Chapter 7 – SOME FURTHER APPLICATIONS AND DEVELOPMENTS

7.1 GENERAL

The present chapter focuses on further developments in the field of DGPS for flight testing, including perspectives for future research activities. Particularly, after discussing a simple method for post-processing recover of DGPS data losses, the most important DGPS/INS integration issues are presented, together with typical integrated systems architectures. Moreover, the design features of an optimal DGPS/ INS Position Reference System (PRS) suitable for flight test applications are presented, together with a new approach to the problem of DGPS integrity augmentation, showing potentials for high precision aircraft applications.

7.2 INTEGRATION OF DGPS AND INS MEASUREMENTS

Although many tasks are fulfilled now by sole means of Differential GPS, there are still areas where integration with an INS is necessary. Particularly, in flight testing of modern navigation systems DGPS cannot provide the necessary information with regard to data rate and data continuity during high dynamic manoeuvres. Many studies have been undertaken in order to investigate the potential of DGPS/INS integration for flight test and other high precision applications. Together with real-time C/A code DGPS, also DGPS using carrier phase ambiguity resolution on-the-fly has been investigated and different options for the INS mechanisation have been considered. The integrated PRS is being conceived primarily for testing of modern navigation and landing systems (e.g., satellite systems and integrated systems); however, due to the high accuracy and data rates obtainable with DGPS/INS integration, the system will also be suitable for other tasks, such as aircraft noise certification, and most of current avionics and armament experimental tasks.

In the following paragraphs only the main results achieved are presented. The fundamentals of DGPS/INS integration are presented in Annex E.

7.2.1 Recovering DGPS Data Losses

A simple method has been developed for post-processing recover of DGPS data losses due to antenna masking, hard manoeuvring or bad satellite configuration. The method utilises the direct integration of data provided by the on-board INS starting from an initial reliable position determined by DGPS (i.e., obtained after a stabilisation of at least 20 seconds, with at least 4 satellites in view and PDOP<3). The integration is carried out up to the next reliable DGPS relief. The difference at the end of integration between the so calculated aircraft position and that provided by DGPS enables the determination of the average value of the inertial drift derivative with respect to time, which is used to minimise the inertial error during reconstruction of the aircraft trajectory for the whole time slice considered. So, it is possible to provide an accurate aircraft trajectory even when the manoeuvres can lead to GPS data losses, without the use of external reference systems (e.g., cinetheodolites, tracking radars) or pilot fixes, which require good weather conditions and properly instrumented test ranges.

In Figure 7-1(a), referring to three consecutive orbits lasting for about eleven minutes, DGPS latitude data are compared with inertial latitude corrected by using the method described above. The difference between the two sets of data (i.e., DGPS/INS latitude error) is magnified in Figure 7-1(b) and compared with the inertial latitude error without DGPS corrections.

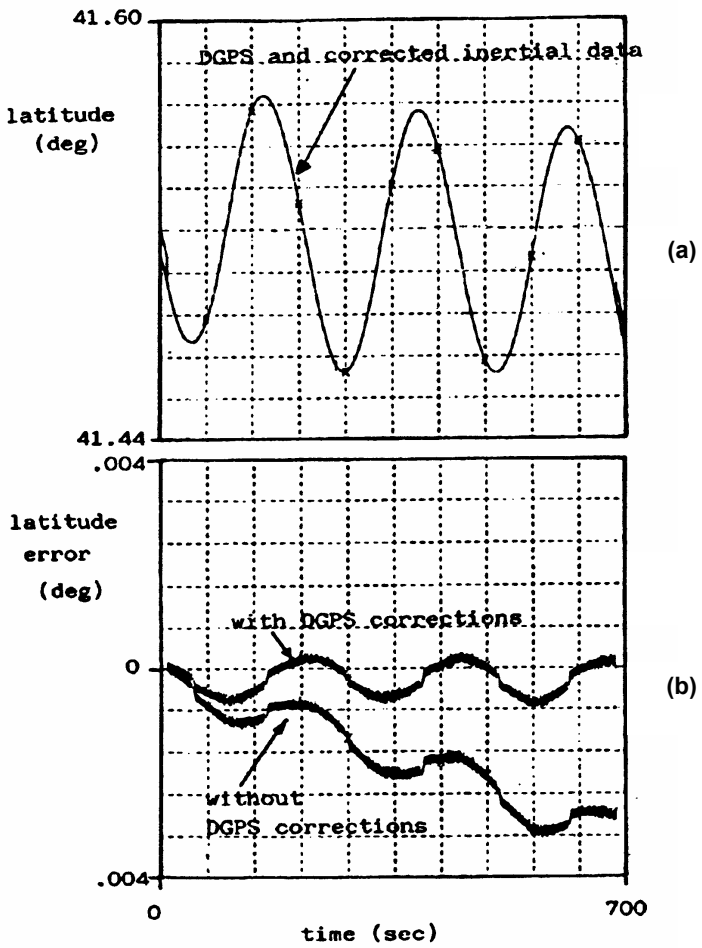


Figure 7-1: Example of DGPS and INS Data Merging.

7.2.2 Integrated DGPS/INS Systems

Although a large number of integrated GPS/INS products are now available on the commercial market, in the following we will specifically examine the DGPS/INS tailored for flight testing applications. In an Integrated DGPS/INS PRS suitable for flight test applications strapdown sensors are preferably used, because the system has to be robust, inexpensive and because compatibility with GPS receivers of different characteristics and accuracy classes is desirable. Therefore, according to the discussion on DGPS/INS integration presented in Annex E, only the Closed-Loop DGPS/INS (CLDI) and Fully Integrated DGPS/INS (FIDI) integration schemes are considered for such a system. However, the instability problems associated with closed-loop architecture, even thought to be solvable by adopting adequate techniques [1], make the CLDI implementation a secondary option.

