D21-34
12 P.

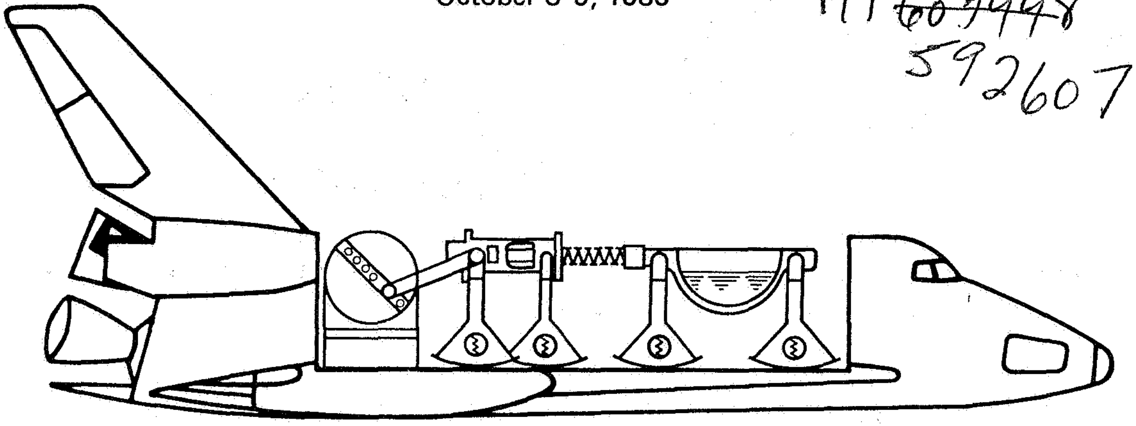
8974

GAS PAYLOAD NO. G-025
STUDY OF LIQUID SLOSHING BEHAVIOUR IN MICROGRAVITY

Prepared by C. R. Gilbert
MBB-ERNO Bremen

Presentation at the Second Get Away Special (GAS) Experimenters Symposium
NASA/Goddard Space Flight Center
October 8-9, 1985

MT ~~603998~~
592607



1. SUMMARY

GAS Payload No. G-025, which flew on Shuttle Mission No. 51-G, examined the behaviour of a liquid in a tank under micro-gravity conditions. The experiment is representative of phenomena occurring in satellite tanks with liquid propellants. A reference fluid in a hemispherical model tank will be subjected to linear acceleration inputs of known levels and frequencies, and the dynamic response of the tank liquid system was recorded.

Preliminary analysis of the flight data indicates that the experiment functioned perfectly. The results will validate and refine mathematical models describing the dynamic characteristics of tank-fluid systems. This will in turn support the development of future spacecraft tanks, in particular the design of propellant management devices for surface tension tanks.

The experiment was mounted on a Payload Support System (PASS) flight unit, identical to the system designed and developed by MBB/ERNO for the Federal German materials science project MAUS. PASS is a standardized structure, power supply, and data processing unit available commercially to GAS users.

2. INTRODUCTION AND OBJECTIVES

The trend to increased use of surface tension as a mechanism for control of liquid propellants in spacecraft has stimulated development of mathematical models which can adequately describe the behaviour of the propellant under a variety of environmental conditions. Of special interest are the behavioural characteristics of fluids under micro-gravity conditions, and the effect of operationally induced disturbances on propellant management. GAS Payload No. G-025 utilized the opportunities of the Get Away Special program to the full, to make a real contribution to product research and development being carried out by MBB/ERNO.

The purpose of this experiment was to generate data regarding liquid sloshing in partially filled tanks under micro-gravity conditions. A transparent, hemispherical tank was subjected to oscillatory disturbances corresponding to inputs used for theoretical simulation and analysis. The validity of such mathematical models will be significantly reinforced by comparison with empirical data, and areas not amenable to modelling will benefit from a review of their behaviour under realistic conditions.

The overall objectives consisted therefore of two parts:

1) investigation of the dynamic behaviour of the tank fluid system, and subsequent correlation with mathematical models, and

2) investigation of the orientation and stabilization of the fluid (propellant) under the influence of a propellant management device (PMD) especially with respect to outflow cases.

