Orbital Acceleration Research Experiment

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An experiment sponsored by NASA's Orbiter Experiments Program to provide data on rarefied aerodynamics in both the transition and the free-molecular-flow flight regimes is under development. It will contain a highly sensitive and accurate triaxial accelerometer capable of measuring Shuttle on-orbit linear accelerations into nanogravity range. Its wide dynamic range will permit acceleration measurements during re-entry down to an altitude of approximately 60 km. These objectives dictate a system with the following components: an electrostatically balanced cylindrical proofmass accelerometer with three dynamic ranges and a precision in-flight calibration subsystem to attain nanogravity accuracy, a 4 Mbyte solid-state memory device for storage of data and control software, and a signal processor and control subsystem that controls the component interactions and also provides a degree of artificial intelligence to the experiment. A number of nonaerodynamic signals can be modeled, predicted accurately, and removed from the flight data, ensuring an accurate measurement of aerodynamic acceleration up to orbital altitudes.

Nomenclature

ACIP = Aerodynamic Coeffient Instrument Package
A/D = analog to digital
APU = auxiliary power unit
c.g. = center of gravity
CPU = computer processing unit
GPS = Global Positioning System
GSE = Ground Support Equipment
HiRAP = High-Resolution Accelerometer Package
HSKP = housekeeping data
IRIG-B = Inter-Range Instrumentation Group B
I/O = input/output
L/D = lift-to-drag ratio
MOS = multitasking operating system
MTS = motor/table subsystem
OARE = Orbital Acceleration Research Experiment
OEX = orbiter experiments (program)
OIS = OARE interface subsystem
OMS = Orbital Maneuvering Systems
OSS = OARE sensor subsystem
PCS = power conditioning subsystem
PROM = programmable read only memory
R = universal gas content
RAM = random access memory
RCS = reaction control system
s = molecular speed ratio, $v/\sqrt{2}RT\infty$
SCS = servo control subsystem
SDCR = sensor data collection routine
SPCS = signal processing and control subsystem
TDRSS = Tracking and Data Relay Satellite System
T_w/T_∞ = wall-to-freestream temperature ratio
v = spacecraft velocity
α = angle of attack

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Introduction

THE use of ultrasensitive electrostatic accelerometers in space is not new. Sensor development was initiated as early as 1958 and versions of an electrostatic sensor have been used successfully on several programs.[1-3] In addition, analyses of Orbiter flight data acquired with the OEX program's High-Resolution Accelerometer Package (HiRAP) have shown that it is possible to use the Orbiter's acceleration measurements to advance aerodynamic prediction technology.[4] However, several problems have arisen in attempting to measure ultrasensitive accelerations in space. The most significant of these problems has been the bias and scale factor measurements, which are extremely difficult to obtain with accuracy in a 1g environment.[5]

Rarefied-flow regime data for a winged entry vehicle such as the Orbiter are difficult to obtain by wind-tunnel measurements. Thus, verification of computational techniques[6] will rely on flight experimentation. In addition, designers who need rarefied transitional-flow regime aerodynamic data have resorted to empirical formulas based primarily on space flight data from past programs.[7] This data gap has been partially filled by repeated Orbiter flights with the HiRAP experiment, which have provided some rarefied-flow flight data.

Both accelerometer and atmospheric measurements are required to obtain component aerodynamic force coefficient information from flight data.[8] Long-range plans include use of atmospheric density data from a mass spectrometer system especially adapted for the Orbiter.[9] However, before the availability of the mass spectrometer data, aerodynamic analysis with accelerometry is limited to the ratio of coefficients, e.g., L/D, since dynamic pressure cancels in its formation.[10]

Similarly, for initial flights of the Orbital Acceleration Research Experiment (OARE), acceleration ratios will be used to explore energy accommodation coefficients in the free-molecule-flow regime as well as angle-of-attack effects.

The OARE results will overlap HiRAP data to confirm and extend its results. Figure 1 shows theoretical predictions using theories by Hurlbut and Sherman[11] and by Schaaf and Chambre[12] for L/D ratios in the free-molecular-flow regime. In this region, at 160 km altitude, HiRAP measurements are made only at a 40 deg angle of attack because of entry constraints. There is some scatter in the data from the different flights; however, the mean L/D value obtained by HiRAP (about 0.13) is above the theoretical values for diffuse reflection (about 0.04). This can also be seen in Fig. 2 in which the measured L/D ratio derived from HiRAP data is plotted vs altitude. In addition, error bars at the higher altitudes emphasize the need for more precise measurements in this region. The OARE measurements will supply this information and extend the free-molecular-flow regime measurements to orbital altitudes and will also corroborate the HiRAP L/D measurements in the transition regime by providing signals down to about 60 km. The OARE measurements will also be obtained under varying angle-of-attack conditions to extend the comparison shown in Fig. 1. Furthermore, additional information is also needed on long-term surface conditioning effects, both at orbital altitudes and during re-entry. The vastly improved resolution of OARE is expected to yield results precise enough to perform such a temporal study. All of these flight measurements will aid in the understanding of how the transition region merges into the free-molecular-flow regime and the understanding of flow phenomena in the free-molecular-flow regime itself.

