6101-6374-RU-000

BSD-TDR-62-9

FINAL REPORT ON LIQUID-GAS INTERFACE IN ZERO-G

31 DECEMBER 1961

Contract No. AF 04(694)-1

Prepared for

HQ BALLISTIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Air Force Unit Post Office, Los Angeles 45, California

SPACE TECHNOLOGY LABORATORIES, INC.
One Space Park, Redondo Beach, California
a subsidiary of Thompson Ramo Wooldridge Inc.

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ABSTRACT

This is the final report of the investigation, conducted by Space Technology Laboratories, Inc., of the behavior of a liquid-gas mixture in a zero-g field. Four experiment units were designed, built, and tested at STL. Each unit houses a movie camera, so placed as to observe and record the interaction of air and water contained in a plastic cube during the 25-minute near-zero-g conditions present on an ICBM flight. Temperature and pressure changes are also recorded.

One of these units was flown 16 September 1960 in an Atlas re-entry nosecone test vehicle (RVX-2A series). Although the flight met most of the vehicle test objectives, the nosecone was not recovered from the ocean as planned. Consequently, the film data from the zero-g experiment were lost and only the telemetered data were available for analysis.

A second experiment unit was flown 10 November 1961, again in an RVX-2A nosecone. In this flight, the booster system malfunctioned during its powered phase and the missile system was destroyed by the launch safety officer. The re-entry vehicle fell into the ocean, scattering debris over a wide area. The experiment unit was lost and no data were received.

One flight-certified experiment unit remains. The fourth unit was used for development testing and does not include the high-speed camera. Although the zero-g investigation has been concluded under the present contract, the Air Force has indicated interest in flying the remaining unit when a recoverable vehicle is available.

CONTENTS

I. INTRODUCTION AND SUMMARY

The study of liquid-gas interface in zero-g (Project Plan 165-54) began in April 1960 under the responsibility of the Systems Design Section of the STL Vehicle Development Laboratory.* The purpose of the study was to observe and report the behavior of liquid-gas mixtures in the absence of an acceleration field.[1] To accomplish this, four experiment units were designed, built, and tested at STL.[2,3] During significant portions of the flight, a high-speed movie camera in the unit observes and records the dispersion and dynamic behavior of a liquid-gas mixture in a transparent cube. In addition to the fluid distribution, temperature and pressure readings are photographed. On-off signals sent by the timer to the camera and light complex are telemetered to the ground, for use in time-correlating vehicle trajectory parameters with observed data.

One of these units was flown on 16 September 1960 in an Atlas re-entry nosecone test vehicle (RVX-2A series).[4,5] In this flight, that portion of the experiment data which was recorded on film was lost, as a result of failure to recover the re-entry vehicle. A second experiment unit was flown 10 November 1961, again in an Atlas re-entry nosecone vehicle (RVX-2A series). In this flight, the booster malfunctioned during its powered phase and the missile system was destroyed by the launch safety officer. The re-entry vehicle fell into the ocean, scattering debris over a wide area. Consequently, no data was received and the experiment unit was lost.

As quoted from the project plan:

"Specifically, the contractor will perform the following tasks:

a) The contractor shall provide the necessary services, labor, facilities and materials for the design, development and fabrication of a

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*Responsibility for completion of the project was later reassigned, along with personnel, to Bioastronautics, Aerosciences Laboratory, Mechanics Division.

suitable device to conduct research on the effects of zero-g on liquid-gas interface. The device will consist essentially of a sealed, transparent cube containing a suitable mixture of gas and liquid. A camera, suitably mounted and employing a mirror system for orthogonal views of the test cube, will be used to record the interaction of the gas and liquid under zero-g conditions. The entire package will be designed and constructed to be compatible with, and suitable for, flight in an Atlas nosecone in conjunction with the current "Piggyback" program. Since recovery of the nosecone is provided for, the device will not require data transmission other than telemetry of camera sequencing events.

b) The contractor shall conduct suitable development testing, including structural and environmental tests to ensure structural integrity, package integration and performance of the experimental device.

c) The contractor shall develop and deliver three complete experimental units. A fourth unit, complete except for camera, will be developed for environmental and test purposes. Two of the complete units will be for flight, the third for backup.

d) The contractor will process the recovered film, perform the necessary analysis, and issue a report defining the results of the experiments.

e) The contractor will coordinate with re-entry vehicle personnel for installation of the experiment in the nosecone, and for data recovery."

