Ferranti's Lightweight Inertial Platform

A Description of the Lightweight Inertial Platform Produced by Ferranti Ltd. for Use with the Ferranti Lightweight Inertial Navigation System and as a Reference System for Aircraft, Space Vehicles and Ships

The January issue of AIRCRAFT ENGINEERING *contained a comprehensive account of the inertial activities of British companies (Ref. 2) including descriptions of the various gyros, accelerometers and platforms currently being manufactured. Although the inertial activities of* Ferranti Ltd. *were covered and the* Ferranti *type* 100 *intermediate stable platform was described in detail, only passing mention was made of the* Ferranti *lightweight platform. This article rectifies that omission.*

THE *Ferranti* lightweight platform, which is designed and manufactured at *Ferranti's* Edinburgh laboratories, was developed as a private venture. A four gimbal, fully-aerobatic, lightweight design, developed primarily for use in aircraft, the platform is also suitable for use with any system requiring a high-accuracy inertial reference, and is the heart of the *Ferranti* inertial navigation system.

The platform and navigation system are currently being considered for several projects both military and civil.

Prototype platforms with associated electronics and navigation computers are undergoing extensive testing and to date experience with this system includes: 1,500 hours laboratory running, 1,000 hours running in a light road vehicle, 120 hours flying in a Dakota, and

REFERENCES TO LITERATURE

(1) J. A. Lees, 'Aircraft Inertial Navigation', AIRCRAFT ENGINEERING, Volume XXXVI, No. 1, 419th Issue, January 1964, p. 2.

(2) 'Inertial Guidance—The British Scene' AIRCRAFT ENGINEERING, Volume XXXVI, No. 1, 419th Issue, January 1964, p. 10.

40 hours flying in a Canberra. An important feature of the system is the inclusion of a fully-automatic alignment system in the platform electronics.

PLATFORM AND ASSOCIATED EQUIPMENT

FIG. 1 shows the basic platform in its standard configuration. However, the platform is sufficiently flexible to be used in a variety of axes and systems and can be coupled to an analogue computer (as in the standard form) or to a digital computer as required.

As far as the platform itself is concerned it carries the following:

Three single-axis, floated rate integrating gyros.

Three single-axis, force-feedback accelerometers and associated pre-amplifiers.

An azimuth fan—this being a small cooling fan used to circulate helium to the instrument cluster, and

A temperature control unit.

