

ELEVENTH AIR NAVIGATION CONFERENCE

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Agenda Item 6 Aeronautical navigation : issues

INTEGRATION OF GNSS AND INERTIAL NAVIGATION SYSTEMS

(Presented by the International Coordinating Council of Aerospace
Industries Associations (ICCAIA))

SUMMARY

This paper gives an overview of the current status of integrated global navigation satellite system (GNSS)/inertial navigation system (INS) applications. The paper shows that significant inertial navigation capability exists in the worldwide aircraft base today. Furthermore, some capabilities based on integration of GNSS and INS have been fielded and are providing operational benefits. However, realizing operational benefits based on these capabilities has been difficult due to a lack of performance based criteria for operational approval.

The paper also describes the potential future benefits that may be enabled by integrated GNSS/INS. This includes a brief discussion of expected future trends in GNSS/INS technology development.

1. INTRODUCTION

1.1 Integrated GNSS/INS applications are recognized as a valuable potential mitigation for the vulnerabilities of GNSS to interference. It should also be recognized that integration with inertial has the potential to improve the capability of GNSS even when there is no interference. Among these improvements are increased availability for any given level of navigation performance and continuity augmentation for precision approach operations.

1.2 Aviation has not ignored the potential benefits of inertial complementation. Many aeroplanes in production today use inertial data to complement performance of the instrument landing system (ILS) deviation data used for approach and landing operations. Also, virtually all current production designs for commercial air transport aeroplanes include some level of integration between GNSS and INS. Unfortunately,

this capability has had little influence on development of standards or operational requirements for GNSS. As a result, hybrid GNSS/INS systems have yet to fully deliver their potential operational benefits.

2. INTEGRATED GNSS/INERTIAL SYSTEMS

2.1 GNSS and inertial navigation systems (INS) or inertial reference systems (IRS) are highly complementary systems because of the contrasting noise and bias characteristics. Table 1 compares the characteristics of GNSS and INS. The technical benefits that can be derived from the synergies of GNSS and INS depend upon the design assumptions and mechanization used for integration. Three basic types of GNSS/INS integration are described in more detail in Appendix A.

Table 1. GNSS/INS synergy

	GNSS	INS
Measurement	Position & Time	Acceleration & Angular Rate
RFI Vulnerability	Yes	No
High Frequency Noise Short Term Accuracy	Yes Good	No Excellent
Biases Long-term Accuracy	No ¹ Excellent	Yes Poor

3. POTENTIAL OPERATIONAL BENEFITS OF INTEGRATED GNSS/INS SYSTEMS

3.1 Integration of GNSS/INS can enhance navigation system performance in terms of accuracy, integrity, availability and continuity. Operational benefit is derived from these improvements because a particular operation requires some specified level of navigation capability. The key benefit of integrated GNSS/INS with respect to interference is its ability to maintain the required level of performance and operate through GPS outages. Widespread adoption of integrated GNSS/INS effectively mitigates the effects of intentional or unintentional GNSS interference. Table 2 below provides estimates of the potential of loosely and tightly coupled GNSS/INS systems to provide availability and continuity improvements based on a horizontal protection level (HPL) with integrity of 10^{-7} /hour. Use of real-time performance monitoring to eliminate systems exhibiting rare normal performance and the use of gravity compensation can extend the coasting times for tightly-coupled systems beyond those shown in Table 2.

¹ Excepting some long correlation distance ionospheric effects which are alleviated by SBAS or GBAS

Table 2. Availability and continuity performance

HPL # Alert Limit	Tightly Coupled		Loosely Coupled	
	Availability	Coasting	Availability	Coasting
4	100%	4 hours	RAIM/FDE	2 hours
2	100%	2 hours	RAIM/FDE	40 minutes
1	100%	20 - 40 minutes	RAIM/FDE	10 minutes
0.3	100%	10 - 18 minutes	RAIM/FDE	3 minutes
0.1	100%	7 -12 minutes	RAIM/FDE	1 minute

3.2 Availability benefits for integrated GNSS/INS systems are already manifest, however, additional details and illustrative examples are given in Appendix B.

4. CURRENT STANDARDS AND CERTIFICATION CRITERIA

4.1 With respect to FAA certification, INS system performance is covered by FAR 121 Appendix G. This document contains no requirements relative to a hybrid GNSS/INS system. Similarly, there is no explicit JAA requirements for performance of integrated GNSS/INS systems. RTCA has published Appendix R (“Requirements and Test Procedures for Tightly Integrated GPS/Inertial Systems”) to DO-229C (“Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment”). DO-229C appendix R includes assumptions, requirements and verification procedures for tightly coupled GNSS/INS systems. However, no advisory circular references this material. Consequently, any airworthiness certification of GNSS/INS systems must be handled as a part of a type certificate (TC) or supplementary type certificate (STC). This lack of clear certification criteria is a problem for retrofitting capability to existing aeroplane designs.

4.2 A larger roadblock to the widespread implementation of GNSS/INS has been the lack of a clear path to obtain operational benefits by deploying these systems. To date, many new operational procedure developments have been based on certain standard equipage (e.g. TSO C-129 GPS approaches). It has been difficult to get any operational benefit for performance enhancements associated with integrated GNSS/INS.