II. BACKGROUND INFORMATION

The development of advanced space systems which depend on the operation of various subsystems during long periods of coast has caused an increased interest in the problems associated with a zero-g environment. One of the major problems which will affect space operations in a zero-g environment is the interaction of liquids and gases in a closed volume.

This problem will be encountered in systems requiring restart of a liquid rocket after periods of coasting flight, in nuclear propulsion systems utilizing working fluids stored as liquids, as well as in the numerous functions of manned systems, such as liquid-oxygen converters, evaporative temperature-control devices, food preparation, cleaning and washing, waste handling and--certainly not least important--digestion and other bodily processes of the crew.

A number of research programs to study various phases of this problem are currently in progress and are utilizing as test facilities either drop-towers or aircraft modified for flights along parabolic arc (zero-g) trajectories. These techniques, though well established and extremely useful for many experimental studies, are restricted to investigations of essentially transient phenomena, since the maximum duration of weightlessness obtained by these research techniques is less than one minute even under optimum conditions. In order to extend the duration of zero-g study periods, useful in the investigation of steady-state phenomena, the experiments should be carried aboard vehicles which have ballistic trajectories lasting about 20 minutes or more. The present experiment represented such an approach to the basic investigation of zero-g phenomena.

Advantages in the use of re-entry test vehicles as platforms for a pickaback experiment of this nature include:

1. Recovery

Provision was made for the recovery of the experimental re-entry nosecone, so that the pickaback experiment could be retrieved without need for special downrange facilities.

2. Zero-G Duration

The computed duration of weightlessness in the design trajectory of the parent vehicle was about 25 minutes. This period is ample for the study of liquid-gas behavior during transition from acceleration to zero-g conditions (and the reverse during re-entry), and is adequate also for the study of stabilization of the liquid-gas mixture during weightlessness.

3. Volume and Weight Availability

The re-entry nosecone had volume and weight allowances available to accommodate the basic package.

4. Minimum Interference

The equipment contained in the experimental nosecone to support the primary objective of the re-entry test flight was relatively simple compared with the intricate instrumentation included in many current experimental space systems. Consequently, there was correspondingly less probability that this experiment would interfere with, or cause a malfunction of, the primary equipment items.

In addition to these considerations, the experiment unit, as planned, was especially well suited for mounting aboard re-entry test vehicles for the following reasons:

1. Negligible Vehicle Modification

No modification of the launching vehicle or nosecone configuration was required other than the provision of six bolts to attach the experiment to a mounting plate in the re-entry vehicle with a single plug-in connection to the vehicle 28-volt dc power supply and telemetry system.

2. Negligible Countdown Interference

The package was completely self-contained and could be installed in the nosecone compartment at any time prior to, or during, the launch countdown. All preflight preparation was completed prior to installation and was not time-dependent; consequently, countdown holds and even launch rescheduling would not necessitate removing the experiment unit from the nosecone.

3. Negligible Downrange Requirements

The primary objective of re-entry test flights requires that the nosecone be recovered so that no special provision was needed for retrieving the exposed film. Furthermore, no special handling or treatment was necessary after recovery to preserve the data for evaluation.

4. <u>No Time Limit on Data Processing</u>

Because of the relatively permanent nature of film, the accumulated data could be stored indefinitely prior to evaluation.

