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COMMON ATTITUDE POINTING SYSTEM (CAPS)
PHASE 'A' STUDY - FINAL REPORT

VOLUME 1 SUMMARY

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HAWKER SIDDELEY DYNAMICS LIMITED
MANOR ROAD HATFIELD HERTFORDSHIRE
Telephone: Hatfield 62300 Cables: HAWSIDYN Hatfield

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COMMON ATTITUDE POINTING SYSTEM (CAPS)
PHASE 'A' STUDY - FINAL REPORT

Compiled by: Dr. J.B. Farrow
Study Manager

Approved by:
P.L.V. Hickman
Executive Director and
Divisional Manager, Space

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SPACE DIVISION
HAWKER SIDDELEY DYNAMICS LIMITED
STEVENAGE
HERTFORDSHIRE

This report comprises three Volumes as follows:

Volume 1 - Summary
Volume 2 - Technical Details
Volume 3 - Programme and Cost Estimates

VOLUME 1

CONTENTS

<u>Figures</u>

LIST OF ABBREVIATIONS AND ACRONYMS

ACS	Attitude Control System
ASPS	Annular Suspension Pointing System
CAPS	Common Attitude Pointing System
CDMS	Command and Data Management System
CPU	Central Processor Unit
CR	Centre of Rotation
EGSE	Electrical Ground Support Equipment
EMI/EMC	Electromagnetic Interference/Compatibility
EPDS	Electrical Power Distribution System
EVA	Extra Vehicular Activity
FMC	Forward Motion Compensation
FSLP	1st Spacelab Payload
2FS	Two Frequency Scatterometer
GCR	Gas Correlation Radiometer
GET	Ground Elapsed Time
GN&C	Guidance Navigation and Control
GSE	Ground Support Equipment
IFOV	Instantaneous Field of View
IMU	Inertial Measurement Unit
I/O	Input/Output
IPS	Instrument Pointing System
IR	Infrared
KB	Keyboard
LLLTV	Low Light Level TV
LOS	Line of Sight
LRIR	Limb Radiance Inversion Radiometer
LV	Local Vertical
MDE	Mission Dedicated Equipment
MGSE	Mechanical Ground Support Equipment
MPM	Miniaturised Pointing Mount
N.A.	Not Applicable
NEA	Noise Equivalent Accuracy
N.S.	Not Specified.
OBC	On-Board Computer
OTF	Orbital Test Flight

PCM	Pulse Code Modulation
PMR	Pressure Modulated Radiometer
RAU	Remote Acquisition Unit
RCS	Reaction Control System
RVDT	Rotary Variable Displacement Transducer
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SIPS	Small Instrument Pointing System
S/L	Spacelab
SLR	Side Looking Radar
SPC	Science Programme Committee
STDN	Satellite Tracking and Data Network
TBD	To be Defined
TCS	Thermal Control System
TDRSS	Tracking and Data Relay Satellite System
UV	Ultraviolet
VFI/VFT	Verification Flight Instrumentation/Test
VV	Velocity Vector

SUMMARY

ESA RFQ 2557 (Technical Specification for CAPS Phase 'A' Study, ESA September 1976) defined the study objectives as follows:-

- "To analyse experiment requirements (passive atmospheric sounders and microwave Earth observations) and compare them with the Orbiter pointing and stability capabilities.
- To assess the adequacy for the various experiments of:-
    - a simple fixed mount relying entirely on the Orbiter control system
    - a simplified CAPS design partly dependant on the Orbiter control system
    - an autonomous CAPS design
- To perform extended CAPS analysis, trade-offs and concept selection
- To evolve systems and subsystems design for a preferred concept and to investigate and define accommodation and operation in Spacelab
- To prepare a development plan consistent with 1st Spacelab Payload (FSLP) and detailed cost estimates clearly identifying critical cost/performance trade-off items
- To assess critical design and development areas".

1. INTRODUCTION

1.1 Study Background

Table 1 summarises the background to CAPS Phase 'A' Study:

Study or Event	Date	Comment
Passive Sounders		
- Passive Sounder Study	Nov. '75 - April '76	See Reference 1
- Extension to Passive Sounder Study	June/July 1976	See Reference 2
LIDAR		
- Phase 'A' Study	1975/76	See Reference 3. ESA SPC meeting in July '76 decided not to develop LIDAR for FSLP. Further study of CAPS was recommended.
Microwave Earth Observations		
- SARLAB Project	1974	See Reference 4
- Microwave Experiments for FSLP	1976	See Reference 5
FSLP Payload		
- Definition of FSLP Payload and Associated GSE	1975/76	See Reference 6
- ESA's Preliminary Call for Proposals	March '76	
- Replies to Preliminary Call	May '76	See Reference 7
- ESA's Final Call for Proposals	Sept. '76	See Reference 8
- Replies to Final Call	Nov. '76	
- Final Selection of FSLP	Early 1977	

Table continues

Study or Event	Date	Comment
CAPS		
- SPC Meeting*	Mid Dec. '76	Decision taken not to include CAPS on FSLP

Table 1 - CAPS Study Background

*The SPC meeting came too late in CAPS study to allow a full appraisal of the impact of that decision.

1.2 Further Details of CAPS Study Objectives

1.2.1 Categories of Experiments

Two categories of experiments are considered as candidates for CAPS:

A. Passive Atmospheric Sounders (UV - IR wavelength)

Operating Mode	Description
A1	Emission from limb, to measure temperature and/or composition
A2	Absorption, or solar occultation, mode
A3	Emission from limb for wind measurements (high resolution instruments, accurate ACS)

B. Microwave Experiments

Operating Mode	Description
B1	Atmospheric sounding (as for A1 or A3)
B2	Earth observations using, for example, a scatterometer (2FS) or synthetic aperture radar (SAR)

1.2.2 Physical Requirements

Two types of CAPS Payloads are considered:-

Type 1

Several experiments of Category A (operating in any of modes A1, A2 or A3) weighing altogether up to 300 kg. Platform mounting area (for 'end-mounted' experiments) or clear viewing area (for 'side-mounted' experiments) is nominally 1m^2.

Type 2

The antenna and minimum associated hardware of one experiment from category B - weight up to 300 kg, diameter up to 3m.

Priority (in accommodation studies) is given to Type 1 payloads.

1.2.3 Guidelines for Study

- Priority is given to the use of CAPS on FSLP - see note at end of Section 1.1. Maximum observation time is provided during periods devoted to experiment activity, particularly when the Orbiter is in its Earth-oriented attitude.
- Maximum use is made of all resources and facilities provided by Spacelab.

1.3 Potential Usefulness of CAPS

Apart from passive sounding and microwave Earth observations, there are other disciplines which could benefit from the use of a pointing system such as CAPS with capabilities intermediate between those of Orbiter/Spacelab and those of the Spacelab IPS.

Potential areas of applications which require a view to space, atmosphere, Earth, Sun, etc, are:-

- Astronomy
- Atmospheric physics (active as well as passive sounding)
- Magnetospheric and ionospheric physics
- Geodesy
- Earth observations
- Solar flux measurements

Figure 1 shows a log-log plot of allowable payload mass versus attainable stability for various platforms. Orbiter/Spacelab itself is capable of carrying very large experiment payloads and supplying a stability level of nominally ±0.1° in each axis (nominal rate of ±0.01°/sec per axis). The capability of the vehicle to select preferred attitudes to suit particular parts of the payload or to effect sightline scanning is very limited.

IPS can carry payloads up to 3,000 kg and point them over wide angles to high accuracy (around 1 arc sec design goal). However, IPS itself weighs between about 500 and 750 kg (depending on the functions it includes). It is therefore impractical for payloads less than, say, 300 kg since, on missions after FSLP, the pointing system mass will be added to that of the payload it carries in assessing the payload launch and operations cost.

CAPS could usefully satisfy payloads in the area shown in Figure 1

Characteristic	Nominal Target	Growth Target
Payload Mass, kg	Up to 300	500
Pointing Range*	Hemispherical	Hemispherical
Accuracy/Stability	Intermediate (~20 arc secs)	Fine (few arc secs)

*A fairly limited pointing range would be satisfactory for most passive sounders on early Spacelab missions. The entire hemispherical coverage must be provided ultimately or if CAPS is to accommodate experiments from other disciplines or cater for a wide range of vehicle attitudes.

CAPS could also be useful for payloads which need a wide pointing range but demand only crude accuracy of pointing.

CAPS control of payloads in the region shown in Figure 1 is challenged by NASA proposed systems (notably MPM) as described in References 9 and 10.

2. EXPERIMENT REQUIREMENTS

2.1 Passive Sounding

Vertical sounding techniques create relatively low demands for pointing accuracy and stabilisation which can generally be satisfied by the Orbiter ACS.

Limb sounding techniques are much preferred for reasons of measurement sensitivity and vertical resolution. All but two of the 18 European passive sounders proposed for FSLP (Ref. 7) are limb sounders. The two exceptions are UV/visible instruments measuring airglow emission; they could benefit from the use of a wide-angle pointing system but do not demand high accuracy.

Figure 2 shows the viewing geometry for limb sounding.

Table 2 summarises the ACS performance requirements for the various operating modes. The accompanying notes expand slightly on the table but, as for all areas described in this volume, reference should be made to Volume 2 for full details.

Note that the worst-case requirements for CAPS for limb sounding are about 20 times more relaxed than those of IPS:

	CAPS	IPS (design goals)
Absolute attitude	0.02° (approx. 1 arc min)	Approx 2 arc secs
Stabilisation	0.005° (approx. 20 arc sec)	Approx 1 arc sec

Notes on Table 2

- Provision of a wide azimuth scan range provides extra measurement versatility for emission experiments since it allows selected or repeat viewing at the limb. A wide azimuth range is essential for Mode A2 for Sun acquisition.

- Limb sounders which yield temperature and composition by imversion of radiometric measurements of thermal emission require a knowledge of the absolute altitude (or more correctly pressure), at some point in the elevation range, to high accuracy and relative angle over the rest of the scan range to equivalent accuracy.

- UV and visible observation of airglow, etc. create lower demands for accuracy (typically about 0.03° in elevation equivalent to 1 km altitude at the limb).

- For reasons given in Volume 2 absolute attitude determination (elevation) to 0.02° is selected as a first goal for CAPS. It is recognised that some sensitive emission measurements demand higher accuracy (to about 0.005°); generally such experiments are capable of providing their own pressure reference by inclusion of additional channels.

- In Mode B2 the sightline would be stabilised by using a solar tracker in a closed-loop control system.
- For Mode A3 the absolute attitude of the LOS must be known about all 3 vehicle axes; values in Table 2 are worst-case, to measure winds to 3m.s^{-1} with the LOS normal to the VV.
- Accurate attitude as given in Table 2 can be re-constituted afterwards if necessary. Real-time attitude data and 'pointing accuracy' to some prescribed position can be considerably relaxed for limb sounding.
- Axis translation from the vehicle frame of reference (Orbiter pitch, roll and yaw) to pointing system drive axes (elevation, azimuth, roll around LOS) depends on the respective orientations of CAPS axes, experiment LOS and vehicle axes (e.g. for LOS perpendicular to VV, elevation is the same as roll; for LOS parallel to VV elevation is equivalent to pitch).
- Required stability rates during a measurement period (60 sec maximum assumed) are given in terms of roll, pitch and yaw. Stabilisation is achieved by measurement of rates in 3 orthogonal axes and computations to give suitable corrections in the 2 drive axes (elevation and azimuth) of CAPS to 'fix' the volume of atmosphere viewed; for the small angles concerned, a third axis of control (rotation around LOS) is not required.
- Maximum scan rate of say 2°/sec is acceptable for all limb sounding modes.

2.2 Microwave Earth Observations (Mode B2)

Nominal Pointing Direction (for SAR experiment)	Earth surface and oceans. Nominal depression of LOS: 45° adjustable over an elevation range of 20-70°. Azimuth position: LOS perpendicular to VV for SAR is preferred, with scan range of about ±5°.

(Note: For a scatterometer (2FS) experiment on FSLP there could be a requirement for conical scanning over a ±45° azimuth range at a depression angle of 45°, variable between 20° and 70°. The exact requirements are still very confused and should be clarified by ESA).

Absolute attitude determination/Pointing accuracy	Relaxed; Orbiter ACS is adequate for early missions.

