DEPARTMENT OF THE ARMY
U S ARMY NATICK LABORATORIES
NATICK, MASSACHUSETTS 01760

IN REPLY REFER TO

AMXRE-AAS

SUBJECT: Change to US Army Natick Laboratories Technical Report 72-16

Defense Documentation Center
Cameron Station
Alexandria, VA 22314

Based on new Department of Defense guidance, we have been directed to make a change to each copy of the subject Technical Report 72-16, Final Engineering Report Parachute Retrorocket Airdrop System that was mailed to you approximately 5 January 1972. It is requested that Reference A on Page 192 be deleted with indelible black ink. Return reply is requested to insure compliance.

FOR THE COMMANDER:

for DONALD L. GELLNICHT
Colonel, QMC
Director, Airdrop Engineering Laboratory

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Stencel Aero Engineering Corp.
Asheville, North Carolina

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
N/A

3. REPORT TITLE
Final Engineering Report - Parachute Retrorocket Airdrop System

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report

5. AUTHOR(S) (First name, middle initial, last name)
Joseph L. Michal
Joseph L. Oates
A.L. Martinez

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1970	410	30

8a. CONTRACT OR GRANT NO.
DAAG17-68-C-0019

b. PROJECT NO.
1M12140D195

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
U.S. Army Natick Laboratories
Natick, Massachusetts 01760

13. ABSTRACT

This report presents the results of an in-depth exploratory study of the Parachute Retrorocket Airdrop System to determine its potential for meeting the technical, economic and operational requirements of an airdrop system capable of delivering supplies and equipment weighing from 2000 to 35,000 pounds from cargo aircraft flying at an altitude of 500 feet or less above the terrain.

Actual airdrops were conducted to demonstrate system capability for loads weighing up to 35,000 pounds from low altitudes. Prototype hardware was then designed for a future program.

It is concluded that PRADS can be used economically and reliably to drop loads up to at least 35,000 pounds from an absolute altitude of somewhat less than 500 feet or higher onto unprepared drop zones. In addition, the load range can be extended to 50,000 pound loads at a reasonable cost. PRADS requires less time to rig and pack parachutes than the present system. Also, drops can be made into small drop zones very accurately or from high altitudes with reasonable accuracy. Special loads can be dropped with very low impact velocity. Engineering development of PRADS appears to be a logical step to advance the state-of-the-art in airdropping.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tests	8		8			
Air Drop operations	8		4			
PRADS	8		10			
Cargo	9		9			
Parachutes	10		10			
Rockets	10		10			
Low velocity drop	4		8			

Unclassified
Security Classification

Approved for public release; distribution unlimited.

AD__________

FINAL ENGINEERING REPORT
PARACHUTE RETROROCKET AIRDROP SYSTEM

by

J. L. Michal
J. L. Oates
A. L. Martinez

Stencel Aero Engineering Corporation
Asheville, North Carolina

Contract No. DAAG17-68-C-0019

Project Reference: 1M121401D195

December 1970

Airdrop Engineering Laboratory
U.S. ARMY NATICK LABORATORIES
Natick, Massachusetts

FOREWORD

This work was performed during the period September 1967 through October 1969 under US Army Natick Contract No. DAAG17-68-C-0019 for the Department of the Army Project No. 1M121401D195 entitled "Low Altitude Airdrop System for Supplies and Equipment".

The Parachute Retrorocket Airdrop System was selected as one of the two most promising concepts out of nine that were studied under a separate preliminary exploratory development study.

This in depth exploratory investigation of the Parachute Retrorocket Airdrop System was conducted to determine its potential for meeting the technical, economic and operational requirements of an airdrop system capable of delivering supplies and equipment weighing from 2000 to 35,000 pounds from cargo aircraft flying at an altitude of 500 feet or less above the terrain.

The work was performed under the direction of Mr. George Chakoian, the Project Engineer for the U.S. Army Natick Laboratories.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

APPENDIX D

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

ABSTRACT

The Parachute Retrorocket Airdrop System (PRADS) combines relatively small parachutes to lower an airdrop load and rockets to slow the descent just before impact for airdropping loads from 500 feet absolute altitude. The system was studied and demonstrated to be feasible under previous contracts with the U. S. Army Natick Laboratories. Testing was then accomplished under an exploratory development program to demonstrate capability for the airdropping of loads up to 10,000 pounds gross weight.

This report presents the results of testing and analysis under an in-depth exploratory development contract. Breadboard hardware was designed or redesigned and manufactured. Testing was then performed which demonstrated system capability for loads of up to 35,000 pounds. Prototype hardware was then designed which is expected to perform economically and reliably. In addition, problems of ground sensing probe swing, rocket exhaust plume convergency and somewhat high sling forces are expected to be eliminated.

It is concluded that PRADS can be used economically and reliably to drop loads up to at least 35,000 pounds from an absolute altitude of somewhat less than 500 feet onto unprepared drop zones. In addition, the load range can be extended to 50,000 pound loads at a reasonable cost. PRADS requires less time to rig and pack parachutes than the present system. Also, drops can be made into small drop zones very accurately or from high altitudes with reasonable accuracy. Special loads can be dropped with very low impact velocity. Engineering development of PRADS appears to be a logical step to advance the state-of-the-art in airdropping.

1.0 INTRODUCTION

1.1 General

The Parachute Retrorocket Airdrop System (acronym PRADS) was developed to its present state of prototype hardware design by Stencel Aero Engineering Corporation, Asheville, North Carolina, under contract DAAG17-68-C-0019 with the Airdrop Engineering Laboratory of the U. S. Army Natick Laboratories, Natick, Massachusetts. Work effort under this contract was performed during the period September 1967 through October 1969.

System operation consists basically of load extraction by standard extraction parachute(s) as in the presently used all-parachute system, standard bag deployment of small main canopies as in the present system, load descent between 55 and 70 feet per second, and retrorocket firing just prior to ground impact. The normal vertical impact velocity is 18 to 28 feet per second.

The intent of this final engineering report is to present the results of contract effort particularly in the areas of testing and analysis.

1.2 Requirements

It is self evident that modern warfare demands that troops, equipment and supplies be airdropped behind enemy lines or in enemy held territory with maximum safety to all personnel. In order to be effective, the delivery operation must contain the element of surprise. The delivery system must be highly reliable under a wide variety of atmospheric conditions, combat conditions and loads.

Further the requirements for maximum surprise and maximum safety (minimum vunerability) can best be met by an aircraft flying and delivering from a) low altitude, i.e. 500 feet or below absolute altitude above the terrain or b) high altitude.

While the present airdrop system is probably satisfactory in many respects, it is lacking in its ability to deliver loads from below 500 feet to avoid radar detection and to deliver very large loads (above 35,000 pounds). In fact the standard drop elevation is 1200 to 1500 feet at the present time.

It is, therefore, necessary to develop a delivery system which will meet the altitude requirement and at the same time be compatible with the aircraft and loads. Cost and complexity must be reasonable. Furthermore, the new system should be compatible with the present standard drop system as far as possible.

1.3 Capabilities

PRADS appears to meet these requirements with the following outstanding characteristics:

1. Low altitude capability (500 feet) over the full range of load weights from 2000 pounds to 35,000 pounds with a wide range of environmental conditions (lower altitudes for loads under 35,000 pounds).

2. Heavy loads up to 50,000 pounds with somewhat larger parachutes (and potentially above 50,000 pounds with additional rocket thrust).

3. Very good drop accuracy from low altitudes and acceptable accuracy from high altitude (above 3000 feet) because of the relatively high descent rate.

4. Flexibility for potential fragile loads or loads too high to fit into aircraft with crush : cardboard requiring impact below 10 feet per second.

1.4 Background

A study was proposed to determine basic hardware requirements and system performance. This study resulted in the requirement of a rather complex system which would deliver loads from about 200 feet minimum.

Preliminary design and testing was then performed to verify study results. These tests proved that the system was feasible. In addition, certain system simplifications were found possible which reduced the overall system complexity appreciably.

Exploratory development was then conducted in the 4000 to 10,000 pound load range to optimize this configuration.

The PRADS program was proposed to extend the weight of the drop loads tested to 35,000 pounds and to further optimize the system through studies.

1.5 Scope

The purpose of this contract was to conduct an indepth exploratory development of PRADS. One specific objective is to extend the demonstrated load weight dropable by the previous GROUND PROXIMITY AIRDROP SYSTEM from 10,000 pounds to a full 35,000 pounds from 500 feet absolute altitude. A second objective is to arrive at a prototype system design as a result of testing, study and analysis.

1.6 System Operation and Description

The following is a step by step description of the functioning of the proposed PRADS prototype design. It should be noted that the system as tested under this contract was similar except for the ground sensing device and size of rocket motors. Furthermore, the system as referred to here is to be used only from approximately 8000 pounds gross weight and up. Small loads can be dropped by parachute. Figure 1.1 illustrates the sequence of operation. Figure 1.2 shows the PRADS configuration as proposed.

1.6.1 Extraction Parachute Release

At the proper time the pilot will release the extraction parachute(s) so it will swing down and out on its pendulum. Once in the airstream it will be carried back. This action is identical with the existing system.

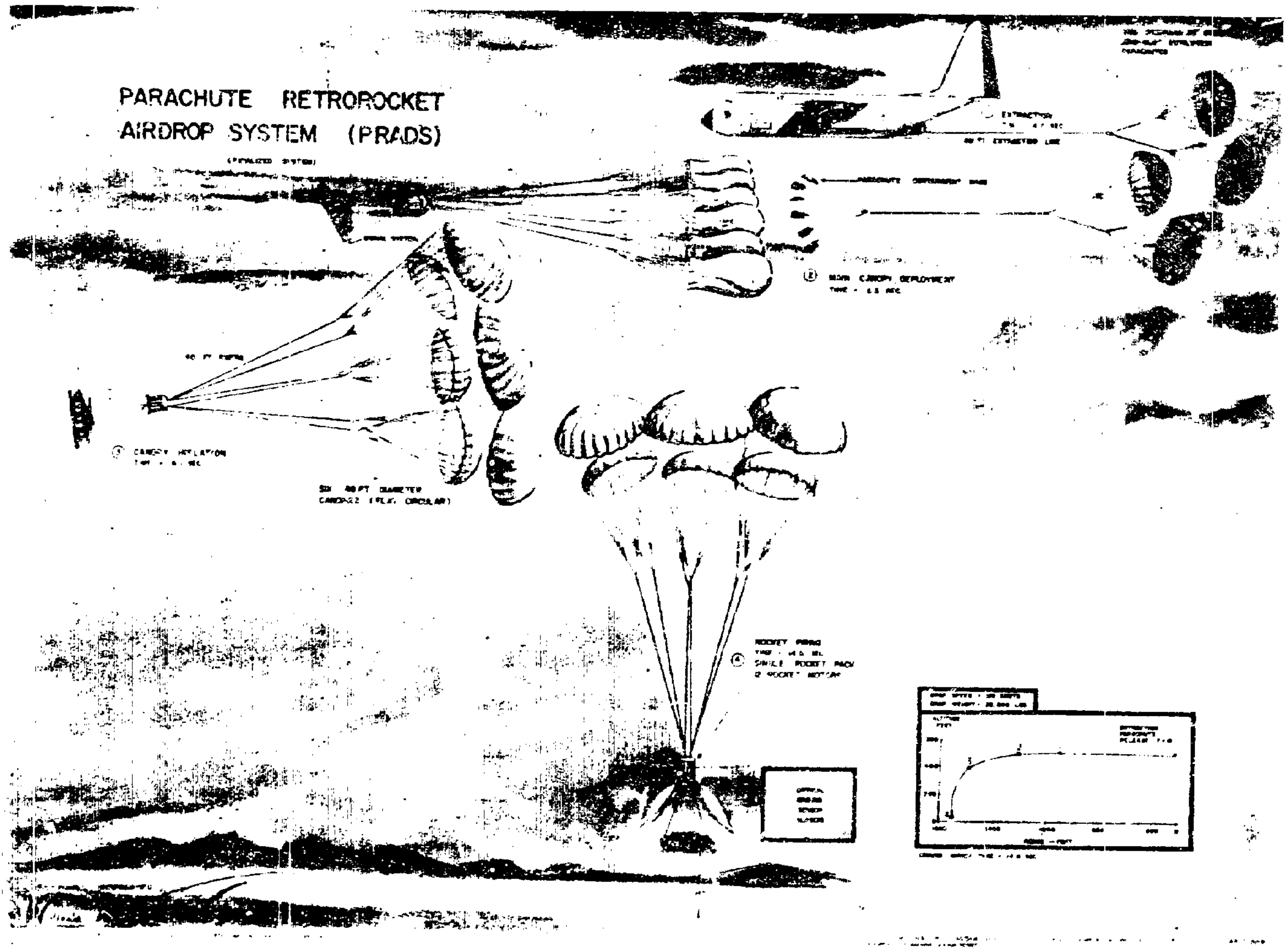


Figure 1.1

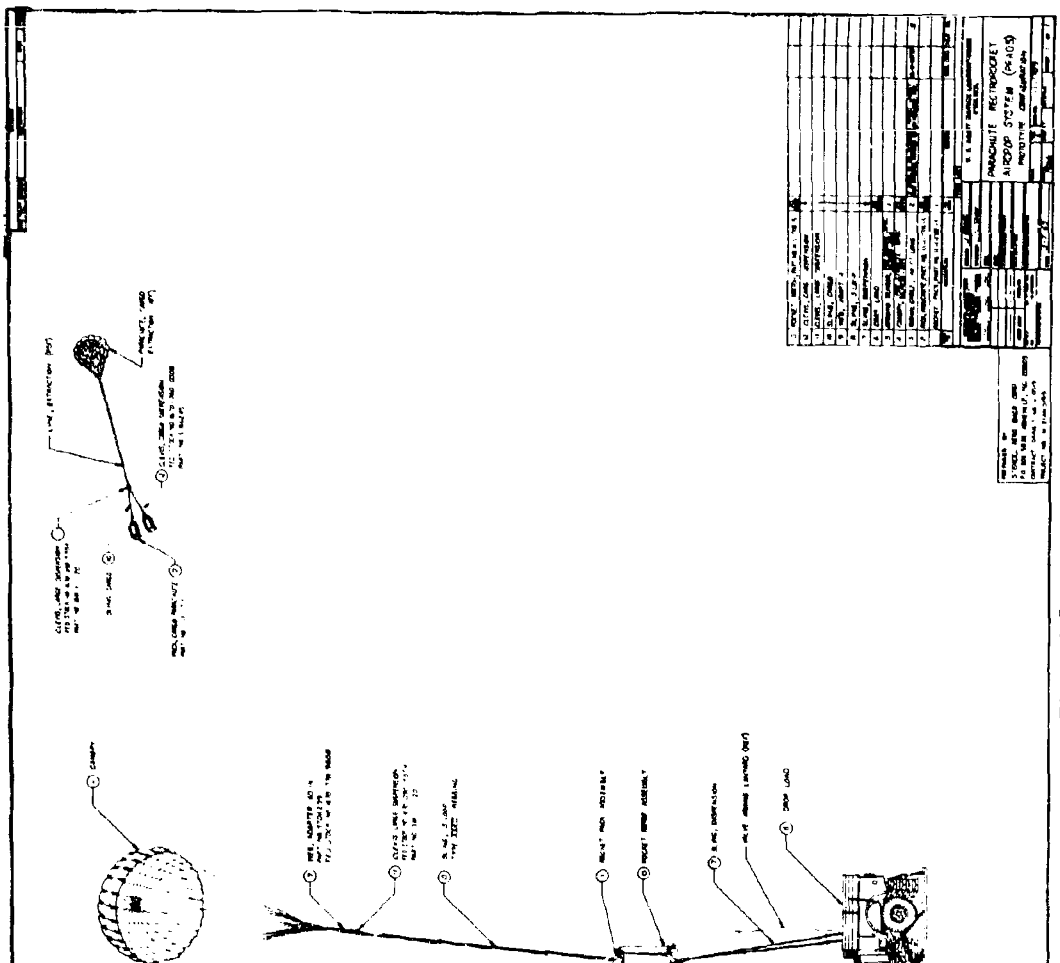


Figure 1.2

1.6.2 Extraction Parachute Deployment

The extraction parachute (s) in its bag goes back and deploys the extraction line. When the extraction line becomes taut the bag strips off the extraction parachute. The extraction parachute then opens. All steps in this phase are the same as the existing system.

1.6.3 Load Release

When the extraction parachute opens, the force rapidly builds up to 1 to 1 1/2 G. The load is released by either 1/2 G or 1 G restraint or by a release actuated by a cable from the extraction line as in the existing system.

1.6.4 Load Extraction

The load is extracted by the extraction parachute as in the existing system.

1.6.5 Extraction Force Transfer

The standard extraction force transfer device is actuated as in the existing system to transfer the extraction force to the main canopy bags as the load leaves the aircraft.

1.6.6 Main Canopy Deployment

The main canopies are deployed from bags extracted from the load by the extraction parachute(s) as in the existing system except the main canopies are smaller. The main canopies will be slotted circular canopies 48 feet in diameter. Slotted canopies are proposed so that opening shock will be reduced. The canopies are used in clusters of from 1 to 6. Since the canopies are smaller than those in the present system, the risers and suspension lines are shorter, and the load is not left unsuspended as long as in the conventional system which reduces the possibility of overturning. The extraction parachute and bags go free of the load after deployment.

1.6.7 Canopies Inflate

After the main canopies are deployed from their containment bags, the canopies open to their full diameter without reefing.

1.6.8 Rocket Pack Extraction

The rocket pack is extracted from the load as the main canopies are opening.

1.6.9 Gas Valve Armed

The gas valve is armed by a lanyard from the rear of the load just before the suspension slings become taut. The gas valve cannot be shuttled and the rockets fired until the safety is actuated.

1.6.10 Load Rotation

The load rotates nose up as the front suspension slings take over the suspension of the load and the canopies inflate.

1.6.11 Ground Sensor Armed

A lanyard from the rocket pack activates the laser ground sensing circuitry with a four second time delay just before the rear suspension slings become taut.

1.6.12 Load Descent

When the main canopies are fully open, the load descends at a medium velocity of 55 to 70 feet per second just after it goes over the "knee" of the trajectory curve.

1.6.13 Ground Sensor Actuates Valve

When the load reaches approximately 23 feet above the ground, the crossed beam from the laser comes in view of the viewing lens and the solenoid valve is actuated.

1.6.14 Rocket Fire

When the gas valve shuttles, high pressure gas is ported to the rocket motors. Dual primers in the rocket motors are fired by gas operated pistons. The rocket motor thrust axis is at 35 degrees with the vertical. The vertical component is approximately 12,900 pounds.

One rocket motor is used for approximately each 3,000 pounds of load. The load is decelerated with approximately 4 G total or 3 G net over a nominal 1/2 second burning time. Figure 1.3 is an actual photograph of the rockets firing during the early part of deceleration of the 35,000 pound drop load.

1.6.15 Rocket Performance

Each rocket motor produces nominally 7250 pound-seconds total impulse or 5940 pound-seconds vertical for acceptable performance in load vertical velocity at impact.

1.6.16 Rocket Pack Performance

The rocket pack must be intact and its thrust must be aligned within approximately 10 degrees of the load cg for stable performance. Its thrust axis must be within approximately 10 degrees of the vertical for acceptable performance in load horizontal velocity at impact.

1.6.17 Load Impact

The rockets nominally burn out above the ground, and the load has a short free fall. Crushable cardboard is used as in the existing system to cushion impact.

It should be noted that during this in-depth exploratory development program that the ground sensor tested was made up of two probes, brakes and detonating fuse trains. Parachutes were 24, 36 or 46 feet in diameter. The preceeding, then, is proposed as a result of analysis.

ROCKETS FIRING (35,000 POUND LOAD)
Figure 1. 3

2.0 PROGRAM EFFORT (In-Depth Exploratory Development)

2.1 General

The program objectives were to develop a system to deliver loads:

a. At aircraft altitude below 500 feet above the terrain.

b. At aircraft speeds from 110 to 150 knots. Compatibility with lower aircraft speeds down to 40 knots should be investigated for possible application to cargo helicopters and VTOL/STOL aircraft.

c. With horizontal impact velocities not exceeding those of the present system in ground winds from zero to at least 15 knots.

d. In operations employing mass formations of aircraft airdropping single and multiple cargo units. A mass formation is here defined as thirty (30) aircraft.

e. With the fewest possible restrictions on drop zone characteristics such as size, unobstructed area and flatness/texture of terrain.

f. With a nominal vertical cargo impact velocity of 23 feet per second and a maximum of 28.5 feet per second at any terrain altitude between zero and 5,000 feet and simultaneously at any air temperature between -65°F and 100°F.

g. Without modification to the cargo being delivered other than minor modifications which can be accomplished without special equipment or tools.

h With a reliability of .995 and an accuracy CEP of 100 meters from the selected impact point at equal conditions.

i. For unit cargo gross weights from 2,000 to 35,000 pounds on airdrop platforms using currently standard and developmental aircraft unloading kits.

j. With minimum requirements for special training of using troops.

k. Without modification to airdrop aircraft other than those that can be accomplished as a minor retrofit.

l. Without reduction of the present allowable cargo size envelope for each type of aircraft.

m. Without reduction of present aircraft utilization for airdrop.

n. Without complicating the rigging, loading and derigging of the airdrop cargo and the evacuation from the drop zone of the airdrop system components.

o. Without interfering with the concept of paratroopers jumping after the cargo from the same aircraft.

p. Under adverse weather conditions as outlined in AR705-15 incorporated herein by reference and made a part hereof including extreme cold and hot weather operating conditions specified except that the requirement for $-80^{\circ}F$ is changed to $-65^{\circ}F$.

The basic program objectives were met including extending the drop weight to 35,000 pounds from 500 feet altitude. It is pointed out, however, that the 35,000 pound load was dropped successfully with reservations. A discussion of the solution of problems is found under engineering analysis of tests.

Simplification and refinement of hardware was also accomplished although relatively little redesign was done except in the prototype design.

Finally, considerable study effort was applied to optimize the system and define its limitations.

2.2 System Hardware

2.2.1 Design

Basically the system hardware was functional but not reliable at the onset of this program. The following specific improvements were made:

A. The probe reelout brake was simplified from both a manufacturing standpoint and an assembly and maintenance standpoint over that used in the previous program. This hardware was used for testing only.

B. Stronger mild detonating fuse (MDF) with end primers crimped in place was purchased for testing only.

C. Slight changes were required in the small rocket pack for additional strength. A protective dome was added to the large rocket pack which remained a very heavy basic design. The rocket packs were designed for the existing rocket motors.

D The intermediate parachute, 36 feet in diameter was strengthened and additional units were purchased. Similarly, 46 foot parachutes were purchased for larger loads and used for testing.

E. The MDF and confined detonating fuse (CDF) clamps were modified to give more efficient clamping and simpler assembly and used for testing only.

2.2.2 Fabrication

Three sets of hardware were manufactured for testing which included ground sensing signal systems, small rocket packs and large rocket packs. Each set of signal systems included two probes, two probe reelout brakes and two probe releases and housings.

Parachute containment bags were fabricated for 24 foot, 36 foot and 46 foot parachutes.

All replacement hardware and expendable hardware was manufactured to support testing both at Stencel (Asheville) and 6511th Test Group (El Centro).

2.3 Testing

2.3.1 Model and Bench Testing

Model testing of the rocket pack configuration was accomplished to determine the plume characteristics desired in the proposed prototype hardware configuration. Appendix A presents the scale model testing.

Bench testing of the ground sensor used in tests was carried out to a) determine the strength of the MDF, b) adjust brake reelout time, c) prove the new MDF insusceptibility to static electricity, d) vibration test the signal system for testing at El Centro, e) cold temperature test the MDF and CDF, and f) determine the pressure build-up time in the rocket packs. This bench testing was done primarily for hardware used in testing since the proposed prototype ground sensor will not use MDF. For this reason details of this bench testing will not be included in this report.

2.3.2 Static Testing

Four static tests of tethered rocket packs were conducted at Stencel to determine stability and structural integrity of the hardware under simulated firing conditions. Conditions and procedure for these tests are summarized in Appendix B and analyzed in Section 3.0.

2.3.3 Drop Testing - Stencel

Eight drop tests with 4600 pound loads were performed at Stencel test facilities to determine the optimum all parachute configuration, to test modifications particularly in the MDF and to check system safety previous to testing at El Centro. Test procedures and conditions are summarized in Appendix C with analysis in Section 3.0.

2.3.4 Drop Testing - El Centro

A series of drop tests were conducted at the Naval Air Facility, El Centro, California, by the 6511th Test Group (Parachute).

Test support was provided by Stencel Aero Engineering Corporation. Recovery parachutes, ground sensor signal systems (using MDF), and rocket packs were provided by Stencel. Extraction systems, drop loads, slings, instrumentation, etc. were government furnished. Conditions and procedure for this series of tests are summarized in Appendix D. Analysis of the tests is found in Section 3. 0.

2. 4 Studies and Analysis

2. 4. 1 Performance of the proposed prototype design is analyzed in Section 4. 0. In addition the results of sensitivity, reliability and safety analysis and a discussion of problem areas are found in Section 4. 0. An IBM .130 computer was used to study performance of the prototype system.

2. 4. 2 Human factors and logistics studies are presented in Sections 5. 0 and 6. 0. Studies were made of cost, maintainability and manpower requirements. Prices were obtained for the proposed system to fulfill the Technical Integration and Evaluation contractor (TIE) requirements.

2. 5 Purchases

2. 5. 1 Sixty new rocket motors and 240 reloaded rockets were purchased from Northrop Carolina, Inc. for use in static rocket tests and system drop tests. These motors were the same as those purchased on the previous contract No. DA19-129-AMC-502(N). See Section 4. 0 for rocket performance. The proposed rocket motor will have about three times the thrust of those used in testing.

2. 5. 2 Parachutes, MDF and CDF were purchased for testing. In addition miscellaneous raw materials and parts were purchased under this contract.

2. 6 Delivery Items

2. 6. 1 In addition to this report, information was submitted to the TIE contractor.

2.6.2 Four progress reports were submitted to Natick Laboratories. "Parachute Retrorocket Airdrop System 120 Day Status Report", "240 Day Status Report" and "360 Day Status Report", contain details of progress throughout the program except for the majority of tests at El Centro and final study results contained in this report.

2.6.3 A documentary film and a continuous coverage film were delivered to Natick Laboratories and the TIE contractor. In addition, prints, charts and test reports were delivered.

3.0 ENGINEERING ANALYSIS OF TESTS AND CONCLUSIONS

An attempt will be made here to give a comprehensive analysis of tests for engineering evaluation. This analysis is a summary discussion of test performance and problem areas. A test by test analysis is found in Appendix E in which, at the risk of being redundant, one may look at performance and problems in order to better understand what happened in each test and how the areas interrelate. Sample calculations and methods are presented in detail for tests 195-1 and 202-19 (Appendix E paragraphs 2.0 and 3.0). In addition, test reports summarizing conditions and results are found in Appendices B, C and D.

3.1 Weight Ranges

To cover the complete weight range from 2000 pounds to 35,000 pounds, two airdrop configurations were tested. Parachutes only, 46 feet in diameter, were used to recover weights of 5000 pounds or less. Loads up to 35,000 pounds were dropped with parachutes and retrorockets. These indicate that PRADS can meet the airdrop requirements for the complete range of loads from 500 feet absolute altitude using the proposed prototype hardware.

3.2 Parachute Opening

In general, telemetry data was complete on testing at El Centro. However, data was lost for test 202-1. The three sizes of parachutes used in testing were 24, 36 and 46 foot diamete Since the 46 foot parachutes are close to the diameter of the 48 foot proposed prototype, the performance will be looked at in more detail for the larger parachute than for the smaller sizes.

3.2.1 Twenty-Four and Thirty-Six Foot Parachutes

Five tests were made with four 24 foot diameter pa achutes (see Appendix C) and six tests were made with six 24 foot parachutes (see tests 202-4, -5, -6, -10, -11 and -12, Appendix D). Three tests were made with five 36 foot parachutes (tests 202-7, -8 and -14), and two tests were made with seven 36 foot parachutes (tests 202-9 and -13). Table 3.1 shows a summary of times from extraction force transfer to average parachute opening including an average of the times for each cluster size and parachute size.

CLUSTER AVERAGE PARACHUTE DEPLOYMENT AND OPENING TIMES

Parachute Size	No. Parachutes in Cluster	No. Tests	Avg. Deployment & Opening Time-Sec.		
			Max.	Min.	Avg.
24	4	5	2.54	2.0	2.27
24	6	6	3.71	2.71	3.19
36	5	3	3.67	3.44	3.56
36	7	2	4.23	3.77	4.00

TABLE 3.1

It is concluded that in general the data shows both the average cluster opening times and the average opening time spread increase with the number of parachutes in the cluster, as is expected. The average cluster opening time, of course, increases for the larger parachutes. Peak sling forces during parachute opening resulted from a combination of 1)rearward momentum of the rocket pack, 2) parachute force and 3)load rotational (pitch) momentum. In general, slower canopy opening times resulted in lower peak sling forces. Comparing tests 202-6 and 202-10 in the special live test analysis in Appendix E, rapid inflation caused peak forces to exceed somewhat 1.5 G, based upon gross load weight, in test 202-6, while slightly slower inflation reduced the peak forces to well below 1.5 G in test 202-10. Peak forces in the former were caused by light parachute forces and load rotational momentum on the front slings, while in the later peak forces were caused by rocket pack momentum and a lower level parachute force on the rear slings.

A similar, if less clear cut, comparison can be made between tests 195-1 and 195-2 (Appendices C and E). While the average parachute opening time was only .2 second shorter in test 195-1 than in test 195-2, the total of the front sling forces was 2.39 G in the former and 2.24 G in the latter. There was a much larger difference in the maximum forces. Also the total peak forces in the rear slings (loaded last in both cases) showed a larger difference (2.34 G versus 1.99 G) than in the slings to be loaded first. It is concluded, then, that the slings to be loaded last (nearest to full parachute opening) tend to feel a large increase in peak forces with a decrease in parachute opening times. Parachute opening times and/or parachute opening shock must be controlled if reefing is not required for smaller parachutes.

No significant damage was inflicted upon any 24 foot or 36 foot parachute although all tests made with these sizes were unreefed except tests 202-7 and 202-8.

3.2.2 Forty-Six Foot Parachutes

Limited testing was done with 46 foot parachutes with the parachutes only system. This system used parachutes as in the conventional system without rockets. See Tests 193-1, -2 and -3 in Appendix C. Parachute opening times are somewhat incomparable because of the reefing in all parachute only systems test except 193-1 and 193-2. Reefing was required with flat circular parachutes to limit sling forces in parachute only tests. In addition, there were center lines in test 193-1 only. On the other hand few parachutes came out to the reefed diameter before line cutters operated, hence probably only a small input was realized by reefing, and that mainly from line drag through the reefing rings.

Deployment times as seen in Table 3.2 increased with riser length and were very consistant except for test 202-1 where deployment time was very short for no apparent reason. Parachute opening times varied in a rational fashion except again for test 202-1. Minimum opening time was shortest for the first parachute in test 193-1, in which there was a center line and no reefing, and longest for the first parachute in test 202-3 where there was reefing and two more parachutes in the cluster. Average opening time was slightly shorter for test 193-2 where there were no center lines, over test 193-1; however, there was more spread in opening times in test 193-1. It is interesting to note that the average opening time in test 193-3, where reefing was employed, was again very slightly less than in test 193-2 and the spread in opening times was even less. The average opening time for the canopies in test 202-3 was significantly longer than that in test 202-2 in spite of the fact that one parachute lagged considerably in test 202-2.

PARACHUTE DEPLOYMENT AND OPENING TIMES
46 FOOT PARACHUTES
LOW MASS LOADING

Test No.	No. Chutes	Total Riser Length-Feet	Deployment Time-Sec.	Opening Time-Sec.		
				Min.	Max.	Avg.
193-1	4	28	1.301	1.47	4.44	3.16
193-2	4	28	1.325	1.83	3.69	2.99
193-3	4	28	1.459	2.33	3.69	2.85
202-1	4	45	1.212	3.015	6.015	4.265
202-2	4	45	1.910	1.962	6.767	3.454
202-3	6	65	2.380	3.10	5.10	4.230

TABLE 3.2

In general, the opening time spread and the average opening times are high for these tests because of the low terminal velocity and low mass loading. Although data was lost on test 202-1, it is evident from results of tests 193-3, 202-2 and 202-3 that the parachute reefing limits sling forces to acceptable levels using 46 foot flat circular parachutes.

Heavy loads, i. e. 24,000 pounds and 35,000 pounds loads, were dropped with 46 foot parachutes. Parachutes with 35,000 pounds were reefed; therefore, opening times are somewhat influenced by the reefing in the largest loads (tests 202-18, -20, -23 and -26). In addition, 46 foot parachutes were used in the later tests in the 14,000 pound and 18,000 pound ranges. The objective was to simulate the prototype system in which only 48 foot parachutes are to be used. Parachute opening data are presented in Table 3. 3

It is immediately evident that the opening times for the parachutes were much longer at the low mass loading than at high mass loading. Comparing tests 202-21 and -25 with tests 193-1, -2, -3, 202-1 and-2, opening times for the low mass loading were 1. 3 to 1. 9 times as long, while the high mass loading was 3. 7 to 5. 2 times as much and the terminal velocity 1. 9 to 3 times as much as with the low mass loading. Opening times were very consistent for the high mass loading and dispersed for the low mass loading, indicating that opening is more consistent and reliable for the PRADS system, even for the same size parachute than for the presently inservice system. It is conceded that there is more time for opening for a parachute only drop because of the low descent velocity.

Comparing heavy drops in Table 3. 3 and Figure 4. 3 Section 4. 1, it can be seen that average parachute opening times go up reasonably predictably with more parachutes in the cluster, and from Table 3. 3 it can be seen that scatter in opening times tend to go up with more parachutes in the cluster. There is a limit to the number of parachutes in a cluster for a low altitude drop because performance literally is not increased beyond some number. See Section 4. 1 for additional discussion.

TABLE 3.3

OPENING TIMES - 46 FOOT PARACHUTES
HIGH MASS LOADING

Test No.	Gross Load Weight-Lbs	No. Chutes	Minimum Opening Time-Sec.	Maximum Opening Time-Sec.	Average Opening Time-Sec.
202-16	5,500	1	1.189	1.189	1.189
202-19	14,000	3	1.999	2.108	2.041
202-24	14,000	3	2.018	2.621	2.424
202-21	18,000	4	1.734	2.736	2.235
202-25	18,000	4	1.715	2.687	2.239
202-22	24,000	5	1.685	3.747	2.251
202-17	24,000	6	1.832	2.730	2.310
202-18	35,000	7	1.638	4.238	2.765
202-20	35,000	7	2.253	3.667	2.909
202-23	35,000	7	1.664	3.264	2.451
202-26	35,000	8	1.681	6.081	3.981

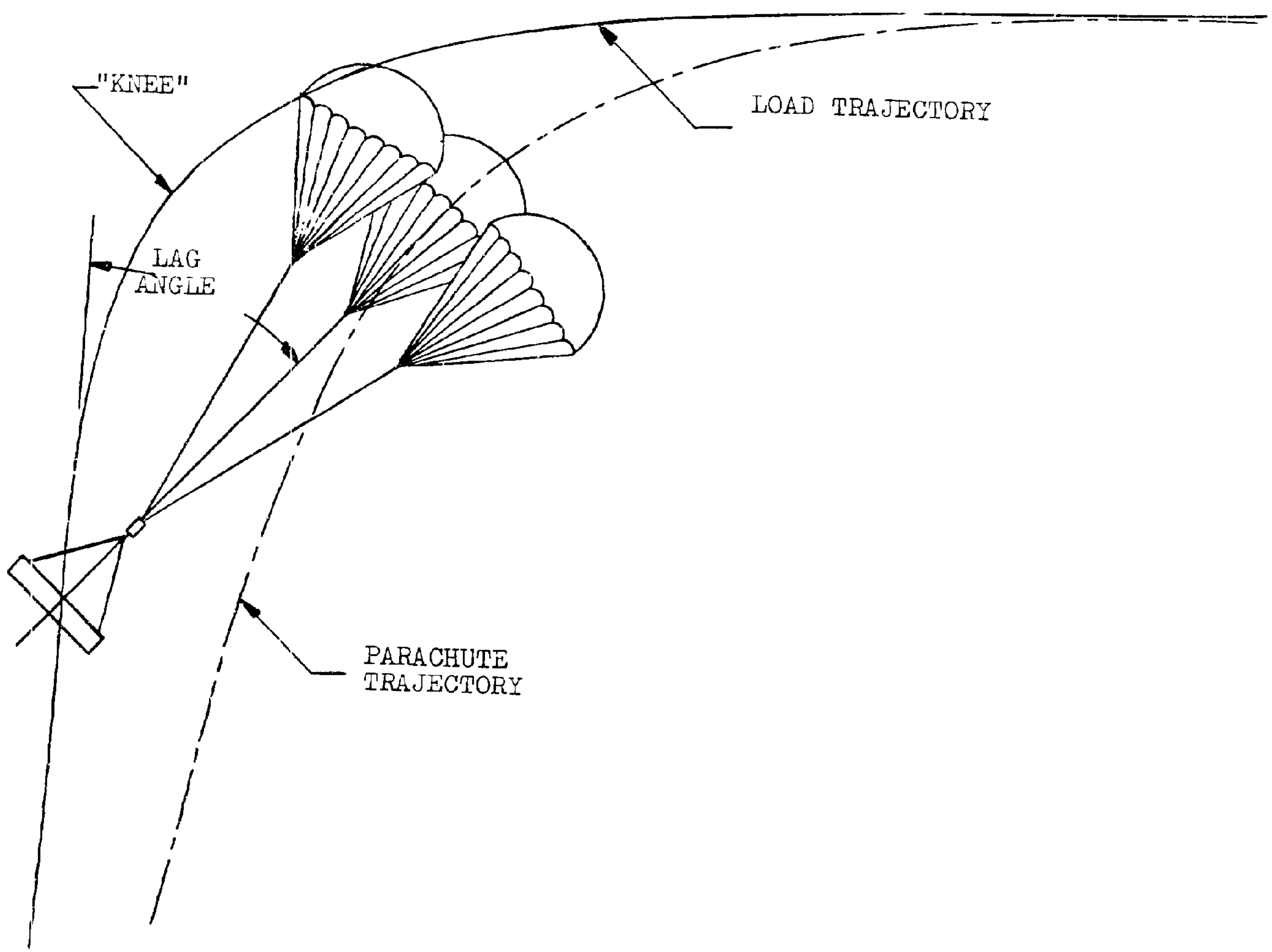
Peak suspension sling forces for all loads in the upper load range, i.e. 18,000 pounds through 35,000 pounds, were acceptable during parachute opening based upon 1.5 G of gross weight per sling. Reefing was not employed in the large load range (over 5000 pound loads) except for the 35,000 pound loads, and that was required primarily because of riser strength. In test 202-19, forces were excessive where three 46 foot parachutes were used. Average cluster opening time (2.041 seconds) was less than any of the heavier tests. In addition forces in test 202-16 were high where average opening time was only 1.189 seconds. (This weight will be dropped by parachutes only in the prototype system; and, therefore, is of only academic interest here.)

It seems evident, then, that larger loads present no problems as far as maximum sling forces go during parachute opening. However, parachutes and risers do feel high, in fact excessive, opening shock forces. Therefore, a parachute should be used which will reduce the opening shocks below those of the flat circular canopies now used to avoid excessively heavy parachutes and risers for large loads and reefing for small loads. See Section 4.1.3 for proposed parachute description. A slight reduction in opening shock will eliminate force problems in the parachute-retrorocket system (above 8000 pounds). An appreciable reduction in opening shock will be required for the parachute only system. A small but real reduction in sling force will be realized in drops, where the highest forces are realized in the first slings to become taut, with the prototype system for loads over 10,000 pounds because of the rocket pack mass reduction in the prototype system which will reduce snatch forces from rocket pack momentum.

It is concluded that parachute performance was generally adequate in tests and that the prototype system can use slotted parachutes which will reduce peak sling forces and be of lighter construction than 46 foot parachutes used in testing. In addition, no reefing will be required.

3.3 Load Descent

Once the slings are taut and the parachutes are open, the load still must swing down to approximately a horizontal attitude and the descent rate must be within approximately the limits of 55 to 70 feet per second. As can be seen from test 202-12 and other tests in Appendix D, the rate of descent tends to build up and then diminish while the horizontal velocity is reduced. The rate of descent then, limits the minimum drop altitude (see Table 1, Appendix E for descent velocities at rocket firing in live tests at El Centro, California). In system drop tests, descent velocity would have limited minimum drop altitude in live tests 202-12, -25 and -26. Load angle was the limiting factor in other tests. To get acceptable load angles and descent rates from low altitudes, the parachutes must be close coupled to the load (short risers), and they must open quickly and consistently and exhibit a high cluster efficiency. Unfortunately, these requirements are conflicting; therefore, a compromise is necessary. The riser extension lengths tested (Table 1, Appendix D) were conservative in that they were longer in proportion to the parachute diameters than the riser extensions called for in the existing rigging manuals for a given number of parachutes in the cluster. Some lagging and some cluster interference was still experienced. Longer riser extensions would increase deployment times and increase lag angle. The lag angle is defined, for the purpose of this report, as that angle between the tangent to the load trajectory and the parachute cluster resultant force, and it is the result of the parachutes lagging the load as the load goes over the "knee" of the trajectory curve. Figure 3.1 illustrates the lag angle. Obviously, the lag angle increases as the distance from the load to the parachutes (total riser length plus slings, etc.) increases. Also the lag angle soon disappears after a short vertical freefall. Lag angle causes the rockets to introduce a rearward load velocity. This can add to rearward velocity caused by swing or partially cancel residual forward velocity from the load trajectory. It is ideal to drop from an altitude sufficient to almost eliminate the lag angle with the longest geometry used. The lag angle based upon computer results, is 5.6 degrees at rocket ignition for 35,000 pounds from 500 feet with standard atmospheric conditions (ρ = .00238 slugs per ft^3). The lag angle increases to 11.3 degrees if the drop is made onto a 5000 foot elevation drop zone at 100 degrees F (ρ = .00183 slugs per ft^3).



PARACHUTE AND LOAD LAG ANGLE
Figure 3.1

Load angle versus time data was not obtained at El Centro as requested, therefore it was reduced at Stencel for live system tests conducted at El Centro.

3.4 Ground Sensing

Testing was conducted with mild detonating fuse (MDF) transmitting a signal from the probes to gas valves. The probes were reeled out by brakes around whose drums the MDF was wound. Two systems were used per system for redundancy.

The first 11 PRADS tests (tests 202-4 through 202-14) had no time delay in probe release. See test 202-6 Appendix E for a typical description. Since test 202-14 resulted in excessive probe swing, a time delay of 2 seconds was introduced into one probe release while the other probe was released instantly when the lanyard was pulled. While probe swing had not been a critical problem with previous tests, probe angle was 45 degrees in test 202-14, which caused rocket ignition to be delayed and firing continued .36 seconds after ground impact of the load. After the time delay was added, no severe oscillation problems occurred. Longer probe reelout time would tend to give the same probe stability as the time delay.

A firing system such as the proposed crossed beam laser prototype system is fixed to the load platform and the sensing height error from system geometry with the laser system is dependent on the platform angle. The error in rocket ignition altitude due to platform angle is determined as follows:

$$E = h\,(1 - \cos \phi)$$

where h = programmed signal height (approximately 23 feet)
ϕ = platform angle with horizontal

A platform angle of 20 degrees would cause a reduction of 1.4 feet in firing height. No degredation of impact velocity would occur except a) at or near 100°F and 5000 feet drop zone conditions or b) where the load had swung past the vertical with an unusual angle. A platform angle of over 20 degrees is unacceptable because of impact attitude and the horizontal velocity component added by the rockets. This platform angle was acceptable in all live airdrops made from near 500 feet or more as seen in Appendix E.

It is concluded that: 1) probe swing can be controlled, or at least reduced, by a time delay in release; 2) instability of the load and probes in the 14,000 pound live tests was particularly poor; 3) a reliable system which did not use probes would eliminate the probe swing problem and give a more consistant rocket firing height. (The laser is expected to trigger the gas valve within ± 1 foot or less.)

3.5 Rocket Firing

After the MDF fired, the gas valves shuttled and gas was ported to the rocket motors, where redundant firing pins struck primers. Gas pressure then built up and ruptured the nozzle closures. This process took approximately 20 milliseconds, during which time the load descended just over one foot. Measured delay times varied from .016 second to .032 second depending upon whether one or both signal systems functioned; therefore, no appreciable rocket firing altitude error was attributable to the delay.

3.5.1 Heat and Blast

During rocket burning a potential problem exists from heat and blast. The extent of the problem was not recognized in testing under the previous contract (DAI9-129-AMC-502(N)) during which as many as 26 rocket motors were used in static tests with a small amount of heat damage in the form of some discoloration and hardening of the unprotected slings. It was believed that light protective covers for the larger load slings would be sufficient protection for up to 32 to 36 rockets. When static testing of 32 rocket motors was performed (test 183-3, Appendix B), flame from the rocket plumes converged onto the slings and load. The slings were severely damaged and failed.

Sling covers made from asbestos cloth or foil backed fiberglass cloth were used in a second static test using 32 rockets (test 186-1). Sling damage again occurred, but no failure resulted. Drop testing with 32 rocket motors and 35,000 pound loads was performed without solving the problem since the scope of the contract did not include rocket motor redesign. Test 202-23 resulted in poor performance primarily because of parachute risers failing. Test 202-26 resulted in good performance except for rocket plume convergence which not only damaged the load, but also set the energy absorbing cardboard on fire. See Appendix D for test details.

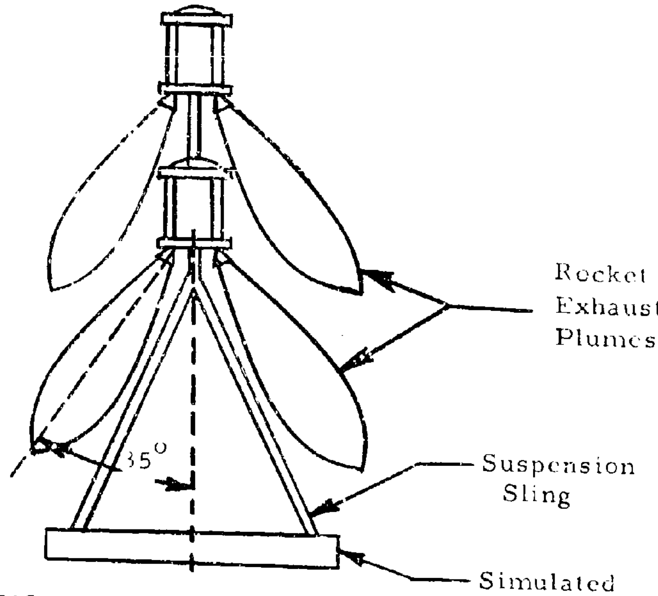
Figure 3.2b shows how the plumes converged. It is believed that this phenomena occurred because air is pumped out of both the outer cone and the inner cone within the plumes, causing low pressure areas which in turn caused the plumes to converge. The proposed prototype system includes a single rocket pack with up to 12 rocket motors. Scale model tests showed that the convergence problem was eliminated or greatly reduced by this arrangement. See Appendix A for a report of the scale model tests.

An additional problem occurred in test 202-25 in which the load buckled and rocket exhaust weakened the front slings so that they failed. See discussion on stability.

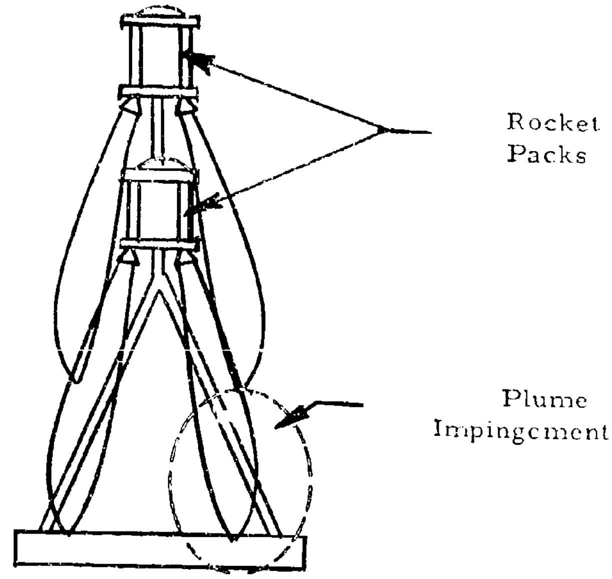
Heat and blast do not appear to be a problem when there is no plume impingement.

3.5.2 Rocket Motor Reliability

Rocket motors delivered under subcontract by Northrop Carolina, Inc. were considered very reliable. Three types of problems still developed with the rockets during testing. In test 183-1, a rocket nozzle which had sharp corner failed on the fifth usage in the locking ring groove. Pressure checking of nozzles for all reloads above normal operating pressures was initiated with the object of producing failures of weak components. A similiar failure of a pressure checked nozzle on the fifth usage occurred



NORMAL FLAME PATTERN
Figure 3.2 (a)



ABNORMAL FLAME PATTERN
Figure 3.2 (b)

in test 186-1. Based upon this experience, only newer nozzles were used in tests for a short time, after which nozzles were reinforced with cap screws. No further problems occurred with the nozzles.

A misfire also occurred in test 183-1. Although the primers had been inserted with a redesigned tool, damage had still been inflicted on the primers and an additional change was made in the tool. Later the primers in new and reloaded rockets were X-rayed. No further problem occurred with misfires.

A head end closure came off one rocket motor upon ignition in the first live test at El Centro, California. (Test 202-6.) This resulted in a catastrophic failure of the rocket pack. Investigation showed that the snap ring holding the head end closure in place was not seated correctly, although small cap screws were used to keep the ring from coming out completely. A measurement was made on each snap ring on rockets used subsequently, and no more failures occurred.

3.5.3 Stability

Load stability during descent was required to allow satisfactory probe deployment. A time delay was used in the release of one probe beginning with test no. 202-16 at El Centro which yielded satisfactory results with the probes mounted on the rear of the load. However, the proposed crossed beam laser ground sensor will eliminate problems of probe reelout; therefore, sufficient load stability will be required only for a) elimination of load tumbling through suspension slings (as happened with the present standard drop system) and for b) the load platform to be within 15 to 20 degrees of horizontal at rocket ignition. The latter is a question of drop altitude and system geometry.

Static testing of from 10 to 32 rocket motors gave marginal stability. See Appendix B for conditions and results. It is realized that the elimination of all restraint forces in the static tests is a far more difficult condition than actual drop tests where parachute forces remain appreciable for most of rocket burning.

Load stability during rocket firing was good in live system tests except where unusual problems occurred.

Ground impact before rocket burnout caused problems in tests 202-14 and 202-23 not related to basic stability. In test 202-25 the load buckled when the rocket motors fired. The front end of the truck bent up and the front slings became partially slack momentarily. The rocket pack tried to correct for this rather violent disturbance with the result that the rocket plumes on the front momentarily impinged upon the slings and caused their failure.

It is concluded that rocket pack stability is adequate for good test performance where other performance criteria are acceptable, i. e. rocket burnout by load impact or within about .040 second after impact and structural integrity of load, slings and rocket pack.

3.5.4 Suspension Sling Forces

Suspension sling forces during rocket burning were high on all tests except where the loading per rocket motor was low. Airdrops with 5000 pound loads and 32,000 pound loads (tests 195-1, -2, and 202-26) resulted in forces under 1.5 G per attachment point based upon gross rigged weight. (Test 202-23 resulted in burning after load impact because of a slightly low altitude drop and the complete loss of two parachutes, resulting in snatch forces on the front slings.)

High forces in other tests were generally caused by "overshoot" of the rocket pack mass. At rocket ignition, the total force in the slings was approximately one G from the parachutes. After the rockets fire, approximately 4 additional G are applied to the rocket pack, and it is accelerated upward with respect to the load. Because of parachute drag, most of the parachute force remains while the slings stretch. Assuming the rocket pack weights 1100 pounds and the suspension sling spring constant is 73,300 pounds per inch, the force trace can be closely approximated. The force trace of the rocket motors used is close to a square wave, hence overshoot is appreciable. Prototype rocket motors are to have a slower force buildup to greatly reduce overshoot. See Section 4.5 for calculations confirming observed data and required force for negligible overshoot.

3.6 Ground Impact

Load impact velocity varied considerably even where the system functioned properly. The variations were the result of 1) variations in firing height due to probe swing; 2) variations in load weight per rocket motor, and 3) malfunctions such as the loss of parachutes which caused extreme load angle and/or velocity at rocket firing

Probe swing, discussed previously, will be eliminated by the laser prototype system and assumed results are given in Appendix E. Variations in load weight per rocket motor will be necessary, but they can be partially nullified by adjusting parachute quantities. Strength of parachute risers and slings must be increased, or the forces must be decreased. The prototype system calls for the latter.

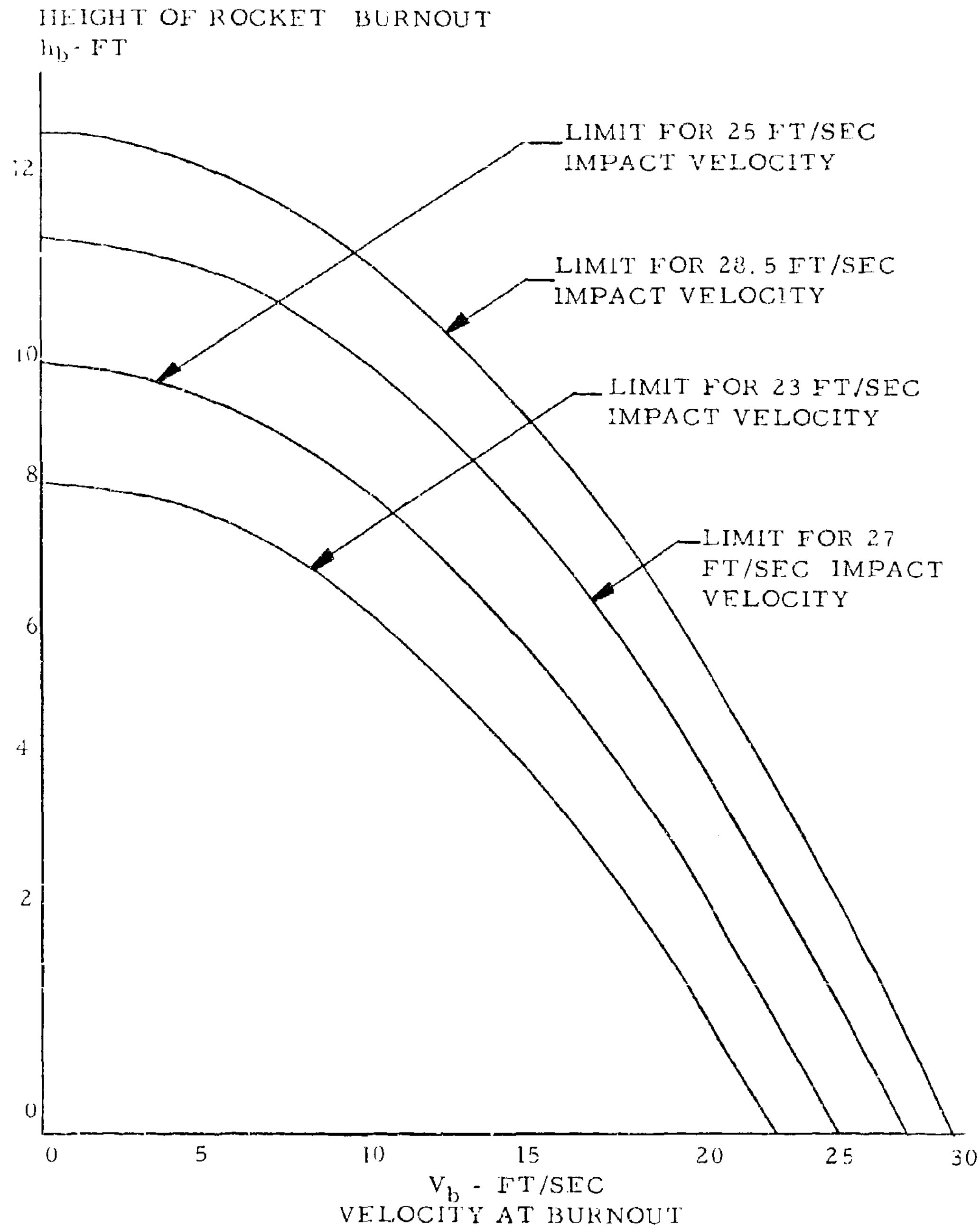
Figure 3.3 shows impact velocity for heights of burnout at different velocities at burnout. Consistant impact velocity can be realized only with a constant ignition height so that descent velocity will trade off with burnout height.

The relationship between impact velocity (Vimp), velocity at burnout (Vb) and height of burnout (h) is:

$$V^2_{imp} = V_b^2 + 2gh$$

The maximum allowable freefall height depends upon velocity at burnout. Zero parachute force is assumed after burnout.

Horizontal velocity was acceptable for all live system tests where vertical impact velocity was within 28.5 feet per second except two. Horizontal impact velocity was marginal for tests 202-21 and 22.



LOAD VELOCITY VERSUS HEIGHT

Figure 3.3

3.7 Criteria for Successful Airdrop

Basically an acceptable drop is one in which the load is recovered in an upright position and undamaged with regard to military effectiveness. The following criteria are specifically applicable to PRADS.

1) Vertical Impact Velocity - maximum 28.5 feet per second.

2) Load angle at impact - maximum 15 to 20 degrees.

3) Load stability during descent - load angle and angular rates at time of rocket firing must be such that conditions in 2 above are met.

4) Horizontal Impact Velocity - maximum 7 to 10 knots not counting wind drift

5) Heat and Blast - no damage.

6) Suspension Sling Forces - not to exceed 1.5 G per sling. While Items 2 and 4 are not defined specifically under this contract, values shown should at least be in the ballpark.

3.8 Parachute Risers

Parachute risers failed in tests of larger loads (Appendix E) because a) of high opening shock of 46 foot flat circular parachute, b) of marginal strength of two loop type X webbing when over age and c) clevises with 5/8 inch diameter bolts were used without sleeves. In addition, riser adapters failed for reasons a and c above, and because some were sewn in a box pattern instead of a "double W". The proposed system, in addition to having slotted parachutes to reduce opening shock, will have 3 loop type X webbing

3.9 Conclusions

It is concluded that although some changes and refinements are needed in the system as tested, the capability of airdropping up to 35,000 pounds with acceptable impact conditions has been demonstrated.

4.0 PRADS PERFORMANCE CHARACTERISTICS

4.1 Rocket Size Trade-Off

A rather inflexible limit on system forces must be placed on the PRADS. The parachute decelerative force has to be constant at about the 1 G level when the rockets ignite and the retardation forces of parachute and retrorocket are combined. This total force is additive into the drop-load suspension slings which are connected to attach points stressed to approximately 1 1/2 times the gross rigged weight of the drop-load as called out in AR705-35 and MIL-STD-814. This force of 1 1/2 times the gross rigged weight is the maximum deceleration level seen in any of the prototype weight ranges. Since steady-state descent cannot be assumed for low-altitude airdrops, conservative analysis precludes using a total decelerative force of 1 1/2 G time 4 attachment points or 6 times the gross dropload weight. Assuming approximately 1G parachute force the rockets could input another 5 G in a stable system. Reduction of the 5 G retrorocket force to a maximum of 4 1/2 G allows some margin for system tolerance and dynamic force buildups in the suspension slings. Throughout the performance tradeoff analysis, the 4 1/2 G rocket force level is not exceeded by the prototype PRADS configuration. This rocket force of 4 1/2 G assumes that characteristics of the "soft" ignition curve of the new rocket motors will prevent force overshoot as seen in the test program under this contract. Further analysis of rocket force buildup is presented in Section 4.5.

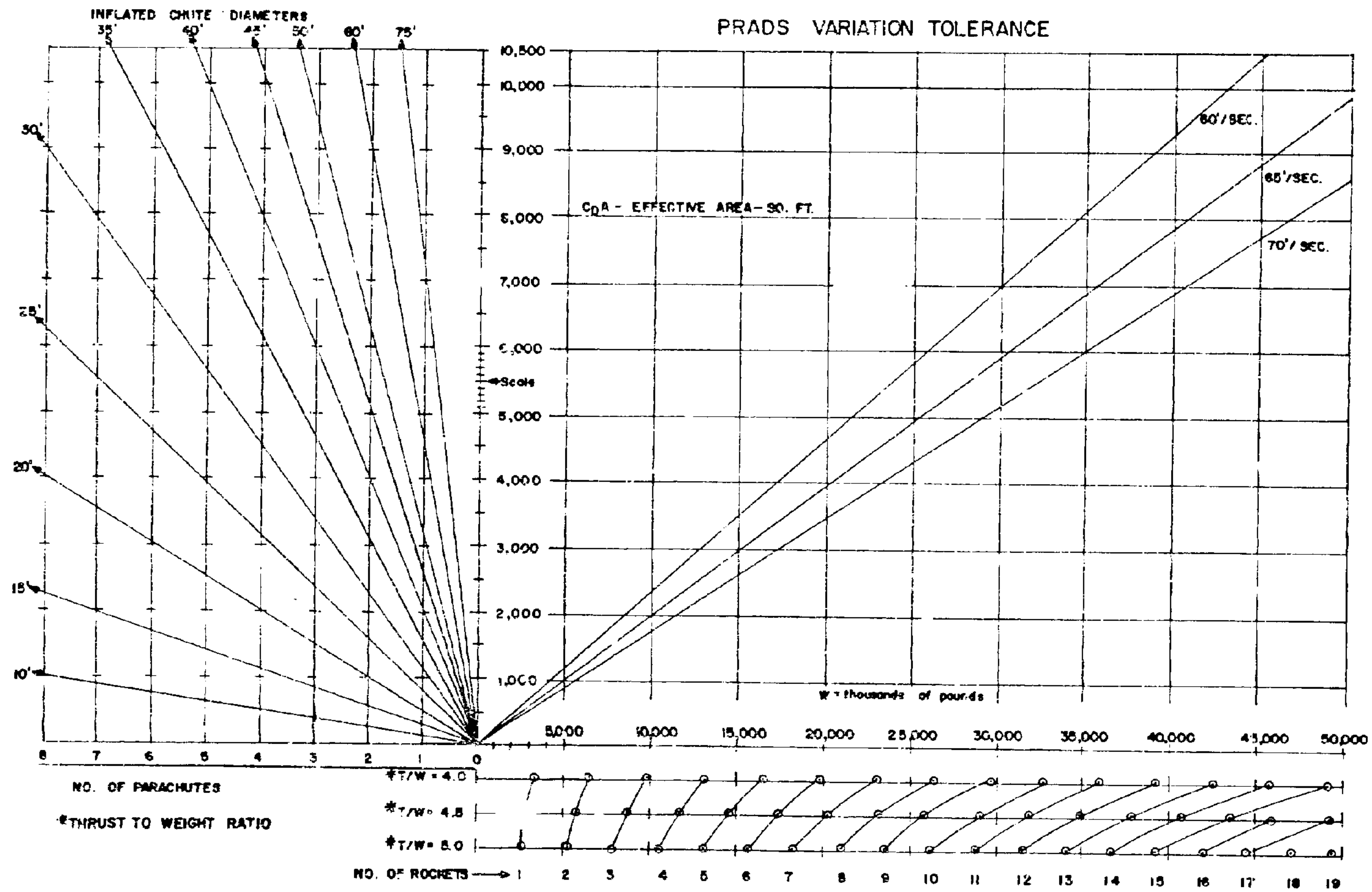
Efforts were then directed toward the design of a simplified rocket pack employing the features of the test hardware, yet easier to rig and foolproof. The working force level of the rocket pack is fixed at a maximum of 5 G rocket force plus 1 G parachute force or 6 times the 35,000 pounds maximum dropload weight required under this contract. The working force level of the rocket pack was fixed at 210 thousand pounds maximum with both parachutes and rocket force and any attendant rocket force "overshoot".

Using the "PRADS-Recovery System Trajectory" computer program, preliminary families of curves were determined to analyze system tolerance to variation in rocket thrust/weight ratio, parachute cluster configuration and parachute terminal velocity. Figure 4.1 summarizes this preliminary analysis. The left side of the figure shows C_DA versus numbers of parachutes for different inflated diameters (approximately 2/3 of the flat circular diameter). The right side of the curve shows C_DA versus load weight for three descent velocities. Parachute size was partially determined as follows. For a 35,000 pound load with a terminal velocity of 60 feet per second, a C_DA of 8,100 square feet is required, or six parachutes with 32.5 feet inflated diameter. A flat circular diameter of 48 feet is equivalent. Based upon this data further work was done using a maximum rocket thrust/weight ratio of 4.5 with a rocket burn time of 0.5 seconds. Parachute steady state velocities were varied holding the rocket force constant at 155,000 pounds or 77,500 pound-seconds impulse.

4.1.1 Parachute Velocity at Rocket Ignition

Figure 4.2 summarizes the prototype PRADS system sensitivity over the design weight range for standard day conditions. Families of curves are shown for descent velocities of 60, 65 and 70 feet per second at rocket ignition. Successful configurations are those impacting at less than 28.5 feet per second with rocket burn-out occurring no more than 50 milliseconds after ground impact. Systems having a rocket thrust to weight ratio high enough to introduce vertical velocity reversal were considered undependable since the dropload can be lifted high enough to allow reacceleration to unacceptably high impact velocities as the load freefalls to the ground under little, if any, controlled parachute decelerative force. Such velocity reversal conditions constitute the lower boundary as shown by dotted line in these graphs. As the similarity of these three graphs would indicate, the PRADS is tolerant of variation in velocity at rocket ignition. This tolerance is present throughout the design range above 10,000 pounds gross rigged weight.

For example, twelve rocket motors are adequate for loads of 28,000 pounds to 33,500 pounds with descent rates from 60 to



PRADS VARIATION TOLERANCE
INFLATED CHUTE DIAMETERS
35'
40'
45'
50'
60'
75'
30'
25'
20'
15'
10'
10,500
10,000
9,000
8,000
7,000
6,000
Scale
5,000
4,000
3,000
2,000
1,000
C_DA - EFFECTIVE AREA - SQ. FT.
60'/SEC.
65'/SEC.
70'/SEC.
W = thousands of pounds
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
8 7 6 5 4 3 2 1 0
NO. OF PARACHUTES
*THRUST TO WEIGHT RATIO
*T/W = 4.0
*T/W = 4.5
*T/W = 5.0
NO. OF ROCKETS → 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

FIGURE 4.1

IMPACT VELOCITY VS DESCENT WEIGHT

THRUST (vertical) = 13,100 LBS. (each rocket) X .50 SEC.
THRUST [illegible] ALTITUDE = 25 FT.
SEA LEVEL STD TEMP. & PRESSURE
INITIAL DROP ALTITUDE = 500 FT.

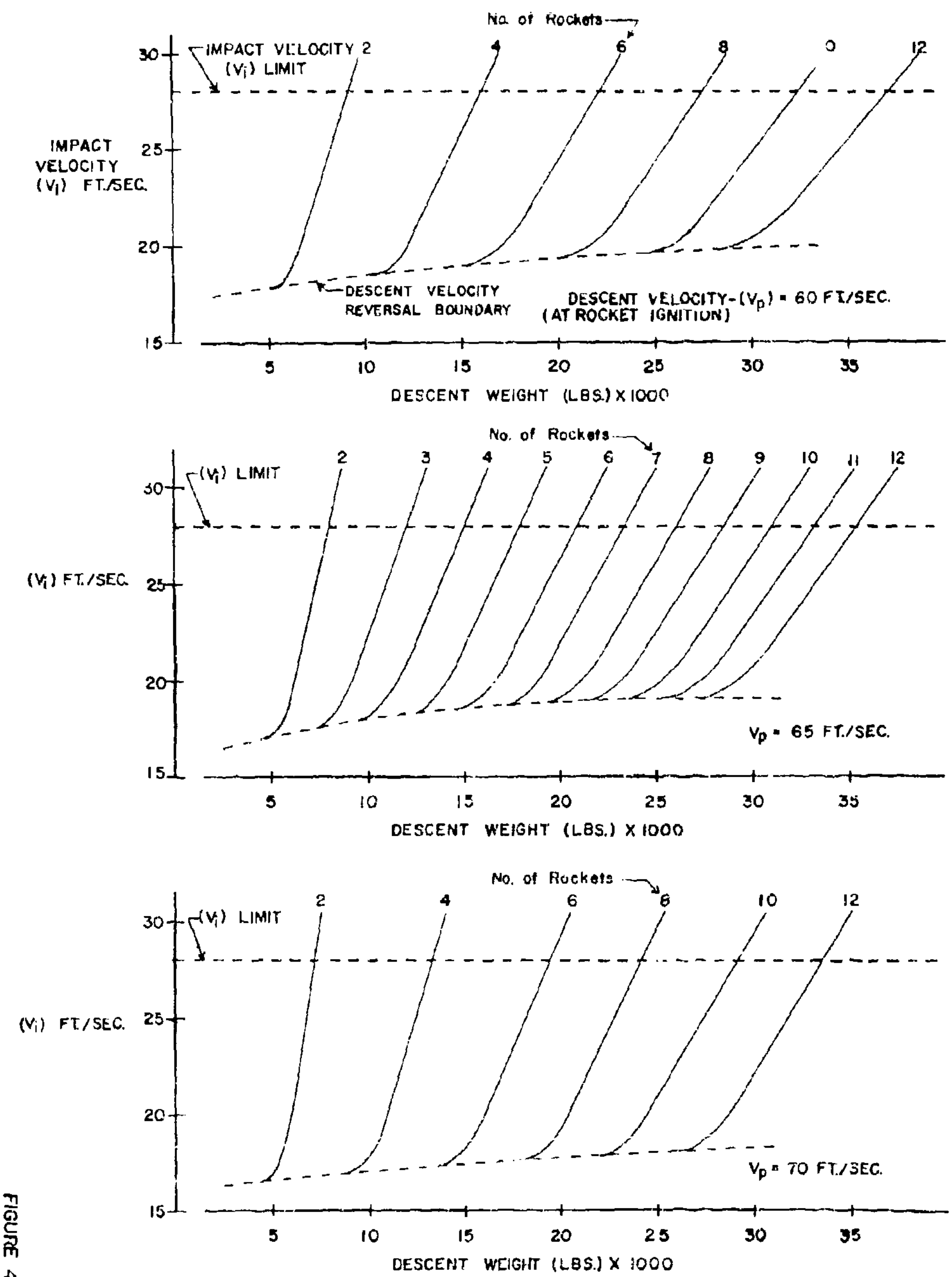


FIGURE 4 2

70 feet per second at rocket ignition at standard atmospheric conditions.

Additional computer runs were made to investigate simulated drops under different temperatures. See paragraph 4.2.1 for results.

4.1.2 Parachute Size Trade-Off

Preliminary sizing of the parachute to be used for the prototype system was determined by the equation for steady state descent.

$$V = \sqrt{\frac{2W}{N F_{CD} \rho_o C_{D_o} S_o}}$$

where

V = terminal velocity, ft/sec

N = total number of parachutes in cluster

FCD = cluster factor as determined from Fig. 4.6

ρ_o = density of air at sea level, 0.00238 slug/ft^3

C_{D_o} = drag coefficient (0.75 for all parachutes listed)

$S_o = \frac{D_o^2}{4}$, ft^2

D_o = nominal diameter of parachute, ft.

Assuming 8 parachutes to be the maximum cluster configuration and an air density variation from 5000 feet altitude at 100^{o}F (ρ = 0.00183 slug/ft^3) to sea level at -65^{o}F (ρ = 0.00318 slug/ft^3) with terminal velocity held to 65 feet/sec. established a parachute diameter range of approximately 45 feet to 50 feet. A matrix solution was then obtained through a series of computer runs with refined input data to establish a single canopy diameter satisfying the velocity range requirements over the entire design weight range of 2000 pounds to 35,000 pounds. The solution to this trade-off is a 48 foot diameter canopy with a typical drag area coefficient of 0.75.

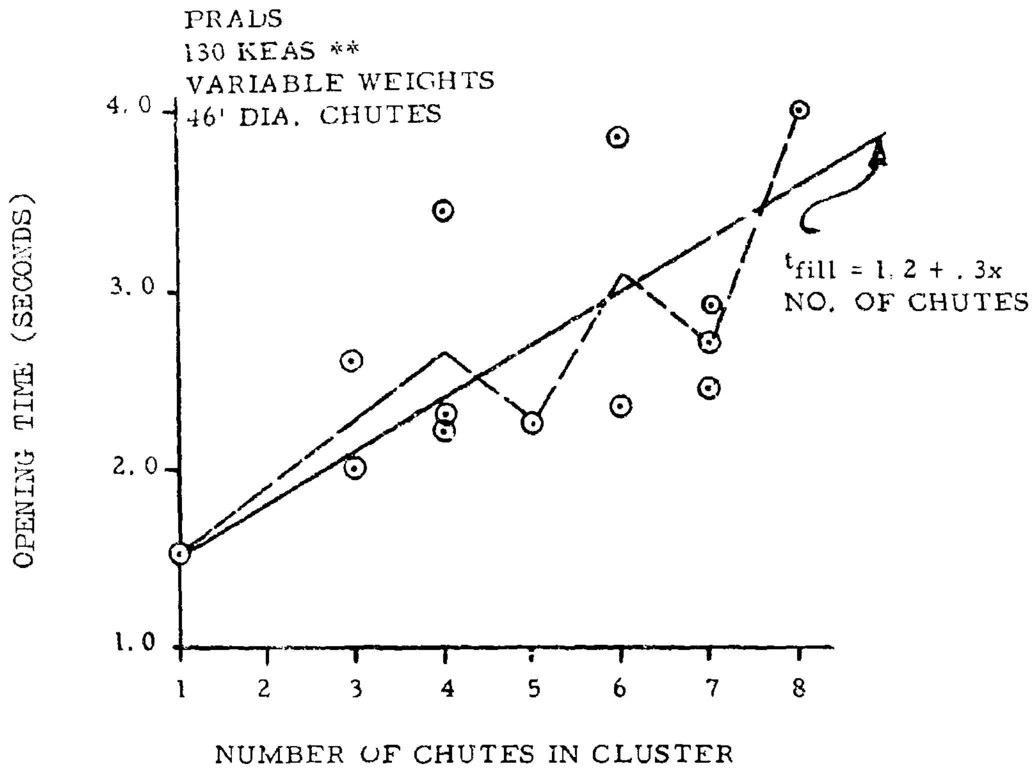
4.1.3 Parachute Performance

Test data on airdrops employing the 46 foot diameter flat circular parachutes was carefully analyzed in order to substantiate calculated performance factors. Characteristics of cluster interference were isolated for each configuration tested and riser extension lengths were empirically adjusted in an effort to minimize the degrading performance usually attendant to a short-coupled cargo airdrop delivery system. The configurations recommended in this report exhibit repeatable parachute cluster performance over the system design range. Inflation times are predicted to be repeatable with normal drag efficiency and acceptable system oscillation characteristics using from 1 to 8 heavy duty 48 foot diameter parachutes. Using the actual inflation times calculated from high speed motion picture test coverage on the 46 foot diameter parachutes, an acceptable relationship was defined for parachute performance versus number of parachutes in a cluster. This data indicated a linear trend and a least squares representation of the PRADS 46 foot diameter parachutes is presented in Figure 4.3 for 1 up to 8 chutes in clusters. The relationship is defined as:

$$t_{FILL} = 1.2 + 0.3 \text{ (No. of Chutes in Cluster)}$$

The average cluster inflation time defined by this equation and shown as the solid line includes actual delays for normal cluster interference and inflation time variations due to different canopy mass loadings.

Since inflation times recorded in the test program for the 46 foot diameter flat circular canopies is limited, yet representative of system operation requirements, the inflation times for the larger



CLUSTER FILL TIME * VS. NO. OF CHUTES IN CLUSTER

* Average Of Individual Chutes in Cluster

* Cluster Inflation Time = $t_{deployment} + t_{fill}$

** Equivalent Air Speed

Figure 4.3

48 foot diameter extended skirt canopies were scaled up according to the increased chute diameter. Thus the 48 foot diameter parachutes will inflate approximately 4 percent slower than the tested system results. The expected inflation times for clusters of the prototype system are shown in Figure 4.4.

Deployment times obtained from tests were compared for the various test configurations. Using the extraction force transfer as the beginning of cluster deployment and parachute container bag separation from the canopy apex as the end of deployment allowed accurate measurement of this time interval. Times were then smoothed using a method of least squares approximation giving the linear relationship of deployment time versus number of parachutes shown in Figure 4.5. Assuming a linear trend, this deployment time is represented by the formula:

$$T_{DEPL} = 0.6 + 0.2 \text{ (No. Chutes Deployed)}$$

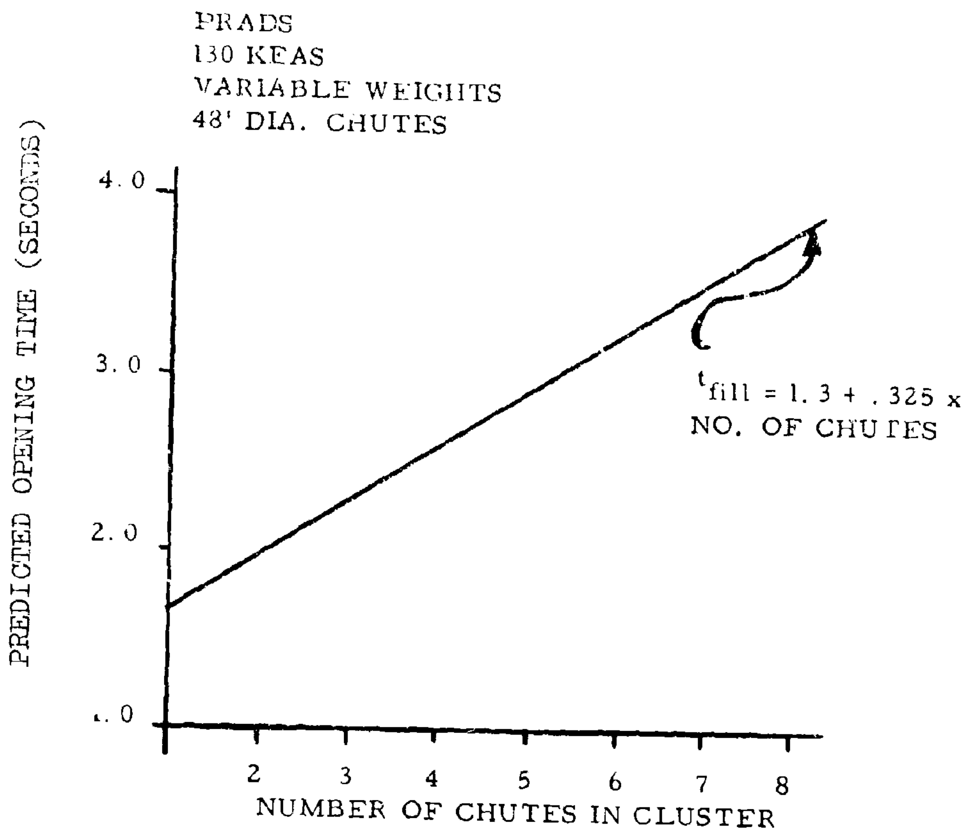
System tests supplied enough raw data to establish trends on both deployment and canopy inflation. There is, however, insufficient data to compile a serious reliability study or the parachute subsystem.

According to presently accepted statistical methods, a minimum of 20 sets of data would be required to establish the population trend and test the values so determined.* It will be necessary to perform a complete reliability study during the engineering development phase of PRADS development in order to satisfactorily determine extremes of performance and system operational reliability levels.

Performance graphs presented in this report make adjustments for varying drag efficiency of the canopies arranged in a cluster. The drag decreases as the number of canopies increases up to

---

*Argentiers, Peter D. and Tolson, Robert H., A NEW METHOD OF TESTING SMALL SAMPLES FOR GOODNESS OF FIT TO NORMAL POPULATIONS. NASA TND-4405, Washington, D. C. March 1968.

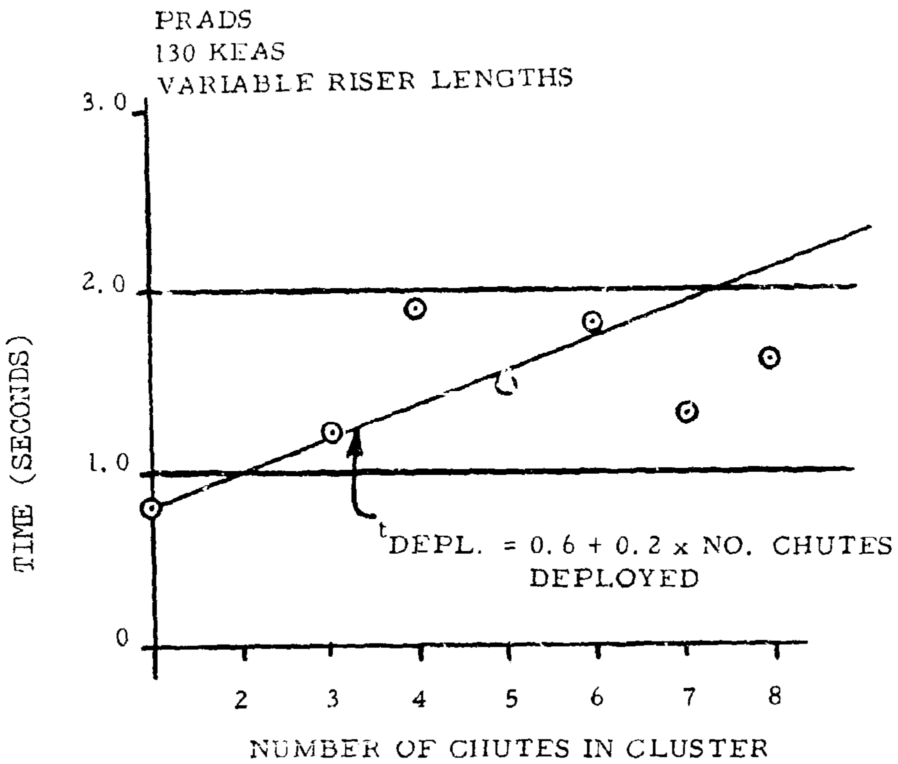


CLUSTER FILL TIME VS. NO. OF CHUTES IN CLUSTER

Average Of Individual Chutes in Cluster

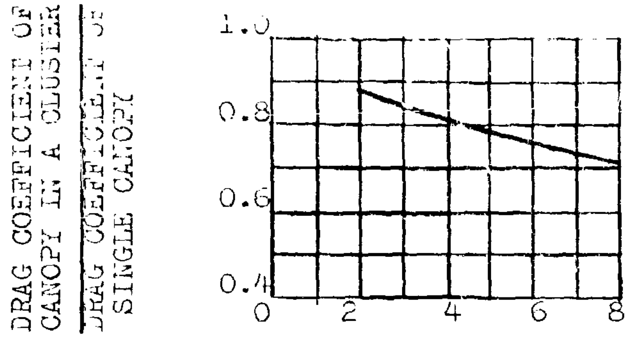
Cluster Inflation Time = $t_{deployment} + t_{fill}$

Figure 4.4



DEPLOYMENT TIME VS. NO. OF CHUTES IN CLUSTER

Figure 4.5



NUMBER OF CANOPIES IN CLUSTER

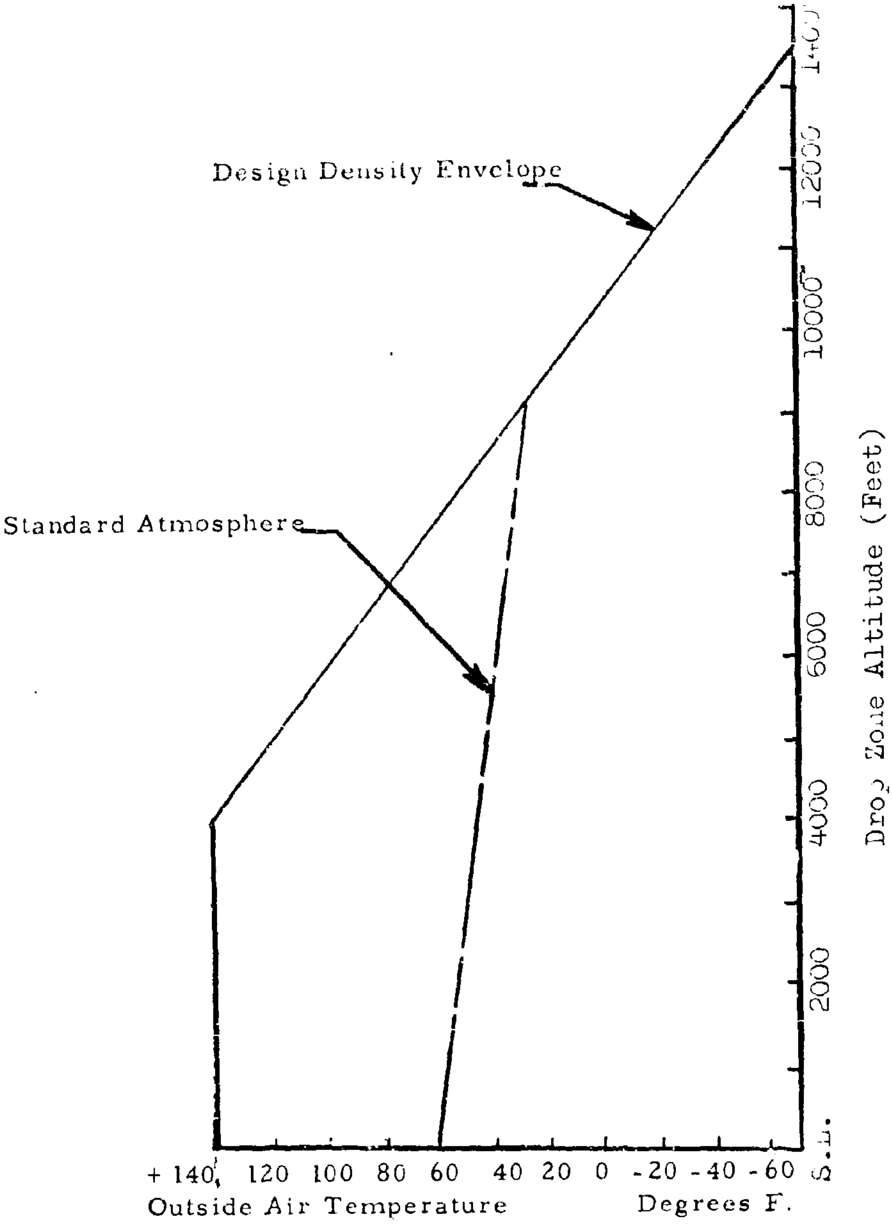
AVERAGE DECREASING DRAG COEFFICIENT RATIO (CLUSTERED)

Figure 4.6

a maximum of 8 parachutes. The drag efficiency reduction factors are taken from document Engineering Design Handbook, AMCP 706-130, Page 3-30. A reproduction of Figure 3-30 is shown above for reference as Figure 4.6

4.2 System Performance Envelope

The prototype PRADS System will be capable of satisfactory performance over a wide range of environmental conditions. Figure 4.7 shows the Air Density Envelope within which successful low altitude airdrops can be expected without system modification or adjustment. This figure indicates that system operation will be repeatable and successful at -65°F sea level or 100°F at 5000 feet above sea level. Further flexibility could be gained by changing the number of parachutes, number of rockets and the rocket ignition altitude if such extreme scenarios were required. Such changes are ruled out of the



DROP ZONE AIR DENSITY ENVELOPE

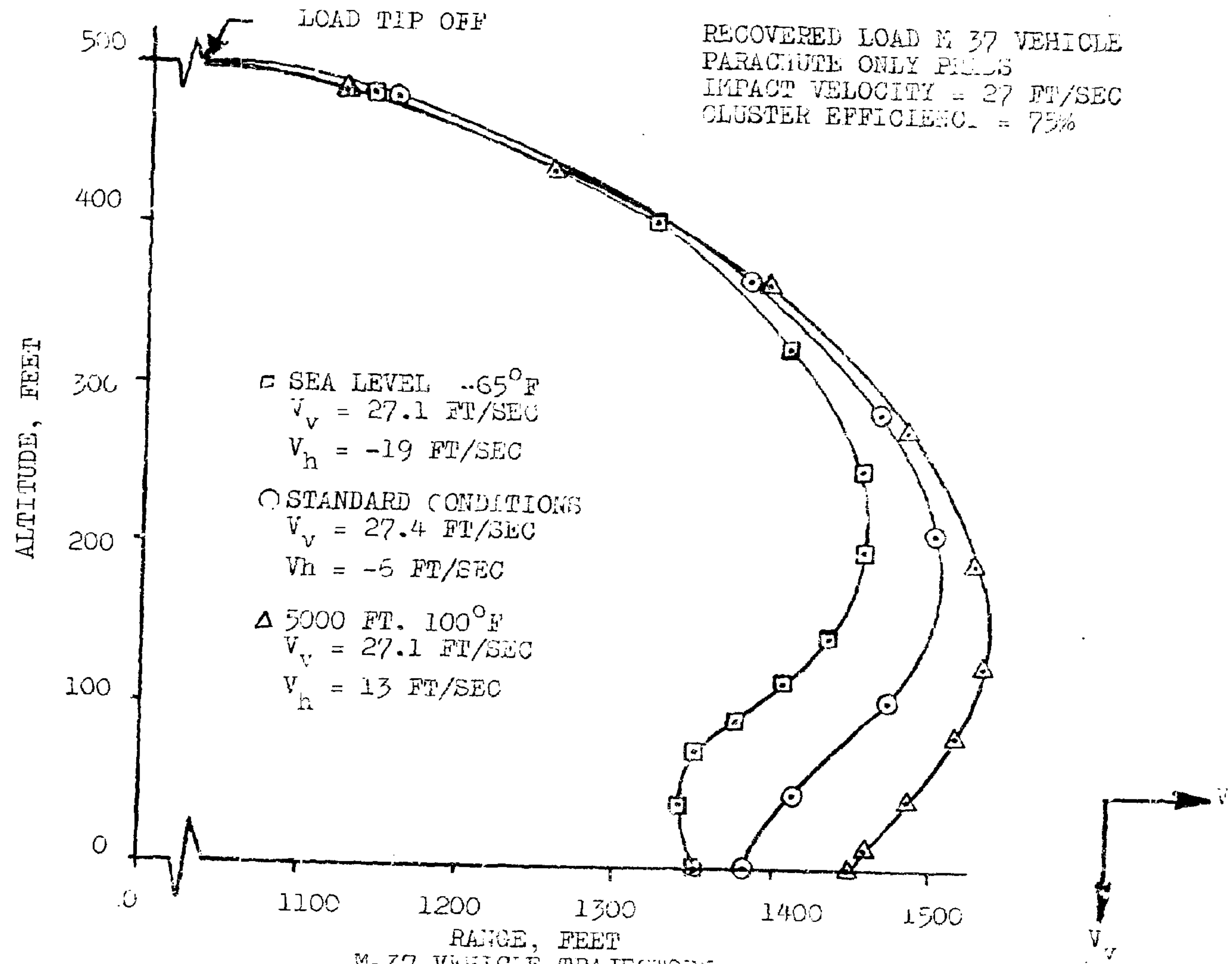
Figure 4.7

present prototype system to keep rigging complexity to a minimum consistant with the human factors study. The flexibility of PRADS is gained through the interrelationship of parachute velocity at rocket ignition and the distance the load freefalls between rocket burnout and ground impact. There is some change in rocket thrust levels and burn times of the motors with temperature. Assuming that the motors will be transported over some given distance before they are airdropped and fired, the extreme cold soak of -65 F will rarely be seen as applied to present airdrop technology. Currently aircraft such as the C-130, C-141 and C-5A are equipped with air conditioning and heating units providing a reasonably comfortable cargo bay allowing efficient crew functioning at all times. Based upon this assumption, the rocket thrust levels will not vary to a substantial degree in a typical range of scenarios involving an airlift of a few hundred miles. The trade off study included performance verification checks at these temperature extremes and the prototype system will function within requirements as the computed trajectories indicate.

4.2.1 Performance Trajectories

Trajectory comparisons for various PRADS configurations are presented to substantiate performance over the required environmental range. This data is taken from the "PRADS Recovery System Trajectory Program" discussed in Section 4.4. The input values used are compatible with performance duplicating trajectories for the live system tests conducted under this contract. Generally, the computed trajectories agree to within plus or minus 5 percent of the test velocity and impact attitude.

Figure 4.8 shows the system trajectories for the M-37 vehicle. This load weighs less than eight thousand pounds and is successfully recovered with a cluster of eight each 48 foot diameter parachutes. As shown, the range of impact zones is approximately 100 feet going from 1350 feet under the conditions en-



M-37 VEHICLE TRAJECTORY

Figure 4.8

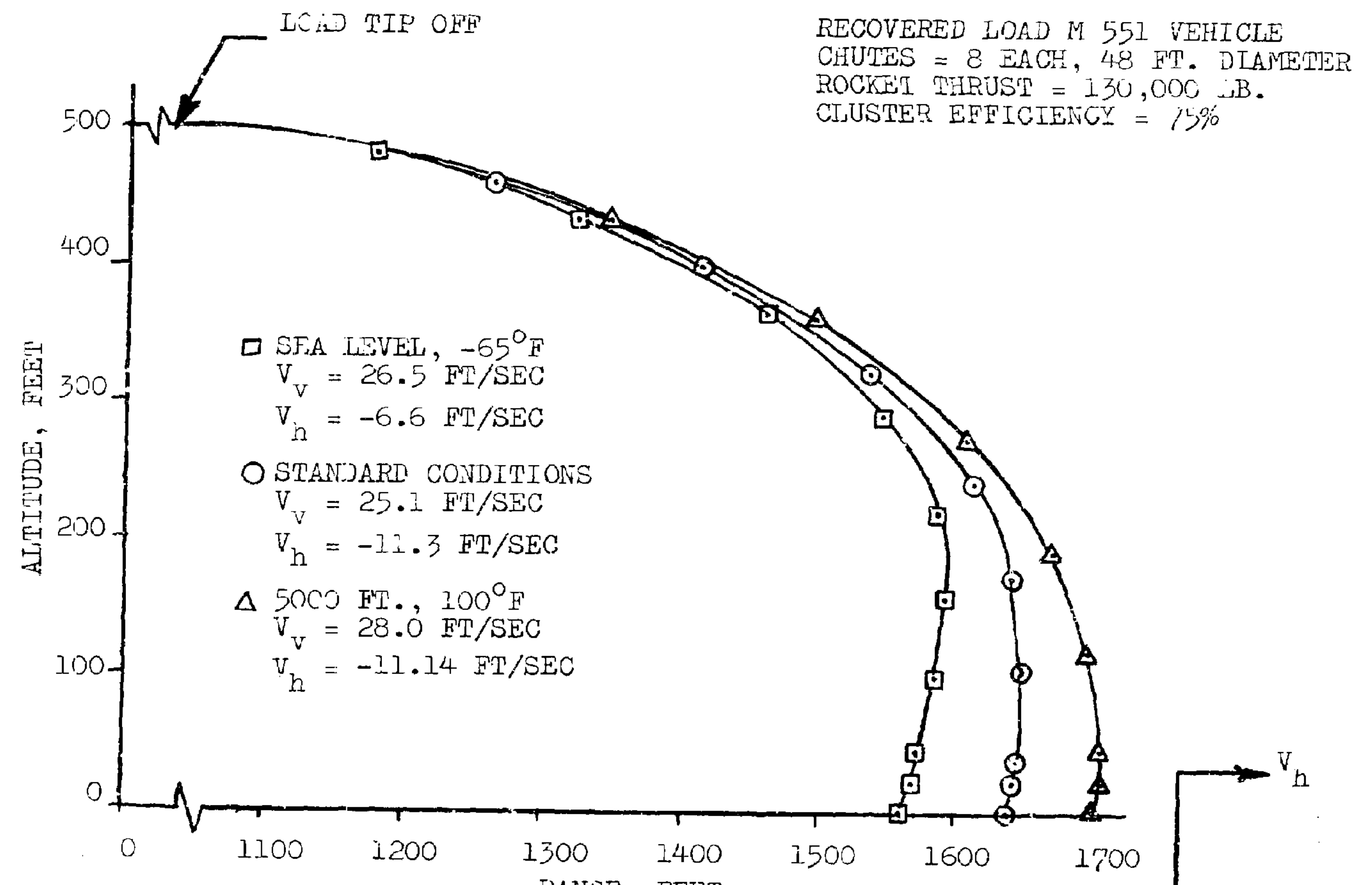
countered at sea level and -65°F up to 1450 feet for a drop zone at 5000 feet altitude with 100°F temperature. The less dense atmosphere decelerates the load with reduced efficiency, allowing the system to fly farther from the load tipoff position. Different conditions of system oscillation introduce a horizontal impact velocity range of from -19 feet per second up to 13 feet per second under these extreme environments. Vertical velocity ranges are from 27.1 up to 27.4 feet per second allowing for only 75 percent cluster drag efficiency.