III. DESCRIPTION OF THE EXPERIMENT UNIT

The basic experiment unit weighs about 16 pounds and consists of several simple components. A transparent plexiglas cube contains a mixture of colored distilled water and air. The container is sealed; its volume and the relative volumes of its contents are known. Three sides of the cube are opaque. By using properly oriented mirrors, images of the other three mutually perpendicular sides are aligned before a camera (see Figure 1). These three sides are uniformly lighted and are marked with grids to minimize distortion errors. The camera records a triple image of the liquid-gas distribution pattern (one for each of three orthogonal planes) during specified time intervals.

These optical records are made for periods of about two minutes, both at the beginning and at the end of weightlessness (separation and reentry), and during twelve 8-second intervals spaced throughout the zero-g portion of the flight. Since the parent vehicle is to be recovered, conventional camera and film are used with no data transmission of optical images during flight. A standard movie camera, with a wide-angle lens (110°) is used. An electromechanical timer activated by a g-switch provides signals to actuate the camera and light at preselected times.

A pressure sensor is connected to the cube to detect any variation in internal pressure. A thermometer is mounted outside the cube to monitor any gross changes in temperature which might affect fluid behavior. Three cantilevered flat spring accelerometers mounted on the faces of the cube provide data on accelerations resulting from residual rotation (0.01 - 0.50 g). (The vehicle accelerometers measure gross acceleration data at values above 0.6 g in three directions.) These environmental data are read directly from the photographs, as are temperature and pressure readings