The OARE feasibility study results have shown that measurement of nanogravity accelerations with long-term accuracy covering the various flow regimes requires the following elements: 1) use of a highly sensitive sensor such as an electrostatically suspended proofmass that contains a high-gain constrainment servo loop in conjunction with a microprocessor controller; 2) an onboard digital filtering capability to enhance the signal-to-noise ratio; 3) a 16 bit digital system and sensor autoranging to provide a wide dynamic range; 4) onboard computation capabilities with a parallel numeric processor; and 5) onboard calibration of the sensor subsystem to provide a high level of precision and absolute accuracy. A key element for achieving experiment accuracy goals is the use of a highly stable, rotating sensor calibration platform. This provides a means of performing an inflight calibration of the sensor bias and determining the scale factor.

Science Objectives

The primary OARE objective is to provide accurate measurement of aerodynamic acceleration along the Orbiter's principal axes in the free-molecular-flow flight regime at orbital altitudes and through the transition regime during re-entry. The current measurement ranges of the operational accelerometer systems on the Orbiter in relation to the OARE are indicated in Fig. 3 for an altitude of 300 km. The approximate resolution of each existing accelerometer system is shown on the ordinate of the figure. The top of the shaded area represents atmospheric drag expected during solar maximum, while the bottom represents that during solar minimum.[13] Two vertical dashed lines denote the area/mass of the Shuttle with minimum and maximum projected frontal areas perpendicular to the velocity vector (i.e., at $\alpha = 0$ and 90 deg respectively). It is evident from this figure that accelerations between 1 ng and 1 mg will be encountered within all the possible cases of Shuttle orientation and solar activity at this altitude. Therefore, an instrument with greater precision than HiRAP, such as the OARE, is needed to extend the Orbiter's acceleration measurements into the free-molecular-flow regime up to typical Shuttle orbit altitudes.

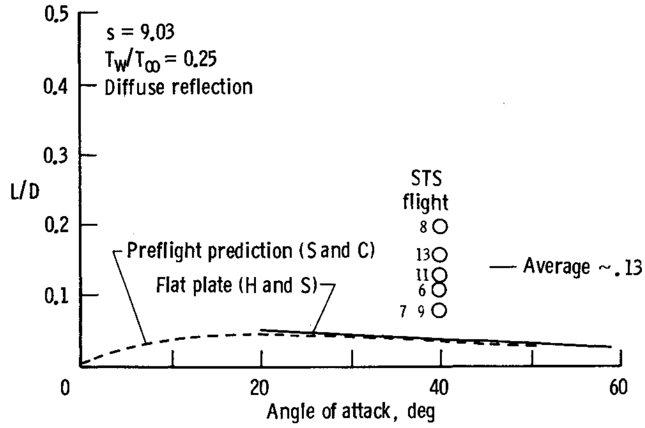

Fig. 1 Comparison of free-molecular-flow flight measurements (HiRAP at 160 km altitude) with preflight predictions from Ref. 14.

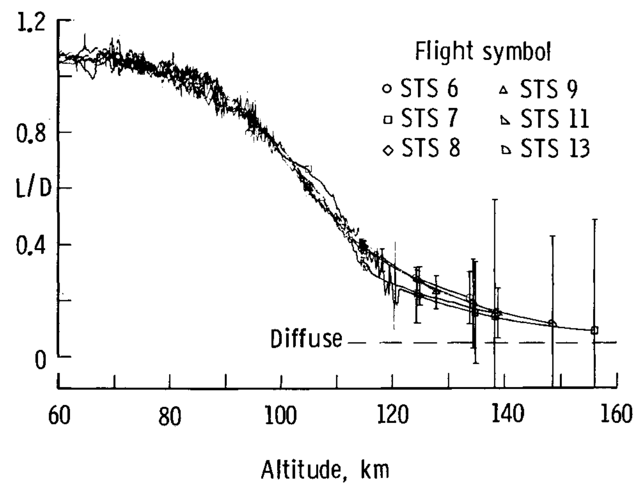

Fig. 2 Measured flight lift-to-drag altitude profiles from HiRAP.

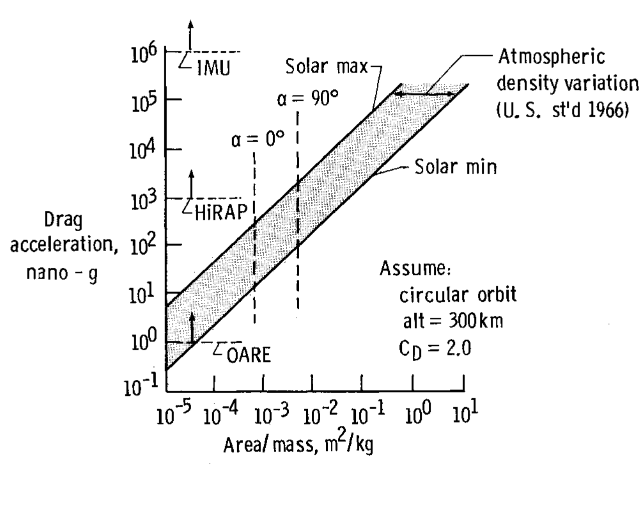

Fig. 3 Shuttle orbital drag acceleration.

