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13. ABSTRACT

This technical report presents the results of an in-depth exploratory development study of an airdrop system utilizing the recovery parachutes to extract as well as recover the airdrop load. The purpose of the study was to achieve a low altitude capability by minimizing the altitude loss from the time that the load clears the aircraft until an acceptable impact velocity is achieved. During the study, mathematical models were developed and programmed for computer solution which simulated the operation of an airdrop system. This analytical tool, coupled with experimental data derived from a limited flight test program, was utilized to conceptualize a configuration for an airdrop system and predict its theoretical performance. From these studies emerged an understanding of possible configurations for a low altitude airdrop system employing the recovery parachutes for extraction.

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AD______________

TECHNICAL REPORT
72-15-AD

LOW ALTITUDE AIRDROP SYSTEM INVESTIGATION EMPLOYING INFLATION-AIDED RECOVERY PARACHUTES FOR EXTRACTION

by

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Contract No. DAAG-17-68-C-0036

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October 1971

AIRDROP ENGINEERING LABORATORY
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FOREWORD

This technical report was prepared by AAI Corporation of Cockeysville, Maryland and constitutes the final report under U. S. Army Natick Laboratories Contract No. DAAG17-C-68-0036 and Project No. 1M121401D195. The contract is for the in-depth investigation of a low altitude airdrop concept for the mass delivery of supplies and equipment to a point where the concept may be selected for further investigation. The in-depth investigation was conducted as one of two coordinated investigations under contract with the U. S. Army Natick Laboratories and responding to a Department of the Army requirement for a low altitude airdrop system for supplies and equipment.

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ABSTRACT

This technical report presents the results of an in-depth exploratory development study of an airdrop system utilizing the recovery parachutes to extract as well as recover the airdrop load. The purpose of the study was to achieve a low altitude capability by minimizing the altitude loss from the time that the load clears the aircraft until an acceptable impact velocity is achieved. During the study, mathematical models were developed and programmed for computer solution which simulated the operation of an airdrop system. This analytical tool, coupled with experimental data derived from a limited flight test program, was utilized to conceptualize a configuration for an airdrop system and predict its theoretical performance. From these studies emerged an understanding of possible configurations for a low altitude airdrop system employing the recovery parachutes for extraction.

I. INTRODUCTION

EXTARP (Extraction by Inflation Aided Recovery Parachutes) is a concept for an airdrop system where the main parachutes, in addition to controlling the descent velocity, are also used to extract the cargo from the aircraft. This contrasts to the standard airdrop system where a separate parachute is used to extract the cargo. The initial step in the sequence of operational events is the deployment of the main parachutes. When first deployed these parachutes are reefed to reduce the drag forces, and at this condition, extraction of the cargo from the aircraft occurs. Shortly after the cargo clears the aircraft, the parachutes are disreefed and application of the parachute forces is transferred to the cargo suspension slings. When disreefing occurs the parachutes inflate rapidly to their maximum drag configuration and the system decelerates quickly to a safe descent velocity. The rationale for this airdrop concept is that it minimizes the elapsed time from the point where the cargo clears the aircraft until it is descending at a safe touchdown velocity. Thus, the altitude loss before a safe descent velocity is reached is also minmized and a low altitude delivery capability is obtained.

The purpose of this program, Contract DAAG17-68-C-0036, was to conduct an in-depth exploratory development of this low altitude airdrop concept. Extraction of the cargo using the recovery parachutes is not a new concept and the ability to airdrop cargoes of special variety using this technique has been well established. However, the feasibility of acquiring a low level airdrop system that could be applied to general cargo use has never been established. It was first extensively analyzed by this contractor under Contract DA19-129-AMC-846(N). During this program mathematical models were developed and programmed for computer solution which simulated the operation of an airdrop system. This analytical tool, plus, experimentation data derived from a limited test program made it possible to conceptualize a configuration for an airdrop system and predict its theoretical performance. From these studies emerged an understanding of possible configurations for a practical low altitude airdrop system which employed the recovery parachutes for extraction. It was indicated that a reefing technique would be effective for controlling the level of the extraction forces as well as protect the fragile G-11A parachute from destruction during the initial stages of the trajectory where absolute velocities are high. The need was recognized for force attenuators to reduce peak loading due to parachute snatch and opening shock forces. The use of inflation aids to reduce parachute inflation time was desired, and further, extraction of the parachutes from the airplane was recognized as a problem of principal concern. This program was addressed to the task of developing practical answers for these problems so that designs might be established for a low altitude airdrop system that can be used for airdrop of general cargoes.

Component and system designs were generated based upon the findings of the previous studies and general knowledge of airdrop techniques. A test program was conducted at El Centro, California by the 6511th Test Group in cooperation with AAI to examine the performance characteristics of different designs. Thirty-five (35) airdrops were accomplished of cargoes ranging from 3500 to 25,000 pounds. Originally it had been planned to airdrop cargoes up to 35,000 pounds and conclude the program with a series of demonstration drops from a 500 foot altitude. Circumstances led to a curtailment of the test program before airdrops of the 30,000 and 35,000 pound cargoes could be achieved. Also, most of the demonstration airdrops from a 500 foot altitude were eliminated and the only airdrops performed at this altitude were for a 15,000 pound cargo. The mathematical models developed in the previous program were checked against the empirical data derived from the tests and refined, where necessary, so that good correlation of the theoretical and empirical data was obtained. The mathematical models were then used to run parametric analyses where the effects on performance of varying individual parameters were computed, plotted and analyzed. This analytical process, insofar as possible, was kept current with the test program and the results used to indicate which component items should be varied and in what manner for subsequent tests. In this manner the program has been used to examine the feasibility, establish practical designs, and predict the performance for this concept of a low altitude airdrop system.

In addition to addressing the basic problems of design and performance, ancillary systems considerations were analyzed in detail and the results of these studies presented in various technical reports. These subjects included systems reliability, aircraft and operational utilization, sensitivity analyses, maintainability, safety and economical factors.

This report presents the principal findings of this program. Since the effort has been rather extensive, it is impractical to report here much of the details which substantiate these findings. These details have been included in other technical reports and reference to this material is provided throughout this report.

II. CONTRACT REQUIREMENTS

A. System Performance Goals

Orientation of this in-depth exploratory investigation shall be towards achievement of a system capable of use with U. S. Army and U. S. Air Force rear loading cargo aircraft under the following conditions:

1. At aircraft altitudes below 500 ft. above the terrain.
2. At aircraft speeds from 110 to 150 knots. Compatibility with lower aircraft speeds down to 40 knots shall be investigated for possible applications.
3. With horizontal impact velocities not exceeding those of the present system in ground winds from 0 to 15 knots.
4. In operations employing mass formations (30) of aircraft airdropping single and multiple cargo units.
5. With the fewest possible restrictions on drop zone characteristics such as size, unobstructed area, flatness and texture of terrain.
6. With a nominal vertical cargo impact velocity of 23 fps and a maximum of 28.5 fps at any terrain altitude between 0 and 5000 ft and simultaneously at any air temperature between -65°F and 100°F.
7. Without modification to the cargo other than minor modifications which can be accomplished without special equipment.
8. With a reliability of .995 and an accuracy C.E.P. of 100 meters from the selected impact point.
9. For unit cargo gross weight from 2000 to 35,000 pounds on present airdrop platforms and developmental aircraft unloading kits.
10. With a minimum requirement for special training of using troops.
11. Without modification to airdrop aircraft other than those that can be accomplished as a minor retrofit.
12. Without reduction of the present allowable cargo size envelope for each type of aircraft.
13. Without reduction of present aircraft utilization for airdrop or interference with paratroopers jumping after cargo.

14. Under adverse weather conditions as outlined in AR 705-15. Noting that $-80^{\circ}F$ is changed to $-65^{\circ}F$.

B. System Design Requirements

The final system must incorporate the following design requirements:

1. In-Flight Requirements

a. Load factors on the cargo and system components must not exceed the following values until initiation of the airdrop sequence.

(1)	Forward	4.0
(2)	Aft	1.5
(3)	Lateral	1.5
(4)	Up	2.0
(5)	Down	7.1

b. Present rigging for inflight cargo restraint shall not be significantly changed.

c. Metal components in the extraction subsystem shall have safety factors of 1.65 ultimate for cargoes with extracted weights under 25,000 pounds and 1.75 ultimate for cargoes over 25,000 pounds. All other metal components shall have a safety factor of 1.65 ultimate. The yield strength for all metal components shall be at least 90% of the above required ultimate strengths.

d. The system shall be usable, within its weight limitations, for the airdrop of all Army material which is now airdroppable.

C. Specific Contract Requirements

Under this contract, detailed functional, operational, and economic analyses of the system, bench and scale model tests, breadboard hardware design, fabrication, and full scale flight tests shall be performed. These analyses shall determine the degree of conformity to the goals, requirements, and characteristics of the system herein described.

1. A complete review of the reports prepared under contracts DA-19- -AMC-846(N) and 851(N) along with familiarization of the work performed in the preliminary exploratory phase shall be conducted. This information combined with the concepts of inflation aids, extraction by recovery parachutes, and vent reefing techniques shall be optimized for the low altitude airdrop system.

a. The following components shall be investigated for reoptimization:

(1) Inflation aids (inflectors or other) - determination of configuration, number and size shall be evaluated.

(2) Centerline reefing - determine length of line.

(3) Reefing line - determine recovery parachute reefing line length used during extraction phase.

(4) Reefing line cutters - determine necessary time delay(s).

(5) Oscillation damping parachute - determine need, configuration and size.

b. Computer studies, performance analysis, scale model tests and full scale drops shall be used.

2. Three aircraft, the C-130, C-141 and C-5A shall be investigated to determine the differing characteristics of each that will significantly affect the results of the studies and analyses performed on the system.

3. Single cargo airdrop, intermittent cargo airdrop from a single aircraft, and multiple consecutive cargo airdrop from mass formations (50 aircraft) shall be investigated.

4. Aircraft safety shall, at all times, be considered in the design of all components. Analyses shall be performed to eliminate any possibility of an event jeopardizing flight safety. Countermeasures shall also be incorporated to counteract any system failures that may affect flight safety.

5. Approximately 25 to 35 tests shall be conducted including flight safety write off tests, component tests and system tests. These tests shall be conducted at the 6511th Test Group, NAF, El Centro, California and shall culminate in a system demonstration to show feasibility of the system.

6. Results shall be presented including trajectories and body motions to determine the effects of the system operation. The system performance envelope shall be defined by parameter variation such as cargo weight, aircraft velocity and altitude, platform length, cargo c.g. location in aircraft, opening times and snatch forces for clustered parachutes. The results will be correlated with the system flight test data to predict the performance of the eventual system which could be developed.

7. A high degree of reliability will be an important consideration in system design.

8. Economy in the system will be inherent, with an effort to keep costs to the lowest possible level consistent with meeting the performance goals.

9. A thorough trade-off analysis shall be performed considering the effect of variation of the detailed parameters. Also, a sensitivity analysis and maintainability study shall be performed for the system.

10. Technical Integration and Evaluation input data required consists of:

a. Identification of all events

b. Projection of elapsed times, maximum forces, gross rigged weight and expected lifetime of system

c. Reliability information

d. Accuracy information

e. Logistics, maintenance, training, rigging and derigging time data

f. Cost information

g. Safety and malfunction

h. Sensitivity analysis

III. SYSTEM DISCUSSION

A. System Definition

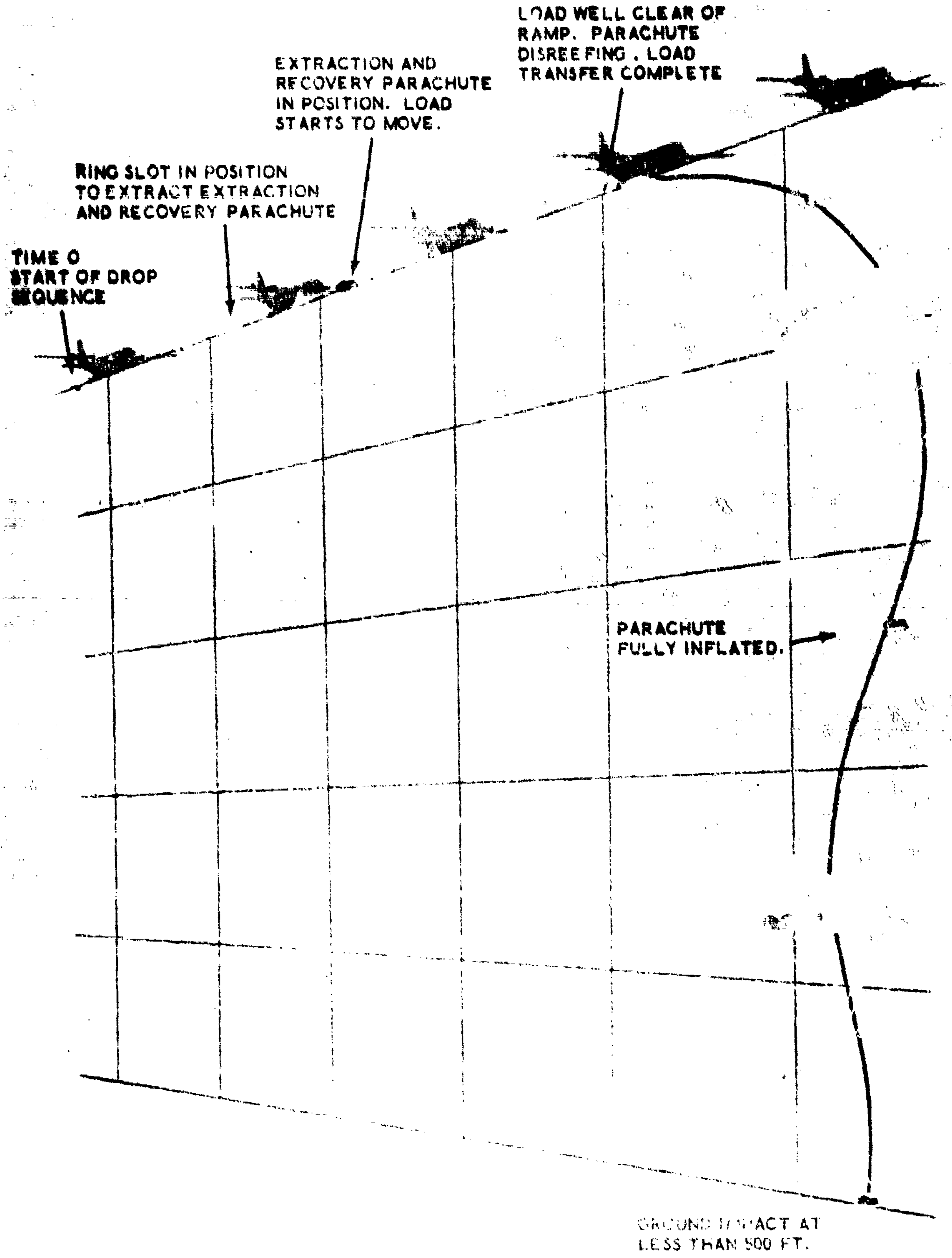
The in-depth study conducted by AAI Corporation employed inflation aided recovery parachutes for extraction and for subsequent descent of cargoes from an airdrop altitude of 500 feet or less. A general description of the low altitude airdrop system utilizing recovery parachutes for extraction is presented in the final report (1) prepared by AAI Corporation for U. S. Army NLABS under Contract DA-19-129-AMC-846(N). Several additions and improvements have been made to this system and these items are described in detail in this section. The airdrop system consists of the following events:

- Pendulum release of the ringslot extraction parachute
- Extraction and deployment of the recovery parachute
- Extraction of the cargo
- Tip-off of the cargo
- Force transfer
- Descent
- Impact

Figure 1 illustrates the basic operation of the system and defines the sequence of events. The operation of the extraction sequence for up to and including four G-11A recovery parachutes, including the pendulum release of the ringslot parachute, extraction and deployment of the recovery parachutes and the extraction of the cargo is shown in Figure 2. When five or more G-11A recovery parachutes are used, a platform is employed to extract the parachutes as shown in Figure 3. After cargo extraction and tip-off, load transfer occurs as illustrated in Figure 4.

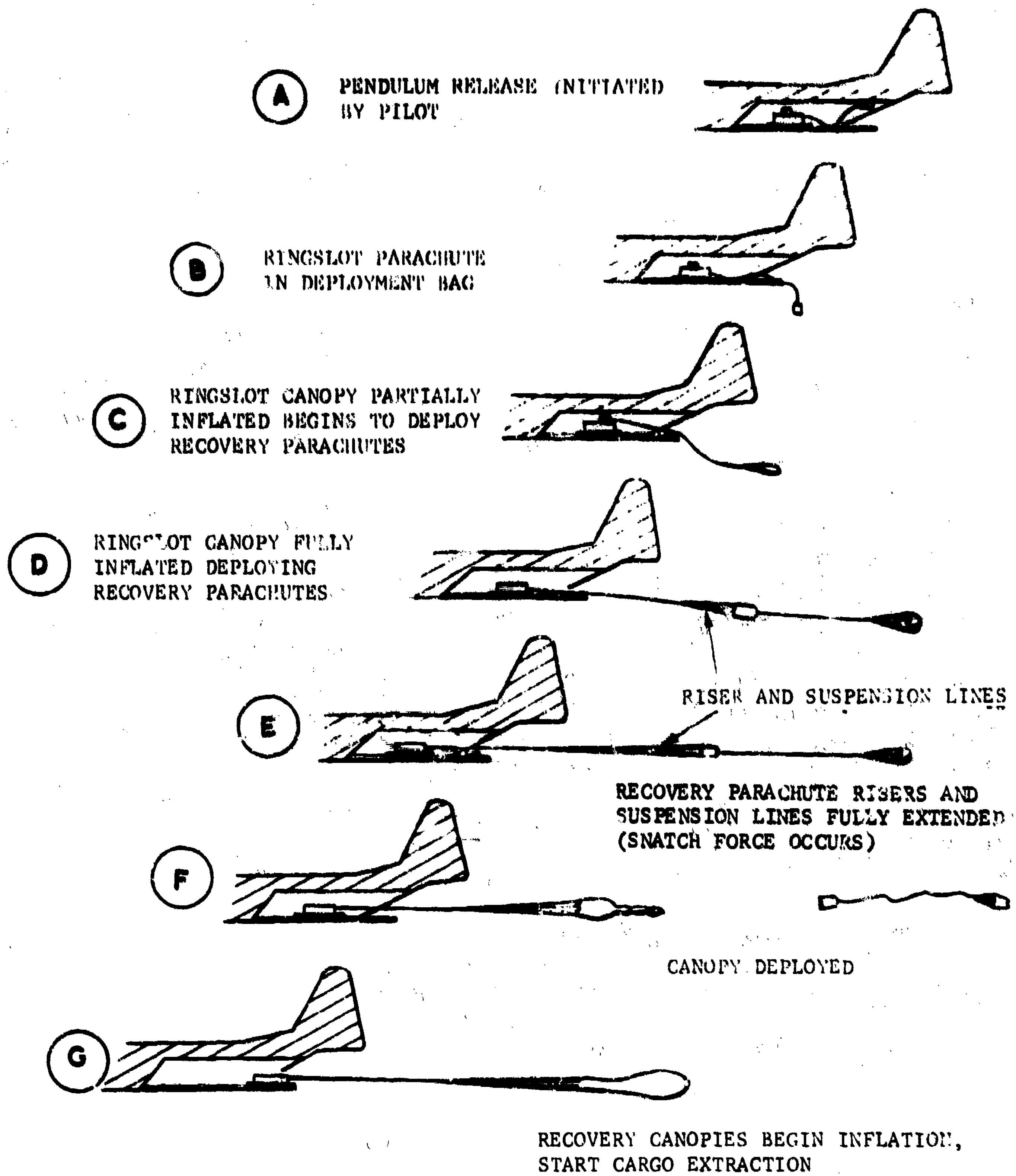
Previous studies have revealed the need for improved recovery parachute inflation, more efficient usage of the parachute deceleration capabilities throughout the trajectory especially during the load transfer event, and reduction in snatch force to satisfy the requirement of not exceeding 1.5 g's on the extraction point. The snatch force is caused by the acceleration of the recovery parachute mass from its velocity at line extension (illustrated in Figure 2) to the velocity of the aircraft. Investigation of numerous techniques to reduce the magnitude of the snatch force have shown that the addition of an energy absorber material, undrawn nylon, in the riser extension line is the most acceptable in terms of force reduction, cost, reliability, and rigging.

Previous flight tests conducted at El Centro, California on Contract DA-19-129-AMC-846(N) have revealed that the parachute force decreases to near zero just after transfer, then rapidly increases as the suspension slings become taut. This occurrence caused two problems in the operation of the extraction by recovery parachute system. First, the rapid reduction in force indicated that the cargo was not being decelerated during the force transfer phase of operation. Secondly, the forces developed in the suspension slings exceeded the structural limit imposed on the suspension fittings. Therefore,



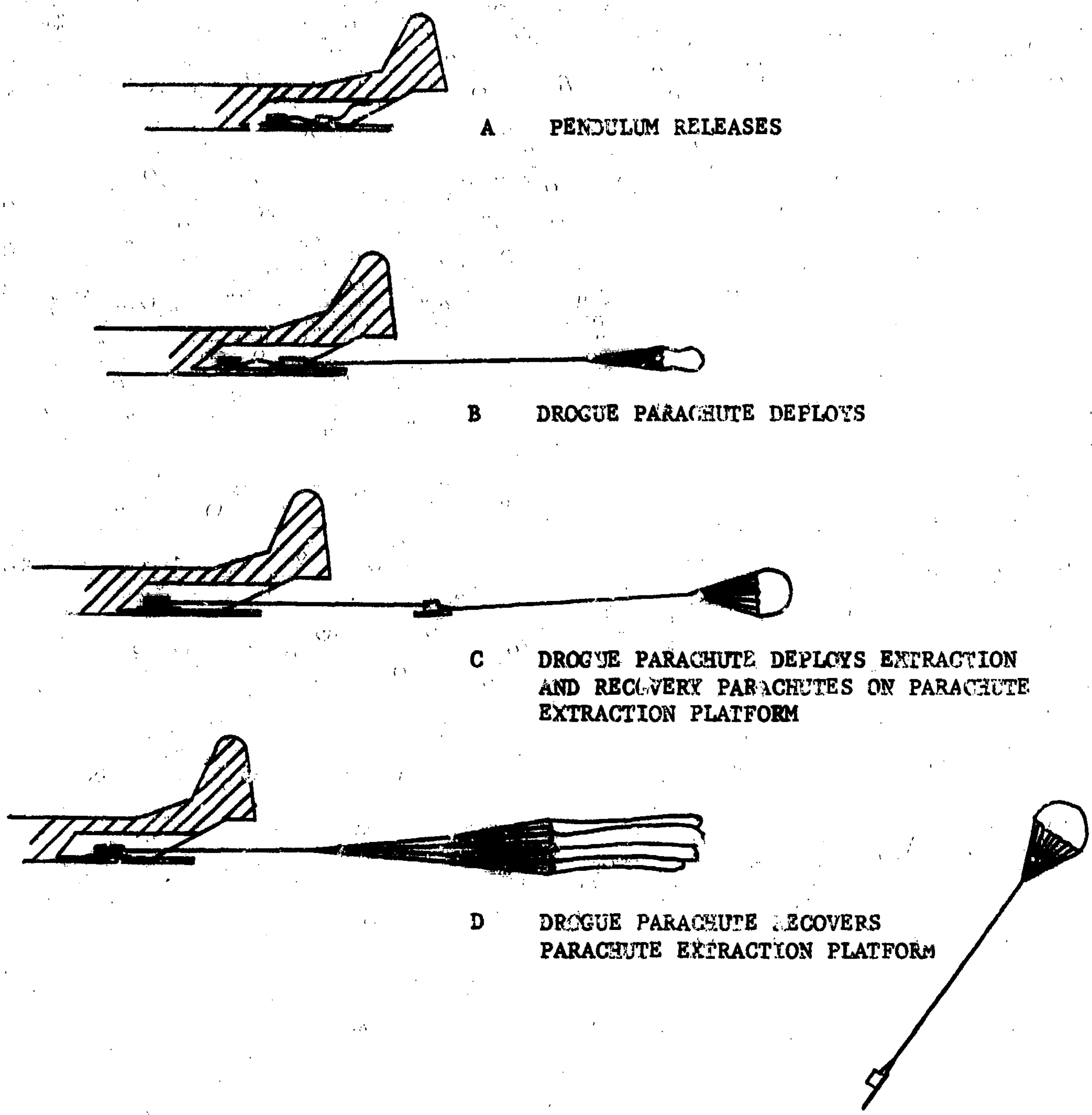
SEQUENCE OF EVENTS

Figure 1



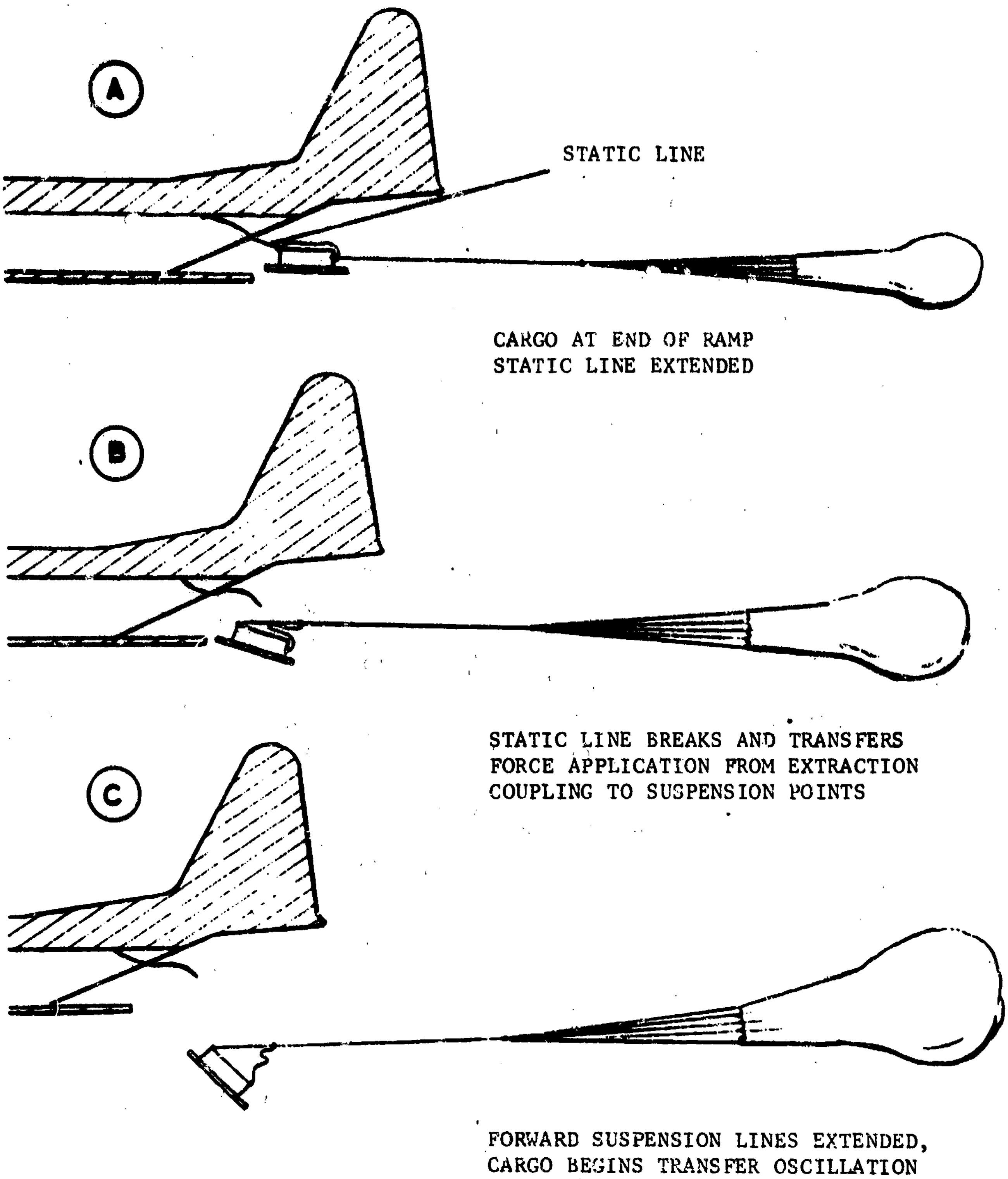
EXTRACTION SEQUENCE - FOUR OR LESS PARACHUTES

FIGURE 2



PLATFORM EXTRACTION SEQUENCE - FIVE OR MORE PARACHUTES

FIGURE 3



FORCE TRANSFER SEQUENCE

FIGURE 4

to resolve these difficulties, undrawn nylon lines have been incorporated with each suspension sling to reduce the peak suspension force and minimize the duration of low force application to the cargo. Figures 5 and 6 compare the extraction and suspension sling force vs time traces with and without the undrawn lines utilized. The rigging modification required for using undrawn nylon slings is described in Section IV.C.

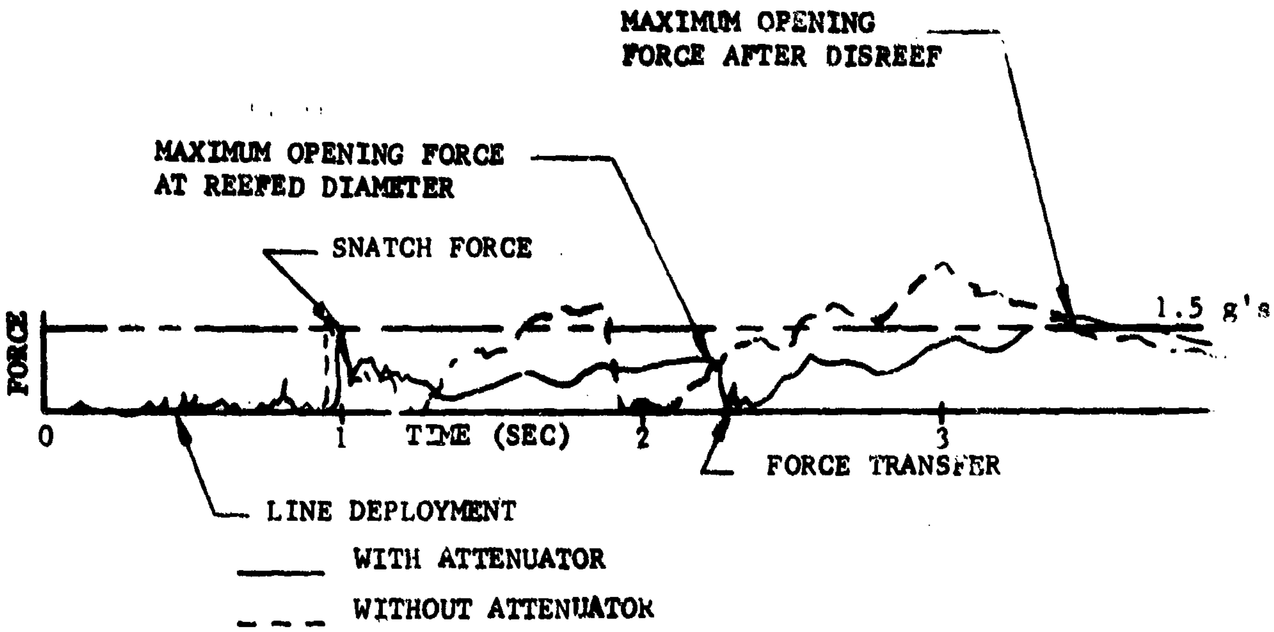
Analytical and experimental studies of the performance of G-11A parachutes have shown that the canopy inflation time is too long to provide acceptable cargo impact characteristics at altitudes of 500 feet or less. In the inflation process of flat circular canopies, the canopy inflates from the apex of the canopy toward the skirt after the opening shock force occurs. A typical inflation sequence of a G-11A parachute is illustrated in Figure 7.

An acceptable method for reducing the canopy inflation time is the use of a centerline which pulls the canopy vent down inside the canopy. The performance of this technique has been illustrated in theoretical and experimental analyses conducted by AAI Corporation, model tests performed by Stencel Aero Engineering and full scale low altitude airdrop tests conducted by the 6511th Test Group. The addition of a centerline attached to the canopy apex does not present any operational rigging problems and results in a desirable modification from an economical basis. Also, the fully inflated canopy shape of a G-11A parachute using a 95 foot centerline developed a significantly higher drag force than the standard G-11A canopy. Selection of the 95 foot centerline as the optimum length is discussed in detail in Section IV.D. The shape of a fully inflated canopy with a 95 foot centerline is depicted in Figure 8.

Using the previously discussed new components and the extraction of the cargo by recovery parachutes, the following cargo weight range has been developed.