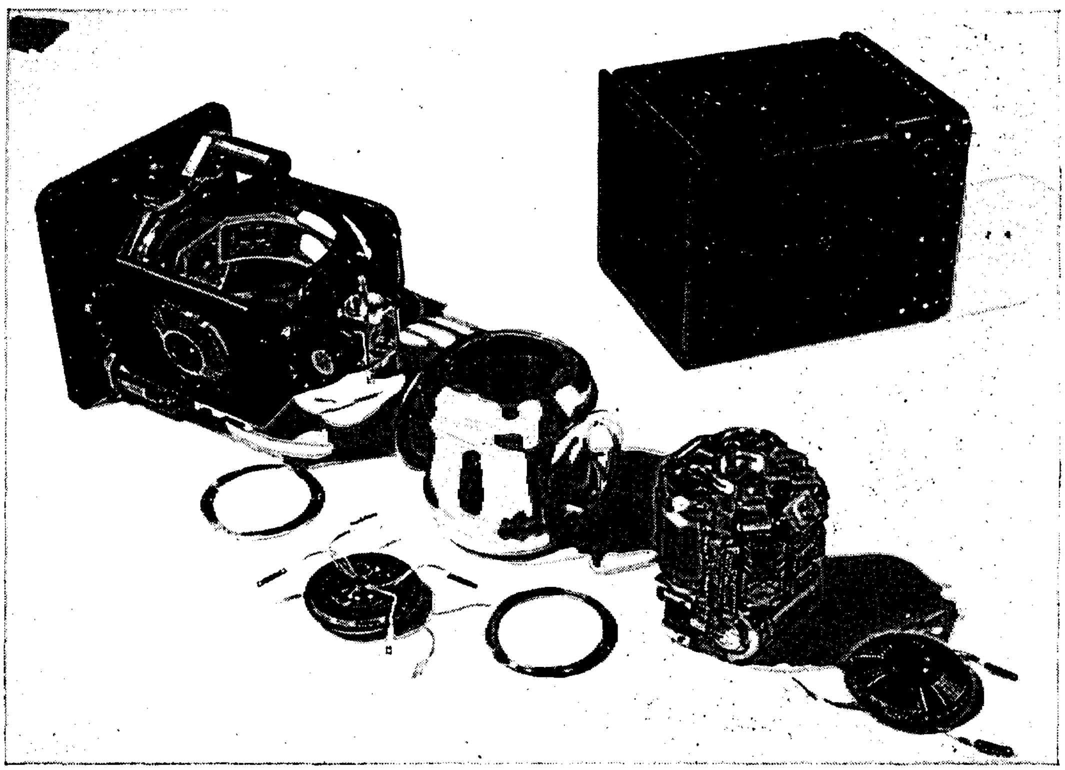

Fig. 1.—The Ferranti lightweight inertial platform which is a three gyro, four gimbal platform featuring full inertial capability, complete aerobatic freedom, direct a.c. motor gimbal drive, minimum size and weight, proven performance, engineered reliability and service, and automatic gyro compassing in noisy environments.

The input axes of one accelerometer and of one gyro lie along each of three orthogonal axes—these being designated North/South, East/West and Vertical.

In the standard system the platform is Schuler-tuned in vertical and North-slaved in azimuth. The vertical to which the platform is erected is the local mass-attraction vertical.

The North/South and East/West gyros are mounted with their output axis vertical in order to minimize *g*-dependent drift terms. The azimuth gyro, by its function, has its input axis vertical and so its drift rate includes any *g*-dependent drifts.

The platform is mounted inside a four-gimbal array and the four gimbals, named from the platform outwards, have the following degrees of freedom:

Gimbal	Freedom
Yaw or azimuth	Unlimited
Inner roll	± 12 deg.
Pitch	Unlimited
Outer roll	Unlimited

Also included in the basic package are: a heat exchanger, a gimbal direct drive a.c. motor and synchro or resolver with an accuracy of ± 2 minutes of arc on each of the azimuth, inner roll and pitch gimbals, a motor and gear drive with synchro or resolver having an accuracy of ± 2 minutes of arc on the outer roll gimbal, and four Size 8 components such as synchros potentiometers, resolvers and/or encoders —gear driven at 1 to 1 with ± ¼ deg. accuracy.

In addition to the basic platform, the system includes the following closely associated electronics: three accelerometer capture amplifiers, three first integrators, four servo amplifiers and spin motor supplies. The power required by the platform is 200 volts, 400 c.p.s. (100 watts) and cooling air at a temperature of less than 35 deg. C. is also required—a representative mass flow being 1·5 lb./min. at 35 deg. C. or 0·3 lb./min. at 10 deg. C.

Gyroscopes

The most critical component of this, and indeed any, platform is the gyro since the type of unit chosen dictates both cost and accuracy. In the case of the *Ferranti* lightweight platform two types of gyro are available.

(a) the type M.2519, a *Kearfott* design manufactured under licence by *Ferranti*, is a single-axis miniature beryllium rate-integrating gyro having full inertial capability. It is considered that this gyro probably represents the best accuracy attainable in this class of instruments at present available.

Drift rates are as follows:

Long term drift rate over at least five warm-ups	
Input axis vertical	0·06 deg./hr./g.
Output axis vertical	0·01 deg./hr.
Random, or short term drift rate	
Input axis vertical	0·01 deg./hr./g.
Output axis vertical	0·003 deg./hr.
Anisoelastic drift rate	0·02 deg./hr./g^2 (max.)

