DEPARTMENT OF AEROSPACE ENGINEERING

UNIVERSITY OF GLASGOW

PROPOSAL FOR

A STUDY ON THE USE OF DGPS FOR THE DETECTION OF "SOFT-OVER" ATTITUDES IN AIRCRAFT

FOR

THE CIVIL AVIATION AUTHORITY

SAFETY REGULATION GROUP

ARB FELLOWSHIPS AND RESEARCH GRANTS

CONTENTS

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1. Introduction.

This proposal addresses the application of Differential Global Positioning Systems (DGPS) as a means of augmenting an aircraft's attitude reference information with the purpose of preventing hazardous "soft-over" manoeuvres and flight-path divergence. Soft-over refers to an unintentional, co-ordinated flight, manoeuvre which results in the aircraft adopting attitudes and trajectories that are outside the permitted operational flight envelope. As the manoeuvre is co-ordinated, the pilot, without the aid of attitude instrumentation, would be unaware that his vehicle is diverging from a desired trajectory. Although the conventional, self-contained, inertial attitude-measuring instruments with integral displays that are used for flight control have an established history of reliability, they are unsuitable for the modern automated aircraft. In modern aircraft, which employ complex multiple-mode automatic flight control systems, there is both physical and functional separation between the attitude sensor and the pilot's display. These separations challenge the reliability performance because system complexity and physical separation tend to degrade reliability. Confirmation of this observation is given in some recent aircraft accident investigations where it is reported that loss of correct attitude information resulted in catastrophic aircraft failures and loss of human life. The aim of the proposed project is to develop a direct attitude position measurement system using the commercially available GPS services and equipment to provide a cost effective enhancement to aircraft safety.

2. GPS For Aircraft Flight Information And Proposed Objectives

A DGPS attitude measurement provides information that is absolute in the sense that it is estimated directly from an aircraft's local vertical. This contrasts with an inertial attitude measurement where the vehicle's acceleration is integrated as a function of time from an initial reference position. Further, because DGPS attitude measurements are not derived from the host aircraft's accelerations, the problematical effects of gravitational accelerations are not an issue.

Although DGPS could be considered in several flight-control augmentation applications, the proposed project will focus on the issue of using DGPS receiving equipment to monitor an aircraft's flight control activity and announce the onset of hazardous "soft-over" manoeuvres. The specific objective for this study is the definition of a system of C/A code GPS receivers, signal-processors, information displays and data processing algorithms for the detection, warning and/or prevention of "soft-over" attitudes in fixed wing aircraft. The definition will include DGPS processing algorithms for attitude measurement, manoeuvre detection and a target specification for a flight qualified system.

By confining the application of the proposed DGPS to the role of monitoring the flight-critical systems without a requirement to couple into qualified equipment the reservations regarding integrity and reliability of GPS systems will be avoided. Apart form addressing the issue of "soft-over" manoeuvre detection, the proposed DGPS system exposes GPS technology in a flight systems application. Applications of this kind are necessary for the advancement of flight-critical GPS systems in future generations of aircraft.

3. Technical Aspects

A diagram of the proposed DGPS attitude measurement scheme, that will be developed for the study is shown in Figure 1. The diagram shows a triad of DGPS receivers that are separated from each other by known distances or base-lines. These base-lines are parallel with the horizontal-plane axes of aircraft. A differential vertical-displacement from a reference plane is sensed by the GPS receivers is and mapped through simple geometric relationships to the aircraft's pitch and roll attitude angles. Unlike the estimates of roll and pitch attitude which can be obtained from a single GPS navigation message the estimate of yaw attitude angle will require a minimum of two GPS messages. The individual GPS receivers are commanded from the controller and attitude processor to track the same group of satellites from an observable GPS constellation. To achieve the best estimate of an aircraft's attitude, the DGPS will operate in two modes. The first mode is referred to as Relative Height Tracking (RHT) and the second mode is called Deduced Height Tracking (DHT).

