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GOBAN : GNSS ROADMAP STUDY

FINAL REPORT

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1.0	20/2/03	Released draft report for review	Editorial corrections + additional material on ASAS according to DG TREN remarks
2.0	26/5/03	Final Report	Incorporation of "Safety assessment and certification issues" in the body of the Final Report + inclusion of the CBA section from the Interim Report as an annex to the Final Report

EXECUTIVE SUMMARY

The objective of this study was to assess the feasibility of progressively establishing GNSS as the sole external service for Civil Aviation in Europe and the other regions of the world, to identify the major technical, operational and institutional obstacles that would have to be overcome and to make recommendations to that effect.

Our starting point is the assumption that GNSS-2 would consist of at least two independently operated yet fully inter-operable constellations (GPS and Galileo), reinforced by regional integrity systems, all of these global and regional systems emitting their signals simultaneously on at least two different frequencies for Safety of Life applications such as aeronautical navigation. All those systems are expected to be operated as general purpose systems meeting not only the needs of Civil Aviation but also of other modes of transportation and of many other fields of application.

In addition to that, the most stringent precision landing requirements would be met by means of local (ground-based) systems dedicated to Civil Aviation and operated on a third frequency.

In that GNSS-2 concept, “fully inter-operable” means that the signal-providing systems are not merely compatible but that their frequency assignments and signal structures are designed so as to allow cost-effective receivers to take advantage of the existence of over sixty satellites simultaneously emitting their positioning signals from space.

The terms of reference of this study called for investigations to be conducted in two key areas: the cost-benefit assessment of the GNSS Sole Service strategy, and the safety issues that could be raised by that notion of sole service.

As regards the cost-benefit assessment we took a conservative view of the benefits by evaluating only directly quantifiable benefits corresponding to the progressive withdrawal on other navigation aids. Other benefits related to safety, flight data consistency, and other Air Navigation Service improvement issues certainly exist. We have discussed some of them without attempting to quantify them.

A detailed cost-benefit assessment was developed in the GOBAN Interim Report, and a revised version of that analysis is annexed to this Final Report. The key assumptions of our comparative analysis are that GNSS costs would be charged to the different user communities based on an apportionment of costs proportional to market size combined with service level, and that GNSS-based Cat II//III GBAS as well as a full decommissioning of other ground navaids would remain out of reach without Galileo, thus limiting the scope of the Sole service strategy. So we conducted a comparison between a baseline scenario (combining GNSS-1 with conventional navaids) and the full fledged GNSS-2 sole service scenario.

The salient conclusions of that economic analysis are:

- The navigation infrastructure and aircraft navigation equipment savings achievable with the GNSS-2 sole service scenario over a period of 15 years (2010-2024) are in the order of 3 bn € worldwide (two thirds on the ground side, and one third on the aircraft side)
- For the ECAC area, the corresponding savings are in the order of 0.85 bn €
- If the GNSS-2 sole service strategy was not adopted by other regions of the world, especially Northern America, the savings made on the aircraft side would be significantly reduced, as large commercial aircraft would have to maintain their DME and ILS Cat II/III equipment indefinitely.

Our conclusion is that there is a clear economic case for adopting a GNSS-2 sole service strategy, even without discussing any additional potential benefits. However, those direct economic benefits become really significant only when reaped on a world-wide basis.

As regards safety, we limited our analysis of sole service risks to two scenarios: 1) an interruption of service during GLS approaches conducted under Cat III conditions (possibly happening at several airports simultaneously) and 2) the manageability of dense and convoluted traffic flows by air traffic control in large TMAs, until the GNSS service resumes.

For our first safety risk scenario, our conclusion (that will need to be consolidated by a more detailed safety analysis) is that the probability of an accident caused by an interruption of the GNSS service would remain well below the Target Level of Safety, although it must be noted that there is a lack of pan-European statistics for determining the probability of simultaneous occurrence of Cat III conditions at several large European airports (the prevalence of such conditions at main airports is in the order of 100 hours per year per airport, but the joint probability for several airports is certainly higher than if Cat III conditions here and there were completely independent events).

For our second safety risk scenario, the feasibility of GNSS sole service can be demonstrated only through realistic large scale simulations. Our opinion is that all the risk-alleviating measures that will have to be defined lie on the ATM operation side, which should result in the definition of a cascade of contingency plans, but that no additional GNSS performance requirements would have to be added beyond the already defined requirements for approach, departure and TMA navigation.

Although the difficult issue of GNSS security was outside the scope of this study, it should be remembered that the same risk reduction techniques would apply to any service interruptions, be they caused by either a system failure or a voluntary jamming of GNSS signals. Therefore, if GNSS service interruptions can be demonstrated to be manageable by Air Traffic Controllers and pilots through carefully designed contingency plans, that would also provide many useful elements for dealing with lingering security concerns.

The only important message for GNSS designers, sole service providers and radio-spectrum regulators that emerges from our analysis is that any regional or even TMA-wide service interruption lasting longer than a few minutes would trigger a dramatic cascade of ATM safety measures (as the contingency plans may consist of temporary suspensions of departures, flight redirections, overall traffic flow reorganisation to increase separation etc.) that would significantly disrupt civil air transport operations.

If it can be proved that air traffic safety is not put into jeopardy by such events, it is however necessary that interruptions do not occur too often: even something in the order of one GNSS-induced traffic management crisis per year might destroy the credibility of the sole service scenario, and would anyway adversely affect the whole business case for aviation.

Therefore, availability and continuity of service are really the key issues for the adoption of GNSS as sole service for navigation, and they are technically even more important than integrity, as the multiple redundancy of signal sources would minimise the risk that a loss of integrity remains undetected to the point of becoming operationally hazardous.

In parallel with these technical and operational analyses, we conducted an analysis of institutional and legal issues taking into account the latest developments at ICAO and Eurocontrol, privileging the so-called “contractual framework” approach, and focusing our recommendations at interim steps that would not require the parties to enter the lengthy process of conventional agreements to be ratified by States. However, the absence of a comprehensive institutional framework remains a long term stumbling block in that area.

Finally, we have defined at the end of this report a roadmap that recapitulates all the tasks to be completed. We tried to identify all the major steps to be taken in the different areas, and we have concluded that if a focused approach is maintained by all the actors, the GNSS sole service scenario could become a reality towards 2015, if all the necessary implementation and safety certification work can be completed around 2010.

On the basis of the analyses summarised above, we have derived a number of recommendations towards different categories of stakeholders.

The four most important ones are:

- ***To GNSS designers and service providers***: there is an urgent need to clarify the integrity monitoring and alerting policy for Galileo and other pending issues (encryption, frequency-sharing scheme…) from both a system architecture standpoint and an institutional/legal one and especially regarding the integration of EGNOS with Galileo ;
- ***to Air Navigation Service providers and their safety regulator***s: the feasibility of GNSS as sole service can be established only after a number of operational risk alleviation scenarios have been tested through large scale simulations addressing especially all main TMA, and an ECAC-wide co-ordinated validation programme should be defined to that effect ;
- ***to commercial air transport users and equipment manufacturers***: a window of opportunity for a cost-effective migration to GNSS-2 equipment should open around 2010 when a single receiver for both Galileo and GPS II/F signals should be available, thus allowing the migration to GNSS-2 capability through a single retrofit operation on most aircraft ;
- ***to national authorities and the European Commission***: there is a risk that the current prevarication in the launching of Galileo and the lack of progress in bi- and multi-lateral regional agreements will make the establishment of GNSS as sole service no longer a realistic and attractive solution to airspace users, with the consequence that the technical and operational potential of the new system will not materialise in full for those users, and that a highly fragmented landscape in respect of the navigation policy will be maintained across the different regions of the world ; in that case, what we have defined in this report as the baseline scenario (GNSS-1 plus classic navaids) for assessing the merits of GNSS-2 would be maintained into the foreseeable future and GNSS-2 might never happen. We therefore recommend that the sense of momentum that existed some years ago in the European GNSS policy be restored through deadlock-breaking political decisions to be taken at the highest level.

TABLE OF CONTENTS

GLOSSARY

ADS	Automatic Dependent Surveillance
ADS-C	ADS-Contract
ADS-B	ADS-Broadcast
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
ASAS	Airborne Situation Awareness System
A-SMGCS	Advanced Surface Movement Guidance and Control Systems
EC	European Commission
ECAC	European Civil Aviation Conference
EOIG	EGNOS Operators and Infrastructure Group
FIS	Flight Information Service
GBAS	Ground Based Augmentation System
GEO	GEostationary Orbit
GNSS	Global Navigation Satellite System
GLONASS	GLObal NAvigation Satellite System
GPS	Global Positioning System
GSP	Galileo Signal Provider
GSTB	Galileo System Test Bed
HLD	High Level Definition Document
IA	Interoperability Assessment
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMF	Integrity Monitoring Facility
IMS	Integrity Monitor Station
ITU	International Telecommunication Union
MASP	Minimum Aviation System Performance (RTCA)
MCC	Mission Control Centre
MEO	Medium Earth Orbit
MOPS	Minimum Operational Performance Standard (RTCA)
MRD	Mission Requirement Document
MS	Monitoring Station
MSAS	Multi-functional transport Satellite-based Augmentation System
OSED	Operational Services and Environment Definition
OSA	Operational Safety Assessment
OPA	Operational Performance Assessment

QoS	Quality of Service
RAIM	Receiver Autonomous Integrity Monitoring
RC	Regulatory Commission
RIMS	Ranging and Integrity Monitor Station
SARPs	Standards and Recommended Practices
SBAS	Satellite Based Augmentation System
SIS	Signal In Space
SoL	Safety of Life
SRU	Safety Regulatory User
TMA	Terminal Manoeuvring Area
TTA	Time To Alter
WAAS	Wide-Area Augmentation System

1 INTRODUCTION

The Interim Report of this study reached the preliminary conclusion that an inter-operable combination of Galileo with GPS and augmentation systems would offer both the level of global redundancy and sub-system independence to pass the technical and political barriers preventing the adoption of GNSS as the sole navigation service for Civil Aviation at the 2015 time horizon for all phases of flight.

Adopting such an approach on a world-wide basis would also bring extremely significant savings to civil air transport.

However, a number of pending issues were identified, especially, on the operational side, in respect of how Air Navigation Service could deal with a GNSS service interruption when it would have become the sole navigation service available for most operations.

This Final Report of the GOBAN study is organised into two main parts:

- a discussion of technical and operational issues of GNSS services, consisting of a discussion of the main findings and of salient pending issues identified during this study, followed by our recommendations on further work that should be conducted, in a globally co-ordinated way, by the different stakeholders (ANS providers, equipment manufacturers, aircraft operators)
- a discussion of the necessary arrangements and regulatory measures that should prepare and accompany the transition to GNSS sole service ; the high level institutional and legal framework is discussed first, followed by recommendations on safety regulations.

As a way of conclusion, an overall transition plan defining a global roadmap is presented, with a number of intermediate target dates included.

A revised version of the Interim Report is provided as an annex to the Final Report.

2 RECOMMENDATIONS ON TECHNICAL AND OPERATIONAL ISSUES

2.1 Summary of study findings and salient pending issues

2.1.1 European GNSS Service Providers and related Communication and Surveillance services

In this paragraph, we will provide recommendations to providers of GNSS services and of other potentially related communication and surveillance services, addressing successively two categories of use: GNSS as a navigation system, and GNSS as a time-synchronisation system.

2.1.1.1 GNSS as a Navigation System

In order for GNSS to be used as sole service for navigation, it is of prime importance to make sure that systems are designed consistently, taking into account the aviation perspectives. What is meant here by consistently, is that the different components of GNSS should be designed according to a global vision, and not separately. For instance, one cannot expect an optimal design by developing on one hand a constellation like Galileo, on another hand an augmentation like EGNOS, and then by finding some possible way of integrating them. Another issue is that the aviation needs must absolutely be considered with high priority in a multi-modal system like Galileo, even if the aviation community will represent a very minor part of Galileo users.

2.1.1.1.1 Core constellations and augmentations : Towards an Integrated Approach

Currently, one constellation is operational, GPS. GPS has been designed more than thirty years ago, for military purposes. At that time, no one could predict the huge number of applications, mainly civil, that would be based on that system. GPS was not designed to meet any civil purpose; thus, all the requirements of civil aviation, especially in terms of integrity, availability and continuity of service have not been considered in the first block of GPS satellites. Even if the situation is evolving, GPS is still under the responsibility of the US Department Of Defence, and no service guarantee can be given irrespective of the geopolitical context. GPS remains a military operated system, entirely controlled by a single country.

In order to improve its performance, GPS has been “augmented” by complementary systems: WADGPS (Wide Area Differential GPS) for regional purposes, LADGPS (Local Area Differential GPS) for local purposes. In the civil aviation context, WADGPS is called SBAS, Satellite Based Augmentation System, which provides integrity information, differential corrections and additional ranging. In the CONUS (Continental US), SBAS is implemented as WAAS (Wide Area Augmentation System), whereas EGNOS (European Geostationary Navigation Overlay System) covers Europe and MSAS (MTSAT Satellite Augmentation System) Japan and its area. Then, for local civil aviation purposes, LADGPS is called GBAS, Ground Based Augmentation System, allowing performance and robustness to better match the requirements of the final approach and landing phase.

Up to that point, some consistency is maintained.

The situation becomes more complex when other constellations are included into the picture: Glonass, the Russian equivalent of GPS, has been designed using quite different techniques. Without going into extensive details, we can mention that whereas GPS uses CDMA (Code Division Multiple Access), meaning that satellites share a same frequency and are discriminated by different codes, Glonass satellites are each allocated a different frequency.

This results in an incompatibility between systems: a user willing to use signals coming from both GPS and Glonass needs to be equipped with one GPS receiver, plus one Glonass receiver, plus one piece of equipment in charge of the data fusion. An advantage is that the two constellations have fully independent failure modes.

This should also serve as an illustration and a reminder that there are always trade-offs to be found so as to optimise the balance between inter-operability and failure independence.

Moreover, nowadays, there is no concept of operation describing how to combine the positioning performance of GPS and Glonass satellites. The consequence of this lack of integration is simple: the dozen functioning satellites in the Glonass constellation are not used by Civil Aviation, and the aeronautical community waits for Glonass to be brought back into full operational capacity before considering any concrete co-ordination.

Another example is the future Galileo constellation. This new system, to be operated under the responsibility of European civil authorities, is expected to be independent from and interoperable with GPS, as both a supplement and competitor to GPS.

Looking at the Galileo signal design, one can see that the Galileo L1 frequency is in the same band as the GPS L1 frequency, allowing receivers to use the same front end amplifiers and filters, and that the Binary Offset Carrier which is used does not interfere with GPS. Yet, this is not completely sufficient to be considered as a fully integrated approach: technically speaking, some issues remain to be solved, such as the code sharing in the L5 band. But the main issue is that a global operational concept has to be put together in order to combine in an optimal way GPS and Galileo.

The feasibility of an adequate positioning accuracy does not raise issues, which is not the case of integrity service provision.

The GPS core constellation does not provide any integrity signal. For that purpose, regional SBAS are currently being implemented. By contrast, the Galileo constellation has a built-in integrity channel, designed to enable the transmission of both world-wide ("global") and regional data. One question is "how does EGNOS fit into Galileo ?" as Galileo is to deliver its own integrity, whereas EGNOS was designed solely for GPS.

One option that is being envisaged in the USA is to extend WAAS, the US equivalent of EGNOS, so that WAAS can provide and independent integrity signal for Galileo. For reasons of legal responsibility and liability, the USA might prefer to use their own WAAS rather than relying on the information provided over Galileo's regional integrity channel.

Similarly, in Japan, MSAS might also be extended to provide integrity information with respect to Galileo. If that scenario of multiple independent regional subsystems, each dedicated to providing independent integrity information for all constellations, is confirmed, that may be at odds with the approach adopted for Galileo.

This dilemma stems from the absence of a global world-wide GNSS strategy, and also from a lack of co-ordination at the level of system design between the various GNSS components.

It may well be that for regulatory and institutional reasons, aeronautical users and their safety regulators will not buy the concept of integrity data being provided by the system in charge of delivering the positioning data, unless a transparently developed safety case demonstrates that common failure modes are not more important than if the two system were independent.

In particular, non-European Air Navigation Service providers or non-European users flying outside Europe, even if he uses Galileo to derive its position, may want the more safety-critical integrity monitoring system to be entirely under the legal responsibility of the country (or the regional organisation) that also has responsibility under the ICAO Convention for the overall safety of civil air traffic.

In that case, in the absence of a world-wide institutional agreement, we could face a situation where the integrity channel of Galileo is used only in Europe, meaning that different regions of the world would adopt different integrity implementation strategies.

As a result of this lack of global coherence, another scenario that could emerge, if that issue of regional integrity is not clarified, is that Air Navigation Service providers may be tempted into leaving aside the Cat I capability supposedly available on a regional base through the two constellations, the aircraft RAIM and the SBAS, and relying instead, even in the long term, on local (ILS or GLS) Cat I systems.

What seems important at this point to the GOBAN team is to maintain the European focus at providing a set of multi-modal global services aimed primarily at civilian users and managed accordingly.

Whether EGNOS as a whole and/or part of its ground infrastructure (e.g. a set of RIMS and associated data links) is used also to implement the integrity feature of Galileo it should still be seen as part of an overall European system, whose operator should be able to make world-wide representations of service through contractual and institutional agreements with other regions of the world.

Two symmetric traps must be avoided:

- Maintaining a completely separate EGNOS system perceived by the other GNSS user communities as an “aviation gadget” having no overall synergy with the complete array of Galileo-provided services,
- Adopting a rigid approach in respect of the provision of integrity services: adopting the same type of “take it or leave it” approach than the USA with their GPS for promoting the regional integrity service of Galileo is certainly not the best approach ; both European authorities on the institutional/legal plane and the Galileo-cum-EGNOS operator on the technical/operational plane should demonstrate a willingness to enter into trans-regional multi-lateral agreements for a shared control on the generation and distribution of the regional integrity signals of Galileo.

In that perspective, deciding whether Galileo should have or not an SBAS component is a secondary technical issue, which should remain subordinated to the clear definition by the European Union of a global policy addressing the shared control of Galileo regional signals.

Our purpose here is not to conclude on what solution should be adopted as far as the respective ways to provide integrity are concerned, but rather to insist on the necessity to develop the technical solutions taking into account institutional matters, and avoiding that the global and regional integrity monitoring alerting services of Galileo be singled out as an “aviation gadget”:

Based on the arguments presented above, here is a first list of recommendations for European GNSS Service Providers:

[R2-1] GNSS Service Providers should be involved in the international working groups reflecting on the concepts of operation of GNSS for Civil Aviation, such as ICAO GNSSP, RTCA and Eurocae, in order for the design to facilitate the integration of the different GNSS components, and to avoid the continuation of the current fragmentation,

[R2-2] In the long term, the development of local solutions should be strictly limited to those functions and service levels which cannot be obtained through the joint use of Galileo and GPS,

[R2-3] The integration of EGNOS into Galileo should reflect a global European policy for the management of Galileo regional signals and not merely an aviation-focused technical view of the problem,

[R2-4] Any other augmentation system foreseen (GBAS, GRAS) should be designed so as to be open to inter-operability with the three constellations (GPS, Glonass and Galileo).

[R2-5] The technical solution adopted for the provision of integrity should be part of a world-wide reflection on legal and institutional issues. In particular, the technical solutions currently under development should allow for the regional integrity signal of Galileo to be a) combined with integrity signals for other constellations b) generated and distributed outside Europe under the operational and legal responsibility of regional organisations completely independent from (yet co-operating with) the Europe-based Galileo signal provider, and c) reflect an overall consolidation of requirements from all user communities and not only from civil aviation.

2.1.1.1.2 Meeting the Aviation Community Requirements : a priority to robustness

As mentioned earlier, even if civil aviation will represent a small minority of Galileo users, it is of prime importance, in order for GNSS to be used as sole means, that the stringent requirements from civil aviation are met by the system.

Special care should be given to the capability to meet integrity, availability and continuity needs; it is relatively easy for GNSS to provide quite an exceptional accuracy, but being able to provide the required level of integrity (both in terms of integrity risk and of time to alarm) for safety-of-life services, while meeting stringent requirements on the continuity of service, taking into account potential failures and interference, may significantly impact the detailed design choices that remain to be made.

For instance, when using spread spectrum techniques, resistance to interference is obtained owing to a high ratio between code rate and data rate. From the standpoint of commercial applications, a high data rate allowing for the transmission of a large amount of data is an attractive approach, yet such a choice would degrade the capacity of the system to cope with unintentional interference as well as with intentional jamming.

This remark does not apply only to application data, but also to the data and processing overload which would be induced by the implementation of encryption and/or authentication techniques. Such mechanisms, which are still mentioned in the Galileo baseline, are not acceptable by the aviation community, and should not be present in the frequency bands used for civil aviation, since they would impact negatively the overall response time of the system, and would degrade its robustness, because of the data transmission overhead implied.

[R2-6] Low data rates should be adopted in the Galileo signal definition, in order to maximise the resistance to interference and jamming.

[R2-7] The implementation of an encryption capability on the safety-of-life service has not been accepted by the aviation community, and that opinion should not be dismissed lightly.

That first batch of recommendations is aimed at promoting an integrated approach to GNSS, and at emphasising the issue of robustness.

Our next set of recommendations addresses the importance of designing GNSS components in an integrated manner, with a view to improving the overall GNSS robustness.

[R2-8] Signals from the different constellations (GPS, GLONASS, Galileo) should not interfere with each other.

For most frequencies, this is already the case. Yet, one problem remains between GPS L5 band and Galileo E5a band, which are the same. Here, the solution that optimises the inter-operability is to have a global set of orthogonal codes allocated in close co-ordination between Galileo, GPS, and their potential augmentations.

[R2-9] Constellations should be designed so as to reduce common modes of failures, and studies should be performed in order to identify and mitigate the cases where such common failures could occur.

[R2-10] Constellations should be operated independently. Systems providing integrity should be operated independently from the constellations.

[R2-11] The Galileo Global and Regional Integrity concepts should be clarified as soon as possible, together with their modalities of integration with WAAS, EGNOS and MSAS.

[R2-12] Our final recommendation for European GNSS Designers and Service Providers is that a strict procedure should be put in place to process the input received from the Aviation Community, especially through some on-going projects such as SAGA and Galilei. A feedback should be formally provided, showing which suggestions have been retained, and explaining the reasons why other suggestions are not being retained.

2.1.1.2 Potential Indirect GNSS dependencies

Potential indirect GNSS dependencies refer to potential side effects derived from the integration of CNS/ATM functions that are not directly linked to navigation.

In the future ATM system, CNS will move from current analogue voice communications, terrestrial navigation, and radio-based surveillance to digital communications, GNSS-based navigation, and automatic-dependent surveillance (ADS). Potential indirect GNSS dependencies will then be related to digital communication networks and to ADS-based surveillance.

2.1.1.2.1 Communication network dependencies

Potential indirect GNSS dependencies of telecommunication networks stem from the possible use of GNSS for network synchronisation. Network-wide time synchronisation is a stringent requirement for ground-ground high throughput and also for air-ground digital communication infrastructures, especially CDMA and TDMA-based systems, where the timing tolerance is below the micro-second.

That constraint makes the use of GNSS very attractive for time synchronisation of telecommunication networks. However, the stringent performance requirements - in terms, for instance, of accuracy, time and frequency stability – may imply a very low tolerance with respect to GNSS service interruption in the absence of adequate back-up systems.

Subsequently, using GNSS-derived time synchronisation within telecommunication networks supporting aeronautical communication and surveillance applications may create a risk of triple failure degrading simultaneously the Communication, Navigation and Surveillance functions.

[R2-13] Because of the risk of simultaneous C, N and S degradation, we recommend not to use GNSS for network synchronisation where such networks are used to support tactical information flows that would become critical for the sustainability of a safe air traffic management environment in the event of a degradation of the navigation service (i.e. any digital link application used for air-ground and ground-ground tactical exchange, especially the ground distribution of surveillance data; this may also include any voice communication channels that would happen to depend exclusively on digital links).

[R2-14] We recommend to carefully study all the potential indirect dependencies on GNSS like those created by the current generalisation of GPS synchronisation within general purpose wide area networks (or for synchronising surveillance radar stations) and their potential impact in the context of CNS integration and of the digitalisation of telecommunications.

2.1.1.2.2 Automatic Dependent Surveillance dependencies

Potential indirect GNSS dependencies with ADS-based surveillance rely on the possible use of GNSS position to report aircraft own position to other users. Used as ADS surveillance information, the aircraft own position is derived from on-board navigation sources that will solely be provided by GNSS services. An ADS-based system will require more or less stringent precision in positioning and time stamping, depending on its application.

For example, the use of GNSS-derived surveillance in support of airport surface navigation is an alternative to ground-based tracking.

In case of GNSS failure, the primary surface radar would remain the most effective way of obtaining information on the position of mobiles in operation in the whole airport area, although other technical means (such as multi-lateration) would also be available.

2.1.1.2.3 Airborne Collision Avoidance System (ACAS) dependencies

The Airborne Collision Avoidance System (ACAS) standards foresee a potential hybrid surveillance capability, consisting in:

- an active interrogation of Traffic for Collision Avoidance System (ACAS/TCAS) for Anti-Collision Avoidance surveillance
- a passive surveillance for Airborne Situational Awareness relying on the reception of data such as Automatic Dependent Surveillance data (ADS-based surveillance)

As stated in the previous section, ADS-based surveillance can rely on the possible use of GPS (GNSS) position data to report aircraft own position to surrounding aircraft. The passive surveillance could then consist in receiving GPS (GNSS) position data broadcast by surrounding aircraft.

It should be outlined that hybrid surveillance is not needed in the currently mandated ACAS/2 system for avoidance in the vertical plan.

Hybrid surveillance could be envisaged for ACAS/3 system for collision avoidance in the horizontal plan. However, at this moment in time, work on ACAS/3 is in a preliminary stage, and no decision has been taken on its development.

In case where hybrid surveillance would be implemented in an ACAS system in the future, for safety purpose, we recommend to keep Separation Assurance data provided by the passive surveillance (Situational Awareness) as independence as possible from Anti-Collision Data provided by active interrogation.

In other words, GPS (GNSS) position data are **not** intended for use as Anti-Collision Data.

2.1.1.2.4 Flight Data Dependencies

The use of GNSS-derived synchronisation for the reconciliation of flight data between the aircraft and the ground is likely to facilitate the implementation of tactical traffic management tools based on 4D trajectory predictions.

The availability of accurate trajectory information allows the ground system to make very precise conflict predictions, which could lead to reductions in separation mediums and hence increased air traffic system capability. Trajectory information can be available on the ground through the use of ADS reports (ADS-C or ADS-B, the use of ADS-B allowing surveillance data to be transmitted at a higher rate). Using GNSS, the accuracy of trajectory data contained in ADS reports would depend on the accuracy of GNSS-derived position.

GNSS time synchronisation should provide a more redundant - due to the two independent constellations - and more accurate means than GPS alone, for ensuring temporal coherence between airborne and ground entities that share action performance (requiring, for instance, flight data coherence), as well as between co-ordinated airborne systems such as those operating ASAS.

