ANALYSIS OF THE PERFORMANCE OF CURRENTLY USED AND PROPOSED NAVIGATION SYSTEMS INVOLVING GPS FOR GA IFR OPERATIONS IN AUSTRALIAN AIRSPACE

by

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Background

Since the introduction of satellite navigation using GPS for civil aviation commenced in the early 1990's, many developments in the satellite constellation and receivers have taken place. Improved performance has resulted from :-

- The increase in the satellite constellation from 18 to more than 24 satellites
- Selective Availability (SA) has been set to zero
- Receivers are available with Fault Detection and Exclusion (FDE)
- GPS has been integrated with the Inertial Reference System (IRS) in the larger aircraft

Further improvements can be expected from Increased reliability of the GPS satellites, ranging signals from geostationary satellites and from GPS at the L5 frequency, new satellite navigation systems such as Galileo, more augmentation systems and development of MicroElectronicMechanicalSystems (MEMS) integrated with GPS and suitable for GA.

It has therefore been timely to review the performance and operation of the currently used and proposed navigation systems involving GPS for GA operations in Australian airspace. Accordingly, the Civil Aviation Safety Authority of Australia contracted FANS PLANS to undertake this study.

Aircraft navigation requires a navigation system to provide an acceptable level of accuracy, availability, integrity and continuity of function. The actual level of performance required varies according to the phase of flight eg en-route, terminal area, non-precision approach & departure and precision approach & landing. The basic satellite constellations such as GPS and GLONASS, of themselves, do not provide the levels of performance needed for the above phases of flight and some form of augmentation is required to provide the necessary integrity.

The augmentation system which has been certificated and is in wide general use is the system of aircraft based integrity monitoring, where the GPS receiver incorporates Receiver Autonomous Integrity Monitoring (RAIM). The basic type of RAIM detects a failure in the satellite system and is called Fault Detection (FD). Further development of RAIM into Fault Detection and Exclusion (FDE) allows the faulty satellite to be identified and excluded from the calculation of position, thus permitting the flight to continue.

RAIM has the big advantage of not requiring any additional space-based or ground-based infrastructure : it is all provided in the airborne GPS receiver.

The focus of the study was the determination of the level of availability of high integrity navigation information from GPS receivers with augmentation from barometric altimetry and using RAIM for integrity monitoring. The determinations were then carried out for a wide variety of satellite constellations and receiver parameters under both normal and degraded conditions.

Methodology

The study examined actual systems (both satellite constellations and receivers) which are in operation and new systems which could reasonably be expected to be available in the next few years.

It would be impracticable to determine the performance of each possible combination of parameters of the satellite constellation and receivers. Rather, a range of likely combinations of parameters were selected for analysis and then a sensitivity analysis was carried out to discern trends.

The performance of GPS in the presence of interference was beyond the scope of this study. Although some studies of GPS vulnerability have been done in various parts of the world, an analysis of the probability of harmful interference to GPS in Australia needs to be carried out. Such a study needs to include the probability of harmful interference to conventional navigation systems eg NDB/ADF in Australia in order to make valid comparisons with GPS.

The study was carried out in three main stages as follows :

In the first stage, the performance was determined by simulation of a typical satellite constellation and receiver over the whole of the Australian airspace. The result showed that the “worst” areas over continental Australia are around Adelaide (SA) and Albany (WA). The Adelaide area was thus selected for the most detailed examination.

In the second stage, simulations were carried out for the Adelaide area over the GPS satellite constellation cycle using some 40 combinations of satellite constellation and receiver parameters to determine the performance of the most likely combinations and to show trends from the sensitivity analyses. This showed the performance at one of the “worst” locations. Better performance could then be expected at all other locations. A limited examination of two “better” locations, Parkes and Toowoomba, was then carried out to show what the “average” performance was likely to be. The plotting of the RAIM performance against time over the whole of the GPS satellite constellation cycle proved to be a powerful tool in analysing performance in detail.

In the third stage, six operational scenarios were constructed for GA flights to a destination. As base-lines for comparison, the first two scenarios were constructed for a flight to a destination using NDB’s. The next four scenarios were for flights using GPS with FD or FDE receivers and with or without a navaid at an alternate. The probabilities for RAIM availability over each phase of a 2 hr flight to the destination were determined.

GPS Satellite Constellations

The 24 satellite constellation as defined in RTCA/DO-229B, which is widely used for the design, testing and performance comparison of GPS systems, has been prudently used in this study. It is recognised that the actual constellation available for navigation currently contains more than 24 satellites. However, the orbital positions of the additional satellites can be such as to not contribute much to the accuracy of the position determination, but can contribute to the overall availability in the event of satellite failure or withdrawal from service.

A recent development has been the provision for GPS compatible ranging signals to be radiated from geostationary satellites. This is equivalent to adding satellites to the constellation with beneficial effects. Although few of the existing GPS receivers are capable of receiving the ranging signals from the GEO's, the new TSO C146 receivers are to have that capability. The beneficial effect of the GEO's is particularly noticeable when there is a failure in a critical satellite.

In accordance with RTCA/DO-229B, the study has used the value of 10^{-4} per hour for satellite integrity failure for the calculations of RAIM availability. The expectation is that failure rates will improve and this will result in a corresponding improvement in RAIM availability.

Receivers

Receivers with a wide variety of characteristics are presently in use and new models with greater capabilities are being developed. The study has therefore divided receivers into three broad groups :-

- Group 1 broadly represents the older receivers meeting TSO C129 which would be used by General Aviation. They are characterised by having FD only and still assuming that SA is on.
- Group 2 represents the performance of receivers meeting FAA Notice N8110.6 for oceanic/remote operations. These receivers have FDE and mask angles down to 0^0. Modifications may be available from the manufacturers to reconfigure them for SA off.
- Group 3 represents the likely performance of the new receivers meeting TSO C146. These would have FDE, SA off, a mask angle specified as 5^0 when using WAAS corrections and can use of the ranging signals from MTSAT and WAAS.