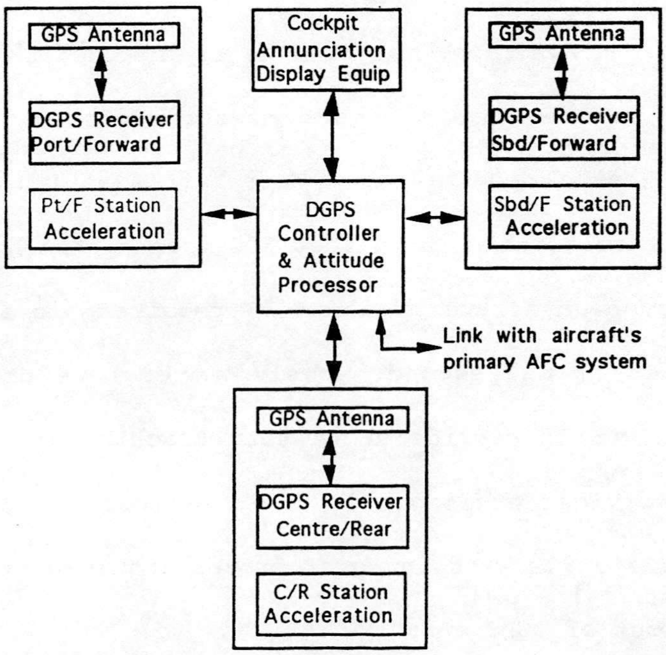

Figure 1: The proposed DGPS attitude measurement scheme

In the RHT mode, the attitude of the aircraft is determined from the differential heights of the DGPS receivers. In the proposed operation of the relative height mode, the GPS receivers are directed to track a satellite configuration that minimises the Vertical Dilution of Precision (VDOP). This contrasts with the conventional geographic position determining application of GPS, where receivers track the satellite group that gives the best Geometric Dilution of Precision (GDOP).

The minimum VDOP is determined by incorporating a conventional GPS navigation mode in the DGPS attitude processor. A previously computed record of GPS satellite positions for the measured position and local time co-ordinate will allow the computation the satellite group that gives the instantaneous best VDOP.

For the DHT, the attitude of the aircraft is deduced from the instantaneous geographical local-level position of the DGPS receivers. From this measured information and the known locations of the receivers on the aircraft, an estimate of the aircraft's attitude can be deduced. This deduced height mode is included because the well known erratic nature of GPS height measurements may mean that an indirect solution of determining an aircraft's attitude may produce more reliable results than the direct RHT mode approach.

The data up-date rate of the DGPS receivers is anticipated to be of the order of one second. Accelerometers are collocated with each DGPS receiver to provide short term tracking of the aircraft's attitude. The devices envisaged for this purpose are relatively low cost solid-state units with integral processing to give an effective continuous output of DGPS data.

The DGPS measured attitude of an aircraft is presented to the pilot. The proposed study will include an evaluation of different methods of presentation. These include various combinations of visual and audible annunciation.

In addition to processing the DGPS data into aircraft attitude and trajectory information, the DGPS controller will include the facility of incorporating algorithms for on-line self-test and GPS system monitoring.

The primary objective of the study is the evaluation of DGPS for detecting "soft-over" manoeuvres. However, the fact that it is uncoupled from all inertial driven Automatic Flight Control (AFC) system functions means that its operation can be extended as an independent monitor of the flight control activity and AFC modes selection.

3.1 Target Attitude Measurement Accuracy

The target measurements accuracy for the DGPS attitude measurement system, shown below in Table 1, is based on the results of work carried out by the proposer for an unmanned vehicle application. The specification is based on the NAVSTAR GPS and should be achieved through the use of novel interferometry and Doppler signal processing techniques. In principle the proposed system is generic and could be based on any GPS (currently GLONASS but future civilian controlled GPS would also be suitable). The proposed system will use the C/A code Standard Precision Service (SPS).

