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CHARGE - 2B DIAGNOSTIC FREE-FLYER PNEUMATIC PAYLOAD EJECTOR TEST AND CALIBRATION REPORT

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The CHARGE-2B sounding rocket, a joint Rome Laboratory-NASA project, is intended to establish the feasibility of using charged particle beams as very low frequency antennas. To obtain control measurements of beam-generated waves in the ionosphere, Rome Laboratory has built the Diagnostic Free-Flyer (DFF) -- a wave receiver subpayload that will be ejected from the beam-emitting main payload during flight. It was necessary to design and fabricate a pneumatic payload ejection system capable of propelling the DFF at several meters per second relative to the main payload while not subjecting the on-board instruments to acceleration exceeding 10 g's. Calibration and reliability test data for the pneumatic payload ejector (PPE) are presented in this report. The calibration will be used together with accelerometer data to determine a payload separation versus time-of-flight profile for use in interpreting DFF wave data. Reliability data for the PPE are required to establish the flight-worthiness of the ejection system.

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Preface

I want to thank Mr. Carl P. Ferioli for the detailed design necessary to fabricate and successfully assemble the Pneumatic Payload Ejector.

CHARGE-2B Diagnostic Free-Flyer Pneumatic Payload Ejector Test and Calibration Report

1. INTRODUCTION

CHARGE-2B is a cooperative sounding rocket mission conducted jointly by Rome Laboratory (RL), NASA, and Utah State University. It is scheduled for launch from the Poker Flats Rocket Range, AK in November 1991. The principal objective of the mission is to establish the feasibility of using modulated charged particle beams as ultra-long antennas for transmitting messages at very low frequencies. To this end, Utah State is building a 2-ampere, 3-kilovolt electron gun that will fly on the main rocket payload. Rome Laboratory is building a fully instrumented nosecone that will separate from the main payload during flight and measure the radio waves generated by the electron beam in space. Rome Laboratory will also field ground-based radio receivers at multiple remote sites in Alaska for the purpose of determining the field strength of the waves at the earth's surface.

The RL nosecone wave receiver, known as the Diagnostic Free-Flyer (DFF), remotely measures both electric and magnetic wave fields radiated by the electron beam during the CHARGE-2B mission. The DFF must attain a large separation from the beam emitting "Mother" payload because of the strong interaction among the ambient plasma, the beam and the counterstreaming return electrons in the vicinity of the Mother. This interaction is the source of significant interference to the DFF wave receiver. Moreover, it is desirable to obtain measurements outside the near field of the radiating system. Near field measurements will

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not properly characterize the strength of the ionospheric wave source for comparison with previously developed theoretical models. The above requirements dictate that the DFF achieve a 2 to 5 km separation from the Mother payload by the end of the mission. Such a separation will place the DFF well outside the disturbed plasma region observed on previous missions and out of the near field for all but the longest wavelength VLF emissions.

2. CRITICAL DESIGN CONSTRAINTS

To obtain a 2 to 5 km separation during the interval from DFF deployment (110.0 seconds after launch) to the end of electron gun sequences (518.0 seconds after launch), it will be necessary to separate at a velocity between 4.9 and 12.3 m/s. A separation velocity of 10.0 m/s was chosen as a reasonable design goal. At this velocity, payload separation will be approximately 4 km at the end of the mission.

A second critical design goal for the DFF ejection system was to minimize the acceleration experienced by the payload instrumentation. This goal stems in part from general systems reliability concerns; namely, the electronics has a small chance of breaking during ejection and this chance increases with increasing shock amplitude. A still more important reason to limit ejection shock was the desire to separate the DFF from the Mother after the deployment of the DFF electric field booms. This would increase the roll moment of inertia of the DFF prior to ejection, thereby reducing the payload coning due to ejection tip-off. In other words, the DFF will rotate more stably about its spin axis if its booms are released before rather than after ejection. To deploy the electric field booms prior to ejection it is necessary to limit ejection shock so as not to shear off the booms during ejection. A maximum acceleration of 10.0 g was selected as a reasonable design goal, based on established boom properties, and contingent upon successful shock testing of the booms at a 20.0 g level, in their deployed configuration.

3. PNEUMATIC VERSUS SPRING EJECTION SYSTEMS

A conventional compression spring ejection system would apply initial acceleration to the DFF that would exceed the 10 g limit. If the spring is operated in a regime in which it obeys Hooke s Law, $F(x) = k(L - x)$, where F is the spring force, L is spring relaxed length, x is spring actual length, and k is a constant, then it can be shown that the initial acceleration of the payload is

$$\frac{v^2}{L-x_0} \qquad (1)$$

where V is final separation velocity, and x_0 is spring compressed length. Generous values for spring length and stroke, $L = 0.5$ m, $x_0 = 0.25$ m, yield 40 g initial acceleration to obtain the intended 10.0 m/s separation velocity. By contrast, an ejection system capable of supplying uniform force over its stroke will supply an initial acceleration given by:

$$\frac{V^2}{2\,(L - x_0)} \,. \tag{2}$$

The DFF Pneumatic Payload Ejector (PPE) does supply roughly constant force, thus offering a factor of 2 reduction in initial acceleration relative to a conventional spring system with the same stroke parameters. Moreover, the pneumatic system is capable of much longer stroke. In particular, we can comfortably use $L = 0.6$ m, $x = 0.1$ m, which yields an initial acceleration of 10.0 g for a 10.0 m/s separation speed.

