

APPENDIX A

COUPLED GNSS/INS OPTIONS

1. CAPABILITIES

1.1 With classical systems, the aircraft operational capability for a given procedure is directly linked to the available ground aids (provided the aircraft has the necessary level of equipage). Aircraft-based augmentation systems (ABAS), including hybrid GNSS/INS can provide the aircraft with improved navigation system capabilities when compared with what could be achieved with the available ground nav aids or space signals alone.

1.2 This presents a problem to air traffic service (ATS) providers in that the operational capabilities of such aircraft are not easily predictable. Bodies in charge of the development of criteria for approaches (e.g. ICAO Obstacle Clearance Panel (OCP)) will have the same problem: they cannot base the determination of criteria simply on aircraft equipage. Rather, the criteria should be based on a clear definition of required aircraft capabilities.

1.3 For example, criteria for APV-I approach procedures may be defined only for guidance based on SBAS. But, APV-I performances may be achievable by on-board GPS-inertial hybridisation. Operators with the GNSS/INS system may not be allowed to perform APV-I procedures because the performances of this ABAS system are not standardized.

1.4 A solution to this problem could be to identify and define required aeroplane capabilities that are required in order to support specific procedures or have access to particular airspace. In other words, use performance based criteria rather than equipage based criteria. Then, it is the responsibility of the operator to determine if the aeroplane capabilities are sufficient for the desired operation. In order for the aeroplane capability to be determined, the level of navigation system performance provided by each navigation aid must be known. Consequently, it is still important to define the performance of the signal-in-space for all navigation aids, satellite signals and GNSS augmentations.

1.5 Use of performance-based criteria will allow the ATS providers to specify the required capability of aircraft and to refer to performance requirements unambiguously in the aeronautical information services. Similarly OCP will be in a position to define the approach criteria for aircraft complying with a given standardized performance level.

1.6 This concept is of course not new. It is in fact the concept of required navigation performance (RNP). In an RNP system the capabilities of aircraft are dependent not only upon the available aids but also upon the aircraft equipage, navigation system integration and flight technical error performance. RNP levels have been defined and standardized and the aviation community continues to develop the concept of RNP as part of an overall trend to move from facility based requirements to performance based requirements.

2. GNSS/INS integration

2.1 The technical benefits that can be derived from the synergies of GNSS and INS depend upon the mechanization used for integration. There are three basic types of GNSS/INS: Loose-, Tight- and Ultra-Tight Coupling.

2.2 Loose-coupling

2.2.1 Loosely-coupled systems are the least complex since they merely amount to position mixing of GNSS and INS. This mixing is typically accomplished in the flight management system (FMS). The technical benefit is an updated position estimate with the high frequency characteristics of an INS without the large time dependent position biases. Another benefit is some ability for INS coasting in the event of the loss of GNSS. This is achieved by reducing the initial position and velocity errors. This limited coasting capability provides an improvement in availability and continuity particularly at larger required navigation performance (RNP) levels. Due to the large INS drift rates, the coasting capability provides little improvement in continuity and availability for smaller values of RNP.

2.3 Availability

2.3.1 An INS has the ability to navigate autonomously (coast) through holes in GPS coverage. It should be noted that there are various interpretations of the definition of coasting. Notwithstanding the precise definition of coasting, the larger the RNP¹ the smaller and less frequent the GNSS outages and the less demanding the requirement on the performance of the INS. At RNP 0.5 and below, where Integrity Containment (at 10^{-5} or 10^{-7}) is appropriate, loose-coupling provides no significant improvement in availability. For larger RNP, loose-coupling may provide some improvement. For large RNP, such as RNP 4, the improvement may be significant. In all cases the loosely-couple system provides robustness to short outages of GNSS that may be caused by aeroplane manoeuvres, or limited duration RFI events.

2.4 Continuity

2.4.1 The above discussion of availability translates directly to continuity but with one extra facet. Whereas the performance of a loosely-coupled system is inadequate to produce significant improvements in availability at smaller RNP it does prove helpful in providing navigation in the event of an aborted GPS approach. The short period over which the system is able to continue to support the needed level of RNP (with integrity containment) can be sufficient to conduct a missed approach or some short terminal area operation.

2.5 Tight-coupling

2.5.1 Tightly-coupled systems are more complex than loosely-coupled systems in that they employ more sophisticated navigation filtering. In a tightly coupled system pseudorange measurements made by the GNSS receiver are combined with inertial sensor measurements using a Kalman Filter or bank of Kalman Filters. The Kalman Filter(s) typically estimates the position, velocity and inertial sensor error states (e.g. accelerometer biases, gyroscope misalignments etc). This level of integration can be accomplished using both open-loop or closed-loop designs. This type of integration may also support integrity coasting based on

the calibrated inertial solution during periods when the GNSS satellite signal is not available. Both RTCA and EUROCAE are developing requirements for this capability.

2.5.2 It is common for the integration of GNSS and INS to be implemented within the INS system. However, the algorithms do not necessarily need to be hosted in the INS (which could be costly to modify). The integration could be implemented in the GNSS receiver, multi-mode receiver (MMR), FMS or other system on the aircraft. Moreover the output of the integration can be formulated to exactly resemble/replace the GNSS input to the FMS. There is no reason to assume that tight-coupling is only economically applicable to forward fit. Tight-coupling brings technical benefits in three areas: Availability, Continuity and in reduced sensitivity to time to alert.

2.6 Availability

2.6.1 A tightly-coupled system has a powerful mechanism for improving availability: improved integrity monitoring. The system is able to examine stored navigation data over long periods to look for correlated errors rather than make snapshot decisions. Furthermore, the system does not require an overdetermined solution (for RAIM based FDE). In fact, the system does not even require a complete GNSS fix but can use whatever individual pseudo-range measurements are available. Such integrated integrity monitoring may produce orders of magnitude improvement in availability — particularly for small RNP values. The availability improvement has more effect at small RNPs because that is where least availability is provided by the current constellation.

2.7 Continuity

2.7.1 In a tightly-coupled implementation the INS is continuously aligned and calibrated. This maximizes coasting capability and hence improves continuity of aeroplane level navigation performance. For maximum coasting performance the system needs to address both faulted and rare normal performance. To eliminate faulted performance requires at least a dual INS/GNSS and a comparator. Rare normal performance can be eliminated by monitoring instrument performance prior to coasting — this technique will allow truncation of the distribution tails and reduce the coasting HPL. Lastly, for maximum performance at very small RNPs, mitigation of the effects of gravity anomalies is required. The simplest technique is to store vertical deflection data and apply real time corrections. A declassified worldwide database of gravity anomalies exists.

2.8 Time-to-alert

2.8.1 A hybrid position solution does not react immediately to failures in the GNSS signal-in-space. Consequently, the system is desensitised to GNSS errors at the aeroplane level and the time-to-alert for the GNSS error is less important. It may be possible to exploit this characteristic of an integrated GNSS/INS system to enable operations that might not otherwise be supported by the GNSS signal in space alone.

2.9 Ultra-tight coupling

2.9.1 Ultra-tightly-coupled systems (probably) require physical integration of the GNSS receiver and the INS into a single unit. This type of system achieves the benefits of tight-coupling plus a 6-12dB

improvement in signal to jamming ratio against interference. Ultra-tight coupling presents significant technical challenges to implement and could be difficult to certify.

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