The trajectory data exchanges defined by Eurocontrol ODIAC demonstrate that the temporal coherence requirement is relatively low (e.g. flight-negotiation-related services such as FLIPCY, FLIPINT require a low transfer time of 30 seconds in 95% of the cases; transfer time stringency is proportional to temporal coherence stringency). This relatively low level of requirement makes it relatively easy to maintain a good synchronisation in case of GNSS failure and thus reduces the dependability problem. Even (still undefined) more constraining tactical applications such as future ASAS applications would probably remain manageable.

2.1.1.2.5 Conclusion on indirect dependencies

In terms of CNS integration connection with the safety analysis, general recommendations related to indirect GNSS dependencies are:

[R2-15] On the operational level, GNSS sole service in itself should not impact indirect dependencies for systems using GNSS as a means of providing time-stamping, since the classic navaids it would replace do not provide for any time-stamping.

[R2-16] For systems requiring a low or medium precision synchronisation there are probably no problems, since backup systems can be used, such as internal clock or radio-synchronised clocks.

[R2-17] For systems requiring a precise time-stamping, the minimum performance levels (especially integrity, availability, continuity) required for safe operation of that type of function should be defined and carefully checked against GNSS sole service performance.

As briefly discussed above, A-SMGCS and 4-D trajectory negotiations would probably require low or medium precision time-stamping and low cost back-up solutions on both the aircraft side and the ground side could be easily implemented. Those back-up means, coupled with the traffic alleviating measures discussed at section 3.2.4.4, should be sufficient to maintain an adequate level of safety.

By contrast, until a full-fledged joint safety case for navigation and communication has been completed, aeronautical communication networks that would require high precision synchronisation should not depend on GNSS for providing that synchronisation, as that dependency may jeopardise the navigation safety case for GNSS sole service, by creating a common failure mode with the tactical communication function, while that function would become highly critical in the event of a GNSS service failure.

In that situation, it is clearly not sufficient to provide independently defined safety cases for each function: a global safety case clarifying all the potential interdependencies of navigation and communication failures should be developed.

2.1.2 Air Navigation Service Providers and their safety regulators

In this section, we provide technical recommendations targeted at Air Navigation Service Providers and their safety regulators, addressing the same two categories of use: GNSS as a navigation system, and GNSS as a time-synchronisation system.

2.1.2.1 GNSS as a Navigation System

When adopting GNSS as a sole means to perform navigation, an Air Navigation Service provider chooses a system offering many advantages, mainly in terms of performance (the precision of GNSS can reach a few centimetres with differential augmentations) and of cost (the GNSS-2 Safety of Life service will be free of charge). However the key word in the aeronautical environment is “Safety”. So, when drafting a strategy which aims at using GNSS as sole means for navigation, the question to be answered: is GNSS safe enough ?

This is quite a valid question, when we consider the signal to noise ratio at input of a GNSS receiver: the user being more than 20,000 km away from the emitting satellites, the level of the signal is much below the level of the noise. This could appear as a major drawback. In fact, due to the use of spread spectrum techniques, this poor signal to noise ratio can be seen as an advantage: it is one of the best technical solutions to limit the effects of narrow band interference and jamming. Nonetheless, some vulnerabilities remain. The purpose of the following paragraphs is to go through identified vulnerabilities, and to propose recommendations for Air Navigation Service providers to mitigate them down to an acceptable level.

As mentioned above, GNSS provides very good performance, especially in terms of precision of position. That is not enough to ensure safety. We also need the system to meet a high degree of integrity: if GPS by itself was not designed for that purpose, the use of regional and local augmentations is quite sufficient to meet the integrity requirement of the aviation community. With Galileo, overall system performance is further enhanced, as the system was designed together with a built-in integrity channel. Now, If precision and integrity are of vital importance, two other characteristics must be considered to make sure that the system is safe: the availability and the continuity of service.

For the sake of clarity, we recall the definitions of these terms:

- Performance: for GNSS, the couple (accuracy, integrity) is denoted as “performance”.

- Continuity: The continuity of a service is defined as the probability that the performance requirements will be met over the time interval of an operation, provided that they are met at the beginning of the operation.
- Availability: The availability of a service is the probability that the performance requirements are met at any point in time.

The couple (availability, continuity) is sometimes referred to as "robustness".

So, when a system presents high performance, i.e. good precision and integrity, safety is catered for if the system also presents high robustness, i.e. good continuity and availability.

What are the problems with availability and continuity, and how can they be overcome ?

Providing that the components of the system are designed in such a way that both the mean time between failure and the time to first fix meet expected requirements, it appears that the weakness of GNSS resides in the space segment, i.e. in the signal propagation through the different layers down to the user's receiver.

Here is a list of known elements that can degrade the propagation of the GNSS signal:

- Ionospheric effects:
  - the propagation through the ionosphere is degraded due to a "curving" effect: instead of travelling through the ionosphere following a straight line, the trajectory of the signal is bent, depending on its frequency. At user's level, the result is that the signal power will significantly vary from one location to another;
  - the signal power is attenuated by a phenomenon called "scintillation", which affects mainly the tropical regions;
- Solar activity: solar bursts are known to create major interference on a wide band scale;
- Unintentional interference: systems operating in frequency bands close to the GNSS bands are likely to cause interference which may result in a signal loss. These systems can be either other aeronautical equipment, such as DMEs or some radars, or equipment external to the aviation community (television broadcast, wireless computer networks, etc…);
- Intentional interference: through the use of jammers, it is possible to interfere voluntarily with GNSS.

Which mitigating measures should be taken by the Air Navigation Service providers to ensure safety while promoting GNSS to a sole means of navigation? In order to protect the GNSS signal, we recommend to act at three levels: technical, operational and legal.

At the technical level, two threads of mitigation can be pursued:

- the reception of the GNSS signal can be improved by implementing appropriate technology into the receivers: for instance, the interference caused by DME is a pulse signal, which can be suppressed by using pulse blanking techniques; another example is jamming, where anti-jamming methods have been developed, mainly in the military domain; a third instance is the use of multiple frequencies to perform ionospheric corrections;
- GNSS can be operated in such a way that a signal loss will have minimal effect: this is possible thanks to the use of multiple frequencies and of optimal combination of core constellations and their augmentations.

The following recommendations, intended for Air Navigation Service providers and their safety regulators, are derived from these two threads of risk mitigation at the technical level:

[R2-18] All necessary actions to protect the GNSS frequency spectrum at ITU level should be taken ;

[R2-19] Continuous studies should be performed to assess the various causes of interference, taking into account all recent developments in wireless technologies ;

[R2-20] Systems should be developed to monitor, report and locate unintentional interference as well as jamming ;

[R2-21] a common reporting system allowing to gather and process information on any detected occurrence of interference should be established on a pan-European scale and be used to tune statistical assumptions on interference ;

[R2-22] Feedback should be given to systems designers in order to place the focus on robustness: for instance, the aviation community should not allow integrity data to be encrypted, as encryption would add complexity and degrade the bandwidth

[R2-23] The aviation community should develop a concept of operation of GNSS in which the use of multiple frequencies is mandated ;

[R2-24] The aviation community should develop a concept of operation of GNSS describing a combination of the different frequencies of the different constellations so that a partial or global failure of one constellation is adequately compensated ;

[R2-25] As far as backup systems are concerned, the level of risk that each service can accept should be assessed, together with the minimum backup systems to be retained for lowering the risk to that level. The associated costs should be evaluated together with how such costs are to be funded ;

On the operational plane:

[R2-26] Procedures should be designed in order to minimise the impact of a loss of GNSS data, even if the probability of such a loss is very low; the capacity of operational staff to apply these procedures should be checked on a regular basis.

That means that controllers should be able to guide all aircraft safely down to the ground in case of a major GNSS failure, and that minor failures should only diminish the traffic capacity without inducing any hazard. Recommendations on contingency measures are further developed at section **Error! Reference source not found.**.

Finally, on the legal and regulatory plane the following recommendations are worth being put forward, as they impact both safety and security issues:

[R2-27] The protection of the GNSS frequency bands should be enforced strictly, and adequate resources should be allocated to the detection and confiscation of sub-standard products that become involuntary sources of interference and any suppliers of such products should be prosecuted.

[R2-28] New regulations should also be introduced in a co-ordinated way in Europe and elsewhere to the effect of preventing the commercialisation of GNSS jammers (today, powerful GPS jammers are on sale through the Internet…)

To achieve that objective of GNSS signal protection, Air Navigation Service Providers should continuously lobby the radio-spectrum regulatory authorities so as to obtain a strict enforcement of ITU regulations, and also make representations towards their national and EU legislators, to the effect of improving the arsenal of legal measures available against offenders.

2.1.2.2 Potential Indirect GNSS dependencies

The way positioning sources are used within an airborne architecture depends on the SUR-NAV strategy envisaged. Within the airborne surveillance device, current ADS-B systems typically use GPS to determine their position.

The GNSS envisaged configuration, composed of two independent constellations (Galileo and GPS + SBAS), is highly redundant. That redundancy potentially offers a diversity of independent positioning sources to input independently to the onboard navigation processing (e.g., GNSS receiver for Galileo and GPS) and to the onboard airborne surveillance processing (e.g., EGNOS receiver for GPS or GNSS receiver for GPS).

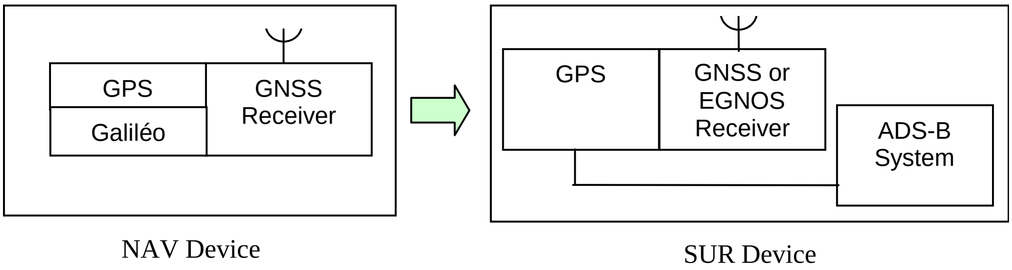

Figure 1: Diversity of Positioning Sources

The redundancy of the envisaged GNSS configuration should increase the provision of guarantees for positioning data. Airborne surveillance integrity should be improved since GNSS position input to airborne surveillance function would no longer depend from a single navigation-shared positioning source. Availability of both navigation and airborne surveillance services should benefit from the high number of satellites composing the Galileo constellation, allowing satellites to be visible at any moment in time so as to serve as positioning source. A constellation of 10 satellites (among the 30 envisaged for final Galileo constellation deployment) should already offer enough world-wide coverage to allow a reduction of conventional surveillance by means of radars.

[R2-29] We recommend to promote a SUR-NAV strategy that makes use of the diversity of positioning sources offered by the envisaged GNSS-2 configuration so as to reduce the multiplicity of radar coverage for en-route navigation.

However, considering the difficulty of traffic management in busy TMAs in case of GNSS failure, it is unlikely that TMA radar coverage could be reduced.

2.1.3 Aircraft operators

In this section, we address the contributions expected from aircraft operators in support of the GNSS sole service strategy, as aircraft operators, and especially commercial air transport companies, have a key role to play in the implementation of that strategy:

[R2-30] Aircraft operators should lobby ANS providers, so as to promote the adoption of the GNSS sole service approach in regional and national Air Navigation Plans ; in particular, the recommendations made above towards European ANS providers should also be promoted by international aircraft operators in other regions of the world.

[R2-31] Aircraft operators should ask the US FAA to reconsider its recent decision made to maintain conventional navaids.

[R2-32] All airspace users should lobby ICAO and their states of registry on the key safety and security issue of GNSS frequency spectrum protection.

[R2-33] as soon as the GNSS sole service strategy is endorsed, airlines should make budgetary plan for a retrofit of their aircraft with GNSS-2 receivers and they should launch that retrofit campaign as soon as the corresponding equipment mandates have been published.

[R2-34] In the case when safety arguments are put forward to maintain classic navaids, then aircraft operators should request that the feasibility of alternative scenarios based on operational alleviating measures be assessed through an independent safety study (cf. our recommendations in the next chapter on the definition and assessment of contingency plans).

[R2-35] In the case where residual security issues are put forward in some States to maintain classic navaids after the migration to GNSS sole service is started, then aircraft operators should request that the cost of such decisions be borne directly by the concerned States, and not financed through route charges.

On the operational plane, and in parallel with our recommendation R2-26 made for ANS providers, aircraft operators should participate directly into the development of mitigating measures:

[R2-36] airlines should develop procedures to minimise the impact of GNSS service interruption, and train their pilots and Operation Centres accordingly.

2.1.4 Aircraft navigation systems manufacturers

On the aircraft equipment side, we expect the GNSS sole service strategy to have the following impact on the activities of manufacturers:

[R2-37] For the market segment of IFR aircraft that have no FMS or even no INS/IRS equipment on-board, the emergence of GNSS as sole service may call for the introduction of low-cost INS solutions (otherwise such aircraft would have to fall back entirely on to VFR operation in case of GNSS failure)

[R2-38] An integrated dual frequency receiver for both GPS and Galileo should be designed as the standard fit for aircraft (re)equipped from 2010 onwards

We can also make 2 broad technical recommendations for industry that are also of interest for defining future RTD activities to be defined and sponsored by the European Commission in the field of GNSS development:

[R2-39] Continuous studies should be carried out to keep improving the robustness of receivers thanks to filtering techniques: pulse blanking, frequency driven adaptive filters, etc…

[R2-40] A continuous assessment should be made of the applicability of anti-jam technology to the civil sector.

3 RECOMMENDATIONS ON LEGAL AND REGULATORY ISSUES

3.1 Institutional arrangements on liability and service guarantees

3.1.1 Assumptions and background elements

3.1.1.1 Timing assumptions

While the original project management plan was based on a medium to long-term institutional framework, it was agreed at the kick off meeting that this study shall focus on the short to medium term solutions, to be implemented by the advent of Galileo. Long term means the 2015+ timeframe.

Naturally, in terms of the institutional mechanism to be defined, a period of 2002 to 2008 makes a big difference in terms of legal arrangements. Where the difference lies is in the extent to which commitments for the long term can be realised. A good example is the number of options open in the effort to establish contractual commitments. An option of contractual arrangements could be realised within the short term and be projected into the long term. This may be compared to a treaty regime which under normal circumstances cannot be realised within a period of 10 years.

Against this view, it should be feasible to implement the options recommended in this report within a period of between 5 and 10 years.

3.1.1.2 The United States and liability

Since the introduction of the Global Positioning System, the United States of America has had an unwavering position on its responsibilities vis-à-vis other states. Its position relate to the responsibilities of states in approving the use of GPS for air navigation, irrespective of the category of use, the liability of the GPS signal provider vis-à-vis users and states, as well as sovereign control over GPS.

In relation to legal responsibilities of states, the US has held the view that while the aviation community may use GPS, and indeed they have consistently offered GPS as a global navigation system to ICAO, *the US shall not take responsibility for the legal approval of states undertaken as part of each state's obligation under the Chicago Convention.* In the opinion of the US, each state has responsibility under Article 28 of the Chicago Convention to authorise and make provision for air navigation services and equipment. Consequently the decision and authorisation to use and the control over the use of any form of air navigation services, including GPS, shall not be the responsibility of the signal provider.

Linked to the position on legal responsibility for approvals is the issue of liability for damage sustained as a result of the use of GPS signals. The position held by the US is that it cannot be held liable for damage sustained by any person relying on GPS outside the US.

Finally, it is assumed that the US shall not be willing to share sovereign control over GPS.

3.1.1.3 Assumptions on the legal relationship between EGNOS and Galileo services

Another major assumption of a technical nature but having a major impact on the legal and institutional analysis is the role of EGNOS in relation to Galileo. While Galileo is being developed as a comprehensive system, the role of EGNOS has been questioned in the determination of, inter alia, legal questions that crop up in relation to its use.

It is assumed in this section that some regional sub-system would be used to ***independently*** monitor the integrity of Galileo.

The retention of an ***independent*** sub-system implies that the integrity service provider take on ***independent*** obligations in relation to the Galileo signal.

The reader should note that this notion of legal independence is not strictly equivalent to our previous discussion of technical architecture options for the integration of EGNOS with

Galileo (e.g. the use of Galileo-provided integrity channels versus other region-dedicated integrity channels).

EGNOS and Galileo could share a good deal of infrastructure and still be legally independent service providers, and conversely EGNOS could still exist as a completely independent physical infrastructure (e.g. for alleviating technical dependability concerns) and yet the corresponding integrity monitoring and alerting service could be subject to a sort of "bundled commitment" made on behalf of the Galileo service provider.

Obviously, the 2 issues are not completely unrelated, as it is easier to make independent service representations when they are based on an independently operated technical infrastructure. However, we have designed some recommendations aimed at maintaining a sufficient level of independence, even if the two infrastructures are managed by a single corporate entity.

As already noted in the technical and operational section, it is likely that in certain regions of the world, ANS providers, aircraft operators and national authorities may want to maintain a direct national or regional responsibility regarding the integrity alert service monitoring Galileo primary signals outside Europe, for the sake of juridical security in the absence of an overall institutional agreement on GNSS liability guarantees.

For that reason, we have privileged the notion of a legally independent integrity service provider at the regional level.

The provision of integrity monitoring signals requires the provision of a service legally distinguishable from the other Galileo-provided services. The operator of that service shall consequently be required to make provision for service guarantees, independent of any service guarantee to be provided by the operator of the Galileo signal.

However, as the analysis will show later on, that service guarantee, even though provided independent of the Galileo signal provider, shall have to be related to the availability of the Galileo signal.

The rationale for this conclusion is that the provision of integrity services is conditioned on the availability of the primary signal: what the integrity alert service provider is responsible for is not the absence of the primary signal it monitors, but only its own potential failure to raise a timely alert when that primary signal becomes inadequate or unavailable.

3.1.2 Legal and Institutional Models

Legal arrangements are engagements between legal or natural persons. In the field of satellite navigation signals for aircraft use, one deals mainly with legal persons who range from private companies to international organisations. References to persons or institutions shall therefore be predominantly to legal persons.

The relevance of personalities is determined by their functional roles. In most cases it is easier to identify the legal person by the function since the personalities may change as the development of Galileo progresses. Thus references will often be made to actors performing the roles. Where necessary specific institutions clearly identified with particular roles will be mentioned.

In relation to the focus of this study, namely the provision of satellite navigation services for safety of life (SOL) there are 6 major functions. The focus on provision of services mean that issues relating to the development, concession, operation of the satellites have been resolved, as is required to be resolved under the ongoing Galilei study.

The relevant functions that will determine the institutional and legal relationships are:

1. The Galileo Agency Role: Included in this role is the ownership and public management of Galileo.

2. The Galileo Service Provision Role: Included in this role is the operation of the Galileo satellites for the generation of Galileo signals. Of particular interest here is the role of the operator of the satellites and the consequent distribution of signals through the various service providers. It needs to be noted that the signal provider may itself reconstitute into a service provider. Whether that is possible or not we consider the next function as independent of the signal generation function. This is done to highlight the legal interfaces.

3. Integrity monitoring facilities: This includes monitoring the signals, when available, to determine their integrity and broadcasting same to either service providers or directly to users. Integrity monitoring facility providers operate eventually as service providers since they provide an enhanced service to a target group.

4. The Service Provision Role: This role involves the distribution of Galileo signals enhanced as the case may be for the particular requirements of the user group. It is certain that even within the safety of life sector such as maritime, rail, road and aviation, the requirements differ. Thus each service provider of each particular group will have different requirements to meet. For the aviation sector it is envisaged that most national air traffic control agencies will fall in this category, but only for providing strictly aviation-dedicated local augmentation signals (airport operators may also qualify for this rule in the case when they are in charge of managing the local navigation infrastructure). Otherwise, they will qualify as users of global and regional signals provided by general purpose service providers.

5. Users: Classic users of satellite navigation for safety of life services are aircraft operators receiving en-route signals from either a regional service provider or a national service provider and receiving local area signals and instructions from a local service provider.

6. Regulatory mechanism: The regulatory mechanism could be classified as international, regional and national. The regulatory role, although not directly related to the provision and usage of satellite navigation services, is essential in regulating the conditions for the provision and usage of such signals. It is envisaged that the regulatory role will consist of: *technical regulations* such as standardisation, certification, and safety; *economic regulation*s shall consist in controlling prices, preventing unfair competition and abuses of dominance. A major regulatory role is the exercise of a nation's sovereign right to authorise the use of satellite navigation signals for use by aircraft registered or operating within its airspace.

3.1.3 Legal Relationships

The type of legal relationships arising from the provision and usage of satellite navigation services by ATSPs and aircraft operators, based on the functional roles defined above, include agreements, regulations and claims. *Agreements* include inter-state agreements often referred to as treaties or conventions, public or private contracts. Under *regulations* are regulations passed by public agencies to authorise or monitor the implementation of decisions. *Claims* is used here mainly to denote claims arising out of a breach of contract or from negligence.

The provision and usage of satellite navigation signals will require different types of *agreements* and *regulations* which are listed below in relation to the function to be performed

Functions	LEGAL INTERFACES
Galileo Agency **(GA)**	1. International Agreement (between states and organisations) on Ownership (and public administration of Galileo) 2. EU Regulation (e.g. JU Proposal) on ownership, capitalisation and global management (short to medium term measure) 3. Eventual International Convention on Galileo and satellite navigation (Long-term measure).
Galileo Signal Provision **(GSP)**	1. Service contracts with service providers 2. Service contracts directly with users 3. International agreement on services to aircraft operators (long term measure)
Integrity monitoring facility **(IMF)**	1. Service contract with users 2. Service contract with service providers 3. International agreement on service provision (long term measure)
Service providers **(SP)**	1. Service contract (license) with Galileo Signal provider 2. Service contract with integrity monitoring facility 3. Service contract with users (aircraft operators)
Safety related users **(SRU)**	1. Service contracts with service providers and integrity monitoring facilities 2. International Agreement on services to aircraft operators (long term measure)
Global regulators	Global International Agreements, including WTO, ITU, ICAO, IMO regimes
European regional regulatory coordinator	European Regulations on Safety and Competition, Consumer Protection, Liability, including product liability
European state regulators	Enforcing Regulations on Safety and Competition, Consumer Protection, Liability, including product liability
Non-European state regulators	Enforcing Regulations on Safety and Competition, Consumer Protection, Liability, including product liability

Table 1: Top-level legal interfaces (from the perspective of service provision - SOL)

In terms of private law agreements the legal relationship can be depicted as a complex web of service agreements directly regulating the provision by one entity of satellite navigation services, another party taking on the signals either in a capacity as a service provider for enhancement and onward transmission to the end user. As can be seen from Figure 2 below, the legal link can at the private law level involve all four parties interlinking through some form of contract.

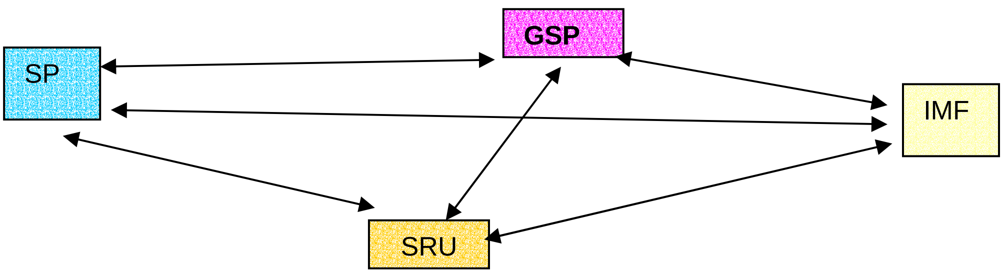

Figure 2: Contractual Chain

The content of such agreements shall differ greatly. However certain core issues will be expected to be included in all types of agreements. These will include but not be limited to:

- guarantee of service,
- default on delivery of guaranteed service
- legal consequences for default
- breach of contract
- negligence,
- liability regime
- dispute settlement mechanisms
- compensation mechanism

3.1.4 On a Long Term Legal Framework

3.1.4.1 ICAO Work on Legal Framework with regard to GNSS

The International Civil Aviation Organisation (ICAO) has since 1994 been working on identifying an appropriate regulatory framework applicable to the Global Navigation Satellite System. Following the adoption by the 32nd Assembly of a *Charter on the Rights and Obligations of States Relating to GNSS Services*, a Secretariat Study Group on Legal Aspects of CNS/ATM Systems studied the number of legal issues involved, including institutional issues, liability issues, a long-term legal framework.

The 33rd Assembly of ICAO considered the report of the Group. On *institutional issues*, it was noted that the European Galileo initiative could assist in giving shape to the continuous debate on an appropriate institutional framework.

On *liability relating to GNSS* the Group observed national law of member states may apply in case of failure or malfunction of GNSS systems. The law is fault based and it requires proof of the fault of ATC agencies. The Group concluded that the substantive law on ATC liability is reasonably adequate to determine and apportion liability arising from accidents involving failure or malfunction of GNSS systems. It is unfortunate that this conclusion was based on a few working papers submitted, without a thorough analysis of the adequacy of national laws.

This issue is still of much importance and requires a thorough comparative analysis to indeed determine the adequacy of national ATC liability laws. For the moment though, suffice it to say that based on French, US and UK law, it could be assumed that the Group's conclusions were right.

It should be noted however that procedural rules, in particular rules relating to jurisdiction are not adequate. This was also noted in its report to the Assembly.

On the issue of the adequacy of national laws and whether there is still the need for a universal regime on liability relating to air navigation services, there was no consensus. As an interim measure it proposed the inclusion of certain issues in contracts regulating the provision of GNSS *services.*

On the issue of a long-term legal framework, there was a lack of consensus on the need for a convention. As an interim measure the group agreed on the use of contracts to regulate certain key issues. In its outline for a contractual framework for GNSS services it opined that it is necessary that a single document listing the required common elements of a contract be adopted as an Assembly resolution.

The work of ICAO on legal and institutional issues has assisted in thrashing out a number of issues. However, many more are yet to be resolved. Some of the issues left unresolved are:

- there are no clear guidelines on the institutional issues
- the use of fault-based liability to regulate GNSS may not assist in a user friendly system. This is particularly of importance to Galileo which intends to use the issue of service guarantee (See below) and liability as a marketing tool for a maximum user acceptance. A simplified strict liability regime, capped as to the limit of liability (cf. the Warsaw Convention liability caps in Section 6 below) would be a more consumer friendly regime.
- the lack of uniform procedural rules can easily result in a maze of conflicting legal requirements from different jurisdictions. Here again the solution found in the Warsaw system offers a better future for the popular use of GNSS.
- the absence of a long-term legal framework regulating issues as rights and obligations of the state in authorising GNSS use within its airspace, sovereign immunity in liability claims, adequate compensation for victims, all affect the global acceptability of GNSS and Galileo.

[R3-1] For the long term, we recommend that a strict GNSS liability regime, capped as to the limit of liability, be adopted to foster user and ANS provider adoption of GNSS, especially in the GNSS sole service perspective; a sensible alternative would be to apply a fault-based liability regime where the burden of proof would be reversed (i.e. to be exonerated, the GNSS service providers would have to demonstrate that the damage to be compensated results from a user's fault or an ANS provider's fault and not a GNSS fault).