The OARE data will support advances in orbital rarefied aerodynamics prediction technology by increasing the data base on the fundamental aerothermodynamic flow phenomena in the upper atmosphere. Confirmation of the aerodynamic prediction of the Orbiter, especially in the transition regime, will be an invaluable aid in the prediction of aerodynamics for advanced re-entry missions that utilize winged entry vehicles. The OARE will also provide data at orbital altitudes to expand the technology to be used for orbital drag predictions in space systems design. Such flight reference data are useful for large space structure mission design, attitude control design, and orbital maintenance and stabilization. The OARE instrument could also be used as the prototype sensor for an autonomous orbital energy maintenance system in large space structure applications, including perhaps, as a backup to satellite tracking via TDRSS or GPS for the space station. In effect, the sensor system, as currently envisioned, will respond directly to the kinetic energy transfer of the spacecraft to the surrounding molecules. This orbital energy depletion is measured continuously and these data can be factored into a decision-making computer to make up the depletion in a manner appropriate to the orbiting mission constraints (e.g., fire thrusters after experiments have been performed, apply low-level thrusts over a period of time, etc.).

The routine operation of the space transportation system will provide a unique opportunity to acquire flight data over a broader range of flight conditions than have been accessible for investigations until now. The specific design goal of the OARE is to extract aerodynamic signals from measurements of linear accelerations to a resolution on the order of 10^{-9} g. This signal is embedded in the total measurement, which contains the Orbiter structural vibration noise produced by vehicular perturbations such as onboard crew activities, RCS jet firings, cabin atmospheric leaks, and water/waste dumps, as well as other effects which contaminate the aerodynamic signal. These are discussed in the subsequent sections.

Perturbation Force Models Considerations

A summary of the perturbation force models examined along with their respective approximate accelerations are listed in Table 1. Each effect is discussed individually in the following sections.

Electromagnetic Effects

There are four electromagnetic effects that can introduce perturbations and noise to the measurement of aerodynamic deceleration: 1) a charged body (the Orbiter) moving normal to the Earth's magnetic field, 2) production of eddy currents in a conducting body traversing a region where the Earth's magnetic field is varying with time and the motion of the body has a component normal to the magnetic field, 3) photoemissive and plasma currents that are induced in a conducting body interacting with the Earth's magnetic field, and 4) electrostatic interaction between the Orbiter's electric charge and the atmospheric plasma. Simplified and conservative worst-case conditions of each of these four have been considered and all produce signals far less than the expected resolution of the accelerometer. Therefore, none of these will produce any detectable error and have been eliminated from further consideration.

Solar Radiation Pressure

This effect will depend on the angle of the sun relative to the surface and on the type of surface. Three types of surfaces have been considered: perfect absorber, perfect specular reflector, and a perfect Lambertian diffusing reflector. The worst case (perfect specular reflector and the sun normal to the surface) will produce an acceleration of only 3.57×10^{-9} g. A more realistic worst-case condition would be with the bottom surface of the Orbiter (considered to be a perfect absorber) directed toward the sun, producing an acceleration of about 1.78×10^{-9} g. Since the resolution of the accelerometer

Table 1 Perturbation force models effects summary

Model	Acceleration
Electromagnetic effects	<1 ng
Solar radiation pressure	1.8 ng
Orbiter mass attraction	0.76 ng/1000 kg at 3m
Gravity gradient and orbital accel	0.41 μg/m
Out-of-orbital-plane effect	0.14 μg/m
Orbiter angular velocity	0.1019 $g/(\mathrm{rad/s})^2/\mathrm{m}$
Structural noise	<1 ng averaged over long period of time
Cabin air leakage	<1 ng
RCS thrusters	4 mg
Vernier thrusters	100 μg
APU	100-300 μg
Venting, waste dumps, and launch springs	Several μg to several mg

is of the same order of magnitude, the effects of solar radiation pressure are of marginal importance. Only a simple correction model with an error of up to 20% will be needed to remove this effect from the data.

Orbiter Mass Attraction

The mass attraction of the combined parts of the Orbiter and its contents will produce a measurable signal on the accelerometer. The distribution of the Orbiter's contents will be changing as the crew moves, satellites are launched, etc. For example, removing mass by launching a satellite of 10,000 kg (22,000 lb) from a position about 3 m from OARE would change the recorded acceleration by 7.6×10^{-9} g. Since this acceleration is indistinguishable from the aerodynamic deceleration, reliable records must be maintained on the distribution of mass within the Orbiter and possible corrections for mass attraction can be made.

