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Rocket-Delivered Test of Strategic Earth Penetrator Weapon: RSP-101 (U)

N. A. Lapotin

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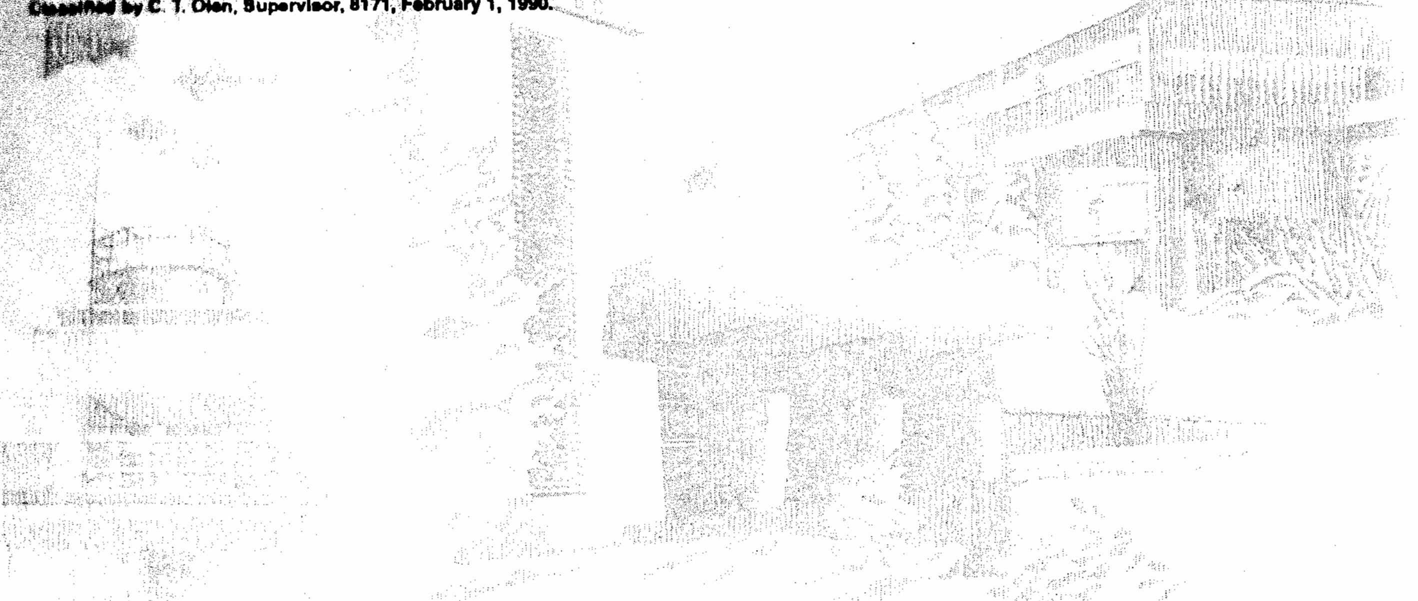

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ROCKET-DELIVERED TEST OF STRATEGIC EARTH PENETRATOR WEAPON: RSP-101 (U)

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ABSTRACT (U)

RSP-101 was a joint SNL/LLNL rocket-delivered impact test of a Strategic Earth Penetrator Weapon (SEPW) design conducted at the Tonopah Test Range on September 28, 1988. The main objective of this test was to evaluate the structural integrity of a Livermore SEPW design with a nuclear explosive-like assembly subjected to a realistic penetration environment.

ACKNOWLEDGMENTS

I would like to extend my special thanks to D. B. Sparger who assisted in most aspects of this test. I would also like to acknowledge the test contributions of J. J. Bahlman, J. P. Gallagher, D. M. McNeill, R. H. Meyer, C. A. Nelson, L. M. Stone, and the personnel at the Tonopah Test Range; the test coordinating contributions of S. G. Cain and E. H. Carrell; the aerodynamic analyses of D. L. Keese and L. R. Rollstin; the instrumentation support from D. R. Baker, T. F. Eklund, and the late H. D. Sorensen; the design support from T. J. Sa and J. Tong; the test assembly contribution of J. Tootle; the geological analyses of H. A. Dockery, J. C. Eichelberger, and J. Lipkin; the photometric contributions of D. M. Abrahams; and the structural analyses of M. L. Chiesa.

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Executive Summary

RSP-101 was a joint SNL/LLNL rocket test of a Strategic Earth Penetrator Weapon (SEPW) design conducted at the Tonopah Test Range on September 28, 1988. The main objective of this test was to evaluate the structural integrity of a Livermore SEPW design subjected to a realistic penetration environment. DOE b(3)

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RSP-101 was recovered and the penetrator case was in good condition.

RSP-101 marked a milestone event since it was the first full-scale test of a Livermore SEPW design with nuclear explosive-like assembly (NELA) and was a key step in establishing the viability of this SEPW design.

Introduction

An advanced development program of the Strategic Earth Penetrator Weapon (SEPW) is currently in progress. This program is conducted in conjunction with the current SEPW Phase 2 study.

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It should be mentioned that a 16 in. Davis Gun is now available for testing at TTR and is an alternate method to test full-scale penetrators (Ref. 2). Though this gun will accommodate the full-scale design, the undesirable reverse g-loading during launch cannot be avoided.

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Test Conditions

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assuming an S number of 1.2 (Ref. 3). The following equation was used to compute the average axial deceleration, a.

$$a = \frac{V^2}{2gP}, \quad (1)$$

where V is the impact velocity and P is the penetration path length.

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To confirm the above axial and lateral loading predictions, an on-board data acquisition system was added to RSP-101. This system was designed to measure and record axial and lateral accelerations and axial and hoop strains along the inside of the penetrator case.

Test Description

RSP-101 Test Vehicle

Mass Properties and External Configuration—The RSP-101 mass properties and external configuration is summarized in Table I. The penetrator body consisted of an ogive nose and a tapered afterbody (see Figure 1). Appendix A provides an SNLL assembly drawing of RSP-101.

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Instrumentation—RSP-101 was instrumented with six axial and lateral accelerometers and nine strain gages mounted along the inside of the penetrator case. An on-board data recording system, developed by Div. 8452, was used to measure and record the real-time response of these channels. This system, referred to as a LDRS (Livermore Data Recovery System), was located in the aft region of RSP-101. Division 8452 documented a complete description of this system (Ref. 6). Table II provides a summary of the instrumentation requirements.

AX-2, mounted on LLNL's aft support, was used to trigger the LDRS (to start recording data from T-40 to T+160 msec) when it sensed +1000 g's during penetration. AX-1, AY-1, and AZ-1 were mounted on LLNL's forward support. AY-3 was mounted directly to the case. AX-3, mounted on the aft support, was added at the last minute to replace the AY-2 accelerometer which was inadvertently excluded from the assembly. AY-2 was to be mounted on the case at 10° near the interstage region (Sta 28.2 in.). The exact locations of the accelerometers and strain gages are specified in the SNLL Assembly Drawing (Appendix A). The accelerometer and strain channels had data resolutions of ,

TABLE II. RSP-101 PENETRATION ENVIRONMENT INSTRUMENTATION

Gage ID	Description	Location	Calibration Range	Freq. Response
AX-1	Axial Accel	Fwd		5.0 kHz
AX-2	Axial Accel	Aft		5.0 kHz
AX-3	Axial Accel	Aft		5.0 kHz
AY-1	Lateral Accel	Fwd		5.0 kHz
AY-3	Lateral Accel	Aft		5.0 kHz
AZ-1	Lateral Accel	Fwd		5.0 kHz
SG-1	Strain, Case	Fwd		5.0 kHz
SG-2	Strain, Case	Fwd		5.0 kHz
SG-3	Strain, Case	Fwd		2.5 kHz
SG-4	Strain, Case	Mid		2.5 kHz
SG-5	Strain, Case	Mid		5.0 kHz
SG-6	Strain, Case	Mid		5.0 kHz
SG-7	Strain, Case	Aft		2.5 kHz
SG-8	Strain, Case	Aft		5.0 kHz
SG-9	Strain, Case	Aft		2.5 kHz