Thus, a pneumatic system is capable of meeting the separation system design goals, whereas a conventional, compression spring system is not. This conclusion led to the . . of the CHARGE-2B DFF Pneumatic Payload Ejector. This report details the calibration and testing of that ejection system.

4. PNEUMATIC PAYLOAD EJECTOR DESIGN

The essential features of the PPE are shown in the assembly drawing of Figure 1. The pneumatic actuator is a Firestone Airstroke Model 38, with a minimum compressed height of 10.9 cm and a compressed volume of 6200 cc. The reservoir bottle contains a volume of 2000 cc. The payload ejector is held in its stowed (compressed) configuration by the manacle band joining the DFF to the adjacent payload section, the Mother recovery system. In the stowed position, the reservoir is valved off from the actuator by a ball-and-seat valve. The ball is attached to one end plate of the actuator while the seat is attached to the other, so that the expansion of the actuator subsequent to the release of the manacle band will allow the reservoir to empty into the actuator. Reservoir gas flowing through a 1.9 cm diameter orifice maintains pressure in the actuator during its expansion.

This design offers the substantial added benefit of allowing the DFF to be mated to the payload while not under spring force. The actuator and reservoir can be pressurized independently through an access door in the fully assembled payload.

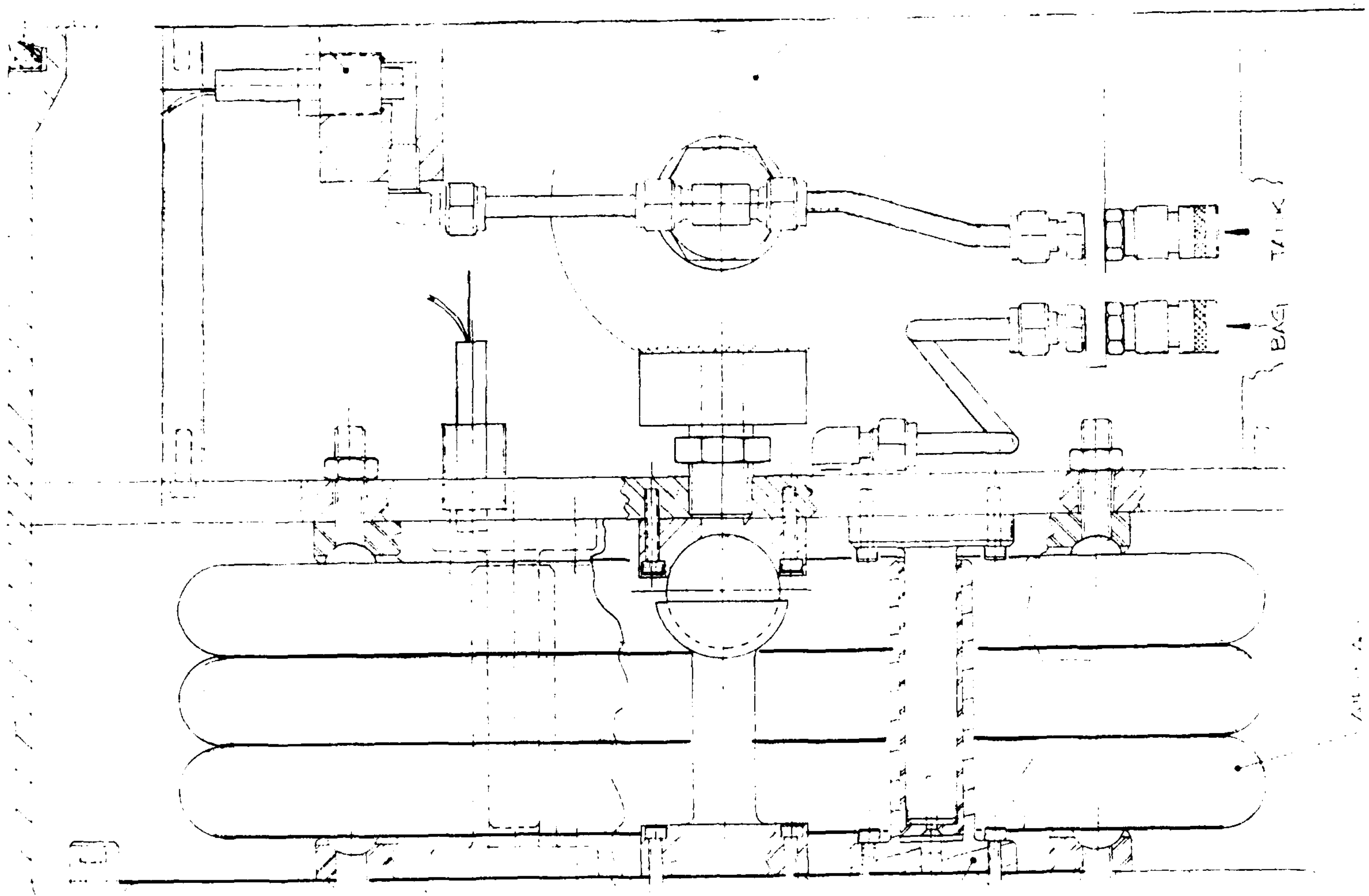

Figure 1. Assembly Drawing Showing Side View of CHARGE-2B Diagnostic Free-Flyer Pneumatic Payload Ejector (PPE). Not to scale.