3.1.4.2 Eurocontrol Proposals on a Framework Agreement

In its quest within ICAO of an appropriate legal framework to govern the provision and use of GNSS, Eurocontrol submitted a working paper to the ICA Secretariat Study Group meeting. The Paper Framework Agreement for the Implementation, Provision, Operation and Use of the Global Air Navigation Satellite System for Air Navigation Purposes, (hereafter Eurocontrol Paper) contains a proposal for the establishment of a contractual framework as medium term solution.

It may be recalled that the Assembly had called for a solution to the issue of crafting a long-term legal framework. In view of the difficulty of reconciling different positions, the Legal and Technical Panel had not succeeded in coming out with a concrete position.

The Eurocontrol paper proposes the establishment of a contractual framework linking the various entities identified above through a formal legal instrument, the Framework Agreement and subsequent contracts.

The Framework Agreement, in the main, is concluded at state level between a group of states. This group can be regional, or even global. Realistically the Framework Agreement may be easily concluded at the regional level. The Agreement provides for a number of institutional and legal provisions deemed necessary for a GNSS contractual framework.

The Agreement is to result in the creation of a GNSS Entity which will have the role at the level of the Agreement with tasks assigned to it. Some of the tasks assigned to this entity may include acting as a facilitator of the contractual framework.

Given the regional context, this role may even be expanded to include a monitoring role. Indeed in the view of the drafters of this proposal, it is foreseen in the European context that the functions of the Entity will be further expanded to include powers to enter into contractual arrangements with the various institutions in the contractual chain.

[R3-2] For the medium term, we support this concept of a Framework Agreement proposed by Eurocontrol, as it can serve to broker sets of agreements between the primary signal provider and other (augmented) service providers and between service providers and users.

Particularly in the aviation sector where ATSPs are not noted for providing services on the basis of a contract this role of the GNSS Entity may result in a drastic change.

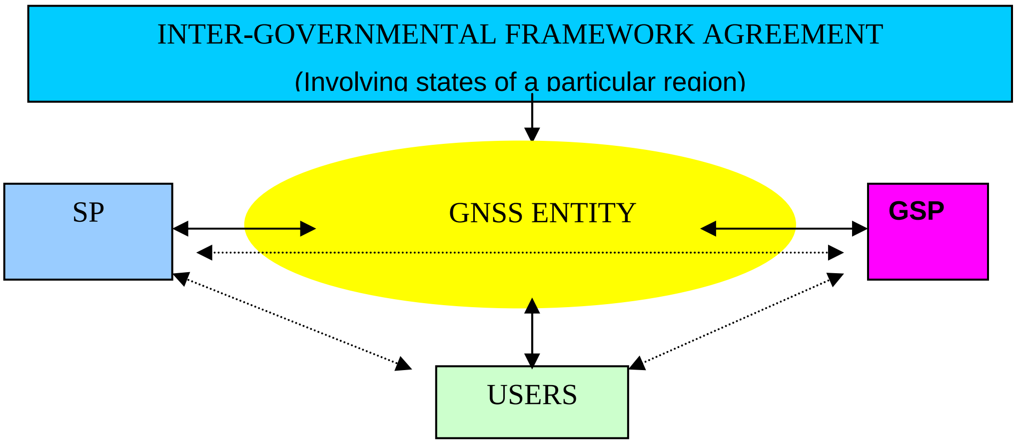

Figure 3: Options for a Contractual Framework

Figure 3 (See above) depicts the relationship between the Framework Agreement, the GNSS Entity, and the other institutions identified.

The bold arrows show one possible role of the GNSS Entity as actively engaged in co-ordinating the conclusion of contracts between the Galileo Signal Provider, the Service Providers and Users respectively.

The other arrows, dotted, show a less active role for the GNSS Entity and a more direct contractual relationship between the institutions. Even in the case of a multitude of direct contracts, a role is left to be played by the GNSS Entity.

The immediate value of the GNSS Entity's intermediary role is the fact that contracts will be limited and standardised. Additionally disputes settlement mechanisms will be easily implemented and enforced. Indeed one of the many roles of the GNSS Entity, as proposed in the Eurocontrol document, will be the co-ordination of an arbitration mechanism.

In terms of service guarantees, see section 5 below, the Entity may be involved in the process of setting standardised levels of service for a particular sector.

3.1.5 Service Guarantees

Following the legal relationships identified in paragraph 3, this paragraph shall examine the kind of guarantees, and potential recourse, that the users and the ATSPs will require from the GNSS service providers.

The provision and use of satellite navigation signals whether for the aviation sector or otherwise is based on certain clearly defined technical specifications or requirements and provided under specific conditions. ICAO's required navigation performances (RNP) are defined for all phases of flight in terms of distinct parameters, namely: accuracy, availability, continuity, reliability, and integrity.

A service guarantee is a technical concept, with legal ramifications, involving the definition of the level of confidence a user of the satellite navigation system or whatever system is at stake, can put on the system in terms of the key parameters accuracy, availability, reliability, continuity and most importantly, integrity.

Accuracy, reliability, continuity and availability determine the technical specifications and consequently the performance of the system when operating under ideal conditions. In legal terms, the primary obligation for service provision either of the GSP, the SP or the IMF is delivering on the agreed *quality of service*.

Integrity to a very large extent is the final measure of the extent of confidence of the user and of the reliability to be placed on it. It is a second level obligation assumed contractually to provide notification and reduce the potential damage that would have been sustained if such notification had not taken place.

Integrity management can be defined as the ability of a system to detect malfunctions and provide timely warnings to users when the system should not be used.

The legal value of the service guarantee is the nature under which the system or service provider is able to commit to both the primary obligation of delivering the agreed quality of service and also the agreed integrity service whenever the primary level obligation cannot be discharged.

While the second tier obligation does not dissolve the legal responsibility of the provider, its discharge can operate to limit the level of damage that could have been sustained by all parties involved.

Apart from the commitment to discharge the two tiers of obligations, there are other additional conditions required to be met, namely that:

- clear rules on default should be established in the contract
- a liability regime is made available. In other words there must be a clearly circumscribed liability regime for the breach of the two contractual obligations (on service quality and integrity warnings) and any potential negligence.
- a compensation mechanism be agreed upon in the contract, and
- an appropriate dispute settlement mechanism be established

The cumulative effect of these measures is to give the user the confidence required in the system. This confidence involves:

- the objective assertion that the provider shall provide in accordance with the technical specifications agreed upon and in accordance with the levels of quality.
- In the event that the agreed service is not available, the provider shall warn the user of any deficiencies and where necessary of the need to stop using it
- Where damage is sustained as a result of the failure to deliver or warn or as a result of any negligence on the part of the provider, an appropriate liability regime, a compensation mechanism and a dispute settlement mechanism is available to the user.

[R3-3] While a guarantee of service is possible to arrange in a single contract and on a case by case basis, a number of elements are best handled outside the contract and preferably in a global or regional regulation.

Thus it may be desirable to agree through a public international agreement what the conditions of failure to discharge a service guarantee obligation should be. This shall then involve a liability regime, compensation mechanism and the establishment of a well-recognised dispute settlement mechanism.

[R3-4] A public agreement can be established either as a global agreement enforceable at state or regional levels or as a regional agreement enforceable at the regional or state levels. In Europe, and taking into consideration the assumptions of this study, it may be desirable for a liability regime to be agreed upon within Europe and possibly under the auspices of the European Union and enforceable through recourse of the mechanism established in national courts with a possible reference to the European Court of Justice.

3.1.6 User/Provider Liability

Against the background of the legal relationships and guarantee of service, this paragraph analyses the problem of claims against carriers, and ATSPs as the case may be, in case of failure of the signal in space not caused by their own negligence and how a combination of short and long term solutions to the liability issues would allow GNSS to develop towards sole service, starting in 2008.

International law and all national legal systems recognise that one is liable to pay damage to another party when the second party suffers damage as a result of a breach of contract or negligence of the first when breach or negligence is the cause of that damage. Liability arising from a breach of contract, referred to as a contractual liability falls outside the scope of this analysis since each contract determines the scope and content of liability of each party. What is dealt with here is liability arising from negligence of any party. This is also referred to as tort liability.

Tort liability arises in all sorts of situations in relation with aircraft operators and air traffic services providers.

3.1.6.1 International aviation liability

There are a number of instruments in the field of international private air law, which deal with liability in aviation matters. One of these instruments is the Warsaw Convention, which places liability on aircraft carriers/operators for damage resulting from air transportation to passengers and goods. Liability is then based on the contract between the passengers or consignors and the carriers/operators

But when the damage inflicted is caused or contributed to by air navigation service, the service provider can also be held liable for the death or wounding and the damage to goods on board the aircraft on the basis of negligence according to tort law. Instead of such direct action by passengers or consignors, the service provider can be held to indemnify the carrier/operator for his contractual liability versus the passenger and consignor. This might be the case when the Galileo signal provider (GSP), and other service provider (SP), provide navigation services whose action or non-performance (especially the integrity monitoring and alerting service) is the cause of an aviation accident.

In the next section we will see that the limitation of liability in international air law instruments might provoke such direct actions by passengers and consignors in order to get full compensation for damages. Next we will look into more detail at the provisions of the international air law instruments which place liability on the aircraft carrier for damages resulting from accidents.

3.1.6.1.1 The Warsaw System

The whole legal framework for liability for damages to passengers and goods inflicted during international air transportation is contained in the Warsaw system. This is based on the *Warsaw Convention* for the Unification of Certain Rules Relating to International Carriage by Air, created in 1929. It provides for uniform international liability rules for the international air transport of passengers, baggage and goods for reward.

3.1.6.1.1.1 Limitation of liability

The Convention emanates from the principle that a limited liability rests on the carrier for damage in case of death or wounding or any other physical damage inflicted to the passenger when the accident that caused the damage took place on board the aircraft or during embarkation or disembarkation (Article 17). For the carriage of goods a similar regime applies.

Based, on one hand, on the principle of a limitation of liability, the Convention, on the other hand, places a general presumption of fault on the carrier. Escape from these conditions is limited.

The carrier can escape liability by proving that he and his agents have taken all necessary measures to avoid the damage or that is was impossible to take such measures (Article 20 (1).

Escape is also possible when damage results from pilot error or in general in case of ‘force majeure’ during the handling of the aircraft (Article 20 (2)). Exoneration of liability for the carrier can also result from proof of negligence on the part of the injured passenger (Article 21).

The Liability limits are set in Article 22. These limits can be raised through a special contract between the passenger and the carrier. The limits mentioned in Article 22 will be lifted in case of wilful misconduct by the carrier, as laid down in Article 25.

Article 28 of the Convention provides rules of jurisdiction. The plaintiff can choose from four competent courts within the territories of the Parties to the Convention. These are:

- the court of the domicile of the carrier
- the court of the principal place of business of the carrier
- the court where the carrier has a place of business by which the contract has been made
- the court at the place of destination

In the *Protocol of the Hague of 1955* the liability limits have been doubled for passenger claims. Moreover the provisions of Article 20.2 were deleted, herewith lifting the escape possibility of the carrier for pilot error. Moreover the wording 'wilful misconduct' in the text of Article 25 was replaced by a new definition covering negligence. The *Guadalajara Convention of 1961* can be seen as a supplementation to the Warsaw Convention as amended, necessitated by the fact that the actual carrier/operator is not always the carrier who has concluded the agreement for transportation with the client/passenger.

3.1.6.1.2 Montreal Convention of 1999

It is worth noting that the Warsaw Convention was modernised in 1999 although not much changed in terms of GNSS related liability. The modernisation of the Warsaw system led to the adoption of the Convention for the Unification of Certain Rules for International Carriage by Air (Montreal Convention). Signed by 52 countries, the Convention will enter into force after ratification by 30 countries. The changes include a two-tier system with strict liability for passengers up to 100.000 SDR and unlimited liability based on presumed fault of the carrier. Furthermore, a sixth jurisdiction has been added to the existing five fora (there were only 4 before), namely; the court in the territory of a State Party in which, at the time of the accident, the passenger had his principal and permanent residence and to or from which the carrier operates his services.

3.1.6.1.3 Rome Convention of 1992

The Convention on Damage Caused by Foreign Aircraft to Third Parties on the Surface, better known as the *Rome Convention of 1952*, is applicable to damage caused to third parties on the ground on the territory of a contracting State by an aircraft of another contracting State. Article 2 of the Convention applies the principle of strict liability. This liability is placed on the operator of the aircraft. However, the owner of the aircraft, who will be easily traceable through the registration marks of the aircraft, will be presumed to be the operator unless he proves that some other party was in control of the aircraft.

The Convention has never become popular as a consequence of a number of restrictions imposed on liability on this basis and the limitations imposed on the amount of compensation. In 1999 only forty-two States had ratified the Convention. An increase of the limits by the Montreal Protocol of 1978 led to adherence of four more states, not including the US, which still considered the new limits not high enough.

3.1.6.1.4 Observation

It is evident from the above that neither the Warsaw system nor the Rome Convention can be applied to directly place liability upon the providers of air navigation services since both systems provide only for liability on the part of the carrier or operator of the aircraft.

It may be recalled that claims from victims for compensation of damage resulting from aviation accidents can give the air carrier or operator the right of indemnification through compensation of the loss. This might be the case when the accident is due to a pilot error or the malfunctioning of the aircraft, caused by or contributed to by air navigation aids.

Services provided by air traffic services providers, or in the case of Galileo by the Galileo signal provider, can in fact cause or contribute to an accident not only by action but also by omission. When the act or omission was the proximate cause of the crash the result can be liability.

Apart from the liability to indemnify the air carrier for his liability claims from the victim it is also possible that the victims file a direct action against the service providers. This action might also be chosen to evade liability limits under the regimes discussed above (Warsaw System and Rome Convention).

3.1.6.2 ANSP and ATSP liability

Air Navigation/Traffic Service Provider's liability is not as nicely regulated as air carrier liability[1]. As seen above, ANSP's could be indirectly linked to claims initiated against air carriers under the Warsaw Convention when damage arises due possibly to erroneous ATC or FIS instructions.

Apart from indemnification cases however, claims can be directly initiated against ANSP's, albeit not by aircraft passengers, either on a breach of contract as in the case of a contractual default, or in negligence.

ANSP's owe a duty of care to aircraft operators, irrespective of the existence or otherwise of a contractual relationship. The duty of care is owed to all those persons relying on the service of the ANSP. This duty is strongly influenced by the safety imperative involved in the service provided by the ANSP. Court cases from France[2], Germany[3] and the US[4] clearly establish that ANSPs are not only liable to being held to account for their negligent acts but also that in view of the safety nature of their service, they are carefully watched by the courts and can be held strictly liable for their acts.

While ANSPs may be held liable in different jurisdictions, it is still not very clear whether this is globally accepted. The report of the ICAO Study Group could not confirm this because the Group undertook no detailed analysis on this issue. Moreover the problem of different procedural rules, as alluded to in an earlier observation in section 4 does not help in creating a confident environment for a proper articulation of ATC liability with GNSS liability.

3.1.6.3 Insuring against ANSP Liability

That ANSPs could be liable in case of damage means that insurance coverage will be required. Currently in the Galilei study, a thorough analysis is being conducted on the liability coverage of the Galileo signal provider. It is also recognised that not all damages are insurable. In other words, the commercial insurance market may have a limit as to how much they can insure.

In much the same vein, it should be recognised that ANSPs will have to insure against their part of any GNSS-related liability claim. Certainly on the basis of providing an ATC service to aircraft operators, ANSPs are the first line of indemnity claims to be initiated by aircraft operators.

This issue is beyond the scope of this study. It is however important to emphasise that the coverage will have to be sought by ANSPs. Secondly, it is also likely that the insurance market may not be in a position to provide complete coverage for the type of damage that could arise.

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[1] The ICAO Legal Committee has for years been considering the issue of air traffic control liability without any successful conclusion. In 1994 it was decided to rather focus on the issue of GNSS liability.

[2] *Musini et Cie Iberia c. Etat Français*, a case involving defective radar equipment and poor communications: the use by the military air traffic control officers in a strike situation caused the collision of two airliners. The French Government was held liable for the damages resulting from the collision.

[3] In *Neckermann und Reisen v. FRG*, the court held the German Government liable for the negligence of air traffic controllers.

[4] In *Springer v. United States*, it was held that the duty of the air traffic controller may sometimes exceed the literal obligations imposed.

[R3-5] The public sector should consider creating a public compensation capable of assuming some of the liabilities over and above that insured on the commercial market. Options worth looking at are national, regional and a global compensation plan. Whether such a compensation will apply only to the aviation sector or also to other modes of transport will largely depend on the complexity of a combined plan. Whatever the situation however, in view of the potential catastrophic effect, a compensation will have to provide coverage for ANSPs.

3.1.7 Agreements with other GNSS providers

This section deals with how to link all parties together, including the GNSS service provider(s), the ANSPs and the airspace users to induce them to act in a manner permitting to gain benefits from Galileo as early as possible.

Galileo as a satellite navigation system is projected for global use alongside the current Global Positioning System of the US. The use of this system for aircraft navigation entails commitments at the international level between the primary system providers, namely Galileo and GPS, between the secondary systems, namely: EGNOS, WAAS, MSAS and any potential augmentation system used in other regions of the world. A third set of agreements to be envisaged is agreements between the primary system providers and the augmentation providers for integrity monitoring facilities. This is a complex link of agreements to regulate interconnectivity, safety and integrity of the systems, security issues and certainly the issues of liability of system providers.

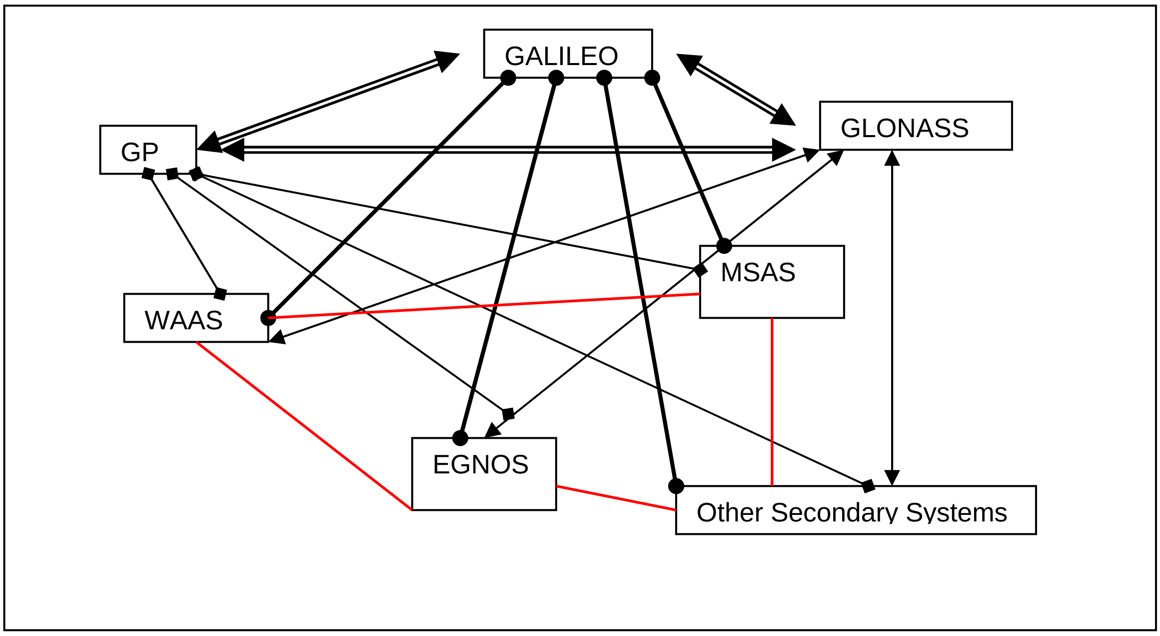

Figure 4: The complex web of inter-systemic agreements

As can be seen from the figure above, the world of inter-systemic agreements is also complicated. It needs to be mentioned that most regional economic groupings who are also involved in air transport related programmes may also wish to enter into some form of memorandum of understanding with the signal providers. Most importantly an institution like ICAO and possibly IATA will also be linked.

Given the complexity involved, it may be recommended to initiate an aviation-oriented interconnection and security arrangements among all primary and secondary system providers.

This could be done through a memorandum of understanding.

The advantage of getting agreements on certain core issues such as on interconnection, responsibilities of primary and system providers as well as civil-military co-ordination through an MoU is that this can be achieved without going through protracted and hard negotiations and will not require ratification.

[R3-6] It is recommended that the possibilities be explored to conclude such an inter-systemic Memorandum of Understanding in order to facilitate easy generation, exploitation and use of Galileo signals by the Civil Aviation community.

3.1.7.1 European arrangements and organisational issues

This section addresses some unique European arrangements relating to the use of Galileo and EGNOS for air navigation within Europe and globally.

One major institutional issue of particular importance to the air transport sector is the role and responsibility of the national and international air traffic service providers in the management of EGNOS and Galileo.

The development of EGNOS was primarily done with the active collaboration of air traffic services providers. Eurocontrol has also been actively involved in studies on EGNOS and Galileo.

One problem to be tackled is whether it is possible for Eurocontrol and/or national ANS providers to get involved in the management and regulation of Galileo, at least as far as the aircraft usage thereof, and still operate in a commercial sense as providers of services to the aircraft operators.

From this perspective, it is important that the management and the regulatory structure of the satellite navigation sector in Europe be so set up to ensure industry participation without creating the opinion of a conflict of interest.

[R3-7] In line with the provisions contained in the Draft Single European Sky Regulation 2001/0236 (on the provision of air navigation services) regarding the distinct regulatory regimes applicable to core ANS and ATS Service Provision, and the perspective of a future unbundling of CNS services from core Air Navigation Services, we recommend to avoid having GNSS services (other than aviation-dedicated local augmentations) managed by ANS providers, especially when such services have to address a much wider spectrum of user communities than just Civil Aviation.

The other issue is the possible maintenance of an adequate level of independence between the integrity service and the other services. The confidence in the integrity role of the system can only be established if it is clear that its management enjoys sufficient freedom.

That level of confidence can be raised through safety regulation measures, and through organisational measures; we can recommend to further investigate the following ones:

[R3-8] In the case when the integration of EGNOS and Galileo translates into a sharing of physical elements of infrastructure and/or a degree of commonality in operational staff and their procedures, then an independent safety assessment should be conducted under the joint authority of all the Aviation Safety entities concerned in Europe.

[R3-9] In the case when basic positioning and integrity monitoring and alerting information are provided by a single company or if (part of) the integrity service provision is done by a subsidiary of the main vehicle company for Galileo, then measures shall be taken to safeguard the independence of the integrity service (including such organisational measures as a direct reporting line from the integrity service operation manager to the Chairman, the appointment of non-executive Directors and/or of a Board of Advisers specifically in charge of monitoring the provision of that service, etc.)

[R3-10] More generally, any European Regulation on satellite navigation should make clear distinctions between the different types of service, and impose adequate measures to enhance the confidence in the integrity service.

While perceived as a complement to basic Galileo and GPS positioning services there are many legal and regulatory issues that may be peculiar to integrity monitoring and alerting.

To always regulate satellite navigation in Europe as if one is only dealing with one system providing one service will raise more questions on integrity and the safety guarantee being built in the system.

3.1.8 Economic Regulation

ICAO addresses the issue of cost recovery in its Statement of ICAO Policy on CNS/ATM Systems Implementation and Operation, adopted by the Council in March 1994. In the policy statement, ICAO notes that such cost recovery must be in conformity with Article 15 of the Convention on International Civil Aviation (the Chicago Convention) and ICAO'S Policies on Charges for Airports and Air Navigation Services (Doc 9082/6), the essence of which are equity and balance in the interests of providers as well as users of air navigation services.

Charges for and the economic regulatory policies for Galileo, in so far as the air transport sector is concerned, apply the same policies given the fact that Galileo is merely an enhanced tool to achieving better air traffic navigation.

ICAO has published two documents addressing economic issues of particular relevance to implementation and operation of CNS/ATM systems, namely: the Manual on Air Navigation Services Economics (hereafter, Doc 9161/3), and the Air Navigation Services Panel (ANSEP) Report on Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite Systems (GNSS) Provision and Operation (hereafter, Doc 9660)

The Manual on Air Navigation Services Economics (Doc 9161/3) provides guidance on organisational structures, accounting and financial control, determining the cost basis for air navigation services charges, setting of charges and their collection, and financing of air navigation services infrastructure.

The broad provisions contained in that Manual have been refined into a Eurocontrol study on “The allocation of GNSS costs” produced with full support from IATA and published in June 2000, that we used as an input to our Cost-Benefit Analysis.

The ANSEP report focuses on such organisational and managerial aspects of GNSS provision as GNSS components being multinational facilities or services, ownership and control considerations, and competition; and financial aspects, including funding sources, cost recovery policy, determination and allocation of GNSS costs, compensation or assistance to States to cover costs of redundancies and/or relocation/retraining, cost recovery methodology, and liability aspects.

The report also contains five recommendations, all of which have been approved by the ICAO Council, dealing with guarantees by States in the context of servicing and repayment of loans, cooperation among States in cost recovery, financial imperatives for accelerating the procedures for amendment of regional air navigation plans, the methodology for allocating GNSS costs attributable to civil aviation among user States, and the role of ICAO in financial and administrative aspects of GNSS implementation.

Given the expected reliance by this sector on Galileo in sole navigation service mode, it is important that the economic regulation of Galileo takes those policies adopted by ICAO into consideration. This is also reiterated in calls from the aviation sector on pricing and economic regulatory policies for EGNOS.

In addition, it should be noted that Galileo signal provision will be a natural monopoly. The monopoly provider will have to be regulated by the public service to ensure a balance of user and provider interests. To do this it may be worthwhile for the economic regulatory mechanism to consider examples from the aviation sector.

In the first place, the provision of safety of life services may be considered as a public services obligation. Secondly, in the institutional arrangements governing Galileo it may be important to ensure that the interests of the users, in particular, SOL users like the aviation sector are seriously taken into consideration. Thirdly, it is important to demand a cap on the prices set for the SOL service.

These three can be achieved through the following mechanism and by referring to existing regulations in the aviation sector for instance. Two privatised companies in the aviation sector: Nav Canada and NATS serve as good examples of how these three issues can be regulated.

The economic regulation of Nav Canada and NATS differ on most issues but still prove useful on many other counts.

3.1.8.1 Nav Canada

Nav Canada was incorporated as a non-share capital corporation under the Canada Corporations Act on May 26, 1995.[5] With a few exceptions, Nav Canada is the only corporation authorized to provide civil air navigation services previously provided by the Department of Transport. [6] It is moreover designated as the authority in Canada responsible for providing aeronautical information services and air traffic control services for the purposes of Annex 4, 15 and 11 of the Chicago Convention.[7] The Corporation is a typical monopoly service provider. The company has the right to plan and manage Canadian airspace for the provision of air traffic control services other than airspace under the authority of the minister of defence[8], and may introduce, increase, terminate or reduce civil air navigation services.[9]

The corporate structure of this company offers an example for the involvement of aviation users in decision making generally and specifically in price setting.

Nav Canada's corporate structure reflects a consensus reached among the stakeholders: government, employees, air carriers and other users of the air navigation services.