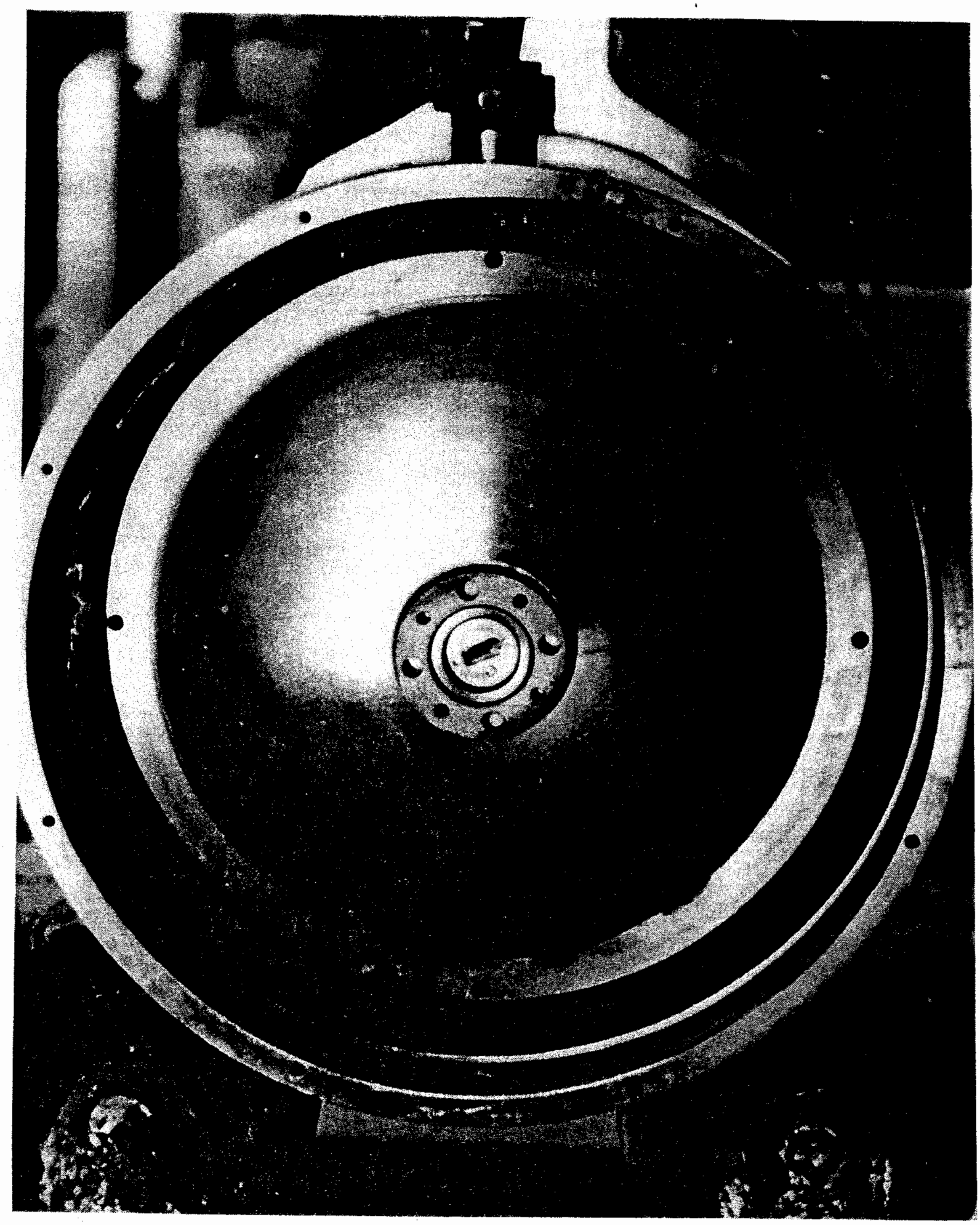

Figure 3. Aft End View of RSP-101

Since Nicad batteries (the primary power source for the LDRS) have behaved poorly on previous tests, two ammonia batteries were added for backup power. Each ammonia battery had an operating life of roughly 3.5 minutes and were installed in the LDRS foam. Though both ammonia batteries were connected in parallel with the LDRS, only one was used during the test. The extra battery would be used only if the other battery had been activated prior to test.

A weight breakdown of the RSP-101 components is provided in Table III

TABLE III. RSP-101 WEIGHT BREAKDOWN

Component	Weight (lbs)

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RSP-101 was assembled at the LLNL Site-300 facility and shipped to and from TTR in a modified H1138 Shipping and Storage Container (see Figure 4).

2-Stage Genie Rocket System

A 2-Stage Genie rocket system was used to deliver RSP-101 to the target area. The first-stage motor propelled the test vehicle during ascent and separated immediately after burnout. The second-stage motor ignited 4.6 sec before impact to obtain the desired impact velocity and remained attached at impact. Figure 5 illustrates the complete payload/rocket assembly. The total weight and length were 214 inches and 2331 lbs, respectively. Each Genie motor weighed 480 lbs, including 321 lbs of propellant. The length and diameter of each motor was 66 and 15 inches, respectively. The Genie burn time was approximately 3 sec and the average thrust was 25 kips. The rocket system spin rate was regulated by preset cant angles on the first and second stage Genie fins: 60 and 19 minutes on the first and second stage fins, respectively. An inter-stage section that included the first-stage Genie motor separation system was used to join the two Genie motors.

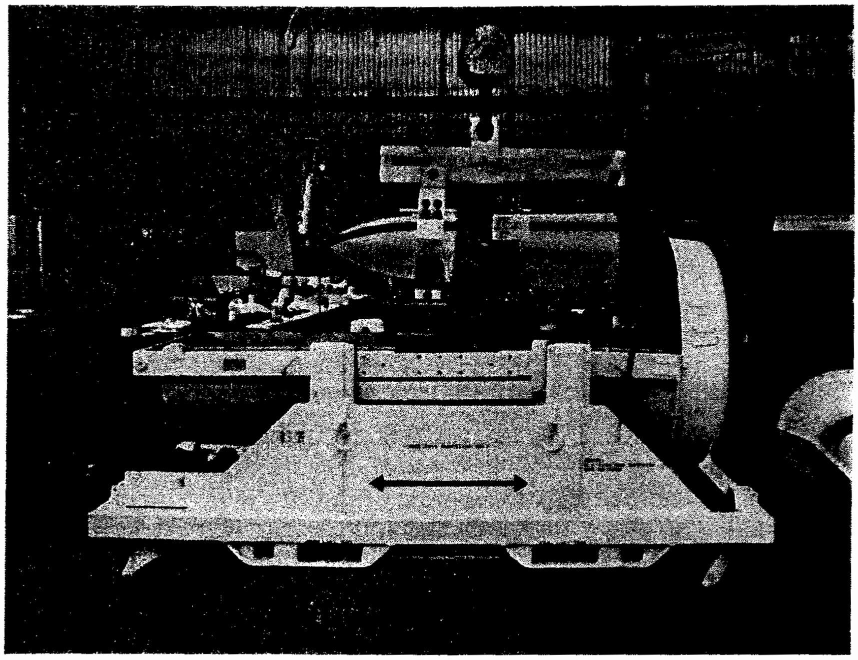

Figure 4. RSP-101 In Modified H1138 Shipping and Storage Container

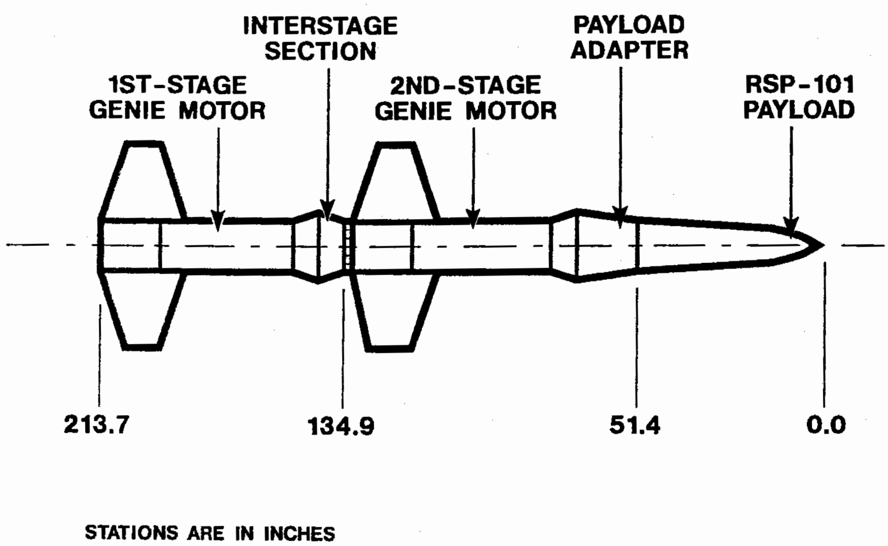

Figure 5. RSP-101/Rocket System Configuration

The payload adapter section was mounted between the RSP-101 payload and the second-stage Genie motor. This section included a control box (for first-stage separation and second-stage ignition), a telemetry system (to transmit flight data prior to impact), and X-band and C-band transponders (to facilitate radar tracking). The weight of the payload adapter section was 91 lbs.

The expended second-stage Genie motor and payload adapter sections remain attached to the RSP-101 payload for aerodynamic stability prior to impact. (The RSP-101 payload itself was not aerodynamically stable.) This tail structure, which weighed roughly 250 lbs at impact, was predicted to break up during the first body-length of penetration of the RSP-101 payload. To ensure that the tail structure would break off during initial penetration, the payload adapter was given a diameter larger than that of the payload. For added precaution, the aft end of the penetrator case was extended to protect the aft closure plate from the tail structure debris. These precautionary measures were successfully demonstrated in the RSP-100 test.