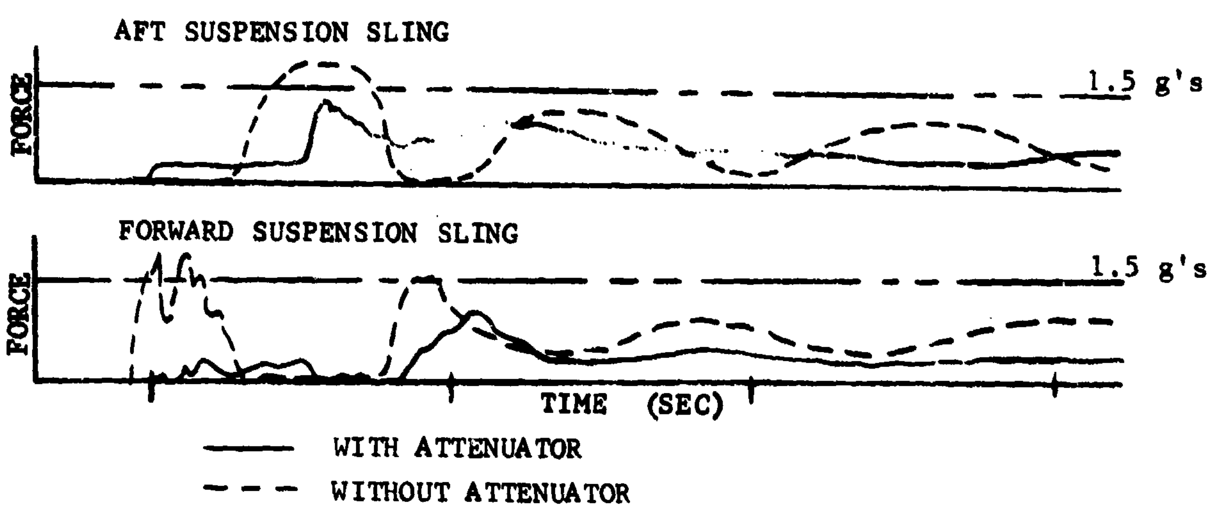
Number of G-11A Parachutes	Total Descent Weight (Cargo + Parachute Weight)
1	2,000 - 5,000
2	5,000 - 10,000
3	10,000 - 15,000
4	15,000 - 20,000
5	20,000 - 25,000
6	25,000 - 30,000
7	30,000 - 35,000

The following parts of this section describe in detail the system operation and required cargo and parachute pre-flight rigging and preparations for the EXIARP system.



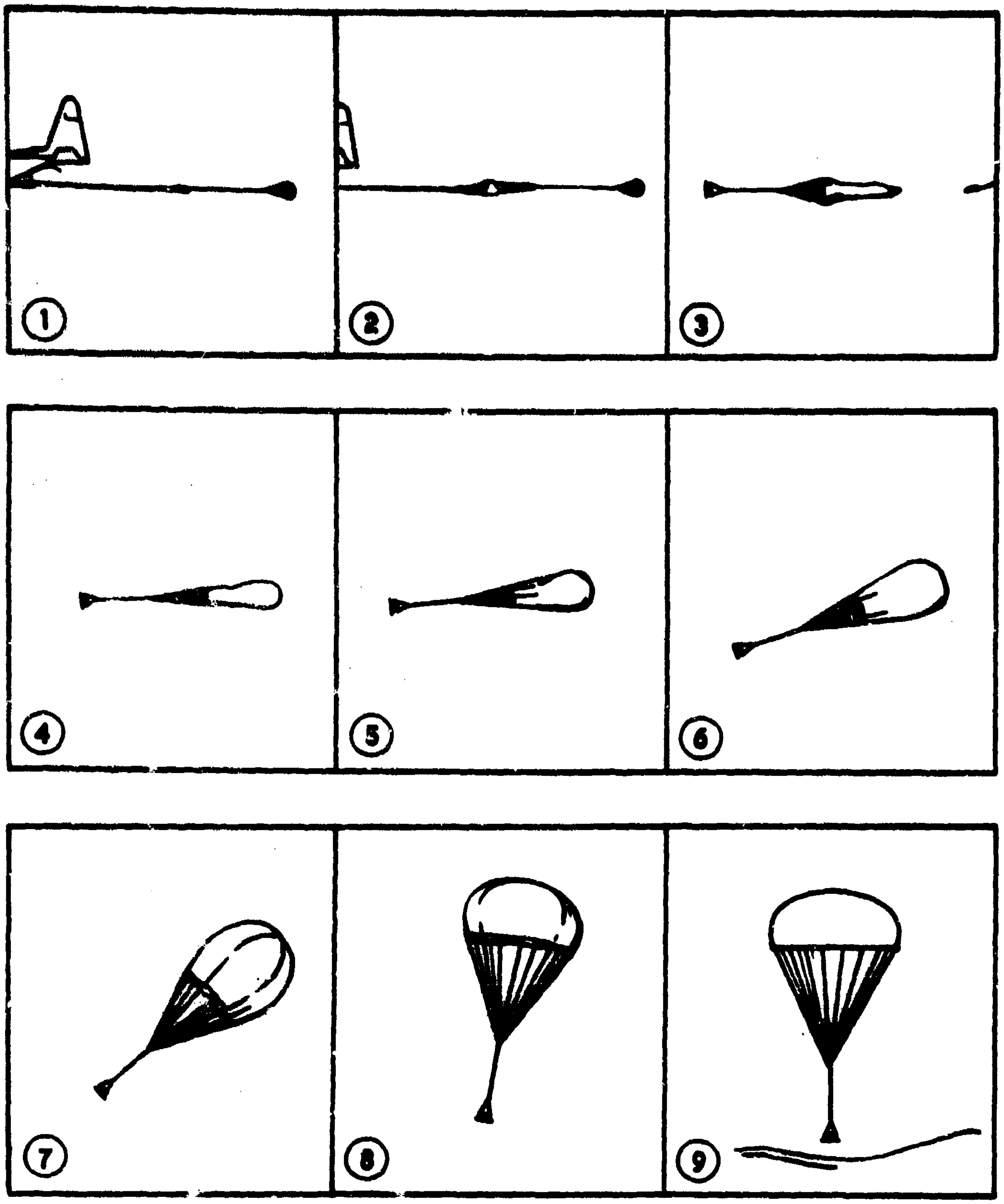
COMPARISON OF EXTRACTION FORCE WITH AND WITHOUT ATTENUATOR

FIGURE 5



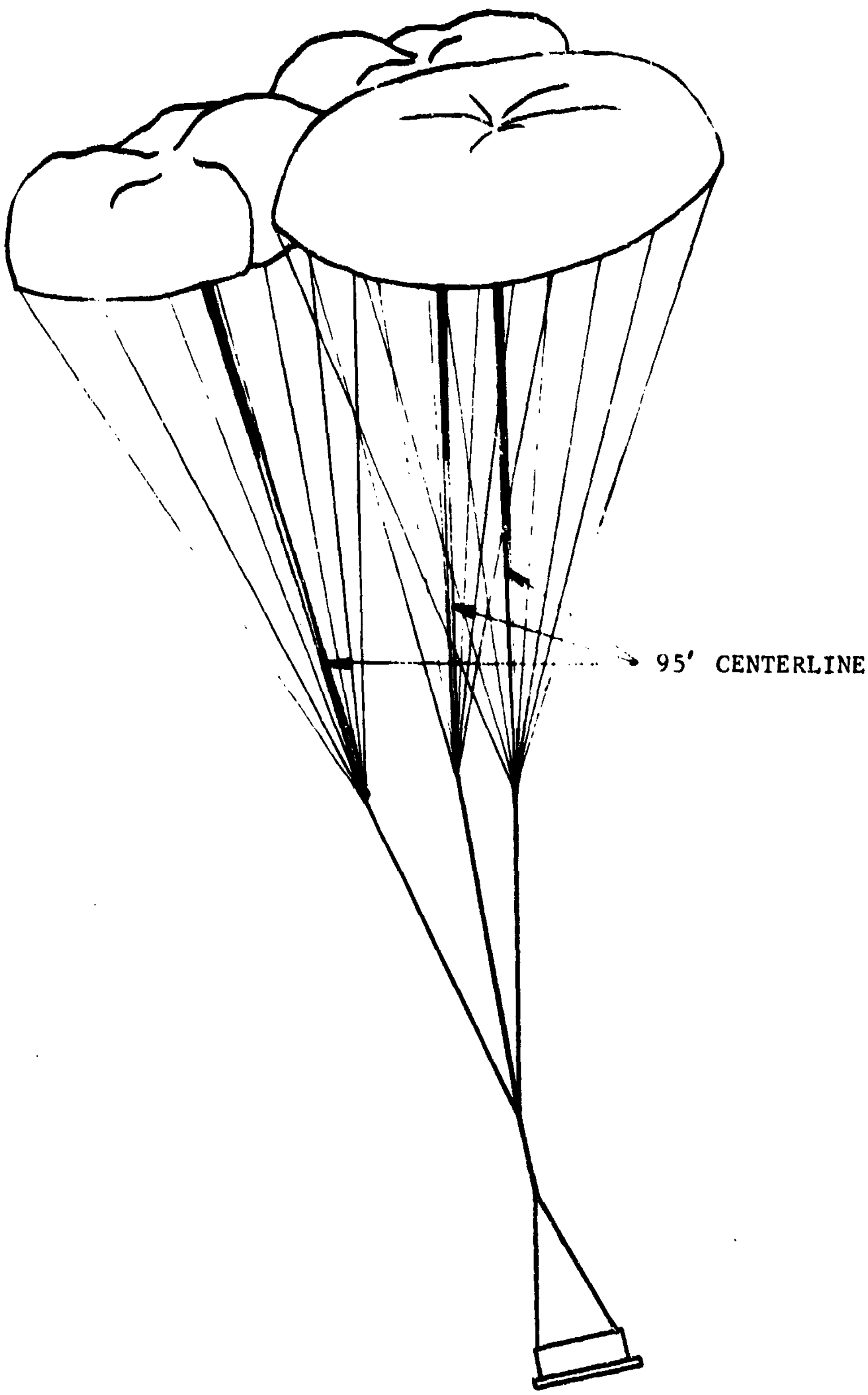
COMPARISON OF SUSPENSION SLING FORCE
WITH AND WITHOUT ATTENUATOR

FIGURE 6



FLAT CIRCULAR CANOPY INFLATION SEQUENCE

Figure 7



FULLY INFLATED G-11A CANOPY WITH 95' CENTERLINE INSTALLED

FIGURE 8

B. Airdrop Preparation

1. Rigging The Parachutes

The rigging procedures for the parachutes to be used with the EXIARP system differed from the standard due to the addition of three components. These components are; (1) dual stage reefing line; (2) centerline; and (3) snatch force attenuator.

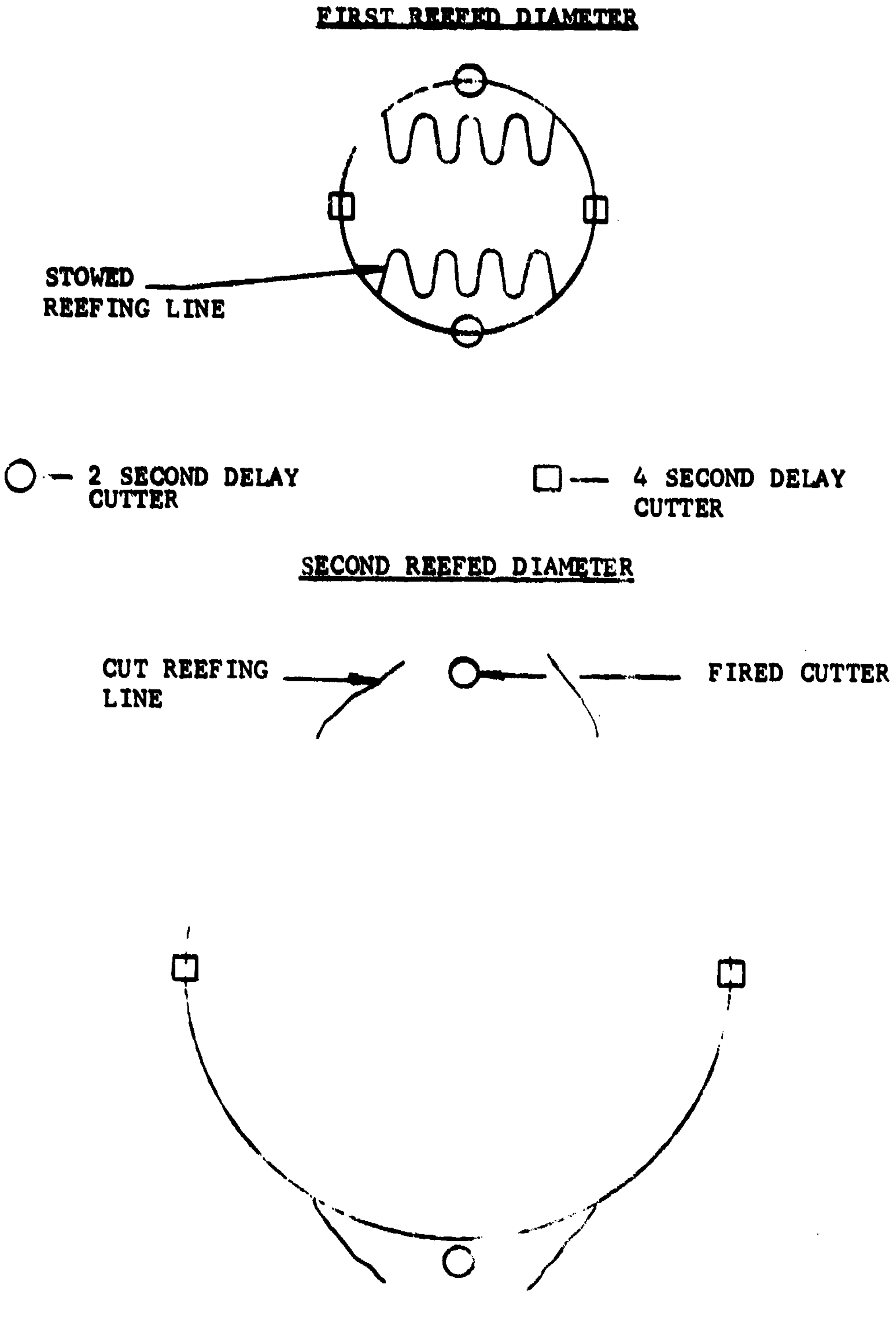
The dual stage reefing line is installed in order to produce acceptable force levels during canopy inflation and provide uniform opening rates for clustered parachute configurations when more than four G-11A parachutes are used. The dual stage reefing technique to be employed is illustrated in Figure 9. The first reef diameter is held until the two second delay cutters fire. The skirt of the canopy then inflates to the second reefing line diameter and is held until the four second reefing cutters fire.

The procedures used to install the dual stage reefing line are similar to the installation of a standard reefing line. The only variations that exist are the stowing of the excess line used to hold the second reef diameter and the use of four second reefing cutters to cut the second stage reefing line.

A centerline or apex control line has been added to the canopy to provide a more rapid inflation and increased load carrying capability for the parachute. As illustrated in Figure 10, the centerline consists of a heavy nylon web connected between the canopy apex and the confluence of the risers. The attachment is made at the apex by looping the suspension lines around a small clevis and then attaching the centerline to the clevis bolt. The centerline does not cause any change to the standard procedures used to fold the canopy into the bag or stow the suspension lines and risers.

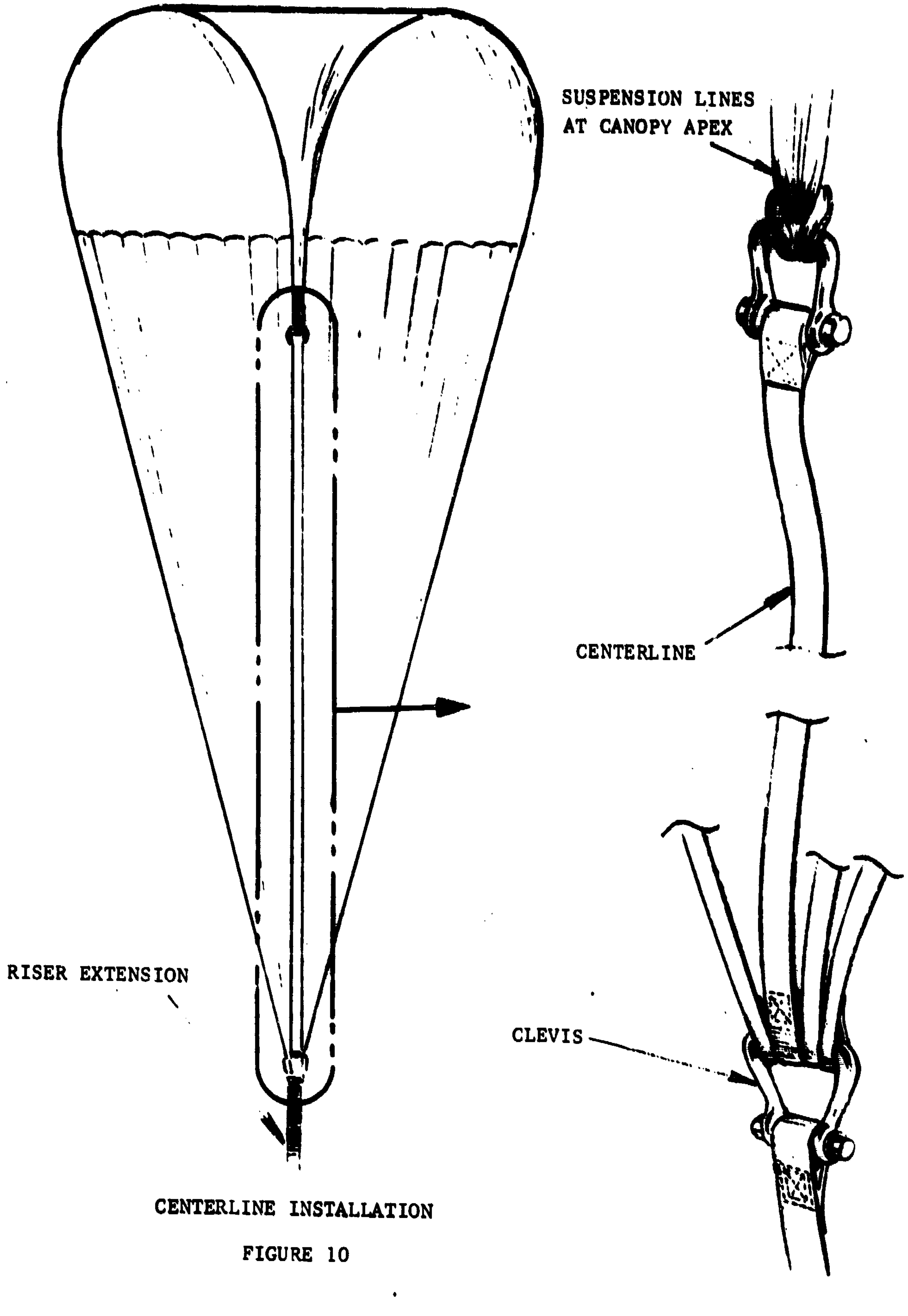
To limit the snatch force to acceptable levels, a multiline snatch force attenuator was developed. This attenuator is installed between the confluence of the risers and the riser extension line. It consists of several undrawn nylon lines strung between the two G-11A clevises, with one end attached to the risers and the other to the riser extension as shown in Figure 11. A ten foot length of riser extension webbing was rigged in parallel to these lines and acts as a safety line and stop when the undrawn nylon has stretched to its desired extension. The G-11A clevis attached to the risers has been modified to accept the multiline snatch force attenuator in addition to the safety line.

The snatch force attenuator is stowed as shown in Figure 12. The clevises used to make up the attenuator are stowed on the outside of the bag. Each clevis is tied to the two bag handles on the forward end of the deployment bag. The safety line and undrawn nylon ropes are stowed under the flap as shown and are tied to the aft end of the deployment bag.



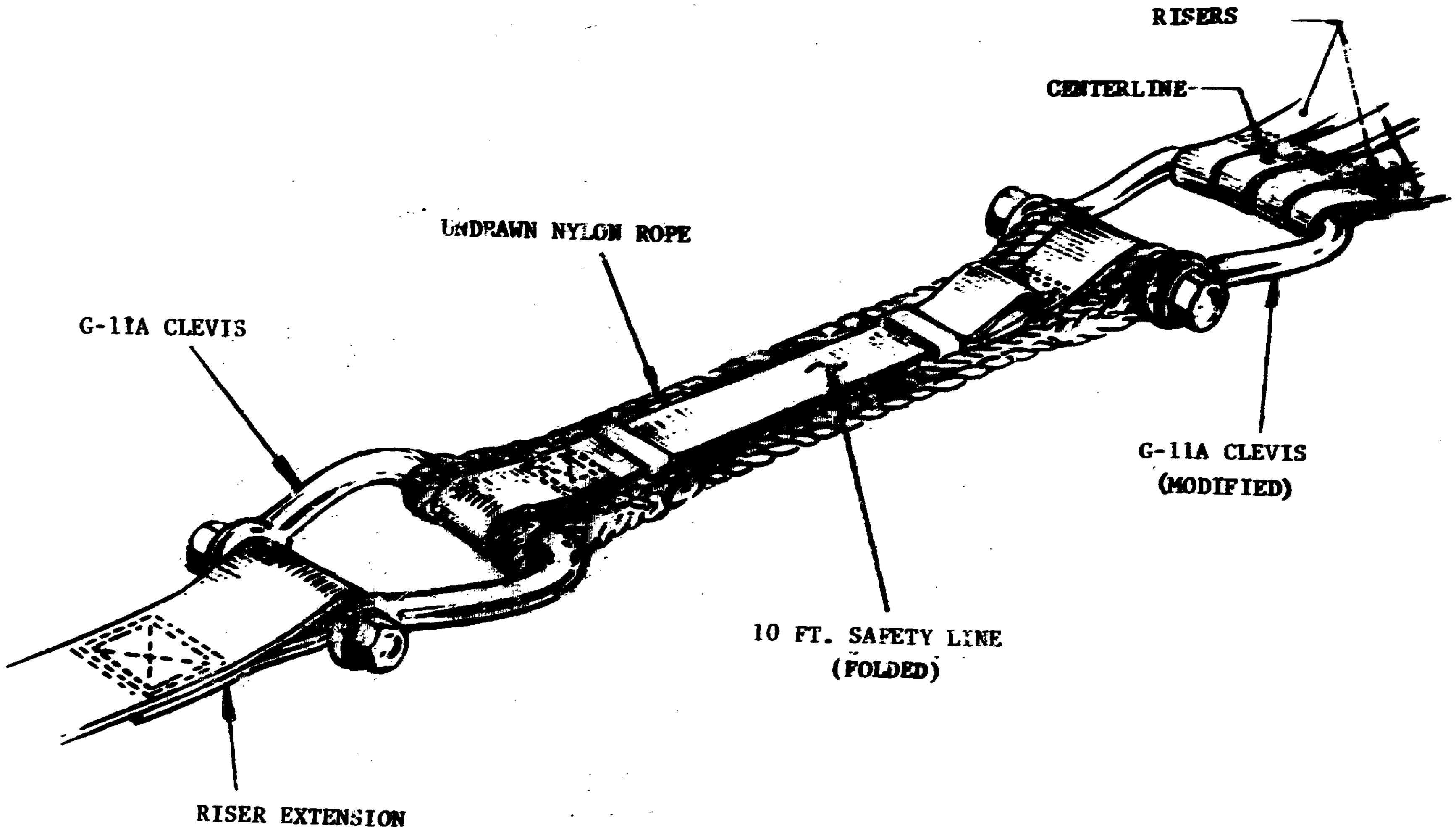
DUAL REEFING METHOD

FIGURE 9



CENTERLINE INSTALLATION

FIGURE 10



MULTI-LINE SNATCH FORCE ATTENUATOR

FIGURE 11

PARACHUTE PACK WITH SNATCH ATTENUATOR INSTALLED

Figure 12

2. Rigging The Cargo

To simplify the rigging of the cargoes for the EXIARP system the procedures used have been kept similar to those used for the standard system. Standard webbing, tie down devices, modular platforms, and paper honeycomb energy dissipators, have been used wherever possible to minimize the amount of new rigging equipment required.

Some rigging hardware and procedure changes were made for specific use on the EXIARP system. To limit the force applied to the suspension sling fittings a suspension sling force attenuator was developed and is pictured in Figure 13. The attenuator consists of several strands of 5/8" diameter undrawn nylon line which are rigged in parallel with the suspension sling. The number of lines used parallel to the aft suspension sling is equal to twice the number of parachutes used to rig the load and the number of lines used parallel to the forward suspension sling was equal to the number of parachutes used. As shown in Figure 13, the undrawn nylon lines are attached to a four pin connector at both ends using cargo suspension clevises. The suspension sling is connected to the four pin connectors and stowed as shown. One connector is attached to the suspension sling attachment point and the other connector is attached to the confluence of the suspension slings using a six foot suspension sling extension.

Since the main parachutes are used to extract the cargo, the rigging of the extraction and transfer lines differs significantly from the standard system. Figure 14 shows a schematic of the rigging of these lines for the standard system and Figure 15 shows the rigging for the EXIARP system. The major difference is that the extraction line is attached directly to the transfer connector in the standard system whereas the extraction line, called the drogue line in the EXIARP system, is attached directly to the main parachute(s).

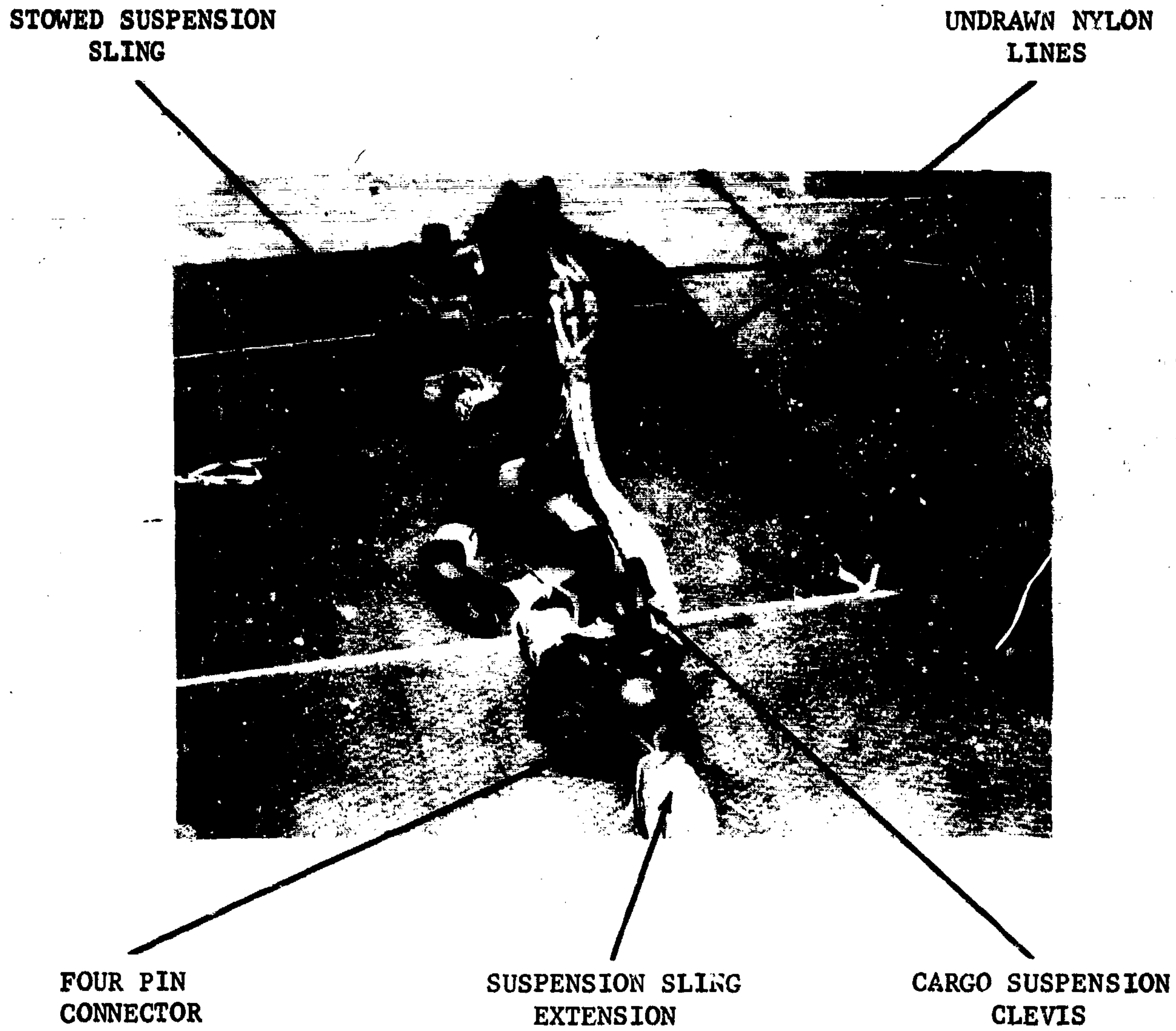
The only other cargo rigging change required involved the deployment of the parachutes. For the standard system and the EXIARP system using up to and including clusters of four parachutes, the parachutes are stored directly on the load. For clusters containing five or more parachutes a separate platform is used to extract the parachutes for the EXIARP system.

3. Pre-flight Preparation

The pre-flight preparation of the cargo involves loading the cargo into the aircraft, restraining the cargo within the aircraft, and attaching the drogue parachute. All of these procedures are the same as those used in the current airdrop system.

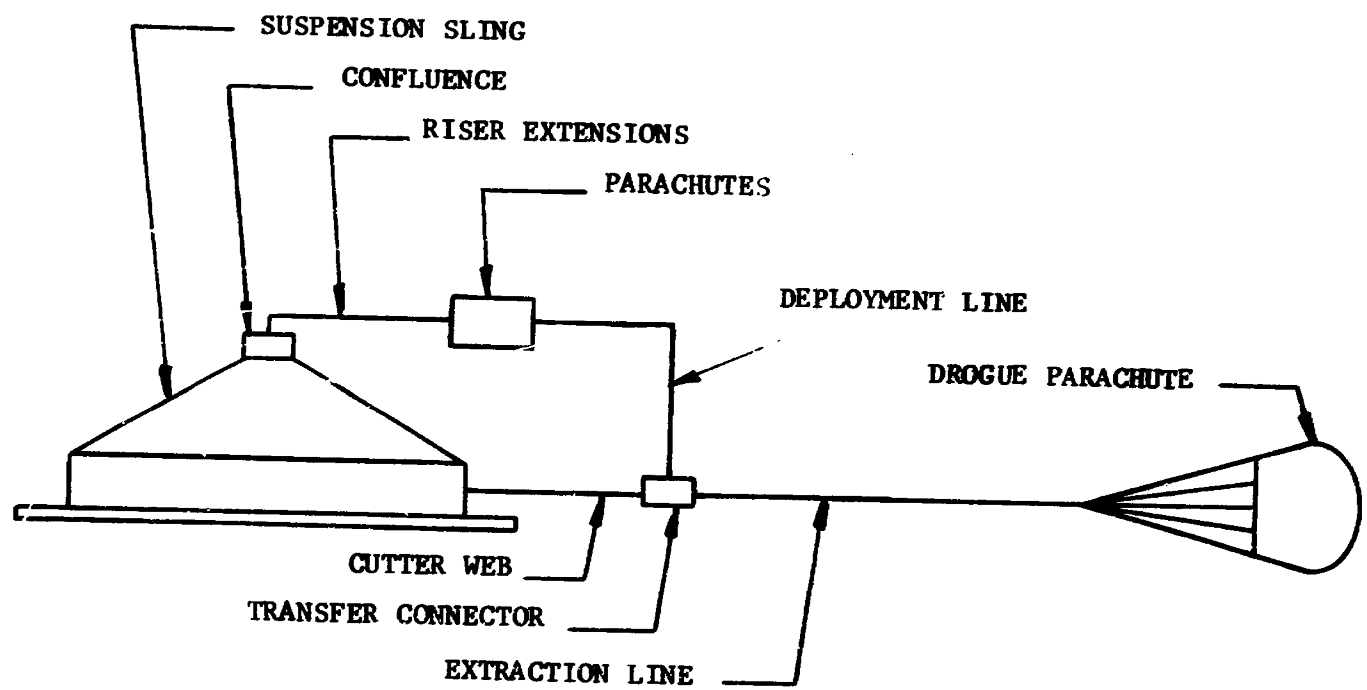
Restraint of the cargo within the aircraft is accomplished using the dual rail indent/detent system. The permanent vertical restraint flange on the rails provides the necessary up restraint. The indent/detent locks on the left hand rail provide the required in-flight forward and aft restraint while lateral restraint is accomplished by the rails. The right hand locks provide forward and aft restraint after the left hand locks are released upon approach to the drop zone. The procedures used to engage the locks for the EXIARP system are the same as the present system and a setting of 1/2 g or 1.0 g is used depending upon the length of the platform. When the parachute extraction platform is used, one lock is set at 4000 pounds to restrain the platform.

The drogue parachute is attached to the pendulum release just as in the standard system. Like the standard system a 60 foot extraction line is used as a drogue line with the drogue parachute. For ballistic deployment of up to and including four parachutes, a preinflation break web is attached to the drogue line and cargo as shown in Figure 16. One end of the drogue line is attached to a large suspension clevis along with the pre-inflation break web and the confluence of the bag bridles.