The Corporation has four voting members who appoint certain of the directors of the Corporation. The members represent the key stakeholder interests. They are the Government Member (appointed by the Minister of Transport), the Union Member, and two user Members. These appoint 3, 2 and 5 Members respectively to the Board.

Nav Canada is consequently governed by a fifteen-member board of directors composed of airlines (4), general aviation (1), and federal government (3), unions (2). These ten then appoint four independent directors and the board appoints the president and chief executive officer.

The uniqueness of the governance structure of this organisation is the fact that paying customers appoint a third of the Board. This is known to mitigate the level of concern customers may normally have with a monopoly service provider.

The usefulness of this model for the governance of Galileo and as a economic regulatory mechanism is in the role of the consumers in management decision –making.

The active involvement of users is also reflected in the other aviation air traffic service organisation, NATS.

3.1.8.2 NATS

The UK NATS was established, operates and is regulated under a set of legislation adopted for that purpose. The most significant statutes and statutory instruments are the Transport Act 2000 and the Air Navigation Order 2000. The company was licensed to provide air traffic services within the UK airspace by the Air Traffic Services License for NATS (En-Route) Limited.

The Board of the NATS comprises a non-executive Chairman and 12 directors: CEO, COO, Finance Director, three Partnership Directors (non-executive) and six other non-executive Directors.

[5] Preamble, ANS Act
[6] S.9 & 10 ANS Act
[7] S.11 ANS Act
[8] S.13 ANS Act
[9] S. 14 ANS Act

The Crown Shareholder appoints the three Partnership directors and the Airline Group (AG) appoints the six other non-executive directors, including the International Air Transport Association (IATA) nominee representing the non-AG airlines.

The Airline Group is a special purpose company whose equity participants are British Airways, British Midland, Virgin Atlantic, Airtours, Britannia, JMC, Monarch and EasyJet, with technical assistance being provided by BT and several European air traffic service providers. The airlines have equal voting rights within the special purpose vehicle.

The most important aspect of NATS construction is the fact that other consumers are also represented on the Board by IATA..

Another aspect of NATS worth considering is its economic regulatory structure.

NATS (En Route) Ltd, a subsidiary of NATS is licensed as a public services obligation company to provide air traffic services in and in respect of the En route (UK) Area[10], and the En route (Oceanic) Area[11]. Among other things, the license and the Transport Act 2000 requires that the UK Civil Aviation Authority (CAA) regulate the pricing policy of NATS.

Part III of the NERL licence contains detailed provisions on price regulation of NERL's services. Charge control conditions are laid down in Conditions 21 to 25 sets of revenue including charges paid to Eurocontrol by users, charges levied by the NERL in respect of the Shanwick Oceanic Control Area; and charges for North Sea Helicopter Advisory Services and Terminal Approach Services.

In setting prices for NATS en route limited the CAA is among others required to take the interests of the users into consideration. In addition, NATS is required to consult users in setting its investment and service plans.

By requiring the involvement of the user group, by including the user group in decision-making, by requiring that the safety of life service be considered a public service obligation and by regulating charging policies for the safety of life services either through a consumer represented Board or an independent regulator, the monopoly signal provider is motivated to operate in accordance with, among others, the ICAO Policies on economic regulation.

3.1.9 Conclusions

This study has undertaken basic assessment of legal and institutional issues associated with the sole service use of satellite navigation services for the air transport sector.

This study, undertaken at the same time as the Galilei study, has been selective of issues of particular relevance to the air transport sector and especially ensuring the needed integrity. Particular attention has been paid to user confidence in that service because that confidence is high in any determination to use satellite navigation services for sole service operations.

The study presented the institutional and legal chain of functions, actors and responsibilities. It also recalled ICAO's work on the legal aspects of CNS/ATM and GNSS in particular paying particular attention to the issue of liability. Service Guarantee a major component of guaranteeing user confidence, was also examined, as was user and provider liability. Sole service confidence can only be ensured if a transparent arrangement exists ensuring technical interconnection of all the different satellite navigation signals. Consequently the study examined the issue of relationships between GNSS providers and the issue of European arrangements.

There are very many institutions involved in the provisions of GNSS services requiring a complex web of international contracts to regulate the various services. To ensure commonality and user confidence in the system, it is recommended that a core set of issues be identified which should be reflected in all contracts on GNSS service provision.

[10] The En route (UK) Area includes London Flight Information Region, London Upper Flight Information Region, Scottish Flight Information Region, and the Scottish Upper Flight Information Region.
[11] The Oceanic Area consists of the following airspace: the Shanwick Flight Information Region and Shanwick Oceanic Control Area

This method is in full recognition of the fact that no two contracts are the same in view of the principle of freedom to contract. A recommendation of model clauses enables parties to take those issues into consideration when negotiating their contract.

A review of work undertaken by ICAO has revealed certain gaps existing in relation to the legal and institutional issues, namely:

- there are no clear guidelines on the institutional issues
- the use of fault-based liability to regulate GNSS may not assist in a user friendly system. This is of particular importance to Galileo which intends to use the issue of service guarantee and liability as a marketing tool for maximising user acceptance. A simplified strict liability regime, capped as to the limit of liability - see the Warsaw Convention liability caps in Section 6 below - would be a more consumer friendly regime.
- the lack of uniform procedural rules can easily result in a maze of conflicting legal requirements from different jurisdictions. Here again the solution found in the Warsaw system offers a better future for the popular use of GNSS.
- the absence of a long-term legal framework regulating issues as rights and obligations of the state in authorising GNSS use within its airspace, sovereign immunity in liability claims, adequate compensation for victims, all affect the global acceptability of GNSS and Galileo.

On the issue of interconnectivity as a means of securing user confidence, it is recommended that a means be sought to create a multi-GNSS signal provider platform through the conclusion of a multiparty memorandum of understanding.

The use of GNSS as a sole service requires a transparent service guarantee. This guarantee can be achieved through a logical commitment to obligations assumed by the service providers as part of the technical specifications. This quality of service should also be complemented by an integrity warning mechanism which should also be backed by a legal commitment to enforce.

Given the essential role integrity is supposed to play in the acceptability of Galileo, it is important that the integrity signals for Galileo be provided after strict safety regulations and corporate disciplines.

The legal commitment to enforce the technical guarantees is achieved in the language of the obligations spelt out in the contract, the provision of a liability regime and an adequate compensation mechanism. Most importantly the legal guarantee is achieved through an effort to reach a commonality in contractual provisions which can be done through the adoption and recommendation of model clauses.

The Eurocontrol approach of concluding a Framework Agreement and a series of standardised contracts, possibly through the GNSS Entity, serving as contracts broker, is a very useful tool to instil in all actors involved the commitment to ICAO standard rules, standardise contracts and facilitate smooth implementation of Galileo

It cannot be overemphasised that monopoly role of the GNSS Signal Provider will require extensive economic regulation.

Moreover it is important that aviation users be actively involved in decision-making and price regulation of the safety of life service. This will certainly accord with ICAO policies on charging for air navigation services.

Galileo will play an essential role in a sole service mode for the aviation sector. Liability of the signal provider as well as service providers and ATSPs, in particular will have to be carefully approached. Insurance will need to be procured against the activities of the ATSPs. Given the doubtful nature of the commercial insurance market being able to secure sufficient insurance for this sector, the public sector may consider ways of providing a means of compensating damage over and above that secured on the commercial market.

3.2 Standardisation and safety regulation issues

In this section, we present:

- the main standardisation bodies and processes of relevance to GNSS,
- a preliminary assessment of sole service safety issues; as sole service is not yet comprehensively covered by existing analyses a considerable amount of effort will have to be spent by appropriate bodies in order to refine and consolidate our description of the critical scenarios and our identification of hazards and mitigating measures,
- a number of general recommendations to GNSS designers/operators, Air Traffic Service providers and their safety regulators, covering the following aspects:
  - Measures to be taken, at the institutional/organisational level, so as to facilitate the certification/approval of GNSS (against agreed international standards produced by the standardisation bodies previously described,)
  - Identification of those key issues that concerns both Commercial Air Transport and General Aviation,
  - The definition and validation of operational contingency plans.

The purpose of standardisation is to design a set of provisions allowing a common and repeated use to be performed in an optimal way for a given context. We can distinguish two approaches to standardisation. The first approach is the “de facto” standardisation, where different actors, generally from industry, come together to define technical documents which they will follow on a voluntary basis. The second approach is the formal standardisation, aiming at the demonstration of the compliance of products and services with the standards, through qualification tests and eventually a certification process. In the context of GNSS, where safety certification processes have to be based on a robust set of assumptions and requirements, this more formal second approach is necessary.

The standardisation function starts from the user needs and intended purpose of the product/service under standardisation. The development of standards is generally performed by forums that converges on a consensus. It uses means and methods such as simulation, models or experiments to complete and validate standards. The control parameters that act on the standardisation process are the regulations (that provide a legal framework), the technological constraints that include current or existing standards, the best practice (i.e. the current know-how), the request or demand for standards development, the operational experience and the economic context (e.g. standardisation used to provide minimum requirement).

When the translation of user needs into technical content has been performed, a standard has to be published formally, and to be promulgated by a regulatory authority that will define means to enforce its application.

Then, systems go through compliance tests and eventually independent certification.

To complete the life cycle, at some point in time, a standard or given version of a standard becomes obsolete and is no longer applicable.

3.2.1 Standardisation Organisations and their processes

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We present in this section the organisations involved in GNSS standardisation activities, their respective procedures, and their on-going processes regarding the production and validation of GNSS standards. ITU, ICAO and AEEC are world level bodies, whereas RTCA, Eurocae, Eurocontrol, FAA and JAA are regional level bodies whose work is constrained by agreements reached in the world level bodies. We therefore present them in that order.

3.2.1.1 ITU

The International Telecommunications Union is established as an impartial, international organisation within which governments and the private sector work together to co-ordinate the operation of telecommunication networks and services and advance the development of communications technology.

3.2.1.1.1 ITU Frequency Spectrum Protection

As far as the radio-electric spectrum is concerned, the radio-communication sector of International Telecommunication Union (ITU-R) is in charge of co-ordinating the repartition of this resource which is limited.

The presently available instruments for regulating the use of frequencies are:

- a strategic frequency planning process in 3 steps: allotment, allocation, and assignment;
- a strategic system planning process also in 3 steps: advanced publication, co-ordination and notification;
- conventional duties in relation to the tactical detection and suppression of harmful interference that occur in contravention with the agreed assignments to notified systems.

Allotment is the process by which certain services are formally defined and a need for frequency planning is recognised, with some parts of the spectrum allotted to this or that service; In the context of this allotment, further frequency management can be delegated to and/or co-ordinated with specific bodies (e.g. the International Civil Aviation Organization (ICAO) for aeronautical services, the International Maritime Organisation (IMO) and the International Association of Marine Aid to Navigation and Lighthouse Authorities (IALA) for maritime ones etc.).

Allocation is the process by which specific frequencies bands are assigned to specific services ; most of the time, this planning is done on a regional basis (the ITU defines 3 regions: Pacific & Far East, Europe-Africa & Russia, Americas) which means that the same service can be delivered on a different frequency in different regions ; however global systems (such as a GNSS constellation) require that certain frequencies be allocated on a global basis.

Also specific technical provisions may be imposed in the allocation plan as regards the level of interference noise that can be tolerated from emitters operating in other regions and/or in other parts of the spectrum, depending on the requirements of the service.

A Table of Allocations is maintained by the ITU. This table serves as a reference for states and operators; it is re-discussed and updated every 2-3 years at World Radio Conferences (the next one is scheduled in 2003).

Assignment is the process by which a State authorises a system operator under its authority to operate a system that emits on a given frequency for a given service ; an assignment must be compatible with the Table of Allocation. Additionally, co-ordination should take place with adjacent states in order to minimise interference with already existing services.

3.2.1.1.2 ITU & GNSS

Within the ITU Radio Regulations, all allocations to GNSS signals irrespective of where they are are classed as RNSS – radionavigation satellite service allocations. Aeronautical radionavigation service (ARNS) allocations can not be used for satellites irrespective of their aeronautical use.

All current RNSS allocations to GNSS, irrespective of where they are in the radio-frequency spectrum are classed as co-primary with other services. A co-primary allocation means that the services using these co-primary allocations operate on a mutual non-interference basis unless otherwise stated in the ITU Radio Regulations. Demonstrating that GNSS does not interfere with other services and vice-versa is known as “compatibility”.

When an operator (be it a private or a public entity) wants to put in place a new satellite-based radio-communication system, it must first circulate a preliminary description of the system as an Advanced Publication, so as to gather any comments that administrations may have in terms of its potential impact on other existing or planned services. The date of advanced publication is used as the priority-setting criterion in case of an assignment conflict between two concurrent proposals.

In case of conflict, a formal co-ordination must take place between the administration sponsoring the new satellite system and the other administrations, so as to adjust the specifications of the new system (and/or the specifications of other systems potentially conflicting with it) by ad hoc technical modifications aimed at minimising interference.

When the co-ordination process has reduced the interference to a level both technically feasible and operationally acceptable by all parties, the new system can be notified and listed on the corresponding National Register as an operating assignment.

Obviously, the system planning process and the frequency planning process are strongly correlated.

If there is no formal distinction at ITU level between safety-of-life services and other services, there is however a recognition that the safety aspects of radionavigation and other safety-of-life services require special measures to ensure their freedom from harmful interference and that it is necessary to take this factor into account in the assignment and use of frequencies.

3.2.1.1.3 GNSS Allocated Frequencies

The following diagram summarises the spectrum allocation/assignment for GNSS services and systems:

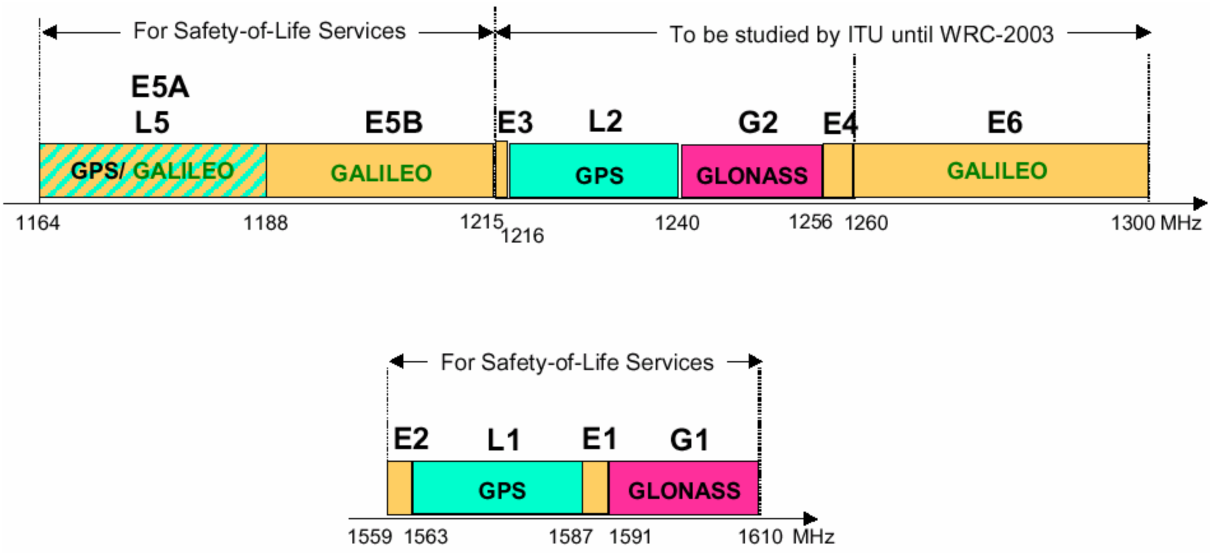

Figure 3.2.1-2: GNSS frequencies

3.2.1.1.4 ITU Procedures

Draft Recommendations can be submitted by Member States to Study Groups meetings. They must be announced by way of an Administrative Circular three months beforehand, the announcement also containing summaries of the draft Recommendations concerned.

Once a draft Recommendation has been adopted by a Study Group, there are two procedures for approval of Recommendations by Member States – approval by consultation and approval at a Radio-communication Assembly. In both cases, the Study Group must have decided at its meeting which of the procedures it wishes to follow for each draft Recommendation. The decision to pursue approval by consultation must be unopposed.

In the case of approval by consultation, draft Recommendations are dispatched to ITU Member States, within one month of their adoption, as blue documents under cover of an Administrative Circular; the draft Recommendations are also sent to Sector Members and Associates participating in the work of the Study Group for information. The Circular also contains the summaries of the draft Recommendations concerned and, where necessary, information on any objections raised during the adoption procedure. As with previous versions of the draft Recommendations, the blue documents are posted on the ITU-R web site.

The blue document versions of the draft Recommendations will contain editorial corrections identified during the adoption period and so will be as technically accurate and editorially correct as possible.

If instead a Study Group decides to forward a draft Recommendation for approval at the next Radio-communication Assembly, the document is dispatched to Member States and Sector Members as a pink document at least one month before the RA. Approval at an RA is advised only in cases of difficulty where, for example, objections have been raised during the adoption procedure. Otherwise, approval by consultation is considered the most expedient manner by which draft Recommendations are approved.

3.2.1.2 ICAO

3.2.1.2.1 ICAO Purpose

The aims and objectives of the International Civil Aviation Organisation are to develop the principles and techniques of international air navigation and to foster the planning and development of international air transport so as to:

- ensure the safe and orderly growth of international civil aviation throughout the world;
- meet the needs for safe, regular, efficient and economical air transport;
- ensure that the rights of Contracting States are fully respected and that every Contracting State has a fair opportunity to operate international airlines;
- promote generally the development of all aspects of international civil aeronautics.

3.2.1.2.2 Standardisation at ICAO

To ensure safety, regularity and efficiency of international civil aviation operations, international standardisation is essential in all matters affecting them, that is, all matters in the operation of aircraft, aircraft airworthiness and the numerous facilities and services required in their support such as aerodromes, telecommunications, navigation aids, meteorology, air traffic services, search and rescue, aeronautical information services and aeronautical charts.

To achieve the highest practicable degree of uniformity world-wide whenever this will facilitate and improve air safety, efficiency and regularity, the ICAO Council adopts International Standards and Recommended Practices (SARPs), and approves Procedures for Air Navigation Services (PANS).

Although the Council has the responsibility for adoption of these Standards and Recommended Practices and approval of these procedures, the principal body concerned with their development is the Air Navigation Commission. In the advancement of solutions to specialised problems requiring up-to-date and specialised expertise, the Commission is assisted by panels. These are small groups of experts, nominated by Contracting States and international organisations and approved by the Commission. The panel members act in their personal expert capacity and not as representatives of their nominators.

The Standards and Recommended Practices (SARPs), which are designed by panel members, finalised by the Air Navigation Commission, and approved by the Council, are published in the Annexes to the Convention on International Civil Aviation. The Standards are specifications, the uniform application of which is necessary for the safety or regularity of international civil air navigation, while the Recommended Practices are specifications, the uniform application of which is desirable in the interest of safety, regularity or efficiency of international civil aviation. At present there are eighteen Annexes to the Convention on International Civil Aviation, seventeen of these are within the air navigation field.

Proposals to amend or add new SARPs may come from ICAO-sponsored international meetings, deliberative bodies of the Organisation, the Secretariat, the United Nations and its agencies or interested international organisations. Before work on a task to amend or add new SARPs is initiated, the approval of the Air Navigation Commission is necessary. Only proposals for which world-wide standardisation is essential are normally approved by the Commission.

Once SARPs have been approved, they become applicable at dates set by the Council. These Standards and Recommended Practices are considered binding. However, if any Contracting State finds it impossible to comply with them, the State is required to inform ICAO of any differences that will exist on the applicability date of the amendment. The differences notified are then published by ICAO in Supplements to Annexes.

In addition to the Standards and Recommended Practices, ICAO also formulates PANS which do not have the same status as the SARPs. The various PANS are developed by the Air Navigation Commission on the basis of proposals coming from the same sources as for SARPs. Following consultation with all Contracting States and interested international organisations, they are approved by the Council and recommended to Contracting States for world-wide application. The PANS comprise, for the most part, operating practices as well as material considered too detailed for SARPs. PANS often amplify the basic principles in the corresponding SARPs to assist in the application of those SARPs. The PANS become applicable on a date set by the Council. Because PANS have a different status from SARPs, Contracting States do not have to notify differences in the event of non-implementation.

To facilitate the implementation by States and to promote the uniform application of SARPs and PANS, technical manuals and guidance material in other forms are issued by the Organisation under the authority of the Secretary General. At the present time there are more than 40 such publications.

3.2.1.2.3 Regional Planning

As not all aviation problems can be dealt with on a world-wide scale, some subjects are considered on a regional basis. ICAO, therefore, recognises nine geographical regions which must be treated individually for planning the provision of air navigation facilities and services required on the ground by aircraft flying in these regions.

Keeping in mind the objective of producing a seamless global air traffic management system, a planning is performed in each region at ICAO Regional Air Navigation meetings. The plan which emerges from a regional meeting is so designed that, when the States concerned implement it, it will lead to an integrated, efficient system for the entire region and contributes toward the global system.

When States require assistance in this regard, help is available through ICAO's seven regional offices, in Bangkok, Cairo, Dakar, Lima, Mexico City, Nairobi and Paris - each one accredited to a group of Contracting States. These offices have, as their main function, the duty of encouraging, assisting, expediting and following up the implementation of the Air Navigation Plans and maintaining them up to date. In addition, regional planning and implementation groups have been established in ICAO regions to assist the regional offices in keeping the regional plans up-to-date and in fostering their implementation.

In three regions, States have created autonomous regional civil aviation bodies which work in close liaison with ICAO and, at their request, receive Secretariat assistance from ICAO. In Europe 31 States are members of the European Civil Aviation Conference (ECAC), formed in 1956; in 1969, the African Civil Aviation Commission (AFCAC) was created, membership in which is open to all African States members of the Economic Commission for Africa (ECA) or the Organisation of African Unity (OAU). It currently has 39 members. The Latin American Civil Aviation Commission (LACAC) was established in 1973, with membership open to States of South and Central America and the Caribbean. There are presently 20 States members of LACAC.

Additionally, regional planning groups with over-all air navigation planning responsibilities have been established by the Council. There are at present five such groups, namely the NAT Systems Planning Group (NAT SPG), the European Air Navigation Planning Group (EANPG), the AFI Planning and Implementation Regional Group (APIRG), the Caribbean/South American Regional Planning and Implementation Group (GREPECAS) and the Asia/Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG). The main objectives of the groups are to ensure continuity in the planning processes for the purpose of maintaining an up-to-date air navigation plan through systems evaluation, monitoring and study in the light of changing traffic characteristics, operational requirements and technological advances.

The Air Navigation Plans agreed by Regional Air Navigation meetings contain between others the Regional Supplementary Procedures (SUPPS), which indicate modes of implementing procedural provisions in SARPs and PANS, specify detailed procedural options for regional application or promulgate a procedure of justifiable operational significance, additional to, but not in conflict with, existing provisions in the Annexes or PANS.

3.2.1.2.4 National Regulations and Requirements

In accordance with SARPs (Annex 15 to the Convention on International Civil Aviation) and the Aeronautical Information Services Manual, Aeronautical Information Publications (AIPs) are published, containing three parts, General (GEN), En-route (ENR) and Aerodromes (AD). In the General part can be found the National Regulations and Requirements, presenting the designated authorities, a summary of national regulations and international agreements/conventions, and the differences from ICAO Standards, Recommended Practices and Procedures.

3.2.1.2.5 GNSS Standardisation

The SARPs and the guidance materials for GNSS and its elements are produced by the GNSS Panel, which belongs to the Air Navigation Commission.

The GNSS Panel was created in October 1994, its terms of reference reading:

- Establish the operational requirements for near-, medium- and longer-term GNSS.
- Develop materials that States and regions could use as guidelines for providing a means to realise early operational and economic benefits from existing satellite based navigation systems.
- Develop SARPs related to existing satellite-based navigation systems and system validation criteria and procedures.
- Develop detailed recommendations for techniques to be used in support of longer-term satellite-based navigation systems and address the interoperability issue raised by the transition between mid and longer term systems.

The Panel is divided into two Working Groups: Working Group A focuses on operational matters, whereas Working Group B is dedicated to technical matters.

ICAO SARPs contain the navigation system performance requirements and specifications for GNSS and its elements. These requirements have to be met in terms of lateral and horizontal accuracy, integrity and time to alert, continuity, availability and associated Required Navigation Performances (RNP), for the different phases of a flight and their types of operation (en-route, terminal, initial approach, intermediate approach, non-precision approach, approach with vertical guidance, Cat I approach).

Additional elements, such as ABAS (Aircraft-Based Augmentation System), SBAS (Satellite-Based Augmentation System) and GBAS (Ground-Based Augmentation System) are also covered.

Finally, the SARPs also address various issues such as vulnerability to interference, combination of constellations, aircraft database, status monitoring, NOTAM, co-ordination with the ICAO Aeronautical Mobile Communications Panel for spectrum protection.

The work of ICAO is supported by other standardisation organisations, such as FAA, JAA, RTCA and Eurocae.

3.2.1.3 AEEC

The Airlines Electronic Engineering Committee (AEEC) is an international body of airline representatives, defining the standards for the avionics equipment used on commercial air transport aircraft. AEEC standards are co-ordinated with many airline organisations including ICAO.

ARINC provides technical and administrative support to AEEC and publishes AEEC documents as ARINC characteristics.

The GPS/XLS subcommittee is responsible for the standardisation of satellite navigation avionics equipment, developing and maintaining the GNSS Sensor – ARINC Characteristics 743A and the MMR – ARINC Characteristics 755.

3.2.1.4 Eurocontrol

The European Organisation for the Safety of Air Navigation (Eurocontrol), an organisation governed by international public law, was constituted in 1960. Its membership today consists of a majority of ECAC member states. Eurocontrol’s aim is to achieve harmonisation and integration in establishing a uniform European air traffic management system.

As far as navigation is concerned, the Agency is mandated by the Ministers of Transport of the ECAC States to implement the ICAO Air Navigation Plan for the European Region (EUR ANP), in co-ordination with the European Air Navigation Planning Group (EANPG). To complete this task, Eurocontrol has set up the Navigation Programme and the GNSS Programme.

The objective of the navigation programme is to perform the work required to enable RNAV based Navigation applications to be realised in line with the navigation strategy. The work covers operational, technical, regulatory and institutional aspects required to ensure a cost-effective, customer oriented and evolutionary transition to a full RNP-RNAV based environment.

The GNSS programme is focusing on the first generation of GNSS (GNSS-1), based on GPS and its regional and local augmentations. This initial step, up to 2005, is intended to provide a navigation service for all phases of flight down to and including Cat I precision approach, through the use of SBAS and GBAS. In Europe, SBAS is called the European Geostationary Navigation Overlay Service (EGNOS) whose development is being overseen by the European Tripartite Group, composed of the European Commission, the European Space Agency and Eurocontrol whose joint activities are outlined in the Tripartite Agreement, dated June 1998. Safety cases and validation activities are currently being performed by the Eurocontrol Experimental Centre.