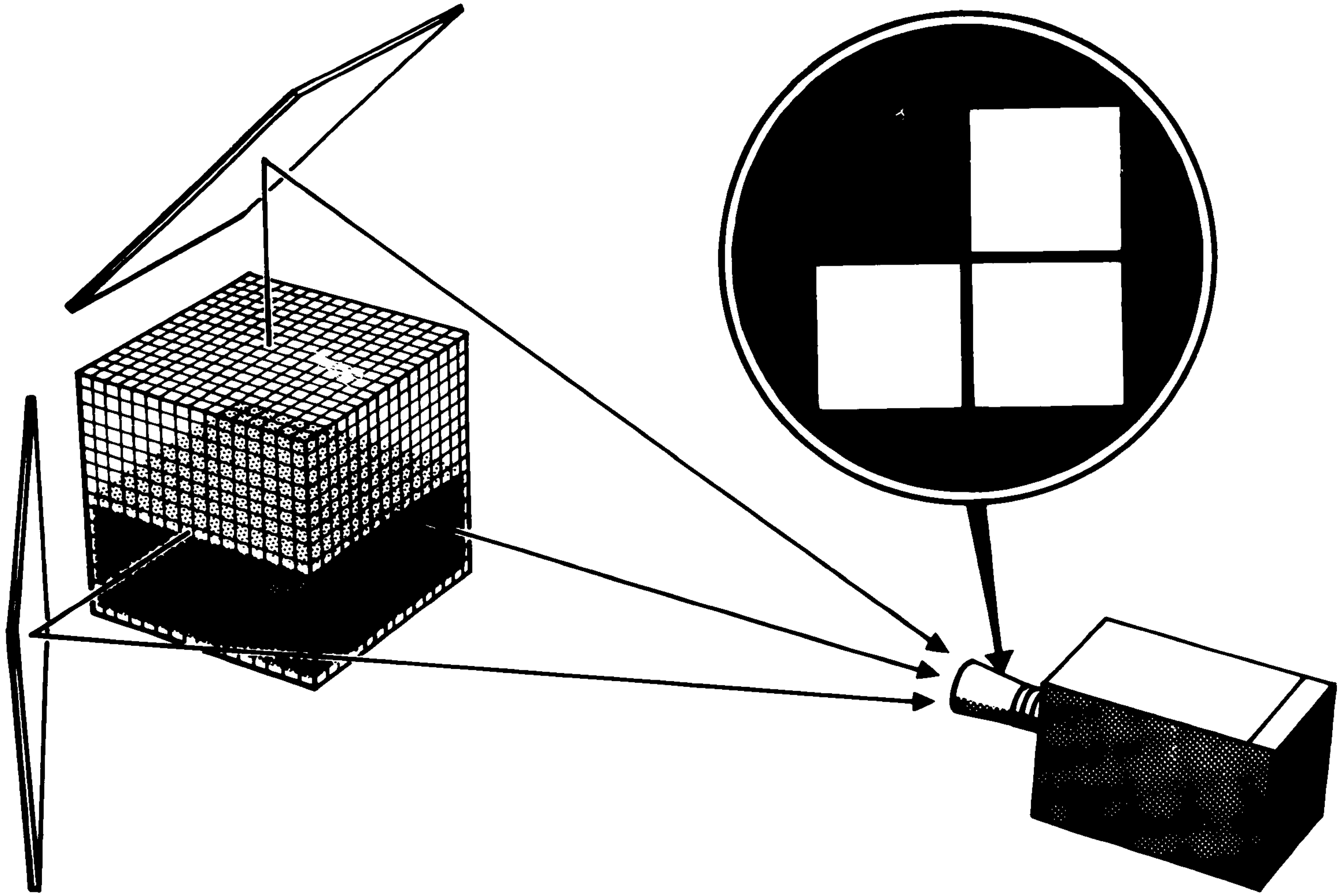

Figure 1. Schematic Representation of the Zero-G Experiment.

on gauges mounted within the camera's field of view. On the two test flights, one segment of a 90-segment commutated channel, at 10 cps, was available in the vehicle temetry system and was used to record times of camera actuation and cutoff. Power for the light, camera, and timer was provided by the 28-vdc power supply of the vehicle.

Special care has been taken to ensure that proper alignment of camera and optical system is not disrupted during the launch phase of the flights. In addition, the entire unit is mounted on a rigid base plate of honeycomb Fiberglas. Photographs of the experiment unit with covers on and off are shown in Figures 2 and 3, respectively.

IV. TECHNICAL PROGRESS

Although the project plan was not formally activated until 1 April 1960, preliminary work was started on the design and mockup of the zero-g experiment in February. During March of that year, the design of the experimental unit was completed and all the detail drawings released to the shop for fabrication. The first flight unit base and mirror assembly was fabricated and operating components (timer, g-switch, temperature and pressure gauges, and camera assembly) were ordered. A mockup of the experiment unit was completed and shipped to the General Electric Company, Philadelphia, with copies of the detail drawings.

Tests were made for the selection of a suitable camera and film. High-speed Ecktachrome film and a Bell and Howell (KB-3) camera were chosen. The camera received a standard high-g modification at Traid Corporation and the shutter speed was increased from 1/500 second to 1/1000 second. The camera was then tested in the STL altitude chamber to determine its high-altitude performance.

In April 1960, test strips of Ektachrome, DuPont 936, and Kodak Plus X film were exposed at different camera settings in the initial flight assembly to determine optimum bubble visibility of colored and clear liquids. The exposure setting selected was f4 for 16 frames at 1/1000 second.