7.2.2.1 Previous Efforts Addressed to the Problem

Various possible architectures have been investigated for the integrated PRS applications. These are based on the results of previous programs involving DGPS/INS integration, conducted by various flight test and research organizations around the world. Particularly, our interest has been focused on four programs conducted by the Dutch National Aerospace Laboratory (NLR), the University of Munich (Germany), the Deutsche Aerospace company (Germany) and the University of Braunschweig (Germany). The systems developed by NLR and the University of Munich are both based on state-of-the-art sensors (i.e., Ring-laser-giro strapdown INS and code/carrier DGPS systems) and both implement a non-cascaded architecture for the

Kalman filter. Particularly, NLR developed a PRS for testing the Fokker 70 aircraft, and the University of Munich (IAPG) designed a high-precision aircraft navigation/landing system based on DGPS/INS integration. The results of the NLR DGPS/INS development program have been published by Van de Leijgraaf [2] and Kannemans [3]. The results of the research conducted at the University of Munich (IAPG) have been described by Hein [4]. The DGPS/INS integrated landing system developed by Deutsche Aerospace has been described by Jacob [5], and the integrated precision navigation system (DGPS/INS) developed by the University of Braunschweig has been described by Shanzer [6].

The most interesting system architectures, from our point of view, are those of the NLR and IAPG systems, both adopting a fully integrated approach. The main difference between the two systems is that they use different DGPS information as input to the Kalman filter. This makes the structure of the various software modules (including the Kalman filter itself) quite different in the two cases. While both systems use similar INS inputs (i.e., RLG and accelerometer raw data), in the first case GPS position (and velocity) data are delivered (de-correlated between update intervals using an ad-hoc algorithm) by a differential processing module (which processes data from both the ground and the airborne receivers), while the system proposed by IAPG uses the raw (uncorrelated) DGPS data (i.e., differentially corrected pseudoranges, carrier phases, range rates) as direct input to the Kalman filter. Both approaches have significant advantages and drawbacks. Therefore, a closer look at the NLR and IAPG systems is important.

7.2.2.2 NLR System

Since the NLR system has been conceived to use either standalone GPS (C/A code), differential code range GPS (C/A code) or differential carrier range GPS (L1 and L2) depending on the required accuracy (i.e., 100 metres, 5 metres, and 0.15 metres respectively), the computer software modules have been designed to accomplish with this requirement. Particularly, the system includes:

- A module for processing C/A code pseudoranges from both the airborne and ground receivers (DCA module);
- A module for processing L1 and L2 carrier ranges from both the airborne and ground receivers (DCR module);
- A module for integration of DGPS and INS measurements (IDI module); and
- A module for comparing the computed positions with a pre-defined aircraft trajectory and sending guidance information to a cockpit display.

In the NLR system, when DGPS data is absent for short time intervals, the calibrated INS maintains the required accuracy. The length of the allowable interruption depends on the required accuracy and the accuracy of the estimated INS errors just before the interruption. The Kalman filter uses an INS error model, raw INS data and DGPS position and velocity data, which are uncorrelated between update intervals.

From the covariance matrix of a full DGPS solution (provided either by the DCA or the DCR module), the position (and velocity) dependent part can be derived (i.e., three dimensional measurement vectors). In fact, the computations of the DCA and DCR modules are performed so that the square root information matrices of the position and velocity solutions are made available for the IDI module. Clearly, the components of an estimated position vector are mutually correlated and so are the components of an estimated velocity vector. By multiplying the difference between the calculated position (and velocity) vector and the raw INS position (and velocity) vector by its associated square root information matrix, a transformed measurement vector with uncorrelated components is obtained. This vector (and its velocity counterpart) are then processed component-wise by the Kalman filter. As the noise on the carrier ranges is much smaller than the noise on the code ranges, the standard deviations of INS error estimates are correspondingly smaller [3].

7.2.2.3 IAPG System

The IAPG system has been designed for using, in real-time, DGPS carrier phase corrections transmitted from the ground Reference Station. Therefore, the system can provide only a high precision DGPS/INS solution (carrier phase positioning about 5 centimetres accuracy). In contrary to the NLR system, there is no provision for a low accuracy (C/A code, 100 metres) or a medium accuracy service (i.e., differential code-range, about 5 metres) to be provided in real-time. The Kalman filter has been designed to accept INS raw data and GPS raw data (i.e., pseudoranges, carrier phases, range rates) corrected with data transmitted from the ground (i.e., pseudorange and carrier phase corrections), in order to provide the high accuracy integrated solution.

The use of GPS carrier phase observation requires that the initial ambiguities have to be determined. It is therefore necessary, for real-time operation, that this starting procedure is performed during the aircraft flight (i.e., OTF ambiguity resolution) as well as after periods of signal loss-of-lock. If cycle slips occur (without a longer period of loss- of-lock) during the operation, the Kalman filter is able to solve for it due to the INS observations. However, there is a time limit for a complete GPS outage in the range of 20 to 40 seconds. If the loss-of-lock period is longer, a degradation in accuracy has to be accepted before the OTF algorithm can perform the initialisation good to the last cycle.

Also for the INS it has been assumed that, in certain operational conditions, a static initialisation (i.e., initial alignment) cannot be performed on the ground and in-flight alignment methods (with related accuracy degradation) have been considered. Furthermore, coning and sculling effects of the INS have been compensated carefully [4].