The telemetry system provided by Division 8451 was located in the payload adapter section and measured the RSP-101 rocket system flight environment from launch to impact. The flight environment sensors, which are described in Table IV, were located within the telemetry system.

An S-Band transmitter (with two antennas 180° apart on the adapter case) sent the flight data to the ground recording stations on a frequency of 2204.5 MHz.The payload adapter section also included C-Band and X-Band transponders to facilitate radar tracking. The C-Band's transmitting/receiving frequencies were 5690/5620 MHz and the X-band's transmitting/receiving frequencies were 9300/9200 MHz. Each transponder used a pair of antennas that were mounted 180° apart on the adapter case.

TABLE IV. RSP-101 FLIGHT ENVIRONMENT INSTRUMENTATION

Designation	Gage	Orientation	Calibration Range
AX-1	Accelerometer	Axial	
AX-2	Accelerometer	Axial	
AX-3	Accelerometer	Axial	
AX-4	Accelerometer	Axial	
AY-1	Accelerometer	0-180°	
AZ-1	Accelerometer	90-270°	
GYR-1	Rate Gyro	Roll	
GYP-1	Rate Gyro	Pitch	
GYY-1	Rate Gyro	Yaw	

Division 1555 was responsible for the RSP-101 aerodynamic analyses (Refs. 7 and 8) of the RSP-101/rocket system. Divisions 7523, 7526, and 9143 conducted the final assembly of the rocket system at TTR. Figure 6 shows the RSP-101/rocket system assembly mounted on the Honest John Mobile Launcher.

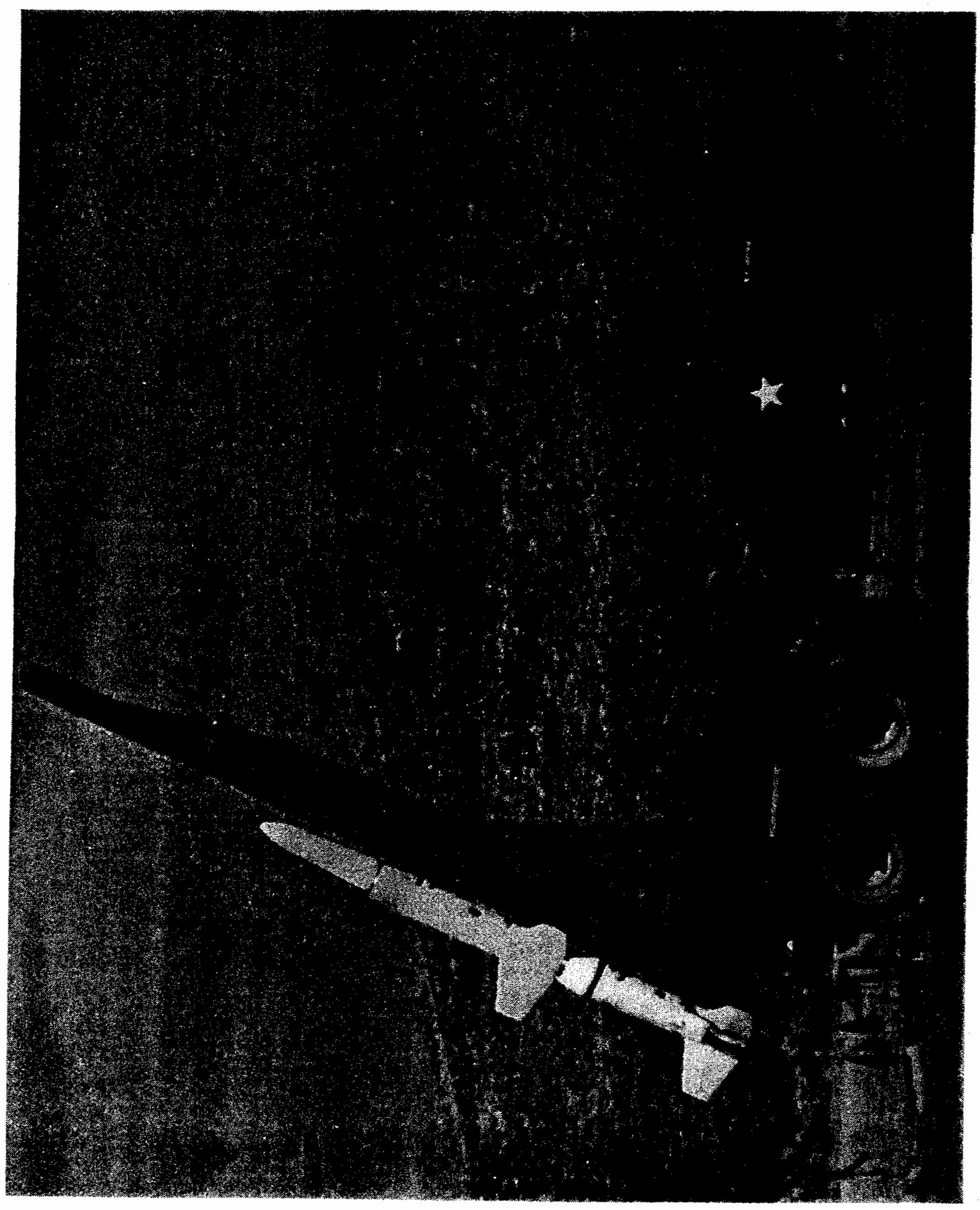

Figure 6. RSP-101/Rocket System on Honest John Mobile Launcher

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Target Area

The target area can be characterized by a 12 (north-south) x 3 (east-west) kft rectangle (see Figure 7). [redacted] identical to that used for the DSP-401 and DSP-403 Davis Gun tests (Ref. 9, see Figure 8). The RSP-101 target area is located at the southern region of TTR. Approximately 30% of the target area was located north of the TTR southern border and the remainder was located south on Range 75 of the Nellis AFB. (Hence this target area was referred to as Tuff-75.)

The RSP-101 aim point was moved 1 kft downrange (south) from that of RSP-100 because the terrain south of the RSP-100 aim point was less "rugged" (Ref. 10). Aiming into this region would decrease the probability of high oblique impact and the corresponding severe lateral loads. Moving the aim point downrange by 1 kft did not change the rocket system's performance (trajectory & impact dispersion area) but the launch point also had to be moved downrange by 1 kft [redacted]

The calculated 3-sigma impact point dispersion area for RSP-101 was elliptical with a downrange variation of +/-2.6 kft and a crossrange variation of +/-2.9 kft. Based on this [redacted]

Test

Flight

RSP-101 was launched from the Honest John mobile launcher on September 28, 1988 at 2:46 pm (see Figure 9). The launch site was located roughly 22 kft uprange of the RSP-101 aim point. The launcher was set with an azimuth of 170.5° true (i.e., 9.5° off south) and with an elevation of 65.7°. The first-stage Genie motor boosted the entire (2331 lb) system off the Honest John mobile launcher. First-stage separation occurred during ascent and second-stage ignition occurred during descent. The peak acceleration during first stage and second stage burn was about 16.2 and 22.5 g, respectively.

Three radars were used to track RSP-101 during flight: R-24 fixed radar (C-Band) on Radar Hill, R-36 fixed radar near the main lake, and the R-39 Mustang mobile radar (X-Band) on Hoot's Hill. Since both on-board transponders (C-Band and X-Band) evidently did not facilitate radar tracking, RSP-101 was tracked in the "skin" (i.e. surface reflection) mode. R-36 provided the best tracking for the first 38 seconds of flight and R-24 provided the best tracking from this point to impact.