Operating Mode	A1 (and B1 without wind measurements)	A2	A3 (and B1 with wind measurements)
Nominal Pointing Direction	Limb (altitudes between 0 and 120 km - see Figure 2)	Limb (altitude range as A1) during sunrise or sunset	As for A1
	Any position in azimuth (except PMR for which LOS is normal to VV)	Azimuth position determined by sun-spacecraft geometry	Some measurements are relaxed if LOS lies close to VV
Attitude Determination			
• Absolute, at some point in scan range	Elevation 0.02° Azimuth 2° Roll around LOS NA	0.02° with respect to solar disc in elevation and azimuth. Roll around LOS NA	Roll 0.02° Pitch 0.02° Yaw 0.02°
• Relative, over scan range of about 4° max	Elevation 0.005°	Not applicable	Elevation 0.005°
Stabilisation	Elevation 0.005° for up to 60 secs Azimuth FMC at appropriate rate to 'fix' FOV Roll around LOS NA	0.02° LOS with respect to solar disc for up to 120 secs in elevation and azimuth Roll around LOS NA	Roll $0.005^\circ/60$ sec Pitch $0.02^\circ/60$ sec Yaw $0.02^\circ/60$ sec

Table 2 - Pointing and Stabilisation Requirements for Passive Sounders

Stabilisation	Short-term rate $< 0.06^{o}$/sec i.e. Orbiter ACS is adequate.
Maximum Scan Rate	2^{o}/sec assumed

2.3 CAPS Requirement Specification - Additional Considerations

2.3.1 CAPS Functions Required for Various Experiments

CAPS could provide some or all of the following ACS functions:-

- Attitude determination
- Stabilisation
- Selection of nominal viewing direction
- Limb scanning

A facility providing all functions may be more than is required for some payloads and could seriously compromise their measurements (e.g. if each of the experiments in a payload requires very different scan rates).

In Table 3 a tick (✓) indicates that all experiments in a particular operating mode share a common requirement. (Note - Type 2 payloads are assumed to comprise a single Category B experiment). Crossed ticks (✓̸) indicate that the function is not essential but could be very useful and crosses (X) indicate that the function is not required.

Function	Passive Sounders				Microwave Earth Observations	
	A1 or A3		A2	B1	2FS	SAR
	Compromised scan or single instrument	Separate Scanners				
Attitude Determination	✓	✓	✓	✓	X	X
Stabilisation	✓	✓	✓	✓	X	X
Selection of View Direction						
- Azimuth	✓̸	✓̸	✓	✓̸	✓	✓
- Elevation	✓	X	✓	✓	✓	✓
Limb Scanning						
- Elevation	✓	X	✓	✓	NA	NA
- Azimuth	✓	X	NA	✓	✓	NA

Table 3 - CAPS Functions Required for Different Modes

(See Volume 2, Section 1.5.1 for details relating to Table 3).

Since ticks appear against all the functions listed in the table, against one mode or another, CAPS should eventually provide all of these functions, e.g. for a group of Mode A1 experiments CAPS must provide attitude determination and stabilisation and it could usefully include the means to obtain wide azimuth coverage and FMC for some instruments; but it need not necessarily include means for elevation pointing and scanning, (i.e. the instruments could have internal scanners to suit their individual requirements). On the other hand, Mode B1 requires all the listed functions with the possible exception of azimuth control on early missions.

2.3.2 Payload Characteristics

Physical characteristics (mass, size, power, etc.) of passive sounders vary over a very wide range for individual instruments. In so far as it is sensible to specify 'typical' values, these are tabulated below based upon averages for the European proposals given in Reference 7.

Parameter	'Typical' Value		Exception
	A. UV - IR	B. Microwave	
Mass, kg	50	250	Large diameter (e.g. 60 cm) cryogenically cooled telescope plus focal plane in instruments ~ 250 kg
Size	0.25 m^3 (e.g. 0.5 x 0.5 x 1)	2m dia. antenna	As above ~ 2m length
Power, W	30	200	Active cooling (i.e. refrigerator) ~ 100W
Data, kb/s	1-5	1-10	LLLTV ~ 1Mb/s

3. MISSION ANALYSIS

3.1 1st Spacelab Mission Parameters

Orbit altitude	250km
Inclination	57^o

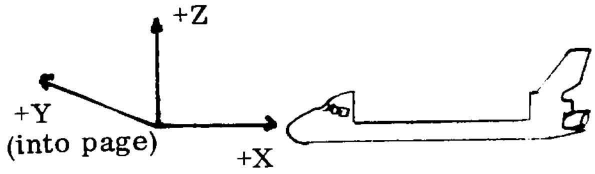
Eccentricity	0, i.e. circular
Launch date	15.7.80
Launch time	0900 EST (preferred for VFT) or 1400 EST (preferred for experiments)
Launch/Landing site	Kennedy Space Centre
Mission duration	7 days
Mission plan	See Table 4 below
Orbit period	90 mins
Eclipse duration	37 mins. per orbit

3.2 Mission Plan for FSLP

Time (GET) hrs.	Flight Phase	Attitude*	Suitable for Passive Sounders**
0- 12	Preparation for orbit	NA	No experiment operation
12- 24	VFT nominal test	+Z LV, Y VV	Yes, most experiments
24- 76	Experiments	+Z LV	Yes, all experiments if X along VV
76- 80	Acceleration tests	Various	Best avoided
80-128	Cold test	+X solar +Z space	No
128-140	Hot test	+Z solar +X to North	Limited to certain modes only
140-156	Experiments	+Z to space	No
156-168	Preparation for landing	NA	No

Table 4 - Mission Plan for FSLP

* Orbiter axes are as defined in this sketch:



** See Volume 2, Section 2.2.2 for details.

Preferably, passive sounders or microwave experiments should operate continuously for as long as possible to maximise the atmosphere and ground coverage. IR and microwave experiments can operate by day or night but UV/visible (airglow) measurements will be generally restricted to the dark side of the orbit only. Mode A2 is only useful during orbit sunrise or sunset (i. e. twice per orbit for a few minutes on each occation).

All passive sounders and/or microwave experiments mounted on CAPS on 1st Spacelab could operate continuously (or repetitively as in the case of Mode A2 or UV/visible instruments) over the period from hour 24 to 76 (52 hours). In addition the period from hour 12 to 24 would be useful for the majority of instruments considered. Additional viewing opportunities arise between hours 76 and 80 but these are best avoided. Limited opportunities for viewing (e.g. Mode A2) occur between hours 128 and 140.

To take advantage of all these viewing opportunities CAPS would have to provide wide coverage, over virtually the entire hemisphere visible from the pallet (neglecting obscurations). Restricting operation to the period during which +Z is along the local vertical allows a limited range (< 10^{o}) to be used in elevation. However, on later missions, or subsequent revisions of the 1st one, a wider elevation range (90^{o}) avoids attitude constraints on the Orbiter.

3.3 Preferred Attitude of Orbiter

The main criteria in selecting the preferred Orbiter attitude for limb sounding experiments on CAPS are as follows:-

- Drag
- Compatibility with nadir viewing instruments
- Available search field for attitude sensors (sun or star)
- Viewing range (azimuth) for experiments
- Mounting position (pivot point of CAPS to provide viewing unobstructed by pallet sill, module, Orbiter structures, etc.)
- Thermal control of CAPS and payload

In general an Earth-oriented mode (+Z along LV) with the Orbiter longitudinal axis (X) in the orbit plane emerges as the preferred attitude. However, the relative importance of the various criteria depends strongly on the package of experiments on CAPS and other experiments on the same Spacelab mission. (See Volume 2, Section 2. 3 for details).

3.4 Orbiter Parameter Selection

Orbit altitude has an effect on the following characteristics of CAPS and its payload:-

- vertical resolution
- depression angle to limb
- return flux of contaminants
- ACS requirements
- baffling to avoid stray light

Inclination of the orbit has a strong impact on:-

- global coverage (and opportunities for high latitude observations)
- occultation events (timing and duration)
- ground coverage (for microwave experiments - zero or minimum drift orbits preferred)

Changes in altitude through the mission (i. e. non-zero eccentricity) cause:-

- variations in resolution and depression angle from nominal values
- complications for microwave experiments (mapping rate, RF power, etc. all depend on altitude)

Launch date and time are important in establishing:-

- ground target illumination
- global day/night coverage
- positions and times of occultation events
- times of pass over ground truth sites

Summarising the conclusions of Volume 2, Section 2.4:-

Orbit Parameter	Are 1st Spacelab Mission Parameters Acceptable ?	Preferred Choice
Altitude	Yes	High (for Earth-oriented attitudes)
Inclination	Yes	Requires detailed optimisation to suit payload
Eccentricity	Yes	Zero
Launch Date/Time	Yes	Requires detailed optimisation

4. SYSTEM OPTIONS

4.1 Control System Concepts

The pointing and stabilisation requirements for passive sounders and microwave experiments were compared with Orbiter ACS capabilities to establish the adequacy of the following concepts:-

- a simple fixed mount relying entirely on the Orbiter control system
- a simplified CAPS concept e.g. using the Orbiter GN and C ability to accept commands from a payload sensor,or with certain functions eliminated
- autonomous CAPS concept

ACS functions which may be required by the payload are:-

- Attitude determination (absolute and relative) and rate sensing - One or more axes
- Stabilisation of the experiment LOS - One or two axes
- Pointing of LOS in a preferred direction - One or two axes
- LOS scanning around mean pointing direction - One or two axes

4.1.1 Simple Fixed Mounting

The capabilities of the Orbiter ACS to provide any of these functions, to the required accuracy for a pallet-mounted payload, is very limited. Nevertheless there is still scope for mounting certain instruments directly (or via a suitable 'shelf') to the pallet. Table 5 defines the minimum acceptable concepts for the various operating modes (see Volume 2, Section 3.2.1 for details).

Key to abbreviations: FM = fixed mount; IS = internal scanner; AS = attitude sensor; GS = gyro stabilisation.

Operating Mode	Wavelength	Minimum Acceptable Concept
A1	UV/visible IR	FM + IS + AS FM + IS + GS (+ AS)
A2	UV/visible/IR	FM + IS + AS
A3	UV/visible IR	FM + IS + AS FM + IS + GS + AS
B1	Microwave	Gimballed platform + GS + AS
B2	Microwave	FM for very limited objectives. Gimballed platform to achieve useful results

Table 5 - Minimum Acceptable Concepts

An internal scan mirror in a 'fixed' instrument could provide the required elevation range (of up to $\pm 5^{o}$ for Modes A1, A2, A3) and up to 360^{o} in azimuth (for A2) if a rotating turret arrangement were used as in Figure 3(c). A much lower azimuth range would generally satisfy Modes A1/A3. Instruments employing cryogenically cooled optics (mainly Modes A1/A3) should be gimbal mounted to avoid the power dissipation associated with an internal scanner.

Gyro stabilisation would be unnecessary for limb sounders if the attitude rate of Spacelab were reduced (or its deadband reduced to the stability level of 0.005^{o}) or if the measurement time is very short (less than 0.5 secs for nominal rate of 0.01^{o}/sec). The first condition would demand excessive propellant; the second condition would be very restricting.

Table 6 lists the advantages and disadvantages of CAPS (assumed to provide all functions) compared to a fixed mount on the pallet for passive sounders (a fixed mount is not appropriate for microwave experiments except for very limited measurement objectives).

Advantages of Autonomous CAPS over Fixed Mount	Disadvantages of Autonomous CAPS compared to Fixed Mount
● Individual experiments can each be smaller/lighter/less complex/cheaper because of the elimination of scan mirror plus drive, attitude and rate sensors, control loop and associated electronics. (But CAPS itself could incur significant penalties in mass, power, cost, etc.) ● A wide scan range (and hence much greater measurement flexibility) can be achieved. In a self-contained instrument the range of the internal scanner is limited due to obscuration by the optics housing. Thus the instruments could only operate when Spacelab is in a preferred attitude and it would be difficult to make selected and repeat observations as preferred. ● Optical contamination/stray-light are relatively lower since, with no scan mirror, the primary optics can be more efficiently baffled. ● All instruments (including cooled telescopes and antennae) can be accommodated. ● Mutual alignment between instruments and co-ordination of measurements is more likely to be achieved. ● Interfaces between CAPS and Spacelab could be less complex than between a number of separate instruments and Spacelab.	● Scan characteristics at any particular time are the same for all instruments sharing the common attitude system. This is actually an advantage as regards scan direction in azimuth with is generally required to be common. However, scan rate at any instant will be a compromise value. ● Supporting services (power, data) must be provided across the gimbal system to the instruments. ● Physical characteristics of instruments are more constrained by the available mounting area, volume and mass limits of a platform/canister. ● CAPS could only be accommodated on missions where sufficient volume is available, whilst separately-mounted instruments could 'fill the gaps' on nearly all missions.

Table 6 - Advantages and Disadvantages of CAPS compared to a Fixed Mount

4.1.2 Simplified CAPS Concepts

(a) Information to Orbiter GN and C System from Payload Sensor (and vice versa)

On the understanding that rate information from the Orbiter IMU will not be available to pallet payloads in suitable form, simplified control concepts of this sort offer little or no advantage over an autonomous CAPS concept (see Volume 2, Section 3.2.2 for details).

(b) Limited Range of Functions

Omitting functions where possible, obviously offers scope for reducing complexity and saving costs. In the long term, to meet the requirements of all operating modes, CAPS must be capable of providing all the listed functions and should be designed with this aim in mind. On early missions the requirements of several instruments could be satisfied with a fixed mounting or a simple one-axis pivot of limited angular range as in Figure 3(a).