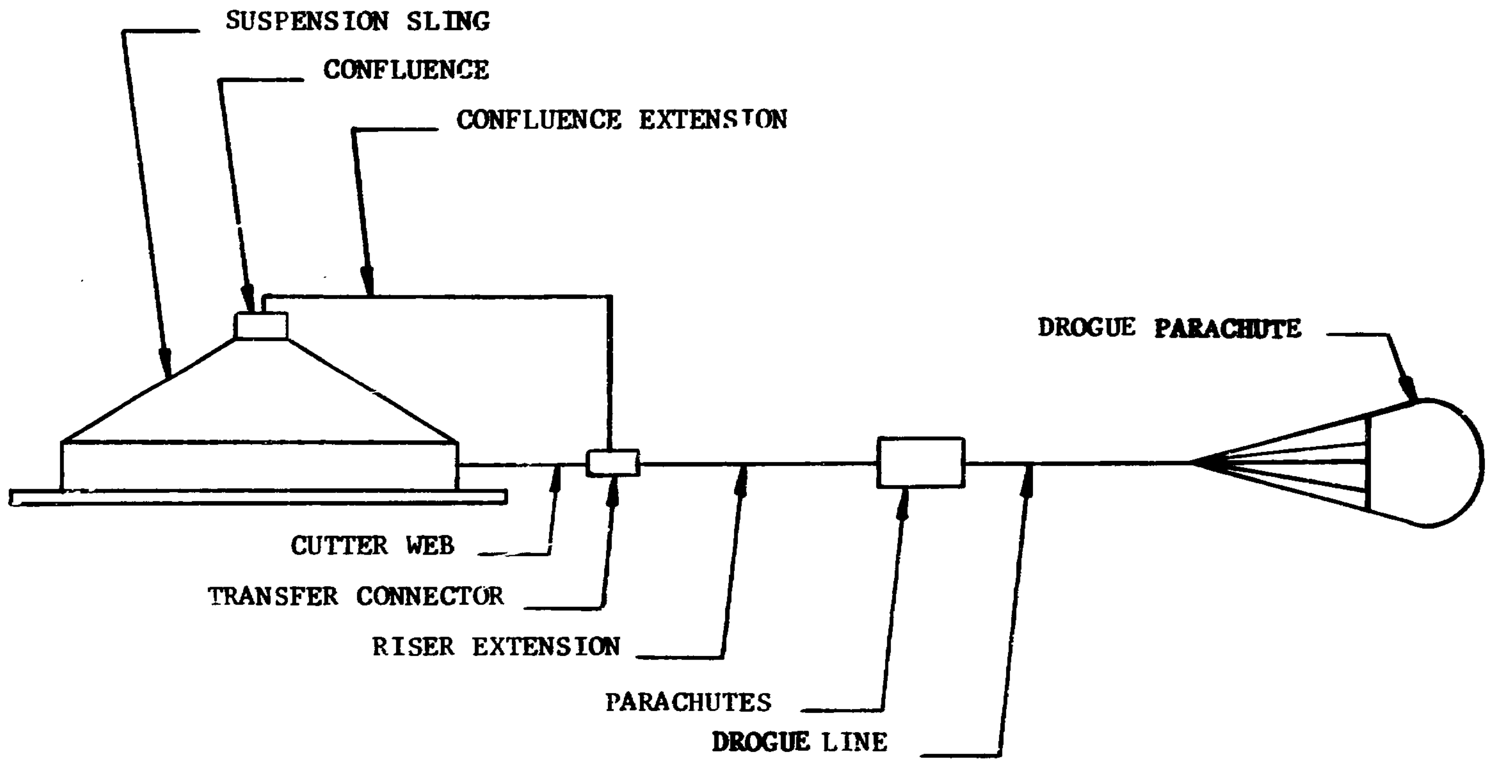
SUSPENSION SLING FORCE ATTENUATOR INSTALLATION

Figure 13



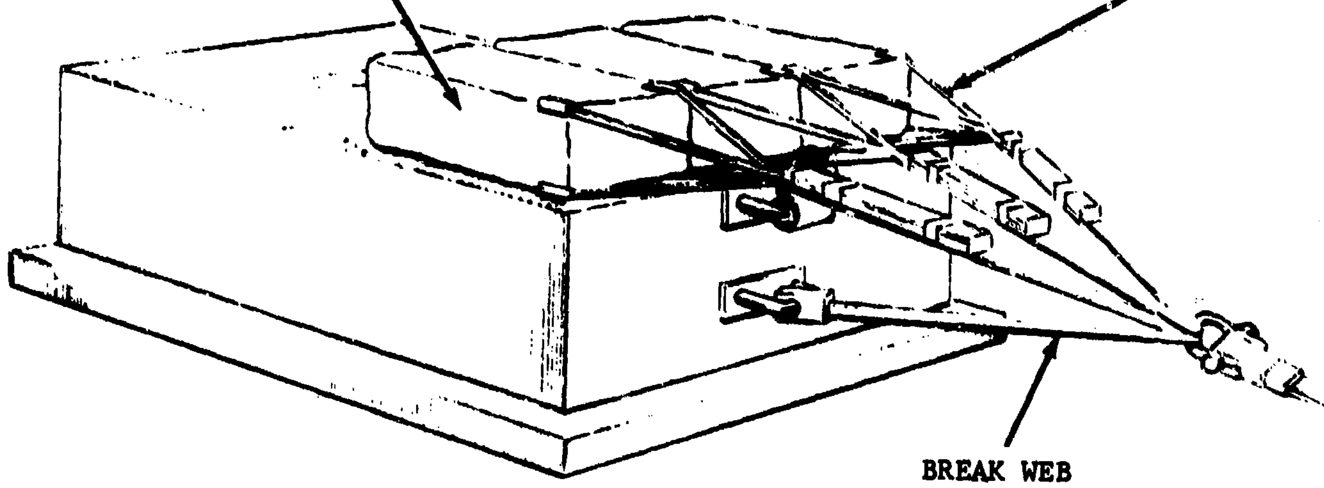
CARGO RIGGING SCHEMATIC - STANDARD AIRDROP SYSTEM

FIGURE 14



CARGO RIGGING SCHEMATIC - EXIARP AIRDROP SYSTEM

FIGURE 15



PRE-INFLATION BREAK WEB INSTALLATION

Figure 16

C. System Operation

1. Recovery Parachute Extraction & Deployment

a. Ballistic Extraction

The normal procedure used to deploy and extract the recovery parachutes using the "extraction by mains" principle consist of mounting the recovery parachutes on the cargo and having a small drogue parachute (which is pendulum released) extract the recovery parachutes off the cargo. This ballistic extraction concept has been used to extract up to and including four G-11A recovery parachutes during several previous tests of the extraction by mains airdrop technique.

The basic principle of this ballistic extraction concept is to "snatch" the recovery parachute through the cargo compartment before they have time to drop a sufficient distance to impact the aircraft ramp. Therefore, the extraction force applied to the recovery parachute bags must be large enough to develop high bag velocities, thus, minimizing the time for the bags to exit the aircraft. The rapid extraction of the parachute bags also prevents the bags from losing excessive altitude during their deployment subsequent to their extraction from the aircraft. The use of too small an extraction parachute will cause the bags to hit the ramp and/or the riser extension lines of the recovery parachutes to rub on the ramp edge.

To insure that sufficient force is developed by the drogue parachute prior to extraction of the main parachutes, a pre-inflation break web is attached between the extraction line and the cargo. The pre-inflation break web prevents motion of the parachute bags until the extraction force breaks this tie. Since the pre-inflation break web is attached directly to the cargo, the cargo restraint must be set at a force level greater than the rated strength of the pre-inflation break web or motion of the cargo will occur prior to extraction of the main parachutes.

To summarize the operational description of the ballistic extraction concept the sequence of events are listed below and illustrated in Figure 2, page 9.

<u>Deploy Drogue Parachute</u>

The drogue parachute is deployed using the pendulum release mechanism available in the C-130 aircraft.

<u>Release Of Recovery Parachute Bags</u>

The drogue parachute riser extension line is connected to a pre-inflation break tie on the cargo. When the drogue parachute develops sufficient drag force to break this tie the force is transferred to the recovery parachute bags and initiates motion of these bags. The cargo is restrained by the detents of the rail system with a force greater than the pre-inflation break force to prevent cargo movement during extraction of the recovery parachute.

Extraction Of The Recovery Parachutes

The drogue parachute extracts the recovery parachute bags out of the aircraft compartment. The bags travel through the cargo compartment without impacting the ramp or the aircraft sides. After the bags exit the aircraft the drogue parachute begins to deploy the recovery parachutes from their deployment bags.

b. Platform Extraction

Successful tests using up to four G-11A parachutes were conducted with the ballistic extraction method, but there was insufficient room on the cargo to store more than four parachutes and maintain adequate clearance with the surrounding aircraft structure. Therefore, beginning with the five-parachute configurations, an alternate method of extracting the parachutes was investigated. In this alternate method the parachutes were placed on a separate platform which was extracted from the aircraft using the dual rail system.

An eight foot platform was flight tested and proved unacceptable because the platform rotated out of the rails and struck a wind deflector plate on the ramp. To prevent this occurrence two separate platforms were designed to provide the needed deployment capability, however, neither of these has been tested. The design of each of these platforms is discussed in Section IV.C. The proposed platform extraction operation will be similar to that used on the test conducted at El Centro.

The sequence of operation for both platforms is illustrated in Figure 3 and is described as follows:

- Drogue Parachute Deployment

  The standard pendulum release system is used to deploy the drogue parachute.

- Restraint Of Parachute Platform During Drogue Inflation

  The drogue parachute begins to inflate and applies longitudinal force to the parachute platform. Longitudinal motion of the platform is prevented by the rail system.

However, a rotation is induced by the force couple consisting of the inflating drogue parachute force and the indent/detent reaction force. The retractable vertical restraints engaged at fuselage station numbers 709 and 720 react against this couple and prevent any rotation from occurring.

- <u>Parachute Platform Movement</u>

  The drogue parachute continues to inflate until it develops a force equal to the restraint setting of the single indent/detent lock, located at aircraft fuselage station number 688.875. This lock is set at its maximum force of 4,000 pounds. After release of the rail restraint, platform motion begins.

- <u>Platform Platform Extraction</u>

  The dual rail system applies lateral restraint to the parachute platform thereby preventing lateral motion during extraction of the platform.

- <u>Main Parachute Deployment</u>

  The main parachutes are deployed from the parachute platform.

- <u>Load First Movement</u>

  At line stretch of the main parachutes the load releases from the indent/detent locks which had been set at a total indicated release of 0.5 g's based on the load weight.

- <u>Recovery</u>

  The main parachutes recover the load and the drogue recovers the parachute platform.

2. Cargo Extraction

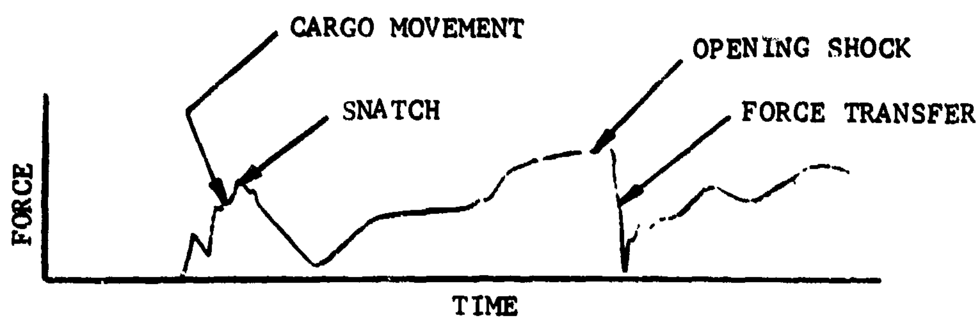
Several points during this operational sequence are critical. These include the final restraint of cargo to aircraft, the parachutes performance, and the aircraft's safety. A pre-determined final aft restraint force of the cargo to the aircraft is necessary to insure that the recovery parachutes being employed to extract the cargo are providing the drag required for proper low altitude performance. Too low an extraction force will; (1) affect the entire drop sequence and change the performance of the parachutes in retarding the velocity and controlling the trajectory of the cargo to the extent that cargoes will be lost upon impact; and (2) seriously affect control of the aircraft during extraction because of the length of time that an extreme center of gravity location change is in effect. Extraction forces in excess of 1.5 g's are prohibited by the specifications because of the strength of the extraction fittings of actual cargoes. Therefore, the operational range for extraction forces is minimal.

The model A/A32H-4 dual-rail cargo handling system used in the C-130 aircraft included 11 detent latch assemblies mounted on each side of the rail assemblies. The left hand side detent latches are used only for in-flight restraint purposes, and are manually released prior to approach to the drop zone. The right-hand detent latches are capable of being set at a variable aft restraining force of 250 to 4000 pounds each. The latch detents are spring loaded such that they engage the platform indents when placed in the engaged position. The platform is then restrained in the aft direction an amount equal to the force preset into the spring. The detents will disengage and remain disengaged when the preset force is overcome by an aft-directed force (extraction parachute) on the platform.

When heavy loads using the longer platform lengths and multiple parachutes are being extracted, allowances must be made for the frictional forces between the platform and the rails. This fact was not recognized until the cause for exceptionally high extraction loads in the four parachute airdrops was investigated. It was found that emperical data had been generated to account for this condition and that a restraint setting of 1/2 g rather than the 1.0 g used for the lighter loads would suffice.

To prevent cargo movement during the extraction of the recovery parachutes, it was necessary to use an aft rail restraint setting that was greater than the break strength of the preinflation break web used to restrain the recovery parachutes to the cargo. The need for the preinflation break web was to affect ballistic extraction of the recovery parachutes as discussed in a previous part of this section.

The desired operational sequence in the EXIARP system is that the aft restraint will be released and cargo movement will begin just prior to peaking of the snatch force as depicted in the following sketch.



3. Parachute Inflation

The system performance is dependent on the inflation of the recovery parachutes. Too rapid an inflation of the parachute will cause structural difficulties to both the parachute canopy and the cargo extraction fitting. Actual flight test results on this program have shown that the rapid inflation of the canopy can cause structural failure of the canopy panels and suspension lines. (This occurred when a parachute disreefed earlier than planned due to the malfunction of a reefing cutter.) The proper inflation sequence is also important to the EXTARP system performance. The deployment of the canopy from its bag causes the snatch force. After this force decays the actual inflation of the canopy begins. Air starts to rush into the canopy mouth and inflate the canopy as depicted in Figure 7 on page 14. If allowed to inflate without some type of reefing the parachute opening shock force developed could cause the parachute to fail structurally. Therefore, a reefing line is inserted in the canopy skirt, this line is threaded through a series of rings located at the canopy skirt, and four reefing cutters which are located symmetrically about the periphery of the skirt. A short piece of line is tied between the reefing cutter and the deployment bag such that separation of the canopy skirt and the deployment bag causes the line to pull an arming pin which starts the time delay. The cutters sever the line upon activation. The reefing line limits the growth of the canopy diameter, thus, limiting the canopy drag forces and the resultant opening shock force. In addition to retarding the force the reefing line cause the total parachute inflation time to increase. This results in higher altitude losses for acceptable cargo impact.

To reduce the inflation time a centerline has been inserted between the canopy vent and the confluence point of the parachute risers as illustrated in Figure 10. The use of a 95 foot centerline has improved the total parachute performance. The inflation time has been reduced significantly and the parachute drag has been increased such that the allowable canopy loading was increased from 3500 to 5000 pounds per G-11A parachute.

Clustered parachute test results indicated a need for a second reefing line to limit the parachute opening shock force after force transfer. During tests of clusters of three and five parachutes individual parachute forces exceeding 19,000 pounds were experienced. No data is available on the maximum force limit of a G-11A parachute equipped with a centerline, but this level of force was considered likely to damage the parachute. By computing the skirt diameter based on the present theory at the time of maximum parachute force, the second reefing line length was determined to be 60 feet for a delay time of 4 seconds. The technique of rigging the dual-staged reefing has been previously discussed.

IV. SYSTEM ANALYSIS METHODS

A. General

The development of an airdrop system for use at altitudes of 500 feet or less has been performed by using several system analysis methods. These include model tests, design studies, flight tests, analytical studies, and systems use studies. A discussion of the results of each of these studies is presented in this section.

AAI conducted model tests of parachute modifications designed to improve the performance of the parachute. These modifications included inflectors, centerlines, and combinations of inflectors and centerlines. The results of these tests were used to predict to some extent the full scale performance which could be expected using the above modifications.

Design studies were performed to either improve the performance of the system or to provide a greater degree of system safety. To improve the performance of the recovery parachute both inflectors and centerlines were designed. To provide an extraction means for parachutes used in clusters of five or more, several extraction platforms were designed. Two safety devices were designed to provide a greater degree of aircraft flight safety during deployment and inflation of the parachute.

In addition to the model tests, AAI conducted a full scale flight test program consisting of two phases. The first phase was a data gathering phase used to provide inputs for the computer analysis and evaluate system component performance. The second phase demonstrated the performance of components used in clustered configurations and demonstrated system feasibility. The results of the flight tests are summarized in this section.

Analytic studies were also employed to evaluate the system. These analyses were made using two-dimensional computer programs developed by AAI. These programs were also used to study the effect of the various system parameters on the performance of the system, and to compare the results of the flight tests and analytical prediction techniques. In addition, the effect of high altitude drop zones on system performance was studied.

Studies were made of the operational use of the system and a brief description of studies in the areas of mechanical reliability, human reliability, and other related studies is given in this section. The complete discussion of the system use studies is presented in the T.I.E. (Technical Integration and Evaluation) report (2).

B. Model Tests

The purpose of the model test program was to permit an efficient survey of candidate parachute inflation aids so as to establish those techniques which were worthy of full scale flight tests. The emphasis in this program was on reducing the overall time to inflate the parachute. Additional areas of interest were identification of potential problem areas and interference effects with multiple parachute configurations.

Scale effects with parachutes are at best poorly understood. In particular, it is not possible to apply a linear scale factor to such items as canopy material thicknesses, material porosity, thread weights, and seam sizes. These problems are amplified when trying to scale the dynamic situation of parachute inflation because the mass, inertia and stiffness of the parachute are significant parameters. By not being able to scale the parachute directly the scaling laws of rigid body motion are not completely satisfied. The addition of aerodynamic considerations tends to further complicate the picture. These problems impose some limitations regarding the extrapolation of data and require that engineering judgement be exercised in analyzing the results.

Since dynamic, rather than steady state, information was the primary goal, it was decided that finite mass testing would yield the most useful information. That is, the deceleration of the system as the parachute is deployed should be taken into consideration since the velocity of the system will change significantly during the filling of the parachute. The largest possible parachutes were used in an attempt to reduce the magnitude of the errors caused by large scale factors. These two considerations led to the conclusion that data for the present program could best be obtained by flight tests as opposed to wind tunnel or tow tests.

Past experience, and the literature (3) indicate that for incompressible fluids scaling on the Froude Number is the proper basis for dynamic scaling, where

$$\text{Froude No.} = \frac{\text{Inertia Force}}{\text{Gravity Force}} = \frac{V}{\sqrt{Lg}}$$

V = velocity

L = characteristic length

g = gravitational constant

Defining:

$$\lambda = \text{scale factor} = \frac{L_{\text{full scale}}}{L_{\text{model}}}$$

Then, for constant "g",

$$W_m = \frac{W_f}{\lambda^3} \qquad (W = \text{weight})$$

$$V_m = \frac{V_f}{\sqrt{\lambda}} \qquad (V = \text{velocity})$$

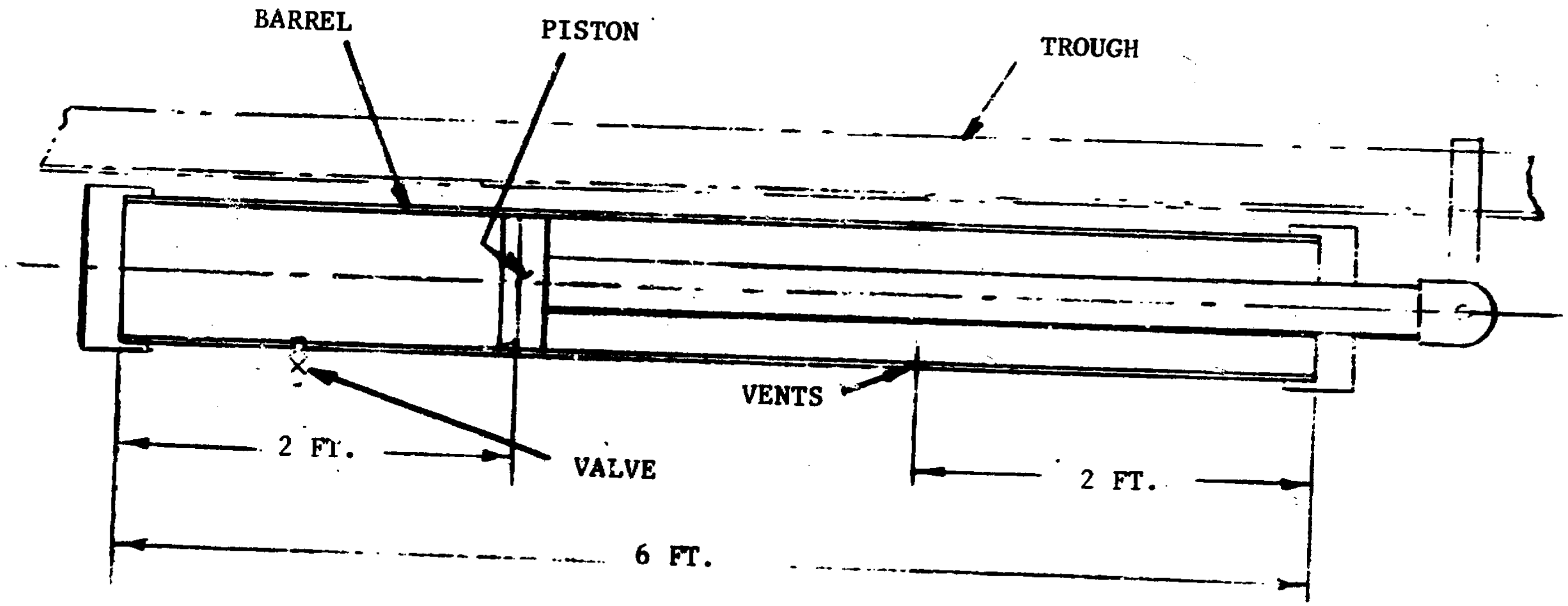
$$t_m = \frac{t_f}{\lambda^2} \qquad (t = \text{time})$$

$$a_m = a_f \qquad (a = \text{acceleration})$$

Two basic cases were of interest: a 3500 pound cargo with one G-11A parachute and a 10,500 pound cargo with three G-11A parachutes. It was thought that these two cases would serve to establish the characteristics of the candidate systems and to represent a reasonable tradeoff between complexity of setup and completeness of data. Therefore, a pneumatic catapult was designed to launch a 10 foot diameter parachute and a 3.5 pound cargo at a speed of 80 fps. This corresponds to extracting a 3500 pound cargo from an airplane traveling 150 knots. By designing to these values it was also possible to accommodate a cluster of three 5-foot parachutes with a 1.2 pound cargo and develop a launch velocity of 57 feet per second. This corresponds to a 10,500 pound cargo with three G-11A's at 150 knots.

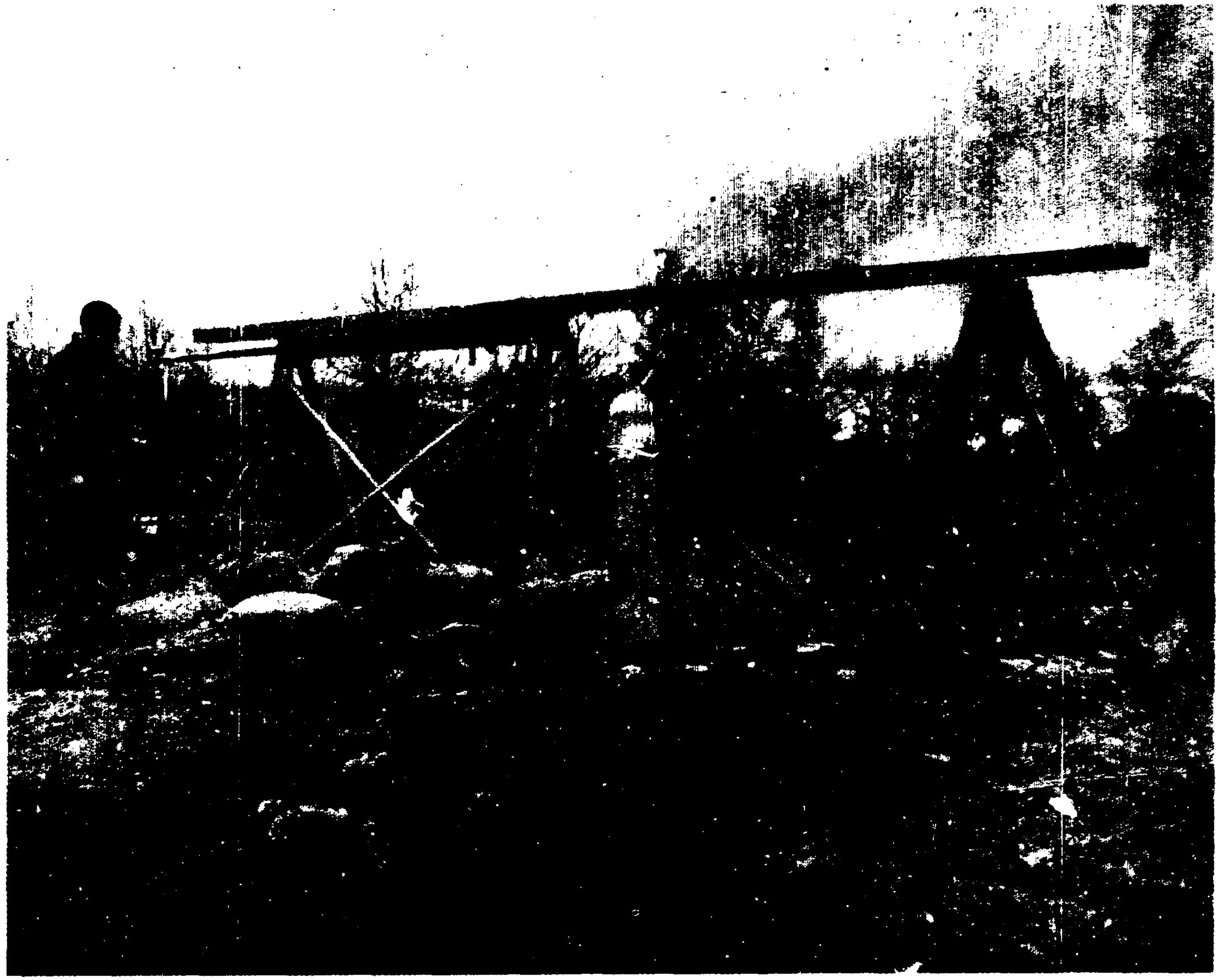
The catapult is illustrated in the schematic of Figure 17 and the photograph of Figure 18. The catapult operates in the following manner. The parachute and load are placed in the launcher support chute and the pusher arm is placed against the rear edge of the cargo. The cylinder is pressurized to the desired level with air from a compressed air cylinder. At the desired time a latch is released allowing the piston to move forward. The load is accelerated through a distance of two feet. At this time the piston passes the vent holes in the cylinder and is subsequently buffed by the remaining column of air. The deceleration causes the pusher arm to fall out of the way so as not to interfere with the parachute as it continues on at constant velocity.

Due to difficulty in obtaining the size parachutes required, a 12 foot parachute was the only size available within the specific time frame allotted to the model test. The 12-foot parachute yields a scale factor of 8.35 on the 100 foot diameter G-11A parachute. This factor dictates a scale weight of 6 pounds to simulate a 3500 pound cargo and indicates that velocities of 64 to 88 feet per second will represent 110 to 150 knot full scale airspeeds. Initial tests with the 12-foot parachute and 6-pound load showed that the parachute was too lightly loaded. It tended to inflate to a flat configuration rather quickly. The problem was that the conventional parachute loading parameter W/C_DA had been reduced by a factor of λ because W varies as λ^3 and A varies as λ^2. Hence, in order to satisfy dynamic scaling it was necessary to violate static scaling. Since the inability to scale material



PNEUMATIC LAUNCHER

FIGURE 17



PHOTOGRAPH OF LAUNCHER TEST FIXTURE

Figure 18

thickness directly gave an overweight parachute, it was thought reasonable to increase the cargo weight. This increase would tend to compensate for the improper parachute-cargo weight differential and also give a more realistic canopy loading factor. The cargo weight was arbitrarily increased to 9.75 pounds. This increase in weight gave the parachute a more reasonable opening. However, it can be seen in the data that in general the parachutes still inflated to a diameter of about 11 feet. It is thought that the motion of the parachute is a good representation of the dynamic situation until a diameter of about 8 feet is achieved. After this point the system is moving so slowly that the situation is more nearly static than dynamic and the effects of the light canopy loading are being felt.

The unmodified 12-foot parachute weighed 1.69 pounds. Together with the 9.75 pound cargo this increase in weight over the design weight for the launcher limited the launch velocity to about 50 feet per second. This corresponds to a full scale speed of 85 knots. While this velocity is somewhat below the true operating range, the effect of testing at the lower velocity should only be reflected in the magnitudes of the filling times and not in their positions relative to each other.

Four parachute configurations were tested: unmodified, vent pull down, inflector, and vent pulldown plus inflector. For these tests control line lengths of 12.25 and 11 feet were used. Significant differences in filling time due to a change in line length were not apparent. The inflector concept has been tested by Stencel (4) and shows promise of reducing inflation times. The inflector design was based on the size recommended in Reference (4) for the G-11A parachute. Lack of time precluded testing of different size inflectors. The vent pull down plus inflector configuration was simply the addition of the vent control line to the parachute with the inflectors.

A total of 29 model tests were conducted. Several tests were eliminated from consideration because of a sudden head wind which gusted just as the parachute was launched. Others were eliminated because of fouling of suspension lines or a severe twisting of the parachute which hampered opening. These problems were probably due to inconsistencies in the launch and in parachute packing. If the push rod was not aligned with the cargo center of gravity, the cargo tended to tumble in flight. This in turn could cause some twisting of the lines. An attempt has been made to consider only those tests in which a clean launch was made and in which there was essentially no wind.

The following table gives the average times to inflate the parachutes to 4-foot and 8-foot diameters. It is thought that these two values give a reasonable measure of the relative merits of the various inflation aids. As previously stated, it is doubtful that the results should be considered beyond the time to inflate to an 8-foot diameter because the velocity is reduced to almost zero and this obviously does not simulate the full-scale condition. The 8 feet also corresponds to the approximate diameter of a 12-foot flat circular parachute in a steady state descent.

PARACHUTE FILLING TIMES

Parachute Type	Time-Sec Parachute Diameter	
	4 Ft.	8 Ft.
Unmodified	.46	1.26
Vent Pull Down	.21	.61
Inflector	.38	.76
Vent Pull Down & Inflector	.35	.70

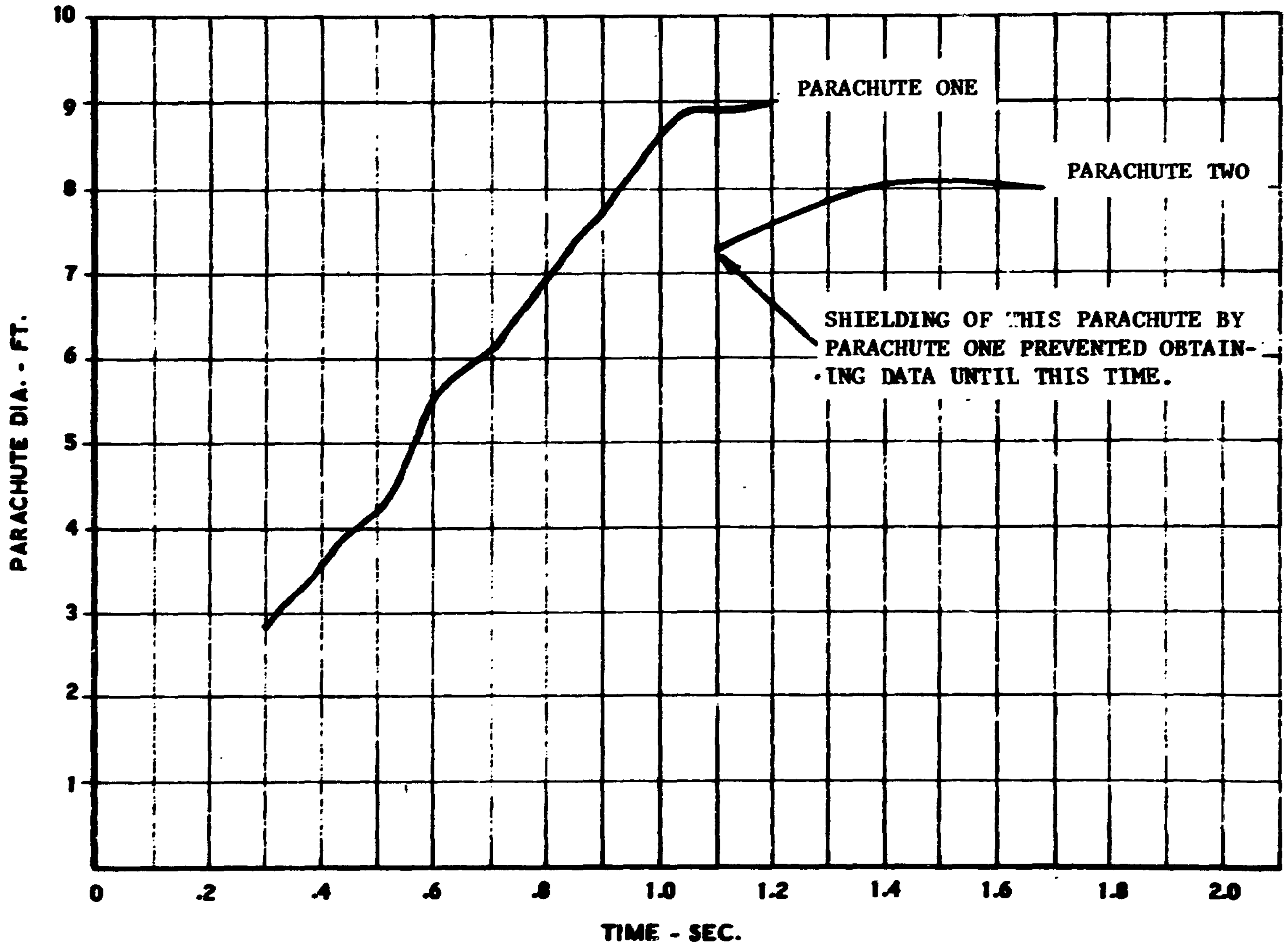
It can be seen that all of the inflation aids significantly reduced the time to fill the parachutes, with the vent pull down technique having the shortest inflation time. The vent pull down was particularly effective in getting the inflation started early and then maintaining a good rate.