3.2.1.5 RTCA and Eurocae

Whereas an organisation such as ICAO is providing general standards for signal interoperability and performance at systems level, RTCA and Eurocae design industrial standards for the equipment, which are based on the ICAO SARPs.

In order to qualify airborne receivers, these industrial standards are defined by RTCA (US) and Eurocae (Europe). These organisations, composed of ATSOs, and of aircraft and avionics manufacturers, edit the Minimum Operational Performance Standards (MOPS) for specifying ground and on-board equipment, and the Minimum Aviation System Performance Standards (MASPS) for defining the interfaces and performances of the ground-air segment systems. RTCA and Eurocae documents have no legal status, until they are referenced by certification authorities such as FAA and JAA.

The following Working Groups are involved in GNSS activities:

- Eurocae WG-28 : Global Navigation Satellite System. The mission of WG-28 is the utilisation of satellite-based systems for navigation and precision approach. One sub-group, SG1, is presently inactive, dealing with MOPS for EGNOS/WAAS receiver for applications down to Non Precision Approaches including recommendations for inclusion of GLONASS and extension to Cat I precision approach operations. Two other subgroups, respectively SG2 and SG3, are dealing with MOPS for Cat I ground subsystems, and for multimode receivers using SBAS and GBAS signals in precision approach Cat I.
- Eurocae WG-62 : Galileo. WG-62 mission is to produce a list of working assumptions for the operational concept of use of GNSS, to develop the MOPS for the first generation of Galileo airborne receivers, and to develop, in conjunction with EUROCAE WG 28, documentation for Galileo (including joint GALILEO/GPS) needed for standardisation of precision approach for both ground and airborne equipment.
- RTCA SC-159 : Global Positioning System (GPS), divided into the following sub-groups:
  - WG 1 : To investigate signal format for 3rd Civil Frequency for GPS (L5).
  - WG 2 : To develop a MOPS for Wide Area Augmentation System (SBAS) airborne equipment. The standard is published (DO-229-B) and evolution is ongoing.
  - WG 2C : To identify issues on GPS/Inertial hybridisation and develop standards if necessary.
  - WG 4 : To develop MASP and MOPS for Precision Landing Guidance (GBAS). MASP (DO-245), Interface Control Document (DO-246-A) and MOPS (DO-253) for Local Area Augmentation Systems (LAAS) are already published. The group is now working on evolutions of these documents.
  - WG 5 : To investigate the use of GNSS in Airport Surface Surveillance (A-SMGCS).

- WG 6 : To investigate all issues related to interference to GNSS signals.

3.2.1.6 FAA and JAA

The FAA (US) and JAA (Europe) are responsible for the provision of airworthiness certificates, to certify that equipment meet the performance and requirements defined by ICAO. They issue regulatory documents called FAR (US) and JAR (Europe), presenting very few differences, which are precisely identified. These regulatory documents are complemented with advisory documents containing interpretations of the FAR and JAR, and means to demonstrate that the requirements are met. The JAA are in the process of being replaced by the European Aviation Safety Agency (EASA).

3.2.1.7 Current standardisation Issues

In the following paragraphs, we will present the GNSS issues being discussed in standardisation bodies. We will first address the issues related to the core constellations, then to the regional elements, local elements, and we will finish with the operational matters.

3.2.1.7.1 Galileo Program

At the last GNSSP WG-B meeting in April 2002, a status report of the overall Galileo program was presented. The last European Summit and the Transport Council of the European Union agreed to definitely move ahead with Galileo. Financing of the development phase (2002-2005) is provided jointly by the European Union and the European Space Agency. The schedule aims at a deployment phase between 2006 and 2007 with operations starting from 2008 onwards. Several activities are ongoing with the objective to consolidate the service definition. Final signal definition is expected by the end of 2002 or early 2003 timeframe.

As far as standardisation is concerned, the European Commission has contracted an industrial consortium, SAGA, to provide input into the required standardisation activities for Galileo.

It was recommended that the GNSSP should take full benefit of the work done by the SAGA team in standardising Galileo. SAGA works by taking system design information and turning this into information papers and draft SARPs to be presented to standardisation bodies such as ICAO and Eurocae.

3.2.1.7.2 GPS SA removal

The U.S. Government discontinued the use of selective availability (SA) effective May 1, 2000. Activities have been started to prepare a slightly revised proposal of SARPs changes resulting from the removal of SA. In particular, the possibility to standardise new range rate and range acceleration bounds is being investigated. The respective amendments to GNSS SARPs are expected for GNSSP/4 (April 2003) with an applicability date in November 2004.

3.2.1.7.3 Modernised GPS

The Basic GPS is evolving to meet civil user needs. The objective is to make the system more robust, increase system availability and reduce the complexity of GPS augmentations. Some planned enhancements include: the addition of a new signal (L2C) on L2 for civil use; the addition of a third civil signal (L5); protection and availability of one of the two new signals for Safety-of-Life Services (ARNS allocation) by 2005; enhanced signal structure and additional signal power.

Although L2 is currently not part of the GPS Standard Positioning Service (SPS), many civil users employ codeless or semi-codeless dual frequency receivers to support their requirements. Consequently, the U.S. Government has determined that the availability of two additional C/A coded signals is essential for many critical GPS uses. The signals are planned to enhance the ability of GPS to support all civil use needs. A second, non-safety-of-life coded signal will be added at the GPS L2 frequency (1227.60 MHz) on satellites scheduled for launch beginning in 2003. A third civil signal (L5) that can meet the needs of critical safety-of-life applications such as civil aviation will be added at 1176.45 MHz. The third signal will be implemented on satellites scheduled for launch beginning in 2005. The L5 signal is a more robust signal with a power level of –154 dB. Until the second coded civil GPS signal is operational, the U.S. will not intentionally reduce the current received minimum radio frequency signal strength of the P(Y) code on the L2 link, nor will the U.S. intentionally alter the modulation codes.

The GPS III program will include satellites with navigation payloads to support increased M Code power, enhanced L1 and L2; and the L5 signal. Program objectives under GPS III ensure the GPS system will meet civil and military requirements envisioned for the next 30 years. GPS III is being developed using a three-phase approach that is flexible, allows for future changes, and reduces risk. The development of GPS III satellites will begin in 2005, be available for launch in 2007 and the full transition to GPS III (operational implementation) is expected to begin in 2009. Challenges that are being addressed include: 1) representing both civil and military GPS user requirements, 2) bounding GPS III requirements within operational objectives, 3) providing a flexibility that would allow for future changes to meet user requirement through 2030, and 4) to provide robustness for the increasing dependency on precise positioning and timing as an international utility

At the WG-B meeting of April 2002 GNSSP, future L2 and L5 civil signals were technically described and deployment schedules were briefly discussed. It is expected that L2C will be fully operational by 2010. However, even if there would be advantages in terms of frequency redundancy in the use of a second GPS signal, the fact that in many States there were conflicting uses of the frequency band could prevent its use for safety critical operations. Therefore, L2C will not been included in the SARPs, which does not prevent the signal to be used on a state by state basis.

3.2.1.7.4 GLONASS

Future evolution of the basic GLONASS is planned to benefit civil users. The objective is to improve performance characteristic of the system, and enhance its capabilities as the one of core GNSS elements. The main improvements are expected to be implemented on stage-by-stage basis, and the next generation of GLONASS known as GLONASS-M include: addition of a new signal on L2 for civil use; enhanced signal structure (including specific parameters allowing better combined use of GLONASS and GPS); modernised onboard equipment (including new generation of frequency standard, etc); implementation of cross-links between satellites; additional signal power on L2; provision an additional information on L2; provision of P-code on L1/L2.

At the WG-B meeting of April 2002 GNSSP, the current status of GLONASS and the proposed modernisation program were presented. The schedule showed that GLONASS-M satellites would be deployed from 2003 until around 2006. These additional satellites, in combination with existing generation satellites, will constitute a 20 satellite constellation. The next step will be the launch of GLONASS-K satellites starting around 2006.

Material for inclusion of GLONASS-M specifications into existing GNSS SARPs have been presented. The proposals include SARPs changes to both the GLONASS and GBAS sections of the SARPs. Several new parameters will be broadcast by GLONASS-M satellites that will improve the processing at a user receiver level (e.g. for leap second management, GPS-GLONASS combination and ephemeris change).

GNSSP WG-B expressed the view that adoption of this material for the SARPs would probably be difficult to reach for GNSSP/4 (April 2003) due to the lack of validation material before an end-state GLONASS-M satellite is available. However, it was stated that receivers designed to the current SARPs could handle safely GLONASS-M satellites without any modifications.

3.2.1.7.5 Interoperability and combination of constellations

Currently, the only operational constellation is GPS. In the future, Galileo and GLONASS will complement GPS. Special care has to be taken so that the different constellations operate in an interoperable manner. Some balance has to be found to guarantee both interoperability and independence. If we want receivers to be able to process as simply as possible various constellations, we also want to reduce the common modes of failure between them.

A drafting group from the GNSS Panel is in charge of highlighting the range of possible benefits of using combined constellations to users under different operational scenarios, in particular sole service as well as supplementary service scenarios.

The aim of the group is to provide evidence that using a combined constellation combination, GNSS would better meet all user requirements and possibly simplify GNSS architecture. They will collect, examine and summarise the results of existing studies on the potential performance and robustness of combined constellations architectures.

3.2.1.7.6 GNSS Vulnerability and need for backup

The vulnerability of GNSS is currently being assessed, in terms of resistance to interferences, ionospheric disturbances, solar activity, spoofing, constellation failure, and other causes identified as being a factor of discontinuity in the service provision.

As far as interferences are concerned, on-going studies check issues such as interference with DME at high altitude, with radar equipment for Galileo E6, and between constellations (GPS L5 and Galileo E5a E5b).

In Canada, a study was performed to check whether operators could take credit for a GPS approach when specifying an alternate aerodrome on a flight plan. The analysis concluded that it would be possible, but that the destination aerodrome would have to be served by a conventional approach to mitigate the risk of interference with GPS at both aerodromes.

At ICAO level, the effects of ionospheric disturbances were discussed at the GNSSP WG-A and WG-B meetings in April 2002, and the conclusions were that inputs were required from service providers and states conducting research in this area. Particular attention should be given to regional effects such as the larger scintillation effects that occur in the geomagnetic equator region. A SAGA/Galilei paper presented at Eurocae WG-62 in July 2002 came to the same conclusion, insisting on the aspects that could induce a disruption of service continuity.

3.2.1.7.7 SBAS

SBAS SARPs for GPS have been published, and three SBAS systems have been identified: WAAS in the USA, EGNOS in Europe and MSAS in Japan.

During the WG-B meeting of March 2001 GNSSP, SARPs enhancements were adopted for the GLONASS parts of SBAS.

3.2.1.7.8 GRAS

GRAS is a blending of Space/Ground-based Augmentation System (SBAS/GBAS) concepts to enhance GPS/GNSS capabilities for supporting civil navigation needs in its national airspace. This approach, is SBAS-like in using a distributed network of reference stations for monitoring GPS, and a central processing facility for computing GPS integrity and differential correction information. But instead of transmitting this information to users via dedicated geo-stationary satellites, GRAS delivers SBAS message data to a network of terrestrial stations for a local check and reformatting. Each site emits a GBAS-like, VHF Data Broadcast (VDB) signal in a TDMA-managed time slot. Users can employ a GPS/GRAS-capable receiver to obtain GPS augmentation data for both en route as well as terminal area approach/departure operations depending on the VHF network coverage. The GRAS approach could be beneficial where a GEO satellite is either not available or too costly to broadcast SBAS data. GRAS also allows for sovereign national control while still providing unified corrections and integrity for en route capability.

The progression path for the development of GRAS SARPs, as defined in April 2002 by WG-B of the GNSSP is:

- Provide a detailed Operational Concept (revise previous submissions).
- Determine the areas where the GBAS Positioning Service SARPs will not meet the operational requirements of a GRAS system.
- Detail these areas in Working Papers, showing the analysis as to why they cannot be met.
- Provide solutions where required with validation material.
- Provide a validation matrix (citing methodology) for all changes to the GBAS Positioning Service SARPs.

The objective is to have GRAS SARPs available for GNSSP/4. If, however, during the review of the GBAS Positioning Service SARPs, it is identified that this objective cannot be achieved, minimal standards will be proposed for GNSSP/4. In that case, work will continue on the development of SARPs material to enable maximum use of the GRAS concept, leveraging, to the maximum extent possible, from the existing GBAS SARPs.

3.2.1.7.9 GBAS

GBAS SARPs for GPS have been published.

During the WG-B meeting of March 2001 GNSSP, SARPs enhancements were adopted for the GLONASS parts of GBAS.

3.2.1.7.10 Cat II and Cat III precision approach using GNSS

A drafting group from the GNSS Panel is currently studying whether GNSS could support Category II/III approach and landing and aerodrome surface operations. Key issues have been identified for the validation of Category II/III standards and for the evolution of Category I GBAS systems to support Category III operations. The report on this task will consider the current GBAS standards as well as future system standards. An objective of the group is to support the update to the ICAO Strategy for the Introduction and Application of Non-Visual Aids to Approach and Landing. It is not likely that all of the high-level performance requirements will be ready for GNSSP/4, in April 2003.

Significant discussions are also going on within RTCA SC-159, EUROCAE WG-28 and the FAA/JAA All Weather Operations Harmonization Working Group.

In Japan, the use of Airport Pseudolites (APLs) as additional ranging sources for GBAS has been studied, showing that noticeable improvement could be expected on the overall navigation system accuracy if pseudolites biases were compensated inside the receivers. Further results will be presented to the next GNSSP WG-B meetings in October 2002.

GBAS message extensions are being studied for the new GPS options (L5 application), for GLONASS-M, and for the local component of Galileo.

As far as Galileo is concerned, some concerns had been expressed on the local component, which principles may have differed from the existing SBAS and GBAS elements. If the ICAO strategy was followed, the reference station was to be implemented to be compatible with both GPS and Galileo, which meant that the SARPs definitions and interfaces would be extended. If not, a separate local component for Galileo could have been proposed. It was decided to follow the ICAO strategy.

In order to maximise the benefit of having independent constellations, the SARPs will have to be changed so that Galileo only mode of operation shall be possible in GBAS, and also to define a combined operation between constellations.

3.2.1.7.11 GNSS service levels

The GNSSP subgroup concerned with GNSS service levels convened on the 22nd and 23rd of April 2002. The subjects of discussion were Working Papers that presented a proposed GNSS classification scheme, service levels and also discussed how to use such a scheme in an operational environment. The group met following discussion in Working Groups A and B that had concluded that the classification scheme and service levels appeared unnecessary and that the added value needed clarification.

The majority position within the group was that for SBAS and GBAS systems no classification scheme would be necessary, as the information required could be provided in either a States Aeronautical Information Publication (AIP) or on specific airfield approach plates.

3.2.1.7.12 Validation of GNSS Standards

In the aeronautical context, standards are considered validated when it is proven that the requirements are necessary, sufficient and achievable. The ICAO usage is for SARPs to be validated before they are accepted. The validation of a portion of the SARPs is generally performed in the year preceding the acceptance at the level of GNSS-P. It consists in three tasks:

- Visual inspection: an editorial review intended to detect and correct inconsistencies, awkward/ambiguous sentences, or unnecessary requirements,
- Completeness check: a review to check that the performance requirements expressed in the SARPs are sufficient to meet the Required Navigation Performance levels; these RNP levels result from the activities of different ICAO panels such as the RGCSP and AWOP, which purpose is to define generic operational requirements for navigation systems in the different phases of flight,
- Feasibility check: experimental systems are implemented to verify that it is possible to meet the specified requirements.

These tasks are performed by GNSSP Members, either on an individual basis, or within the framework of sub-groups.

SARPs for the first generations of GPS, GLONASS, SBAS and GBAS have already been validated.

The current SARPs validation activities concern GRAS and GLONASS-M. They have to be completed before adoption at GNSSP4 in April 2003.

Future validation tasks will deal with :

- The extension of GBAS to Cat II/III,
- GPS L5 : validation is expected to be completed after a satellite is on orbit, in 2005,
- Galileo : the first package of Galileo SARPs, covering the core system and the regional augmentation, is expected for 2004, and the second package, covering ground based augmentation and precision approach is expected for 2008. For the first package, it may be difficult to obtain complete test results by 2004. Therefore, ICAO is contemplating approving the sections which will be validated by 2004 and delay the approval of other sections. This will require at least the core system to be validated.

3.2.1.7.13 Validation of GNSS Systems

In order for a system to be accepted operationally, it is necessary to check the compliance of the system to the standards. In this context, validation activities are performed to prove the ability of the system to be used in a safe way.

In the following sub-paragraphs, we will describe the new ICAO requirements applicable to the introduction of new systems in the ATS environment.

3.2.1.7.13.1 New ICAO Requirements in Annex 11

ICAO has introduced in the Annex 11 to the Convention to International Civil Aviation new requirements concerning the ATS safety management.

As of 27 November 2003, ICAO requires that the acceptable level of safety and safety objectives applicable to the provision of ATS within airspace and at aerodromes shall be established by the States or State concerned. When applicable, safety levels and safety objectives shall be established on the basis of regional air navigation agreements.

These provisions will be applicable to any significant safety-related change to the ATC system, including the implementation of new separation minima, system or procedures changes. The introduction of these changes will not be possible anymore without having demonstrated, through a safety assessment, than an acceptable level of safety will be met and all users of the new system, procedure, etc. have been consulted.

In addition and when appropriate, provisions should be made for an adequate post-implementation monitoring of the system to verify if the defined levels of safety continue to be met.

The acceptable level of safety will have to be specified, depending on the nature of the change, in quantitative or qualitative terms. ICAO is giving some examples of which measures or metrics could be considered as acceptable means to express the level of safety:

- A maximum probability of undesirable events such as collision, loss of separation, or runway incursion;
- A maximum number of accidents per flight hour;
- A maximum number of incidents per aircraft movement;
- A maximum number of valid short-term conflict alerts per aircraft movement.

Details on the implementation of the above are given in the ICAO Procedures for Air Navigation (PANS) on Air Traffic Management.

3.2.1.7.13.2 ICAO PANS on Air Traffic Management

The ICAO PANS on Air Traffic Management (PANS-ATM) describes in detail the Standards and Recommended Practices (SARPs) included in the Annex 11. PANS-ATM makes clear that the safety management processes are referring to both the provision of ATS and the supporting infrastructure, i.e. communication, navigation and surveillance.

The requirement of setting safety levels and objectives on the basis of regional air navigation agreements comes from the need to facilitate the harmonisation of ATS and supporting infrastructure in adjacent airspace.

In addition, PANS-ATM defines the objectives of safety management as being:

- To ensure that the established level of safety applicable to the provision of ATS within an airspace or at an aerodrome is met;
- To ensure that safety-related enhancements are planned whenever necessary.

It is also recommended that safety management processes should be implemented, when required, on the basis of regional air navigation agreements.

PANS-ATM recommends that an safety management programme should include, amongst other things, the following elements:

- Monitoring safety levels and detection of adverse trends;
- Safety review of ATS units;
- Safety assessments in respect of the planned implementation of airspace re-organisations, the introduction of new equipment, systems or facilities, and new or changed ATS procedures;
- A mechanism for identifying the need for safety enhancing measures.

All these activities shall be fully documented and any related documentation retained for a sufficiently long period of time, as specified by the concerned authorities.

PANS-ATM also addresses the need for collecting and evaluating safety related data. The safety data should come from a wide variety of sources. A formal incident reporting process should be established and it should facilitate the collection of information on actual or potential hazards related to the provision of ATS, including, amongst other things, procedures, communication, navigation and surveillance systems. This process should also include reports concerning the serviceability of ATS facilities and systems, such as failures and degradations of communications, surveillance and navigation systems in order to detect any trend in the operation of such systems that may have an adverse impact on safety.

3.2.2 Preliminary safety assessment: critical operational scenarios

This section presents the approach taken and the conclusions reached as regards the assessment of two critical operational scenarios already discussed in our Interim Report, that we consider as the most critical issues for adopting a GNSS sole service strategy.

It starts with the description of two critical operational scenarios concerning a) the interruption of service for aircraft executing Cat II/III approaches at airports in Europe with published Cat II/III procedures and infrastructure, and b) the interruption of service for all aircraft not equipped with INS in all phases of flight, i.e. en-route and non-precision instrument approaches in IMC.

A safety assessment will then be presented, based on the GNSS high level architecture, going through the operational hazards and their severity levels, studying their causes in order to present mitigation measures, and comparing the probabilities of accident with the Target Level of Safety.

Two critical operational scenarios have been identified for which a safety assessment needs to be done:

- Service interruption for aircraft executing Cat II/III approaches at airports in Europe with published Cat II/III procedures and infrastructure.
- Service interruption for all aircraft not equipped with INS in all phases of flight, i.e. en-route and non-precision instrument approaches in IMC.

Before these scenarios be discussed a number of assumptions regarding Operational Environment Elements and Operational System Elements have to be clarified, so as to specify the context into which the GNSS as a sole service for navigation will be integrated.

The assumptions associated to the Operational Environment are aimed at clarifying functionality issues. Assumptions associated to the Operational System are aimed at clarifying - the respective roles of the pilot and of the aircraft equipment in the scenarios.

3.2.2.1 Operational Environment Elements

In the following table, we have summarised the operational environment elements that, in our opinion, will characterise the context of operation for GNSS as sole service :

OPERATIONAL ENVIRONMENT ELEMENT	ASSUMPTIONS
CURRENT AND FUTURE CNS/ATM CAPABILITIES	**[A3.2.2-1]** COM: VOICE AND DATA COMMUNICATIONS BETWEEN ATC AND AIRCRAFT. **[A3.2.2-2]** NAV: GNSS, GBAS EQUIPPED AIRCRAFT ONLY (MIXED APPROACHES WERE GIVEN SOME CONSIDERATION, BUT MORE DETAILED ANALYSIS IS NEEDED). **[A3.2.2-3]** SUR: RADAR IS CONSIDERED AS POSSIBLY PRESENT BUT IS NOT ASSUMED TO BE A REQUIREMENT. ADS-B WILL BE PRIMARY.
SEPARATION	**[A3.2.2-4]** WAKE TURBULENCE SEPARATION OR MINIMUM RADAR SEPARATION ON FINAL APPROACH AND EN-ROUTE.

TRAFFIC CHARACTERISTICS	**[A3.2.2-5]** TRAFFIC AT FULL CAPACITY (4000 A/C AT A TIME IN THE ECAC AREA IN 2015).
AIRCRAFT NAVIGATION PERFORMANCE	**[A3.2.2-6]** GBAS APPROACHES FOR MULTIPLE RUNWAYS. SCENARIO 1 AIRCRAFT (AND AIRCREW) CERTIFIED FOR CAT-II/III APPROACHES. SCENARIO 2 AIRCRAFT CERTIFIED FOR CAT I APPROACHES.
AIRCRAFT EQUIPMENT ISSUE	**[A3.2.2-7]** REDUNDANT FMS-INS ON BOARD ALL AIRCRAFT CAPABLE TO EXECUTE CATII/III OPS. (SCENARIO 1) **[A3.2.2-8]** NAVIGATION OF AIRCRAFT NOT EQUIPPED WITH INS-AND WITHOUT ANY GROUND NAVAIDS (SCENARIO 2)
ATC CENTRE PROVISIONS	**[A3.2.2-9]** PROVISIONS AVAILABLE FOR MONITORING AND CONTROL OF GBAS **[A3.2.2-10]** IT IS ASSUMED THAT IN 2015+ ATC IS BASED ON DELEGATION OF SEPARATION TO PILOTS, MEANING CONTROLLERS ARE WORKING MORE ON A STRATEGIC THAN A TACTICAL LEVEL.
AIRPORT INFRASTRUCTURE	**[A3.2.2-11]** MULTIPLE RUNWAYS ON A SINGLE AIRPORT AND TAXIWAYS CAPABLE OF HANDLING THE TRAFFIC IN ALL WEATHER OPERATIONS WITHOUT AN EFFECT ON THE DECLARED RUNWAY CAPACITY, I.E. A-SMGCS AVAILABLE. (SCENARIO 1) **[A3.2.2-12]** (MULTIPLE) RUNWAYS ON A SINGLE AIRPORT AND TAXIWAYS NOT CAPABLE OF HANDLING THE TRAFFIC IN ALL WEATHER OPERATIONS (SCENARIO 2)
WEATHER CONSTRAINTS	**[A3.2.2-13]** NO CONSTRAINTS (SCENARIO 1) **[A3.2.2-14]** CAT II/III CONDITIONS.(SCENARIO 2)
OPERATIONAL PROCEDURES	**[A3.2.2-15]** (CAT II/III) ILS-LOOK A LIKE FINAL APPROACH REMAINS THE REFERENCE MODEL. (SCENARIO 1)

Table 3.2.2-1: Operational Environment Elements

3.2.2.2 Operational System Elements

Operational System Elements with which GNSS service will be integrated are:

3.2.2.2.1 Human aspects

- Pilot tasks including pre-flight activities and flight preparation (e.g. checking NOTAMS), communication with ATC, selection of GBAS approach, changeover from en-route navigation equipment to GBAS, capturing the GBAS signal, monitoring final approach, decision-making with respect to conducting a missed approach, contingency arrangements (e.g. in event of failure of GBAS system).
- ATC tasks.
- Ground station operational/maintenance tasks.
- Training (ATC, Flight Crew and ground station operational/maintenance personnel), working methods of controllers.

3.2.2.2.2 Procedural aspects

- Flight plan identification.
- Communications procedures.

- Emergency/reversionary (contingency) procedures (including ATC procedures covering the case when all aircraft lose GBAS facility simultaneously).
- Availability of reversionary (contingency) operational procedures.
- Performance monitoring.
- Interference monitoring and control.
- Flight inspection procedures.
- Issue of NOTAMS charts and AIS procedures in general.
- Ground station database input management (including production and processing of database information). In particular GBAS related data and Final Approach Segment data.
- Predicted ranging source availability.

3.2.2.3 Safety Scenario 1: Service interruption during a Cat II/III approach

[A3.2.2-16] In this scenario it is assumed that the service interruption is unscheduled with an unknown duration, and is caused by a ground-originated interference; a GNSS failure or GBAS malfunction, that may occur on two different scales, either :

- locally, affecting a TMA and/or at a high capacity and complex airport or
- regionally (e.g. ECAC region), affecting several TMA's and/or high capacity airport operations.

[A3.2.2-17] When the service is interrupted under CATII/III conditions, relevant hazards need to be identified for the following situations:

- Missed approach
- Take-off followed with immediate approach to land
- Combination of missed approach and take-off followed with immediate approach to land.

As from the very beginning of the service interruption, measures need to be taken immediately to reduce traffic in concerned airspace.

[A3.2.2-18] Mitigation measures have to be defined for a worst-case situation when one does not know when the interruption will be over.

The operational challenge for ATC is to safely bring all aircraft on the ground as soon as possible:

- for a local service interruption, at the destination airport : at the flight's planned alternate airport or at other airports not operating in Low Visibility Conditions.
- For a regional service interruption, at an airport outside the effected region (this might have an effect on the Concept of Operations with respect to additional fuel to carry to reach a destination outside the affected region).

If the service comes back into operation after some time then a transition scenario "back to normal business" is triggered.