The possibility of arriving at the eventual aim (autonomous CAPS) via a series of growth steps from an initial simple system has been considered. Two examples of possible development sequences are described:-

(i) Commence with a single-axis flexural system for pointing, scanning and stabilisation over a small elevation range (limited to about 10° by the flexural system). Later add a second axis of similar form. To achieve wider angles in azimuth, mount the 2-axis flexure system on a turntable (bearings). Finally a wide elevation range could be added by a second (bearings) drive, though not without complication.

(ii) Develop a bearings-only system from the start. Commence with a single drive axis of low-performance standard (no off-loader, no cable follow-up) which would satisfy limited experiment requirements. Improve performance by adding an off-loader for the bearings and a cable follow-up for low-friction torque. Add a 2nd axis and additional payload services (power converter, data interface, etc.) as and when required.

For reasons given in Volume 2 (Section 3.2.2 and Appendix 10) the second approach is preferred. But note that the baseline CAPS to be described is a 2-axis system providing a wide range of functions, to the required performance, as well as main payload services (i.e. it is autonomous). Simplifications as suggested here should be adopted only if emphasis is placed on a very cheap initial version of CAPS and if the payload can accept the reduced performance.

4.1.3 Autonomous CAPS Concept

The autonomous CAPS concept (providing all important functions and services - see later system description) will be assumed throughout the remainder of this volume.

4.2 Gimbal Configuration

Figure 4 illustrates four alternative gimbal configurations:

Configuration	Description
1	Balanced twin; side-mounted payload (i.e. experiment LOS parallel to plane of platform)
2	Unbalanced about both axes; end-mounted payload (i.e. LOS normal to platform)
3	Girth ring plus yoke; end-mounted
4	Elevation axis balanced; out-of-balance about azimuth; side-mounted payload

It had earlier been understood that unbalanced configurations were unacceptable because of the error resulting from disturbance torques from man-motion and reaction control thrusting -see References 2 and 10. However, simulations carried out by Dornier Systems and by HSD during the study (see 6.1) show that a large offset between CAPS centre-of-rotation and the payload centre-of-mass is tolerable.

These configurations were compared according to the following trade-off critieria (roughly in order of importance)

- System performance (accuracy, stability)
- System mass
- Payload accommodation
- Cost
- Clamping
- Swept volume
- Inertia
- Mutual alignment

- Performance testing
- Growth potential (higher accuracy/stability)
- Payload growth (larger payloads)
- Thermal control
- Experiment integration
- Commonality with IPS

(See Volume 2, Section 3.3 for details).

Configuration 1 emerged as the clear favourite with the others of approximately equal ranking. However, Configuration 1 (balanced twin) is unsuitable for certain payloads (those which cannot sensibly be divided such as a single large instrument). It must therefore be readily adaptable to Configuration 4 (which is essentially just half of the elevation drive of 1 plus an identical azimuth drive) for such 'asymmetric' payloads. If the drive assembly is suitably designed to take a load on either end of the shaft, as required if 1 is to be adaptable to 4, it will be equally capable of use in Configuration 2 by modification of the drive-to-payload platform structure (e.g. to carry a microwave antenna). Thus Configuration 1 is the most adaptable.

4.3 Sensor Options

A gyro package must be used to measure attitude rates as part of the control loop to stabilise payload sightlines (Modes A1/A3/B1). For Mode A2 the control loop can be closed around a sun sensor. An attitude sensor is required

(a) to provide absolute attitude information for LOS position determination and

(b) to allow the gyro to be calibrated and drift terms corrected

- For Modes A1/B1 options include horizon, sun or star sensor (possibly supported by experiment measurements) - see below
- For Mode A2 a sun sensor provides attitude and rate information
- For Mode A3, determination of attitude in 3 axes to high accuracy requires star sensing. At lower accuracy other possibilities exist (e.g. sun sensor plus horizon sensor)
- In other potential applications of CAPS the preferred choice may be more obvious e.g. a sun sensor for solar measurements, star sensor(s) for astronomy

The preferred attitude sensor will depend on the following factors:-

- Performance (attitude determination, stabilisation)
- Physical characteristics
- Target availability (i. e. positions and times for viewing)
- Commercial availability and cost
- Operating constraints and computing requirements

Using a star or sun sensor, gyro drift can be calibrated in orbit to high accuracy so that subsequently the update period can be one hour or more. Thus star viewing can be made on an intermittent basis, on the dark side of the orbit only, thereby relaxing the requirement to reduce stray light. A star sensor, without a complex baffle stack, is assumed in the baseline CAPS system to be described (except where modes other than A1/A3/B1 are under discussion). A sun sensor could be considered as a viable alternative (provided that solar viewing can be assured without obscuration - depends on mission parameters, vehicle attitude and payload mounting position). A horizon sensor could satisfy limited performance requirements on an early mission.

4.4 'Services' Provided to Payload

The main 'services' required by CAPS payloads are:-

- power
- date handling
- thermal control

Over limited angular ranges and for low performance targets, a cable bight directly linking CAPS platform-mounted experiments to suitable connectors for power and data (and thence to Spacelab EPDS and CDMS) is not out of the question. Power and data services would then be no more complex than for individual instruments on fixed mounts. A cable follow-up with wide angular freedom and low friction torque will obviously be necessary ultimately.

Problems of thermal control of CAPS experiments cannot be considered in detail until the layout and power dissipation within the payload are known. For close thermal control of medium-to-high power experiments a dedicated active system (thermal canister) based on heat pipes and/or fluid pumps will be necessary. However, modest thermal control requirements of the payload (i. e. 'typical' values for passive sounders or microwave experiments) could be satisfied by a passive thermal system as assumed in the baseline CAPS.

It may then be necessary to exclude high-power experiments from early missions or place the responsibility for their control on the experimenters themselves - as will be the case for fixed-mount instruments except where these are coupled to pallet cold plates or heat exchangers.

5. PREFERRED SYSTEM DESCRIPTION

5.1 CAPS Configuration

- Alt-azimuth drives mounted via a support structure to the pallet as shown in Figure 5 for a balanced configuration.
- Minor modification allows the payload to be accommodated in an unbalanced manner when it cannot sensibly be divided into two roughly equal halves.
- In either case the payloads (for passive sounding) are side-mounted i.e. LOS parallel to platform.

5.2 CAPS Assemblies/Subsystems

● Attitude Measurement	- Star sensor assumed, depends on payload.
	- 3 orthogonal rate gyros.
● Support Structure (Pedestal)	- Lattice structure assumed.
	- Pivot point raised to allow unobscured limb viewing for +Z along LV.
● Alt-Az Mount (Gimbal Assembly)	- Elevation and azimuth drive; almost identical.
	- Each drive includes redundant motors and resolvers; cone clamp; cable follow-up; pyrotechnics for locking during launch and landing.
● Experiment Platform(s)	- 2 x $1m^2$ nominal mounting area for balanced configuration in Fig. 5.
	- Supports CAPS sensors and electronics as well as experiments.
	- Thermal Control surfaces on rear face.
● Payload Envelope	- $1m^2$ nominal forward viewing area assumed (i.e. $1m^3$ of payload volume).

- Thermal Control
  - Drive assembly controlled by heater mats and radiation from exterior.
  - Passive control (plus heaters for cold test) of payload by conduction through and radiation from platform.
- Electronics
  - Spacelab experiment computer used in control loop.
  - Power and data taken through gimbals via cable follow-up.
  - Power converter on platform converts 115V, 400Hz supply to levels required by CAPS units.
  - RAU on platform provides data interface with CDMS for CAPS units and the payload.

5.3 CAPS Payload Accommodation

- Mounting and Viewing Area; Volume
  - See above. Nominal values should not be regarded as strict limits. Longer or wider-than-average experiments can be accommodated subject only to limits imposed by:- pallet accommodation, performance, moment.
- Mass
  - Nominal 300kg assumed in performance estimates; comments as above for area and volume.

5.4 CAPS Performance Characteristics

- No. of axes controlled
  - Elevation and azimuth
  - Possible to add a 3rd axis (roll around LOS) but not required in applications considered.
- Angular rates
  - Up to 2.5°/sec (limit set by gyros)
- Scan range
  - 360° in azimuth; 90° in elevation (i.e. entire hemisphere).

- Attitude determination – As specified in requirements table (Table 2). See Section 6.1 for details.

5.5 Supporting Services to Payload

- Power – Wiring via flat-strip cable for platform power of 300W (Higher levels could be allowed using heavier-duty cable).
- Data – Flat strip cable allows up to 1Mbps from payload. (RAU limit is 64 kbps).
- Thermal Control
  - Up to 200W from experiments by radiation from platforms in balanced configuration.
  - 125W for unbalanced configuration.
  - Higher power dissipation would demand use of heat pipes plus radiator (e.g. 240W limit for 0.75m² radiator viewing Earth in unbalanced configuration).

5.6 Spacelab Resources Required for Baseline CAPS (excluding Payload)

5.6.1 Mass Budget

	Mass (kg)
Attitude Measurement	10.5
Support Structure	35.0
Alt-Az Mount	30.8
Experiment Platform(s)	10.0 each
Thermal Control	2.0 per platform
Electronics and Harnesses	11.4 (excluding RAU)

Total for balanced configuration (2 platforms) 112kg.

5.6.2 Power

	Mean Operating Power (W)
Attitude Measurement	23
Alt-Az Mount (i.e. Drives)	29
Thermal Control	-
CAPS Electronics on Platform	8
RAU's (Platform and Pallet)	20
	80W

During the (non-operational) cold test period on FSLP it will be necessary to provide heater power for CAPS units (and experiments) to prevent their temperatures from falling to very low levels; total standby power requirement including that for a package of experiments consuming 110W during operation, would be about 200W during this cold test period.

5.6.3 Data

Approx. 11kbps total data rate for CAPS units (sensors, resolvers, etc.) via the CDMS/RAU system.

5.6.4 Spacelab Computer

Memory size required:	13.4k x 16 bit words.
CPU time:	Approx. 10-20% of S/L experiment CPU time during gyro calibration period. Possibly only half of this for remainder of operating period.

6. SUBSYSTEMS DESIGN

6.1 Pointing and Stabilisation Subsystem

6.1.1 Control Loop

CAPS control loop is shown in Figure 6, it includes gyros (for Modes A1/A3/B1) and attitude sensors and Spacelab's experiment computer, (see Section 6.4). A simpler closed-loop control system incorporating a sun sensor is preferred for Mode A2. In operation, the LOS of CAPS mounted experiments has to be stabilised against unwanted motions of the vehicle. Torque motors have to be driven to counteract such motions, to select preferred viewing directions and, in some cases, to scan the LOS about the nominal direction. In addition it may be necessary to slew from the limb and acquire a suitable source (sun or star) at infrequent intervals to obtain an absolute attitude measurement (and to remove gyro drift).

In an Earth-pointed mode the Orbiter rotation about the Earth has to be counteracted if the field of view is to be locked on to a fixed 'target'.

The essential feature of these control modes is the presence of demanded rates to the gyros. To adequately represent these types of motion it is necessary to use Eulers' 3 axes equations of motion with cross-coupling terms. This has the following implications:-

- 3 gyros are required, with mutually orthogonal input axes, to measure the total motion.
- Integration of rate to provide angle cannot be performed inside each gyro since this would ignore important cross-coupling terms. Hence the gyros must be caged and operated in the rate mode.
- 3 axis integration must be performed in Spacelab's experiment computer and the results processed to produce demanded torques for the gimbal drive motors.

It will be necessary to perform an in-orbit calibration of the gyro, at the beginning of CAPS operational period, to obtain a low residual drift rate of about 0.005°/hr; the calibration would take about 10 to 20 minutes cumulative time during which the sensor LOS would be locked on to a suitable source. Gyro torquer scale factor can also be calibrated in orbit (if a star sensor is used) by slewing between two sources a known distance apart; the ground measured linearity of about 0.1% can be reduced to less than 0.02% by this means.

Gyro misalignment (i.e. non-orthogonality) can also introduce errors in attitude determination and stabilisation; a figure of 3/4 arc minute is assumed as a reasonable target for the resultant of ground alignment and any shifts during launch.

6.1.2 Attitude Determination

Quantitative error budgets for attitude determination in elevation (Modes A1/B1) are presented in Table 6 for various types of sensor. (See Volume 2 Section 4.3.1 for details).

Error Term	Type of Sensor		
	Horizon	Sun	Star
a) Sensor			
Sensor accuracy (3σ)	0.030	0.006	0.006
Sensor alignment	0.004	0.004	0.004
In-orbit misalignment	0.008	0.008	0.008
b) Gyro			
Gyro drift	-	0.008	0.005
Gyro misalignment	-	0.011	0.003
Gyro torque-linearity	-	0.010	0.002
c) Axis Translation (Celestral to Earth Frame)			
Tracking Error	-	0.005	0.005
Modelling error	-	0.005	0.005
RMS Total	0.031	0.021	0.015

Table 6 Error Budgets (Angles in Degrees) for Attitude Determination of Experiment Sight-line with respect to Earth's Limb

For Mode A2 (no gyro terms) the attitude of the LOS would be determined to an accuracy of about 0.01° with respect to the Sun.