Agreement between different tests of a given configuration is good with an exception of the vent pull down plus inflector design. Both the fastest and the slowest modified parachute inflation times were recorded with this design. These results suggest that this design may have the greatest potential; but may also be the least consistent. This aspect of the problem was studied carefully in the full scale tests.

Several two-parachute configurations were launched in an effort to establish the effects of the inflation aids on the filling of clustered parachutes. As stated earlier, it had been planned to conduct these tests with clusters of three 5-foot parachutes, but the inability to procure the parachutes within the allowable time frame limited testing to the 12-foot units. Structural limitations of the catapult precluded launching heavier simulated cargoes so it was necessary to use the 9.75 pound weight with the two-parachute clusters. Since a single parachute was capable of decelerating the cargo at a rapid rate it is difficult to draw strong conclusions from the cluster test data. If one parachute got ahead of the other during the first tenth of a second of filling, it decelerated the system very quickly and the second parachute did not fill. If the two parachutes started to fill at the same instant they usually continued at a fairly uniform rate. A plot of parachute diameter versus time for a cluster of two 12-foot parachutes with inflectors is shown in Figure 19. The fact that the filling time is longer than for the single parachute is due partially to some interference effects between the parachutes and partially to the fact that with two parachutes the system decelerates so quickly that the mass rate of flow of air into the parachutes is reduced. The following table summarizes the general performances of the clustered parachutes.

FILLING TIME - TWO 12 FT. DIAMETER PARACHUTES WITH INFLECTORS

FIGURE 19



Configuration	Both Parachutes Opened Uniformly	One Parachute Lagged Badly
Unmodified	1*	1
Vent Pull Down	1	1
Inflector	3	
Vent Pull Down plus Inflector	0	3

* This number designates the number of tests

It will be recalled that the widest variation in performance with the single parachutes was with the vent pull down plus inflector design. This result and the above cluster result suggest that this configuration will present the most problems in full scale tests. The vent pull down or the inflector holds promise of reducing the filling time of a parachute by a factor of two. From an operational point of view, the vent pull down configuration is probably preferable since it requires a minimal modification to existing hardware.

C. Design Studies

Several new pieces of hardware were designed while conducting the flight tests to either improve the system performance or to provide a greater degree of safety for the EXIARP system. This hardware included;

- Multi-line snatch force attenuator
- Suspension sling attenuator
- Parachute inflectors
- Parachute centerline
- Parachute extraction platform
- Fail-safe and breakaway safety devices

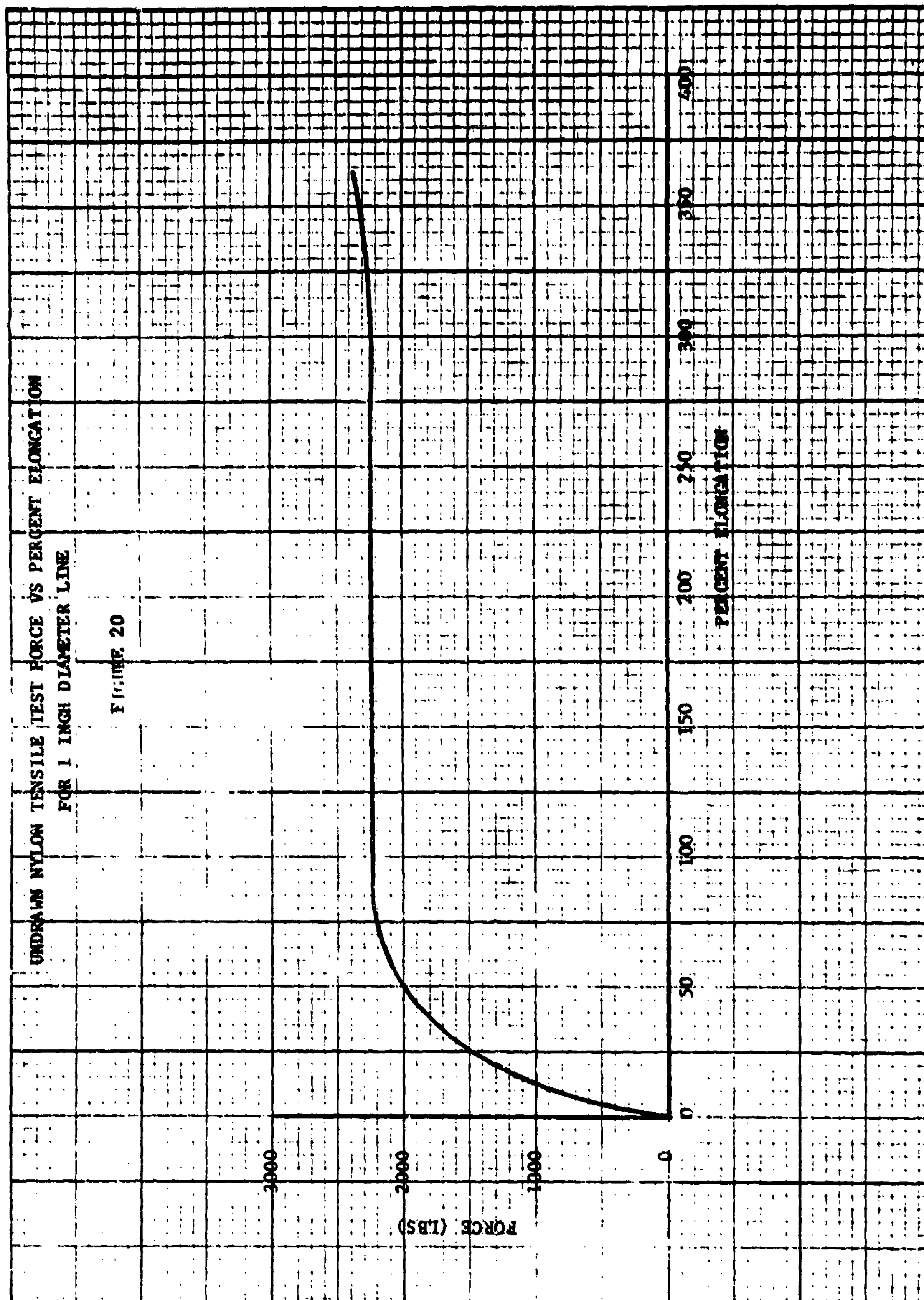
Multiline Snatch Force Attenuator

Since the extraction force connection fittings on all airdrop loads are designed to carry a maximum working load of 1.5 g's, the forces applied to these fittings by the main parachutes during their deployment and inflation must be kept below that limit.

The device developed is shown in Figure 11 and is termed the multi-line attenuator. It consists of four lines of 5/8 inch diameter undrawn nylon line in parallel with a 10 foot long safety line. When the parachute lines become taut during the deployment sequence, force is applied to the undrawn nylon lines. These lines elongate until the safety line begins to carry the parachute force. The lengths of the safety line and nylon lines were selected such that the undrawn nylon line when stretched to the safety line length, had an elongation of 350 percent. This elongation results in a nearly constant force energy absorbtion. The tensile force versus elongation curve shown in Figure 20 for a one inch diameter undrawn nylon line shows that after an elongation of 75% and prior to an elongation of 350% the force required to stretch the line is nearly constant.

Suspension Sling Attenuator

Each suspension fitting of airdroppable loads is limited to 1.5 g due to design constraints imposed on these fittings. To limit the force applied to these fittings, an attenuator similar to the snatch force attenuator was employed. The undrawn nylon lines were rigged in parallel with existing suspension slings. For the suspension sling lengths used in the flight tests the undrawn nylon line length was selected to maximize the energy absorbtion capabilities of the nylon lines. After numerous flight tests the most desirable combination of undrawn nylon lines was determined. This configuration was to install two undrawn lines parallel to each aft suspension sling and one line parallel to each forward sling per parachute. Consequently, a three parachute configuration would use 6 undrawn lines on each aft sling and three lines on each forward sling.



UNDRAWN NYLON TENSILE TEST FORCE VS PERCENT ELONGATION
FOR 1 INCH DIAMETER LINE

FIGURE 20

The primary purpose of using these suspension sling attenuators was to limit the suspension forces to 1.5 g's. However, an additional requirement was to obtain a system which minimized the time interval after force transfer when no parachute force was being applied to the cargo. In the present airdrop system significant altitude is lost during the force transfer phase because the parachute deceleration force is not being applied during the time required to extend the suspension slings. Figure 21 illustrates this occurrence.

Parachute Inflectors

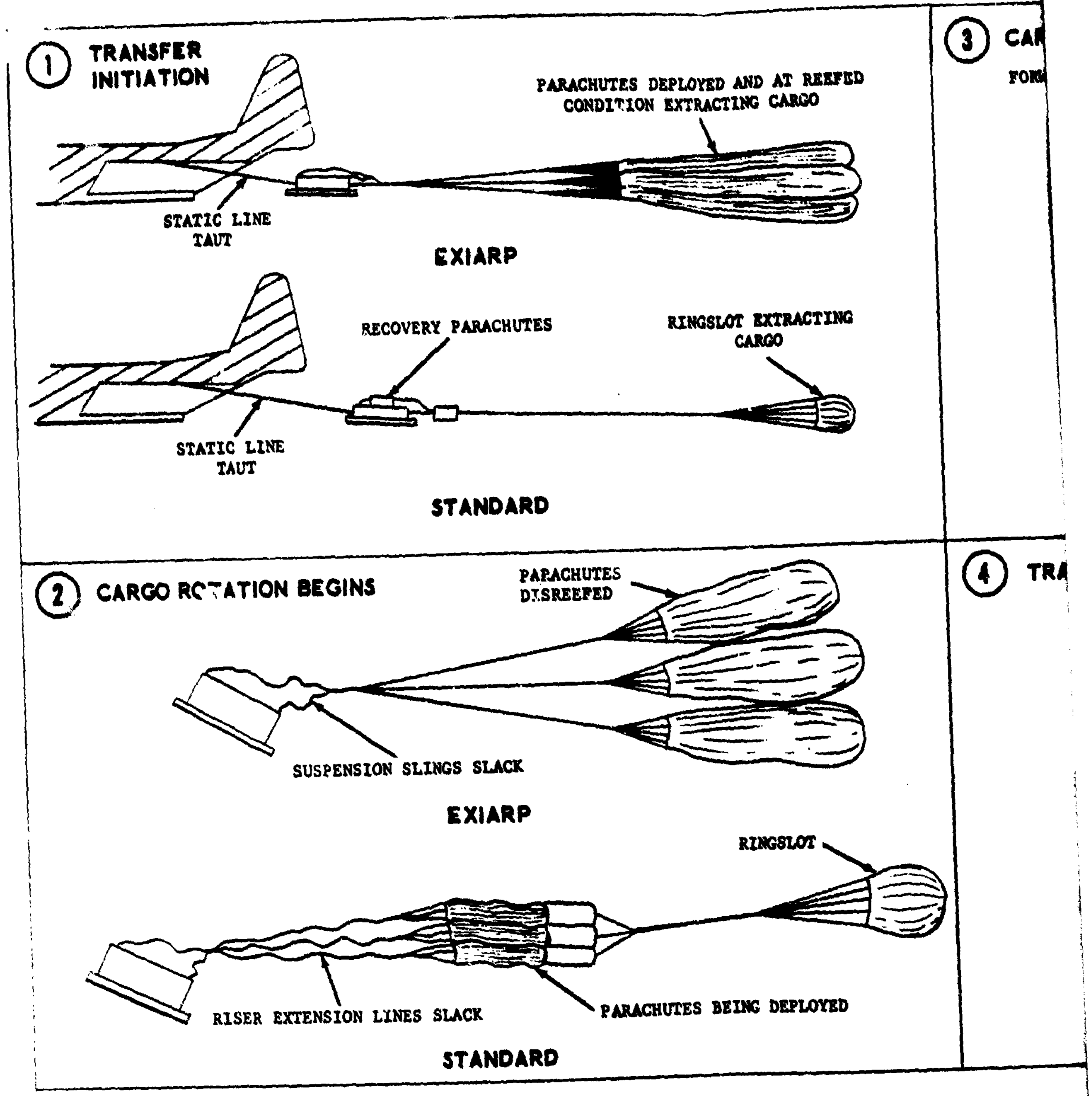
Model tests conducted by Stencel Aero Engineering have revealed the possibility of decreasing the canopy inflation time with the use of inflectors sewn into the skirt area of the canopy. The purpose of the inflector is to generate a radial force component at the canopy skirt and aerodynamically force the canopy skirt open as illustrated in Figure 22. This inflation aid reduces the lag time between the rapidly inflating apex segment of the canopy and the canopy skirt; hence, decreasing the inflation time and improving the aerodynamic performance of the parachute. To determine the effect of using an inflector at the canopy skirt, several different size and type inflectors were designed.

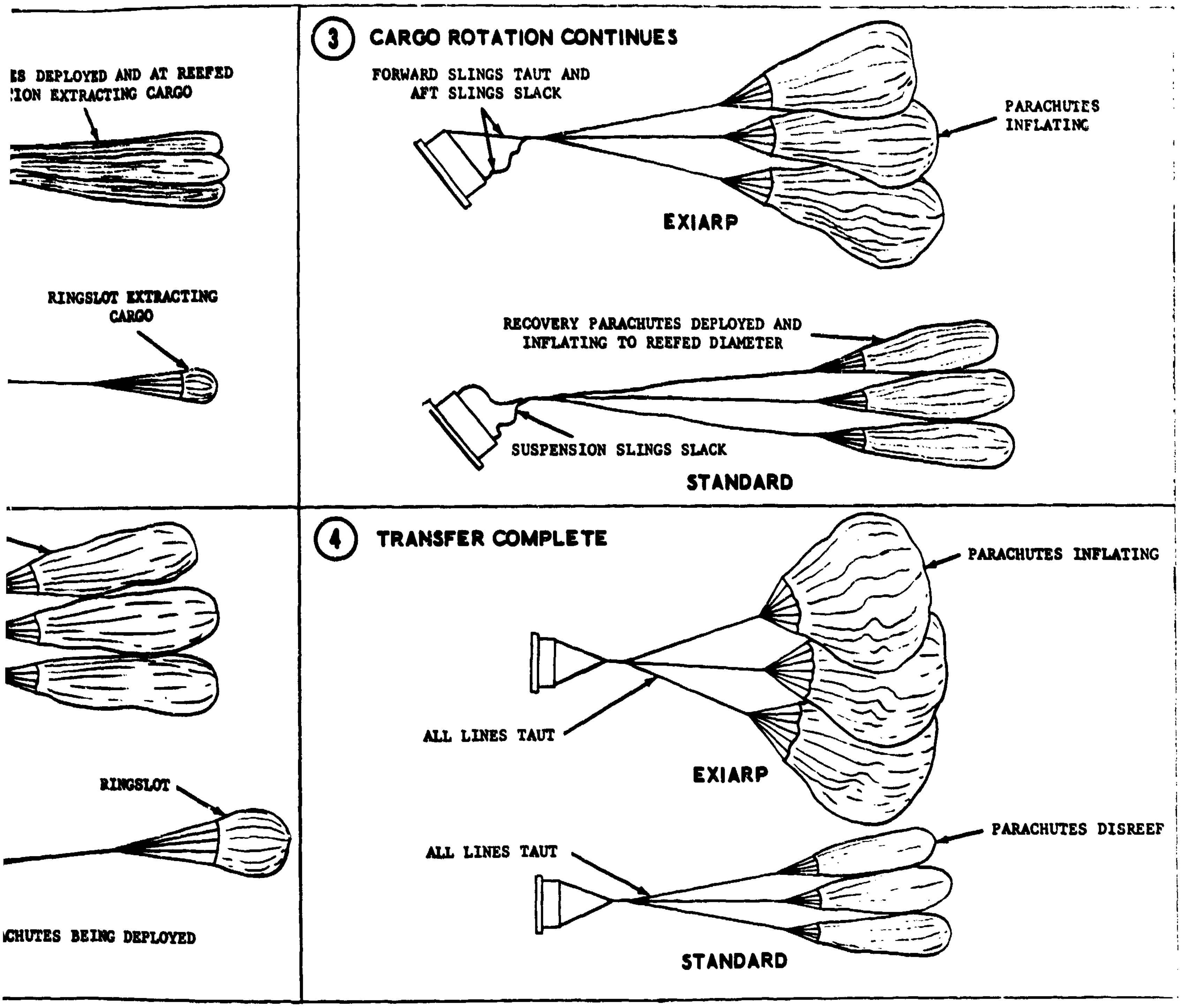
The first type of inflector inflation aid, shown in Figure 23 used a nylon web to hold the canopy skirt out in the airstream. The web was attached to the canopy by cutting the suspension line free from the connector link and piercing a hole on the inside of the canopy. The suspension sling was then pulled through the pierced hole and reattached to the connector link. The inflector web was then stitched to the canopy and suspension line, and the reefing ring stitched in place. Circumferential bands were added to the canopy above the pierced hole to provide reinforcement for the canopy. Three different size inflectors of this type were fabricated for use in the flight test.

The second inflector design simplified the parachute modification and decreased the fabrication time. Shown in Figure 24, this inflector replaced the triangular web with a nylon band. The method of attachment and reinforcement remained the same.

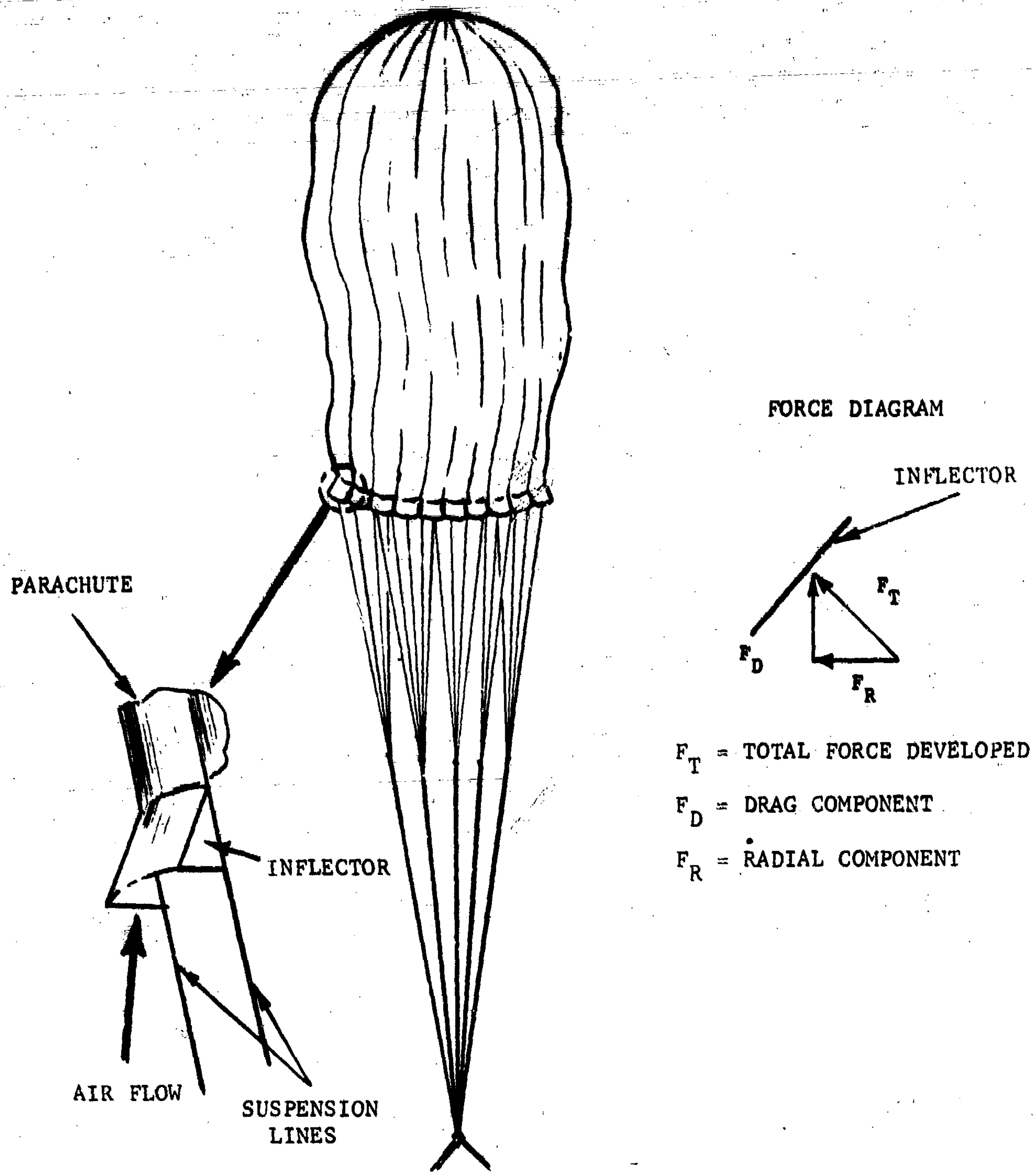
Parachute Centerline

A second inflation aid used was the apex control line or centerline. The centerline was a heavy nylon web with a break strength of approximately 15,000 pounds. This line was attached between the canopy apex and the confluence point on the parachute risers. Figure 10 on page 18 illustrates the centerline inserted in the parachute.


1 TRANSFER INITIATION
PARACHUTES DEPLOYED AND AT REEFED CONDITION EXTRACTING CARGO
STATIC LINE TAUT
EXIARP
RECOVERY PARACHUTES
RINGSLOT EXTRACTING CARGO
STATIC LINE TAUT
STANDARD
2 CARGO ROTATION BEGINS
PARACHUTES DISREEFED
SUSPENSION SLINGS SLACK
EXIARP
RINGSLOT
RISER EXTENSION LINES SLACK
PARACHUTES BEING DEPLOYED
STANDARD

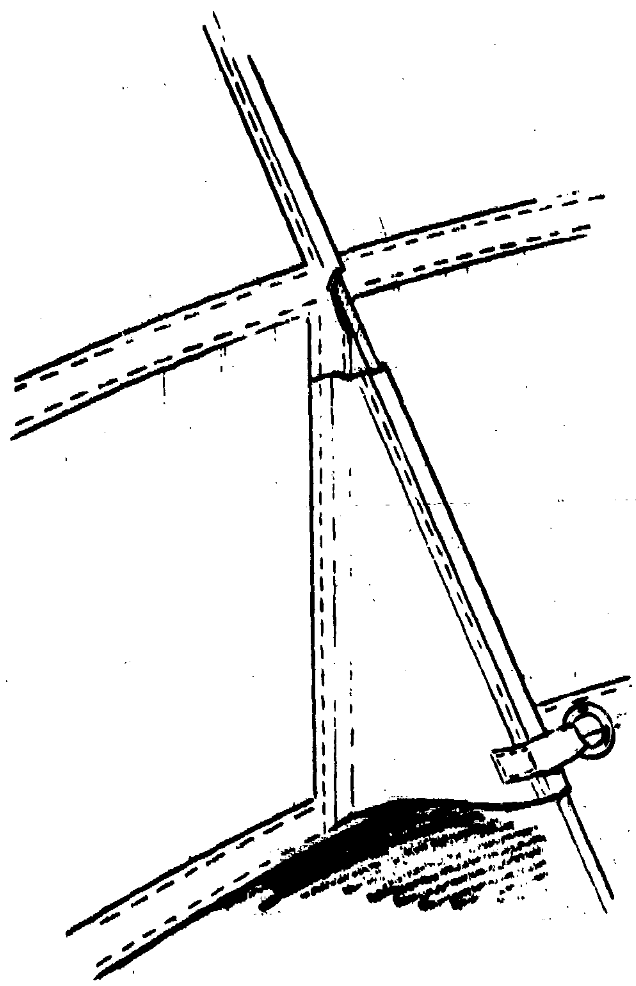


COMPARISON OF EXIARP AND STANDARD SYSTEM FORCE
TRANSFER OPERATION
Figure 21

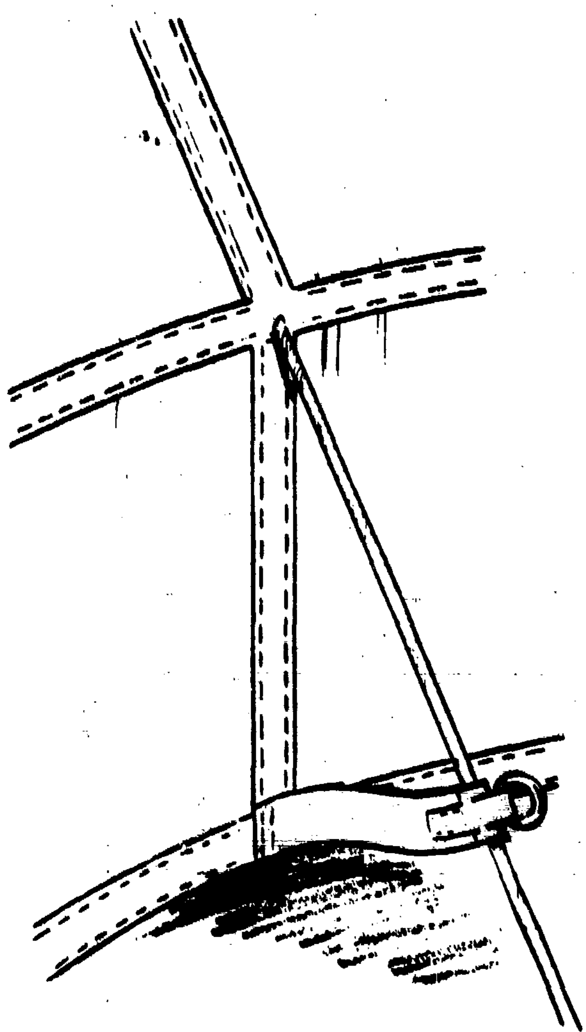


INFLECTOR PARACHUTE OPERATION PRINCIPLE

FIGURE 22



TRIANGULAR INFLECTOR MODIFICATION
FIGURE 23



BAND TYPE INFLECTOR MODIFICATION
FIGURE 24

Previous studies revealed that using a centerline reduced the inflation time because the centerline carried approximately 30 to 50 percent of the parachute force, hence reducing the force in each suspension line. Since the total suspension line force is reduced, the radial component of that force, which tends to retard the outward motion of the canopy skirt, is reduced. This results in a more rapid inflation of the parachute canopy.

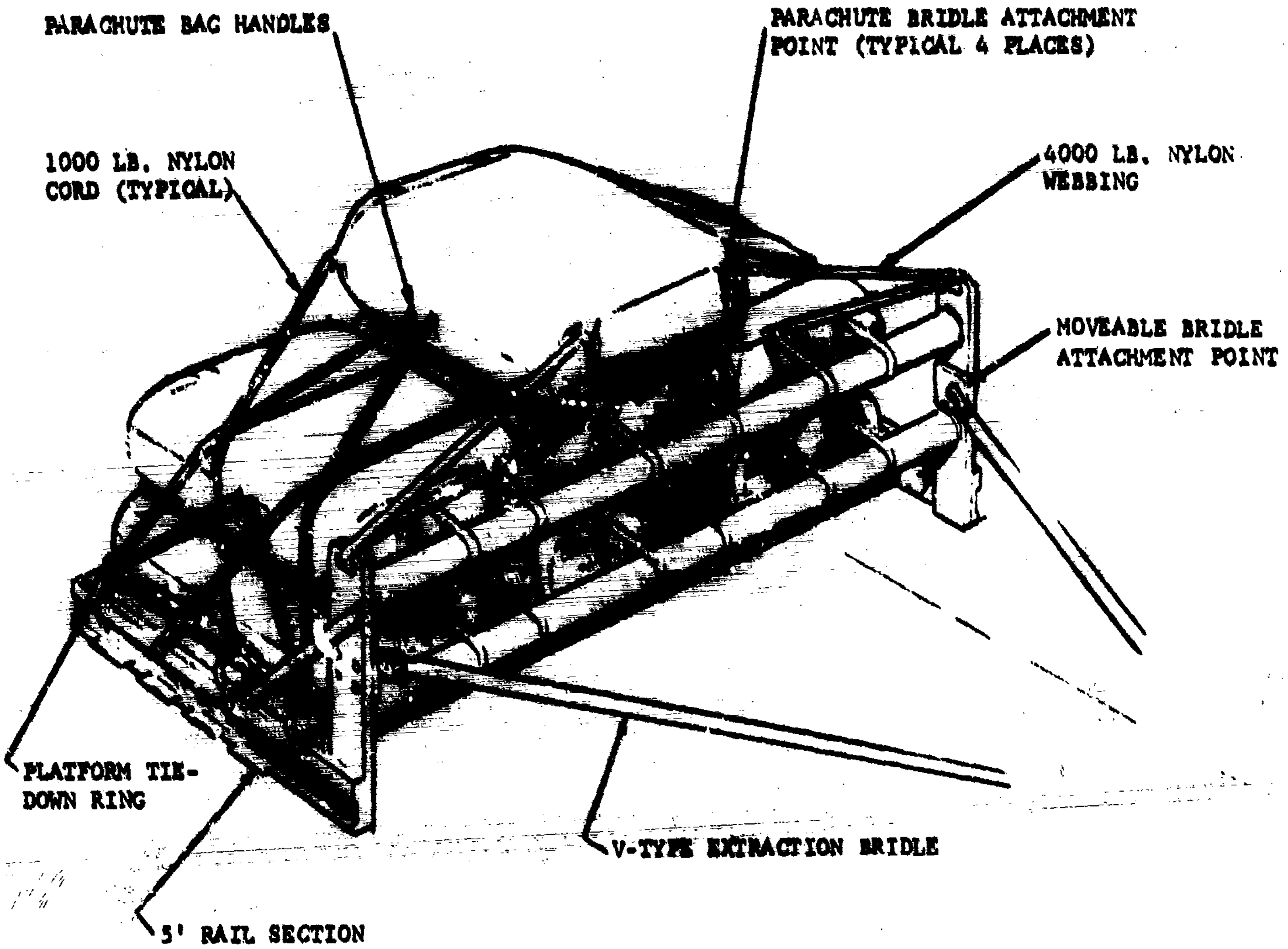
In addition to decreasing the inflation time, the centerline increases the load carrying capability of the canopy. This results from the change in canopy shape which occurs when a centerline is installed. The canopy tends to flatten out and the drag area is consequently increased provided the proper centerline length is used.

Parachute Extraction Platform

Clusters of up to and including four parachutes have been successfully extracted through the aircraft cargo compartment during previous test programs. However, the lack of adequate clearance between the parachutes and the sides of the aircraft and the aircraft ramp when more than four parachutes are used, required that a new extraction technique be developed. To accomplish this a parachute extraction platform was designed and is shown in Figure 25 . This platform consisted of two eight-foot rail sections with a four-foot modular panel riveted between them flush with the forward end. An aluminum stiffener bar was attached to the aft end on the rails using two attachment blocks. These same blocks were used for attachment of a "V" type extraction line. Restraint of the parachutes to the platform was accomplished by tying lines from the parachute bags to the rails and to two chains strung diagonally from the aluminum attachment blocks to the opposite rail. Flight test of this platform revealed that it was unsafe for use; consequently two additional extraction platforms were designed. These platforms have not been tested.

The "structured" extraction platform design is shown in Figure 26 , and is made up from two eight-foot rail sections cut to a length of five feet. A four-foot modular panel is riveted to the rails flush with the uncut end using standard rivet locations. This leaves a one-foot length of rail protruding at the aft end of the platform. This additional one-foot length is provided for the attachment of the structural members shown in Figure 26 . It also increases the platform length-to-width ratio. Although the feasibility of deploying a four-foot long modular platform was demonstrated and reported by Waite(5), it is felt that this increase in length will provide an additional margin of safety in preventing binding of the parachute platform in the rail system.

PARACHUTE EXTRACTION PLATFORM - 8 FT CONFIGURATION
Figure 25



"STRUCTURED" PARACHUTE EXTRACTION PLATFORM CONCEPT

Figure 26

The structural members added to the platform consist of several vertical plates and horizontal tubes. These members have been designed to withstand the maximum g forces developed by a 28 ft. ringslot parachute. (This parachute is used for extraction and the recovery of the parachute platform.) The extraction platform structure provides for shifting the attachment location of the "V" type extraction bridle so that the extraction force is applied directly through the center of gravity of the parachutes and platform, since the c.g. shifts with the change in recovery parachute number.

The main parachutes are restrained to the parachute platform. This is accomplished by tying 4000 pound breaking strength nylon web through the parachute bridle attachment points and around the horizontal tubes. The top parachute is restrained by loops of 4000 pound breaking strength nylon webs tied through the parachute bridle attachment points and the attachment point provided in the top of the vertical plates. The restraint is provided by loops of 1000 pound break strength nylon cord tied through the bag handles and tie-down rings on the platform.

After the extraction of the platform and deployment of the main parachutes has been completed, the ringslot parachute recovers the parachute platform and main parachute bags. The terminal velocity of the structural platform and parachute bags being decelerated by a 28-foot ringslot parachute is defined in the following table.

Number of Parachute	Terminal Velocity (fps)
5	36.9
6	37.7
7	38.5
8	39.2

These velocities will be low enough to prevent damage to the parachute platform.

Although the selection of the ringslot parachute has been based primarily on its ability to recover the parachute platform without structural damage, its size is also important for proper deployment of the main parachutes. As the size of the ringslot decreases for a given number of main parachutes, the time to deploy them increases. Since the parachutes experience the force of gravity during deployment, the increase in time causes an increase in the vertical drop. This "sag" could have two detrimental affects. First, the riser extension lines could rub on the aircraft ramp edge and be damaged or catch on a roller and pull a section of rollers loose. Second, the "sag" would decrease the initial altitude of the parachutes, thereby increasing the possibility of experiencing excessive impact velocities because insufficient altitude would exist to decelerate the cargo. It is therefore obvious that it is extremely important to extract and deploy the main parachutes as rapidly as possible.