Gravity Gradient, Orbital Centripetal Acceleration, and Out-of-Orbital-Plane Effects

If everything except the Earth's gravity and the centripetal acceleration due to orbital motion is ignored, there is only one point in the Orbiter that is in a precise zero g condition. It lies in the orbital plane and is close to, but is not exactly coincident with, the Orbiter's center of gravity. A point farther from the Earth will experience slightly reduced gravitational acceleration and slightly increased centripetal acceleration, giving a combined gradient of -0.41 μg/m if the Orbiter is stabilized relative to the local Earth vertical. Under such conditions, points directly ahead or behind the neutral point are not subject to longitudinal accelerations; these occur only if the Orbiter is rotating in the orbital plane relative to the local vertical. A point not in the orbital plane will experience an acceleration of 0.14 μg/m toward the orbital plane, because of the misalignment of the gravitational and cetripetal acceleration vectors at that point. As the attitude of the Orbiter relative to the gravity vector changes, the accelerations detected at points other than the neutral point will change. The accelerometer will not be positioned exactly at the neutral point. Therefore, the false acceleration signals generated must be corrected by calculations, using recorded Orbiter attitude data and the estimated position of the neutral point. The neutral point in the Orbiter is a negligible distance from the center of mass and the latter can be determined from an Orbiter mass distribution model or from Intertial Measurement Unit (IMU) angular rates and OARE accelerations as the vehicle is rotated about three axes.

Orbiter Angular Velocity

The Orbiter rotates in inertial space about an axis through its center of mass, which for the Orbiter is essentially at its c.g. Since the accelerometer will not be exactly at the c.g., it will sense an angular acceleration because of the rotation, with a scale factor of 0.102 $g/(\mathrm{rad/s})^2/\mathrm{m}$. At a distance of 3 m from the c.g., a false 1 ng signal will be generated by a rotation rate of 5.72×10^{-5} rad/s, or one revolution in 30.5h. This angular rate is detectable by the current onboard rate gyros. With the Orbiter stabilized relative to the local Earth vertical, the effective rate of rotation will be one revolution in approximately 90 min, giving a false signal of 0.41 μg at a distance of 3 m from the Orbiter c.g. Attitude changes generated by the RCS thrusters may be associated with angular rates that are high enough to cause temporary range changes or even saturation if the accelerometer is several meters from the c.g. The false signal must also be corrected, by calculation, employing the output of the onboard navigation rate gyros and the calculated position of the Orbiter c.g.

Structural Noise

Since no external forces are involved, the long-period average of the signals caused by structural noise will be zero. However, they must be heavily attenuated before sampling to avoid aliasing and saturation of the A/D converter. The averaging technique will be a variable in the experiment due to availability of onboard processing.

Mass Expulsion Signal Sources

Mass expulsion sources include RCS main and vernier thruster pulses, APU exhaust pulses, waste dumps, venting of any other gases and liquids, satellite launch spring impulses, and leakage of cabin atmosphere. Best estimates of worst-case, cabin-air leakage (undirectional) show it to be barely detectable and thus can be ignored.

Unlike cabin-air leakage, the other perturbations in this category are mostly relatively large pulses that can be identified in the signal fairly easily. Since the main RCS, vernier, venting, dump, and launch spring pulses are of short duration, data taking or data processing can be simply suppressed while they last. The APU pulses present a different problem. They can be 100–300 μg in amplitude, at a frequency of 1 Hz, for a period of 35 min during re-entry. The aerodynamic deceleration from the deorbit burn to early re-entry is of interest and, therefore, datataking cannot be suppressed when the APU's are operating. By switching to a high-data-rate mode, the aerodynamic signal can be separated from the APU signal during ground processing, as is currently done with the HiRAP data.

Crew Motion and Miscellaneous Forces

This category includes, for a given time interval, zero-mean perturbations that are not Orbiter structural resonances, such as crew motion, unbalanced prelaunch satellite spinups, and pulses or vibrations because of other mechanisms. On the basis of the limited data currently available, saturation is unlikely to be a problem. Crew motions, when averaged over a long period of time, will be zero. However, a relatively long-term oscillatory signal, such as that from an unbalanced satellite spin-up, must be considered in the autonomous design feature of the experiment. The crew motion may require separate postflight data analysis because of the possible nonrandom signals into each channel over short-period data intervals.

Blue Consideration

Sensor bias is a perturbation in the sense that it is an unwanted signal. It is unlike any of the perturbations discussed so far in that it orginates within the sensor itself. It must be determined and corrected in orbit, since its determination in a 1 g environment is impossible at present. The bias itself will be somewhat temperature dependent and must also be corrected in orbit. In-flight calibration of the sensor is conceptually straightforward, although this experiment contains the first attempt to incorporate a complete flight accelerometer calibration station. This is discussed in a subsequent section.