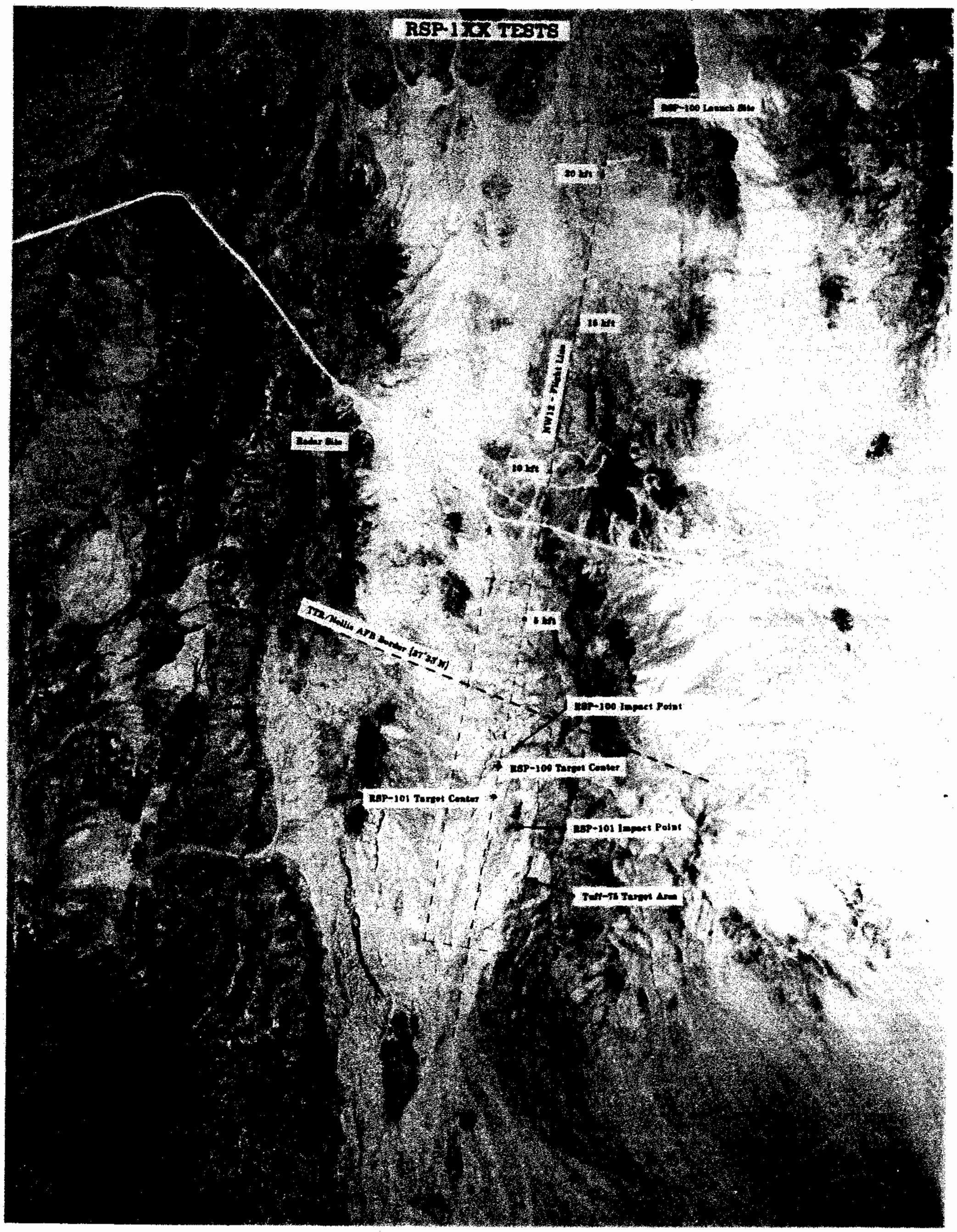

Figure 7. Aerial View of Tuff-75

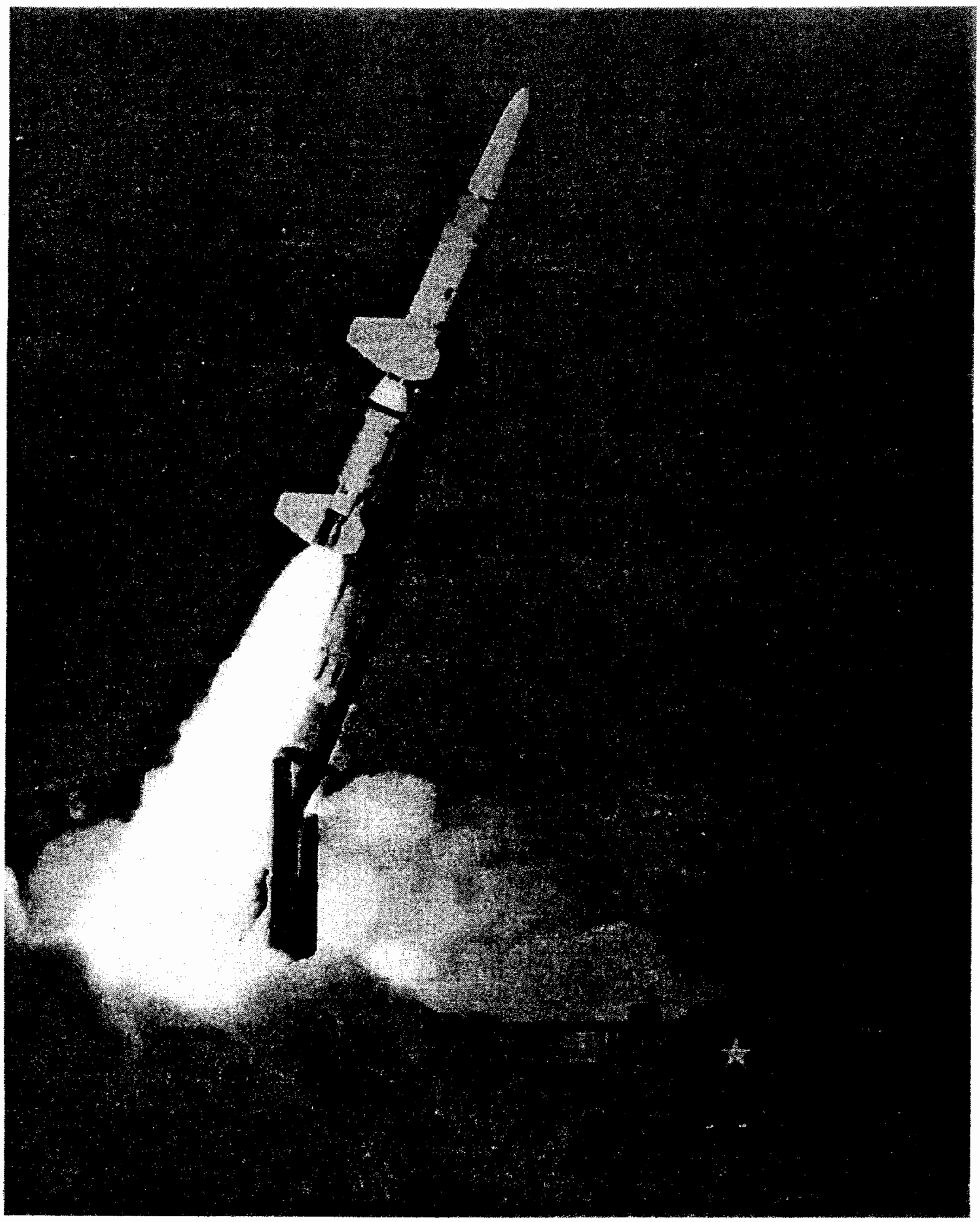

Figure 9. RSP-101/Rocket System Launch

Table V summarizes the sequence of events of the RSP-101 mission. Appendix B provides a post-test report on the flight environment.

TABLE V. RSP-101 FLIGHT SEQUENCE OF EVENTS TIME

Time (sec)	Event	Vel (fps)	Flight Angle	Range (ft)	Altitude (ft msl)
0.0	1st-Stg Ignition	0	65.7°	0	5500
3.1	1st-Stg Burnout	987	65.7°	800	7222
4.9	1st-Stg Separation	950	65.7°	1200	8087

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Impact

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For optical coverage of impact, eight fixed remotely-controlled cameras that operated at 60 frames/sec were setup along the RSP-101 target center (Ref. 11). The cameras covered an area roughly 1800 feet long and 1200 feet wide. RSP-101 impacted within the field of view of two of the eight impact cameras (see Figure 10).

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Recovery

Using earth moving equipment, RSP-101 was recovered on October 5 (see Figure 13). The recovery operation took approximately three and a half working days. Debris from the payload