(b) The *Ferranti* type 122 is a lower performance but cheaper gyro for use where the high accuracies of the

M.2519 are not required. The companies drift rates for this gyro are:

Long term drift over at least five warm-ups	
Input axis vertical	0·25 deg./hr./g.
Output axis vertical	0·04 deg./hr.
Random or short term drift	
Input axis vertical	0·08 deg./hr./g.
Output axis vertical	0·02 deg./hr.
Anisoelastic drift rate	0·1 deg./hr./g^2 (max.)

The two types of gyro are interchangeable since they have the same format and external dimensions. The operating life of the gyros is at least 3,000 hr.

The final gyro combination chosen is a function of the particular application for which the platform is intended, the accuracy required and the cost.

It is worth noting that the two vertical gyros are mounted with their output axis vertical and so the smaller drift figures apply. As the azimuth gyro is mounted with the input axis vertical the g-dependent figures which are larger apply.

The gyros with their input axis lying in the horizontal plane are included in the servo loops which establish the vertical (hence the nomenclature—'vertical' gyros). The drift rate of the vertical gyro with it input axis pointing due East is the prime factor in dictating the accuracy which can be attained in gyrocompassing. The vertical gyros are always quoted as of the same type. This is because the calibration procedure adopted by *Ferranti* employs gyrocompassing on the North/South gyro as well as on the East/West gyro.

Accelerometers

As far as accelerometers are concerned, the platform mounts either two or three single-axis, force feedback accelerometers—*Kearfott* type 2401 or *Ferranti* type FA.2A. The type FA.2A accelerometer incorporates the following design features: (i) use of ceramic for components where the highest possible physical stability is important, (ii) design of pick-off and restoring circuits such that the need for ligaments is eliminated. This is accomplished in the pick-off by employing a bridge circuit and using a single aluminium spade as the sensing elements, while the ligaments on the restoring coil have been made redundant by using the hinge as the conducting circuit to the pendulum. (iii) Use of magnetic attraction to reduce the residual bias to a minimum. This feature eliminates the necessity for the physical bending of a bracket and thus results in a more stable accelerometer. (iv) The design makes allowance for liquid filling if any particular application requires this feature. Liquid filling allows simplification of the associated electronic equipment and the increased internal damping enables the instrument to give accurate reading even when subjected to particularly severe vibration. The FA.2A accelerometer has overall dimensions of 2·12 in. by 1 in. diameter and weighs 0·18 lb. Range of measurement is ± 20 g.

The total weight of the platform package with its cylindrical case is 16·25 lb. and the external dimensions are 7$\frac{3}{8}$ in. diameter by 9 in. long. This weight does not include the vibration isolators. In an alternative version of the platform these are positioned inside the case but in the current configuration they are mounted external to the case so that, if necessary, they can be altered or removed to suit any particular vibration environment. The eight anti-vibration mounts have a natural frequency of 22 c.p.s., in the standard form. The weight and size of the various electronic units associated with the platform will depend on the particular application for which the platform is being used.

However, to provide by way of illustration an idea of how much a typical system might weigh, Table 1 shows the components weight breakdown for a *Ferranti* inertial reference system for the ELDO launcher vehicle up to the time of spinning up of the third stage with the platform functioning in conjunction with a digital computer.

PLATFORM VARIANTS

The four variants of the *Ferranti* lightweight inertial platform are as follows:

Type 700A. This incorporates high quality (*Kearfott* M.2519) gyroscopes in the inertial platform. The platform and associated electronics are contained in a rectangular package.

Type 700B. This incorporates type M.2519 gyros, but the platform and associated electronics are contained in a cylindrical package.