The primary advantage of PRADS in this load weight range lies in the performance of the close-coupled parachute subsystem. System deceleration is achieved repeatably and with less altitude loss than currently possible with a conventional airdrop system using G-11 or G-12 parachutes.

Figures 4.9 and 4.10 present the trajectory extremes for the M-551 vehicle or a similar 35,000 pound gross dropload weight. The purpose of showing two different configurations is to emphasize the flexibility of the PRADS System in the heavier load ranges. While either of these two systems will meet performance requirements, the 6 parachutes, 12 rocket motor system is selected because it affords more optimum performance r serv and generally lower impact velocities over the required range of environmental conditions.

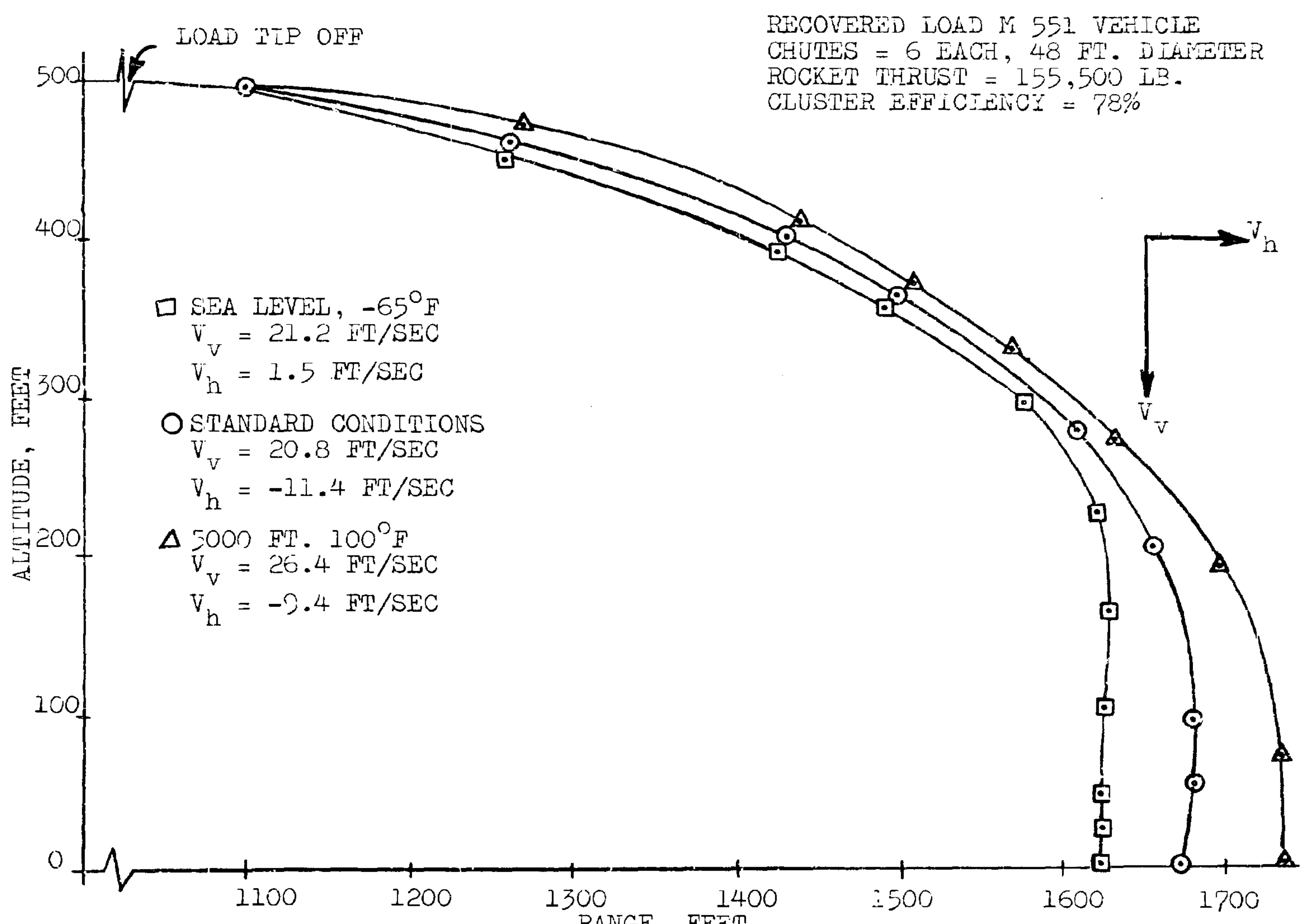
Referring to Figure 4.9, 8 parachutes and 10 rocket motors, the vertical impact velocity range varies from 25.1 feet per second up to 28.0 feet per second. As indicated, by the range of horizontal velocities, -6.6 feet per second to -11.3 feet per second, the system is resistant to velocity inputs from excessive oscillation. There is little margin for a serious parachute failure in this configuration. Excessive cluster interference will certainly allow ground impact at greater than 28.5 feet per second since full cluster inflation is programmed to occur about one second before rocket ignition assuming a 500 foot release altitude.

Figure 4.10 shows predicted trajectories for the selected 35,000 pound dropload configuration. With vertical impact velocities



M-551 VEHICLE TRAJECTORY (8-48' Chutes, 10 Rockets)

Figure 4.9



M 551 VEHICLE TRAJECTORY (6-48' Chutes, 12 Rockets)
Figure 4.10

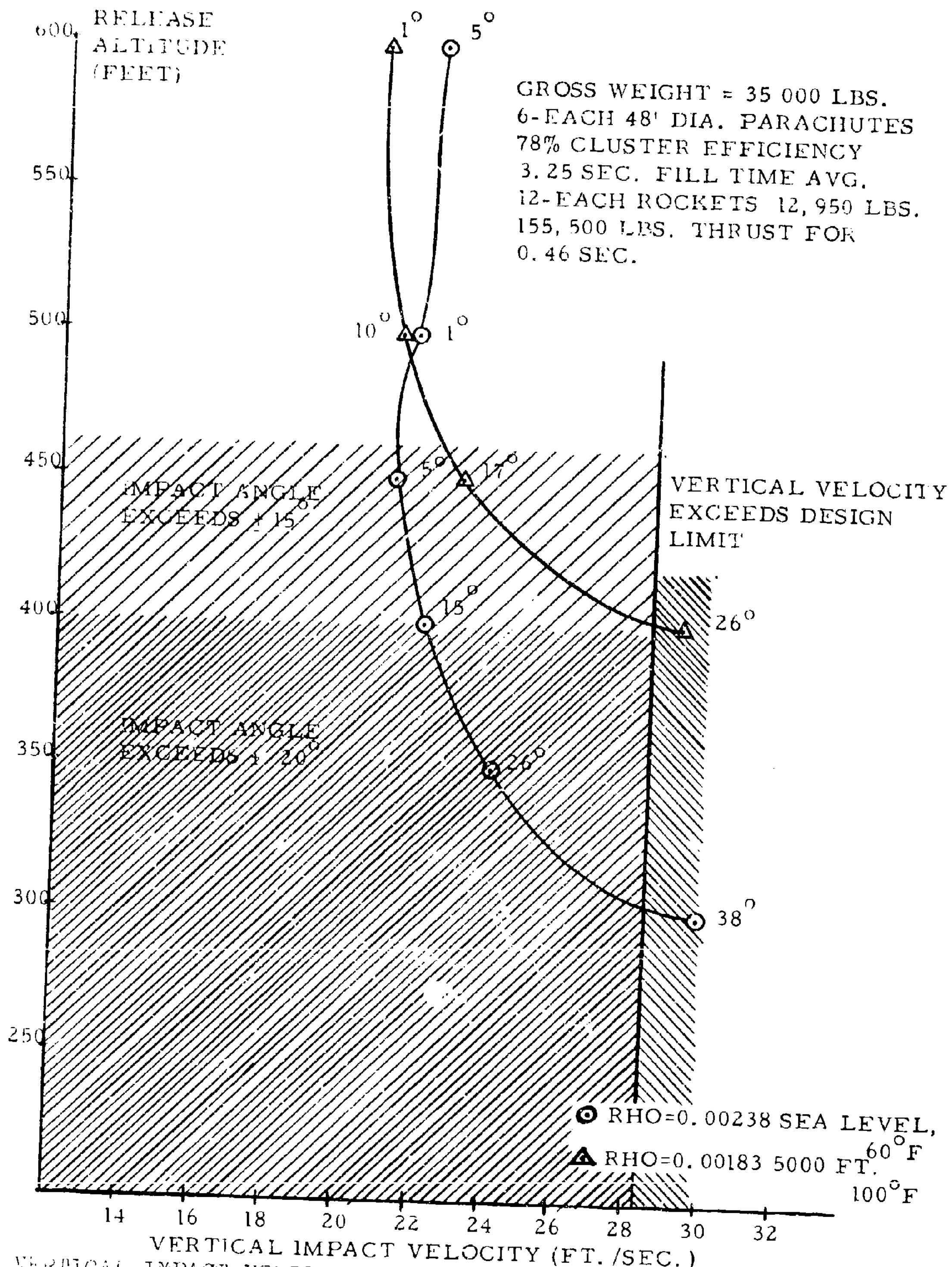
ranging from 20.8 feet per second up to 26.4 feet per second a more controlled system deceleration is achieved with a nominal impact velocity near 23 feet per second. The spread of horizontal impact velocities varies from 1.5 feet per second to 11.4 feet per second allowing an impact range of 120 feet variation over the environmental extremes. This small variation is another contributor to the overall drop accuracy of PRADS. This configuration will operate more repeatably and at a higher overall performance level than the other usable combinations of rocket and parachutes. For this reason, it is selected as the heavy load range PRADS system. Figure 4.11 illustrates the sensitivity of this configuration by comparing impact angle and impact vertical velocity against the release altitude. The lightly cross hatched area exceeds 15° at impact. The darkly cross hatched area exceeds 28.5 fps impact velocity. As shown, system performance is acceptable from 460 feet absolute and higher for the required environmental envelope. For this illustration an impact angle greater than $\pm$ 15° is considered excessive. Similiar trade-off and performance requirements were placed on each different load range PRADS configuration and the sys[illegible]as selected exhibit comparable performance over the d[illegible]ed operation range.

4.2.2 Drop Zone Of 5000 Feet At 41°F

For a drop zone altitude of 5000 feet at 41°F, no changes are required to any of the rigged configurations. Specifically, the M-551 vehicle will impact at 20.2 feet per second with a velocity vector normal to the assumed ground level. The M-37 vehicle will impact at 28.0 feet per second at an angle of 5° off the vertical axis. This performance is expected since the drop zone is well within the contract requirements which extend up to 5000 feet at 100°F.

4.2.3 Drop Zone Of 10,000 Feet At 23°F

In order to extend the application of PRADS to higher altitude drop zones certain changes in system configuration are required. These changes are minor in nature and are direct enough to



VERTICAL IMPACT VELOCITY VS RELEASE ALTITUDE FOR 35,000 LB. DROPLOAD

Figure 4.11

permit making the changes at the field rigging level if adequate supervision is available.

In order to utilize the PRADS at 10,000 feet at 23°F, further changes are required to the basic system. The M-37 vehicle will not meet the performance requirements with an all parachute recovery system. This 4 x 4 cargo truck requires 3 each 48 foot diameter parachutes and 2 each standard rocket motors. The load will be falling at about 60 feet per seoncd at rocket ignition. The rockets apply about 1.75 g-seconds deceleration and the load impacts at about 26 feet per second vertical velocity with less than 1 foot per second horizontal velocity.

Rocket burnout occurs at about 3.5 feet above the ground with the load in a stable descent condition. A heavier load such as the M-551 vehicle requires adjustments in the parachute velocity at rocket ignition to be used at this drop zone. The addition of one additional parachute, making a cluster of seven 48 foot diameter parachutes and utilizing the 12 rocket motors as in the standard system allows rocket ignition to occur at a velocity of about 73 feet per second. Rocket burnout is 2 feet above the ground and vertical impact velocity is 20.1 feet per second. Horizontal impact velocity is -6.5 feet per second with the load impacting 1 degree from vertical. No additional adjustments are necessary for these particular droploads and similar rigging changes throughout the weight range allow operation at this drop zone.

4.2.4 Drop Zone Of 15,000 Feet At 6°F

Further deviations from the basic rigging configurations allows system operation at these conditions. The M-37 vehicle requires 4 each 48 foot diameter parachutes and two standard rocket motors. Vertical velocity at rocket ignition is 55.6 feet per second with the load in a stable attitude. Rocket burnout occurs 5.4 feet above ground level and the load impacts at 26.4 feet per second vertical velocity with no horizontal velocity component. The

M 551 vehicle will require a cluster of 8 standard PRADS parachutes and 12 standard rocket motors for this scenario. Vertical velocity at rocket ignition is 74 feet per second. After the 2.22 g-seconds deceleration, rocket burnout occurs about 1.8 feet above ground level. Vertical impact velocity is 20.5 feet per second and the horizontal impact velocity is -6.9 feet per second. Impact attitude is only 2 degrees off the vertical reference for this trajectory.

Table 4.1 summarizes these specific drop zone altitude parameters as determined by the "PRADS Recovery System Trajectory" computer program.

TABLE 4.1

PERFORMANCE PARAMETER	DROP ZONE CONDITIONS		
	5000' 41°F	10,000' 23°F	15,000' 6°F
	M-37 Vehicle, Weight 8000 Lbs.		
a. No. PRADS Parachutes	8	3	4
b. No. PRADS Rockets	0	2	2
c. Initiation Altitude	--	22.0 Ft.	22.0 Ft.
d. Parachute Velocity at rocket ignition	--	60.0 Ft/Sec.	55.6 Ft/Sec.
e. Impact Vertical Velocity	28.0 Ft/Sec.	26.0 Ft/Sec.	26.4 Ft/Sec.
f. Impact Horizontal Velocity	13.5 Ft/Sec.	1.0 Ft/Sec.	-6.9 Ft/Sec.
g. Impact Angle from Vertical	5°	3.4°	2°

TABLE 4.1 (Con't)

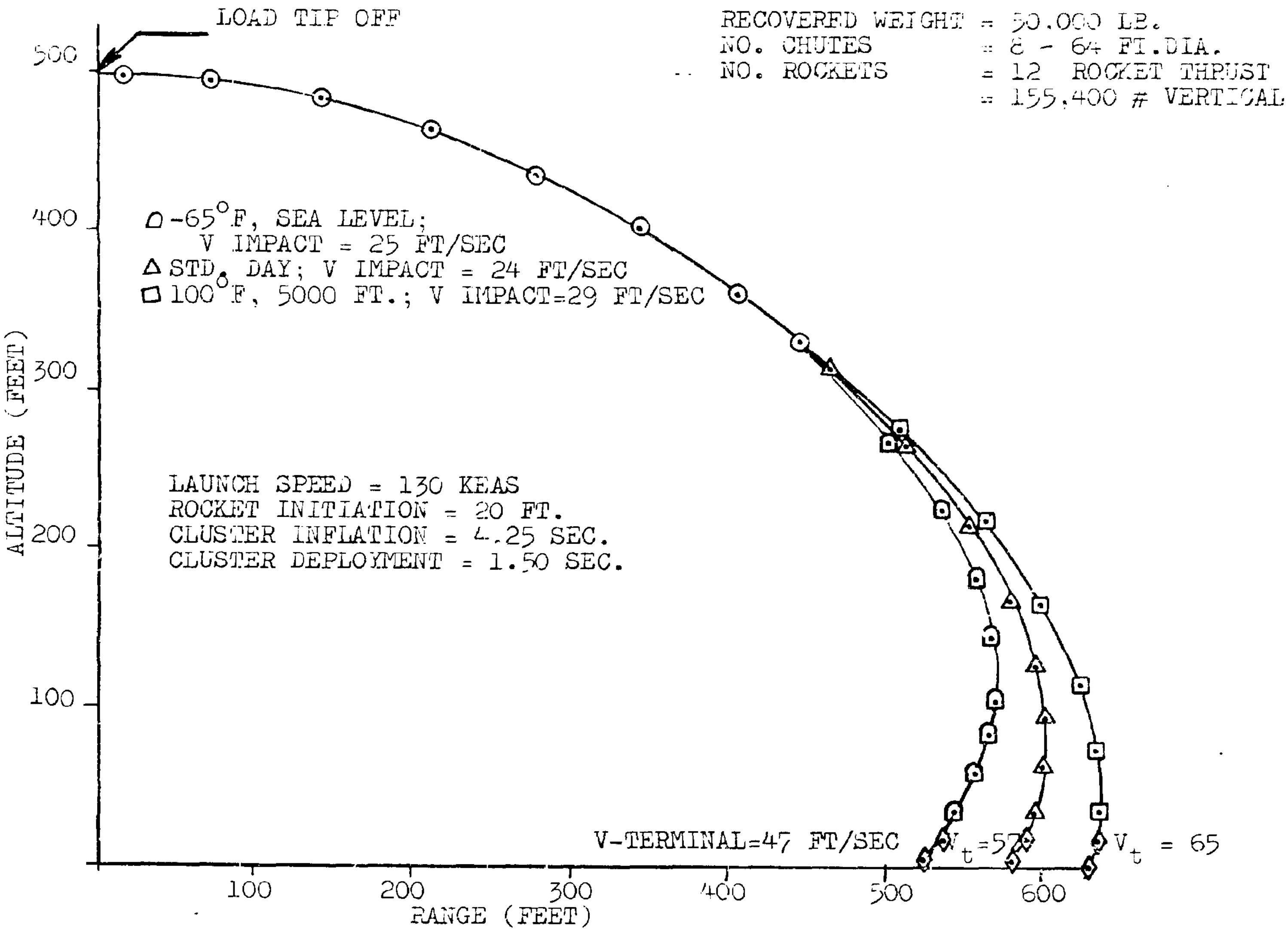
	M-551 Vehicle, Weight 35,000 Lbs.		
a. No. PRADS Parachutes	6	7	8
b. No. PRADS Rockets	12	12	12
c. Initiation Altitude	22.0 Ft.	22.0 Ft.	22.0 Ft.
d. Parachute Velocity at Rocket Ignition	72.9 Ft/Sec	73.0 Ft/Sec	74.0 Ft/Sec
e. Impact Vertical Velocity	20.2 Ft/Sec	20.1 Ft/Sec	20.5 Ft/Sec
f. Impact Horizontal Velocity	-6.2 Ft/Sec	-6.5 Ft/Sec	-6.9 Ft/Sec
g. Impact Angle from Vertical	0^{o}	1.0^{o}	20^{o}

4.2.5 50,000 Pound Loads

Figure 4.12 is included to show the application of PRADS to the delivery of a 50,000 pound dropload. The overall trajectory is about the same as for the present 35,000 pound load. In order to achieve this performance, special heavy duty 64 foot diameter parachutes are required. Inflation aids are also necessary to assure repeatable rapid cluster inflation. These aids may be either aerodynamic or ballistic as presently described by state-of-the-art technologies. Consideration to force modulating devices or techniques may be necessary to prevent destruction of the load attachment points if the 1.5 G per point is maintained as a system requirement. Heavy duty webbing, Type XXVI or stronger, will be required in the suspension slings, risers and riser extension.

4.3 Recovery System Trajectory Computer Program

The trajectory data presented is derived from the "Recovery System Trajectory" program. System dynamics are calculated



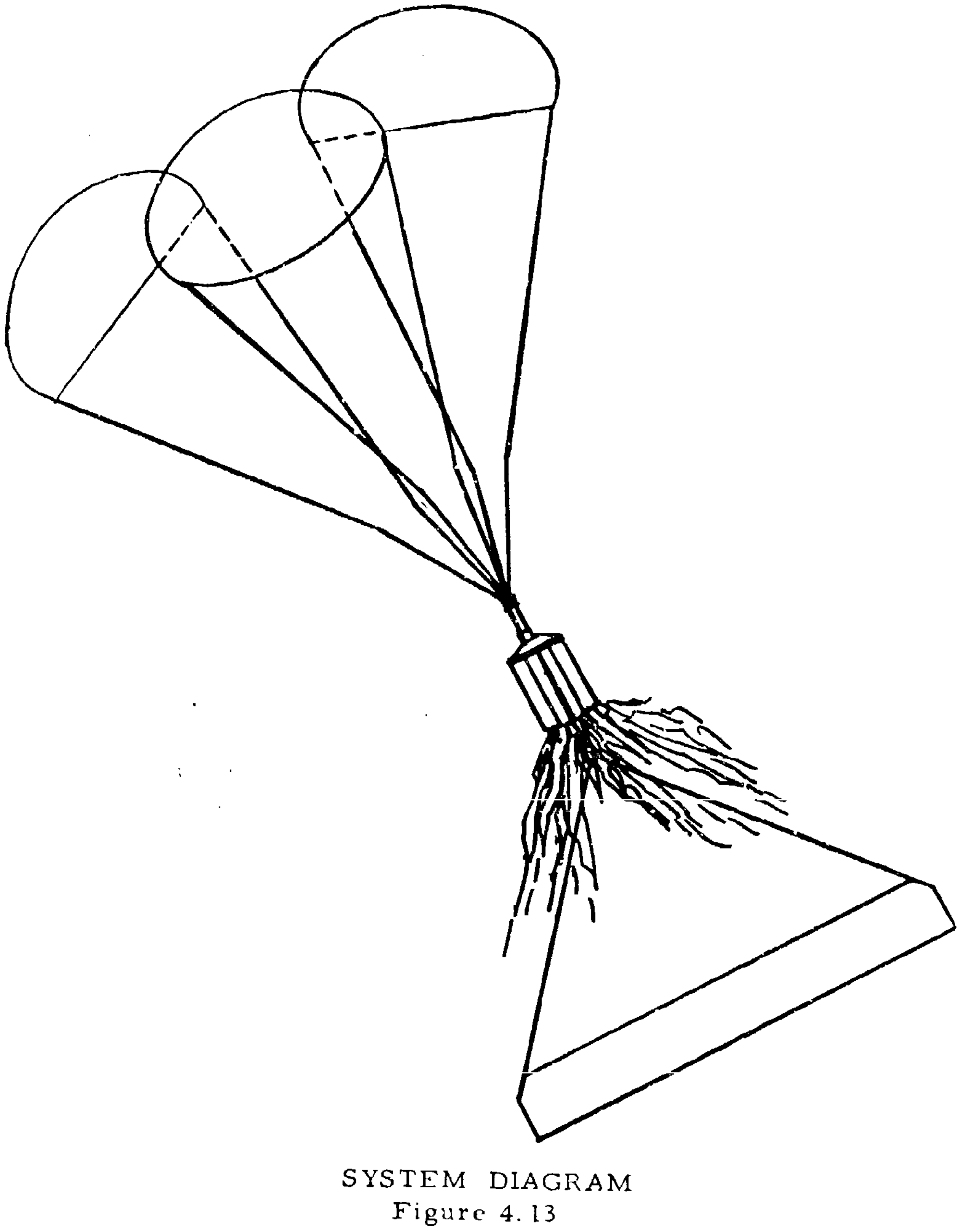
PRADS TRAJECTORY

Figure 4.12

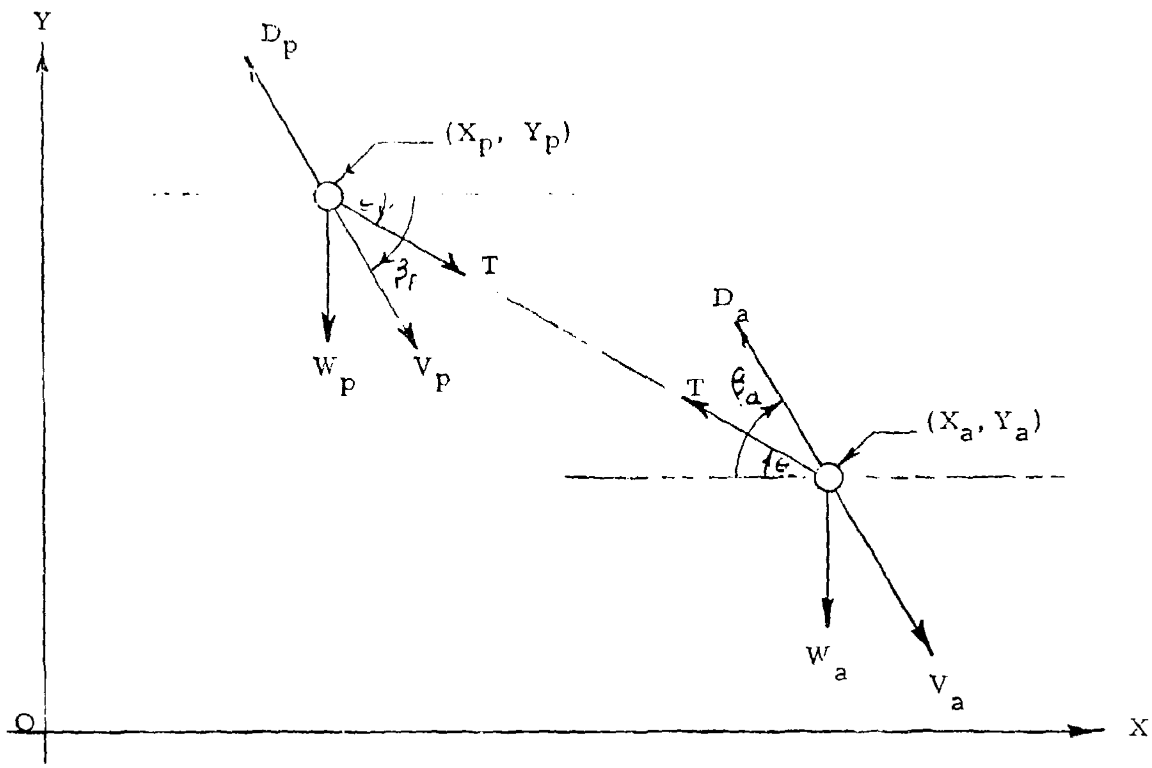
in two dimensions with the parachute and payload free bodies connected by an elastic coupling. Motion of each body is a function of mass, velocity, and the external forces of drag and tension. Figure 4.13 shows a deployed system with rocket pack above the payload. Figure 4.14 shows the two body model for the system. This program is written in FORTRAN IV language for the IBM 1130 computer system.

4.3.1 Recovery System Trajectory Definitions

WA	Weight of payload (pounds)
XA	Initial payload range (feet)
YA	Initial payload altitude (feet)
VXA	Initial payload horizontal velocity (feet per second)
VYA	Initial payload vertical velocity (feet per second)
THROA	Air density. If there is no input, the program determines air density on the basis of payload initial altitude.
ROCTS	Rocket table indicator. If zero, constant rocket thrust is input for RØ. If positive, a rocket thrust vs. time is used, and the thrust is multiplied by the value of ROCTS. (pounds)
VPE	Initial velocity of parachute extraction (feet per second)
PHI	Deployment angle of parachute (degrees)
AVOLK	Effective entrapped air volumn constant
AINER	Air inertia value
FILLK	Parachute opening exponent
DELT	Computing time increment (seconds)
FILLT	Parachute opening time (seconds)
TRSTM	Rocket thrust time if rocket table is not used (seconds)
PRNTM	Computer print-out interval (seconds)
SØ	Unstressed suspension line length (feet)
AREAX	Area of pilot chute (square feet)
CA	Drag coefficient of payload
RØ	Rocket thrust, if table is not used (pounds)
RØALT	Rocket initiation altitude (feet)



SYSTEM DIAGRAM
Figure 4.13



x, y	Horizontal and vertical reference planes
Xp, Yp	Parachute position (feet)
Wp	Weight of the parachute (pounds)
Vp	Velocity of the parachute (feet per second)
βp	Trajectory angle of parachute (degrees)
Dp	Drag of the parachute (pounds)
Xa, Ya	Position of payload (feet)
Wa	Weight of payload (pounds)
Va	Velocity of payload (feet per second)
βa	Trajectory angle of payload (degrees)
Da	Drag of payload (pounds)
θ	Angle defined by "x" axis and the force line between the payload and the parachute (degrees)

TWO BODY MODEL

Figure 4.14

CP	Parachute drag coefficient
ZØ	Constructed diameter of parachute (feet)
AREAA	Drag area of payload (square feet)
WP	Effective weight of parachutes (pounds)
ZØN	Number of parachutes
ELASK	Elastic coefficient of suspension lines (pounds per foot of elongation)
RHØA	Air density (slug ft.^{3})
VXP	Horizontal velocity of parachute (feet per second)
VYP	Vertical velocity of parachutes (feet per second)
VA	Total speed of aircraft (feet per second)
VP	Total speed of parachute (feet per second)
T	Time (accumulation of increments) (seconds)
S	Distance between payload and parachute (feet)
THETR	Angle between payload and parachute, measured from horizontal (degrees)
Z	Parachute diameter at time "T" (feet)
EINFT	Time since parachute began inflating (seconds)
E	Effective air volumn entrapped in the parachute
PMASS	Parachute mass (slugs)
TENS	Tension between payload and parachutes (pounds)
DRAGP	Parachute drag (pounds)
DXP	Horizontal vector of parachute drag (pounds)
DYP	Vertical vector of parachute drag (pounds)
CXP	Parachute horizontal force (pounds)
FYP	Parachute vertical force (pounds)
FP	Total force of parachute (pounds)
THETP	Parachute force angle (degrees)
AXP	Acceleration of parachute, horizontally (feet per second^{2})
AYP	Acceleration of parachute vertically (feet per second^{2})
DRAGA	Drag of payload (pounds)
DXA	Horizontal vector of payload drag (pounds)
DYA	Vertical vector of payload drag (pounds)
R	Rocket thrust (pounds)
FXA	Horizontal force on payload (pounds)
FYA	Vertical force on payload (pounds)

FA	Total force on payload (pounds)
THETA	Force angle on payload (degrees)
AXA	Horizontal acceleration of payload (feet per second^2)
AYA	Vertical acceleration of payload (feet per second^2)
VXA	Horizontal velocity of payload (feet per second)
VYA	Vertical velocity of payload (feet per second)
VA	Total velocity of payload (feet per second)
BETAA	Trajectory angle of payload (degrees)
BETAP	Trajectory angle of parachute (degrees)

4.3.2 Recovery System Trajectory Input Definitions

WA	Weight of payload (pounds)
XA	Initial range of payload (feet)
YA	Initial altitude of payload (feet)
VXA	Initial horizontal velocity (feet per second)
VYA	Initial vertical velocity (feet per second)
TRHOA	Air density (otherwise program solves it based on initial altitude) (slugs/ft^3)
ROCTS	Rocket table indicator. If zero, a constant rocket thrust is input later (RO). If positive, rocket table is used to determine thrust, then thrust is multiplied by the value given to ROCTS. (integer)
VPE	Initial velocity of parachute extraction (feet per second)
PHI+	Angle from horizontal at which parachute is initially extracted. (degrees)
AVOLK	Effective entrapped air volumn constant
AINER	Air inertia value
FILLK	Parachute filling exponent (integer)
DELT	Computing time increment (seconds)
FILLT	Parachute fill time (seconds)
TRSTM	Rocket thrust time if rocket thrust table is not used (seconds)
PRNTM	Computer print-out interval (seconds)
SO	Suspension line length (feet)
AREAX	Area of pilot parachute (square feet)
CA	Drag coefficient of payload
RO	Rocket thrust if table is not used (pounds)

ROALT	Rocket initiation altitude (feet)
CP	Drag coefficient of parachute
ZO	Cut diameter of parachute (feet)
AREAA	Drag area of aircraft (square feet)
WP	Effective weight of all parachute canopies (pounds)
ZON	Number of parachutes
ELASK	Elastic coefficient of suspension lines (pounds per foot of elongation)

The initial parameters are established which have not been defined thoroughly by input data. The density of the air is determined based on the system initial altitude, in the absence of input for that value.

$$\rho = 0.00238/e^{(0.0000415\ Y_a)}$$

where ρ = air density

The parachute initial velocity is determined (in the "x" direction) by

$$Vxp = V_{pe} \cdot \cos \emptyset + V_{xa}$$

where V_{xp} = initial horizontal velocity of the parachute (ft/sec.)

$\emptyset$ = extraction angle of the parachute (degrees)

V_{xa} = initial horizontal velocity of the payload (ft/sec.)

The parachute initial vertical velocity is determined by

$$V_{yp} = V_p \cdot \sin \emptyset + V_{ya}$$

where V_{yp} = initial vertical velocity of the parachute (ft/sec)

V_{ya} = initial vertical velocity of the payload (ft/sec)

The total velocity of the payload is determined by

$$V_a = \sqrt{V_{xa}^2 + V_{ya}^2}$$

where V_a = total velocity of the payload

The total velocity of the parachute is determined by

$$V_p = \sqrt{V_{xp}^{\;2} + V_{yp}^{\;2}}$$

where V_p = total velocity of the parachute

The primary loop of the program follows the determination of the initial conditions.

The distance between the parachute and the payload is determined by

$$S = \left[(X_a - X_p)^2 + (Y_a - Y_p)^2\right]^{1/2}$$

where S = absolute value of the distance between the parachute and the payload.

The relative angle between the payload and the parachute is determined by a horizontal line through the payload and the line between the payload and the parachute and is measured with the second quadrant being positive.

$$\theta_r = \text{atan}\left[-(Y_a - Y_p) \; / \; (X_a - Y_p)\right]$$

The time is incremented by

$$t_i = t\,(i-1) + \Delta t$$

where t_i = total time at iteration number "i"
Δt = computational time increment

If the suspension lines have been extracted to their full length, the parachute begins to open.

$$Z = \frac{2.\, Z_o \cdot\, (T_e/T_f) * K_f}{3}$$

where Z = diameter at time "t"
Z_o = cut diameter of the parachute
T_e = time elapsed since line stretch
T_f = total time required for parachute opening to complete

K_f = constant which defines parachute opening curve

(If a particular table of parachute diameter vs. time has been input, the table is used in lieu of the above equation). When the parachute reaches its maximum diameter of $2/3 . Z_o$, it ceases increasing.

The drag area of the parachutes is defined by

$$A_p = \left[(0.785 . Z^2) + (0.005 . Z_o^2) \right] . N_z$$

where A_p = total circular drag area of all parachutes
N_z = total number of parachutes

The length of the squid during inflation is determined by

$$E = \left[\frac{Z_o^2}{4.93} - \frac{Z^2}{4} \right]^{1/2} . K_{av}$$

where E = total squidded length
K_{av} = air volumn constant

Then the parachute mass is

$$M_p = A_p . \rho . E + Z_n . W_p / 32.2$$

where M_p = mass of the parachutes

Payload mass is defined as

$$M_a = W_a / 32.2$$

where M_a = mass of payload

Tension between the parachutes and the payload is defined as

$$T = K_e . (S - S_o)$$

where T = tension
K_e = elastic coefficient of the suspension lines
S_o = length of the suspension lines when not under load

The drag of the parachutes is defined by

$$D_p = C_p \cdot A_p \cdot 0.5 \cdot \rho \; V_p^2$$

where D_p = drag of the parachutes
C_p = drag coefficient of the inflated parachute

The drag is broken up into horizontal and vertical components by trignometric relationships.

$$D_{xp} = D_p \cdot \left| V_{xp} / V_p \right|$$

$$D_{yp} = D_p \cdot \left| V_{yp} / V_p \right|$$

where D_{xp}=drag of the parachutes in the horizontal direction
D_{yp}= drag of the parachutes in the vertical direction.

The drag values are then signed according to the appropriate direction, and the total forces on the parachutes, are solved and summed.

$$F_{xp} = D_{xp} + \frac{T \cdot (X_a - X_p)}{S}$$

$$F_{yp} = D_{yp} + \frac{T \cdot (Y_a - Y_p)}{S} - W_p$$

where F_{xp} = force exerted on the parachutes in the horizontal direction
F_{yp} = force exerted on the parachutes in the vertical direction

Total parachute force is the following:

$$F_p = \sqrt{F_{xp}^2 + F_{yp}^2}$$

where F_p = total force on the parachutes

The force angle of the parachutes is defined by

$$\Theta_p = \operatorname{atan}\left(\frac{F_{yp}}{F_{xp}}\right)$$

where Θ_p = force angle of the parachutes

The accelerations of the parachutes are defined horizontally and vertically:

$$A_{xp} = \frac{F_{xp}}{M_p}$$

$$A_{yp} = \frac{F_{yp}}{M_p}$$

where A_{xp} = parachute acceleration, horizontally
A_{yp} = parachute acceleration, vertically

The velocity of the parachutes is

$$V_{xpi} = V_{xp}(i-1) + A_{xp} \cdot \Delta t$$

$$V_{ypi} = V_{yp}(i-1) + A_{yp} \cdot \Delta t$$

where V_{xpi} = parachute horizontal velocity at time increment "i"
V_{ypi} = parachute vertical velocity at time interval "i"

Total parachute velocity is

$$V_p = \sqrt{V_{xpi}^2 + V_{ypi}^2}$$

where V_p - total velocity of the parachute

The positions of the parachute are found to be:

$$X_{pi} = X_{p\,(i-1)} + V_{xp\,(i-1)}\Delta t + 1/2 \,.\, A_{xp} \,.\, (\Delta t)^2$$

$$Y_{pi} = Y_{p\,(i-1)} + Y_{yp\,(i-1)}\Delta t + 1/2 \,.\, A_{yp} \,.\, (\Delta t)^2$$

where X_{pi} = horizontal position of the parachutes
Y_{pi} = vertical position of the parachutes

Behavior of the payload is similarly determined, with the exception that rocket thrust vectors are added to the suspension line tension vectors in the aircraft force equations.

$$D_a = C_a \,.\, A_a \,.\, 0.5 \, \rho \,.\, V_a^2$$

where D_a = drag of the payload (total)
C_a = drag coefficient of the payload

The total drag is broken up into horizontal and vertical components by trignometric relationships.

$$D_{xa} = D_a \,.\, \left| V_{xa}/V_a \right|$$

$$D_{ya} = D_a \,.\, \left| V_{ya}/V_a \right|$$

where D_{xa} and D_{ya} are horizontal and vertical drag forces, respectively.

The drag forces are signed appropriately and the horizontal force vectors are summed, including the rocket force when appropriate.

$$F_{xa} = -D_{xa} - T \cdot \frac{X_a - X_p}{S} - R \cdot \frac{X_a - X_p}{S}$$

where F_{xa} = total horizontal force exerted on the payload
R = total rocket force

The total vertical force also includes the rocket vector, plus the payload weight.

$$F_{ya} = -D_{ya} + T \cdot \frac{Y_p - Y_a}{S} - W_a + R \cdot \frac{Y_p - Y_a}{S}$$

where F_{ya} = total vertical force vector for the payload.

The total force exerted on the payload is

$$F_a = \sqrt{F_{xa}^2 + F_{ya}^2}$$

where F_a = total force exerted on the payload.

The angle at which the force is exerted on the payload is

$$\Theta = \operatorname{atan}\left(\frac{F_{ya}}{F_{xa}}\right)$$

where Θ = payload force angle.

The accelerations of the payload are described by

$$A_{xa} = F_{xa} / M_a$$
$$A_{ya} = F_{ya} / M_a$$

where A_{xa} and A_{ya} are horizontal and vertical accelerations, respectively.

The velocities of the payload are

$$V_{xai} = V_{xa(i-1)} + A_{xa} \cdot \Delta t$$

$$V_{yai} = V_{ya(i-1)} + A_{ya} \cdot \Delta t$$

where V_{xai} and V_{yai} are horizontal and vertical velocities, respectively, at the "i" th time interval. The total velocity of the payload is the vectoral sum;

$$V_a = \sqrt{V_{xai}^{\ 2} + V_{yai}^{\ 2}}$$

where V_a = total velocity of the payload

The tangent to the payload trajectory at time "t" is

$$\beta_a = \text{atan} \left(\frac{-V_{yai}}{V_{xai}} \right)$$

where β_a = angle (in the second quadrant) of the payload trajectory.

The position of the payload at time "t" is determined by

$$X_{ai} = X_{a(i-1)} + V_{xa} \cdot \Delta t + 1/2 \cdot A_{xa} \cdot (\Delta t)^2$$

$$Y_{ai} = Y_{a(i-1)} + V_{ya} \cdot \Delta t + 1/2 \cdot A_{ya} \cdot (\Delta t)^2$$

The following information, in addition to all inputs, is printed at the time interval specified in the input:

T	time elapsed since system activation (seconds)
YA	new altitude of the payload (feet)
XA	new range of the payload (feet)
VYA	vertical velocity of the payload (feet per second)
VXA	horizontal velocity of the payload (feet per second)
Q	angle between the horizontal and the tension vector (degrees)
S	distance between payload and parachutes (feet)

DRAGA	total parachute drag (pounds)
Z	individual parachute diameter (feet)
TENS	tension in the suspension lines (pounds)
R	rocket thrust (pounds)
YP	parachute altitude (feet)
XP	parachute range (feet)
VYP	vertical velocity of parachutes (feet per second)
VXP	horizontal velocity of parachutes (feet per second)
BETAD	trajectory angle of the payload (degrees)
DRAGP	parachute drag

4 4 Reliability

The overall operational reliability of the PRAD System is very high. The prototype system has eliminated the deficiencies discovered in the test hardware performance and a concerted effort to simplify the entire system has yielded significant improvement in rigging procedures. Further modifications will become apparent during the engineering development program. Most of these problems are solved by an overall system approach to the hardware and rigging requirements. Every effort has been expended to assure universal rigging procedures throughout the dropload weight range. This simplification has allowed the tremendous reductions in system preparation time and placed minimum emphasis on the need for highly skilled rigging personnel at all levels except the final rigging checkout procedure.

Table 4.2 lists major hardware improvements based upon deficiencies discovered during exploratory system testing.

TABLE 4.2

Known Test Problems	Proposed Design Fix
Riser Extension Failures	Stronger Extensions
False Altitude Sensing by Probes	Laser Altimeter Proposed
Suspension Sling Failure due to rocket blast	Single Rocket Pack with Nozzles Spaced Farther About a Larger Radius
Excessive Tip-Off Rates	Change to Longer Extraction-Force Transfer Lanyard
Excessive Force Inputs Into Suspension Slings at Rocket Ignition	Change Rocket to a "Soft" Ignition Design to Minimize Bridle Dynamic Loads
Rocket End Cap Failure	New Rocket Motor Design
Excessive Parachute Opening Shock	Modified Parachute Design With Open Ring Near Apex
Complicated Ignition System Circuit	Simplified Electric Solenoid Gas Valve Proposed Incorporating Full Protection from Unprogrammed Rocket Ignition

4.4.1 Rigging Procedure Errors

As with conventional aerial delivery systems, the most prevalent PRADS failure is due directly to procedure errors. This further indicates that the complexity of any airdrop system has to be minimized to increase the operational reliability levels. The adaptation of "fail-safe" procedures in the rigging of vehicles for airdrop is seen as one major area of needed improvement. The continuation of 100 percent inspection of all rigging stations and procedures is necessary to attain satisfactory operational reliability levels. It became obvious during the test program that the complexity of the safety system was contributed to by the several different lanyards which pulled pins, activated timers and allowed series events to occur was avoidable by a better design approach. The prototype system allows a more positive time sequencing, yet is straight forward using two lanyards and an electronic timing circuit to program rocket initiation. These series events allow positive control over system arming, yet they are easily rigged and checked. Close observance of human factors engineering requirements has provided significant overall improvement in the specific rigging steps and contributed to a higher overall system reliability.

4.4.2 Parachute Packing Improvements

The parachute packing procedure for the PRADS 48 foot diameter parachutes will be essentially the same as for the 46 foot parachutes tested under this contract. The packing bag thus evolved will be straight forward with a design that permits self-checking and inspection of all important phases of the packing procedures. The light weight of the packed parachute will be such that critical inspection of pack closing operations should not be omitted because of difficulty in lifting the pack or in turning it around for closer inspection.

The basic bag design allows self-checking at minimum inconvenience further simplifying packing by isolating the canopy, suspension lines, and risers into separate compartments within the bag assembly. Reasonable care exercised during the packing procedure will increase the probability of successful chute deployment.

Utilization of pack length zippers along both sides of the pack allows easy closing of the pack with quickly secured break ties at the bottom flap and at locations along the interior stows of the risers, suspension lines and canopy material, make difficult many of the frequent packing errors now common with in-service cargo parachutes.

Since the canopy and suspension lines are of heavy duty design, operational reliability will be very high throughout the design range of requirements. Overall parachute reliability should be capable of exceeding 0.998 at the 90 percent confidence level.

4.4.3 Parachute System Reliability

The heavy duty 48 foot diameter parachute is constructed strong enough to withstand opening shock under infinite mass loading at 130 knots airdrop conditions without failure. The airdrop failures associated with the parachute disconnect mechanism have been eliminated since this device is not used in PRADS. The adaptation of heavy duty riser extensions and risers will assure higher margins of safety and enhance system reliability. An overall parachute subsystem operational reliability is estimated to be greater than 0.998.

4.4.4 Ground Sensing System Reliability

As demonstrated under the test phase of this contract, the flexible ground sensing probe has reliability problems when placed in an active environment such as cargo airdrops. For this reason, alternate altimeter methods were investigated and a simple laser system was selected to trigger the rocket initiation sequence. Section 4.6 presents the supporting information developed for this trade off analysis. A major factor in reliable operation of the altitude sensing unit is the ease of installation of the unit in a fail-safe manner. Presently, details are not sufficiently defined to offer a complete explanation of the mounting system required. Further work is indicated in this area and prototypes should be completely analyzed with human factors the preeminent consideration. The achievement of a workable design will be dependent upon a very high reliability at the rigging level with supervisory requirements both easily identified and checked as to their correctness.

The altitude sensing system will be required to demonstrate ultra high reliability as a part of its qualification program. Proof of operation at a reliability level of 0.9999 at a 90 percent confidence level is required by the subsystem specification. Since the unit is electronic and easily refurbished, this high reliability can be established at a moderate cost level.

4.4.5 Rocket Motor Reliability

The rocket motor reliability must be very high for the PRAD System. The failure of one rocket motor in a given configuration will allow excessive impact velocity causing an unknown degree of damage to the dropload. The design goal for rocket reliability has been established as 0.999. This value is to be determined by methods other than a full reliability demonstration program. Comparison of the design and manufacturing procedures to existing motors of high reliability and component testing programs will have to supply the data required in order to keep the motor qualification costs at a reasonable level.

4.4.6 Rocket Pack Reliability

The incorporation of nondestructive tests and competent design practices assure the rocket pack of a high operational reliability. The mass and strength of the pack afford good protection for this item in field use. The high pressure gas system is considered a part of the rocket pack for this discussion. This gas supply subsystem will be subjected to a full qualification program at minimum cost since the unit suffers no damage in its operation cycle. The unit is fully enclosed within the rocket pack and will see little or no destructive forces in actual airdrop operation. The operational reliability of the rocket pack assembly is estimated to be at least 0.999.

4.4.7 Overall System Hardware Reliability

The subsystems as herein discussed operate as series events in airdrop operation. The overall hardware reliability is established by multiplying the individual reliabilities of these components together. This would indicate an inherent operational reliability level of from 0.984 to 0.975 over the system configuration range. The reliability of the all parachute M-37 type vehicle is defined as a parallel event constituted by performance of each of the eight parachutes. This argument indicates that the inherent reliability for this configuration is:

1.000 - (No. chutes * chute failure rate)
= 1.000 - (8 x .002)
= 0.984

The inherent reliability of the configuration required to airdrop the M-551 vehicle or other 35,000 pound dropload is somewhat more complicated since 12 rocket motors and the rocket pack and the altimeter system must perform according to their design specifications in addition to each of the six 48 foot diameter parachutes. This reliability is defined by:

parachute system reliability * altimeter reliability

*rocket pack reliability * rocket motor system reliability

(1.0 - 6 x .002) * 0.9999 * 0.999 *
(1.0 - 12 * .001) =

0.988 * 0.9999 * 0.999 * 0.988 = 0.975

This analysis assumes that the failure of one parachute or one rocket will effect system operation significantly and, therefore, treats them as series events in the reliability network.

Refinement of these reliability estimates is dependent upon analysis of the prototype hardware under field test conditions and use and upon a continued improvement program. Actual qualification test data for the rockets and parachutes will have a major part in improving the reliability estimates for PRADS. Achievement of a system reliability of 0.995 will be possible and will not require system improvements other than minor design and human factors concessions.

4.5 <u>Sling Force At Rocket Firing</u>

<u>Glossary of Symbols</u>

a, b, Θ_2 & Θ_3 - Arbitrary constants used in computation.

C_1 - Fraction of total burn time to full thrust.

D - Damping constant.

F_B - Suspension sling total force.

F_m - Total rocket vertical thrust.

K - Suspension sling force elongation constant.

m - Mass of rocket pack.

SR - Slope of rocket force buildup (ramp).

T - Period of natural frequency of rocket pack with respect to load.

t_1 - Time to full rocket thrust from ignition.

t_b - Total rocket burn time.

x - Position of rocket pack with respect to load.

x - Velocity of rocket pack with respect to load.

4.5.1 Problem Statement

Can a reduction in the peak forces occurring in the suspension bridle lines be accomplished by generating a ramp type of thrust rise in the retrorocket for a parachute-retrorocket recovery system?

4.5.2 Assumptions

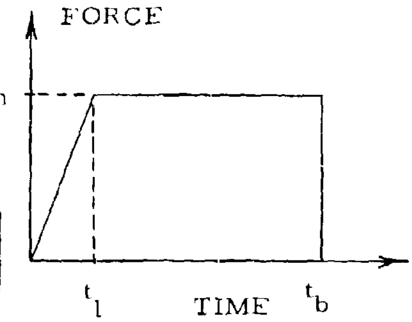
a. The rocket thrust shall be a ramp function to maximum force level at t_1 ($t_1 = C_1\ t_b$) and shall be constant thereafter until burnout t_b.

b. As the slope of the ramp function is varied, the total rocket impulse will remain constant at 1000 units.

c. The test results on the PRADS drop at El Centro will be used as basis for determining the system parameters.

4.5.3 Calculation of Ramp Slope

$$t_1 = C_1 t_b \quad \ldots\ldots\ldots\ldots \quad 1$$



$$\text{Total impulse} = F_m \left[\frac{C_1 t_b}{2} + t_b - C_1 t_b \right]$$

$$= F_m t_b \left[1 - C_1/2 \right] = 1000 \text{ units} \quad \ldots\ldots \quad 2$$

$$\therefore \quad = F_m = \frac{1000}{t_b \left(1 - C_1/2\right)} = \frac{2000}{t_b \left(2 - C_1\right)} \quad \ldots\ldots \quad 3$$

$$S_r = \text{Ramp Slope} = \frac{F_m}{t_1} = \frac{2000}{t_b^2 C_1 \left(2 - C_1\right)} \quad \ldots\ldots \quad 4$$

in the PRADS tests $t_b \cong 0.5$ sec.

$$\therefore \quad S_r = \frac{8000}{C_1 \left(2 - C_1\right)} \quad \ldots\ldots\ldots\ldots \quad 5$$

C_1	.02	.04	.06	.08	.1	.12
S_r	202,000	102,000	68,800	52,200	42,100	35,500

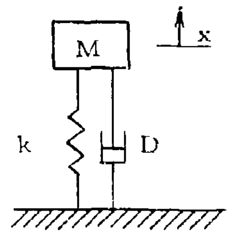
C_1	.14	.16	.18	.20	.3
S_r	30,750	27,200	24,400	22,200	15,700

4.5.4 <u>Calculation of Suspension Sling Forces</u> (Figure 4.15)

AT: $t = 0, \quad x = \dot{x} = 0$

LET: $a = \dfrac{D}{2m}$

$$b = \sqrt{\frac{K}{m} - a^2}$$



Simplified System Schematic

Then for time in the interval: $C_1 t_b \leq t \leq t_b$,

$$F_b = S_r \left\{ t-(t-C_1 t_b) + \frac{e^{-at}}{b} \operatorname{Sin}(b_t + \Theta_2) - \frac{e^{-a(t-C_1 t_b)}}{b} \left[\operatorname{Sin}\left[b(t-C_1 t_b) + \Theta_2 \right] \right] \right\} *$$

$$= S_r \left\{ C_1 t_b + \frac{e^{-at}}{b} \left[\operatorname{Sin}(b_t + \Theta_2) - e^{+aC_1 t_b} \operatorname{Sin}(b_t + \Theta_3) \right] \right\} \text{-------} 6$$

where $$\Theta_2 = \text{ARCTAN} \left[\frac{b/a}{1 - \frac{K}{2ma^2}} \right]$$

$$\Theta_3 = \Theta_2 - b\, C_1 t_b$$

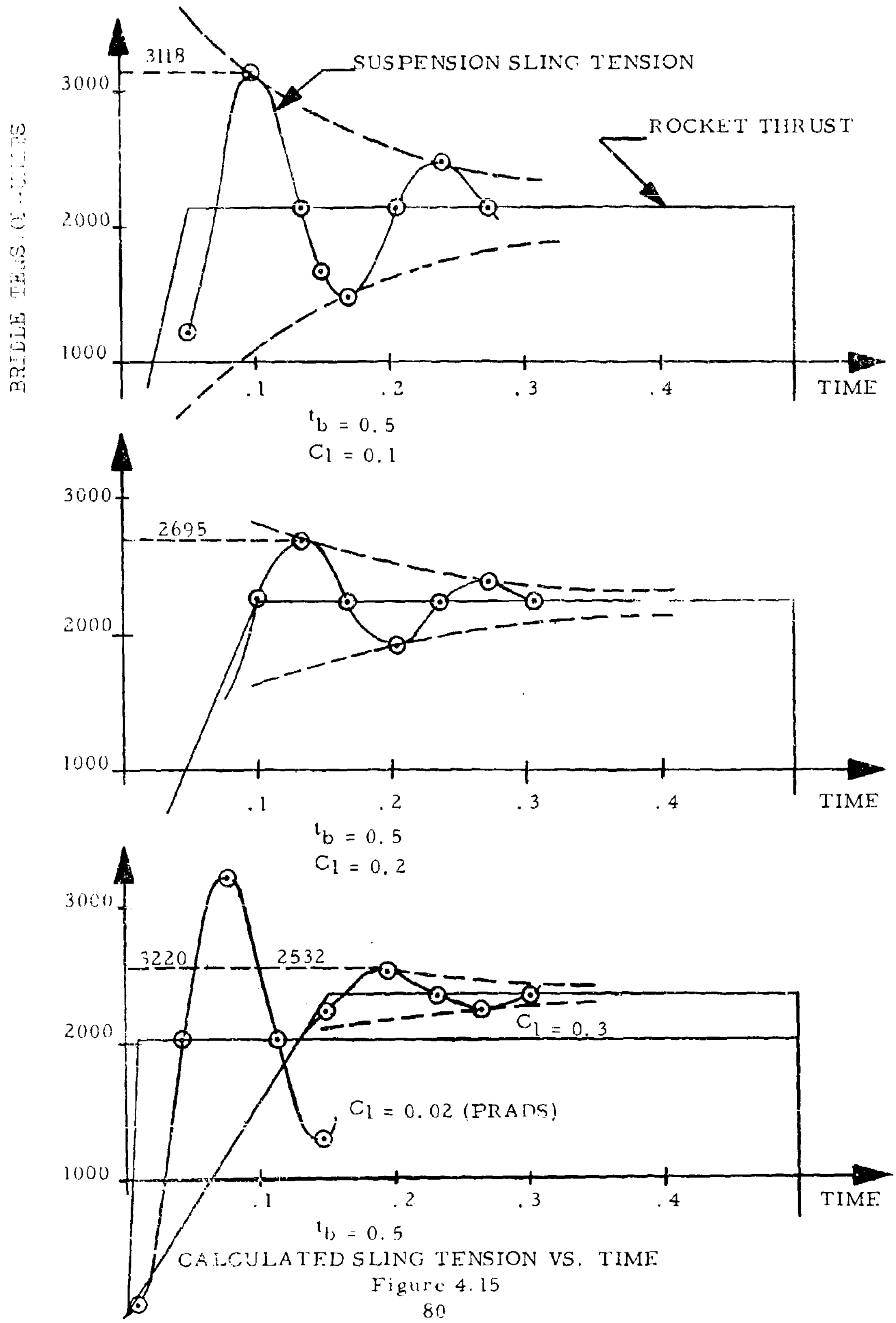
*Applied mathematics for Engineers and Physicist, Louis A. Pipes, Chapter VIII

4.5.5 <u>Parameter Evaluation</u> (Figure 4.16)

In PRADS Test No. 202-19, the following values were realized

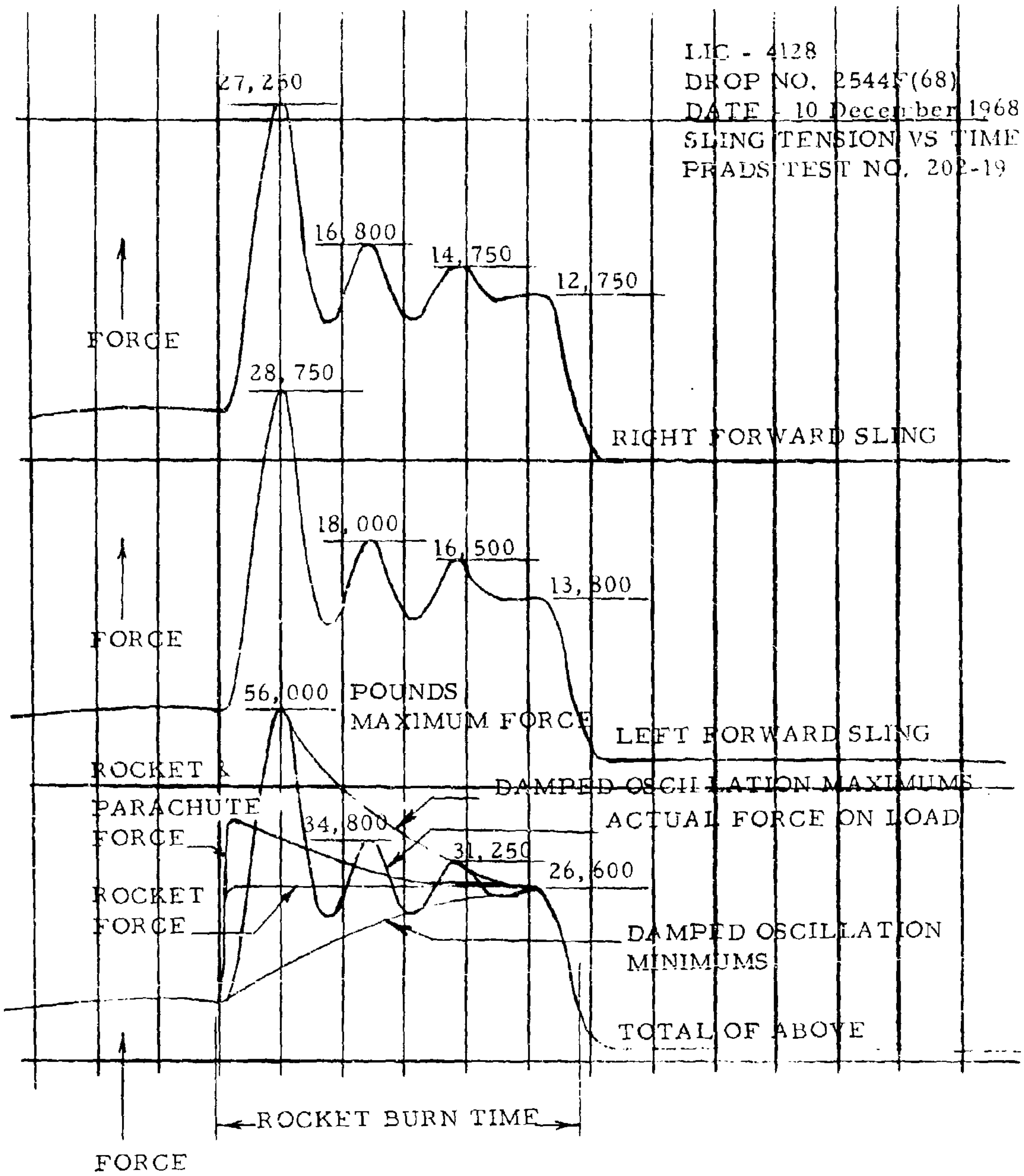
$$T = \frac{.28}{2} = .14 \text{ sec.}$$

$$b = \frac{2\pi}{T} = 44.9 \text{ Rad./Sec.}$$



CALCULATED SLING TENSION VS. TIME

Figure 4.15



ACTUAL SLING TENSION VS TIME

Figure 4.16

in the period of 2T, the amplitude of bridle force decayed from 37/16" to 5/16 inch and therefore: Ref. Figure 4.16

$$e^{a(2T)} = 1.70/.23 = 7.4$$

$$a(.28) = \ln 7.4 = 2.0$$

$$a = \frac{2.0}{.28} = 7.14$$

4.5.6 System Constants :

$$m \text{ (rocket pack)} \cong \frac{1140}{32.2} = 35.4 \text{ Slugs}$$

$$D = 2m\,(a) = (70\ 8)\,(7.14) = 506 \text{ lb./ft/sec.}$$

$$K/m = a^2 + b^2 = (7.14)^2 + (44.9)^2 = 51 + 2015 = 2066$$

$$K = (35.4)(2066) = 73,100 \text{ lb/ft}$$

$$\Theta_2 = \text{ARCTAN}\left\{\frac{44.9/7.14}{1 - \frac{2066}{2(51)}}\right\} = \text{ARCTAN}\left\{\frac{6.29}{19.25}\right\}$$

$$= 162^{\circ} = 2.83 \text{ RAD.}$$

$$\Theta_3 = 2.83 \text{ RAD} - C_1\,(22.45)$$

4.5.7 Calculated Force - Curves

4.5.7.1 $C_1 = 0.1$

$aC_1t_b = .357$, $bC_1t_b = 2.245 \text{ RAD} = 128.8^{\circ}$

$S_r = 42,100$; $\Theta_3 = 2.83 - 2.245 = .585 \text{ RAD}$

$$F_b = \frac{42,100}{44.9}\left\{2.245 + e^{-7.14t}\left[\begin{matrix}\text{Sin } (bt+2.83) - \\ - 1.429 \text{ Sin } (bt+\Theta_3)\end{matrix}\right]\right\}$$

$$F_b = 938\left\{2.245 + e^{-7.14t}\left[-.951 \text{ Sin } bt + .309 \text{ Cos } bt - 1.191 \text{ Sin } bt - .789 \text{ Cos } bt\right]\right\}$$

$$= 2105 + 938e^{-7.14t}\left[-2.142 \text{ Sin } bt - .480 \text{ Cos } bt\right]$$

$$= 2105 - 2060e^{-7.14t} \text{ Sin } (bt + .220)$$

$$b = 44.9 \text{ RAD/Sec}$$

t	bt	Sin (bt+.22)	$e^{-7.14t}$	F_B
.05	2.245	.626	1/1.429	2105 - 903 = 1202 Units
.099	4.44	-.999	1/2.028	2105 + 1013 = 3118 Units
.150	6.74	.626	1/2.916	2105 - 442 = 1663 Units
.135		0		2105 Units
.2055	9.222	0		2105 Units
.170	7.63	+1.0	1/3.36	2105 - 613 = 1492 Units
.240	10.765	-1.0	1/5.53	2105 + 372 = 2477 Units
.276				2105 Units

$\therefore$ % Overshoot = $\frac{1013}{2105}$ = 48.1%

4.5.7.2 $C_l = 0.2$

$$aC_l t_b = .714$$

$$bC_l t_b = 4.49 \text{ RAD.}$$

$$S_r = 22,200$$

$$\Theta_3 = 2.83 - 4.49 = -1.166 \text{ RAD.}$$

$$F_b = 2220 + 495e^{-7.14t}\left\{\text{Sin } (bt + 2.83) - e^{.714} \text{ sin } (bt - 1.66)\right\}$$

$$= 2220 + 495e^{-7.14t}\left\{-.951 \text{ Sin } bt + .309 \text{ Cos } bt - 2.04\left[-.089 \text{ Sin } bt - .996 \text{ Cos } bt\right]\right\}$$

$$= 2220 + 495e^{-7.14t}\left\{-0.769 \text{ Sin } bt + 2.344 \text{ Cos } bt\right\}$$

$$= 2220 + 1221e^{-7.14t}\left[-.312 \text{ Sin } bt + .950 \text{ Cos } bt\right]$$

$$= 2220 - 1221e^{-7.14t} \text{ Sin } (bt - 1.253)$$

% Overshoot = 21.4%

$C_l = .2$, $.2t_p = .1$

t	bt	$\frac{\text{Sin}}{\text{Cos}}(bt-1.253)$	$e^{-7.14t}$	F_B
.10	4.49	-.095	1/2.04	2220+56.8 - 2277
.132	5.945	-1.0	1/2.575	2220+475 = 2695
.168	7.536	0		2220
.203	9.086	+1.0	1/4.26	2220-287 = 1933
.238		0		2220
.273	12.228	-1.0	1/7.0	2220+175 = 2395
.308				2220

4.5.7.3 $C_1 = 0.3$

$aC_l t_b = 1.071$

$bC_l t_b = 6.74$

$S_r = 15,700$

$\Theta_3 = 2.83 - 6.74 = -3.91$ RAD

$$F_B = 2355 + 350e^{-7.14t}\left\{\text{Sin}\,(bt + 2.83) - 2.92\ \text{Sin}\,(bt - 3.91)\right\}$$

$$= 2355 + 350e^{-7.14t}\left\{(\text{Sin}\ bt)\left[-.951 + (.719)(2.92)\right] + (\text{Cos}\ bt) - \left[.309 - (2.92)(.695)\right]\right\}$$

$$= 2355 + 350e^{-7.14t}\left\{(\text{Sin}\ bt)\ (1.149) - (\text{Cos}\ bt)\ (1.721)\right\}$$

$$= 2355 + 724\ \left\{\text{Sin}\ (bt - .982)\right\}\ e^{-7.14t}$$

t	bt	$\frac{\text{Sin}}{\text{Cos}}(bt-.982)$	$e^{-7.14t}$	F_B
.15	6.74	-.501	1/2.92	2355 - 124 = 2230
.162	7.265	0		2355
.197	8.836	+1.0	1/4.08	2355+177 = 2532
.232	10.407	0		2355
.267		-1.0	1/6.71	2355-108 = 2247
.302				2355

% Overshoot = 7.5%

4.5.7.4 $C_1 = .02$ (PRADS Rocket Approximation)

$aC_1t_b = .0714$
$bC_1t_b = .449$
$S_r = 202,000$
$\Theta_3 = 2.83 - .449$

$$F_B = 2020 + 4500e^{-at}\left\{\text{Sin}(bt+2.83) - 1.074(\text{Sin } bt + 2.381)\right\}$$

$$= 2020 + 4500e^{-at}\left\{-.951\text{ Sin } bt + .309\text{ Cos } bt + 1.074(.724)\text{Sin } bt - 1.074(.690)\text{ Cos } bt\right\}$$

$$= 2020 + 4500e^{-at}\left\{(.777 - .951)\text{ Sin } bt + (.309 - .741)\text{ Cos } bt\right\}$$

$$= 2020 + 4500e^{-at}\left\{-.174\text{ Sin } bt - .432\text{ Cos } bt\right\}$$

$$= 2020 - 2100e^{-at}\left\{\text{Sin}(bt + 1.189)\right\}$$

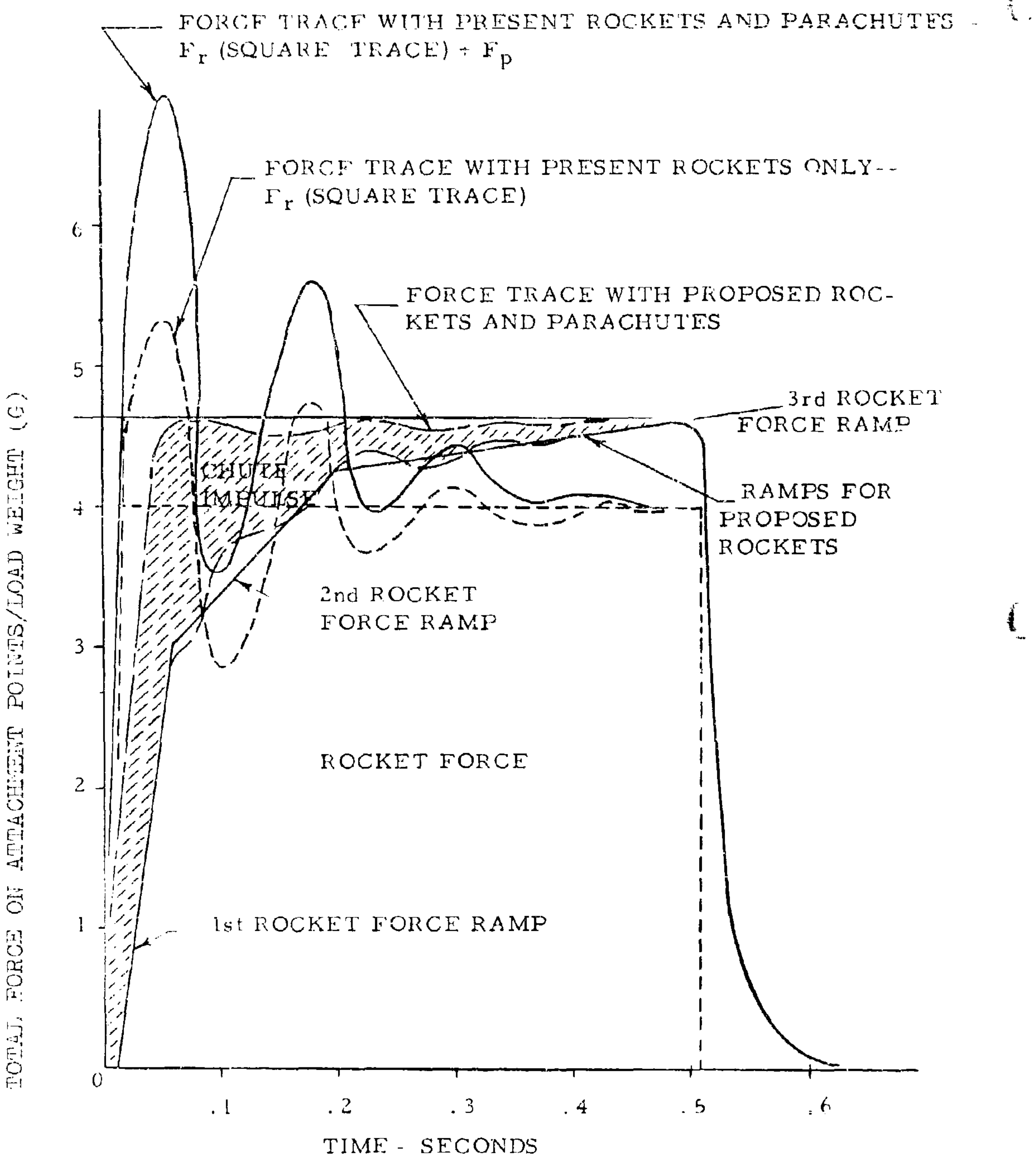
t	bt	Sin (bt+1.189)	$e^{-7.14t}$	F_B
.01	.449	+.998	1/1.074	2020-1950 = 70
.0436	1.953	0		2020
.0785	3.524	-1.0	1/1.752	2020+1200 = 3220
.1134	5.095	0		2020
.1485	6.665	1.0	1/2.88	2020-730 = 1290

$\therefore$ % Overshoot $= \frac{1200}{2020} = 59.5\%$

4.5.8 <u>Conclusions</u>

1 A ramp type of thrust rise will reduce the resulting sling tension overshoot from as much as 60% to less than 10%. Refer to Figure 4.17.

ROCKET THRUST, F, IS OUTLINED BY RAMPS 1, 2, 3 and TAILOFF



ROCKET THRUST RAMPS
Figure 4.17

2. The optimum slope for the ramp is a function of the mass of the rocket pack and the elongation spring constant of the sling. The ramp rise time should be in the order of 70 percent of the rocket pack oscillation period.

3. Progressive burning of the rocket grain should be provided after the initial ramp type thrust rise to compensate for the first overshoot and for the parachute riser forces.

4.6 Absolute Altitude Sensing

A review of the system proposed for PRADS - The Parachute Retro-rocket Airdrop System.

Statement of the Problem

Because of certain combinations of speed, attitude, altitude, and motion rates, the recovery of a dropload via a system which requires ignition of a recovery rocket presents special problems to an altitude sensing system.

Without belaboring a description of complete system performance requirements and problematical situations, it may be briefly stated that not only must the selected system satisfy many dynamical requirements, but it must also be reliable, accurate, light, relatively inexpensive, and be capable of unambiguous determination of absolute altitude above a surface able to support the recovered dropload.

Background

Fruitful research of the literature (Ref. 1 and 2), considerable experience with and testing of similar systems (Ref. 3 and 4) and liaison with manufacturers of applicable equipment (Ref. 5 thru 8) has facilitated the selection of a system which, at this time, most satisfactorily meets the requirements.

Final selection was made from five candidate systems, and a summary of the characteristics of the systems which were eliminated, and a technical discussion of the selected system, are provided for comparison.

Pseudo-Random-Noise Altimeter

In the Pseudo Noise Altimeter, a noise like signal is used to modulate an r-f carrier. The time delay between transmitted and received signals is proportional to altitude. Digital sequences are often used as the noise modulation signals since they are relatively easy to implement and control. The advantages of the pseudo noise system are: (1) range ambiguities can be avoided (2) peak power is avoided since the signal is transmitted continuously; (3) the correlation functions, which are used to measure time delay and thereby altitude, resemble short, narrow impulse functions, thus providing an inherent capability for high resolution. A disadvantage is that the noise modulation ranging techniques are relatively new and undeveloped. This system is resistant to extraneous inputs which cause false altitude readings. A development program can solve most of the present restrictions on this system as state-of-art advances are frequent in this area. Presently, development cost estimates for this system are high and lead time is about six months. For these reasons, Pseudo-Random Noise Radar Altimeters are a second choice to a laser system.

Pulse Radar

A pulse radar determines altitude by measuring the time delay between transmitted and received (echo) pulses. In order to avoid interference between transmitted and received signals, short pulses are required. For this application, the pulse width requirement is a fraction of a nanosecond, which is currently achievable. One of the primary advantages of a pulse radar technique is its relative simplicity. This simplicity is reduced as protection circuits are added to minimize ECM and other false signals to which the basic system is vulnerable.

Sonic Altimeter

Sonic altitude sensing principles are similar to radio altitude sensing principles except for the medium utilized. Sonic devices have a relatively slow reaction time as compared to radio devices. Compensation for the slow reaction time involves added system complexity. Further complexity results by making the sensing accurate over a range of temperatures and atmospheric pressures.

Mechanical Probes

The basic mechanical probe is a device, extended from the vehicle on command prior to reaching the critical altitude, to sense when contact is made with the landing surface. Two general types, flexible and rigid, with numerous variations in techniques, have demonstrated capability in similar applications. Mechanical probes are highly reliable and can operate independently of ambient light levels and the presence of dust, rain or fog. The flexible probe's accuracy is degraded by oscillation of the load platform and wind conditions. Because of its dependence upon stable conditions at activation, the mechanical probe requires major improvements to be usable as an initiation signal for rocket ignition.

Optical Altimeters

Optical altimeters in general are subject to calibration problems created by variable attenuation and reflection problems. Dust, fog, rain and snow produce varying attenuation of light. In addition, some optical altimeters are affected by varying ambient light levels such as the contrast between day and night.

Active Optical Altitude Sensors (Laser)

The Active Optical Altimeter determines altitude by the reflected image of a laser light source being focused into a prealigned photocell and lens system. The photocell then triggers the required rocket initiation signal. The unit being considered is a laser system utilizing a gallium arsenide coherent infrared transmitting cell with simple optics, and a silicon photocell receiving unit, with simple optics and filters, arranged in a crossed beam geometry. This altimeter is sensitive to pitch and roll motions of the dropload since the accuracy is dependent upon line-of-sight distance to the ground. Development of a more complex system results in the sampling of an area the shape of a pyramid or cone thereby eliminating sensitivity to oscillations in pitch and roll. The critical parameters of terrain reflectance values and background "noise", separately, and combined, have been studied, and solutions are available which do not compromise performance. This system is resistant to extraneous inputs which cause false altitude readings. Low development costs, comparatively low unit costs, and prompt delivery make this system very attractive.

Based upon a trade-off of the available data, the Active Optical Altimeter is the best choice for a rocket initiation signal system in the PRADS.

Selection

The method selected to determine altitude and fire the rocket motors for the PRADS shall be an Optical Ground Sensor. This unit is a solid state infrared optical sensor which provides a firing pulse to ignite the retrorockets when the load platform reaches a height of 25 feet above the ground surface.

Technical Discussions

Crossed Beam System Concept

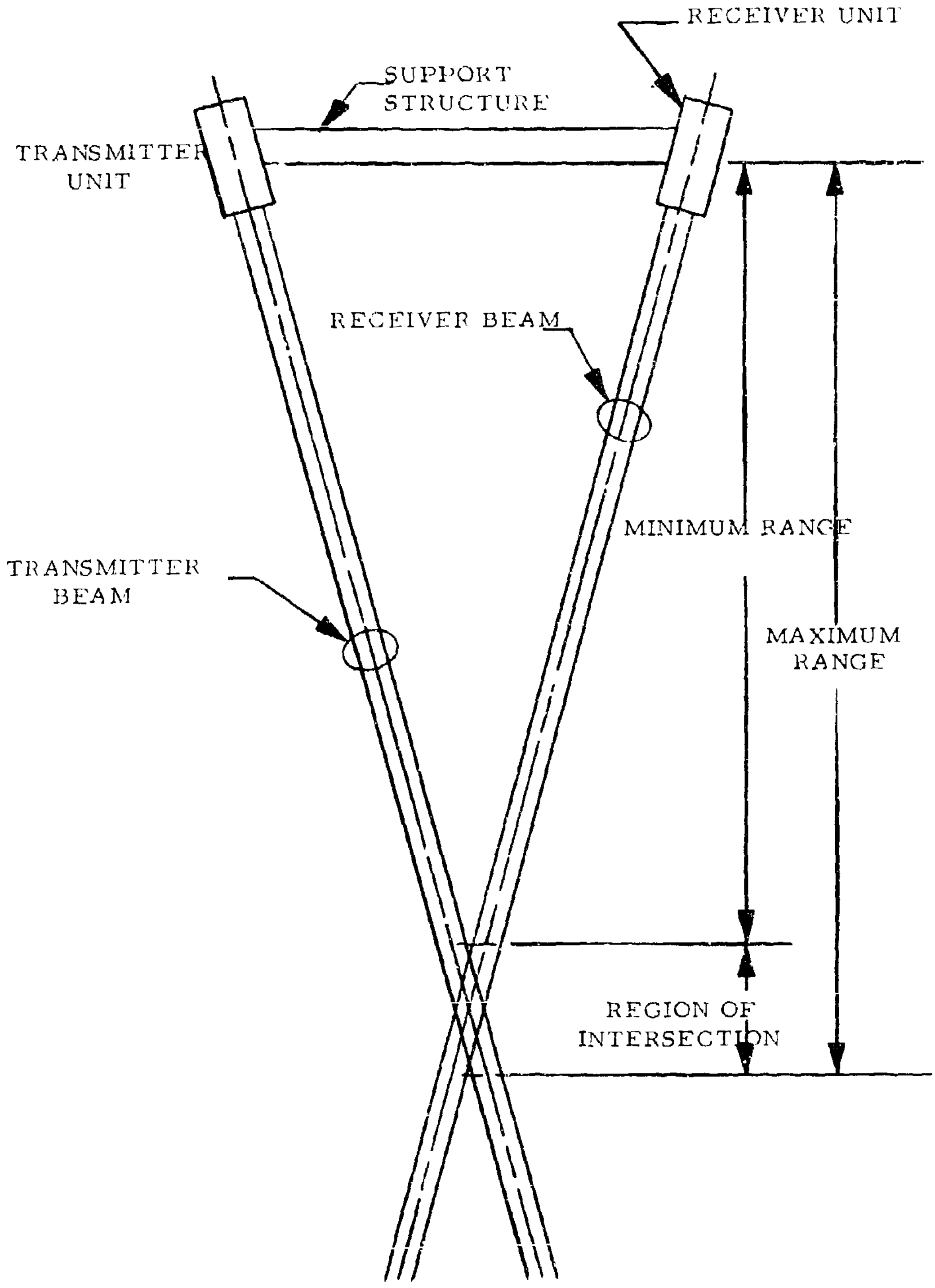
The Optical Ground Sensor consists of an optical transmitter and receiver units configured in a crossed beam system that provides an output when a predetermined distance from the ground has been reached. This crossed beam system produces the distance indication with a high degree of accuracy without resorting to complicated and expensive signal processing circuitry. The area being scanned will be perpendicular to the bottom of the dropload platform. An altimeter of this configuration will be capable of functioning acceptably at pitch or roll angles on the order of plus or minus 20 degrees.

Figure 4.18 illustrates the operation of the crossed beam technique. The transmitter and receiver units are mounted on a support structure that separates the two units by a fixed distance and rigidly maintains the optical alignment between the two units. The transmitter and receiver radiate and receive energy in a very narrow beam along the optical axis.

The transmitter beam is formed by emitted light energy. The receiver accepts light energy only from sources inside a narrow volume formed by the intersection of the transmitted beam and the receiver acquisition beam. The angle between the beams is such that the transmitter beam and receiver beam intersect a predetermined distance from the units. The volume of intersection extends over a range of distances due to the finite dimensions of the two beams. The maximum and minimum range shown in Figure 4.18 defines the limits of this region of intersection. Infrared light from the transmitter beam reflected by the ground, located at a distance greater than the maximum range does not fall in the receiver beam. When the sensor-to-ground range decreases to a point that the ground is found in the region of intersection, energy from the transmitter reflected by the ground is detected by the receiver and the Optical Ground Sensor produces an output indicating the presence of the ground. No transmitted energy is detected from a target at a range less than the minimum range, however, this is of little concern since the desired ground target must proceed through the region of intersection before passing through the minimum range.

Performance of the Crossed Beam System

The performance of the crossed beam system can be evaluated by considering the effects of various parameters on the receiving signal power. The power level of the light beam arriving at the receiver is proportional to several factors as shown in the following equation:



CROSSED BEAM SYSTEM GEOMETRY
Figure 4.18

$$P_R \propto \frac{P_T \eta_T A \eta_R \rho}{R} \quad \text{where}$$

P_T - transmitter optical power

η_T - transmitting lens efficiency

A - target surface area common to both transmitting and receiving beams

ρ - target reflectivity

η_R - receiving lens efficiency

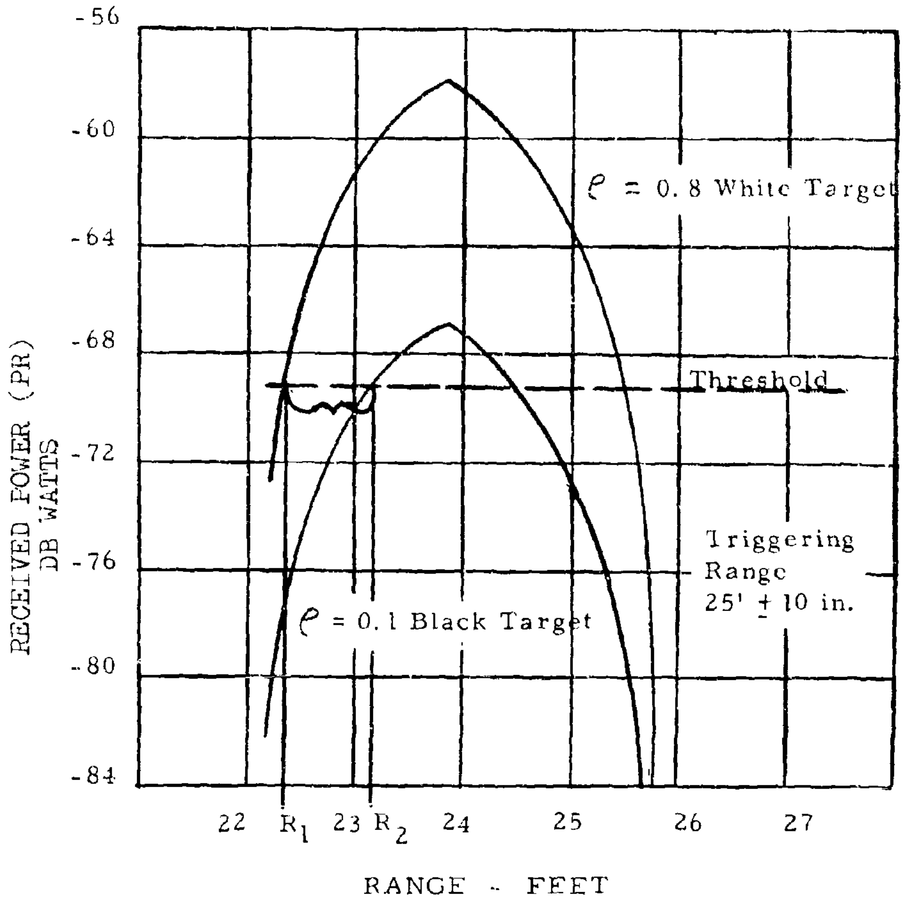
R - range between optical sensor and target

The common surface area of the target, A, is not a constant but varies with range, R, separation of the transmitter and receiver, S, beamwidths of the transmitter, Θ_T, and receiver Θ_R, and tilt of the optical aces, ϕ. At ranges greater than maximum range or less than the minimum range, the value of A is zero. Between the two limits, the value of A reaches a maximum when the full area of the receiver beam overlaps the transmitter beam. Thus, the surface area A can be written:

$$A = A(R, S, \Theta_T, \Theta_R, \phi)$$

The relationships involved have been developed and programmed for computer solution. Figure 4.19 shows P_R vs. R assuming the transmitter and receiver have beam widths of 0.2 degrees, a separation of 28 inches, and a tilt of 1.75 degrees. The two curves shown are for target reflectivities of 0.8, (high) and 0.1 (low).

The receiver circuitry contains a threshold detector set to produce a "fire" signal if the received power exceeds a predetermined level. A line has been drawn on the received power versus range plot of Figure 4.19, to indicate this threshold level. The crossed beam system circuitry produces an output indicating target detection when the received power curve intersects the threshold level line. The Figure reveals that R_1 is the



CROSSED BEAM FUZE RECEIVED POWER VS. RANGE

Figure 4.19

target detection range for a high reflectivity target and R_2 is the range associated with low reflectivity.

Parameters influencing the target detection range have been shown to be Θ_T, Θ_R, S, $\emptyset$, and ρ. Each of the first four terms is a constant for a crossed beam system, thus variation in detection range will be dependent upon target reflectivity only.

Optical Ground Sensor Block Diagram

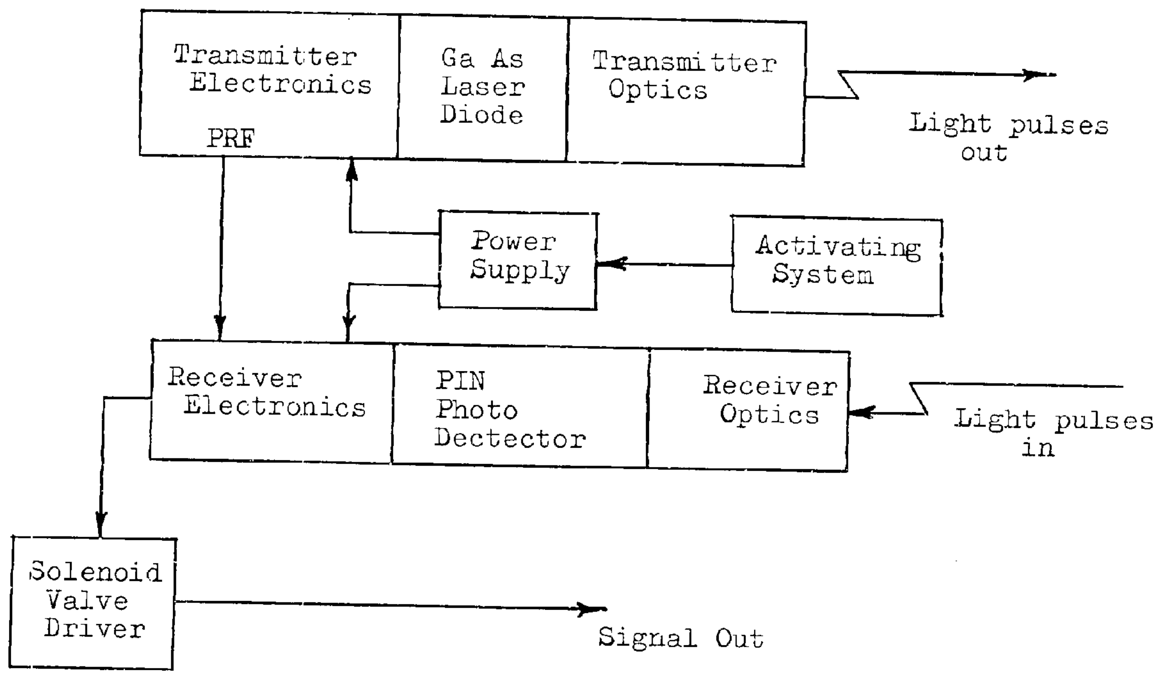
A block diagram of the Optical Ground Sensor is given in Figure 4.20. The sensor system transmits pulses of light energy and the receivers detect energy reflected from targets at the proper range. Ranging is determined entirely by the crossed beam geometry, and pulsed system is used because of the thermal limitations of the laser diode.

A description of each of the major subsections is given in the succeeding paragraphs.

Transmitter

The transmitter electronics consists of a PRF generator and a laser diode modulator. A 1 kHz pulse train is generated and used to trigger the modulator. At the typical ground approach speed of 65 fps, the Optical Ground Sensor travels only 0.78 inches during the 1 ms interval between transmitter pulses and, therefore, pulsing at a 1 kHz pulse rate is more than adequate to maintain overall system accuracy of $\pm$ 1 ft. The modulator charges an energy storage circuit during the interpulse period and then transfers this energy to the laser diode during the pulse. A signal indicating the time of the pulse is also sent to the receiver circuitry for noise gating purposes.

The semiconductor laser diode used is a p-n junction gallium-arsenide injection-laser diode which emits radiation at a wave length of 9050 angstroms, in the near infrared. The light output pulse width is approximately 0.15 microseconds and has a peak amplitude exceeding 2 watts.



OPTICAL GROUND SENSOR
BLOCK DIAGRAM

Figure 4.20

Each transmitter optical system uses a two lens system that collects the light emitted from the laser diode p-n junction and collimates this energy into a beam. In the process an image of the p-n junction is projected upon a target at a range of approximately 23 ft. The junction and its image are rectangular in shape resulting in an overall beam width of 0.2 degrees in a plane common to both beams and typically 0.6 degrees perpendicular to this plane.

Receiver

The receiver optical system is used to collect light energy from any object in the receiver beam and focus this energy on the photo-detector. The optical system uses two lenses and a rectangular photo-detector to provide a beam width of 0.2 degrees by 0.6 degrees. The use of asymmetrical beam widths in both the transmitter and receiver allows accurate crossed beam range determination without demanding extremely critical alignment of the system perpendicular to the plane common to both beams.

The electronics portion of the receiver begins with the photo-detector; a silicon planar PIN photodiode. The spectral response of the unit peak at 9000 angstroms to provide an optimum emitter-detector match with the gallium arsenide laser diode. At this wave lenght the spectral response has a typical value of 0.5 microamps per microwatt. An integrated circuit video amplifier is used to amplify the signal output of the photo-diode and its associated bias circuitry. Following the video amplifier is a gating circuit, pulse integrating network, and a threshold detector. The gate allows the amplified video signal to pass only for a period of 0.3 microseconds after the beginning of the transmitted pulse. Pulses present at the video amplifier output during this time are combined in the integrating network to form a DC voltage with an amplitude proportional to the pulse amplitude. The threshold detector then compares this voltage with a present reference and produces an output when this threshold has been exceeded. This system ignores noise occurring during the interpulse period and will not fire on single high amplitude noise spikes coincident with the gate on time.

Activating System

The Optical Ground Sensor is activated by mechanically energized battery. A force of 20 to 40 pounds is required to break a safety wire and allow activation of the battery by lanyard tension. The sensor is turned off when the battery is dormant. A time delay of approximately 2 seconds occurs after the battery has been energized before the transmitter begins emitting light pulses. During this time delay, current from the battery is used to charge an energy storage capacitor in the rocket initiation circuitry. At the end of the 2 second delay, the capacitor is fully charged, the transmitter is turned on and the sensor becomes operational.

Rocket Initiation Signal

The output signal from the altimeter will be sufficient to shuttle the electrical solenoid valve on the high pressure gas supply bottle. Redundant signals to the rocket pack are produced when the optical signal return occurs which exceeds the threshold in the receiver. The threshold detector in the receiver triggers the switch driver circuitry and delivers that energy stored in the capacitor as an output signal to the rocket through 20 GA cables to an MS connector on the motor initiator.

Power Supply

The Optical Ground Sensor power supply consists of thermal battery and associated current distribution and voltage regulation circuitry. These batteries feature compact size, environmental resistance, and long shelf life.

Physical Design

Overall Configuration

Each electro-optical subassembly will be mounted in a rectangular structure and will be installed such that the four transmitting units will be in one end of the structure and the four receiving units will be in the opposite end. This structure will be about 24 inches long, 5 inches wide and 5 inches high. The center section of this structure will house the power supply, the PRF generator and laser diode modulator for the transmitter lenses, and the video amplifier-threshold detector circuits. The unit will be completely sealed and will have windows protecting the transmitting and receiving lens systems. Routine cleaning of these windows will be required. The unit shall weigh approximately 10 pounds including the battery.

Environmental and Performance Considerations

Reference is directed to the altitude sensor specification - SAEC Technical Data Document No. S68-421-0005.

References

1. A Study to Select Optimum Altitude Sensing Devices; Sylvania A58-4-E. 0-17 (Two Volumes) - F. Wilkins, Et. Al NASA Contract No. NAS9-1098.

2. Advanced Mars Orbiter and Surveyor, Communication System and Science Payload; NASA N68-34018

3. Parachute Retrorocket Air Drop System (PRADS), Full Scale Test Program: U. S. A. Prject IM121401D195, Stencel Aero Corporation

4. Parachute Retrorocket Air Drop System (PRADS), Joint Flight Test Program - Optical Radar Ground Sensor; U. S. A. Project 1M121401D195, Stencel Aero Engineering Corporation.

5. A Proposal for A High Range Resolution Height Sensing Radar; AVCO AVSSD-D755-418- AVCO Space Systems Div.

6. An Acoustic Release Device for Parachute Landing; A. D. Jones, Inc., Electro-Optics Div. - John W. Wood, Jr.

7. A Proposal For a Pseudo-Random Noise Coded Radar Altitude Sensor; Magnavox Company

8. Development Program For Optical Ground Sensor; Motorola Proposal No. 6528-178

4.7 PRADS Safety Consideration

Extensive efforts have been required to prevent unprogrammed rocket initiation for the PRADS test motors. This safety engineering has been even more concentrated on the design of prototype hardware. Significant advances in electroexplosive devices now allow their application to the rugged requirements for safe rocket ignition. Proper protection of the electric solenoid valve will assure safe handling over the wide range of field conditions possible. Shielded electric cables are commercially available which resist stray electromagnetic radiation and the entire firing circuit can be fully protected from radio frequency stimuli.* These methods are incorporated into the prototype system along with full protection from electrostatic discharges under both storage and airdrop conditions.

