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A GENERAL PURPOSE STABILISED BALLOON PLATFORM

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ABSTRACT

A requirement exists in the U.K for a general purpose stabilised balloon platform. To meet this requirement MSDS designed and are now developing a three axis stabilised platform capable of being operated in three modes of increasing accuracy. The system relies on angular motion sensing for primary feedback with linear accelerometers, magnetometers and a star sensor for positional information. When under primary control the system will acquire and stabilise on any accessible part of the celestial sphere, a video verification systems is included to provide pointing confirmation. Under improved accuracy control the star sensor is used to lock onto a target star.

1. INTRODUCTION

The Science Research Council awarded MSDS Ltd a Design Study contract to propose a suitable system to meet a requirement in the United Kingdom for a general purpose Stabilised Balloon Platform onto which varied astrophysics experiments could be mounted with the minimum of integration complexity. This short paper is based on the Design Study which has led to a development contract being awarded which started in January and should lead to a flight of a prototype platform in September 1975.

The basic requirement is for a platform capable of being orientated to degree accuracy in a coarse mode with the facility for pointing at a visible source to arc minute accuracy and then, later, utilising experiment derived pointing error signals, to arc second accuracy. A facility to offset the experiment from the visible source in the arc minute mode by up to 5 degrees is included, with an optional extension to point towards the sun if required. To verify the pointing direction of the platform it is proposed to include a video verification system to provide a slow scan image of the star field towards which the platform is being orientated.

2. SYSTEM REQUIREMENTS

General

The control system will orientate the three axes of a balloon payload with respect to a specified accessible part of the celestial sphere. It will be controllable by telecommand and will be capable of observing and verifying an indefinite sequence of targets.

The system will ultimately be capable of being flown in three modes:

(a) Degree Guidance Mode

Using a primary control system to acquire and stabilise on any accessible part of the celestial sphere.

(b) Arcminute Guidance Mode

Using a star sensor or, if necessitated by later experiments, a sun sensor, to improve the system accuracy by locking onto the visible object. The target area may not contain a suitable guide star and it may be necessary to offset the star sensor. The rotation of the field of view due to diurnal rotation will then be removed by telecommand or otherwise.

(c) Arcsecond Guidance Mode

Using an experimenter's error signal in order to give a further improvement in pointing bias.

Applicability

The Stabilisation equipment may be used with a variety of inertial loads other than the nominal 250Kg mass at a radius of gyration of 0.7m.

Provision will be made for adjustment of the control loop gains and any other parameters affected to accommodate experiment masses from zero to the maximum of 500Kg without degradation of accuracy.

Performance - Definitions

If a record is made of the pointing error over a typical observation period of 1 hour and a least-squares fit is made to this record by adjusting the parameters a and b of the time function a + b.t, then the bias error is defined as the term, a, the drift error as the coefficient, b, and the noise error as the rms deviation remaining after the least squares fit has been made. The term lateral refers to the elevation axis and the orthogonal axis of star-sensor boresight line movement. The term twist refers to motion of the platform about the boresight line of the star sensor (in the degree guidance mode, about the nominal experiment boresight line).

Performance - Degree Guidance Mode

In this mode the following limits will not be exceeded:

Lateral	Bias	1°
Lateral	Drift	6 arcminutes/hr
Lateral	Noise	1 arcminute rms
Twist	Bias	1°
Twist	Drift	unspecified
Twist	Noise	1 arcminute rms

Performance - Arcminute Guidance Mode

In this mode the following limits will not be exceeded:

Lateral	Bias	2 arcminutes
Lateral	Drift	1 arcminute/hr
Lateral	Noise	10 arcseconds rms
Twist	Bias	24 arcminutes
Twist	Drift	12 arcminutes/hr
Twist	Noise	2 arcminutes rms

Performance - Proposed Arcsecond Guidance Mode

Although forming no part of the present contractural requirement, the system developed under the present contract is expected to be capable of later extension to achieve the following performance limits when fed from a suitable error sensor forming part of the experimenter's optical system:

Lateral Bias	1 arcsecond
Lateral Noise	2 arcseconds rms

Angular Range Requirements

In azimuth the package will have unrestricted angular range. In elevation the package will be capable of directing the boresight axis of the experiment (in the plane of the platform and perpendicular to the elevation axis) from 0° to 95° from the local vertical, however, operation with a star sensor is not required for angles under 20° to the local vertical.