The direct extraction design has the desirable feature that the new hardware required is minimal. The extraction platform design is similar to that proposed for use with the structured platform concept. A four-foot modular section with two rails; cut to four-foot lengths makes up the extraction platform. The required tiedowns of the parachute bags to the platform are made using standard cord which is a stock item in the U. S. Army Airdrop inventory. The parachute bags will be tied to each other through the carrying handles to improve the tiedown of the bags to the platform.

To develop the correct confluence point of the lines from the bags to the extraction parachute riser extension, a series of special types of bridles is used. A typical series of lines and bridles is illustrated in Figure 27 for a six recovery parachute configuration. For example the five and six parachute bag stacks have different center-of-gravity locations causing the location of the confluence point of the bag connection lines to vary.

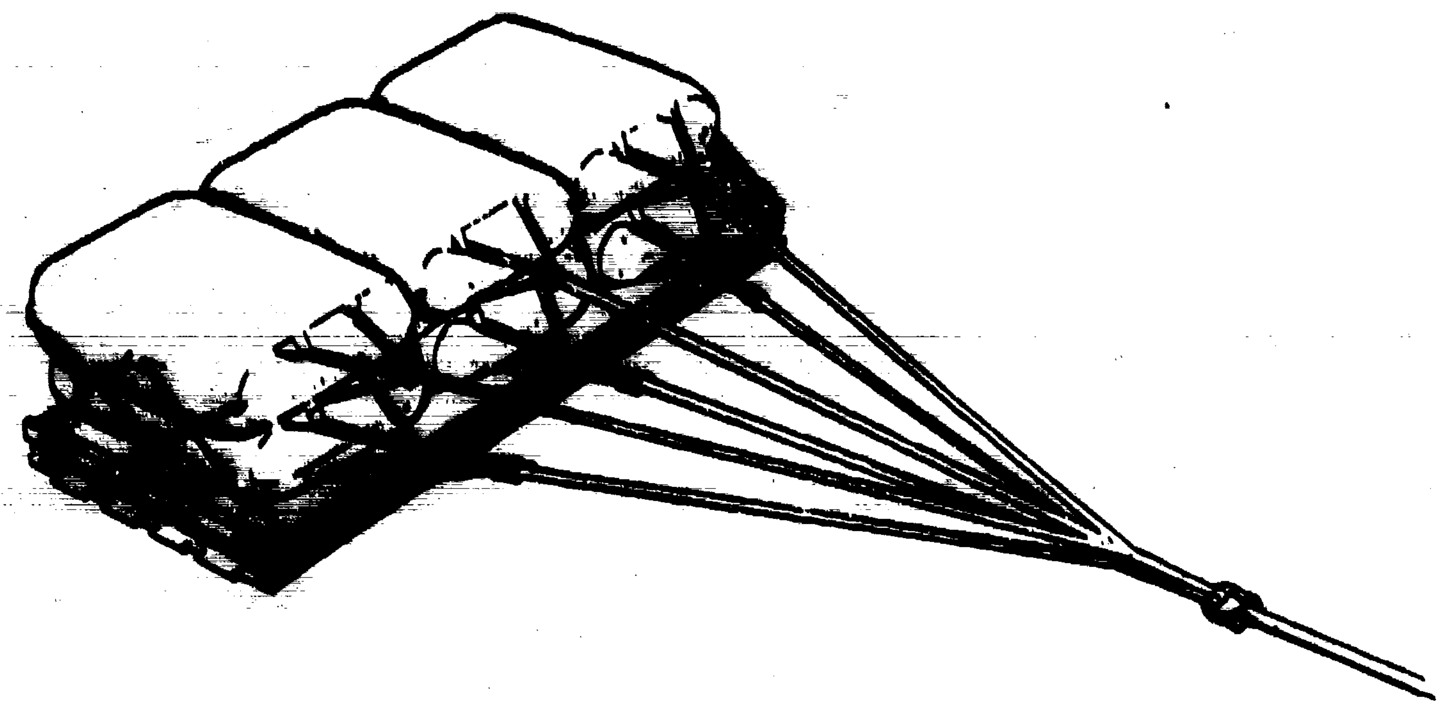
The additional hardware needed in the direct extraction concept is a connecting bracket for the line from the clevis of the four-legged bridle to attach to the platform. Three connecting brackets are required to attach each of the recovery parachute bags in the bottom row of the parachute stack to the platform. These connectors can be attached to the existing platform structure without modifying the modular platform. The approximate location of these components and the method used to attach them to the platform is shown in Figure 27.

The design illustrated in Figure 28 for these connecting brackets is typical of the final configuration. The bracket can be riveted to the aft end of the platform without any difficulty.

Safety Devices

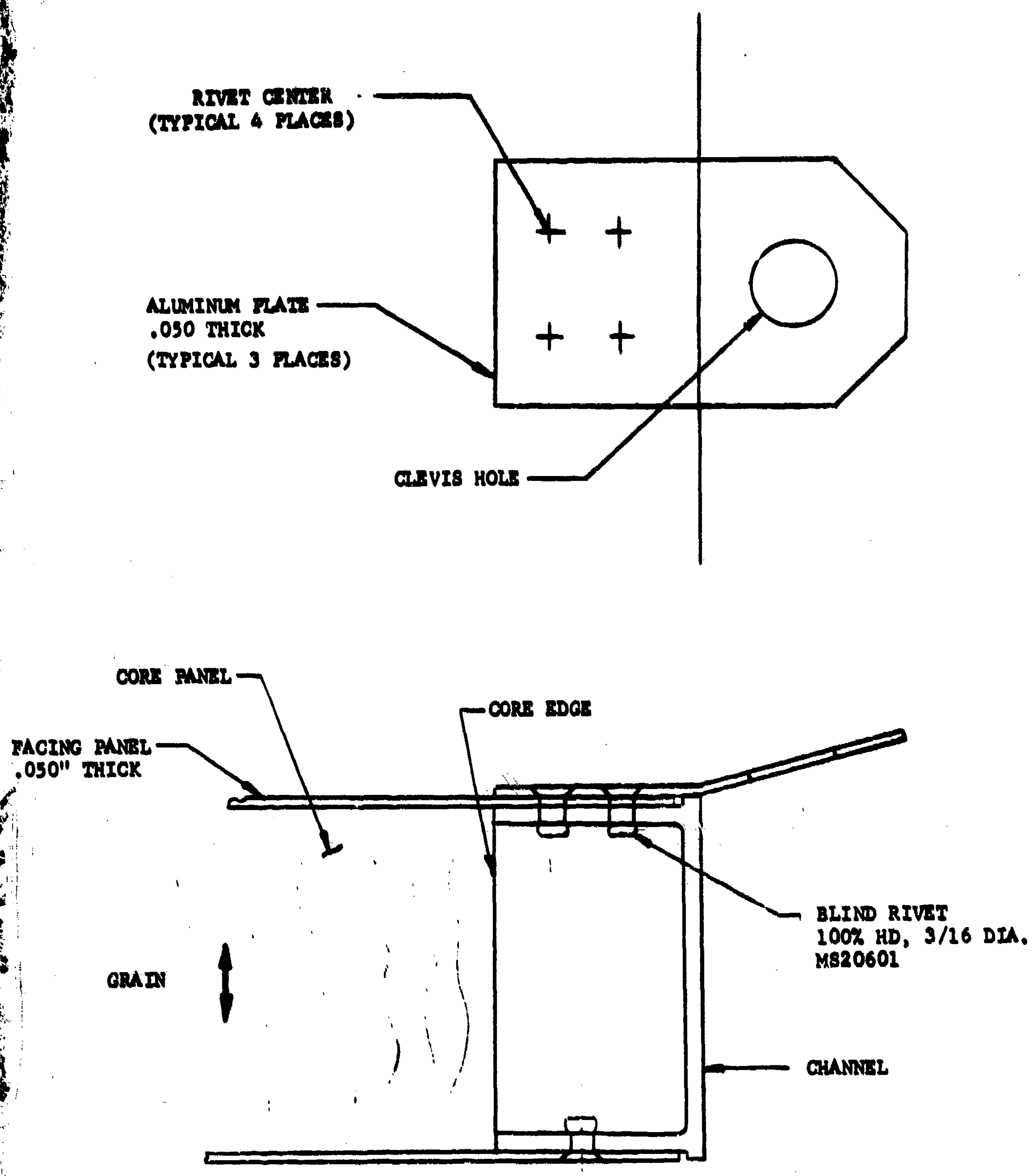
In the event that a cargo would jam in the rails during the extraction of the load, the high forces which would then be applied to the aircraft by the inflating parachutes would pose a safety problem to the aircraft. In order to eliminate this problem, a mechanism was needed to provide a parachute jettisoning capability if the cargo did not move.

To provide this capability a fail-safe safety fitting was designed. The fail-safe safety fitting is a mechanically operated latching mechanism coupled with a safety break link designed to separate, and thus release the parachutes in the event of a jammed load in the aircraft.



"DIRECT" PARACHUTE EXTRACTION CONCEPT

Figure 27



ATTACHMENT BRACKET CROSS-SECTION

FIGURE 28

However, in normal operation as the load begins to extract from the airplane, the first motion operates a mechanical latch which is designed to allow the fitting to accept the full recovery force of up to 3.0 g's.

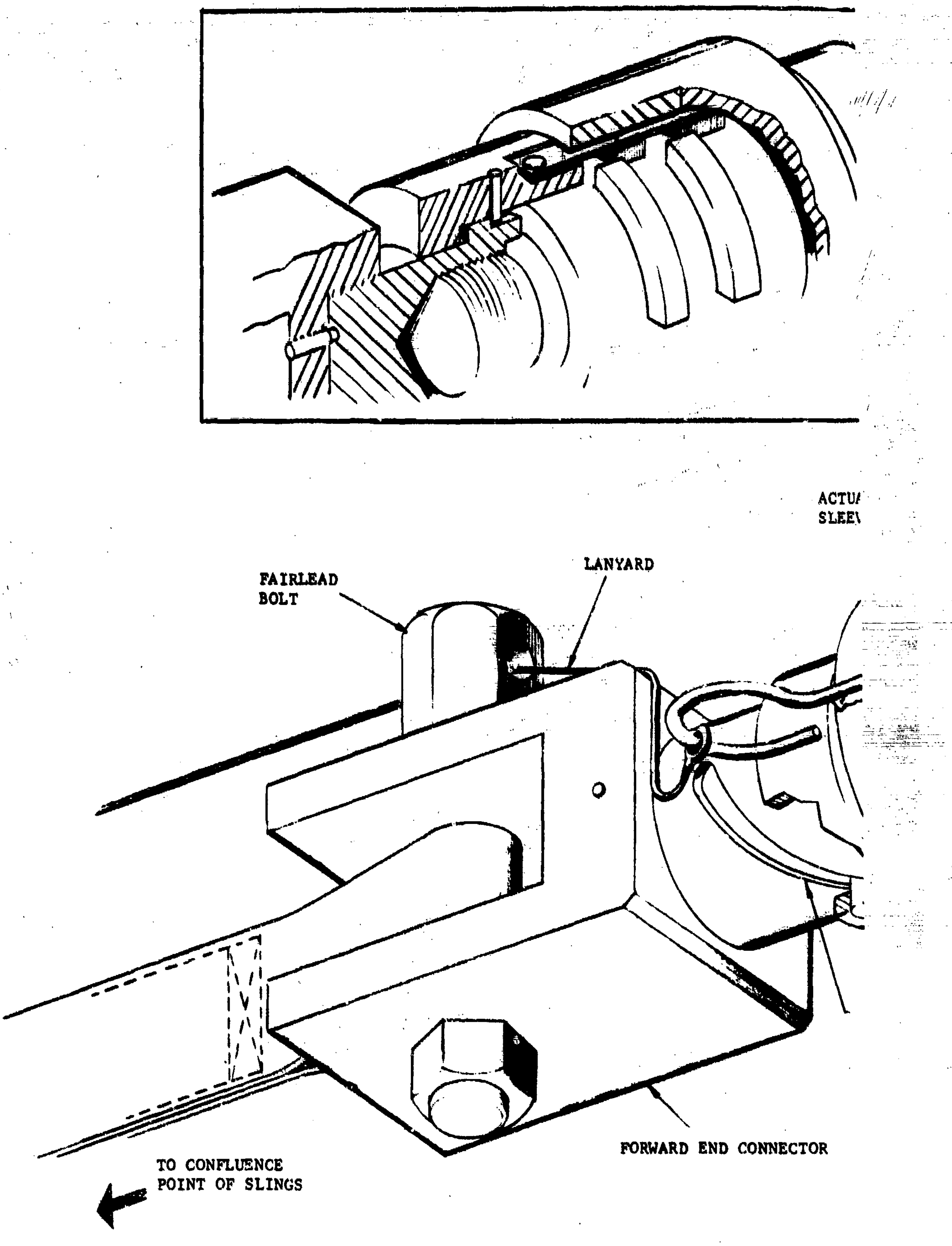
Figure 29 shows a cross-sectional view of the safety fitting. As can be seen from the drawing, it consists of seven major parts. Two of these are end connectors which connect the link in series with the system. Near the aft end an adapter provides the means of attaching the aft end connector to both the break link and the outer lock sleeve. The outer lock sleeve contains a guide groove and the female part of the locking lugs. The forward end connector attaches to the inner lock piece. This has a spiral cam groove (to provide rotation for locking) and the male locking lugs. It also has an internal shoulder that holds one end of the break link. The actuating sleeve fits over both the inner lock piece and the outer lock sleeve and has an attachment loop on the outside to connect a static line to the aircraft. It also contains a guide pin which fits into a straight groove on the outer lock sleeve and a camming pin which rides in a cam groove in the inner lock piece. First motion of the load causes the static line to move the actuating sleeve forward and the cam to rotate the locking lugs into engagement.

In its normal ready position, the only connection between the load and the parachutes is through the break link. A shear pin through the outer lock sleeve and through the inner lock piece prevents accidental rotation and lockup of the lugs. A roll pin through the outer locking sleeve prevents unwanted axial motion in the adapter. In order to prevent the unit from unlocking once the lugs have been rotated into the lock position a small leaf spring is provided that snaps up when the operating sleeve has moved through its full travel and prevents any return motion.

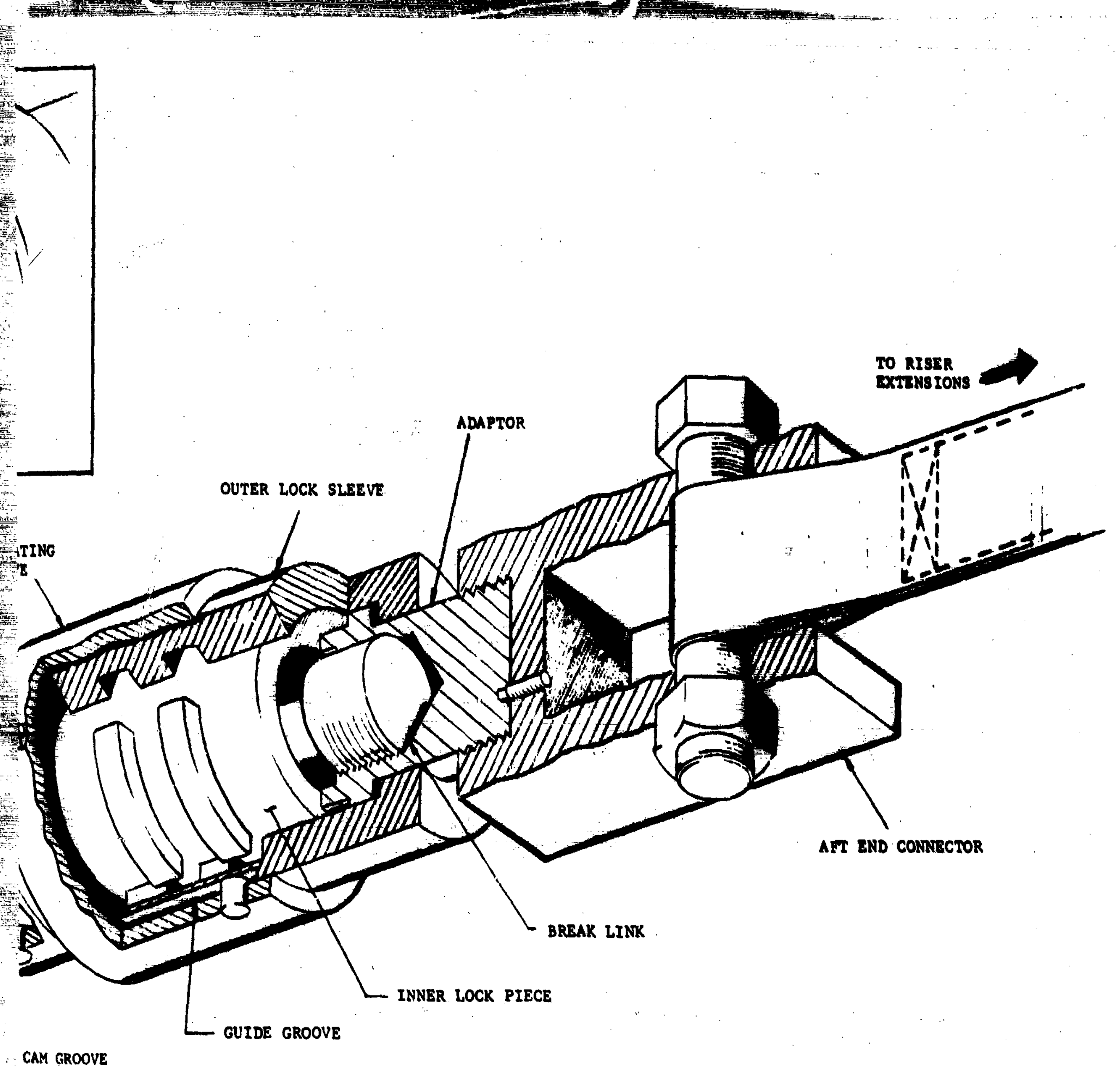
A second safety device made use of an Air Force go-no go fitting which, when used in conjunction with the guillotine cutter, would provide the required jettison capability. However, to jettison with the go no-go fitting the guillotine cutter must be manually actuated which means that the system is not fail safe. A breakaway safety fitting was designed to add a fail-safe feature to this jettison capability.

This unit uses the same break link that is used in the previously described safety fitting. The link is held between two adapters as shown in Figure 30 . The aft end connector illustrated in Figure 29 is used as one of these adapters.

In its normal ready position the extraction force is carried entirely through the break link and the go no-go fitting is in the open position, held together only by a small shear pin. As the load begins to move, the safety fitting is carrying the extraction force while the first motion of the load is causing the lanyard to move the go no-go fitting

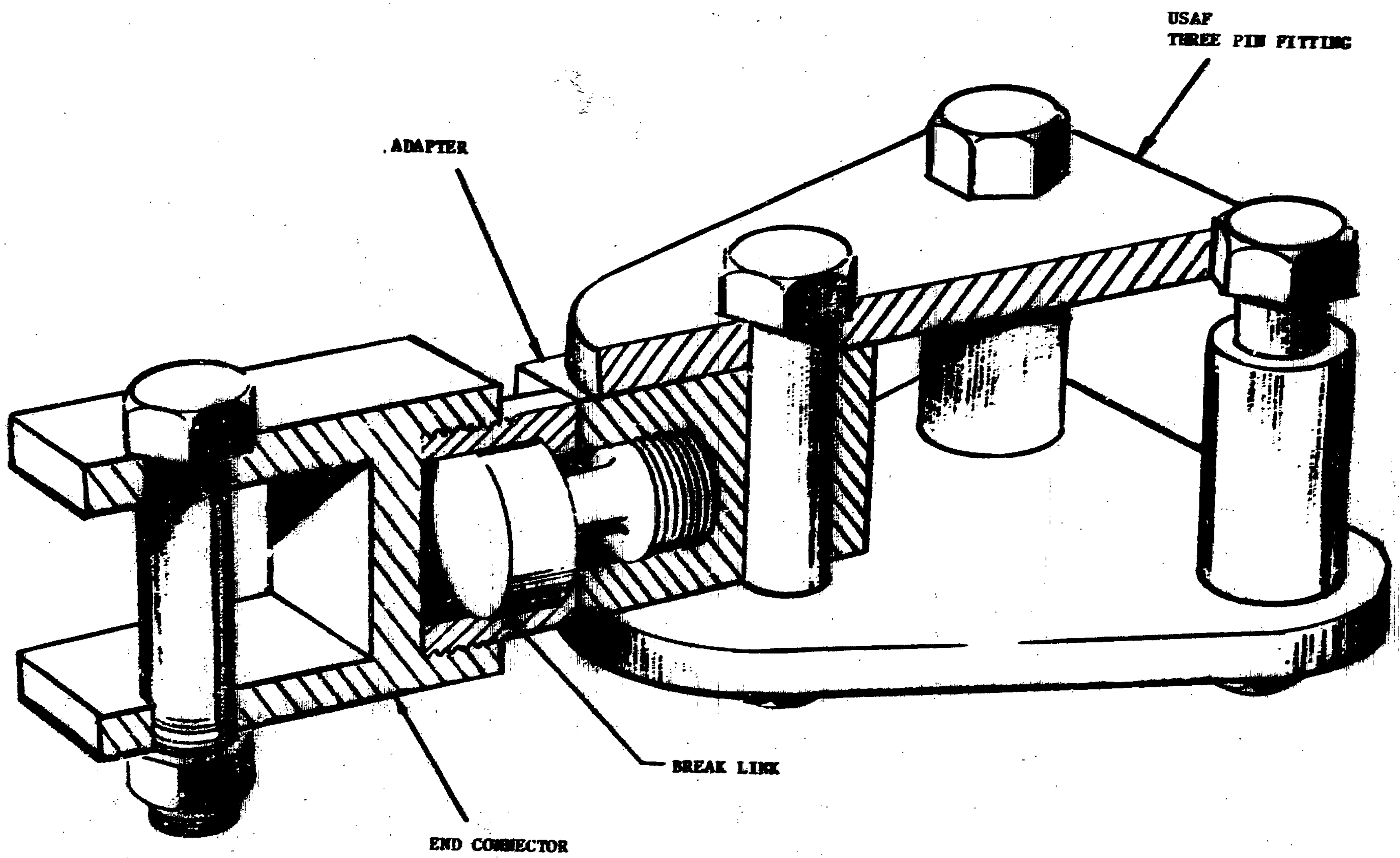


FAIRLEAD
BOLT
LANYARD
FORWARD END CONNECTOR
TO CONFLUENCE
POINT OF SLINGS



FAIL-SAFE SAFETY FITTING CROSS SECTION

Figure 29



BREAKAWAY SAFETY FITTING

FIGURE 30

into its locked position. After transfer, when the cutter cuts the extraction line, the safety fitting no longer has any load and is in effect out of the system.

If for some reason the load jams in the airplane, two safety means exist. A crew member may manually operate the transfer cutter guillotine, or if the extraction forces exceed 1.75 g's, the safety fitting break link will automatically break and free the parachutes, since the go no-go fitting is in its open position before first motion of the load.

Although these devices were presented to the Air Force for use during the test program, they were never used. It was felt that the use of the go no-go safety device in conjunction with the guillotine cutter would provide sufficient aircraft safety.

D. Flight Tests

1. Test Discussion

AAI conducted a two phase flight test program under the subject contract. A total of 39 tests were conducted during this program. These tests included flight safety write off tests, component tests, and system tests. These were to be followed by system demonstrations but the early termination of the test program prevented all the demonstration tests from being run. All testing was done at the 6511th Test Group, Naval Air Facility, El Centro, California using C-130 aircraft. The test facility provided the aircraft and support for the rigging of the loads, aircraft loading, clearing of the drop zone, and operation of the special Government owned instrumentation. This instrumentation included motion picture coverage both from the air and ground; transmission and recording of test data by telemetry; and cine-theodolite tracking of the cargoes. AAI provided technical and support personnel at the test facility to insure that the test program was conducted in an expeditious manner and that valid results were obtained.

Phase I of the test program consisted of a total of twenty-four tests, and was designed primarily as a data gathering phase. Data on the performance of the various system components as well as the safety write-off of some of these components was obtained during this phase. This data also provided inputs for trade-off, sensitivity, and consistency of performance analyses.

Phase II of the test program was designed to prove out the performance of the system components when used in multiple parachute drop configurations, and to demonstrate the feasibility of the system. A total of fifteen tests were conducted in attempting to accomplish the above objectives. The components which exhibited the best performance on the Phase I single and dual parachute tests were integrated into a system and this system tested using clusters of three to five G-11A parachutes and three G-12D parachutes. Throughout the program changes were made to several components to improve the systems performance. The program was to conclude with a series of three demonstration airdrops but the early termination of the test series eliminated these tests. Three low altitude predemonstration airdrops, however, were accomplished with very encouraging results.

2. Presentation of Results

The results of the two phase test program are presented in this section. Table I summarizes the test configurations and list the forces in the extraction and suspension lines during each test as well as the horizontal and vertical impact velocities for a descent of 300 feet. The detail test results and discussions of the individual tests were presented in the 120 day status reports prepared on this contract (AAI Engineering Report No's. ER-5170A(6); ER-4170B(7); and EP-5170D(8)). The results of investigations in the following areas are discussed.

- a. Snatch force attenuation
- b. Suspension sling force attenuation
- c. Recovery parachute centerlines
- d. Recovery parachute inflectors
- e. Recovery parachute reefing
- f. Recovery parachute line length
- g. Recovery parachute extraction platform
- h. System oscillation reduction
- i. System feasibility

a. Snatch Force Attenuation

The first snatch force attenuator configuration used consisted of a single length of undrawn nylon line in parallel with the riser extension line. This attenuator was used on eight of the first nine tests. The results of these tests are shown in Table I and indicate that the snatch forces generated using this attenuator exceeded the 1.5 extraction force limit. The films of several of the airdrops were studied to determine the reason for these high forces. These films revealed that the canopy deployment from the deployment bag was initiated at the beginning of the elongation of the undrawn line. Canopy deployment from the bag was complete prior to full extension of the undrawn line, and hence, when the riser extension became taut the total canopy cloth mass was accelerated. Due to the total mass being accelerated at one instant the inertia forces that resulted were higher than expected.

A multi-line snatch force attenuator was designed to replace the single line attenuator and alleviate the problem of early canopy deployment. The design of this attenuator was discussed in detail in Section IV.C The configuration used on each test is described in Table I.

The multi-line attenuator was used on eleven of the last twelve tests in the Phase I test program. In these tests the number of undrawn nylon lines used was varied in attempting to find the best configuration. In addition to varying the attenuator configuration, the drogue parachute, which extracts the main parachutes, was reefed in three of these tests. Since reefing the drogue parachute decreases the force applied to the main parachutes during their extraction and consequently decreases the velocity of the main parachutes relative to the aircraft at line extension, the snatch force was decreased. The combination of reefing the drogue parachute and use of the

TABLE I. FREE FLIGHT TEST SUMMARY - PHASE

El Centro Test No.	AAI Test No.	No. & Type Recovery Chutes	Extracted Weight (lb)	Centerline Length (ft)	Reefing Line Length (ft)	Inflector Type	Riser Extension & Confluence Extension Length (ft) **	Aircraft Restraint Setting (g's)	Drogue Chute Size (ft) and Reefing Line Length (in)	Fuselage Station Number Of Forward End Of Platform	Snatch Force Attenuator Configuration	Snatch Force (g's)	Opening Shock Force (g's)	
0133	1	1/G11A	3300	-	25	-	40/3	Max	15/0	537	Single 10' Length	2.48	-	
0134	2	1/G11A	3300	-	25	-	40/3	1.06	15/0	617	---	2.08	2.03	
0297	3	1/G11A	3300	106	25	-	40/3	1.06	15/0	617	Single 8.5' Length	2.42	2.72	
0298	4	1/G11A	3300	98	[illegible]	-	40/3	1.06	15/0	617	Single 8.33' Length	2.67	2.58	
0320	5	1/G11A	3300	-	19	-30	40/3	Max.	15/0	610	Single 8.4' Length	2.35	2.27	
0321	6	1/G11A	3300	106	25	-	40/3	1.06	15/0	610	Single 8.4' Length	*	*	O O
0417	7	1/G11A	3300	94	25	-	40/3	1.06	15/0	517	Single 8.4' Length	*	*	T O
0418	8	1/G11A	3300	85	25	-	40/3	1.06	15/0	630	Single 8.5' Length	3.03	2.57	O N
0683	9	1/G11A	3300	-	19	-30	40/3	1.06	15/0	570	Single 10' Length	2.42	1.51	T O
0676	10	1/G11A	3300	-	25	-	60/3	1.0	15/0	617	-	1.67	1.36	O N
0894	11	1/G11A	3300	95	25	-	40/3	1.0	15/0	617	-	2.21	1.71	T O
0962	12	1/G11A	3300	85	25	-	20/3	.99	15/0	617	-	2.36	2.30	((

...Y - PHASE I

Opening Shock Force (g's)	Force Transfer Attenuator Configuration	Peak Force On Right Aft Suspension Sling (g's)	Peak Force On Left Aft Suspension Sling (g's)	Peak Force On Right Forward Suspension Sling (g's)	Peak Force On Left Forward Suspension Sling (g's)	Peak Centerline Force (g's)	A/C Ground Speed (fps)	Platform Length (ft)	Drop Altitude (ft)	Horizontal Velocities at 500 ft. (fps)	Vertical Velocities at 500 ft. (fps)	Comments
-	-	-	-	-	-	-	222.9	8	2283.5			Tow Test
2.03	-	-	-	-	-	-	248.8	8	2260.0	25	21.4	High Winds At Altitude
1.72	-	-	-	-	-	1.15	236.8	8	2229.4	15	19.2	
1.58	-	-	-	-	-	*	233.2	8	2079.0	21	20.0	
1.27	-	-	-	-	-	-	202.4	-	2305.9	-	-	Tow Test
*	One Aft 3.3' One Fwd 5.9'	1.74	1.40	1.20	1.00	1.06	208.9	8	2246.3	33	18.6	
*	Two Aft 3.2' One Fwd 2.0'	.94	.64	.70	1.03	*	228.1	8	2266.9	29	16.3	
.57	One Aft 3.0' None Fwd	*	1.09	.83	1.21	1.12	234.4	8	2079.8	13	21.3	
.51	Two Aft 4.5' One Fwd 5.8'	.50	.55	1.00	.91	-	227.9	12	1976.7	16	14.5	Special Cargo Incomplete Transfer
.36	One Aft 33' None Fwd	1.03	1.02	.68	.99	-	242.6	8	2023.5	44	17.4	
.71	Two Aft 3.3' One Fwd 3.0'	.79	.68	.48	.82	-	227.5	8	1968.6	28	16.6	
.30	One Aft 2.3' One Fwd 2.3'	1.29	.97	.71	1.26	-	245.5	8	2058.3	18	23.2	

TABLE I. FREE FLIGHT TEST SUMMARY - PHASE I (con

El Centro Test No.	AAI Test No.	No. & Type Recovery Chutes	Extracted Weight (lb)	Centerline Length (ft)	Reefing Line Length (ft)	Inflector Type	Riser Extension And Confluence Extension Length (ft) **	Aircraft Restraint Setting (g's)	Drogue Chute Size (ft) and Reefing Line Length (in)	Fuselage Station Number Of Forward End Of Platform	Snatch Force Attenuator Configuration	Snatch Force (g's)	Opening Shock Force (g's)	Force Transfer Attenuator Configuration
1000	13	1/G11A	3300	-	19	-20	40/3	.99	15/0	605	5 Lines	2.39	1.49	One Af None F
1002	14	1/G11A	3300	95	25	-	40/3	1.06	15/0	630	5 Lines	1.89	1.88	Failed
1050	15	1/G11A	3300	85	32	-	40/3	1.06	15/0	610	Continuous Loop (Failed)	*	*	Three Two Fw
1448	16	1/G11A	3300	-	20	-	40/3	1.06	15/0	610	4 Lines	1.82	4.29	Two Af Two Fw
1447	17	1/G11A	3300	-	19	-10	40/3	1.06	15/0	610	3 Lines	2.12	2.88	Two Af Two Fw
1457	18	1/G11A	3300	95	25	-	40/3	1.06	15/0	600	4 Lines	2.12	3.03	Two Af Two Fw
1449	19	2/G11A	6850	-	25	-	40/3	1.02	15/0	610	4 Lines	1.58	2.78	Four A Four F
1469	20	1/G11A	3300	95	19	-10	40/3	.53	15/0	610	4 Lines	2.00	1.50	Three Three
1488	21	1/G11A	3300	-	32	-	40/3	.83	15/0	610	4 Lines	1.51	2.00	Two Af Three
1489	22	1/G11A	4250	85	19	-10	40/3	.47	15/148	610	4 Lines	1.15	.825	Failed
1531	23	1/G11A	3300	95	19	-10	40/3	.53	15/260	610	---	2.00	1.61	Three Three
1532	24	2/G11A	6900	95	19	-10	40/3	1.09	15/0	610	4 Lines	.81 .94	.64 1.32	Five A Five F

tinued)

	Peak Force On Right Aft Suspension Sling (g's)	Peak Force On Left Aft Suspension Sling (g's)	Peak Force On Right Forward Suspension Sling (g's)	Peak Force On Left Forward Suspension Sling (g's)	Peak Centerline Force (g's)	A/C Ground Speed (fps)	Platform Length (ft)	Drop Altitude (ft)	Horizontal Velocities at 500 ft. (fps)	Vertical Velocities at 500 ft. (fps)	Comments
t wd	1.53	.81	.98	1.24	-	247.8	8	2131.2	19	26.3	
To Transfer	-	-	-	-	-	246.5	8	2115.9	8	19.9	One T-10 Oscillation Damping Parachute
Aft d	*	*	*	*	*	264.8	8	2010.7	5	21.4	Incomplete Transfer, One T-10 Oscillation Damping Parachute
t d	1.24	1.58	.73	.76	-	227.5	8	2000.2	-	-	High rail restraint
t d	1.18	1.39	.97	.91	-	242.1	8	2096.9	5	22.5	High rail restraint
t d	1.48	1.61	1.30	1.39	1.85	228.1	8	2138.5	-	-	
ft wd	*	*	.94	.96	-	249.5	8	2187.6	20	21.7	High rail restraint
Aft Fwd	.70	.73	1.03	.94	1.09	227.7	8	2034.4	8	19.8	Incomplete Transfer
t Fwd	1.15	.42	.76	1.33	-	238.7	8	2062.3	0.4	19.0	Incomplete Transfer, Two T-10 Oscillation Damping Parachute
To Transfer	-	-	-	-	1.65	232.7	8	2096.5	18	15.0	
Aft Fwd	.67	.61	.82	.88	2.43	225.7	8	2176.8	42	25.1	Incomplete Transfer
ft wd	1.07	.85	1.23	1.22	-	221.4	8	2249.9	48	24.2	