Hardware Implementation

The purpose of OARE is to provide data from which the molecular flow aerodynamic force coefficients of the Shuttle Orbiter in orbit and during early re-entry can be determined. Acceleration measurements are required along three orthogonal axes, because in orbit the Shuttle Orbiter may have any attitude relative to the velocity vector. Since the extreme sensitivity of the OARE sensor does not permit valid scale factor, bias, and temperature coefficients calibration in a laboratory environment, an in-orbit calibration capability is provided. Although the OARE controller will contain a nominal sequence of operations for calibration and acquisition of deceleration data, the in-orbit acceleration environment will not always be nano gravity to low micro gravity levels because of RCS and OMS thruster firings, crew movements, payload launching, and APU operation. The OARE will detect these events and adjust its modes of operation appropriately and autonomously so as to minimize loss and/or corruption of data. The data processor will employ signal processing algorithms and a control scheme to cycle the system through the various operational modes and calibrations. Further, the data processing and control will be flexible and the system will be readily reprogrammable to allow modifications based on flight-derived experience.

The nature of the acceleration signals to be processed and collected dictates that the OARE data processing elements possess a wide dynamic range capability. Some of the anticipated data processing algorithyms are numeric computation intensive, so that the hardware and/or software to maximize the operational speed of these algorithyms will be incorporated. A non volatile solid-state memory will be used to store experiment data (tape recording) to enhance system reliability.

Figure 4 shows a block diagram of the proposed OARE system architecture with the above requirements as drivers. A triaxial accelerometer sensor within the OSS mounted on the motor/table subsystem converts the input accelerations to analog electrical signals. These analog signals are filtered and digitized by the data acquisition portion of the OARE interface subsystem. The digital data are subsequently routed to and processed by the signal processor and control sybsystem where desired features are extracted from the data and stored in the solid-state memory.

The signal processor and control subsystem also monitor the data for events which require a chnage in modes. It directly controls the sensor, servo control, and interface subsystems to effect the required mode changes.

The OARE interface subsystem also connects with a ground-based GSE to permit acquired data to be downloaded and applications software to be uploaded. The IRIG-B time is supplied to the experiment to time tag the recorded data with spacecraft-based time for data correlation with other flight data during postflight data processing. A high-data-rate path is also provided to transfer "unprocessed" digitized sensor data to the OEX tape recorder. This is required for the initial flights to validate the onboard processing methodology.

The sensor acceleration analog signals are digitized by the OARE interface subsystem (OIS) under control of the signal processor and control subsystem (SPCS). Prior to sampling, the sensor acceleration signals are passed through antialiasing filters to reduce the errors from high-frequency noise. The filtered, sampled sensor signals are then transfered to the SPCS for processing. The sensor also provides a commutated analog line of housekeeping data to the OIS where signal conditioning (gain, offset, and filtering) is applied before sampling and transfer to the SPCE.

The filter process operates on the digitized data representing the triaxial accelerations received from the OARE interface subsystem. In this process, various filtering algorithms will be applied to enhance the data's signal-to-noise ratio. Transient data can also be removed in this process.

The filtered data are then operated upon by the feature extraction process. Here, the desired features of the data such as median, mean, average, variance, etc., are recovered. Decimation techniques may also be performed in this process. The processed, low-sample-rate data are then formatted with time code and housekeeping in preparation for storage in the solid-state memory.

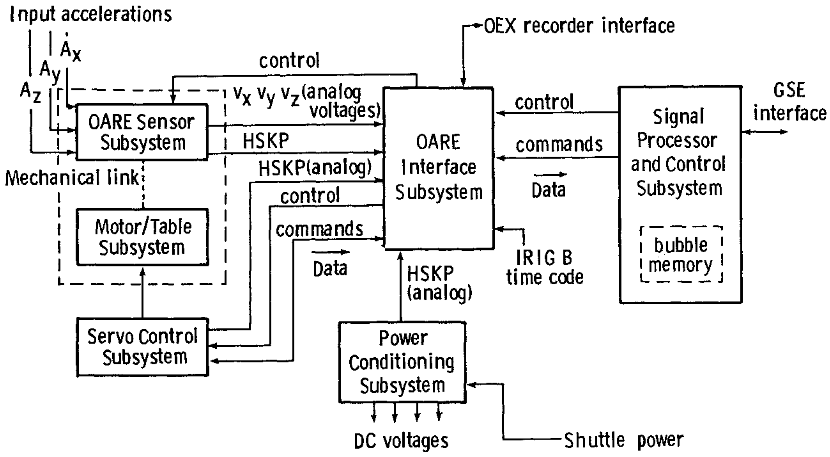

Fig. 4 OARE system flow block diagram.

A secondary data flow path includes the event detection and mode control processes. The event detection process is used to detect events that necessitate a change in system operating modes. Such events may include APU initiation, temperature or voltage drifts requiring recalibration, RCS firings which force the sensor into the capture mode, and sensor gain change requirements. The detected events are sent to the mode control process where appropriate control action is initiated. The SPCS then stores the processed data in memory.

The real-time clock process decodes the IRIG-B spacecraft time code to within ±1 ms. The time code is then used to update the real-time clock maintained by this process and all system timing requirements are also provided. The GSE processor provides the interface to the GSE equipment. There are several features of the GSE discussed later, but the primary purpose of this processor is to download the acquired data and to upload new application programs to OARE.