7.2.3 An Optimal PRS for Flight Testing

An optimal PRS should include solutions from both the NLR and IAPG systems. Particularly, according to flight test requirements, the PRS should be able to cover various accuracy classes:

- A low accuracy class with stand alone GPS (C/A-code, nominal position accuracy 100 m 2D-RMS and less than 50 m practical in the absence of SA) updating the INS. This is required for the evaluation/certification of medium-range navigation sensors and systems (VOR/DME, TACAN, NDB, ADF, etc.); and
- A high accuracy class (3-D position accuracy at the decimetre level), in which differential carrier range measurements can be used to update the INS. This is required for a number of applications, such as aircraft noise certification, evaluation of landing systems and determination of aircraft take-off and landing performance.

A bi-directional data link would be required to transmit the differential corrections from the ground reference station to the aircraft. This would enable real-time position calculation in the aircraft and provide (optionally) guidance information to the pilot. Without the data link the system will automatically degrade to the low accuracy mode (e.g., out-of-range operations).

7.2.3.1 Hardware Set-up

Based on the results of our investigation, the basic hardware set-up shown in Figure 7-2 is considered an ideal solution for flight test applications. The computer receives raw data from the airborne GPS (i.e., pseudoranges, carrier phases, satellite orbit parameters), correction data from the ground GPS receiver at the Reference Station (i.e., pseudoranges and carrier phase corrections), and raw data from the INS.

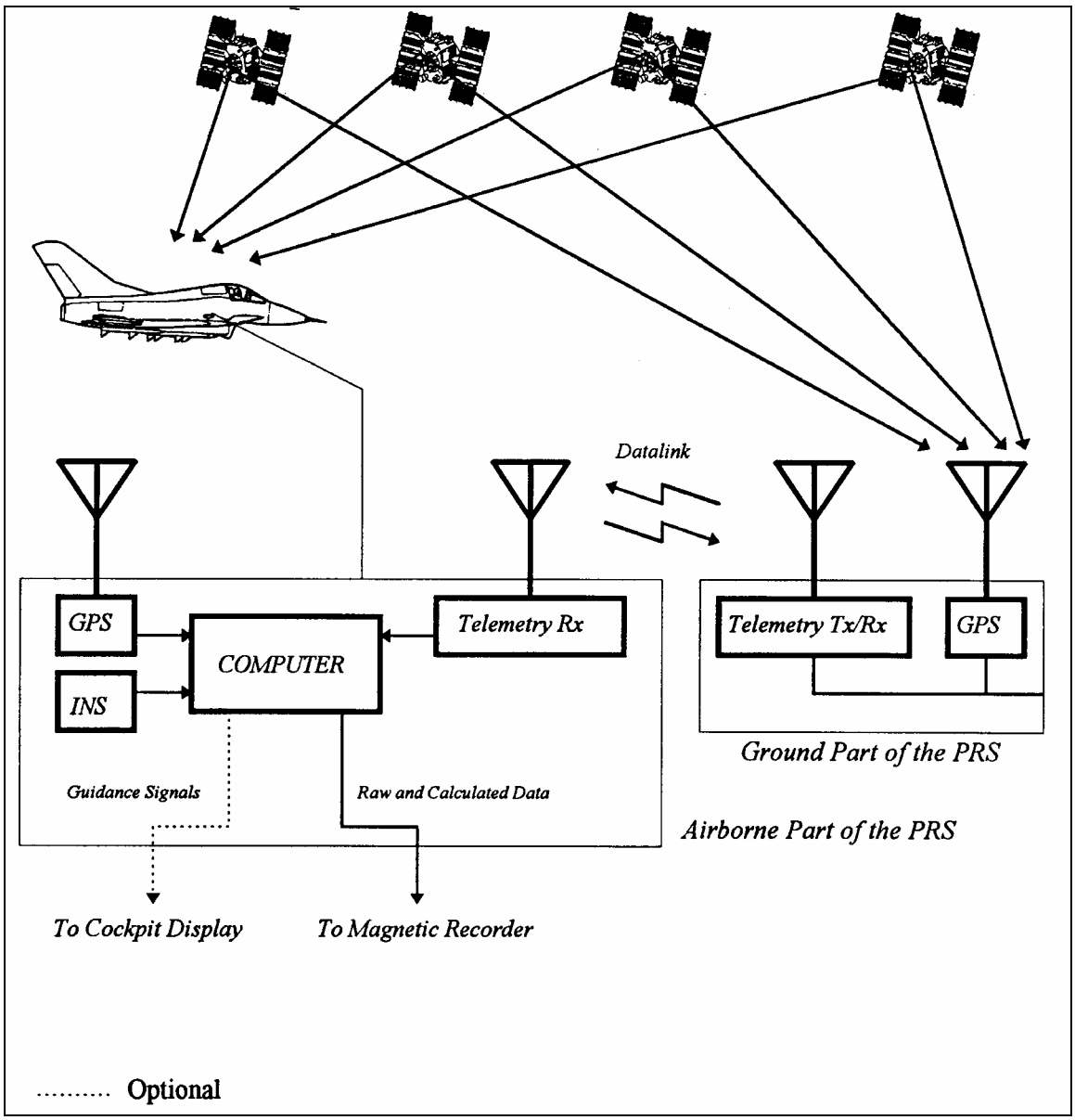


Figure 7-2: PRS Hardware Layout.

If only a telemetry uplink is used instead of a bi-directional link, real-time monitoring from the ground would not be performed. Moreover, when using raw data from the ground receiver instead of pseudorange and carrier phase corrections computed at the reference station, problems may arise of time sensitivity and telemetry load [7].