Attitude: 1 metre baseline	0.30 deg (RMS)
3 metre baseline	0.10 deg (RMS)
5 metre baseline	0.06 deg (RMS)
Position	100 meters (SEP)
Differential Position	3-5 metres (SEP)
Velocity	0.2 metres/s (RMS)

For three angle attitude (Azimuth, Pitch and Roll) determination a minimum of three GPS satellites must be in view.

Table 1: Target accuracy for the DGPS attitude system

3.2 Tasks For The Proposed Study

Task 1 The Development Of A Aircraft Flight Simulation.

A generic six degrees-of-freedom, non-linear, flight simulation will be adapted to incorporate the DGPS attitude measurements system. The particular requirements of the simulation will be routines that translated the centre of gravity motion to the stations that are defined as the GPS receiver reference locations (the GPS antenna positions). This study-task will examine possibility of developing the simulation for a hardware-in-the-loop (HITL) evaluation. The proposed configuration for both types of simulation is shown in Figure 2.

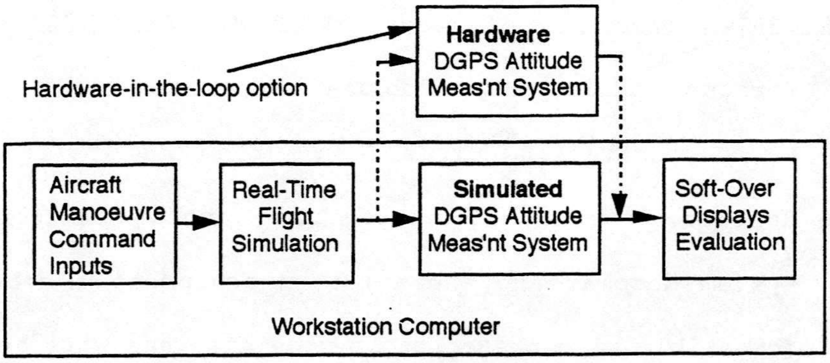

Figure 2: Proposed evaluation apparatus for the DGPS attitude measurement study.

The option of a hardware-in-the-loop simulation is subject to the availability of a suitably configured DGPS receiver equipment and funding resource.

Task 2 Development Of "Soft-Over" Attitude Detection Algorithms.

The development of real-time algorithms and a processing environment for both the Relative Height Tracking (RHT) and Deduced Height Tracking (DHT) modes. For this task it is proposed to consider the facility of GPS and DGPS in the role of monitoring an aircraft's guidance and control activity. Methods of associating data from high-bandwidth, low-accuracy acceleration responses with the low-bandwidth, high-accuracy DGPS position data for the purpose of aircraft flight guidance and control will be examined. The "soft-over" detection algorithms will be evaluated against simulated flight trajectories and the option of introducing measured flight trajectories will be examined.

Task 3 Design Of A Soft-Over Manoeuvre Annunciation Display.

Various display and annunciation schemes will be examined. For demonstration purposes an autonomous instrument will be defined. For final integration into operational aircraft system display and annunciation equipment a scheme that is compatible with the multiple-mode displays will be defined.

Task 4 Definition Of A POC Demonstrator.

The definition and design of an airborne DGPS attitude-measurement-system proof-of-concept demonstrator. The objective of the design will be an apparatus that can be fitted an aircraft and function independently from the other systems in a trials aircraft. The only fit-for-flight qualification that should be necessary for the purpose of flight testing the "soft-over" attitude detector will be an EMC emission test.

4. Previous Experience And Background

The proposer leads a small group within the University Of Glasgow's Department Of Aerospace Engineering. The group have been engaged in research that is concerned with the application of GPS and DGPS systems. These applications are directed towards the use of GPS in real-time guidance and control. The particular characteristic of these applications is the requirement of a measurements band-width that a stand-alone GPS cannot meet. Thus the focus of the group's research are data association algorithms that augment low band-width GPS data with high band-width inertial data. Some of the algorithms that will be developed for the proposed project will evolve from this activity of group's current research. Of particular relevance to the proposed "soft-over" detection project is the groups work on identifying and tracking the NAVSTAR satellites that yield the best GDOP, VDOP or HDOP for any given location and time co-ordinate.