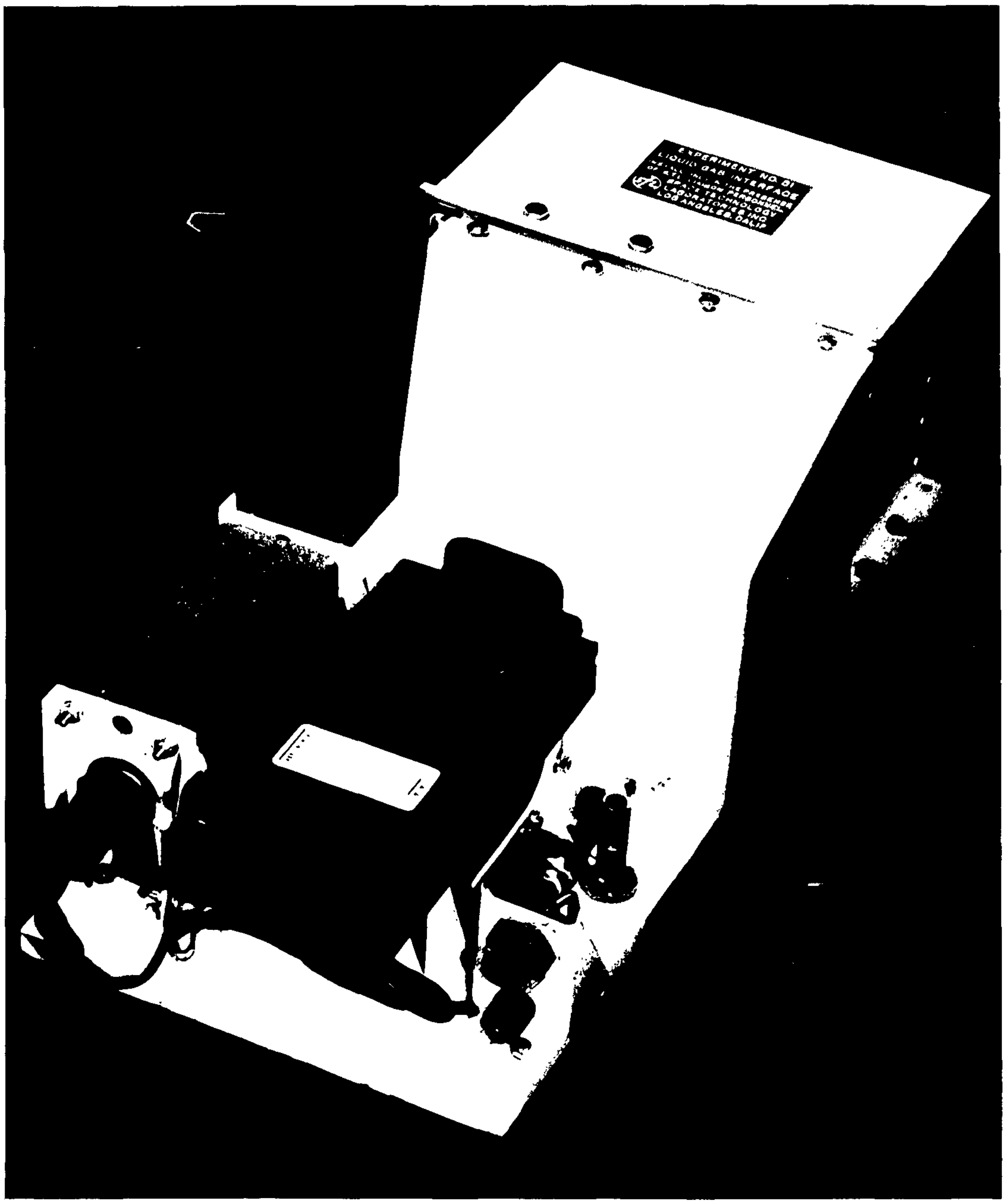

Figure 2. External Configuration of Zero-G Experiment Unit.