Using a bi-directional telemetry link and differential corrections from the ground reference station, high accurate DGPS data can be recorded in flight, used to provide guidance information to the pilot, and transmitted to the ground for real-time monitoring with high DGPS accuracy (see Chapter 3).

The on-board telemetry transmitters/receivers can be equipped with two antennas (i.e., up/down concept) to avoid signal interruptions. The computer merges the data and sends its solution to a magnetic tape recorder for further processing and analysis after the flight. Optionally, the PRS may be able to send information to a display in the cockpit to provide real-time guidance to the pilot.

7.2.3.2 Software Architecture

The Kalman filter should use an INS/DGPS error model, and accept raw INS and DGPS data (i.e., pseudoranges, carrier phases and range rates) differentially corrected using the signals transmitted from the ground Reference Station (i.e., pseudorange and carrier phase). The basic structure of the filter should be the same for the low and high accuracy applications. In the first case, the on-board GPS delivers the data; in the latter case, data should be delivered by a Differential Processing module (DPM) in which the ground reference corrections are applied. The basic structure of the PRS computer is shown in Figure 7-3.

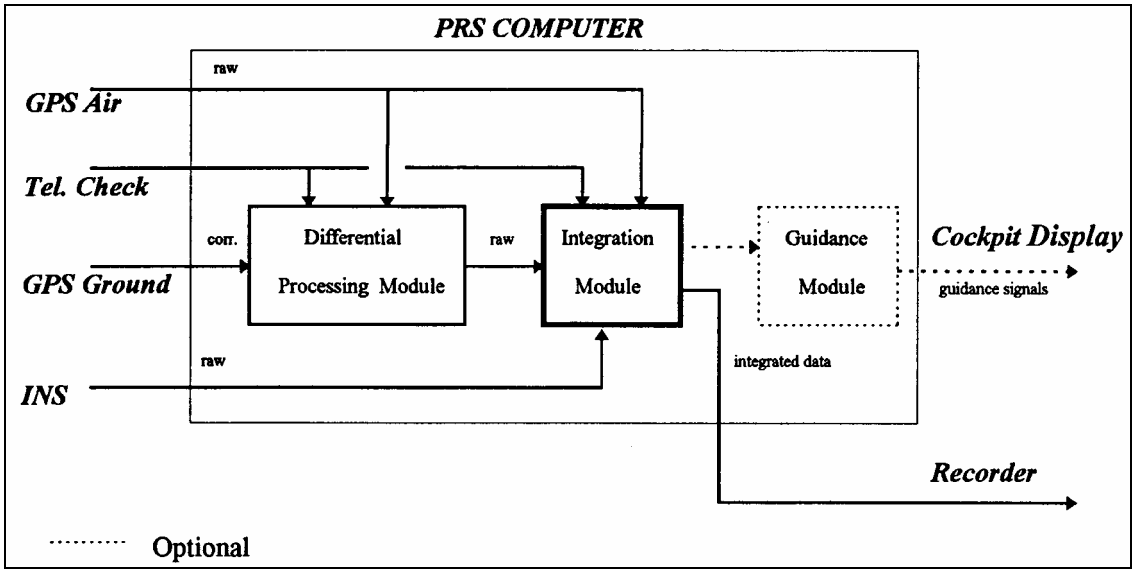


Figure 7-3: PRS Computer Functional Diagram.

The integration module will include the Kalman filter and will use GPS (on-board) or differentially corrected (DPM) data, depending on availability of the telemetry data link. Moreover, the DPM module should include:

- A sub-module for detecting and fixing cycle slips;
- A sub-module for solving the integer ambiguities; and
- A sub-module for calculating the aircraft position (double differenced carrier ranges).

At the moment, cycle slip fixing and ambiguity resolution algorithms are not mature enough to be used in real-time aircraft applications. However, the software has to be developed bearing in mind that an upgrade to the real-time system will be carried out as soon as enough confidence in the real-time performance of the algorithms will be established.

7.2.4 Equipment Selection

Regarding the INS selection, laser gyro instruments are considered. Currently available high-accuracy strapdown systems are, for example, the Honeywell H-423, H-764, HG-1050 or LaserNav, the Litton LTN-92, LN-100 or related strapdown instruments of that family. In fact, all of these systems do not really belong to the class of high-accuracy INS (i.e., the Honeywell Geospin inertial platforms or the Litton LASS), but they are commercially available and are of strapdown type, offering a good compromise between cost and performance. Moreover, their error models are well known and their dynamic behaviour is fully characterised. This is also true for high precision accelerometers [4, 8]. It should be stated,

however, that some of these units have aggressive filtering on the data output. For some applications the phase delay associated with these filters may determine lower data rates than required. For high dynamics applications, also the Litton LN200 FOG unit and the Honeywell HG1700 IMU are considered, which can provide data rates of up to 400 and 600 Hz respectively.

Regarding the DGPS component, various dual frequency eight to twelve channels GPS receivers are considered, delivering pseudoranges and carrier phases with full wavelength also in the presence of the P(Y)-code, through cross-correlation or similar techniques. Examples are the TurboRogue SNR-8000 of Allen Osborne Associates Inc., the Trimble 4000-SSE, and the ASHTECH Z-12 and X-treme GPS receivers.

The airborne computer should be based on a state-of-the-art microprocessor and the interface between the systems should be made with an ARINC-429 or MIL-STD-1553-B avionic bus, while communications with the telemetry receiver and the airborne GPS receiver can be guaranteed via RS-232 serial interfaces. The computer boards and the GPS receivers should be designed for airborne use. However, since this can be a serious constraint in the development phase, commercially available equipment can be initially installed in flight qualified housing to protect them by the severe conditions that can be encountered in the aircraft environment (i.e., temperature, vibrations, EMI) and vice versa.