5. CALIBRATION TESTING

In August 1990, a prototype Pneumatic Payload Ejector (PPE) was field tested to calibrate expected separation velocity as a function of pressure in the reservoir tank. This calibration will be utilized as an adjunct to accelerometer data from the flight. The accelerometer output will be integrated directly during the ejection to obtain the final separation speed. The ejector calibration will be applied to the telemetered values of actuator and reservoir pressure at the time of payload ejection. We will thereby obtain two independent estimates of the final DFF separation velocity for use in the analysis of the DFF wave data.

Under the test procedure, the ejector system was placed on level ground and loaded with a 100-pound dummy payload. In order to simulate the in-flight payload release mechanism, the PPE was restrained by a flight manacle band placed in machined joint grooves on the dummy payload can and on a test fixture. The manacle band allen bolts were not utilized. Instead a quick-release belt was placed around the payload circumference to trap the manacle band. The system was safed during the pressurization of the actuator and reservoir by bolting the dummy payload to the test fixture. Subsequent to pressurization, the safety bolts were removed and the PPE was ready for testing.

The test results were documented by a data-quality, time-coded video recorder. Using the resulting video tape, event times could be determined to ±15 msec.

To accomplish the test, the quick release belt was unfastened, permitting the Pneumatic Payload Ejector to launch the dummy payload vertically upward against gravity. The dummy payload typically reached an apogee of 15 to 20 feet during the tests. Since this distance of travel was much greater than the actuator stroke, the payload separation velocity in the absence of gravity can be estimated (±5 percent) by comparing the time of full actuator extension to the time of apogee. Test results are shown in Table 1:

Table 1. PPE Calibration Test Results

Pr	Pa	Pf	Tr	Ta	Ti	Vs
129.7	31.0	18.0	30.35	30.79	31.33	4.9
137.9	32.1	22.2	34.11	34.61	35.01	4.5
175.4	30.2	25.7	11.46	12.06	12.63	5.9
170.0	37.0	26.1	8.84	9.40	10.00	5.8

where Pr = pressure in reservoir prior to test (PSIA)

Pa = pressure in actuator prior to test (PSIA)

Pf = final system pressure (PSIA)

Tr = time of actuator full extension (s)

Ta = time of dummy payload apogee (s)

Ti = time of dummy payload impact (s)

Vs = calculated separation velocity (m/s)

= 10.0 * (Ti - Tr)/2.0

10.0 m/s^2 is taken to be gravitational acceleration

Separation velocity is approximately proportional to the square root of the reservoir pressure, as would be exactly true if the system succeeded in maintaining constant pressure in the actuator throughout its stroke. We will extrapolate to a separation velocity of 6.0 m/s at a reservoir pressure of 200 PSIA. These will be the flight parameters unless additional calibration testing is performed at higher reservoir pressures.

The separation velocities of Table 1 must be corrected to account for the fact that the Diagnostic Free-Flyer (DFF) is separating from a Mother payload of finite mass rather than the infinitiely massive earth. If I is the total impulse applied to each payload during ejection, then

$$\left(\frac{1}{m_1} + \frac{1}{m_2}\right) \cdot I \tag{3}$$

is the separation speed of the DFF with respect to the Mother, where m_1 is the DFF mass, and m_2 is the Mother mass. The DFF and Mother will be moving at speeds I/m_1 and I/m_2, respectively, away from the Pneumatic Payload Ejector (PPE), while the PPE proceeds at the center of mass velocity - since the PPE is attached to neither payload. In correcting for finite Mother mass, it is necessary to recall that the total impulse applied to each payload in flight will be less than that applied to the dummy payload during ground tests. This results from the lesser contact time between the PPE and the payloads during flight. The correction factor to be applied to the measured separation velocities can be obtained for constant ejection acceleration:

$$\sqrt{1 + \frac{m_1}{m_2}} \, . \tag{4}$$

For m_1 = 45.4 kg (100 lbs. = DFF anticipated weight), m_2 = 454 kg (1000 lbs. = Mother anticipated weight), this factor is 1.05, which is relatively small. Thus, a 6.0 m/s separation during the ground test configuration translates into 6.3 m/s during flight. This implies a relative speed of 5.7 m/s between the PPE and DFF, and 0.6 m/s between the PPE and Mother

The field test also demonstrated that the Pneumatic Payload Ejector maintained contact with the dummy payload for approximately 75 msec, regardless of reservoir pressure. Due to finite Mother mass this interval will be reduced to 68 ms during flight. From this acceleration interval, we can compute a constant acceleration of 8.8 g for a 6.0 m/s separation velocity.

6. VIBRATION AND SHOCK TESTING

Launch vehicle vibration or motor separation shock could cause the ball valve in the PPE actuator to unseat, allowing reservoir gas to enter the actuator prematurely. This event would have two negative effects. First, it would greatly increase the initial acceleration experienced by the DFF -- to a value as great as 40 g for 200.0 PSI initial reservoir pressure. Such an acceleration would jeopardize both the instrumentation electronics and the deployed electric field booms. Second, it could, in principle, cause the Airstroke actuator to exceed its rated maximum pressure, possibly causing it to rupture. In practice, this is not a concern, as the worst case actuator pressure for a leaking ball valve at 200 PSI reservoir pressure will be 64 PSI, well beneath the rated maximum of 100.0 PSI.

As a result of these concerns, a pressurized prototype Pneumatic Payload Ejector was subjected to vibration and shock testing on 23 and 28 August 1990. The PPE was secured to a test fixture by a manacle band with the associated allen bolts installed. The test fixture, in turn, was bolted to the shake table. The system was weighted with a dummy payload weighing 100 lbs. The dummy payload consisted of a sand-filled, covered aluminum can.