[A3.2.2-19] Aircraft not equipped with FMS-INS and without CATII/III capabilities, are not part of the traffic landing at or taking off from airports where CATII/III conditions prevail.

Such weather conditions occur mostly during the morning hours in the aeronautical winter period (October – March) at airports in the European Region.

[A3.2.2-20] During peak hours it is assumed that approximately 100 aircraft per hour will request to land at each major airport.

[A3.2.2-21] The probability of a large number of airports being under Cat II/III conditions at the same time is limited, because Cat II/III means fog and you will not have fog all over Europe at the same time. So, part of the traffic is able to divert and land at airports in the vicinity of the destination airport where such conditions do not prevail and the workload of the controllers will be limited.

However, an overview of the CFMU monthly reports reveal that areas encompassing a group of airports can be affected by low visibility conditions at the same time, e.g. London area covering Heathrow, Gatwick and Stansted or Milan area covering Linate and Malpensa.

The same reports reveal that similar weather conditions may occur at different airports at the same time in the European Region. Therefore, ***we recommend to conduct a detailed survey based on MET statistics to assess the probability of occurrence of Cat II/III conditions at European airports.***

Aircraft landing under Cat II/III conditions is safe as soon as it touches ground and rolls out on the runway. The critical phase is what happens during the preceding seconds when the aircraft have to execute a missed approach, in absence of the navigational signal. The identified hazard is the loss of navigation capability.

The following paragraphs outline the methodology used to identify hazards and the summing up of relevant hazards. In a next step mitigation measures to the identified hazards are being discussed roughly, with to reduce the involved risks to an acceptable level of operation.

3.2.2.3.1 PHASES OF THE HAZARDS ANALYSIS

For the identification of hazards a step-wise analysis consisting of three phases, has to be developed:

- **Pre-phase**: high level hazard identification with the aim to feed forward into a definition of the Concept of Operations.
- **Post-phase**: more in-depth analysis using the Concept of Operations and feeding forward into development of phraseology, flight planning etc.
- **Detailed phase:** detailed analysis of defined procedures and human tasks.

At the current stage of maturity in GNSS service definition and operation, only the pre-phase is examined.

3.2.2.3.1.1 PRE-PHASE RELEVANT HAZARDS

The intentionally relevant hazard issues requiring attention or further investigation for scenario 1 (and 2) are the following:

- Concept of Operations
- Flightdeck Issues
- Communication and Phraseology
- Aircraft Systems
- Ground Station Systems and ATM
- Procedure Design
- Airline / ATC Procedures and Training
- Flight Planning and Flight Plan Issues
- ATC Display / User Interface
- Interference Monitoring and Control
- Meteorological Conditions

3.2.2.3.1.2 Concept of Operations

- Implications for NOTAMS (coding/phraseology of NOTAMS and the way NOTAMS are updated).
- Responsibilities, e.g. checking availability of GNSS service
- Functionality to provide availability information (Flight Plan, approach type, aircraft capability, (alternate) airport capability)
- Diversions and alternate planning - a GNNS failure could affect approaches to both main and alternate airports and hence (fuel) planning should be investigated further within the Concept of Operations.
- Changeover from en-route to approach navigation
- Definition of operational limitations - capturing the final approach path and the impact of bank angle on the visibility of satellites
- Switching GBAS on/off - there might be differences with ILS in terms of the frequency of approaches being switched off and on.
- GBAS serving multiple approaches - confusion during co-ordination between controllers following a GBAS failure
- Angle of approach
- Clarification of approach selection timing - in the context of the flightdeck becoming aware of a problem with GBAS at an earlier stage as the signal would be picked up earlier

3.2.2.3.1.3 Flightdeck Issues

- Air crew (workload, ability to perform pilot's functions....)
- Errors in assigning or selecting GBAS approach channel:
- Channel referencing and approach naming - co-ordinate reference path identifiers/ channels (e.g. ensure at least 3 digits change) and approach names, including those at proximal airports.

3.2.2.3.1.4 Communication and Phraseology

- Development of a standard phraseology for NOTAMS and wider requirements for phraseology changes to take account of GBAS.

3.2.2.3.1.5 Aircraft Systems

- Aircraft functional capabilities (Loss of position...)
- Consider an FMS credibility check - a check that the selected approach is credible to guard against dialling in the wrong channel number. The mitigation from such a measure would clearly be limited to FMS equipped aircraft.
- Capture angle - airworthiness will need to address antenna coverage during aircraft banking
- Approach deviation tolerances - these need to be defined for the flightdeck user interface
- Check effect of switching off GBAS when aircraft on approach
- Cockpit User Interface to show GBAS availability status - possible requirements for the User Interface to show specific GBAS availability status (e.g. individual approaches).

3.2.2.3.1.6 Ground Station Systems

- Functional capabilities of the ground part of the CNS/ATM System
- Transmission of operating runways Final Approach Segment only - this would reduce the chance of attempting to fly the wrong approach.

- Upload times - a check needs to be made that this is unlikely to be a significant cause for late clearances.

3.2.2.3.1.7 Procedure Design

- Ability to provide safe Air Traffic Management Services (magnitude of problem...)
- Changeover issues - procedure design with respect to changeover from en-route via terminal transition to the final approach.
- Restrict GBAS capture angle - procedure design will need to take account of banking limitations caused by use of the satellites. It is essential that the requirement used in airworthiness is the same as that used in procedure design.

3.2.2.3.1.8 Airline/ ATC Procedures

- Air Traffic Controllers (workload, ability to perform his/her functions...)
- Use of GBAS below Decision Altitude
- Contingencies when GNSS is lost - ATC actions when GNSS is lost.
- Switching / deselection of approach paths - ATC operational procedures need to be in place to cater for switching or deselecting approaches.
- Reassignment of approaches after Final Approach Point - potential for reassigning approach after the final approach point.

3.2.2.3.1.9 Flight Planning

In the case of mixed mode operations clear indications of aircraft capability need to be available to controllers:

- Include information in the flight plan indicating whether the GNSS approach capability is appropriate for the approach procedure to be flown.

3.2.2.3.1.10 ATC Display / User Interface

- ATC needs one indication of whether GBAS is functioning or not
- Status monitoring requirements
- ATC needs to know which approaches are being broadcast

3.2.2.3.1.11 Meteorological Conditions

Solar winds might create a negative effect.

3.2.2.3.2 MITIGATING MEASURES

This requirement covers:

- The complete life cycle of the CNS/ATM System, and, in particular, its constituent parts.
- Human, procedural and equipment (hardware, software) elements of the CNS/ATM System as well as its environment of operations.

3.2.2.3.2.1 CNS/ATM issues

3.2.2.3.2.1.1 Communication

Aircraft on final approach noting the loss of GNSS signal will inform approach or aerodrome control that they are executing a missed approach (or continuing visually if possible) due to equipment problems. Aircraft not yet on final, noting the problem will report this to ATC, but not en-mass, clogging the VHF channel. The first one to report will be heard by others on the same frequency and the information will not be repeated by others.

An automatic signal from the aircraft needs to be investigated for its usefulness in order to overcome such potential problems.

3.2.2.3.2.1.2 Navigation Systems during missed approach

If the GNSS service is interrupted, pilots operating aircraft applicable to scenario 1, can fall back on terrestrial nav-aids and on Inertial Navigation Systems on board of the aircraft. The INS would slowly lose positional accuracy when not updated by GNSS or terrestrial nav-aids, which might preclude the accurate navigation required for safe separation of the air traffic, which is identified as a hazardous situation in the high-density terminal airspace.

3.2.2.3.2.1.3 Surveillance

Surveillance is needed to get aircraft to a point from which it can be lined up on the final approach or to feed the aircraft again into the en route airspace, irrespective of how the aircraft is navigating. If there is no signal to make a GNSS approach, another and/or a back up procedure will be executed. Under current procedures,a majority of aircraft could require vectoring from air traffic control in order to remain safely separated from each other as they are directed away from the interference area. Missed approach procedures may have to be redesigned so as to minimise interference, and reduce the controller’s workload. As all aircraft executing a missed approach under Cat II/III conditions would remain autonomously RNP 0.3 capable for about 10 NM (then RNP1 capable for at least 30 NM), the main potential source of problems comes from lesser equipped aircraft operating under Cat I condition in a busy TMA.

3.2.2.3.2.2 Airspace management

Coping with a sudden large amount of aircraft requesting assistance might require immediate re-allocation of tasks from strategic to tactical, which might need measures and trained skills from air traffic controllers.

3.2.2.3.2.3 Ensure ATC and airport capacity:

The large amount of aircraft involved when a loss of signal is occurring, will call upon an adequate number of human resources to vector the aircraft from the affected area. It needs to be investigated how many extra controllers need to be kept on standby who need to assist in diverting the traffic.

3.2.2.3.2.4 Air Traffic Flow Management

The load imposed on the ATC system during the outage needs to be covered by a sound contingency plan.

3.2.2.3.2.5 Procedures and separation minima

The loss of satellite signals could severely affect busy en route airways and TMA’s which may require new ATC procedures to maintain safe traffic separation.

3.2.2.3.2.6 Development of MET plans:

It is envisaged that MET forecasts on a regional level are necessary in order to cope with consequences of a loss of the signal in space affecting a complete region.

3.2.2.3.2.7 Development of Contingency plans:

Contingency plans need to be developed and need to take into account the following issues :

- Number of additional sectors required and consequently the required human resources

- Centralise the proficiency of MET data on a regional basis.

3.2.2.3.3 Conclusion on scenario 1

For Commercial Aviation, we conclude that the introduction of GNSS as sole service will have a deep and widespread impact at the operational level. Operational procedures will have to be modified and validated so as to prevent critical events to occur.

3.2.2.4 Scenario 2: Service interruption for non-INS aircraft in all phases of flight

3.2.2.4.1 Context of scenario 2

In Europe, about 37000 General Aviation Aircraft operate today. However General Aviation only accounts for 6% - 7% of the total number of IFR flights according to Eurocontrol statistics. Therefore 92% - 93% of the General Aviation aircraft are operating in accordance with VFR flight rules. In essence, any navigation equipment in the cockpit in which the flight is operating in accordance with the VFR rules can only be considered to be an aid to visual navigation. It means that a VFR pilot using GNSS equipment can only be using it as an aid to his/her visual navigation. Still, even though there is a small number of General Aviation IFR movements these aircraft still have to be able to operate within the system. Most are unlikely to have any form of INS and therefore the total loss of GNSS could constitute a critical event. Although it does not seem necessary to perform a Safety Case for General Aviation, the analysis of this critical operational scenario may lead us to give some recommendations as far as the training of pilots is concerned.

3.2.2.4.2 Analysis of scenario 2

[A3.2.2-22] We assume that the service interruption is unscheduled with an unknown duration, and is caused by a ground-originated and/or en route interference; or a GNSS failure or GBAS malfunction that may occur on two different scales, either :

- On a local scale, affecting a TMA and/or at a high capacity and complex airport
- On a regional scale (e.g. ECAC region), affecting TMA's and/or high capacity airport operations

[A3.2.2-23] When the service interruption occurs in IMC, it is assumed that the following phases of flight are critical for which relevant hazards need to be identified and for which a safety assessment needs to be made, i.e.:

- En-route
- Approach to land
- NPV missed approach (fall back to VFR and non precision)
- Take-off followed with immediate approach to land
- Combination of missed approach and take-off followed with immediate approach to land.

Immediately after initiation of the service interruption measures need to be taken to clear the skies. The aircraft need to land safely at the airport of destination or :

- Locally : at an alternate airport or at an other suitable airport
- Regionally : at an other suitable airport within the region or outside the affected region.

[A3.2.2-24] It is understood that traffic, other than the traffic under consideration in this scenario, forms a part (% to be defined) of the total traffic, that needs to land as well.

The methodology to identify hazards and the summing up of relevant hazards are similar to the ones mentioned under scenario 1 and therefore they will not be reiterated (see paragraph 3.2.2.1). The same applies partly for the mitigation measures. Only additional or specific measures applicable to scenario 2 are taken into account.

3.2.2.4.3 MITIGATING MEASURES

3.2.2.4.3.1 CNS/ATM:

3.2.2.4.3.1.1 Navigation

Due to the fact that these aircraft are not equipped with INS, which means that the position in space from the pilot point of view can not be secured and there is no reliance on ground aids, the task of the controller is to give immediately directions to the pilot in order to bring the aircraft at a level height safely separated from other traffic and preferably in an area where VFR could be applied.

3.2.2.4.4 Conclusion on scenario 2

In the event of a total loss of GNSS, General Aviation aircraft may have to revert to VFR rules. As many pilots are now using GNSS receivers (the actual number is difficult to assess, as these can be hand-held receivers), there is a potential risk that they may not maintain their capacity to navigate without any other means than a map, a tachometer and a magnetic heading indicator.

In order to avoid an excessive dependence to GNSS, ***we recommend that the training, licence delivery and licence renewal procedures integrate a verification of the ability of pilots to navigate without GNSS equipment.***

3.2.3 System Safety Assessment

In order to identify the high level safety requirements, related to the "sole service" satellite navigation, the following methodology is applied:

- First, the high level architecture of the GNSS sole service is presented so as to identify the different components of this system
- From the high level architecture, the different Operational Hazards are identified and a severity level is assigned for each of those hazards in function of the critical operational scenario (identified in the previous part – 3.2.2)
- In the next step, the causes leading to those operational hazards are investigated in order to precise recommendation (dependability specification and mitigation means if possible)
- Finally, estimating probabilities of accident on a European scale, the comparison will be made with the TLS

It must be clear that this safety assessment is not intended to be a Functional Hazard Assessment but only a mean to identify what seem to be the most credible and severe hazards. This analysis could be reused in future analyses but those ones, to be more systematic, shall be consolidated with experts opinion on the Operational Hazards definitions and on the severity levels. And more time should be spent on system definition with consolidation with experts too.

<u>Initial assumptions</u>

[A3.2.3-1] Inertial Navigation is currently considered to meet RNP 4 position fixing requirements when updated automatically every 2 hours maximum. Decrease in accuracy with time (in general less than 2 NM/hr) : so when GNSS will stop, FMS will try to continue with INS and the last inputs from GNSS

[A3.2.3-2] Internationally agreed levels of service separately committed to and guaranteed by both GPS and Galileo operators ;

[A3.2.3-3] The independent provision of GNSS signals on at least 2 distinct channels (possibly 3 channels for Cat II/Cat III) ;

[A3.2.3-4] A Galileo-based (respectively GBAS-based) integrity monitoring of GPS and Galileo primary signals compatible with Cat I grade (respectively Cat III grade) time to alarm and missed alarm probability ;

[A3.2.3-5] The definition of a stand-alone failure recovery scenario, including the safety of aircraft trajectories after a missed approach under non precision (respectively Cat III precision) landing conditions.

3.2.3.1 High level architecture for the GNSS sole service

3.2.3.1.1 GNSS presentation

The GNSS sole service high level architecture is presented here decomposing this sole service in its different sub-systems (called segments in the figure).

Those sub-systems are satellites (Galileo, GPS, GLONASS and GEO), the ground part (control centre for Galileo and for SBAS and GBAS) and the users part (aircraft).

Figure 3.2.3-1 presents those different parts of the GNSS sole service and the most important data exchanges between those sub-systems.

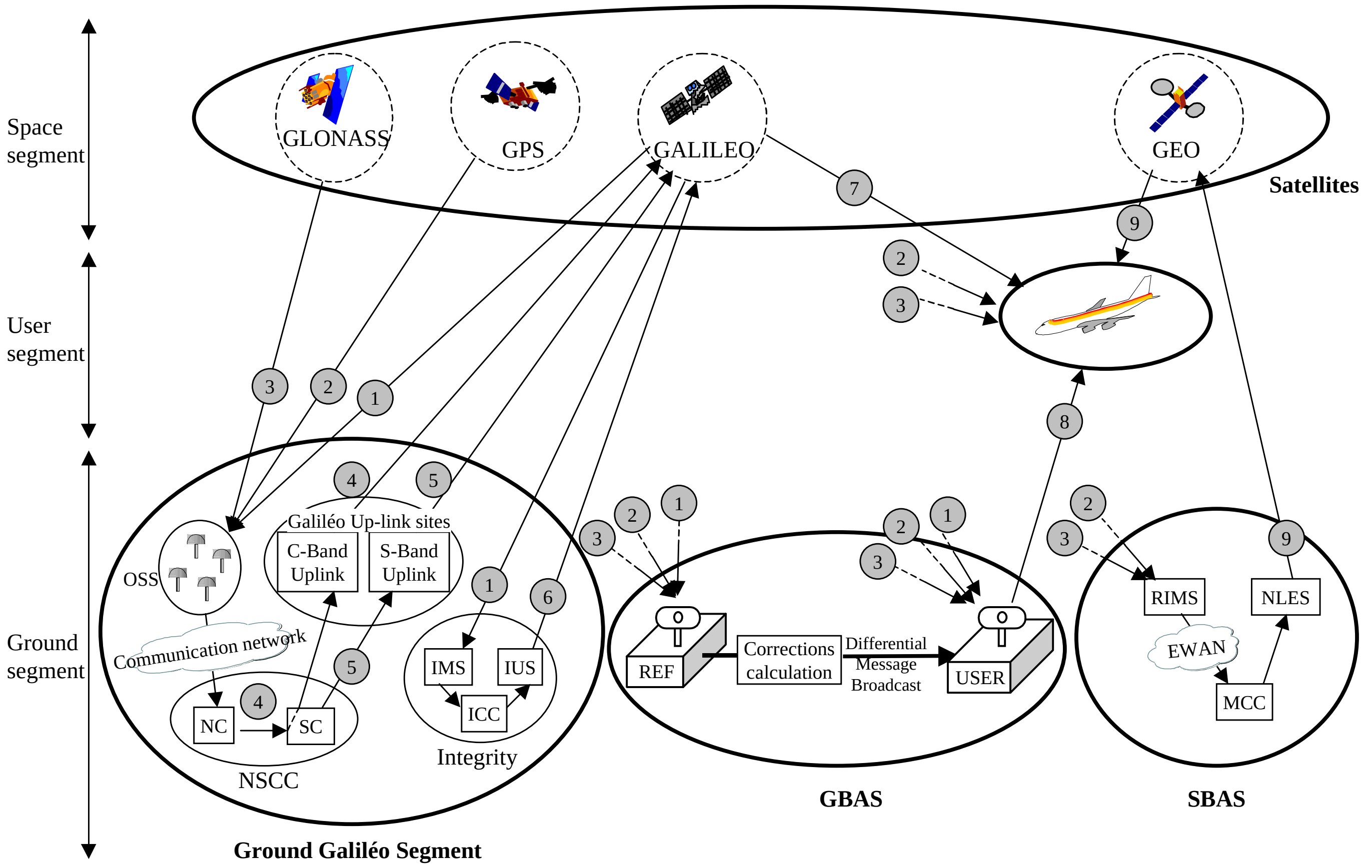

Figure 3.2.3-1: High level architecture scheme

The signal exchanges are presented in the following list:

1: raw measurements / navigation messages received from Galileo satellites

2: raw measurements / navigation messages received from GPS satellites

3: raw measurements / navigation messages received from GLONASS satellites

4: Correction data (estimation of ephemeris and clock error)

5: Satellite housekeeping and orbit control messages

6: Integrity flags

7: Navigation data messages (SIS + correction data + Integrity flags)

8: High integrity computed corrections from GBAS

9: GPS like signals with integrated precision and integrity messages

ICC: Integrity Control Centre

IMS: Integrity Monitoring Station

IUS : Integrity Up-link Stations

MCC Monitoring Control Centre

NC: Navigation Control

NLES: Navigation Land Earth Station

NSCC: Navigation System Control Centre

OSS: Orbitography and Synchronisation Stations

RIMS: Ranging and Integrity Monitoring Station

SC: Satellite Control

3.2.3.1.2 GNSS performances

For the analysis, the performance of the different parts of GNSS are needed. In order to have a vision of the performance offered by the different systems composing the GNSS system, the following table has been done:

GNSS part	**Accuracy**	**Integrity risk**	**Time To Alarm**	**Continuity**	**Local availability**
EGNOS (European land Masses)	H – 16m V – 7.7 to 4m	2.10^{-7} in any 150s	6s	8.10^{-5} in any 150s	0.99
Galileo (Safety of Life service)	H – 4m V – 8m	$3.5.10^{-7}$ in any 150s	6 s	10^{-5} in any 15s	0.998
GPS	H – 13 to 36m V – 22 to 77m	–	–	?	0.99 to 0.9
GBAS	Able to serve Cat-I operations. Advanced operations such as Cat-II/III or A-SMGCS are under consideration by ICAO GNSS Panel				

Table 3.2.3-1: GNSS system performance comparison

The GNSS architecture is roughly presented in this paragraph. The intend of this step is to present methodically the GNSS system at a high level in order to identify a first set of high level possible failures. This is done in the following paragraph.

3.2.3.2 Typology of events leading to GNSS service interruption

3.2.3.2.1 Used methodology

In order to have a vision of the conceivable failures, the different services interruption or degradation that can occur and lead to hazards have been investigated in tables presented in annex 1. This has been done looking for internal failures and looking for external events that could lead to failure in the system.

For severity assessment, we have based the analysis on GNSS used as sole service ; i.e. aircraft are provided with only one external navigation service, based on GNSS, (withdrawal of ground beacons) but may use data from their own Inertial Navigation System, if they are equipped with such a system.

3.2.3.2.2 Analysis content

For the internal failures, the possible internal high level malfunctions have been analysed. The analysis has been done investigating the high level failures at the segment level only (data treatment, reception and distribution are not analysed in the different segments). This table is presented in the first part of annex 1 and presents the following information:

- **Segment**: name of the segment to be analysed
- **Failure mode**: Failure modes for the segment
- **System effect**: Effect of the segment failure mode on the system (data already provided, diminution in term of performance…)
- **Operational consequence**: impact on users' work (flight crew and controllers), accounting for operational mitigation means allowing to continue provision of degraded service. Sentences underlined present the Operational Hazards
- **Sev. Sc1**: severity level allocated according the operational consequences and according to the first scenario presented in paragraph 3.2.2
- **Sev. Sc2**: severity level allocated according the operational consequences and according to the second scenario presented in paragraph 3.2.2
- **Comments / Questions**: recommendations or demands for clarification

For the external events that can lead to failures, some external events have been investigated in the second table of annex 1 ; this table presents the following information:

- **External event**: presents the external event that can lead to a failure
- **Signals affected**: describe the signals of the architecture scheme (Figure 3-1) that can be affected by the external event
- **Failure mode**: failure mode for the affected signals
- **System effect**: effect of the failure mode on the system
- **Operational consequence**: impact on users' work (flight crew and controllers), accounting for operational mitigation means allowing to continue provision of degraded service. Sentences underlined present the Operational Hazards
- **Sev. Sc1**: severity level allocated according the operational consequences and according to the first scenario presented in paragraph 3.2.2
- **Sev. Sc2**: severity level allocated according the operational consequences and according to the second scenario presented in paragraph 3.2.2
- **Comments / Questions**: recommendations or demands for clarification

3.2.3.2.3 Resulting hazards

The different operational hazards we have identified are listed hereafter. For each critical operational scenario, the level of severity has been assigned in accordance with ESARR 4 and with Eurocontrol SAM methodology.

For each hazard, only the most important severity is analysed for the 2 different critical operational scenarios that have been identified in 3.2.2:

- sc. 1: Service interruption for aircraft executing Cat II/III approaches at main airports in Europe
- sc.2: Service interruption for GA aircraft not equipped with INS in all phases of flight, i.e. en-route and non-precision IFR approaches in IMC

Operational Hazards	**Failure modes**	**Severity (sc. 1)***	**Severity (sc. 2)***
Total loss of GNSS navigation data	Loss of all the space segment	2-3	2
Undetected corruption of GNSS navigation data	Undetected corruption of data from GNSS	2	2-3
Accuracy and integrity services reduction in <Galileo satellite loss> proportion	Loss of Galileo constellation Loss of all the Galileo ground segment Loss of the 'Integrity' Galileo ground centre	4	4
Accuracy and integrity services reduction in <GPS satellite loss> proportion	Loss of GPS constellation	5	5
Accuracy and integrity services reduction in <GLONASS satellite loss> proportion	Loss of GLONASS constellation	5	5
Accuracy and integrity services reduction in <GEO satellite loss> proportion	Loss of all GEOs Loss of all the SBAS Ground centre	4	4
Accuracy and integrity services reduction in <Galileo 'navigation and control' ground centre loss> proportion	Loss of the 'navigation and control' Galileo ground centre	5	5
Total loss of GBAS data	Loss of the GBAS equipment	3	5
Undetected corruption of GBAS data	Undetected corruption of data from GBAS	2	5
Total loss of GNSS navigation data for one a/c	Loss of all GNSS navigation data receiver for one a/c	3	2-3
Undetected corruption of GNSS data for one a/c	Undetected corruption of GNSS navigation data for one a/c	2	2
Accuracy and integrity reduction for geographical parts	Reduction of the reception of the receiver (mountainous environment)	5	5
Total loss of GBAS navigation data for one a/c	Loss of GBAS receiver for one user	3	5
Total loss of SBAS navigation data for one a/c	Loss of SBAS receiver for one user	4	4
Total loss of Galileo navigation data for one a/c	Loss of Galileo receiver for one user	5	4
Accuracy and integrity services reduction in <Ionospheric scintillation> proportion	Loss, in identified locations, of several GNSS signals	4	4
Accuracy and integrity services reduction in <Ionospheric propagation> proportion	Delay in signals reception	5	5
Accuracy and integrity services reduction in <unintentional interference> proportion	Loss, in a limited region, of several GNSS signals	2-3	2

Table 3.2.3-2: GNSS operational hazards list

*: Severity levels are graded from 1 to 5 and 1 is the most stringent level

3.2.3.2.4 Operational risks of sole service

In order to conclude on this table of hazards, we present in detail the critical points for the operational risks.

For the hazard that concerns the loss of GNSS signal, two points are to be foreseen:

- The first concerns the seconds following the navigation signal disruption, that can lead risk of accident for the aircraft that are in landing phase. This point is seen in detail in 3.2.3.4. For this particular case, we just want to highlight the risks encompassed by the fact that, doing a missed approach while the GNSS data are no more provided, the airprox combining missed approach and take-off shall be more likely to occur.
- The second concerns the restrictions that will follow the GNSS signal disruption: in case of a total loss of GNSS while poor meteorological conditions are present, aircraft will be re-routed on airports where visibility is better. We discuss this point in more details.

Consideration shall be taken of the fact that in 2015, aircraft in TMA will have to be RNP 0.3: that will need a precise view of the procedures to be applied in case of a GNSS disruption as the accuracy of the aircraft will decrease quickly.

In case of a total GNSS disruption, aircraft will have to rely on Inertial data. As a result of this degradation, accuracy will slowly degrade following a linear decay of 2 nautical miles per hour (taking the worst degradation envisaged).

As a result of this decay, RNP 0.3 will be kept during approximately 9 minutes and RNP 1 during half an hour. In that case, the concerned airports will have to ask some aircraft to go to other airports (if possible) and to have clear contingency plans for that sort of cases.