All of the subsystems will be mounted on an aluminum mounting shelf and enclosed in a vented cover to control the humidity. The relative position of each component without the cover is illustrated in Fig. 5.

Performance Specifications

Triaxial Accelerometer Sensor

The measurable performance parameters defining the sensor subsystem performance include the following:

1) Sensor. The electrostatically balanced cylindrical proofmass accelerometer sensor has three orthogonal sensing axes outputs. The three full-scale ranges are selectable by autorange or by external programmed command.
2) Dynamic range. The three axes will be capable of being individually scales for full-scale input limits as given in Table 2.
3) Resolution. The sensitive proofmass cylindrical (X axis) and the two radial axes (Y, Z axes) will have minimum input response in each range as given in Table 3.
4) Accuracy.
   a) Scale factor. The scale factor of each range will be calibrated during the final factory acceptance test of the accelerometer such that the resultant scale factor will be within ±10% of the nominal value. The scale factor measurement accuracy, as determined during the final factory tests, will be $\pm 1 \times 10^{-7} g$ because of the test fixture accuracy; however, the inflight scale factor accuracy will be a function of the in-flight calibration table accuracy.
   b) Bias. The predicted on-orbit bias will not exceed 10 μg on any scale.
   c) Axis alignment. The X axis will be orthogonal to any other axis to within ±10 arc min and the Y, Z axes shall be orthogonal to ±20 arc min. The orthogonality of all axes will be measured by the factory test to within ±20 arc s with respect to the alignment references.

The OARE will be required to operate as autonomously as possible, with its modes of operation commanded by the controlling computer on the basis of preplanned regular intervals or in response to the output signals from the accelerometer. In descending order of priority, the modes are:

1) Capture—to restore normal sensor operation after it has saturated, i.e., an automatic initiation.
2) Re-entry-1—triggered by APU noise detection or by ground command.
3) Calibration—commanded at regular intervals, performed in Normal recording mode.
4) Re-entry-2—commanded at regular intervals for obtaining a high-data-rate sample.
5) Normal—usual mode of operation when modes 1-4 are not required.

Motor/Table Calibration

Laboratory measurements of the sensitivity (scale factor), the bias, and the temperature dependence of each are currently impossible for an accelerometer such as that contemplated for the OARE. Because of its nano gravity accuracy potential, this will most likely continue to be the case, certainly in the foreseeable future. For this reason, it is mandatory that the OARE possess a system to calibrate it in a near-zero gravity environment, such as on orbit.

The subsystem employed for calibration consists of an inner gimbal (azimuth) axis bearing mounted in a yoke assembly. The yoke is rotated by an outer gimbal (elevation) axis bearing mounted in the base structure. Each axis contains a separate torque motor and incremental encoder mounted on a drive and support bearing assembly. Rate and position servo loops are implemented with a microprocessor controller time shared by each axis.

The servo control subsystem will accept commands to position the sensor's primary axis parallel to any of the six directions in the orthogonal Shuttle axis. To achieve these positions, physical data will be defined on the base of the

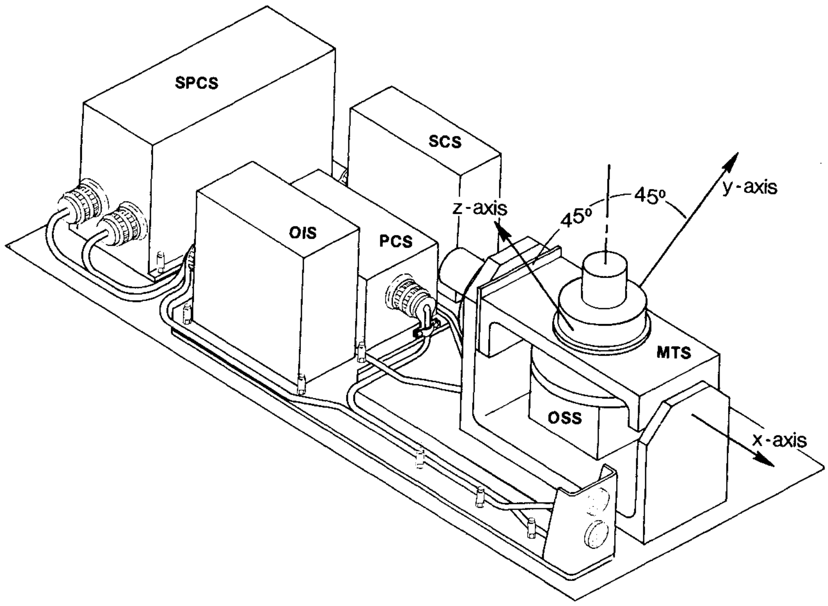

Fig. 5 OARE preliminary packaging concept.

motor/table subassembly (MTS) to permit alignment to the Shuttle axes. The six discrete commanded positions required will then be referenced to these data. In operation, the MTS will align the sensor's primary axis parallel to anyone of the six directions defined by the physical datums to within ±30 arc s and will be able to achieve any of the six required positions within 5 s.