If the roll axis is defined with respect to a nominal (Mean) elevation of the boresight axis of $32\frac{1}{2}^{\circ}$, as the projection of the boresight line into the plane normal to the local vertical, and bearing in mind that the roll axis so defined will depart from the horizontal for elevation angles other than the nominal, then the angular freedom required about this roll axis is a minimum of $\pm 15^{\circ}$.

Video Verification

A video verification system is required to confirm the pointing attitude of the platform. The system will have a field of view and sensitivity sufficient for a mean probability that 10 stars of sufficient magnitude can be viewed in order that the pointing direction can be confirmed by a star pattern recognition technique.

3. CONFIGURATION

In designing the Balloon Platform every attempt has been made to make it general purpose so that a variety of experiments (of different weights and sizes) could be flown with the minimum of complexity and time required for the integration operations. Unlike a number of stabilisation systems where the experiment is orientated within the gondola the present design allows for the whole platform/gondola to be rotated on a three axes gimbal cluster suspended below the balloon. This approach has the very distinct advantage of producing a very flexible system but does produce some control problems which will be discussed in a later section.

The complete system can be considered as two sub-systems namely the mechanics, consisting of the platform, the gimbal cluster including the actuators and the sensors comprising linear accelerometers, magnetometers, and star sensor.

To facilitate easy repair the platform will be a hybrid made up of straight aluminium I-section extrusion and a panel of honeycombe sandwich (aeroweb) material. Equipment mounted on the platform would be rather vulnerable should the platform roll on landing, so a protective cage of fibre glass tubes will be fitted. This will also arrest the suspension column so that it does not collapse onto equipment after the parachute has been released. An advantage of using fibre glass tubes is that they can be repaired in the field with an epoxy glued bandage so avoiding the use of welding.

The gimbal cluster assembly is the heart of the stabilised platform providing both rotational and translational movements. The assembly provides 360 degrees freedom in azimuth, plus 70 to minus 5 degrees in elevation and plus or minus 15 degrees in roll. The gimbals are orientated to the required angles by 9 inch diameter "on shaft" slab D. C. motors. Experiments will normally be mounted directly onto the platform and associated equipment such as the tele-package, batteries etc. arranged to maintain balance. In order to reduce the gimbal motor size a cross slide translational mechanism is incorporated into the gimbal assembly to ensure that the centre of mass of the entire controlled payload remains below the balloon suspension point, so largely eliminating out of balance torques. The translational mechanism will consist of a linear slide formed by a three point support, the axis being defined by 2 recirculating ball bush units working on a hollow tubular shaft and rotation about the bushings being prevented by a third location consisting of a pad of rollers working either side of a parallel platform.

The slides are duplicated with one on top of the other to provide 2 orthogonal axes. The rotational gimbal assembly and hence the platform suspension point will be driven along the slides by means of cranks thus removing the necessity for limit stops. In order to reduce the effort required to drive the weight of the platform along the slides when inclined, a 35 degree wedge will be included between the plane of the slides and the platform so that for the platform elevation range of minus 5 to plus 75 degrees the cross slides are inclined by plus or minus 40 degrees to the horizontal.