The ejector system was shaken and shocked in one lateral axis and in the thrust axis. Table 2 shows system pressures after each test and lists the figures containing individual test accelerations.

Table 2. PPE Vibration and Shock Test Results

Date	Test	Pa'	Pr'	Figure
23 Aug	prior to testing	31.19	117.82	
23 Aug	lateral random vibration	31.10	117.28	2
23 Aug	lateral shock (-25 g)	31.05	116.70	3
23 Aug	lateral shock (25 g)	30.97	115.96	4
23 Aug	lateral sine vibration	30.86	115.31	5
28 Aug	prior to testing	29.32	100.50	
28 Aug	thrust random vibration	29.35	100.29	6
28 Aug	thrust shock (25 g)	29.43	99.70	7
28 Aug	thrust sine vibration	29.42	99.66	8

where Pr' = pressure in reservoir after test (PSIA)
Pa' = pressure in actuator after test (PSIA)

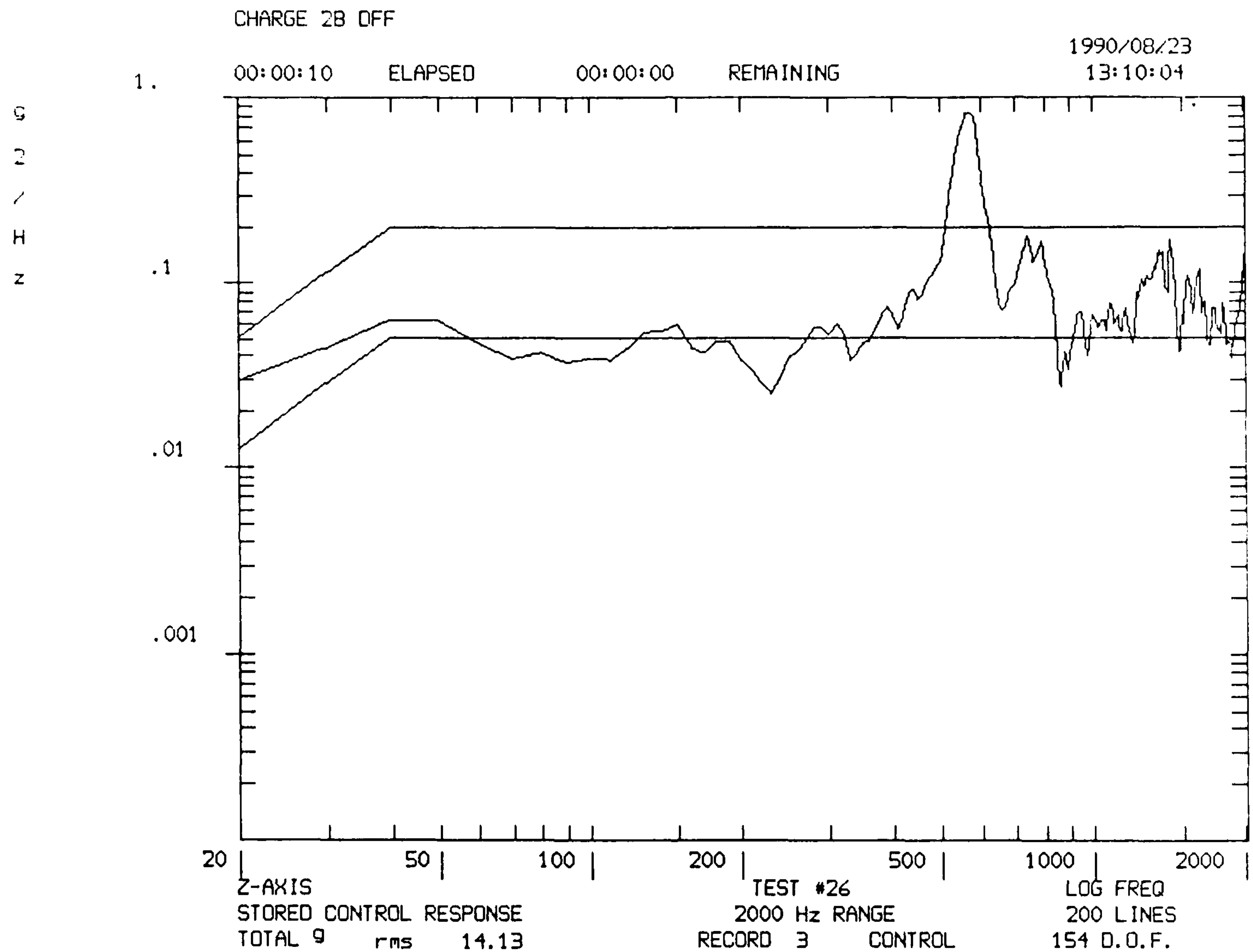

Figure 2. Response Acceleration Observed During Lateral Random Vibration of PPE. Drive 20 to 20,000 Hz. 20 Hz to 40 Hz at 6 dB/oct (14.0 g rms). Flat spectrum at 0.100 2g/Hz above 40 Hz.