The MTS will accept commands from the signal processor via the servo control subsystem to rotate either gimbal at one of five constant rates of 0.127–2.0 rad/s for scale factor calibration. Constant-rate operation about both axes is required, but both axes will not be commande simultaneously. Constant-rate operation at the steady-state commanded rate will be required for a minimum of 190 deg for both axes; gimbal freedom will, therefore, be determined by the additional travel required for acceleration to and deceleration from the steady-state commande rates. The peak error in the steady-state angular rate will not exceed 0.1% of the commanded angular rate.

The following commands will be included in the set of commands recognized by the servo control subsystem (SCS):

1) Position. After this command is issued, the SCS will receive data indicating one of the six predefined orientations to which the sensor is to be rotated.
2) Rate. After this command is issued, the SCS will receive data indicating one of five discrete rotation rates, including direction and axis about which the table is to be rotated.
3) Status request (position error, rate error, voltages, or temperature). These commands will be recognized if the desired status information is to be returned as a digital word. After the command is issued, the SCS will place the appropriate data word on the data lines.

In-flight calibration may be accomplished by the following procedure. Moving between positions 180 deg apart and differencing the output readings gives twice the applied acceleration, free of bias error; summing the two readings gives twice the bias. Driving the turntable at two accurately controlled rates and then differencing the output readings gives a scale factor calibration. Recording the temperature of the sensor at the time of each calibration will allow models of bias and scale factor behavior to be built up, with the possibility of eventually reducing the frequency of calibrations.

Signal Processor and Control Subsystem

The signal processor and control subsystem (SPCS) is a sophisticated microcomputer that implements all of the functional processes required for OARE. It controls, via internal software algorithms, the sensor and calibration activites, the acquisition of data from the analog interface subsystem, and the processing of these data and storage of the processed data in the nonvolatile solid-state memory. During ground operation, it communicates with the GSE to download recorded data and upload new application software. Built-in test and diagnostic routines are also loacted in the SPCS. The two most significant performance parameters associated with the OARE SPCE are numerical processing capability and memory size. The former is important because the filter, feature extraction, and event detection processes are computation intensive; whereas memory sizer is important from the standpoint of uploading new application software from the GSE. The application software code will first be uploaded to the solid-state memory and then transferred into RAM by a real-time, multitasking operating system upon application of power to the OARE. These considerations require a system with a minimum of 19 bytes of PROM and 128 bytes of RAM.

Table 2 Dynamic range of OARE sensor

	Full-scale input limits, $\pm \mu g$	
Range	X cyl. axis	Y, Z radial axes
A	10,000	25,000
B	1,000	1,770
C	100	150

Table 3 Resolution of OARE sensor

	Resolution, ng	
Range	X axis	Y, Z axes
A	320	800
B	32	57
C	3.2	4.8

Since the OARE data processing requirements will evolve as new data from each flight are analyzed, the hardware and software must be capable of modifications to meet these requirements. With respect to hardware this requirement dictates that the SPCS have a bus structure to allow the addition of extra memory, input/output (I/O), or processing capability. The SPCS will use 16-bit architecture to optimize the processing of 16 bit digitized data and ensure adequate throughput capability.

The SPCS must also contain capability for anumeric data co processor to adequately implement the various anticipated or future data processing and event detection algorithms. Serial I/O will be provided for communication with the GSE; and command and status interfaces to the motor/table sybsystem, the analog interface, and the OARE sensor will be implemented with parallel I/O.

A necessary part of signal processing is the choice of filters to smooth the signal to usable accelerations as a function of time. The electrostatic sensor standard configuration has a cutoff frequency of 1 Hz, with a single-pole rate of attenuation of 20 dB/decade. This provides the first stage of the required 6 pole/20 dB/decade/pole before digital sampling. The remaining five stages will be accomplished by analog filters with a cut off frequency in the range of 0.8–1.0 Hz.

A subsequent digital filter must accept data at 10 samples/s and provide attenuation so that the output signal can be sampled once every 25 s without significant aliasing or ringing. For this purpose, a median or a trimmed mean filter will be used initially.

Memory

The OARE system requires approximately 1 Mbyte (8 Mbits) of memory to satisfy the system data storage requirements. Feasibility studies have shown that a solid-state memory provides adequate storage with high reliability. In order to accommodate changes in the software and perhaps storage requirement in future missions, at least 4 Mbytes will be employed.

Software

The software will operate through the signal processing and control subsystem and must be capable of accepting asynchronous analog data and of controlling sensor, table orientation, and data storage functions based upon feature in the incoming data. Furthermore, it must be possible to update the SPCS software easily in order to make OARE operation conform to future updates based upon flight experience.