TABLE I. FREE FLIGHT TEST SUMMARY - PHASE II

El Centro Test No.	AAI Test No.	No. & Type Recovery Chutes	Extracted Weight (lb)	Centerline Length (ft)	Reefing Line Length (ft)	Inflector Type	Riser Extension & Confluence Extension Length (ft) **	Aircraft Restraint Setting (g's)	Drogue Chute Size (ft) and Reefing Line Length (in)	Fuselage Station Number Of Forward End Of Platform	Snatch Force Attenuator Configuration	Snatch Force (g's)	Opening Shock Force (g's)
2545	25	3/G11A	12860	85	19	-	32/12	.934	22/0	537	4 Lines	1.27	1.06
0001	23	3/G11A	11200	85	19	-	32/12	.938	22/0	551	4 Lines	*	*
0026	27	3/G12D	7150	54	13	-	14/12	1.050	15/0	551	3 Lines	1.12	.98
0086	28	3/G11A	10850	85	23	-	32/12	.948	22/0	557	4 Lines	1.20	2.03
0237	29	3/G11A	12450	95	23	-	32/12	.844	22/0	537	4 Lines	1.27	1.53
0064	30	3/G12D	7175	54	13	-	32/12	1.050	15/0	567	3 Lines	1.78	1.67
0284	31	4/G11A	17350	95	23	-	44/24	.925	28/0	447	4 Lines	1.58	2.62
0316	32	4/G11A	19350	95	23	-	44/24	.828	28/0	435	5 Lines	1.18	*
0463	33	3/G11A	13100	95	20	-10	32/12	.802	22/0	500	4 Lines	*	*
0516	34	3/G11A	13100	95	20	-10	32/12	.802	22/0	517	4 Lines	1.68	1.30
0488	35	5/G11A	23550	95	23		54/24	.297	28/0	319	5 Lines	1.04	1.71
0301	36	3/G11A	14250	95	23	-	32/12	.738	22/0	532	4 Lines	*	*
0642	37	3/G11A	13100	95	20	-10	32/14	.802	22/0	537	5 Lines	1.61	1.30
0876	38	3/G11A	14250	95	23	-	32/14	.738	22/0	550	4 Lines	*	*
0962	39	3/G11A	14320	95	23	-	32/14	.738	22/0	547	4 Lines	1.43	1.25

* Telemetry Failure

** Addition 10 Ft. Added To Riser Extension Length Due to Snatch Attenuator Safety Line

(continued)

Force Transfer Attenuator Configuration	Peak Force On Right Aft Suspension Sling (g's)	Peak Force On Left Aft Suspension Sling (g's)	Peak Force On Right Forward Suspension Sling (g's)	Peak Force On Left Forward Suspension Sling (g's)	Peak Centerline Force (g's)	A/C Ground Speed (fps)	Platform Length (ft)	Drop Altitude (ft)	Horizontal Velocities at 500 ft. (fps)	Vertical Velocities at 500 ft. (fps.	Comments
Six Aft Three Fwd	*	*	*	*	*	215.5	12	1926.2	27	22.2	
Six Aft Three Fwd	.500	.538	.410	.493	-	-	12	-	-	-	Tangled Parachutes
Four Aft Two Fwd	1.29	1.22	.902	.958	-	225.5	12	2136.9	14	29.6	
Six Aft Three Fwd	*	*	*	*	-	221.9	12	2080.2			Confluence Extension Line Failed
Six Aft Three Fwd	.682	.763	.763	.570	-	224.3	12	2104.5	22	13.5	
Four Aft Two Fwd	1.09	1.26	.823	1.17		230.2	12	2094.5	11	31.1	
Eight Aft Four Fwd	1.32	*	1.18	1.31	-	234.0	24	2194.7	10	24.5	
Seven Aft Four Fwd	1.50	1.53	1.09	1.18		252.1	24	2243.6	25	25.2	
Six Aft Three Fwd	*	*	*	*	-	-	12	-	-	-	Go No-Go Safety Device Failed
Six Aft Three Fwd	.978	.993	.985	.955	-	238.1	12	2132.9	6	27.3	
Ten Aft Five Fwd	1.19	1.27	.998	1.04	-	240.4	24	2087.4	36	21.0	
Six Aft Three Fwd	*	*	*	*	-	230.4	12	608.0	21	22.1	
Six Aft Three Fwd	1.54	1.47	1.08	1.20	-	241.8	12	1971.9	13	29.5	
Six Aft Three Fwd	*	*	*	*	-	-	12	-	-	-	
Six Aft Three Fwd	1.19	1.22	.866	.782	-	227.8	12	519.6	no data		

multi-line snatch force attenuator resulted in acceptable snatch force magnitudes as shown in the following table.

Test No.	Description	Drogue Reefing Line (in) & Maximum Force Applied per Main Parachute (lbs)	Snatch Attenuator	Snatch Force (g's)
2	Unmodified Canopy	None/5400	None	2.08
21	Unmodified Canopy	None/5400	4 Lines	1.51
12	85' Centerline	None/5400	None	2.36
22	85' Centerline - 10 Inflector	148/2430	4 Line	1.47 *

* This value based on 3300 pounds for extracted weight.

This table indicates that acceptable snatch force magnitudes can be obtained by using a four line snatch force attenuator and extracting the main parachutes with a drogue force of 2430 pounds per parachute. The above results also indicate that the 85 foot centerline case developed a higher snatch force than an unmodified canopy. The reason for this is that the mass per unit length of the canopy during deployment from its bag is increased, and hence, a larger mass at any instant during line stretch is being accelerated, causing higher forces.

The multi-line snatch attenuator was used throughout the entire Phase II of the test program.

The snatch force exceeded 1.5 g's in only four of the fifteen Phase II tests. These tests were the two inflector parachute tests, a G-12D parachute test and a four G-11A parachute test. The high snatch force encountered in the inflector tests was attributed to the increase in canopy weight when the inflectors are added to the skirt. It has been shown that the canopy mass per length is a major parameter affecting the snatch force.

The optimum snatch force attenuator for use with G-12D parachute had not been determined, and hence, the snatch was high in one of the two G-12D tests. Finally, in one of the four G-11A parachute tests the snatch force developed was 1.58 g's and no reason for this increase has been found.

b. Suspension Sling Force Attenuation

The operation and performance of the suspension sling attenuator has been excellent throughout both phases of the test program. In most cases, as shown in Table I, the forces developed during the transfer phase have been kept well below the 1.5 g limit for each suspension sling connection point. The number of lines used in each attenuator configuration was varied throughout Phase I of the test program in order to determine the most desirable configuration. This configuration was used throughout the Phase II tests.

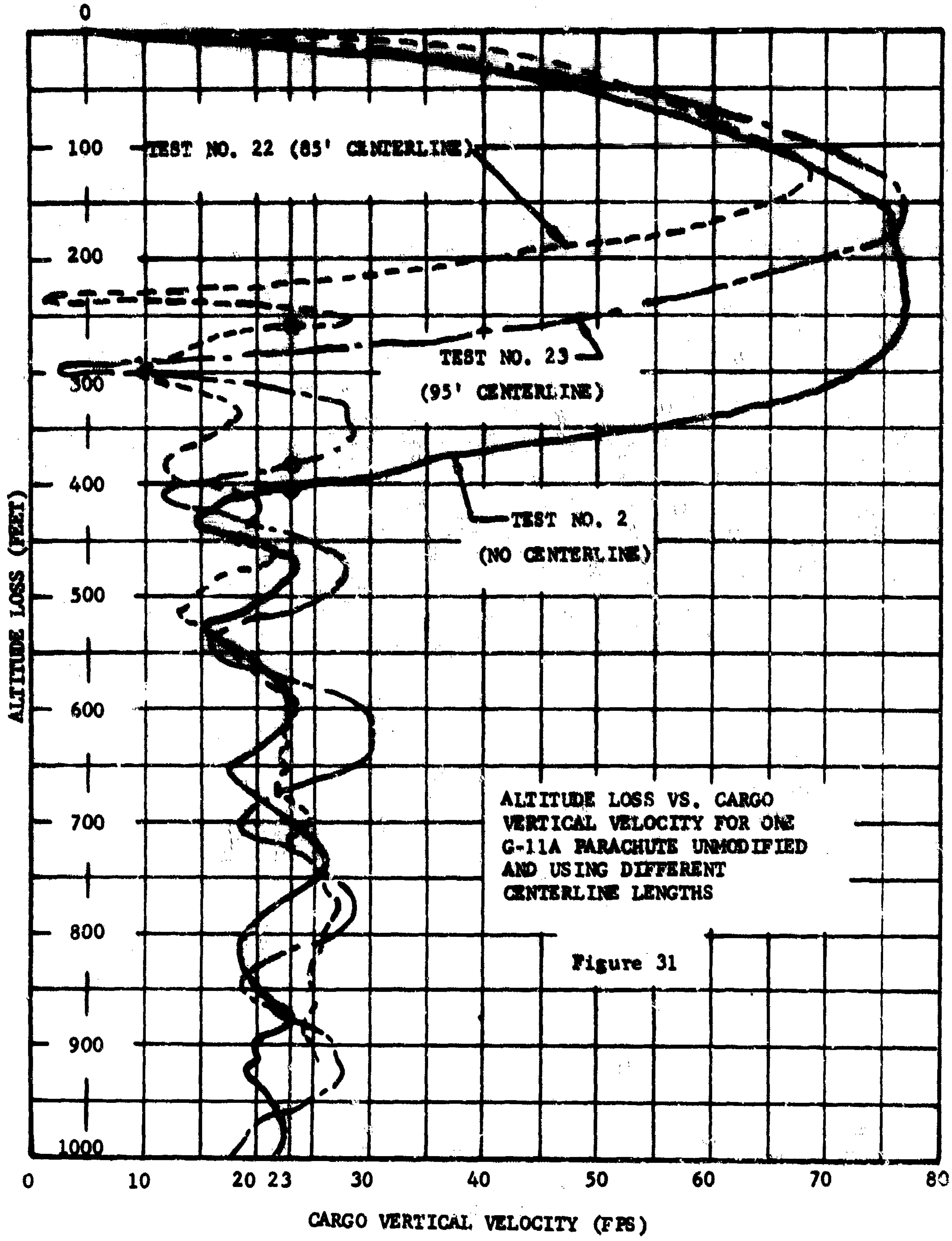
In addition to limiting the force developed in each suspension sling to 1.5 g's, the attenuator was required to develop forces in the system as rapidly as possible after force transfer. This is accomplished through the stretching of the undrawn nylon lines. As illustrated in Figure 21 on page 44 , after force transfer is initiated the cargo begins to rotate and the forward suspension slings become taut. During this rotation no force can be developed by the standard system until the suspension slings become taut. Since the undrawn nylon lines are shorter than the suspension slings, they become taut first and the time duration when no system forces exist is decreased.

c. Recovery Parachute Centerlines

In order to increase the inflation rate of the parachute a centerline or apex control line was installed as shown in Figure 10, page 18. In an attempt to determine the optimum centerline length, AAI conducted tests using lengths ranging from 85 to 106 feet on the single parachute tests. The results indicated an improvement in the performance as the centerline length was decreased. The 85 foot long centerline developed the smallest altitude loss to acceptable vertical velocities. The curves of Figure 31 illustrate the improved performance.

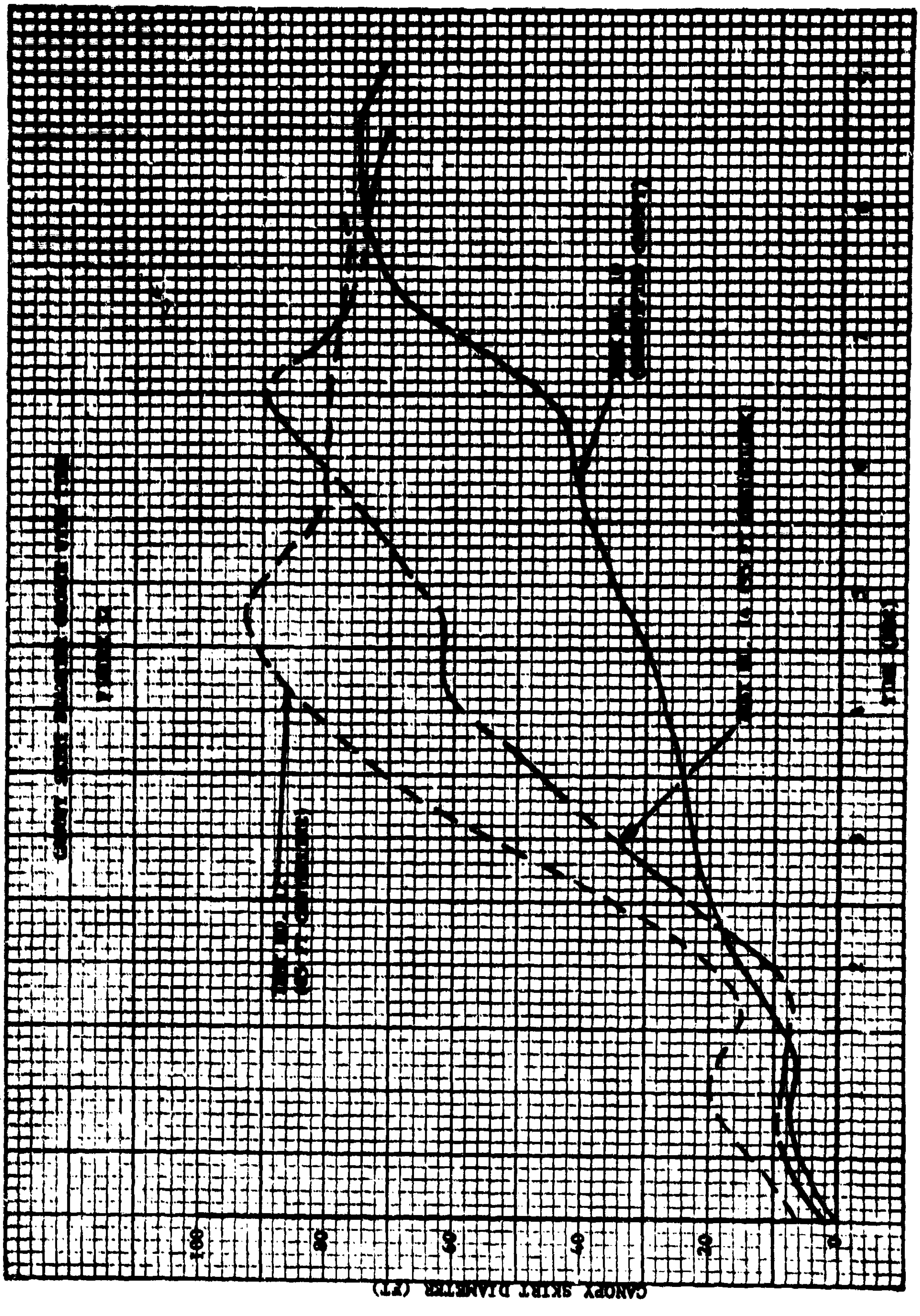
To determine the cause of this improved performance, the 16mm film records were studied. The canopy diameter versus time curves developed in this analysis illustrate that the canopy inflation time decreases with a reduction in centerline length. Also, the slope of these curves increased for the shorter lengths causing increased drag and deceleration at all times during inflation when compared to an unmodified canopy. Figure 32 shows the canopy skirt diameter growth with time for an unmodified canopy and canopies with centerline lengths of 85 and 95 feet.

However, reducing the canopy inflation time causes an increase in the oscillatory motions of the descending cargo. In the initial portion of the trajectory, this rapid inflation of the canopy causes a rapid horizontal deceleration of the system with a correspondingly small loss in altitude. This action quickly reduces the horizontal velocity of the system close to zero. The system then begins to rotate with the cargo picking up vertical velocity much faster than the parachute due to its weight/drag ratio being much higher than that of the parachute. This action causes the cargo to swing down and under the parachute and a pendulum type oscillation ensues. These oscillatory motions are characteristics of an extraction by mains system and are readily observed when altitude loss versus horizontal displacement, of the cargo, is



ALTITUDE LOSS VS. CARGO VERTICAL VELOCITY FOR ONE G-11A PARACHUTE UNMODIFIED AND USING DIFFERENT CENTERLINE LENGTHS

Figure 31


CANOPY SKIRT DIAMETER (FT)
100
80
60
40
20
0

plotted. There is a pronounced interaction between these horizontal oscillations and the vertical descent velocity of the cargo which accounts for the oscillatory character of the descent velocity parameter. The cargo trajectories of Figure 33 depict the difference in the oscillatory motion of an unmodified canopy and a canopy with an 85 foot centerline installed.

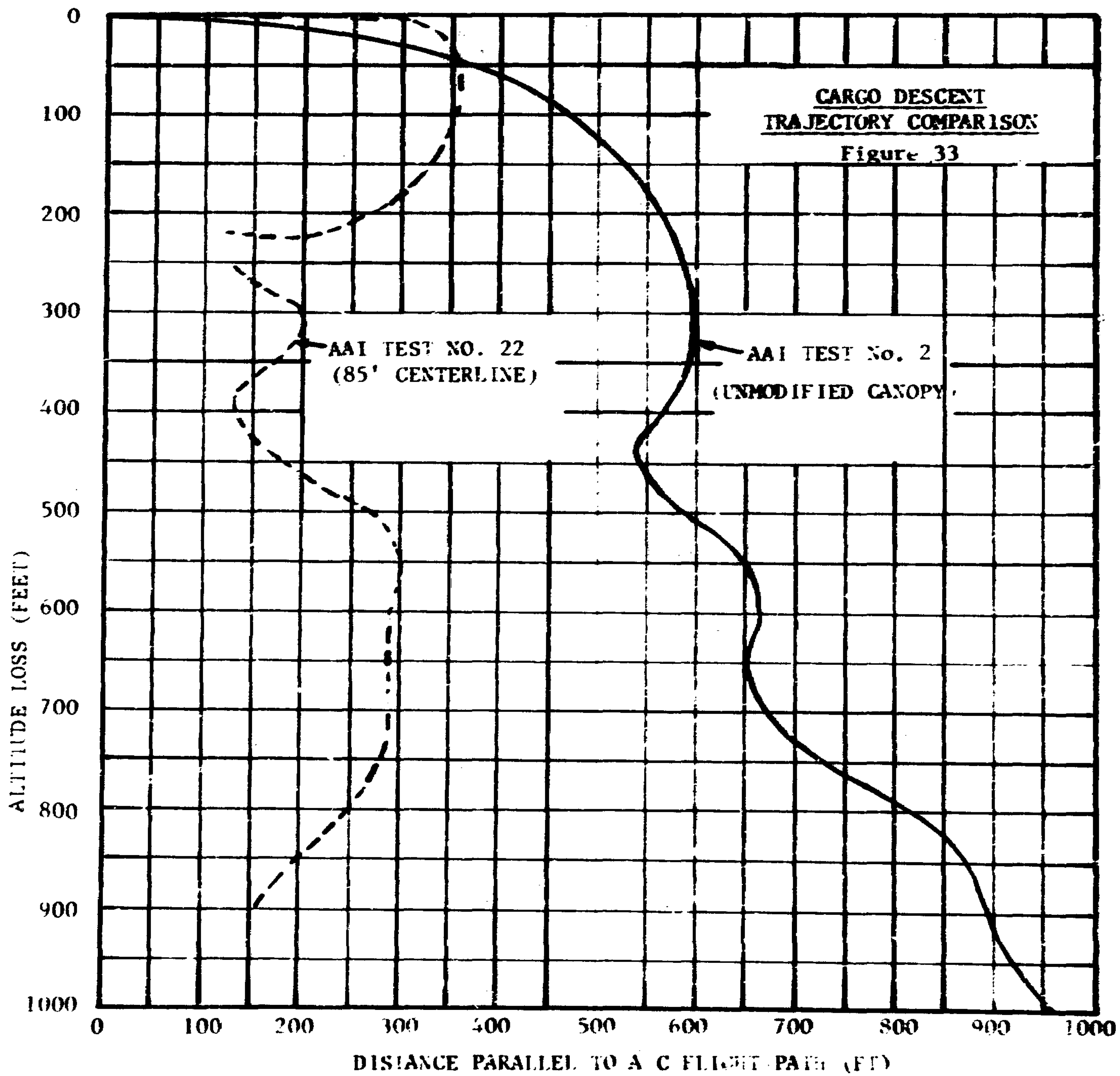
To reduce the cargo oscillations, the cargo weight was increased from 3550 to 4500 pounds (rigged weight). The effect of this increase in canopy loading is illustrated in Figure 34. The results of the 4500 pound weight test using a centerline of 85 feet exhibited the most desirable performance of the vent pull down tests conducted during the Phase I portion of the test program.

To determine the cause of the reduction in canopy inflation time when using a centerline, the ratio of centerline force to riser extension force versus time was plotted for several tests. These results illustrate that a large percent of this total parachute drag force is being carried by the centerline. Force ratios from .3 to .5 are common as illustrated in Figures 35 and 36. This means that the force in the suspension lines is substantially reduced; consequently, the force retarding radial motion of the canopy skirt is greatly reduced and the canopy inflation rate is increased.

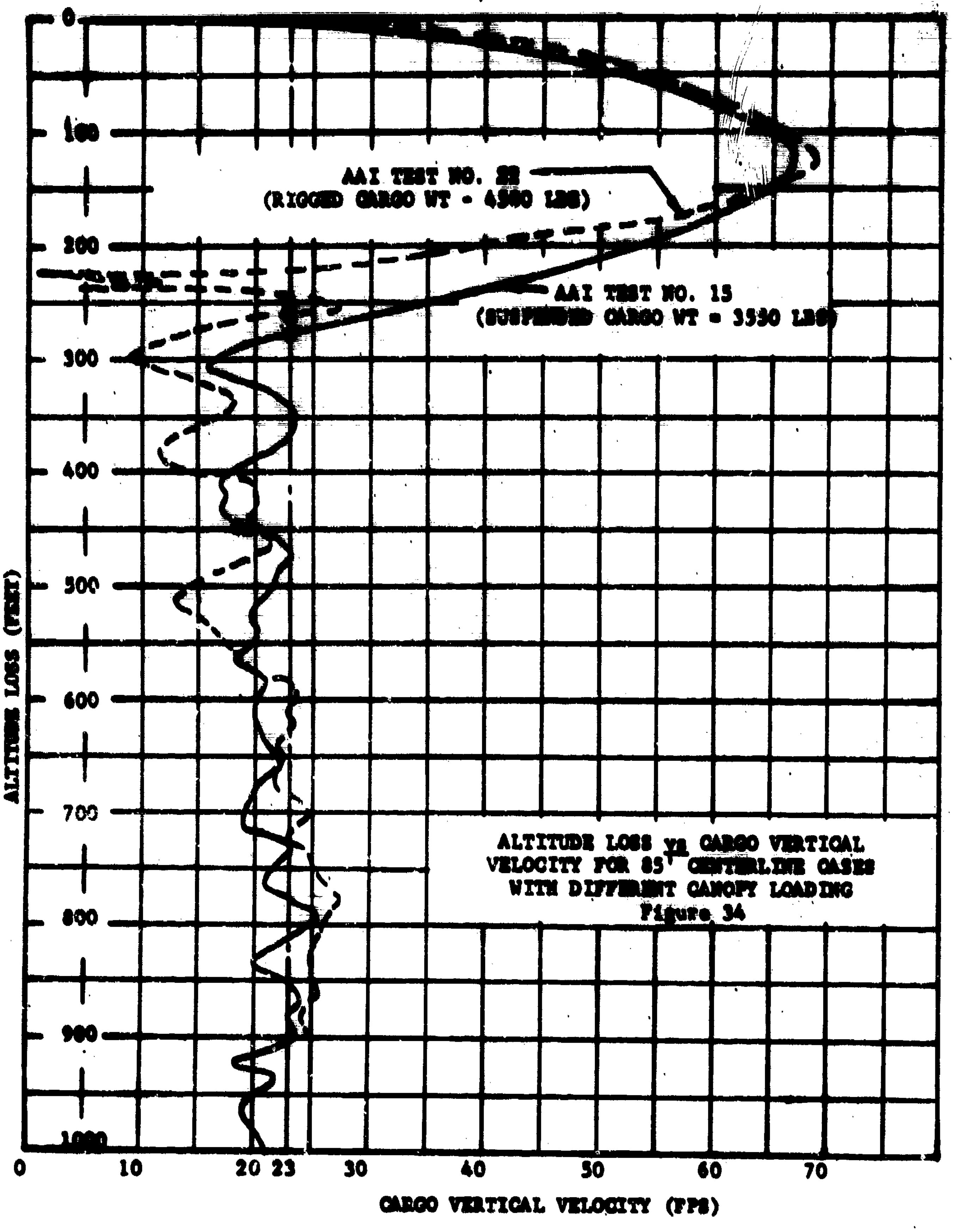
Since the best centerline performance on a single parachute test was obtained using an 85 foot centerline with a canopy loading of 4500 pounds, the first test conducted during the Phase II portion of the test program made use of a cluster of three G-11A parachutes with 85 foot centerlines installed to decelerate a cargo weighing 12,060 pounds. This test resulted in a terminal velocity which exceeded the goal of 23 feet per second. This indicated that the performance of G-11A parachutes in clusters (of at least three) using an 85 foot centerline might differ significantly from the performance of a single G-11A parachute using the same centerline length. Further study of the single parachute data using an 85 foot centerline revealed that the cargo vertical velocity beyond a 500 foot altitude loss was continually increasing during the descent, however, at altitude losses less than 500 feet the vertical velocity was quite low. Apparently in the clustered configuration, the parachutes were not able to decelerate the cargo to as low a velocity initially as in the single parachute configuration. Consequently, the cargo vertical velocity increased to its terminal value much more rapidly in the clustered parachute configuration.

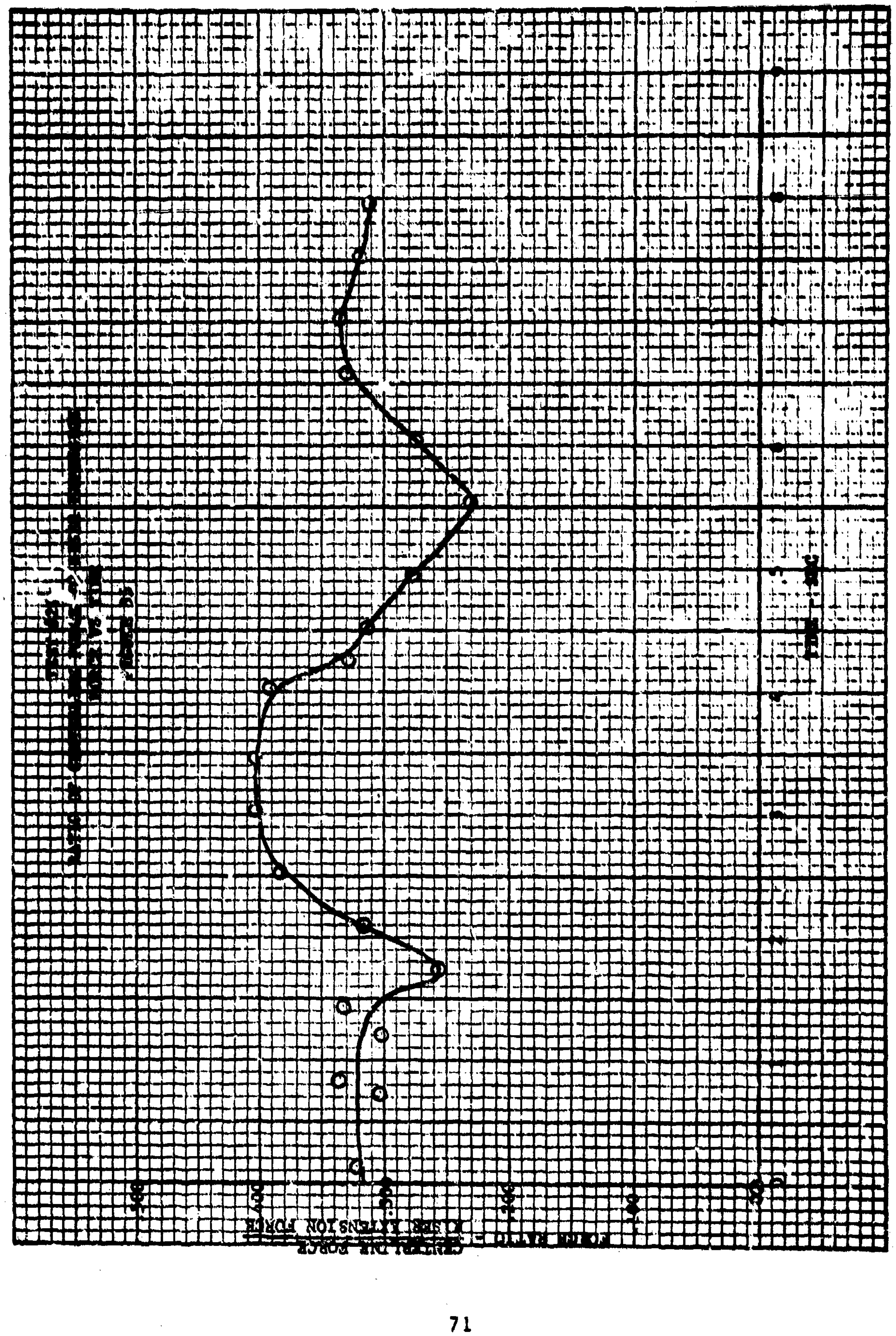
Other flight tests were conducted by the Air Force* at the F, El Centro, using extraction by recovery parachute with a centerline employed. A study of the unpublished corrected space position data generated on this program resulted in several plots of the cargo performance. The most important results were illustrated by the altitude versus cargo vertical velocity. For several tests with the same initial conditions such as aircraft speed and cargo weight, the curves of Figure 37 show that the altitude loss to acceptable vertical velocities was reduced as the centerline length decreased. The centerline lengths used varied from 95 to 115 feet.