The use of a mechanical safety is an added precaution to preclude any action by the gas supply system until the forceful removal of the pin from its safe position. This pin removal is such that it requires conscious manual effort on the high energy levels created as the parachute cluster decelerative forces deploy the rocket pack to its operational position in the airdrop configuration. This safety is removed at one specific event time, the full deployment of the rocket pack, and is controlled by tensioning a flexible lanyard connected between the rocket pack and the dropload. A force of approximately 70 pounds is required to pull the safety pin.

---

*Proceedings of the Fifth Symposium on Electroexplosive Devices The Franklin Institute, Phila., Pa., pp 2-8.1 - 2-9.8.

An electronic timing circuit is incorporated into the altitude sensor which prevents arming of the unit until four full seconds after a flexible lanyard attached between the parachute bags and the altimeter is tensioned. This delay allows approximately 350 feet separation between the rocket pack and the cargo delivery plane before the full rocket initiation system is armed and capable of firing the motors. When the arming pin is pulled with a force of approximately 70 pounds, a resistor limits the current to the condensor required to operate the solenoid valve. See Figure 4.21 for details of the safety lanyard, arming lanyard and pins.

The rocket motor initiators are designed to completely preclude ignition under any handling conditions and rigging operations. Abuse to any degree which leaves the motor physically intact will not result in rocket ignition. These conditions are to be tested in the motor qualification program.

As called out in the altimeter specification, the rocket ignition signal cannot be generated by weather conditions such as fog or snow and cannot be picked up from other objects in the airdrop scenario such as nearby airdrop loads of a similar configuration. The ignition signal can therefore be generated only as the unit passes from some higher altitude down through the firing gate of 23 feet above some very large reflective surface.

With these considerations currently incorporated into the prototype system, a high operational safety is assured.

5.0 HUMAN FACTORS ENGINEERING STUDY

5.1 Introduction

To assure maximum effectiveness of the man-system combination in the operational environment, (and because the human activity is an extremely important part of overall performance), human factors engineering (HFE) is required on the proposed PRADS system.

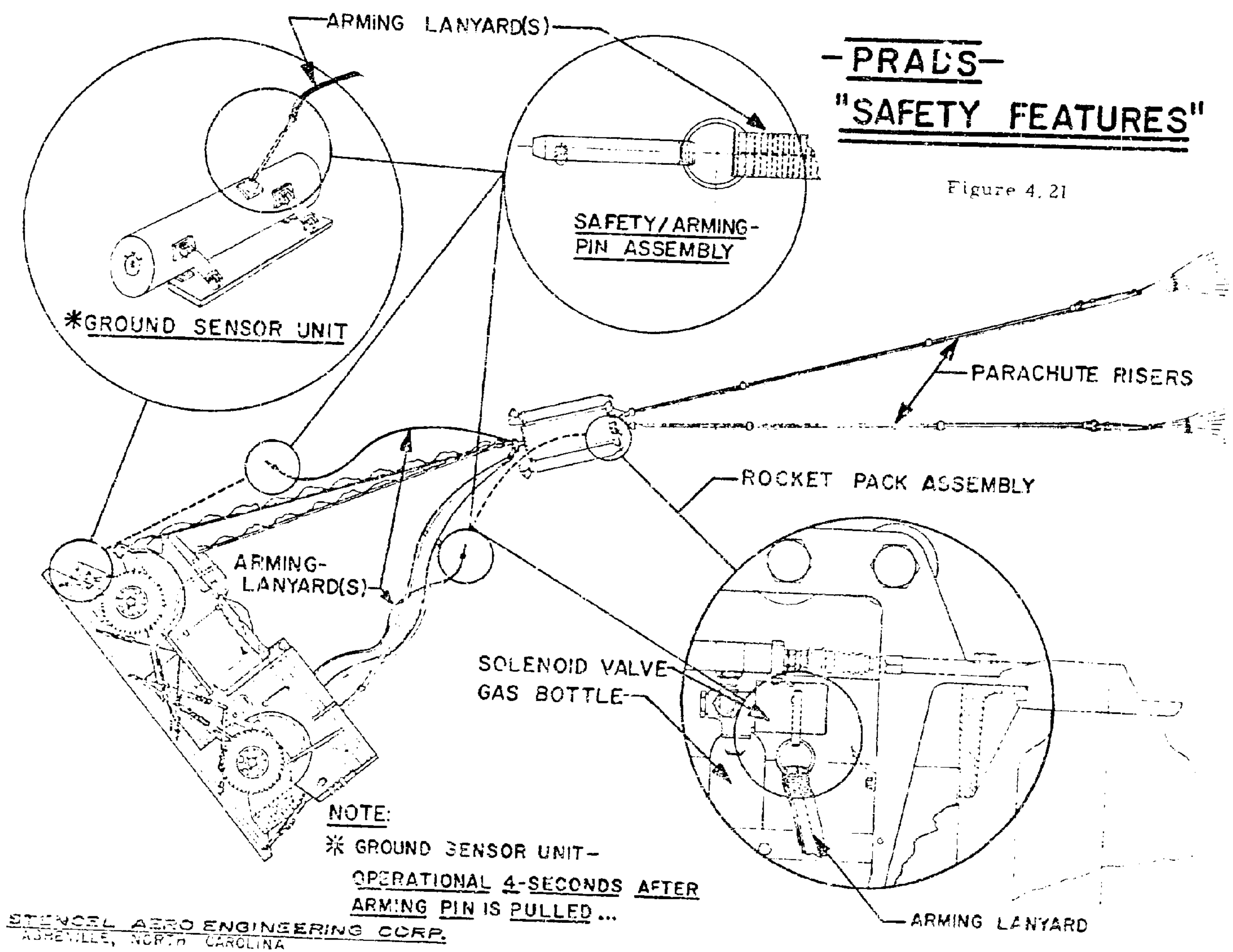

-PRADS-
"SAFETY FEATURES"
ARMING LANYARD(S)
SAFETY/ARMING-PIN ASSEMBLY
*GROUND SENSOR UNIT
PARACHUTE RISERS
ROCKET PACK ASSEMBLY
ARMING-LANYARD(S)
SOLENOID VALVE
GAS BOTTLE
ARMING LANYARD
NOTE:
* GROUND SENSOR UNIT-
OPERATIONAL 4-SECONDS AFTER
ARMING PIN IS PULLED...
STENCEL AERO ENGINEERING CORP.
ASHEVILLE, NORTH CAROLINA

Figure 4.21

5.2 Objectives

The objectives of this study are (1) to investigate the operational utilization and maintenance requirements of the proposed optimized system for compatibility with the human limitations existing at the operational level and (2) to examine how system reliability is affected by the operational and requirements of the PRADS design. The most important result of this study is that the system design should possess features of HFE, thereby simplifying or lessening the requirements imposed on men. Because of the nature of the system and the human factors involved, it is imperative that HFE principles, procedures, and criteria, as applicable in this case, be applied during all phases of equipment design. This will assure that operational and maintenance tasks and skill requirements are achievable within the framework of the existing organization or with reasonable difference in training and other supplements.

5.3 Applicable Documents

To meet requirements for a system embodying design and operational features that stem from human factors engineering, HEL Standard S-4-65 "Human Factors Engineering Requirements for the Development of U. S. Army Material" is the guideline for activity in this area. Other documents listed in the reference also provide applicable information concerning HFE.

5.4 Discussion

5.4.1 Assignment of Functions

Examination of the PRADS program reveals that characteristics required for the system and for the HFE study itself, are: (1) low cost, (2) simplicity, (3) similarity to other systems (in-service), (4) primary application to combat environments, (5) design expediency (minor degree) and (6) high reliability.

Other considerations which determine the extent of HFE study and design effort are: (1) non-man rated system, (2) significant mission complexity and (3) use by Army EM.

By comparison, the PRADS can be said to require certain human engineering and serviceability functions during system development. Under the Engineering Design Phase, pre-design and early design activities would include: (1) the review of system requirements and analysis of mission, (needs less attention to HFE considerations as a part of other engineering effort), (2) preparation of serviceability and maintainability analysis, (needs active formal participation of HFE, this activity continues and is refined over the duration of the program) and (3) assistance in determining trade-offs involving human performance and serviceability as well as participation in preliminary design reviews (needs less attention to HFE considerations as a part of other engineering effort and this activity continues and is refined over the duration of the program). Under the Hardware Development and Operations Phase, development and prototype test activities would include: (1) monitoring the incorporation of HFE and serviceability criteria, (needs less attention to HFE considerations as a part of other engineering effort), (2) assisting in the development of operational and maintenance procedures, (needs active formal participation of HFE), (3) participation in mock-up and training procedures, (needs active formal participation of HFE), (4) participation in pre-release design reviews, (needs less attention to HFE considerations as a part of other engineering effort), and (5) investigation and analysis of human error sources (needs less attention to HFE considerations as a part of other engineering effort).

Probable sources of performance degradation are human errors made during rigging. Not only is this the last effective catch for faulty components, but improperly installed or utilized material will predetermine the fate of the airdrop. For this reason, the key to successful operations, high operational reliability and combat effectiveness lies with system design simplification and considerations of human performance characteristics, both at the operational level where approaches are too often idealistic and not well coordinated with practical limitations.

Fig. 5.1 shows the relationship of HFE to other general study functions. It is important to note that HFE is a primary function, and activity in this area has a direct effect on other functions.

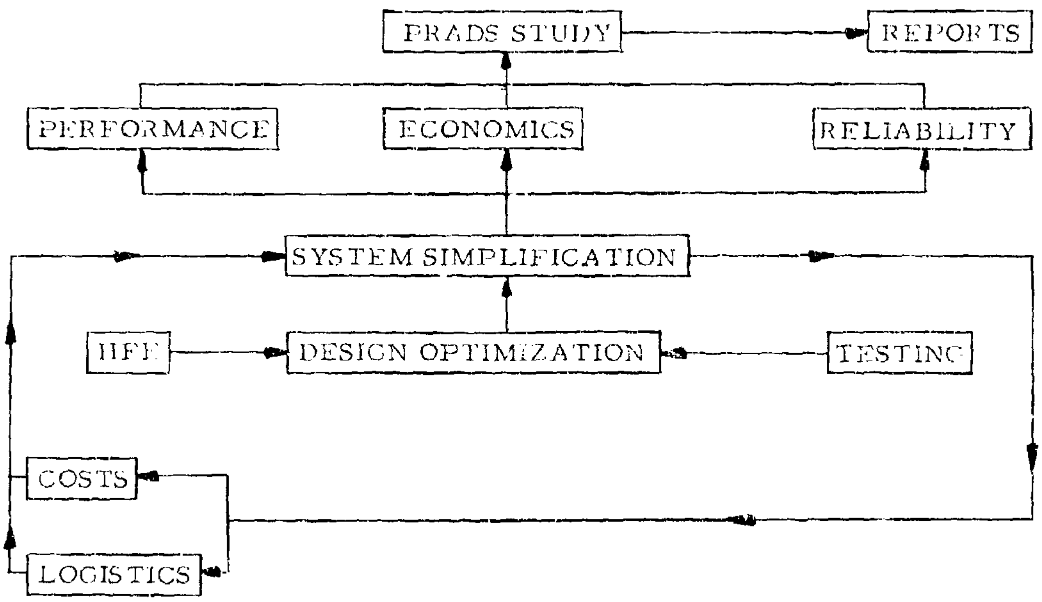
5.4.2 Mission Analysis

The PRADS system is unique in that all of the basic functions and events that it performs are fast operating and irreversible, the success of which depend wholly upon system design and preparation prior to initiation of the functional sequence. The sequence of basic functions and events during system life includes: (1) system feasibility study, (2) system in-depth exploratory development, (3) system development and qualification program, (4) production program, (5) training program, (6) rigging and handling, (7) airdrop mission, (8) de-rigging and handling and (9) maintenance.

5.4.2.1 Sequencial Resolution

The system feasibility study involves (1) definition of limitations accomplished, (2) system configuration concept developed, (3) performance goals defined and (4) limited verification testing accomplished.

System exploratory development entails (1) performance goals achieved analytically and (2) design requirements defined. Under (3) detailed functional and operational analyses come (a) performance, reliability and sensitivity analysis, (b) economic study, (c) human factors engineering study, (d) rigging study, (e) maintainability study, (f) manpower analysis, (g) training requirements study, (h) aircraft and operational utilization study, (i) safety analysis and (j) logistics study. Remaining activities include: (4) reoptimization and redesign and verification test program, which involve (a) design adequacy, (b) safety feature effectiveness defined, (c) performance characteristics and



HFE AND OTHER STUDY RELATIONSHIPS

Figure 5.1

reliability, (d) possible operating problems defined, (e) h rdware improvement or redesign and data acquisition; including service life, sensitivity and maintainability. Final item would be (6) prototype design drawings.

The System Development Program involves (1) program management, (2) design coordination and engineering effort, (3) procurement of R, D, T, & E test hardware, (4) vendor coordination, (5) testing and evaluation program, including (a) preliminary flight rating tests, (b) flight safety testing, (c) engineering design testing, (d) service testing, and (e) system tuning, as well as the ( ) preparation of documentation (TM Drafts & POM's prepared, (7) training program, including (a) training curriculum development, (b) initial retraining and formal training, (c) facilities, (d) equipment and (e) aids, (8) logistics program, including (a) maintenance, facilities, equipment and tools, (b) support system, facilities and identification and traceability. Under the Production Program Implemented fall (1) Value Analysis and (2) Quality Control, followed by the Training Program Implemented and Rigging and Handling with human factors effects. Airdrop Mission involves loading the aircraft, (securing the load and extraction chutes) and operational sequence. Table 5.1 below illustrates the events which occur during an airdrop. Finally under Mission Analysis comes de-rigging and handling covering the discovery of (1) field handling problems, and the definition of damage sources and transportation problems. Concluding this analysis is maintenance, including (1) parachute packing, (2) system refurbishment and (3) Quality Control.

NOTE: An approximate time line analysis is provided above for the mission operational sequence only. Load rigging and parachute packing time line analyses are presented as a part of the cost analyses.

5.4.2.2 Operational Sequence of Events

TIME (SECONDS)	EVENT
0	Aircraft arrives at CARP and crew reacts, extraction parachute

	release operated.
2.5	Extraction parachute pack in air-stream, pack starts to open.
2.8	Extraction parachute applies force to rail latch release system.
2.9	Extraction parachute fully inflated.
3.0	First load motion, approximately 1/2 G horizontal deceleration (Max load extraction force 1 to 1 1/2G).
4.7	Load clears ramp.
4.8	Extraction Force Transfer Device functions.
4.9	Extraction parachute starts to deploy main cluster parachutes.
5.2	Deployment bags stripped off canopies.
5.3	Rocket pack moves off, pad and gas valve safety is pulled and altitude sensor is activated through a four second time delay circuit.
5.5	Front suspension slings come taut applying nose up itching movement.
6.4	Rear suspension slings become taut.
6.5	Maximum parachute deceleration applies approximately 3.5 G.
6.8-8.8	Cluster canopies fully inflated.
10.6	Altimeter senses ground.
10.7	Rocket motor ignition.
10.8+	Rocket impulse, approximately 3 G resultant deceleration.
11.2	Rocket burnout.
11.35	Load impact, (Max. vertical impact force applied - approximately 14G).
11.4	Paper honeycomb shock absorbers fully stroked.

II. 4	Horizontal motion of load stopped.
II. 4+	1G ground reaction.

Table 5.1

5.4.3 Functions Analysis

Because the PRADS system shares with man a broad interface area where failure due to human error can be programmed into the system for later manifestation during automatic phases of operation, a conventional function analysis is not applicable. The following remarks, though, are applicable to the critical interface during rigging.

For the purpose of this category, the essential features of the PRADS configuration as it will exist in use must be described: (1) one size rocket pack, (2) one rocket pack for any load, (3) modular rocket pack, (4) combinations of from two to twelve rockets, (5) one parachute size, (6) combinations of from one to six parachutes, (7) no parachute reefing required, (8) laser absolute altimeter and (9) electro-pneumatic rocket ignition system.

When compared with previous GPAD Ground Proximity Airdrop, greater simplification is evident; and when compared with an all-parachute system the difference lies principally with the use of rockets and laser altimeter.

An examination of the existing organization of manpower at the interface of the airdrop system and man shows that even if training programs and skill levels are adequate, there may be a breakdown in workmanship and quality control simply because of the forgetfulness of the relationship of detail requirements to total system performance. There is a current need for cognisance of the effects of human error on system performance at the rigging function level.

It must be recognized that airdrop is a sophisticated mode of deployment of force, and as such, is due as much respect as the deployment of supplies and equipment via other means of transportation. Losses due to mistakes can be as high as those encountered in combat before the loads even see actual combat hazards.

There appears to be no need to rearrange organization, and the general manpower (MOS's classification of rigger and detail man) will be adequate, but training in new areas and a more specific job description and responsibility will be necessary for the PRADS, also definite benefit will be derived from a positional and functional assignment on a rigging line or load.

Combinations of men must now be employed in a "Buddy System" mode for the purpose of improving human factors effects on reliability.

The alternative to specialization would be to build proficiency of any function into all men, this is a recognized asset (out of necessity anybody might have to do anything under certain conditions). But until that level of proficiency is attained by personnel who might conceivably be required to rig an airdrop load, the recommendation that well trained and experienced riggers do the work should be adhered to. It is also recommended that when detail men must be utilized, that they be much more closely supervised and checked than present information suggests.

Using what we know about the rigging function as a point of departure, we can observe that, except for unforseen mechanical failures, most inadvertent airdrop failures are due to human error. Presumably any system must possess adequate capability including performance, strength, insensitivity, etc., to be of any value so for the sake of argument, we shall accept workability as a fact. That leaves us wtih human factors and those characteristics about a system which affect human performance.

Hardware, then is the first place to look for the source of error. Scrutiny of the PRADS system shows that considerable work had to be done to alleviate physical complexity and complicated operational sequences before it was feasible to examine human factors effects. As a result of a design simplification effort, the hardware became less sensitive to variations in human functional performance.

Definite progress has been made since it previously appeared that the present human functions skill levels could not reliably cope with the system requirements. It may be said that at this time, although the general rigging function is still the most critical, that because of design simplification efforts, the optimized hardware should not require additional operational manpower functional capability beyond the scope of present technological ability at the organizational level.

5.4.4 Task Analysis

Because it is not practical or useful to describe every small motion involved in a procedure, and because the resolution required for analysis is really the accomplishment of elemental configuration, the rigging task analysis will not be a detailed time and motion study estimate but will be more concerned with the ability of organizational personnel to dependably complete discrete steps.

Previous studies (Ref. 11 & 12) have considered airdrop rigging and parachute packing tasks in detail, and attention is directed to them for rigging and packing details.

The most desirable situation would be one where there is a net reduction of requirements: individual functions, tasks, number of personnel, skill level, etc.; in the case of the PRADS, every effort is being made to realize simplicity, but there are new or different requirements and these differences are what we are most interested in. Using the existing scheme as a point of departure, significant elimination, addition, or changes in task will be discussed.

5.4.5 Maintainability Analysis

5.4.5.1 Parachute System Maintenance, Handling and Packing

The obvious improvements have to do with the reduction in size when compared with an all-parachute system. The optimized PRADS parachute has a forty-eight (48) ft. nominal diameter (seventy-two gores and suspension lines), weighs less, (total weight with bag is about ninety-five (95) pounds), is easier to pack, (does not require fans, long lofting space or lifting aids) is more rugged and damage resistant because of the requirement for additional strength due to the increased loading while performing, so maintenance is reduced; and, the parachutes do not require any reefing at all, which means only one parachute configuration to be concerned with.

The logistic, maintenance, and handling requirements, while similar to that now existing, are drastically simplified and facilitated by the PRADS parachute concept.

Reference is directed to the following documents which would be emulated for the PRADS parachute:

TB 10-505-1/TO 13C5-7-3 Parachutes: Packing and Maintenance of Parachutes, Cargo

TM 10-1670-222-23P Organizational and Field Maintenance Repair Parts and Special Tool Lists

The rockets themselves will not be subject to periodic maintenance, except for reloading and refurbishment which will be accomplished by the original equipment manufacturer or an arsenal. Spent rockets will require some care in handling during retrieval, storage, packing and shipping.

Reference is directed to the preliminary model specification for characteristics which preclude ordinary preventive maintenance and outlines the properties necessary for satisfactory performance.

5.4.5.2 Rocket Pack Maintenance, Handling and Assembly

The modular rocket pack concept complies in most ways with desirable human factors considerations since (1) it is not complex (minimum number of different parts), (2) it is uncomplicated (minimum number of total parts), (3) it is "Murphy-proof" (unilateral-self checking assembly), (4) it is rugged (all steel minimum-maintenance, the heaviest individual part is the core, at about two hundred fifty (250) pounds), (5) assembly operations and time are minimized, and (6) no special tools are required for rocket pack/segment/rocket assembly.

This structure will be composed of components which by virtue of their strength, material, and method of manufacture, will require only cleaning and inspection for possible damage and electrical actuation of the solenoid valve as a functional check after use.

5.4.5.3 Platform Rigging and Suspension System

These groups will remain essentially unchanged and therefore would require maintenance according to existing procedures:

TM 10-500/TO 13C7-1-5 Airdrop of Supplies and Equipment, General (and auxiliary Ref. documents.)

Except for the rocket pack, smaller parachutes, and the altimetry system, the physical configuration of any rigged load is essentially unchanged.

Depending on the outcome of further development and testing, there may be some changes of material for the bridle support subsystem, load covering tarps and other webbing materials, i.e. it may be desirable to use 3" wide webbing.

The rocket pack will be located nozzles forward on top of loads which permit it, and standing up with nozzles down, behind loads which are already h[illegible].

Cardboard honeycomb will be used to build a form fitted interface between rocket pack and irregularities on a load, and the simple expedient of cut-and-break-away cords, tapes, and webs will be utilized to lash the rocket pack through the honeycomb to the load. In some cases, honeycomb will be used instead of plywood for the construction of small platforms or decks as they may be required.

Parachutes, being smaller than the G-11's or G-12's now used, will be more readily positioned near the rocket pack and because of their flexibility, can be lashed in place, as above, with a minimum of transitioning materials.

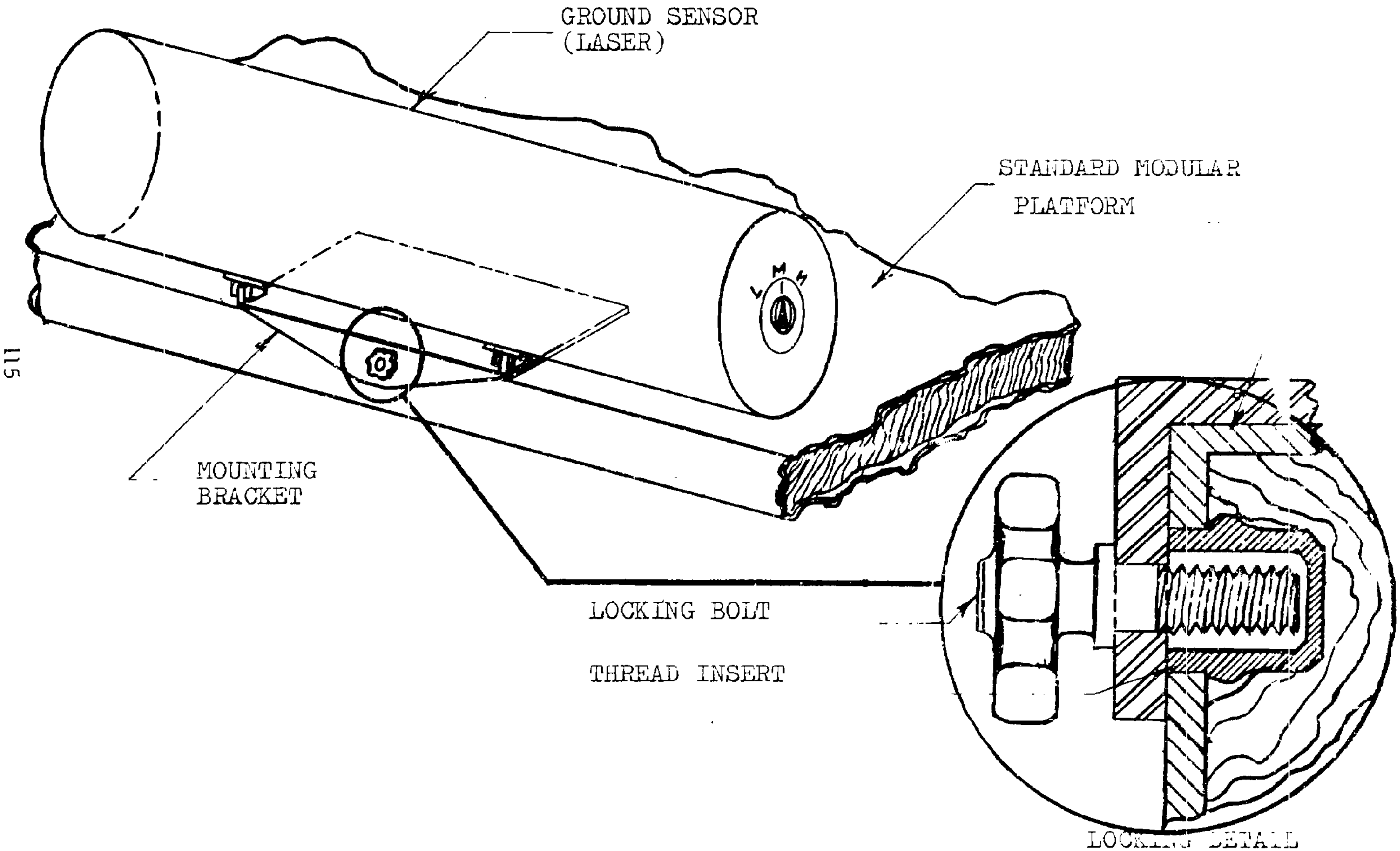
The attitude sensor system will be attached to the end of the platform in a position which precludes interference with the aircraft system and other platforms and will include features which attenuate drop damage.

Provisions for mounting of the altitude sensor system will maintain interchangeability of platform sections and will apply to any platform. See Figure 5.2 for sensor mounting details.

There will be a requirement for additional honeycomb on top of all loads to minimize damage by the rocket pack to itself or to the load, but the effect on personnel is only one of additional time and materials required.

Attention to the above is required at this point, and frangible accessories will have to be adequately protected: this step will remain essentially unchanged without any critical increase in precision or vigilance required.

Lashing remains unchanged except for rocket pack restraint.



SENSOR MOUNTING

Figure 5.2

Attachment of parachutes, rocket pack, extraction system and restraint system, and installation of altitude sensor is the most complicated and critical phase, manuals would be prepared to elaborate on the effort, but we may at this time, with benefit of having actually rigged out a PRADS load, think about present characteristics and point out things as required so that organization troops will not have to wrestle with serious problems. It may, therefore, eventually be said that rigging the PRADS is no major problem.

Here again, system simplification is really the answer; the smaller parachutes have helped tremendously, the modular rocket pack will be very efficiently utilized, and positioning of the various components will be straight forward. There will be a difference in configuration but as it is seen now, organizations will have no problems with the new tasks.

Closer supervision at this stage is imperative. However, because adherance to manuals is essential for engineering reasons, i.e., lanyard lengths, safetying procedures, signal line lengths, stowage to avoid handups, whipping, and breakage, etc., that will not be obvious to detail men. It will be necessary at this stage to perform one task at a time with supervision and inspection and then for someone to evaluate the consequence of the task to determine whether, in operation, the sequence of events would result in breakage of important components, particularly the signal lines. This is really an exercise in observation and, it is granted at this time at least, that a certain amount of intuition will be required and that sensible, concientious individuals must be assigned to those tasks.

5.4.5.4 <u>Maintenance, Testing, Handling and Assembly of Altitude Sensing and Signal System</u>

Extensive testing and analysis of testing results and a study of other characteristics of the redundant flexible probe sensors resulted in the recommendation that another approach be taken to perform the function of absolute altitude sensing. Aside from the problems associated with the dynamics of the double flexible probe system, such as vertical error caused by swinging, or low reliability, the mechanisms were complex and complicated, and maintenance and refurbishment factors appeared high.

Radar and laser altimeter systems were then investigated and because of cost/performance trade-offs, the laser system is adopted as the subsystem for the optimized system.

The laser altimeter meets the criteria of (1) applicability, (2) high reliability, (3) availability and (4) low cost for general part selection considerations, therefore, system development is at a point where meaningful analysis can be performed.

The essential operations to be performed on the altimeter subsystem are as follows:

(a) Testing: Prior to each rigging installation, the transmitter/receiver unit must be physically checked for general condition, battery condition and calibration. This necessitates the arrangement of a short range on the top of packing tables or suitable bench, pointing the unit target from the correct distance, and testing the unit by activa[illegible] a calibration switch.

Prior to this, the batteries are checked with suitable equipment. Regardless of condition, batteries will probably be replaced every six months. Battery life under average conditions is expected to be nine months, but because of failure distribution and environmental conditions, the value must be adjusted to insure reliability.

Batteries will be marked with the check date and the replacement date, and checking will probably be performed monthly, and always just prior to use, and will be stored separately.

The laser unit will be tested before and after use. Ordinary carbon - zinc batteries will be used except in climates which are ordinarily below $0^{\circ}F$ where thermal batteries or battery heaters must be used.

(b) Maintenance: Although the type of battery proposed for use can be charged to a limited extent, it must be accomplished on a careful cummulative time basis, and because of the equipment required, cost, time and manpower considerations, and limited return, charging is not contemplated at this time.

In the event that the laser transmitter/receiver unit is tagged for repair because it is inoperable or out of calibration, the detailed procedure for checking and calibration must be observed. At this time it is not possible to define the exact procedure, but some of the aspects of the process are: (1) check for presence of beam, (2) check for dirty or broken lenses or windows, (3) check for faulty laser cell, (4) check for faulty sensor cell, (5) replace cells as required, (6) clean or replace lens housings as required, (7) repeat (1), (8) perform functional calibration check and (9) calibrate as required (mechanical adjustments).

If the outlined procedure fails in some way, the unit will probably have an elementary failure in which case a circuit check will be required. As far as maintainability is concerned however, all of the critical elements are easily replaceable, and because of the logistic trade-offs concerning the remainder of the individual circuit elements in the unit in the case of an elementary circuit failure, return of the defective module to the manufacturer for repair is recommended. The expected service life is high and this also tends to corroborate the above.

Signal Lines: When checked alone, an audible continuity check will be performed while hand flexing of the cable is accomplished. This procedure minimizes the possibility of not discovering intermittent opens or shorts.

(c) Handling and Assembly: All of the subsystems components are rugged enough to withstand extraordinary handling, and there are provisions to check the subsystem installation. Concealed, illuminated, push-to-test buttons are provided for output circuit continuity tests, and the system may even be functionally tested safely with the rockets in place. The gas bottle is then charged, and the transmitter/receiver clamped in place. Mechanical and electrical interlocks are provided for safety and sequencing. These features are desirable because the highest probability of failure is due to rigging errors rather than mechanical or electrical deficiencies.

5.4.6 Time Line Analysis

As part of the cost analysis, rigging factors, refurbishing factors, and parachute work estimates were prepared which generally show that total man-hours are reduced for a PRADS load. This is meaningful only in the sense that preparation time is reduced, and primarily because the parachutes are smaller. Actually, physical complexity is increased in those areas where there is no experience and considerably greater care must be exercised where human functions are performed.

It is not practical to subject this system's human functions to a detailed time line analysis because confidence in the results would be lacking, and it would serve no purpose because the hardware is not developed in the final configuration; also no time and motion studies have been performed.

5.4.7 Link Analysis

To determine the importance, frequency, and adequacy of links, we must presume the existence of the hardware as it is conceived now, in order that deficiencies, if found, can be rectified before hardware gets off the board. This may effectively be accomplished by listing and consideration of critical link interface as they occur chronologically:

OPERATION	IMPORTANCE	FREQUENCY	ADEQUACY
Handling	Moderate	8 Times/yr.	Good
Testing	Major	8 Times/yr.	Excellent
Calibration	Major	2 Times/yr.	Good
Rigging	Primary	4 Times/yr.	Good
De-Rigging	Minor	4 Times/yr.	Good
Maintenance	Secondary	2 Times/yr.	Good

interpretation of the above is that rigging, testing, and calibration, in that order, are the critical areas; of these, testing involves the simplest and most fool-proof procedures. Calibration of the altimeter is important because it involves the setting of a fundamental system function and certification of operational readiness.

Rigging is the last ordered catch for faulty equipment or human errors, and is, therefore, the most critical link interface. Interpersonnel links during rigging can best be utilized by the mutual checking of performed operations, and the operational assurance of the ground sensing subsystems is linked to human effort via built in visual or audible testing circuitry.

Once a successful rigged configuration is established, every effort must be maintained to duplicate this repeatably, and comprehensive TM/TO's will provide the basis.

5.4.8 HFE Analysis of Environmental Considerations

Although by the very nature of the PRADS, the fineness of adjustments to be performed by man is not of such a critical scale that a load could not be prepared under extreme conditions, there are material limitations which further limit conditions under which this system may be prepared and maintained. The result is that because parachutes, paper honeycomb structures, and other climatic sensitive elements must be assembled under conditions which do not result in degraded performance, the entire operation must take place under conditions which coincide with human comfort zones and therefore no degradation in human performance due to environmental conditions should result in degradation of system performance.

5.4.9 HFE Integration in Equipment Design

5.4.9.1 Anthropometrical Considerations

The PRADS system configuration, maintenance, and assembly requirements establish the need for two or more men at most tasks; this is not a change when compared with the existing system, and weights, reaches, operation, force applications, and motions are compatible with that mode. The heaviest component is the rocket pack which, without rockets weights about 250 pound or the weight of a G-11 parachute pack.

5.4.9.2 Operator Information and Response Requirements

There do not appear to be any functions or tasks requiring attributes in excess of those normally required of organizational personnel, although it is imperative that they be cognizant of the consequences of inattention to detail or lack of alertness to potentially dangerous situations. Riggers and detail men must understand what they are doing and, physically, why it is done in a certain fashion. Adequate explanation, training, and experience will suffice here.

5.4.9.3 Control/Display Requirements

The use of checklists to ascertain the accomplishment of the more important tasks should be required, if for no other reason than safety.

5.4.9.4 Communications

An atmosphere of trust and honesty will be required where individuals are installing, safetying, arming, or otherwise working with sensitive elements, it must be possible for a detail man, rigger, or anyone else associated with the delivery system as a whole to admit a mistake, without prejudice, rather than contend with the results of the mistake. This aspect is particularly important where casual detail men or trainees (everyone on a learning curve) are concerned.

The concept of having two or more men working together on the same task, while important from the anthropomorphic standpoint, is also beneficial as a "buddy-system" or self-checking mechanism: each man effectively watches what the other is doing, and more often the job is done better. And, of course, the efficient dissemination of materials, handbooks and other information essential to understanding of the PRADS will be required as part of training and orientation programs.

5.4.9.5 Traffic Flow

The principles outlined in Reference 9 and its auxiliary references, with suitable changes and additions, will provide guidance for U. S. Army units concerned with the PRADS.

5.4.9.6 Safety Requirements

This is a sensitive area for the PRADS, because it is incomparable with the existing system, which utilizes active components to a very limited extent. The existing system utilizes reefing line cutters, spring loaded devices, and heavy components, but the total amount of potential energy dissipated at any time does not compare with the capability of the PRADS rocket system.

The design and testing of the active PRADS components comply with rigid specifications, but specifications are limits, and it behooves everyone handling or using these components to understand the relationship of their job responsibility to system limits and therefore, safety. Warnings will be obvious where applicable, but because it is still possible to defeat safety mechanisms, a new material control procedure will be desirable, similar to other heavy ordnance control procedures.

5.4.10 Mock-ups and Models Required

Eventually, everyone with the need to know and use the PRADS must become familiar with it; and because mock-ups and models are all things to all men where texts, drawings and even pictures are not, the value of such aids is considerable. At least one complete mocked up system per using division is recommended, and the parts can be genuine except for the pyrotechnic components which can be simulated.

Divisional back-up stock can be the source for some of the required items. It is also recommended that because of the magnitude and scale of production quantities for the system, that prior to prototype development or test hardware construction that the rockets, rocket pack, and altimeter subsystems be mocked up just for dimensional and functional checking of interfaces, envelope, compatibility, or possible interference with aircraft and load, etc.

5.4.11 Dynamic Simulation and Special Studies Anticipated

Industrial engineering time and motion studies, (similar to one described in Ref. 11 for the purpose of establishing TOE manpower authorization criteria), work measurement time standards, and rigging factors will be necessary so that airdrop rigging operations may be planned with more accuracy than with the estimates made in the course of this study.

There will also be the possibility that things which are not known during development will require investigation, such as newly developed vehicles or loads for airdrops, the adoption of improved parts, and a program of continuous development for the extension of system performance to lower altitudes, or heavier loads, and/or higher speeds.

5.4.12 Integration of HFE in System and Subsystem Trade-off Studies

Human factors principles are a continuous consideration during trade-offs, and the use of knowledge and experience as a basis has often resolved selection in favor of the human element, not altogether for its own sake, but because selections which reduce cost, simplify design, and even improve performance and reliability naturally tend to be more compatible with HFE principles.

5.4.13 Proposed Design Review

Critical HFE problem areas are handling, rigging, packing, maintenance and safety. Contributing to each of these are weight, size and complexity. The important single factor is safety.

HFE advantages are designed and built into the hardware so the immediate considerations are those that apply to design. An analytical effort is useless unless the results of a study are utilized, so it is strongly recommended that the next phase of development include a continuation of HFE participation in design and review activities.

5.4.14 Personnel Requirements Anticipated

5.4.14.1 Manning Levels

The first consideration is that in all likelihood, the PRADS will be utilized primarily for assault missions as it is too expensive for resupply tasks except for larger loads, and existing systems appear to function well enough for small loads at higher altitudes.

The tentative manning level involves three divisions, and based on the results of the economic study, additional manning will not be necessary; and, unless the PRADS mission capability is imposed as an added capability instead of just a diversion of capability, the existing organizations can adjust to suit the new scheme. Therefore, at this time, the net requirements for the PRADS will approximate the requirements for the existing airdrop system.

5.4.14.2 Duty Positions

The duties of personnel are generally defined in AR 611-101 and AR 611-201 with additional information provided by Ref. 9. Special notice should be taken that all company officers and warrant officers and all enlisted personnel directly concerned with the maintenance and operation of quartermaster airdrop equipment are qualified parachute riggers on parachute duty. From this, it is seen that a lengthy analysis would not result in useful output; the existing information provides sufficient guidance that with discretion, a command may structure duty rosters and positions in the manner most suitable to the variable mission requirements and operations. Furthermore, it is a goal and intent to avoid changes in organizational routines which tend to complicate or increase manpower allocations and assignments; at this time, significant changes in this aspect of organization are not visualized.

5.4.14.3 Skill Requirements

The PRADS introduces some new situations into the lives of those who will be directly concerned with the system. As has been indicated before, the important single factor to be considered is safety; the active system components are potentially dangerous, and concientious performance of duty will be important. It appears that a high level of proficiency will be invaluable for complete system success, even though the skill level requirements will change little. Similar to the existing system, the consequences of mistakes may be the loss of a load, except that if the mistake somehow involves the aircraft system or the rocket safe and arm sequence, the losses may involve more than just the load.

To the best of knowledge, the rocket systems currently concerning the Army are expendable weapon system types, and the PRADS is a reusable work horse. The nature of the two types are different, involve different sequencing, purpose, and handling. The PRADS does incorporate devices which have low safe usage, but because of reuseability factors and other characteristics, safeties are different and possibly capable of being more easily defeated. It should be pointed out that there are two safeties in series. one on the ground sensor and one on the solenoid; therefore, some margin of error can be tolerated without being disastrous. Arming sequence depend upon the proper functioning of other elements of the system, which in turn are installed or arranged by personnel. The tasks themselves do not require special dexterity or mental concentration, but thoroughness as to detail and workmanship can not be overemphasized.

5.4.15 Training

5.4.15.1 Training Devices

The best recommendations that can be made are that subsequent to the preparation of preliminary operation manuals, that full scale mock-ups be used for component familiarization, and that loads actually be rigged and checked and eventually dropped. Basic and intermediate training should also enjoy maximum utilization of audiovisual techniques, not just to convey the full impact of the system, but because of the proven efficiency of the medium. The documentation requirements, manuals, texts, handbooks and other instructional techniques are entirely worthy of emulation for the PRADS, and combined with on the job instruction, should result in the desired capability.

5.4.15.2 Job Aids

Because of many common denominators between the existing all-parachute system and the PRADS, existing facilities and equipment can be utilized to a very large extent. There are a number of documents which outline the necessary and available materials, such as TM 10-1670-222-23P, and formal preparations of the PRADS manuals should incorporate much of the existing information and materials on the basis of this commonality. Special tools and other aids will be minimized, but some will of course be necessary, and pertain primarily to the rocket pack subsystem and the altitude sensor and signal system.

5.4.16 HFE Participation in Testing and Evaluation

5.4.16.1 Test Objectives

The objective of HFE testing, whatever the form, will be to verify the adequacy of certain design features with respect to the adopted criteria, and to recommend changes where discrepancies are discovered.

5.4.16.2 HFE Test Methods and Equipment

The HFE testing will be integrated with the proposed system development test series, and although no special HFE requirements are established for many tests, the tests will be monitored for human factors effects. The requirements for the ancillary equipment which may become necessary for specific HFE testing will be acquired or devised as the need arises. The fundamental plan is as follows:

(a) Engineering Development Phase: A detailed step by step sequence of system handling requirements from the shipping crates thru one complete cycle of all possible events for critical components and safety devices shall be prepared by the design activity and scrutinized by the HFE activity. The performance shall be completed as early in the engineering development phase as practicable, so that necessary revisions may be facilitated.

(b) Development Test Phase: Dry runs with mock-ups and inert pyrotechnics will be performed to discover any further shortcomings.

(c) Qualification Test Phase: All tests will be monitored for human factors effects.

REFERENCES

(1) HEL Standard S-4-65: Human Factors Engineering Requirements for the Development of U. S. Army Material; Human Engineering Laboratories, Aberdeen Proving Ground, Maryland - Robert F. Chailley, January 1965.

(2) MIL-STD-470: Maintainability Program Requirements
MIL-STD-471: Maintainability Demonstration

(3) MIL-STD-721B: Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety.

(4) MIL-STD-1472: Human Engineering Design Criteria for Military Systems, Equipment, and Facilities.

(5) AD 670 578: Human Factors Data Thesaurus (An Application to Task Data): System Development Corp., Dayton, Ohio - Robert G. Oller, March 1968.

(6) NASA SP-6506: An Introduction to the Assurance of Human Performance In Space Systems.

(7) AMCP 706-130: Engineering Design Handbook - Design for Air Transport and Airdrop of Material.

(8) AR 611-201 Pages 399 to 402, incl.; Duties, Skills, Knowledge, Physical, Mental, and Other Requirements for a Parachute Rigger, MOS 43E.

(9) FM 10-8: Air Delivery of Supplies and Equipment in the Field - Army.

(10) AFM 55-130: Troop/Cargo/Airdrop Carrier Aircrew Operational Procedures - C-130-USAF.

(11) ST 10-501-1-1: Airdrop Operations (Special Text).

(12) TM 10-500: Airdrop of Supplies and Equipment (Series).

(13) TB 10-505-1/TO 13C5-7-3 Parachutes: Packing and Maintenance of Parachutes, Cargo.

6.0 TRADE-OFF ANALYSIS

6.1 Introduction

The intent of a trade-off is to determine, by various methods such as analysis, experimentation, or experience, which of a number of conflicting requirements are to be satisfied, and in what order of priority, with the least compromise of cost, performance, reliability, safety, or other considerations.

System optimization is the determination of which of a number of methods or techniques of accomplishing a function is best, with each element, subsystem, or part of a system working at maximum efficiency so that the system is of minimum weight, volume, and complexity.

It can then be seen that an optimized system, while meeting performance, reliability, and safety requirements, may not be of acceptable cost, or may not be consistent with the limitations imposed on system design, such as the need to use existing equipment, and therefore, in actuality, the purpose of a study would be to define a system which complies with the limitations to the extent that the limitations and system performance requirements are mutually compatible, and that the weight, volume, durability, etc., are acceptable, and that performance, reliability, and safety are assured, and that the resulting overall cost is as low as can be achieved.

The above efforts must be continuous throughout a program to be effective.

6.2 Objective

This discussion is intended to present a brief summary of various forms of justification for the existence of the proposed new PRADS configuration, along with pertinent facts about the development history of the system to date.

6.3 Purpose

The purpose of this report is not only to describe what has already been done concerning system optimization, and some of the trade-offs that were made, but also to provide further direction and to recommend further effort in certain areas during future development which should prove beneficial.

6.4 Philosophy

Previous work had already found that the system performance goals were realistic, and that they could be feasibly achieved by a system utilizing rockets and parachutes. Furthermore, it may be accomplished with greater efficiency and possibly have an even greater capability than an all parachute system or other concepts which were concocted.

With the benefit of and experience with an existing capability and the desire to utilize the existing hardware to the maximum extent possible, it was only necessary to integrate a rocket and altitude sensing subsystem into the total system to achieve what was essentially a lower altitude capability.

Now, presumably, any acceptable system must possess adequate capability: strength, insensitivity, etc., to be of value, so once certainty of success is assured, workability can be accepted as a fact, and the effort becomes one of improving the function and other effectiveness parameters of the system and its components while eliminating design and functional problems as they present themselves along the way, and finally, tuning the system, as applied to various conditions, for uniform smooth performance.

6.5 General

The need for a system that fulfills the performance goals requires large order performance improvements of the decelerator subsystem, combined with high reliability, with the best weight efficiency and cost effectiveness achievable, flexible enough to operate conventionally with, and be compatible and safe with existing and future aircraft systems, and preferably, minimize modification or re-design of present equipment, or the associated logistic structure, and be readily available.

The first consideration is that in all likelihood, the PRADS will be utilized primarily for assault missions, as it will be more expensive for resupply tasks than existing methods which appear to function well enough in that capacity.

6.6 Trade-Off Analysis

6.6.1 Critical Trade-Off Parameters are:

a) Performance and Reliability

b) Operational Utilization.

c) Economics.

d) Safety.

6.6.2 The logical system criteria are then:

a) The optimized system, whatever the ultimate configuration, should meet or exceed the performance goals established by the contract.

b) The PRADS concept should equal or exceed the utilization factors of the existing all parachute system.

c) All costs should be minimized.

d) The PRADS should not increase the risk to personnel, aircraft, or other equipment.

e) The design should take full advantage of materials, methods, and techniques which enjoy the best of the state-of-the-art, consider the possibilities of the present frontier of the state-of-the-art which may be tomorrow's achievable stat of the art, and satisfy the following supplementary criteria for general part selection:

Applicability.

High Reliability.

Availability.

Low Cost.

6.6.3 Approach

Early analysis and testing showed that every subsystem aspect might benefit from a concerted system optimization and simplification effort.

The extrapolation of knowledge of the previous exploratory GPADS configuration which was employed as an expedient for the test program indicated that considerable work or a redesign was justified and necessary to alleviate physical complexity, complicated operational sequences, weight, and costs, before it would begin to pay to perform subsequent analyses on the system.

The Human Factors Engineering Study, The Altitude Sensor Study, The Economic Analysis, The Performance Analysis, The Safety Analysis, The Aircraft Utilization and GFE Compatibility Studies, and the Component Design Specifications more completely describe the progress made in those specific areas, so this discussion will deal primarily with criteria and in generally qualitative terms and parameters.

There were other considerations which affected decision making, and among them were:

The system design should take into account and consider the possibility of a capability to deliver loads up to 50,000 pounds under the same conditions.

The system design should take into account other considerations which gave the PRADS an advantage regardless of altitude.

6.6.4 The Rocket Pack and Rockets

Consideration of all of the above and experience with the GPADS, and AFOADS which showed promise of success with parachutes only for loads up to fifteen or twenty thousand pounds favored the larger load range for the PRADS.

Additional requirements for a redesigned rocket pack would be that various combinations of the number of rockets should balance forces as well as possible. Examination of the various possibilities resulted in a single rocket pack which would utilize twelve rockets instead of two rocket packs and thirty-six rockets, for the 35,000 pound load. Any combination except one or eleven rockets will balance forces perfectly, and the automatic stabilization feature of the rocket pack will provide satisfactory realignment with eleven rockets. This results in a rocket system which overlaps all possible load requirements except for a small gap between three and four rockets, and between two and three rockets, and a cut off below what load can be recovered with two rockets before excessive rocket loads are induced.

This way the discontinuities are bridged by adjustments in the number of parachutes required, and the range capacity for the PRADS extends well into the range that an all parachute system can work in.

At the same time, it is possible to recover loads via parachutes only up to the weight range where there are no discontinuities in capability using the PRADS parachute and/or G-12's.

This means that the smallest load on which it would pay to use the PRADS will be about 11,000 pounds. This would seem to make the provision for a combination of two or three rockets superfluous, but in view of the requirements for force balance and load overlap from 11,000 pounds up, it is not. Also, with this configuration the load range is extended to 40,000 pounds with suitable parachute additions.

This coincides nicely with the probability that missions will not be fl wn at lower than 500 feet or so, at which point loads above

15,000 pounds get questionable. Some of the lighter loads will of course be capable of recovery at altitudes down to 350 feet, either with the PRADS in two or three rocket combinations, or with parachutes only.

Later in the program, the promised solution of the heat and blast problem by the new configuration corroborated the choice.

The rockets themselves were of course redesigned, providing for the larger total impulse required, but at the same time, ignition will be softened, allowing some progressivity during burn, which should alleviate the force control problem which exists with the old system.

6.6.5 The Parachutes

From the standpoint of logistics, human factors, and cost, it is desirable to have only one type of parachute; and from the standpoint of performance, clusters of nine or more parachutes complicate rigging, deployment and inflation, and there has to be compatibility with the rockets with respect to incremental load recovery capability. The desirability of a parachute subsystem which would function without reefing, parachute disconnects, and the large opening forces associated with certain designs are obvious.

Rigorous investigation of the parachute requirements with respect to size, number, load increment, descent velocity, inflation time, opening force, impact velocity, stability, altitude, temperature, and the aforementioned considerations resulted in the selection of the parachute which incorporates features which fulfill the requirements.

6.6.6 The Absolute Altitude Sensor

There was considerable trading in this area.

Examination of the subsystem configuration which was incorporated into the test program resulted in the necessity for another approach.

Aside from the problems associated with the dynamics of the double flexible probe system, the mechanisms are complex and complicated, and the maintenance and logistic requirements are formidable. The cost of ownership would be very high due to attrition, maintenance, and refurbishment. The hydro-mechanical-explosive concept requires replacement of certain parts after every use and continuous maintenance of the hydraulic section. There are many human error sources, and because of reliability, the concept requires redundancy, which doubles some problems.

A number of systems were investigated, the best of which are described in the section on Absolute Altitude Sensing, and a type was selected for application.

6.6.7 The Rocket Ignition System

This area proved to be very fertile from the standpoint of reliability, safety, and cost.

The original concept utilized mild detonating fuse (MDF) between the mechanical probes and the probe housings, where a ballistic interface was provided between the probe reelout brake mechanism and the confined detonating fuse (CDF) signal line to a shuttle valve (in a rocket pack) which, when functioned, allowed stored N_2 to pneumatically activate the rocket ignitors.

The MDF-CDF was expendable but expensive and some problems arose concerning electrostatic susceptibility and generally, safety and dependability. Economics, performance, and safety considerations prompted further study of other methods. Various laser, electrical, and pneumatic systems were evaluated, but were discarded for the same reasons, for instance, low powered electrical systems were still unsafe, other systems still required refurbishment, or were fragile, expensive, or functionally time consuming.

The selected system is a relatively high powered, non electrostatic sensitive, reuseable electrical system utilizing rugged off-the-shelf redundant cables, which operates a highly reliable, relatively inexpensive solenoid valve, still pneumatically firing the rockets with stored N_2 in a rechargeable system. Further development of the N_2 charging system is necessary to determine whether it is necessary to use a tankage source for high pressure N_2 or whether inexpensive expendable sources or even dry air sources or compressors would be better.

6.7 Conclusions

6.7.1 Supplementary Trade-Off Parameters are:

a) Capability and Dependability

b) Durability

c) Failure Dependency or Independency

d) Maintainability and Serviceability

e) Vulnerability and Survivability

f) System Effectiveness

g) Weight

6.7.2 Methodology

Some of the above are recognized as being associated with Human Factors, or other areas which are considered in other parts of this whole study, but they are reiterated here to assist in the thoughtful evaluation of the system and its components, and to substantiate the following:

There are many ways in which a function may be achieved, and barring human error, any configuration, no matter how conceived, will work if it is finally developed, tuned, and durably built. But we cannot eliminate or neglect the interfaces between man and machine, and machine and machine, otherwise a device will be doomed to outright failure or to some place within the gradient of relative efficiency.

Therefore, the considerations are manifold, and the evaluation itself is filled with potential problems, but when the absolute and relative merit of devices are compared with trade-off parameters for acceptability, and an effort is maintained to not only start with workable concepts but to persist in the improvement of techniques right up to the frontier of the known or predictable state of the art, the probability of success is enhanced.

Because no device or system functions completely independently, free from all the environment, the evaluation of a concept is performed as an integrated system of relatively important components, and therefore, much of the evaluation is performed from the basis of systems analysis.

A useful systems analysis method is outlined in Figure 6.1.

Note that depending upon the degree to which the results of a stage can be visualized, a subsequent stage may be bypassed. Many of the decisions will be made on the basis of experience or intuition, which may after all, be a form of extrapolated experience.

6.8 Summary

6.8.1 The prerequisite study and understanding of the proposed system imply that intra-program trade-offs favored the following, and in the approximate order shown.

a) Performance
b) Reliability
c) Cost
d) Safety
e) Durability
f) Weight

6.8.2 Other equipment, supplies, and materials, which are not specifically considered here, were found to be compatible with and satisfactory for use with the PRADS, to the extent that they are

SYSTEM ANALYSIS

I. Specify the system to be studied and imagine a simple PHYSICAL MODEL whose behavior will match sufficiently closely the behavior of the actual system.

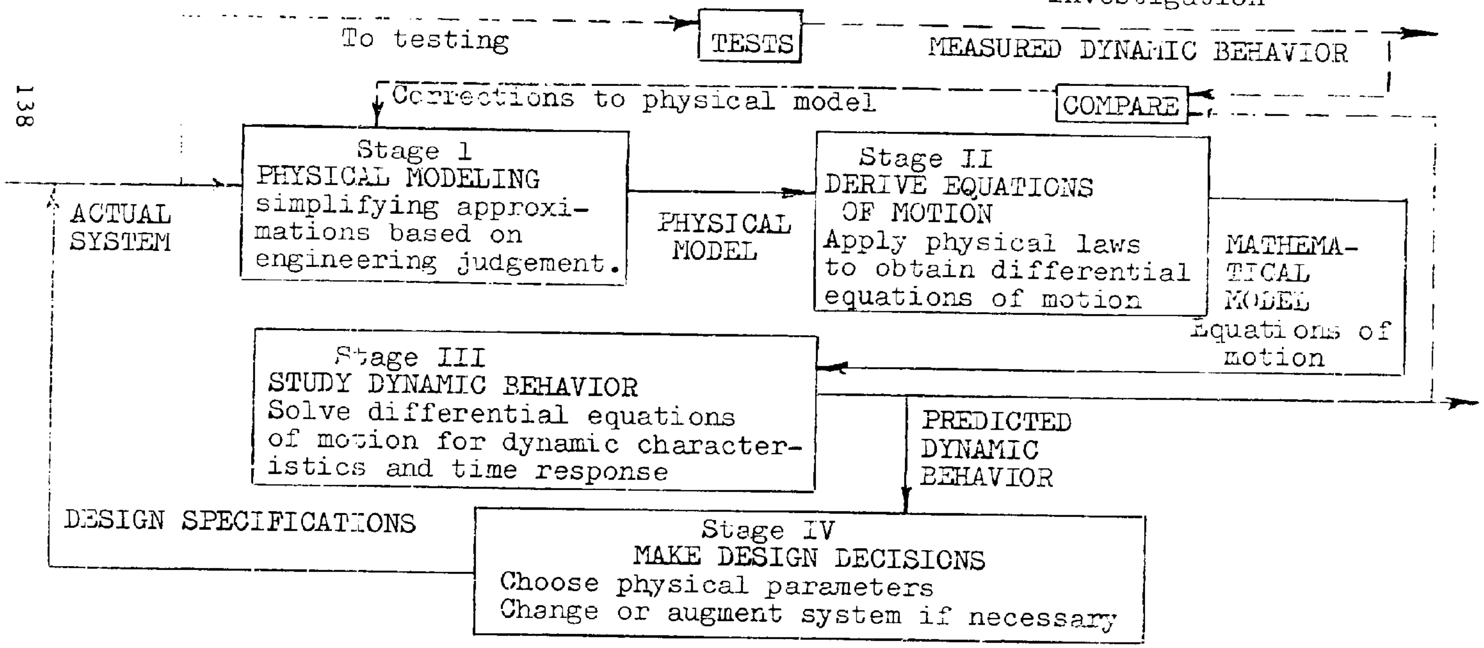
II. Derive a mathematical model to represent the physical model: that is, write the differential EQUATIONS OF MOTION of the physical model.

III. Study the DYNAMIC BEHAVIOR of the mathematical model, by solving the differential equations of motion.

IV. Make DESIGN DECISIONS; i.e., choose the physical parameters of the system, and/or augment the system, so that it will behave as desired.

Figure 6.1

The stages of a dynamic investigation



dependent on the function and performance of PRADS as treated here.

6.8.3 The areas still requiring further work are:

Rocket pack weight reduction (re-affirmation of modular concept).

Parachute force/time tuning (see proposed parachute specification).

Parachute/rocket pack suspension system tuning (riser extension, bridle, and various force transfer etc. lanyards).

7.0 AIRCRAFT UTILIZATION AND COMPATIBILITY

7.1 Introduction

A design objective for the PRADS is to achieve a degree of utilization and compatibility with certain cargo aircraft and other Government Furnished Equipment which is equal to or better than the existing system.

7.2 Scope

The C-5A, C-141, and C-130 were examined with respect to aircraft limitations and other characteristics concerning airdrop operations to determine whether PRADS rigged loads are compatible with the aircraft systems which would utilize the PRADS, and to what extent utilization was enhanced or changed.

Other aircraft were also examined for possible application, and information is provided pertaining to physical characteristics. Attention is directed to the Performance Analysis for additional information pertaining to relationships involving considerations related to speed and altitude.

Comparison of current limitations of the various aircraft and equipment with the airdrop system performance goals define the areas of incompatibility, and various combinations of parameters further limit compatibility.

Flight Safety analysis is treated in a separate section, but where it limits cargo size or weight it becomes a consideration here.

7.3 Purpose

The information presented here can be used as a brief guide to current limitations, and references are provided for additional study.

7.4 General

The capability of cargo aircraft and other ancillary equipment to meet the new demand imposed by the PRADS is an important consideration in this study.

Load factor limitations, recovery system forces and equipment requirements, and aircraft speed requirements, cargo compartment dimensions, ramp loads and conveyor mechanisms are other considerations.

The following paragraphs present the results of the study performed, along with pertinent remarks where problem areas are anticipated.

7.5 Discussion

7.5.1 The PRADS concept and the equipment areas in which the differences occur, do not affect compatibility with an aircraft from a performance standpoint since the proposed system will function similarly to the current system while the load is within the aircraft, because it utilizes the same extraction technique and equipment.

At this particular point in development, PRADS loads enjoy an average weight utilization factor of .93 compared with .91 for an all-parachute system. This means that the PRADS load is .98 as heavy as an all parachute system load. The other significance is that this is a weight reduction of almost 30% in the weight of the recovery system alone.

For planning purposes, the gross rigged weight of material to be airdropped from aircraft can be approximately estimated by using the following equation:

$$\text{Gross rigged weight} \cong 1200 + 1.14 \times \text{Airdrop Weight}$$

7.5.2 The combined Rocket Pack - Parachute system will occupy less space than all parachute system.

The platform size requirements will remain the same with the use of modular type platforms.

The requirements for rigging and handling A-22 containers and other standard loads (Ref. 1, 2, & 3) are compatible with the C-130B & F and the performance goals of the proposed PRADS.

The airdrop configuration of the C-130 B & E will use the dual rail system only (Ref. 4) which uses the modular platform only (Ref. 3 & 5), which is consistent with the current requirements for airdrop of supplies and equipment.

7.5.3 At this time, there exists mutual compatibility between the PRADS equipment configuration, contract performance goals, C-130 B & E aircraft limitations, and standard and non-standard airdrop loads, up to and including individual loads of 35,000 pounds and composite loads up to the load capacity of the aircraft.

When compared with the current conventional parachute airdrop system, the PRADS concept is found to vary essentially with respect to performance; space utilization, weight, ground handling, and extraction sequences are similar.

Aircraft load distribution for single or composite loads, with single or multiple aircraft, remain unchanged, for the C-130.

Formation flying procedures, as outlined in Ref. (6) are unchanged for the C-130.

7.5.4 According to Ref. (7), no airdrops are permitted unless restraint rail mechanisms are individually locked (but not with the remote control locking system), and the airdrop system may not be used until test programs are complete; however, when airdrop is operational utilizing the C-141, if the airdrop mechanical system used is compatible with current platform and extraction requirements, then no special problems are visualized. This is exclusive of any flight limitations established for the aircraft.

The extraction phase, particularly the roller loads and extraction line requirements are thought of as being the problem areas.

7.5.5 The PRADS concept maintains compatibility with the concept of interspersed airdrop of troops and cargo, with the necessity of being aware of the timing required because of the differences in performance between the PRADS and personnel recovery systems, particularly when mass formation drops are performed.

Attention to and the study of the references listed at the end of this work is recommended, as the characteristics of aircraft and airdrop systems change regularly, and it is considered important to maintain awareness of current limitations of the most reliable systems being utilized.

Duplication of data subject to change in this work would be classified as UNCONTROLLED, and therefore, would not be in the best interests of the coordinated development of the airdrop capability as a whole.

7.5.6 Sufficient data on the C-5 i not available to render findings either as to the advisability of the actual airdrop of the PRADS. Reference (9) and (10) provide some of the data however. There is no reason to believe that PRADS will impose any limitation upon use of the C-5. In fact, if the present airdrop system can be used with a longer extraction line, PRADS will be compatible.

REFERENCES

(1)	T. O. 1C-130A-9	Technical Manual - C-130
(2)	TM 10-500	Airdrop of Supplies and Equipment - General
(3)	ASNPSP-1	Criteria for Non-Standard Airdrop Loads
(4)	ASD-TR-61-579	Chapter 5, Section 2
(5)	TO 1363-4-1	
(6)	AFM 55-130	Troup Carrier Aircrew Operational Procedures - C-130
(7)	T. O. 1C-141A-9	Technical Manual - C-141
(8)	AR705-35	Criteria for Air Portability and Airdrop of Material
(9)	AMCP-706-130	Engineering Design Handbook - Design for Air Transport and Airdrop of Material
(10)	AFFDL-TR-66-97	Study of Heavy Equipment Aerial Delivery and Retrieval Techniques

8.0 COST ANALYSIS

8.1 Introduction

All costs which are discussed or presented are those which begin at the onset of the next phase of the PRADS program, current costs being thought of as being necessary to acquire this information.

Past and current cost, even when added to other relatively insignificant cost factors, form only a very small part of the total cost of development, acquisition and operation of the system over a period of five to ten years or longer.

In some cases, the data is presented in the form of manhours for comparative purposes and because further conversion to dollar values was uncertain.

The data presented is budgetary only, and does not constitute either an actual or implied proposal. All costs are shown in 1969 dollars. The estimates exclude spare parts.

8.1.1 Discussion

The fallout from the economic study is manifold:

1. It is more economical to use reloadable or refurbishable components than it is to use expendable ones. (Ref. Table L)

2. It is more economical to use reusable components (not requiring refurbishment) than it is to use refurbishable ones.

3. The system simplification and design optimization effort has resulted in the following configuration:

   a. one size rocket pack
   b. one rocket pack for any load
   c. modular rocket pack
   d. combinations of from two to twelve 8000 lbs-sec. rockets

e. one parachute size
f. combinations of from one to six parachutes
g. no parachute reefing required
h. low individual recovery system weight
i. electro-optical altitude sensor
j. electro-pneumatic rocket ignition system

4. Because of inspection and quality control requirements, and the attendant facilities, equipment, and the extraordinary documentation, maintenance, training, and manpower requirements, it is recommended that rocket refurbishment be accomplished only by the original equipment manufacturer. All the rocket manufacturers consulted in this matter concurred.

5. The effects on cost by the PRADS manpower requirements is uncertain. Examination of Paragraph 8.4, which is realistic, shows that for the particular samples chosen that the PRADS requires less manhours. The difference is about 5% and appears to be well within the scope of capability of existing TOE's for airborne companys and their back-up.

The whole operation is contingent upon operational scheduling, but it appears fair to conclude that some decrease in manpower can be expected, and that labor cost is decreased.

6. The bulk of the total cost for comparison purposes is constituted essentially of the production supply costs and the cost of ownership.

7. The cost of ownership for a capability for any hardware items ultimately becomes the total cost of the system minus the surplus value of what is left, unless used at a continuously diminishing rate till depletion through attrition.

8.1.2 Analysis

In this analysis, an estimate of costs to fully develop and qualify the system for production is most easily determined if tentative chronological and manpower schedules are prepared.

Table A is an estimate of costs for the SAEC effort to prime contract, develop, coordinate, and test the system.

Table B shows an approximate schedule for SAEC and its supporting vendors to coordinate, develop, and qualify the system components, and prequalify the system.

Table C is an estimate of costs for items which will be required for prequalification of the integrated system, the components of which are already fully developed, tested, and individually qualified.

Table D is a summary of estimated costs for design, development, and qualification for the items listed.

Table E is a summary of estimated costs for production of various numbers of components.

Table F is a summary of total estimated program costs to the Government, exclusive of GFE and other additive Government expenses for the system development.

Table G thru J summarize other cost considerations.

Table K is a summary of key PRADS items requiring development, qualification and production, and shows the results of computation using the TIE Contractor provided data for examples of the determination of the initial order for new components. Also shown are the results of computation using the TIE Contractor provided data for type and quantity of loads assumed to be dropped per division per year in training, but with the benefit of formula (1), which provides a more refined estimate of actual quantities required, although the example initial order quantities may be used for cost comparison purposes.

8.2 Cost Analysis Quantity Requirement Study

(Ref. Table K)

A useful lumped parameter for the determination of quantities required, over a number of uses is the use life of an item, or drop life, as we will refer to it here.

This may be thought of as the total useful life in terms of the number of times it may be used or dropped, due to any cause.

The reciprocal of this number may be thought of as the probability of loss of an item due to any cause, when an item is used either singly, multipally, or simultaneously with others.

This principle is also more refined than an estimation of back up quantities, because it relates attrition to drop life, and a good evaluation of drop life is available from an analysis of design attributes such as simplicity, ruggedness, and maintainability within the operational environment.

The principle need not apply to expendable, or one-shot items, for then, the quantity required is simply the same as the total number of individual uses.

For all other cases, however, the losses due to probability are added to achieve the original level for each use, thus, for any initial capability, the initial supply is determined by the following:

$$G_1 = N_d \left[H_1 + (M_1 N_1 - 1) \left(\frac{H_1}{L_1} \right) \right] \qquad (1)$$

where

G_1 = initial supply.
N_d = total number of divisions performing airdrop.
H_1 = total number of items per division per drop.
N_1 = total number of drops per division per year.
L_1 = total non-combat drop life of item.
M_1 = total years non-combat drop use of item.

NOTE:

Weights and possibly cost can be reduced for loads under 8000 pounds in Table K if G-12 parachutes are used; however, performance from 500 feet altitude is marginal and one size parachute only (48 feet dia.) is ideal from a logistics standpoint. In addition, rockets could be used for loads between 6000 and 8000 pounds with a resultant weight savings; however, a cost saving can be realized with parachute only in reuse.

TABLE A

ACTIVITY NUMBER	ACTIVITY TITLE	TRAVEL MAN WEEKS	TOTAL MAN WEEKS
100	PROGRAM MANAGEMENT	2	102
200	VENDOR COORDINATION	8	64
300	ENGINEERING DESIGN EFFORT	4	304
400	SYSTEM TEST PROGRAM	40	275
500	ENGINEERING DOCUMENTATION	22	258
	GRAND TOTAL MAN WEEKS	76	1003
	TOTAL COST = $798,663	(1969 rates	including fees)

Activity 100 includes management, scheduling, and controlling all effort on Table B.

Activity 200 will be required for activities 300.

Activity 300 includes all SAEC calculations, design and shop drawings.

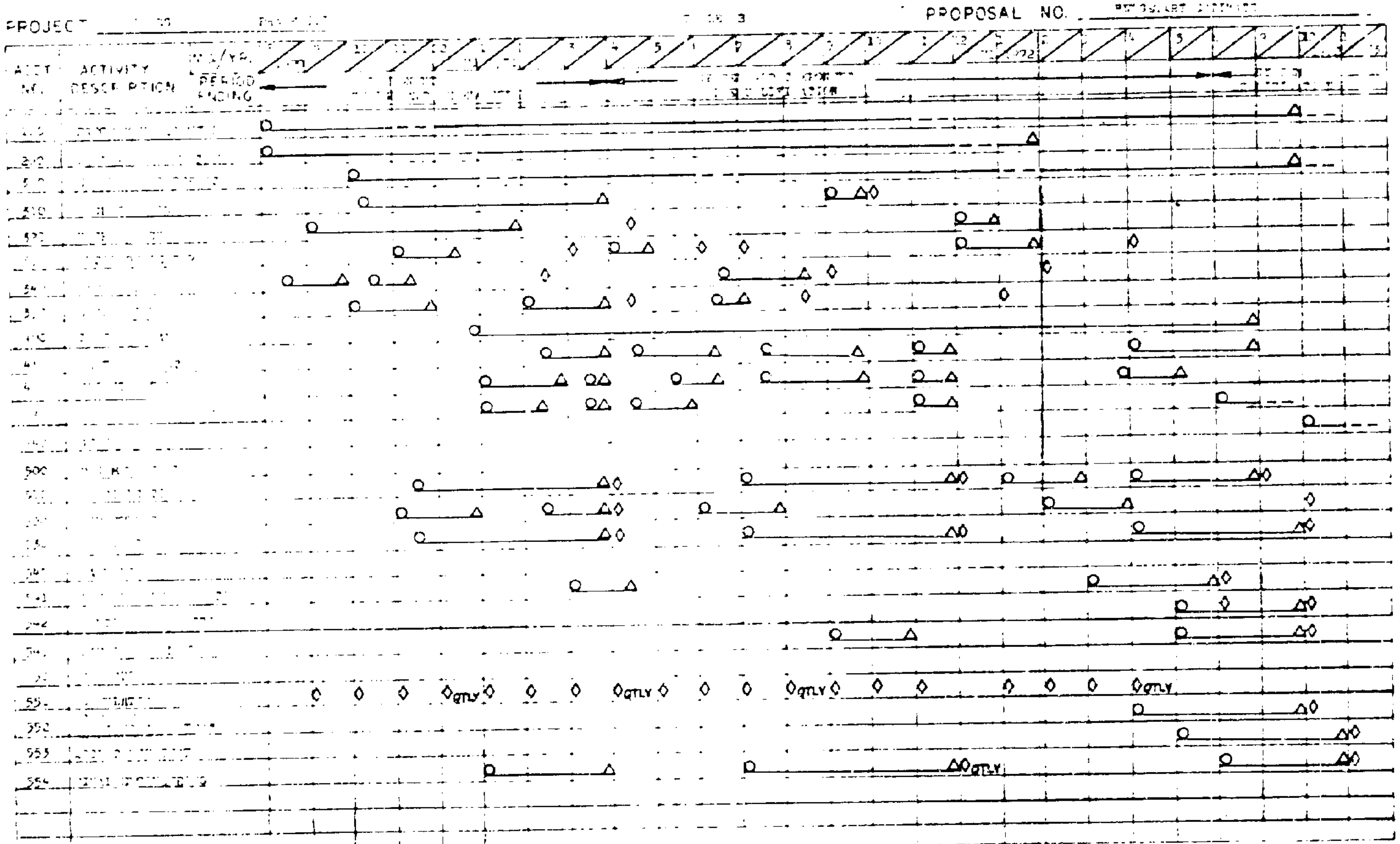
Activity 400 includes all testing at SAEC and at a government facility, by SAEC personnel.

Activity 500 includes drawings, specifications, manuals, and reports to military standards for hardware designed at SAEC, coordination of vendor documentation, and analysis of test results and data at a Government facility; also included are HFE and training criteria.

Activity 500 will be coordinated with the aviation command.

PROJECT SCHEDULE

PROJECT ____ PROPOSAL NO. ____



SYMBOLS: [═══] = SCHEDULE LINE ◊ = DELIVERIES O= Δ=

PAGE __ OF __

TABLE C

Items Required for System Prequalification Testing

	ITEM	QUANTITY	$ COST
1.	Sensor, Altitude	6	9,000 *
2.	Cable, Signal	10	600 *
3.	Rocket Pack Assy.	6	10,450 *
4.	Parachute System	15	10,500
5.	Mounting Kit - Rocket Motor	31	4,636 *
		Total Cost (With Fees)	46,833
6.	Rocket Motor (31 + 89 reloads)	120	63,500
		Grand Total	110,333 (1969 Rates)

NOTES:

A. This Test Program consists of the following sample:

(1) 5 Tethered Rocket Tests
   (a) One (4) Rocket Test
   (b) Two (8) Rocket Tests
   (c) Two (12) Rocket Tests

(2) 6 Drop Tests at SAEC
   (a) Two Parachute-Only Tests
   (b) Two Inert System Tests
   (c) Two (2) Rocket Tests

(3) 9 Drop Tests at Government Facility
   (a) Three (4) Rocket Tests
   (b) Three (8) Rocket Tests
   (c) Three (12) Rocket Tests

B. Cost Items marked * are included in the total, but some may be suitable leftovers from the individual component development and qualification phase.

C. All items are assumed to be purchased by Stencel except rocket motors which are assumed to be G. F. E. Stencel profit and administrative costs are added into total for items 1 through 5.

D. Cost estimates are within approximately ± 15 percent.

TABLE D

Items Requiring Individual Development and Qualification

	Item	Design, Dev., Tooling PFRT, Qual. Testing (Non-Recurring Costs)	Prototype and Qual. Test Hdwe. (Recurring Costs)
1.	Sensor, Altitude	60,600*+9800**+9000****	28,100 (incl. 20 units)
2.	#Cable, Signal	200 ##	800 (incl. 10 units)
3.	#Rocket Pack Assy.	13,000***+3300##	34,835 (incl. 20 units)
4.	#Parachute System	4500***+3000##	16,000 (incl. 20 systems)
5.	#Rocket Mount Kit	2400***	6,132 (incl. 41 units)

Total (with fees) = $255,109

6.	Rocket Motor	**** 221,048*+27,100***+ 49,800	(incl. 41 rockets)

Grand Total = $553,057 (1969 Rates)

NOTES:

1. Recurring Costs are itemized where the information is available as a separate item

2. Cost estimates are within approximately ± 15 per cent.

3. All items except rocket motors (number 6) are assumed to be subcontracted by Stencel; and therefore, total cost includes Stencel profit and administrative costs on these items. (Rocket motors are assumed to be G. F. E.)

LEGEND:

*Design and Development Engineering
**Finalize Design
***Tooling
****Subcontract for Manufacturing or Qual. environments
#Items wholly designed and tested at SAEC, the labor for which is included in Table A.
##Instrumentation

TABLE E

Summary of Estimated Cost for Production Items

ITEM		QUANTITY	AVERAGE UNIT $COST	HIGH $COST EST.	LOW $COST EST.	REMARKS
1.	Sensor, Altitude	3000	205	236	174	
2.	Cable, Signal	3000	40	65	32	
3.	Rocket Pack Assy.	3000	1195	1400	875	
4.	Rocket Motor	5340	635**	878**	540	
		26,700	565**	781	470	
5.	Rocket Motor Reloads	16,020	218**	247#	185	
		80,000	169**	191	144	
6.	Parachute System	3,914	545	594	496	
		7,482	514	544	484	
		11,223	495	510	480	
7.	Rocket Mounting Kit	5,340	83	96	65	##
		26,700	73	85	55	##

* Includes Recurring and Non-Recurring Costs
** Estimate Excludes 298,000 for R, D, T, & E (Northrop)
\# Estimate Includes R, D, T, & E (Atlantic Research)
\## This item is to be supplied as part of each rocket.

NOTE:

1. Rocket pack assemblies (number 3) and rocket mounting kits (number 7) are prices as assembled and delivered by Stencel and includes Stencel administrative and profit costs. It is expected that the average cost of these items can be reduced by value engineering. All other items are assumed purchased by government.

2. Under quantity, upon which prices are based, numbers are somewhat different than those found in Table K for all items. Quantities were obtained for using rockets for all loads down to

6340 pounds rigged weight; however, it is possible with very little change in minimum drop altitude to use all parachutes up to approximately 8000 pounds with a resultant reduction in cost per drop upon reuse.

TABLE F

Summary of Estimated System Development Costs

ACTIVITY	COST
SAEC Program (Table A)	$ 798, 663
System Prequalification Hardware (Table C)	110, 333
Subsystem Development (Table D)	553, 057
	$ 1,462, 053

8.3 Other Cost Considerations

Test Aircraft Operation: Test aircraft will be required during the test programs but because the test set ups are not exactly known now, only general information can be provided.

As mentioned in the aircraft utilization section, research has produced a document which provides data based on a similar study.

The results of the study will be useful for the determination of effectiveness of the PRADS and therefore the following specific contents and Tables G and H are provided.

AFFDL-TR-66-97 Study of Heavy Equipment Aerial Delivery and Retrieval Techniques.

Pages: 125-130, 247, 252, 256-301, 321-336, 349-354, 356-369

TABLE G
COST EFFECTIVENESS PARAMETERS

Parameter	AIRPLANES			HELICOPTERS			Tilt Wing VTOL	Direct Lift VTOL
	C-130	C-141	C-5	A	B	C		
V-Cruise, Kts.	290	440	440	145	140	95	485	635
Range (loaded), N. Mi.	1900	3800	2700	615	215	220	1000	1000
Cruise Alt., Ft.	25,000	30,000	30,000	5000	5000	5000	20,000	30,000
Crew Size (Officers)	4	4	4	2	2	3	4	4
	1	1	2	1	0	0	1	1
No. & Type Eng.	4-prop	4-jet	4-jet	2-rotor	2-rotor	2-rotor	4-prop 2-jet	20-jet
T.O. ESHP	4050@			1300@	2650@	4050@	14,300@	
T.O. Thrust, Lb.		21,000@	41,000@				7000@	(4-15,800@) (12-11, 700@) (4-10,000@)
Prop. Wt., Lb.	7200	17,960	28,040	590	1160	1740	36,000	32,000
Emp. Wt., Lb.	73,000	135,800	318,300	11,933	17,878	17,240	94,000	86,000
Prop. Cost, Million $	.352	1.2	2.56	.09	.190	.28	1.65	3.75
Plane Cost, Million $	1.8	5.5	12.0	.83	1.66	2.0	5.57	7.87
Fuel Cap. Gals.	9680	23,080	49,000	1544	617	880	3000	6000
Avg. Fuel Cons. Lb/Hr	3450	9700	19,550	1160	2300	3460	10,900	22,000
Mean TBO, Hr.	4800	2500	2500	2500	2500	2500	2500	2500
Reliability, %	96	94	98	78	78	78	90	90
Availability, %	75	75	75	65	65	65	75	75
Vulnerability	1	2.08	3.45	11.88	22.00	29.7	25.1	30.0
V-Retrieval, Kts.	120	120	120	0	0	0	0	0

TABLE H
COST RESULTS

	AIRPLANES			Tilt Wing VTOL	Direct Lift VTOL	HELICOPTERS		
	C-130	C-141	C-5			A	B	C
Airframe Labor Cost/Hr/A/C	42.55	60.30	129.85	39.35	38.30	21.75	23.55	23.55
Airframe Material Cost/Hr/A/C	17.78	58.58	98.08	42.58	44.58	10.61	17.95	20.48
Engine Labor Cost/Hr/A/C	6.08	14.20	20.52	18.80	69.64	4.02	4.38	4.76
Engine Material Cost/Hr/A/C	20.92	94.08	202.20	21.61	29.06	3.12	7.13	10.73
Total Maintenance Cost/Hr/A/C	87.33	227.16	450.65	122.84	181.58	39.50	53.01	59.32
Fuel Cost/Hr/A/C	51.80	145.50	293.25	98.20	183.11	9.69	29.05	48.95
Crew Cost/Hr/A/C	20.30	22.00	22.00	20.30	20.30	11.00	9.25	13.90
Operational Cost/Hr/A/C	159.53	392.96	765.90	241.34	384.99	60.19	91.31	122.17
No. Planes for $\$100 \times 10^6$	54	18	8	18	12	120	60	50
Fleet A/C Oper. Cost/Hr.	8609.22	7073.28	6127.20	4344.12	4619.88	7222.80	5478.60	6108.50
Fleet Helium Cost/Hr.	4317.11	1913.90	854.81					
Fleet JATO Cost/Hr.	64,501							
System Fleet (with JATO)	774,273.30							
Operating Cost/Day (without JATO)	129,263.30	89,871.80	69,820.10	43,441.20	46,198.80	72,228.00	54,781.00	61,085.00

Estimate of cost to set up an Army training program sufficient to retrain existing support personnel and train replacements in the operation of the system.

8.3.1 Sample Training Schedule

Duration	Sequence	Personnel
		2 Instructors (SAEC Project Engineers)
		2 Tech Reps (SAEC Group Engineers)
	TRAIN	
3 Wks		22 A.D.A.E.S. Co. 82nd Airborne Div., Ft. Bragg, N. C.
	then	4 O's, 2 WO's, 16 NCO's, & possibly 1 CO & 3 NCO's.
3 Wks.		2 Tech Reps left after training.
	while	
		2 Instructors
	TRAIN	
3 Wks.	then	22 A.D.A.E.S. Co., XXnd Airborne Div., etc. as above.
3 Wks.	while	2 Tech Reps left after training.
		2 Instructors
	TRAIN	

Duration	Sequence	Personnel
3 Wks.		22 A.D.A.E.S. Co., YYnd Airborne Div., etc. as above.
	then	
3 Wks.		2 Tech Reps left after training.

Using the Airborne Division Air Equipment Support Company, 82nd, Airborne Division at Fort Bragg, North Carolina, (TOE 10-337F, Ref. FM 10-8 Chap. 5) as the first example, we can see how established facilities and manpower might be employed in the training program.

The training schedule is organized in such a way that minimum numbers of personnel may promulgate information to key organization personnel whom then proceed with organizational training in the way designated within the command.

The schedule would coincide with the delivery of hardware, manuals, training aids, and other equipment essential to the program.

Two tech reps would remain with the company after formal training, and the two instructors would then repeat the cycle within another organization, then the two tech reps would transfer there, and so on, till all three divisional capabilities had been started up.

If more time is required, that would easily be arranged.

Realistically, there may be scheduling snafu's and the time would protract, but the estimated schedule is realistic if other aspects progress satisfactorily.

8.3.2 The cost estimate is as follows:

Manpower	Time (wks)	Time (hrs)
(2) Instructors	9	720
(2) Tech Reps	9	720

Subsistance = 4(9) = 36 weeks
Travel and car rental

Manuals (excluding preparation):

Quantity required = (26/company) (3 companys) = 78
SAEC = 10
Other = 12
100

Approximate total for training only
Assuming $10 each, 100 (10) = $1,000.00
Total Cost = $35,440
Training Aids:

1 Rocket Pack Assembly (complete)
14 Rockets
2 Altimeter Systems
8 Parachutes
1 Lot PRADS miscellaneous hardware
1 Lot 16mm films and still photos
(The above materials are left over from the testing and evaluation phases, and precede the delivery of production systems)

1 Lot Charts
1 Lot displays
1 Lot prepared films

The bulk of the investment of the above items is constituted primarily of the labor cost of preparation - refer to Table J for manpower costs.

Again this cost is in terms of the present rates.

Note that the cost of revising and printing the rigging manuals is not included. Approximately one-third of the manual pages will require some revision.

TABLE J

Estimate of Curriculum Development And Material Preparation Cost

ACTIVITY	MANPOWER	TIME (HRS)
Training Program	Group Engineer	800
Training Films	Engineering Technician	800
Training Charts	Tech Writer	2400
Training Displays	Scientific Photographer	400
	Photo Technician	400

Total Cost = $77,428

COST OF KEY ITEMS TABLE [illegible]

Item No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]			[illegible]		[illegible]		[illegible]	Total of Reloads [illegible] Number of Rocket Firings Required
1	M[illegible] 3/4 Ton Truck With [illegible]	[illegible]	[illegible]		[illegible]	[illegible]		0											
2	M[illegible] 3/4 Ton Cargo Truck	9519?	[illegible]	[illegible]	2?	0?		0		3?	0?			2?		269?		0	
3	[illegible] Load Tour 4?2 [illegible]	1340?	134?	[illegible]	[illegible]	[illegible]		0		7	2?			2		2119?		0	
4	[illegible] 3/4 Ton Trailer With [illegible]	5190?	1	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]				0?				0	
5	[illegible] With Tool Chest	8130	[illegible]	1?	[illegible]	2?		[illegible]		[illegible]	[illegible]			[illegible]		[illegible]		80	
6	[illegible] 1/4 Ton Carriers	7790	[illegible]	[illegible]	0	0		0		3	0			0		192		0	
7	M[illegible] 3/4 Ton 4 x 4 Utility Truck	3275	104?	[illegible]	0?	0?		[illegible]		[illegible]	[illegible]			[illegible]		455?		0	
8	[illegible] 1/4 Ton Trailer With [illegible]	2600?	37?	144?	0	0		[illegible]		3	0			[illegible]		[illegible]		0	
9	M[illegible] 2-1/2 Ton Truck With [illegible]	17960	[illegible]	26?	1	6		1		3?	9			5?		[illegible]		54	
10	3/4 Ton 4 x 4 Repair Truck With [illegible]	11717?	17?	[illegible]	[illegible]	4		1		2?	17?			17		[illegible]		63	
11	[illegible] Rocket Pods [illegible]	14283	1?	[illegible]	1?	3		[illegible]		2	17?			17?		[illegible]		65	
12	M113 Armored Personnel Carrier	23937?	[illegible]	[illegible]	[illegible]	2		[illegible]		[illegible]	7			7?		[illegible]		42	
13	[illegible] General [illegible] Vehicle	34910?	6	24?	1	12		1		[illegible]	2?			[illegible]		[illegible]		72	
14	[illegible] Cargo Container	1752	45?	240?	0	0		0		3	2?			0		[illegible]		8	
	Total No. Per Division Per Drop R_1		.522?					[illegible]			92			92		4551		389	389
	Total No. Per Division for 4 Drops/Yr S_1 *			[illegible]				[illegible]			106			106		2710?		680	875
	Total No. for 5 Divisions Per Drop $5R_1$		1566?								276			276		4593?		1157	1157
	Total No. for 5 Divisions for 4 Drops/Yr $5S_1$			8204?							312			312?		7150?		2040	2625
	Total No. for 5 Divisions for 5 Years *			[illegible]1730?				[illegible]			540			540		[illegible]		6710	[illegible]600
	Example of Total No. for Initial Order for Expendable Items = (4)(2)(3)(R_1) =																		9336
	Example of Total No. for Initial Order for Reusable Items = (2)(1.5)(3)(R_1) =										828			828		435?		3500	
	Example of Total No. for Initial Order for Expendable Items = (4)(1.5)(3)(R_1) =																		[illegible]
	Example of Total No. for Initial Order for Reusable Items = (2)(5)(R_1) -															15906		2334	
	Example of Total No. for Initial Order for Expendable Items = (4)(1.5)(5)(5)(R_1) =																		5010?
	Example of Total No. for Initial Order for Reusable Items = (2)(5)(5)(R_1)										2760			2760				[illegible]373	

* Ref. Formula (1) Page 30
(4) Indicates No. of Items Used Per Year
(2) Indicates 100% Backup Above Division
(1.5) Indicates 50% Backup Above Division
(3) Indicates Three Division Force
(5) Indicates Five Times the Amount

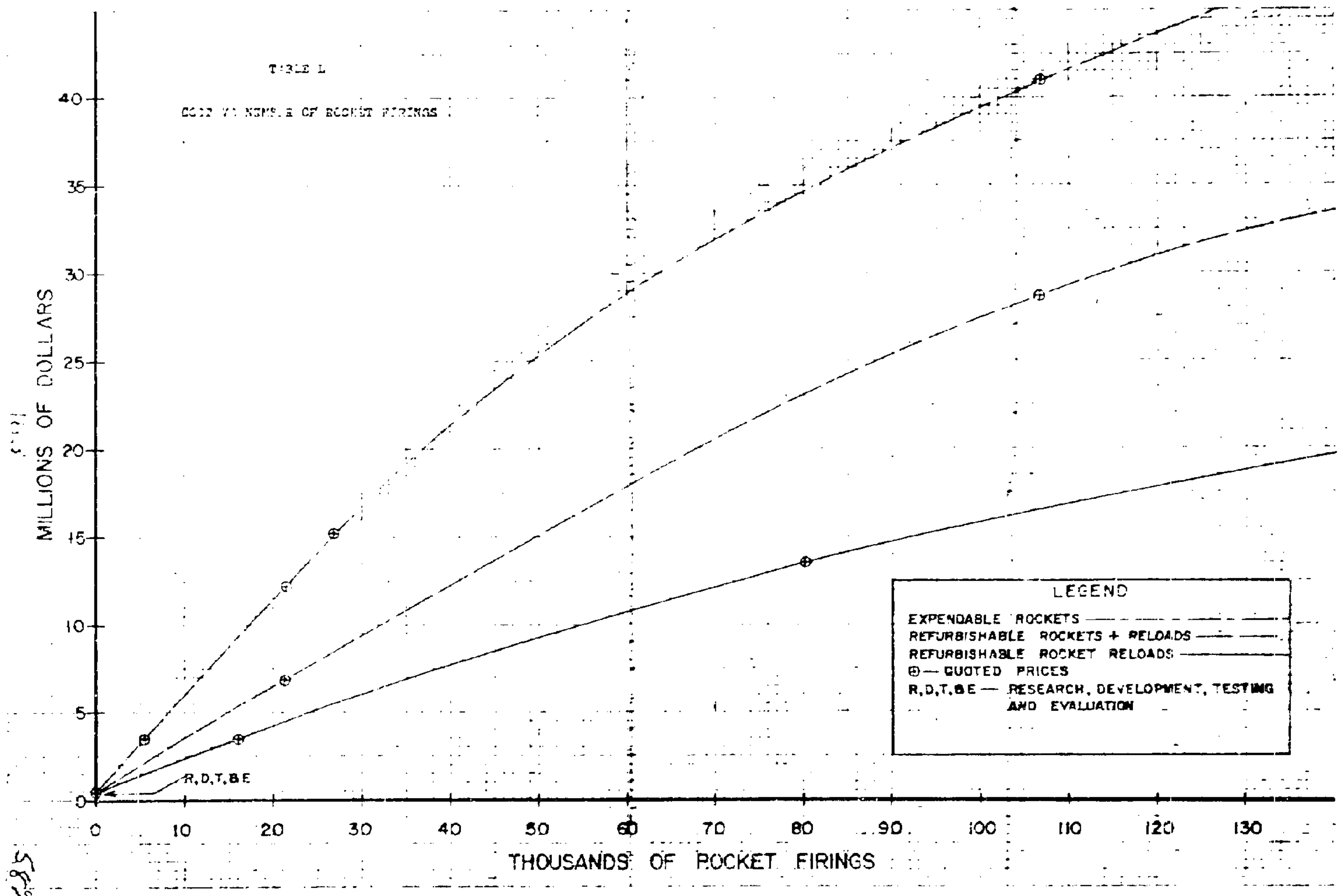


TABLE L
COST VS NUMBER OF ROCKET FIRINGS
MILLIONS OF DOLLARS
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
THOUSANDS OF ROCKET FIRINGS
R,D,T,&E
LEGEND
EXPENDABLE ROCKETS
REFURBISHABLE ROCKETS + RELOADS
REFURBISHABLE ROCKET RELOADS
⊕ — QUOTED PRICES
R,D,T,&E — RESEARCH, DEVELOPMENT, TESTING AND EVALUATION

8.3.3 Estimate of cost to modify the existing logistic support system.

The following documents describe the structure, purpose, responsibilities, phases, policies, operations, capabilities, duties, costs, and other considerations of logistics, and because it is felt that at this time the whole system is adaptable, with modification, to the PRADS and because some of the pertinent logistic cost factors are undeterminable at this time, reference to them is recommended for substantiation of the findings.

ST 10-501-1-1	Airdrop operation (Air Equipment Support Company, Airborne Division, TOE 10-337F)
FM 10-8	Air delivery of supplies and equipment in the field.

(1) Maintenance

(a) Facilities. Existing facilities such as warehouses, shops, dumps, magazines, sheds, etc. are compatible. Additional facilities probably will not be required because field refurbishing or repair of rockets is not recommended, and other items can be handled at some existing level or sent back to the manufacturer. Ref. ST 10-501-1-1 Section IV, FM 10-8 Chapter 5.

(b) Equipment. Undetermined in total at this time. Ref. ST 10-501-1-1 Section II, 6g, Table I, Table VII.

(c) Tools. Ref. ST 10-501-1-1 Section II, 6f, Table VII. TM 10-1670-222-23P: Organizational and Field Maintenance Repair Parts and Special Tool Lists.

(2) Logistic Support System

(a) Facilities. Ref. FM 10-8 Chapter 2, Section II, III, IV Chapter 5, Section II.

(b) Identification, traceability, documentation, and forms- The requirements for these activities will be invoked during the production program but only the requirements for identification and traceability will affect cost. Because it places additional burden on the equipment suppliers and manufacturers, the cost should accurately be determined by RFQ for a special end item or material. This appears to be outside the scope of this analysis, and impractical to perform at this time.

The cost of documentation is constituted primarily of the cost of preparation. Refer to Table A for lumped manpower costs. The cost of forms and all other manifestations of the Federal Supply System, stock number assignment, data management requirements, etc. is part of an existing capability and is difficult to cost. It is suggested that because the capability is constantly maintained, that its effect on cost be neglected.

8.3.4 Cost Comparison

Estimates of cost to drop a load for each load weight are shown in Table M. Figures are shown for combat conditions and for training or resupply. The cost of PRADS is somewhat higher than the present system in combat conditions where attrition is high. The cost of PRADS is considerably higher for training or resupply. Resupply would not require PRADS necessarily, and training could be done with an all parachute system for lighter loads with the signal system for checking proficiency of the rigging crew.

8.3.5 Configuration Comparison - PRADS and Conventional System

Tables N & 0 summarize basic component comparisons for the airdrop systems currently in operation and the prototype PRADS. This table reflects the improved volumetric efficiency of costs of the two systems. This table is valid only for standard day drop zone conditions.