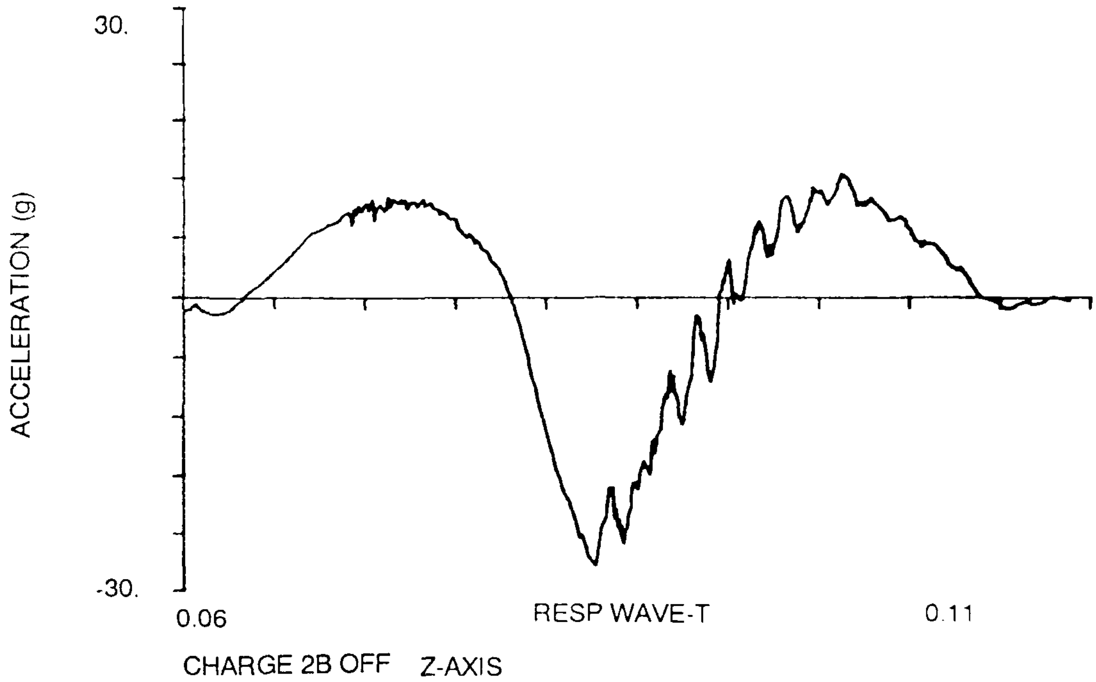

Figure 3. Response Acceleration During Negative Shock. 11 ms, 25g.

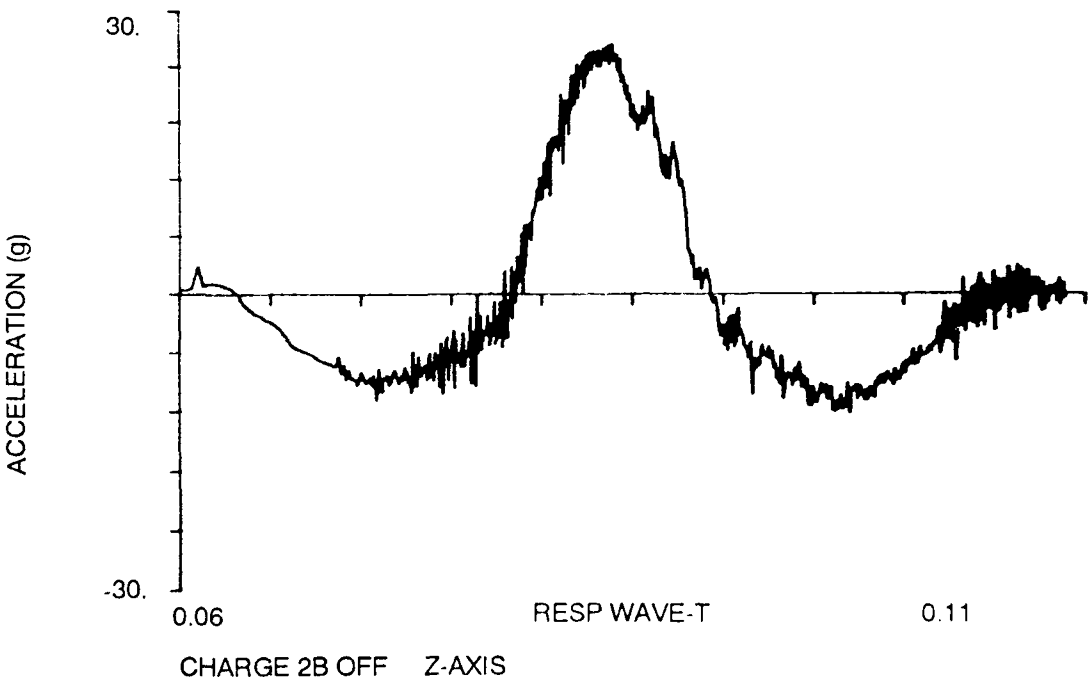

Figure 4. Response Acceleration During Positive Shock. 11 ms, 25g.