Suspension of the platform gimbal assembly to the balloon suspension train is by means of a column. The primary functions of the column are to enable the gimbal rotary drives to react upon the suspension train to produce pitch and roll torques and also to position the azimuth sensing magnetometers away from the platform borne equipment in order to reduce magnetic disturbances to an acceptable level. To control float altitude it is necessary for a balloon package to carry a considerable mass of ballast which can be released on command. This ballast presents a problem because if mounted on the controlled platform it would change the centre of mass considerably when released. To overcome this it is proposed to provide accommodation for a ballast container within the column assembly above the gimbals and to arrange for the ballast to be safely ejected below the platform via the hollow centre tube.

Primary stabilisation feedback for the rotational gimbal motors is provided by an angular motion sensing package mounted close to the gimbal assembly on the platform. When under degree mode control positional information is obtained from magnetometers for azimuth and linear accelerometers for elevation and roll. A two axis fluxgate magnetometer is used with the elements lying in a nominally horizontal plane (a third axis may be included to provide for electronic orthogonalisation of the elements). The outputs from the magnetometer are resolved by multiplying DACs whose gain is controlled by the sine and the cosine of the required azimuth attitude (fed by telecommand) and summed to provide a single error signal having a stable null at the required azimuth position. Positional information for control about the other two axis is obtained from a three axis linear accelerometer package sensing the three components of the earth's gravitational field resolved into the axes of the platform. The outputs from the accelerometers will be resolved by multiplying DACs in the proportions necessary for a particular platform attitude in a similar way to the magnetometers. To avoid alignment problems between the accelerometer package measuring actual position and the experiment which is required to be pointed in a particular direction it is proposed to mount the package on or within the experiment.

When under minute mode control, high accuracy position signals are derived from a star sensor aligned to and mounted on or within the experiment. The sensor provides 2 error signals, one about the elevation axis and the other about the orthogonal axis of the boresight line movement. The elevation error can be used to control the elevation gimbals direct but the orthogonal error controls both the azimuth and roll gimbals in proportions depending on the elevation angle. The star sensor has an AGC system with a range of 60 dB making it possible to view stars between minus 1 and plus 5 magnitudes (visible). The equivalent noise angle when viewing a +5Mv star is 5 arc seconds rms in an 8Hz bandwidth. Should an experiment require to view the sun, then, when under minute control, the star sensor is to be replaced by a twin axis sun sensor.

In addition to the units within the main sub-systems a facility for providing offset guidance is included. The star (or sun) sensor will be mounted on a two axis gimbal assembly capable of being rotated through plus or minus 5 degrees in each axis with a resolution of 1 arc minute. Control of each gimbal will be by means of precision lead screw driven by a stepper motor. Final position will be determined by counting the number of stepper motor drive pulses from a datum null as defined by a variable reluctance pick-off.

To assist in the ground control of the balloon platform whilst in flight and to verify to an experimenter the area of sky that his experiment is viewing it is proposed to include a video verification system. The system will consist of a standard ruggedized closed circuit television camera and a suitably modified control unit to provide a very slow scan rate so that the video signal can be relayed from the balloon by means of a low bandwidth telemetry link. The camera will have a field of view of approximately 120 square degrees and will be capable of discriminating stars down to magnitude (visible) plus 5. The line angular resolution and the resolution along a line will be less than 3 arc minutes. A complete frame will be scanned in less than 20 seconds and the positions of 10 stars monitored. In order to scan a complete frame and yet monitor only 10 stars the system video gain will be adjustable by telecommand so that the limiting magnitude can be varied from plus 1.5 to plus 5 (visible) in 7 increments.

4. CONTROL LOOP CONFIGURATIONS

The stabilised balloon platform utilises gimbals which complicate the control loops because of cross coupling and interaction. The system at present envisaged has sensors mounted on both the platform and the suspension, their errors being routed to the gimbal control motors in proportions depending on the elevation angle. The elevation control loop is the only one to have a unique set of sensors feeding its controlling motor at all times. To avoid ambiguity it is necessary to define two sets of axes, one set for the gimbals and the other for the platform. The gimbal axes are defined as azimuth, elevation and roll whilst the platform axes are defined as twist, elevation and yaw.