7.2.5 Kalman Filter Design

The DGPS/INS Kalman filter may include up to 98-error states [9], but simplifications are possible, and provide acceptable performance with significant state reduction [10]. Covariance analysis is an efficient and powerful tool for sensitivity performance analysis to determine the contributions of distinct error sources. It is essential for developing a robust filter design of minimum state size. Its simulation analysis consists of three major components [2, 11]:

- An aircraft trajectory generator which provides nominal flight data;
- A reference sensor error truth model which characterises all the sensor errors; and
- The reduced-order Kalman filter design to be evaluated.

To conduct sensitivity performance analysis, a covariance analysis is performed with the reduced order Kalman filter, and the gain history is recorded. Then another covariance analysis is performed using the truth model for all sensor errors, with the Kalman filter gain computed from the earlier step. The performance obtained in the second covariance analysis represents the predicted performance of the reduced order filter design [10]. Detailed guidance information for the DGPS/INS Kalman filter design may be found in reference [8, 10, 12, 13].

7.2.6 PRS Testing

Once enough confidence has been gained in the performance of the Kalman filter, laboratory testing should be carried out in order to optimise the hardware and software architectures and to give a first estimation of the overall system accuracy. Flight test requirements for a PRS should be similar to the navigation system. test requirements described in Chapter 4. Therefore, in order to prove that a PRS based on GPS/INS integration meets its accuracy requirements, an independent reference system. is needed with an accuracy of at least a factor 3 (preferably 10). Moreover, the verification should be carried out in the environment where the PRS has to operate: on the runway and over the full flight envelope of modern military aircraft. Unfortunately a reference system with the required accuracy in the relevant operational environment is not available. Therefore, the above-described philosophy must be traded in for a practical test philosophy, which would still enable the establishment of the system performance. In fact, a PRS consists of a number of components, each contributing to the total error. The practical test philosophy should be as follows [14]:

- A theoretical evaluation of each PRS component results in the definition of the dominant error sources of the components and their sensitivity to the environment: height, speed, acceleration, attitude and attitude rate, etc. Either by analysis or by measurement the sensitivities are determined.
- A prediction of the total system accuracy over the envelope is calculated from the error contributions of the components.
- The calculated values are verified by carrying out operational system tests in a limited, but sufficiently relevant part of the flight envelope.

7.3 A NOVEL DGPS INTEGRITY AUGMENTATION METHOD

During flight test activities with DGPS, we verified that one or more of the following events could determine data outages:

- The aircraft reaching the Critical Bank Angle (CBA) associated with a particular aircraft/aircraft configuration;
- Critical satellite geometries and low satellite SNR values;
- Aircraft DGPS datalink antennae coverage limitations;
- Interference, at the airborne GPS antenna, caused by the data link signals; and
- Multipath caused by GPS and datalink signals reflected by the aircraft body surfaces.

It is evident that these limitations do not apply to flight test DGPS systems only, but they hold true for other high integrity applications of DGPS, such as precision approach (Figure 7-4).

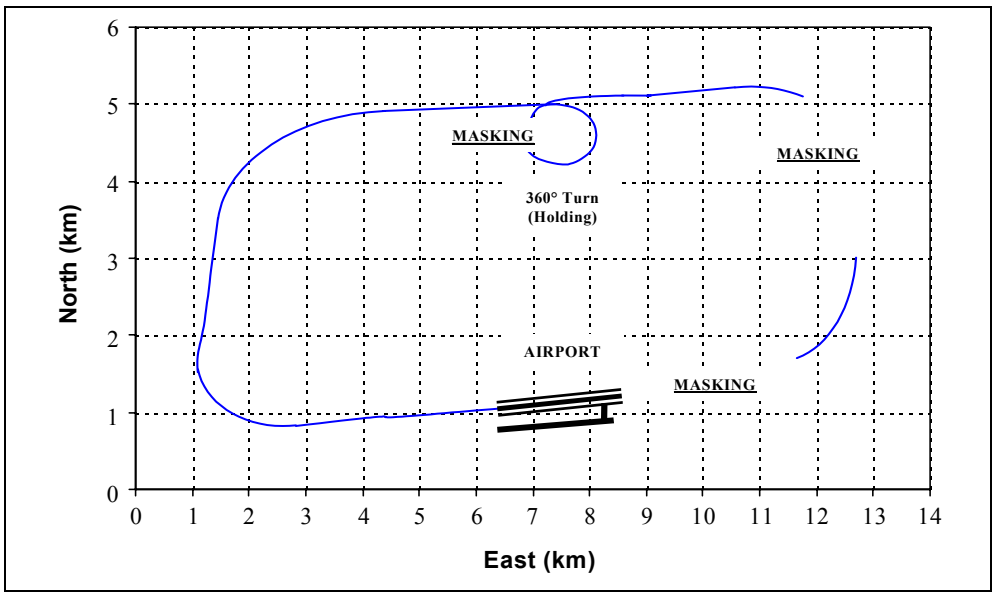


Figure 7-4: Approach Manoeuvres with Loss of Lock to the Satellites.