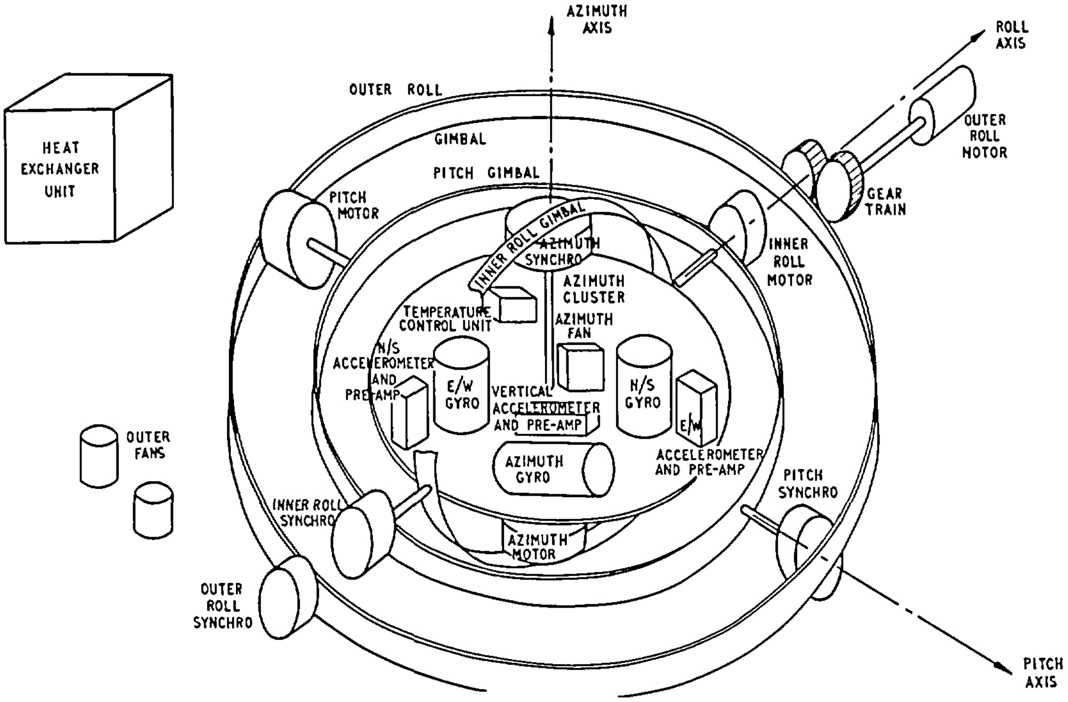

Fig. 2.—Schematic diagram of Ferranti lightweight inertial platform.

Type 710A. The same as the type 700A, but incorporates type 122 gyros, which are cheaper and less accurate than the type M.2519.

Type 710B. The same as the type 700B, except that it incorporates type 122 gyroscopes.

DESIGN PHILOSOPHY

The Platform Package

In the mid-'fifties, the size of inertial navigation gyroscopes destined for aircraft use, was greatly reduced, and, by a process of evolution, single- axis instruments of this type stabilized to a frame size around 2 in. × 3 in. In designing the platform, care was taken to ensure that as many as possible types of this class of instrument could be fitted.

The limiting size chosen for the instrument frame is 2$\frac{1}{8}$ in. × 3$\frac{1}{8}$ in. and a very wide range of instruments fall within this envelope. Further, trunnion of centre flange mounting can be accommodated. Thus the decision on gyro type determined the dimension of the azimuth cluster and the task then was to pack four gimbals around the cluster in a form of construction which gave the strongest and lightest package of the least dimensions.

THE PROBLEMS

Thermal Effects

The gyros do not require a particularly stable or exact temperature environment, but large drifts occur if the thermal gradient across the gyros changes. Consequently, since the attitude of the gyros within the cluster changes as aircraft heading changes, it is essential that a uniform temperature gradient is established within the cluster. For this reason the cluster is enclosed in a sealed aluminium cylinder which is maintained at a uniform temperature by means of a cascaded heat exchanging process. Regardless then of how much the cluster may turn, each gyro is always faced by a smooth aluminium surface at uniform temperature. The heat-exchanging process consists of fan circulation of helium gas within the cylinder, whereby heat is rejected to reduce thermal gradients in the gas and to uniformly reject heat to the outside surface. The method has been shown to be completely effective, and has rendered the platform insensitive to attitude changes as far as thermal effects are concerned.