TABLE M

COST COMPARISON
DOLLARS PER DROP
PRADS vs PRESENT STANDARD SYSTEM

		PRADS		STANDARD SYSTEM	
Gross Weight Pounds	Unrigged Weight Pounds	Combat Conditions	Training or Resupply	Combat Conditions	Training or Resupply
18,000	17,000	5800	1900	4700	800
22,000	20,700	6300	2200	5400	900
35,000	33,000	8600	3200	7400	1240
50,000	47,000	11,500	4200	9400	1550

8.4 Manpower Requirements

Estimate of work measurement standard for rigger rolling, layout, and packing of PRADS 48 foot diameter parachute. (two man team)

Operation No.	Description	Time (Minutes)
1.	Carry parachute to work area, remove from bag, stretch out and untangle	4.29
2	Rigger roll and tag for maintenance	7.04

TABLE N CONFIGURATION COMPARISON

Item	Load	STANDARD SYSTEM Number P'chutes	Rigged Weight-Pounds	PRADS System No. 48' P'chutes	No. Rockets	Rigged Weight-Pounds
1	M38 ¼ Ton Truck	2	4180	5	---	4230
2	M37 3/4 Ton Truck	2	7409	8	---	7789
3	Mass Load Four A22 Cont.	2	6070	7	---	6340
4	M101 3/4 Ton Trailer	2	5030	6	---	5190
5	105MM Howitzer	3	8626	2	2	8530
6	M274 Four ½ Ton Carriers	2	7160	8	---	779[illegible]
7	M151 ¼ Ton Truck	1	3088	4	---	3278
8	M416 ¼ Ton Trailer	1	2520	3	---	2600
9	M35 2½ Ton Truck	6	18,364	3	6	17,960
10	3/4 Ton 4 x 4 Truck	4	11,947	3	3	11,794
11	Two 762 MM Rockets	5	14,631	3	4	14,311
12	M113 APC	6	22,150	4	7	21,937
13	M551 G.S. Vehicle	10*	35,000	6	12	34,975
14	Mass Load One A22 Cont.	1**	1962**	3	---	2167

*At least 10 G-11 parachutes required to recover 35,000 lb. load at 285 ft/sec at 100°F and 5000 ft. altitude

**One G-12 parachute used for this load. All other loads listed use G-11 parachutes.

TABLE O Rigging List for Slings and Risers
Proposed PRADS System

		Slings				Risers			
Type Load	Gross Load Wt.	No.	Sling Length Ft.	Type Webbing	No. Loops	Riser Length Ft.	No. Risers	Type Webbing	No. Loops
105 MM Howitzer	8,530	2 2 1 1	16 Wheels 17 Rear 17 Front 10 Front	X X X X	2 or 3# 2 or 3# 2 or 3# 2 or 3#	20	2	X	3
M35 2½ T Truck	17,960	2 2	20 Front 16 Rear	XXVI XXVI	3 or 4# 3 or 4#	20	3	X	3
Two 762 MMRockets	14,283	6 10 2 2 2 2	20 Front 9 Rear 11 Front 8 Rear 10 Center 16 Center	X X X X X X	2 or 3# 2 or 3# 2 or 3# 2 or 3# 2 or 3# 2 or 3#	20	2	X	3
M113 APC	21,937	2 2	16 Front 17 Rear	XXVI XXVI	3 or 4# 3 or 4#	40	4	X	3
M551 G.S. Vehicle	34,920	8 or 4	24 24	XXVI *	3 or 4# 3	40	6	X	3
3/4 Ton 4 x 4 Truck	11,767	4	24	X	3	20	2	X	3

* 40,000 pound tensile strength webbing, 3" wide

\# Slings with fewest loops are adequate. Slings with additional loop may be substituted if more readily available.

3.	Carry parachute to maintenance storage	0.37
	Total rigger roll cycle time	11.70
	PFD allowance (20%)	2.34*
	Time/rigger rolled parachute	14.04
1.	Carry parachute to work area, remove from bag, stretch out and untangle lines	4.29
2.	Sort lines and insert tension strap	4.00
3.	Apply tension	1.91
4.	Tie risers, suspension lines, and canopy	3.23
5.	Get bag and stow canopy in bag	2.92
6.	Close bag and tie lines	2.00
7.	Make 4 lock stows	2.87
8.	Make paper wrap	1.26
9.	Install line and riser retainer tapes	1.85
10.	Make "zig-zag" stow (lines and risers)	4.16
11.	Lace bag cover and connect bridle loop to risers	3.97
12.	Carry parachute to storage area	0.37
	Total pack cycle time	32.83

PFD allowance (20%)	6.57*
Time/Parachute	39.40

Table Time: 39.40

Layout and Pack

Rigger Roll:

$$14.04 \times \frac{14.3^{**}}{100}$$

Time for Pack of 48 ft. dia. cargo parachute 2.01

41.41

$$= \frac{41.41}{60} = 0.69 \text{ hrs.}$$

= 0.69 (2) - 1.38 Man hrs.

$$\text{No. of parachutes packed/team/hour} = \frac{60}{41.41} = 1.45$$

$$\frac{\text{No. of parachutes packed/team/hour}}{\text{No. of men/team}} = \text{Parachutes packed/man/hour}$$

$$\frac{1.45}{2} = 0.725 \text{ Parachutes packed/man/hour}$$

* PFD allowance has been included and is an accepted allowance in time study to account for personal time, loss of productiveness due to fatigue and unavoidable delays in the operational sequence.

** Experienced airborne supply, packing, and maintenance officers at Fort Bragg, North Carolina, were consulted regarding the proportion of parachutes rigger rolled. On the basis of their estimates, the proportion established for use in this study was 1 parachute rigger rolled to seven parachuted packed (14.3%).

Comparison of estimates of work measurement standards for rigging of loads, refurbishment of units and rigger rolling, layout, and packing of parachutes follows.

EXISTING SYSTEM

Item No.	Rigging Time (man-hours)*	Parachute Reqts (G-11A)	Packing Time (man-hours)**	Total man-hours
2	3.3	2	5.838	9.138
5	2.6	3	8.757	11.357
9	8.8	6	17.514	26.314
14	0.8	1**	1.868	2.668
				49.5

PRADS

Item No.	Rigging Time (man-hours)#	Parachute Reqts (48 ft)	= Parachute Time (man-hours)	Refurb-ishment (man-hrs)##	Total (man-hrs)
2	4.4	8	11.04	--	15.44
5	3.3	2	2.76	2.1	8.16
9	11.6	3	4.14	3.7	19.44
14	0.8	3	4.14	--	4.94
					47.7

Notes:

- * Ref. ST10-501-1-1 Table IX Rigging Factors
- ** Ref. ST10-501-1-1 Annex B (2.919 man-hours/G-11A)
- *** G-12D = .64 (2.919) = 1.868 man-hours/G-12D
- \# Ref. Table M & P. 26 (1.38 man-hours/48 ft. parachute)
- \#\# Ref. Table N using item A, B, C and G

EQUIPMENT AND TOOL FORECAST

Much work remains to be done during subsequent development phases, among which will be Ground Support Equipment and Spares.

The following is a list of new material which will be required, and it is as yet undetermined whether these items will be available at that time or whether they must be provided, and at what cost, because depending on the methods, sources, and quantities, the cost may vary considerably. These items, however, may not constitute a large total or relative investment.

ITEM	METHOD
N_2 Source, 2000 PSI with all plumbing, gauges, etc.	Bottles, Air Compressor & dryer or both
Batteries, Altitude Sensor 22.5 & 45 volts	
(0^oF to 125^oF):	Carbon/zinc
(-65^oF to 0^oF):	Thermal
Optical Range, Altitude Sensor	Compact Mirror Type Instrument or Constructed Bench Type
Tester, Signal Cable	Special plug-in type instruments or multimeter

9.0 CONCLUSIONS AND RECOMMENDATIONS

From the tests and studies performed the following conclusions and recommendations are made.

9.1 System Advantages

The PRADS is a low altitude airdrop system capable of delivering loads up to 35,000 pounds from 500 feet absolute altitude. Improved drop accuracy and lack of signature characteristic result from the low altitudes possible for successful airdrop. In addition, this low altitude reduces the probability of radar detection as well as the distance from which the aircraft can be spotted by ground observers.

PRADS is comparable in cost to the existing airdrop system under combat conditions where attrition is high. In a training situation, however, PRADS is more expensive than the existing airdrop system. The weight of PRADS is somewhat less than the existing airdrop system for the entire range of 8000 to 35,000 pounds where rockets are to be used. The PRADS capability can be extended to airdrop 50,000 pound loads.

The reliability of PRADS is as good as or better than the existing airdrop system for achieving successful airdrop and will be much greater under combat conditions where reliability of the total operation is considered when the airdrop is made into defended hostile areas.

9.2 Future Development

It is strongly recommended that PRADS be further developed and qualified for the heavier loads in the weight range of 12,000 to 35,000 pounds gross rigged weight. The logical life cycle steps would include advanced development, engineering development, production and operation. The system would include the proposed rockets, ground sensing system, parachutes and rocket pack.

It is also recommended that the PRADS capability be extended to 50,000 pounds through the development of 64 foot diameter parachutes with inflation aids. All hardware of the PRADS including the rocket pack would be useable without additional changes.

It is recommended that PRADS be further developed for the recovery of fragile loads at very low impact velocities and for the recovery of helicopter fuselages and/or VIP aircraft passenger compartments.

Both in the airdrop of material and in the recovery of ejectable capsules or inhabited fuselage sections, it appears that PRADS not only holds the greatest possibility of state-of-art advancement but also is the key to continued technological leadership of the United States.

9.3 PRADS Components

The rocket motors in their present configuration are highly reliable. All rockets fired successfully out of the last 176 used after improved quality control procedures were instituted and reinforced nozzles were incorporated in the majority of the motors.

The proposed rocket motors, delivering approximately three times the total impulse of the tested motors, will reduce cost and will eliminate flame impingement problems. The size is optimum for loads of approximately 8000 pounds to 35,000 pounds gross rigged weight. Suspension sling force overshoot will be controlled by slightly slower rocket pressure build-up and somewhat progressive burning.

It is concluded that the crossed beam laser ground sensing system for rocket ignition is optimum because it is expected to be considerably less expensive, easier to refurbish, simpler to maintain and more consistant in performance. No special handling of the crossed beam laser ground sensing systems should be required. Reliability is expected to be high because of a) inherent simplicity, b) solid state circuitry, c) a built-in check circuit and d) easily checked and adjusted accuracy of signal distance above the ground. No accidental firing of rockets can occur because of interference of one load with another as long as aircraft fly normal airdrop patterns and delivery passes are separated by at least 15 second to allow time for the parachutes to float to the ground and collapse.

The parachutes used in the tests performed had solid flat circular canopy designs however it is proposed that slotted parachutes (disk-gap-band design) be used for the final system for reduced suspension sling forces and improved cluster inflation performance. The parachute weight is estimated as 100 to 110 pounds which compares to approximately 125 pounds for a packed G-12 parachute.

9.4 System Reliability and Accuracy

Based upon tests and analyses performed, it is concluded that the fully engineered and developed system will be at least as reliable as the existing system. This conclusion is based upon the following: a) no more time will be required to rig PRADS than the present system; b) rocket motors will be factory refurbished, c) the ground sensing system circuitry can be checked in place; d) other critical parts will be simple to maintain, assemble and check; e) parachutes will not be marginal for larger loads and will not require reefing; and f) no load disconnects will be required (8000 to 35,000 pound loads with retrorockets).

Airdrop accuracy is improved by the lower altitude required for airdrop and the much higher descent velocity of the load under inflated parachutes. It is concluded that the best airdrop accuracy of the existing system under average wind conditions can be equaled by PRADS even from altitudes as high as 3000 or 4000 feet. Thus, PRADS is very versatile and is suitable for use in any type terrain and against many different defenses.

9.5 Minimum Cost Training

It is concluded that the majority of the training drops of PRADS could be made with additional parachutes and using dummy rocket motors from slightly increased airdrop altitudes. All system component functioning could be fully checked by having the ground sensing sytem ignite a visible signal (smoke bomb or flash bulbs). The major training cost is thereby eliminated and training costs become comparable to those of any other airdrop system.

APPENDIX A

SCALE MODEL ROCKET TESTING

Document No. 67409-005

SCALE MODEL ROCKET TESTING
Document No. 67409-005

1.0 INTRODUCTION

The proposed design for the Parachute RetroRocket Airdrop System includes the use of solid propellant, canted nozzle, fast burning, high pressure rockets, which require an investigation of the heat and blast effects of the exhaust plumes.

2.0 OBJECTIVES

Because of the fragility of airdropped structures, it must be known what the reaction of the recovered load is to the near field effects of the retrorocket exhaust plumes.

Research and experience with similar systems predicts that certain heat transfer mechanisms limit radiative thermal effects for the 0.5 second burn time of the rockets so we are principally interested in the possible effects of plume or hot gas impingement and plume flow patterns.

3.0 PURPOSE

The results of the tests should provide correlation with full scale tests already performed with exploratory hardware, and sufficient information to predict the environment created by the retrorockets associated with a proposed new configuration.

4.0 BACKGROUND

Experiments at SAEC have shown that dependable results are obtained with 1/20 scale models using compressed nitrogen gas provided that care is exercised to control configuration and performance parameters and to properly apply simularity factors and interpret the results. Scale model testing to develop environmental data and duplicate effects created by exhaust gases of solid rocket motors (SRM's) is very practical, economical and productive; and sufficient confidence in the results derived with scale models is held, b cause cross-correlation has been validated between full scale results and scale model results.

The basic characteristics of SRM's that influence the environment created by exhaust plumes are chamber temperature and pressure, mass flow, expansion ratio, propellant chemical composition, and burn time. Propellant composition primarily influences temperature, pressure, and mass flow which are the major contributors to the plume environment and effects.

The chemical products in the exhaust are influenced by propellant composition, and are also an important consideration, particularly with respect to radiated thermal energy.

Simulation of actual rocket plumes with scale model nozzles can be accomplished easily if a set of similarity laws are available. Eight parameters are defined, (9. 0 B) each one of which allows duplication of one of the following plume characteristics: Shape, transmitted shock position, mass flow, momentum, enthalpy, thrust, kinetic energy and internal energy. However, these parameters are functions of two thermodynamic properties - ratio of specific heats (γ) and jet exit temperature parameter (RT_J); and two nozzle characteristics - jet exit Mach number (M_J) and nozzle exit area (A_J). Obviously, exact simulation requires that all eight parameters be duplicated. However, it is equally obvious that a maximum of four may be duplicated with the four variables. The four plume characteristics of most importance to this program are then: shape, transmitted shock position, mass flow, and momentum.

This particular testing program used compressed nitrogen gas as the model rocket flowing medium and a 1/20 scale mode. This means that both γ and the gas constant R cannot vary; therefore, at least one more plume characteristic cannot be duplicated. The model jet exit temperature required to simulate full scale mass flow approaches absolute zero. To satisfy the jet momentum parameter, the model nozzle exit area approaches the full scale val ie.

The parameters for simulating plume shape and transmitted shock position are both primarily a function of jet exit Mach number and as such, both cannot be simulated at the same time. However, If a model rocket is tested at freestream conditions, matched with the full scale rocket, and both plumes have the same exit pressure to plume boundary pressure ratio ($P_J/P\infty$) both plume shape and transmitted shock position parameters are equal to:

$$M_J^2 \left(1 \; M_J^2\right)^{-1/2} \qquad (1)$$

Therefore, a different model nozzle is required for each parametric test condition so that $P_J/P\infty$ may be matched.

Before simulation, the actual plume shape must be known. Calculating this shape can become extremely difficult since the exact chemical composition of the propellant gases are not known at each point in the flow. These gases can be considered thermally perfect if we assume that the effects, on intermolecular forces, of the high gas pressure are offset by the effects of the high gas temperatures. The gases are not calorically perfect, however.

To prevent the problem from becoming prohibitively complex, calculate an artificial value for γ by simultaneously solving the following equations:

$$\frac{P_J}{Pc} = \left[1 + \left(\frac{\gamma - 1}{2}\right) M_J^2\right]^{-\frac{\gamma}{\gamma - 1}}$$

$$\frac{A_t}{A_j} = \left[\frac{\gamma + 1}{2 + (\gamma - 1) M_J^2}\right]^{\frac{\gamma + 1}{2(\gamma - 1) M_J}} \qquad (2)$$

where P_J/Pc is an experimentally determined rocket exit to chamber pressure ratio and A_t/A_j is the nozzle area ratio.

Using the calculated value for γ, the propellant gases can be treated as calorically perfect even though this value for γ is strictly valid only at the nozzle exit, and for pressure and Mach number calculations only.

The flow is expanded from the nozzle exit conditions by the method of characteristics for three-dimensional, asymmetrical flow defining a plume shape for each test parameter.

When a model nozzle exit diameter is arbitrarily established, an expansion ratio is required to provide the proper exit Mach number to satisfy relation (1) for each test condition. A value of expansion ratio is used to calculate the model nozzle divergency angle which in turn establishes the model nozzle exit Mach number. The method of characteristics is again applied and the actual plume shapes can be duplicated, by adjusting the model nozzle chamber pressure.

With all the variables to correlate and with the problems associated with the accurate duplication of jet exit Mach number and expansion ratio, a simpler modified method was devised to simulate plume shape within useful accuracy.

The full scale expansion ratio was utilized in the model, along with the same nozzle divergency angle, requiring an adjustment of the chamber pressure.

Expansion ratio effects were not evaluated by scale model tests but the results of underexpansion or overexpansion can be conservatively extrapolated from ideal expansion data.

In order to determine the effects of varying chamber pressure, Figure 1 shows the trends established when the ratio of jet exit pressure to ambient pressure is plotted with respect to the initial turning angle, α_n, of the plume boundary for a series of jet exit Mach numbers. The referenced work was performed in a vacuum chamber at 0.0014 lb/ft^2 (corresponding to about 312,000 ft. altitude) using air as the medium.

The ratios of total pressure to ambient pressure were 22×10^6, 17×10^6, and 15.5×10^6 for Mach number 1, 3, and 5 nozzles respectively.

The corresponding ratios of jet exit pressure to ambient pressure were 1.2×10^7, 4.9×10^6, and 3.2×10^5.

The range of chamber pressure varied from 21.5 $\times 10^3$ lb/ft.^{2} Abs to 30.7 $\times 10^3$ lb/ft^2 Abs.

The angle α_n represents an isentropic expansion angle with no corrections for nozzle losses or condensation effects, and depends on the correlation of nozzle exit angle, exit Mach number, ratio of specific heats, and ambient pressure. Note that the magnitudes of impingement parameters may be reduced by increasing the exit Mach number or by decreasing the jet flow turning angle.

Figure 2 lists the characteristics of the three nozzles represented in Figure 1.

The tests represented by Figure 1 indicate that the parametric impingement pressure distribution peaks approximately at the jet boundary station and falls off rapidly after that. This relationship to α_n establishes the approximate departure shape of the plume away from the nozzle, and if the actual plume boundary varies with P_J/P_∞ as defined in (1) the plume boundary or shape is also established by M_J and, therefore, becomes the critical simulation parameter.

This still necessitates the examination of the effects of adjusting the model chamber pressure for the arbitrarily established nozzle configuration as defined by proportional scaling of linear dimensions of the nozzles.

The effects of time must now be considered, because some nozzle configurations and groups of nozzles operating in each other's near field will interact, or are otherwise sensitive to entrainment effects in the atmosphere.

Neglect of these effects can negate analytical results and may present undesirable surprises. For example, when only some initial conditions are examined at steady state, without consideration of the previous dynamic history of operation of one or more nozzles, and without scrutiny of the interaction with one another or the total environment with respect to time, the effects of the onset of and progression of entrained flow will be overlooked.

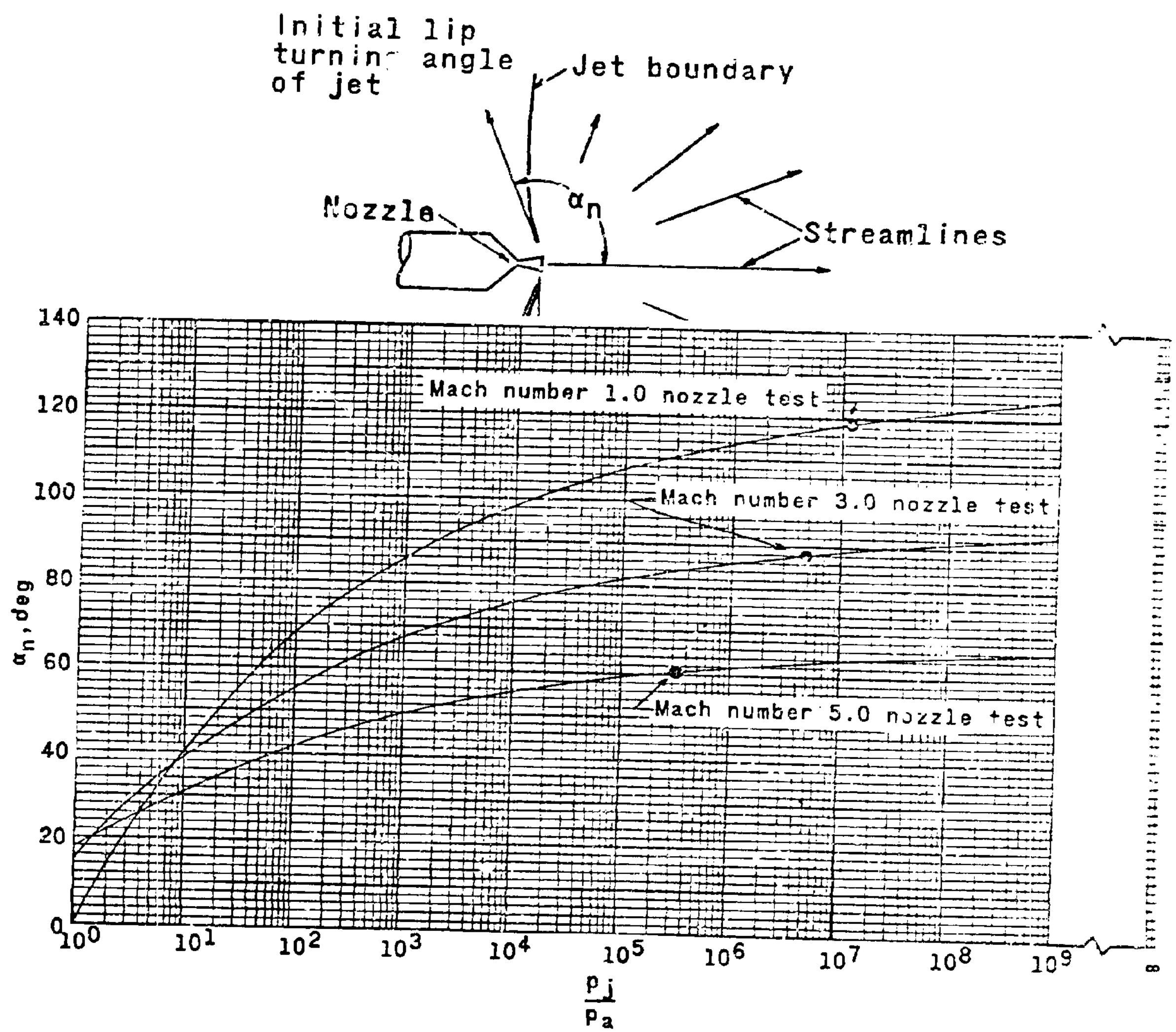
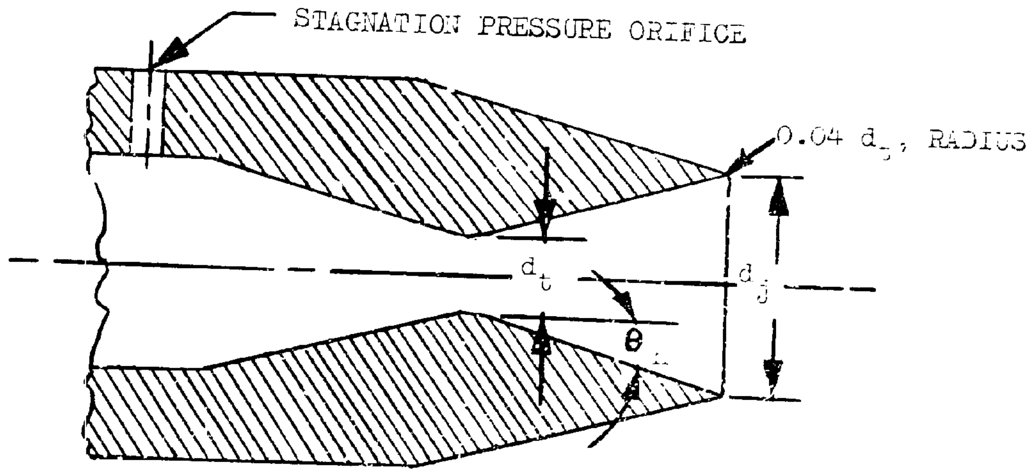


Figure 1 Variations of the initial turning angle with the ratio of jet exit pressure to ambient pressure for the nozzles. (Ref. 9.0 G)



M_j, nominal	M_j, theoretical	d_t		d_j		θ_n, deg	$\frac{p_j}{p_a}$
		in.	cm	in.	cm		
1.0	1	0.125	0.318	0.125	0.318	0	1.2×10^7
3.0	2.96	.125	.318	.252	.640	15	4.9×10^6
5.0	4.92	.129	.327	.625	1.588	15	3.2×10^5

(c) Nozzle Characteristics
Figure 2

In the course of this particular investigation, full scale static and dynamic tests with exploratory PRADS configuration displayed a phenomenon involving Bernoulli's principle associated with the operation of a close packed group of canted nozzle rockets arranged in two staggered circles in each tandem group.

The combined effects due to high atmospheric pumping efficiency of entrained air and Bernoulli's effect resulted in the convergence of all the plumes into one large plume with devastating results to equipment and materials located within the area aft of the nozzles.

Discovery of the magnitude of the effects contributed to a redesign of and a scale model verification test program for the redesign, as well as scale model duplication of the phenomenon associated with the offending configuration.

Experience with the exploratory configuration indicated a need to determine the extent of interaction between the nozzles of the new configuration using up to twelve rockets, which are three times as large, arranged in a circle in only one rocket pack.

No such problem was found to be associated with the new configuration herein analysed. However, the same phenomenon is associated with an individual plume to some extent when operated in a fluid, or in the atmosphere.

Apparently, given sufficient time, and combined with the tendency for relatively hot exhaust gases to contract due to cooling, and the onset and progression of pumping action, plus differential plume and plume boundary velocities resulting in differential internal and external plume pressures, result in convergence of the actual plume(s).

Consideration of the above, by various methods, now enable the evaluation of the effects of adjusting or varying chamber pressure of the subject model.

Since the primary effects parameters which establish plume configuration are governed by heat and pressure, and with consideration of other effects, we qualitatively expect the plume envelopes obtained with the model to be conservatively larger and fuller than expected as cold gas is used, operation time is longer than real, and operation is in freestream under quiescent, incompressible (low subsonic) conditions.

5.0 TEST CONFIGURATION AND APPARATUS

Design of the full scale rocket resulted in the selection of HEX-12 as the propellant (9.0 A) in order to minimize size, weight, and for its clean exhaust.

HEX-12 is a double-base, solventless extruded propellant which delivers little smoke traces of toxic products and no corrosive materials or solid particles. The exhaust is essentially gaseous with vaporized liquids, which minimizes incandescence and therefore radiation.

5.1 Illustrations

Figure 3 is a sketch of the 1/20 scale model of the exploratory configuration, and simulates the tandem rocket packs, and the arrangement of the individual rocket nozzles.

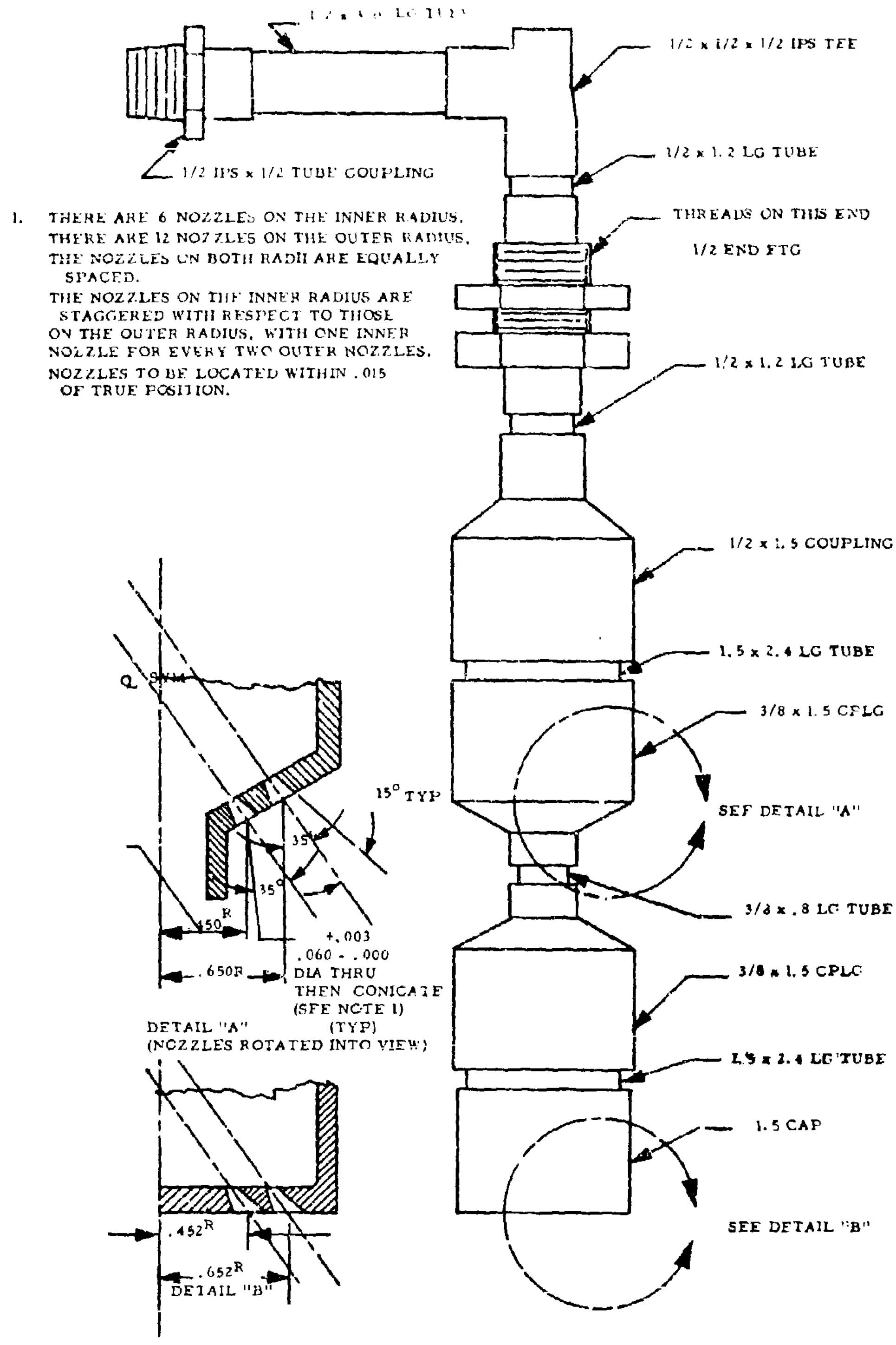
Figure 4 is a sketch of the 1/20 scale model of the proposed new configuration with twelve rockets arranged in a single circle on one rocket pack.

Figure 5 shows the flow pattern obtained with the tandem configuration at 100 PSIG chamber pressure.

Figure 6 shows the flow pattern obtained with the new configuration at 100 PSIG chamber pressure.

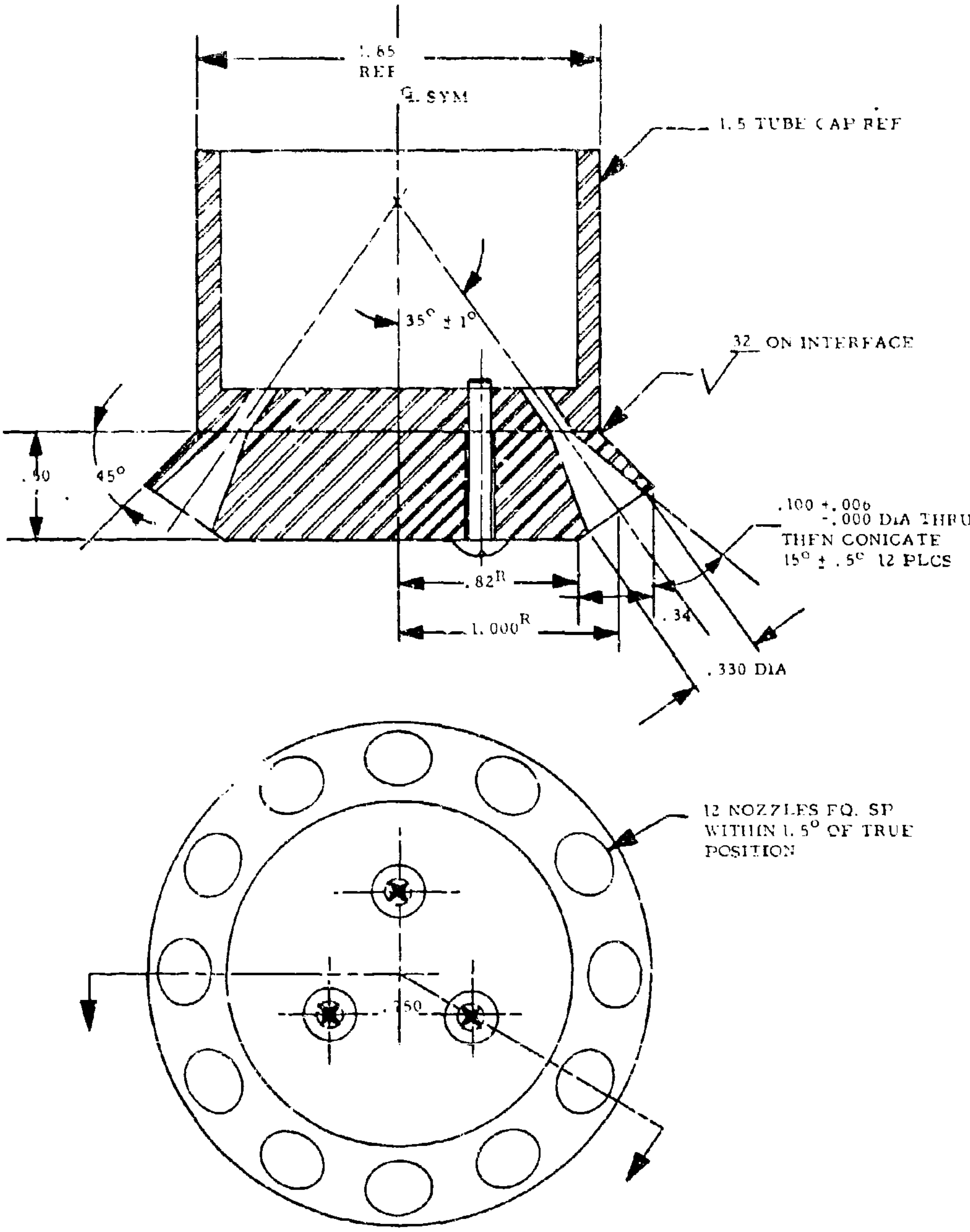
5.2 Instrumentation and Equipment

Hewlett-Packard Model 5246L	Electronic Digital Counter Ser. No. 816-01542



1/20 SCALE MODEL TEST HARDWARE (DOUBLE ROCKET PACK ASSY)

Figure 3



1 REQD AS SHOWN AISI 303 OR EQ

1/20 SCALE MODEL TESTS NOZZLE (PROPOSED CONFIGURATION)

Figure 4

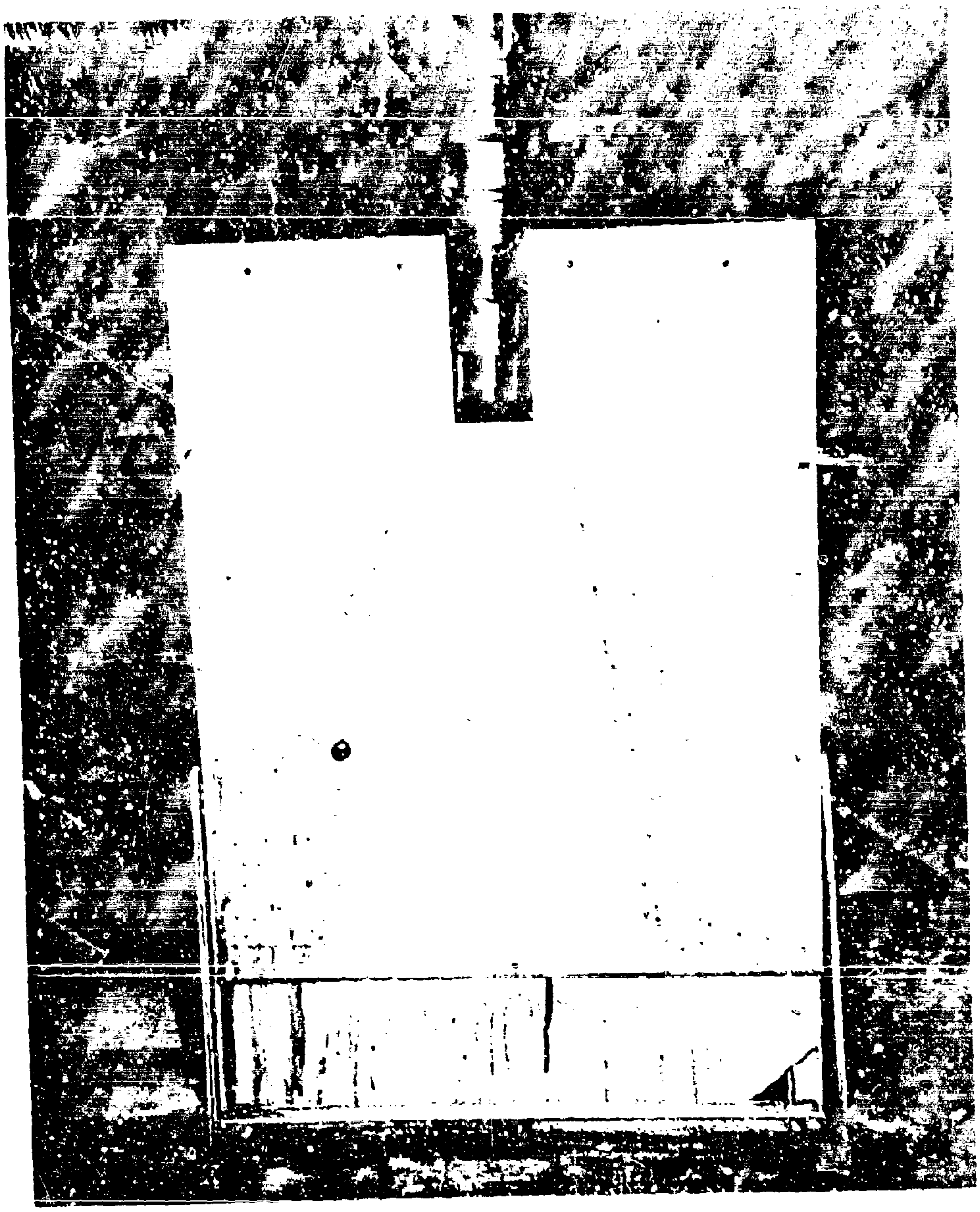


FIGURE 5

FLOW PATTERN - TANDEM CONFIGURATION

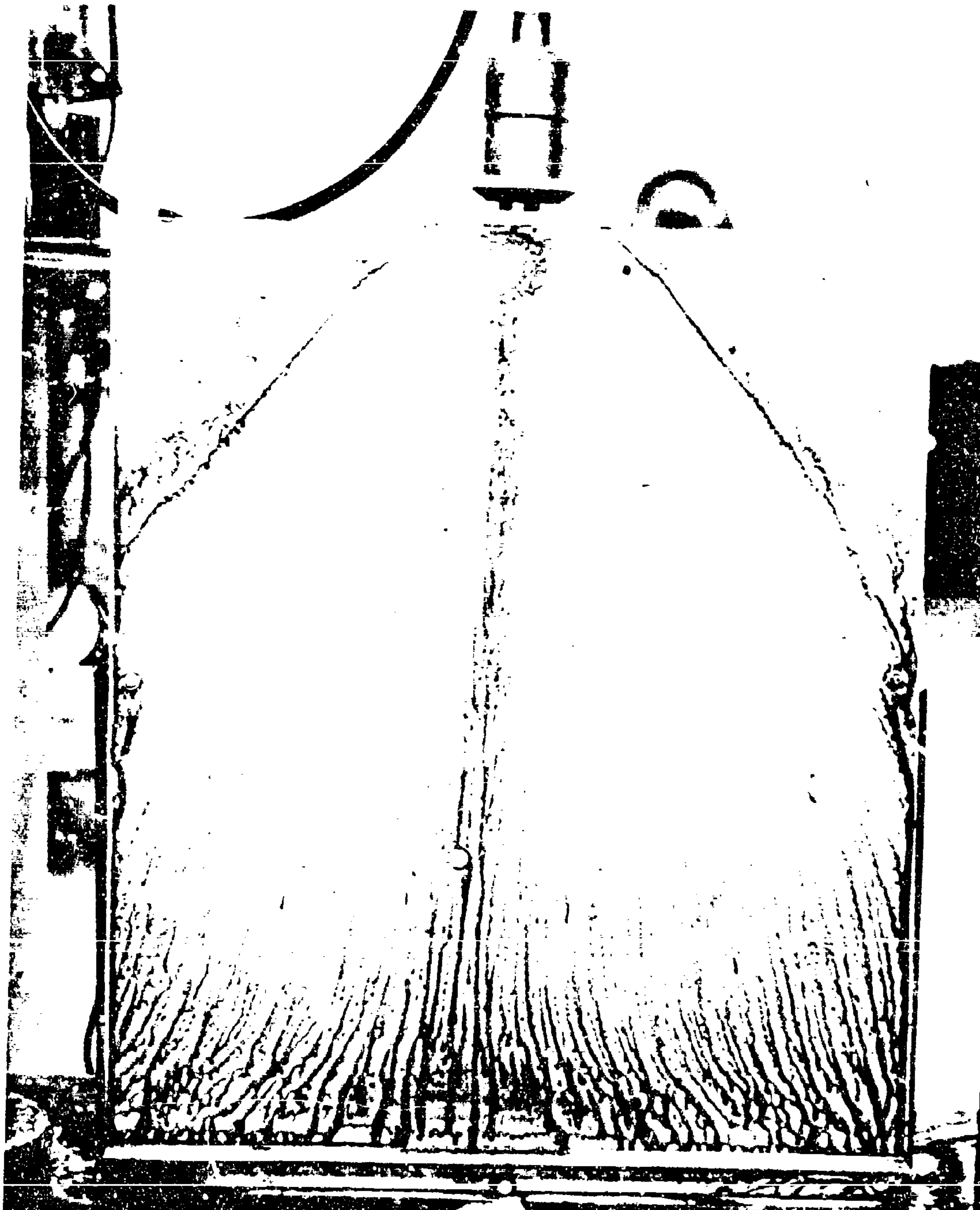


FIGURE 6

FLOW PATTERN - FUTURE CONFIGURATION

Hewlett-Packard Model 5265A	Digital Voltmeter (plug in) Ser. No. 514-01600
SAEC	Dual Channel D. C. Amplifier Ser. No. 2
B-L-H Type Ul-1K	Load Cell (0-1000 lb.) Ser. No. 48684
Macarco Model J4000	Pressure Gauge (0-400 PSIG)
Macarco P/N 4797M14	Micrometer Valve (.5 IPS)
Toledo	Scale Weights

Other Equipment

Tank Farm - 3 tanks @ 2000 PSIG
Miscellaneous Flexible hoses, fittings, and valves

5.3 Procedure

5.3.1 All instruments were individually calibrated, and calibration charts were prepared.

5.3.2 The sprung hardware was weighed individually, and in place on the test fixture with all the gear in place, using the load cell, in order to obtain correction data for thrust determination for the two configurations.

5.3.3 Tests were performed to obtain correlation between indicated chamber pressure and measured thrust, for the two configurations.

5.3.4 Tests were performed at chamber pressures of 25 PSIG, 50 PSIG, 100 PSIG, 150 PSIG, and 200 PSIG to determine the effects of varying chamber pressure on the two configurations, to obtain oil smear photographs of the plume [illegible] patterns, and to compare the performances of the two co[illegible]ations.

6.0 SUMMARY OF RESULTS

The technique employed graphically shows plume configurations, satisfactory simulation of the full scale tandem phenomenon, and the gross difference in performance between the two configurations.

Variation of chamber pressure of a configuration made only a small difference in the near field flow pattern of the collective jet boundary, and was manifested as an increase of αn for the single rocket pack configuration, and as a decrease of αn for the tan[redacted] 25 [redacted]

Because good simulation and cross correlation was obtained for the tandem configuration, and the performance of the new single rocket pack appeared to be sufficient preview of what to expect at full scale, testing was not carried further.

7.0 CONCLUSIONS

The tests indicate no significant tendency for the plumes of the single rocket pack configuration tested to converge together in a deleterious fashion.

To avoid convergency problems, the ways in which combinations of chamber pressure, expansion ratio, operation time, nozzle arrangement, nozzle distribution, and number of nozzles, must be scrutinized for possible mutual plume interference or impingement, or other characteristics which enhance atmospheric diffusion pumping efficiency when used in groups or clusters.

The obviously simple combination of techniques adopted for this test series gives satisfactory results where refined data is not required, and large order differences are expected between two or more parametric test conditions.

8.0 RECOMMENDATIONS

The full scale configuration for the proposed new design rocket pack should provide for the largest rocket centerline mounting circle diameter practicable. (presently 30.0").

Geometric porosity thru the core of the rocket pack may be beneficial.

A reduction of thrust with a proportionate increase of burn time would further reduce heat and blast problems.

9.0 REFERENCES

[redacted]

B. Jet Simulation In Ground Test Facilities; AGARDograph 79, NATO Advisory Group for Aeronautical R & D - Pindzola, M.

C. Solid-Propellant Rocket Exhaust Effects (SPREE) And Methods of Attenuation, Vol. I: Project Summary; Martin -

CR-65-93 (Vol. I) - E. A. Darrow, E. Lays. NASA N66-30606.

D. Jets in Free Vortex Surroundings; G. E. R67SD42- A. I. Barcilon, NASA N67-38920.

E. Emittance and Radiance Calculations for Solid Propellant Rocket Exhausts; Philco-Ford Corp., Aeronautics Div. -D. J. Carlson, A. J. Laderman. NASA N68-18093.

F. Helicopter Parachute Retrorocket Recovery System (HELPRS) Scale Model Rocket Tests; U.S.N. Contract No. N00 178-68-C-0174, Stencel Aero Engineering Corp. - A. L. Martinez.

G. Forces and Moments Due to Air Jets Exhausting Parallel to Large Flat Plates in a Near Vacuum; NASA TN D-5147 - J. J. Janos, S. Hoffman.

APPENDIX B
Static Rocket Testing

1.0 GENERAL

Static rocket tests were conducted on a static test tower located at the Stencel plant facilities, Asheville, North Carolina. A diagram of the tower and a typical test setup is shown in Figure 1-1.

Four tests were performed with different numbers of rocket motors to determine component structural integrity and system stability. A summary of test conditions is found in Table 1-1.

Tests were made with a small rocket pack, Stencel Dwg. SK48-001-001-1, or one or two large rocket packs, Stencel Dwg. SK48-022-001-1. The rocket motors were Northrop Carolina Dwg. SK2000-1001 with a nominal thrust of 5100 pounds, a nominal impulse of 2540 pound-sec., and a nozzle angle of 35 degrees from the vertical. The nominal vertical thrust was 4180 pounds. A platform was free to pivot at its center. The platform simulated a load and weights were added to simulate loads with different moments of inertia. Slings were attached from the "load" to the rocket pack with strain gages to measure forces.

The rocket pack was pretensioned by means of a winch, a cable and a hook connected to the rocket pack by means of loops of 6000 pound tensile strength cord. A bypass support of two slings of three loop Type X webbing was used to support the rocket pack after rocket burnout.

On initial rocket burning, these loops were severed by means of electroballistic line cutters which were activated by heat sensing microswitch circuitry. A bypass support of 8 ft. long slings constructed of MIL-W-4088, Type X, 8700 lb. nylon webbing was provided to support the rocket pack after rocket burn out.

Rocket Pack ignition was accomplished by porting compressed nitrogen gas (1800 PSI) to the rocket initiator by means of the rocket valve assembly. The rocket valve assembly was activated by means of the standard Mark I electrically fired squib. A flash bulb was provided for a visual indication of initiation. The

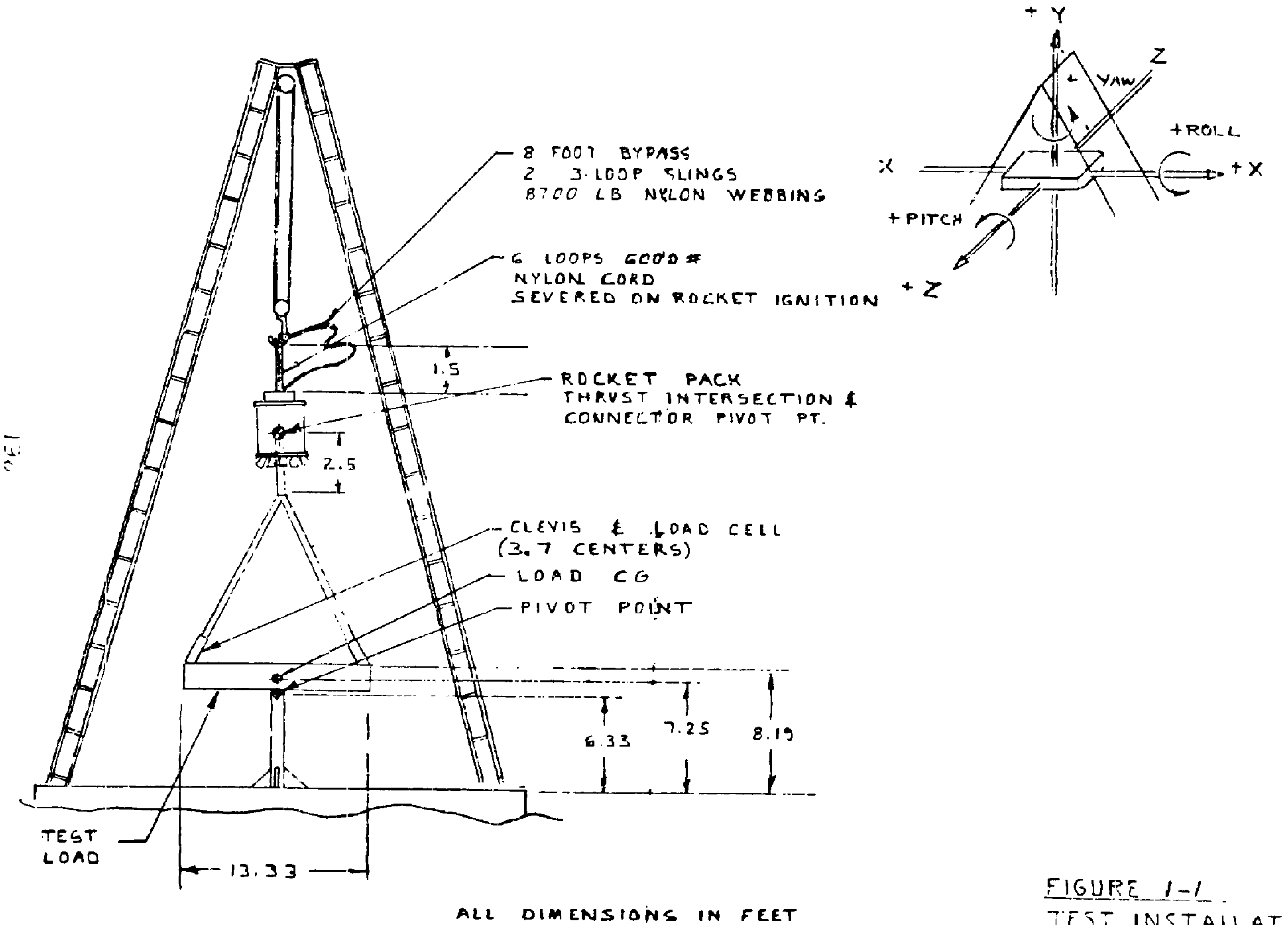


FIGURE 1-1
TEST INSTALLATION
TEST NO. 183-1

TABLE 1-1
SHEET 1 OF 2
TEST SUMMARY
OF
STATIC ROCKET TESTS
OF TETHERED ROCKET PACK

Test No.	Test Date	Nominal Simulated Load Weight Pounds	No. Rockets	Initial Rocket Pack Misalignment With Load CG-Deg.	Size Rocket Pack (No.)
183-1	20 Jan. 1968	18,000	18	3¼	Large (1)
183-2	8 March 1968	12,000	10	4½	Small (1)
183-3	17 April 1968	32,000	32	0	Large (2)
186-1	20 June	32,000	32	0	Large (2)

TABLE 1-1
SHEET 2 OF 2
TEST SUMMARY
of
STATIC ROCKET TESTS
OF TETHERED ROCKET PACK

Test No.	Suspension Slings: Length Ft.	Suspension Slings: No. Loops/Sling	Suspension Slings: No. Slings/Corner	Suspension Slings: Type Webbing (Strength-Lb.)	Covering	Platform Moment of Inertia Slug-Ft.^{2}: Pitch	Platform Moment of Inertia Slug-Ft.^{2}: Roll	Platform Effective Radius of Gyration - Ft.: Pitch	Platform Effective Radius of Gyration - Ft.: Roll
183-1	18	3	2	X (8700)	Cotton Cloth	11,000	3000	4.44	2.32
183-2	20	3	2	X (8700)	Cotton Cloth	6700	2000	4.25	2.32
183-3	19	4	2	XXVI (15,000)	Nylon Cloth	23,650	6500	4.88	2.56
186-1	24	4	2	XXVI (15,000)	Asbestos Cloth or Fiber Glass Cloth	23,650	6500	4.88	2.56

initiation impulse was recorded electrically on the oscillograph.

A consolidated Electro Dynamics Corporation Model 5116 recording oscillograph was used to record the output of the load cells. Cameras activated remotely by electrical signals were used to record the test photographically. Two cameras viewed the load from the side to show pitch and two viewed from the end to show roll.

2.0 TEST SUMMARY

The following is a test by test summary of the static rocket tests. Test conditions are tabulated in Table 1-1.

2.1 Test No.:

183-1

Type of Testing:

PRADS Static Rocket Test

Date of Testing:

20 January 1968

Number of Rockets Tested:

18

Purpose of Testing:

The purpose of this test was twofold. The first purpose was to assure the structural integrity of the system slings, webbings, rocket pack, etc. The second purpose was to ascertain system stability and component function.

Test Procedure:

Eighteen rockets were mounted into the large load range rocket pack. The weight of the rocket pack installation including the rocket valve assemblies and the loaded rockets was 1354 lbs.

The test installation was as shown in Figure 1-1. The weight of the load was 17,190 lbs. The moment of inertia was 11,000 slug-ft.^{2} in the pitch plane and 3,000 slug-ft.^{2} in the roll plane. The load was supported by means of two three-loop slings of MIL-W-4088, Type X, 8700 lb. nylon webbing at each corner. These slings were covered with the Stencel SK409-020-1 sleeve which was constructed of cotton cloth. These slings were 18 ft. long. An additional 20.5 inches was added to their length by the clevis and load cell linkages mounted to the load at each corner. The load cells were 120,000 lb. capacity strain gauge type units provided and calibrated by the USAF

651lth Test Group. The load was supported in an initially level position.

These slings were attached to the connector of the rocket pack. The rocket pack was supported with an initial offset of 3 1/4 degrees.

Ambient temperature at the time of the test was 51°F.

Test Results:

The rocket nozzle on rocket motor, serial number 244, was blown from the rocket as the result of rocket nozzle failure at the point of radius on the rocket nozzle retaining groove. The serial number of this nozzle was No. 61. As a result of this nozzle failing, stability in this test while not completely unacceptable was definitely marginal. In addition, one rocket motor failed to fire as a result of two damaged primers.

Data from this test was as follows:

Film

	T_o to rocket fire	.02 sec.
	T_o to rocket burnout	.58 sec.
	Rocket fire to burnout	.56 sec.

Oscillograph

Results from the 120K force transducers.

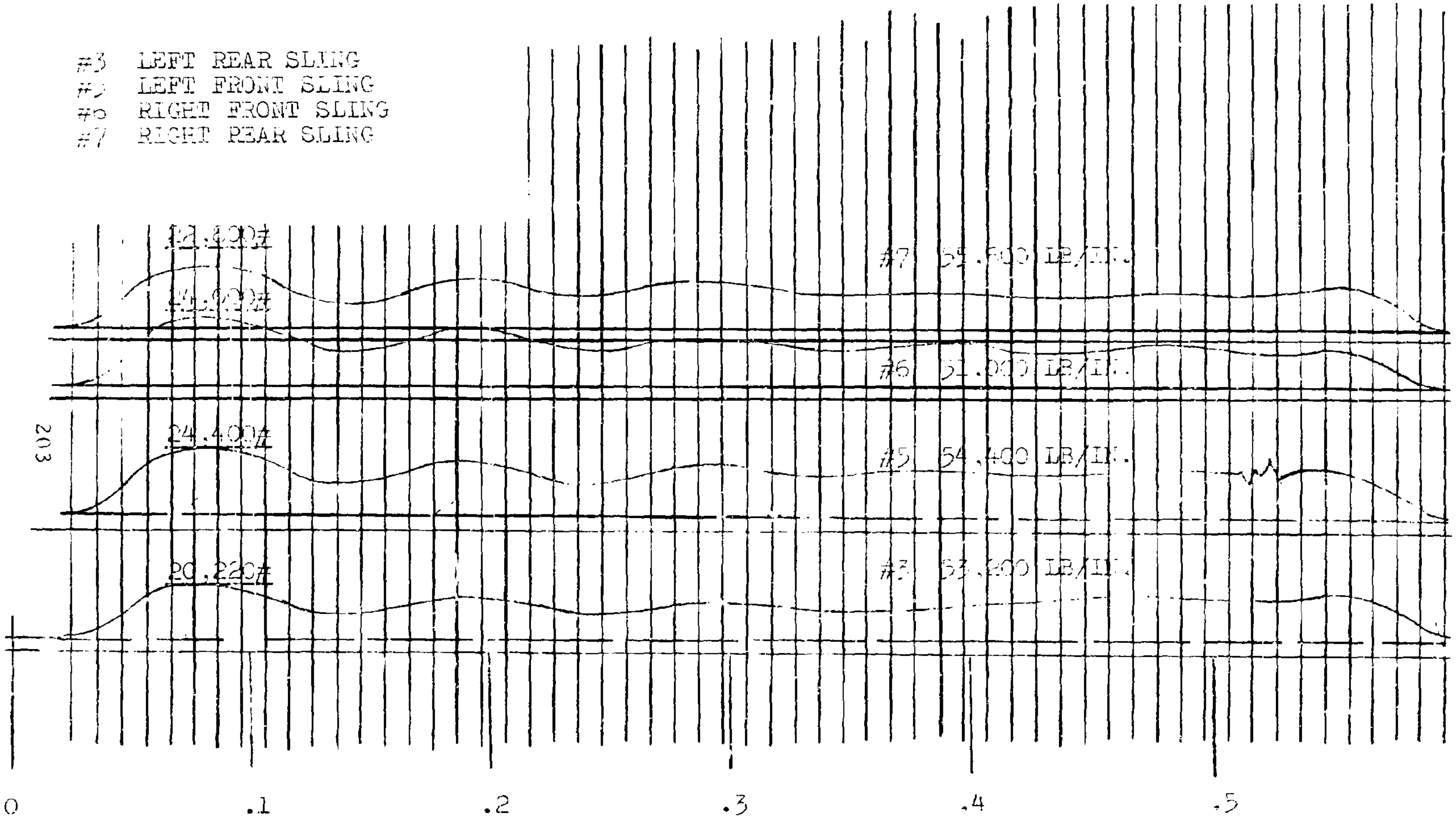
#3	Total Time	.577 sec.
	T_o to lst rise	.0293 sec.
	Peak force	20,220 lbs.
	Total impulse	7,050 lb.-sec.
	Average force	12,210 lbs.
#5	Total time	.576 sec.
	T_o to lst rise	.0293 sec.
	Peak force	24,400 lbs.
	Total impulse	8,960 lb.-sec.
	Average force	15,550 lbs

#6	Total time	.565 sec.
	T_0 to 1st rise	.0299 sec.
	Peak force	24,000 lbs.
	Total impulse	7,650 lb.-sec.
	Average force	13,540 lbs.
#7	Total time	.571 sec.
	T_0 to 1st rise	.0293 sec.
	Peak force	22,800 lbs.
	Total impulse	10,350 lb.-sec.
	Average force	18,100 lbs.

Figure 2.1-1 depicts the oscillograph force traces.
Figure 2.1-2 depicts payload angle (pitch vs. time).
Figure 2.1-3 depicts payload angle (roll vs. time).

Conclusions, Recommendations and Corrective Action:

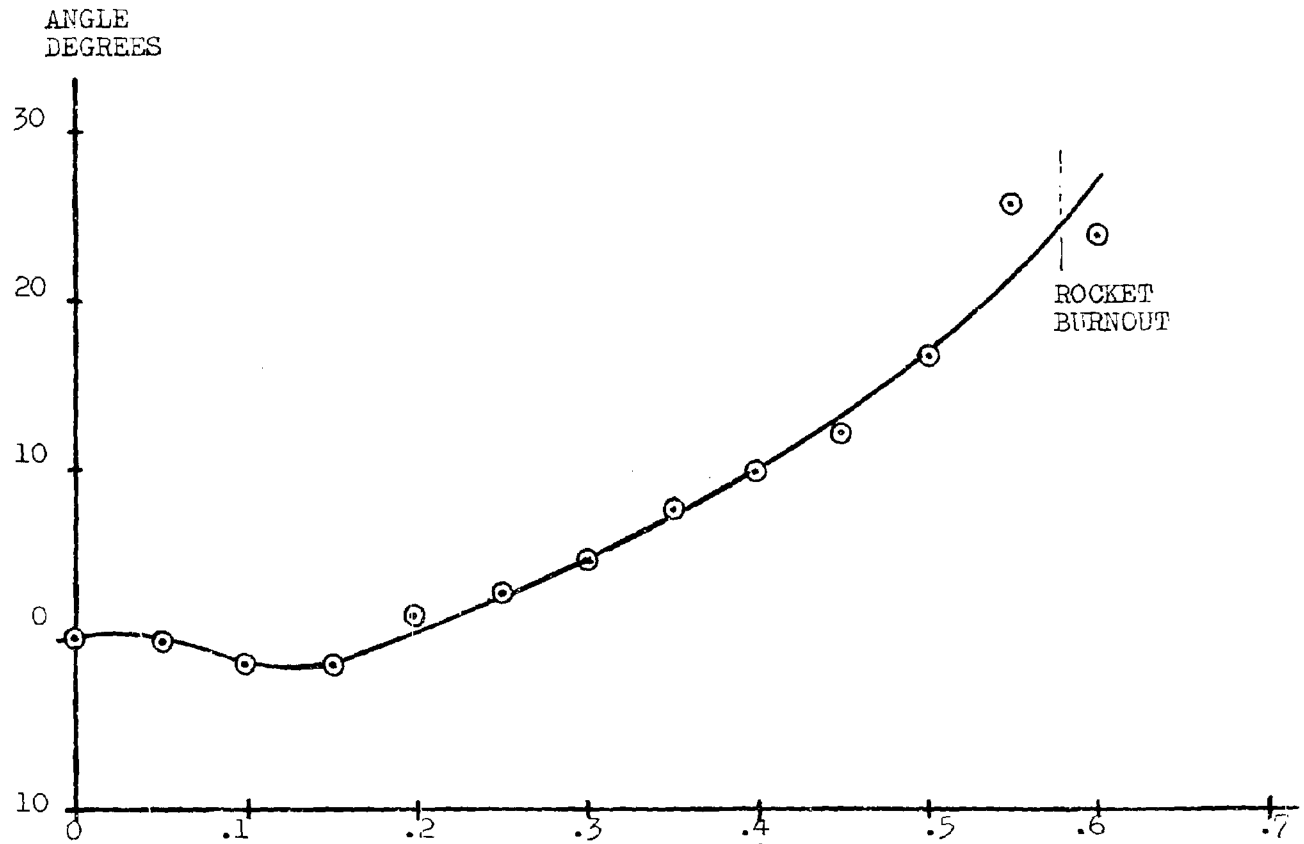
With the exception of the failing rocket nozzle, this test is concluded to be successful. For subsequent incorporation into the PRADS system it is recommended that the retaining shoulder on the rocket nozzle of the Northrop SK2000-1001 rocket motor be modified by incorporating a larger radius to preclude stress concentration in this area.



TIME - SECONDS

OSCILLOGRAPH TRACE TEST NO. 183-1
BRIDLE TENSION FORCES

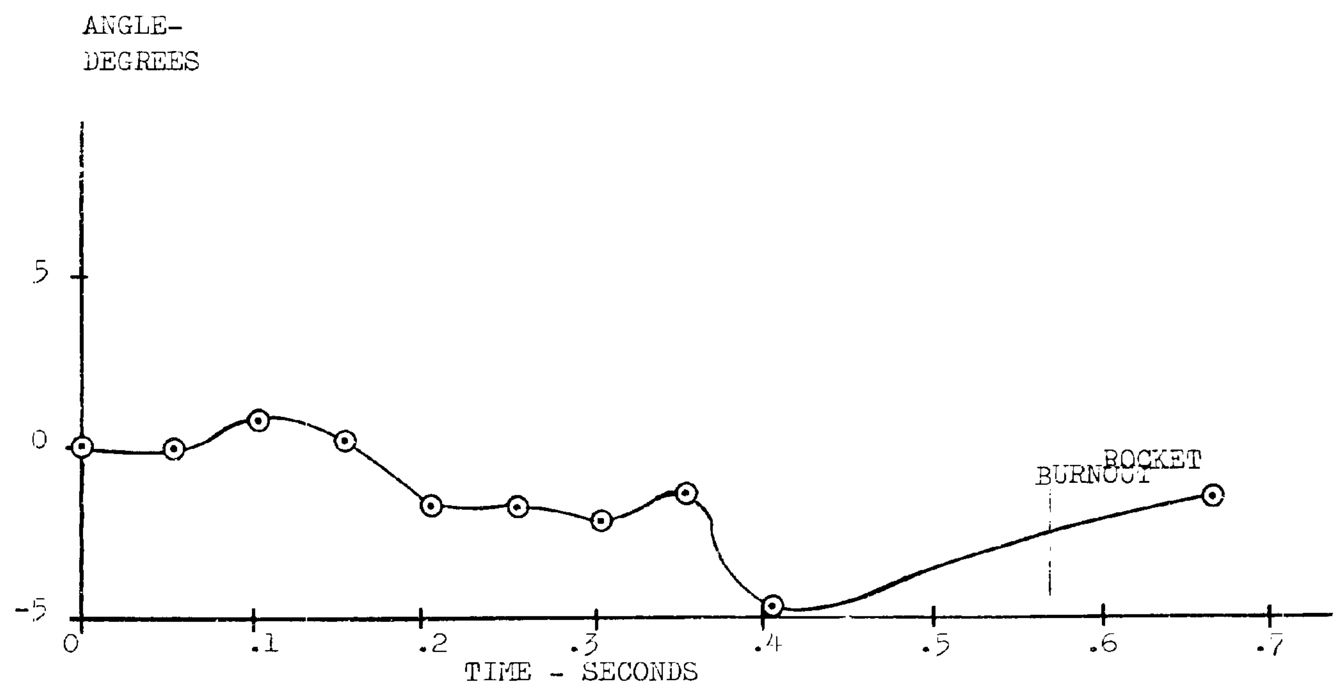
Figure 2.1-1



PAYLOAD ANGLE (PITCH)
VS TIME

TEST NO. 183-1

Figure 2.1-2



PAYLOAD ANGLE (ROLL) VS TIME TEST NO. 183-1

Figure 2.1-3

2.2 Test No.:

183-2

Type of Testing:

PRADS Static Rocket Test

Date of Testing:

8 March 1968

No. of Rockets Tested:

10

Purpose of Testing:

The purpose of this testing was twofold. The first purpose was to assure the structural integrity of the system slings, webbings, etc. The second purpose was to ascertain system stability and component function.

Test Procedure:

Ten rockets were mounted in the small load range rocket pack. The weight of the rocket pack installation was 565 lbs.

The test installation is shown in Figure 1-1.

The load was supported by means of two three-loop slings of MIL-W-4088, Type X, 8700 lb. nylon webbing at each corner. These slings were covered with Stencel SK409-0020-1 sleeves constructed of cotton cloth. The slings were 20 feet long. An additional 20.5 inches was added to their length by the clevis and load cell linkages mounted to the load at each corner. The load cells were 120,000 lb. capacity strain gauge type instruments provided and calibrated by the USAF 6511th Test Group. The load was supported in an initially level position.

These slings were attached to the connector of the rocket pack. The rocket pack was supported in a vertical position with an offset of 4 1/2 degrees.

Ambient temperature at the time of test was 60 degrees Fahrenheit.

Test Results:

All compents functioned properly in this test. System stability was good.

Data was as follows:

Film

T_o to rocket fire	.015 sec.
T_o to rocket burnout	.560 sec.
Rocket fire to burnout	.545 sec.

Oscillograph

Results from the 120K force transducers.

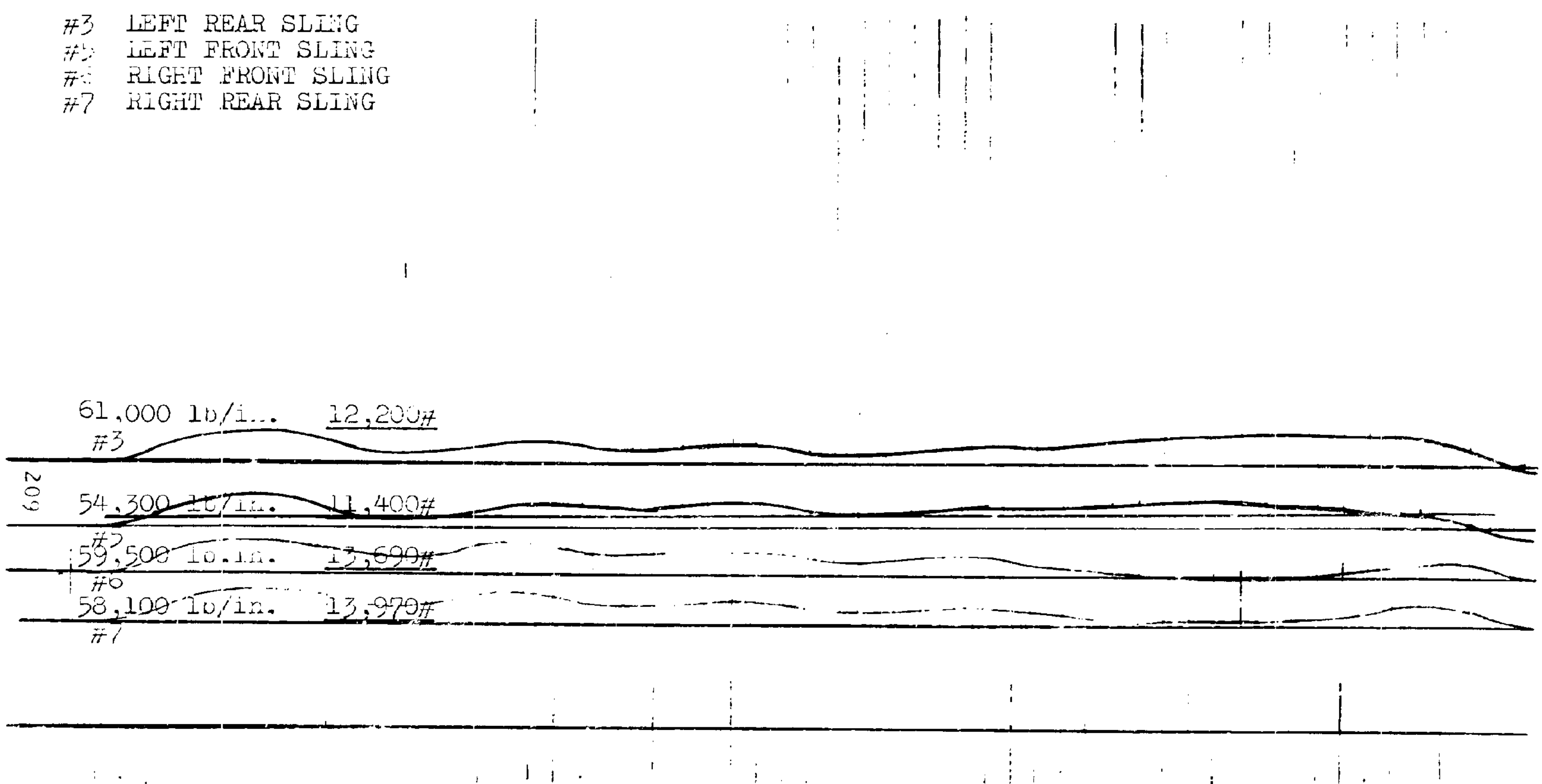
#3	Total time	.452 sec.
	T_o to 1st rise	.0196 sec.
	Peak force	12,200 lbs.
	Total impulse	3,250 lb.-sec.
	Average force	7,190 lbs.
#5	Total time	.443 sec.
	T_o to 1st rise	.020 sec.
	Peak force	11,400 lbs.
	Total impulse	3,095 lb.-sec.
	Average force	6,990 lbs.
#6	Total time	.461 sec.
	T_o to 1st rise	.0207 sec.
	Peak force	13,690 lbs.
	Total impulse	2,650 lb.-sec.
	Average force	5,750 lb.

#7	Total time	.454 sec.
	T_o to 1st rise	.0202 sec.
	Peak force	13,970 lbs.
	Total impulse	2,620 lb.-sec.
	Average force	5,790 lbs.

Figure 2.2-1 depicts the oscillograph traces for this test. Figure 2.2-2 depicts the payload angle (pitch vs. time). Figure 2.2-3 depicts the payload angle (roll vs. time).

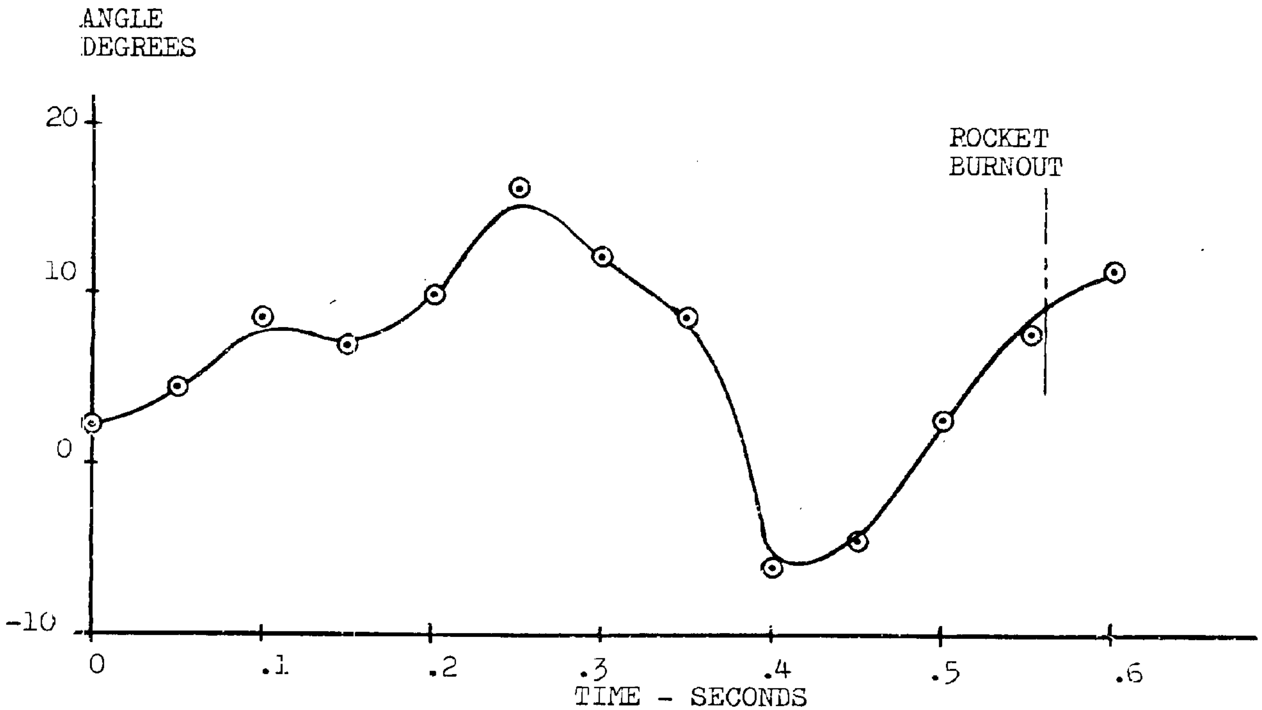
Conclusions, Recommendations and Corrective Action:

This test was an excellent test. No corrective action or modifications are recommended.



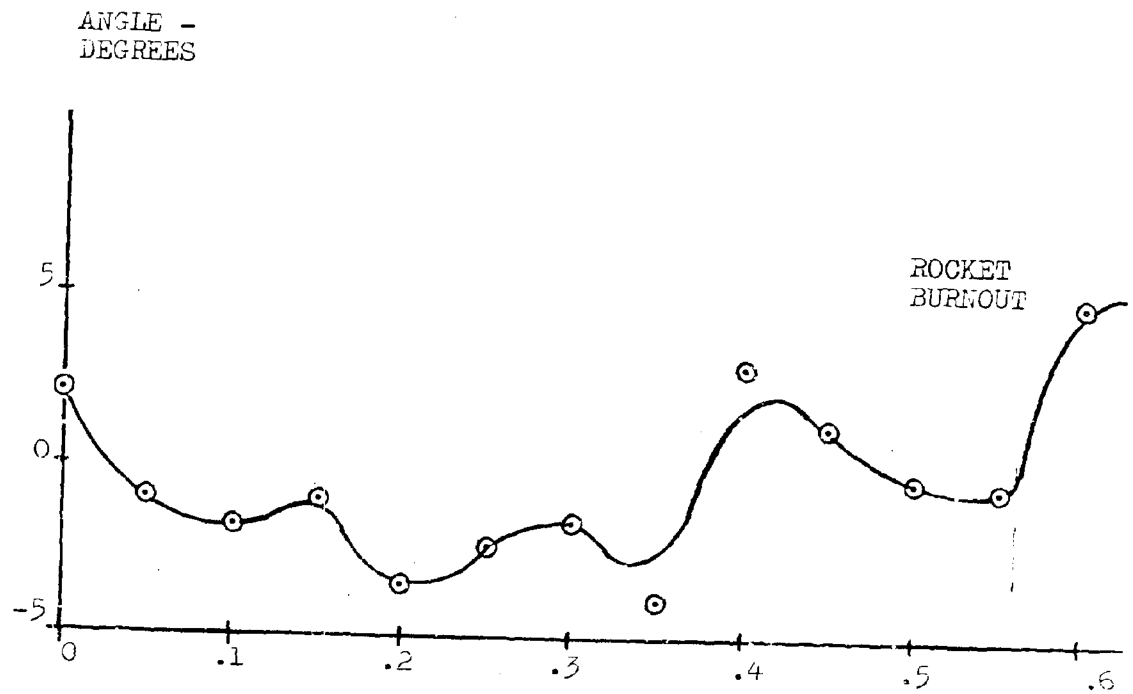
OSCILLOGRAPH TRACES
BRIDLE TENSION FORCES
TEST NO. 185-2

Figure 2.2-1



ROCKET PACK ANGLE (PITCH) VS. TIME TEST NO. 183-2

Figure 2.2-2



ROCKET PACK ANGLE (ROLL) VS TIME TEST NO. 185-2
Figure 2.2-3

2.3 Test No.:

183-3

Type of Testing:

PRADS Static Rocket Test

Date of Testing:

17 April 1968

Number of Rockets Tested:

32

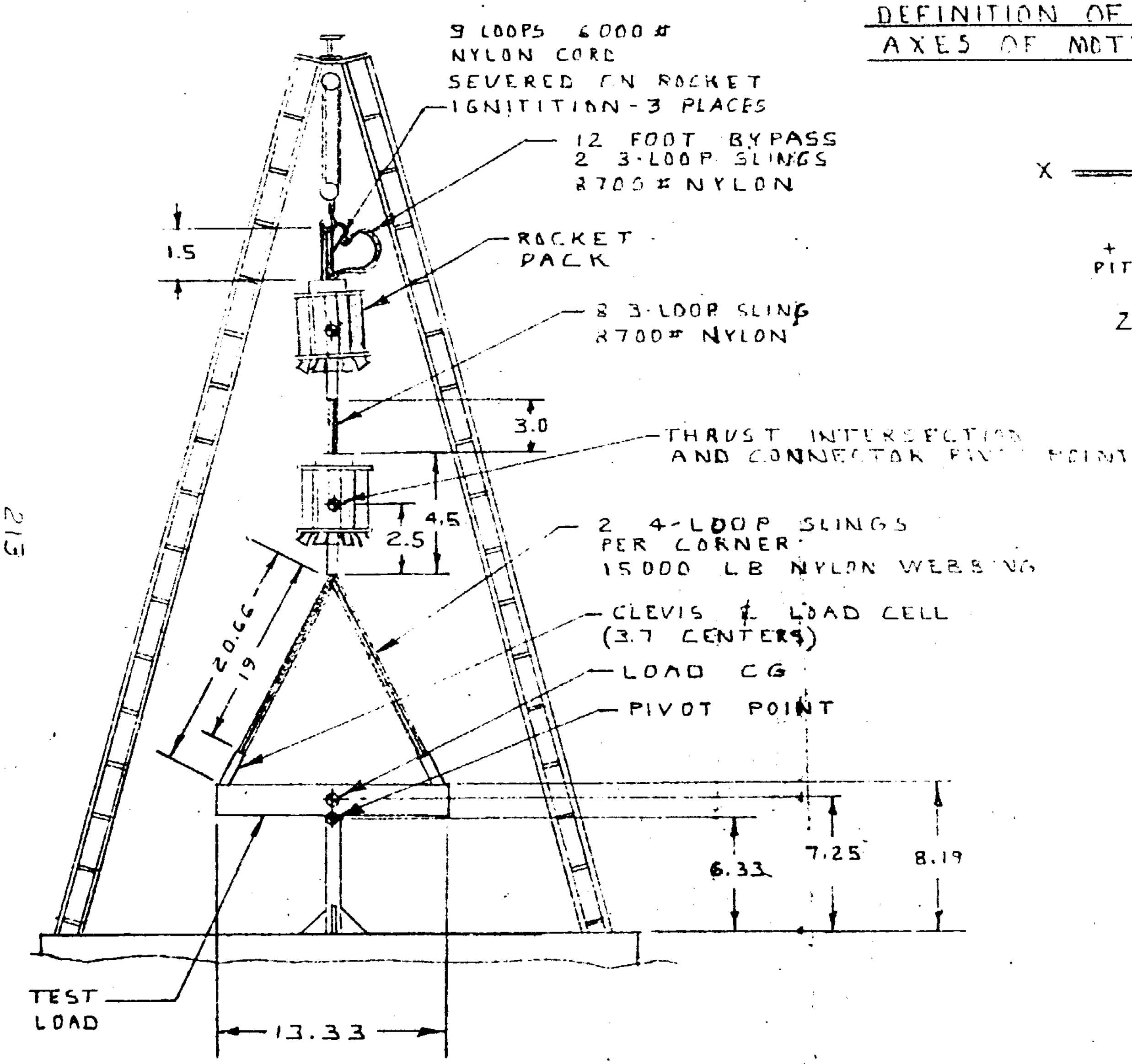
Purpose of Testing:

The purpose of this testing was twofold. The first purpose was to assure the structural integrity of the system slings, webbing, etc. The second purpose was to ascertain system stability and component functions.

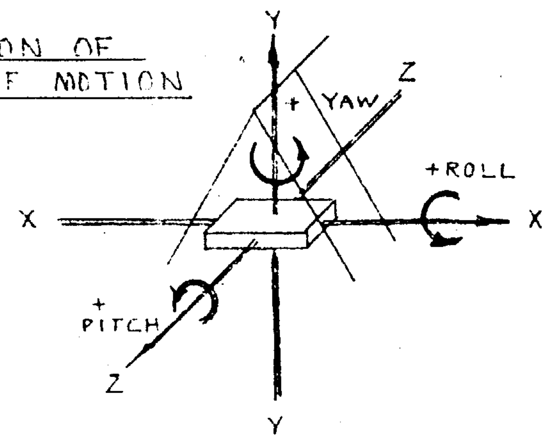
Test Procedure:

Thirty-two rockets were used. Sixteen of these rockets were used in the Stencel SK48-022-001-1 large rocket pack assembly which was suspended in the upper position and weighed 1276 lbs. The remaining 16 rockets were mounted in the Stencel SK48-022-001-1 Revision A, large load range rocket pack which was suspended in the lower position and weighed 1429 lbs. These rocket pack weights included the complete rocket pack with the rockets and the rocket valve assemblies.

The piggy back installation was used as shown in Figure 2.3-1. The load was supported by means of two four loop slings of MIL-W-4088, Type XXVI, 15000 lb. nylon webbing at each corner. These slings were covered with the Stencel SK409-020-1 Revision A sleeve which was constructed with nylon cloth and impreg-



DEFINITION OF AXES OF MOTION



LOAD DATA

LOAD WT. — [illegible]
I, PITCH — 23 [illegible] SLUG FT.²
I, ROLL — [illegible] SLUG FT.²

ROCKET PACK DATA

WT (UPPER PACK) — 127.5 LBS.
WT (LOWER PACK) — 142.9 LBS
NO. ROCKETS — 16 PER PACK
PRETENSION — UNMEASURED

FIGURE 2.3-1
TEST INSTALLATION
TEST NO. 183-3

(99)

nated with Dow Corning, RTV 118 silicone rubber. The slings were 19 feet long. An additional 20.5 inches was added to their length by the clevis and load cell linkages mounted to the load at each corner. The load cells were 120,000 lb. capacity strain gauge type units provided and calibrated by the USAF 6511th Test Group. The load was supported in an initially level position.

These slings were attached to the connector of the lower rocket pack. The lower rocket pack was supported in a vertical position with no offset. The lower rocket pack was attached to the upper rocket pack by means of eight, 3-foot long, three loop slings constructed of MIL-W-4088, Type X, 8700 lb. tensile strength nylon webbing.

Rocket ignition was accomplished by porting compressed nitrogen gas (1800 PSI) to the rocket initiator by means of Stencel SK48-024-001-1 large load range rocket valve assembly.

Ambient temperature at the time of test was 63 degrees Fahrenheit.

Test Results:

Just prior to rocket burnout, all bridle slings failed at the point of attachment to the load. The failure was apparently caused by heat due to the large amount of hot gases produced by the rocket burning. These gases converged and impinged upon the slings and the load.

Impact damage was sustained by the unrestrained rocket packs, the test facilities, and part of the instrumentation.

Data was as follows:

Film

Times from

T_o to rocket fire	.02 sec.
T_o to rocket burnout	.575 sec.
Rocket fire to burnout	.555 sec.

Oscillograph

Results from the 120K force transducers:

#3	Total time	.470 sec.
	T_0 to 1st rise	.0304 sec.
	Peak force	45,200 lbs.
	Total impulse	12,800 lb.-sec.
	Average force	27,400 lbs.
#5	Total time	.436 sec.
	T_0 to 1st rise	.0292 sec.
	Peak force	49,800 lb.-sec.
	Average force	26,960 lbs.
#6	Total time	.497 sec.
	T_0 to 1st rise	.0286 sec.
	Peak force	52,400 lbs.
	Total impulse	12,470 lbs.
	Average force	28,700 lbs.
#7	Total time	.468 sec.
	T_0 to 1st rise	.0286 sec.
	Peak force	45,200 lbs.
	Total impulse	11,600 lb.-sec.
	Average force	24,750 lbs.

Figure 2.3-2 depicts the oscillograph traces for this test. Load angle versus time figures are not available.

The almost vertical path of the unrestrained rocket packs demonstrated excellent stability for this test had the structural failure not occurred.

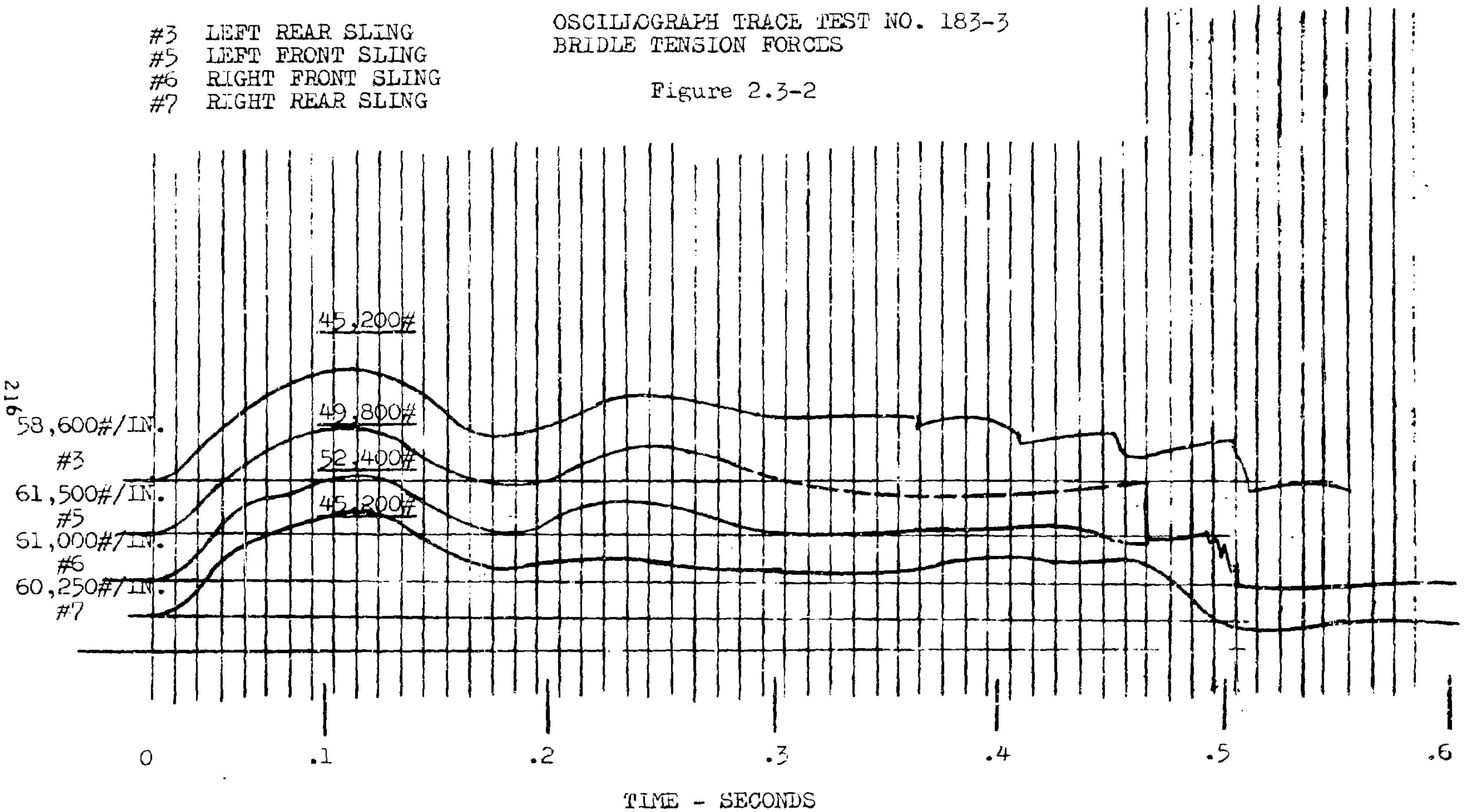
Conclusions and Recommendations:

In the present system the suspension slings are not adequately shielded from heat and, therefore, present a hazard.

It is apparent that a solution to the flame impingement problem must be found. It is recommended that this test be repeated.

OSCILLOGRAPH TRACE TEST NO. 183-3
BRIDLE TENSION FORCES

Figure 2.3-2



2.4 Test No.:

186-1

Type of Testing:

PRADS Tethered Rocket Test

Date of Testing:

20 June 1968

Time of Testing:

1700 Hours

No. of Rocket Tested:

32

Purpose of Testing:

The purpose of this testing was to evaluate two different sling covering materials for structural integrity and for heat damage on longer slings than used before.

Test Procedure:

Thirty-two rockets were used. Sixteen of these rockets were used in each Stencel SK48-022-001-1 Revision A rocket pack assembly. One was suspended in the upper position and the remaining rocket pack was suspended in the lower position. Each rocket pack weighed 1429 lbs. The rocket pack weight included the complete rocket pack with the rockets and the rocket valve assemblies.

The piggy back installation was used as shown in Figure 2.3-1. The load was supported by means of two four loop slings of MIL-W-4088, Type XXVI, 15,000 lb. tensile strength nylon webbing at each corner. These slings were covered with the Stencel SK409-0020-1

Revision B sleeves of two materials. The two front slings were covered with asbestos cloth sleeves, and the two rear slings were covered with fiberglass cloth with aluminum backing. The slings were 24 feet long. An additional 20.5 inches was added to their length by the clevis and load cell linkages mounted to the load at each corner. The clevises had 2" diameter spools for the slings to seat on. The load cells were 120,000 lb. capacity strain gauge type units provided and calibrated by the USAF 6511th Test Group. The load was supported in an initially level position.

These slings were attached to the connector of the lower rocket pack. The lower rocket pack was supported in a vertical position with no offset. The lower rocket pack was attached to the upper rocket packs by means of eight, 3-foot long three loop slings constructed of MIL-W-4088, Type X, 8700 lb. tensile strength nylon webbing.

Three temperature sensitive paints were applied to the top of the load and the lower ends of the suspension slings. The three paints were capable of liquifying at 300, 400 or 500 degrees Fahrenheit respectively. In addition, temperature monitoring labels were taped to the top of the load and the lower ends of two slings.

Ambient temperature at the time of test was 80 degrees Fahrenheit.

Test Results:

The load appeared stable during rocket burning and the suspension slings remained intact. Nozzle serial number 67 on rocket serial number 336 experienced a material failure. This nozzle had a sharp corner in the locking ring groove. The nozzle came off the rocket motor and broke out a section of the rocket pack lower plate. This in turn caused damage to some of the rocket connectors due to pivoting of several rocket motors. No motors became separated from the rocket pack. The nozzle had been pressure checked to 4500 psi prior to reloading. The nozzle had been fired three times previously and had been dropped once without firing.

All slings remained intact; however, there was some damage. The covers were ripped and the slings suffered some visible heat damage. It is not known how much if any heat damage was contributed by rocket number 336 whose grain burned at low pressure or "chuffed".

Results of film analysis showed that the rocket exhaust plumes changed directions during rocket burning from along the nozzle axis at 35 degrees to the vertical to almost straight down. As a result, the slings and load were subjected to direct impingement of the rocket exhaust blast during the last part of rocket burning. The measured plume angles at times during rocket burning were as follows:

Time from Rocket Initiation - Sec.	Plume Angle With Vertical - Deg. Upper Pack	Lower Pack
.010	31	35
.015	31	32.75
.020	32.25	34.75
.035	35.5	--
.045	30.5	--
.065	26.25	--
.135	27.25	--
.205	23.5	--
.360	22	19
.390	0 (Approx.)	0 (Approx.)
.5	0 (Approx.)	0 (Approx.)

Oscillograph Data

Results from the 120K force transducers:

#3	Total time	.558 sec.
	T_0 to 1st rise	.022 sec.
	Peak force	54,200 lbs.
	Total impulse	14,130 lb.-sec.
	Average force	25,350 lbs.

#5	Total time	.549 sec.
	T_o to 1st rise	.0251 sec.
	Peak force	58,700 lbs.
	Total impulse	14,900 lb.-sec.
	Average force	27,100 lbs.
#6	Total time	.547 sec.
	T_o to 1st rise	.0251 sec.
	Peak Force	55,100 lbs.
	Total impulse	13,700 lb.-sec.
	Average force	25,050 lbs.
#7	Total time	.553 sec.
	T_o to 1st rise	.0239 sec.
	Peak force	56,400 lbs.
	Total impulse	13,850 lb.-sec.
	Average force	25,050 lbs.

Figure 2.4-1 depicts the oscillograph traces for this test. Lead angle versus time figures are not available.