The last two problems can be adequately prevented or reduced by existing technology solutions (i.e., choosing a VHF/UHF datalink, filtering the radio frequency signals reaching the GPS antenna, identifying suitable locations for the GPS antenna and providing adequate shielded of the antenna itself, either by physical devices or via dedicated software masks). At the moment, however there is little to nothing one can do in order to prevent the aircraft from reaching the CBA during realistic test/training

manoeuvres and particular approach procedures (e.g., curved/segmented approaches) performed with high performance military aircraft. In fact, in the majority of military test/training missions it is not possible to maintain stabilised flight conditions before initiating the critical turns, and the re-acquisition times of currently available GPS receivers (i.e., 5 to 20 seconds) are not compatible with many test data requirements. Furthermore, although in some cases a careful mission planning may significantly reduce the number of DGPS outages, the adoption of specific aircraft piloting strategies (using the information currently available in the aircraft cockpits) cannot effectively avoid the occurrence of these events.

A study was therefore undertaken in order to identify a new integrity augmentation method, suitable for current and likely future aircraft DGPS applications. The so-called Aircraft Autonomous Integrity Augmentation (AAIA) method is described below.

7.3.1 Coupled Aircraft/DGPS Integrity Analysis

As a first step, a dedicated analysis (based on mathematical algorithms and experimental evidences) of the aircraft turning performance is required in order to determine the actual flight envelope limitations associated with the use of DGPS both during test/training missions and during the approach phases of flight. Such a method is intended for adoption in a dedicated ground-based simulation tool, as well as for a successive incorporation into the aircraft avionics systems; thus allowing for augmentation of the DGPS integrity in flight. The procedure described below gives an idea of the concepts involved in the proposed AAIA solution.

STEP 1

By simulation and flight testing the following data are gathered:

- The worst case CBA values (e.g., PDOP ≥ 4 and 5 satellites in view) associated with a particular aircraft (in all relevant aircraft configurations);
- The Critical Satellite Geometries (CSG) related to adverse configurations of the satellites in view (e.g., less than 4 satellites over azimuth angles of 180° or greater, low elevations of the satellites) and low SNR values; and
- The airborne DGPS Datalink Antennae Coverage (DAC) limitations (i.e., airborne datalink antennae masking matrixes and ground/airborne antennae radiation patterns).

STEP 2

The turning performances (manoeuvring envelope) of the aircraft are determined using the following input data (Figure 7-5):

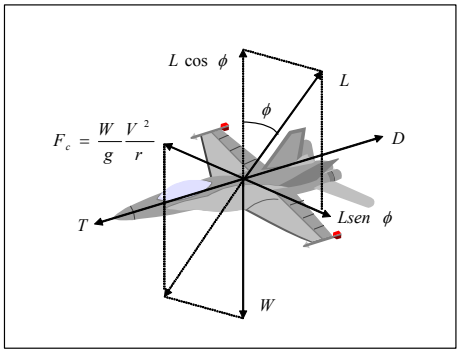
- Aircraft structural characteristics (Weight W, Wing Surface S);
- Polar curves for the various aircraft configurations [Lift Coefficient C_l vs. Drag Coefficient C_d as a function of the Mach Number M];
- Thrust available at various altitudes without (DRY) and with After-Burner (A-B); and
- Atmosphere characteristics (air density ρ, air temperature T).

Particularly, the following output data are obtained:

- Turn Radius Diagrams – TRDs [Turning Velocity (V_v) as a function of Minimum Turn Radius (r) and Bank Angle (Φ)]; and
- Thrust-Velocity Diagrams – TVDs [Thrust Needed for a Turn (T_{nv}) as a function of V_v and Bank Angle (Φ)].

$$\begin{cases} W = L\cos\phi \\ F_c = Lsen\phi \\ T = D \end{cases} \Rightarrow \begin{cases} W = \frac{1}{2} C_l \rho S V^2 \cos\phi \\ \frac{W}{g}\frac{V^2}{r} = \frac{1}{2} C_l \rho S V^2 \cos\phi \\ T = \frac{1}{2} C_d \rho S V^2 \end{cases}$$

$$F_c = m\omega^2 r \Rightarrow F_c = \frac{Q}{g}\frac{V^2}{r}$$



$$tg\phi = \frac{\frac{W}{g}\frac{V^2}{r}}{W} = \frac{V^2}{rg}$$

$$V_t = \sqrt{\frac{2W}{C_l \rho S \cos\phi}}$$

$$r = \frac{2W}{gC_l \rho S \sin\phi}$$

$$n = \frac{L}{W} = \frac{1}{\cos\phi}$$

$$T_{nt} = \frac{C_d W}{C_l \cos\phi}$$

L	=	Lift
D	=	Drag
T	=	Thrust
W	=	Weight
F_c	=	Centrifugal force
ϕ	=	Bank angle
C_l	=	Lift coefficient
C_d	=	Drag coefficient
m	=	Mass
g	=	Gravity acceleration
ω	=	Angular velocity
ρ	=	Air density
S	=	Wing surface
V_t	=	Velocity
r	=	Turn radius
n	=	Load factor

Figure 7-5: Stabilised Turn Equilibrium Equations and Flight Parameters.

STEP 3

Knowing the CBA, CSG and DAC limits, together with the manoeuvring requirements of specific flight test missions or the standard procedures (e.g., turns, holding patterns) associated to specific airports approach/landing procedures, it is possible to identify by ground-based simulation the aircraft configurations/manoeuvres that are potentially critical for the on-board GPS system.

STEP 4

Having identified the critical conditions (configurations/manoeuvres), it is possible to develop suitable models which describe the critical trends.

STEP 5

Using these models (e.g., polynomial coefficients, which can be easily incorporated into real-time software look-up tables), and comparing them with the boundaries set by the required Time-to-alarm (TTA) thresholds, it is possible:

- To determine if a specific manoeuvre required for flight test or precision approach can be performed with/without DGPS outages; and
- To generate timely warnings when the aircraft is performing critical manoeuvres prone to induce DGPS outages.