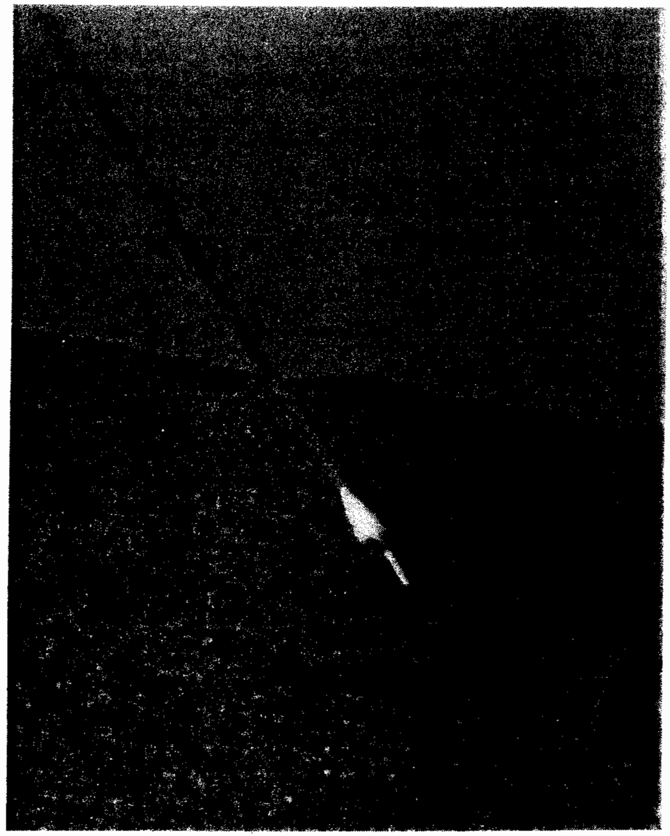

Figure 10. RSP-101 Prior to Impact

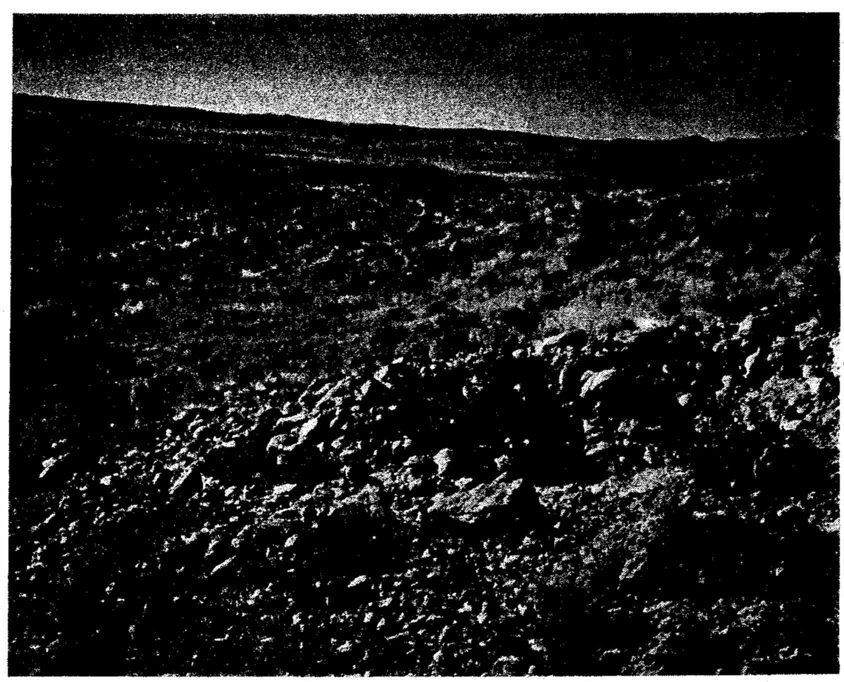

Figure 11. RSP-101 Impact Site

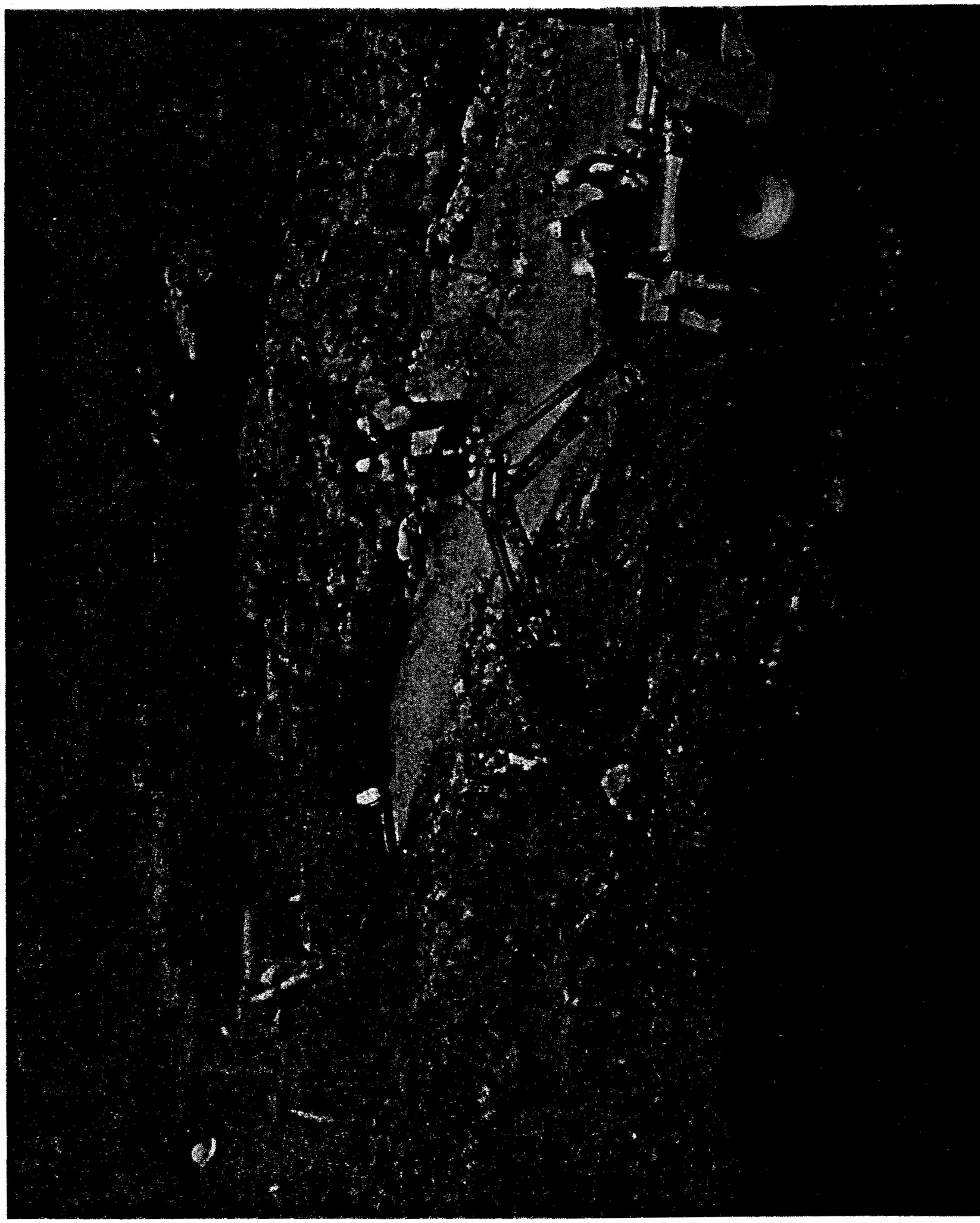

Figure 13. RSP-101 Recovery Using Earth Moving Equipment

adapter and the expended 2nd stage rocket motor was found all along the penetration cavity. In fact, some of the payload adapter parts were recovered within inches of the aft end of RSP-101.

Upon recovery, the penetrator case appeared to be in good condition (see Figures 14 and 15). However, the aft closure plate was damaged (see Figure 16).

On October 13, RSP-101 was radiographed while still at TTR to examine the structural integrity of the nuclear package. The radiographs indicated no major internal structural damage. RSP-101 was then transported back to Site-300 on December 21 for disassembly.

Post-Test Activities

Impact Site Survey

Disassembly and Postmortem Examination

The first step in the RSP-101 disassembly was to remove the LDRS which was located in the aft region. However, this step was complicated because the aft threaded ring would not unthread due to slight deformation of the aft end of the RSP-101 case that occurred during penetration.

Access to the aft end of RSP-101 was achieved instead by using a milling machine to cut a hexagonal section, measuring 8.5 inches across, from the titanium aft stiffener (see Figure 21). After the parted hexagonal section was removed, it was apparent that the damage of the umbilical connector assembly extended into the LDRS (see Figure 22). The external force which apparently forced the umbilical connector inward was also responsible for displacing the LDRS package laterally by roughly 0.5 inches. The center of the LDRS steel cover plate was indented, and the umbilical cable between the LDRS and umbilical connector assembly was severed (see Figure 23).Examination of the LDRS after it was removed from the RSP-101 assembly revealed that no useful penetration data was obtained. It became evident that the physical damage experienced by the LDRS disrupted its electrical performance.

Disassembly continued by using the milling machine to remove both the aft threaded ring and what was left of the aft stiffener. Next, the LDRS support foam (40 lb/ft^3 polyurethane foam), which was still in good condition, was removed. This exposed the aft support plate

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[3] C. W. Young, "Equations for Predicting Earth Penetration by Projectiles: An Update," Sandia National Laboratories, SAND88-0013, 7/88.

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[11] D. M. Abrahams, "Impact Photography of RSP-101," memorandum to distribution, 9/2/88.

[12] H. A. Dockery, "Geology of RSP-101 Impact Site, TTR," Lawrence Livermore National Laboratory, 7/24/89.