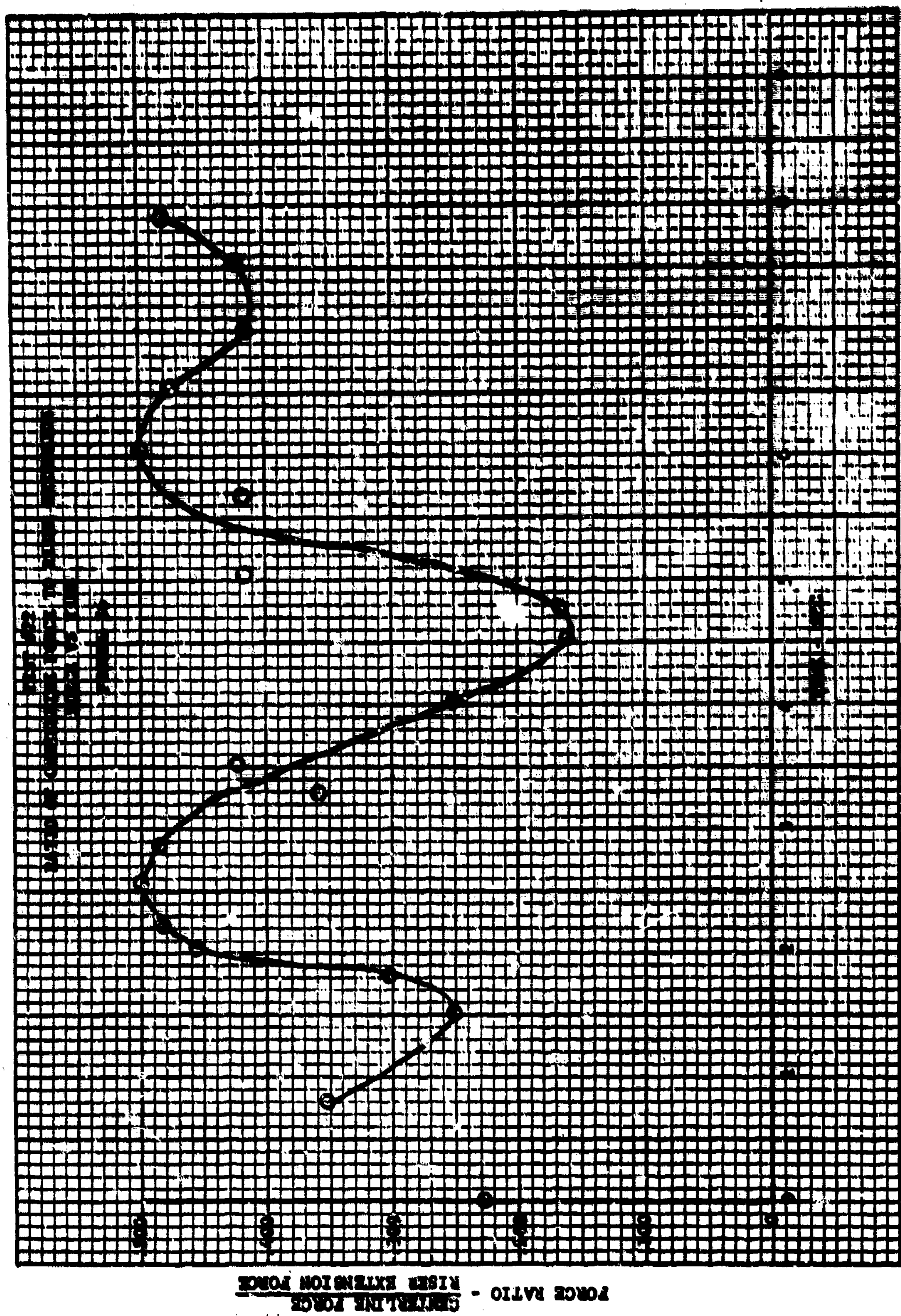
* Data supplied by NIABS, program LIC 5057

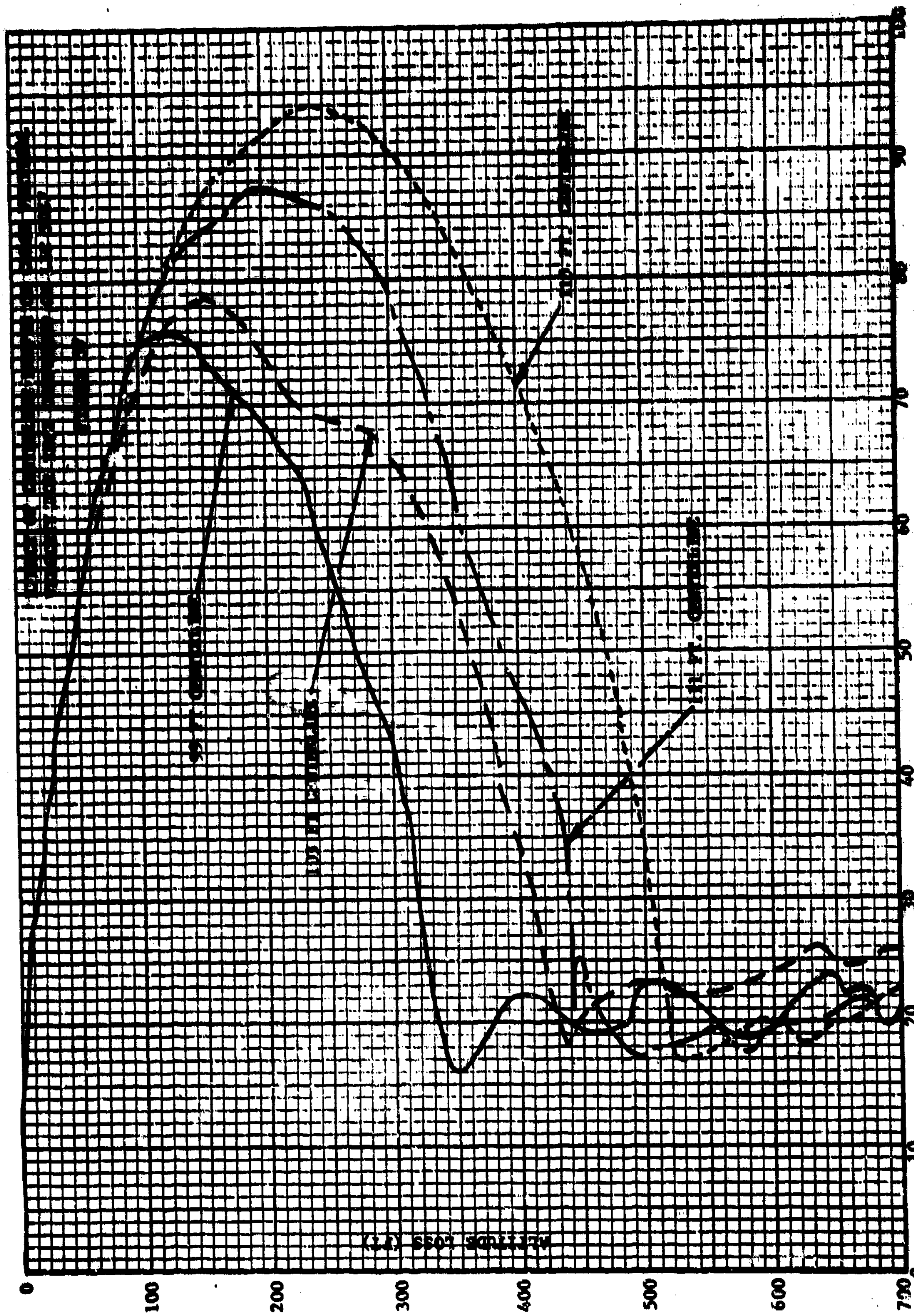


CARGO DESCENT
TRAJECTORY COMPARISON
Figure 33
AAI TEST NO. 22
(85' CENTERLINE)
AAI TEST No. 2
(UNMODIFIED CANOPY)
0
100
200
300
400
500
600
700
800
900
1000
ALTITUDE LOSS (FEET)
DISTANCE PARALLEL TO A C FLIGHT PATH (FT)


AAI TEST NO. 22
(RIGGED CARGO WT - 4300 LBS)
AAI TEST NO. 15
(SUSPENDED CARGO WT = 3530 LBS)
ALTITUDE LOSS vs CARGO VERTICAL VELOCITY FOR 85' CENTERLINE CASES WITH DIFFERENT CANOPY LOADING
Figure 34
0
100
200
300
400
500
600
700
800
900
1000
ALTITUDE LOSS (FEET)
0
10
20
23
30
40
50
60
70
CARGO VERTICAL VELOCITY (FPS)




FORCE RATIO - CENTERLINE FORCE / RISER EXTENSION FORCE


VERTICAL VELOCITY (FPS)
0
10
20
30
40
50
60
70
80
90
100
ALTITUDE LOSS (FT)
0
100
200
300
400
500
600
700

This data indicated that the drag of the G-11A parachute was optimum using a 95 foot centerline. Consequently on test number 29 the centerline length was changed to 95 feet. The results of this test and test number 25 are compared in the plots shown in Figure 38 . In both cases the oscillatory motion appears to damp out rapidly. However, the cargo vertical velocity, using the 95 foot centerline was always less than 23 feet per second after first vertical while with the 85 foot centerline the 23 feet per second velocity was exceeded throughout most of the drop. The 95 foot centerline also produced the lower altitude loss to acceptable impact conditions.

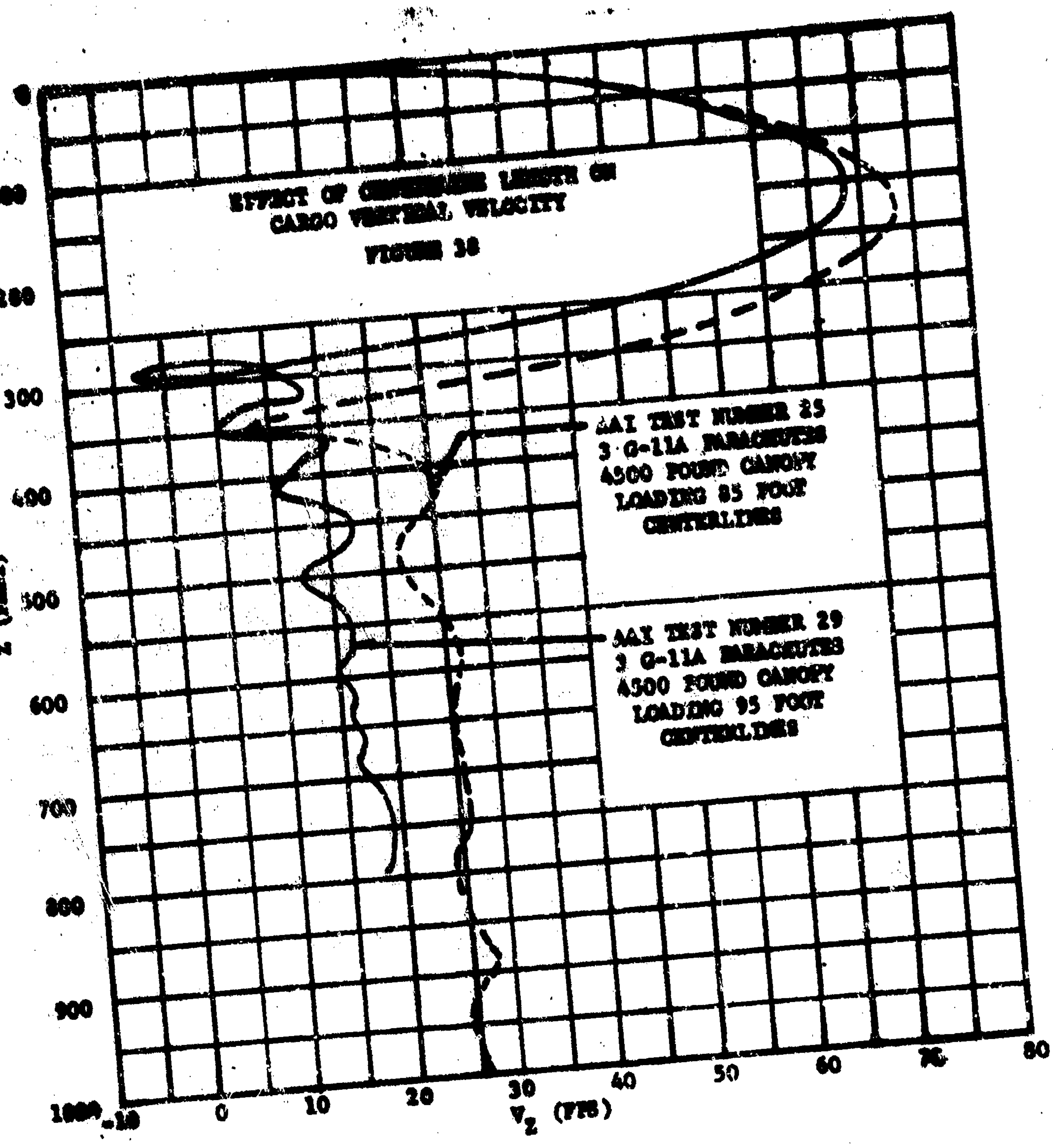
As stated above the cargo vertical velocity never exceeded 23 feet per second after first vertical using the 95 foot centerline. This indicated that the drag produced was sufficient to allow the canopy loading to be further increased from the 4500 pounds per parachute used. The canopy loading was increased to 5000 pounds on tests 36 and 39. These tests were conducted from an altitude of 500 feet and the impact velocities were 22 and 16 feet per second respectively.

Since no tests were conducted during Phase I of the test program using a G-12D parachute with a centerline installed, the length of the centerline to be used on the G-12D parachutes in Phase II was determined analytically. The centerline length was arrived at by multiplying the ratio of the total line length for a G-12D parachute to that for a G-11A parachute by the centerline length, 85 feet, used on the G-11A parachute. This resulted in a 54 foot length. This centerline was used on tests 27 and 30. The cargo vertical velocity versus altitude loss plots are presented for both tests in Figure 39 , and like the 85 foot centerline G-11A test (test number 25), high terminal velocities resulted. The favorable results obtained by changing the centerline length from 85 to 95 feet on the G-11A parachutes is expected to apply to the G-12D clusters as well, but the opportunity to test this effect was not available.

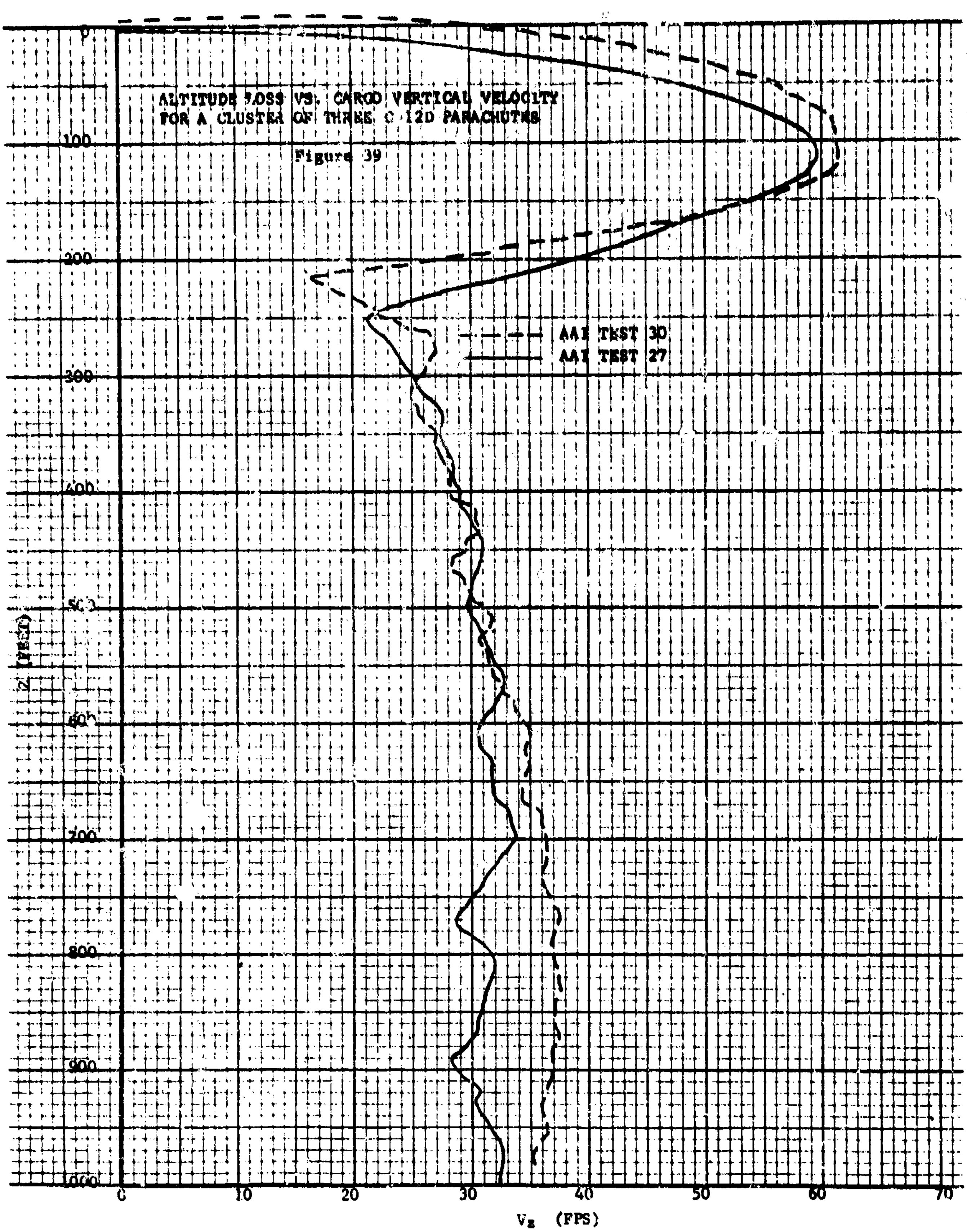
d. Recovery Parachute Inflectors

Two types of inflectors were studied during Phase I testing, (1) a triangular web inflector sewn into the canopy at the skirt as illustrated in Figure 23 on page 46 ; and (2) a band inflector inserted in the canopy skirt as shown in Figure 24 on page 47 . The size of the triangular inflector was varied, and the performance of each size was investigated. However, the insertion of this inflector into the canopy skirt caused damage to the casing of the 550 pound suspension lines which resulted in frayed suspension lines when the parachute was airdropped. The band inflector was developed to try to simplify the changes to the parachute. Although they did not give quite the same parachute shape, investigation of the canopy after each band inflector test revealed no canopy damage.

The curves of altitude loss *vs* vertical velocity for the large triangular inflector and the band inflector show that both inflation aids



EFFECT OF LENGTH ON
CARGO VERTICAL VELOCITY
FIGURE 38
AAI TEST NUMBER 25
3 G-11A PARACHUTES
4500 POUND CANOPY
LOADING 85 FOOT
CENTERLINES
AAI TEST NUMBER 29
3 G-11A PARACHUTES
4500 POUND CANOPY
LOADING 95 FOOT
CENTERLINES
Z (FEET)
0
100
200
300
400
500
600
700
800
900
1000
-10
0
10
20
30
40
50
60
70
80
V_Z (FPS)



ALTITUDE LOSS VS. CARGO VERTICAL VELOCITY
FOR A CLUSTER OF THREE C-12D PARACHUTES
Figure 39
AAI TEST 30
AAI TEST 27
Z (FEET)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
V_z (FPS)

induce oscillations such that the vertical velocity of the cargo reached 30 fps or more during these oscillations. These curves, shown in Figure 40, also reveal that the equilibrium velocity of the cargo is larger than that developed by an unmodified parachute.

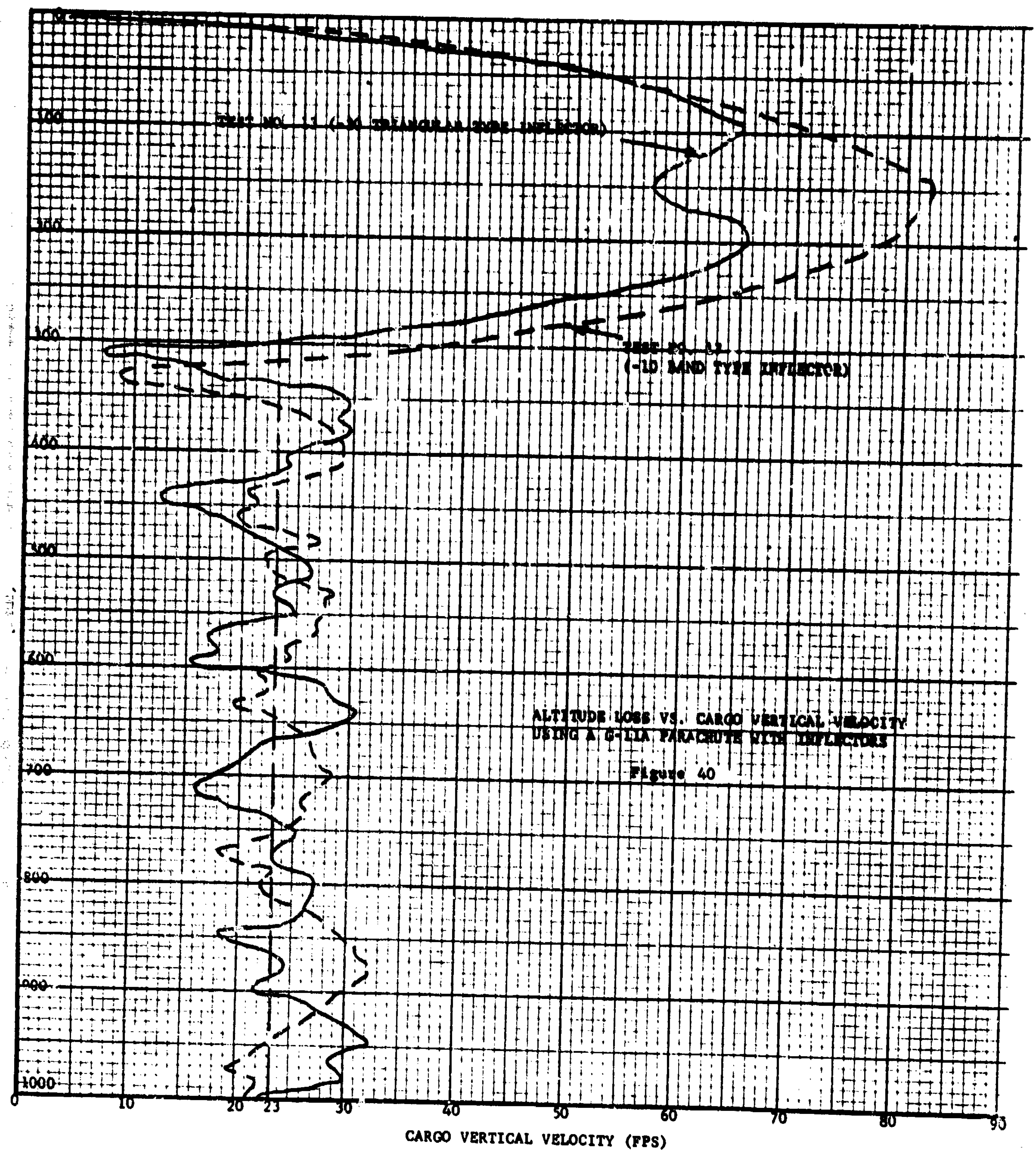
The results of Phase I of the test program indicated that the parachutes equipped with inflectors had a tendency to produce a large system oscillation. It was felt that the inherent stability of a cluster of three parachutes might damp these oscillations and produce acceptable impact conditions. However, as shown in Figure 41 the expected damping did not occur. Figure 41 compares the results of test number 37, with inflectors, to test number 29, without inflectors. The inflectors again caused high system oscillations, thereby, causing the vertical velocity to exceed the nominal of 23 feet per second in many instances.

Figure 41 also indicates that the inflectors have no significant effect on the early inflation process. As shown in the figure, the shape of the first "knee" is simiiar for the two tests. Since this portion of the curve is mainly a function of the opening rate of the canopy and the cluster efficiency, it is apparent that the inflector has little effect on the clustered opening process.

Figure 41 shows that the terminal velocity of the inflector cluster is higher than the unmodified cluster indicating that the inflectors cause a reduction in drag. The vertical velocity in all configurations exhibit an oscillatory nature and this is particularly pronounced on the inflector modified drops. This means that the instantaneous velocity periodically reaches values considerably higher than the mean or average velocity. The curves clearly indicated poor performance of the inflector modification in this respect.

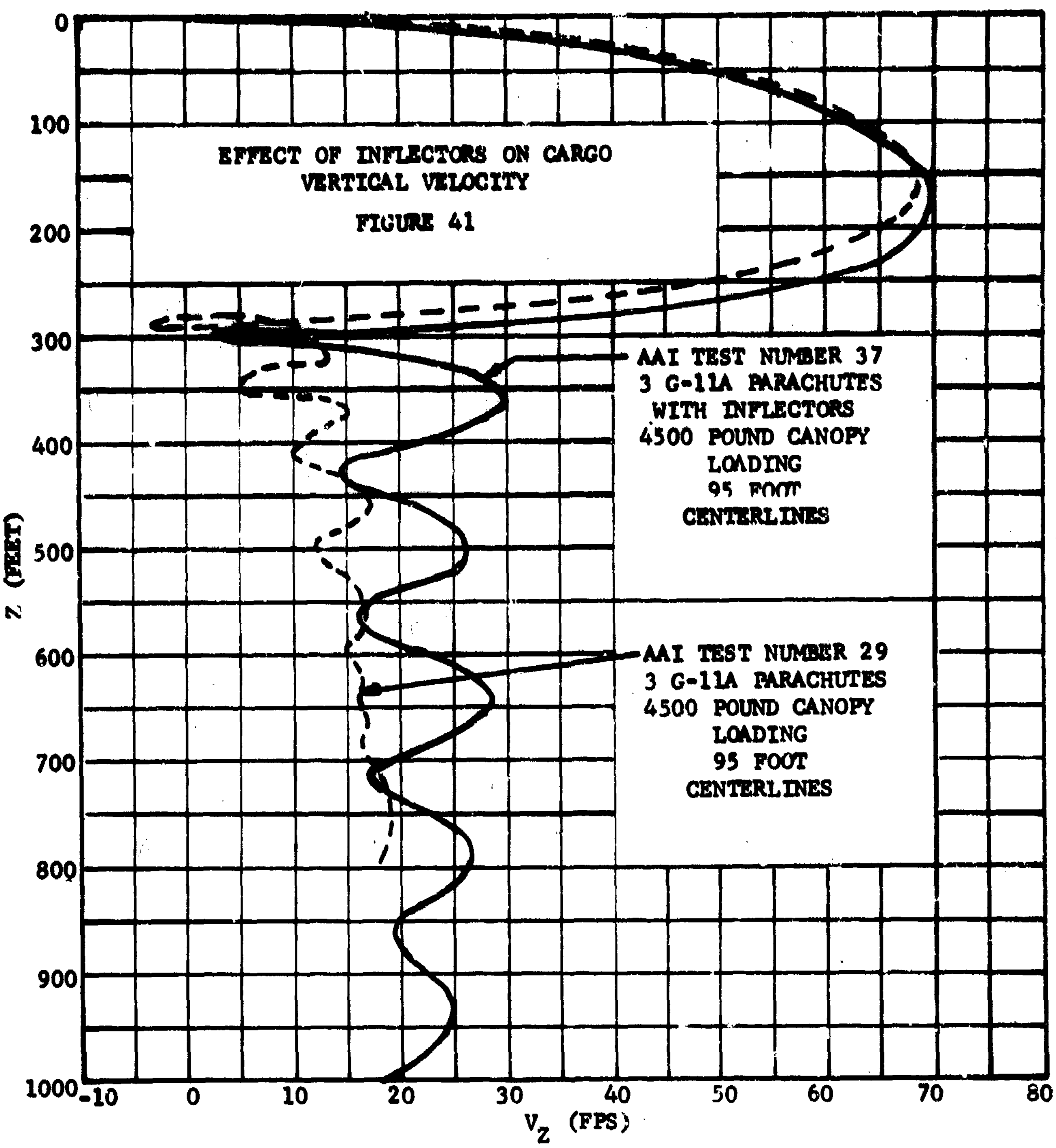
e. Recovery Parachute Reefing

On single parachute airdrop tests conducted during Phase I of the test program the purpose of the reefing line is to limit the opening shock force to an acceptable value. The reefing line length was varied in the tests conducted from 19 to 32 feet. As expected, the opening shock force increased with increasing reefing line length. The 19 foot length resulted in acceptable force values when used in combination with the multi-line snatch force attentuator. The results are summarized below.



ALTITUDE LOSS VS. CARGO VERTICAL VELOCITY
USING A G-11A PARACHUTE WITH INFLECTORS

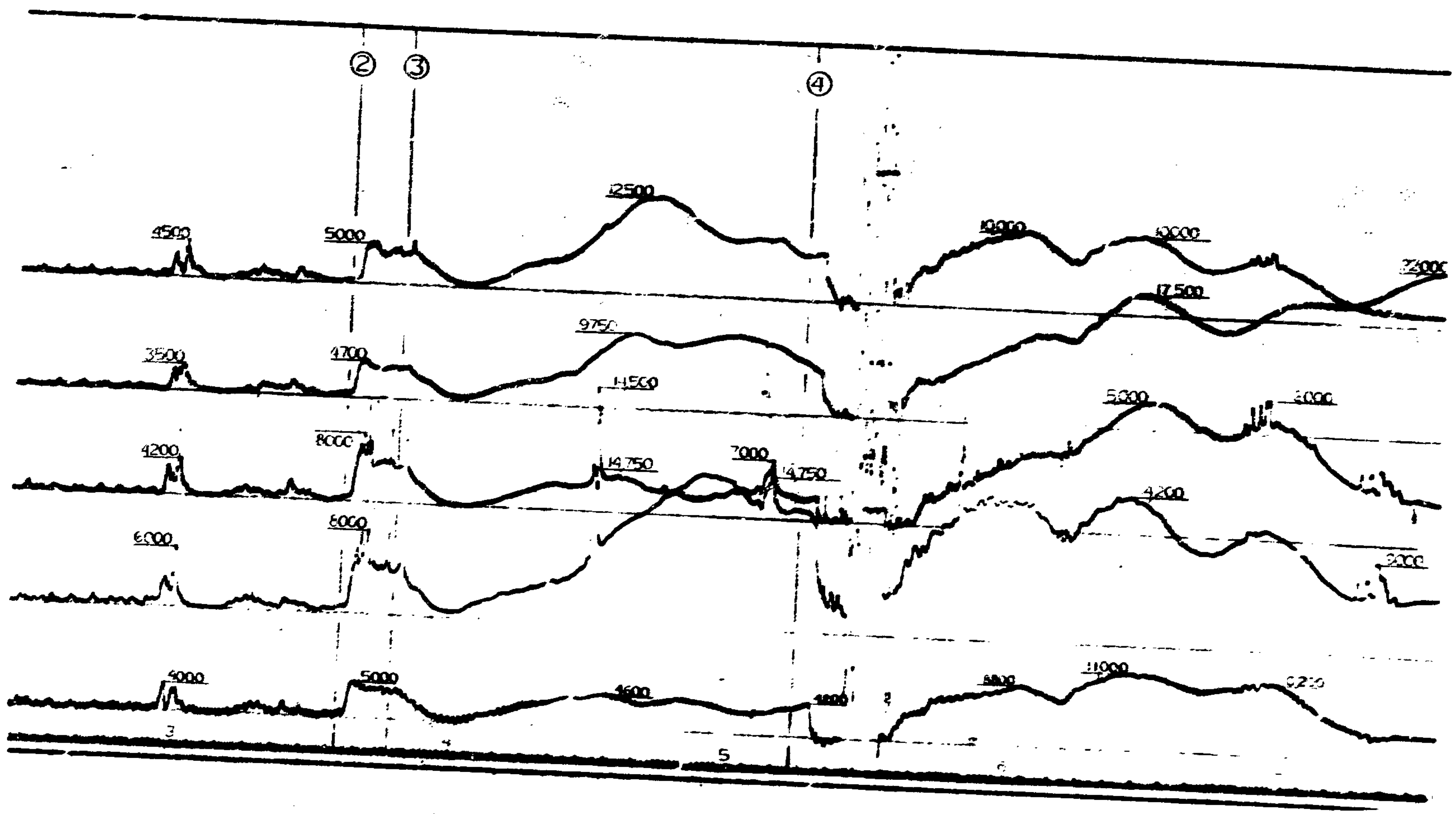
Figure 40


EFFECT OF INFLECTORS ON CARGO
VERTICAL VELOCITY
FIGURE 41
AAI TEST NUMBER 37
3 G-11A PARACHUTES
WITH INFLECTORS
4500 POUND CANOPY
LOADING
95 FOOT
CENTERLINES
AAI TEST NUMBER 29
3 G-11A PARACHUTES
4500 POUND CANOPY
LOADING
95 FOOT
CENTERLINES
Z (FEET)
0
100
200
300
400
500
600
700
800
900
1000
-10
0
10
20
30
40
50
60
70
80
V_Z (FPS)

Test No.	Description	Reefing Line Length (ft)	Snatch Attenuator	Opening Shock Force (g's)
21	Unmodified Canopy	32	4 Lines	2.00
11	95' Centerline	25	None	1.71
23	95' Centerline - 10 Inflector	19	None	1.61
20	95' Centerline -10 Inflector	19	4 Lines	1.51
22	85' Centerline -10 Inflector 148" Reefed Drogue	1[illegible]	4 Lines	1.21

This length reefing line was used on the first test, number 25, of the Phase II portion of the test program and the results (See Table I) indicate that the 19 foot reefing line developed an opening shock force well below the 1.5 g limitation. Although it is required to stay below the 1.5 g limit, it is also desirable to be as close as possible to the force limit in order to get the most efficient use of the parachute. By assuming the theory of Berndt and DeWeese (9) applies for predicting the drag area and the opening shock force is equal to the sum of the drag force produced by the parachute and the inertia force of the parachute, a new reefing line length of 23 feet was determined. The new reefing line len[illegible] resulted in opening shock forces less than but close to the [illegible] g li[illegible], based on an extracted weight of 4750 pounds per parachute for the remainder of the acceptable tests with the exception of test number 35.

[illegible] second possible problem, which is shown in the telemetry traces of F[illegible]re 42 for test 35, was the uneven filling of the parachutes. One parachute, although it suffered no damage, filled faster and consequently carried a greater load, up to 22,000 pounds, than any other parachute. A weaker canopy may have failed under such extreme loads. If this performance is typical, then a second reefing line would have to be installed to provide a more even inflation of the parachutes by holding the parachute which is inflating faster at a known diameter while the others are catching up. This of course, would increase the altitude loss to acceptable impact conditions and could conceivably cause the allowable drop altitude to exceed 500 feet. The early termination of the test program prevented further investigation of this area.