For Modes A1/B1 the measured position of the Sun or star can be transformed from the celestral frame (right ascension, declination) to CAPS frame (elevation and azimuth) to the required accuracy.

For Mode A3 in which the attitude must be determined in all 3 axes (spacecraft pitch, roll, yaw) two reference sources are required. A single star sensor proves adequate with sightings made on more than one source.

If it were necessary to direct the LOS towards some prescribed point to high accuracy (not a requirement for passive sounders but often necessary for astronomy payloads) the pointing accuracy achievable would be the resultant of the attitude determination errors and the stability errors (see below).

6.1.3 Stability

The stability error budget is given below for the elevation plane assuming the FMC is carried out over a (maximum) measurement period of 60 secs. (See Vol.2, Section 4.3.2 for details).

Error Term	Stability (Degree)
Gyro drift (after calibration)	0.0001
Gyro misalignment (15° FMC)	0.0033
Gyro torquer scale factor (nominally fixed elevation position).	-
Friction	0.0010
Noise	0.0003
Disturbance	0.0012
Resultant	0.0049°

For periods shorter than 60 seconds, the dominant term due to misalignment will be smaller. This term is introduced as a result of the operating mode assumed for limb sounding. In other applications (e.g. astronomy) where the viewing direction is nominally fixed during a measurement period (apart from any effects of Orbiter rotation (4°/ min, in an Earth-oriented mode) the stability will be the resultant of the control loop errors only (last 3 terms above), plus the small gyro drift (i.e. around 0.0016° or 6 arc secs.).

For Mode A3 LOS stabilisation is required with respect to roll, pitch and yaw axes. Rates in 3 orthogonal axes are measured by the gyros and transformed to gimbal axes (elevation and azimuth) in which stabilisation is achieved to the required levels. Roll around the LOS is tolerable for the small angles involved.

In Mode A2 (using sun sensors is closed loop) the stability target is easily achieved.

6.1.4 Control Loop Analyses

A mathematical model was established as part of the study to simulate the effects on the control system of the following factors (see Vol. 2 Section 4.3.3 and Appendix 9 for details):-

- Gyros
- Payload
- Motor
- Support structure

- Friction
- Man-motion disturbances

6.2 Structure and Mechanisms

The overriding requirement for the structural design of CAPS is that safety shall be assured. A structural model will be developed, comprising all elements of the primary structure for testing under realistic loads. The alternative approach - to design CAPS to higher factors of safety - would have a significant mass impact and would be less cost effective in the long term.

An installation area for CAPS on the forward port side of the pallet is assumed for FSLP as agreed with ESA. Some overhang could be allowed beyond the forward frame of the pallet. To simplify CAPS, it is a design philosophy at all times to keep within the cargo bay envelope.

CAPS configuration (see Figure 5) may be regarded as three separate assemblies with discrete interfaces:

- Support Structure
- Experiment Platform
- Alt-azimuth Mount

Direct payload-to-pallet interfaces (for external clamping or off-loading) have been avoided; it proves adequate to off-load/clamp the payload within the alt-az mount.

a) Support Structure

The preferred design and mounting position for the support structure depend on:-

- operational requirements of experiments
- Orbiter attitude
- overall payload on Spacelab mission

For limb sounders on an Earth-oriented mission (+Z along LV) CAPS pivot point must be about 2.5m above the pallet central floor in order to allow unobstructed viewing for a 1m² payload height. A lattice structure picking up on 4 hard points is assumed as baseline.

Further trade-offs will be necessary to select between a lattice or monocoque structure taking full account of mass, cost and dynamical structural analyses. A much smaller support structure picking up on only 3 hard points would be suitable for limb-sounding from a 'sideways' attitude of the Orbiter (+Z normal to orbit plane).

Since CAPS platform carries the sensors together with the payload, the support structure is not required to maintain alignment with the pallet to better than a degree or so.

b) Experiment Platform

The experiment platform design depends on the number and type of experiments in the payload and thermal control requirements for a passive approach. Each platform (2 for the balanced configuration of Figure 5) is nominally 1m^2 in area but could be tailored to suit the payload within reasonable bounds. Where all experiments cannot be mounted directly to the platform (e.g. if the 4 experiments in Figure 5 were to be accommodated in the unbalanced configuration) additional supporting platforms and struts will be required.

6.2.2 Alt-Azimuth Mount

Figure 7 shows the preferred design of drive assembly for the balanced CAPS configuration; the only difference from the unbalanced configuration (Figure 8) is in the cable wrap-ups and payload adaptor plates on the elevation drive.

The three main sections in each case are:

- Cable wrap-up
- Main drive cluster incorporating 'off-loader'
- Payload interface adaptor.

These sections are flanged to allow separate assembly and testing; elevation and azimuth drive units are near identical.

The drive unit consists of 2 motors and 2 redundant resolvers for coarse shaft positioning. The shaft is supported by 2 sets of angular contact bearings with lead film lubricant. The 'off-loading' mechanism consists of a cone clamp which provides braking and some load by-pass. The cone system is driven by a motor and screw-thread arrangement. Redundant pyrotechnic actuators provide positive locking for launch and landing.

Brushed DC torque motors are recommended (1.4 Nm torque) for the drives and off-loading systems.

Within the cable wrap-up round cables (power and data) are transferred to flat strips which are loosely wound on the shaft to give a low friction torque.

6.3 Thermal Control

A thermal analysis (see node diagram of Figure 9) was carried out for CAPS and its payloads, in both balanced and unbalanced configurations, to establish the limits of a passive approach.

For CAPS subsystems, the drive assemblies raise the most important thermal control problems; they can be kept within reasonable operating limits, with acceptable gradients, by radiation from their outer (high emittance) surfaces. There is a general requirement for heaters during non-operational periods in the cold soak (+Z oriented to space) to prevent the temperatures of CAPS units (mechanisms, electronics, sensors,) from falling to below damage or failure levels.

CAPS payload is presently undefined and it has been necessary to assume somewhat arbitrary values as a guide to what can be achieved.

Passive thermal control techniques are capable of handling up to 200W experiment power for the double platform configuration and 125W with a single platform. Lower powers can be accommodated by altering the insulated area of the platform. The simplicity of the system is offset by the heater power requirement during non-operation and the constraints on hot-spots on the platform. The cold soak heater power required is about equal to the experiment power during operation for the passive system.

The following temperatures were predicted (see Vol. 2 Section 6 for details).

Configuration	Mean Power Dissipation		Temperatures		
	Drives	Experiments on Platform	Drive Max.	Drive gradient	Platform max.
Single Platform	15W/axis	100W	40°C	22°C	32°C
Double Platform	15W/axis	150W	49°C	21°C	30°C

These are representative cases in which 75% of the available radiating area on the platforms is in use.

The advantages of the passive system over active methods are that:

- it is much simpler (cheaper)
- it avoids the constraints on payload envelope size which could result from the use of a standard, or to a lesser extent, a modular thermal canister.

Various possibilities for an active system (regarded as a growth item for later missions) are:-

- pumped fluid loop + radiator
- variable conductance heat pipe + radiator
- simple heat pipes + louvres.

6.4 Electronics

The major tasks to be performed by the CAPS electronic system are:-

- Close the control loop from gyros to torque motors.
- Compute gyro drift rates and introduce appropriate compensating signals.
- Provide co-ordinates of appropriate stars (for a star sensor option) to maintain accurate inertial reference information via the gyro system.
- Control the CAPS mechanisms during deployment, stowage and emergency states.
- Provide manual control and display facilities in order to optimise experiment sequences by means of man interaction.
- Support the experiment by giving CAPS status information; conversely use experiment status to influence the performance of CAPS.
- Monitor CAPS performance and provide out-of-limit warnings and safety functions.
- Thermal control and other housekeeping functions.

- Provide a pointing timetable that maximises experiment observing times and gives flexibility to observation sequences.

The basic philosophy is as follows:-

- Maximum use of digital computer to give flexibility of design
- Minimum hardware on pallet and experiment platform
- Minimum cabling across gimbal.

The last two objectives are conflicting; the solution adopted for CAPS is to reduce cabling at the expense of fairly simple units which distribute signal and power.

The location and functions of CAPS main electronics units are summarised in Table 7.

Unit	Location	Major Functions
CAPS - A Electronics	Pallet	Torque motor electronics; resolver electronics; clamp electronics; emergency control; house-keeping. (Controlled and monitored via RAU-A)
RAU - A (Spacelab item)	Pallet	Interfaces CAPS - A to CDMS (some spare capacity available).
CAPS - B Electronics	Platform	Thermal control; housekeeping; power switching; signal interface for data buses to and from RAU-B. (Controlled and monitored via RAU-B).
RAU-B	Platform	Interfaces CAPS-B and experiments to CDMS
Gyro Electronics	Platform	Interfaces gyro to RAU-B and EPDS.
Star sensor electronics	Platform	Interfaces star sensor to RAU-B and EPDS.
Experiment electronics	Platform	Interfaces experiments to RAU-B and EPDS.

Table 7 Summary of CAPS Electronics Units

Figure 10 shows the main data flow paths for CAPS and a model payload.

Detailed processing requirements for CAPS will depend to some extent on mission and payload characteristics. However, it is anticipated that the peak processor loading and program storage requirements will not vary greatly. The actions to be carried out can be split into (a) frequent input/output and computational processes required to close the feedback loop around the drive units and (b) slower speed requirements associated with the pointing timetable.

It is understood that no computer interrupts are available for CAPS. It is assumed that input/output operations associated with the RAU's are real-time synchronised and that a computational 'slot' can be allocated to CAPS between each input/output sequence associated with sensor input and the output to the torque motor. The processing requirements of CAPS during this 'slot' are discussed at length in Volume 2 (Section 7.6) from which the conclusions are:-

- Total memory size not including 'standard' sub-routines:
  - 13.4k x 16 bit words (approximately 21% of the available 64k capacity).
- CPU time
  - major contributors to CPU activity are the control loop and gyro update computations. In the worst-case (gyro calibration at start of CAPS operating period) approximately 10 to 20% of S/L experiment CPU time may be required.

6.5 Ground Support Equipment (GSE)

The following items of GSE are required to support CAPS development, test and integration.

a) Mechanical GSE

- Transport container for CAPS plus payload
- Support structure transport container
- Drive unit transport container
- Equipment platform transport container
- CAPS handling trolley
- CAPS lifting sling
- Drive unit lifting sling.

b) Electrical GSE

i) Spacelab Simulators

- RAU hardware simulator providing representative interfaces
- EPDS simulator providing AC/DC power
- CDMS software simulation on dedicated mini-computer with suitable input/output (of which the RAU simulation forms a part).

ii) Additional Items

- EGSE harness
- 19" racks to house simulators
- Sensor unit testers

c) Optical GSE

i) For CAPS assembly and test (drives, sensors, gyros)

- Standard items of optical test gear including:-
  - autocollimator, reference cubes, micro-alignment telescope
- Source/Collimator for star simulation
- Test rig with kinematic mounting points.

ii) Payload

- Standard items as above for alignment
- Special test equipment shall be the responsibility of the experimenters.

7. DEVELOPMENT PROGRAMME AND COSTS

Model philosophy, development test plans and programmes were derived for CAPS on the assumption that it would be required for FSLP; this entailed delivery for Spacelab Level 4 integration in mid-to-late 1979. (Clearly the decision not to include CAPS on FSLP will have a significant impact on programme. However, there has not been time in this study to carry out a full re-assessment nor was it requested In any case programme milestones, delivery dates, etc., are not known for missions after the first one).

7.1 Model Philosophy

It has been shown on earlier space programmes that relaxation of design requirements has very small impact on costs when the science/ application is aimed at performing a very difficult function. Only elimination of hardware has a significant impact and this has been difficult due to the need to demonstrate that all requirements are met with high reliability. The retrieval/return capability of Spacelab gives added confidence that the requirements will be met, if not initially.

There are several model philosophies which could be considered for Spacelab payloads namely:-

- Single flight model + spare units
- Development critical subsystems + single flight model + spare units
- Development engineering/integration model + engineering/ integration model + flight model + spare units.
- Development structure/thermal model + engineering/integration model + flight model + spare units.
- As above + spare flight model in lieu of spare units.

The last two philosophies are more appropriate to conventional programmes for spacecraft experiments. The first two philosophies (essentially single model) obviously carry an element of risk. They have been considered for CAPS but, as a result of the development and structural tests envisaged - see below, the 3rd philosophy is preferred. However, the Engineering Model is degraded as far as possible to reduce costs to a minimum whilst maintaining adequate test capability.