Specific aims were:

- o definition of all significant natural frequencies and damping of the fluid in the low frequency range to 6 Hz;

- determination of the generalized propellant mass, to facilitate necessary analysis assumptions;

- determination of sloshing forces and the pressure distribution in the fluid and tank;

- observation of the dynamic behaviour of the propellant under quasi zero-gravity conditions;

- observation of the fluid orientation stability effect, including the shape of flow during critical operational phases.

3. PAYLOAD CONFIGURATION

This GAS payload is of modular construction. A standardized support system provides physical accommodation, electrical power, experiment command and control functions, and data recording. Space is assigned, in the form of two horizontal mounting platforms, for the integration of experiment hardware. The volume so provided is about half that of the standard 5 cu.ft. GAS container.

3.1 Payload Support System

The tank experiment assembly is mounted on a standard payload support system (PASS) which meets NASA requirements for payloads flying in Get Away Special containers. PASS can accommodate a wide variety of GAS-type experiments, and offers a range of services to experimenters within a framework of standardized interfaces.

A unitary structure provides primary physical location and support for experiments. Within this structure are provisions for an electrical power supply, in the form of batteries, and electronic assemblies which regulate the operation of the experiment and record the data produced.

The structure is attached to the GAS container experiment mounting plate via an adapter ring. Six longitudinal posts are located equidistant from each other around the adapter ring and carry two further platforms for equipment and experiments.

The battery assembly is also attached to the adapter ring, and contains 80 silver-zinc cells providing 1.8 kWh of energy at 30 V min. Main power supplied to the experiment is unregulated but limited by fuses. A power conditioning unit provides regulated outputs at ± 15 V and + 5 V, 100 mA, which can be utilized, for example, for sensor operation and command signals.

Experiment control and data management is performed by a centralized electronic assembly, mounted on the underside of the lower experiment platform. The overall function of this assembly is carried out by two subassemblies: the experiment command unit, and the data acquisition unit.

The command unit produces software-controlled on/off commands for up to 12 experiment-dedicated channels, acts as a function generator (4 analog channels available), surveys experiment-generated parameters and initiates ongoing incremental changes to the experiment as required.

The experiment run is executed and controlled by the sequential switching of pre-selected command channels. Besides this pre-programmed switching function, certain events can be initiated if, for example, pre-determined boundary conditions are exceeded.

The control sequences can run for up to 200 hours. The program operates on an 'action point' basis, in which the data status is reviewed and the appropriate commands are issued. The shortest time interval between action points is 1 second, and the total sequence can handle up to 599 action points, with a corresponding command storage capacity of 4 Kbytes. If a particularly complex program is required, the memory available can be best utilized by grouping as many control activities together as possible at the same action point.

The data acquisition unit consists of a microprocessor-controlled multiplexer unit with digital and analog inputs. The analog signals are converted internally into digital data with a 10-bit word format for subsequent processing and storage. Of the 32 analog inputs, 16 are available for the experiment. An additional thirty digital status channels are available for suitable data inputs.

The data acquisition unit also carries out the selection of measurement data for special control activities, together with the surveillance of limit-sensitive data. Where necessary, data is transferred to the command unit, which then issues the appropriate control signals to the experiment.

Data which is to be retained is coded into PCM format and assembled to the channel designation, making a complete word of 16 bits. It is then fed into a buffer and held there, together with a time signal, until the buffer is full. At that time the buffer contents are read into a serializer, which in turn triggers a tape recorder and feeds the serialized data stream to the recording head at 2.5 kHz. The buffer continues to re-fill itself with incoming data.

The payload support system also provides a housekeeping subsystem, which monitors a range of signals relating to the well-being of the system itself and basic services.

The signals cover

- all battery voltage, 10 channels
- pressure in the GAS container
- pressures in the Silver-Zinc battery housings, 2 channels
- temperature within the GAS container
- 3-axis acceleration levels on the upper experiment platform.

The accelerometer range is $\pm 5 \times 10^{-3}$ g, with a resolution of 10^{-5} g.

The acquisition rate for housekeeping data is variable. Typical values are 1 measurement per 10 seconds for voltage and temperature, 1 measurement per second for pressure and acceleration. High-rate bursts up to 30 Hz are possible over short, pre-determined periods. However, a balance has to be struck between the experiment data requirements and the need for housekeeping data.