APPENDIX B—RSP-100 POST-TEST FLIGHT ANALYSIS
RSP-101 POST-TEST FLIGHT ANALYSIS

UNCLAS[redacted]D

Sandia National Laboratories

Albuquerque, New Mexico 87185

Date: July 1, 1987

To: N. A. Lapetina, 8152

Larry Rollstin F. V. Wyatt

From: L. R. Rollstin, 1555, and F. V. Wyatt, 1551

Subject: RSP-100 Flight Environment Data Summary

Ref: Memo, W. R. Barton, 1555, to G. L. West, 7173, dtd. 11/25/86
Subject: Range Safety Approval Request for the Genie-Genie/RSP Flight Testing at the Tonopah Test Range

The reduction and post-processing of the flight data for the Genie-Genie boosted RSP-100 penetrator flight test are complete. This payload was boosted into an "antelope" tuff target at Tonopah Test Range (TTR) on February 18, 1987. The track from the R-24 radar at TTR was combined with the rawinsonde data to determine a history of vehicle flight parameters. The telemetered axial accelerometer data were digitized and integrated to obtain a more accurate pattern of velocity change during periods of extreme acceleration (boost and higher drag phases). The accelerometer data were compared to the radar track during periods of minimum velocity change to determine correction factors for these data to force agreement with the track. A history of the velocity magnitude from the track and from the corrected accelerometer is presented in Figure 1. A lack of adequate signal output from one of the radar transponder antennas on the vehicle apparently caused the noisy velocity history as obtained by the radar. The accelerometer output required a scale factor correction factor of 0.955, a bias factor correction of +1.16 g,

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The Mach number (M) and dynamic pressure as determined from the corrected accelerometer and rawinsonde data are presented in Figures 2 and 3, respectively. Also, pretest parameters, as determined from a trajectory simulation, are presented for comparison. Computations of drag coefficient and motor thrust force are summarized in Figures 4 and 5, respectively. The subsonic drag coefficient data were computed for the time intervals from stage separation (t+5 sec) to t+20 sec and from t+35 sec to t+46 sec (second-stage motor ignition). The supersonic drag coefficient data were computed for the time interval from t+49 sec (near second-stage motor burnout) to t+51 sec (second-stage vehicle

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second-stage motor burnout) to t+51 sec (second-stage vehicle impact). The radar track was erratic over the time interval from t+20 sec to t+35 sec which prevented an accurate adjustment of the accelerometer over this interval. Also, the deceleration of the vehicle during this time period is less than 0.1 g. Therefore, an accurate drag force was not computed for this interval. An axial accelerometer with a measurement range of no more than zero to -2g or -5g is recommended for use on future tests for more accurate drag force determination. Such a transducer could be substituted for one of the backup lateral accelerometers.

The subsonic drag coefficient computed from flight test data should reflect the total drag level since it was determined for the coasting period prior to second-stage motor ignition. A linear data fit of these coefficient data produced a level which was approximately 0.93 of that used in the pretest trajectory simulations. This factor was used to adjust the first-stage vehicle forebody drag to allow the computation of the first-stage motor thrust history. The supersonic drag coefficient computed from flight data should also reflect the total drag after the second-stage motor burnout. However, the pressure in the vehicle base region after second-stage burnout may not have reached that of full base drag (the difference between forebody and total drag). The Genie motor has an extended thrust tailoff period (some sources indicate that zero thrust is not reached until 5 sec after ignition). Also, motor outgassing after burnout may alter the base pressure from that expected with full base drag. The time from second-stage motor ignition to vehicle impact was approximately 5 sec. Thrust data for the second-stage Genie motor was determined using the forebody drag with a 0.91 multiplying factor. This factor lowers the pretest forebody drag at M=2 to the agglomeration of flight data at the corresponding M. The first-stage Genie delivered a computed 223.9 lb-sec/lb specific impulse. The corresponding second-stage computation was 239.7 lb-sec/lb. The motor manufacturer's specification value is 233 lb-sec/lb.

A trajectory profile plot featuring measured and pretest simulation data is presented in Figure 6. The pretest simulation profile reflects a number of changes from that presented in the Reference. Changes include field-measured vehicle weights, estimated increased drag because of the launcher shoe profile extensions (required one week prior to launch), and the launch angle change (68.0 deg to 67.0 deg) to maintain a constant predicted ground range to impact. The first-stage booster impact was 370 ft left and 840 ft downrange of nominal (a 0.9 sigma impact). The second-stage vehicle impact was 340 ft left and 620 ft uprange of nominal (a 0.8 sigma impact).

LRR:1555:bnr RSP100.wm

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GENIE-GENIE/RSP100

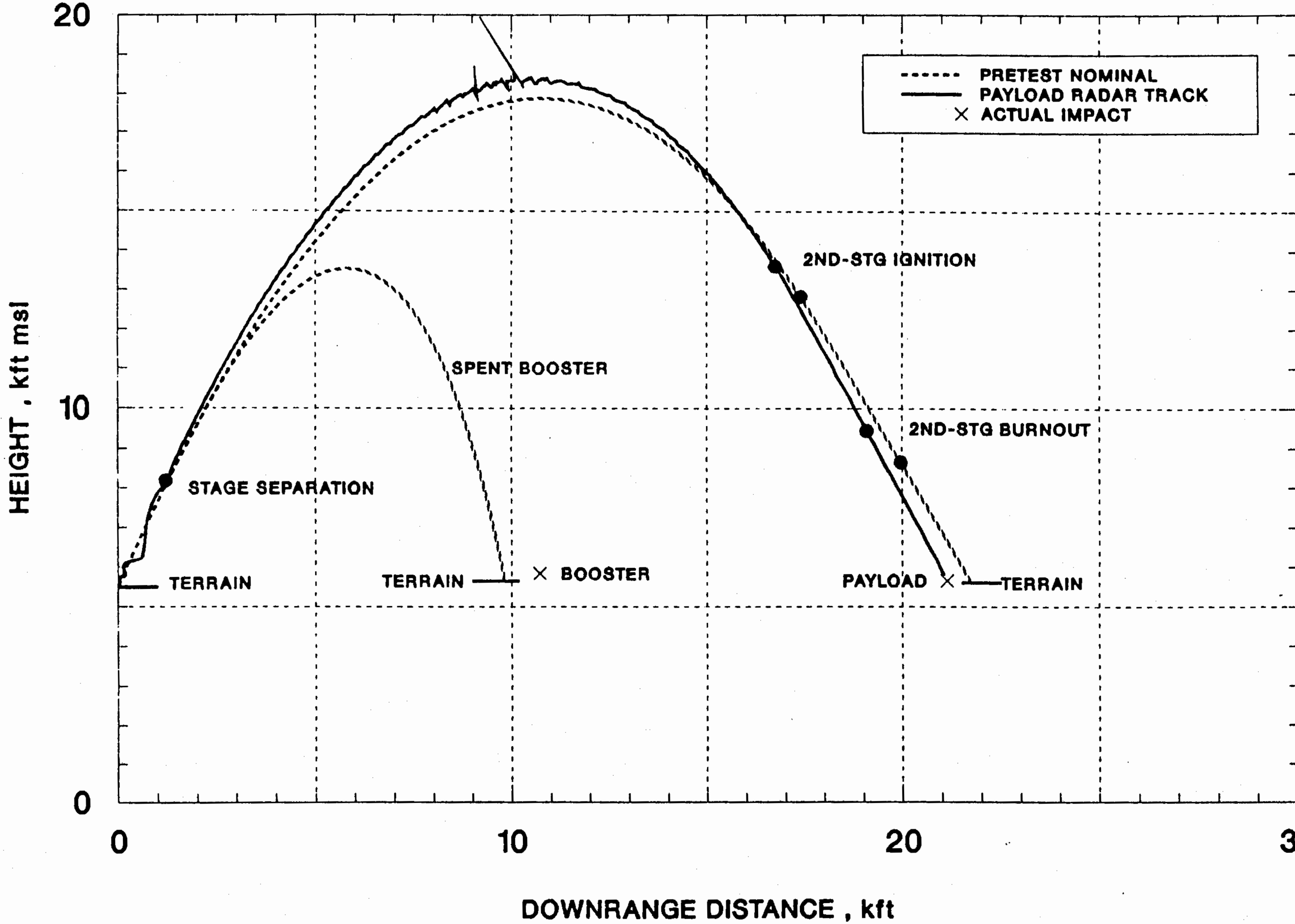

FIGURE 6

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Sandia National Laboratories
Albuquerque, New Mexico 87185

date: April 19, 1989

to: N.A. Lapetina, 8436

from: David L. Keese, 1555

subject: RSP-101 Postflight Analysis

References:

1. "Range Safety Approval Request for RSP-101 at the Tonopah Test Range," memo from W.R. Barton to G.L. West, dtd September 1, 1988.

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Introduction

This memo summarizes the completed postflight dynamics analysis for the RSP-101 sounding rocket test. This test was successfully completed at the Tonopah Test Range on September 28, 1988, in support of the Sandia Livermore and Lawrence Livermore penetrator development program. [redacted]

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The remaining sections of this report provide a description of the booster system and review the general performance of this system with comparisons to preflight predictions. Critical impact conditions derived from onboard telemetry data and radar observations are also presented, and impact accuracy is discussed in light of the launcher corrections used to account for atmospheric winds conditions during the test. A brief discussion of fin cant angle and the subsequent vehicle roll history is also included.

System Description

The complete Genie-Genie/RSP system used in this test is illustrated in Figure 1. The entire system is 214 inches long and weighs 2323 lbs. Each Genie motor contains 320 pounds of propellant and weighs 480 lbs fully loaded. The motors are 66 inches long and have a cylindrical diameter of 15 inches. The payload section is 14.2 inches in diameter (at the base), 51.4 inches long, and weighs 910 pounds. A more complete description of the total system including its mass properties can be found in Reference 1. This system was fired from an Honest John mobile launcher at a remote site in order to obtain impact into the Antelope Tuff target area south of the TTR range boundary.