Magnetic Effects

The instrument cluster, as attitude and heading change, must be maintained in a uniform and constant magnetic field. Any gradients or changes will cause drift.

Because of these effects, conventional, direct-drive d.c. torque motors for gimbal drive could not be used because of the large leakage fields involved. A direct drive, multiple a.c. torque motor was designed with an excellent electrical efficiency, which solved the magnetic problem and removed the high, inertial-loading effects which would have resulted from the use of a gear-driven device.

Size Reduction

To achieve a compact assembly of minimum size and maximum strength, the design is arranged so that the packs which contain the bearings, slip and rings torque motor or synchro occupy a position at the same pitch radius of a sphere. The three innermost gimbals each pivot on two bearing packs. These gimbals are all orthogonal to each other and there are positions through which torque motors, etc. cannot pass as the gimbals revolve. The design makes use of these spaces with resulting maximum size reduction. Another factor is the use of a very light pitch gimbal, which is closely wrapped round the inner roll gimbal. giving an inside-out arrangement, so that the inner roll torque motor and synchro packs can be pushed out, to yield a most compact and symmetrical arrangement.

If gimbals were to be designed to be stiff enough in themselves, excessively large and heavy sections, with difficult and expensive bracing webs, would have resulted. A special bearing configuration was designed which looks like a full ball joint and will take load in both directions as well as provide the necessary rotation. The design aim was to ensure that the platform stiffness was derived basically from the inside gimbal, and the stiffness was then transferred outwards from gimbal to gimbal. This method is the reverse of the conventional one and has proved to be advantageous.

Thus, we have the inner roll gimbal which is a strong, round cylinder, with two bearing packs which contain the very thin and relatively fragile pitch gimbal wrapped around the cylinder. In this way, the thin pitch ring becomes very stiff, as, in essence, the design is a strong ring with two very stiff pin joints to a thin wrap-round ring. In a similar manner, the stiffness is transferred by the next bearing pin to the roll gimbal. This construction has resulted in many advantages, mainly due to the very high natural frequency of over 140 c.p.s. obtained.

SIMPLICITY

A simple design is a successful design, and this has been achieved by standardization and ease of the assembly of the components.

Standard bearing packs, incorporating either a torque motor or a synchro, have been used throughout. There is a torque motor pack and a synchro pack to each gimbal and these packs have the same external appearance and weight. Any one or all of these components can be removed and replaced with a screwdriver, with access easy and unobstructed. No skill is necessary during removal or replacement as all the precision work has been done at the sub-assembly

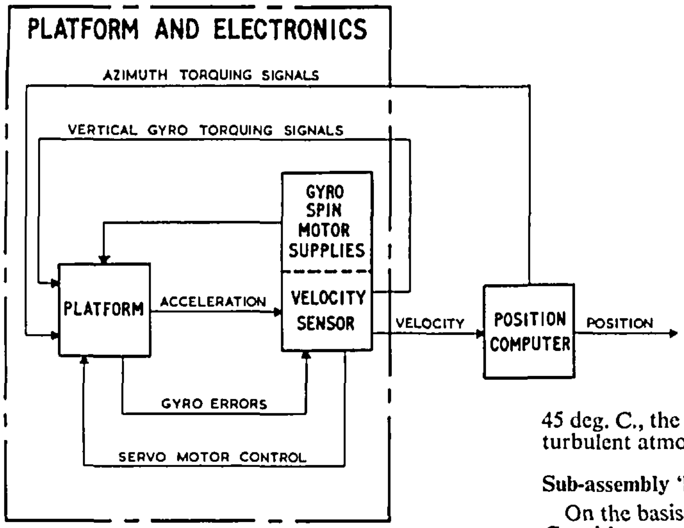

Fig. 3.—Simplified block diagram of Ferranti lightweight inertial platform.

stage, including the accurate setting of bearing pre-loads. No shims are necessary and soldering is unnecessary since all joints are mechanically wrapped.