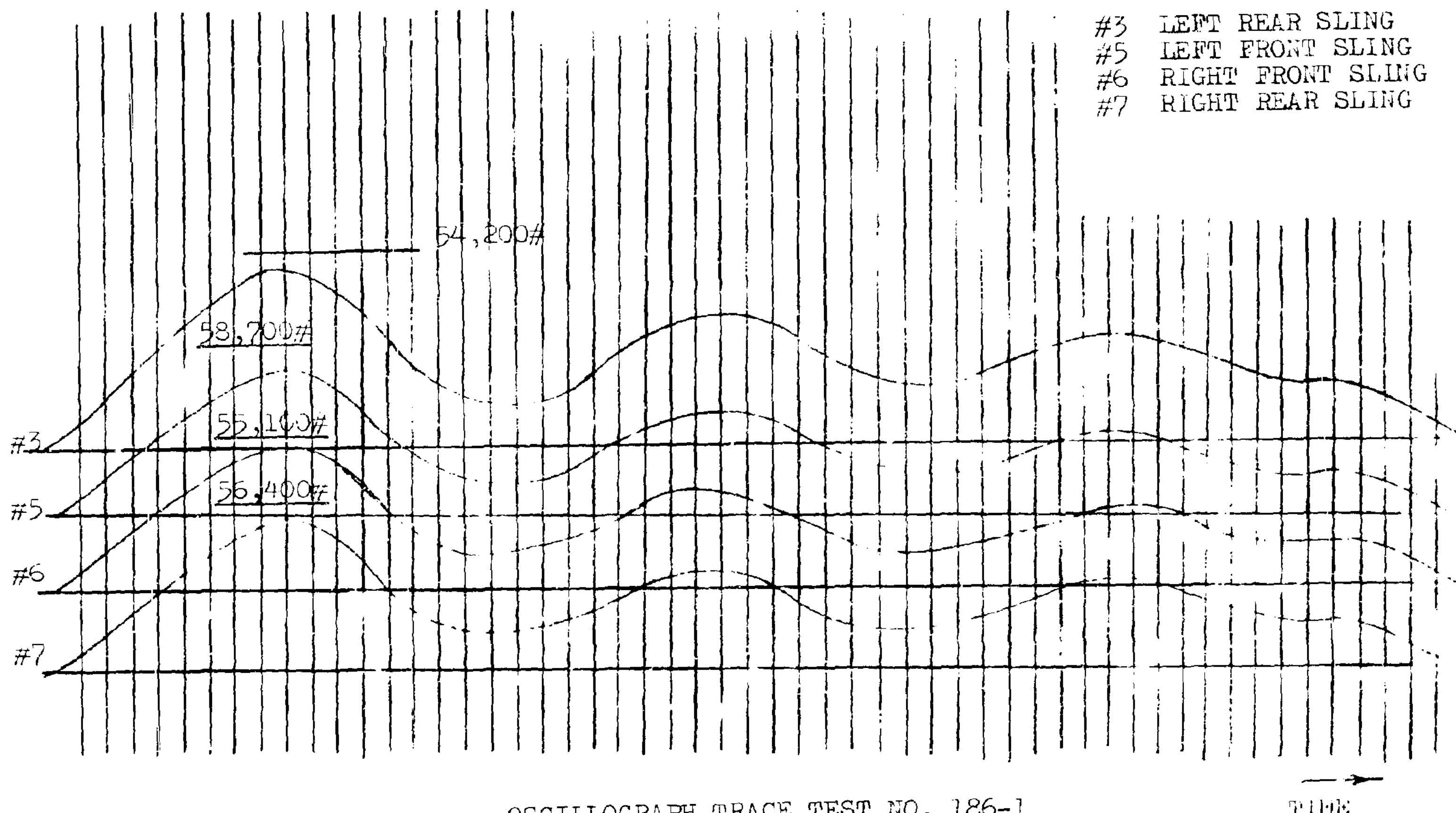
The rocket nozzle which failed hit the load and glanced into the cable which supported the pretensioning and arresting hook. The cable was damaged and failed when the cable felt the weight of the rocket packs after burnout. The rocket packs were damaged when they fell on the load.

Temperature Measurement:

The temperature sensitive paint did not give valid results because of the short period of exposure and the blast. The temperature monitoring labels indicated a temperature above 500° Fahrenheit.

Conclusions and Recommendations:

The slings are structurally adequate for 32 rocket motors with either covering tested and a 2" diameter spool around the large clevis; however, due to the configuration and the large amount of exhaust gases the gases converged and the results are very un-



OSCILLOGRAPH TRACE TEST NO. 186-1
BRIDLE TENSION FORCES

Figure 2.4-1

desirable from a standpoint of reusing the slings.

Drop tests with 32 rocket motors should be made to ascertain if the rocket exhaust flame is deflected somewhat by the load downward velocity. In any case, it is expected that a smaller number (12) of large rockets equally spaced around the pack would reduce or eliminate the problem of convergence of exhaust gases.

The nozzles which have sharp radii should not be used for more than two firings without some type of reinforcement. Other nozzles which have radii in the grooves can be fired additional times.

APPENDIX C

Airdrop Testing - Stencel

1.0 GENERAL

Airdrop testing was carried out at the old Asheville-Hendersonville Airport near Asheville, North Carolina, utilizing the company owned TBM aircraft.

Testing was conducted to (a) investigate the parachute only system (range 2000 to 8000 pounds) in tests 193-1, -2, and -3; (b) check the signal system (MDF) and safeties in tests 194-1, -2 and -3 without rockets; and (c) check the complete system operation in tests 195-1 and -2 with the complete system using rockets. A summary of test conditions is found in Table 1.2.

The drop load was a steel tub constructed in accordance with Stencel Dwg. No. ST48-001-001. The load was suspended from short rails on which it could slide. The rails were suspended from the aircraft bombay by a box beam.

The load attachment centers were eight feet lengthwise and four feet in width.

The extraction parachute was a 15 foot diameter canopy of the ringslot construction. The extraction line was 60 feet long and constructed of one loop of MIL-W-4088, Type X, nylon webbing. The extraction parachute was ballistically projected. The extraction parachute bag was the bag modified for ballistic projection, and the extraction chute projection gun was fabricated in accordance with Stencel Dwg. No. 27-05-001. The risers were constructed of 8700 lb. nylon webbing, MIL-W-4088, Type X two loop construction. To each corner of the load a 16 foot long sling was attached to a 20K load cell or a pressure cylinder where noted and a standard clevis. The slings were constructed of three loops of 8700 lb. nylon webbing.

On an electric impulse from the pilots release switch, a standard Mark I squib actuated a normally closed valve. The opening of the valve allowed compressed nitrogen gas to be ported to the piston which retracted the number one load release and then to the piston which retracted the number two release pin. Stroking of the second piston allowed the gas to then be ported to an M28 gas fired

DATA SUMMARY FOR AIRDROP TESTS

STENCEL
TABLE 1.2

Test No.	Date	Gross Load Weight Pounds	Release Altitude Ft.	Flat Circular Recovery Parachute		MDF Length Ft.	No. Rockets Used (Fired)	Descent Vel. at Rocket Firing Ft./Sec.	Horizontal Impact	Vertical Impact Velocity Ft./Sec.	
				Dia.-Ft.	No.						
193-1	25 Jan. 1958	5060	490	46	4	--	--	--	22	28	Parachute Only Test
193-2	30 Jan. 1968	5060	480	46	4	--	--	--	5.6	31	
193-3	7 Feb. 1968	5060	400	46	4	--	--	--	0.4	29	
194-1	14 Feb. 1968	5060	400	24	4	28	--	--	20	52	Inert System Tests
194-2	23 Feb. 1968	5060	400	24	4	28	--	--	1.4	74	
194-3	4 March 1968	5060	410	24	4	28	--	--	5.6	72	
195-1	11 March 1968	5120	400	24	4	28	4 (4)	59	0.8	24	Live System Tests
195-2	14 March	5120	315	24	4	27	4 (4)	70	1.3	28	

General Data: Load Weight - Approx. 4600 Pounds - Suspended
Extraction Parachute - 15 Ft. Dia. Ringslot
Release Speed - 130 KIAS

ballistic initiator. The output of the ballistic initiator operated the extraction parachute projection gun. A break cord was provided to restrain the load from moving until the extraction forces reached the level of 1500 lbs. The unrestrained drop load was then pulled from the test aircraft by the force of the extraction parachute.

Subsequent to clearing the aircraft rails, two redundant lanyards activated the force transfer device, which consisted of three T-30 mechanically fired initiators which operated three gas powered line cutters. The extraction line connection to the load extraction point was severed by the line cutters allowing the main parachutes to be extracted.

2.0 TEST SUMMARY

The following is a test by test description and summary of airdrop tests. Test conditions are tabulated in Table 1.2.

2.1 Test No.:

193-1

Type of Testing:

PRADS Parachute Only Low Load Range Drop Test

Date of Testing:

25 January 1968

Time of Testing:

1640 Hours

Purpose of Testing:

The purpose of the testing described herein was to demonstrate the capability of the parachute only configuration for the low load range, to discover any deficiencies in the system, and to provide the performance data on this configuration.

Test Procedure:

This test was performed with a drop load of 5060 lbs. gross weight. The four main parachutes were 46 foot diameter flat circular canopies. The suspension lines were 41.5 feet in length. Each riser was 40 feet long plus a four-branch extension which was 5 feet long. The parachutes were provided with a 47 foot center line.

The main parachute bags were fabricated in accordance with Stencel Dwg. No. SK409-0016.

The standard 1670-799-8597 load coupler was used as a confluence point attachment connecting the parachute risers with the load supporting slings. At the end of these slings was attached an Olin Matheson pressure cylinder type force gauge. These, in turn, were attached to the standard clevises at the four corners of the load.

Figure 193-1-1 depicts the test configuration. Refer to Figure 193-1-2 for a pictorial representation of the sequence of events for this test.

Test Results:

In general, this test proved to be good. Deployment was good; however, main canopy opening times were more rapid than desired. Peak opening forces were somewhat excessive, and minor damage to the main canopy deployment bags was experienced.

Vertical impact velocity was 28.2 feet per second. Horizontal impact velocity was 22 feet per second.

Peak opening forces for each load attachment point are as follows:

Right front	1.69 G
Left front	1.76 G
Right rear	Unmeasured
Left rear	Unmeasured

Loading is based upon gross load weight. Event times are taken from the time of first load motion and are as follows:

Load clears ramp	.497 sec.
Extraction force transfer	.769 sec.
Line Stretch	1.925 sec.
Canopy Stretch	2.07 sec.

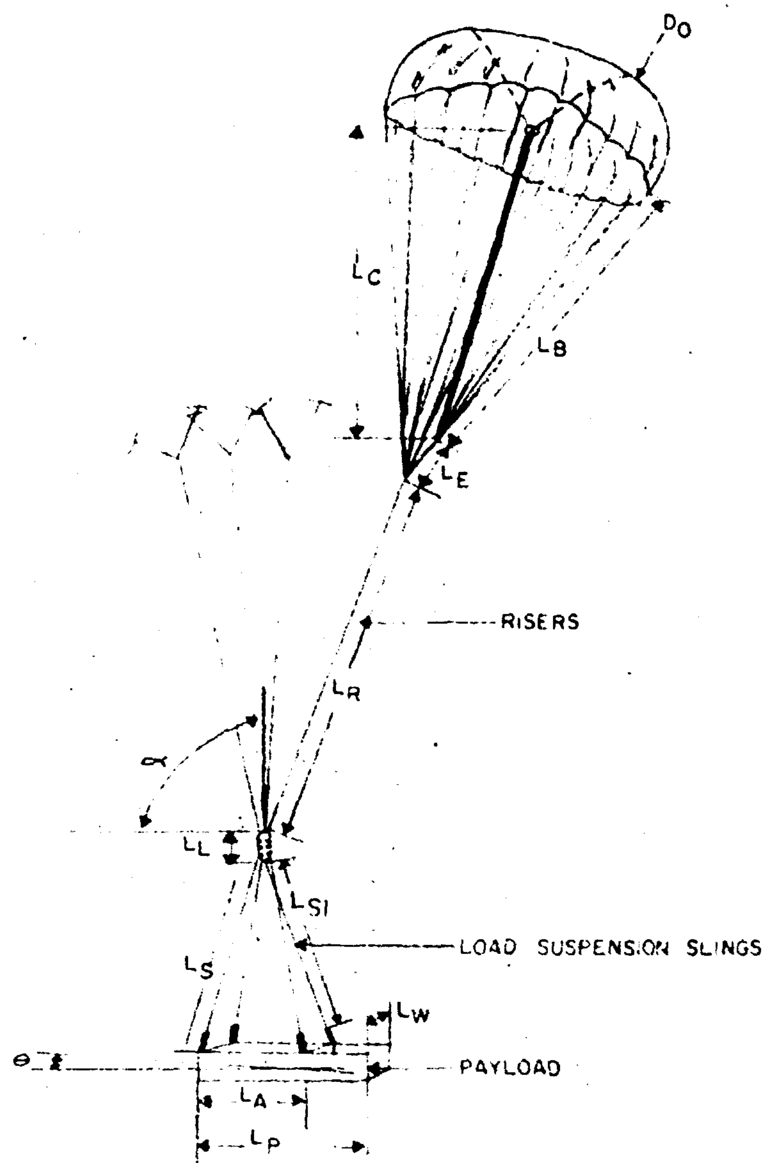
Full inflation of each parachute	1	3.54 sec.
	2	5.08 sec.
	3	5.78 sec.
	4	6.51 sec.
Average inflation		5.23 sec.

Figure 193-1-3 depicts the load trajectory.

Conclusions, Recommendations and Corrective Actions:

The basic design is concluded to be good. The peak opening forces are excessive and must be reduced. Opening times are not con-

SAEC AIRDROP CONFIGURATION



SYMBOL	DESCRIPTION	VALUE
θ	Payload Angle from Horizontal	Initially Zero
α	Average Riser Angle	
L_S	Suspension Sling (With Clevis and Load Cell)	17.5 Ft.
L_{SI}	Suspension Sling (Webbing Only)	16 Ft.
L_W	Sling Attachment Centers (Width)	4 Ft.
L_A	Sling Attachment Centers (Length)	8 Ft.
L_P	Length of Payload	12 Ft.
L_L	Connection Fitting	10 Inches
L_R	Riser Length	40 Ft.
L_E	Riser Extension	5 Ft.
L_B	Suspension Line Length	41.5 Ft.
L_C	Length of Center Line	47 Ft.
D_O	Flat Canopy Diameter	43 Ft.
W	Suspended Wt.	4828 Lbs.

FIGURE 193-1-1
TEST CONFIGURATION

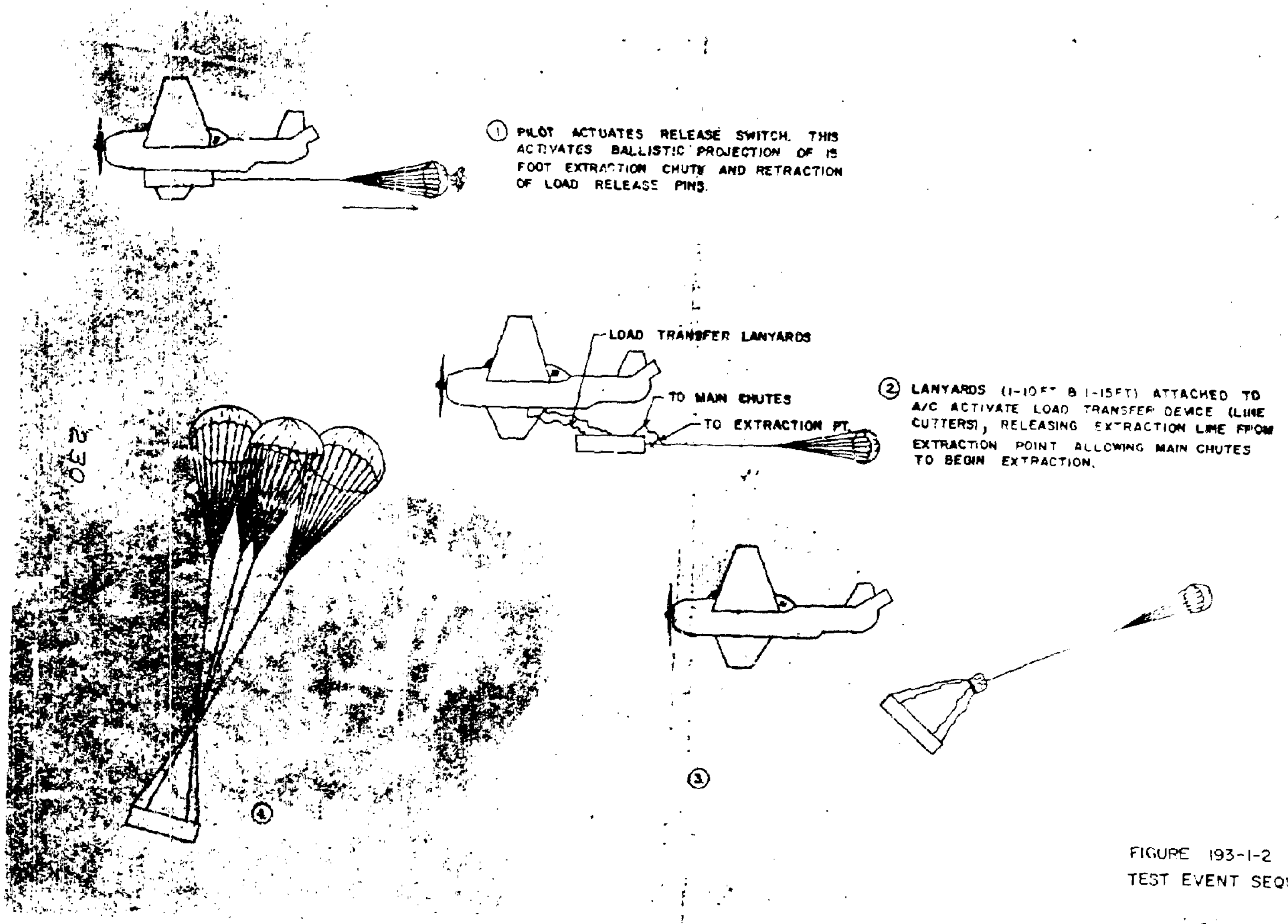
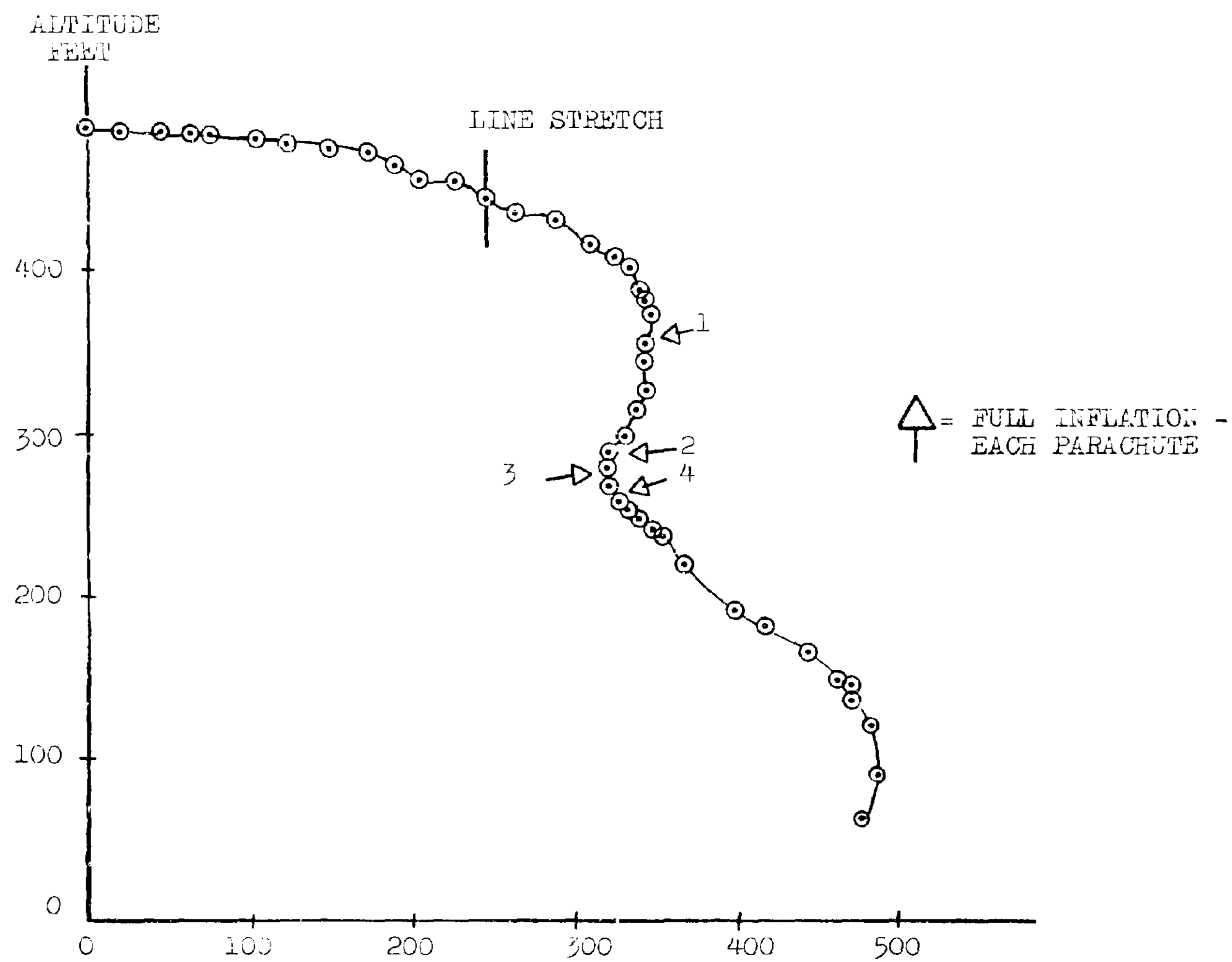


FIGURE 193-1-2
TEST EVENT SEQUENCE

230



LOAD TRAJECTORY TEST NO. 193-1

Figure 193-1-3

sistent, and the spread from the earliest to the latest opening must be reduced.

The recommended corrective action for the next test is to eliminate the center line.

2.2 Test No.:

193-2

Type of Testing:

PRADS Parachute Only Low Load Range Drop Testing

Date of Testing:

30 January 1968

Purpose of Testing:

The purpose of the testing described herein was to demonstrate the capability of the parachute-only configuration for the low load range and to demonstrate a reduction in parachute opening force.

Test Procedure:

This test was performed with a drop load of 5060 lbs. gross weight. The four main parachutes were 46 foot diameter flat circular canopies. The suspension lines were 41.5 feet in length. The risers were 40 feet long plus a four-branch extension which were five feet long. The parachutes had no center lines.

The main parachute bags were fabricated per Stencel Dwg. No. SK409-0016.

The standard 1670-799-8795 load coupler was used as a confluence attachment connecting the parachute risers with the load supporting slings.

Figure 193-1-1 depicts the test configuration. Refer to Figure 193-1-2 for a pictorial representation of the sequence of events for this test.

Test Results:

This proved to be somewhat of an improvement over the previous test. Deployment was good. Main canopy opening times were a little better than in the previous test. Peak opening forces were still somewhat excessive, and minor damage to the main canopy deployment bags was still experienced.

Vertical impact velocity was 30.6 feet per second. Horizontal impact velocity was 5.6 feet per second.

Peak opening forces for each load attachment are as follows:

Right front:	1.443 G
Left front:	1.47 G
Right rear:	1.57 G
Left rear:	1.89 G

Event times were taken from the time of first load motion and are as follows:

Load clears ramp		.595 sec.
Extraction force transfers		.775 sec.
Line stretch		1.905 sec.
Canopy stretch		2.10 sec.
Full inflation of each parachute	1	3.93 sec.
	2	5.03 sec.
	3	5.62 sec.
	4	5.79 sec.
Average inflation		5.09 sec.

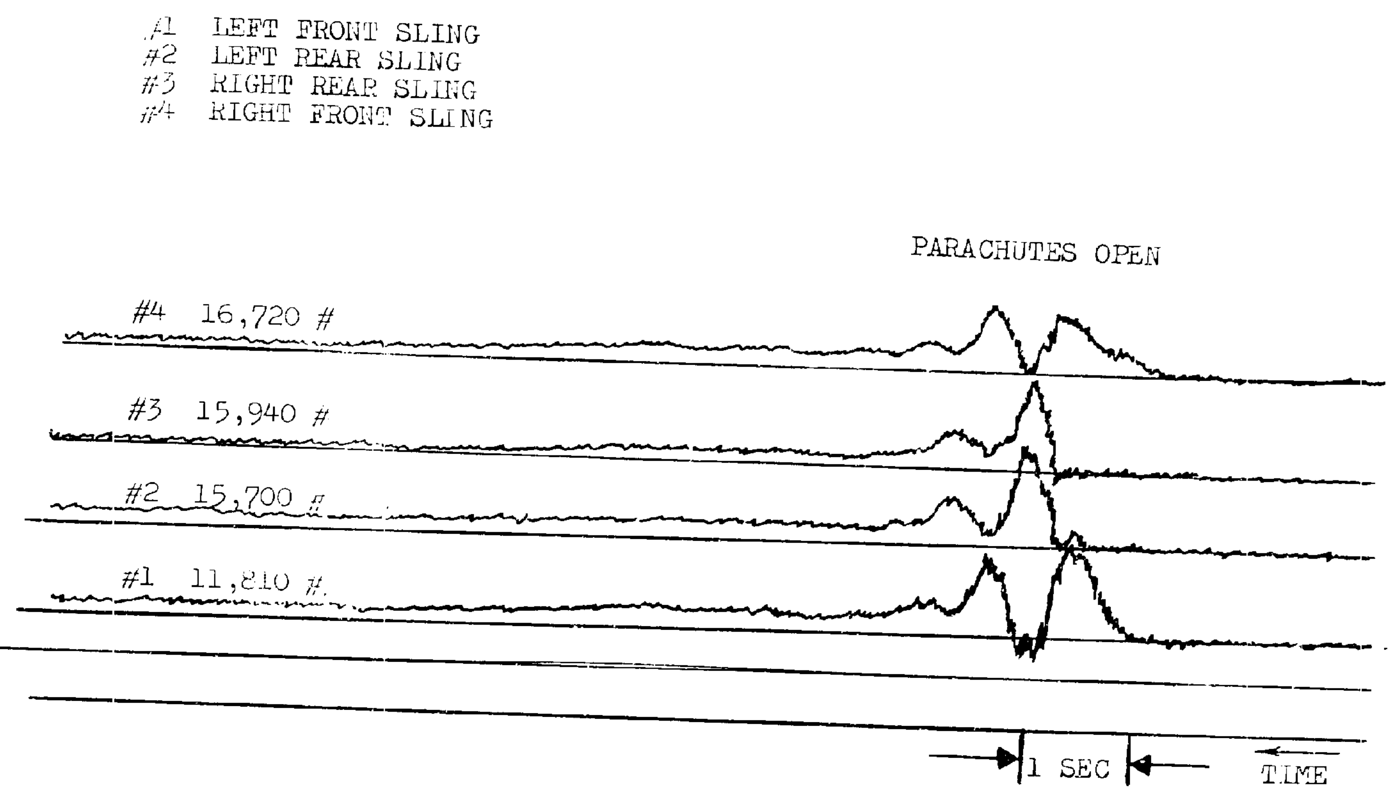
Stability was excellent

Figure 193-2-1 depicts the oscillograph traces of load attachment force vs. time.

Figure 193-2-2 depicts the load trajectory.

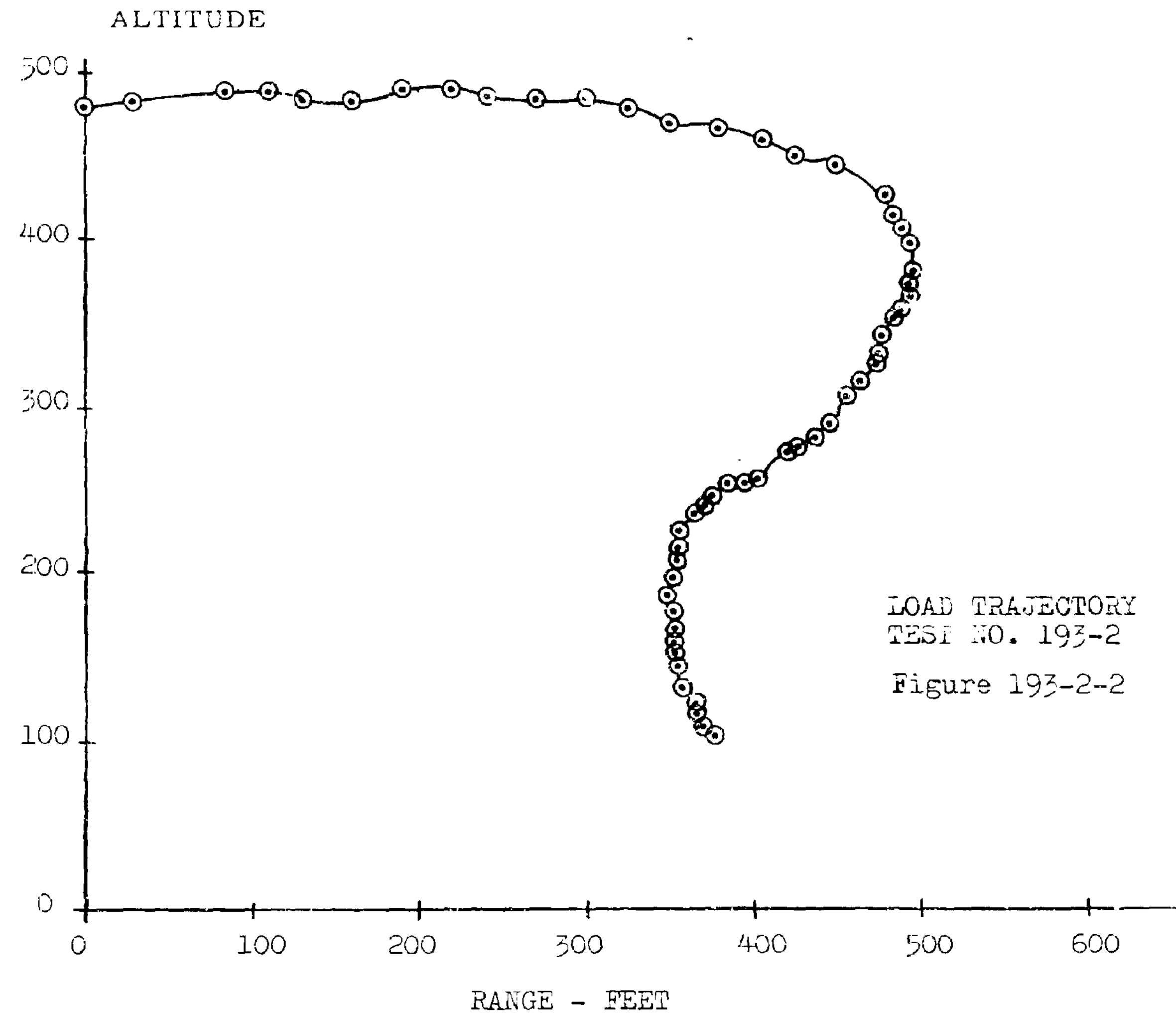
<u>Conclusions, Recommendations and Corrective Actions:</u>

The elimination of the center line in this test proved to be a good modification. However, opening times are still somewhat rapid,



OSCILLOGRAPH TRACES OF LOAD ATTACHMENT FORCES VS TIME
TEST NO. 193-2

Figure 193-2-1



LOAD TRAJECTORY
TEST NO. 193-2

Figure 193-2-2

and opening shocks are still somewhat high.

It is recommended that for all subsequent tests under this program, the center line continue to be eliminated, and in addition to this modification, it is recommended that the corrective action be taken to include incorporation of main canopy reefing to a diameter of 23.7 feet for a period of 2 seconds from the time of main canopy deployment. (It is not expected that reefing will be required with the proposed system using 48 foot slotted parachutes.)

2.3 Test No.:

193-3

Type of Testing:

PRADS Parachute Only Low Load Range Drop Testing

Date of Testing:

7 February 1968

Purpose of Testing:

The purpose of the testing described herein was to demonstrate the capability of the parachute-only configuration for the low load range, with reefed main parachutes to reduce parachute opening force.

Test Procedure:

This test was performed with a drop load of 5060 lbs. gross weight. The four main parachutes were 46 foot diameter flat circular canopies. They were reefed to a diameter of 23.7 feet. This reefing was accomplished by means of a reefing line 74 feet long. Disreefing was accomplished by means of two two-second delay line cutters per parachute which were activated by lanyards attached to the canopy risers on parachute deployment. The suspension lines were 41.5 feet in length. The risers were 40 ft. long plus four branch extensions which were 5 ft. long. No center line were used.

The main parachute bags were fabricated per Stencel Dwg. No. SK409-0016.

The standard 1670-799-8795 load connector was used as a bridle confluence attachment connecting the parachute risers with load supporting slings.

Figure 193-1-1 depicts the test configuration.

Refer to Figure 193-1-2 for a pictorial representation of sequence of events for this test.

<u>Test Results:</u>

This test proved to be very good. Deployment was good. Peak opening forces were acceptable. Deployment times were acceptable. Minor damage to the main canopy deployment bags was experienced.

Vertical impact velocity was 29.4 feet per second.

Peak opening forces for each load attachments are as follows:

Right front:	1.16 G
Left front:	1.14 G
Right rear:	1.37 G
Left rear:	1.23 G

Event times are taken from the time of first load motion and are as follows:

Load clears ramp		.56 sec.
Extraction force transfer		.781 sec.
Line stretch		1.99 sec.
Canopy stretch		2.24 sec.
Full inflation of each parachute	1	4.57 sec.
	2	4.77 sec.
	3	5.08 sec.
	4	5.93 sec.

Average inflation	5.09 sec.

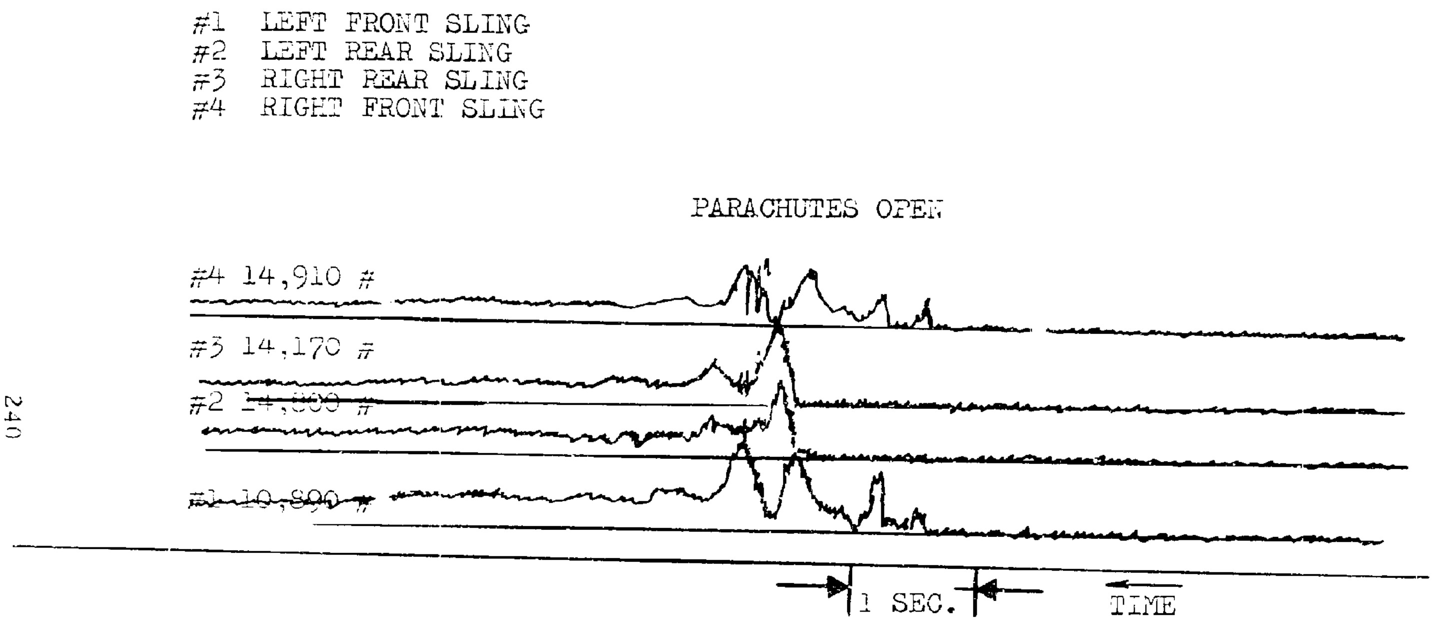
Stability was acceptable.

Figure 193-3-1 depicts the oscillograph traces of the load attachment forces vs. time.

<u>Conclusions, Recommendations and Corrective Action:</u>

The modifications previously incorporated are concluded to be good. It is recommended that this configuration be accepted for the low load range, parachutes only. The one remaining problem experienced in this and the previous two tests was minor bag damage. The recommended correction for all subsequent testing and for incorporation into the system is that modification be made to the main chute bags in such a manner as to reinforce the areas in which damage occurred.

Impact velocity was slightly higher than acceptable. One additional parachute should be used for loads of this suspended weight (4600 pounds).



OSCILLOGRAPH TRACES OF LOAD
ATTACHMENT FORCES VS TIME
TEST NO. 193-3

Figure 193-3-1

2.4 Test No:

194-1

Type of Testing:

PRADS Inert Rocket System Test

Date of Testing:

14 February 1968

Purpose of Testing:

The purpose of the testing described herein was to evaluate the effectiveness of the modifications and corrective actions incorporated in the retrorocket system since the previous test program. Parachute operation, ignition train performance, and general operation, in particular, were studied.

Test Procedure:

This test was performed with a drop load of 5060 lbs. gross weight. Four main parachutes were used. These parachutes were 24 foot flat circular canopies. Suspension lines were 21.5 feet in length. Each parachute riser was 20 feet long plus a two-branch extension which was eight feet in length. All remaining tests were made with this parachute configuration.

The main parachute bags were fabricated per Stencel Dwg. No. SK409-0018 on this test and the remaining airdrop tests.

For this test a dummy rocket pack fabricated in accordance with Stencel Dwg. SK48-009-001 was used. The main chute riser was attached to the top of this dummy rocket pack. To the bottom of this dummy rocket pack was attached the four load support slings. At the end of each of these slings was attached an Olin Matheson pressure cylinder type force gauge. These, in turn, were attached to the standard clevises at the four corners of the load.

On this test, even though it was an inert rocket test, the complete rocket ignition train system was used in order to fully evaluate the performance of the probe and the MDF and the CDF assemblies, consisting of the SK32-006-001-1 probe assembly, the SK48-005-001-1 rocket valve assembly, the Ensign-Bickford 213093 CDF assembly, and the Ensign-Bickford No. 213092 MDF transfer assembly. These units were activated by lanyards as shown in Figure 194-1-2.

Operation:

The load was extracted identically the same as in the previous parachute only tests. After the extraction line connec ion to the load extraction point was severed by the line cutters allowing the main parachutes to be extracted, the dummy rocket pack was extracted from the load under the action of the main canopy. Attached to the dummy rocket pack was a lanyard 14 feet long which activated the probe release mechanism. The probe reeled out from the probe reelout brake under the force of gravity. The amount of MDF reeled out was 28 feet. When the load had descended to a height of 28 feet above the ground, the probe was activated on contact with the ground and, in turn, activated the Ensign-Bickford MDF assembly sending the actuation signal up to the probe reel out brake At the probe reelout brake the signal was then transferred to the Ensign-Bickford CDF assembly which in turn carried the signal up to the rocket valve assembly.

Figure 194-1-1 depicts the test configuration.

Refer to Figure 194-1-2 for a pictorial representation of the sequence of events for this test.

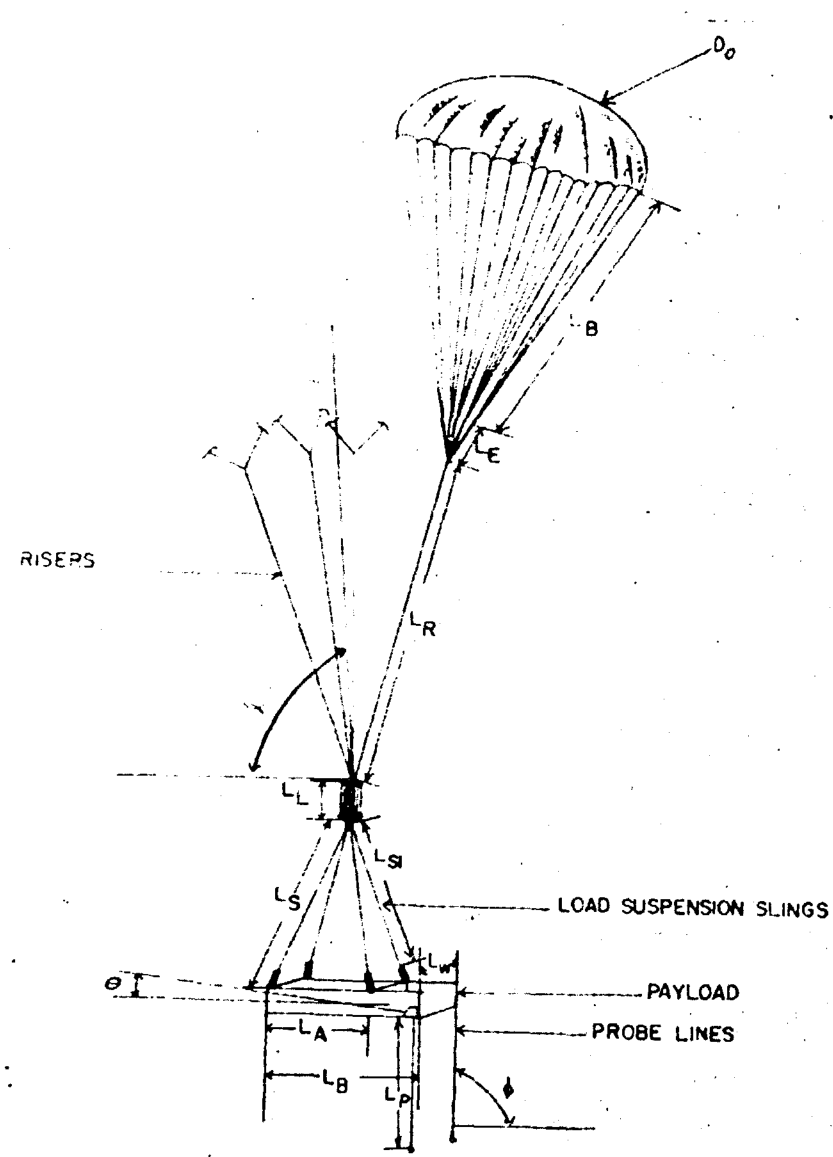
Test Results:

In general, this was a very good test. The only problem of any significance that occurred on this test was the fact that the lining of one of the probe reel out brake shoes cracked thus preventing the probe from reeling out the full 28 feet of MDF. Peak parachute opening forces were reasonable. Opening times were acceptable.

Vertical impact velocity was 52.4 feet per second. Horizontal impact velocity was 20 feet per second.

Peak opening forces for each load attachment point as determined by the crusher cylinder type force gauge are as follows:

SAEC AIRDROP CONFIGURATION



SYMBOL	DESCRIPTION	VALUE
θ	Payload Angle from Horizontal	Initially Zero
α	Average Riser Angle	
L_S	Suspension Sling (With Clevis and Load Cell)	17.5 Ft.
L_{S_1}	Suspension Sling (Webbing Only)	16 Ft.
L_W	Sling Attachment Centers (Width)	4 Ft.
L_A	Sling Attachment Centers (Length)	8 Ft.
L_P	Length of Payload	12 Ft.
L_L	Dummy Rocket Length	38 Inches
L_R	Riser Length	20 Ft.
L_E	Riser Extension	8 Ft.
L_B	Suspension Line Length	21.5 Ft.
D_0	Flat Canopy Diameter	24 Ft.
W	Suspended Wt.	4628 Lbs.
L_P	MDF Length	38 Ft.
ϕ	Probe Line Angle	

FIGURE 194-1-1
TEST CONFIGURATION

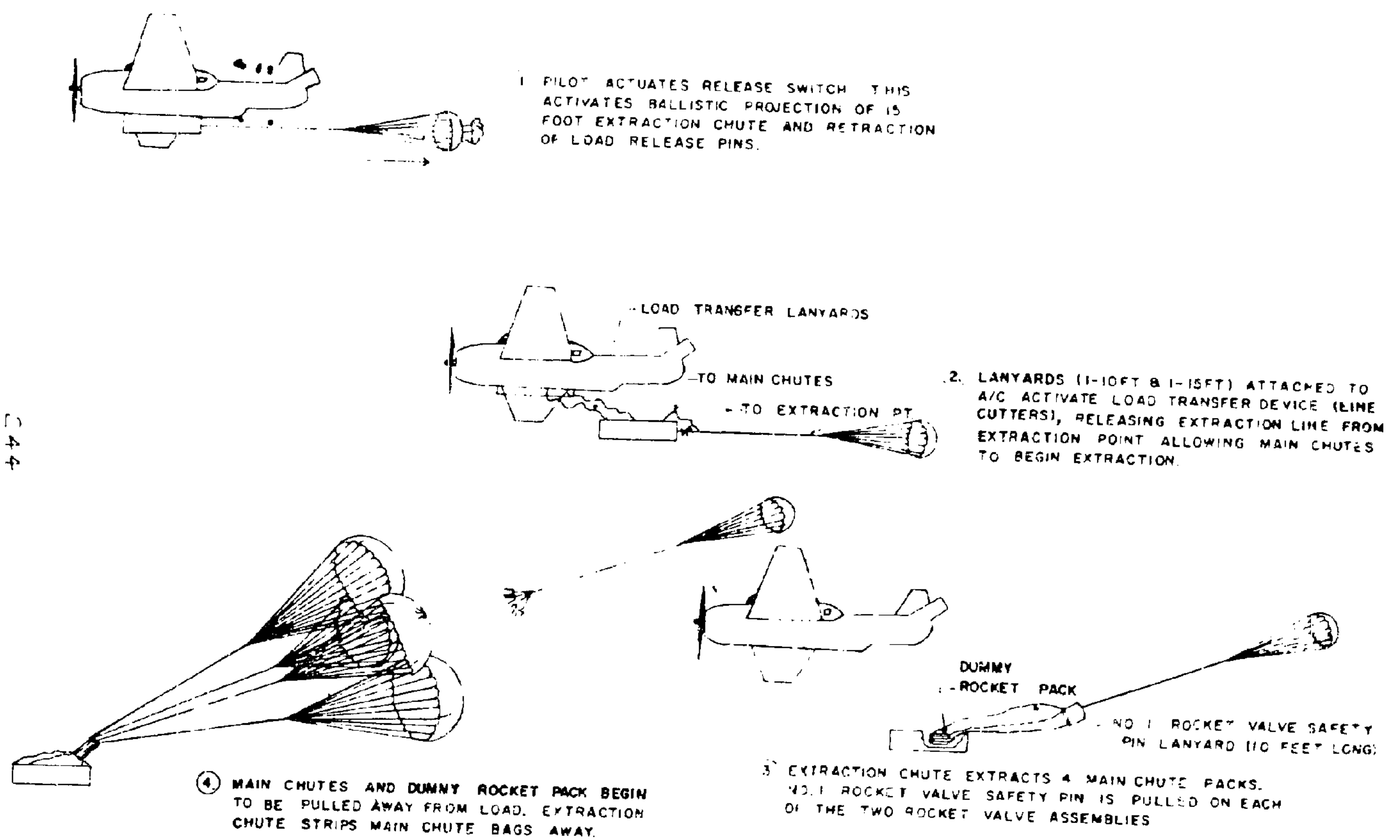


FIGURE 194-1-2
(SHEET 1 OF 2)
TEST EVENT SEQUENCE

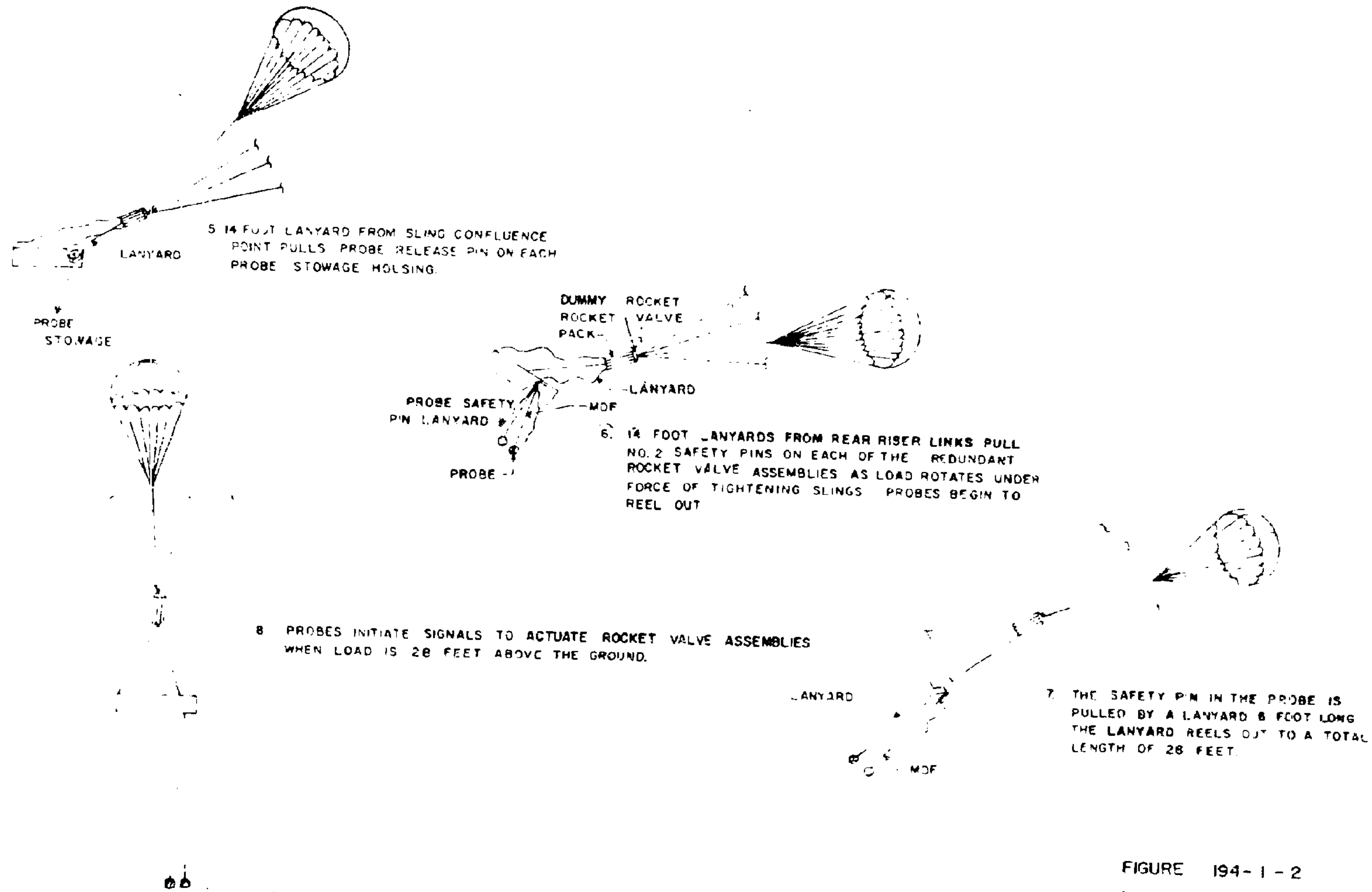


FIGURE 194-1-2
(SHEET 2 OF 2)
TEST EVENT SEQUENCE

Right front:	1.12 G
Left front:	1.02 G
Right rear:	1.17 G
Left rear:	1.27 G

Event times are taken from first load motion and are as follows:

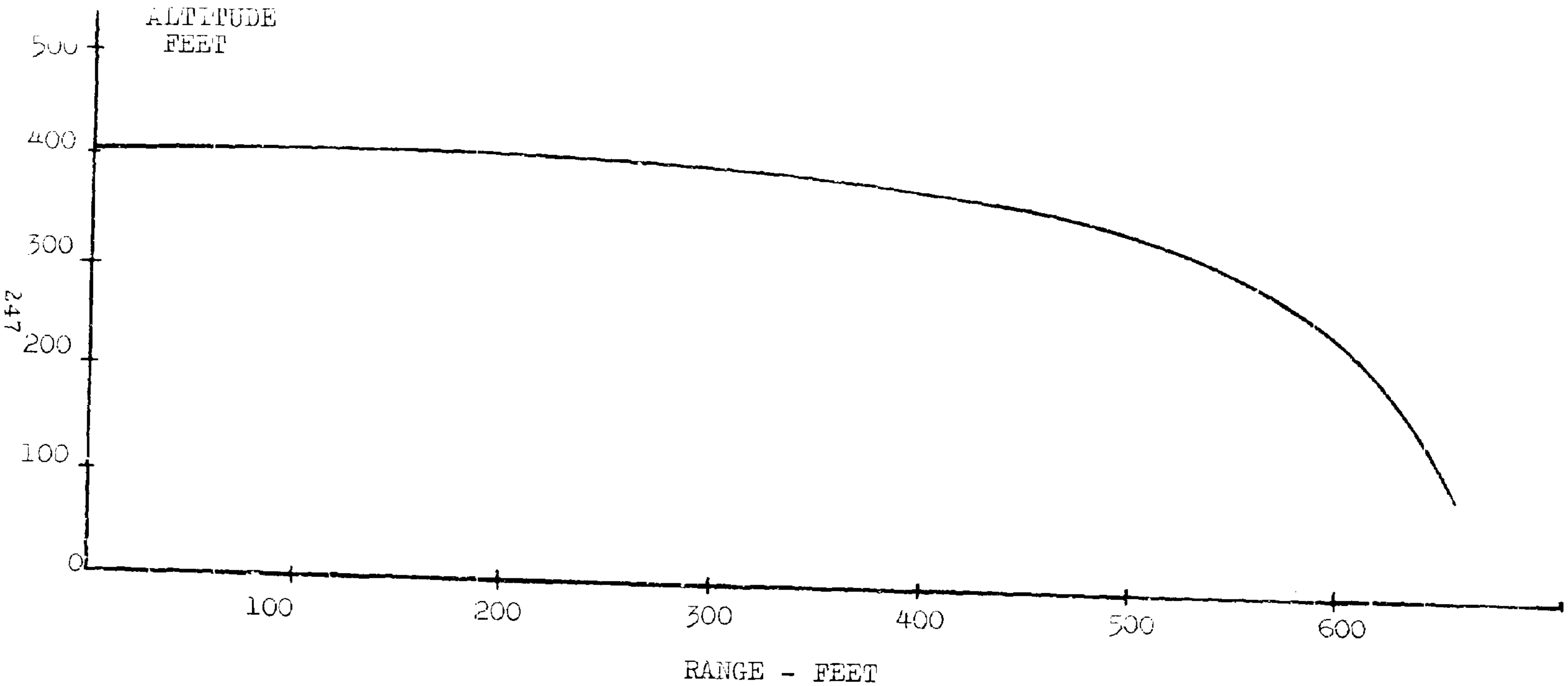
Load clears ramp		.525 sec.
Extraction force transfer		.73 sec.
Line stretch		1.355 sec.
Canopy stretch		1.44 sec.
Inflation of each parachute	1	2.53 sec.
	2	2.71 sec.
	3	1.85 sec.
	4	3.31 sec.
Average inflation		2.85 sec.
Probe release		No Data
Probe full extended		No Data
1st probe impact		7.86 sec.
2nd probe impact		7.88 sec.
Load impact		8.24 sec.

Stability was acceptable.

Figure 194-1-3 depicts the load trajectory.

Conclusions, Recommendations, and Corrective Action:

From this test, it is concluded that the basic design seems good. The problem of the cracked brake shoe lining which prevented the probe from reeling out the full 28 feet of MDF can be prevented in subsequent tests by using brake linings which have been carefully inspected. This brake lining had been used for many tests and was apparently in need of replacement.



LOAD TRAJECTORY TEST NO. 194-1

Figure 194-1-3

2.5 Test No.:

194-2

Type of Testing:

PRADS Inert Rocket System Test

Date of Testing:

23 February 1968

Purpose of Testing:

The purpose of the testing described herein was to evaluate the effectiveness of the modifications and corrective actions incorporated since the previous test program. In addition, modifications to the brake lining in the probe reelout brake were checked under drop conditions.

Test Procedure:

This test was performed with a drop load of 5060 lbs gross weight.

At the lower end of each of the suspension slings was attached an Olin Mathieson pressure cylinder type force gauge. This in turn was attached to the standard clevises at the four corners of the load.

The inert system configuration and operation was the same as in test 194-1.

Figure 194-1-1 depicts the test configuration.

Refer to Figure 194-1-2 for a pictorial representation of the sequence of events for this test.

Test Results:

This test proved to be a very good test except for the fact that the probe arming lanyard wrapped around one of the probes and prevented arming of that probe.

Vertical impact velocity was 74.2 fps, horizontal impact velocity was 1.4 fps. Peak opening forces for each load attachment point as determined by the pressure cylinder type force gauges are as follows:

Right front:	1.14	G
Left front:	1.23	G
Right rear:	1.39	G
Left rear:	1.19	G

Event times are taken from the time of first motion and are as follows:

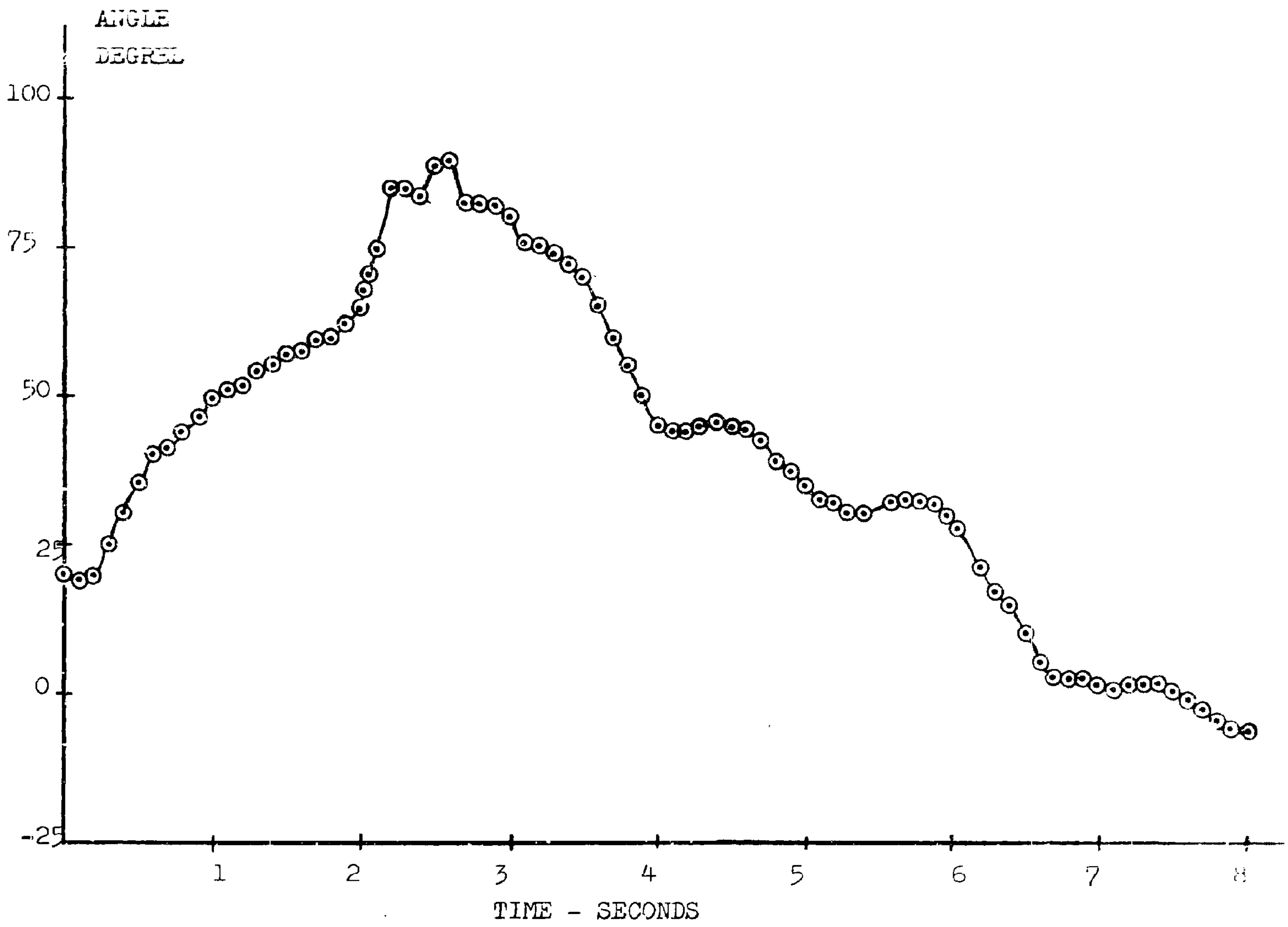
Load clears ramp	.422	sec.
Extraction force transfer	.688	sec.
Line stretch	1.27	sec.
Canopy stretch	1.405	sec.
Full inflation of each parachute	2.36	sec.
	2.48	sec.
	2.92	sec.
	3.50	sec.
Average inflation	2.82	sec.
Probe release	2.22	sec.
Probe full extended	3.52	sec.
1st probe impact	7.48	sec.
2nd probe impact	7.52	sec.
Load impact	7.9	sec.

Stability was acceptable.

Figure 194-2-1 depicts the load angle vs. time.

Conclusions, Recommendations, and Corrective Action.

The basic design still seems to be good. The problem with the probe arming lanyard entangling with the probe can be prevented on future



PAYLOAD ANGLE VS TIME TEST NO. 194-2
Figure 194-2-1

tests by redesign of the probe arming lanyards stowage pockets.

This corrective action is being taken.

2.6 Test No:

194-3

Type of Testing:

PRADS Inert Rocket System Test

Date of Testing:

4 March 1968

Purpose of Testing:

The purpose of the testing described herein was to evaluate the effectiveness of the modifications and corrective actions incorporated since the previous test program. In addition, a check was made of the probe arming lanyards with a modified stowage procedure.

Test Procedures:

This test was performed with a drop load of 5060 lbs. gross weight.

At the lower end of each of the suspension slings was attached an Olin Mathieson pressure cylinder type force gauge. These in turn were attached to the standard clevises at the four corners of the load.

The inert system configuration and operation was the same as in test 194-1.

Figure 194-1-1 depicts the test configuration.

Refer to Figure 194-1-2 for a pictorial representation of the sequence of events for this test.

Test Results:

This test was very good. No problems of any nature occurred. Vertical impact velocity was 71.9 feet per second. Horizontal impact velocity was 5.6 feet per second.

Peak opening forces for each load attachment point as determined by the crusher cylinder type force gauges were as follows:

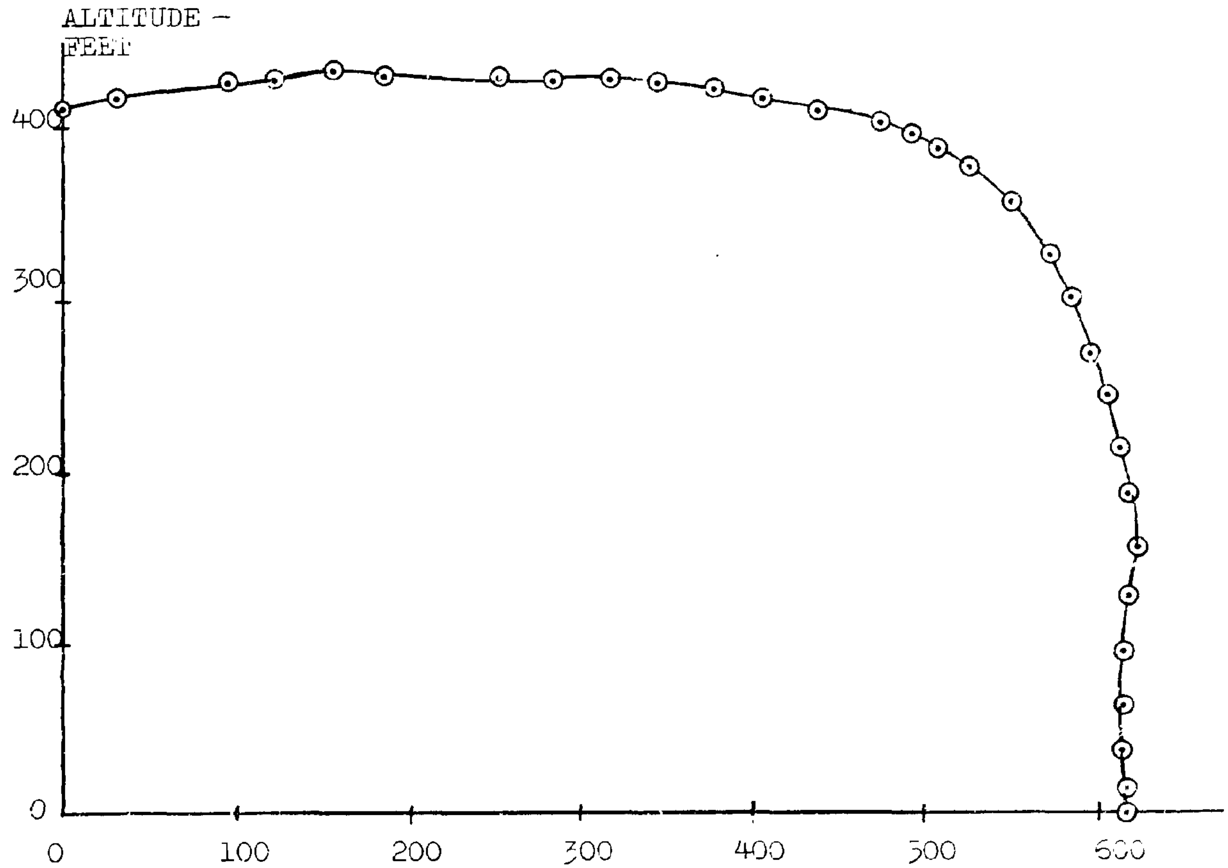
Right front:	1.13 G
Left front:	1.02 G
Right rear:	1.18 G
Left rear:	1.22 G

Event times are taken from the time of first motion of the drop load and are as follows:

Load clears ramp	.49 sec.
Extraction force transfer	.835 sec.
Line stretch	1.605 sec.
Canopy stretch	1.995 sec.
Full inflation of each parachute	2.67 sec.
	2.71 sec.
	2.96 sec.
	2.99 sec.
Average inflation	2.83 sec.
Probe release	2.52 sec.
Probe full extended	4.05 sec.
1st probe impact	7.68 sec.
2nd probe impact	7.70 sec.
Load impact	8.0 sec.

Stability was excellent.

Figure 194-3-1 depicts the load trajectory.



TEST NO. 194-3

LOAD TRAJECTORY

Figure 194-3-1

Conclusions, Recommendations and Corrective Action:

This test concluded the series of three made under the inert rocket system test. No problems or deficiencies occurred in this test. Therefore, it is recommended that the system as presently designed be accepted for further testing under this program.

2.7 Test No.:

195-1

Type of Testing:

PRADS Full System Test

Date of Testing:

11 March 1968

Purpose of Testing:

The purpose of the testing described herein was to evaluate the complete PRADS System performance under airdrop conditions of 130 knots airspeed, to discover any system deficiencies, and to determine suitable corrective actions for the deficiencies. In addition, the gas valve safety and arming devices were checked under system conditions.

Test Procedure:

This was a full system test using four Northrop SK2000-1001 rockets having a nominal thrust of 5100 lbs. each. The Stencel SK48-001-001-1 small load range rocket pack was used. The weight of the rocket pack loaded with the rockets was approximately 361 lbs.

This test was performed with a drop load of 5120 lbs. gross weight.

The main parachute bags were fabricated per Stencel Dwg. No. SK409-0018.

To the bottom of the rocket pack was attached four 16 ft. long support slings. At the end of each of these slings was attached strain gauge-type load cells of 20,000 lbs. capacity. The load cells were in turn attached to standard clevises at the four corners of the load

Operation:

System operation was identical to the previous inert tests up to main parachute deployment. As the main canopy parachute bags were being pulled away from the drop load, lanyards (connected to one of the main parachute bags and attached at the other ends to the rocket valve assembly Number 1 safety pins) were pulled, thereby, activating the Number 1 rocket valve assembly safety pins. A lanyard was provided for each of the two redundant rocket valve assemblies. After the main canopies were completely deployed, the extraction parachute line and the main parachute bags were separated from the main canopy and allowed to go free. The rocket pack was pulled away from the drop load. A 14 foot lanyard connected to the rocket pack activated each of two probe release pins as the rocket pack was being pulled away. Also, as the rocket pack was being pulled away from the load, two lanyards (attached to the rear riser links on the drop load and to the Number 2 rocket valve assembly safety pins on the rocket pack) were pulled, thus completely arming the rocket valve assemblies.

The probe assemblies, which during this time were being reeled out, were armed by means of two lanyards six feet long attached to the drop load and to the arming pins on the probes themselves. With these probe arming pins pulled, the PRADS system was then completely armed.

The system was allowed to descend under the retarding action of the main canopy drag forces. When the load reached the height of 28 feet above the ground, the probe contacted the ground and activated the ignition train system. The signal was transferred from the probe via the MDF assembly to the probe reelout assembly. The signal was then transferred from the probe reelout assembly to the rocket valve assembly by the CDF assembly. Activating the rocket valve assembly allowed compressed nitrogen gas to be ported to the rocket motor firing device causing the Northrop SK2000-1001 rockets to fire. The retroaction of these rockets allowed the load to descend gently to the ground.

Figure 194-1-1 depicts the test configuration

Refer to Figure 195-1-1 for a pictorial representation of the sequence of events for the test.

Test Results:

Basically this was a very good test. One major problem did occur, however. The probe stowage housing broke away from the drop load after release from the aircraft. It is believed that the mounting bolts for this unit had sustained fatigue damage in previous testing. Peak opening forces were reasonable. Opening times were acceptable.

Vertical impact velocity was 24 feet per second. Horizontal impact velocity was 6.5 feet per second.

Peak opening forces for each load attachment point as determined by the load cells are as follows:

Right front:	.93 G
Left front:	1.46 G
Right rear:	1.20 G
Left rear:	1.14 G

All loadings are based upon gross load weight. Event times taken from the first load motion are as follows:

Load clears ramp		.272 sec.
Extraction force transfer		.5[illegible] sec.
Line stretch		1.20 sec.
Canopy stretch		1.26 sec.
Full inflation of each parachute	1	2.22 sec.
	2	2.49 sec.

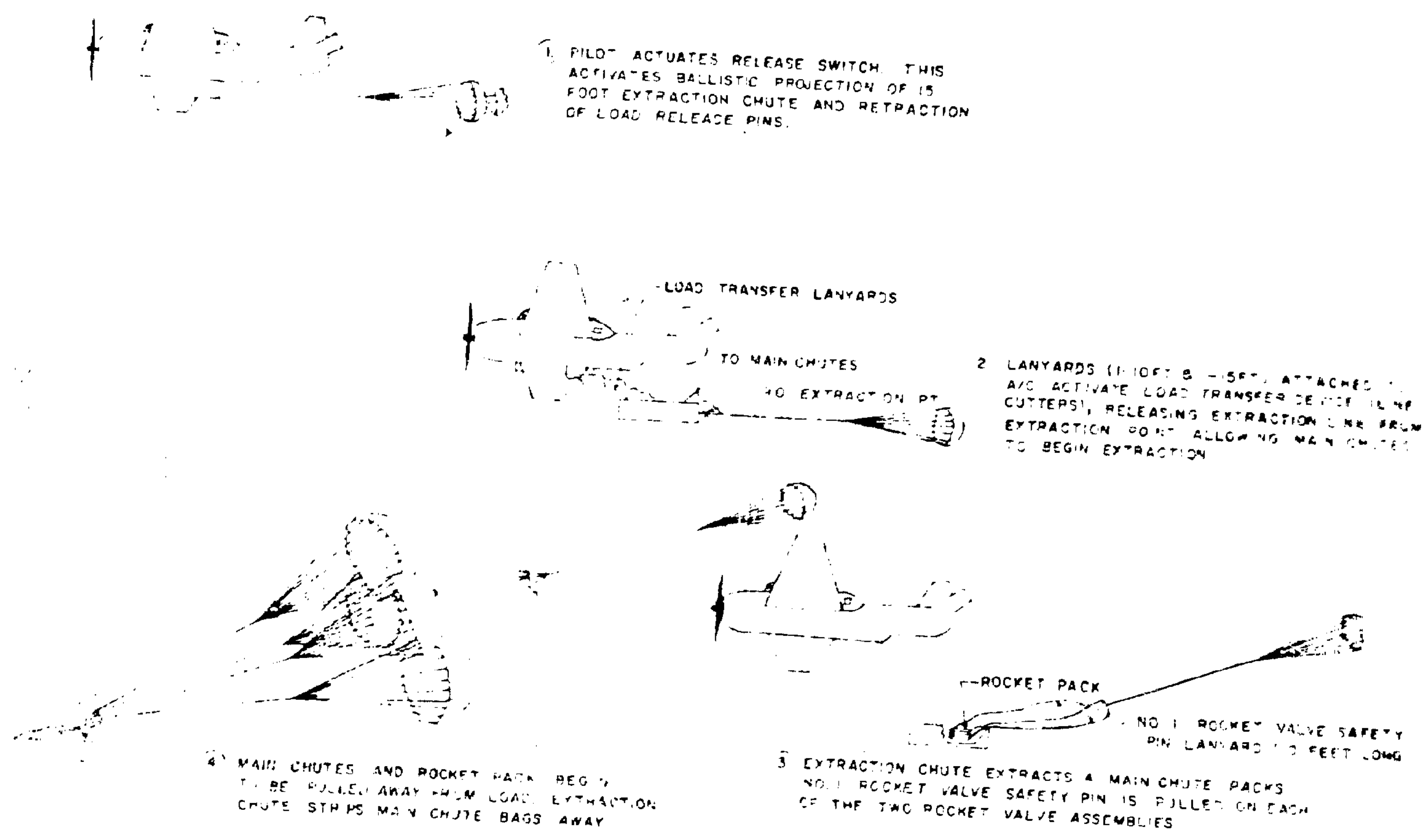


FIGURE 193-1-.
(SHEET 1 of 2)
TEST EVENT SEQUENCE

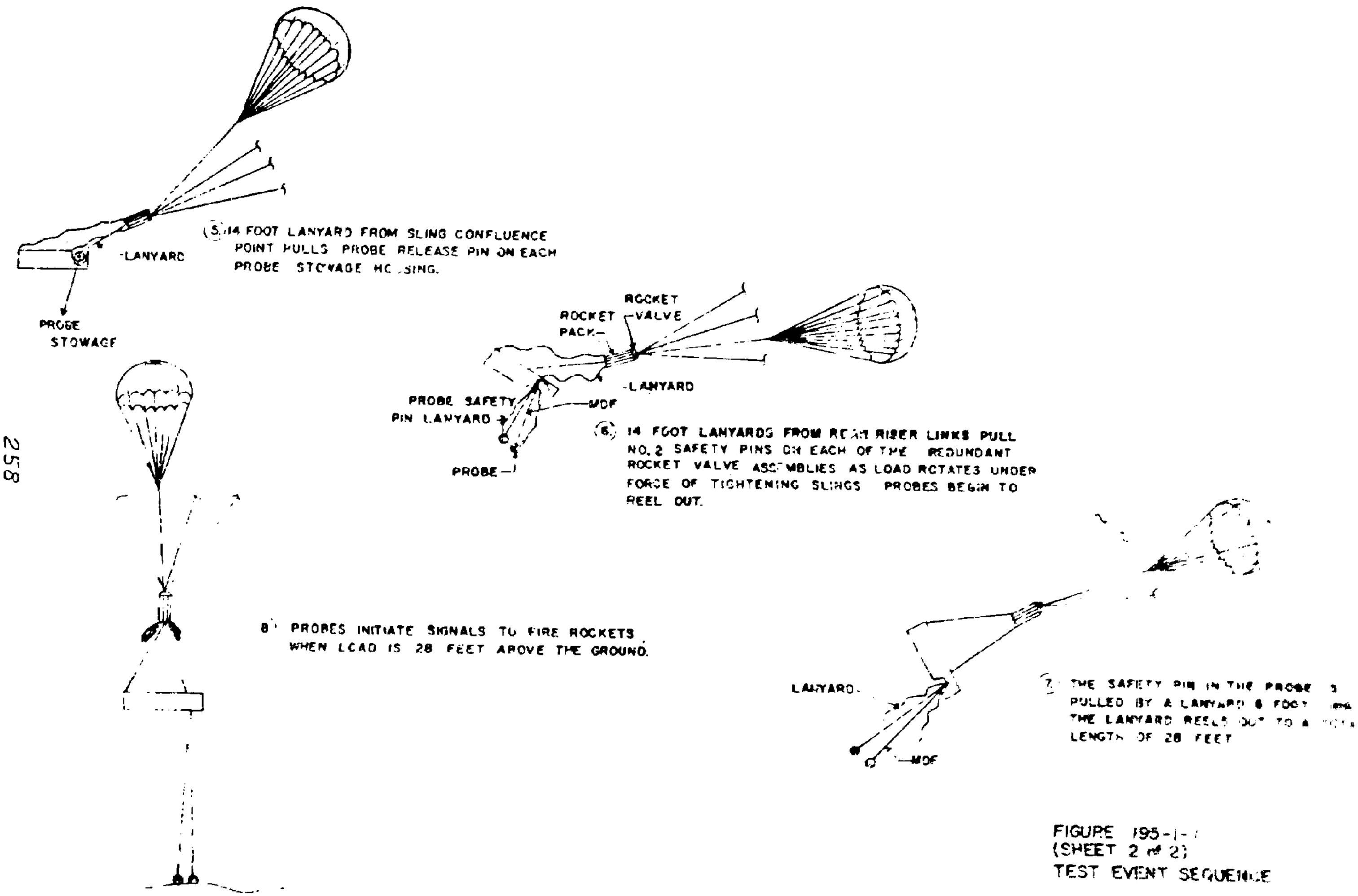


FIGURE 195-1-1
(SHEET 2 of 2)
TEST EVENT SEQUENCE

	3	2.55	sec.
	4	4.27	sec.
Average inflation		2.88	sec.
Probe release		1.77	sec.
Probe fully extended		2.79	sec.
1st probe impact		6.4	sec.
2nd probe impact		(broke)	
Rocket fire		6.44	sec.
Rocket burnout		6.97	sec.
Load impact		7.19	sec.

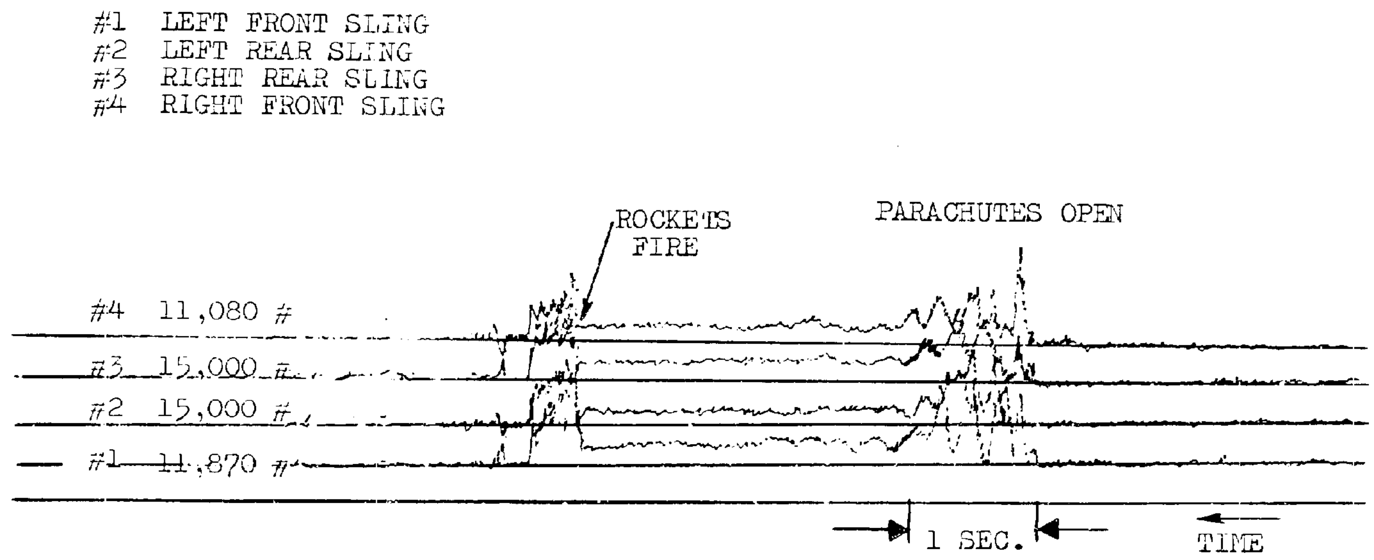
Stability was acceptable.

Figure 195-1-2 depicts the oscillograph traces of the load attachment forces vs. time. Figure 195-1-3 shows load angle versus time.

<u>Conclusions, Recommendations and Corrective Action:</u>

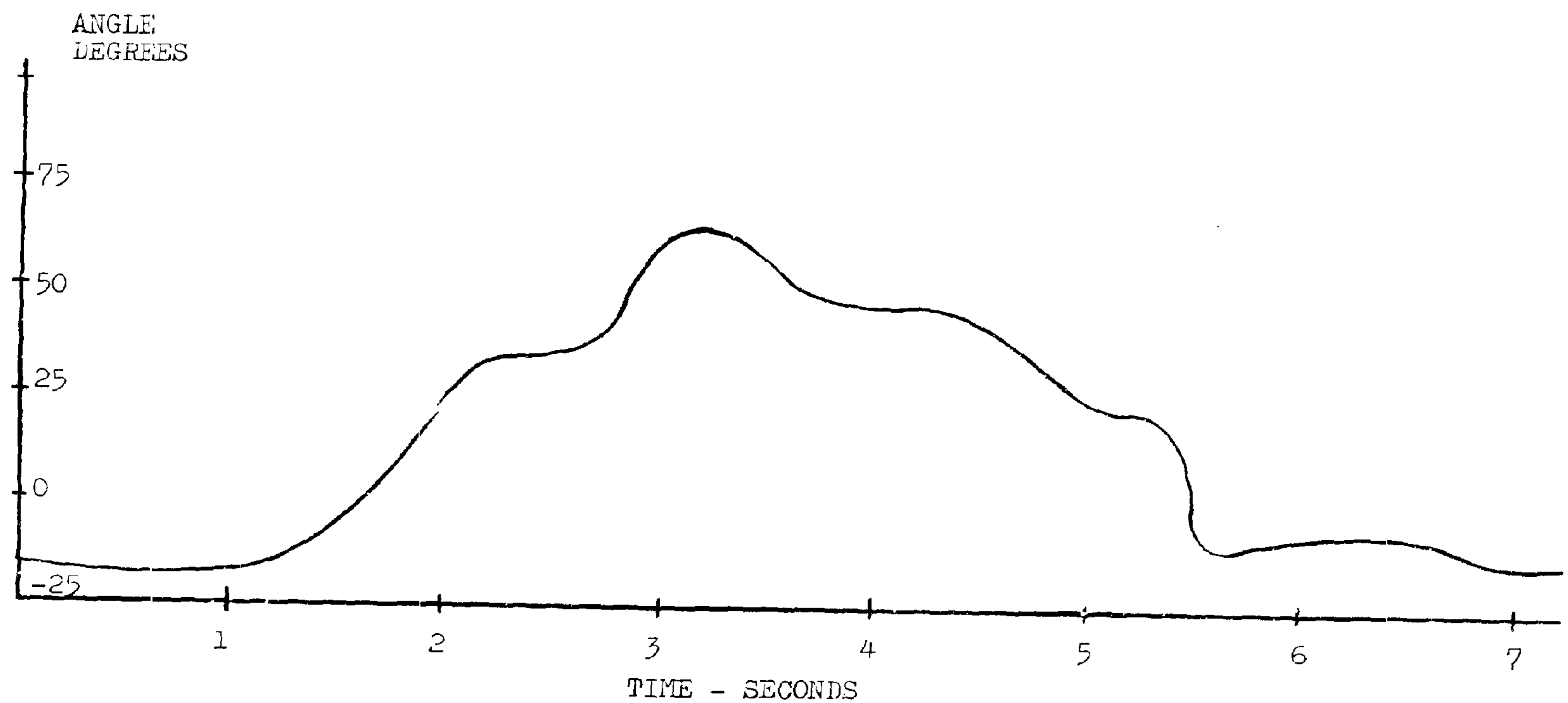
The PRADS system based on this test is concluded to be good.

It is recommended that the corrective action for the next test be the reinforcing of the probe stowage housing attachment to the drop load.



OSCILLOGRAPH TRACES OF LOAD
ATTACHMENT FORCES VS TIME
TEST NO. 195-1

Figure 195-1-2



LOAD ANGLE VS :F TEST NO. 195-1

Figure ·i-3

2.8 Test No.:

195-2

Type of Testing:

PRADS Full System Flight Test

Date of Testing:

14 March 1968

Purpose of Testing:

The purpose of the testing described herein was to continue to evaluate the complete PRADS System performance under airdrop conditions of 130 knots airspeed, to discover any system deficiencies, and to determine suitable corrective actions for the deficiencies.

Test Procedure:

This was a full system test using four Northrop SK2000-1001 rockets.

The test was performed with a drop load of 5120 lbs. gross weight.

The test configuration and operation were identical to test 195-1 except that the length of MDF reeled out was shortened from 28 feet to 27 feet.

Figure 194-1-1 depicts the test configura n.

Refer to Figure 195-1-1 for a pictorial representation of the sequence of events for this test.

Test Results:

This proved to be a most excellent test. No problems of any nature were encountered.

Vertical impact velocity was 28 feet per second. Horizontal velocity was 5.9 feet per second.

Peak opening forces for each load attachment point as determined by the load cells are:

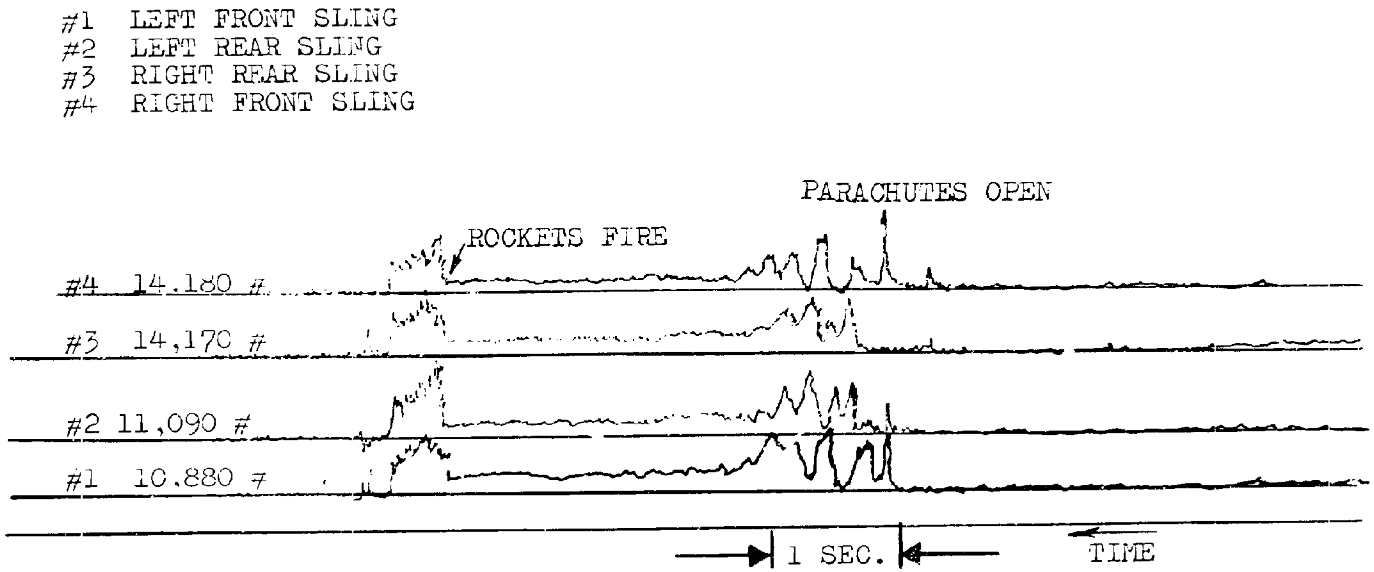
Right front:	1.22 G
Left front:	1.02 G
Right rear:	1.17 G
Left rear:	.82 G

All G loading is based upon gross load weight. Event times are taken from the first load motion and are as follows:

Load clears ramp		.375 sec.
Extraction force transfer		.545 sec.
Line stretch		1.38 sec.
Canopy stretch		1.485 sec.
Full inflation of each parachute	1	2.54 sec.
	2	2.88 sec.
	3	3.08 sec.
	4	3.84 sec.
Average inflation		3.08 sec.
1st probe release		2.16 sec.
2nd probe release		2.61 sec.
Probe full extended		3.23 sec.
1st probe impact		6.22 sec.
2nd probe impact		6.23 sec.
Rocket fire		6.24 sec.
Rocket burnout		6.79 sec.
Load impact		6.90 sec.

Stability was excellent.

Figure 195-2-1 depicts the oscillograph traces of the load attachment forces vs. time.



OSCILLOGRAPH TRACES OF LOAD
ATTACHMENT FORCES VS TIME
TEST NO. 195-2

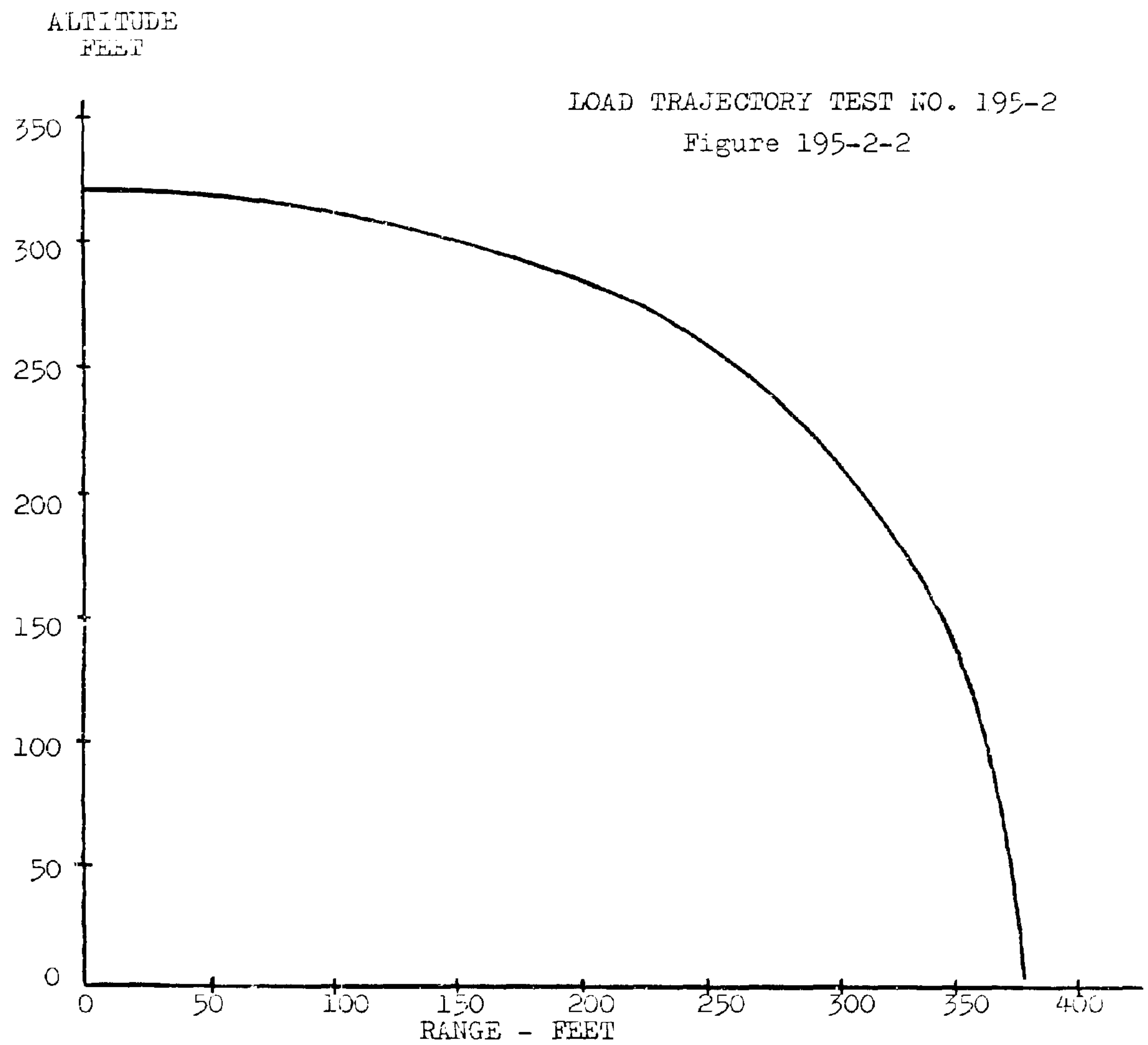
Figure 195-2-1

Figure 195-2-2 depicts the load trajectory.

<u>Conclusions, Recommendations and Corrective Action:</u>

This test proved to be excellent. No changes or corrective actions are recommended.

It is recommended for this load range that this exact configuration be accepted



LOAD TRAJECTORY TEST NO. 195-2

Figure 195-2-2

APPENDIX D

Parachute Retrorocket Airdrop System
System Flight Tests/NAF El Centro, California
Contract DAAG17-68-C-0019
U. S. Army Natick Laboratories
Test Nos. 202-1 thru 202-26

Prepared By: Richard R. Higgins
Project Test Engineer

Note: Typical data sheets are included; refer to complete test report for additional data.

TABLE OF CONTENTS

1.0 PURPOSE

1.1 System Flight Tests/NAF El Centro, California

The system flight tests/NAF El Centro, California were conducted to:

1) Demonstrate flight safety and compatibility of the PRADS with existing airdrop techniques.

2) Establish rigging procedures (general) for preparing various load configurations for airdrop.

3) Explore system stability characteristics during extraction, deployment, descent, and rocket burning.

4) Examine system hardware under field use.

5) Determine impact velocity.

6) Identify and recommend correction of any system oriented problems.

2.0 ADMINISTRATIVE DATA

2.1 General

All tests were conducted using a C-130 B or E model type aircraft and were released at requested airspeeds from 110 to 150 knots indicated airspeed, and at requested altitudes of 2000 to 500 feet absolute altitude. All tests were performed at the foothill drop zone of the Department of Defense joint parachute test facility, U. S. Naval Air Facility, El Centro, California.

2.2 Drop Test Load and Platform

The test load was a steel weight tub which could be ballasted to produce desired weight, CG location, and moment of inertia. One drop test was conducted using an actual Army vehicle. This was an M215

2 1/2 ton truck. Weight tubs were used from 8 to 22 feet in length, and the accompanying modular platform (type 2 siderails) was used in lengths from 8 to 24 feet.

2.3 Extraction Parachute and Extraction Line

The extraction hardware was furnished by the Air Force Flight Test Center, 6511th Test Group (Parachute) and was as near standard as flight safety permitted. The deviation from standard consisted of an open link safety device located between the extraction point disconnect and the confluence point of the recovery parachute deployment bridles. The open link safety device was locked after the load moved a preset distance by a static lanyard to the anchor line cable in the drop aircraft. Extraction force transfer was timed to occur as the forward end of the load cleared the aircraft ramp.

2.4 Cluster Parachute Hardware

2.4.1 Cluster parachutes tested were the 24 ft. D_O, 36 ft. D_O, and 46 ft. D_O, part number 1242410, 1363610, and 1464610 respectively. No major problems were observed in the performance of the cluster parachutes.