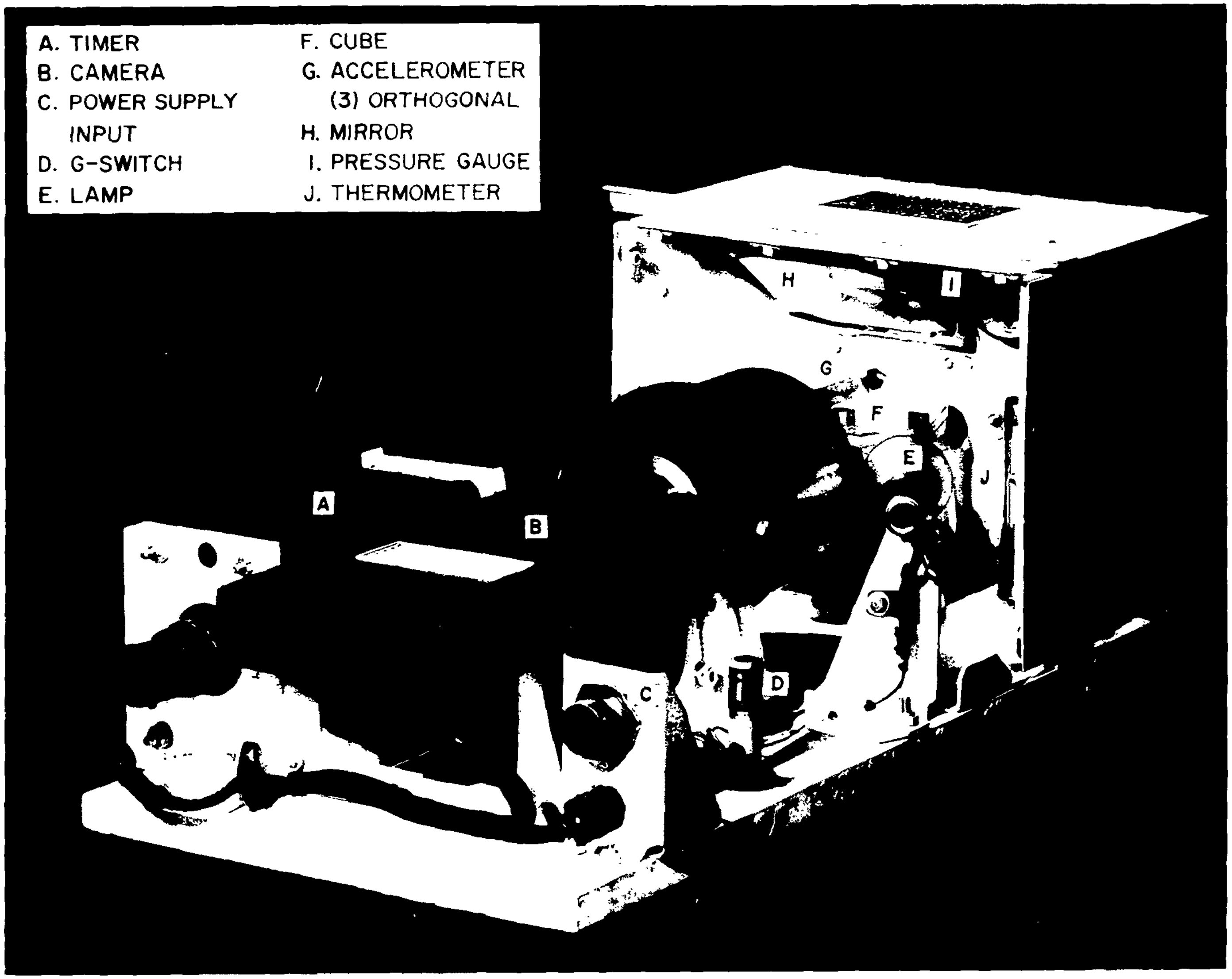

Figure 3. Internal View of Zero-G Experiment Unit.

Arrangements were made for GE personnel on board the recovery ship to develop the film recovered from the nosecone.

During a visit to GE, a sample roll of film was exposed. Half of the roll was processed at GE, using the downrange processing equipment and procedure. The remaining half was sent to the Eastman Kodak Company, for processing. The two films were then compared to check the optimum exposure setting for the downrange process. No appreciable difference was noted.

