceed costs.

3.1.2 Complexity could increase, as GNSS evolves, if there will be a proliferation of airborne receivers that use different combinations of independent GNSS elements in different ways. It is also anticipated that there will be architectures that further enhance capability by integrating GNSS with inertial systems. The market will naturally preclude architectures that use combinations failing to provide economic benefits, but fragmentation could undoubtedly occur. Air navigation services providers, aircraft operators and manufacturers will have to work together to match capability to required navigation performance and published approach procedures in order to maximise benefits.

3.1.3 It was suggested that air navigation service providers would require a real time indication of whether various combinations of GNSS system elements support published levels of service, accounting for users with various capability levels. This approach stems from the current system monitoring philosophy, where the air navigation service provider can monitor individual terrestrial aids and where each aid provides a defined service. However such approach probably will not suit future GNSS operations, in particular when multiple signals and constellations are introduced. Therefore the current status monitoring concept should be revisited.

3.1.4 The standardisation of a multiple combination of elements could become difficult to manage for ICAO, depending on the implementation strategy for SARPs introduction. The best option could be to standardize the new signals individually supplementing SARPs with guidance material on the use of these new signals and signal combinations.

3.2 System cost for aircraft operators and service providers

3.2.1 From the user's prospective, the introduction of additional signals and constellations will require replacement of existing receivers and aircraft antennas. These receivers and antennas will be more complex and will likely cost more than the current generation of GNSS avionics. However, with the continuous advances in receiver technology, these cost increases are likely to be relatively modest.

3.2.2 The most viable strategy for aircraft operators could be to retrofit only when a business case is positive. The cost of retrofitting could be reduced if manufacturer' designs allow for software or simple hardware upgrades. The other part of this strategy would be to procure new aircraft with avionics that match the state of GNSS development. This will require advance knowledge of standards and plans for the introduction of new signals.

3.2.3 In the case of GBAS, a system capable of augmenting two core constellations (e.g. GPS/GLONASS or GPS/Galileo) may be more expensive due to the increased complexity in reference receivers and antenna elements. On the other hand, service providers using relatively new GBAS equipment, which augments a single constellation, would not rush to introduce new equipment and take decisions for system upgrades primarily based on nominal life cycle considerations.

3.2.4 In order to minimise the potential cost impact and to maximise the benefits, ICAO, in developing standards for new GNSS elements and signals, should develop recommendations on the most promising combinations of elements and signals.

3.3 Repercussions of regulatory restrictions

3.3.1 Current GNSS avionics automatically select which satellites and augmentation elements to use*. In the future, State regulations could require or prohibit the use of certain GNSS elements or their combinations. Such situation could result in significant costs for users in terms of additional cockpit controls and procedures, crew training and maintenance support. If each independent GNSS element had to be selected, the avionics interface would become very complicated. Crew training for use of this interface and system operation modes that should be selected in various parts of airspace would be costly. Furthermore, a complex avionics interface could increase pilot workload and become a safety issue.

3.3.2 These potential repercussions require ICAO to encourage States, in their planning for implementation of GNSS services, to avoid limitations on the use of specific GNSS elements for institutional reasons.

4. CONCLUSIONS

4.1 GPS, GLONASS and Galileo will offer independently operated satellite constellations and independent signals. Thus, GNSS service failures when a combination of constellations is implemented will be extremely unlikely.

4.2 Therefore, the increasing number of GNSS signals and constellations offers significant benefits to civil aviation in terms of improved robustness, as well as performance improvements, GNSS ground architecture simplification and alleviation of institutional concerns.

4.3 The implementation of a multiplicity of different possible combinations of elements would result in overall system complexity and negative economic impact particularly on the user side. This problem can be avoided by the thorough assessment and selection of the most promising combinations for general implementation.

4.4 If the issues related to the use of independent core satellite constellations, other GNSS elements and their combinations are properly addressed, the introduction of new constellations and additional signals will facilitate the transition to GNSS as a global system for all phases of flight.

4.5 ICAO, in developing Standards for new GNSS elements and signals, will address the issues associated with the use of multiple signals and their combinations, and develop guidance on the most promising combinations of GNSS elements.

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* This is true with the exception of GBAS precision approach that has a channel selection capability to direct the receiver to use a specific GBAS augmentation system.