2.4.2 Riser adaptors were fabricated from type 26, 15,000 pound tensile strength webbing per Stencel Aero Engineering Corporation drawing SK409-0031. Problems were encountered with these risers because of two errors. The first problem occurred when type 19 webbing was used inadvertently, and resulted in tensile failure in drop test. The second problem was in the improper installation of chaffing strips, and this resulted in stitch failures at a low load level in drop test.

2.4.3 Parachute deployment bags tested were SK409-0018, SK409-0017, and SK409-0016, for the 24, 36, and 46 foot diameter parachutes respectively. The parachute deployment bags performed well in all tests but construction should be with heavier cloth to reduce wear and tear during extended use.

2.5 Description of Propellant and Cartridge Actuated Devices Used During Flight Testing

2.5.1 Rocket Initiation System

2.5.1.1 The firing system contained:

1. The ground sensing probe.

2. An M-47 percussion detonator.

3. A connecting piece of two grain/foot PETN mild detonating fuse (MDF).

4. An output primer containing one grain of PETN.

5. The MDF storage reel

6. An acceptor primer containing one grain of PETN.

7. A connecting length of two grain/foot confined detonating fuse (CDF)

8. An output primer containing one grain of PETN.

9. The gas valve (rocket valve assembly)

2.5.1.2 The firing system (MDF, CDF) and end primers were electrically shorted to preclude the possibility of accidental firing from static electricity or RF hazards.

2.5.1.3 The firing system also included mechanical safetys which:

1. Prevented the probe from firing until it had displaced six feet from it's protective housing.

2. Prevented arming of the gas valve until the load was cleared of the drop aircraft.

3. A self sealing vent which prevented a pressure buildup in the ignition pneumatic system in the event of small leaks into the manifold system.

2.5.1.4 One set of gas valve safety pins and the probe release pins were operated by lanyards arranged to pull as the load rear suspension slings become taut. This event occurs at about two seconds from aircraft ramp exit. Using a calculated separation velocity of 50 fps minimum, pulling these pins could not occur closer than 100 feet from the drop aircraft.

2.5.1.5 The second gas valve safety was pulled by an F-1B timer set at four or five seconds and armed by the deployment of the main parachutes.

2.5.1.6 Arming lanyards for all pins were stowed in storage bags. Payout was controlled so that the last stow out pulls the safety pin. If a lanyard fouled or snagged, arming was delayed until full lanyard deployment.

2.5.2 Components

2.5.2.1 M-47 Percussion Detonator

The M-47 detonator picks up the mechanical impact of the ground sensing probe and begins the initiation sequence. It was a standard Picatinny Arsenal detonator containing a percussion sensitive mixture and an output charge of RDX. Initiation requires an impact of 15 inch-ounces by a firing pin shaped in the form of a cone of 60 degrees included angle with a .012 inch flat on the tip. Assembly of the M-47 detonator in the system was in a Stencel Aero Engineering Corporation fabricated housing providing for support and a conductive epoxy bond to the unconfined MDF to assure an electrically shorted system.

2.5.2.2 Mild Detonating Fuse

The MDF used in the PRADS initiation system conforms to the Ensign-Bickford Company drawing number 213092. As fabricated for Stencel Aero Engineering Corporation the MDF unit consisted of a 28 to 30 foot length of two grains per foot PETN explosive and a 1.0 grain of PETN booster output primer assembled into an integral electrically shorted unit.

2.5.2.3. MDF Playout Brake

The brake acted as a storage and deployment controlling device; there were not explosives other than the MDF associated with the playout brake.

2.5.2.4 Confined Detonating Fuse

The CDF initiation system conforms to Ensign-Bickford Company drawing number 213093 or drawing number 213099 Revision B. Number 213093 was for use with a single rocket pack, 213099 Revision B was for use with tandem rocket packs. Each assembly as fabricated for Stencel Aero Engineering Corporation contained approximately 36 feet of two grain per foot PETN explosive and two or three booster primers of 1.0 grains PETN each. In the larger load ranges suspension sling length made it necessary to use an added eight foot section made up to Ensign-Bickford Company drawing number 213093. Further difficulty arose because of the lack of electrical continuity on part number 213099 Revision B. It was necessary to use a separate length of wire, 18 gauge copper stranded, to provide the desired electrical short between the load and the rocket pack.

2.5.2.5 Gas Valve Assembly

SK48-005-001 Revision A, or SK48-024-001 Revision A. The gas valve included a high pressure gas reservoir, a shuttle valve assembly, dual safety pins, and automatic or self sealing vent for minor leakage, and a booster primer energy source.

2.5.3 Rocket Motor Assembly SK2000-1001

The PRADS rocket motor was fabricated by Northrop-Carolina, Inc. to the conditions of Stencel Aero Engineering Corporation Specification 32.6 Rocket Motor Ground Proximity Aerial Delivery System. The propellant in the motor was type HE-X12. The motors were initiated by application of a minimum of 500 lbs. per square inch pneumatic pressure. The igniter proper contains dual primers which were fired by independent pneumatically driven firing pins. The propellant in the igniter was black powder of F_g granulation. Net explosive content of black powder plus the HE-X12 propellant was 11 lbs. per rocket motor.

2.5.3.1 Rocket Pack

Either the large or small Stencel Aero Engineering Corporation fabricated rocket pack contained mounting provisions for installing pairs of rockets. Interval manifolding of the initiator gas was performed by the rocket pack upper ring. The gas valve, reference Para. 2.5.2.5, mounted on the rocket pack, there were no other explosive devices used on the rocket pack. Figure 2-1 shows the large rocket pack being loaded with rocket motors.

2.5.4 Reefing Line Cutters

Reefing line cutters used on the PRADS program were the M-21A two second delay line cutters.

2.5.5 Ballistic System Safety Considerations

Past experience had been given full review and the system used reflected experience gained from the earlier program. Most significant was the design of an electrical short throughout the MDF and CDF ignition subsystem to eliminate spark gaps. This feature prevented ignition which might have otherwise occurred because of electrical discharge through the explosive. Additional protection was provided by using PETN explosive throughout since it is more resistant to ignition by electrical discharge than was the previously used lead azide. All explosive devices were safetied until after the load was clear of the drop aircraft. The referenced safety devices were naturally designed to withstand lock shut firing without failure. This prevented rocket motor ignition until the load was clear of the drop aircraft. Autoignition temperatures of various explosives used are tabulated: (Source AMCP-706-177)

LARGE ROCKET PACK
Figure 2-1

System	Explosive	Auto-Ignition Temp. °Fah.
MDF CDF	PETN	522° (After 0.1 sec.)
Rocket Motor	Black Powder	510° (After 0.1 sec.)
Rocket Motor	HE-X12	Above that of black powder

2.6 Instrumentation Requirements

The following instrumentation was required to support the PRADS test effort at El Centro. All instrument calibrations were maintained within specified calibration due dates, and further all instrument calibrations are traceable to the National Bureau of Standards (NBS).

2.6.1 Telemetry Package

A twelve channel capability was provided. Five channels of force data were measured. There were four events of time recorded. Either three rate gyros or three axis accelerometers occupied the other channels of telemetry.

2.6.2 Load Cells

Bonded strain gauge load cells were provided in 20,000 lb., 50,000 lb., and 100,000 lb. capacities. A minimum of five of each size load cell were required. A copy of the calibration record of each load cell is on file at NAF El Centro, California, with necessary cross referencing to provide traceability. The measurement accuracy was within ± 2 percent across the load range.

2.6.3 Time Measurements

Instrumentation support was required to obtain telemetry data on T_0 (time of drop initiation by pilot), T_1 (time of first load motion), T_2 (time of extraction force transfer), T_3 (time to load clears the drop aircraft ramp). In addition special instrumentation was needed to obtain the time of the rocket initiation gas valve arming.

This was provided by Stencel Aero Engineering Corporation and consisted of a power supply, microswitch and flash bulbs. This was used on inert system tests only.

2.6.4 Accelerometers

Accelerometers were required capable of measuring x, y, and z axis accelerations. The instrumentation provided was sensitive to acceleration from -5 g's to +10 g's ± 0.1 g, but was capable of withstanding normal platform impact accelerations.

2.6.5 Rate Measurement of Platform

The pitch, roll, and yaw of the platform had to be measured and for this it was necessary to have rate gyros, two each, capable of measurements of 300 degrees per second; and one each, capable of 50 degrees per second. The accuracy range was ± 2 1/2 degrees per second.

2.6.6 Space Positioning Data

A minimum of three cinetheodolites were available for each drop test to provide space positioning data.

2.6.7 Photographic Support

A minimum of the listed cameras were required to support the PRADS airdrops. Others were requested at the time of the drop if special consideration was warranted.

2.6.7.1 Plane to Air - 2 each 16 mm, 200 fps, color.

2.6.7.2 Ground to Air - 3 each 16 mm, 200 fps, color.

2.6.7.3 Ground to Air - 1 each 16 mm, 100 to 128 fps, black and white. The film for this camera was provided by Stencel Aero Engineering Corporation along with an exposure rating and was shipped immediately after each test by the resident Stencel Aero

Engineering Corporation project test engineer to Stencel to be developed.

2.6.7.4 Ground to Air - 1 each 70 mm, 10 to 30 fps, color.

2.6.7.5 Stills - 4 x 5 negative, color or black and white as requested.

2.7 Data Reduction

The following data was required. Tabular form was provided, where noted a graph was required.

Suspension Sling Force Right Front	TM/Oscillograph
Suspension Sling Force Right Rear	TM/Oscillograph
Suspension Sling Force Left Front	TM/Oscillograph
Suspension Sling Force Left Rear	TM/Oscillograph
Time of Drop Initiation by Pilot	TM/Oscillograph
Time of First Load Motion	TM/Oscillograph
Time of Load Clearing Ramp	TM/Oscillograph
Time of First Gas Valve Safety Pull	Time Reported Tabular
Time of Second Gas Valve Safety Pull	Time Reported Tabular
Time of Extraction Force Transfer	TM/Oscillograph
Time of Deployment Bags Clear Parachutes	Time Reported Tabular
Time of Each Parachute in Cluster to Full Open	Time Reported Tabular
Time of Rocket Initiation System Firing	Time Reported Tabular
Time of Rocket Ignition	Time Reported Tabular
Time of Ground Impact	Time Reported Tabular
Altitude versus Time	Graph
Rate of Descent versus Time	Graph
Total Velocity versus Time	Graph
Altitude versus Horizontal Dist.	Graph
Load Impact Attitude	
Load Impact Velocity	

2.8 Security Classification

Unclassified.

2.9 Dates of Testing

16 May 1968 to 27 February 1969.

2.10 Tests Conducted By

Personnel of Stencel Aero Engineering Corporation and the 6511th Test Group (Parachute) under the direction of Mr. Richard Higgins, Project Test Engineer, Stencel Aero Engineering Corporation; and Mr. Marvin Tingdahl, Project Engineer, United States Air Force.

3.0 TEST PROGRAM DESCRIPTION

3.1 General

The test effort on Phase 202 was originally scheduled for 27 tests to be performed at the Naval Air Facility, El Centro, California. The program was to include three parachute only tests, seven inert system flight tests for establishing flight safety, and seventeen live rocket system tests to demonstrate system operation. The weight range tested on this program was 3550 lbs. to 4500 lbs. for the parachute only system, and from 7500 lbs to 35,000 lbs. for the retrorocket system. The test effort closely followed the proposed program. In all three parachute only tests were conducted, twelve inert system tests were conducted, and eleven live rocket system tests were conducted. Varied conditions were: airspeed, altitude, load weight, load position in the aircraft, extracting force, and size and number of parachutes in the recovery/stabilization cluster.

3.2 Test Support

This report covers the test effort conducted on the PRADS program at NAF El Centro, California. The test program was supported by a Stencel Aero Engineering Corporation project test engineer and two technicians, and by the United States Air Force 6511th Test Group (Parachute). Stencel Aero Engineering Corporation's support of the test program consisted of, but was not limited to, providing system hardware and software, the maintenance of system hardware, and by supervising the packing rigging and performance of each test drop. The 6511th's support of the program included, but was not limited to, an Air Force assigned project engineer, technicians as required to pack parachutes, rig the platform, and install instrumentation Facilities and equipment support included office space, parachute packing area, load rigging area, explosive storage and assembly area, data acquisition, data reduction, drop loads, drop load handling and recovery and a C-130 type drop aircraft.

4.0 TEST DATA SUMMARY

General

The following section contains a test by test description. Table 1 includes a description of individual test conditions and a brief summary of test results.

CONTRACT NO. DAAG 17-68-C-0019

PRADS DATA SUMMARY

STENCEL AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

TEST NUMBER SAEC / AF DROP NO.	DATE	FLIGHT PARAMETERS				DROP LOAD TEST CONDITIONS					LOAD EXTRACTION DATA						SUSPENSION SLING DATA								ROCKET SY[STEM]			
																	FRONT				REAR							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
202-1 1003 F	16 MAY 1968	C-130 S/N 358	1000/955	130/141	5/350°	3550	3150	8' TUB 8'	48"	46.2"	15' R W 260°	60' 2 PLY	*	*	*	11.66	6 PLY TYPE I	X	*	11.66	6 PLY TYPE I	X	*				
202-2 1048 F	20 MAY 1968	C-130 S/N 358	500/563	130/141.5	2/210°	3550	3150	8' TUB 8'	48"	33.75"	"	"	1.0/3550	1.395	1.489	"	"	1.29/4500	1.11/3900	"	"	1.17/4100	1.17/4100				
202-3 1049 F	17 JUNE 1968	C-130 S/N 358	500/524	130/134	3/040°	4500	3900	8' TUB 12'	72"	43.33	15'	"	1.25/5625	850	870	"	"	.80/3540	.885/3990	"	"	1.13/5080	.88/3990				
202-4 1052 F	25 JULY 1968	C-130 S/N 525	500/319	110/109.5	6/210°	7500	6900	11¾' TUB 16'	96"	41.5	15'	"	.56/4200	2.297	2.319	15.66	"	1.3/9800	1.57/11900	15.66	"	1.50/11250	1.52/11400	INERT	8	—	26
202-5 1255 F	30 JULY 1968	C-130 S/N 525	500/380	150/160	2/270°	7500	6900	11¾' TUB 16'	96"	34.83	15'	"	.98/7375	677	.731	"	"	1.46/11000	1.58/11950	"	–	1.30/9800	1.21/9500	"	8	—	26
202-6 1534 F	6 AUG 1968	C-130 S/N 358	2000/2087	130/135	4/140°	7500	6900	11¾' TUB 16'	96"	37.17	15'	"	.69/5200	1.940	1.951	"	"	1.56/11750	1.67/12600	"	"	1.16/8750	—	SK 2000 1001	8	8 SEE REMARKS	26
202-7 1800 F	26 AUG 1968	C-130 S/N 525	500/428	130/135	3/040°	14100	13000	22' TUB 24'	139"	36.83	22'	60' 6 PLY	.73/10250	1.956	2.133	24	"	.62/9800	.74/10400	24	"	.81/11500	.80/11300	INERT	LARGE DUMMY PACK	—	26
202-8 1820 F	5 SEPT 1968	C-130 S/N 358	500/504	130/139	3/090°	14100	13000	22' TUB 24'	139"	41.23	22'	60' 6 PLY	.72/10200	1.910	1.918	24	"	.98/13800	.92/12900	24	"	.78/11000	1.13/16000	INERT	"	—	26
202-9 1996 F	11 SEPT 1968	C-130 S/N 358	500/336	130/138.5	6/120°	18190	16990	22' TUB 24'	151"	41.33	28'	60' 8 PLY	1.18/21500			24	8 PLY TYPE XXVI	.92/16800	.98/17800	24	8 PLY TYPE XXVI	.95/17300	.81/14700	INERT	"	—	26
202-10 1923 F	16 SEPT 1968	C-130 S/N 525	2000/2085	130/137	4/360°	7500	6900	11¾' TUB 16'	96"	37.3"	15'	60' 2 PLY	.76/5680	1.737	1.701	15.66	6 PLY TYPE X	.68 1.36 5100 10160	.81 1.40 6.00 10500	15.66	6 PLY TYPE X	.90 1.87 6720 14000	1.34 1.95 6040 14600	SK 2000 1001	8	8	26

PRADS DATA SUMMARY

TEST SERIES 202

TABLE I

AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

SHEET 1 OF 2

[illegible] DATA			ROCKET SYSTEM DATA						CLUSTER PARACHUTE DATA			
Type Slings	REAR RR ε, Δ m	C.F. Δ m	Type of Rockets	No. Used	No. Fired	MT Lg. Feet (Reelout)	[illegible]	Rocket Pack & Gas Valve Data Sys. #1/#2	No. Used	Nom. Dia. Feet	Reefed Dia. Feet	Reefing Cutter Time Lag Sec.
20	21	22	23	24	25	26	27	28	29	30	31	32
4 PLY TYPE I	*	*	—	—	—	—	—	—	4	46	23.8	2
	1.17/4100	1.17/4100	—	—	—	—	—	—	4	46	23.8	2
	1.15/3900	885/3940	—	—	—	—	—	—	6	46	23.8	2
	1.50/11250	1.52/11400	INERT	8	—	26	#1 OK / #2 OK	#1 OK / #2 OK	6	24	—	—
"	1.30/9800	1.20/9500	"	8	"	26	#1 OK / #2 NO FIRE SEE REMARKS	#1 OK / #2 NO FIRE SEE REMARKS	6	24	—	—
"	1.16/8750	—	5K 2000 1001	8	8 SEE REMARKS	26	#1 OK / #2 NO FIRE SEE REMARKS	#1 OK / #2 NO FIRE SEE REMARKS	6	24	—	—
	81/11500	80/11300	INERT	LARGE DUMMY PACK		26	#1 OK / #2 OK	#1 OK / #2 OK	5	36	20.2	2
	78/11000	1.15/16000	INERT	[illegible]	—	26	#1 OK / #2 OK	#1 OK / #2 OK	5	36	20.2	2
4 PLY TYPE XX	95/2500	81/1470	INERT		—	26	#1 OK / #2 OK	#1 OK / #2 OK	7	36	—	—
4 PLY TYPE X	90/97/4120/4000	1.34/1.95/6040/14600	5K 2000 1001	8	8	26	#1 OK / #2 OK	#1 OK / #2 OK	6	24	—	—

CLUSTER PARACHUTE DATA			Time to Inflation — seconds											IMPACT DATA				REMARKS & CONCLUSIONS
Parachute Type	Riser Lg.	Riser Type	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	Ave. Inflation	V. Prior to Ign. fps	Ver Imp. V fps	Horiz. Imp. V fps	Platform Angle Imp.	
33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
FC	45	4 PLY TYPE I	7.506	8.206	8.806	10.506	—	—	—	—	—	—	8756	NA	18	7.8		* NO DATA
FC	45	"	7.442	7.734	8.329	12.247	—	—	—	—	—	—	8.938	NA	24.6	15.6		
FC	65	"	8.620	8.820	9.420	10.420	10.620	—	—	—	—	—	9.75	NA	20.0	13.1		
FC	37	"	7.302	7.589	7.639	7.657	7.726	8.619	—	—	—	—	7.622	65.7	62	13		
FC	37	"	5.822	6.230	6.319	7.347	—	—	—	—	—	—	9.20	62.9	62	13.9		BENCH TESTING PROVED THAT OIL EXPANSION IN THE HEAT 100-110° F HERE COMPARED TO FILL TEMP 68-75° F WAS LOCKING THE SAFETY PIN IN PLACE PROBES WERE BLED
FC	37	"	6.650	7.453	7.470	7.693	7741	7775	—	—	—	—	7.467	59.4	59.4	14.4		MOTOR # 366 HAD AN IMPROPERLY INSTALLED RETAINING RING, THE HEAD END FAILED AND CAUSED PACK FAILURE. ALL 8 MOTORS CAME FREE. ARMING LANYARD FOULED PISTON, TORE BAG CUT PROBE NOT ARMED
FC	45	"	6.976	7.343	7.633	7.890	8.090	—	—	—	—	—	7.586	57	57	17.6		
IC	37	"	7.210	7.410	7.410	9.910	8.810	—	—	—	—	—	7.890	51	5	10		
FC	45	"	7.174	7.220	7.475	8.895	9.095	9.095	—	—	—	—	8.29	63	63	14	10°-20°	EXCESSIVE ANGLE AT IMPACT
FC	37	"	6.108	6.867	6.989	7.402	7.747	8.637	—	—	—	—	7.291	62	19	6.9	0	FUNCTIONED AS DESIGNED, ROCKET PACK DAMAGED AT LOAD/PACK COLLISION AT IMPACT. FIELD REPAIR C° LOWER RING WAS POSSIBLE.

** TM CHANNELS NOT PROPERLY IDENTIFIED.

a

CONTRACT NO. DAAG 17-68-C-0019

PRADS DATA SUMMARY

STENCEL AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

TEST NUMBER SAEC / AF DROP NO.	DATE	1 Type Acft.	2 Rel. Alt./Alt. Act	3 Rel. Vel./V. Act	4 Grd. Wind (knots)	5 Load Wt. (Gross) lbs.	6 Load Wt. (Susp.) lbs.	7 Type Load Length	8 CG location in. fr. F.S.	9 Pos. of load in acft.	10 Ext. Para. Chute Dia.	11 Ext. Line Ply & Type	12 Max. F.	13 First Motion to Load clear ramp (sec.)	14 First Motion to Ext. trans. (sec.)	15 Lg. (feet)	16 Type Slings	17 MP F. G	18 LF F. G	19 Lg. (feet)	20 Type Slings	21 MP F. G	22 LF F. G	23 Type of Rockets	24 No. Used	25 No. Fired	26 MDF Lg. Feet	27	28
		FLIGHT PARAMETERS				DROP LOAD TEST CONDITIONS					LOAD EXTRACTION DATA					SUSPENSION SLING DATA FRONT				SUSPENSION SLING DATA REAR				ROCKET SYSTEM DATA					
202-11 1998 F	19 SEPT. 1968	C-130 S/N 358	2000/ 1947	130/ 139	8 240°	7500	6900	11½' TUB 16'	96"	40.5	15	60 2 PLY X	.78 5840	2.001	1.975	15.75	6 PLY X	1.14 1.37 8575 10250	1.26 1.71 9420 12800	15.75	6 PLY X	.88 2.01 6600 15100	.80 1.90 6000 14240	SK 2000 1001	8	8	26	#1 OK #2 OK	#1 OK #2 OK
202-12 2061 F	26 SEPT 1968	C-130 S/N 358	500/ 514	130/ 143	3 360°	7500	6900	11½' TUB 16'	96"	41.5	15	60 2 PLY X	.75 5490	2.528	2.513	15.75	6 PLY X	.71 1.41 5300 10060	.96 1.60 7220 12000	15.75	6 PLY X	1.03 1.91 7720 14330	N.D.	SK 2000 1001	8	8	26	#1 OK #2 OK	#1 OK #2 OK
202-13 2065 F	1 OCT 1968	C-130 S/N 358	500/ 512	130/ 138	5 100°	18500	17300	22' TUB 24'	151"	40.5	28	60 8 PLY X	1.16 21400	1.529	1.477	24	8 PLY XXVI	.93 17250	1.00 18500	24	8 PLY XXVI	1.15 21250	.98 18000	INERT	---	---	26	#1 OK #2 OK	#1 NO FIRE #2 OK
202-14 2101 F	15 OCT 1968	C-130 S/N 358	500/ 539	130/ 148	12 360°	14100	12560	22' TUB 24	139"	38.33	22	60 6 PLY X	.78 11033	1.817		24	8 PLY XXVI	1.99 2.22 28000 31200	2.27 1.86 32000 26250	24	8 PLY XXVI	1.41 1.74 19900 24500	1.23 1.79 17300 25310	SK 2000 1001	14	14	26	#1 OK #2 OK	#1 OK #2 NO FIRE
202-15 2184 F	24 OCT 1968	C-130 S/N 358	1000/ —	130/ —	2 170°	24000	21400	22' TUB 24'	117"	38.75	28	60 8 PLY X	—	NOT AVAILABLE DROPPED 20-30 SEC. EARLY		24	10 PLY X	.88 20850	.91 19500	24	10 PLY X	.62 14800	.74 18000	INERT	—	—	26	#1 OK 2 SEC DELAY RELEASE #2 OK	#1 OK #2 SEE REMARKS
202-16 2255 F	30 OCT 1968	C-130 S/N 358	500/ 430	130/ 139.5	3 180°	5480	5100	8' TUB 12'	72"	40.5	15	60 2 PLY X	.97 5325			12.75	6 PLY X	1.28 7000	.91 5000	12.75	6 PLY X	1.87 10250	1.46 8000	INERT	—	—	26	#1 SEE REMARKS #2 OK	NOT USED
202-17 2247 F	7 NOV 1968	C-130 S/N 358	500/ 526	130/ 139.5	5 350°	24000	21400	22' TUB 24'	117"	42	28	60 8 PLY X	.53 22250			22	6 PLY XXVI	.96 23000	.96 23000	22	6 PLY XXVI	.96 23000	.96 22900	INERT	—	—	28	#1 OK #2 OK	#1 OK #2 OK
202-18 2424 F	5 DEC 1968	C-130 S/N 358	600/ 570	137/ 141.5	4 030°	35000	32300	22' TUB 24'	138"	43.75	28 (2)	60 12 PLY XXVI	.94 33000			25	8 PLY XXVI DUAL	1.00 35000	1.13 39500	25	8 PLY XXVI DUAL	.74 26000	.66 23000	INERT	—	—	28	#1 OK #2 OK	FIRED TO COF CONNECTING MECH FAILURE AT THIS PT
202-19 2544 F	10 DEC 1968	C-130 S/N 358	500/ 523	130/ 140	4 270°	14100	12560	22' TUB 24'	139"	43	22	60 6 PLY X	.78 11000			24	8 PLY X	2.34 33100 .93 27750	2.8 34800 2.04 28750	24	8 PLY X	1.29 18250 .82 2500	1.42 20000 1.55 21875	SK 2000 1001	14	14	28	#1 OK #2 OK	#1 OK #2 OK
202-20 2601 F	16 DEC 1968	C-130 S/N 358	600/ 646	137/ 150.5	9 240°	35000	32300	22' TUB 24'	138"	41.2'	28 (2)	60 12 PLY XXVI	.99 34700			25	8 PLY XXVI	1.03 35900	.92 32000	25	8 PLY XXVI DUAL	.80 28000	.87 30500	INERT	—	—	28	#1 OK #2 OK	#1 OK #2 [illegible]

CONTRACT NO. DAAG 17-68-C-0019

PRADS DATA SUMMARY

STENCEL AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

TEST NUMBER SAEC / AF DROP NO.	DATE	1 Type Acft.	2 Rel. Alt./Alt. Act	3 Rel. Vel./V. Act	4 Grd. Wind (knots)	5 Load Wt. (Gross)	6 Load Wt. (Susp.)	7 Type Load Length	8 CG location	9 Pos. of load in acft.	10 Ext. Para. Chute Dia.	11 Ext. Line Ply & Type	12 Max. F.	13	14	15 Lg. (feet)	16 Type Slings	17 MP F. G	18 LF F. G	19 Lg. (feet)	20 Type Slings	21 MP F. G	22 LF F. G	23 Type of Rockets	24 No. Used	25 No. Fired	26 MDF Lg. Feet	27	28
		FLIGHT PARAMETERS				DROP LOAD TEST CONDITIONS					LOAD EXTRACTION DATA					SUSPENSION SLING DATA FRONT				SUSPENSION SLING DATA REAR				ROCKET SYSTEM DATA					
202-21 2587 F	19 DEC 1968	C-130 S/N 358	500/ 436	130/ 122.5	5 080°	18500	16000	22' TUB 24'	151	41'-3"	28	60 8 PLY X	1.1 20250			24	8 PLY XXVI	1.34 24800 1.55 28600	1.27 23500 28000	24	8 PLY XXVI	1.23 22800	1.15 21250 1.53 28250	SK 2000 1001	18	18	28	#1 OK #2 OK	#1 OK #2 OK #3 OK #4 OK
202-22 2609 F	27 DEC 1968	C-130 S/N 358	500/ 473	130/ 129	CALM	24000	21200	22' TUB 24'	117	43'-3"	28	60 8 PLY X	.77 18400			24	8 PLY XXVI	.96 23000 1.55 37250	1.05 25250 1.75 42000	24	8 PLY XXVI	1.04 25100 1.08 26000	1.06 25400 1.03 23600	SK 2000 1001	24	24	28	#1 OK #2 OK	#1 OK #2 OK #3 OK #4 OK
202-23 2623 F	2 JAN 1969	C-130 S/N 358	500/ 442	137/ 138.5	4 300°	35K	32.7K	22' TUB 24'	138	41'-3"	28 (2)	60 8 PLY XXVI	.96 33500			24	8 PLY XXVI DUAL	.91 31800 1.92 67200	1.01 35300 2.24 78800	24	8 PLY XXVI DUAL	.83 29000 1.25 43750	.83 28500 1.24 43250	SK 2000 1001	32	32	28	#1 OK #2 OK	#1 OK #2 OK #3 OK #4 OK
202-24 0003 F	8 JAN 1969	C-130 S/N 358	500/ 450	130/ 130	CALM	14000	12900	22' TUB 24	139	39'-1"	22	60 6 PLY X	.78 11000			24	8 PLY X	.76 11150	.89 12400	24	8 PLY X	.95 13400	1.38 19300	INERT	—			LASER GOOD PERFORMANCE	
202-25 0092 F	14 FEB 1969	C-130 S/N 358	500/ 596	130/ 134.5	9 230°	18600	16780	2½ TON TRUCK 24'	144	41'-3"	28	60 8 PLY X	1.03 19120			22	6 PLY XXVI	.87 16250 1.09 20250	.86 16000 1.02 19000	19	8 PLY X	.95 17650 2.15 39950	.94 17500 2.15 39900	SK 2000 1001	18	18	28	#1 OK #2 OK	#1 OK #2 OK
202-26 0063 F	27 FEB 1969	C-130 S/N 358	600/ 624	137/ 138.5	CALM	35000	31620	22' TUB 24'	138	41'-3"	28 (2)	60 8 PLY XXVI	.77 27000			25	8 PLY XXVI DUAL	.93 32500 1.42 49800	1.03 36000 1.42 49800	25	8 PLY XXVI DUAL	1.00 35000 .98 33600	.78 27250 1.00 35000	SK 2000 1001	32	32	28	#1 OK #2 OK	[illegible]

PRADS DATA SUMMARY

TEST SERIES 202

TABLE I

SHEET 2 OF 3

NCEL AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36–45 Time to inflation — seconds	46	47	48	49	50	51 REMARKS & CONCLUSIONS
15.75	6 PLY X	.88 2.01 6600 .0100	.80 1.90 6000 .14240	SK 2000 1001	8	8	26	#1 OK #2 OK	#1 OK #2 OK	6	24	—	—	FC	37	4 PLY X	6.505 6.968 7.018 7.156 7.413 8.613	7.452	65	11	13	12.5°	FUNCTIONED AS DESIGNED, NO PROBLEMS. ROCKET PACK RECEIVED MINOR DAMAGE AT IMPACT.
15.75	6 PLY X	1.03 1.91 7720 4330	NO	SK 2000 1001	8	8	26	#1 OK #2 OK	#1 OK #2 OK	6	24	—	—	FC	37	4 PLY X	6.953 7.088 7.521 7.550 7.641 9.031	7.589	62	11	7	5°	FUNCTIONED AS DESIGNED NO PROBLEMS. RUCKET PACK HAD 2 THICKNESSES OF EA. CARDBOARD NO DAMAGE OCCURED AT LOAD/ PACK [illegible]
24	8 PLY XXII	1.5 21250	9F 18000	INERT	—	—	26	#1 OK #2 OK	#1 NO FIRE #2 OK	7	46			FC	45	4 PLY X	6.747 7.147 7.347 7.747 7.747 7.947 8.947	7.690		59.2	18		GOOD DROP ONE CDF TRAIN BROKEN OR CUT DURING DEPLOYMENT OR DESCENT
24	8 PLY XXII	1.41 .74 19400 24500	1.22 1.79 17300 25500	SK 2000 1001	4	4	26	#1 OK #2 OK	#1 OK #2 NO FIRE		46			FC	37	4 PLY X	6.517 6.419 6.955 8.010 8.422	7.228	60	42	35	13°	PROBE OSCILLATION RESULTED IN FIRING LATE ONLY 3-4 FEET ABOVE GROUND—RECOMMEND DELAY RELEASE OF PROBES. TENSILE FAILURE OF CDF
24	10 PLY X	62 14800	75 18000	INERT	—	—	26	#1 OK 2 SEC. DELAY RELEASE #2 OK	#1 OK #2 SEE REMARKS	6	46			FC	53	6PLY X	NO RELIABLE ASKANIA DATA						CDF TENSILE FAILURE AT LOWER ROCKET PACK—FIRED TO THIS POINT LOAD DROP ABOUT 20 SEC. EARLY APPARENT MALFUNCTION OF EXT P/C RELEASE
22.75	6 PLY X	1.87 10250	1.46 8200	INERT	—	—	26	#1 SEE REMARKS #2 OK	NOT USED		46	—	—	FC	8	6 PLY X	5.107	5.307		58.8	21		THIS PROBE HAD 2 SEC DELAY ON RELEASE ALL MDF WAS RECOVERED LEAD SHIELDING CRIMPED JUST OUT OF CLAMP-CAUSED BY PROBE FREE TO TURN IN HOUSING
22	8 PLY XXII	96 23000	96 22400	INERT	—	—	26	#1 OK #2 OK	#1 OK #2 OK	5	46		—	FC	53	6 PLY X	7.104 7.604 7.902 8.000 8.202	7.78		48.7	18		PROBES BOTH ABOUT 3' AFT OF PLATFORM 1 NORMAL REL., OTHER 2 SEC. DELAYED REL.
24	8 PLY XXII	1.4 25000	66 23000	INERT	—	—	26	#1 OK #2 OK	FIRED TOP CDF [illegible] OF THIS PT	7	46	24	2	FC	53	6 PLY X	7.516 7.916 8.316 8.716 8.716 10.116	8.87		77.1	1.8		* SOME SMALL AMOUNT OF MDF FIRED ON REEL, INDICATED BY SEEMING EXCESS OF DEBRIS IN REEL THREE PARACHUTES BROKE AWAY FROM THE LOAD, # 1 & 2 FAILED RISER ADAPTERS, # 3 FAILED RISER EXTENSION
24	X	4210 2500	2000 2875	SK 2000 1001	3	3	28	#1 OK #2 OK	#1 OK #2 OK		46	—		FC	45	6 PLY X	7.589 7.607 7.698	7.631	54	17	0	18°	GOOD TEST
	XXII	25000	505	INERT	—	—	28	#1 OK #2 OK	#1 OK #2 OK	7	46	24	2	FC	53	6 PLY X	7.810 8.016 8.112 8.615 [illegible]	8.57		55.4	2.0		1 PARACHUTE BROKE AWAY OTHERWISE A GOOD DROP.

PRADS DATA SUMMARY

TEST SERIES 202

TABLE I

SHEET 3 OF 3

[illegible] AERO ENGINEERING CORPORATION
ASHEVILLE, NORTH CAROLINA

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36–45 Time to inflation — seconds	46	47	48	49	50	51 REMARKS & CONCLUSIONS
24	8 PLY XXII	22800	25000	SK 2000 1001	8	8	28	[illegible]	[illegible]	4	46	—	—	FC	45	6 PLY X	7.165 7.470 7.678 8.164	7.67	54	27	19.7	0	EXCELLENT DROP TANDEM ROCKET PACKS, 8 MOTORS PER PACK. ONLY 2 BROKEN BRACKETS ON ROCKET PACKS.
24	8 PLY XXII	25000 1.08 25000	25000 1.03 21600	2000 1001	24	24	28	[illegible]	[illegible]		46		—	FC	53	6 PLY X	7.898 7.557 8.167 8.150 8.900	8.45	60	17	22.5	10	* F1-8 TIMER DID NOT BREAK WAX CORD (1 TURN # 35 LB) VALVE COULD NOT OPERATE BOTH PACKS FIRED GOOD DROP
	XXII	[illegible]	[illegible]				28	[illegible]	[illegible]		46	24	2	FC	53	6 PLY X	7.438 7.538 8.138 8.438 8.838 9.038	8.38	65	45	6.0	30°±	* MDF NOT ALL OUT ON SYSTEM WITH TIMER CUT ITSELF OFF IN BRAKE. 2 P/C BROKE AWAY, 1 RISER, 1 RISER ADAPTER LOAD HIT AT HIGH ANGLE 40 % BURNING AFTER IMPACT OVERTURNED LOAD.
	X	[illegible]	[illegible]			2 SEC		[illegible]			46			FC	45	6 PLY X	7.334 8.097 8.097	7.90		48.6	20.7		SPECIAL 16 FT. FS ANTI-OSCILLATION P/C USED—LOCATED 8' ABOVE ROCKET PACK, USING ONE CLUSTER RISER AS ℄.
	X	[illegible]	[illegible]					[illegible]			46			FC	45	6 PLY X	6.784 7.013 7.672 7.946 * BROKE AWAY AT 6.827	7.30	67	41	5.2	—	# 215 2½ TON 6X6 PER TM 10-500-47-5, 1 P/C FULL OPEN, RISER FAILED. IGNITION OK, TRUCK FRAME FAILED AT IGNITION. TRUCK IMPACTED NOSE DOWN, TEST VEHICLE DESTROYED.
	XXII	[illegible]	[illegible]					[illegible]			46	24	2	FC	53	6 PLY XXII	[illegible]	9.58	53	20	1	16	* TIMER F1A, SET AT 5 SEC, RAN FOR 2½ SEC AND STOPPED. GOOD DROP FIRE AFTER DROP BURNED ALL E.A. CARDBOARD, STRAW LINK WIRING, SUS SLINGS, ONE RISER & OTHER FIRE DAMAGE

4.1 Test No.:

SAEC 202-1, Air Force 1003-F-68

Test Date:

16 May 1968

Purpose:

202-1 was a parachute only system test of a 3500 lb. gross rigged weight load performed to demonstrate the performance of parachute only configuration.

Conditions and Procedures:

The test load weighed 3550 lbs. gross rigged weight. The suspended or recovered load weighed 3150 lbs. The requested release altitude and airspeed were 1000 ft. absolute, and 130 knots indicated airspeed. Actual release altitude and airspeed were 953 ft. absolute and 141 knots indicated airspeed. The eight foot test load was mounted on an eight foot modular platform and was extracted from the aircraft by a 15 foot ringslot extraction parachute reefed with a 260 inch long permanent reefing line. During extraction, and after a predetermined amount of load movement an open link safety device was locked by a static lanyard tied off to the anchor line cable in the C-130 drop aircraft. As the front end of the load was exiting the ramp of the drop aircraft extraction force transfer was triggered. After extraction force transfer four, 46 foot D_0 parachutes with 45 foot long cluster risers were conventionally deployed. The extraction parachute was not retained. In this test, the cluster parachutes were reefed to 23.8 feet diameter. Disreefing was by two M-21A two second delay reefing line cutters per parachutes activated at complete parachute suspension line deployment. During descent the load was suspended by four equal length suspension slings of type 10 webbing, 8700 lbs. per ply, six ply, 11.66 feet long including strain links.

Results:

All items under evaluation functioned as planned on this test. A malfunction of the onboard telemetry package caused a loss of data making it necessary to repeat the test.

Conclusions and Recommendations:

This test was satisfactory but it is necessary to repeat the test to fulfill contract obligations. No problems were observed on this test.

4.2 Test No.:

SAEC 202-2, Air Force 1048-F-68

Test Date:

20 May 1968

Purpose:

Test 202-2 was a repeat of 202-1.

Conditions and Procedures:

The same as test 202-1.

Results:

Test 202-2 was satisfactory, no problems were observed. Vertical impact velocity was 24.6 feet per second, horizontal impact velocity was 15.6 feet per second.

Peak opening forces for each load attachment point were as follows:

Right front:	1.29	G
Left front:	1.11	G
Right rear:	1.17	G

Left rear: 1.17 G

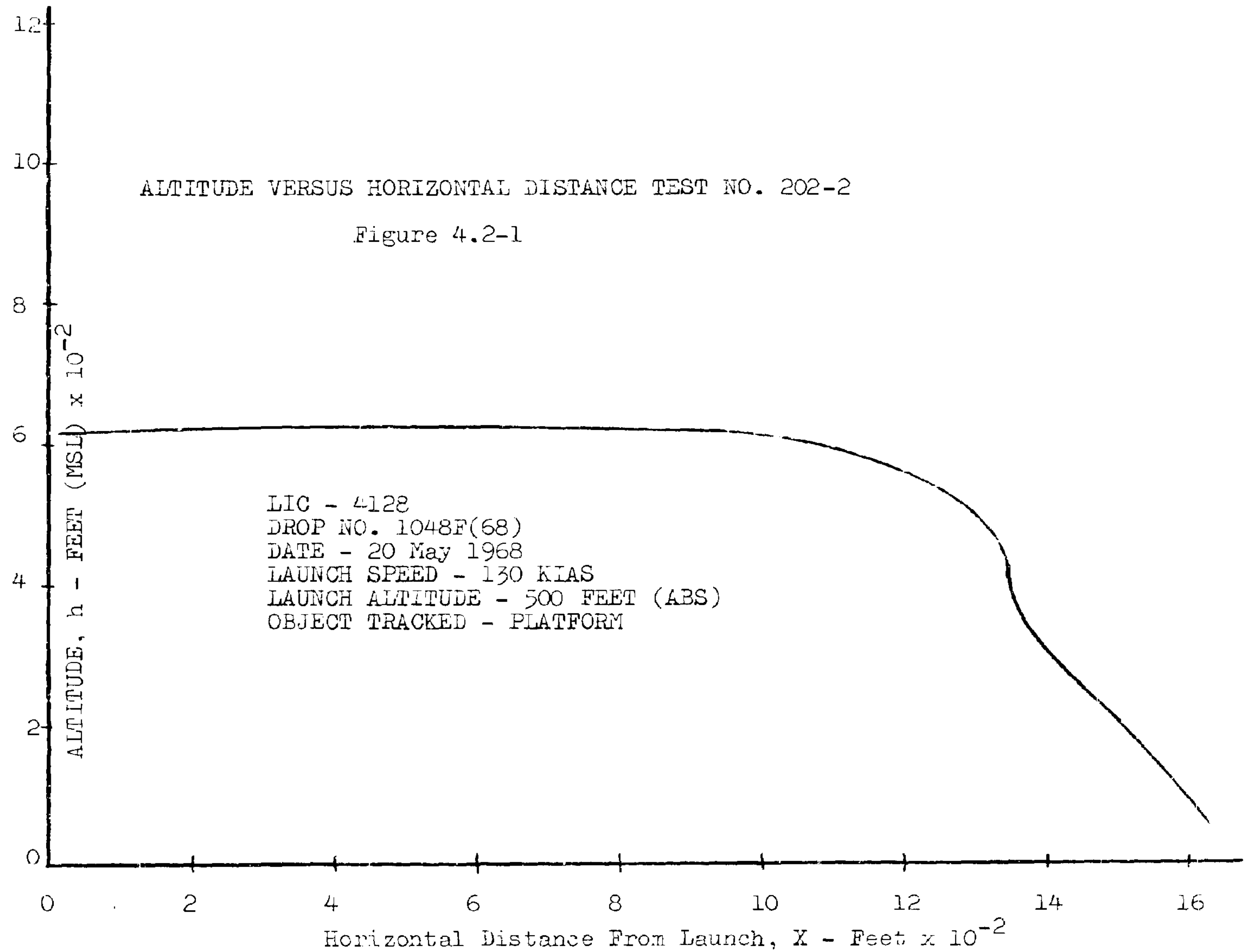
Event times are taken from the first sighting of the extraction parachute and are as follows:

First sighting of extraction parachute - T_0
Extraction force transfer - 3.57 seconds
Load clears ramp - 3.60 seconds
Deployment bags separated from apexes of main parachutes - 5.48 seconds
Average time to cluster inflation - 6.94 seconds
Load impact - 23.26 seconds

Load stability was acceptable on this test as defined in Section 3.5.3. Reference Figures 4.2-1 through 4.2-3 for typical force time history and rate of descent versus time, altitude versus time, total velocity versus time, and altitude versus horizontal distance, graphs for this test.

Conclusions and Recommendations:

Test 202-2 was satisfactory from a performance standpoint. No system hardware sustained damage.

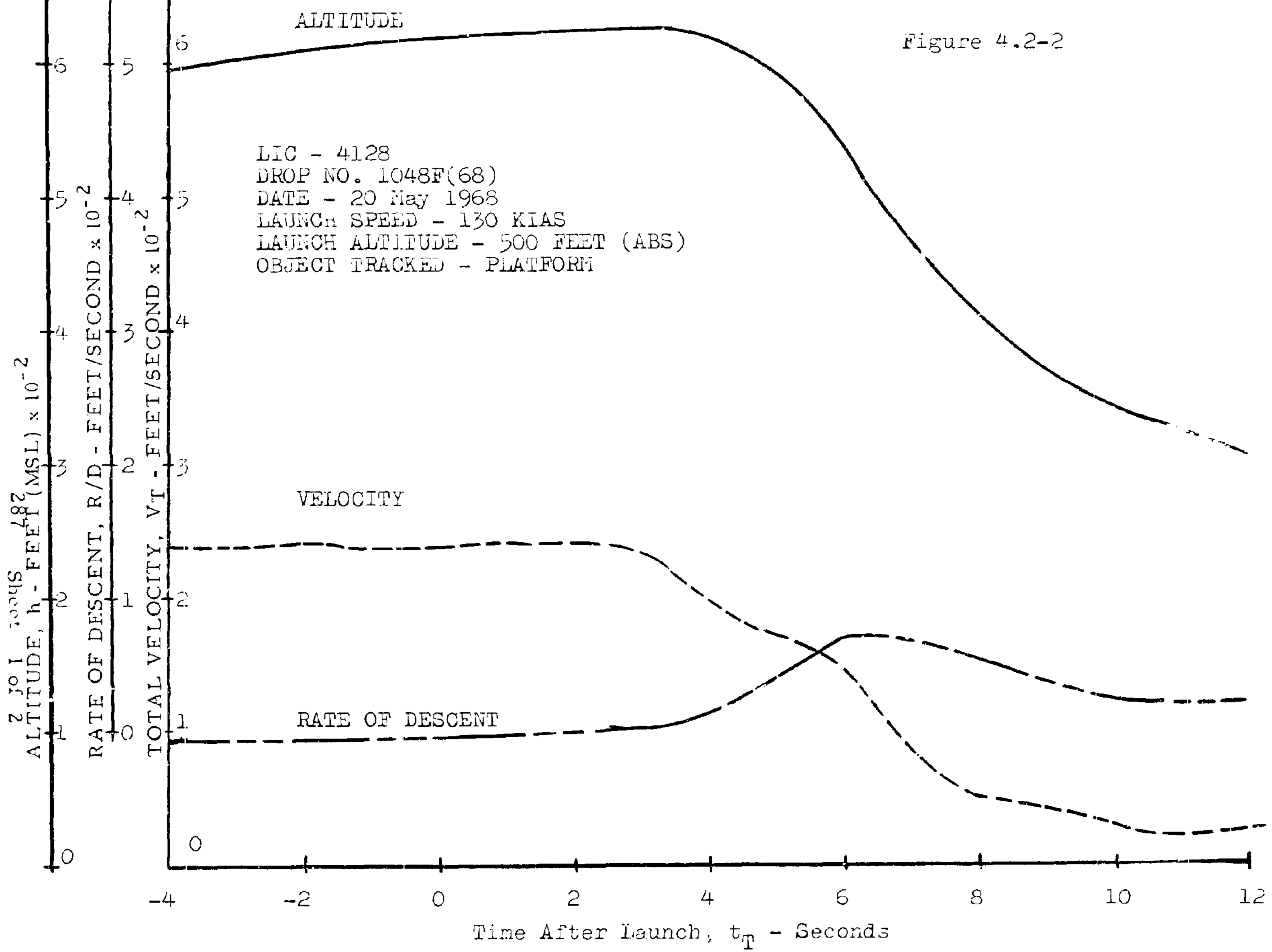


ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-2

Figure 4.2-1

ALTITUDE, RATE OF DESCENT, AND TOTAL VELOCITY VERSUS TIME TEST NO. 20-2

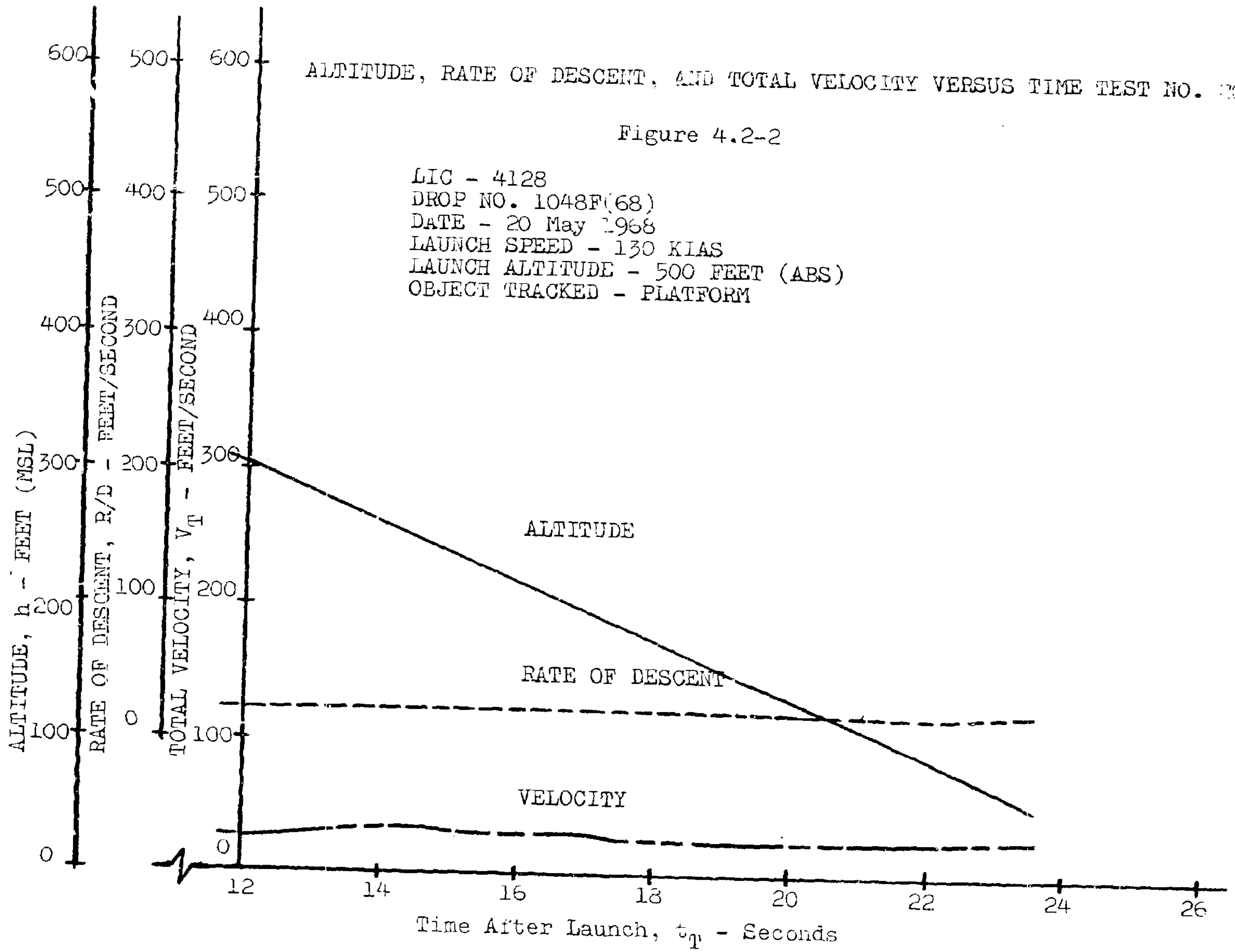
Figure 4.2-2



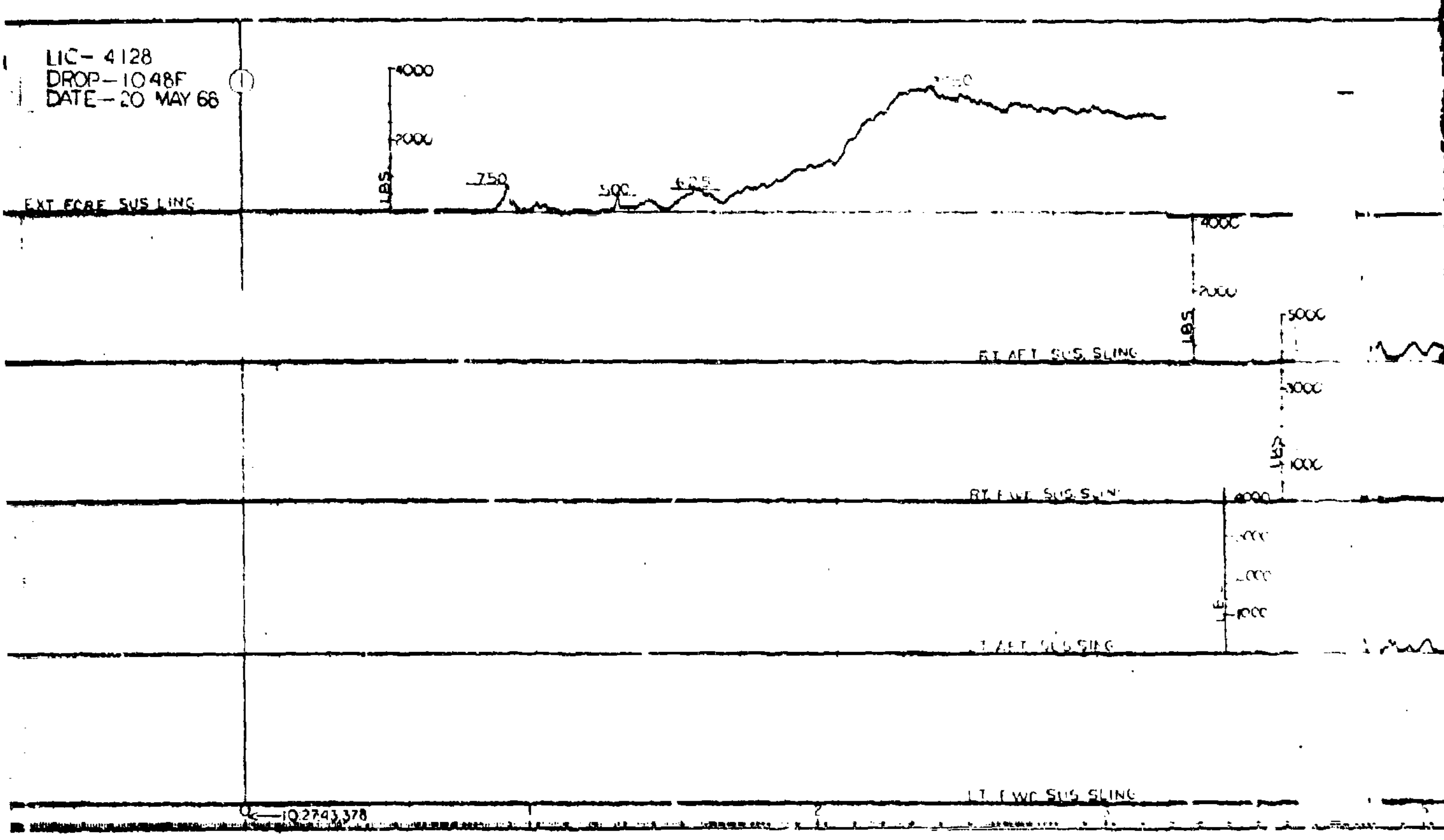
ALTITUDE, RATE OF DESCENT, AND TOTAL VELOCITY VERSUS TIME TEST NO. 302-

Figure 4.2-2

LIC - 4128
DROP NO. 1048F(68)
DATE - 20 May 1968
LAUNCH SPEED - 130 KIAS
LAUNCH ALTITUDE - 500 FEET (ABS)
OBJECT TRACKED - PLATFORM



a


LIC- 4128
DROP-1048F
DATE-20 MAY 66
4000
2000
LBS
750
500
625
EXT FCRE SUS LING
4000
2000
LBS
5000
3000
1000
RT AFT SUS SLING
4000
1000
LT FWD SUS SLING
10,2743,378

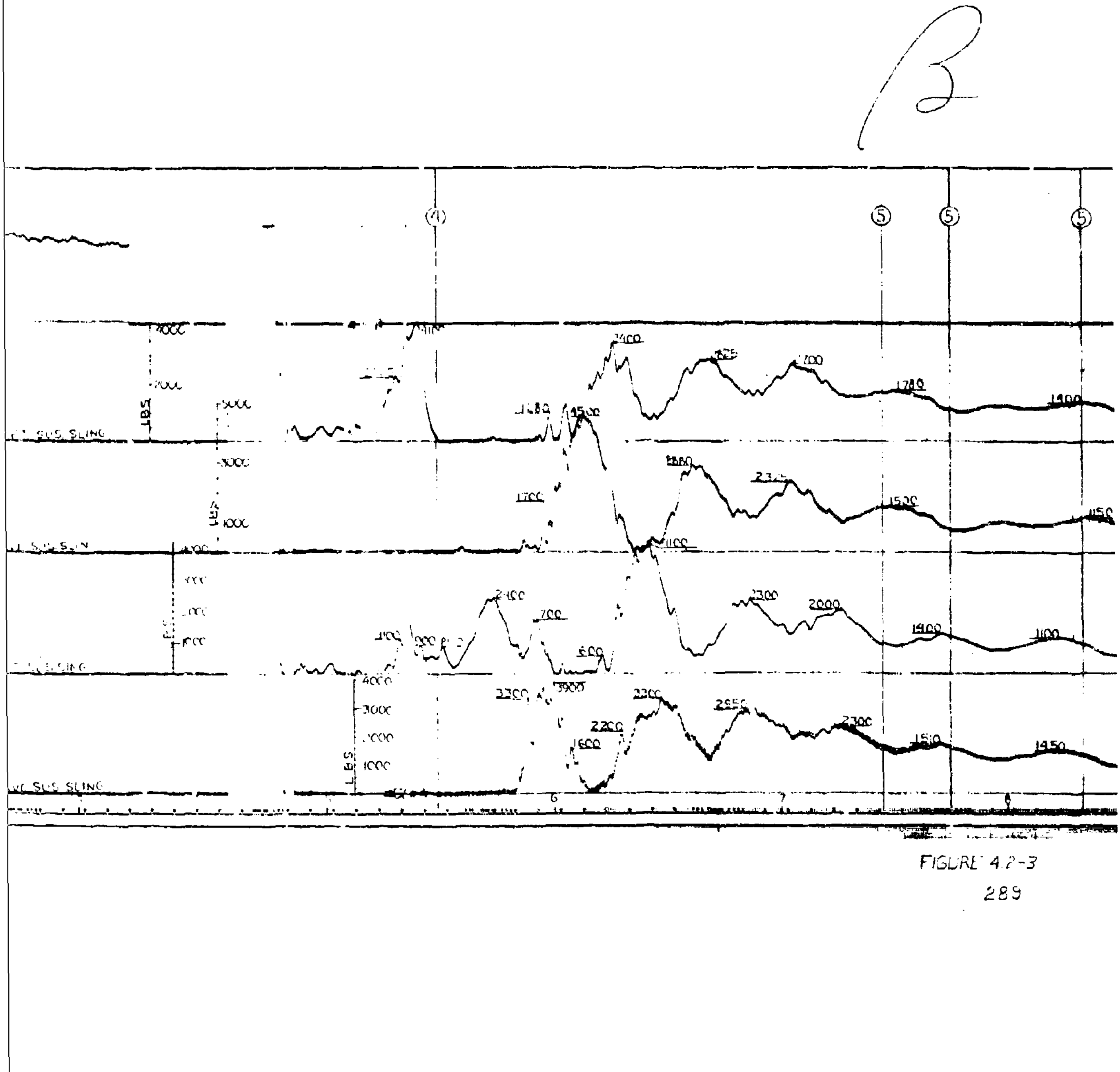


FIGURE 4.2-3

4.3 Test No.:

SAEC 202-3, Air Force 1049-F-68

Test Date:

17 June 1968

Purpose.

Test 202-3 was performed to demonstrate parachute only system test of a 4500 lb. gross rigged weight load.

Conditions and Procedures:

Test 202-3 weighed 4500 lbs. gross rigged weight. The suspened or recovered load weighted 3900 lbs. The requested altitude and airspeed were 500 feet absolute altitude and 130 knots indicated airspeed. Actual release altitude and airspeed were 524 feet absolute and 134 knots indicated airspeed. The test load was mounted on a twelve foot modular platform and was extracted by an unreefed 15 foot ringslot extraction parachute. During extraction, and after a predetermined amount of load movement, an open link safety device was locked by a static lanyard tied off to the anchor line cable in the C-130 drop aircraft. As the front end of the load was exiting the ramp of the drop aircraft extraction force transfer was triggered. After extraction force transfer six, 46 foot D_0 parachutes with 65 foot long cluster risers were conventionally deployed. The extraction parachute was not retained in this system. In this test the cluster parachutes were reefed to 23.8 feet diameter. Disreefing was by two M-21A two second delay line cutters per parachute activated at complete parachute suspension line deployment. During descent the load was suspended by four equal length suspension slings of type 10 webbing, 8700 lbs. per ply, six ply, 11.66 feet long including strain links.

Test Results:

Test 202-3 was satisfactory. No problems were encountered on this test. Vertical impact velocity was 19.9 feet per second, horizontal impact velocity was 13.1 feet per second. Maximum opening forces seen at each load attachment point were as follows:

Right front:	.80 G
Left front:	.89 G
Right rear:	1.13 G
Left rear:	.98 G

The following event times were measured from the first sighting of the extraction parachute:

First sighting of extraction parachute - T_o
Load off ramp - 3.12 seconds
Extraction force transfer - 3.14 seconds
Deployment bags separate from apex of recovery parachutes - 5.52 seconds
Average inflation time of cluster parachutes - 9.75 seconds
Load impact - 66.70 seconds

4.4 Test No:

SAEC 202-4, Air Force 1052-F-68

Test Date:

25 July 1968

Purpose:

Test 202-4 was performed to demonstrate flight safety using an inert rocket system test containing all system components with the exception of live rocket motors. Arming delays of the gas valve were to be demonstrated on this test.

Conditions and Procedures:

The test 202-4 was a 7500 lb. gross rigged weight load. The load was rigged on a 16 foot modular platform. The suspended weight was 6900 lbs. The requested release altitude was 500 feet absolute and the requested release airspeed was 110 knots indicated airspeed. Actual release altitude was 319 feet absolute and release airspeed was 109.5 knots indicated airspeed. The 11 1/2 foot long test load mounted on the 16 foot modular platform weighed 7500 lbs., gross rigged weight. Suspended weight of this system was 6900 lbs. The load was extracted by an unreefed 15 foot ringslot extraction parachute. During extraction, and after a preset length of load travel an open link safety device was locked by a static lanyard tied to the aircraft. As the forward end of the load was exiting the ramp of the drop aircraft, the extraction force was transferred to effect the deployment of the main recovery parachutes. The cluster parachutes used in this test were six each, 24 foot D_o flat circular parachutes using cluster risers 37 feet long. During descent the load was suspended by four equal length suspension slings of six ply type 10 webbing 15.66 feet long including strain links.

Results:

Drop 202-4 was a successful test. Load stability was acceptable in this test. The MDF/CDF firing system functioned as designed. No problems were revealed in this test which would create any flight hazard. Load recovery was satisfactory and no damage occurred to the test load. Vertical impact velocity was 65.7 feet per second; horizontal impact velocity was 13 feet per second. Peak opening forces for each sling attachment were as follows:

Right front:	1.3 G
Left front:	1.57 G
Right rear:	1.50 G
Left rear:	1.52 G

Event times as taken using the first sighting of the extraction parachute as T_o:

First sighting of extraction parachute - T_o
Load off ramp - 4.88 seconds
Extraction force transfer - 4.91 seconds

Deployment bags separated from apexes of main parachutes - 6.17 seconds
Arming of rocket pack gas valves - 7.28 seconds
Recovery chutes full open average inflation time - 7.62 seconds
Load impact - 10.85 seconds
Impact velocity - 62 fps

4.5 Test No:

SAEC 202-5, Air Force 1255-F-68

Test Date:

30 July 1968

Purpose:

This test was an inert 7500 lb. system test and was performed to gain additional data about the reliability of the rocket ignition system with respect to performance and flight safety. Evaluation of system performance at 150 knots indicated airspeed was a goal of this test.

Conditions and Procedures:

The requested release altitude and airspeed were 500 feet absolute altitude and 150 knots indicated airspeed respectively. Actual release altitude was 380 feet absolute and release airspeed was 160 knots. The 11 1/2 foot long test load mounted on a 16 foot long modular platform weighed 7500 lbs., gross rigged weight. Suspended weight of the system was 6900 lbs. The load was extracted by an unreefed 15 foot ringslot extraction parachute. During extracting and after a preset length of load travel an open link safety device was locked by a static lanyard tied off to the aircraft. As the forward end of the load was exiting the ramp of the drop aircraft extraction force was transferred. After force transfer six, 24 foot D_o flat circular parachutes with 27 foot long cluster risers were conventionally deployed by the released extraction parachute. During descent the load was suspended by four equal length suspension slings of six ply type 10 webbing, 15.66 feet long including strain link.

Results:

Drop 202-5 was a successful test. Load stability was acceptable. A minor problem occurring on this test was damage to two of the cluster parachutes. One MDF/CDF firing system did not operate. Examination of the ground sensing probe revealed a jammed safety pin. The other firing system performed normally and would have fired the rockets had this been a live system test. Load recovery was satisfactory and no damage occurred to the test load. Vertical impact velocity was 62.9 feet per second and horizontal impact velocity was 13.9 feet per second. Peak opening forces for each sling attachment were as follows:

Right front:	1.46 G
Left front:	1.58 G
Right rear:	1.30 G
Left rear:	1.21 G

Event times are taken using the first sighting of the extraction parachute as T_0.

Extraction force transfer - 3.54 seconds
Load off ramp - 3.62 seconds
Deployment bags separated from apexes - 4.44 seconds
Recovery parachutes average full inflation - 9.20 seconds
Load impact - 11.13 seconds

Conclusions and Recommendations:

Reference the parachute problem on test 202-5, although the drop was performed at 160 knots indicated airspeed, ten knots above the maximum design speed of the system it is felt that the parachute strength was marginal. Future consideration of this system should involve strengthening the parachute. The jammed probe safety pin was found to be caused by inadequate allowance in the probe for oil expansion due to high ambient temperatures. Future use of the probes was necessary on this program so the probes were bled of small quantities of oil, checked for proper operation and continued in service with no more problems of this type occurring. Future manufacture of the ground sensing probes should allow for more expansion and contraction in the hydraulic system.

4.6 Test No.:

SAEC 202-6, Air Force 1534-F-68

Test Date:

6 August 1968

Purpose:

This test was performed to demonstrate completely system operation of the small load range system. Further, this test was to demonstrate flight safety with a live rocket system.

Conditions and Procedures:

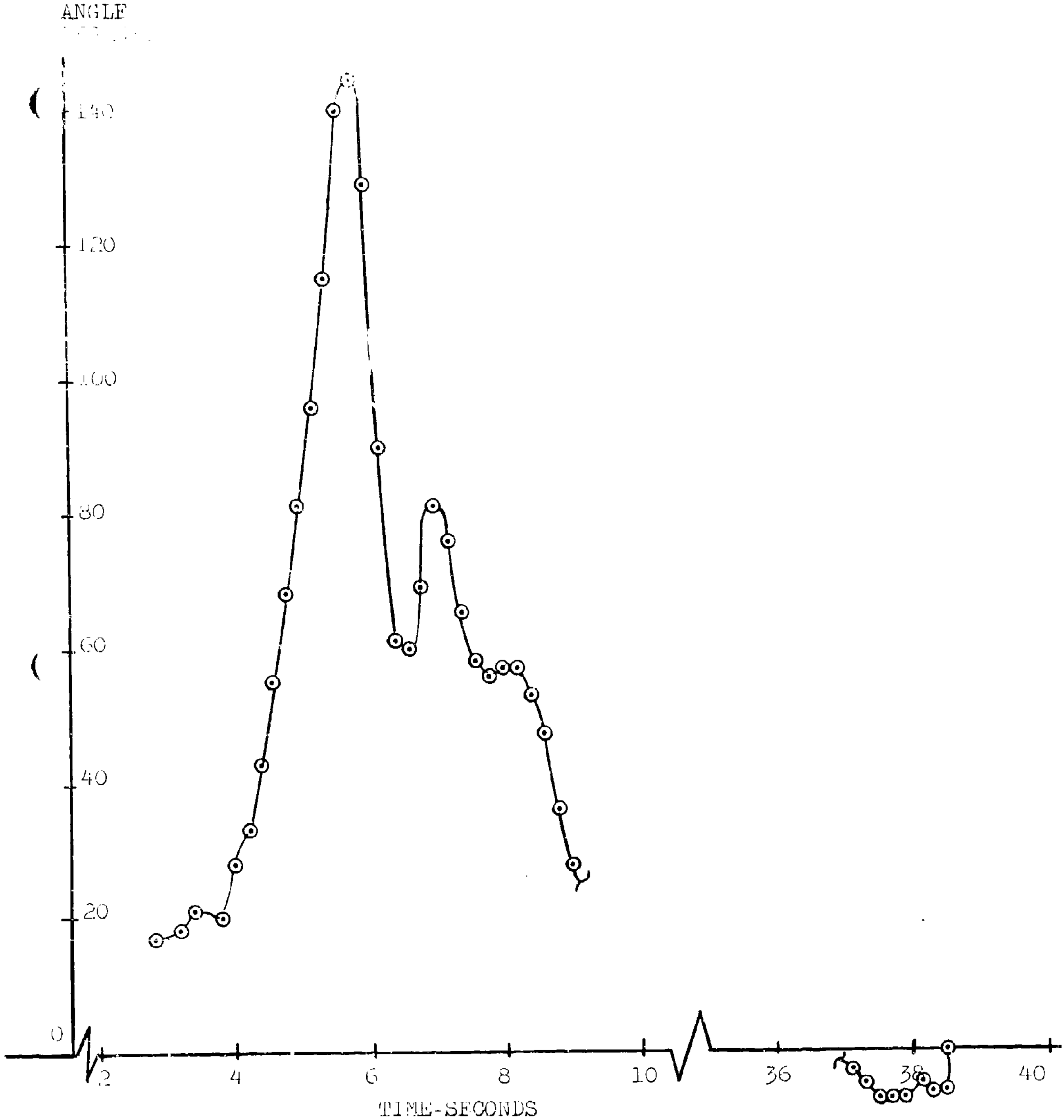
Test 202-6 was a live system test of a 7500 lb. gross rigged weight vehicle. Eight SK2000-1001 rockets were mounted in the small load range rocket pack. The suspended weight of this test was 6900 lbs. Requested release altitude and airspeed were 2000 feet absolute altitude and 130 knots indicated airspeed. Actual release altitude and airspeed were 2087 feet and 135 knots. The 11 1/2 foot long test load mounted on a 16 foot long modular platform was extracted by an unreefed 15 foot ringslot extraction parachute. During the extraction and after a preset length of load travel an open link safety device was locked by a static lanyard tied off to the aircraft. As the forward end of the load was exiting the ramp of the drop aircraft extraction force transfer was triggered. After extraction force transfer six each 24 foot D_0 flat circular parachutes with 37 foot long cluster risers were conventionally deployed. During descent the load was suspended by four equal length suspension slings of six ply type 10 webbing, 8700 lbs. per ply, 15.66 feet long including strain links. At the start of parachute deployment, arming cables were pulled for two FIB timers. These timers after running the set four seconds pulled the final arming cable to the gas shuttle valves on the rocket pack. As the parachutes develop and the load assumes a four point suspension the tightening of the rear suspension slings causes static lanyards to become taut pulling the first arming pin from each gas shuttle valve on the rocket pack, and separate lanyards release the ground sensing probes from the probe protection housings. After the probes have deployed six feet from the protection housings, they are armed by separate static lanyards.

Results:

Parachute deployment and inflation were normal. Load descent and stability were normal, and rocket ignition occurred at the proper time and was normal. Immediately after ignition one rocket motor, serial number 366, failed at the head end closure resulting in total structural failure of the rocket mounting pack. All eight motors were freed from restraint and were spun off to distances as great as 0.3 miles. Vertical impact velocity was 61 fps. See Figure 4.6 for load angle versus time curve.

Conclusions and Recommendations:

This test was unsuccessful. The rocket failure in this test was caused by faulty assembly and lacks quality control. Future occurr-



LOAD ANGLE VS TIME TEST NO. 202-6
Figure 4.6

ences should be prevented by more careful assembly, and by more stringent quality control. Also, in the future each unit should be inspected by the resident Stencel representative. It is recommended that the mounting pack for the rockets be reinforced to provide restraint sufficient to retain the rockets in the pack in the event of a similar type malfunction.

4 7 Test No.:

SAFC 202 7 Air Force 1800 F-68

Test Date:

26 August 1968

Purpose:

This inert system test was performed to demonstrate operation of the PRADS at the intermediate load level with particular emphasis on flight safety aspects

Conditions and Procedures:

For this test, the requested release altitude was 500 absolute and the requested release airspeed was 130 knots indicated airspeed. The actual release altitude was 428 feet absolute, and the release airspeed was 135 knots indicated airspeed The 22 foot long weight tub mounted on a 24 foot long modular platform weighed 14,100 lbs gross rigged weight Suspended weight was 13,000 lbs. Load extraction was standard utilizing a 22 foot D_o ringslot extraction parachute. After force transfer a cluster of 5.36 foot D_o flat circular parachutes were deployed. These parachutes were reefed to 20.2 feet with a two second delay on disreefing. Disreefing was activated at full parachute suspension line stretch. Cluster parachute risers were 37 feet long The rocket pack used was the large inert rocket pack ST409-033. During descent the load was suspended by four equal length suspension slings of six ply type 10, 8700 lbs per ply webbing 24 feet long including strain lengths In this test, the gas valves on the rocket pack were instrumented with microswitches and flash bulbs to record the event of first arming pin pull, second arming pin pull and gas valve shutting.

Results

Test 202-7 was a completely successful drop. Load stability was acceptable. The MDF/CDF ignition system performed without flaw.

Load recovery was satisfactory and no damage occurred to the test vehicle. Vertical impact velocity was 58 feet per second. Horizontal impact velocity was 17 feet per second. Peak opening forces for each suspension point were as follows:

Right front:	.62 G
Left front:	.74 G
Right rear:	.81 G
Left rear:	.80 G

Event times are taken using the first sighting of the extraction parachute as T_o.

Conclusions and Recommendations:

Test 202-7 was acceptable from a performance standpoint. It is recommended that live testing proceed on this load configuration after one further investigatory drop without rigging change.

4.8 Test No:

SAEC 202-8, Air Force 1820-F-68

Test Date:

15 September 1968

Purpose:

This inert system test was performed to demonstrate operation of the PRADS system at the intermediate load level with particular emphasis on flight safety aspects. Additional data was being collected on the performance of the ground sensing ignition system.

Conditions and Procedures:

For this test the requested release altitude was 500 feet absolute, and the requested release was 130 knots indicated airspeed. The actual release altitude was 504 feet absolute and the release airspeed was 130 knots indicated airspeed. The 22 foot weight tub mounted on a 24 foot long modular platform weighed 14,100 pounds gross rigged weight. The suspended weight of the test load was 13,000 pounds. Load extraction was standard utilizing a 22 foot ringslot extraction parachute. During extraction an open link safety was locked after a pre set amount of load movement. At force transfer, a cluster of five 36 foot flat circular parachutes were deployed. The parachutes were reefed to 20.2 feet with a two second delay on disreefing activated at full parachute suspension line stretch. The cluster parachute risers were 37 feet long. Rocket pack used was the large inert rocket pack ST409-033. During descent the load was suspended by four equal length suspension slings of six ply type 10 8700 lbs per ply webbing 24 feet long including strain links. In this test the gas valves on the rocket pack were instrumented with microswitches and flash bulbs to record the events of first arming pin pull second arming pin pull, and gas valve shuttling

Results:

Test 202-8 was a successful inert system test. Load stability was excellent. The MDF/CDF ignition system performed without flaw. Load recovery was satisfactory and no damage occurred to the test vehicle. Vertical impact velocity was 51 feet per second. Horizontal impact velocity was 10.8 feet per second. Peak opening forces for each sling attachment were as follows:

Right front:	.98 G
Left front:	.92 G
Right rear:	.78 G
Left rear:	1.13 G

Event times are taken using the first sighting of the extraction parachutes as T_0:

Load off ramp - 4.21 seconds
Extraction force transfer - 4.22 seconds
Deployment bags separated from apexes - 5.31 secs.
Recovery parachutes average full inflation time - 7.89 seconds

Load impact - 12.63 seconds

Conclusions and Recommendations:

Test 202-8 was completely acceptable from a performance standpoint confirming the results from test 202-7. It is strongly recommended that live testing proceed on this load configuration without rigging alterations.

4 9 Test No.:

SAEC 202-9, Air Force 1996-F-68

Test Date:

11 September 1968

Purpose:

This drop was conducted to permit flight safety evaluation of the PRADS test configuration for an 18,000 lb. load. Also, each drop test served as a test bed for the MDF/CDF system to permit continuous surveillance of the ignition system.

Conditions and Procedures:

The drop vehicle had a gross rigged weight of 18,190 lbs. The suspended weight of the test vehicle was 16,990 lbs. In this test, the 22 foot weight tub mounted from a 24 foot modular platform was to be extracted from an altitude of 500 feet absolute and at an airspeed of 130 knots indicated. Actual release altitude was 338 feet absolute and release airspeed was 138.5 knots indicated. The load/platform was extracted by a 28 foot ringslot extraction parachute. After force transfer a cluster of seven, 36 foot D_0 flat circular recovery parachutes were conventionally deployed. Cluster parachute risers were 45 feet long. During descent the drop vehicle was suspended by four equal length suspension slings of 8 ply type 26 webbing 15,000 lbs. per ply. 24 feet long including strain lengths.

Results:

Test 202 9 was successful although the load impacted at an extreme pitch angle. There were no problems with load stability. The requested release altitude was 500 feet absolute, and the requested release airspeed was 130 knots indicated. The actual release altitude was 338 feet absolute. The low release altitude appeared to be the sole cause of the extreme load angle at impact. The test vehicle was not damaged even under the extreme conditions at impact Vertical impact velocity was 63 feet per second. Horizontal impact velocity was 11.0 feet per second. Peak opening forces for each suspension sling were as follows:

Right front:	.92 G
Left frong:	.98 G
Right rear:	.95 G
Left rear:	81 G

Event times are taken using first sighting of the extraction parachute as T_0

Conclusions and Recommendations:

This test appeared to satisfactorily demonstrate performance of the system at this weight range Because of the extreme angle of the load at impact, although most likely due to the low release altitude, it is recommended that this test be repeated.

4.10 Test No.:

SAEC 202-10. Air Force 1923-F-68

Test Date:

16 September 1968

Purpose:

Test 202-10 was performed to demonstrate the PRADS small load range delivery system. This test was a live motor system test with emphasis on performance as related to flight safety.

Conditions and Procedures:

This drop was a 7500 lb. gross rigged weight vehicle. Suspended weight was 6900 lbs. The 11 1/2 foot load mounted on a 16 foot modular platform was extracted by an unreefed 15 foot ringslot extraction parachute. The requested release altitude was 2000 feet absolute and the requested airspeed was 130 knots indicated. Actual release altitude was 2085 feet absolute and actual release airspeed was 137 knots indicated. After force transfer, a cluster of six, 24 foot D_0 flat circular recovery parachutes were conventionally deployed. Cluster parachute risers were 37 feet long. During descent the load was suspended by four equal length suspension slings of type X webbing 8700 lbs. per ply, 15.75 feet long including strain links. The load was decelerated for impact by eight SK2000-1001 rocket motors mounted in the small rocket pack, Drawing No. SK48-001-001.

Results:

Test 202-10 was successful, all systems functioning as designed. The load was recovered with no damage to the platform, energy absorbing cardboard, load restraint or test vehicle. Load impact velocity was 19 feet per second. Minor damage was sustained by the rocket pack when it impacted on the load after burnout. Peak forces in each suspension sling resulting from parachute action were as follows:

Right front:	.68 G
Left front:	.81 G
Right rear:	.90 G
Left rear.	1.34 G

Peak forces in each suspension sling resulting from retrorocket action were as follows:

Right front:	1.36 G
Left front:	1.40 G

Right rear: 1.87 G
Left rear: 1.95 G

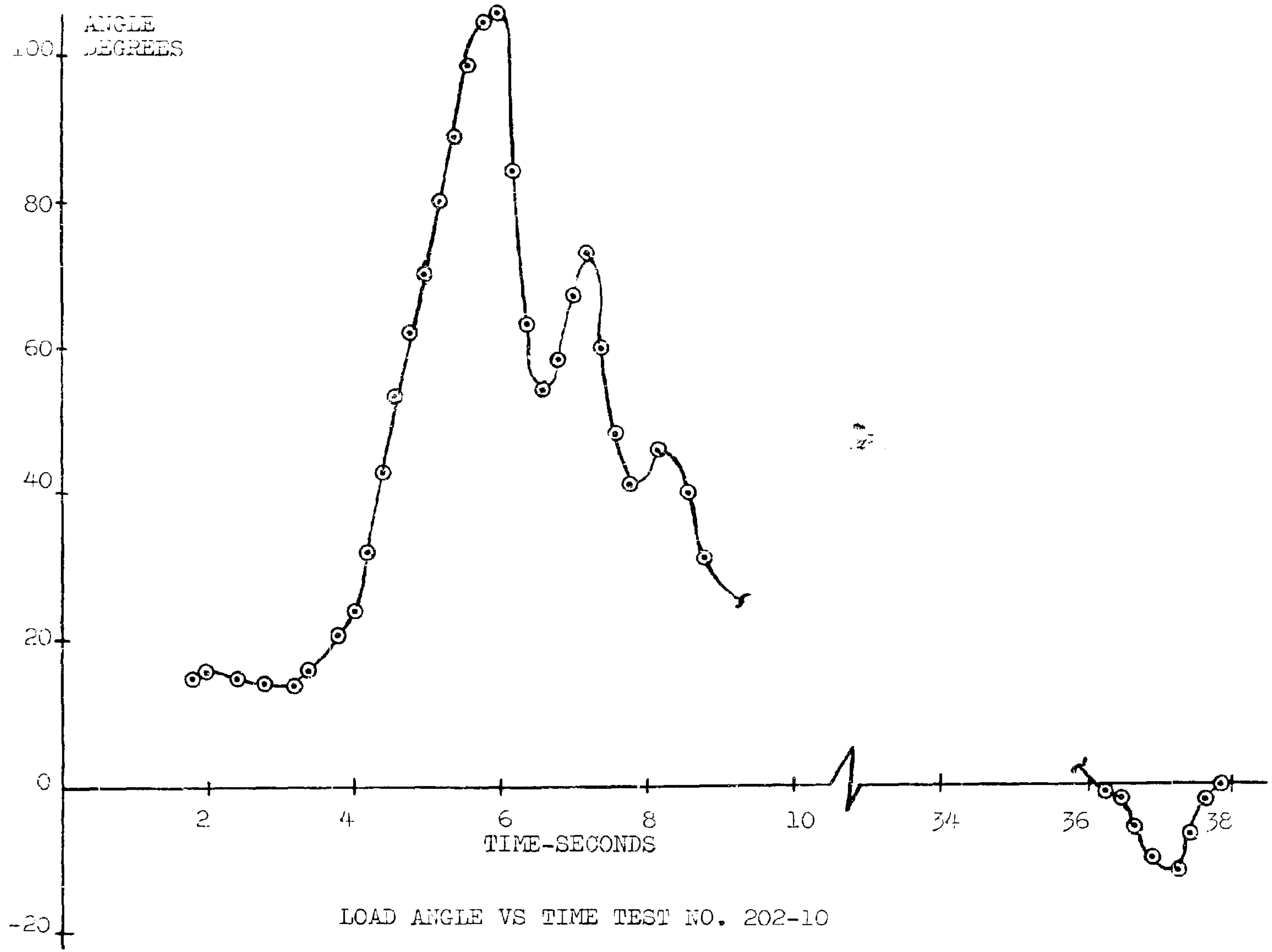
See Figure 4-10 for load angle versus time curve.

Event times are taken using the first sighting of the extraction parachute as T_0:

- Extraction force transfer - 3.95 seconds
- Load off ramp 3.99 seconds
- Deployment bags separated from apexes - 4.3[illegible] seconds
- Recovery parachute full open time average - 7.45 seconds
- Rocket ignition - 37.46 seconds
- Load impact - 37.83 seconds
- Impact velocity - 19 fps

Conclusions and Recommendations:

Based upon the performance of this test there appeared to be no particular problems with the small load range system proceeding to a demonstration test. The second test at this altitude and airspeed will be conducted to gather further data on system performance with respect to aircraft and flight safety. Rocket pack reinforcement does appear necessary if further use of this design is considered.



LOAD ANGLE VS TIME TEST NO. 202-10

Figure 4.10

4.11 Test No.:

SAEC 202-11 Air Force 1998-F-68

Test Date:

19 September 1968

Purpose.

Tests 202-11 was performed to demonstrate the PRADS small load range system. This was a second live motor system test performed to demonstrate flight safety.

Conditions and Procedures:

This test drop was a 7500 lb. gross rigged weight vehicle. Suspended weight was 6900 lbs. The 11 1/2 foot load mounted on the 16 foot modular platform was extracted by an unreefed 15 foot ringslot extraction parachute. After force transfer, a cluster of six, 24 foot D_0 flat circular recovery parachutes were conventionally deployed. No reefing was used in these parachutes. Cluster parachute risers were 37 feet long. During descent a load was suspended by four equal length suspension slings of type 10 webbing, 8700 lbs. per ply, 15.75 feet long including strain links. The load was decelerated for impact by eight SK2000-1001 rocket motors mounted in the small rocket pack Drawing No. SK48-001 001.

Results:

Test 202-11 was completely successful. All systems functioning as designed. The requested release altitude was 2000 feet absolute and the requested airspeed was 130 knots indicated. Actual release altitude and airspeed were 1947 feet absolute and 139 knots indicated respectively. The load was recovered with no damage to the platform, energy absorbing cardboard, load restraint, or test vehicle. Load impact velocity was 11 fps. Minor damage was sustained by the rocket pack when it collided with the load after rocket burnout. Peak forces in each suspension sling resulting from parachute action were as follows:

Right front:	1.14 G
Left front:	1.26 G
Right rear:	.88 G
Left rear:	.80 G

Peak forces in each suspension sling resulting from retrorocket action were as follows:

Right front:	1.37 G
Left front:	1.71 G
Right rear:	2.01 G
Left rear:	1.90 G

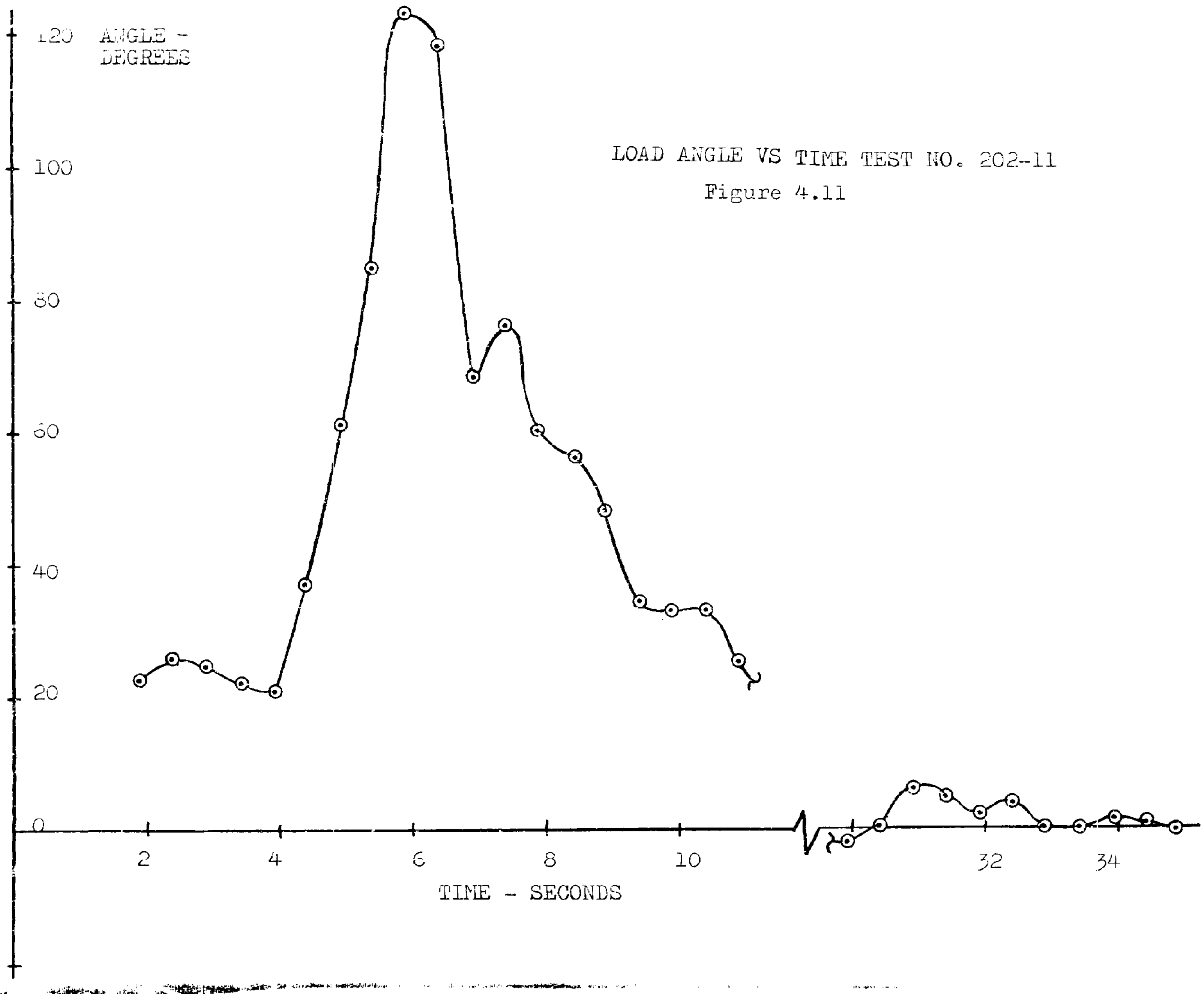
See Figure 4-11 for load angle versus time curve.

Event times are taken using the first sighting of the extraction parachute as T_0:

- Extraction force transfer - 3.96 seconds
- Load off ramp - 3.99 seconds
- Deployment bags separated from apexes - 4.89 seconds
- Recovery parachutes full open average inflation time - 7.45 seconds
- Rocket ignition - 34.508 seconds
- Load impact - 35.70 seconds
- Impact velocity - 11 fps

Conclusions and Recommendations:

The performance of this test indicates there will be no problems in proceeding with a small load range system demonstration test. Rocket pack reinforcement will be mandatory if future use of this design is desired. Although suspension sling forces were above design limits of 1.5 g's per attachment point during rocket burning, this is a problem that can be controlled through redesign of the



LOAD ANGLE VS TIME TEST NO. 202-11
Figure 4.11

rocket motor. Future testing will probably utilize a redesigned rocket motor and at this time this minor problem can be considered.

4.12 Test No.:

SAEC 202-12 Air Force 2061-F-68

Test Date:

26 September 1968

Purpose:

Test 202-12 was performed to demonstrate performance of the PRADS at operational altitude and airspeeds.

Conditions and Procedures:

Test 202-12 was a 7500 lb. gross rigged weight test vehicle. Suspended weight of the test load was 6900 lbs. The 11 1/2 foot load mounted on a 16 foot modular platform was extracted by an unreefed 15 foot ringslot extraction parachute. The requested airspeed was 130 knots indicated. Actual release airspeed was 143 knots indicated. After force transfer, a cluster of six, 24 foot D_o flat circular recovery parachutes were conventionally deployed. Cluster parachute risers were 37 feet long. During descent the load was suspended by four equal length suspension slings of type 10 webbing, 8700 lbs. per ply 15.75 feet long including strain links. The load was decelerated for impact by eight SK2000-1001 rocket motors mounted on the small rocket pack Drawing No. SK48-001-001.

Results:

Test 202-12 was a completely successful system test. All items under evaluation functioning as designed. The load was recovered with no damage to the platform, energy absorbing cardboard, load restraint, or test vehicle. Load impact velocity was 11 fps. No damage was sustained by the rocket pack after rocket motor burnout on this test.

Peak forces in each suspension sling resulting from parachute action were as follows:

Right front:	.71 G
Left front:	.96 G
Right rear:	1.03 G
Left rear:	No data

Peak forces in each suspension sling resulting from retrorocket action were as follows:

Right front:	1.41 G
Left front:	1.60 G
Right rear:	1.91 G
Left rear:	No data

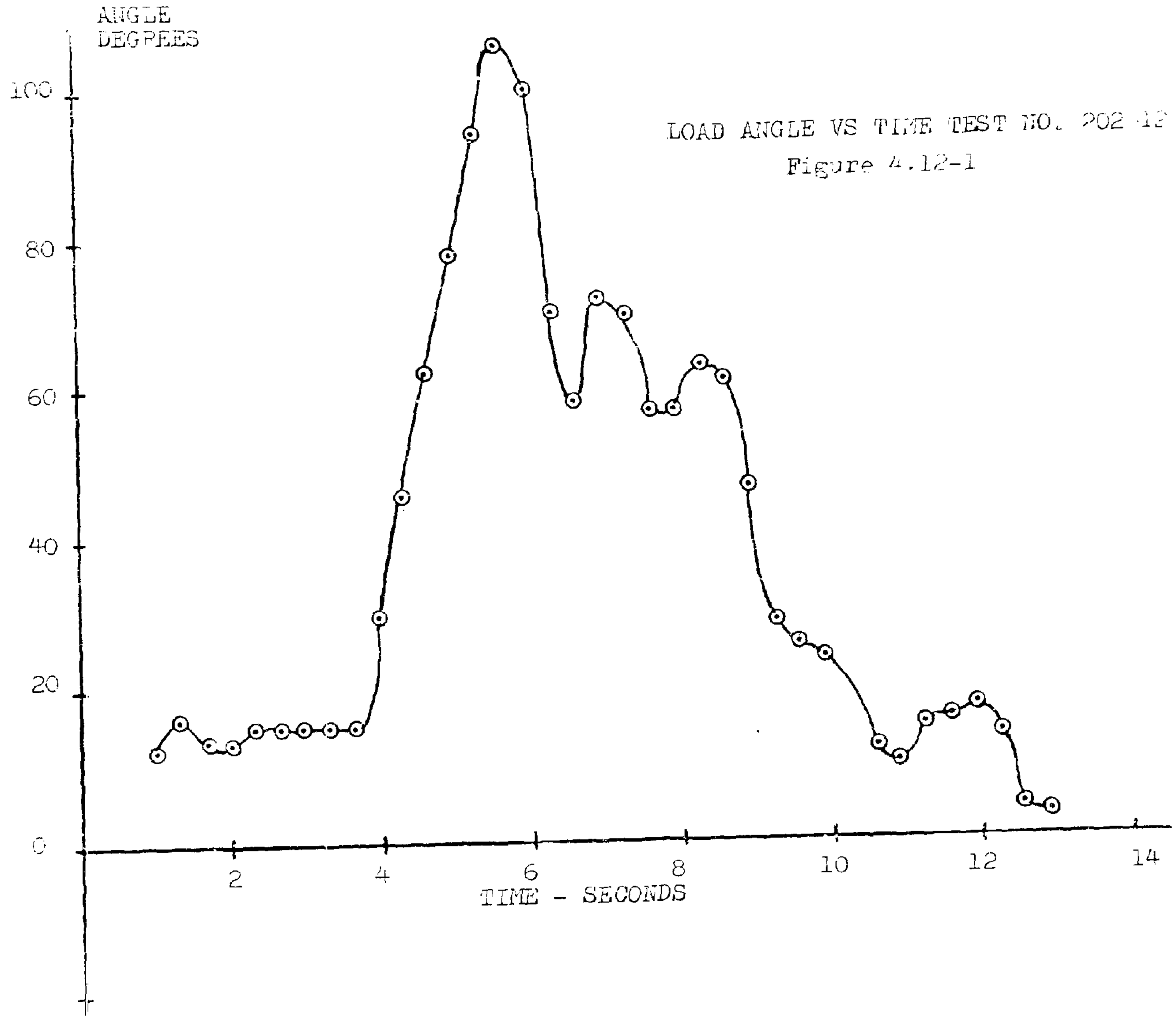
Event times are taken using the first sighting of the extraction parachute as T_0:

- Extraction force transfer - 3.88 seconds
- Load off ramp - 3.90 seconds
- Deployment bags separated from apexes - 4.87 seconds
- Recovery parachutes full open average inflation time - 7.59 seconds
- Rocket ignition - 12.63 seconds
- Load impact - 13.14 seconds
- Impace velocity - 11 fps

Reference Figure 4.12-1 through 4.12-4 for typical force versus time curves, rate of descent versus time, altitude versus time, total velocity versus time altitude versus horizontal distance curves for a system test of a small load, and load angle versus time curve.