7.3.2 TORNADO-IDS Case Study

- A case study was performed in order to determine the potentials of an AAIA system on the TORNADO-IDS aircraft. For simplicity, only the experimentally determined aircraft CBA limits are considered here. The TORNADO-IDS experimental CBA values (one dorsal antenna) for the various aircraft wing configurations (A, B and C) are given in Figure 7-6.

- ***CONF. A – 25° ⇒ 42° CBA***
- ***CONF. B – 45° ⇒ 47° CBA***
- ***CONF. C – 67° ⇒ 55° CBA***

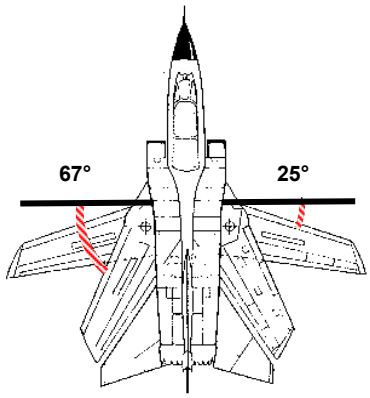


Figure 7-6: TORNADO-IDS CBA Values.

After analysis, the following results were obtained:

- Determination of the manoeuvring envelope areas were the CBA can be reached;
- Aircraft turn radius limitations at various altitudes and with various engine power settings; and
- Verification of compatibility between the profiles/procedures required for test and training (e.g., the altitude, velocity), and the CBA limitations.

The main results of the TORNADO-IDS case study are the following:

- The manoeuvring limits are compatible with currently published ILS/MLS approach procedures in the configurations A and B;
- The manoeuvring limits far exceed the DGPS flight test procedures for optimal data gathering (navigation/landing systems flight test applications);
- The CBA can be reached in all aircraft wing configurations (A, B, and C) for altitudes MSL between 0 and 5000 metres;
- The CBA can be reached between 7000 and 10000 metres MSL only with configurations B and C; and
- The CBA can be reached at an altitude of 10000 metres only with the configuration C.

An example of the results obtained for the TORNADO-IDS aircraft in configuration C (67° wing sweep) at an altitude of 0 ft MSL (Z = 0) are shown in Figure 7-7, where the envelopes applicable to navigation systems flight test and ILS/MLS precision approach tasks (curved and segmented approaches) are over-imposed to the aircraft TVD and TRD diagrams obtained by analysis.

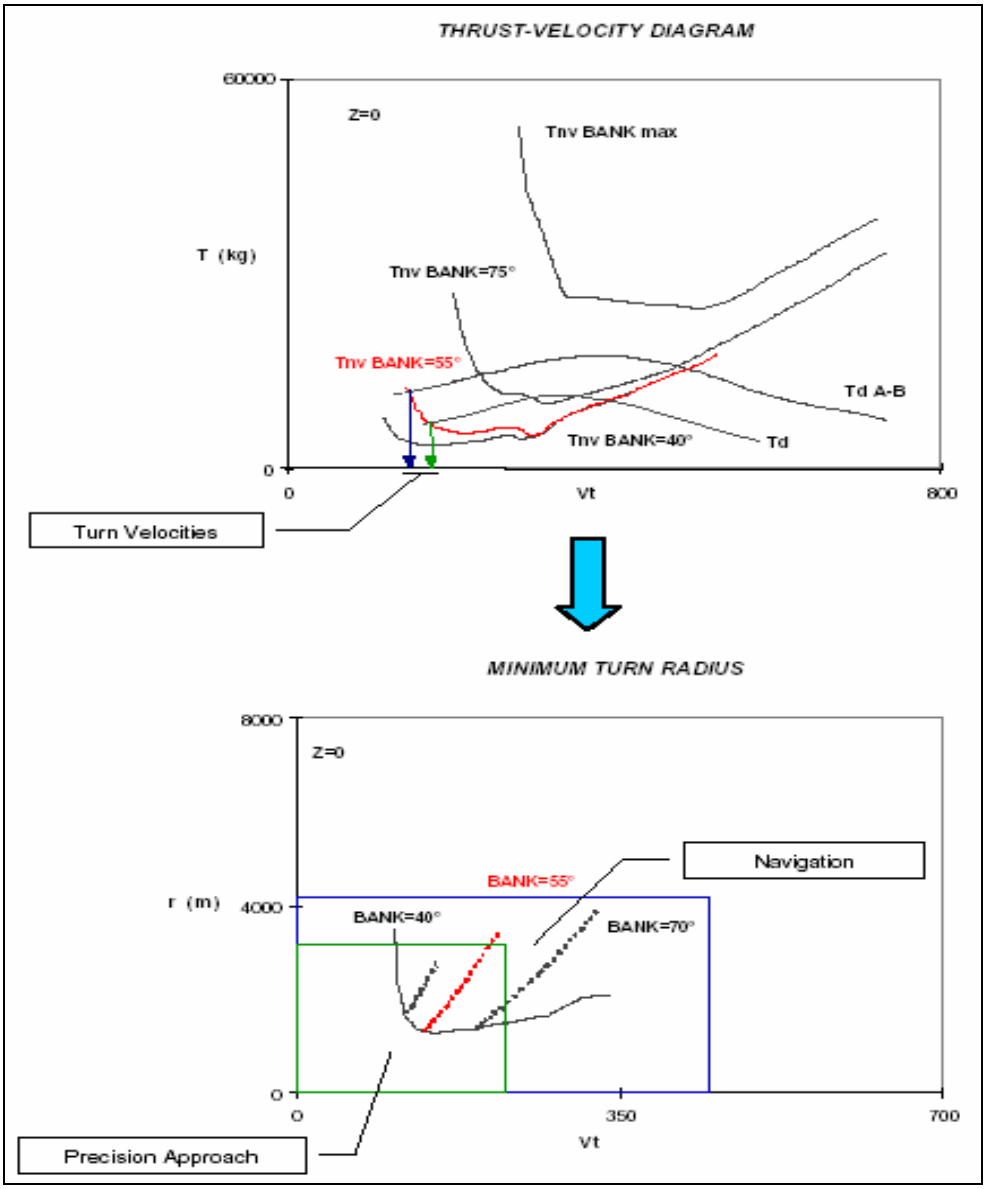


Figure 7-7: Performance Analysis Results (Examples).