The proposer is currently undertaking research work for companies in both the systems and airframe manufacturing sectors of the aircraft industry. These association have revealed the emerging concerns regarding the issue of "soft-over" manoeuvres and aircraft safety.

5 The Work Programme And Resource Requirement

The required resource is to support one researcher working on a three year programme. The manufacture of hardware-in-the-loop option, mentioned under Task 1, is not included in this funding profile.

The programme has four milestone that identify the completion of each of the four tasks. Interim reports will be produced at the conclusion of each task. The programme concludes with the delivery of a final report. The report will include the all the algorithms, computer programmes, system design data and the definition of a POC demonstrator.

The proposed programme schedule is shown as bar-chart in Figure 3. Task duration is shown as the bold line with the slack margins shown as a broken line. The four programme milestone are scheduled to occur eight, twenty-two, thirty and thirty-four months from the start of the project.

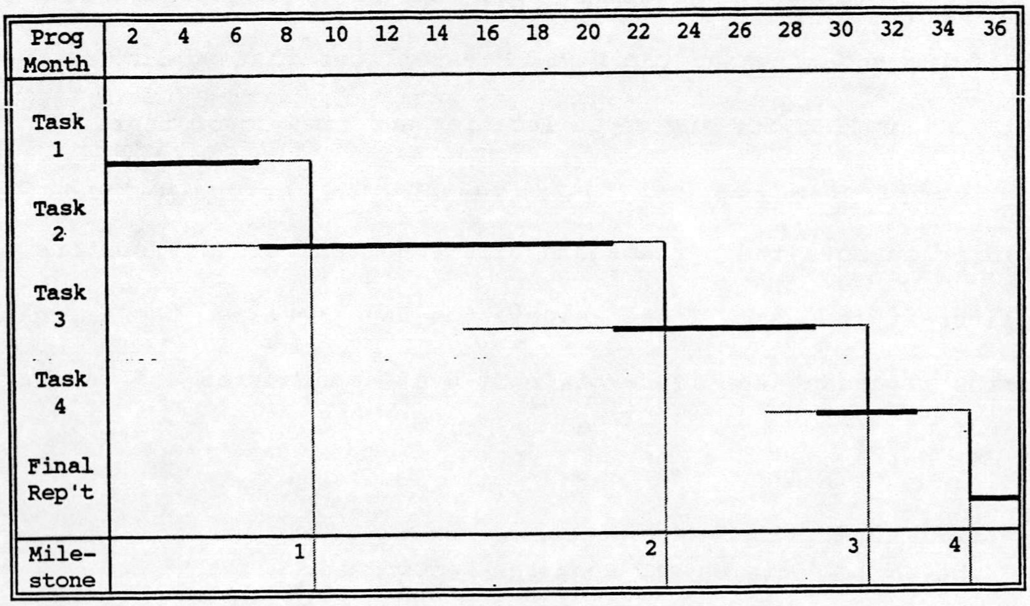

Figure 3: Proposed programme schedule

6. Project Costs

It is proposed to undertaken the project as a post-graduate study that leads to a University of Glasgow Ph.D. The resources and programme schedule are devised to complete the project in a three year frame. Funding is required to support the equivalent of a University of Glasgow post-graduate researcher with computer and technical services support. Table 2 shows the cost estimates for the three year programme.

Resource	Year 1	Year 2	Year 3	Item Total
Researcher/B-Fee	£11500	£11788	£12083	£35371
Travel & Subs	£1200	£800	£800	£2800
Comp/Tech Assist	£2000	£1000	£1000	£4000
Comps & Equip	£7000	0.0	0.0	£7000
Annual Total	£21700	£13588	£13883	£49171

Table 2: Resource funding estimates