RELIABILITY

The problem is to engineer reliability. The *Ferranti* philosophy is to set down a series of rules, based on sound engineering experience, coupled with a design flexibility which will enable new state-of-the-art techniques to be introduced without prejudice to the basic concept. It is worth discussing some of these rules.

Gyro bearings

Experience has shown that ball bearings can be made reliable, provided that the basic geometry is studied, and that extra precision in manufacture and assembly, associated with scientific mensuration, is used. By these means it is ensured that the fundamental design principles are maintained throughout the complete environmental envelope to which the assembly is subject. Ten years of development effort has resulted in established techniques, which yield 20,000 hrs. of life from high-speed, ball bearing assemblies.

A final, major contribution to high-speed bearing engineering is the development of the ability to monitor gyroscope bearings, and thereby indicate that a gyro is going to fail before it actually has failed, in the inertial sense. It should be understood, however, that an indicated failure in the inertial sense is nowhere near failure of the gyro as a vertical gyro.

De-rating of Components

The failure rate of components is very much dependent on the electrical loading to which they are subjected, and there is a wealth of information to substantiate this, Thus, a component running at one-third nominal power rating is much better and three times more reliable than one running at full power.

Thus, as a design basis, components are split into two groups:

(i) Those with design ratings of less than 10 per cent of full power rating,

(ii) Those with design ratings of less than 30 per cent of full power rating.

Two-thirds of the system components fall into the first group and the remainder are in the second group.

Similar criteria are applied to voltage rating of components, which also divide into two groups:

(i) Components with design ratings of less than 30 per cent rated voltage.

(ii) Components with design ratings of less than 60 per cent rated voltage.

Sixty per cent of the components fall into the first group and forty per cent into the second.

Temperature and Humidity

Critical parts of an inertial navigation computer must be accurate under all conditions to better than one part in 10^4. This creates a difficult problem to overcome with normal dip-coated electronics.

The answer is to create a stable environment for the components and to have everything within a sealed, pressurized box, with a built-in heat exchanger. In this way, provided an external supply of cooling air is available, at 14 lb,/sq. in. and at not greater than 45 deg. C., the electronics can be maintained in a dry, turbulent atmosphere, at uniform temperature.

Sub-assembly 'burn-in'

On the basis that the equipment will run at 45 deg. C., with component design ratings as already quoted, the assemblies are 100 per cent subjected to at 100 hr. test at:

(i) Full voltage rating,

(ii) At 70 deg. C. ambient,

(iii) With full vibrational environment applied.

This routine test procedure does ensure that, if an equipment is going to fail, it will do so during this period.

SERVICEABILITY

Particular attention has been paid to the following:

(i) Adoption of a form of packaging of units which logically breaks the equipment up into manageable items, and still provides maximum protection against the expected environment with a minimum weight penalty.

(ii) Adoption of maximum reliability sub-unit and sub-assembly packaging which is still repairable within the capabilities of the user.

(iii) Adoption of proved reliable circuits, which support the theoretical MTBF and avoid problems associated with drifts.

(iv) Adoption of high-standard, electro-mechanical assemblies with quoted life in excess of 3,000 hrs. operating in an ideal environment, thereby avoiding problems associated with routine servicing, such as lubrication, etc.

(v) Adoption of printed-circuit, inter-sub-unit wiring, and of wrapped-joint connections, which greatly improves the reliability and simplifies the interconnection problems. In particular, wrapped joints provide the ideal monitoring facility so essential for efficient servicing, by allowing the study of individual current and voltage waveforms without disturbing the assembly.

(vi) Adoption throughout the sub-system of fully-interchangeable sub-assemblies (and common types of circuits when full interchangeability is not feasible), thereby greatly simplifying the problems associated with sub-unit and component spares, and easing servicing procedures.