Trajectory Overview

The nominal trajectory for RSP-101 was intended to replicate the flight profile obtained with RSP-100 in February 1987. The external configurations for both tests were identical and mass properties were also similar. The major difference between the tests was the translation of both launch and impact locations 1000 feet downrange for more desirable impact terrain. Figure 2 illustrates the nominal trajectory profile planned for the RSP-101 flight test. Nominal launcher quadrant elevation (QE) and azimuth for this test were to be 67.0 degrees and 168.0 degrees, respectively. The predicted impact and dispersion estimates for this test (from Reference 1) are shown in Figure 3.

The actual trajectory obtained during the test operation at TTR was remarkably close to that predicted with preflight simulations. All the critical parameters such as event times, apogee altitude, and impact velocity and angle agreed very well with predicted values. The following table highlights the major trajectory events and compares the actual test results with predicted values.

Nominal Time	Actual Time	Source	Event
0.0	0.0	NA	First Stage ignition
3.0	3.1	Accelerometers	First stage burnout
4.0	4.9	Radar video	First stage separation
28.3	28.5	Radar track	Apogee
46.1	46.1	Radar video	Second stage ignition
49.1	48.7	Accelerometers	Second stage burnout
50.8	50.7	Telemetry LOS	Impact

In this table booster burnout was identified by a measured axial acceleration level of less than 0.25 g's.

Radar data from R24 and R36 were used by the Test Data Analysis Division (7522) to produce a composite profile of the actual trajectory (Reference 2). Figures 4-6 compare the predicted and actual time histories of altitude, velocity, and flight path angle (γ). The measured altitude history appears almost identical to the predicted behavior and actual apogee altitude was within 30 feet of the predicted 17,850 nominal value. The radar velocity profile shown in Figure 5 is fairly noisy but does agree closely with the predicted curve. [redacted] is probably not a realistic measurement since velocity would not increase after burnout. [redacted] The following table summarizes the critical impact conditions for this flight test.

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Figure 7 describes the axial acceleration history for the RSP-101 flight. Maximum accelerations predicted during first and second stage burns were 16.6 g and 23.3 g, respectively. The measured acceleration profile was corrected using an approach derived by L.R. Rollstin and F.V. Wyatt (1555). This method adjusts the raw accelerometer data so that it more closely agrees with the the flight profile obtained from radar data. The accelerometer data required a scale factor correction of 0.984 and a bias correction of 1.157 gs. The resulting peaks observed during first and second stage burns were 17.0 gs and 23.8 gs or 2.6% and 2.1% higher than preflight predictions. The integrated acceleration history shown in Figure 8 also presents some interesting information. After four seconds of flight time, the actual integrated acceleration level was approximately 5% higher than the prediction. During the period of time from t=4 to t=10, the predicted decrease in acceleration is twice as high as was observed in flight. These facts suggest that the first stage performance was from 2-5% higher than expected. The vehicle also may not have decelerated as rapidly as predicted due to the nearness of the released first stage and the lack of fully developed base drag on the remaining second stage. Integrated acceleration during second stage burn also shows a 2.4% increase above the predictions. The increased acceleration levels observed during both the first and second stage burns could account for the increased range observed during the test.

Impact Accuracy

The Honest John mobile launcher used to fire the RSP-101 system was located at 37.60017 deg latitude, 116.58467 deg longitude, and an altitude of 5499.5 feet (msl). The target point was 21,936.5 feet downrange along an azimuth of 167.9885 deg at 37.54126 deg latitude and 116.56893 deg longitude. Target area elevation was 5583.5 feet (msl). Both the launch and target locations had been moved approximately 1000 feet downrange from RSP-100 in an attempt to obtain more desirable impact terrain. However, the area surrounding the target contained many hills and ravines and presented a generally irregular surface plane. The relative positions of the target and impact points were shown in Figure 3. This figure also illustrates several patches of hard Dacite Lava near the target point. [redacted]

Based on flight test analysis, it appears as though a portion of the downrange error in impact location was produced by an increase of 2-5% in booster performance. Gusty wind conditions are also considered to be a contributing factor to the downrange error as well as the crossrange error. During launch operations, surface winds were variable at

10-15 knots from the north to northwest. Winds above 8000 feet (msl) were 15-20 knots from the north to northeast. Launch angle corrections of -1.3 degrees in elevation and 2.5 degrees in azimuth were made prior to first stage ignition to compensate for effects of the current atmospheric wind profile on the vehicle trajectory. Nominal launcher quadrant elevation (QE) and azimuth were 67.0 and 168.0 degrees. The final settings reflecting the adjustments for wind effects were 65.7 and 170.5. These corrected settings were strongly dependent on surface wind conditions and any variation in winds at the moment of launch would have direct effects on the final impact of the system.

Vehicle Roll Rate

Prior to the test, some concern was expressed relating to the potential for high structural loadings in the payload case if the roll rate at impact were to exceed 540 deg/sec (1.5 Hz). For this reason, a 20 minute (0.33 deg) cant angle was selected for the second stage fins. First stage cant angle was set to an average of 59 minutes (0.98 deg) to maintain a vehicle roll rate lower than the expected 720 deg/sec (2 Hz) critical frequency of the system at first stage burnout. These cant angles were determined based on actual test results from RSP-100. First and second stage cant angles for RSP-100 were 75.4 minutes and 34.1 minutes. These settings produced roll rates of 691 deg/sec and 807 deg/sec respectively at first stage burnout and impact. Simple ratios based on the RSP-100 results indicated that roll rates for RSP-101 were predicted to be 550 deg/sec at first stage burnout and 473 deg/sec at impact.

The roll rate history for RSP-101 is plotted in Figure 9 along with the computer predictions based on estimated fin roll effectiveness. Roll rate at impact was approximately 505 deg/sec (1.4 Hz) compared to the 473 deg/sec based on RSP-100 ratio results. It is apparent that the computer model for the fin effectiveness overpredicts actual roll behavior during the entire trajectory. This is primarily due to the difficulty in accurately modeling the downwash effects created by the upstream fins on the first stage fins. During the flight, measured roll rate was less than the system pitch frequency, and no angle of attack amplification was seen due to roll-resonance phenomena.

Summary

Postflight analysis of the RSP-101 test data indicates that the actual flight profile obtained during the test was exceptionally close to the predicted trajectory. All major flight events occurred as scheduled and impact time was within 0.2% of the predicted nominal. The important impact parameters of velocity and angle were also within the desired experimental [redacted] within the field of view of the impact camera array. The majority of this miss distance was attributable to the gusty surface wind conditions during the test and to slightly higher than expected booster performance.

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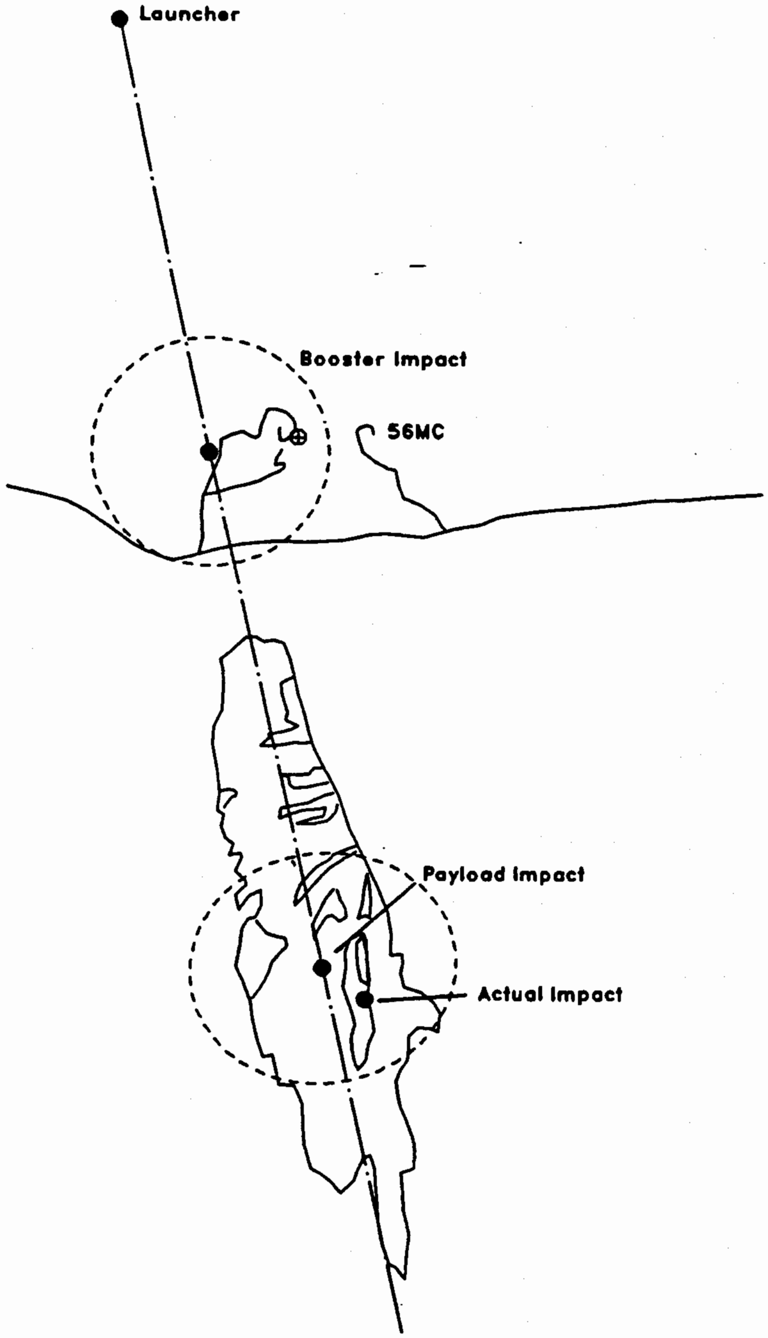