Changes of acquisition rates for selected channels can of course be pre-programmed to occur at selected phases in the experiment run.

The physical space available for experiments is related to the position of the experiment platforms. A maximum height of 8.5 inches (218 mm) is available between the platforms; the corresponding height above the upper platform is then 6.7 inches (170 mm). In this position the upper floor is not obstructed by the support posts, and the full dynamic envelope is available, that is 19.75 inches (501 mm) diameter. Due to clearance requirements, however, the allowable hardware diameter is limited to 18.8 inches (478 mm).

The upper experiment platform height is adjustable, to provide the optimum accommodation for individual experiments. The adjustment range is nearly four inches in 1-inch increments. When the upper floor is lowered, the envelope is additionally limited by the support posts projecting above the plane of the platform. Cut-outs can be made in the upper platform to accommodate experiments with particular height requirements, provided that the approach is structually feasible.

3.2 Experiment Assembly

The central feature of the experiment is a hemisperical plexiglas tank suspended in a rocking mechanism such that purely linear, nearly frictionless oscillation can be induced within a limited displacement range. Mechanical motion is initiated by a stepping motor and crankshaft connected via a pivot assembly to a transmission coupling system. The speed of the motor and hence the oscillation frequency can be varied during operation of the experiment. Similarly, the moment arm of the pivot assembly and hence the linear displacement can be varied.

The transmission coupling system, which transfers the linear oscillation generated by the drive train to the tank, comprises a concentric rod and helical spring assembly. One end of the rod is permanently attached to the tank, but the other end can either be held fast or left free. This is achieved by an electro-magnetic clutch. For continuous operation (i.e. sinusoidal oscillation), the clutch is engaged; for pulsed operation, the clutch is released following the pulsed input allowing the tank oscillations to decay.

The hemispherical plexiglas tank and the transmission coupling system are supported by rocking assemblies which assure that a one-dimensional oscillation is experienced by the tank and contents, with negligible transverse components. The foot of each rocker has a cylindrical profile which provides a translation amplitude of ± 20 mm to the tank. Each rocker is held in place on the support system experiment platform by tangential leaf-spring yoke fittings. The rockers are additonally held down to the platform with helical springs, which also serve to give the assembly a neutral bias. The tension in one pair of these springs can be adjusted during the experiment to change the natural frequency of the moving assembly.

Besides the hemispherical test tank, initially 50 % filled with fluid, a second evacuated aluminum container is provided, connected to the test tank by a tube and solenoid valve. Outflow of propellant from the test tank is achieved by opening the valve at specific times.

A high-speed camera is used to make a visual record of the fluid behaviour at critical phases. The camera is mounted on the propellant transfer tank and views the test tank and contents via a mirror. A source of diffuse light is provided for illumination of the fluid.

Generation of the necessary data is accomplished by a variety of sensors located at strategic points on the experiment assembly. The instrumentation consists of the following sensors:

Parameter	Sensor
Output force of the transmission coupling system	force transducer
Input force to the tank	force transducer
Acceleration of the transmission coupling system	accelerometer
Acceleration of the tank	accelerometer
Pressure within the tank (4 locations)	piezzo resistive transducer
Temperature of the fluid	thermocouple

In addition to the basic program control and data processing facilities provided by the PASS flight unit, an experiment dedicated electronics unit is used for control of the three electric motors, the camera and illumination source, the electro-magnetic transmission coupling actuator, the solenoid fluid transfer valve, the instrumentation sensors and position switches. This unit is driven by the pre-programmed commands issued by the PASS control unit, and data signals generated by the instrumentation sensors are conditioned and relayed back to the support system for processing and storage. The assembly is mounted on the lower experiment platform.

4. EXPERIMENT OPERATION

In-flight operation of the experiment was controlled by a program in the PASS command module. The experiment run was divided into five distinct phases each with specific operating modes and objectives, as mentioned in the introduction. An important requirement for the experiment is the condition that the fluid in the tank be in a state of equilibrium, and stationary at the start of vibration inputs. Therefore time was included between operations for the fluid to reach this condition. Of the total run time of just over 3 hours, 60 % was occupied by active operations, the rest being reserved for fluid stabilization requirements.