7.2 Development Test Plan

A development test plan for CAPS is proposed (see Figure 11) with the object of minimising costs utilising a low risk programme. There are no clear requirements specified in ESA documentation on performance, reliability, etc., for Spacelab payloads; thus the plan shown in Figure 11 should be regarded as tentative only. In proposing the plan it has been assumed that CAPS is a 'facility payload' rather than a 'Spacelab facility', which would impose higher reliability requirements.

In formulating the plan given in Figure 11 the following guidelines have been adopted:-

- Safety - demonstrate that CAPS presents no hazards by performing suitably designed test.
- Reliability - perform sufficient environmental tests and functional checks at unit level to give reasonable confidence that a successful mission will be achieved.
- Performance - verify the performance of CAPS by adequate ground testing at unit, subsystem and system levels.

The plan may be generalised as follows:-

- Unit tests - performance; vibration - functional check; thermal soak - functional check.
- Subsystem tests - performance; Spacelab interfaces; vibration - functional check; thermal soak - functional check.
- System tests - performance; EMC; Spacelab interfaces; thermal soak and acceptance vibration.

Performance testing is assumed to be as follows:-

- Thermal vacuum testing will be carried out on the drive assemblies only (plus thermal canister if required for later missions).
- System performance testing will be carried out at ambient pressure.

A dummy load will be adequately representative provided it is supported by mathematical modelling.

7.3 Programme and Costs

To deliver CAPS for Level 4 integration in Spacelab by late 1979 it would not be possible to fulfil the normal practice of (a) competitive Phase B and (b) selected contractor and co-contractors for Phases C/D - since this would leave only 18 months for the development phase which is inadequate. A new approach would be required in which Phases B/C and D are bid simultaneously with Phase B incorporated into the overall system and subsystem design activities. Figure 12 illustrates such a programme which is essentially one of overlapping and streamed activities.

Details of this programme and of the cost estimates for CAPS are given in Volume 3.

8. CRITICAL DESIGN AND DEVELOPMENT AREAS

From the last section it is clear that it would be difficult to develop CAPS for FSLP to meet the required delivery in mid-to-late 1979. This could only be achieved by eliminating a separate Phase B activity; even then, programme timescale would be very tight. (The recent decision not to include CAPS on FSLP obviously relaxes this constraint).

Regarding the selection of a preferred system for CAPS this has been seen to be strongly dependent on the payload. It is therefore essential that ESA should define, at an early stage, the most likely number and type of experiments to be carried on the first CAPS and a mission model for subsequent flights.

The indications from this Phase A study are that the performance required for limb sounding can be achieved without 'stretching' present technology; indeed a degraded control system (e.g. higher friction) would still be acceptable for most operating modes. Whether it is wise to consider in more detail a system of lower performance depends on policy decisions by ESA such as:-

- what is the expenditure limit for the first version of CAPS ?
- will CAPS be required for high accuracy applications e.g. astronomy payloads ?

The main subsystem areas which need to be investigated in more depth in a subsequent study or proposal phase are as follows:-

- Drive Units
  - further design and stress analysis of the proposed cone clamp (materials, surface finish, threaded drive-up system) to establish the degree of off-loading/load by-passing which it provides (and the payload mass/moment limit which could be tolerated).
  - friction and stiction levels of the cable follow-up need to be assessed, preferably by practical tests, to establish how critical this area will be and to give realistic levels for the control loop simulation.
- Structure
  - stress/dynamic analysis of the support structure to establish a preferred design and to generate reliable mass estimates.
- Thermal
  - to extend the thermal analysis for a passive system more information will be required on the layout of experiments within the payload and their power dissipation.
  - if ESA wish to persue the design of an active system results should be made available from the recent Dornier study on this subject. (Though study results have not been made available to HSD it is understood that serious design and development problems could be involved in a thermal canister approach).
- Electronics
  - the decision to use Spacelab's experiment computer for CAPS control loop assumes that the processing and storage requirements can be satisfied; this depends on the entire payload and its requirements on any mission.
  - further definition of the control loop implementation will require more details about Spacelab software capabilitites.
  - the control loop routines will require proving, at the earliest opportunity, with the mechanism in order to avoid cost and timescale impacts. For this reason it is essential to have a Spacelab CDMS hardware and software simulator early in the CAPS development programme.

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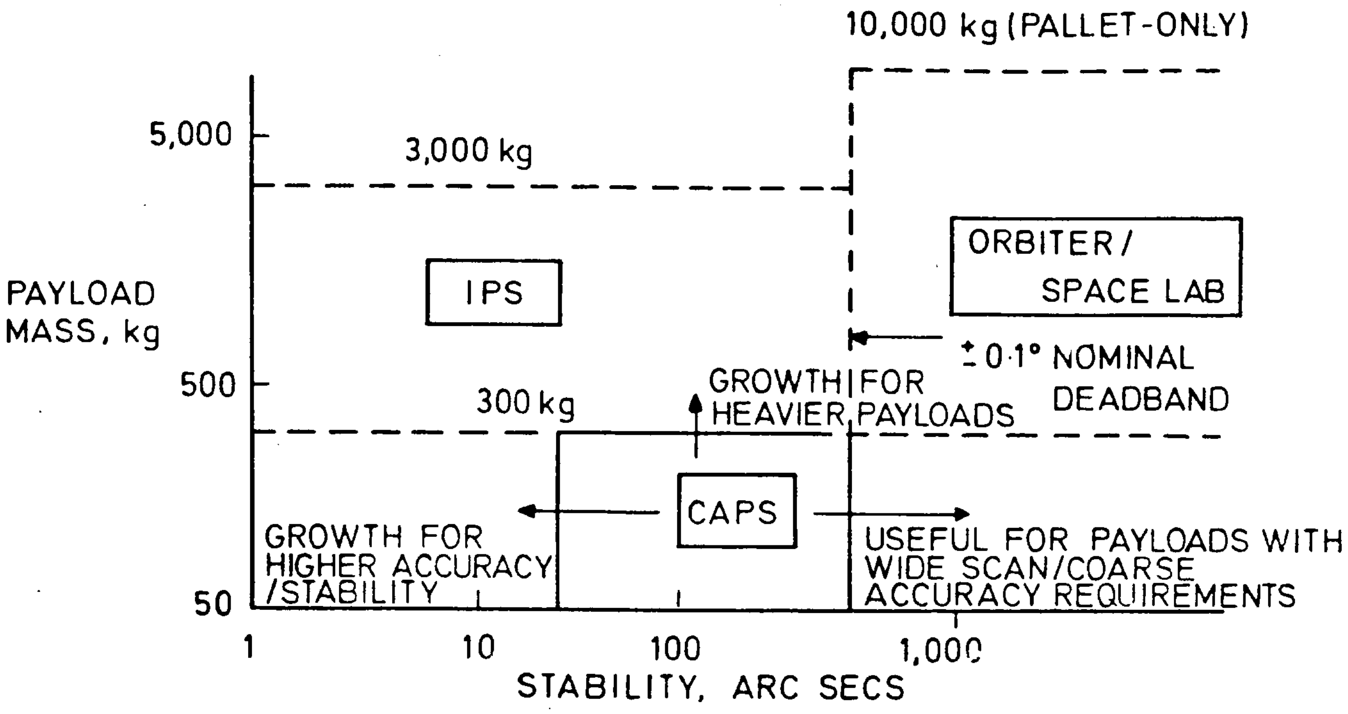
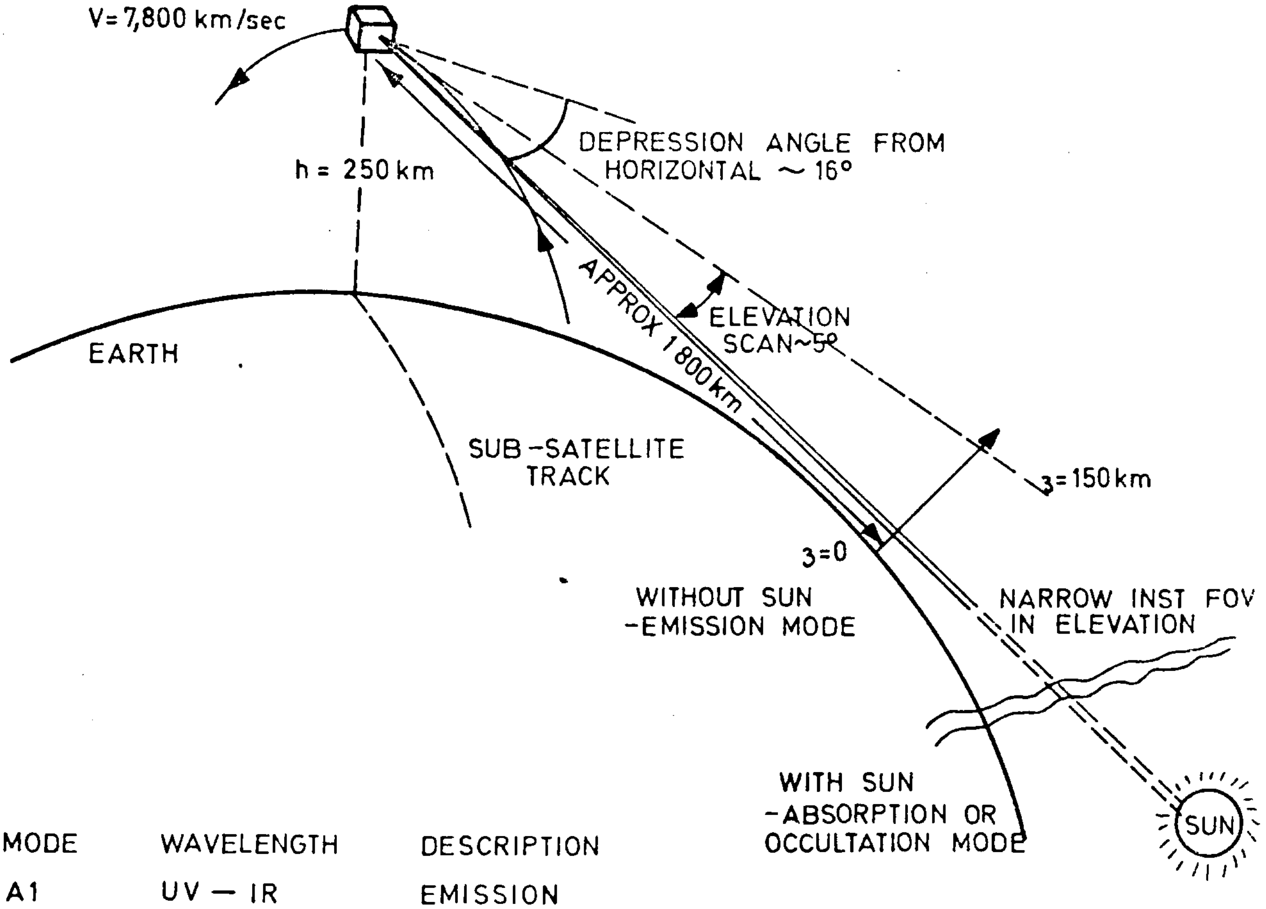


CHARACTERISTIC	NOMINAL GOAL
PAYLOAD SIZE	LOW-TO-MEDIUM (TO 300 kg)
POINTING RANGE	WIDE (HEMISPHERICAL COVERAGE)
ACCURACY/STABILITY	INTERMEDIATE (~ $^1/_3$ ARC MIN.)