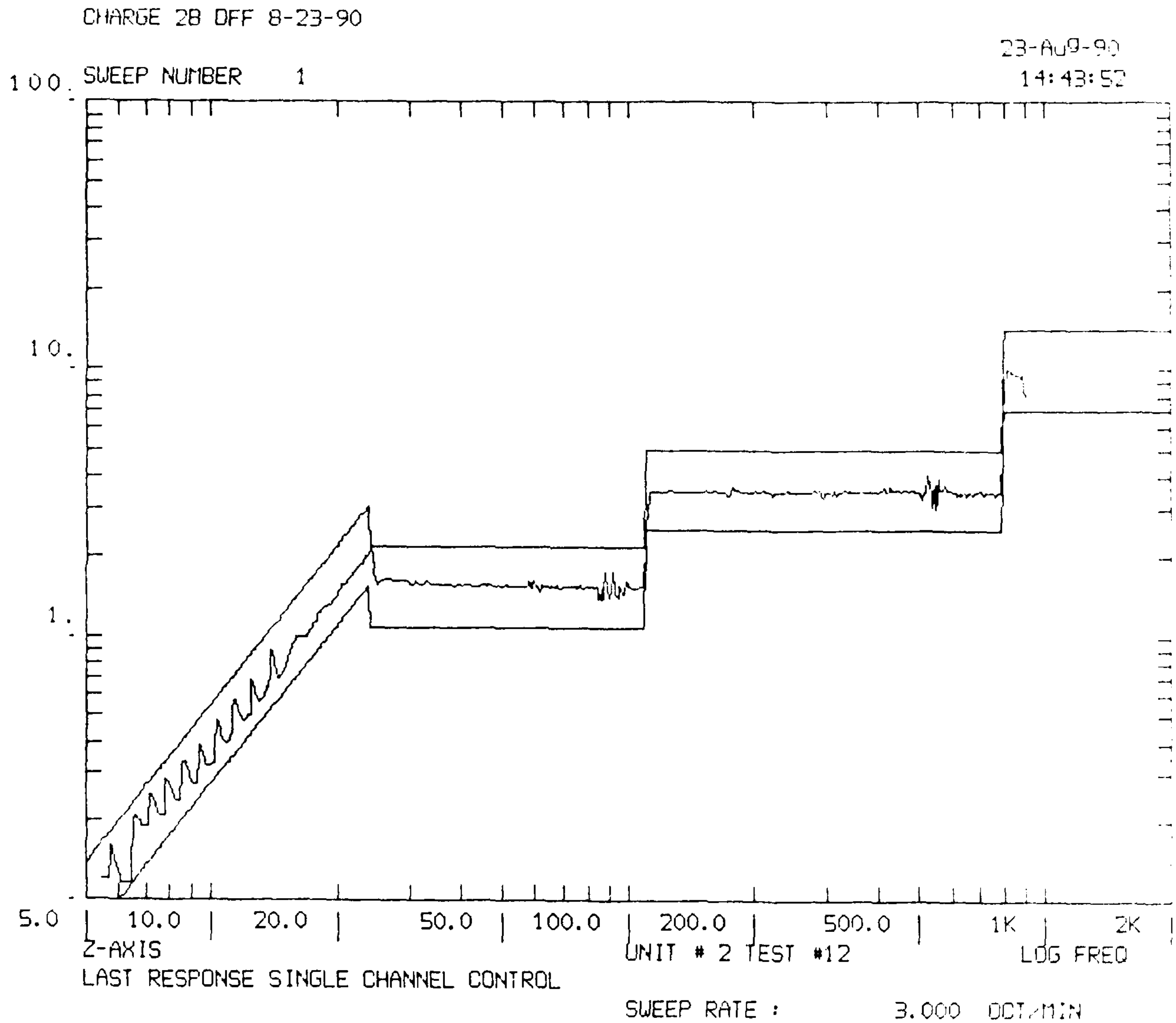

Figure 5. Response Acceleration Observed During Lateral Sine Vibration of PPE

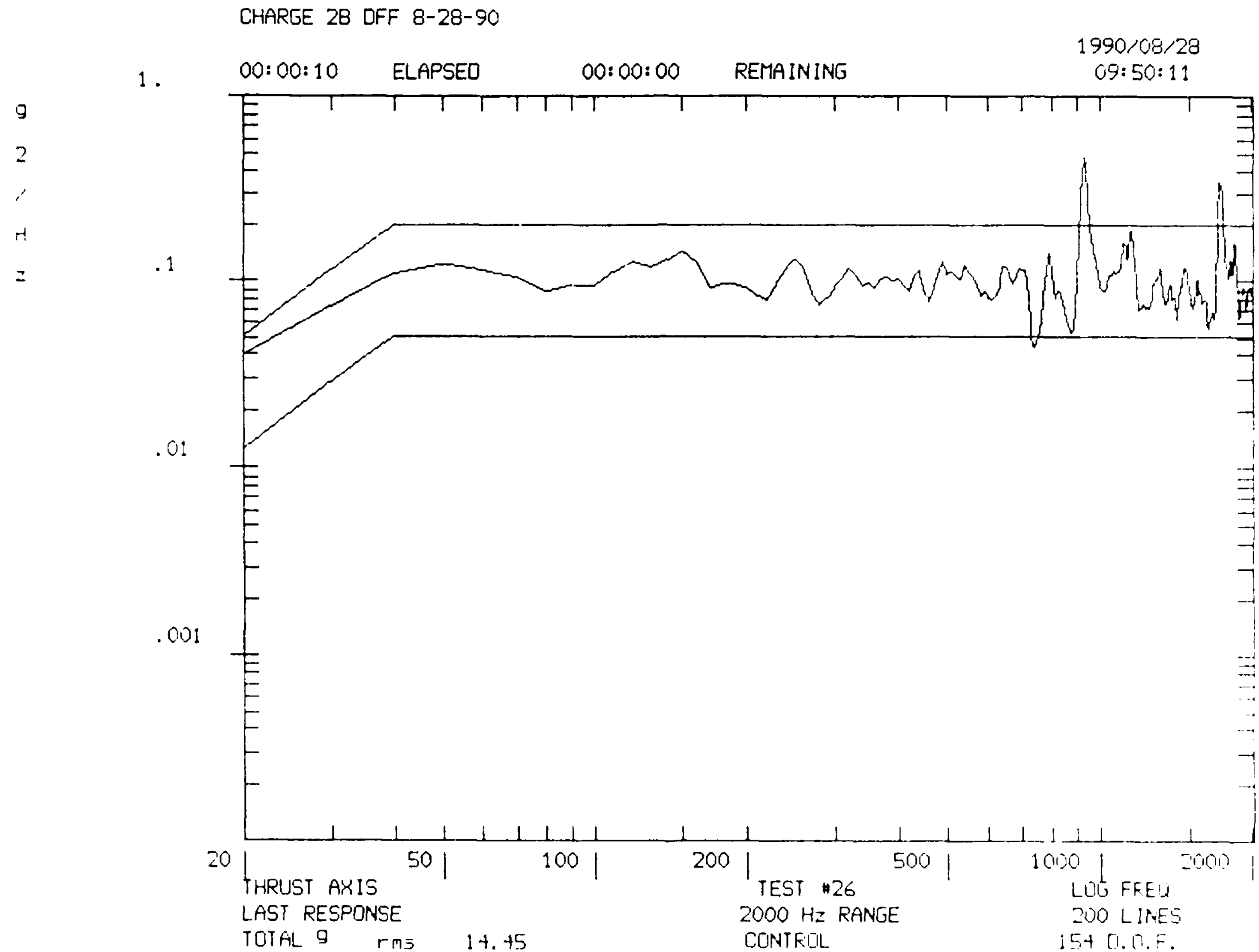

Figure 6. Response Acceleration Observed During Thrust Axis Random Vibration of PPE. Same levels as in Figure 2.

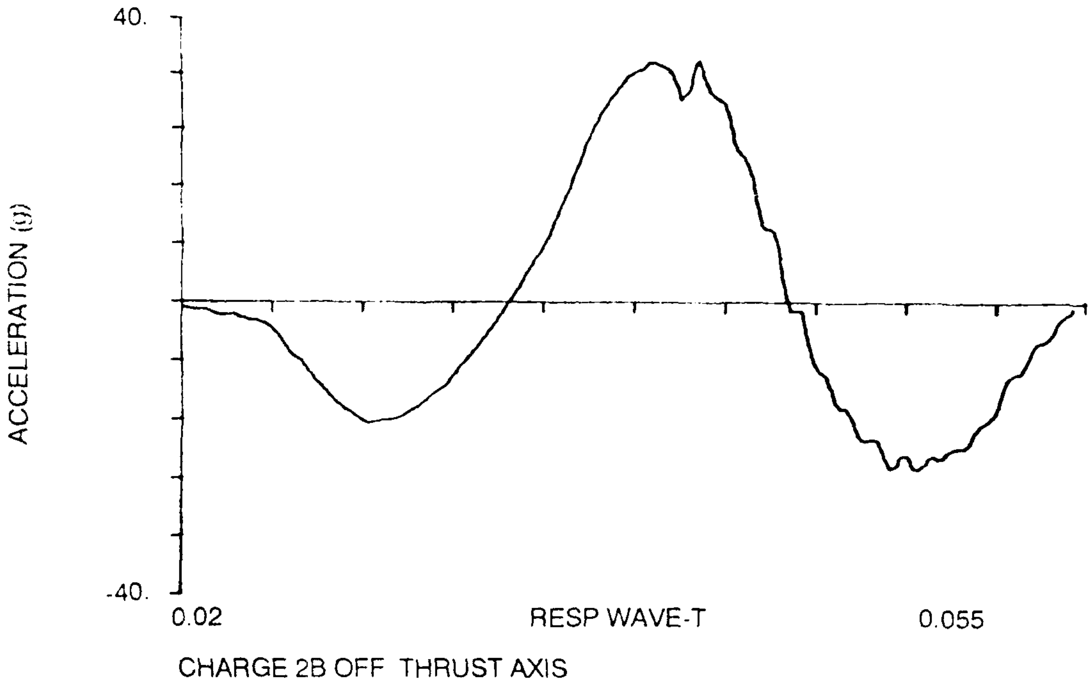

Figure 7. Response Acceleration During Thrust Axis Shock. 11 ms, 25g.

The figures show that the response acceleration of the Pneumatic Payload Ejector exceeded test limits for all vibration tests. This was due to shaky construction of the dummy payload, and does not alter the fact that the PPE itself performed flawlessly in all tests. The valve maintained an adequate seal throughout the vibration and shocks. The slight downward trend in pressure is not significant, and can be attributed to cooling of the system in the test facility.

7. SHOCK TESTING OF THE DFF ELECTRIC FIELD BOOMS

Figure 8 shows the response acceleration of the CHARGE-2B Diagnostic Free-Flyer electric field booms during a 20 g, 11 ms sine pulse. The boom was installed in its hinge mechanism and shocked along an axis normal to its length. While this was not a direct test of the Pneumatic Payload Ejector, it is relevant because it bears on the question of whether or not the PPE will subject the deployed field booms to excessive shock during ejection. The boom, a 1.0-in. O.D., 1/16-in. wall thickness tube made of G-10 fiberglass, performed well during the test and exhibited no mechanical defects upon subsequent inspection. We conclude that the electric field booms may be safely deployed prior to payload ejection.