7.3.3 Possible AAIA System Architecture

Once the reliability of the mathematical algorithms for AAIA is established, a DGPS integrity augmentation system can be implemented (in the aircraft) for alerting the pilot when the critical conditions for DGPS signal losses are likely to occur (within the specified maximum TTA). The possible architecture of an AAIA system is shown in Figure 7-8.

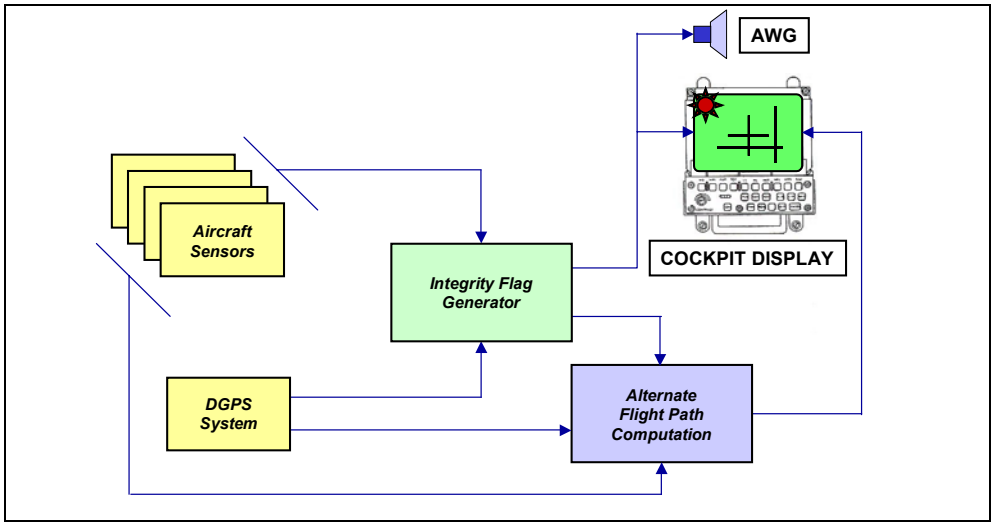


Figure 7-8: Possible AAIA System Architecture.

The aircraft on-board sensors provide information on the aircraft relevant flight parameters (navigation data, engine settings, etc.) to an Integrity Flag Generator (IFG), which is also connected to the on-board DGPS system. The IFG can be incorporated into one of the existing airborne computers or can be a dedicated processing unit. Using the available data on DGPS and the aircraft flight parameters, integrity signals are generated which can be displayed on one of the cockpit displays and/or sent to an Aural Warning Generator (AWG). At the same time, an alternate flight path is computed taking into account the geometry and the tracking status of the available GPS satellites, together with the current mission requirements and the information provided by the aircraft sensors.

A possible cockpit integration scheme for the AAIA system on-board the TORNADO-IDS aircraft is shown in Figure 7-9.

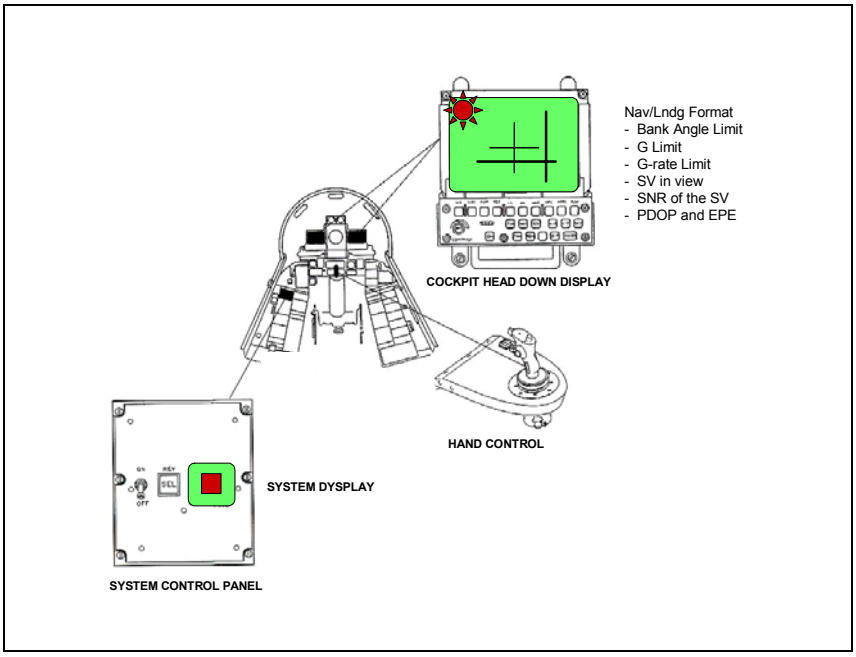


Figure 7-9: Example of AAIA Cockpit Integration.

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