5. FLEET EQUIPAGE AND CAPABILITIES

5.1 Aircraft position determination changed significantly in 1982 when the laser inertial reference system was certified on the B757 and B767. The innovation was the first aircraft certification of a strapdown²

² Compared to the conventionally gimbaled INS, the distinguishing feature of the strapdown INS, is the absence of a gimbaled mounted reference table. In the strapdown system the gyros and accelerometers are mounted directly to the vehicle frame.

navigation system resulting from two critical technological advances; strapdown navigation sensors (in particular the Laser gyroscope) and the advancement of processing technology to the point where the required computations could be done on a single card in an affordable configuration. The major achievements in technology combined to provide the airlines and OEMs with a significant reduction in price, improvement in performance consistency and two orders of magnitude improvement in reliability over the previous mechanical technology. Since 1982, all currently manufactured aviation inertial navigation equipment has transitioned to laser gyro based strapdown inertial reference units and over 45 000 units have been installed on over 17 000 commercial aircraft.

5.2 At this time, all **Airbus** A300, A310, A318, A319, A320, A321, A330, A340, **Douglas** MD-10/11, MD-90, **Boeing** B717, B737, B747, B757, B767 and B777 aircraft as well as **Cessna** Citation X, **Gulfstream** G-100, G-200, G-300, G-400, G-500, G550 **Bombardier** Challenger, 604, RJ, GEX and Dash-8, **Dornier** 328, 728, 928, Envoy 7, **Dassault** F-50, F-900, F-2000, F-7x, F-200, **Embraer** ERJ-135, 140, 145, 170, 175, 190, 195, Legacy, **BAE** RJ, **Tupolov** 204, **Ilyushin** 96M **Hawker** Horizon, **Folker** F-70 and F-100 aircraft are equipped with a long range inertial reference system capable of providing independent inertial position determination. There exist today numerous configurations of the inertial positioning equipment as well as aircraft navigation architectures, however all aircraft are equipped with either two or three positioning devices. In general, all of the inertial devices delivered since 1982 have similar navigation performance characteristics because they are required to perform between the TSO requirements on the low side and the ITAR export restrictions on the high side.

6. TECHNOLOGY TRANSITION

6.1 Since 2001, a micro electro-mechanical system (MEMS) sensor technology has begun to evolve into the navigation marketplace. The MEMS technology allows designers to create a moving silicon element inside a silicon component to be designed and manufactured using normal etching processes. These moving elements become elements in a sensor, which can be used to sense various external stimuli, but specifically rotational motion and linear acceleration of the device. A number of companies have introduced products and performed trials, which demonstrate the capability of this technology to meet the TSO requirements for attitude heading reference systems (AHRSs). As the technology evolves the performance will continue to improve and the MEMS based products are expected to evolve to a navigation grade capability.

6.2 The evolution of these new systems will be enhanced through the integration of information from GNSS. The GNSS signals will be integrated with the inertial measurements to allow for calibration of the inertial sensors, integrity monitoring and navigation backup of the GNSS satellite signals. Many studies and demonstrations of these capabilities have already been performed in both airborne and land applications.

6.3 The advantages of this new technology are obvious. First, the size and power requirements for these new sensors, coupled with lower power electronics, will result in devices which are $< \frac{1}{4}$ the size, weight and power of the current system sold on aircraft today. Second, the price of these devices will be significantly lower than their legacy navigation sensors. Finally, the expected reliability of these sensors is more than three times the reliability of the current systems. Figure 1 provides a timeline of the technological evolution of inertial sensor technology along with the relative size and weight.

6.4 Today, the capabilities of MEMS based devices are limited to attitude sensing and the required performance of the internal sensors will have to improve 100 times from where it is today before it is capable of stand alone navigation. While the challenges are significant, the demand for and the capability of the technology hold the promise that competitively priced aviation hardware will be available within the foreseeable future, sometime around 2015.

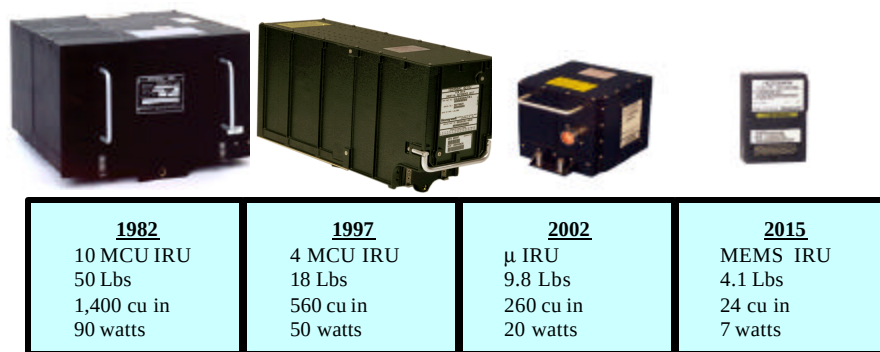


Figure 1. Typical inertial reference receiver technology timeline

7. SUMMARY AND CONCLUSIONS

7.1 Inertial navigation equipment has become standard on all modern air transport and high-end business aviation aircraft. The equipment is of varying design but is capable of providing navigation performance of 2 NM/hr, with a 95 per cent probability. These systems can be integrated internally or externally with GNSS to enhance the capability and operational utility of both the inertial and the GNSS position determination performance and integrity.

7.2 In addition to the capabilities offered by systems available today, future systems will utilize new sensor technologies, which will continue the trends established by today's sensors. Specifically, to reduce the size, weight, power and price of the navigation sensors while also improving performance and integrity.

7.3 The conference is invited to use information in this paper in its deliberations on Agenda Items 1 and 6. The conference is invited to consider the need for future ATM operational concepts to incorporate performance based criteria in order to take advantage of the potential benefits to be provided by GNSS/INS systems and ABAS systems in general.

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