POTENTIAL USEFULNESS OF CAPS

FIG. 1

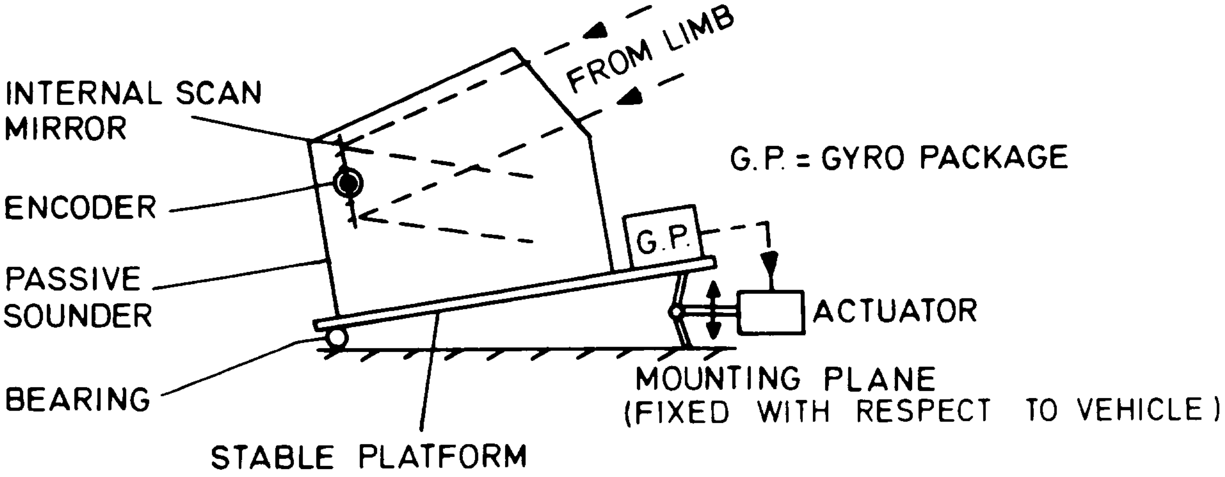
PASSIVE SOUNDERS - MODES OF OPERATION



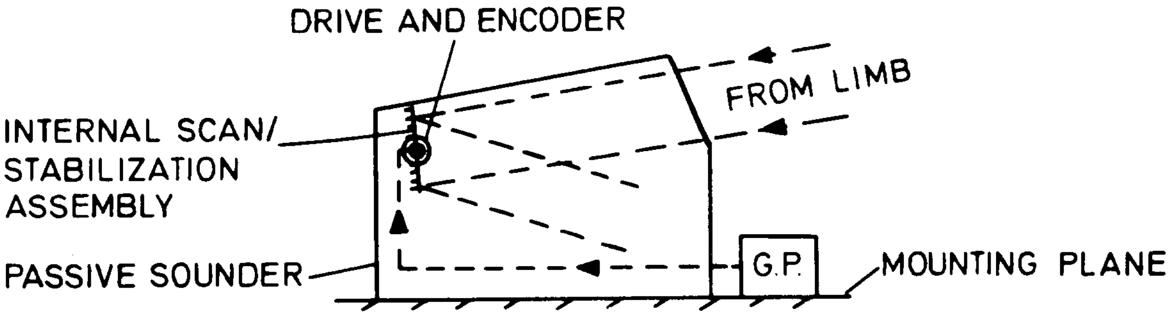
MODE	WAVELENGTH	DESCRIPTION
A1	UV — IR	EMISSION
A2	UV — IR	ABSORPTION
A3	UV — IR	EMISSION FOR WINDS
B1	MICROWAVE	EMISSION (ATMOSPHERE)
B2	MICROWAVE	PASSIVE OR ACTIVE (EARTH)