RAIM Availability Plots

Simulations were carried out to examine RAIM Availability Performance for both FD and FDE as a function of time for Adelaide, Parkes and Toowoomba. The RAIM performance function (Horizontal Protection Level (HPL) in the case of FD and

Horizontal Exclusion Level (HEL) in the case of FDE) was plotted for each minute of the time period (1436 min) of the GPS satellite constellation cycle.

GPS receivers must indicate an alert when inadequate or invalid navigation signals would cause unacceptable navigation for a particular phase of flight/navigation mode. The Horizontal Alert Limits (HAL) implemented in receivers are set out in RTCA/DO-229B for the En-Route (EnRte), Terminal Area (TMA) and Non Precision Approach (NPA) phases of flight. These HAL's are also plotted with the HPL and HEL so that the time periods when RAIM is not available can be seen.

RAIM Performance

The periods of unavailability of FD and FDE due to geometric considerations for both normal and fault conditions were shown in the simulations and these periods are repeatable and predictable based on the knowledge of the GPS satellite constellation, the receiver characteristics and the geographical location. With a comprehensive GPS forecast available before the flight, the RAIM unavailability does not constitute a safety hazard, provided it is taken in account when planning the flight.

The simulations showed the benefit of the FDE receiver (either N8110.6 or TSO C146) which has the capability to exclude a faulty satellite from the position determination and thus allows the flight to proceed using the remaining satellites with the FDE or FD function. As was shown in most of the simulations, FDE was available after a faulty satellite was excluded. In all simulations, the receiver could revert to FD in the EnRte and TMA. Receivers with FD only (ie most of the TSO C129) are rendered unserviceable by the radiation of an erroneous signal from any faulty satellite in view, even though there are sufficient remaining satellites to support the flight.

RAIM Availability under various Scenarios

There are two main causes of RAIM being unavailable. The first was mentioned above and occurs because of insufficient satellites of appropriate angular spacing. The second occurs because of a random failure of a satellite during the flight. The first cause of RAIM unavailability is predictable before the flight and if the GPS forecast is taken into account in the flight planning, it does not constitute a safety hazard. This procedure is assumed to take place during the following scenarios. The probability of the occurrence of the second cause of RAIM being unavailable during a flight because of a random failure of a satellite was examined in the scenarios.

Scenario 1 is one of the baseline scenarios and is for a flight to a destination with an NDB when no alternate is required.

Scenario 2 is another of the baseline scenarios and is for a flight to a destination with an NDB when an alternate with a navaid is required.

Scenario 3 is for a flight to a destination using GPS (FD receiver) with a navaid at an alternate. This scenario represents the procedures put into operation for the introduction of GPS NPA.

Scenario 4 is for a flight to a destination using GPS (FD receiver) when no alternate is required. This scenario represents what could be done with navigation by a GPS FD receiver alone (generally representative of TSO C129).

Scenario 5 is for a flight to a destination using GPS (FD receiver) when there is no navaid at the alternate (the GPS FD receiver used at alternate).

Scenario 6 is for a flight to a destination using GPS (FDE receiver) when there is no navaid at an alternate (the GPS FDE receiver used at alternate). This scenario represents what could be done with navigation by a GPS FDE receiver alone (generally representative of TSO C146). This scenario has the considerable advantage in that, if any satellite in view fails during the flight, it will be excluded and the flight can continue to the destination.

Comparison of Performance under the various Scenarios

The performance under Scenario 4 compares favourably with Scenario 1. The availably of navigation guidance for NPA is about the same, but Scenario 4 has the advantage of providing En-Route navigation all the way to the destination and giving earlier warning when navigation guidance for NPA will not be available at the destination. Improvements in GPS satellite reliability and integrity will result in a corresponding improvement in the performance of Scenario 4 compared with Scenario 1.

Scenario 3 compares favourably with Scenario 2 and has the same advantages as mentioned for Scenario 4 above. Again, improvements in GPS satellite reliability and integrity will result in a corresponding improvement in the performance of Scenario 3 compared with Scenario 2.

The performance under Scenario 5 is considerably inferior to Scenarios 2 and 3 due to the problem that receivers with FD only are rendered unserviceable by the radiation of an erroneous signal from any faulty satellite in view. Even with likely improvements in GPS satellite reliability and integrity will not improve performance to the level of Scenarios 2 and 3.

The best performance is obtained under Scenario 6 due to the superior capabilities of a receiver such as one complying with TSO C146 (FDE and ranging from geostationary satellites). As previously mentioned, if any satellite in view fails during the flight, that satellite will be excluded and the flight can continue to the destination. The probability that RAIM would not be available for an NPA at either the destination or the alternate is very small. It does not constitute a hazard because RAIM will be restored by executing a missed approach and switching to the TMA phase. RAIM for the NPA will then become available in a short time and the NPA can be recommenced. The performance under this scenario is many times better than the other scenarios.

A comparison of the scenarios is shown in Table 1.

Table 1

Comparison of Scenarios for Non Precision Approach

Scenario	Destination	Alternate	Comparison
#1	NDB	Not Required	Base-line
#2	NDB	NDB	Base line
#3	GPS (FD)	NDB	Slightly better than #2
#4	GPS (FD)	Not Required	Slightly better than #1
#5	GPS (FD)	GPS (FD)	Worse than #3
#6	GPS (FDE)	GPS (FDE)	Better than all

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