A point should be made on the fact that in case of GNSS disruption, there's a possibility to be in a multi-airport (all the airports of a city) or multi-cities (e.g. Amsterdam + Brussels + Dusseldorf + Frankfurt) Cat III weather conditions.

The additional workload for ATCOs should also be taken into account..

Considering the GA operating in accordance with IFR, severity of the loss of GNSS data as sole service seems more important as the they will have a lesser capability of autonomous navigation. Other kind of independent system would have to be present in those aircraft.

For the GA operating in accordance with VFR, any navigation equipment in the cockpit can only be considered to be an aid to visual navigation. However, VFR pilots will have to maintain their training (GNSS complacency must be avoided).

Recommendations made in the next paragraph are made taking into account this list of operational hazards.

3.2.3.3 Recommendations and mitigation strategies for the Operational Hazards

Following the hazards identification, failures that have been identified are analysed in 2 different ways.

For the internal failures investigated in the first table of annex 1, the recommendations that can be issued concern the development of the different systems composing the GNSS, for which safety objectives and safety requirements are assigned. Recommendations can be issued concerning the training and the possible contingency plans too in case of failure.

For the external events leading to hazards, mitigation means and recommendations are under investigation.

3.2.3.3.1 Internal failures

As said above, safety recommendations are made in this section as a function of the severity levels that have been found for the different hazards.

Recommendations concerning dependability issues will be all the more restrictive that the severity level is high (i.e. near from 1)

According to FHA methodology, failure modes leading to Operational Hazards of severity:

- level 1 will have to be less than extremely improbable (i.e. $1.55.10^{-8}$)
- level 2 will have to be less than extremely remote (probability will be integrated in a next revision of ESARR 4)
- level 3 will have to be less than remote (probability will be integrated in a next revision of ESARR 4)
- level 4 will have to be no more than probable (probability will be integrated in a next revision of ESARR 4)

For each hazard, a more detailed analysis, based on agreed probabilities, must be done to check that assigned target levels are within reach..

For this analysis, the severity levels that have been assigned to the different Hazards shall be reviewed by operational staff in order to be consolidated.

After consolidation, the appropriated requirements must be issued.

Concerning the other mitigation means, contingency plans implementation shall be assessed in order to be sure that in case of GNSS disruption, all the relevant actions will be implemented. This shall be verified at the ATCOs level too.

For GA operating in VFR, as said above, the level of training for the VFR operations must be maintained.

3.2.3.3.2 External events

Mitigation means will have to be implemented to prevent the system from those external events. Here is a description of the events and of possible mitigation means.

3.2.3.3.2.1 Malicious intent

This study is not aimed at analysing malicious intent. This can appear to be a great risk among potential risks to the GNSS signals.

With GNSS as sole service, the resulting effect would be simultaneous loss of GNSS navigation data by all aircraft. If interference is created in a co-ordinated way at several places in the European Core Area, the net effect may be roughly equivalent to a region-wide failure.

3.2.3.3.2.2 Unintentional interference

For this part of the study, we investigate the different signals that are near the GNSS signals frequency as those are likely to interfere if their transmission is out-of-band.

For the approach phase of flight and consequently, at the particular airports surroundings, a particular attention may be addressed concerning the respect of the transmit power and of the band frequency.

For GNSS, the allocated frequency bands are the following:

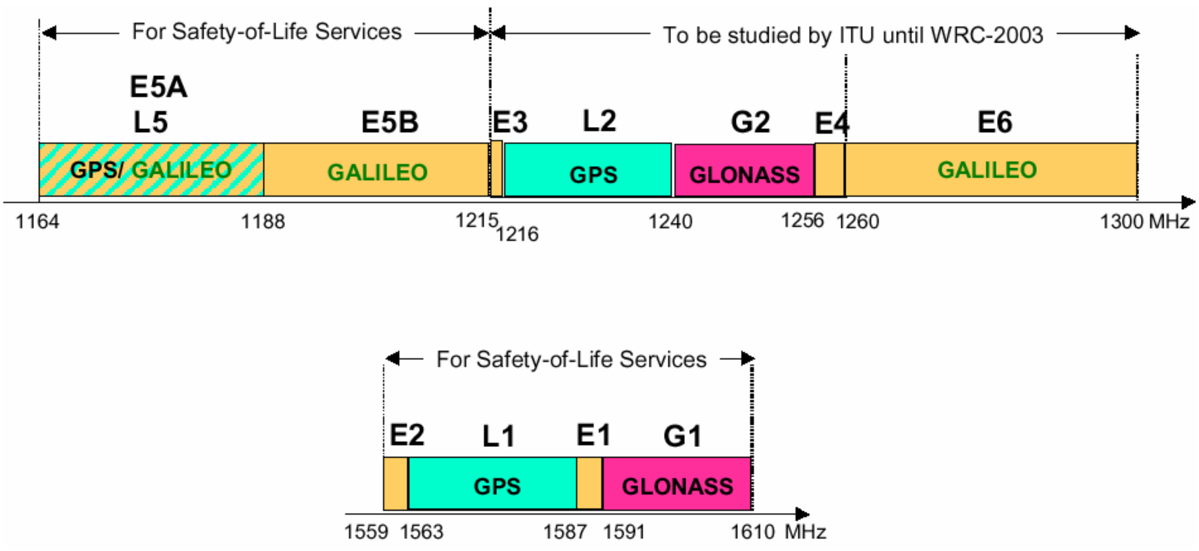

Figure 3.2.3-2: GNSS frequencies

The bands able to interfere with the GNSS allocated frequencies are:

- the band 1555-1559 MHz "satellite signals for cellphone" (from space to earth)

- the band 1610-1610.6 MHz "satellite signals for cellphone" (from earth to space)
- the band 1300-1350 MHz "aeronautical radars"
- the band 960-1215 MHz "aeronautical radionavigation"

Moreover, attention should be paid to the fact that no interference is possible between the different GNSS signals. Verification shall be done that all the recommendations have been issued.

Vulnerability studies are in progress concerning the interferences. Results should be presented to GNSSP WG-B in october 2002.

3.2.3.3.2.3 Ionospheric propagation

The effects of Earth's atmosphere on signals beamed from space can be a significant source of error if it is not compensated at least approximately. A means to correct it is to use the two signal frequencies provided by the satellites: as the refraction effect is inversely proportional to the square of the transmit frequency, the first order refraction can be computed from the difference in time of arrival (higher order terms are exceedingly small). Less accurate correction can also be done considering location, time of day, approximate time within the current solar cycle and line of sight elevation angle.

The effect of this phenomenon shall not be significant until non-precision approach but we will consider it in detail for Cat I/II/III.

At the high solar activity period, three types of resulting phenomena have to be considered: increased Total Electron Content, increased geomagnetic storms and increased scintillation. Attention shall be paid on the worst case at the high solar activity period

3.2.3.3.2.4 Ionospheric scintillation

Concerning ionospheric scintillation, at certain times and locations, this can lead to diminish GNSS signals below receiver thresholds. Then, some satellites signals will be lost with the corresponding reduction in positioning accuracy and in RAIM technique use. The regions where this phenomenon is most severe are the equatorial and auroral regions (between 65° and 72° N and 15° ± 10° N for the northern part of the earth).

For GPS, a great loss of availability had been observed because of this phenomenon, and it is likely to affect also Galileo.

3.2.3.3.3 Resulting recommendations

In term of procedure to implement for the different scenarios or of procedures to apply:

- concerning ionospheric scintillation, if the service is predicted to be interrupted, concerned personnel shall be informed and procedures shall be developed accordingly
- concerning ionospheric propagation, correction that can be done shall be tested for the most stringent required performance (Cat III during peak solar activity period)
- For the signals identified in 3.2.3.3.2.2, attention shall be kept for the emitters situated in the airport surroundings (restrictions for those particular emitters or periodicity of maintenance: *install a monitoring of the maintenance of those emitters* ??). A detailed analysis concerning the possible perturbations and consequent restrictions shall be done.
- All the relevant safety specifications concerning the system dependability shall be implemented following the hazards identification.
- Attention shall be paid on the fact that all the contingency plans are in place in the case of a GNSS failure.
- For GA operating in VFR, as said above, the level of training for the VFR operations must be maintained

- For GA operating in IFR, either an autonomous navigation capability would have to be present in those aircraft (this is likely to be the case for high end GA such as business jets) or the additional ATCO workload implied for guiding them into the VFR airspace should be demonstrated to be manageable.

In the absence of any certainty about the ability of security policy and spectrum management measures to guarantee an interference-free environment, the contingency plans and mitigating measures recommended in case of GNSS service interruptions would also be of relevance for those types of interruption.

3.2.3.4 Total system performance assessment with respect to TLS

The hazards that have been identified can lead - associated with the failure of the mitigation mechanisms - to accidents on which Target Level of Safety have been assigned.

Regarding the table of hazards in 3.2.3.2, the most severe ones have been assigned considering the landing phase. So at this phase, it seems interesting to investigate in some detail the system performance with respect to TLS (keeping in mind that others systems than the GNSS could fail and lead to an accident at the landing phase, so comparison to the TLS will be to have an idea of the possibility to be compliant with Safety Objectives).

The TLS is of 1.5510^{-8} per hour

3.2.3.4.1 Scenarios leading to an accident

A high level Fault Tree is presented hereafter, where the combinations leading to accidents (on which is assigned the TLS) are quantified.

The different hazards we are interested in for this phase are the ones that had a high severity in the table 3.2.3-2, and are presented hereafter:

- Undetected corruption of GNSS navigation data
- Undetected corruption of GBAS data
- Undetected corruption of GNSS data for one a/c
- Total loss of GNSS navigation data
- Total loss of GBAS data
- Total loss of GNSS navigation data for one a/c

Only failures internal to the GNSS system are investigated here.

The other hazards are not investigated in detail as their contribution to an accident in the landing phase in Cat II/III should be non-existent.

For the corruption part, a quick analysis of the failures that will lead to this hazards reveals that it will need a combination of the undetected loss of all the integrity data (Galileo, SBAS and GBAS) at the same time combined to the corruption of the navigation data.
In this case, it seems highly improbable that such an event occurs unless a common failure is conceivable. Future and deeper safety assessment should evaluate the possibility of common causes of failures leading to this hazard.

Resulting hazards investigated are roughly presented in the following figure:

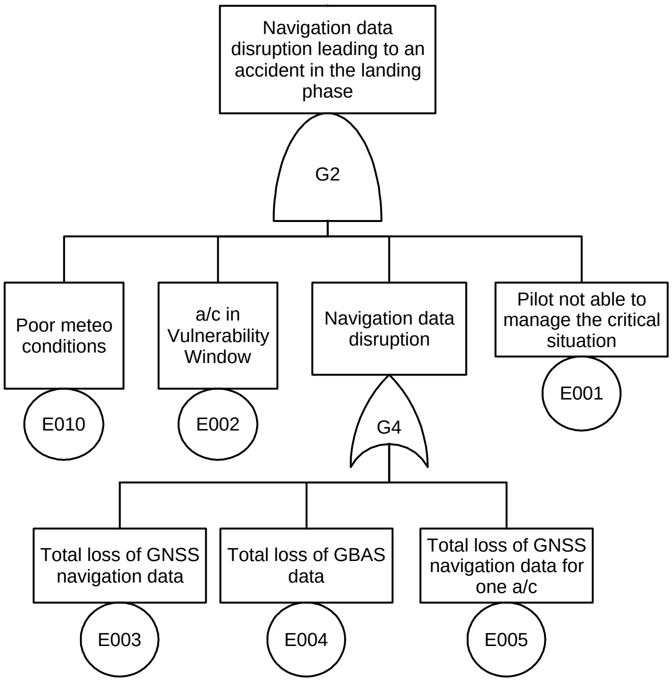

Figure 3.2.3-3: High level presentation of the scenarios leading to a landing accident

We are now going to assess the scenarios identified in figure 3.2.3-3, for the disruption hazards and for the corruption hazards.

3.2.3.4.2 Navigation data disruption (direct effect) scenarios

For each event, we are going to evaluate their probability. The definition of this scenario is the hazard leaded when a disruption of the navigation data provided by GNSS occurs while an aircraft is in the time delay when a missed approach can no longer be entered.

3.2.3.4.2.1 Poor meteorological conditions

Having looked at the different data from different airports in Europe, we assume as a an upper value an occurrence of meteorological conditions of Cat III level of 100 hour per year (approximately 1.1% of the time).

Additionally, for the particular case of the total loss of GNSS navigation data, we have to consider that the bad meteorological conditions can appear on several airports at the same time. The assumption is made that 80% of the time, this will be a mono-airport event affecting 2 landing runways, 15% of the time a multi-airport one (e.g. all Paris or London airports simultaneously) affecting 5 landing runways, and 5% of the time, a multi-cities one (e.g. Amsterdam + Brussels + Dusseldorf + Frankfurt) affecting 10 landing runways. This lead for the GNSS case to multiply the probability of accident by 2x0.8+5x0.15+10x0.05 = 2,85

3.2.3.4.2.2 Aircraft in Vulnerability Window

Waiting for more accurate estimation, we assume for the moment that

- the Vulnerability Window is of 10 seconds,
- The landing rate in Cat III conditions is of 15 landing per hour;

The total vulnerability time will be consequently of 4,17% of the time.

3.2.3.4.2.3 Pilot not able to manage the critical situation

Waiting for more accurate estimation, we assume for the moment that pilot will be unable to manage the critical situation 10% of the time, which is really a worst case analysis as in the last seconds of flight below the decision height, the auto-landing system is designed to be self-sufficient.

3.2.3.4.2.4 Total loss of GNSS navigation data

This failure would mean simultaneous failure of Galileo and of GPS augmented with EGNOS:

- Galileo has a continuity level of 10^{-5} in any 15s (what means a probability of $2{,}4.10^{-3}$ /h);
- GPS augmented with EGNOS has a continuity level of 8.10^{-5} in any 150s (what means a probability of $1{,}92.10^{-3}$ /h)

That means that the probability of a matter of continuity for all the GNSS constellation can be estimated to $4{,}608.10^{-6}$ per hour.

We do not take into account the case when predictable events leading to a general loss of GNSS signals appear (like a solar storm during the high solar activity period) as in those particular cases, as said previously, the concerned persons shall be informed of the situation. We also assume that the other causes of service interruption are independent for the two systems.

3.2.3.4.2.5 Total loss of GBAS data

Making the hypothesis that GBAS will be able to serve Cat III operations, the continuity will be at least 2.10^{-7} in any 15s (Signal in space performance requirement for Cat III operations). That means $4{,}8.10^{-5}$ per hour.

3.2.3.4.2.6 Total loss of GNSS navigation data for one aircraft

We are interested in this paragraph only in the GNSS part of the aircraft navigation receivers. For this estimation, we make the assumption that the loss will have a probability of 10^{-9} /h (estimated to the normal loss of an airborne equipment)

3.2.3.4.2.7 Total scenario probability result

The probability of the scenario is the probability of one of the disruption scenario, combined to the probability of an aircraft to be in the vulnerability window, to the Cat III meteorological conditions and to the inability of a pilot to manage the critical situation.

The result probability that we have found is presented hereafter:

$(4{,}8.10^{-5} + 2{,}85 \times 4{,}608.10^{-6} + 10^{-9}) \times 0.011 \times 0.0417 \times 0.1 = 2{,}8.10^{-9}$ /h

which is four orders of magnitude better than the TLS.

3.2.4 General recommendations for safety regulation

Below are given some general recommendations to facilitate the approval/certification of GNSS, taking into account the operational context, the main hazards and the mitigating measures described in the previous section. These recommendations provide guidelines as far as the following questions are concerned:

- What is approval/certification?
- How to perform approval/certification?
- Who should perform approval/certification?

3.2.4.1 What is approval/certification ?

In the GOBAN Interim Report, we have described the different steps of an approval/certification process, together with its associated terminology. We have seen that the term “certification” refers to a very stringent process, which is actually applied for airborne equipment.

For the infrastructure outside the aircraft, such as the ground systems and networks, the applied process does not meet the required characteristics to be called “certification”.

Whereas it makes sense to say that an aircraft transponder has been certified, it is not possible to certify the GNSS concept in general. What is possible is to state that some local authority, most frequently at national level, has approved a specific operational use of GNSS in a specific context.

For instance, some day, we could read a statement from a national air navigation regulator, in which it would be written that the combined use of Galileo and GPS augmented with GBAS, in a given configuration, has been approved for performing Category I approaches at a given airport.

Whereas the term “certification” applies to a given component of a system (usually airborne), the term “approval” applies to the use of a specific system to meet a specific operational need. Therefore, as far as GNSS is concerned, we should avoid the term “certification” and prefer the term “approval”.

[R3-11] The use of GNSS shall be approved based on a contextual basis, depending on the environment of the systems and procedures to be approved. The term “certification”, which is appropriate for aircraft equipment, should be avoided for GNSS, and the term “approval” should be preferred.

3.2.4.2 How to perform approval/certification?

In order to approve the use of GNSS in a specific context, we need to know the requirements that will serve as a baseline for determining whether the use of GNSS can be approved or not. These requirements, expressed in terms of Safety, Performance, Interoperability, Quality of Service, must be defined as end-to-end requirements.

[R3-12] End-to-end requirements should be defined in order for an authority to approve or not the use of GNSS for a given context, and a methodology should be followed for producing harmonised requirements.

Below are given some elements on the methodology that could be applied to define harmonised end-to-end requirements.

3.2.4.2.1 End-to-end process purpose

For classic technologies, ICAO has standards in order to ensure world-wide interoperability between any aircraft and any ATS provider under the responsibility of the contracting States. The use of more interactive new systems between ATS providers and aircraft improves the service provided to aircraft, but also increases system complexity. Because of this increased complexity, ATS supported by data information (such as GNSS) requires a high degree of co-ordination among the stakeholders and approval authorities to ensure compatibility between operator use and ATS provision.

This link between the ground and airborne segments requires not only to ensure that “systems perform their intended functions” but also that “systems adequately implement the services required for the intended operations”.

Therefore, a new system which provides services based on links between the aircraft and the ATS can be approved only if the three approvals/certifications (aircraft certification, operator operational approval and ATS system operational approval) have been granted. Those separate and distinct approvals collectively define the concept of “end-to-end Approval”.

This conceptual end-to-end approval will be based on end-to-end requirements since the increased interaction between ATS and aircraft systems will have to be specified through specific safety, performance and interoperability (and Quality of Service) requirements in order to ensure that the overall system performs safely its intended function.

3.2.4.2.2 End-to-end process phases

End-to-end approval process includes the following major phases:

- Co-ordinated requirements determination,
- Requirements validation and harmonisation,
- Requirements implementation,
- Co-ordinated approval/certification processes,

There are many participating stakeholders and their participation has to be co-ordinated.

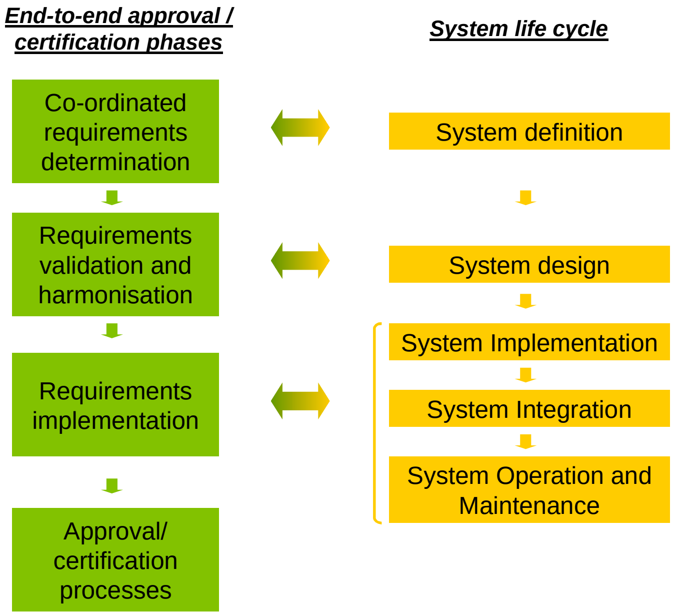

Figure 5: End-to-End Approval Process

The EUROCAE ED78A ("Guideline for Approval of ATS services based on data communication") document provides guidance on how to determine co-ordinated safety, performance, interoperability and operational requirements. The proposed process is technology independent and can therefore be applied to any project that implies aircraft and ground systems.

The following information is obtained using this proposed process:

- OSED (Operational Services and Environment Definition) : provides the description of the operational services and the operational environment. The necessary standards (MASPS, MOPS, …) and regulation issues are taken into account. It is the base for the other documents,
- OSA (Operational Safety Assessment) : process through which the safety requirements are provided,
- OPA (Operational Performance Assessment) : process through which the performance requirements are provided,
- IA (Interoperability Assessment) : process through which the interoperability requirements are provided.

As a result, the Safety, Performance, Interoperability and Operational requirements are allocated to each segment (aircraft, ground segment , others, such as space segment) and provided in the SPR (Safety and Performance Requirements) and INTEROP documents, so that each stakeholder has the list of applicable requirements to be implemented.

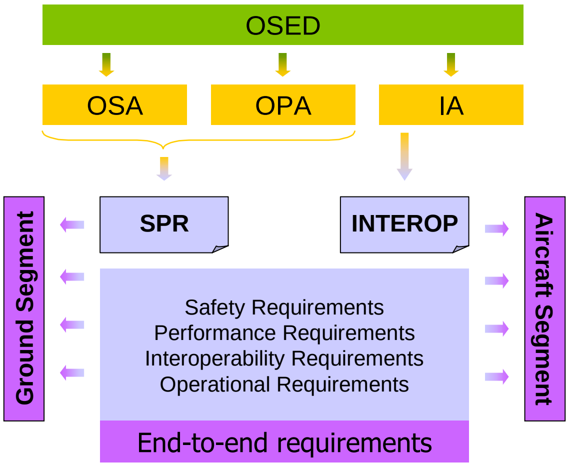

Figure 6: EUROCAE ED78A Methodology to Determine Co-ordinated Requirements

The end-to-end process facilitates the certification / approval because in the process both the approval/harmonisation entities and the stakeholders are involved.

Once the requirements are identified for each segment, they are validated as follows:

- Aircraft Segment: safety, performance and interoperability requirements are validated by the JAA. The requirements acceptance is done through a TGL (Temporary Guidance Leaflet), which provides information about what has to be done at the Aircraft level,
- Ground & Space Segments: in Europe, the safety requirements are harmonised by the SRC (Safety Regulation Commission, EUROCONTROL). The Performance, Interoperability and Quality of Service (QoS) requirements should be reviewed by the new EUROCONTROL Regulatory Commission (RC), since without a specific certification authority, there is lack today at the European level for the provision of an harmonised view on interoperability and performance requirements. The use of GNSS can be supposed to be part of the ground segment and therefore subject to the same process.

3.2.4.3 Who should perform approval/certification ?

In the GOBAN interim report, we mentioned that each State was responsible for the approval/certification of ATS services and aircraft certification/operational approval (if registered in that State).

However, even if the approval responsibility remains at national level, the requirements against which the approval is conducted can be harmonised, as described in the previous paragraph.

In order to facilitate this approval cycle, we provide the following recommendations:

[R3-13] End-to-end requirements should be harmonised by a specific entity (cf. role of the EUROCONTROL SRC/SRU for ATM).

[R3-14] A GNSS certification/approval authority could be created, mandated to define the safety policy to be applied in each specific part of the GNSS system.

3.2.4.4 Safety regulation for Commercial Air Transport

In order to ensure the safety of Commercial Air Transport, we will now list a few recommendations based on a worst case situation, such as the sudden and total disruption of GNSS operating as sole service, while poor meteorological conditions are present on a major TMA.

In such a situation, all aircraft may have to be re-routed safely to airports where visibility is better, and they should be able to navigate using inertial data only, the precision of which will typically decrease following a linear decay of 2 nautical miles per hour.

Consequently, we make the following recommendations:

[R3-15] MET forecasts and proficiency of MET data on a regional level shall be developed in order to help mitigate the effects of a GNSS deficiency.

[R3-16] It shall be demonstrated through realistic simulations directly involving the concerned air traffic controllers, that in the case of a sudden and total GNSS disruption, aircraft will be able to rely on their inertial navigation data during the time needed for the air traffic control centres to keep them out of the concerned TMA, and/or to highly increase separation minima for aircraft already in that TMA. Safety cases shall be performed for every individual TMA beyond a certain size.

[R3-17] Studies shall demonstrate that in case of GNSS disruption occurring after the Missed Approach Point (MAPt: missed approach no more possible after this point), aircraft can operate a safe landing, using only its independent navigation data.

[R3-18] Pilots and controllers shall be properly trained to react adequately when such contingency procedures are activated.

[R3-19] Pilots and controllers shall be able to detect a drift of the GNSS provided position, or any other malfunction of the GNSS system.

[R3-20] Studies shall be carried out to define the most efficient way to inform pilots and controllers in the case of a GNSS drift detected by the avionics.

[R3-21] An appropriate incident reporting shall be designed for pilots and controllers to provide feedback on the use of GNSS.

3.2.4.5 Safety regulation for General Aviation

As far as General Aviation is concerned, two modes of operation exist: IFR and VFR.

For IFR operations, the situation is similar to Commercial Air Transport, and the recommendations provided in the previous paragraph also apply.

For VFR operations, the situation is quite different, since any navigation equipment in the cockpit can only be considered to be an aid to visual navigation. What we need to ensure safety is to avoid any GNSS complacency. Consequently:

[R3-22] General aviation pilots shall develop and maintain their capacity to navigate without GNSS, through appropriate initial and continuous training and a periodic verification of their ability should become part of the pilot license.

3.2.4.6 Contingency plans

As mentioned earlier, in order for GNSS to be used as sole service, safety must be guaranteed thanks to the definition of contingency plans, whose purpose is to mitigate the effects of a GNSS failure.

First, we will provide general recommendations for the setting of contingency plans.

These recommendations, though not being GNSS specific, are highly relevant for implementing GNSS sole service.

Then, we will present some guidance as far as contingency plans for navigation are concerned.

Finally, we will address contingency plans related to the use of GNSS as a time synchronisation system.

3.2.4.6.1 General recommendations for the setting of contingency plans

3.2.4.6.1.1 Context and responsibilities

In 1984, the ICAO Council approved the Assembly Resolution A23-12, which emphasised the importance of properly defining contingency plans in order to mitigate the effects of any system failure. Since then, there have been numerous changes to the European airspace design and nature of traffic. For instance, the operational inception of the Central Flow Management Unit (CFMU) that modified the way of allocating the slots, and the flexible use of airspace have resulted in an increase of the traffic capacity. An immediate consequence was the need to improve the preparation and planning of contingency. In 1997, the EATCHIP Project Board agreed the need for co-operation on bilateral and/or sub-regional contingency planning as well as the definition of CIP objectives on that matter. This intention resulted in the definition of guidelines to help States planning and optimising the provision of air traffic services in the event of a disruption of any system, in order to maximise business continuity to the extent possible while maintaining levels of safety.

Following a similar logic, we will now describe a few recommendations, which are not specific to GNSS, but which are also applicable to the definition of contingency plans to mitigate GNSS failures.