Conclusions and Recommendations:

Based on this test performed at operational altitudes and airspeeds the small load range configuration appears to be satisfactory for demonstration of air cargo. There were no system oriented problems resulting in this test.



LOAD ANGLE VS TIME TEST NO. 202 12
Figure 4.12-1

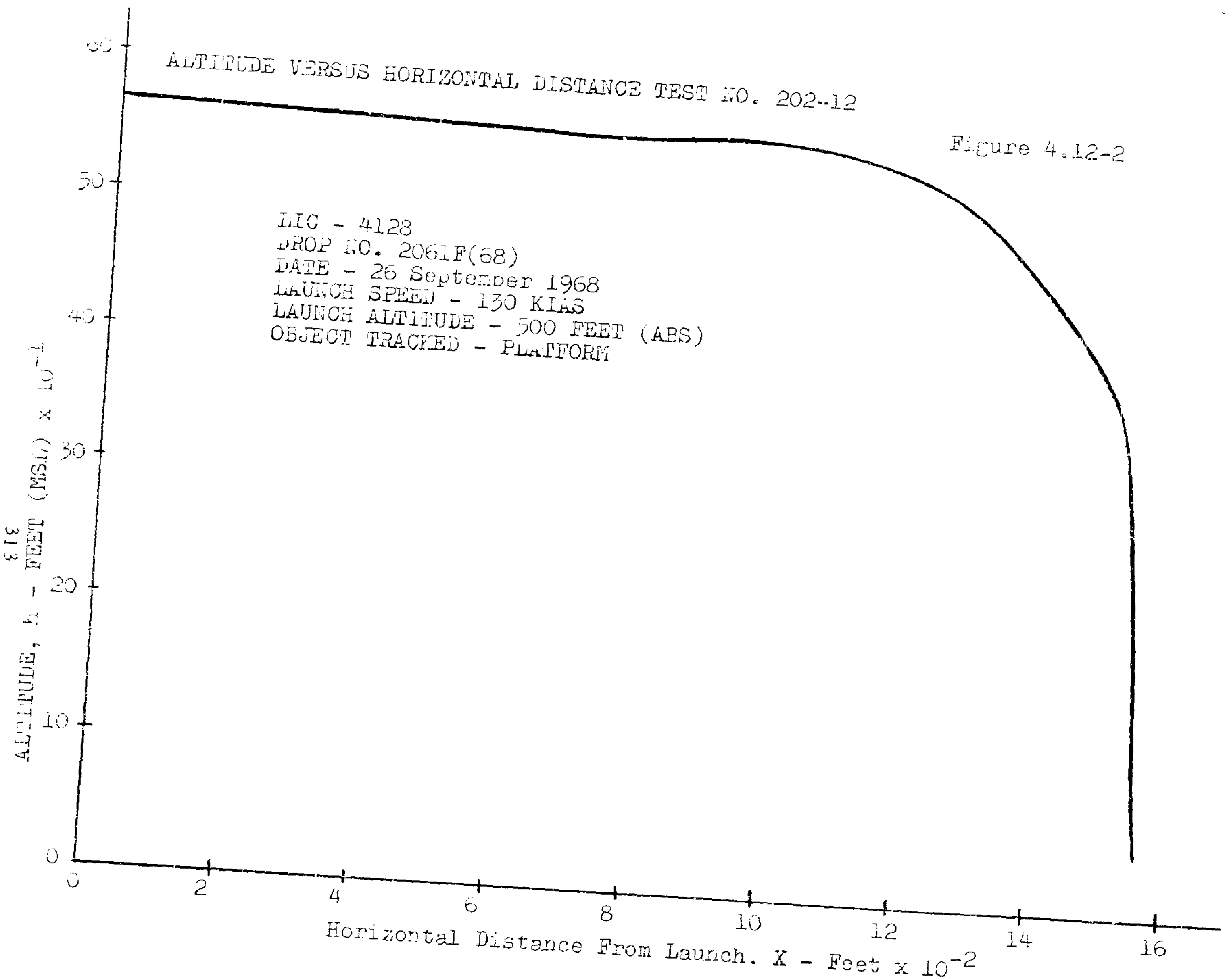
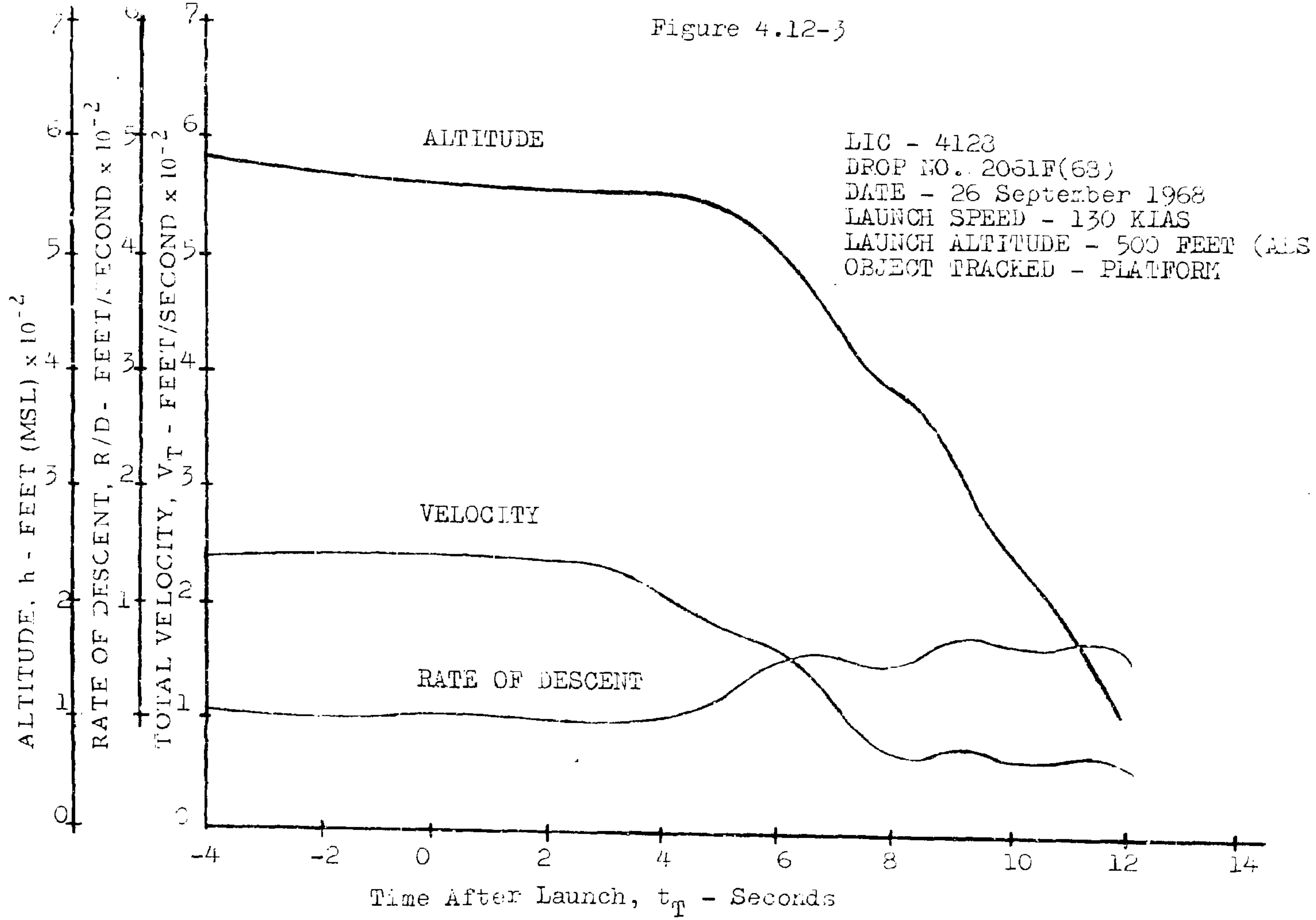

ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-12
LIC - 4128
DROP NO. 2061F(68)
DATE - 26 September 1968
LAUNCH SPEED - 130 KIAS
LAUNCH ALTITUDE - 500 FEET (ABS)
OBJECT TRACKED - PLATFORM
ALTITUDE, h - FEET (MSL) x 10^-1
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
Horizontal Distance From Launch. X - Feet x 10^-2

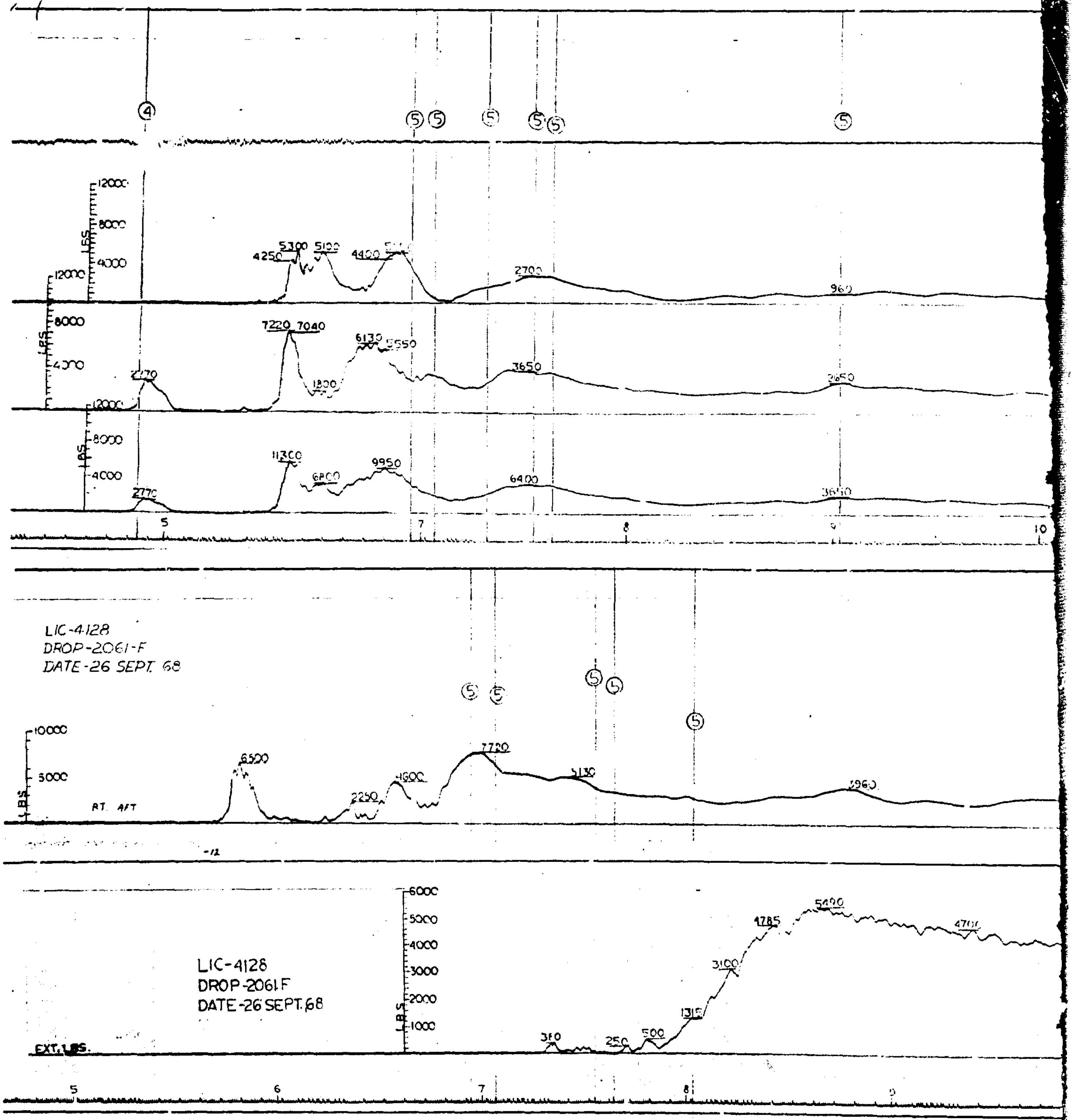
Figure 4.12-2

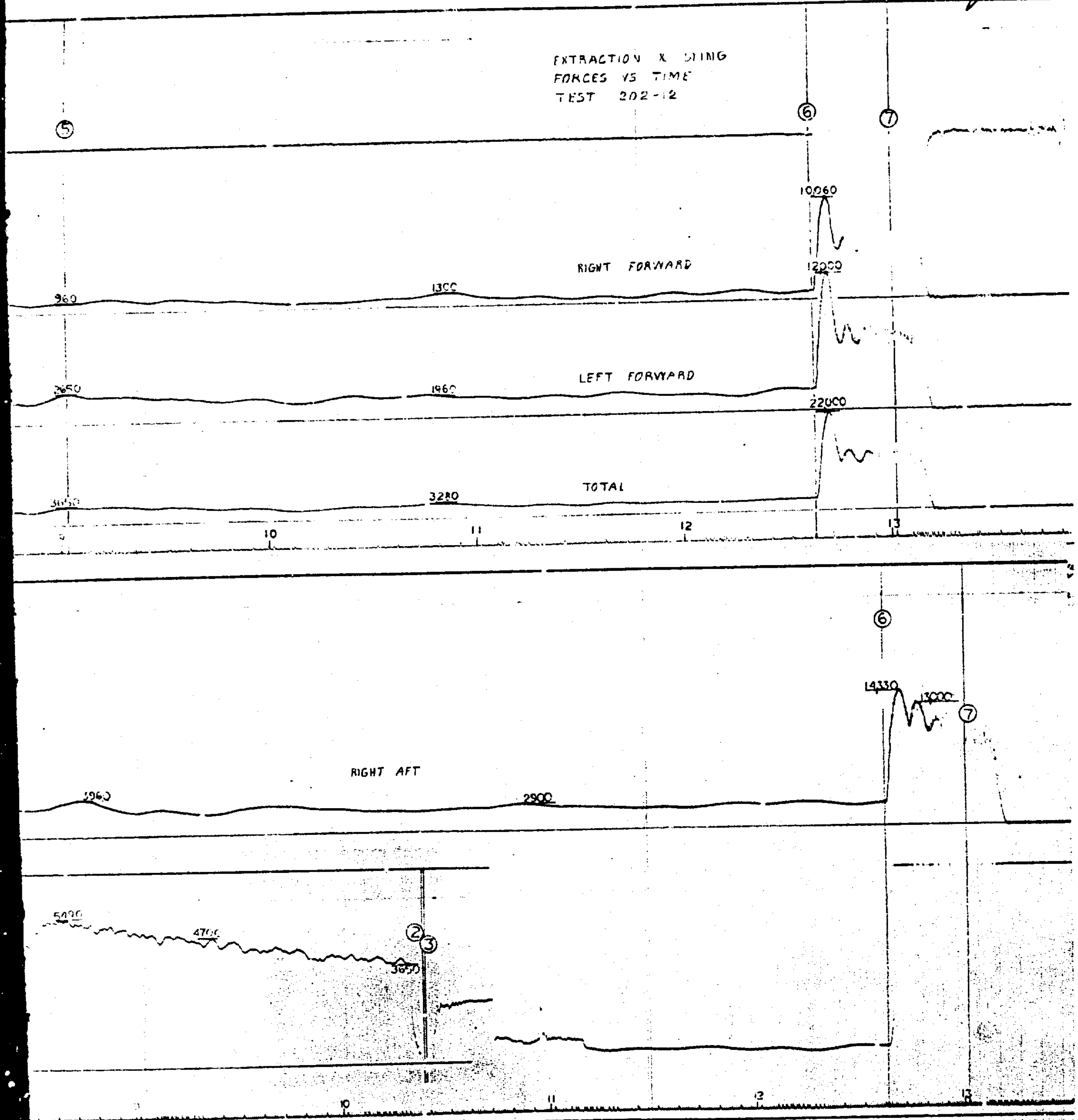
ALTITUDE. RATE OF DESCENT AND TOTAL VELOCITY VERSUS TIME TEST NO. 2.2-.2

Figure 4.12-3



7


LIC-4128
DROP-2061-F
DATE-26 SEPT. 68
RT. AFT
LIC-4128
DROP-2061 F
DATE-26 SEPT. 68
EXT. LBS.
LBS.



EXTRACTION X SLING
FORCES VS TIME
TEST 202-12
RIGHT FORWARD
LEFT FORWARD
TOTAL
RIGHT AFT
10,060
12000
22000
960
1300
2650
1960
3280
14330
13000
2900
4700
3650
10
11
12
13

FIGURE 4.12-4

4.13 Test No.:

SAEC 202-13, Air Force 2065-F-68

Test Date:

1 October 1968

Purpose:

To demonstrate flight safety and system performance at the 18,000 lb. load range. This test is also a repeat of test 202-9 which was dropped too low to provide a fair evaluation of system performance.

Conditions and Procedures:

The drop vehicle had a gross rigged weight of 18,190 lbs. Suspended weight was 16,990 lbs. In this test a 22 foot weight tub was mounted on a 24 foot modular platform and the load platform extracted by a 28 foot ringslot extraction parachute. Requested release altitude was 500 feet absolute and requested release airspeed was 130 knots indicated. Actual release altitude was 512 feet and actual release airspeed was 138 knots indicated. After force transfer a cluster of seven, 36 foot D_o flat circular recovery parachutes were conventionally deployed. Cluster parachute risers used in this test were 45 feet long. During descent the drop vehicle was suspended by four equal length suspension slings of 8 ply type 26 webbing, 15,000 lbs. per ply, 24 feet long including strain links.

Results:

The load was successfully recovered and system stability was good. The rocket ignition system functioned 100 percent on one firing system. The other firing system operated up to a failure in the CDF. The CDF had been overloaded and had parted approximately midway along its length. Maximum suspension sling forces were right front - .93 G, left front - 1.00 G, right rear - 1.15 G, and left rear - .98 G.

Event times were measured using the first sighting of the extraction parachute as T_0:

Load off ramp - 3.97 seconds
Extraction force transfer - 3.92 seconds
Deployment bags separated from apexes - 5.05 seconds
Recovery parachutes full open average - 7.69 seconds
Load impact - 14.23 seconds
Impact velocity - 63 fps

Conclusions and Recommendations:

This test satisfactorily demonstrated performance at the 18,000 lb. weight range. The apparent problems on test 202-9 are concluded to have been directly related to the lower than requested release altitude.

4.14 Test No.:

SAEC 202-14, Air Force 2101-F-68

Test Date:

15 October 1968

Purpose:

Test drop number 202-14 was conducted for the purpose of demonstrating system performance at the intermediate weight range, 14,000 lbs. gross rigged weight.

Conditions and Procedures:

The 14,100 lb. gross rigged weight drop load was extracted by a 22 foot ringslot extraction parachute. The load had a suspended weight of 12,560 lbs. The requested release altitude was 500 feet absolute, actual release altitude was 539 feet absolute. The release airspeed requested was 130 knots indicated airspeed, actual release airspeed was 148 knots. A twelve knot tail wind gave this high reading, actual airspeed was approximately 136 knots indicated. After force transfer five. 36 foot D_0 flat circular parachutes were deployed conventionally. The cluster parachute risers were 37 feet long. A large rocket pack was used and mounted in the rocket pack for 14 SK2000-1001 rocket motors. Probe reclout length was 26 feet and there was no delay between release of the first and the second probe.

Results:

Extraction, deployment, and inflation were normal. The load had a higher pitch rate than test 202-7, and 202-8 but stability was acceptable. Rocket ignition was normal. Because of probe oscillation the probes fired too near the ground and burned only 0.195 seconds prior to impact. The remaining rocket energy was sufficient to pick up the load and to turn the load around 180°. The load was not overturned or damaged The rocket pack was destroyed when the load in the unusual conditions present landed on the rocket pack at impact. One CDF system failed due to tension overload. This was a material break and was not a design failure. Peak forces in the suspension slings from the parachutes were as follows:

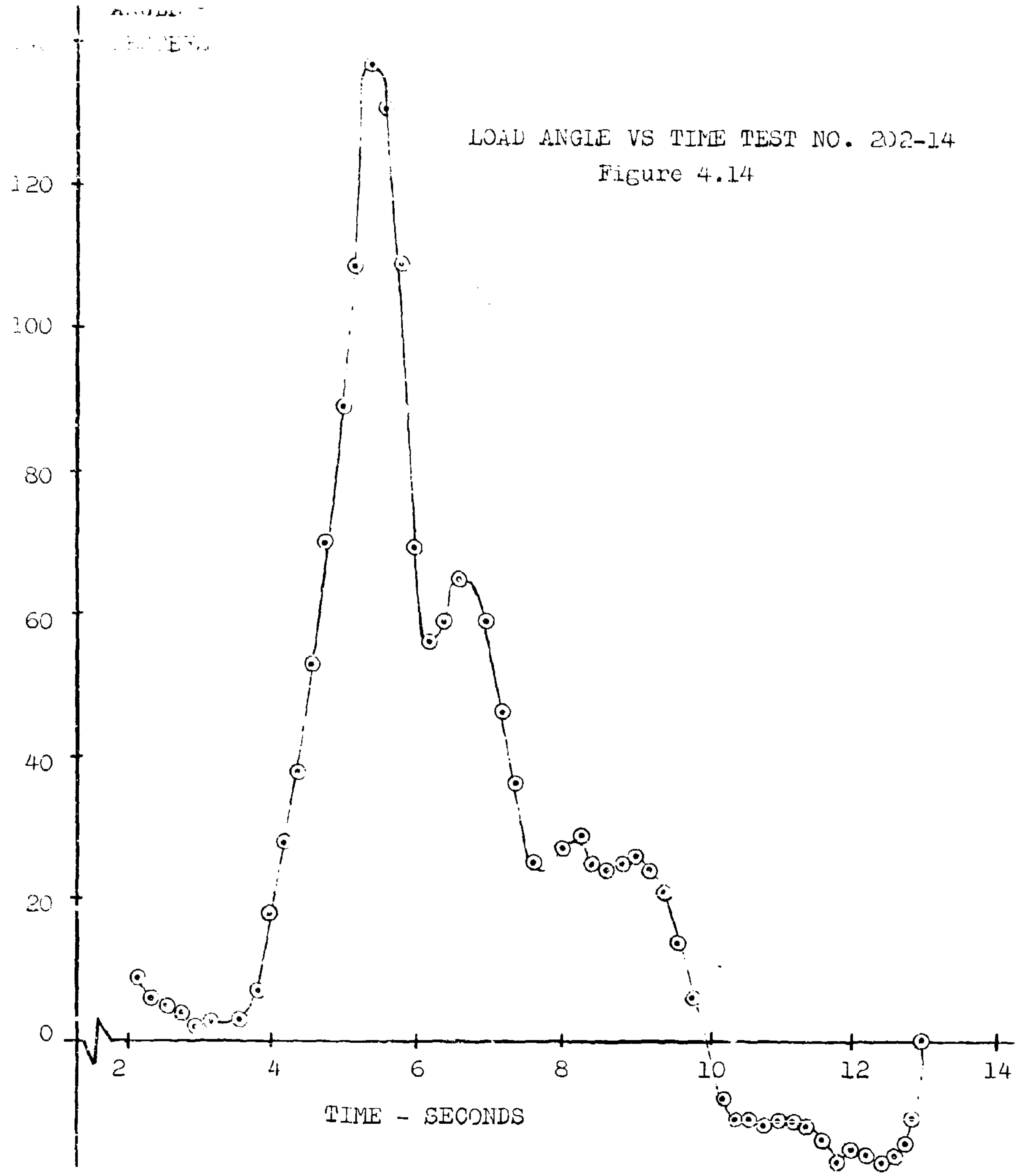
Right front:	1.99 G
Left front:	2.27 G
Right rear:	1.41 G
Left rear:	1.23 G

Peak forces in the suspension slings from the rocket reaction were as follows:

Right front:	2.22 G
Left front:	1.86 G
Right rear:	1.74 G
Left rear:	1.79 G

See Figure 4-14 for load angle versus time curve. Event data times are taken using the first sighting of the extraction parachute as T_0:

Extraction force transfer - 3.78 seconds



LOAD ANGLE VS TIME TEST NO. 202-14
Figure 4.14

Load off ramp - 3.95 seconds
Deployment bags separated from apexes - 4.86 seconds
Recovery parachutes full open - 7.23 seconds
Rocket fire - 12.76 seconds
Load impact - 12.92 seconds
Impact velocity - 42 fps

Conclusions and Recommendations:

The test was not successful. The problem with ignition too near the ground is an ignition system design problem, and for future testing one probe will be released two seconds after the first. This will permit each probe to have a separate oscillation period, and chances are good that one probe will fire at proper height.

4.15 Test No:

SAEC 202-15, Air Force 2184-F-68

Test Date:

24 October 1968

Purpose:

This test was conducted to obtain performance data on a 24,000 lb. load with emphasis on flight safety.

Conditions and Procedures:

The 24,000 lb. gross rigged weight drop test load was extracted by a 28 foot ringslot extraction parachute. The load had a suspended weight of 21,400 lbs. The requested release altitude for this drop was 1000 feet absolute and the requested release airspeed was 130 knots indicated. Actual altitude and airspeed are not available because the drop was released approximately 30 seconds early. After force transfer the extraction parachute deployed a cluster of six, 46 foot D_o flat circular parachutes. The cluster parachute risers were 53 feet long. Two inert large rocket packs were used on this drop, one attached to the other by six, 3 foot long eight ply suspension slings constructed of type 26 webbing (15,000 lbs. per ply). The drop test load was suspended during descent by four equal length suspension slings of 10 ply type 10 webbing 8700 lbs. per ply, 24 feet long including strain links. Probe reelout length was 26 feet long and on this test one probe was altered so that it was released two seconds after the first probe. The alteration involved restraining the probe with 550 lb. cord and cutting the cord at the proper time with an M21 two second delay reefing line cutter.

Results:

This test was released from the drop aircraft approximately 30 seconds early. From evidence available this drop was satisfactory. There is no acceptable space positioning or event timing on this drop since it was released early. It will be necessary to repeat this test at a later time for data. One CDF train was broken approximately midway along its length due to tension overload.

Conclusions and Recommendations:

Test 202-15 appeared easily capable of dropping at 500 feet absolute. The next test of this weight range will be airdropped at 500 feet absolute altitude and at an airspeed of 130 knots indicated.

4 16 Test No.:

SAEC 202-16, Air Force 2235-F-68

Test Date:

30 October 1968

Purpose:

To establish the possibility of using one parachute only in the parachute retrorocket mode of delivery. System stability will be evaluated since there is some question whether without ...er parachute damping load stability will be acceptable at the required time of rocket ignition.

Conditions and Procedures:

Test 202-16 was an inert system test of a 5480 lb. gross rigged weight drop load. Suspended weight was 5100 lbs. The eight foot tub mounted on a 12 foot modular platform was extracted from the C130 drop aircraft at an altitude of 430 feet absolute, and at an airspeed of 139.5 knots indicated. Requested release altitude and airspeed were 500 feet absolute and 130 knots indicated respectively. After extraction force transfer, a single 46 foot D_0 flat circular parachute was conventionally deployed. The parachute riser was eight feet long. During descent the load was suspended by four equal length suspension slings of six ply type 10 webbing, 8700 lbs. per ply, 12.75 feet long including strain links.

Results:

This test drop demonstrated satisfactory stability for use with the parachute retrorocket combination. All systems under evaluation performed well. The MDF firing system functioned normally. The CDF portion of the ignition system was not used on this drop since there would be no particular problems with use of the CDF. Maximum forces in each suspension sling were as follows:

Right front:	1.28 G
Left front:	.91 G
Right rear:	1.87 G
Left rear:	1.46 G

Event times are reported using the first sighting of the extraction parachute as T_0:

Extraction force transfer - 3.35 seconds
Load off ramp - 3.50 seconds
Deployment bags separated from apexes - 4.12 seconds
Recovery parachutes full opened - 5.31 seconds
Load impact - 12.48 seconds
Impact velocity - 62 fps

Conclusions and Recommendations:

It appears from this test that the concept evaluated would be satisfactory for use with the retrorockets in the small load range. Prior to use in this system for live tests further drops are recommended.

4.17 Test No.:

SAEC 202-17, Air Force 2247-F-68

Test Date:

7 November 1968

Purpose:

To repeat test 202-15 and gain performance data on the 24,000 lb. test with respect to flight safety.

Conditions and Procedures:

The 24,000 lb. gross rigged weight drop test load was extracted by a 28 foot D_0 extraction parachute. The load had a suspended weight of 21,400 lbs. Requested release altitude and airspeed were 500 feet absolute and 130 knots indicated respectively. Actual release altitude and airspeed were 526 feet absolute, and 139.5 knots indicated. After force transfer the extraction parachute deployed a cluster of five 46 foot D_0 flat circular parachutes. The cluster parachute risers were 53 feet long. Two inert large rocket packs were used on this drop, one attached to the other by six 3 feet long eight ply suspension slings constructed of type 26 webbing (15,000 lbs. per ply). The drop test load was suspended during descent by four equal length suspension slings of six ply type 26 webbing (15,000 lbs. per ply, 22 feet long including strain links. Probe rollout length was 28 feet and on this test and all future tests one probe was altered so that it was released two seconds after the first probe. The alteration involved restraining the probe with 550 lb. cord and cutting the cord at the proper time with an M21 two second delay reefing line cutter.

Results:

Test 202-17 was completely successful. The use of five parachutes appeared adequate. Flight safety was successfully demonstrated with this weight range load and rigging configuration. The use of six parachutes on 202-15 was planned, but better utilization of parachutes is obtained using five for a load of this weight range. Both rocket firing systems operated normally. Peak forces in each suspension sling were as follows.

Right front	.96 G
Left front	.96 G
Right rear	.96 G
Left rear	.96 G

All suspension sling forces were under the 1.5 G per attachment point limit. Event times are taken using the first sighting of the extraction parachute as T_0.

Extraction force transfer - 4.21 seconds
Load off ramp - 4.31 seconds
Deployment bags separated from apexes - 5.47 seconds
Recovery parachutes full opened average inflation time - 7.78 seconds
Load impact - 13.06 seconds
Impact velocity - 61 fps

Conclusions and Recommendations:

This test configuration appeared satisfactory from progressive to live tests. It is recommended that live system tests proceed on this weight range without rigging change.

4.18 Test No.:

SAEC 202-18, Air Force 2424-F-68

Test Date:

5 December 1968

Purpose:

To investigate the performance envelope on the 35,000 lb. system. Primary emphasis will be on rigging techniques and flight safety.

Conditions and Procedures:

The 35,000 lb. gross rigged weight test vehicle was extracted by dual 28 foot D_o ringslot extraction parachutes. The test load had a suspended weight of 32,300 lbs The requested release altitude was 600 feet absolute, and the requested release airspeed was 137 knots indicated. Actual release altitude and airspeed were 570 feet absolute, and 141.5 knots indicated respectively. After force transfer the extraction parachute deployed a cluster of seven, 46 foot D_o flat circular parachutes. The cluster parachute risers were 53 feet long. In this drop the cluster parachutes were reefed to 24 feet diameter. Reefing line cutter activation was at complete parachute suspension line stretch and disreefing occurred two seconds later. Two inert rocket packs were used on this test, one attached above the other. The drop load was suspended during descent by eight equal length suspension slings attached at four places on the test vehicle. The suspension slings were each constructed of eight ply type 26 webbing 15 000 lbs. per ply.

Results

Test 202-18 performed satisfactorily but lost three of the cluster parachutes to two causes. Two of the parachutes failed at the riser adaptors. One riser adaptor was fabricated from type 10 webbing the other from type 19 webbing and type 26 mixed. The type 10 webbing failed in tensile tests at 6660 lbs. per ply. The type 19 webbing failed at 10, 140 lbs. per ply. Also, two types of failure existed. The one on the type 10 webbing was a tensile overload type failure and the other on the type 19 webbing was primarily a stitch failure. The other parachute lost was caused by a failed riser extension. The webbing was type 10 six ply and failed in lab tensile tests at 6000 lbs per ply as opposed to rated 8700 lbs. per ply. The cluster parachutes suffered damage on this drop. Peak forces in each suspension sling were:

Right front:	1.00 G
Left front:	1.13 G
Right rear:	.74 G
Left rear:	.66 G

Event times are taken using the first sighting of the extraction parachute as T_o:

- Load off ramp - 4.33 seconds
- Extraction force transfer - 4.50 seconds
- Deployment bags separated from apexes - 5.88 seconds
- Recovery parachutes full opened average - 8.82 seconds
- Load impact - 1?.85 seconds
- Impact velocity - 61 fps

Conclusions and Recommendations:

Drop 202-18 demonstrated a need for more careful riser design and selection. It is recommended that this test be repeated using all type 26 riser adaptors.

4.19 Test No.:

SAEC 202-19, Air Force 2544-F-68

Test Date:

10 December 1968

Purpose:

Test drop 202-19 was conducted for the purpose of demonstrating system performance at the intermediate weight range, 14,000 lbs. gross rigged weight.

Conditions and Procedures:

The 14,100 lb. gross rigged weight drop load was extracted by a 22 foot ringslot extraction parachute. The load had a suspended weight of 12,560 lbs. The requested release altitude and airspeed were 500 feet absolute and 130 knots indicated respectively. Actual release altitude and airspeed were 523 feet absolute and 140 knots indicated. After force transfer three 46 foot D_o flat circular parachutes were deployed conventionally. The cluster parachute risers were 45 feet long. A large rocket pack was used and mounted in the rocket pack were fourteen SK2000-1001 rocket motors. Probe reelout length was 28 feet and there was a delay of two seconds between the release of the first and the second ground sensing probe

Results:

This test was completely successful. The load exhibited the same characteristics as 202-14 but rocket firing was at the proper altitude and load recovery was complete. Peak forces in the suspension slings from the parachutes were as follows.

Right front:	2.34	G
Left front:	2.31	G
Right rear:	1.29	G
Left rear:	1.42	G

Peak forces in the suspension slings from the rocket reaction were as follows:

Right front:	1.93	G
Left front:	2.04	G
Right rear:	1.52	G
Left rear:	1.55	G

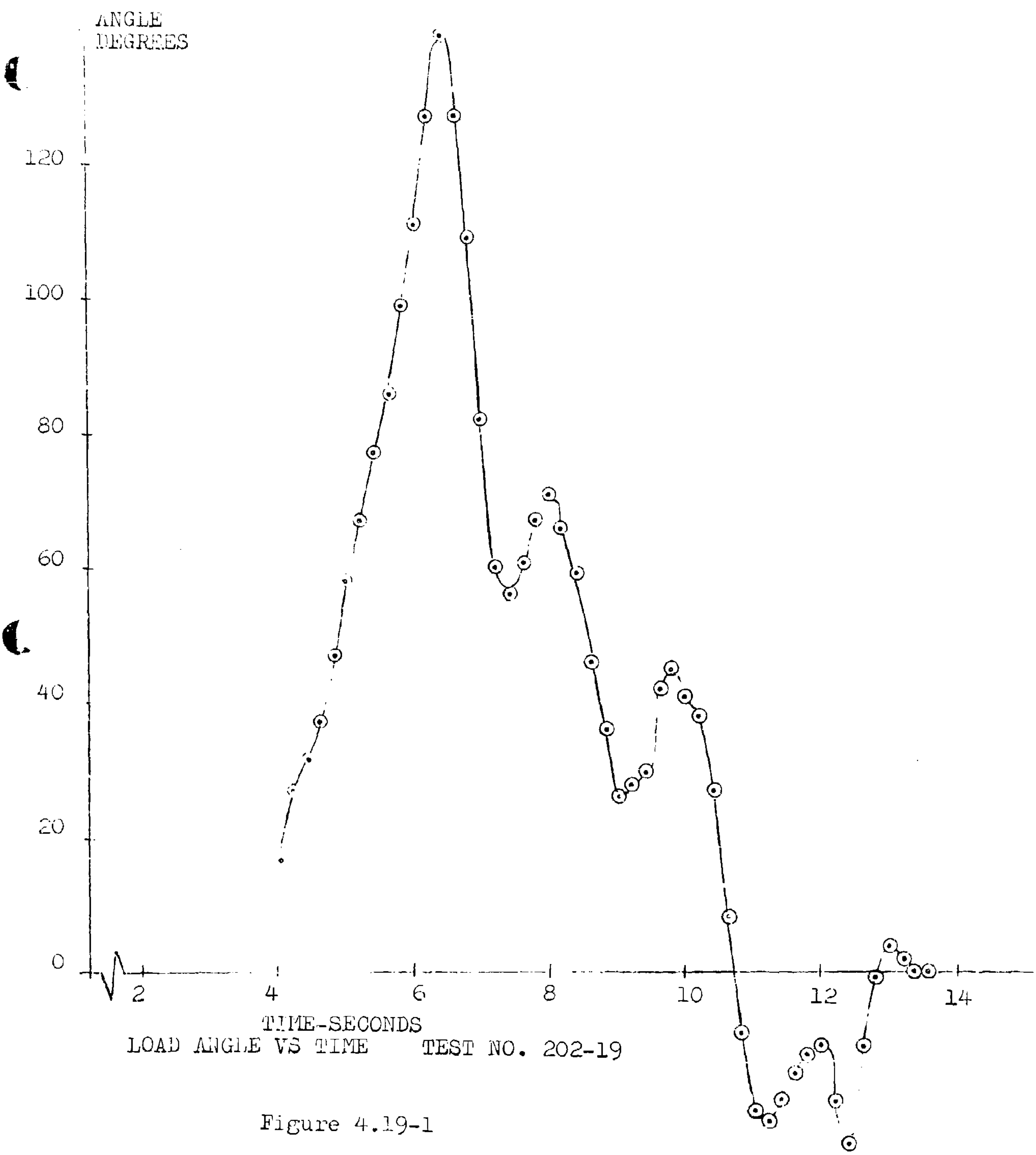
Event data times are taken using the first sighting of the extraction parachute as T_0:

Load off ramp - 4.19 seconds
Extraction force transfer - 4.37 seconds
Deployment bags separated from apexes - 5.59 seconds
Recovery parachutes full open - 7.63 seconds
Rockets fire - 13.24 seconds
Load impact - 13.74 seconds
Vertical impact velocity - 17 fps

Reference Figures 4.19.1 through 4.19.4 for typical force versus time, altitude versus time, rate of descent versus time, total velocity versus time, a trajectory curve for a 14,000 pound live system test, and a load angle versus time curve.

Conclusions and Recommendations:

Test 202-19 successfully demonstrated system operation at the 14,000 lb. level. The probes timed to be released two seconds apart seemed to insure ignition at sufficient altitude for load recovery. No changes are recommended in this system if further testing is to be conducted.



LOAD ANGLE VS TIME   TEST NO. 202-19

Figure 4.19-1

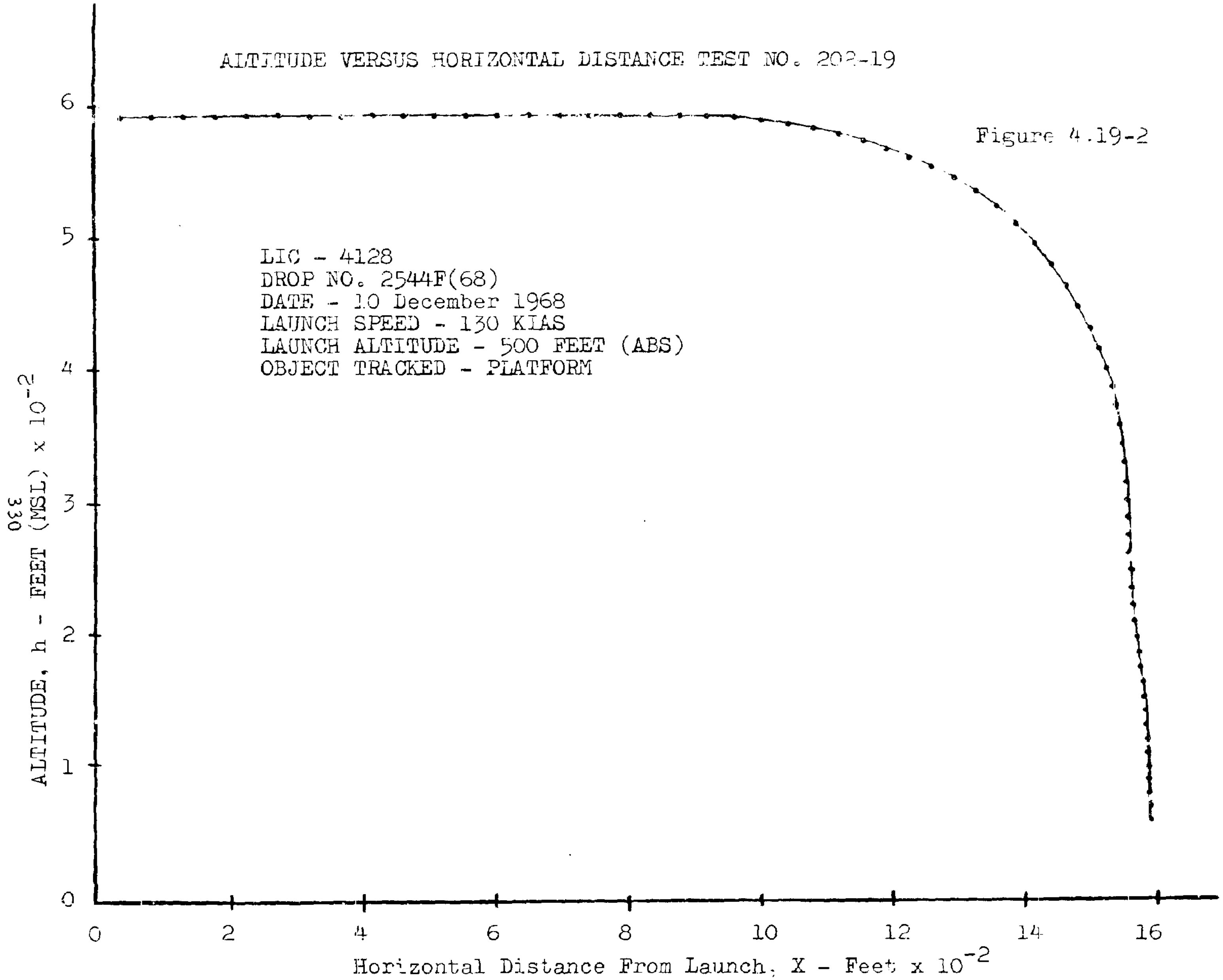
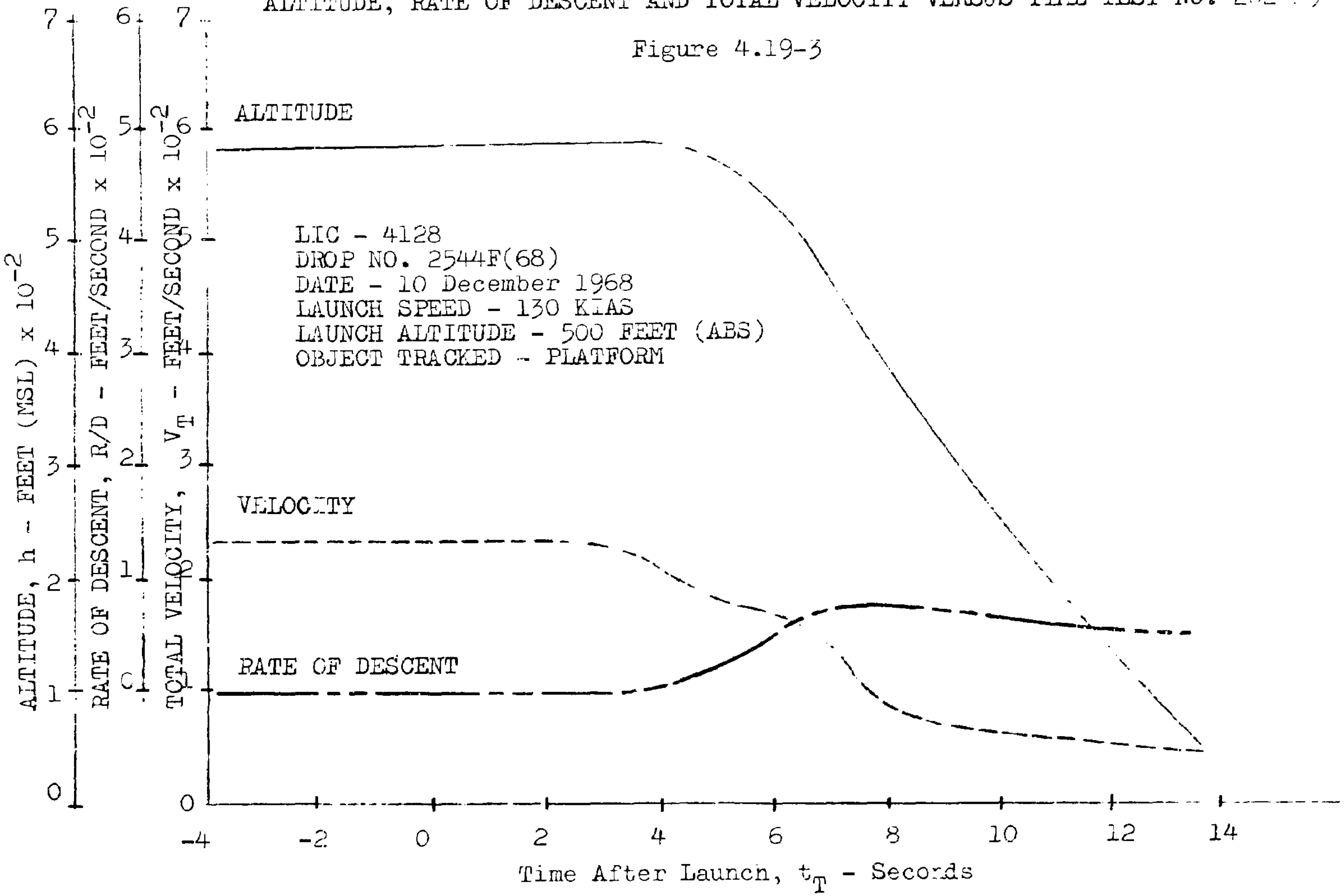

ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-19
LIC - 4128
DROP NO. 2544F(68)
DATE - 10 December 1968
LAUNCH SPEED - 130 KIAS
LAUNCH ALTITUDE - 500 FEET (ABS)
OBJECT TRACKED - PLATFORM
ALTITUDE, h - FEET (MSL) x 10^-2
Horizontal Distance From Launch, X - Feet x 10^-2
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16

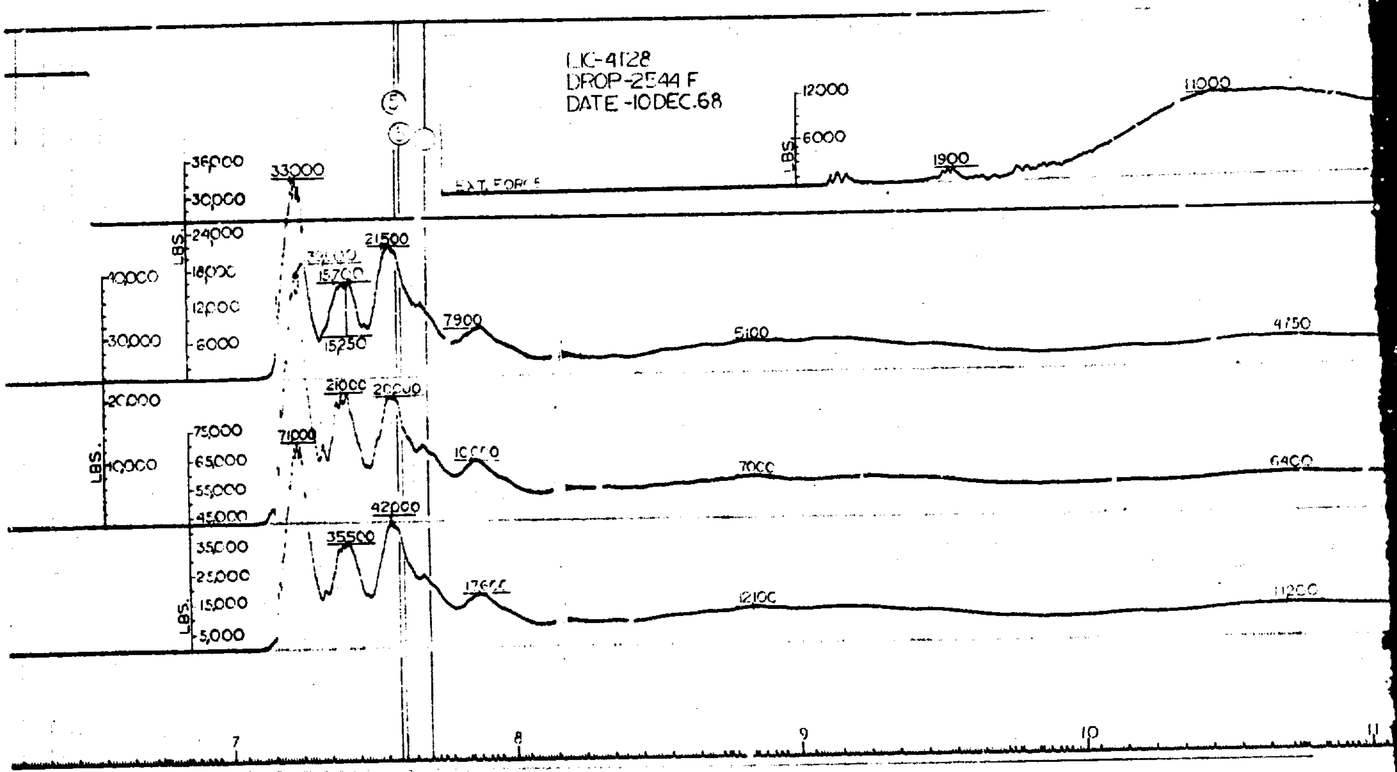
Figure 4.19-2

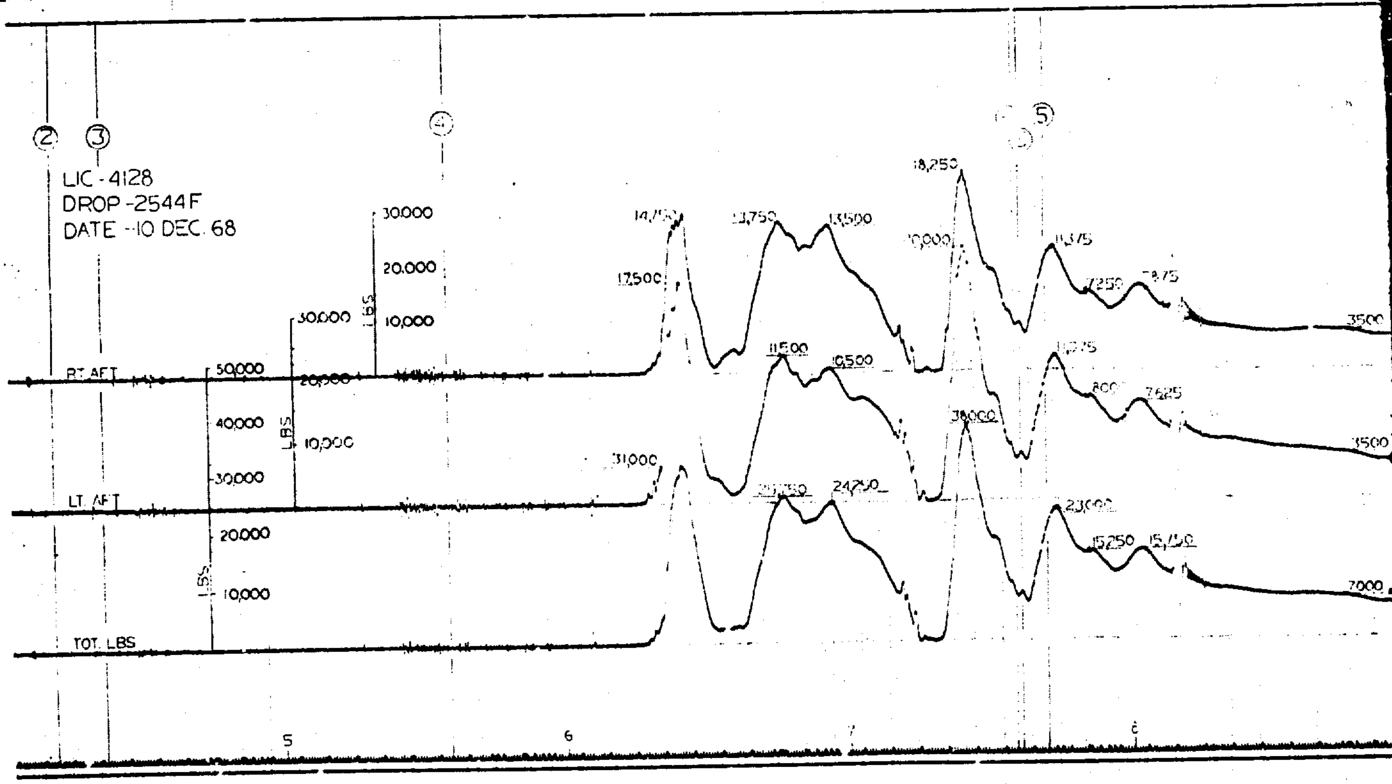
ALTITUDE, RATE OF DESCENT AND TOTAL VELOCITY VERSUS TIME TEST NO. 202-19

Figure 4.19-3



a


LIC-4128
DROP-2544 F
DATE -10 DEC. 68
EXT. FORCE
LBS.
33000
21500
7900
5100
4750
1900
11000
42000
35500
12100
11200


LIC-4128
DROP-2544 F
DATE -10 DEC. 68
RT. AFT
LT. AFT
TOT. LBS
LBS.
18,250
3500
7000

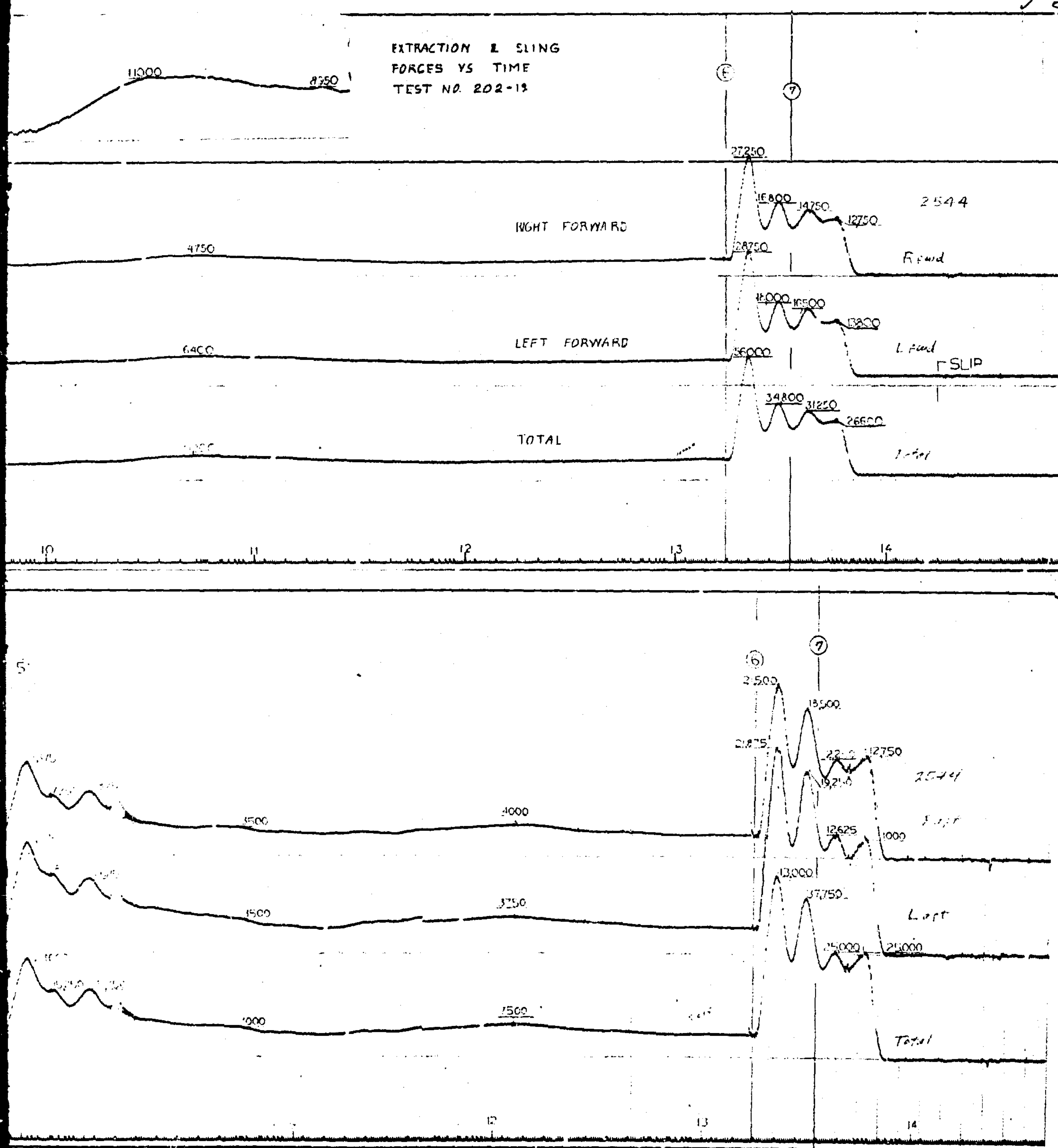

EXTRACTION & SLING
FORCES VS TIME
TEST NO. 202-13
11000
8950
27250
16800
14750
12750
2544
RIGHT FORWARD
4750
28750
R fwd
16000
16500
13800
LEFT FORWARD
6400
36000
L fwd
SLIP
34800
31250
26600
TOTAL
Total
10
11
12
13
14
21500
13500
21875
12750
2544
19250
1500
4000
12625
1000
13000
37750
Left
1500
3250
25000
25000
1000
7500
Total
12
13
14

FIGURE 4.19-4

4.20 Test No:

SAEC 202-20, Air Force 2601-F-68

Test Date:

16 December 1968

Purpose:

To investigate the performance envelope of the 35,000 lb system. Primary emphasis will be on flight safety, rigging techniques.

Conditions and Procedures:

The 35,000 lb. gross rigged weight drop test load was extracted by dual 28 foot D_0 ringslot extraction parachutes. The test load had a suspended weight of 32,300 lbs. The requested release altitude was 600 feet absolute and the requested release airspeed was 137 knots indicated. The actual release altitude and airspeed were 646 feet absolute and 150.5 knots indicated respectively. After force transfer, the extraction parachute deployed a cluster of seven, 46 foot D_0 flat circular parachutes. The cluster parachute risers were 53 feet long. In this drop the cluster parachutes were reefed to 24 feet diameter. Line cutters activated at complete parachute suspension line stretch disreefed the parachutes after a two second interval.

Results:

Test 202-20 performed satisfactorily but lost one parachute out of the cluster of seven. This parachute failure was due to a riser extension which apparently failed due to a simple overload. This riser was constructed of six ply type 10, 8700 lbs. per ply tensile strength webbing. Peak forces in each suspension sling were:

Right front:	1.03 G
Left front:	.92 G

Right rear: .80 G
Left rear .87 G

Event times are taken using the first sighting of the extraction parachute as T_0:

Load off ramp - 4.26 seconds
Extraction force transfer - 4.31 seconds
Deployment bags separated from apexes - 5.56 seconds
Recovery parachutes full open average inflation time - 8.57 seconds
Load impact - 13.73 seconds
Vertical impact velocity - 57 fps

Conclusions and Recommendations:

Drop 202-20 demonstrated successful recovery of the 35,000 lb. load. There were no problems related to aircraft safety. It was decided to proceed to a live 35,000 lb. test based on the information gained in this test.

4.21 Test No.:

SAEC 202-21, Air Force 2587-F-68

Test Date:

19 December 1968

Purpose:

To demonstrate system performance at the 18,000 lb. weight range. Dual large rocket packs were used to demonstrate the large load range concept.

Conditions and Procedures:

Drop No. 202-21 was a live rocket 18,000 lb gross rigged weight system test. Suspended weight was 16,000 lbs. A 22 foot tub mounted on a 24 foot modular platform was extracted by a 28 foot

D_o ringslot extraction parachute. After force transfer a cluster of four 46 foot D_o flat circular parachutes were conventionally deployed. The cluster parachute risers were 45 feet long. The requested release altitude was 500 feet absolute. The requested release airspeed was 130 knots indicated. The actual release altitude and airspeed were 436 feet absolute and 122.5 knots indicated respectively. During descent the load was suspended by four equal length suspension slings of 8 ply, type 26 webbing (15,000 lbs. per ply) 24 feet long including strain links. Two large rocket packs were used with nine SK2000-1001 rocket motors mounted in each rocket pack. The rocket ignition system used had a 28 foot probe reelout length and a two second delay between the first and the second probe.

Results:

Test 202-21 successfully demonstrated performance of the PRADS at the 18,000 lb. weight range. There were no problems with performance or system hardware. Maximum forces in the suspension slings from the parachute system were as follows:

Right front:	1.34 G
Left front:	1.27 G
Right rear:	1.23 G
Left rear:	1.15 G

Maximum forces in the suspension slings due to the rockets was:

Right front:	1.55 G
Left front:	1.51 G
Right rear:	No data
Left rear:	1.53 G

Event times are taken using the first sighting of the extraction parachute as T_o:

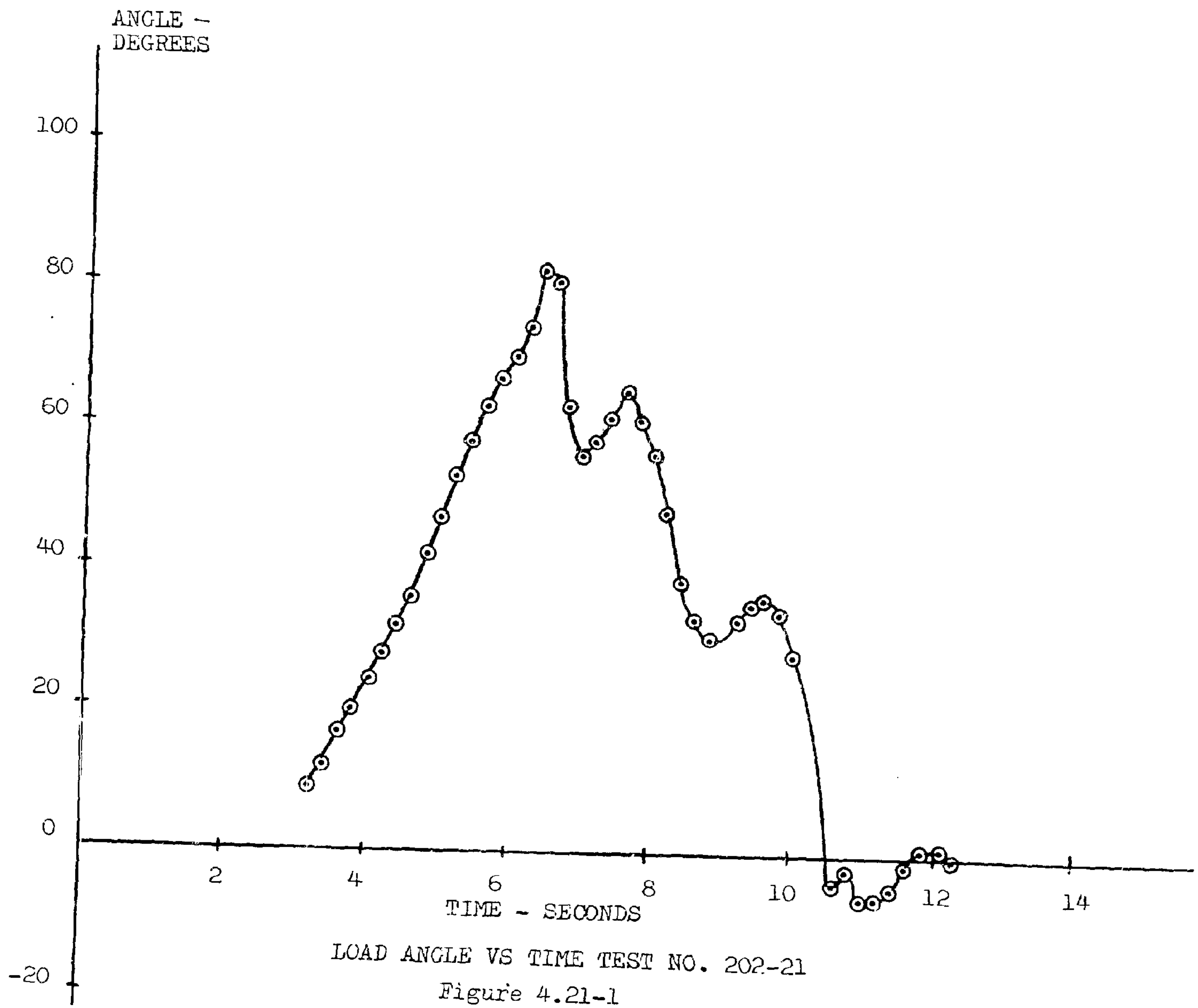
Load off ramp - 3.95 seconds
Extraction force transfer - 4.13 seconds
Deployment bags separated from apexes - 5.43 seconds
Recovery parachutes full open average - 7.67 seconds

Rockets fire - 11.64 seconds
Load impact - 12.35 seconds
Impact velocity - 27 fps

Reference Figures 4.21-1 through 4.21-4 for force versus time, altitude versus time, rate of descent versus time, total velocity versus time, and altitude versus horizontal distance curves, for an 18,000 pound live system test, and a load angle versus time curve.

Conclusions and Recommendations:

This test was completely satisfactory. No changes are recommended for this test configuration.

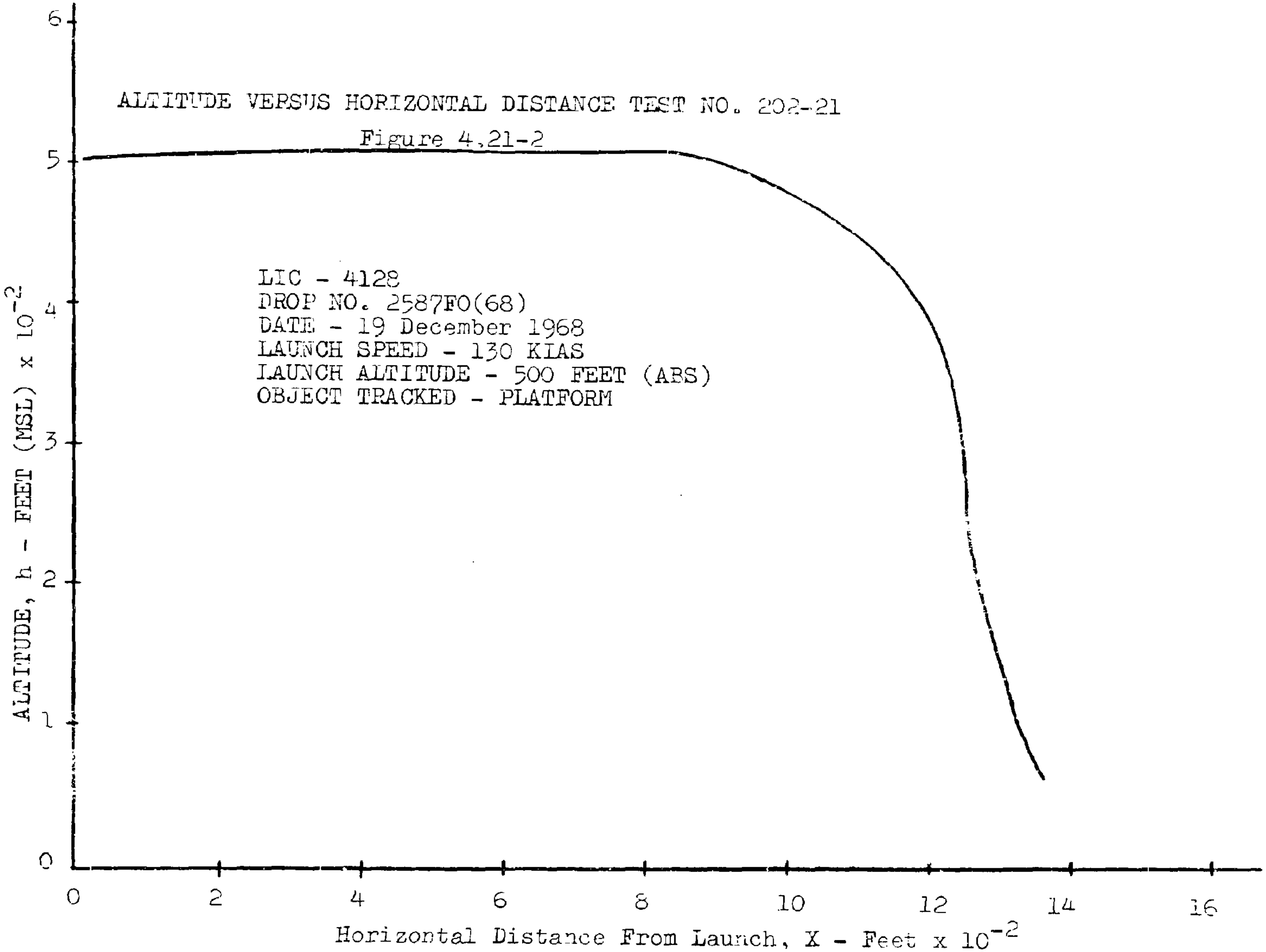


LOAD ANGLE VS TIME TEST NO. 202-21

Figure 4.21-1

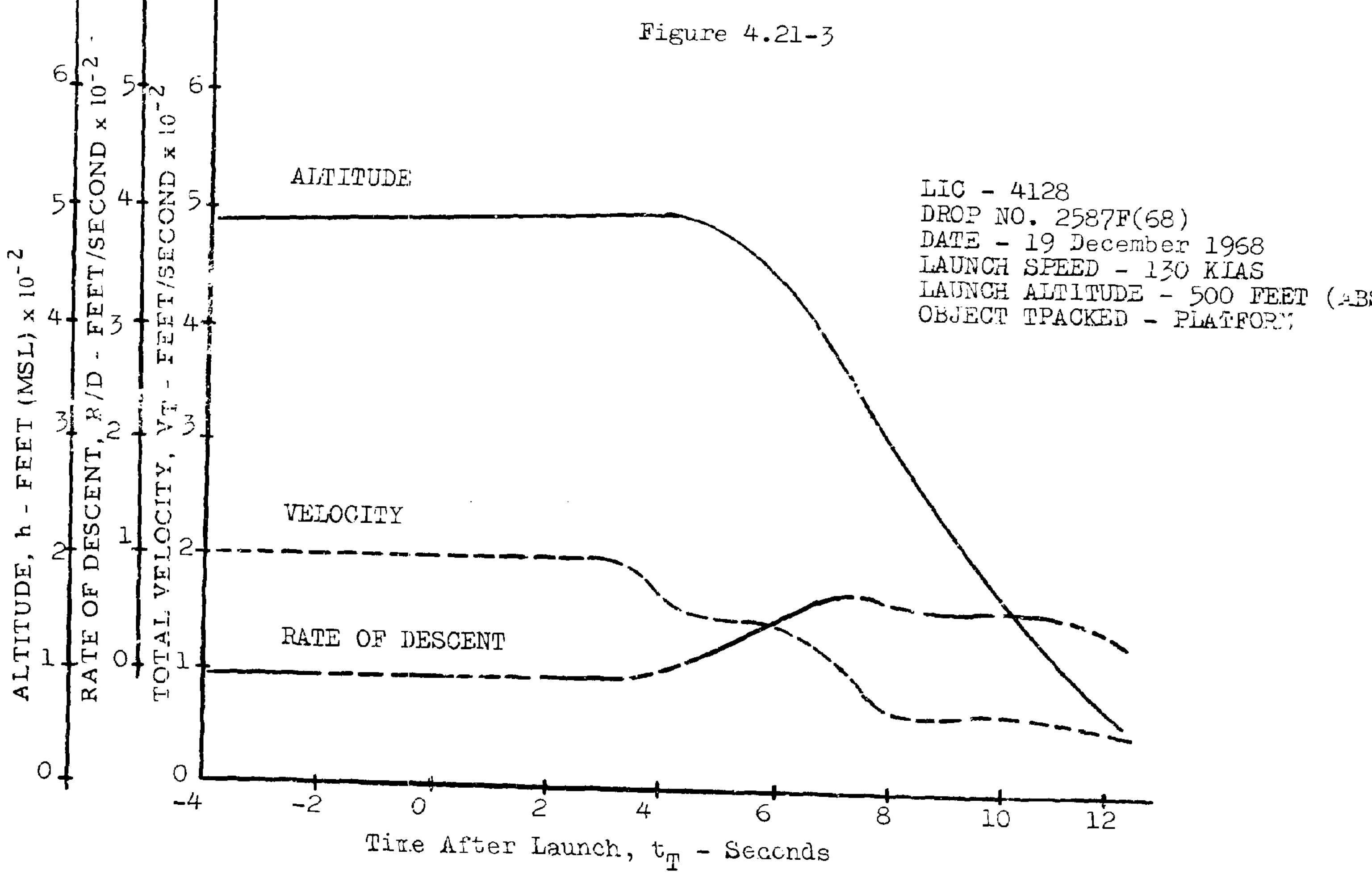
ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-21

Figure 4.21-2

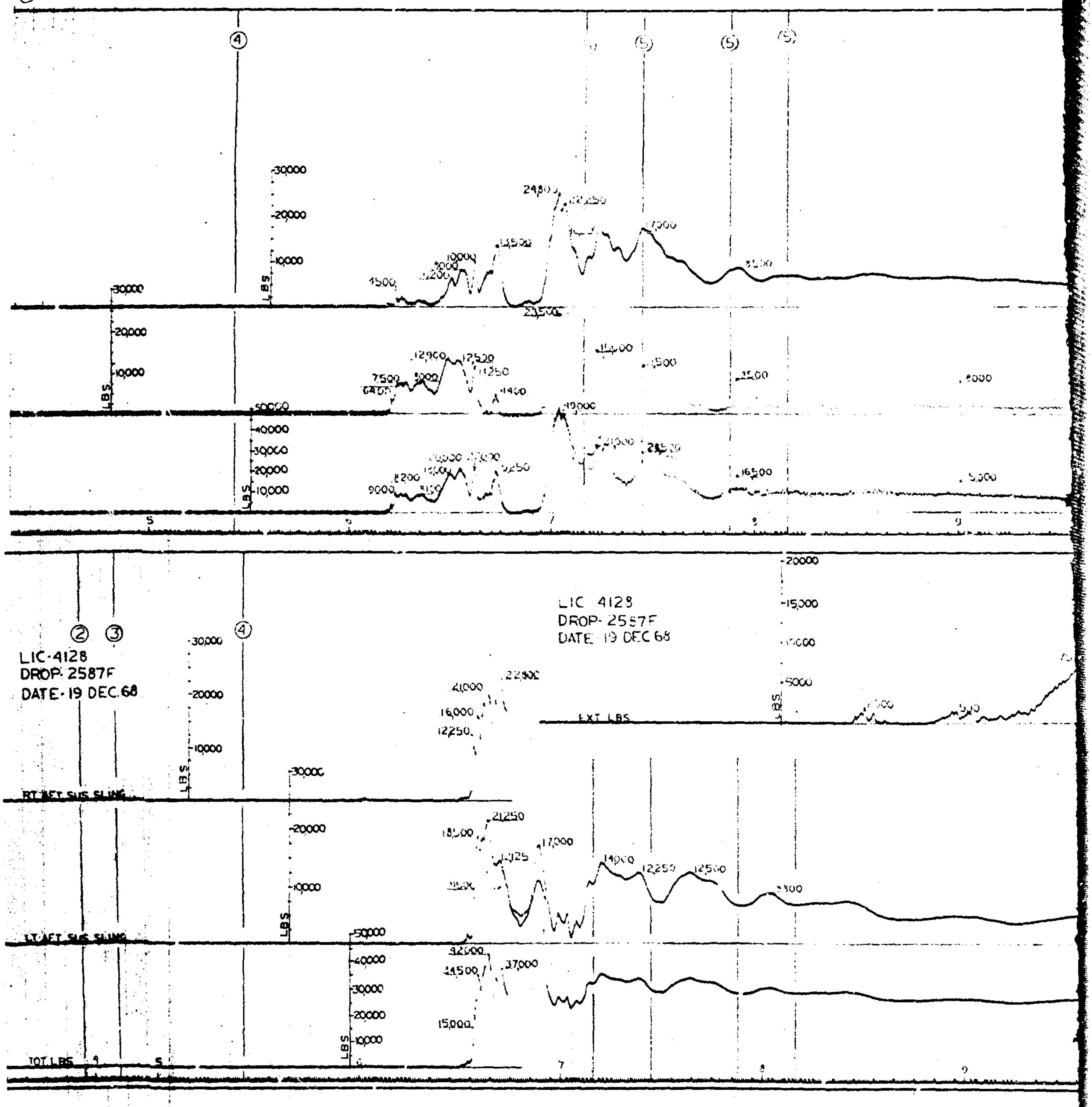


ALTITUDE, RATE OF DESCENT AND TOTAL VELOCITY VERSUS TIME TEST NO. 202-21

Figure 4.21-3



a



LIC-4128
DROP-2587F
DATE-19 DEC. 68
LIC 4128
DROP-2587F
DATE 19 DEC 68
RT AFT SUS SLING
LT AFT SUS SLING
TOT LBS
EXT LBS
LBS

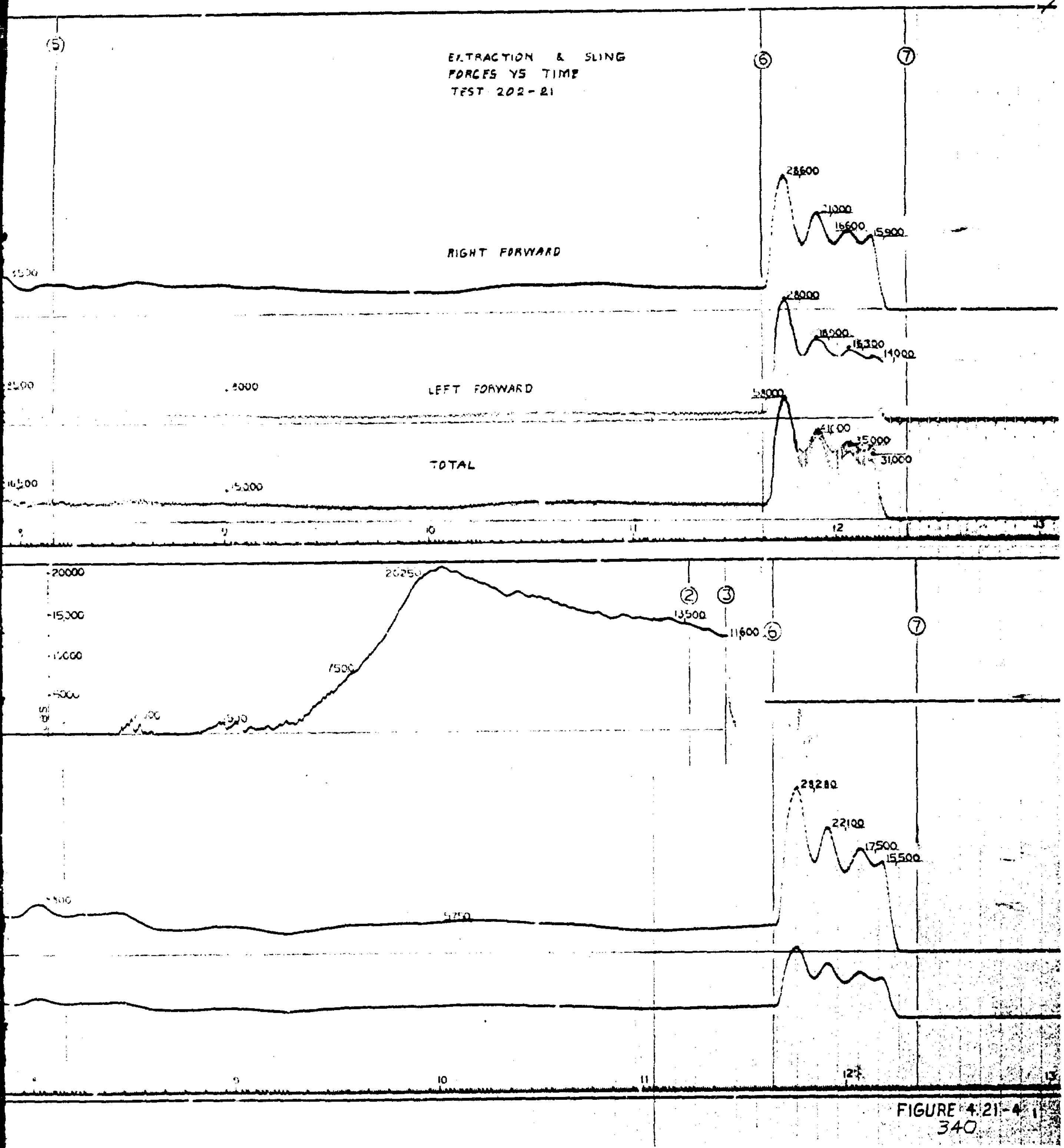


FIGURE 4.21-4
340

4.22 Test No.:

SAEC 202-22, Air Force 2609-F-68

Test Date:

27 December 1968

Purpose:

To demonstrate system operation at the large load range level.

Conditions and Procedures:

Drop No. 202-22 was a live rocket system test having a gross rigged weight of 24,000 lbs. The suspended weight of the test load was 21,200 lbs. The 22 foot weight tub mounted on a 24 foot long modular platform was extracted by a 28 foot ringslot extraction parachute. After force transfer a cluster of five, 46 foot D_o flat circular parachutes were conventionally deployed. The cluster parachute risers were 53 feet long. The requested release altitude and airspeed were 500 feet absolute, and 130 knots indicated. The actual release altitude and airspeed were 473 feet absolute and 120 knots indicated respectively. During descent the load was suspended by four equal length suspension slings of eight ply, type 26 webbing, 15,000 lbs. per ply, 24 feet long including strain links.. Two large rocket packs were used each holding twelve SK2000-1001 rocket motors. The rocket ignition system used had a 28 foot probe reelout length and a two second delay between the release of the first probe and the second probe.

Results:

Test 202-22 successfully demonstrated performance of the PRADS at the 24,000 lb. weight range. System stability was excellent during descent and rocket burning. In the lower rocket pack one of two FIB timers used to delay arming of the gas shuttle valves until the load is well cleared of the drop aircraft (approximately 4 seconds after force transfer) failed to exert enough force to break a safety tie and so did not arm one gas valve on the lower rocket pack. The other valve functioned and both valves operated in the upper rocket pack. No explanation is available for the low force from the FIB timers. Maximum forces in the suspension slings from the parachute system were as follows:

Right front:	.96 G
Left front:	1.05 G
Right rear:	1.04 G
Left rear:	1.06 G

Maximum forces in the suspension slings from the retrorockets were as follows:

Right front:	1.55 G
Left front:	1.75 G
Right rear:	1.08 G
Left rear:	1.03 G

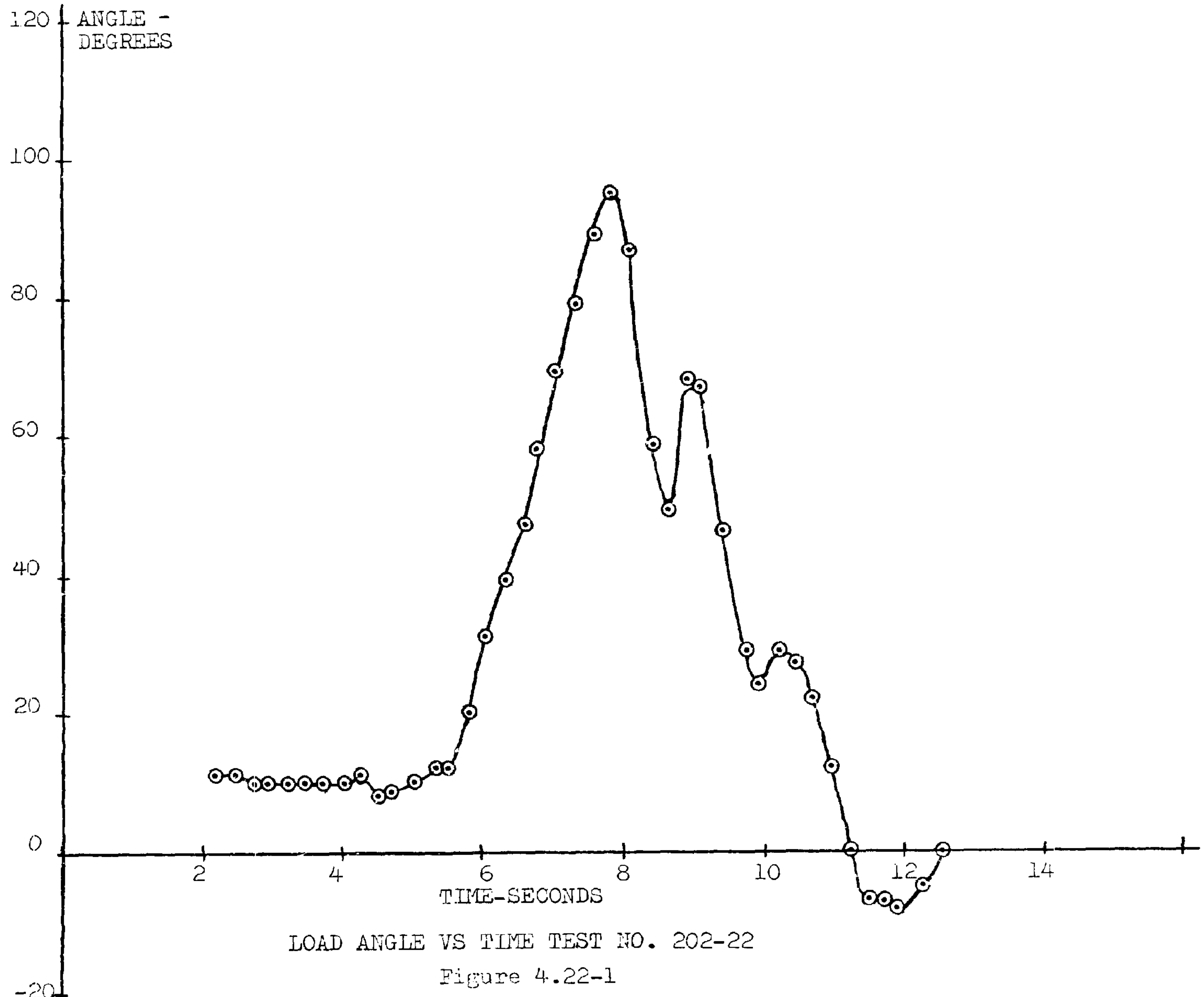
The parachute suspension sling forces were all well within the 1.5 G maximum force per attachment point limit. The rocket sling forces were slightly over the 1.5 G maximum limit. Event times are taken using the first sighting of the extraction parachute as T_0:

Load off ramp - 4.53 seconds
Extraction force transfer - 4.75 seconds
Deployment bags separated from apexes - 6.20 seconds
Recovery parachutes full open average - 8.45 seconds
Rocket fire - 11.90 seconds
Load impact - 12.55 seconds
Impact velocity - 20 fps

Reference Figures 4.22.1 through 4.22.4 for typical force versus time, altitude versus time, rate of descent versus time, total velocity versus time, and altitude versus horizontal distance curves for a 24,000 pound live system test, and a load angle versus time curve.

Conclusions and Recommendations:

This drop was completely successful. No system or rigging changes are recommended for this test configuration. Removal of the FIB timer is recommended for future applications.