TEST PROCEDURES

First Line

Dependent on the type of navigation equipment associated with the platform is the type of test facility available. In general, however, the navigation equipment is designed so that the operator is automatically provided with 'Go/No Go' type of test, with the additional facility of fault diagnosis down to sub-unit level in the case of 'No Go', without the assistance of additional personnel or equipment. That is, the first line test facilities are, as it were, built into the equipment.

The system exhibits a pattern of performance during the alignment and check phases which can automatically provide indication of malfunction of the system. This gives the operator a 'confidence check' without any delay. To this can be added, on demand, switched tests which allow isolation of any fault to single unit level.

Second Line

Second line testing calls for a quantity of special-to-type test equipment, which is limited to the provision of unit-operating equipment such as power supplies, input simulation and simulated loads. The self-check capability of the equipment and general avoidance of second line adjustments reduces the amount of sophisticated measuring equipment required. The extensive monitoring facility built into the electronic packaging enables the equipment to be operated without disturbance and permits the use of standard measuring techniques.

Accurate diagnosis and system reporting from first line could simplify the task of further servicing, but provision is generally made for system checking at second line. This is particularly important for the platform, which, it is recommended, should only be checked at second line, and then returned for repair to third line, where environmental and inspection facilities can be provided economically. In the case of electronic units, no problems exist in controlling the environment to the required degree during servicing or assembly.

Third Line

Third-line assembly servicing calls for test equipment whereby items returned from second line may be thoroughly checked and repairs effected right down to component level. This requirement is best met by factory-type test equipment designed to test individual or similar types of sub-units. Although this implies 'special-to-type' test stations, great reliance is placed on normally-standard test equipment to meet the majority of measuring and fault-finding requirements. Provision would have to be made for replacement of platform sub-assemblies, such as gyros and accelerometers, in a reasonably clean environment. Repairs of a more complex nature, such as platform gyro rebuilt, are considered as fourth line tasks on economic grounds.

TABLE I

Ferranti Lightweight Platform—Breakdown of Component Weights and Sizes for ELDO Launcher complete system

Sub-assembly	Individual		No. off	Total	
	Weight	Size		Weight (lb.)	Size (cu. in.)
Basic platform package	16·25 lb.	cylinder 7⅞ in. × 9 in.	1	16·25	440
Anti-vibration mounts	1 oz.	Fit into redundant corner area of cylinder	8	0·5	Fit into redundant corner area of cylinder
Accelerometer capture amplifier	3·75 oz.	2 cu. in.	3	0·7	6
Gimbal servo amplifier	6 oz.	4 cu. in.	4	1·5	16
Spin motor supplies	3·5 lb.	42 cu. in.	1	3·5	42
Power supplies (inc. 400 c.p.s. inverter)	6 lb.	6 in. × 6 in. × 6 in.	1	6·0	216
No. 1 gimbal repeater and resolver	0·5 lb.	2 in. × 1 in. × 3·5 in.	1	0·5	7
Analogue/digital convertor	7 oz.	4 cu. in.	3	0·9	12
Pulse torquing circuit	2 oz.	1·5 cu. in.	3	0·4	5
No. 2 axis repeater	0·25 oz.	2 in. × 1 in. × 1 in.	1	0·25	2
Angle encoders	9 oz.	3 in. diameter × 1·6 in.	3	1·7	30
Case	2·65 lb.	Long ¼ ATR case	1	2·65	2·25 in. × 19·5625 in. × 7·625 in.
Internal structure	6 lb.	Included above	1	6·0	Included above
Batteries	2 lb.	cylinder 43 mm. diameter × 160 mm.	2	4·0	30
Heat exchanger	3 lb.	arranged as convenient	1	3·0	arranged as convenient

Total Weight
Platform (including A.V. mounts) = 16·75 lb.
Associated electronics (including case) = 24·1 lb.
Batteries = 4 lb.
Heat exchanger = 3 lb.
47·85 lb.