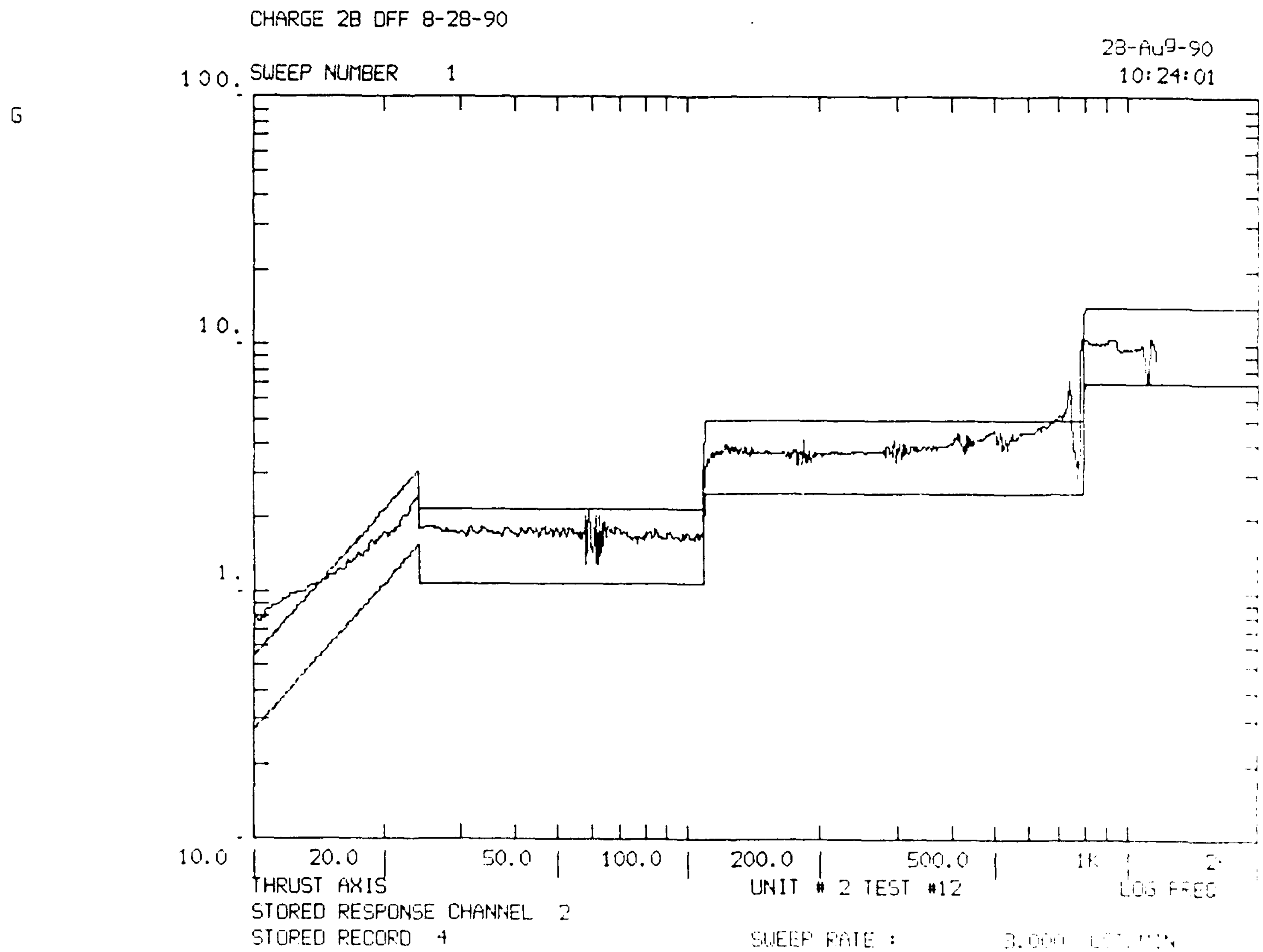

Figure 8. Response Acceleration Observed During Thrust Axis Sine Vibration of PPE

8. DISCUSSION

A prototype version of the CHARGE-2B Diagnostic Free-Flyer (DFF) Pneumatic Payload Ejector (PPE) was calibrated and tested in August 1990. It was tested against design goals of 4.9 m/s minimum separation speed and 10 g maximum acceleration, derived from both scientific and engineering considerations. The tests were conducted for an anticipated 100 lb (45.4 kg) payload, and the system performed successfully -- achieving minimum design goals and not leaking under vibration and shock. As a result of the tests, we would expect to fly with one atmosphere in the actuator and 200 PSIA in the reservoir. A 100 pound payload would achieve a separation speed of 6.0 m/s, and experience a maximum acceleration of 8.8 g.

In fact, the final weight estimates for the DFF and Mother payloads are 148 lb and 780 lb respectively. Applying our calibration results and corrections for finite Mother mass, we expect a separation speed of approximately 4.4 m/s between the Mother and the DFF, and 0.7 m/s between the Mother and the PPE. This projected separation speed fails to meet minimum design goals. Additional calibration testing would be required before increasing the reservoir or actuator pressure to regain intended separation speed.

Prototype vibration and shock testing is complete. However, the flight unit will be subjected to vibration and shock according to the NASA Sounding Rocket Handbook.[1] This will be accomplished with the PPE pressurized to anticipated flight levels.

Finally, shock testing of the DFF electric field boom assemblies demonstrated that the booms may be deployed prior to payload ejection without risk of damage due to excessive shock.

[1] (1988) *Sounding Rocket User's Handbook*. NASA Goddard Space Flight Center, Wallops Flight Facility, VA 23337.

References

1. (1988) *Sounding Rocket User's Handbook*, NASA Goddard Space Flight Center, Wallops Flight Facility, VA 23337.

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