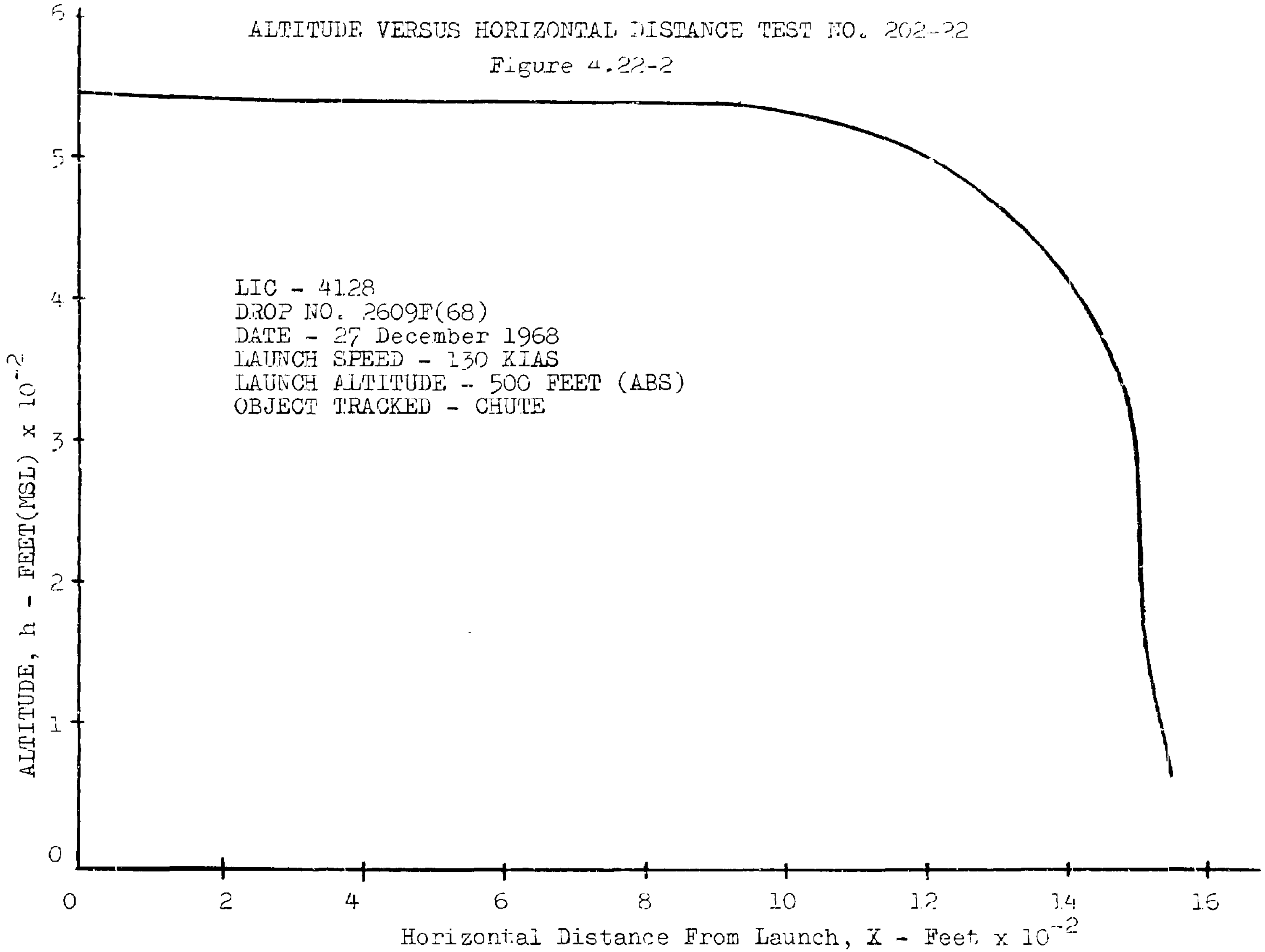


LOAD ANGLE VS TIME TEST NO. 202-22

Figure 4.22-1

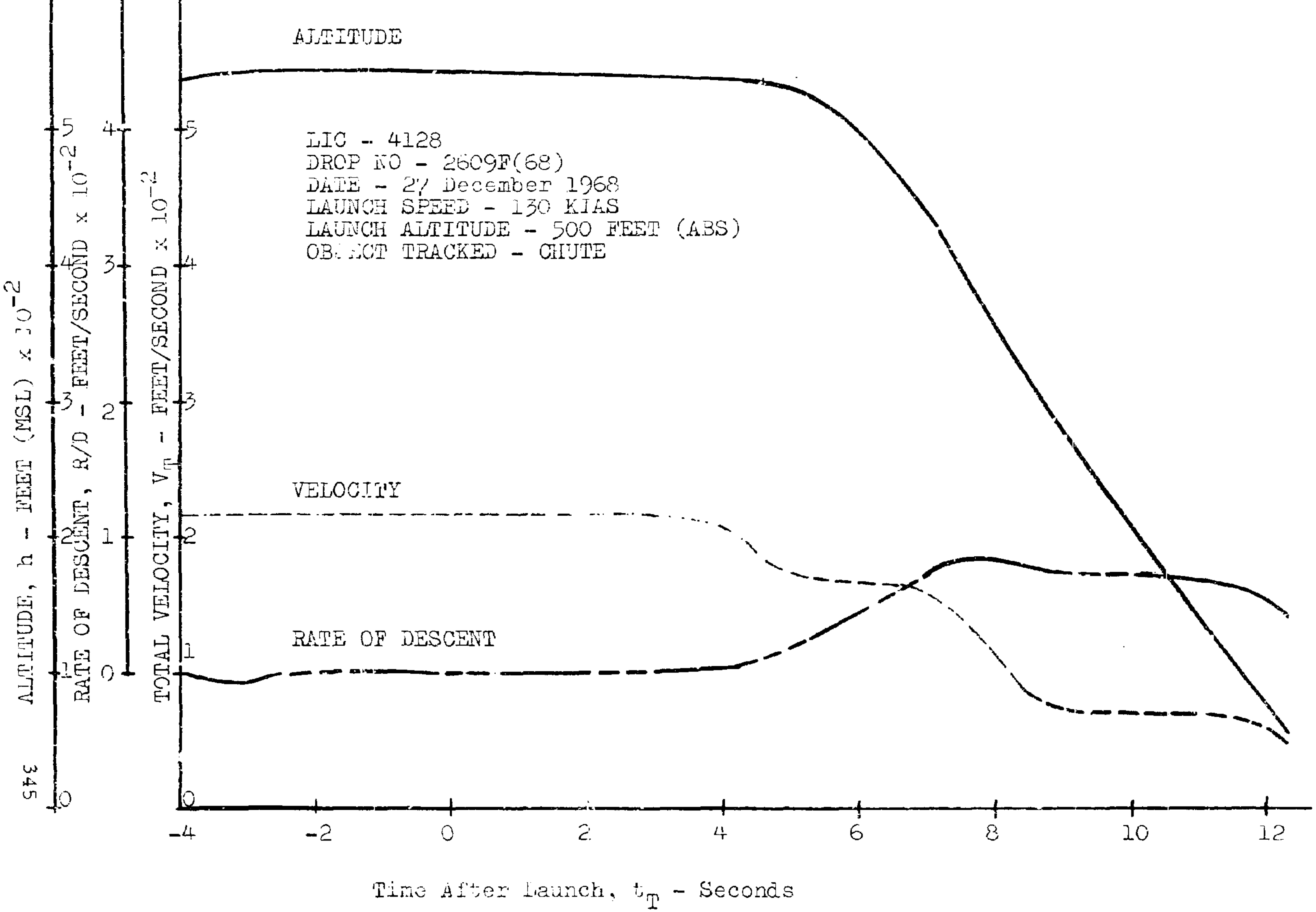
ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-22

Figure 4.22-2

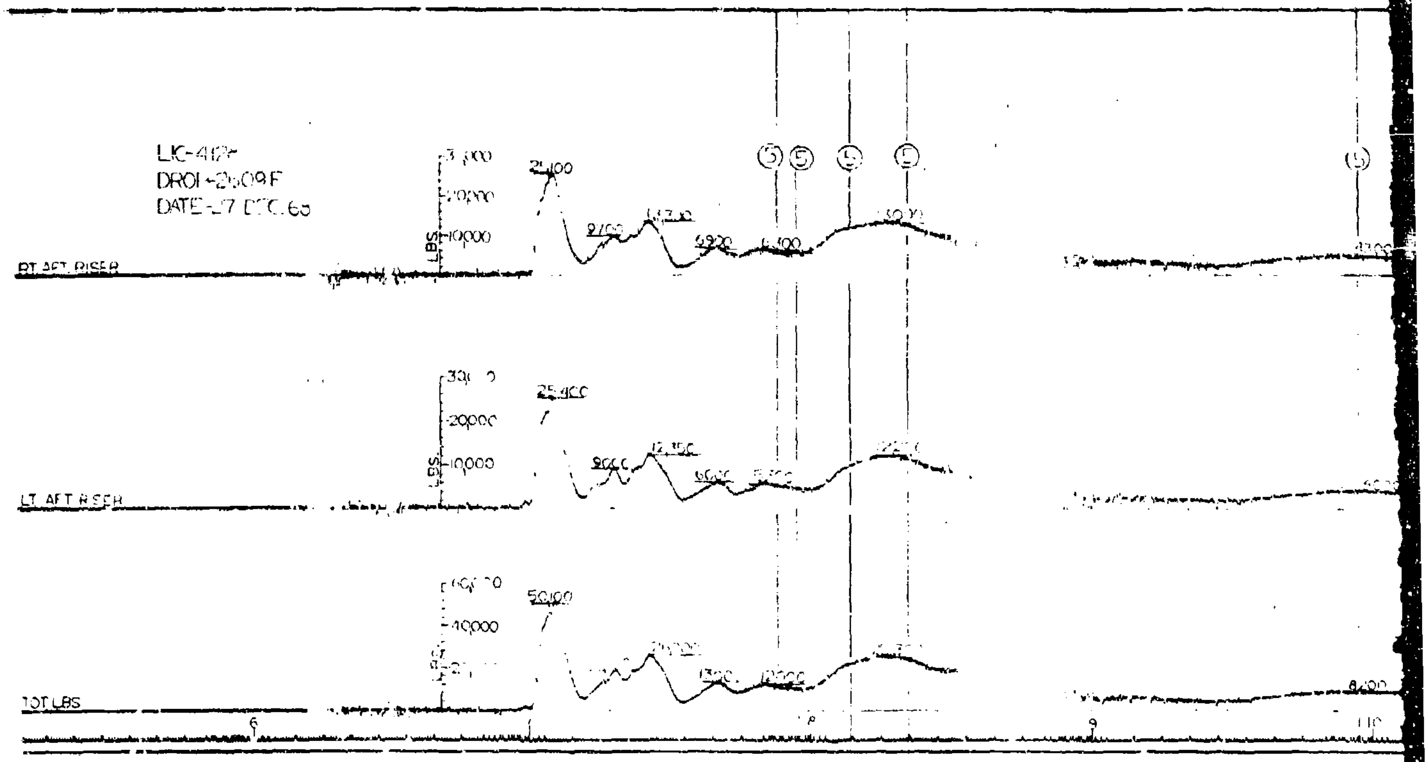


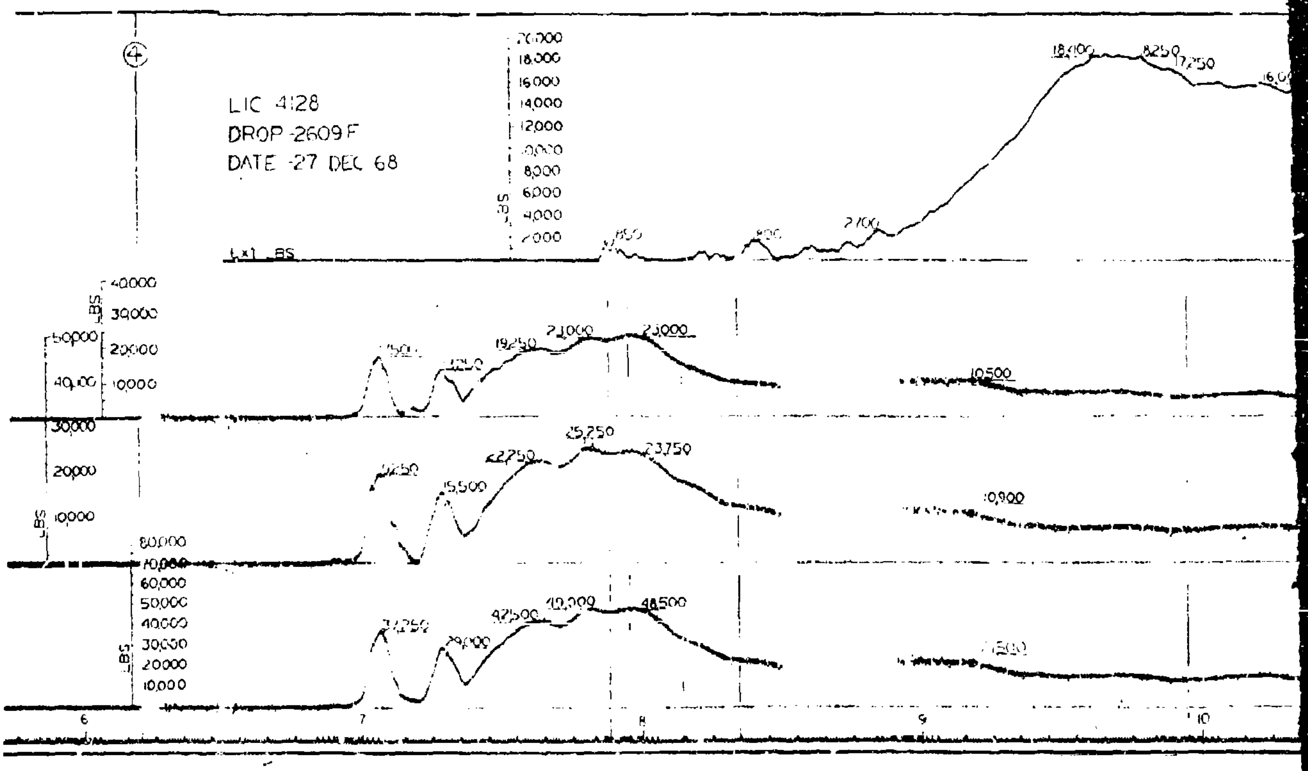
ALTITUDE, RATE OF DESCENT AND TOTAL VELOCITY VERSUS TIME TEST NO. 202-22

Figure 4.22-3



a


LIC-4128
DROP-2609 F
DATE-27 DEC 68
RT AFT RISER
LT AFT RISER
TOT LBS
LBS
10,000
20,000
25,400
50,000
40,000


LIC 4128
DROP-2609 F
DATE -27 DEC 68
LBS
20,000
18,000
16,000
14,000
12,000
8,000
6,000
4,000
2,000
40,000
30,000
20,000
10,000
80,000
60,000
50,000
19,250
21,000
23,000
10,500
25,250
23,750
15,500
10,900
42,500
48,500
18,100
17,250

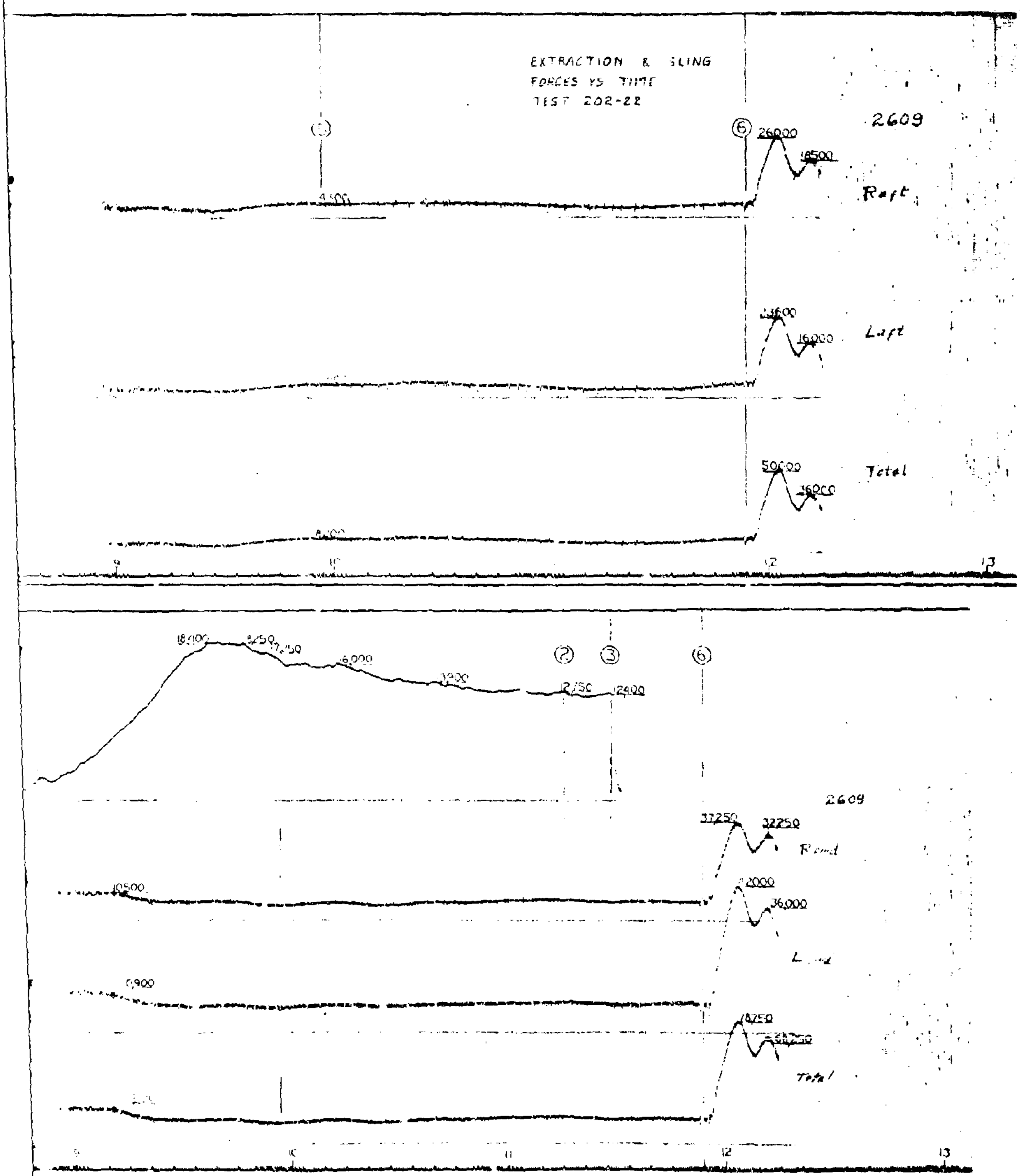

EXTRACTION & SLING
FORCES VS TIME
TEST 202-22
2609
26000
18500
16000
50000
36000
18,100
16,000
12,750
12400
2609
32250
32250
36,000
10500
9
10
11
12
13

FIGURE 4.22-4

4.23 Test No.:

SAEC 202-23, Air Force 2623-F-68

Test Date:

2 January 1969

Purpose:

To demonstrate system operation at the largest load level.

Conditions and Procedures:

Drop No. 202-23 was a large rocket system test having a gross rigged weight of 35,000 lbs. Suspended weight was 32,700 lbs. The 22 foot weight tub mounted on a 24 foot long modular platform was extracted by two 28 foot ringslot extraction parachutes. After force transfer a cluster of seven, 46 foot D_0 flat circular parachutes were conventionally deployed. The cluster parachute risers were 53 feet long. The cluster parachutes were reefed at 24 foot diameter. Disreefing was activated by two second delay line cutters fired at complete parachute suspension line stretch. The requested release altitude and airspeed were 500 feet absolute and 137 knots indicated, respectively. The actual release altitude and airspeed were 443 feet absolute and 138.5 knots indicated respectively. During descent the load was suspended by four dual equal length suspension slings of eight ply type 26 webbing, 15,000 lbs. per ply, 24 feet long including strain links. Two large rocket packs were used each holding sixteen SK2000-1001 rocket motors. The rocket ignition system used had a 28 foot probe reelout length and a two second delay between the release of the first and the second probe.

Results:

Two parachutes broke away, one riser failed, and one riser adaptor failed. The riser adaptor failed because of improper stitching at the connector link attachment loops. The type 10 riser failed apparently because of an overload. There was moderate parachute damage. The delayed probe had not reeled out all the way since the load impacted early because of the lost parachutes. The MDF cut itself off in this break and did not transfer to the CDF. The other ignition signal assembly successfully ignited the rockets. The load impacted aft end first and with the rockets still burning when all the force went on to the front slings, the load overturned backwards. There was a secondary fire in the energy absorbing cardboard, as a result of flame impingement on this drop. Maximum forces in the suspension slings from the parachute system were as follows:

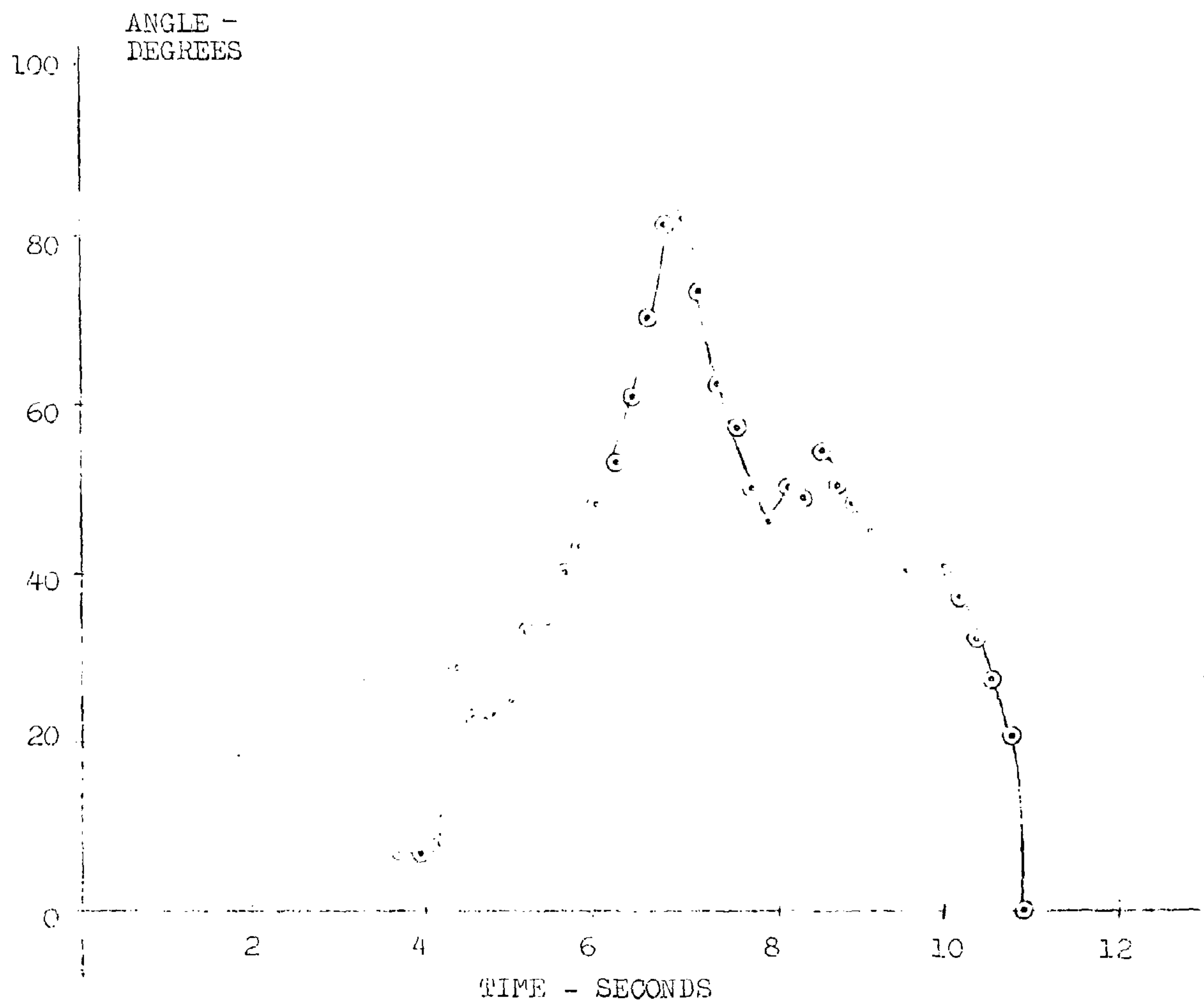
Right front:	.91 G
Left front:	1.01 G
Right rear:	.83 G
Left rear:	.83 G

Maximum forces in the suspension slings and the retrorockets were as follows:

Right front:	1.92 G
Left front:	2.25 G
Right rear:	1.25 G
Left rear:	1.24 G

See Figure 4-23 for a load angle versus time curve. The parachute suspension forces were all well within the 1.5 g maximum force per attachment point limit. The rocket sling forces were over the limit. Event times are taken using the first sighting of the extraction parachute as T_O:

- Load off ramp - 4.40 seconds
- Extraction force transfer - 4.50 seconds
- Deployment bags separated from apexes - 5.77 seconds
- Recovery parachutes full open average - 8.38 seconds
- Rockets fire - 10.68 seconds
- Load impact, obscured - No data
- Impact velocity - 45 fps



LOAD ANGLE VS TIME TEST NO. 202-23

Figure 4.23

Conclusions and Recommendations:

This drop was unsuccessful. It is recommended that riser adaptors be modified to assure the proper manufacturing techniques. It is further recommended that the riser extensions be fabricated of stronger webbing before repeating this test

4.24 Test No.:

SAEC 202-24 Air Force 0003-F-69

Test Date:

8 January 1969

Purpose:

The purpose was to test an anti-oscillation parachute on a test load that had proven most likely to be marginal in load stability, the 14,000 lb. load. (Tests 202-14 and 202-19) This test was to also provide a test bed for a cross beam laser ignition system and was fabricated by Motorola, Government Electronics Division, Aerospace Center.

Conditions and Procedures:

Drop No. 202-24 was an inert rocket system test having a gross rigged weight of 14,000 lbs The suspended weight of the test load was 12,900 lbs. A 22 foot load mounted on a 24 foot modular platform was extracted by a 22 foot D_o ringslot extraction parachute. After force transfer, three, 46 foot D_o flat circular cluster parachutes were deployed by the separating extraction parachute. The cluster parachute risers were 45 feet long. The requested release altitude and airspeed were 500 feet absolute and 130 knots indicated. The actual release altitude and airspeed were 450 feet absolute and 130 indicated During descent the load was suspended by four equal length suspension slings of type 10 webbing 8700 lbs per ply, 24 feet long including strain links. The laser system installation is shown in Figure 4.24.

LASER SYSTEM INSTALLATION
Figure 4.24

The laser was adjusted to fire two flash bulbs at a height of 25 feet above the ground. The anti-oscillation parachute was mounted on one cluster riser, utilizing the riser as a parachute centerline. The sixteen foot D_O anti-oscillation parachute was stowed in the riser compartment of one of the main cluster parachutes.

Results:

This test was successful. Load recovery was satisfactory and there was no damage to the test vehicle. The laser ignition system functioned perfectly with the flash bulbs firing at a height of 24.8 feet above the ground. It was impossible to determine if there was any effect from the anti oscillation parachute. Parachute force in the suspension slings were as follows:

Right front:	.76 G
Left front:	.89 G
Right rear:	.96 G
Left rear.	1.38 G

These forces are well within the 1.5 G per attachment point maximum allowable force. Event data is taken using the first sighting of the extraction parachute as T_O:

Load off ramp - 4.51 seconds
Extraction force transfer - 4.18 seconds
Deployment bags separated from apexes - 5.48 seconds
Recovery parachutes full open average - 7.90 seconds
Laser fire - 11.08 seconds
Load impact - 11.44 seconds
Impact velocity - 60 fps

Conclusions and Recommendations:

It is recommended that investigation of an anti-oscillation parachute as tested be dropped and not pursued further on this contract. For the future PRADS system it appears that the laser ignition system will offer the best solution into rocket ignition.

4.25 Test No.:

SAEC 202-25, Air Force 0092-F-69

Test Date.

14 February 1969

Purpose:

To demonstrate system performance at the intermediate load level using an actual vehicle as the test bed.

Conditions and Procedures:

Drop No. 202-25 was a live rocket system test of a 18,600 lb. gross rigged weight drop vehicle. The test load suspended weight was 16,780 lbs. The M-215 2 1/2 ton truck was mounted on a 24 foot modular platform and was extracted by a 28 foot ringslot extraction parachute. After force transfer four, 46 foot D_O flat circular parachutes were conventionally deployed. The cluster parachute risers were 45 feet long. The requested release altitude and airspeed were 500 feet absolute and 130 knots indicated respectively. The actual release altitude and airspeed were 596 feet absolute and 134.5 knots respectively. During descent the load was suspended by suspension slings of eight ply type 10, 8700 lb. per ply or 6 ply 18 feet long rear. This length included strain links. One large rocket pack was used with 18 SK2000-1001 rocket motors mounted in it. The rocket ignition system used had a 28 foot probe reelout length and a two second delay between the release of the first and the second probe.

Results:

At full inflation of the first cluster parachute its riser failed. This was a six ply type 10 riser 8700 lbs. per ply and was the first failure occurring in a load of this weight range. Descent was otherwise normal. Ignition was normal. Immediately after ignition the truck frame buckled and permitted the load suspension slings to get into the rocket blast and be burned. As a result just at burnout the rocket pack separated from the load and landed approximately 200 feet away. There was minor damage to the rocket pack. The truck was destroyed by the failure of the frame and the excessive impact velocity resulting. Maximum force in the suspension slings was from the parachute as follows:

Right front:	.87 G
Left front.	.86 G
Right rear:	.96 G
Left rear:	.94 G

The maximum forces in the suspension slings from the rockets were as follows:

Right front:	1.09 G
Left front:	1.02 G
Right rear:	2.15 G
Left rear:	2.15 G

See Figure 4.25 for a load angle versus time curve. The parachute suspension sling forces were all well within the 1.5 G maximum force per attachment point limit. The rocket suspension sling forces were over the 1.5G maximum force per attachment point limit. Event times are taken using the first sighting of the extraction parachute as T_0:

Load off ramp - 3.76 seconds
Extraction force transfer - 4.06 seconds
Deployment bags separated from apexes - 5.07 seconds
Recovery parachutes full open average - 7.30 seconds
Rockets fire - 13.70 seconds
Load impact obscured - No data
Impact velocity - 41 fps

Conclusions and Recommendations:

This test was unsuccessful. It appears that the overloading of the rear suspension slings caused the failure of the truck frame. This

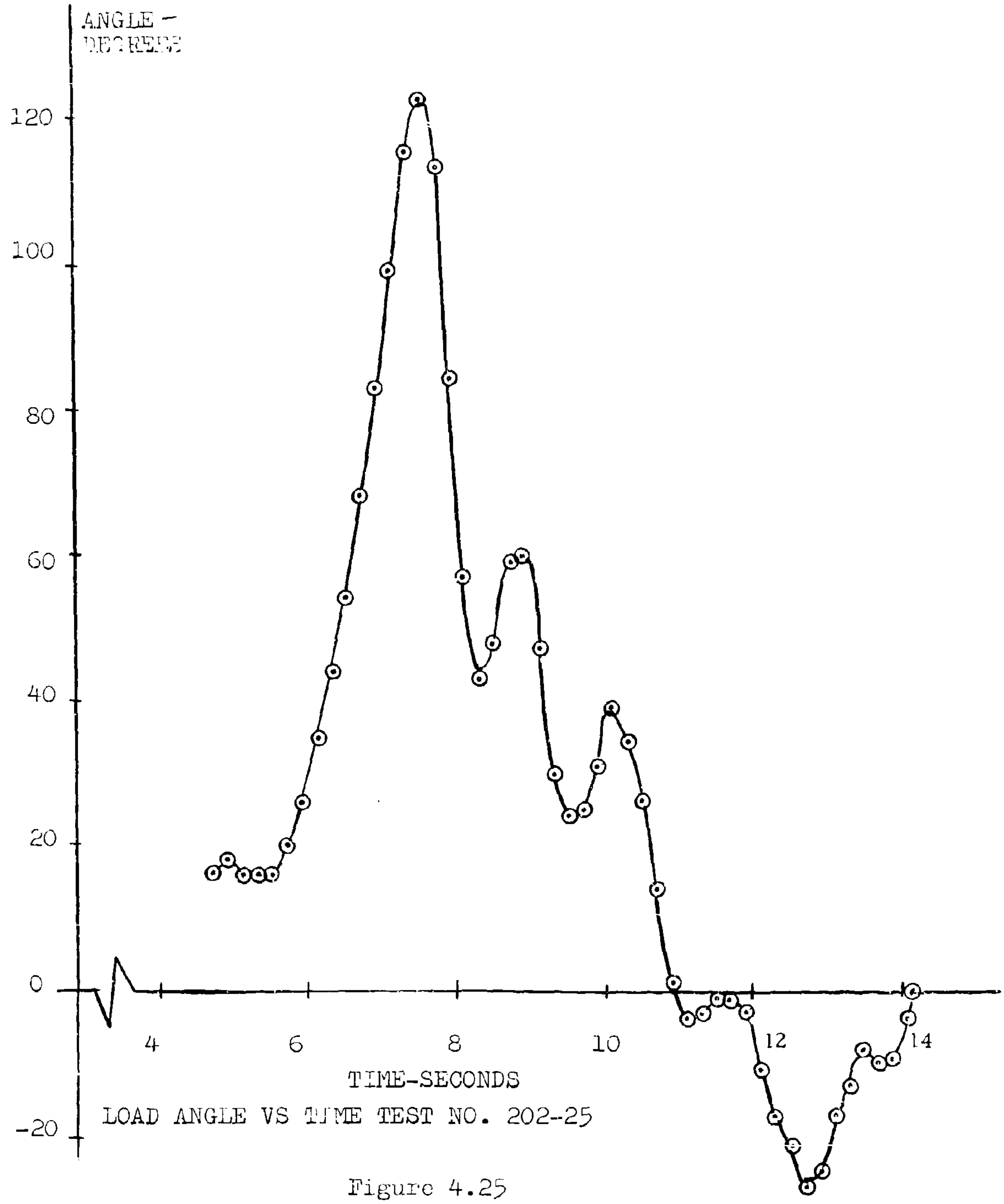

ANGLE - DEGREES
120
100
80
60
40
20
0
-20
4
6
8
10
12
14
TIME-SECONDS
LOAD ANGLE VS TIME TEST NO. 202-25

Figure 4.25

cannot be positively concluded as the truck had been used numerous times in other drop tests. It is possible that preexisting damage contributed to the failure. It is recommended that the future rocket motor be designed to eliminate the sharp ignition peak force of the present motor.

4.26 Test No.

SAEC 202-26 Air Force 0063-F-69

Test Date:

27 February 1969

Purpose:

To demonstrate system operation at the largest load range level (35,000 lbs.)

Conditions and Procedures:

Drop No. 202-26 was a live rocket system test having a gross rigged weight of 35,000 lbs. The suspended weight of the system was 31,620 lbs. The 22 foot weight tub mounted on the 24 foot long modular platform was extracted by two 28 foot ringslot extraction parachutes. After force transfer a cluster of eight, 46 foot D_O flat circular parachutes were conventionally deployed. The cluster parachute risers were 53 feet long and were fabricated of 15,000 lb. webbing as opposed to risers in past 35,000 lb. load tests fabricated of 8700 lb. webbing. The cluster parachutes were reefed to a diameter of 22 feet and were disreefed by a two second delay reefing line cutter fired at complete suspension line stretch. The requested release altitude and airspeed were 600 feet absolute and 137 knots indicated respectively. The actual release altitude and airspeed were 624 feet absolute and 138.5 knots indicated respectively. During descent the load was suspended by four dual equal length suspension slings of eight ply type 26 webbing, 15,000 lbs per ply, 24 feet long including strain links. Two large rocket packs were used each holding sixteen SK2000-1001 rocket motors. The rocket ignition system used had a 28 foot probe reelout length and a two second delay between the release of the first and the second probe.

Results:

Test 202-26 successfully demonstrated performance of the PRADS at the 35,000 lb. weight range. System stability was excellent during descent and rocket burning. In the upper rocket pack one of two FlA timers used to delay arming of the gas shuttle valves until the load is well clear of the drop aircraft approximately four seconds after force transfer failed to fire. It ran 2 1/2 seconds of a set five seconds and so did not arm one gas valve on the upper rocket pack. The other valve functioned and both valves operated in the lower rocket pack. The reason for the FlA timer failure apparently was sand and dust jamming the operating mechanism. Maximum forces in the suspension slings from the parachute system were as follows:

Right front:	.93 G
Left front:	1.03 G
Right rear:	1.00 G
Left rear:	.78 G

Maximum forces in the suspension slings from the retrorocket were as follows:

Right front:	1.42 G
Left front:	1.42 G
Right rear:	.98 G
Left rear:	1.00 G

The parachute suspension forces were all well within design limits. The rocket sling forces were also within the limit. Event times are taken using the first sighting of the extraction parachute as T_0:

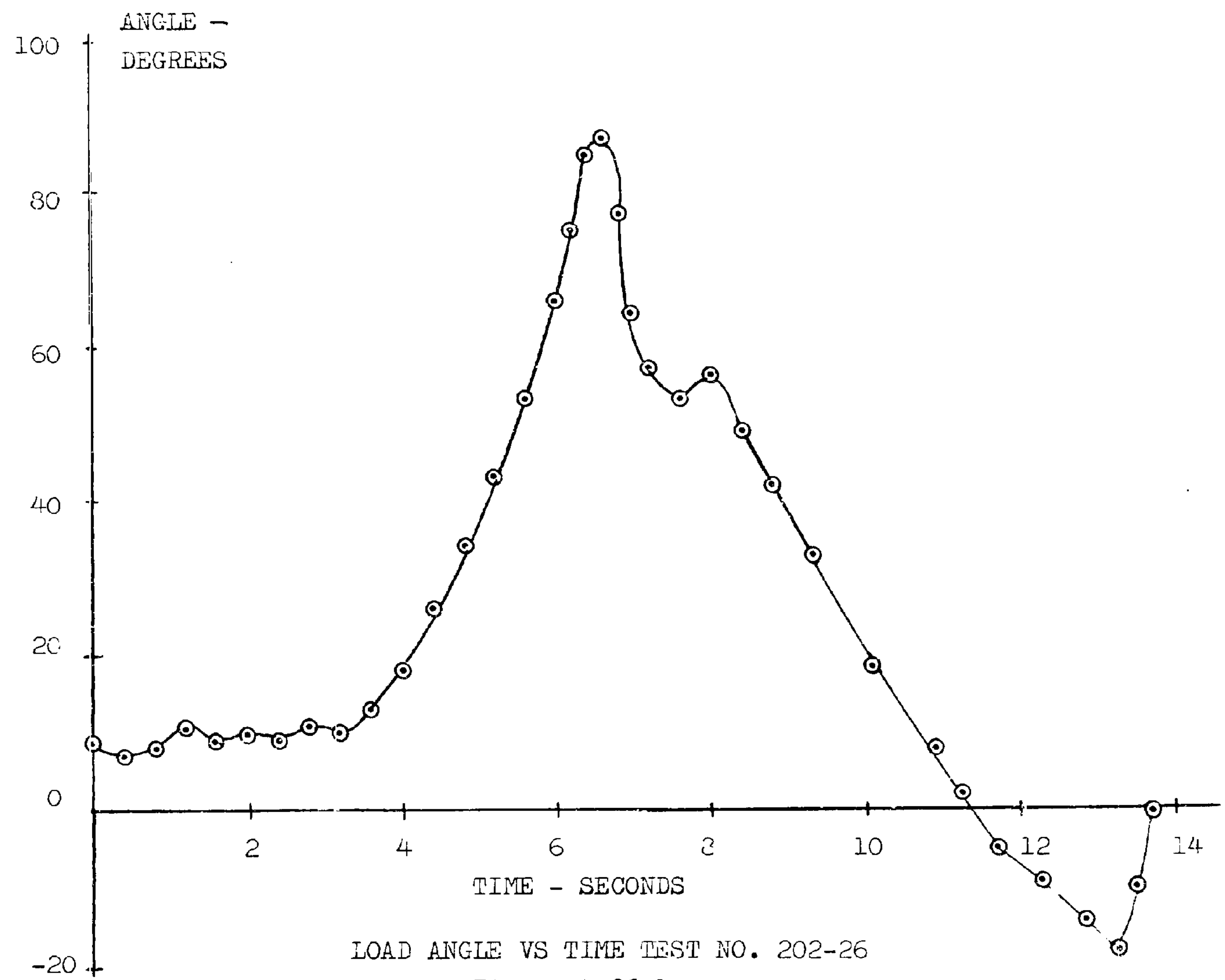
Load off ramp - 4.00 seconds
Extraction force transfer - 4.15 seconds
Deployment bags separated from apexes - 5.61 seconds

Recovery parachutes full open average - 9.58 seconds
Rockets fire - 13.31 seconds
Load impact obscured - No data
Impact velocity - 20 fps

A secondary fire resulted on this test after impact. It was caused by flame impingement on the load. Reference Appendix A for additional data on this pheonomena. Reference Figures 4.26-1 through 4.26-4 for typical force versus time, altitude versus time, rate of descent versus time, total velocity versus time, altitude versus horizontal distance curves for a 35,000 pound live system test, and a load angle versus time curve.

Conclusions and Recommendations:

This drop was completely successful. No system or rigging changes are recommended for this test configuration. The removal of the FIB or FIA timers is strongly recommended for future applications. The single rocket pack design as considered for the future program will prevent the secondary fire resulting from flame impingement on the load. Note the fact that no problems occurred on this program where the single rocket pack was used, even where there were as many as eighteen motors per pack.

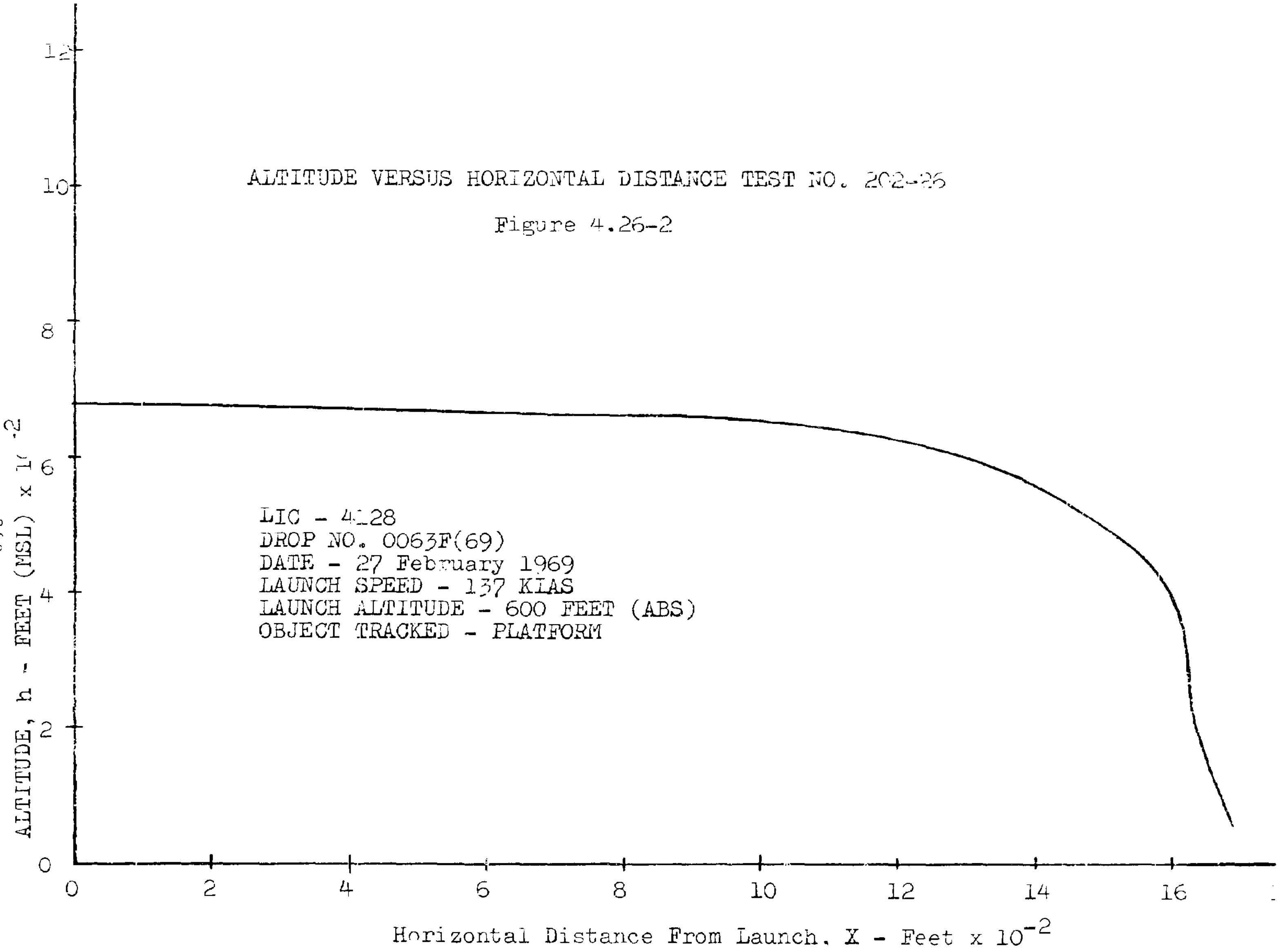


LOAD ANGLE VS TIME TEST NO. 202-26

Figure 4.26-1

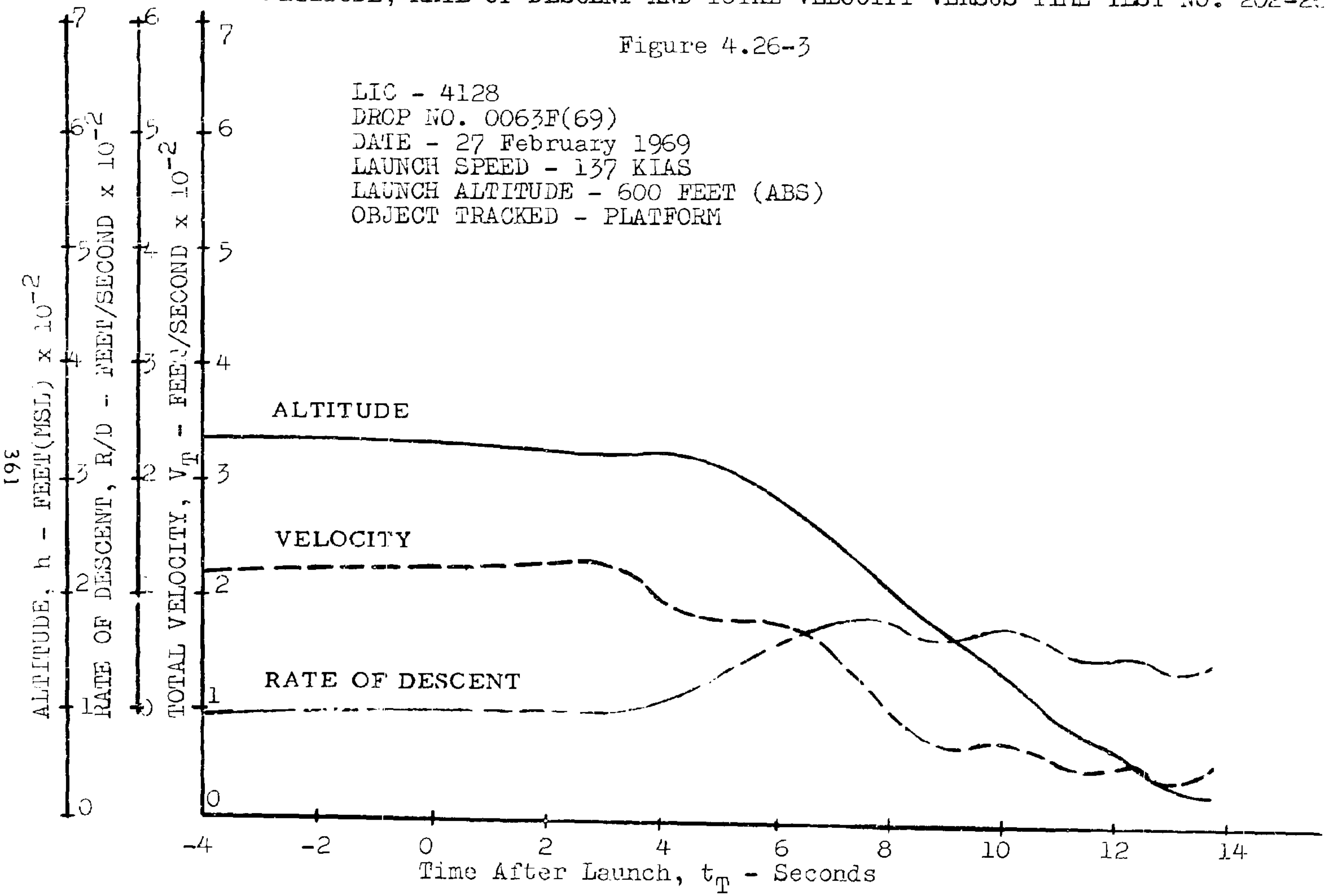
ALTITUDE VERSUS HORIZONTAL DISTANCE TEST NO. 202-26

Figure 4.26-2

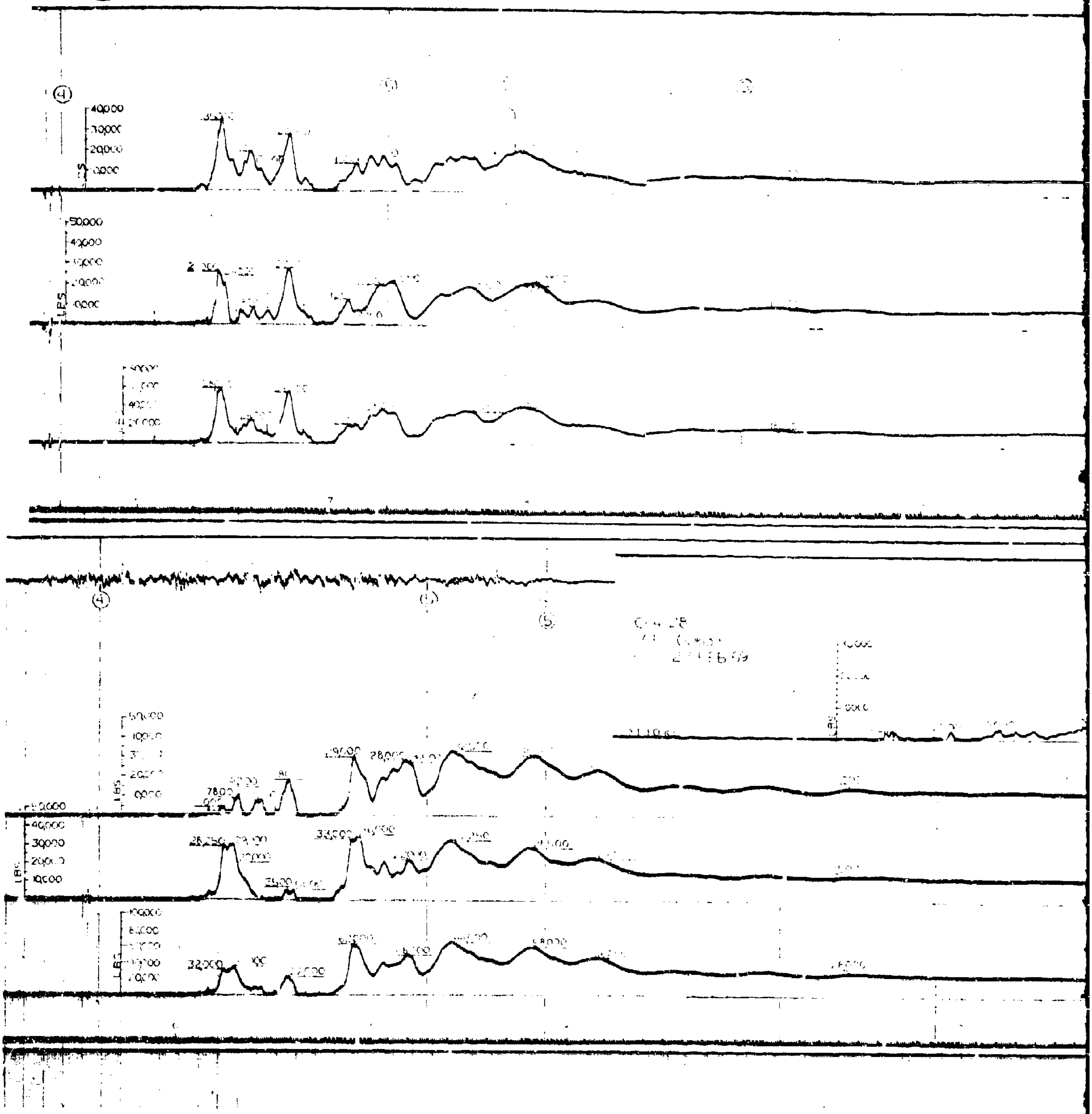


ALTITUDE, RATE OF DESCENT AND TOTAL VELOCITY VERSUS TIME TEST NO. 202-26

Figure 4.26-3



a



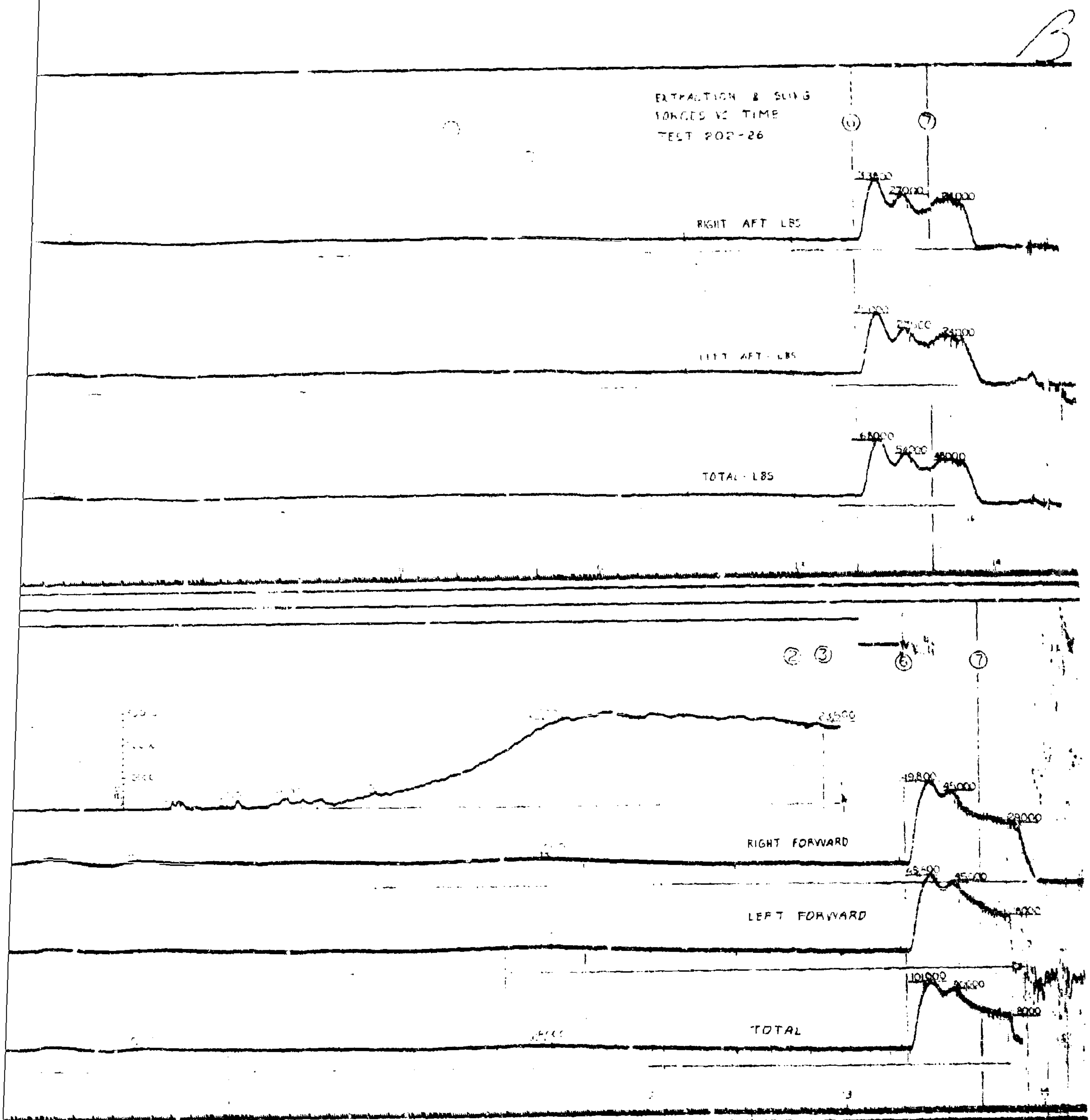

EXTRACTION & SLING
FORCES VS TIME
TEST 202-26
RIGHT AFT LBS
27000
24000
LEFT AFT LBS
TOTAL LBS
68000
54000
48000
RIGHT FORWARD
45000
28000
LEFT FORWARD
TOTAL
101000

FIGURE 4.26-4

5.0 SUMMARY

The test program conducted on the PRADS at NAF El Centro, California, satisfactorily demonstrated system capability for recovering loads from 2000 to 35,000 pounds at airspeeds from 110-150 knots indicated airspeed, and from altitudes as low as 500 feet absolute. The major problem areas and corrective action were as follows:

5.1 Flame Impingement

On dual rocket pack tests using from twelve motors up per rocket pack some impingement on the test load was expected. This impingement was observed during tethered dynamic tests at Stencel Aero Engineering Corporation. Reference Appendix B for a description of this phoenomena. A single rocket pack configuration should eliminate the problem and this is the approach for future testing. Also, no problems were observed with a single pack configuration during system test performed on the PRADS at El Centro under the test program.

5.2 Riser Adaptors

Riser adaptor failures were another problem area. The riser adaptors causing failures were found to be manufactured of improper material, and/or by improper manufacturing practice. Corrective action consisted of assuring proper materials, and defining and inspecting manufacturing technique.

5.3 Riser Extensions

Riser extension failures were caused by material failure of the 8700 lb. per ply type 10 webbing. All risers failing were of 6 ply construction. Corrective action consisted of fabrication of six ply, 15,000 lb. per ply, type 26 riser extensions for use on PRADS testing.

5.4 Confined Detonating Fuse, CDF Braking

CDF failures occurred on three drops. These drops all had 24 foot long suspension slings, and by trying to use available CDF which was marginal in length for suspension slings 24 feet long, tensile failures of the CDF resulted. Future tests using 24 foot long suspension slings utilized a CDF junction block and an eight foot long CDF extension. The CDF extension prevented future tensile failures of the CDF units

5.5 MDF Failures to Fire

1) Safety pin locked in place. This type of failure was caused by oil expansion resulting in the safety pin being locked in. Corrective action consisted of bleeding the excessive oil from the ground sensing probe and continuing the item in service. 2) Arming lanyard fouled piston. This failure occurred on one drop resulted in the probe not arming. Corrective action consisted of reinforcement of the attachment of the arming lanyard stowage pocket and extreme care in the stowing of the arming lanyard. 3) MDF pinched by improper installation in probe housing - this type failure occurred one time and was corrected by installation of a bushing in the probe housing to prevent improper installation of the ground sensing probe. 4) MDF not all out of probe reelout brake. This type failure occurred on one test and the MDF cut itself off in the brake and did not transfer to the CDF. This type failure, although a failure to fire, is actually desirable since it does demonstrate an inherent safety feature of the MDF system. That is, if all MDF is not deployed, the system would cut itself off and not fire early. Note that emphasis is drawn to the fact that on all drops where ignition system problems occurred the other system ignited or activated the rocket system.

5.6 F1B Timers

F1B timers failing to arm or operate properly. In test numbers 202-22, 2609-F-68 an F1B timer failed to exert sufficient force to arm one gas valve. The timer had run properly and there was not a determinable reason for the low force. In Test Number 202-26, 0063-F-69 an F1A timer ran for 2 1/2 seconds of a preset 5 seconds. After test examination revealed the probably cause was dust and debris in the timer housing mechanism. Corrective action for this problem will consist of deletion of mechanical timer of this type in future system application

5.7 Rocket Pack Damage

In nearly every test using the SK48001-001 or SK48-022-001 rocket packs, minor to extensive damage resulted to the rocket pack. Although occasional damage occurred to the female snap tight rocket couplings the principal damage was in the area of the rocket mounting brackets and/or the lower ring of the rocket pack. This damage is not considered significant because if future testing is conducted, it will be with the redesigned rocket motor and rocket mounting structure. In approximately four live tests, the rocket pack impacted the load and was damaged. Two rocket packs were damaged when they broke loose in tests. The load hit on the rocket pack in test 202-14.

5.8 Parachute System

The parachute system as tested on the PRADS seldom suffered damage, however, the parachutes are considered to be marginal because of instances where damage did occur. It is recommended that parachutes considered for future PRADS systems be reinforced to reduce to a minimum routine parachute maintenance. The parachute deployment bags used on the PRADS testing performed very well, however, heavier construction overall is recommended to reduce wear and tear and it is recommended that an improved means of tying the bags together be incorporated in the new design.

5.9 Probe Oscillation

Probe oscillation was a problem; the possible result of which was ignition too close to the ground. Impact was at a higher than acceptable velocity because of incomplete rocket burning prior to impact.

Corrective action on this problem resulted in two approaches. The first was a delay of two (2) seconds in release of the second probe after the first probe. This did not stop oscillation, but it did provide a ground sensing probe with a second and independent period of oscillation. The chance of ignition at the proper altitude was much greater using this technique.

The second and final approach to this problem was an evaluation of ground sensing systems in general. The most promising system was a cross beam laser ignition system as fabricated by Motorola, Government Electronics Division, Aerospace Center This system is not sensitive to secondary oscillation induced by platform pitch during descent. Under conditions of a field test Test Number 202-24, 0003-F-69 the laser ignition system performed exactly as designed

5.10 Suspension Sling Forces

Sling forces were over 1.5 G each during parachute opening in tests 193-1, -2, 202-4, 5, -6, -14, -16, and -19, and over 1.5 G each during rocket burning in tests 202-10, -11, -12, -14, -19, -21, -22, -23 and -25. Rocket force must reach maximum more slowly. Parachute opening force must be reduced by slotted parachutes at least for loads under 18,000 pounds.

APPENDIX F

TEST ANALYSIS

LIVE SYSTEM TESTS

[illegible].0 ANALYSIS OF LIVE SYSTEM TESTS

Table 1 depicts test results such as drop velocity, probe angle, load height and load angle at rocket ignition, velocity and load height at rocket burnout, and load angle and velocity at load impact. In addition Table 1 gives some test conditions. For a complete description of tests and test conditions for all inert and live drops, consult Appendices C and D. Also results from a lower altitude are given in Table 1 where the platform would first have become horizontal at ground impact. This low altitude is not the minimum altitude from which the load could have been dropped at El Centro with a drop zone altitude of 60 feet, since the load may impact at up to at least ∓ 15 degrees without overturning the load. However, these drop altitudes will be acceptable throughout the range of conditions from -65 degrees F and sea level to plus 100 degrees F and 5000 feet drop zone altitude.

Vertical and horizontal velocities were determined for all tests made at Stencel and for live tests made at El Centro by analysis of test film using load length as a reference. See analysis of test 202-19 for example of determination of impact velocity by direct measurement correcting for acceleration. Vertical and horizontal velocities for inert tests at El Centro were taken from Askania data. Askania data could not be used in live tests because of data smoothing.

The following is an analysis and a discussion of test results for each live test.

TABLE 1

RESULTS OF 1 [illegible]E SYSTEM TESTS
Page 1 of 2

Test No.	Load Wt.--Lbs.	Descent Rate - Ft./Sec. Rocket Fire	Descent Rate - Ft./Sec. Rocket Burnout	Descent Rate - Ft./Sec. Ground Impact	Load Angle - Deg. ** Rocket Fire	Load Angle - Deg. ** Ground Impact	Result
195-1	5120	59	13	24	-7	-9	Successful
195-2	5120	70	22	28	8	0	Successful
202-6	7500	61	*	61	0	0	Unsuccessful #
202-10	7500	62	2	19	0	0	Successful #
202-11	7500	65	3	11	0	12.5	Successful #
202-12	7500	62	-5***	11	–	5	Successful #
202-14	14,100	60	*	42	-12	-10	Unsuccessful #
202-19	14,100	54	*	17	24	18	Successful #
202-21	18,500	54	-2***	27	0	0	Successful #
202-22	24,000	60	6	17	7½	10	Successful #
202-23	35,000	63	*	45	–	*	Unsuccessful #
202-25	18,600	67	*	41	9	*	Unsuccessful #
202-26	35,000	53	13	20	-17	-16	Successful

* See Test Analysis for Explanation
** Positive Angle is Load Nose Up
*** Negative Descent Rate is Up
\# Suspension Sling Forces exceeded 1.5 G each

TABLE 1
RESULTS OF LIVE SYSTEM TESTS
Page 2 of 2

Test No.	Probe Angle Deg.	Load Height At: Probe Firing Ft.	Load Height At: Rocket Burnout Ft.	Actual Absolute Drop Altitude Ft.	Absolute Drop Alt. for Level Platform
195-1	15.5	26	5.9	400	366
195-2	10	25.6	4.7	315	315
202-6	3.5	26	*	2087	317
202-10	31	20.9	5.6	2085	NA *
202-11	22.5	24	2	1947	456
202-12	36	21	2	514	372
202-14	45	12.6	*	539	360
202-19	[illegible]	26.6	*	523	358
202-21	[illegible]	26.5	9.7	436	343
202-22	2	27.7	3.8	473	375
202-23	---	---	*	4[illegible]	NA *
202-25	26	23.2	*	596	NA *
202-26	9.5	27.3	NA	624	464 *

*See Test Analysis for Explanation

2.0 TEST 195-1

General Discussion

This test was made from the Stencel TBM aircraft, and therefore, the weight was limited to just over 5000 pounds. The gross weight of this test load was 5120 pounds, the parachute suspended weight was 5000 pounds; and the weight suspended under the rocket pack was 4626 pounds.

The gross weight approached the top end of the weight range for four rocket motors and four 24 foot parachutes. This weight range is good for air densities encountered at a 5000 foot drop zone altitude and 100 degrees Fahrenheit as well as sea level and -65 degrees Fahrenheit. For additional discussion of air densities, see Section 4.0. The drop zone altitude for this test was approximately 2000 feet above sea level, and the temperature was approximately 60 degrees Fahrenheit. The air density, then, was near the middle of the extremes, therefore, the performance should have been well within specifications.

Analysis

The load was extracted by a 15 foot ringslot extraction parachute. As the load came off the aircraft, it tended to pitch nose up as in a drop from a cargo aircraft; however, extraction force transfer was delayed by redundant lanyards 10 and 15 feet long. This caused the load pitch to be almost negated by continued high extraction force pulling at the rear of the load. The front slings became taut and pitched the load nose up.

Parachute performance was considered good with no lagging in opening. The rocket pack was pulled from the load while the parachutes were opening, and after the first three parachutes opened both front slings were snatched taut by the rearward motion of the rocket pack. The left front sling felt a force slightly less than the 1.5 times the weight of the load (G) called for in the contract as the limiting force on each attachment point. It is assumed here that the loading is based upon the gross rigged weight. This force (1.46 G) was higher than that on the right front sling (.93 G). This distribution of forces is not typical and therefore is assumed to be a random effect. The asymmetrical loading did, however, contribute to a yaw. The rear slings then felt snatch forces of roughly 1.2 G. These peak forces were a combination of parachute, rocket pack snatch and load pitch snatch forces. One probe was released, was armed and reeled out normally. The second probe failed to reel out, because the probe housing came loose and fouled the MDF and probe. The gas valves were armed and the one valve shuttled in the signal system which reeled out. The other valve did not shuttle because the fouled probe and MDF did not fire.

Load angle at rocket firing was 7 degrees nose down, and rotated slightly and impacted at 9 degrees nose down. It is significant that the load did not swing past the horizontal but it yawed 180°, primarily during parachute opening. The load apparently retained a slight nose down bias after the 180° yaw. This means that, in effect, the system did not oscillate, stability was excellent and damping was near perfect. Fig. 195-1-3 in Appendix C shows load angle versus time where load angle is pitch (positive nose up). The descent rate of 59 feet per second at the time of rocket firing is well within the range of 55 to 70 feet per second expected. It should be pointed out that the load descent rate is changing during descent and does not necessarily reach a true terminal velocity in a low level drop.

Probe firing occurred with the front of the load 26 feet above the ground. Rocket firing (first visible plume) was 0.0175 second ± .005 second later. Complete rocket burnout was approximately .54 second after rocket firing with a load descent rate of 13.6 feet per second. Peak forces on the slings during rocket burning were right front .85G, left front .9 G, right rear 1.44 G, left rear 1.34 G. All forces were well within 1.5 G, since, as stated, the load was at the high end for the rocket impulse. Ground impact velocity was 23.7 feet per second and impact occurred .315 second after rocket burnout with a free fall of 5.9 feet. Measurements are considered very accurate in this test because the load could be seen to impact, the camera frame rate is accurate within 2 percent or less, and the impact velocity determined by two methods (each using camera frame rate) agreed within .1 foot per second. In addition, impact time was determined by a microswitch and flash bulb.

Method

The following is a line of reasoning and method for the analysis of this test which is typical for test 195 2 also.

1. Descent Velocity at Rocket Firing Movie film from a hand-held 16 mm Milliken camera running at 400 fps was analysed on a Vanguard film analyser. A painted stripe on the load 8 feet long gave an accurate distance reference when the side of the load was within 5 degrees of a plane perpendicular to the line of sight. Load descent velocity was averaged over 14.8 feet of load travel during .25 seconds before probe firing, resulting in 59.2 feet per second just before rocket firing. The theoretical terminal velocity would be 61.4 feet per second based upon ρ = .00221 slugs per ft^3 assuming a cluster efficiency of 83 percent. Rocket firing was 3.56 seconds after average parachute inflation time.

2. Descent Velocity at Rocket Burnout. Descent velocity at rocket burnout was obtained similarly to the descent velocity at rocket firing except that a correction was made for the rocket deceleration. Here a distance of 4.96 feet was measured during t = .235 second resulting in an average descent velocity of V_{ave} = 21.1 feet per second. The average rocket deceleration was calculated as follows, assuming that no parachute force was present and that the deceleration was constant over the entire time of visible flame from the rocket.

$$a = \frac{4 \; I \cos 35^{\circ} \cos B \quad (32.2)}{\frac{W}{32.2} \quad t}$$

Where:

I = total impulse of each rocket (2540 pound sec.)
B = angle of rocket pack with vertical (9°)
W = suspended weight of the load (5000 pounds)
t = time of visible flame (.54 seconds)
35° = fixed angle of nozzle's rocket axes

Therefore

$a = 63.3 \text{ ft/sec}^2$

During time Δt the load decelerated $\Delta V = a \, \Delta T$ or 14.9 feet per second. Velocity at burnout, then, was $V_{b.o.} = V_{a} - \frac{\Delta V}{2}$ or 13.6 feet per second. Although rocket force diminished almost to zero before the end of visible flame, rocket pack inertia caused the load to feel full force approximately until the end of visible flame. Parachute force had diminished to below 10 percent of the original force (equal to the weight of that load).

3. Vertical impact velocity. The impact velocity was checked by two methods. First, velocity at burnout was added to velocity pickup due to free fall neglecting any possible parachute force. Therefore $V_{imp} = V_{b.o.} + t(32.2)$ for 23.7 feet per second where t is time of free fall equal to .315 second. The time of freefall was taken from last rocket flame to a flash bulb triggered by a microswitch on the bottom of the load.

The second method was more direct, but probably less accurate because of the short period of time measured. Two microswitches, one switch two feet below the load and one on the bottom of the load each triggered flash bulbs. A time interval of .090 sec. was measured. Again this velocity was corrected for freefall acceleration. Therefore

$V_{imp} = \frac{D}{\Delta t} + \frac{\Delta t \cdot 32.2}{2}$ or 23.6 feet per second. The close agreement between the two methods tends to confirm the high degree of accuracy expected.

4. Rocket Firing Height. The actual rocket firing height was assumed to be the height at first visual sighting of rocket exhaust. It was obtained from the length of MDF reeled out and corrected for MDF angle, height loss during signal transfer, location and physical geometry. Rocket firing height was:

$$h = l \cos \phi - V(t) - K$$

Where:

l = MDF length (28 ft.)
ϕ = MDF angle with vertical (15.5°)
V = Descent rate of load (59.2 ft/sec)
t = time delay in firing rockets (.0175 sec.)
K = length of MDF in brake (.4 ft.) plus height from ground to probe housing (.6 ft.)

Therefore h = 25 feet

5. Rocket Burnout Height. Rocket burnout height was calculated from $h = V_{b.o}\, t + \frac{32.2\ t^2}{2}$ where t is the free-fall time.

The burnout height or freefall height was 5.9 feet.

6. Load Angle Versus Time. Load angle during descent was taken from a hand-held movie camera used by an experienced photographer. Load angle is uncorrected for elevation and azimuth line of sight; therefore, distortion is appreciable during the early part of descent, where angles should be taken as qualitative and not quantitative. However, angles close to impact are accurate within ± 2 degrees, because distortion is nil, the camera was horizontal within one degree and load angle was read to the nearest 1/2 degree.

7. Times and Forces. Event times were taken from photographic film primarily. This film yielded event times for extraction force transfer, parachute opening, rocket pack motion, load oscillation, probe readout, MDF firing, rocket firing and flash bulb firings. At 400 frames per second the resolution was .0025 second. Sightings of MDF rocket and flash bulb firings are accurately determinable, while parachute opening time is more difficult to pinpoint.

Force-time traces were obtained for each suspension sling on a portable oscillograph with a paper speed of 3/4 inch per second. Calibration was a maximum of 15,000 pounds per inch. Calibration accuracy was approximately ± 50 pounds. The trace was read to the nearest .01 inch; therefore an accuracy of ± 200 pounds is claimed.

8. Horizontal Impact Velocity. Horizontal impact velocity was taken as $V_H = V_{ave} + (V_{ave} - V_O)$.

Where:

V_H = horizontal impact velocity

V_{ave} = average horizontal velocity during rocket burning

V_O = horizontal velocity before rocket firing or

V_H = 0.8 ft/sec

Performance With Prototype Signal System

Although it is hypothetical to assume that descent conditions would be identical in the prototype system as with tests because of parachute size, load weights, etc., it is of interest to look at performance if the LASER optical ground sensor had been used to fire the rockets. It is assumed that the ground sensor triggering height would have been 23 feet, based upon analysis of requirements for the complete range of conditions from -65 degrees Fahrenheit sea level to 100 degrees Fahrenheit at 5000 feet drop zone altitude. Actual rocket firing height was 25 feet. Height of rocket firing with the LASER ground sensor would be:

$h = l \cos \theta - V(t) - K$

Where

l = assumed LASER triggering distance (23 feet)
θ = LASER beam angle with vertical (7^{o} same as load angle)
K - height from ground to LASER (assume 0 feet)
t = assumed rocket firing delay (.0175 sec.)

Therefore h = 21.8 feet

Burnout, then, would be 5.9 - (25 - 21.8) = 2.7 feet. Impact velocity would be $V = \sqrt{V_{b.o.}^2 + 64.4h}$ or 18.9 ft/sec. with ample reserve for low air density drops. This reduction in impact velocity would be entirely due to the lower height of ignition and therefore less freefall. The MDF length was obviously too long under these conditions: however, the MDF could not be shortened a great deal and still be adequate for changes in drop altitude, air density and the possibility of probe swing without allowing rocket firing after ground impact.

Drop Height

See analysis of test 195-2 for a low or minimum altitude drop.

3.0 TEST 195-2

General Discussion

Test 195-2 was almost identical to test 195-1 except for drop altitude. Such test conditions as load weight, rigging configuration, etc. were the same as in the previous test. Drop altitude was only 315 feet, somewhat lower than the planned 400 feet however, the actual drop altitude was near the minimum for an acceptable impact velocity. The drop zone altitude was again 2000 feet and the temperature was approximately 48 degrees Fahrenheit.

Analysis

Operation and performance in this test was very similar to the previous test except as discussed below. The front slings became taut after the rocket pack was pulled off the load and after the first main canopy opened. The second canopy then opened, the rear slings became taut and the last two canopies opened. The two front slings felt forces of 1.347 on the right and 1.129 on the left indicating reasonably symmetrical loading. It is significant that in this test the load did not yaw. The rear slings each received about 1 G (1.162 on the right and .911 on the left). All forces then were well below 1.5 G and showed a normal pattern. Both probes reeled out normally after release. Two arming pins were pulled in each gas valve and both signal systems operated normally through rocket firing.

The load angle was 8 degrees nose up at rocket firing and rotated to approximately horizontal at impact. This rotation was in the first swing and indicated that if the drop had been from a lower altitude the load would have impacted with a nose up angle. Descent velocity at rocket firing was 70.1 feet per second. This value was an average of two sets of measurements. Calculated terminal velocity for load with c [illegible] .00226 would be 60.7 feet per second, therefore, terminal velocity had not been approached even though the load had descended 3.16 seconds after average parachute inflation time.

Probe firing occurred with the rear of the load 25.6 feet above the ground. Rocket firing occurred .02 second later with the load 24.2 feet above the ground. Velocity at rocket burnout was calculated as 22.2 feet per second; however, this velocity is not claimed to be necessarily accurate because of uncertainties in parachute input during rocket burning. Peak forces on the slings during rocket burning were right front .95 G, left front 1.53 G, right rear 1.27 G, left rear 1.08 G. The left front sling force exceeded 1.5 G. It is assumed that lag angle plus a load roll condition caused the high force. (See Section 3.4 for a definition of lag angle.) Impact occurred

.2 second after rocket burnout with a freefall of 4.8 feet. Impact velocity calculated from the above is 28.6 feet per second. A more accurate calculation of impact velocity can be obtained from microswitches and flash bulbs which were employed as in the previous test. Results of this method gave an impact velocity of 28.2 feet per second.

Although the impact velocity was the maximum acceptable, this test resulted in excellent performance with all items functioning normally.
Horizontal impact velocity was 1.3 feet per second.
Performance With Prototype Signal System

Again, it is of interest to compare impact velocity if the drop conditions had been the same except for a LASER ground sensor signal system. Assuming a 23 foot triggering height for the LASER ground sensor, rocket firing would have been 21.3 feet instead of 24.2 feet actual height. Rocket burnout height, then, would have been 1.8 feet instead of 4.7 feet. Impact velocity would have been 24.7 feet per second, allowing for drops throughout the range of air densities from 315 feet.

Drop Height

Any higher descent velocity before firing would increase the ground impact velocity and cause a positive load impact angle. It is concluded then that this drop altitude (315 feet absolute) is minimum for this weight and configuration at this air density using the probes tested. A drop at lower air densities could be negotiated from this altitude if the LASER signal system were used. Obviously, additional parachute area and/or rocket impulse for the load weight would result in better performance, i.e. lower impact velocity for a given drop altitude or a lower drop altitude capability for the weight.

4.0 TEST 202 6

General Discussion

Since this was the first live test conducted at El Centro, California, under the program, the drop was made from approximately 2000 feet altitude.

Analysis

The load was extracted by a 22 foot extraction parachute from the C-130 aircraft normally. A guillotine cut loops of webbing to effect extraction force transfer just after the load cleared the aircraft ramp. Six 24 foot parachutes were deployed and opened and controlled the descent of the load. Descent velocity stabilized at approximately 61 feet per second with an estimated load angle under 5 degrees after descending 405 feet from the first sighting of the extraction parachute.

The two probes were released by lanyards to the rocket pack. These lanyards were to be pulled as the load rotated nose up after the front slings became taut. This arrangement was to give maximum time for the load to stabilize before the probes were released for the purpose of reducing snatch force and instability experienced in the previous contract No. DA19-129 AMC-502(N). However, since the load rotated during parachute and rocket pack deployment, the rear slings became taut first. The probes were released, then, before any slings were taut. With the probe reelout brakes on the rear of the load, no problem was encountered from snatch force or load instability during reelout on this test. (See analysis of test 202-14 for additional comments).

A safety pin in each gas valve was pulled by a lanyard to the rocket pack as it was pulled from the load. A second pin was pulled in each gas valve by an F1A or F1B parachute timer after a time delay of approximately 4 seconds. The timers were initiated by lanyards to the main parachutes as they were pulled from the load.

Force on the right rear sling was 1.16 G based upon the gross rigged weight. This peak force occurred just after the first main parachute opened. Force on the left rear sling was not recorded. The right and left front slings then felt peaks of 1.56 and 1.67 G respectively. The five other main parachutes opened fully in quick succession. The peak forces felt by the front slings were the result of 1) nose down load rotation introduced by the rear slings, and 2) parachute force by one parachute being open fully and the other five being almost fully open. It is concluded, then, that slightly slower parachute opening would have reduced the peak front sling forces to under 1.5 G. Parachute opening was very consistant except for one early opener. Descent rate was 61 feet per second at rocket firing. Terminal descent rate is calculated as 59.9 feet per second using $C_d = .8$ and cluster efficiency = .73 percent.

The MDF length was 27 feet. Reelout was normal and if there was probe swinging after reelout it apparently damped out. Probe firing occurred at 26 feet height and rocket firing at 24.9 feet. Load angle was essentially flat at rocket firing. Horizontal impact velocity was 18.3 feet per second. At rocket ignition, one rocket head end closure came off because a snap ring was not seated. (See Appendix D for details.) All snap rings were checked after this test, and no more operational problems were encountered with the rocket motors.

If the rockets and rocket pack had remained intact, burnout would have been approximately 7 feet high with a velocity of 0 feet per second. Impact velocity would have been approximately 21 feet per second, leaving ample safety margin for low air density.

Performance With Prototype Signal Systems

If the LASER optical ground sensor had been used with a triggering height of 23 feet, the rocket firing height would be 21.9 feet; the burnout height would be 4 feet, and the impact velocity would be 16.1 feet per second.

Drop Height

If the LASER ground sensor had been used, the minimum drop height would have been approximately 340 feet. This minimum would be limited by the load angle rather than the descent rate. A slight increase in this minimum would be required for low air density.

5.0 TEST 202-10

General Discussion

This test was identical to test 202-6 except that rocket nozzles were reinforced, and the snap rings were checked

Analysis

After force transfer and main parachute deployment, the rear slings became taut with peak forces of .9 G on the left and 1.34 G on the right. One parachute opened fully and the front slings became taut with .68 G on the right and .81 G on the left. Not until later did the other main parachutes open fully. It can be concluded for this test that the rear slings felt roughly the same peak forces as in test 202-6 due mainly to rocket pack momentum but the forces on the front slings were considerably less than in test 202-6 because parachute opening time was appreciably longer in test 202-10 than in test 202-6.

The probes swung at least 31 degrees. Descent rate approached 62 feet per second after a descent of 375 feet.

At rocket firing the descent rate was measured as 62.4 feet per second. Probe firing occurred at 22.1 feet and rocket firing at 20.9 feet load height. These heights were low because the probe angle was 31 degrees. Descent rate at burnout was measured and calculated to be 2.2 feet per second. During rocket firing the forces on the rear slings exceeded 1.5G (1.87 right and 1.95 left) based upon gross load weight. Forces on the front slings were 1.36 right and 1.4 left. Forces tended to be high because of somewhat low load weight for the number of rockets and force overshoot.

Descent rate at rocket burnout was measured and calculated to be 2.2 feet per second. The load freefell approximately [illegible] and impacted at approximately 9.1 feet per second. While this impact velocity is not accurate, it is thought to be a maximum velocity. Horizontal impact velocity was 6.9 feet per second.

Performance With Prototype Signal System

If the LASER had been used and had triggered at 23 feet, the impact velocity would have been 20.8 feet per second with a free fall of 6.6 feet. With probe swing the actual impact velocity was lower than with the theoretical results from the prototype system because of the short distance of actual freefall.

Drop Height

If the LASER prototype system were used the drop could have been made from 380 feet. Again this minimum would be limited by load angle. It is assumed herein that the LASER ground sensor would be on the rear of the load.

6.0 TEST 202-11

General Discussion

This test was very nearly the same as test 202-10 and was also dropped from close to 2000 feet absolute altitude.

Analysis

The rear suspension slings felt low forces just before the front slings felt their peak forces of 1.14 G on the right and 1.26 G on the left. The rear slings then felt peak forces of .88 G on the right and .80 G on the left. The parachutes opened soon afterwards. The relatively low suspension sling forces with rapid parachute inflation appear to be the result of timing. The load was pitching nose up the rear slings became taut, and stopped the rearward pitching. The front slings immediately became taut, assuming part of the rocket pack snatch force.

The probes swung at least 32 1/2 degrees. Descent rate was 65 feet per second at rocket firing. Probe and rocket firing occurred slightly higher than in test 202-10 (24 feet and 22.7 feet respectively). Descent rate at rocket burnout was 3 feet per second. Impact velocity was not certain. Various methods of calculations resulted in 7 feet per second to 23 feet per second depending upon when the load impacted the ground. It is believed that ground impact occurred about .23 seconds after rocket burnout and that impact velocity was actually close to 11 feet per second. Horizontal impact velocity was 13 feet per second.

Performance with the prototype signal system is of questionable value since actual impact velocity is uncertain, but the results would be very close to actual data.

Drop Height

The drop could have been made from 428 feet absolute altitude under these atmospheric conditions (ρ = .00221 slugs per ft^3).

7.0 TEST 202-12

General Discussion

This test was very similar to tests 202-10 and 202-11 except that the drop altitude was reduced to 514 feet absolute to more closely demonstrate PRADS capability.

Analysis

After force transfer, the rear slings became taut. No data was obtained for the left rear sling. The left rear sling felt a low peak, the front slings then felt .71 G on the right and .96 G on the left. Later the right rear sling felt 1.03 G. The action was similar to that in test 202-11 except the last peak forces appeared higher in this test because of slightly later parachute opening.

[illegible] rate at rocket firing was 62 feet per second. It is pointed out that this rate was exceeded at high elevations, and the load took longer to slow down than previous tests.

The probe angle was 36 degrees with the vertical at probe firing. This angle caused probe firing to occur at 21 feet and rocket firing at 19.8 feet. Velocity at burnout was measured and calculated to be 5 feet per second upward. The high probe angle caused burnout to be close to the ground (approximately 2 feet). Impact velocity was roughly 11 feet per second. Again impact time was not known for sure. Obviously, the rockets took out more impulse than necessary. Horizontal velocity was 7 feet per second at impact.

Performance with Prototype Signal System

Due to probe swing in this test, it is calculated that rocket ignition would be higher if the LASER signal system had been used, burnout would be higher, and the impact velocity would be greater than with the actual probe system. In addition, performance with other load weights and other air densities would be more consistant.

Drop Height

This load could not have been dropped from a much lower altitude because of a combination of high rate of descent, high load angle and high probe angles. Since probe swing angle is not known throughout the drop, and probes are not to be used in the prototype system, minimum drop height will continue to be given assuming the prototype signal system. Minimum drop height, then, would be 315 feet absolute. Here load angle is the limiting factor.

8.0 TEST 202-14

General Discussion

This test was the first live test in the large load range, i.e. over 10,000 pounds.

Analysis

The load was extracted with a peak force of slightly less than one G. After extraction force transfer, the load pitched well over 90 degrees nose up. The rear slings became taut with forces under 1.5 G's inducing a high nose down rate. The front slings became taut with 1.99 G's on the right and 2.27 G on the left at which time three parachutes were nearly open. Stability was poor after probe release.

Tests 202-7 and -8 (inert tests) were much more stable with much lower peak sling forces. While the reason is not completely established, it appears that the load cg was forward of the intended location, since the load remained nose down before impact.

Descent rate was only 60 feet per second at rocket firing; however the probes had swung to 45 degrees. The probes fired at only about 12 feet altitude of the front of the load, and the rockets fired with the front of the load only about 10 feet high. A delay of .032 second occurred because only one MDF system fired. Impact occurred at about 42 feet per second after only .16 second rocket burning. The load impacted the ground slightly nose down, the slings became slack, and the front of the load was snatched up. The load was almost turned over. Sling forces were about 2 G on the front and about 1.75 G on the rear. The load landed on the rocket pack. Horizontal velocity was 35.4 feet per second at impact. Accuracy of this value is questioned since print-out data gave 12.4 feet per second before firing.

Performance with Prototype Signal System

The LASER signal system, if set to trigger at 23 feet, would have fired the rockets at 21.2 feet. Burnout would have occurred at .06 second after the nose of the load impacted at 10.6 feet per second.

Drop Height

A better drop would have occurred from 355 feet with the

LASER system because the load angle would have been tail down.

9.0 TEST 202-19

General Discussion

This test was a repeat of test 202-14. Conditions were the same except a time delay of two seconds was added in one probe release to 1) reduce swinging in that probe, and 2) to prevent probes from swinging together. It was reasoned, and born out, that the two probes swing in separate planes. In addition, three 46 foot main parachutes were used instead of five 36 foot parachutes. Vertical impact velocity was 17 feet per second. Horizontal impact velocity was 0.

Analysis

Again high peak forces (2.34 G and 2.81 G) occurred in the front slings after acceptable peak forces in the rear slings. The load was unstable and again it tended to stay nose down.

Forces exceeded 1.5 G at rocket firing.

10.0 Analysis of Drop Load Motion from Rocket Ignition to Ground Impact PRADS

1. Data Required:

a) Impact velocity
b) Impact load angle
c) Descent velocity at rocket ignition
d) Height of load at rocket ignition
e) Time from rocket burnout to impact
f) Load height at rocket burnout
g) Probe angle at probe firing
h) Double check on V and load height at rocket firing if possible

2. Test No.: 202 1972-64
Date: 12/10/68

3. Data Given:

a) Gross load weight 14,100#
b) Parachute suspended weight - 13,800#
c) Load suspended weight - 12,525#
d) Platform dimensions - 8' wide x 24' long
e) Suspension sling length - 24'
f) Film rate - 250 fps (Camera No. 6)
g) Rocket impulse - 2540 lb.-sec. each (@ 35^{o})

4. Assume:

a) Constant rocket force (load deceleration) from ignition to burnout
b) Probe swinging in vertical plane parallel to longitudinal axis of load
c) Impact when first part of load impacts ground

5. Theory:

a) Time Change $\Delta t = \frac{f}{250}$ where:

$f = N$ frames

b) Distance Change $d = \frac{d(R_1 - R_2)}{R_d}$

Where: d = Actual length of measured distance (corrected for yaw, etc.)
R_d = Film reading of distance d
R_1 & R_2 = Film reading of load positions

c) Load Yaw Angle $\theta = \tan^{-1} \frac{Rw}{Rl} \frac{L}{W} \cos \alpha$

Where:

Rw = Load width reading from film

Rl = Load length reading from film

L = Actual length of platform

W = Actual width of platform

α = Load Pitch (or roll) angle (actual)

d) Net Average Deceleration During Rocket Burning

$$a = \frac{\Delta V}{t_b}$$

Where:

ΔV = total calculated change in velocity

t_b = time of rocket burning

e) Velocity at t_2 $V_{t_2} = \frac{\Delta d}{\Delta t} - \frac{a(\Delta t)}{2}$

Where:

t_2 = time at end of Δt

f) Change in velocity during rocket burning (calculated)

$$\Delta V = \frac{I\cos\beta}{\frac{W}{32.2}} - t_b\,(32.2)$$

Where:

W = weight of load

I = impulse from rocket motors or load cells

β = angle of force with vertical

g) True Load Angle $\alpha = \tan^{-1} (\tan \lambda) \cos \theta$

Where:

λ = measured load angle

6. Calculations:

a) Load Yaw Angle (at rocket firing)

Data:

Rw = 1.445 (#5)

Rl = 1.120 (#5)

Assume $\alpha = 24^{o}$

$$\theta = \tan^{-1} \frac{1.445}{1.12} \frac{24}{9} \cos 24^{o} \text{ (5c)}$$

$$= 72.3^{o}$$

b) Load Pitch Angle (at rocket firing)

Data:

$\lambda = 56^{o}$

$$\alpha = \tan^{-1} (\tan 56^{o}) \cos 72.3^{o} \text{ (5g)}$$

$$= 24.2^{o}$$

c) Check load Pitch Angle

Data:

h = 1.678 (#5)

d = (Width of load) = 9' (Cos 90-72.3)

= 8.58'

$$\frac{H}{1.678} = \frac{8.58}{1.445}$$

H = 9.95'

$$= \sin^{-1} \frac{9.95}{24}$$

$= 24.5^{o}$ (checks with 6b)

d) Descent Velocity (at rocket firing)

Data:

Frames = 64 fps

$R_1 = 1.533$
$R_2 = .056$
$W = .929$

$$\Delta d = \frac{8.58\ (1.533 - .050)}{.929}$$

$= 13.7'$

$$\Delta t = \frac{64}{250} = .256 \text{ sec.}$$

$V = 53.5'/\text{sec.}$

e) Load Yaw Angle (2/3 of burning)

Data:

Rw = 1.538
Rl = 1.074

Assume: $\alpha = 20^{\circ}$

Time = .312 sec. of ing

$$= \tan^{-1} \frac{1.538}{1.074} \ \frac{24}{9} \ \text{Cos } 20^{\circ}$$

$= 74.4^{\circ}$

(Load width = 9' Cos $(90^{\circ} - 74.4) = 8.66'$)

f) Load Pitch Angle (2/3 of burning)

Data:

$\lambda = 53^{\circ}$

$\alpha = \tan^{-1} (\tan 53^{\circ}) \text{ Cos } 74.4^{\circ}$

$= 19.6^{\circ}$

g) Load Pitch Angle (Impact)

Assume: Constant pitch rate during burning

$$\alpha_{imp} = 24.2 - \frac{.408}{.312} (24.2 - 19.6)$$

$$= 18.2^{\circ}$$

$\Delta \alpha$ during burning $= 24.2 - 18.2$
$= 6^{\circ}$

h) Impact Velocity (After .408 sec. rocket burning)

Data:

Frames = 22 (#6)
R_1 = 1.558 (#6)
R_2 = 1.372 (#6)
w = .887 (#6)
d = 8.66 (6e)

$$\Delta d = \frac{8.66 \; (1.558 - 1.372)}{.887}$$

$$= 1.82'$$

$$\Delta t = \frac{22}{250} = .088 \text{ sec.}$$

$$V_{ave} = \frac{1.78}{.088} = 20.7'/\text{sec.}$$

i) Calculate Load Deceleration from Rocket Impulse

Data:

Burn time to impact = .408 sec.
Total rocket burn time = .560 sec.

$$\Delta V = \frac{.408 \, (14) \, (2540) \; \text{Cos } 35^{\circ} \; \text{Cos } 21^{\circ}}{(.56) \; \frac{13,800}{32.2}} - .408 \, (32.2) \qquad (5f)$$

$= 46.2 - 13.1 = 33.1$ '/sec.

Deceleration $= \frac{33.1}{.408} = 81'/sec.^2$ Average

j) Correct Impact Velocity (6h)

$$V_{imp} = 20.7 - \frac{.088}{2} (81)$$

$= 17.0'/sec.$

k) Check Change in Velocity During Rocket Burn to Impact

$V = 53.5 - 17.0 = 36.5'/sec.$

$36.5 - 33.1 = 3.4'/sec.$ (assumed to be taken out by parachute)

l) Height of Firing (Rocket Burning Distance)

Data:

Net length of MDF in brake = .4'
$\Delta\alpha = 6^{\circ}$ (6g)
MDF length = 28'
Rocket ignition delay = 0.24 sec.

$$Height = 28' \cos 32.1 - 53.5 (.024) - 24 \sin 24.2^{\circ}$$

$$+1/2 (24) \sin 6^{\circ} - .4'$$

$= 13.5'$

m) Theoretical Height of Firing (Rocket Impulse)

Data: $\Delta V = 36.4'/sec.$ (6k)

$$D = 53.5\,(.408) - 1/2\ \frac{36.4}{.408}\ (.408)^2$$

= 14.4' (Larger than 6l) because of early parachute contribution)

n) Calculated Change in Velocity (Suspension Sling Forces)

Data: Total impulse = 23,020 lb. - sec.
Load weight = 12,525
Sling Angle = 28.4°
Average Load Angle = 21°

$$\Delta V = \frac{23{,}020\ (\cos 28.4)\ \cos 21 - 12{,}560\ (.408)}{\frac{12{,}525}{32.2}}$$

= 35.4'/sec. (Measured V = 36.4'/sec.) (6k)

7. Conclusions:

a) Change in velocity (ΔV) measured from film is 36.5'/sec. (6k). Calculated ΔV is 33.1'/sec. (6i). The difference is roughly the contribution of the parachutes during the early part of rocket burning. A triple check of ΔV from the impulse from the suspension slings gave 35.4'/sec. (6n). This close agreement with the measured ΔV tends to prove the accuracy of both methods.

b) The apparent height of firing corrected for probe angle load angle, firing delay, change in load angle and length of MDF in probe reelout brake was 13.5' (6l). The theoretical height of firing based upon measured velocity at firing and measured ΔV was 14.4' (6m). The difference is approximately that contributed by the parachutes during rocket firing. This agreement tends to further prove the accuracy of measurements and calculations of the dynamics of load motion after rocket firing.

c) It is concluded that the impact velocity can be calculated within 3 to 6'/sec. where a direct measurement cannot be made, depending upon the yaw angle of the load. When direct measurement is made, an accuracy of 2 to 4'/sec. is claimed, depending upon the quality of the film coverage.

d) In this test (202-19) it is believed that the impact velocity (front was 17'/sec. (6j) ± 2'/sec. Further while the load impacted at approximately 24° nose down the load was being decelerated after the front of the platform impacted the ground. The rockets burned for approximately .14 sec. after this impact. During this time the front of the platform was being deformed, cardboard was being deformed and the load was rotating toward a level position. It is believed that the load actually felt an average impact velocity of under 17'/sec. It is further believed that the load cg still had a descent velocity at rocket burnout because of the crushing and rotating. Appreciable burning after impact can cause the load to be picked up after impact.

e) The Askania data is "smoothed out" so that the load descent velocity at rocket firing is not accurate because of the sudden slowing by the rockets.

f) Horizontal velocity was 2.9 feet per second before firing of rocket and approximately 0 at impact.

Performance with Prototype Signal System

A LASER, if fired at 23 feet altitude would result in an impact velocity of 23 feet per second.

Drop Height

This load could have been made from 370 feet if the LASER system had been used.

11.0 TEST 202-21

General Discussion

This test was conducted to demonstrate a larger drop load.

Analysis

Sling forces were about 1.3 G on the front and about 1.2 G on the rear during parachute opening.

Load stability was better than in previous tests. Descent rate was 54 feet per second at rocket firing.

The load was level at rocket firing. Probe firing occurred at 26.5 feet altitude and rocket firing at 25.2 feet. Rocket burnout was at about 9.7 feet high with a negative descent rate of about 2 feet per second. Impact was about 27 feet per second. Forces at rocket firing were just over 1.5 G per attachment point. Horizontal impact velocity was 19.7 feet per second.

12.0 TEST 202-22

General Discussion

Drop weight continued to increase so that problems could be seen as early as possible and test hardware could be conserved.

Analysis

Parachute forces on the slings were very low (about 1 G) because the parachutes opened slowly. Load stability was fair and descent rate was 60 feet per second at rocket firing. Probe firing occurred at 27.7 feet and rocket firing at 26 feet. Velocity at burnout was calculated to be 6 feetper second and impact velocity 17 feet per second. Freefall was about 3.8 feet. Sling forces at rocket firing were slightly over 1.5 G on the front and just over 1 G on the rear. Horizontal impact velocity was 22.5 feet per second.

Performance with Prototype Signal System

If the LASER had fired at 23 feet, impact velocity would have been 15 feet per second. The reduction is due to very slightly less freefall (3.5 feet).

Drop Height

This drop could have been made from 405 feet with the LASER signal system.

13.0 TEST 202-23

General Discussion

This was the largest load tested to demonstrate near the maximum capactiy of the presently designed system.

Analysis

Parachute opening time was somewhat long because of seven 46 foot parachutes in the cluster and because of reefing. Average parachute opening time, however, was less than would have occurred if a parachutes had remained attached. Sling forces were about 1 G or less, and would have been more if all parachutes had remained attached. Two risers failed, because of high forces and old risers possibly deteriorated somewhat. One riser adaptor also failed.

Descent rate was still only 63 feet per second at rocket firing, particularly because of the low altitude of the drop (442 feet). The rockets fired for only .20 second before ground impact. Approximately 18 feet per second descent rate was taken out, assuming little loss of effective thrust. Impact velocity was 45 feet per second. The rockets continued buring and turned the load over. The front slings felt snatch forces of about 2 G each. Horizontal impact velocity was 6 feet per second.

Rocket exhaust plume convergency occurred as was feared.

Performance with Prototype Signal System

Impact velocity would have been 25 feet per second, assuming an effective rocket thrust, i. e. small thrust on load from rocket plume convergence.

14.0 TEST 202-25

General Discussion

An actual M215 2 1/2 ton truck was dropped. This truck had a load of 2500 pounds of weight added in the bed near the rear of the cab.

Analysis

Although the load experienced a high pitch angle and the parachutes were not reefed, the sling forces were all less than one G.

One riser failed and the load descent rate was 67 feet per second at rocket firing. When the rockets fired, the front slings felt about 1 G each and the rear slings felt about 2 G each. The frame buckled at the rear of the cab, and the nose of the truck bent up. There was no reason to believe that the frame was damaged before dropping; however, the frame appeared slightly bent after parachute opening and before rocket firing. The descent rate was 67 feet per second at rocket firing.

When the frame bent, the front slings became slack, the rocket pack corrected for the misalignment, and the front slings were swept by the rocket exhausts. The front slings failed and the load was dumped nose first onto the ground. Impact velocity was about 41 feet per second. Horizontal impact velocity was 5.2 feet per second.

Performance with Prototype Signal System

If the LASER signal system had been used and the truck frame had not bent, the impact velocity would have been 26 feet per second.

15.0 TEST 202-26

General Discussion

A repeat of test 202-23 was necessary if a satisfactory test was to be accomplished with a drop load of 35,000 pounds. Although it was realized that rocket plume convergence would occur, this test was made to demonstrate the large load. The test was performed with risers and riser adaptors of newer or stronger material. Also an extra parachute was added. Finally the reefed diameter was reduced. The drop was made from a slightly higher attitude than desired. In addition, a higher altitude than required was requested to be sure that the test was not lost from excessive drop altitude error on the low side.

Analysis

Parachute opening was slow as would be expected with a smaller reefed diameter and a cluster of 8. Sling forces were about 1 G or less.Descent rate was only 53 feet per second at rocket firing.

The probes fired at 27.3 feet and the rockets fired at 25.8 feet altitude. Impact velocity was between 13.2 feet per second and 28.6 feet per second, depending on how much freefall there was and how much force from rocket exhaust was acting on the load. An average of 20 feet per second is thought to be a realistic impact velocity. Horizontal impact velocity was 1 foot per second.

Performance with Prototype Signal System

If the LASER signal system had been used and exhaust pressure on the load was negligible, impact would have been at 17 feet per second.

Drop Height

This drop could have been made from 430 feet with the same assumptions as above. Load angle would be the limiting factor.