VIEW GEOMETRY FOR LIMB SOUNDERS

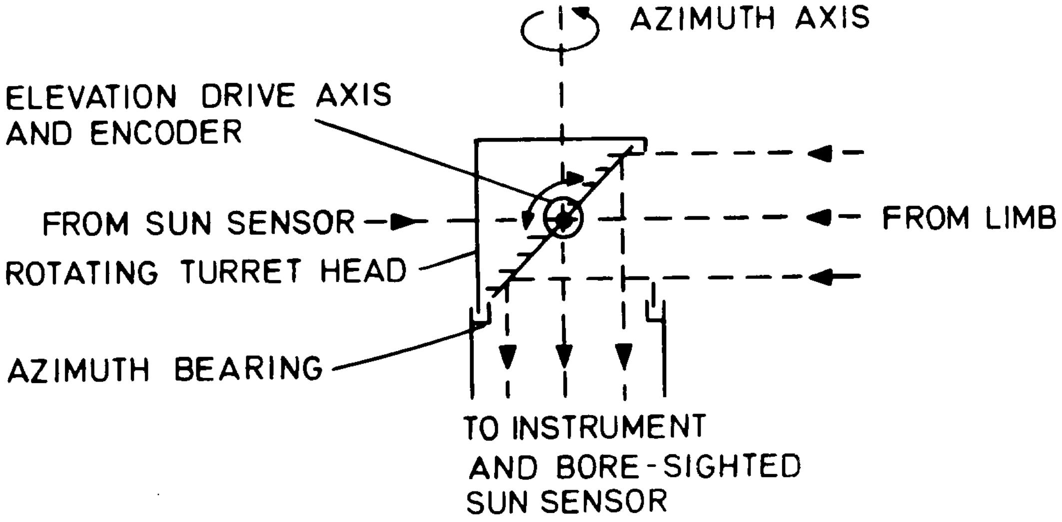
FIG. 2



a) PIVOTTED INSTRUMENT PLATFORM

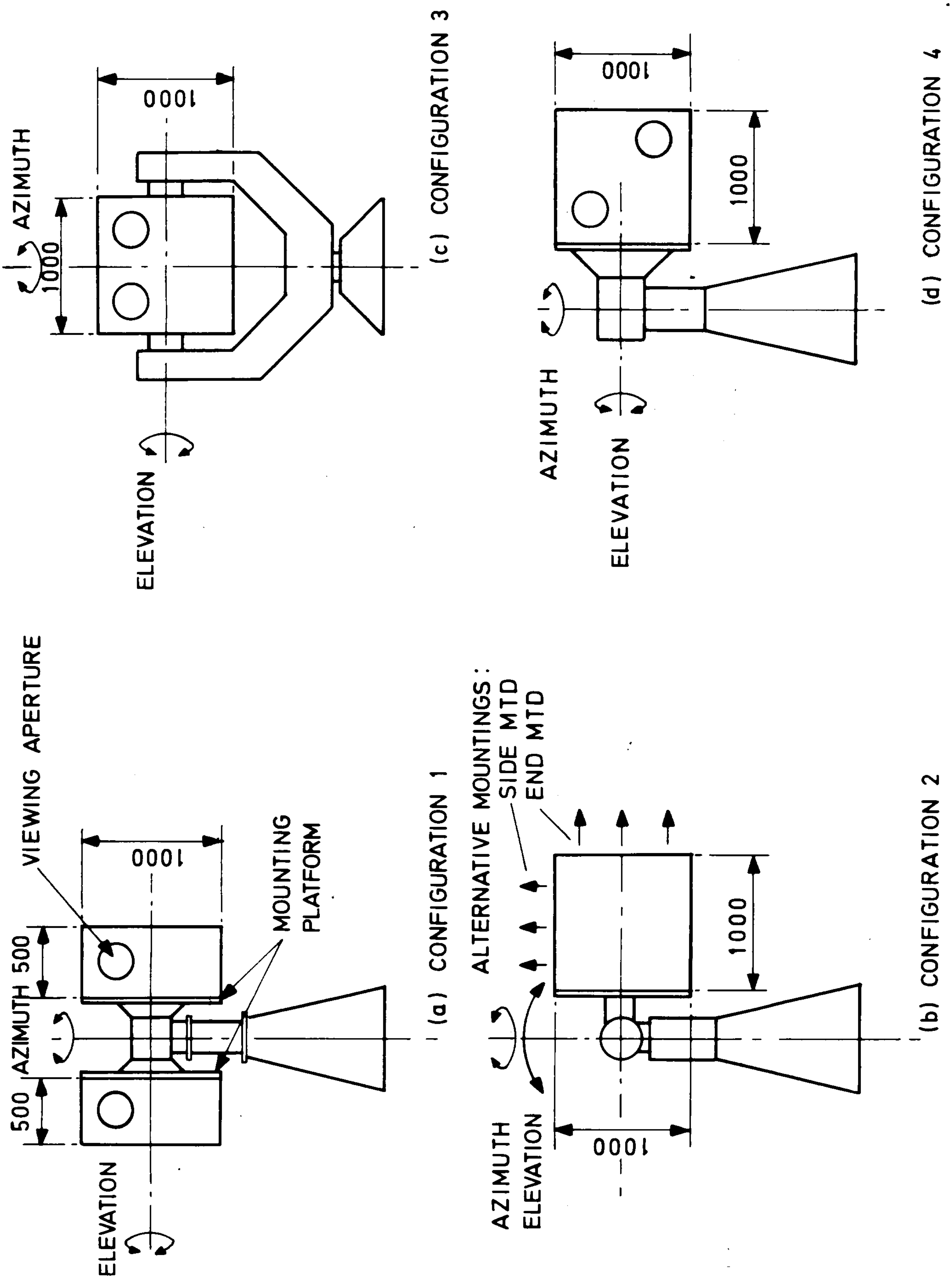


b) STABILIZATION SUPERIMPOSED ON INTERNAL SCAN ASSEMBLY



(c) WIDE AZIMUTH, NARROW ELEVATION RANGE SCAN / STABILIZATION ASSEMBLY

POINTING AND STABILISATION FOR FIXED-MOUNT INSTRUMENTS FIG. 3



(a) CONFIGURATION 1

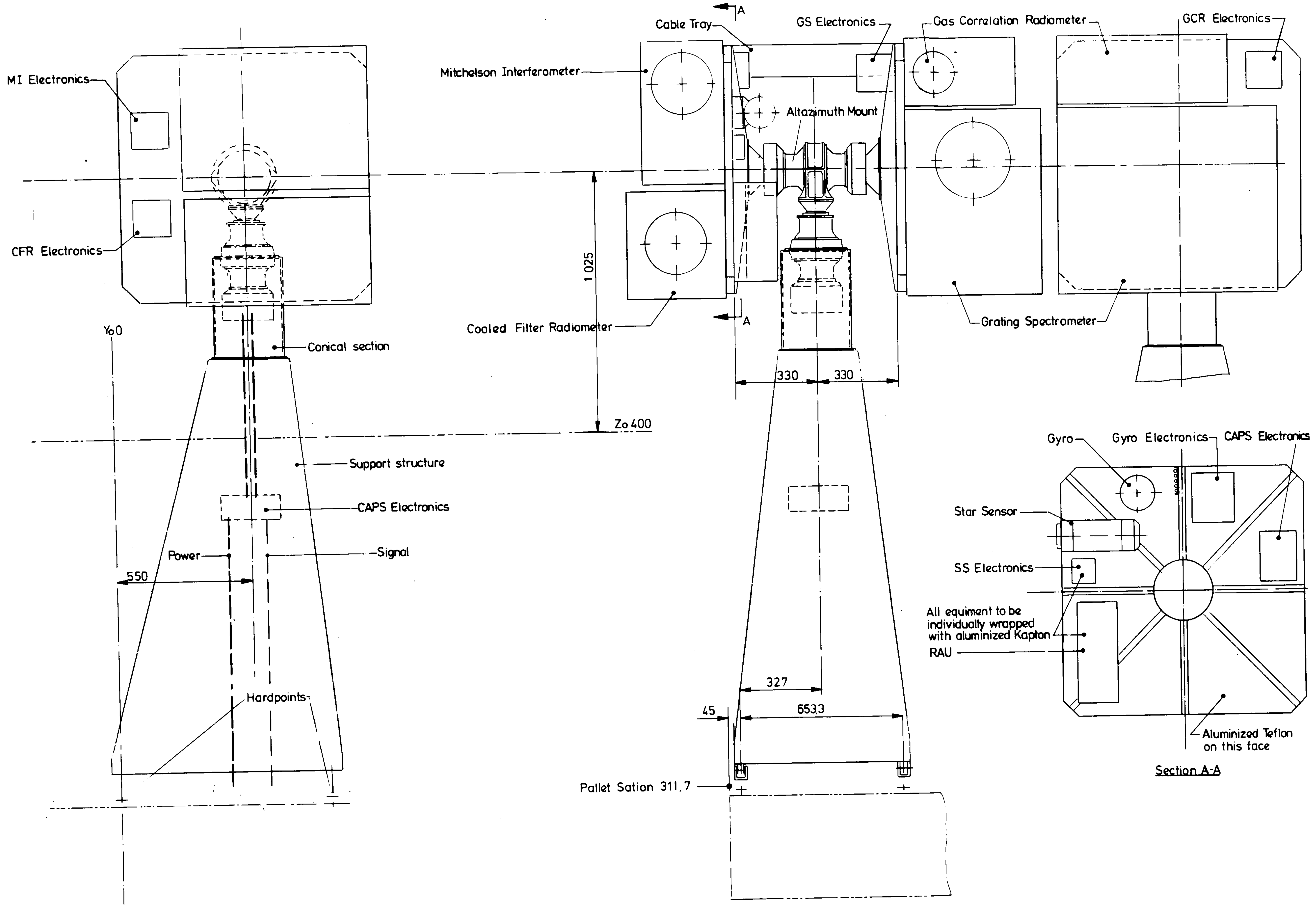
(b) CONFIGURATION 2

(c) CONFIGURATION 3

(d) CONFIGURATION 4

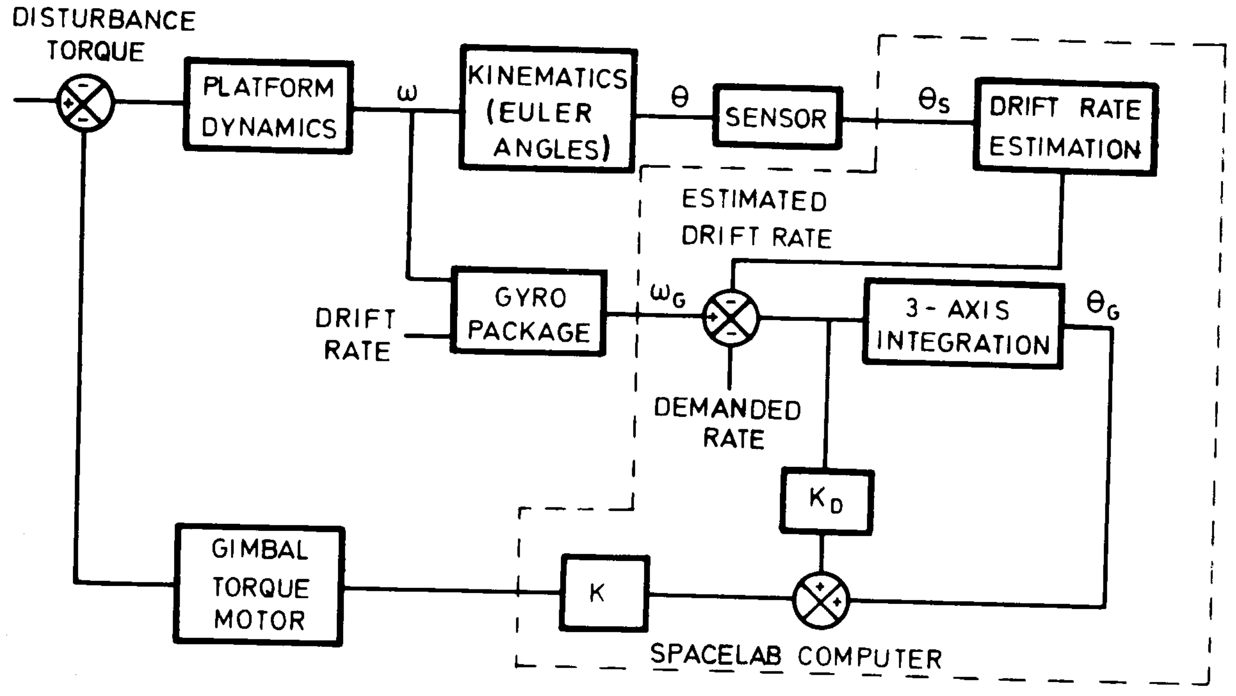
GIMBAL CONFIGURATIONS

FIG. 4



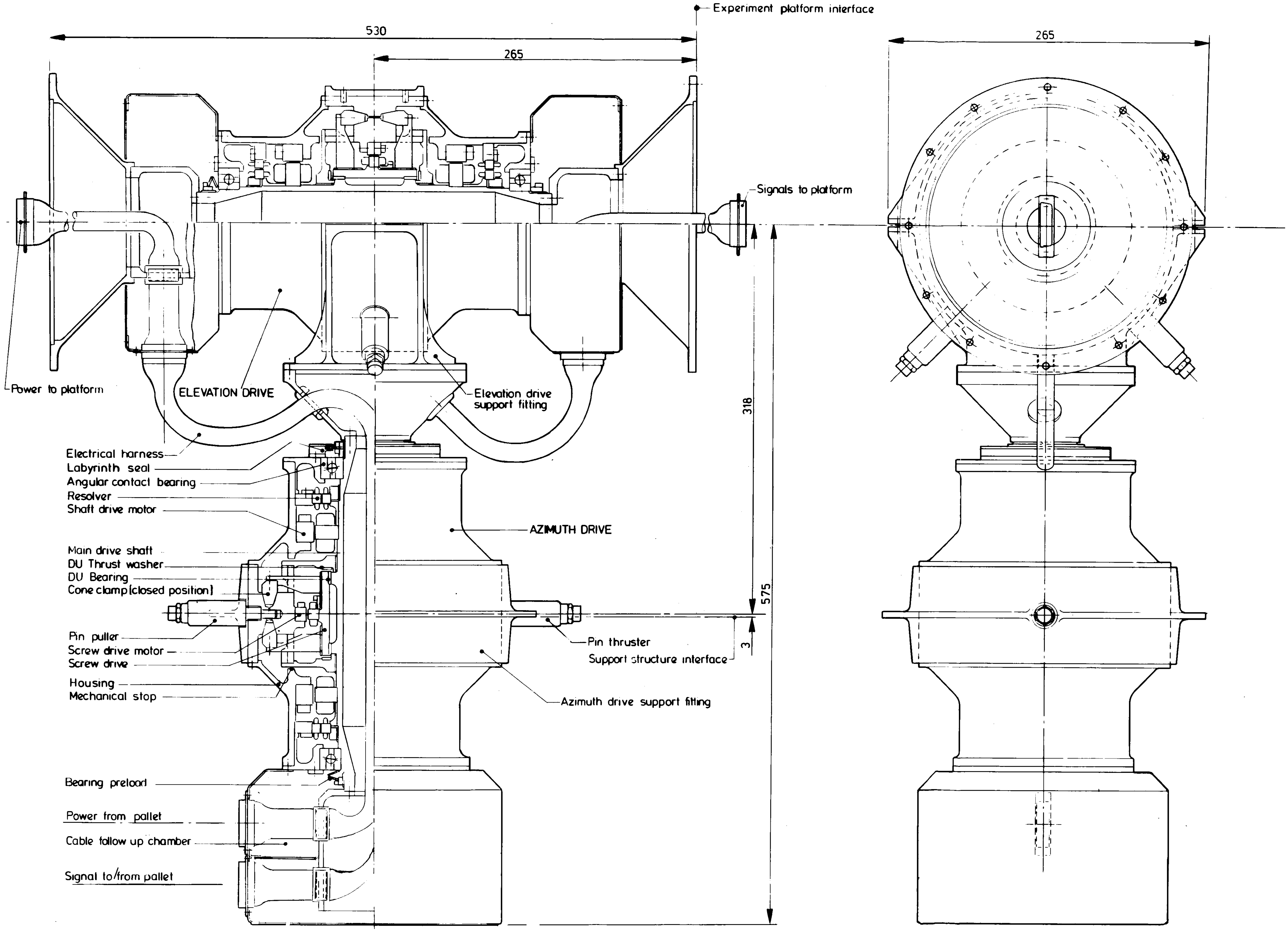
GA OF BALANCED CAPS CONFIGURATION

FIG. 5



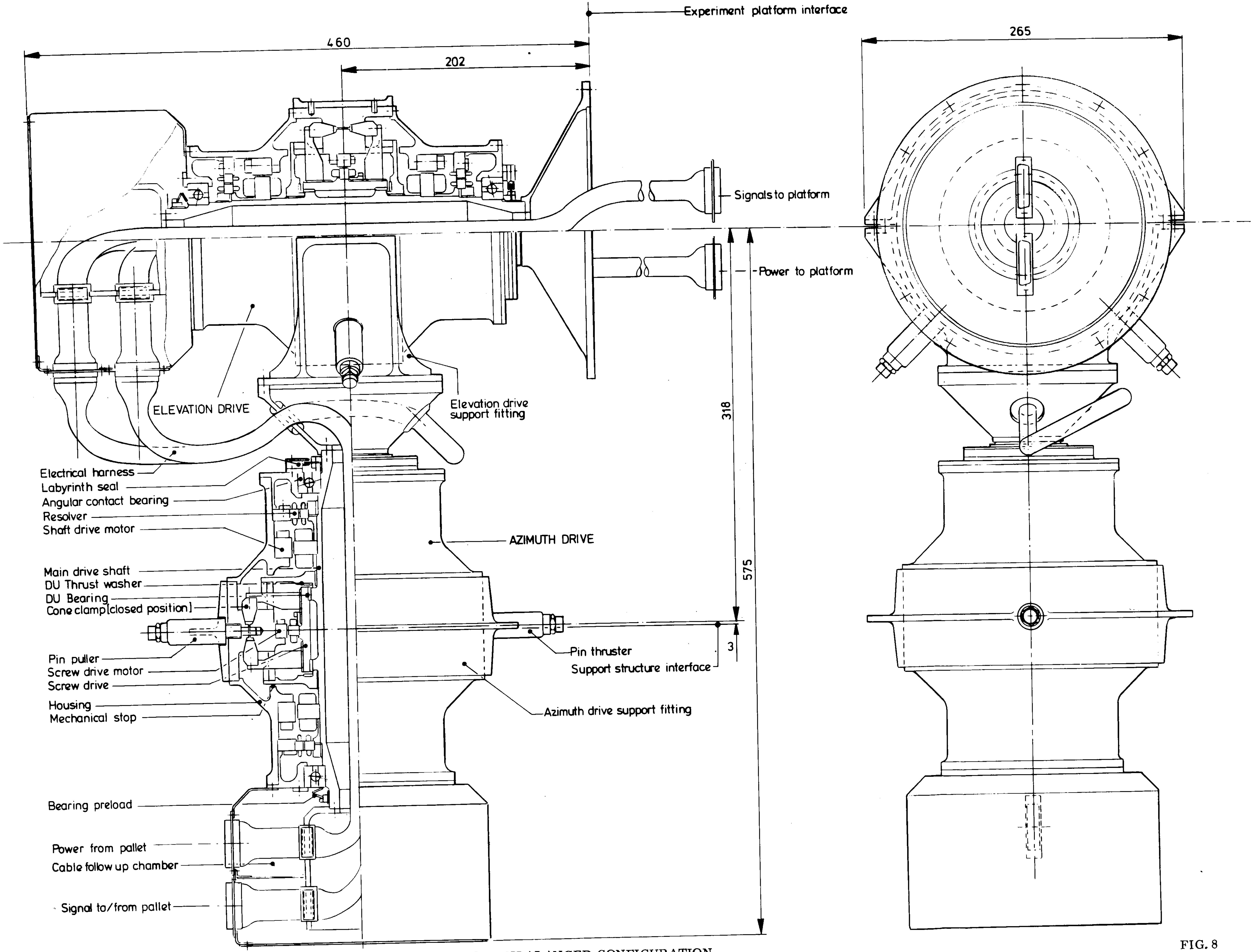
CAPS CONTROL LOOP

FIG. 6



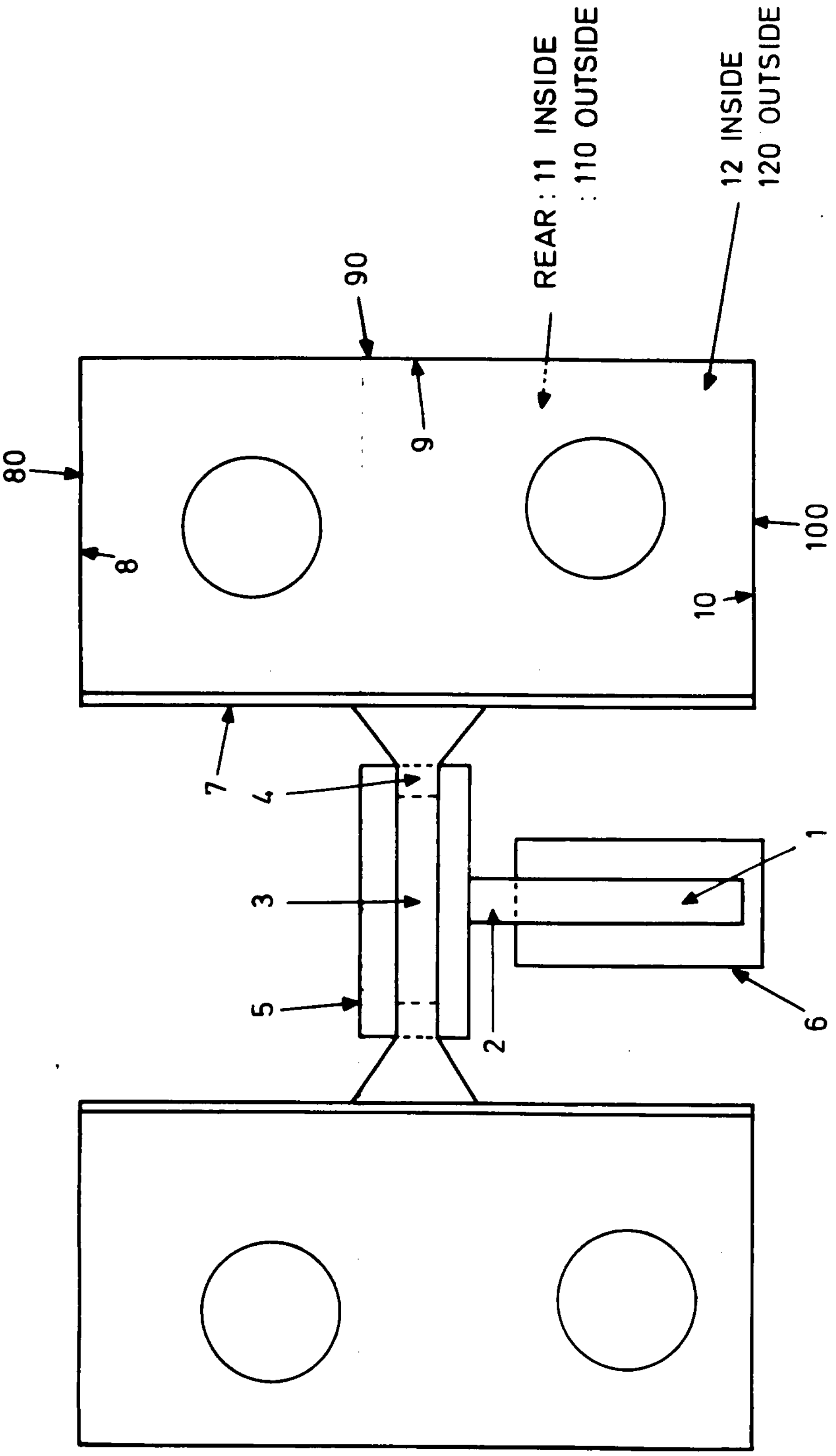
DRIVE ASSEMBLY FOR BALANCED CONFIGURATION