Considering the elevation control loop for the degree mode, primary stabilisation is by means of a rate loop consisting of a multiple integrator and a notch filter producing integral control of 4th order. Positional information derived from summed resolved accelerometer signals is suitably shaped to give a high order roll over and summed into the rate loop as a velocity demand. In view of the large platform weights envisaged and the corresponding loading of the gimbal bearings leading to high bearing friction it is proposed that the motors be pulse driven. Instead of a gradual build up of motor torque until it overcomes stiction the motor will be pulsed all the time so that in theory the bearing is never stationary. A pulse width modulator is proposed producing pulses (both positive and negative) at a constant frequency with varying width depending on the analogue error input from the error processing circuits. The use of a pulsed motor drive has the additional advantage that a simple power amplifier can be used, required to operate in only two states, on or off. Dissipation within the amplifier is kept to a minimum and parasitic instability problems are avoided.

In order to keep the gimbal control motors down to a reasonable size and yet be able to cope with reasonable margins of centre of mass uncertainty the cross slide system has been incorporated into the gimbal assembly to maintain the centre of mass below the platform suspension point.

It is proposed that a cross slide mechanism should be brought into operation when the torque required from a gimbal motor exceeds 30 per cent of its stall torque. There seems little possibility of the platform receiving a sudden rate input which would demand a restoring torque greater than that available from the gimbal motors but large position errors will exist when a new platform attitude is demanded and these will have to be limited so that not more than approximately 60 per cent of the motor torque is demanded. In practise the slewing rate of the platform will be governed by the speed at which the cross slide system can follow the centre of mass offset giving rise to the large demanded motor torques.

The roll control loop is similar to the elevation the only difference being that the rate error is derived from a pair of gyros mounted on the platform, the proportion from each depending on the elevation angle. At present it is proposed to mount a bank of sine/cosine potentiometers on the elevation gimbal shaft but since only gain parameters are involved a more elegant solution is being sought to reduce the number of interconnections.

The azimuth loop is very different from the other loops since the torques involved are lower. Rate signals are again derived from a pair of sensors after suitable resolution by the elevation angle. The position signals are derived from the magnetometers.

Minute mode guidance is achieved by transferring the positional control to the star sensor wherever possible. In the case of the elevation control loop this can be done all the time but the proportion of star errors feeding into the other loops is again dependant upon the elevation angle.

In the ultimate mode of arc second guidance the star sensor error signals will be replaced by signals derived from within the experiment or at least utilising the same primary optics in order that bias errors due to alignment inaccuracies can be reduced to a minimum.

5. CONCLUDING REMARKS

It is hoped that this brief paper gives some idea of the type of platform that Marconi are now developing and of the performance that is anticipated. Once developed and in service it will provide many experimenters of different disciplines with a general purpose platform onto which they can mount their experiments with the minimum of interface problems leaving them free to concentrate on instrument development and hence to further their scientific research.

Whilst a complex problem to model a representative balloon platform including effects caused by the suspension train early simulation results have shown the system noise to be less than 2 arc seconds peak to peak. These results were obtained based on a model including simulated ball races with the usual high stiction values. The possibility of incorporating "flex pivots" with their linear friction/displacement characteristic is being investigated which may lead to a further improvement.

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DISCUSSION SUMMARY — PAPER 4.8

A question was asked about how a flex pivot works. It was described as a suspension arrangement having a linear restoring torque for angular displacements and a linear restoring force for lateral displacements. One cylinder is suspended inside another with these pivots. (Ordinarily the lateral displacements are very small.)

In answer to inquiries about the cost, the initial development cost was estimated at $450,000 and the production platform cost tentatively at $50,000.

The mass is estimated to be 300 kilograms without the telescope and without NCAR telemetry.

The two experiments from British Universities proposed for initial flights on the platform are an infrared telescope and an ultraviolet instrument. Work on the platform was started January 1, 1974.