First, in order to set the context, we shall remind the different responsibilities as far as contingency plans are concerned:

- The strategic planning is to be defined by ATS providers, and reviewed by the national regulators, which are responsible for approving the safety case presented with the plans.
- In airspace where the provision of ATS has been delegated to a unit from another State, the responsibility remains with the State to which responsibility has been delegated, unless the delegating State temporarily terminates the agreement.
- At airports where ATS is ensured by entities other than the national ATS provider, it is still the national ATS provider which is responsible for the definition of contingency plans.

3.2.4.6.1.2 Recommendations

The effect of a service disruption upon international traffic flows and on the provision of ATS in adjacent airspace can, depending on duration and circumstances, be substantial, therefore:

[R3-23] Contingency plans should be prepared, tested and promulgated in consultation with adjacent States and ICAO, at regional level.

[R3-24] In the planning definition phase, it is important that airspace users provide input to potential solutions.

[R3-25] It is recommended to establish Regional High Level Contingency Planning Groups, composed of experts and users of the related area.

[R3-26] In view of the complexity of air traffic flow management and its sensitivity to even local ATS outages, it is recommended to involve CFMU (or its equivalent outside Europe) in the consultation process for the definition of contingency plans.

[R3-27] As service interruptions can affect both civil and military users, military authorities should be kept informed of the contingency planning arrangements and, in conformity with applicable national legislation, should be consulted in the planning phase.

[R3-28] Studies should assess whether it is possible to use military ATC facilities to help mitigating outages.

3.2.4.6.2 Navigation-related contingency plans

3.2.4.6.2.1 Required contingency plans

Procedures shall be implemented and checked in order to operate safely with GNSS used as sole service:

[R3-29] Contingency plans shall be defined, taking into account all combinations of failures and context, by international teams consisting of GNSS technical and operational experts

In the GOBAN interim report we have established a list of failure modes that would have to be investigated, and of the associated operational hazards. More investigation has to be done on the probabilities of the different scenarios, and the severity of those scenarios will have to be assessed with operational staff in order to define precisely the contingency plans to apply.

[R3-30] A uniform methodology shall be adopted and consistently applied in Europe for building up and validating contingency plans according to a common framework of identified failure modes, operational hazards and their probability and severity.

For instance, a contingency plan will be activated should a GNSS disruption occur in a multi-airport environment. This contingency plan will take into account that the weather conditions may be bad, and that without GNSS data, the accuracy of INS/IRS navigation data degrades by up to two nautical miles per hour. The starting point of the contingency plan will have to be assessed. It may be that below 2 minutes, a missed approach can be triggered for the next aircraft in approach, and that after 2 minutes, in the case of a multi-airport environment, a different contingency plan has to be activated, the nominal escape lane becoming too narrow for a safe missed approach to be performed by aircraft with an already reduced navigation precision.

[R3-31] When the complete cascade of contingency plans has been defined, each with its triggering event(s), further studies should be conducted in all airspace (especially in densest traffic areas) to fine tune the timing for triggering each contingency plan and make any additional adaptations to local conditions.

3.2.4.6.3 Initial recommendations for contingency plans implementation

In order to initiate a reflection on specific contingency plans, we will now present two safety related cases, highlighting the directions which further studies should investigate in the design of procedures.

It should be stressed that, while the two cases addressed below are identified as worst cases, their probability of occurrence is likely to be negligible. In order to assess this probability with significant precision, studies should be launched, based on statistical meteorological information. When trying to make a first assessment, we discovered that such information is not readily available today: only a patchwork of heterogeneously managed information concerning individual airports exist.

[R3-32] A data-base should be created and filled, containing detailed statistical information on meteorological conditions (especially the occurrence of CAT II & CAT III conditions) for all major TMA and airports in Europe. Such a project could be led by Eurocontrol.

3.2.4.6.3.1 Landing Phase

For the particular case of the landing phase (in the seconds following the GNSS disruption), when performing a missed approach while the GNSS data are no more provided, the probability of an airprox involving missed approach and take-off is higher.

[R3-33] For the landing phase, missed approach trajectories shall be checked in order to be sure that the GNSS disruption event will not cause any operational hazard.

[R3-34] Missed approach procedures may be re-designed in order to avoid controller's overload in case of loss of GNSS for all aircraft in the local area.

This situation is represented in the following scheme:

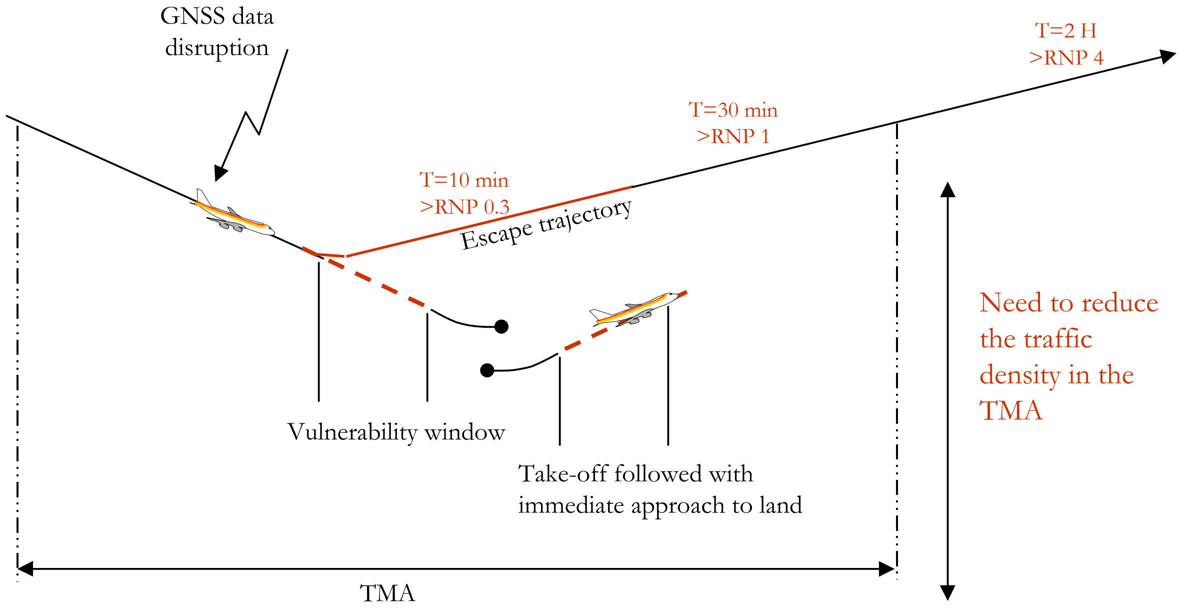

Figure 7: Missed Approach

3.2.4.6.3.2 TMA

Procedures will have to take into account that in 2015, aircraft in TMA will have to be RNP 0.3.

In case of a GNSS loss, aircraft will have to rely on inertial data, and the accuracy of the aircraft navigation data will decrease following a linear decay of up to 2 nautical miles per hour.

[R3-35] The contingency plan designed for the reallocation of aircraft to other airports, shall take into account that after 9 minutes, RNP 0.3 may no more be met.

[R3-36] Attention shall be paid to the fact that there's a possibility to be in a multi-airport (all the airports of a city) or multi-cities (e.g. Amsterdam + Brussels + Düsseldorf + Frankfurt) Cat III weather conditions.

Some predictable phenomena can cause a GNSS partial disruption. Those phenomena are for instance ionospheric scintillation, ionospheric propagation or solar activity.

[R3-37] Procedures should be designed so as to establish all required restrictions in the time-frame where GNSS is known to be more vulnerable due to predictable phenomena.

3.2.4.6.4 Indirect GNSS dependencies contingency plans

3.2.4.6.4.1 Communications dependencies

The EUROCONTROL Navigation Strategy identifies as communication dependencies the following needs for data link services:

- For routine exchange of necessary information between air-ground and ground-ground elements of integrated Navigation and Surveillance systems

- Air-to-air data links to support emerging ground – or satellite-based augmentation systems for satellite navigation so as to serve the navigation, the surveillance and the aeronautical information service function

The above dependencies show that the Navigation and Surveillance systems depend on Communication systems. Then, except whether it is intended to use GNSS-derived time for aeronautical network synchronisation – what we have recommended not to do - a GNSS failure should not compromise the safety of communication systems.

Time synchronisation being a stringent criterion mainly for air-ground aeronautical communication infrastructure, the use of GNSS-derived time synchronisation creates a potential risk of C, N and S degradation in case of GNSS failure.

For commercial aviation, in case of service interruption for aircraft executing CAT II/III approach at airports in Europe with published CAT II/III procedures and infrastructure, the operational challenge for ATC is to bring safely all aircraft down to the ground as soon as possible. As mitigating measures particularly related to communication, aircraft on final approach noting the loss of GNSS signal will inform approach or aerodrome control that they are executing a missed approach (or continuing visually if possible) due to equipment problems. Aircraft not yet on final, and noticing the problem, will report this to ATC, but not en-mass, clogging the VHF channel. The first one to report will be heard by others on the same frequency and other pilots shall not repeat the information.

[R3-38] In case of loss of GNSS service, the usefulness of an automatic signal emitted from the aircraft should be investigated in order to overcome potential problems.

[R3-39] In terms of communication, technical considerations for contingency plans should address:

- Air-Ground Communication
  - Available frequencies – possible interference
  - Remote control
- Ground/Ground Voice Communication
  - Telephone and Intercom communication (ensure that sufficient telephones are available including telephone requirements for testing at operational and other positions)
- Ground/Ground Data Communication
  - AFTN / CIDIN
  - OLDI connections
  - Printers/Strip printers and respective connections

Particular care should be taken about spectrum management so as to ensure that future 3G aviation communications RF signals will not interfere with GNSS.

3.2.4.6.4.2 Surveillance dependencies

[R3-40] In terms of surveillance, technical considerations for contingency plans should address:

- Radar infrastructure in terms of radar availability
- Radar data sharing
- Radar coverage requirements

The following section aims at addressing elements of radar coverage requirements to scope with the use of ADS in case of GNSS.

The ECAC Surveillance Strategy indicates that in the period up to 2015, a “sole means” ADS surveillance implementation is not expected.

The ECAC Surveillance Strategy foresees that:

- In high-density airspace, ADS-B techniques and technologies will mainly be used from 2010 onwards for co-operative separation assurance (air-to-air surveillance). Primary Surveillance Radar (PSR) will be maintained for major TMAs to support a strategic safety element for basic surveillance. From 2005, Monopulse Secondary Surveillance Radar (MSSR) systems will be phased out and replaced by Mode S Elementary Surveillance systems so as to provide co-operative independent surveillance.
- In medium density airspace:
  - There is neither a mandate for Independent Surveillance (PSR) in medium density airspace, nor a necessity to implement Mode S Elementary Surveillance as a ground infrastructure (due to RF pollution problems).
  - For basic surveillance, overall surveillance coverage may be extended or improved through the use of ADS-B techniques in areas where it is impractical or uneconomic to provide a conventional MSSR infrastructure. Widespread use of ADS-B could potentially facilitate the removal of older SSR equipment leaving a basic single coverage MSSR ground infrastructure overlaid, for safety purposes, with an ADS-B system. ADS-B techniques could be used as well, from about 2007 onwards, for Enhanced Surveillance (for Air Derived Data (ADD)) and for Intent based Surveillance.
  - Co-operative Separation Assurance would be required, as well as a radar structure TIS service to provide traffic situational awareness to all aircraft
- In low-density airspace (oceanic regions and continental regions where basic surveillance is limited or non existent), up to 2005, as basic surveillance, ADS-C using SATCOM will be used in support of procedural separations so as to improve the safety of the system. From 2005, ADS-B will be used with a high ADS-B equipage rate required, possibly with MSSR to provide basic surveillance (Dependent surveillance sole mean). From 2007, for Intent based Surveillance, infrequent Flight Plan intent would be more appropriately provided by ADS-C, but possibly by ADS-B systems too. It is not envisaged that Mode S EHS would be used to provide this service. Co-operative Separation Assurance will provide full operational benefits.

According to ADSP ICAO, the ADS-B application will be capable of providing a warning to pilot and controller whenever the navigation accuracy is degraded below that required to operate in the airspace, as this will affect the application of separation.

In a mixed ADS-B/radar surveillance environment, the source of surveillance data should be readily apparent to the controller.

In case of a total GNSS disruption, aircraft will have to rely on inertial data. As a result of this degradation, accuracy will slowly degrade following a linear decay of 2 nautical miles per hour (taking the worst degradation). As a result to this decay, RNP 0.3 would be kept for about 10 minutes (RNP 1 for at least half an hour). In that case, inertial data would become the position input to ADS-based surveillance.

The rapid degradation of GNSS derived position accuracy – a consequence of the degradation of navigation performance- would require immediate measures to be taken to stop using ADS-based surveillance triggering a back-up surveillance mean based on the PSSR infrastructure. Those measures should be triggered more or less urgently after receipt of ADS-B degradation warning.

[R3-41] Within busy/major TMAs - that have a RNP < 1 requirement and that benefit of a PSSR coverage surveillance – mitigating measures should be triggered relatively rapidly upon receipt of ADS-B degradation warning.

[R3-42] For dense en-route airspace - that have a RNP 1 RNAV requirement and that benefit of a PSSR coverage surveillance – mitigating measures should be triggered less urgently than in busy TMAs.

[R3-43] Medium density airspace should benefit from a radar coverage as the back-up to ADS-based surveillance. In low-density airspace, a possible back-up to ADS-based surveillance would be procedural separations.

In case of service interruption for aircraft executing CAT II/III approach at airports in Europe, surveillance is needed to get aircraft to a point from which it can be lined up on the final approach or to feed the aircraft again into the en route airspace, irrespective of how the aircraft is navigating. If there is no signal to make a GNSS approach, another and/or a back up procedure will be executed.

Under current procedures, a majority of aircraft could require vectoring from air traffic control in order to remain safely separated from each other as they are directed away from the interference area.

Missed approach procedures may have to be redesigned so as to minimise interference, and reduce the controller's workload. As all aircraft executing a missed approach under Cat II/III conditions would remain autonomously RNP 0.3 capable for about 10 minutes (then RNP1 capable for at least 30 minutes), the main potential source of problems comes from lesser equipped aircraft operating under Cat I condition in a busy TMA.

[R3-44] To address a potential partial GNSS failure, we recommend the NAV-SUR strategy to make the best use of the diversity of data sources offered by the GNSS envisaged configuration, allowing ADS-based not to be dependent from a single source of surveillance data, increasing safety.

The high number of satellites composing the Galileo constellation should allow an availability of ADS-based surveillance that would allow reducing surveillance by means of radar.

4 OVERALL TRANSITION PLAN

In this chapter, we assume that the technical and organisational recommendations made in previous chapters are taken up for implementation by the various parties involved, and we provide a global roadmap towards GNSS Sole Service, by identifying their individual duration, their interdependencies, and any additional lead times required in the whole process.

The result is a global view of the transition scenario to GNSS, including an estimate of the implementation timeframe for each major step.

In order to take into account the various scheduling uncertainties that affect different aspects of the transition scenario, we have attached a “slippage factor” to each time scale proposed, varying from 0 (no delay is currently foreseen) to 3 (up to 3 years of delay is not unlikely).

The assumptions made in relation to the different aspects of that transition plan have been compared to the roadmap for strategic actions contained in the “Navigation Strategy for ECAC” published by Eurocontrol (document NAV.ET1.ST16-001 Edition 2.1 dated 15 March 1999) and hereafter denoted as the “ECAC Roadmap”.

The GOBAN Team has also taken into account the latest information available to its experts at the time when this report was written (end of January – beginning of February 2003).

4.1 GNSS infrastructure deployment phases

4.1.1 GNSS-2 constellations

4.1.1.1 GPS Block II/F

The deployment of GPS Block II/F was until recently planned to take place between 2008 and 2011. However, it was officially announced (at an RTCA meeting in January 2003) that the new target date for the completion of GPS II/F deployment is now 2015. As a consequence, a complete dual frequency constellation would not be available before that date (although it is still planned that the GPS constellation replacement policy willl include such dual frequency satellites in operation starting in 2008).

4.1.1.2 Galileo

The development of Galileo is under way, and the next ITU Conference (WTC 2003) is expected to consolidate the frequency assignments for the Galileo signal-in-space.

The deployment of Galileo is still officially planned to take place between 2006 (In-Orbit Validation phase with 4 satellites in different orbital planes) and 2008 (Full Operational Capacity with 27 satellites), however it seems prudent to include into this roadmap a slippage factor of 1 to 2 years, as the Joint Undertaking (public-private entity in charge of conducting the production and launch of both the constellation and the ground mission control infrastructure) is not yet in place. (The ECAC Roadmap did not include any schedule for Galileo.) A major consequence of a slippage of the IOV phase would be that the frequency assignment obtained at WTC 2000 could be challenged at WTC 2006. Some interim deployment should then be organised in time to retain the assignment.

4.1.1.3 Glonass

The evolution of Glonass at the 2010-2015 time horizon is uncertain, therefore the Russian constellation is not in our GNSS-2 scenario. The latest event has been the launch of 3 Glonass-M satellites in December 2003, thus maintaining a dozen of satellites in operation. The long term suitability of Glonass for civilian operations remains unclear (Glonass has not been included into the ECAC Roadmap either.)

4.1.2 Regional overlays to GPS

4.1.2.1 EGNOS

In Europe and Africa, the EGNOS testbed is in place, as an integrity monitoring supplement to the current GPS providing up to the NPV2 level of service. An operational service could be feasible by 2006 (this is consistent with the 2005 date found in the ECAC roadmap.) Extensions of EGNOS towards the Mid-East and beyond are also envisaged.

The main factors of uncertainties regarding the integration of EGNOS with Galileo have been discussed at chapter 2, and a model for the functional distribution of legal responsibilities between the two entities has been discussed at chapter 3.

It should be noted that the rationale for choosing a scenario depends also on institutional issues rather than merely technical ones: if no agreement is reached amongst the providers of primary signals regarding responsibility and liability issues, then maintaining a GPS-related EGNOS service could be the sole way of providing the required level of GPS signal integrity guarantee to European users.

In any case, the eventual decommissioning of EGNOS should not take place before several years of combined operation of Galileo and GPS have demonstrated the operational validity of the GNSS2-without-SBAS scenario, that is, not before 2012-2013 at the earliest, supposing that enough GPS Block II/F have been put in operation by then ; this is why we have not considered the suppression of the EGNOS service as a potential benefit of GNSS-2 and we have not introduced it in this roadmap.

4.1.2.2 WAAS and MSAS

In Northern America, the current GPS and its WAAS supplement would also provide for an NPV2 level of operational service in 2004, with an extension to Latin America and also to Western Africa in subsequent years.

In Eastern Asia, the MSAS supplement to GPS should also be operational in the same time frame, with an extension foreseen to Australia and New Zealand. In the medium term, it may be expected that an almost complete coverage of the world (with a good deal of overlap) by regional integrity service providers would be available.

4.1.3 GBAS Cat I

GBAS Cat I in ILS-like operations is expected to be available for operational use in 2006 in Europe, and a progressive deployment (starting at non-ILS airports or airports where ILS service is difficult to maintain) could be completed by 2010.

The ECAC Roadmap foresees the progressive introduction of GBAS Cat I in the 2005-2012 time interval, with all ILS Cat I being decommissioned by 2014. In our scenario, GNSS-2 would have replaced ILS Cat I by 2012.

In the USA, the potential deployment of Cat I (called LAAS) is also foreseen to start in 2006, however, no plan exists for a complete decommissioning of ILS Cat I in the USA. According to a recent announcement, the FAA intends to maintain a number of ILS for security reasons.

4.1.4 GBAS Cat II/III

GBAS Cat II/III (also for conducting ILS-like approaches) could be made available for operational use in 2009-2010, as 3-4 years of validation will be necessary after the standards are published, and 3 years are necessary to elaborate and publish the relevant international standards (cf. the section on standardisation and certification).

The ECAC Roadmap also indicates the 2009-2012 time range for the deployment of GBAS Cat II//III. However, no plan exists for a complete decommissioning of ILS Cat II/III in the USA (the FAA intends to maintain those ILS for security reasons).

The following table is a synthesis of the preceding assumptions on the operational deployment of the different elements of the GNSS infrastructure :

Years	<03	03	04	05	06	07	08	09	10	11	12	13	14	15	>15
GNSS-2 constellations															
Galileo IOV															
Galileo FOC															
First GPS Block II/F															
Full GPS Block II/F															
Regional augmentations															
SBAS testbed															
EGNOS operational															
Local augmentations															
LAAS operational															
EUR GBAS Cat I initial															
USA GBAS Cat I initial															
EUR GBAS Cat I final															
GBAS Cat II/III initial															
GBAS Cat II/III final															

Table 2: Assumptions for Operational Deployment of GNSS elements

4.2 Standardisation and certification processes

The successive steps towards the procurement and deployment of GNSS equipment and systems are:

- the publication of international standards (ICAO SARPs for the characterisation of the different types of GNSS signals-in-Space)
- the publication of industry standards (Eurocae/RTCA MASPs and MOPS) that are consistent with and supplement the SARPs
- the certification of equipment against applicable airworthiness requirements (as defined by JAR and FAR codes)
- the validation of signal-providing systems at Operational Requirement Reviews (ORR)

In practice, SARPS, MOPS and equipment prototypes are all developed in parallel, and become available roughly at the same time.

Putting in place a type approval mechanism for an aircraft equipment (or a type/unit approval mechanism for ground equipment) before the production of operational systems can begin, may take up to one additional year once a reference prototype has been built.

For signal-providing systems, the time required to go from the FQR stage (Factory Quality Review, or system verification) to the ORR stage is estimated as one year.

Regarding the different elements of the GNSS operational chain, the current situation is as follows:

- GPS SARPs have been published several years ago, and GBAS Cat I SARPs have been published in November 2002, while GBAS Cat II/III SARPs are still under development and are not expected before 2005-2006
- The publication of Galileo SARPs has recently been postponed to 2006 (announcement made at the Eurocae WG 62 Meeting of February 2003)
- The Eurocae GBAS Cat I specifications (developed by Eurocae WG-28) are also available as:
  - ED-95 for MASPS
  - ED-88A for the Multi-Mode Receiver (MMR MOPS)
  - ED-114 for the ground subsystem (Ground GBAS MOPS)
- Equivalent RTCA specifications exist for the US-designed LAAS system ; for both Eurocae and RTCA specifications only GPS sources are required (Glonass, SBAS or pseudolite sources may be optionally considered, but there is not reference to Galileo for the time being)
- Airworthiness-certified GPS+GBAS receivers are being made available for pre-operational validation purposes (the first "red label" MMR are now available)
- MOPS for multi-frequency GNSS-2 MMR receivers should be available at around the same time as Galileo SARPS (2006)

Years	<03	03	04	05	06	07	08	09	10	11	12	13	14	15	>15
GPS SARPs	■														
SBAS SARPs	■														
GBAS Cat I SARPs	■														
GBAS Cat I MMR		■													
Galileo SARPs					■										
GBAS Cat II/III SARPs				■	■										
GNSS-2 MMR MOPS					■	■									
EGNOS Validated					■										
Galileo Validated								■	■						
GBAS II/III Validated							■								

Table 3: Standardisation and Certification Process Status

4.3 Validation of ATM systems and procedures

In parallel with the development and validation of the GNSS infrastructure, a number of other stages have to be passed on the ATM side, regarding the safety validation of services and the publication of procedures:

- The publication of PANS-OPS documents describing the procedures to be put in place when integrating the new system into operational Air Traffic Services,
- the definition of a comprehensive generic Safety Assessment encompassing the Total System, for relevant scenarios of operational use of GNSS as the sole navigation service relied upon by ATS providers and aircraft operators (in the long term, that could evolve towards the implementation of a formal certification process for all ATM/CNS systems, equivalent to the JAR-FAR system)

Conducting a generic Safety Assessment for the use of a new system in a given operational context (including such material as guidelines for the conduction of site approval and/or system operation approval processes) may take 3 to 5 years (including recourse to a variety of means such as large scale realistic simulations and pre-operational trials).

The operational use of a service may be constrained to local specificity requiring additional safety investigations, that may lead to additional restrictions (to be approved by the local safety regulator) before a specific implementation of GNSS-based procedures can be declared operational in a given portion of airspace.

Since such additional investigations and restrictions are a local issue, they are not included into this roadmap, but merely factored in as a 2 year slippage factor.

Our assessment of the current situation is as follows:

PANS-OPS Criteria for Cat I as ILS-equivalent OPC/13 operations have been published in October 2002

Eurocontrol has completed the definition of the first part of the GBAS Cat I Safety Assessment (Functional Hazard Analysis) in 2002, and the subsequent steps (the PSSA, that is the quantification of risks against the TLS, then the operational validation roundup) should take about 3 years, and be completed at the beginning of 2006; this is done for the current L1 frequency GPS.

On this basis, the development of similar material for Galileo+GPS and for GBAS Cat II/III may take 5 to 6 years; for providing an estimate, we have aligned the availability of PANS-OPS criteria with the availability of SARPs, as was achieved for GBAS Cat I.

At the level of overall navigation procedures in Europe, it should be noted that, according to the ECAC Roadmap, RNP1 RNAV and 4D RNAV are expected to be mandated for en route in 2010, as well as RNP RNAV in TMA. This target date is compatible with the provision of GNSS-based RNAV in Europe (for both en route and TMA).

Years	<03	03	04	05	06	07	08	09	10	11	12	13	14	15	>15
GBAS Cat I PANS-OPS															
GBAS Cat I Safety Case															
GNSS-2 PANS-OPS															
GNSS-2 Safety Case															
GBAS Cat III PANS-OPS															
GBAS Cat III Safety Case															

Table 4: Overall Navigation Procedures

4.4 Institutional arrangements and mandates

In this section we look at the intermediate steps to be taken in relation to responsibility and liability issues, and how equipment mandates should be scheduled.

For each equipment mandate, we provide for a 4-5 years lead time between the publication of the mandate and the entry into force of the mandate in relation to the existing fleet (based on the maintenance cycle of aircraft) and we make the same assumption for decommissioning mandates (although an 2-3 years increase in the lead time is not unlikely in those cases).

The proposed model for the progressive development of a comprehensive legal and regulatory framework is described in section 3.1, we summarise here the key steps of the approach:

- Adoption of a GNSS Contractual Framework at ICAO,

- Negotiation of inter-regional agreements amongst global/regional GNSS signal providers,
- Adoption of an EU regulation implementing the ICAO Framework,
- Publication of European service standards for GNSS (detailed technical descriptions of the various service guarantees)

The following table summarises the different steps foreseen, and their expected impact on fleet equipment and the installation/decommissioning of ground systems ; (this part of the roadmap is certainly the most affected by non-technical factors and the most likely to drift due to policy uncertainties and political concerns):

Years	<03	03	04	05	06	07	08	09	10	11	12	13	14	15	>15
ICAO GNSS Framework			■												
Inter-regional agreement					■	■	■								
European Service Standards					■	■									
Contracts with GNSS entity							■	■							
GNSS-2 MMR Mandate								■	■						
Mandate for GNSS Sole Service									■						
Cat I ILS decommissioning mandate							■	■							
VOR decommissioning mandate					■	■									
DME decommissioning mandate									■	■				■	
Cat II/III ILS decommissioning															■

Table 5: Institutional Arrangements and Mandates

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