FIG. 7



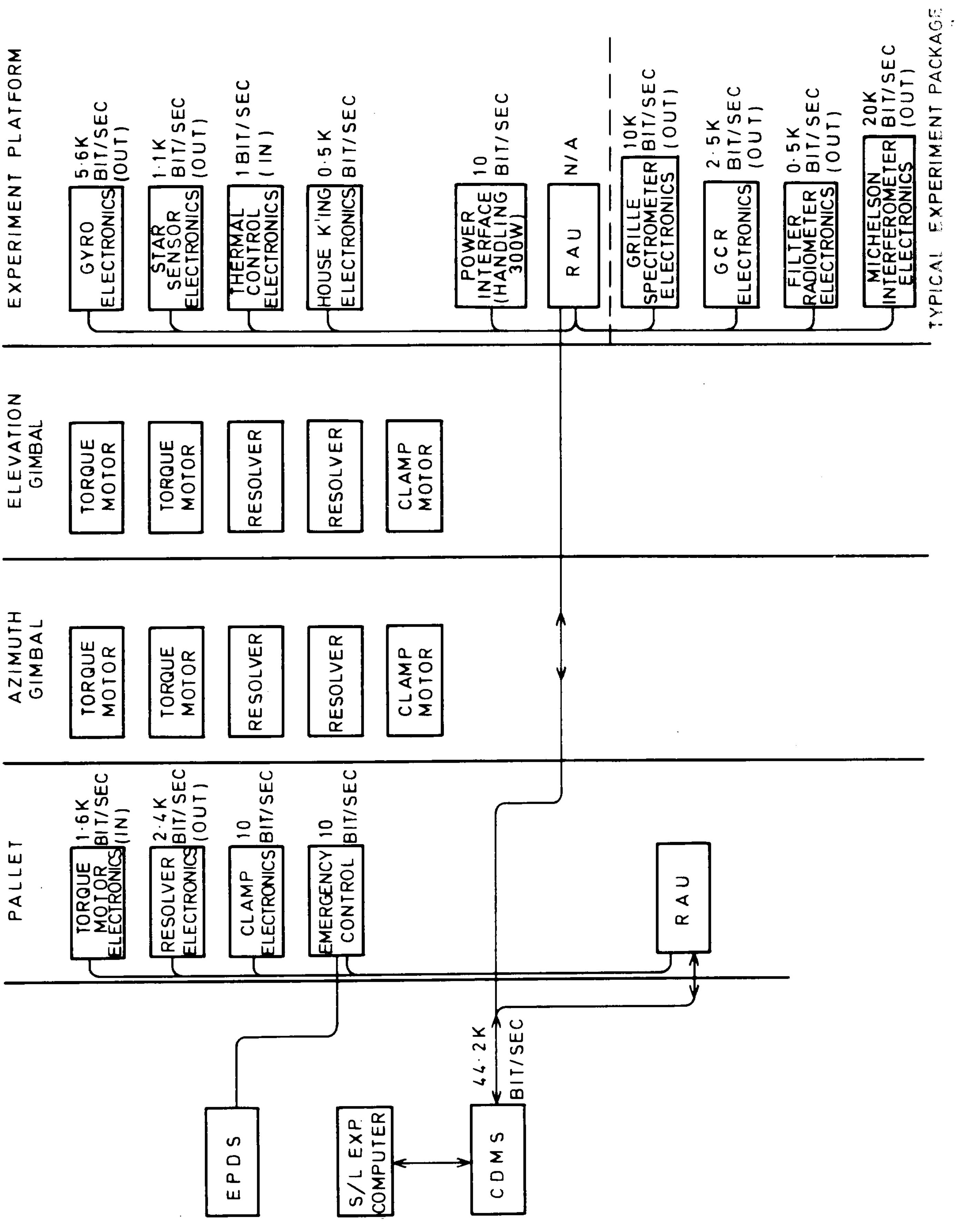
DRIVE ASSEMBLY FOR UNBALANCED CONFIGURATION

FIG. 8



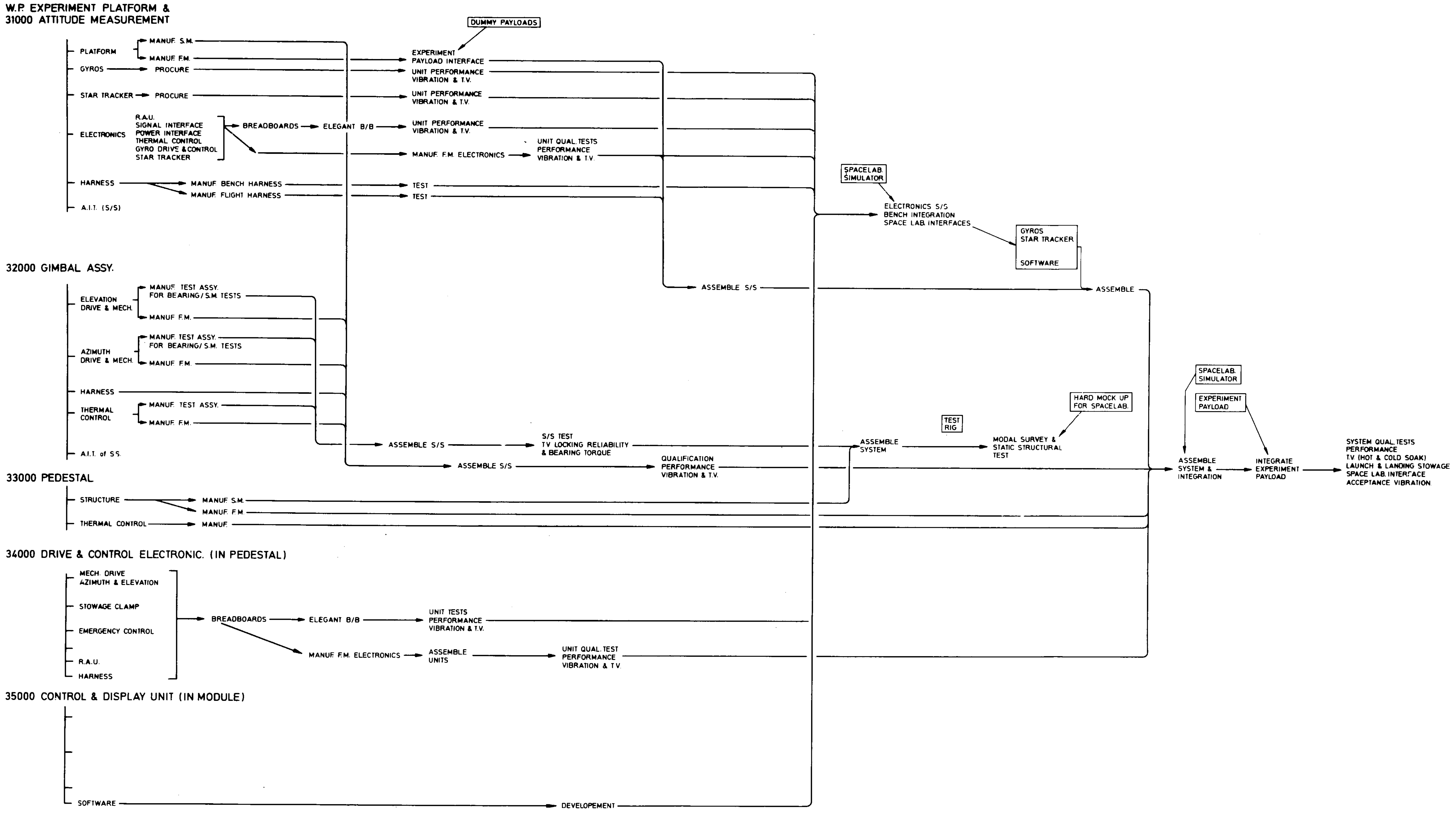
THERMAL NODE DIAGRAM

FIG. 9



DATA RATES FOR CAPS AND PAYLOAD

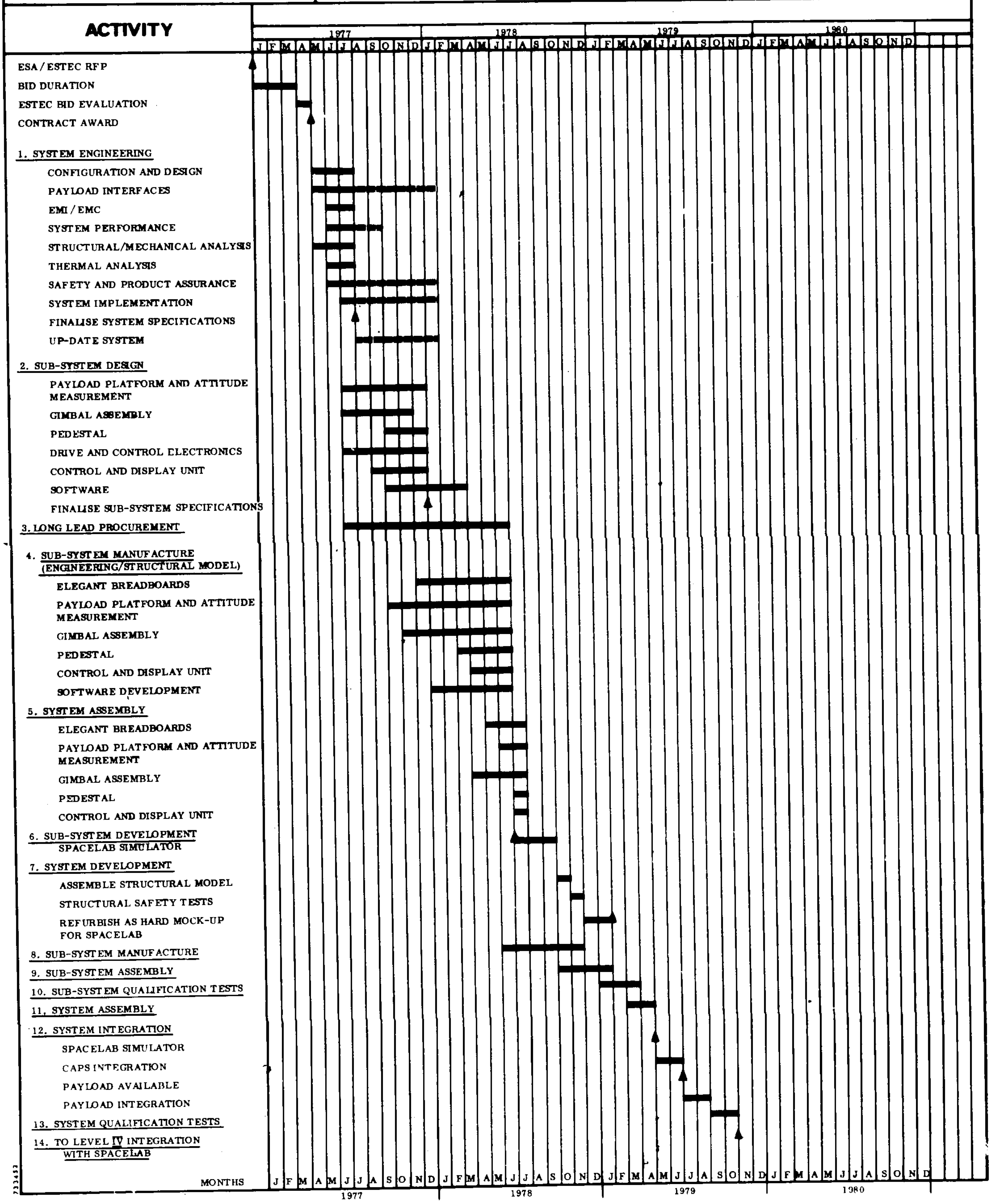
FIG.10



DEVELOPMENT TEST PLAN

FIG. 11

PROJECT COMMON ATTITUDE POINTING SYSTEM (CAPS)	ISSUE No 1	REF. No	DESCRIPTION C.A.P.S. PROGRAMME (NO SEPARATE PHASE B)
ORIGINATING COMPANY	APPROVED BY	ISSUE DATE 16th NOVEMBER 1976	



PROGRAMME FOR CAPS DEVELOPMENT

FIG. 12