Inhouse testing indicated that the immersion of exposed film in sea water at 35 psi (equivalent to a 60-foot depth prior to recovery) for periods of 3, 20, and 45 hours did not cause image deterioration on film which was tightly wound. However, a waterproof seal was found to be desirable to protect the camera as well as to preserve the photographic data. A plastic sealer was investigated and tested on simulated equipment subjected to vacuum conditions in an environmental chamber and then immersed in water at 35 psi. No leaks were detected.

Difficulties were encountered with the cameras when all three were discovered to be out of focus. This problem was corrected by the supplier, Traid Corporation.

Environmental tests of the components continued; in particular, a test program to develop a proper mounting for the Hayden timer in a specified vibration environment. The vibration specifications were later relaxed in view of experimental flight test data obtained from Convair and new omnidirectional mounts were investigated. After further testing, and after discussions with Hayden personnel had disclosed considerable uncertainty regarding acceptable vibration tolerances, vibration isolating mounts were discarded and the timer was rigidly attached to the base plate.

The first flight article, although readied for shipment to GE-Philadelphia, was held up pending rescheduling due to flight-time slippage.

Two changes were made to the experiment unit early in May as a result of a visit to GE-Philadelphia: 1) a cover was provided to protect the experiment against stray flying parts inside the re-entry vehicle; and 2) a double lamp, instead of a single lamp, was installed to increase reliability. The first flight unit was delivered to GE on 3 June 1960.

Compatibility test and checkout procedures for STL personnel were prepared. Support activities and facilities to be provided by GE were defined and this information was transmitted to GE-Philadelphia.

In June 1960, the type test unit and the backup article successfully met GE structural integrity specifications; both were vibration-tested without malfunction and the camera and timer went through a complete cycle without incident. The design and performance of the experiment unit and the backup unit were approved by the Air Force Ballistic Missile Division.

The first-flight article was assigned space as Experiment No. 51 aboard an RVX-2A nosecone (No. 422) to be flown on vehicle 76-D. No mounting diagrams were supplied by GE to the AFBMD Program Office. Consequently, it was not discovered until integration checkout of the nosecone at GE, Philadelphia, that Experiment 51 had been mounted at the periphery of the mounting plate. Original specifications supplied to GE had designated that the nosecone axis should intersect the experiment cube, so that the contained fluids would lie near the vehicle c.g. and would thus "see" minimum rotational acceleration. This deviation from the specified location introduces as much as 5.1×10^{-4} g to the cube environment, assuming a residual rotation rate of only one RPM about each axis at separation. Since the "equivalent zero-g" of many fundamental fluid-behavior phenomena is in the range of 10^{-6} to 10^{-8} g, the "zero-g" quality of the anticipated data was significantly degraded. Scheduling limitations prevented correction of this error.

Following successful checkout of the experiment at Philadelphia and at AMR, the shot was made from Cape Canaveral on 16 September 1960. The launch and flight of the vehicle were completed as planned, but the attempt to recover the re-entry vehicle failed. As a result, the zero-g experiment data which was recorded on film was lost. The operation of the camera-sequencing timer was telemetered, and these data, except for a brief period where telemetry was lost due to masking by interference, are presented in Table 1. Scrutiny of the data reveals that the individual incremental errors fall well within the allowable limits, as does the total composite error which had an allowable range of ±18 seconds. The g-switch which activated the timer motor was nominally rated at 5.0 g, and actually closed during flight at a value of 4.985 g, an error of about 0.3 percent.

At the request of GE-MSVD, Experiment Unit No. 2 was shipped to Philadelphia in March 1961, following functional checkout at STL. Experiment Unit No. 4 was thoroughly tested during April, resulting in some minor adjustments to the camera-magazine assembly, and it was decided that Unit No. 4 would be the prime flight article for the next mission, to be flown on Atlas Missile 32E. Unit No. 4 was installed in the RVX-2A nosecone (No. 424A), at Philadelphia on 5 May 1961. Unit No. 2 was returned to STL, Los Angeles, for preparation for use as the flight backup experiment.