Figure 3. Impact and Dispersion Map

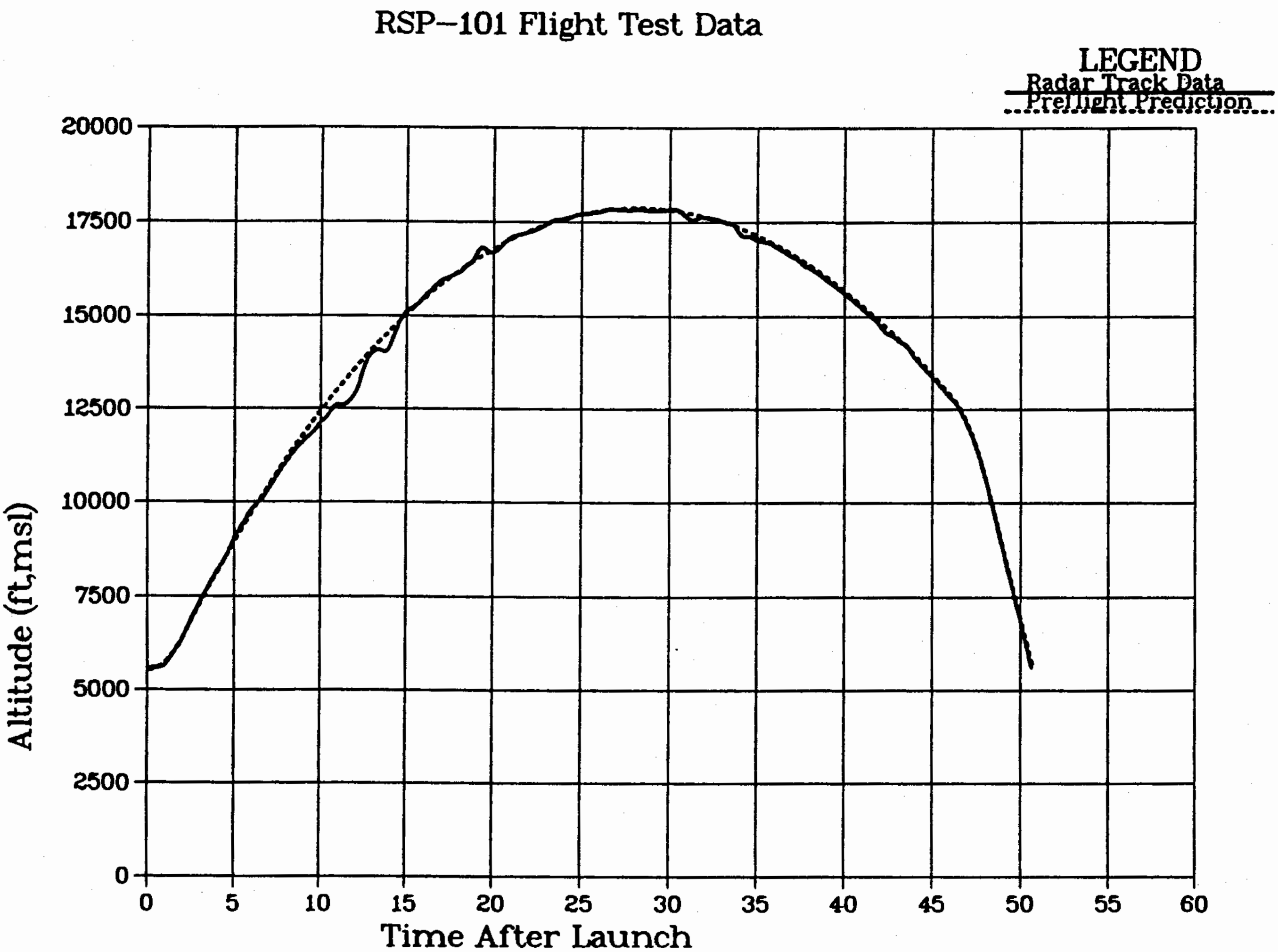

Figure 4. RSP-101 Altitude History

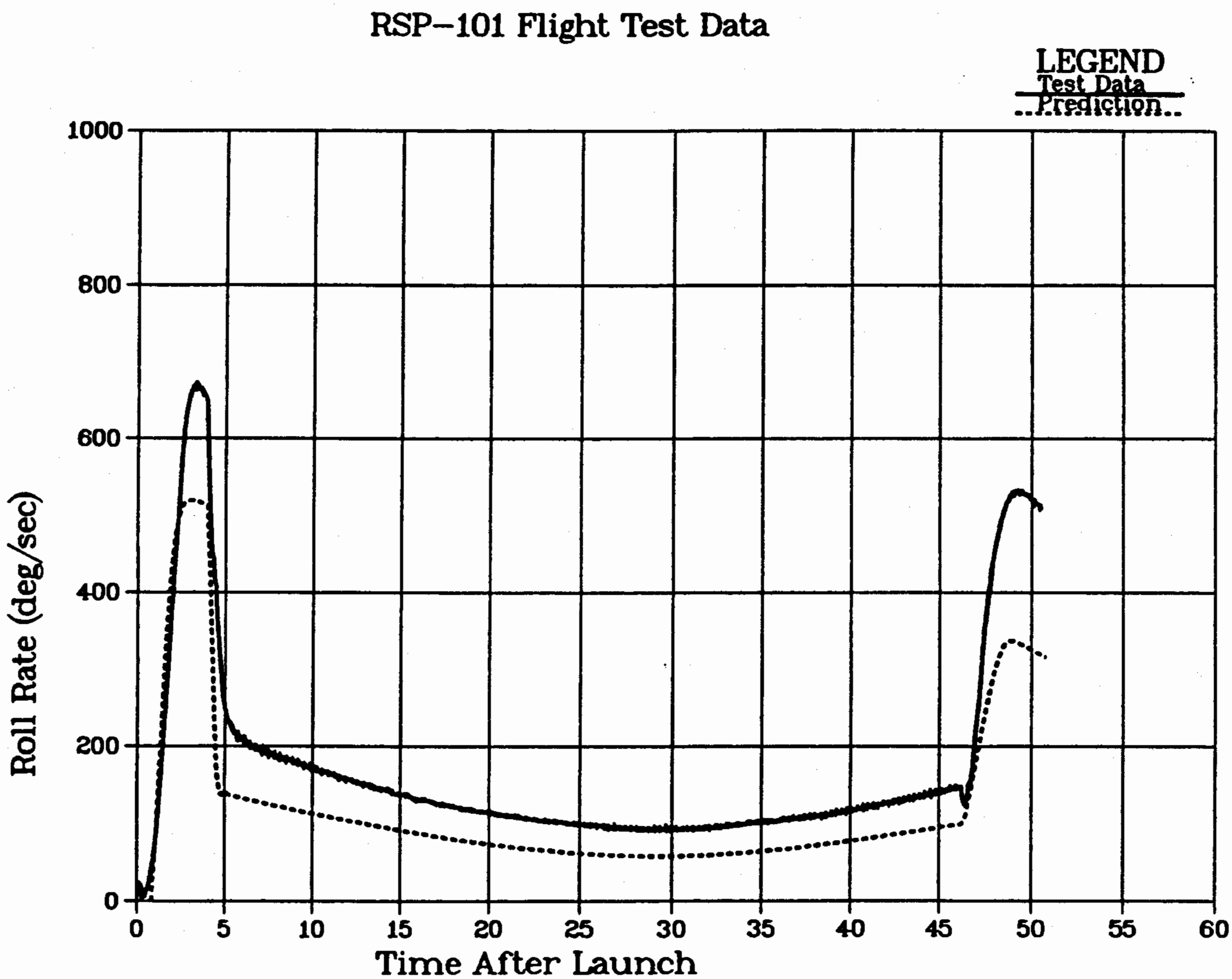

Figure 9. RSP-101 Roll Rate History

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