The SPCS will operate as a multitasking operating system (MOS), i.e., the total system software requirement will be divided into discrete tasks. Each task will have control over the computer resources (CPU, memory, and I/O) and will have its own set of registers and its own stack. The MOS will distribute CPU time among the various tasks by assigning each task a priority. This is necessary because various events can occur during each flight that must logically preempt other activities in which the SPSC might be engaged.

The majority of the OARE software will be written in a high-level language; "C" is a likely candidate. Assembler language will be used only for interrupt handlers and possibly device drivers for the memory and table controller.

OARE software will be defined and developed in a modular fashion and will use all input and output data structure and timing requirements for each module. Modules that interface directly with hardware will not have OARE specific processing parameters built into them. They will not need to be changed unless a hardware interface parameter is changed. All other modules will be defined as separate tasks or executable programs and will be individually loadable. Interfaces between tasks will be made as general as possible so that a given functional change will most likely offset only one module. Processing algorithms and mode change criteria will be parameterized with the arameter values declared ina consistent location in all source modules to allow easy change without changing the code.

The SPCS will contain software designed to communicate with a GSE computer in order to load and modify application programs in memory onboard the Orbiter. This software will have the capability of minor modifications as flight-to-flight updates and also of major modification to onboard processing routines if necessary.

Ground Support Equipment

The ground support equipment is an important part of the OARE because conducting a sensitive experiment on the Shuttle with multimission international goals requires quick access to the data. Sensor data will be reduced so that relevant measurements such as accelerometer readings, calibration factors and their temperature dependences, temperature, and time can be read directly with the GSE. There will be no lengthy preliminary reduction of these data; reduced data records can be read directly with the GSE out to a hard disk compatible with the experimenter's computer. These data can be used directly for quick analyses and anomaly identification. These will, in turn, lead to decisions involving the time and frequency of different types of data sampling, ordering of priorities, and alteration of filtering techniques. Thus, decisions can be made and modifications to the OARE software can be implemented for more quickly than with previous experiments of this type and still be consistent with the host vehicle objectives and timelines.

Software and hardware will exist within the SPCS with the specific aim of supporting communication with a GSE computer via a serial interface port. Functions supported via this interface are: loading of application programs into memory, dumping of data files, initialization of memory files, testing SPCS hardware, and investigation of any problems via a software debugger. Two interrupt handlers will assist the terminal I/O task, one for character input and one for output. Both handlers will operate on buffered strings of characters, rather than individual characters, in order to support high-data-rate file transfers.

Installation Objectives

The OARE will be mounted in the Orbiter as close to the center of gravity as possible so as to minimize the corrections that must be made for gravity gradient, orbial centripetal acceleration, out-of-plane, and Orbiter angular velocity effects. Since the center of gravity will be reasonalby close to the point of zero net Orbiter mass attraction, corrections for this effect will also be diminished. Structural noise effects will be lower if the instrument can be placed at a nodal point in the Orbiter structure. It is also highly desirable that the OARE be reasonably accessible for repair and that the GSE interface port be at a convenient location for ease of postflight data access. However, meeting all of these requirements may be impractical, especially considering the structure and space available onboard the Orbiter.

The total OARE assembly will be mounted on an aluminum mounting shelf and enclosed in a cover assembly. Its estimated weight and dimensions are 96.8 lb and 17.0 × 41.5 × 13 in. There are several locations that fit the requirements of the experiment mentioned above. These are located below the payload bay in the midwing area. The exact location and method of mounting the experiment equipment have been developed concurrently with the hardware buildup to eliminate potential installation and operation problems.

In order for the acceleration measurements along the three axes of the instrument to be applied to the aerodynamic investigations of the Orbiter, the instrument must be alighned within the Orbiter. The OARE assembly will, therefore, be aligned to within ±10 arc min of the Orbiter body axes coordinates as defined by the Orbiter IMU and will be pinned to assure placement to the correct tolerances. The alignment will be measure to obtain alignment data to within ±2 arc min. In addition, the OARE orientation with respect to the IMU input axes will be known for postflight correlation analysis.

Conclusions

The Orbital Acceleration Research Experiment is under development to measure accelerations onboard the Shuttle to a resolutino in the nano gravity range. It will contain an electrostatically balanced cylindrical proofmass accelerometer sensor with three orthogonal sensing axes outputs. The experiment features a complete onboard calibration station to achieve absolute accuracy levels required for rarefied aerodynamic determinations of the Orbiter. Its data will extend the measurements of the current High-Resolution Accelerometer Package to orbital altitudes in order to provide information on surface reflection properties and drag prediction useful to the operation of future large space structures such as the space station. A number of effects have the capacity of being erroneously interpreted as aerodynamic decelerations, but all of these can be modeled and predicted accurately and removed from the instrument's signal. The instrument will possess three dynamic ranges, two sampling rates, and an extremely effective filter network. These will enable the measurement of acceleration from orbital altitude down through the rarefied-flow transition region during reentry. It can, therefore, serve as independent corroboration for the HiRAP data taken in this altitude range. The design of the experiment includes onboard software that can be changed easily from one flight to another as is needed due to a versatile signal processing and control subsystem and versatile ground support equipment.

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