GE-MSVD advised that the ablative heat shield on this RVX-2A nosecone required additional material: that portion of the nosecone was returned to Avco for the necessary modification. The experiment mounting plate, with experiments in place, remained in Philadelphia until late Fall when the complete nosecone was assembled and shipped to Florida, for a November launch. Unit No. 2 was flight-certified at STL and delivered to Florida as the backup unit.

Preliminary checkout of the flight article at AMR revealed rust discoloration of the cube as a result of its long storage in an inverted position, during which time water was in contact with the pressure tap. Therefore it was decided to use the backup unit as the flight article. This unit underwent final checkout in November and was installed in the RVX-2A nosecone.

Table 1. Timer Performance

Event	Timer Specification		Ground Test		Flight Test	
	Time (sec)	Interval (sec)	Time (sec)	Interval (sec)	Time (sec)	Interval (sec)
Liftoff	0.0	120	0.0	120*	0.0	116.5
"G Switch Closes Activating Timer	120	125 ±18	120.0*	121.0	116.5	118.3
Camera On	245	100 ±6	241.0	101.0	234.8	102.2
Camera Off	345	100 ±6	342.0	96.7	337.0	96.8
Camera On	445	8 ±1	438.7	8.0	433.8	8.0
Camera Off	453	100 ±1	446.7	100.3	441.8	100.0
Camera On	553	8 ±1	547.0	7.8	541.8	8.0
Camera Off	561	100 ±1	554.8	100.2	549.8	100.1
Camera On	661	8 ±1	665.0	8.0	649.9	8.0
Camera Off	669	100 ±1	663.0	100.0	657.9	100.1
Camera On	769	8 ±1	763.0	8.0	758.0	8.0
Camera Off	777	100 ±1	771.0	99.8	766.0	100.1
Camera On	877	8 ±1	870.8	8.0	866.1	8.0
Camera Off	885	100 ±1	878.8	100.1	874.1	100.0
Camera On	985	8 ±1	978.9	7.9	974.1	8.0
Camera Off	993	100 ±1	986.8	100.5	982.1	100.1
Camera On	1093	8 ±1	1087.3	8.1	1082.1	8.0
Camera Off	1101	100 ±1	1095.4	100.1	1090.1	
Camera On	1201	8 ±1	1195.5	7.8	Telemetry Lost During This Period	
Camera Off	1209	100 ±1	1203.3	100.4		
Camera On	1309	8 ±1	1303.7	8.0	1298.0	8.0
Camera Off	1317	100 ±1	1311.7	100.1	1306.0	100.1
Camera On	1417	8 ±1	1411.8	8.1	1406.1	8.0
Camera Off	1425	100 ±1	1419.9	100.0	1414.1	100.1
Camera On	1525	8 ±1	1519.9	8.0	1514.2	8.0
Camera Off	1533	100 ±1	1527.9	100.0	1522.2	100.0
Camera On	1633	8 ±1	1627.9	8.1	1622.2	8.0
Camera Off	1641	100 ±1	1636.0	100.0	1630.2	94.1
Camera On	1741	160 ±12	1736.0	--	1724.3	--
Camera Off	1901		--		--	

*Assumed

The second Liquid-Gas Interface Experiment was flown on 10 November 1961. The flight was interrupted during its powered phase when the booster malfunctioned. The missile system was destroyed by the launch safety officer approximately 23 seconds after launch and the re-entry vehicle fell into the ocean approximately 100 miles from shore.

Debris was widely scattered and a search was begun to recover components or parts. All that was recovered from the zero-g experiment was a portion of the camera. This was returned to STL and then delivered to the Air Force.

One flight-qualified article remains. Although the zero-g investigation has been concluded under the present contract, the Air Force has indicated interest in flying the remaining flight article when a recoverable vehicle is available.

Information on the STL zero-g experiment may be obtained from Mr. Neville Barter at Space Technology Laboratories, Inc.

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