The five operation phases were of course designed to provide an overview of the natural behaviour of the tank/fluid system in micro-gravity, and to enable a systematic examination of the fluid dynamics under the combination of several variable parameters. The variables were:

- oscillation/pulse frequency
- oscillation/pulse amplitude
- tank vibration stiffness
- fluid quantity

The major portion of the active operations was assigned to data production by transducers and sensors. The time allowed for filming was very limited, because the high speed employed rapidly used up the film; hence only critical phases were filmed, where sensor data could not provide an adequate picture of the fluid behaviour.

Although the film returned is therefore of limited duration, the opportunity to view the fluid characteristics is a valuable supplement to the considerable amount of sensor data generated.

5. CONCLUSIONS

The operation operated perfectly, and generated a considerable quantity of data which has still to be analysed in depth. In principal, the underlying mathematical models developed by MBB/ERNO for the design of surface tension tanks have been supported by the experiment results, and the validity of current product design features has been confirmed. The results will provide additional insight into the effect of fluid sloshing on spacecraft attitude control systems.

ORIGINAL PAGE IS
OF POOR QUALITY

The considerable investment represented by this experiment has been amply rewarded by these flight results. At least one re-flight is planned, with a modified experiment run profile, to examine certain aspects in more detail.

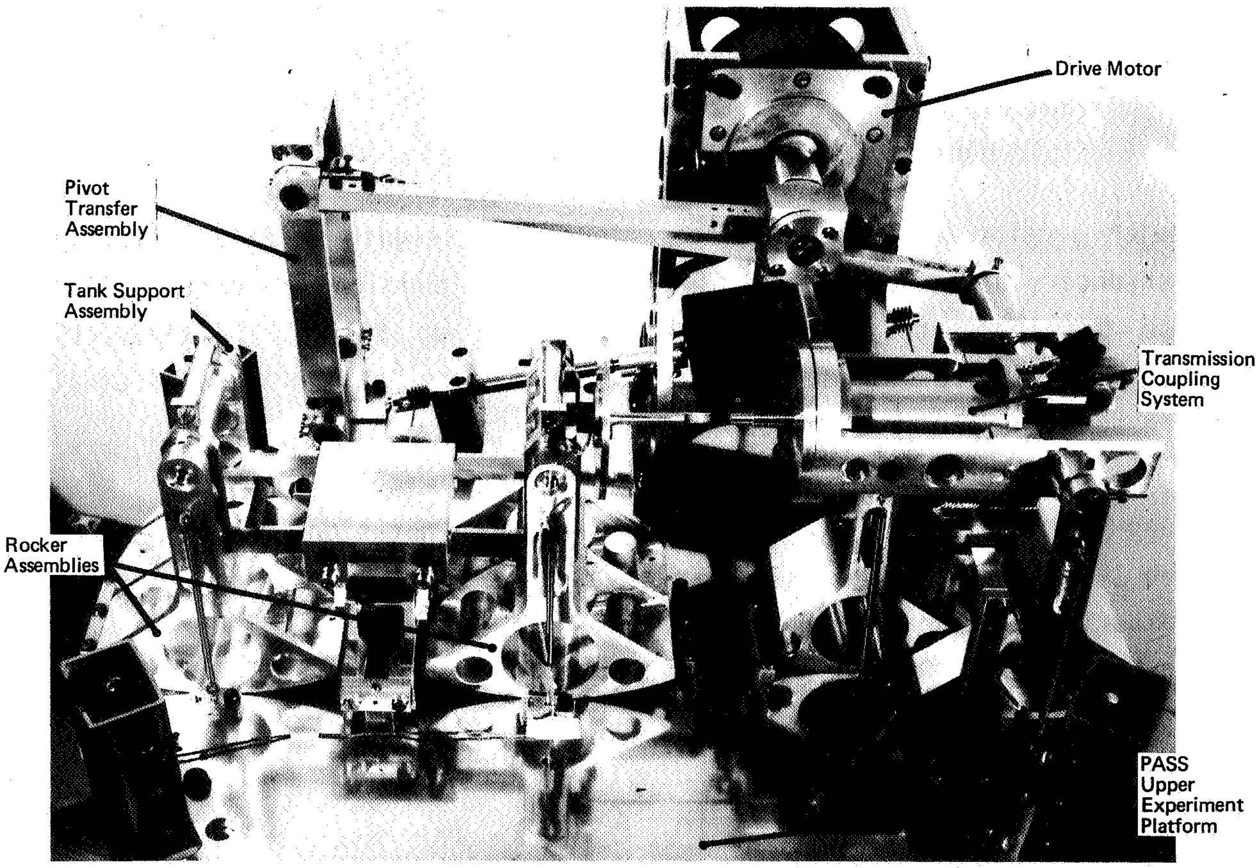


Figure 1. Experiment Basic Mechanical Assembly

ORIGINAL PAGE IS
OF POOR QUALITY

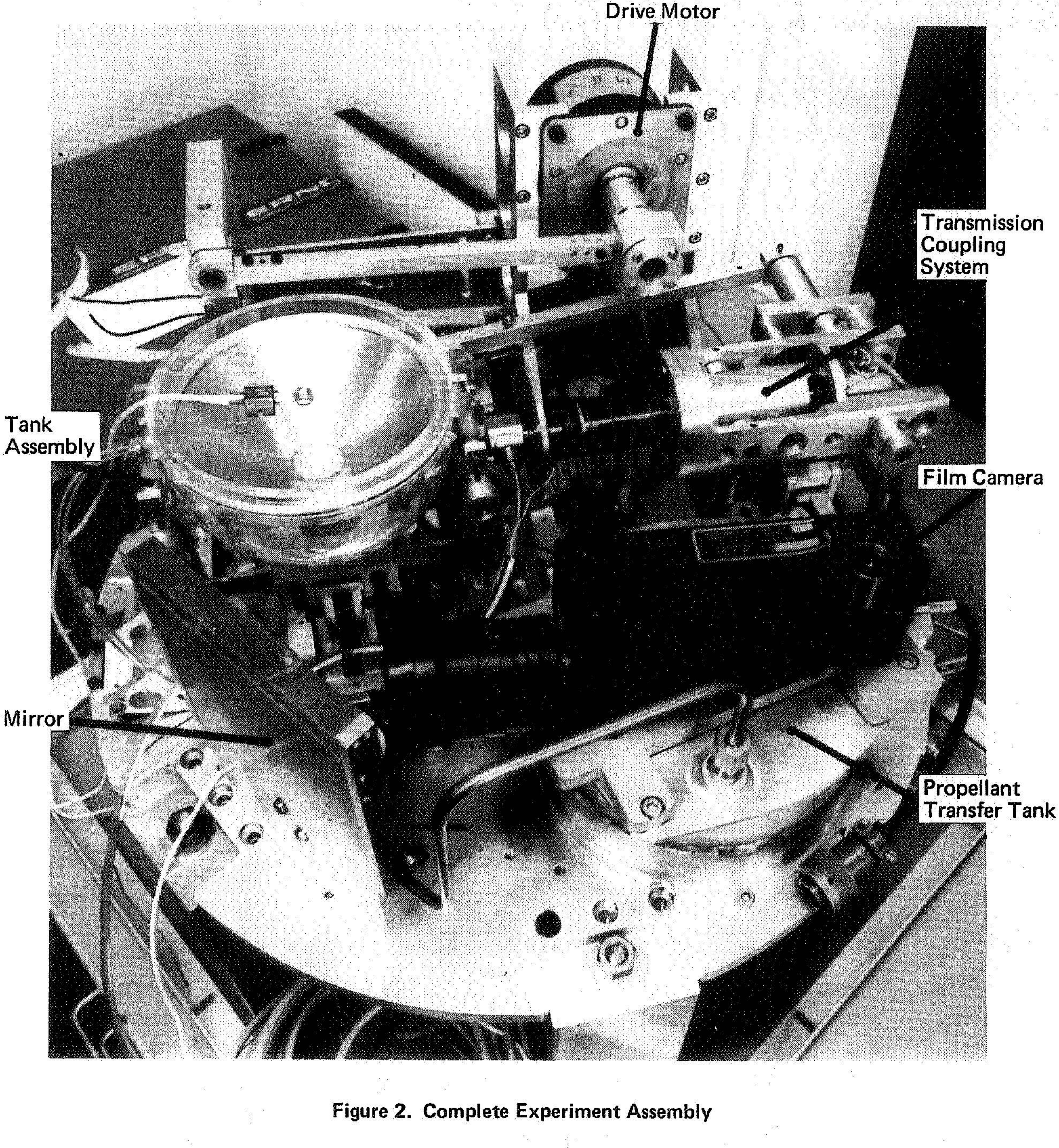


Figure 2. Complete Experiment Assembly

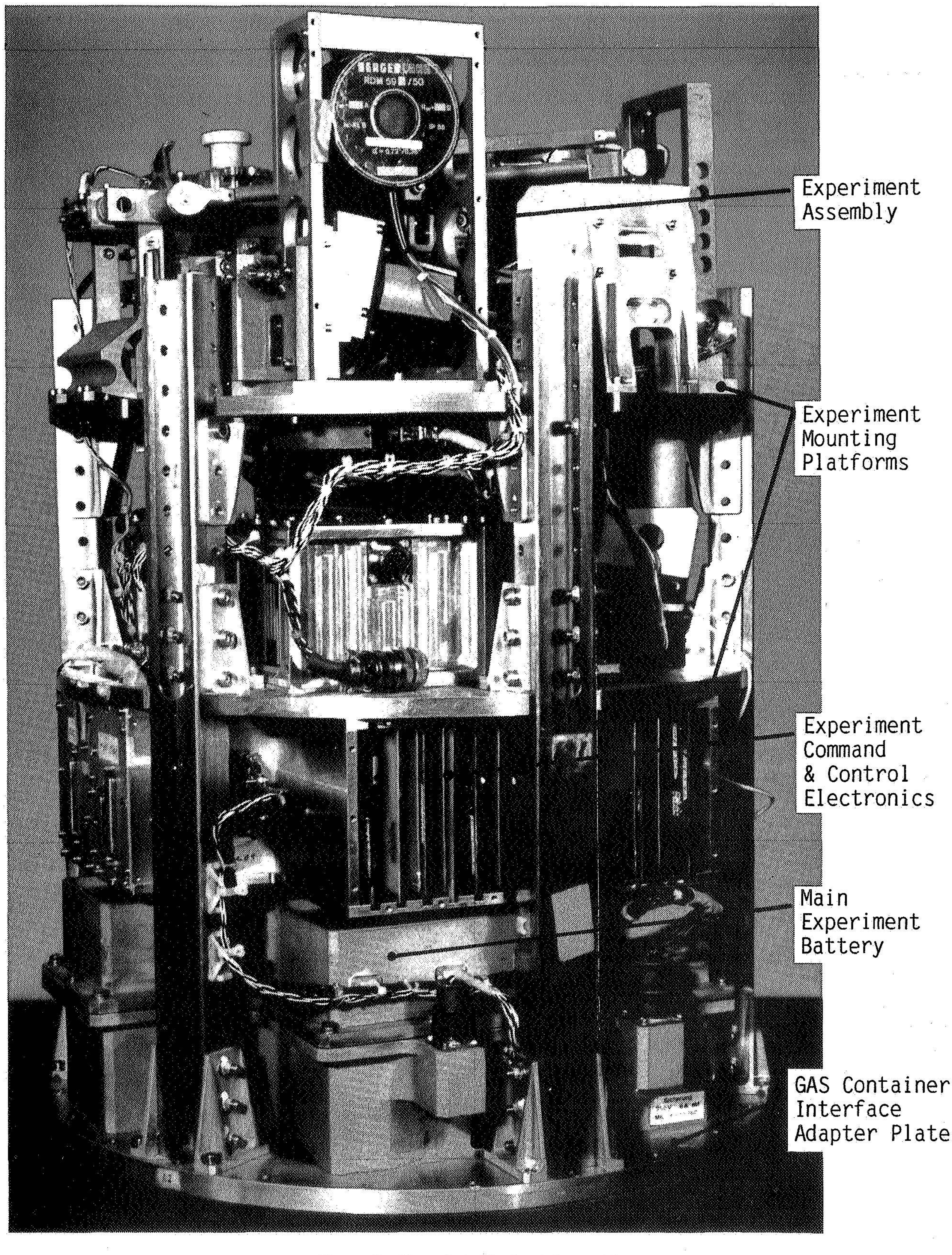


Figure 3. Complete Payload Assembly