TEST 35 - PARACHUTE FORCE VS. TIME TRACES
Figure 42

f. Recovery Parachute Line Length

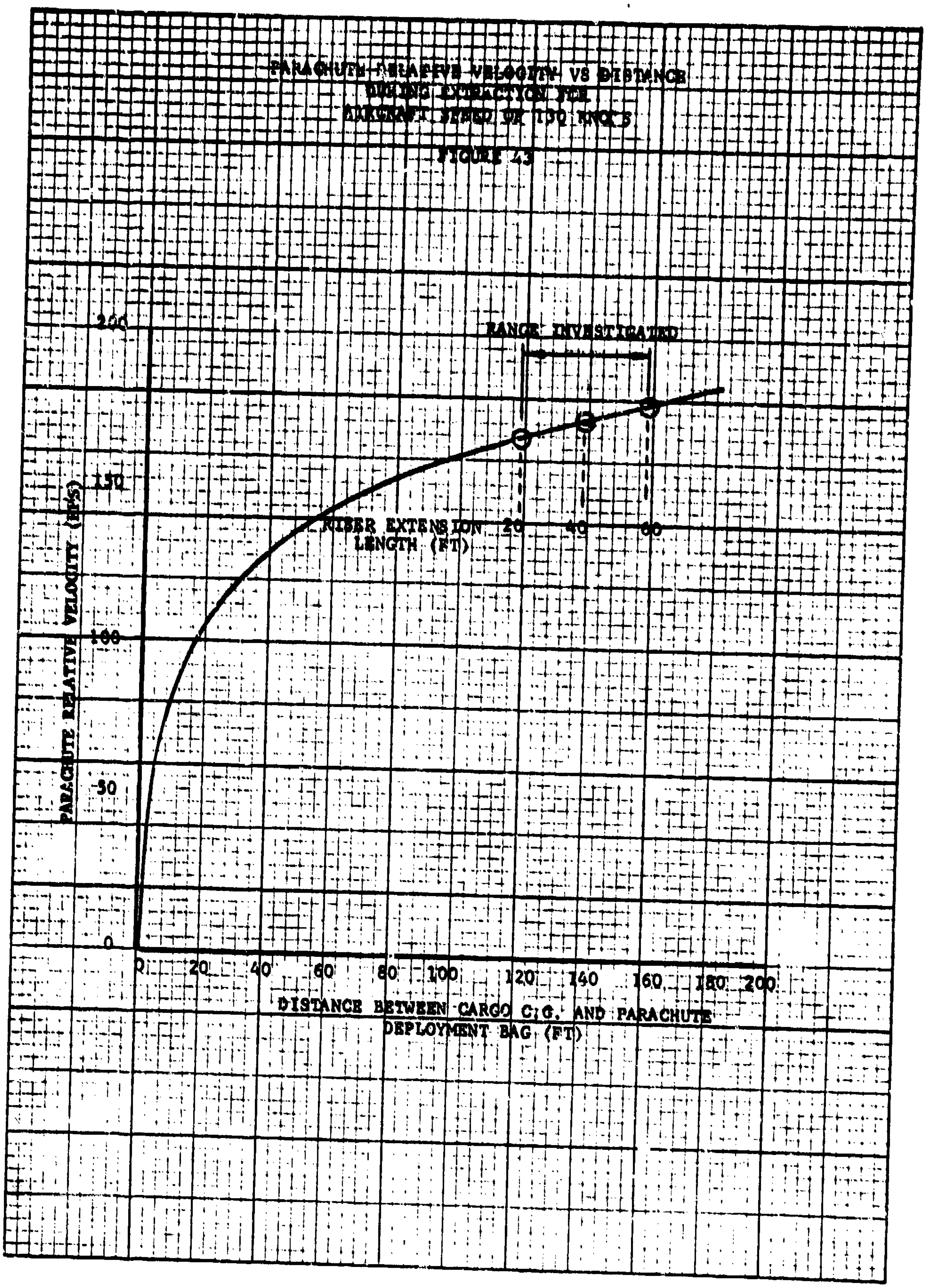
The riser extension line length was varied during Phase I of the test program from 20 to 60 feet in 20 foot intervals to determine the most desirable length. The Snatch forces resulting for each different riser extension length were:

Test No.	Length Of Riser Extension (ft)	Snatch Force (g's)
10	60	1.62
11	40	2.21
2	40	2.08
12	20	2.36

Each of these tests were similar in the respect that no snatch force attenuators were used.

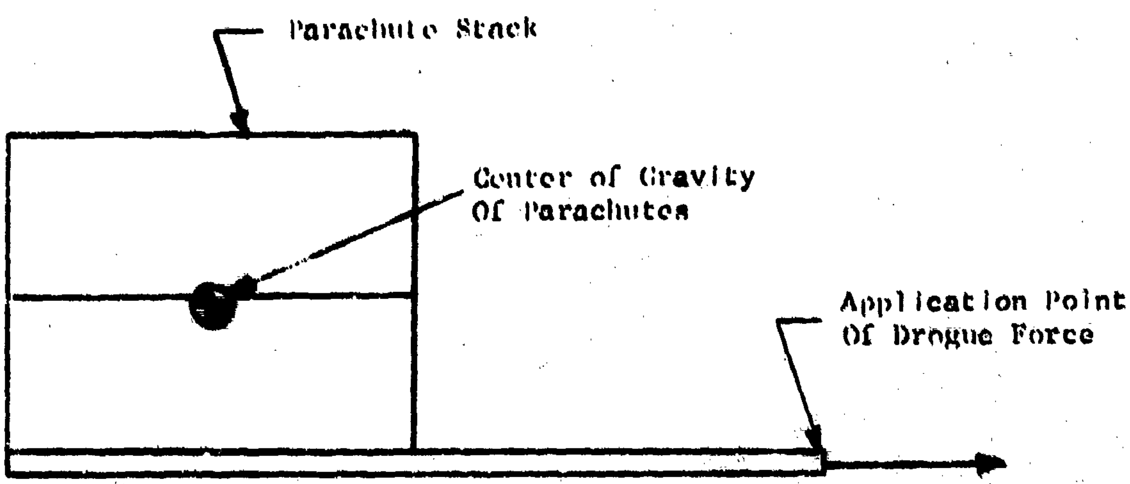
The results illustrate that reducing the riser extension length increases the snatch force. The forces of the two 40 foot line length tests differ because a 95 foot centerline was used on Test No. 11. The increase in snatch force with increase in line length is attributed to the dependence of this force on (1) the relative velocity between the cargo (restrained in the aircraft) and the recovery parachute in its deployment bag; and (2) the spring rate of the lines connecting the cargo and the parachute. The curve in Figure 43 of the relative velocity versus distance between the cargo and parachute centers of gravity illustrates that the change in relative velocity is small for the increased distance along the flat portion of the curve. For the test conducted, the relative velocity variation for the lengths tested is negligible and the predominate factor is the line spring rate. Hence, increases in line length which, in effect, cause a reduction in the line stiffness, result in decreasing the snatch force.

The selection of the most desirable riser extension line length is dependent on the value of the snatch force and the resulting system performance. Investigations reveal that the shortest length develops the best performance in terms of minimum descent altitude, and cargo oscillations whereas, the longest length results in the lowest snatch force, the largest altitude loss, and the highest horizontal velocities. The 40 ft. riser extension length has been selected as the most desirable length since this length develops acceptable cargo impact results and a snatch force value which can be decreased by use of a force attenuator plus a reefed drogue parachute.


PARACHUTE RELATIVE VELOCITY VS DISTANCE
DURING EXTRACTION FOR
AIRCRAFT SPEED OF 130 KNOTS
FIGURE 43
RANGE INVESTIGATED
RISER EXTENSION LENGTH (FT)
20
40
60
PARACHUTE RELATIVE VELOCITY (FPS)
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
DISTANCE BETWEEN CARGO C.G. AND PARACHUTE DEPLOYMENT BAG (FT)

8. Recovery Parachute Extraction Platform

Since there is insufficient room to store more than four parachutes on a load and extract them ballistically with adequate clearance above the cargo compartment floor, a separate parachute extraction platform was designed. (See Figure 25 page 49). This platform was used on test number 35. During the deployment of the platform it rotated forward in the aircraft and translated laterally enough to graze a wind deflector mounted on the aircraft ramp. The forward rotation was caused by the combination of the drogue parachute force being applied below the center of gravity of the parachutes as shown below, and the lack of vertical restraints being applied to the platform.



Although retractable vertical restraints were located on the rails at the position of the platform in the aircraft, none of these had been engaged. Were they engaged, the reaction force between the restraints and the platform could have prevented the forward rotation.

The lateral translation which occurred resulted from the aft restraint force being applied on the right side of the platform only. The indent/detent locks are located on the right rail. One lock had been engaged in the platform and was set at its maximum of 4000 pounds. As the drogue parachute inflated it applied force to the platform which was distributed evenly to both platform rails. This force was reacted by the engaged lock on the right hand rail which induced a cocking moment in the platform. When the drogue parachute force was sufficient to disengage the lone rail lock, the platform rotated because of the cocking moment and hit the wind deflector on the ramp.

Grazing the wind deflector induced a rotation of the platform about the line of flight of the aircraft. The parachutes still deployed with no tangling or damage and were able to successfully recover the load.

b. System Oscillation Reduction

Several tests were conducted during the Phase II portion of the test program to determine the effects of using a parachute for reducing the system oscillation. The tests using an oscillation damping parachute, also included a centerline in the recovery parachute. This was done because the parachutes using a centerline developed larger oscillations during inflation than an unmodified canopy. A single I-10 solid flat circular canopy approximately 35 feet in diameter was employed on two tests using recovery parachutes with centerline lengths of 85 and 95 feet as shown on the following sketch. The performance of the system in response to the single oscillation damping parachute for each of these tests was very similar as shown in Figures 46 and 47.

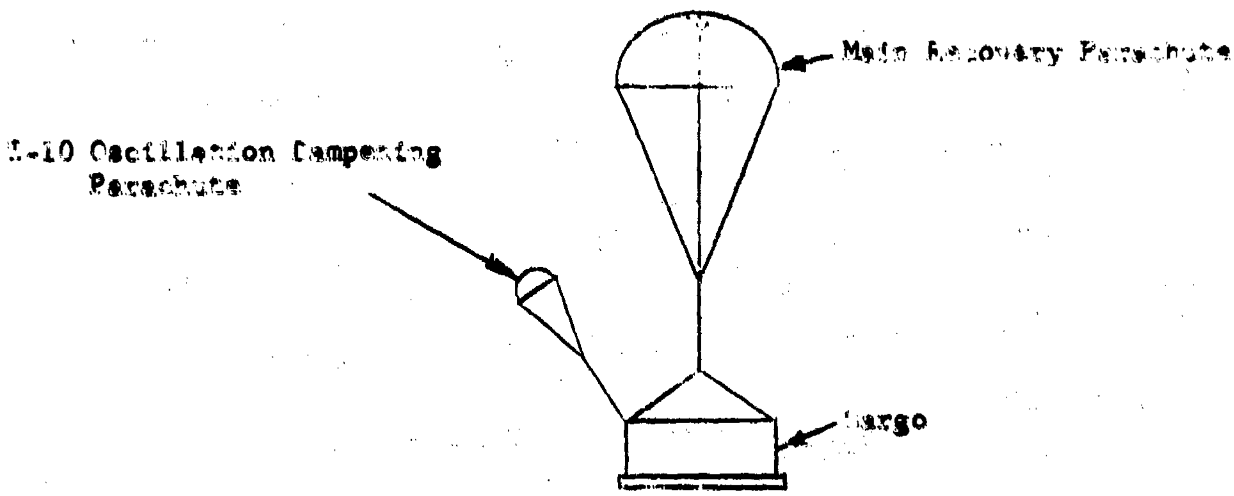
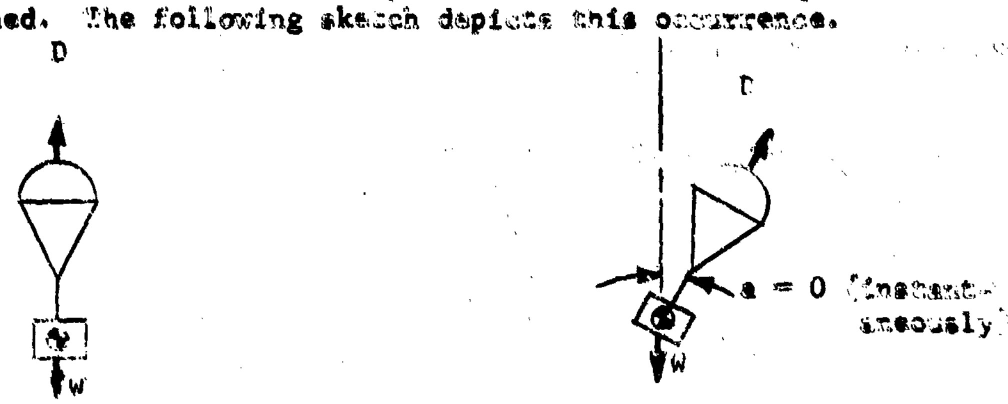


Figure 45 shows that little oscillation of the cargo with respect to the vertical occurred. This plot also illustrates the system oscillation when equilibrium conditions are reached. The following sketch depicts this occurrence.



$W = D = K\,V_z^2$

$V_z = \sqrt{\dfrac{W}{K}} = \text{constant}$

$W = D \cos \alpha = K\,V_z^2 \cos \alpha$

$V_z = \sqrt{\dfrac{W}{K \cos \alpha}}$

$V_z = f(\alpha)$

Where:

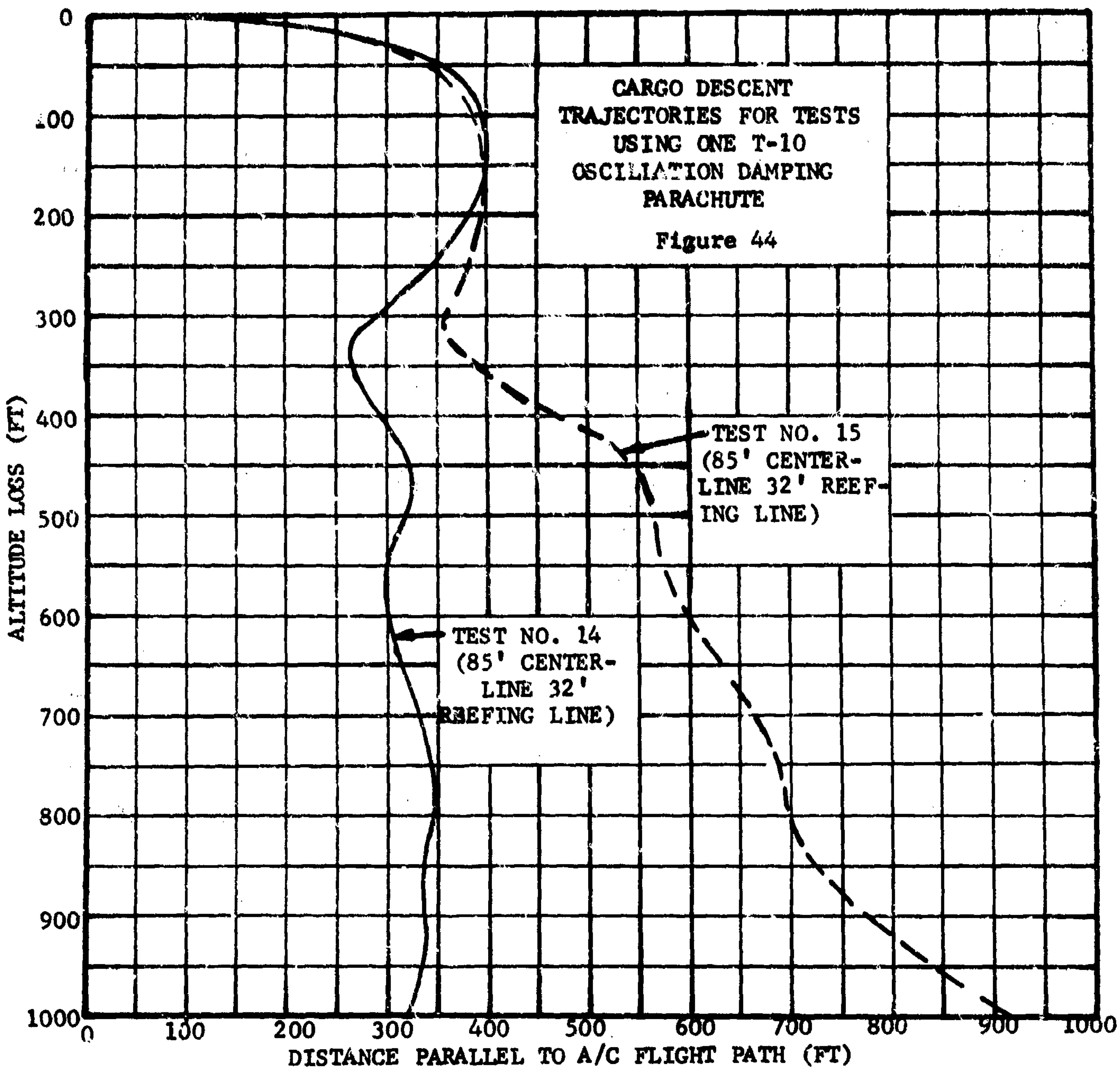
W = weight

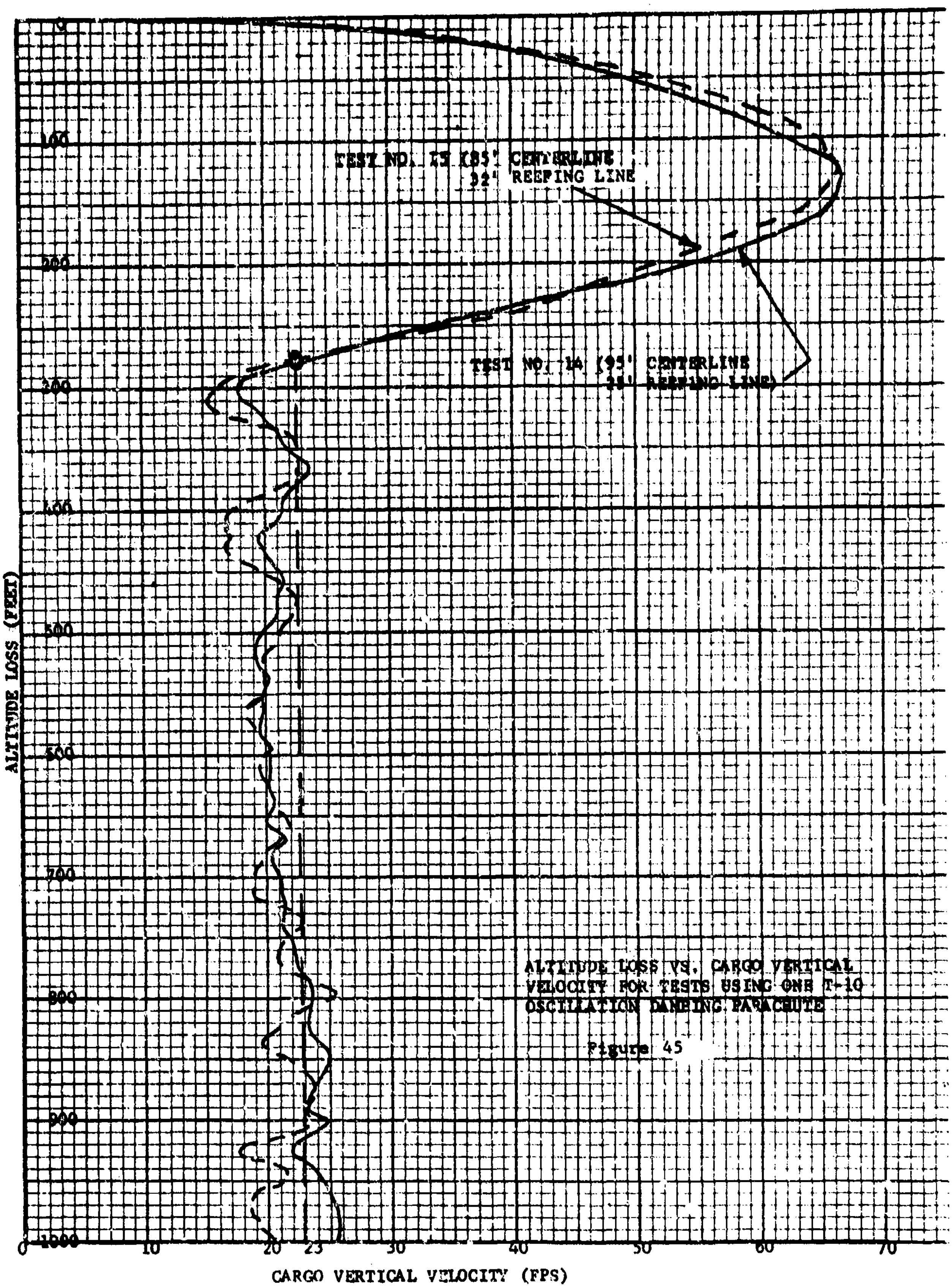
D = drag

V_z = vertical velocity

K = drag constant

a = angular acceleration


CARGO DESCENT
TRAJECTORIES FOR TESTS
USING ONE T-10
OSCILLATION DAMPING
PARACHUTE
Figure 44
TEST NO. 15
(85' CENTER-
LINE 32' REEF-
ING LINE)
TEST NO. 14
(85' CENTER-
LINE 32'
REEFING LINE)
ALTITUDE LOSS (FT)
0
100
200
300
400
500
600
700
800
900
1000
0
100
200
300
400
500
600
700
800
900
1000
DISTANCE PARALLEL TO A/C FLIGHT PATH (FT)



ALTITUDE LOSS VS. CARGO VERTICAL VELOCITY FOR TESTS USING ONE T-10 OSCILLATION DAMPING PARACHUTE

Figure 45

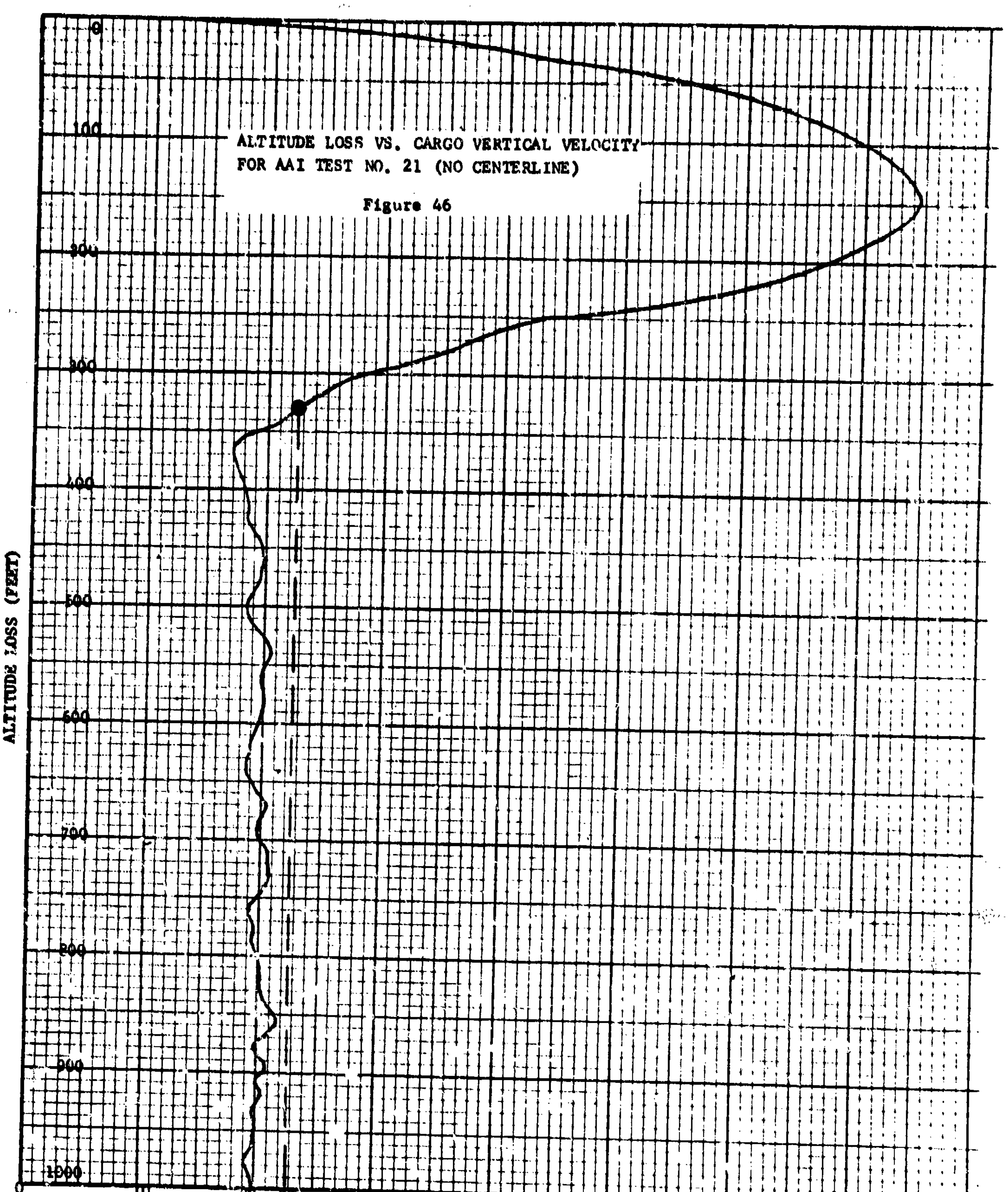
Therefore, if no oscillation is occurring the vertical velocity at equilibrium is a constant, and if oscillation is occurring then the value of the vertical velocity is constantly varying about some equilibrium value.

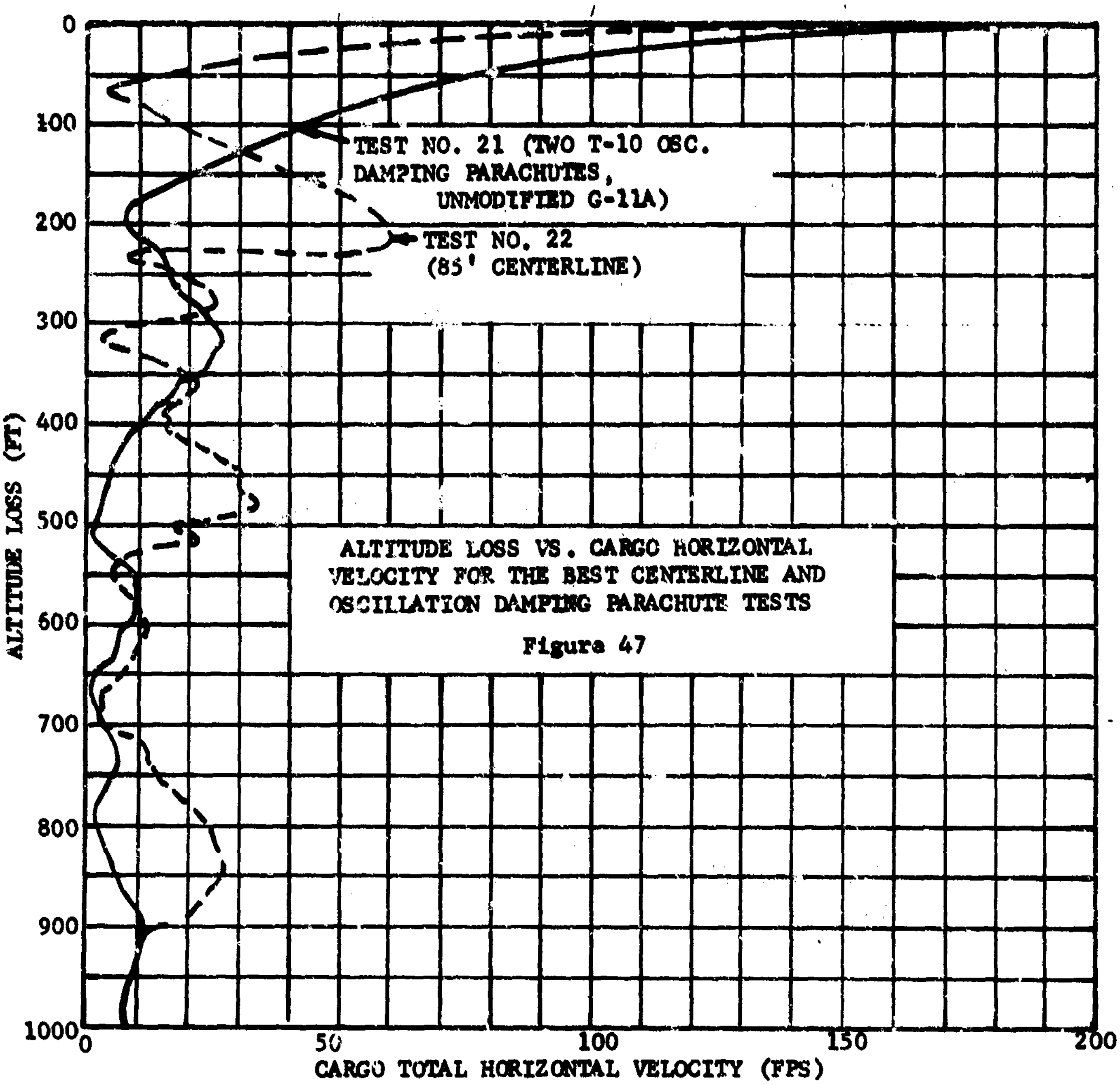
The results for a cargo descent with little oscillation are shown in Figure 46 . These results are for test No. 21 which included two T-10 parachutes for reduction of the oscillation, and an unmodified recovery parachute. The wind velocity was light, approximately 5 knots, and the performance which resulted was excellent. The altitude loss to acceptable vertical velocities was higher than several of the tests which included centerlines, however, the altitude loss was more than acceptable at a value of 325 feet. The resulting horizontal velocity at equilibrium was the lowest recorded, as was the oscillation angle. The results of this test are compared to the performance of the best centerline test (test No. 22 which utilized an 85 ft centerline) in Figures 47 , 48 and 49 . The comparative plots reveal the desirability of the system using an unmodified recovery parachute and two T-10 parachutes for damping as opposed to a single recovery parachute with an 85 foot centerline and a 22% increase in canopy loading. However, combining the use of an 85 foot centerline length, and two T-10 oscillation damping parachutes, and increasing the canopy loading by approximately 20% should result in the optimum performance.

i. System Feasibility

A major objective of the Phase II portion of the test program was the demonstration of the feasibility of delivering cargoes weighing up to 35,000 pounds at altitudes less than 500 feet. Due to the termination of the test program the only attempt to deliver a cargo from 500 feet was confined to a cluster of three G-11A parachutes extracting and recovering a cargo with a total system weight of approximately 15,000 pounds. Three tests, numbers 36, 38 and 39, were conducted from this altitude using this configuration. These tests were highly successful. The only damage incurred during the tests was a bent platform on test number 36. Space positioning data was obtained for tests 36 and 39 only. The vertical velocities obtained from this data were 22 and 16 feet per second respectively. Three tests were conducted in the heavier cargo weight range (20,000 pounds and above) from an altitude of 2000 feet. Two tests, number 31 and 32, using four G-11A parachutes on a 20,000 pound cargo and dropped at 2000 feet provided little useful information. High aircraft rail restraint and the early disreef of one of the parachutes in the cluster in each test caused the lack of useful data.

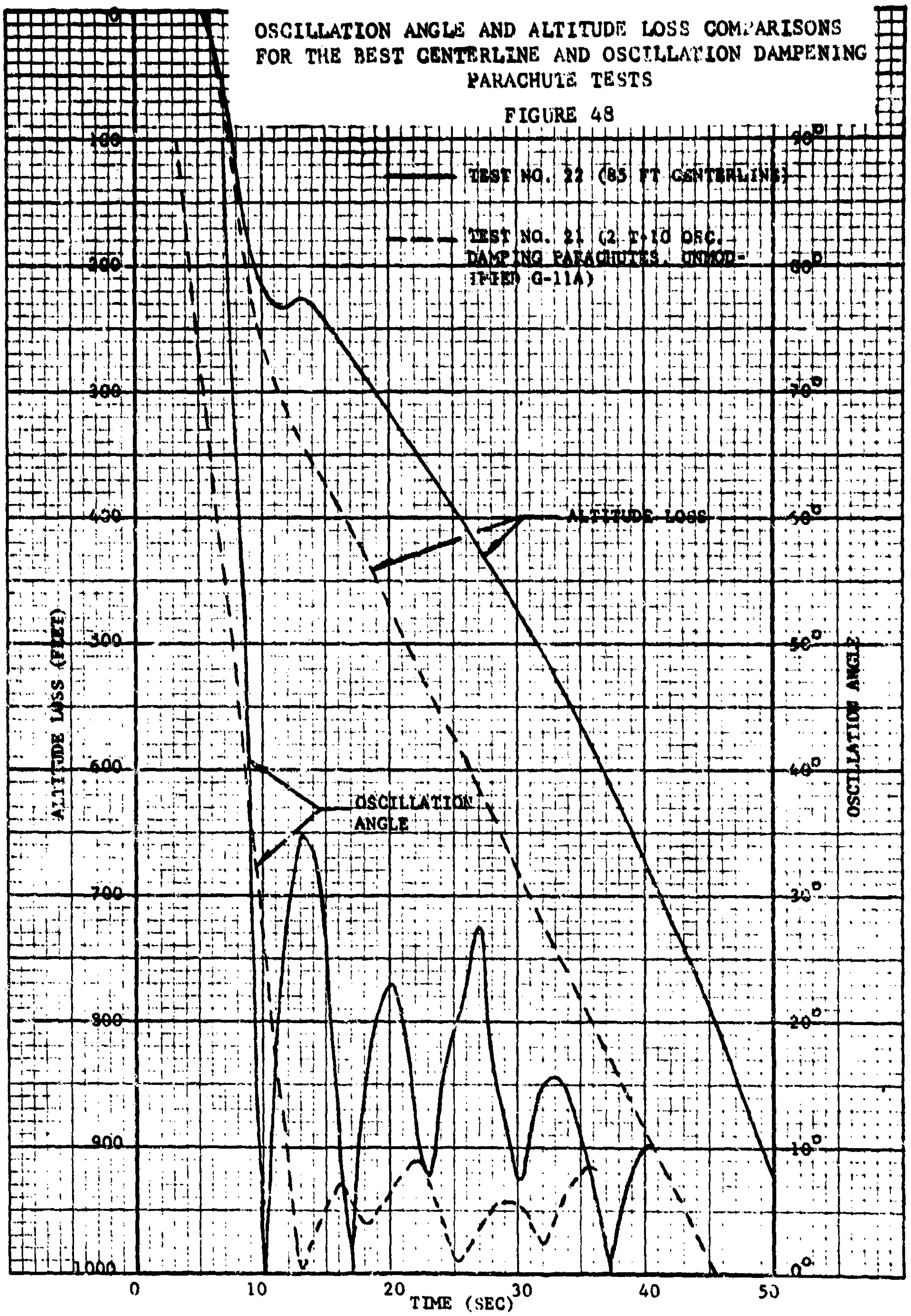
The third test, number 35, using five G-11A parachutes on a 25,000 pound load was quite successful and the data obtained is both useful and encouraging. As shown on the plot of the vertical velocity versus altitude for this test, Figure 50 , the altitude loss to acceptable vertical velocities was within the 500 foot limit. The horizontal velocity and impact angle at 500 feet were approximately 36 feet per second and 15 degrees


ALTITUDE LOSS VS. CARGO VERTICAL VELOCITY
FOR AAI TEST NO. 21 (NO CENTERLINE)
Figure 46
ALTITUDE LOSS (FEET)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
23
30
40
60
70
80
CARGO VERTICAL VELOCITY (FPS)

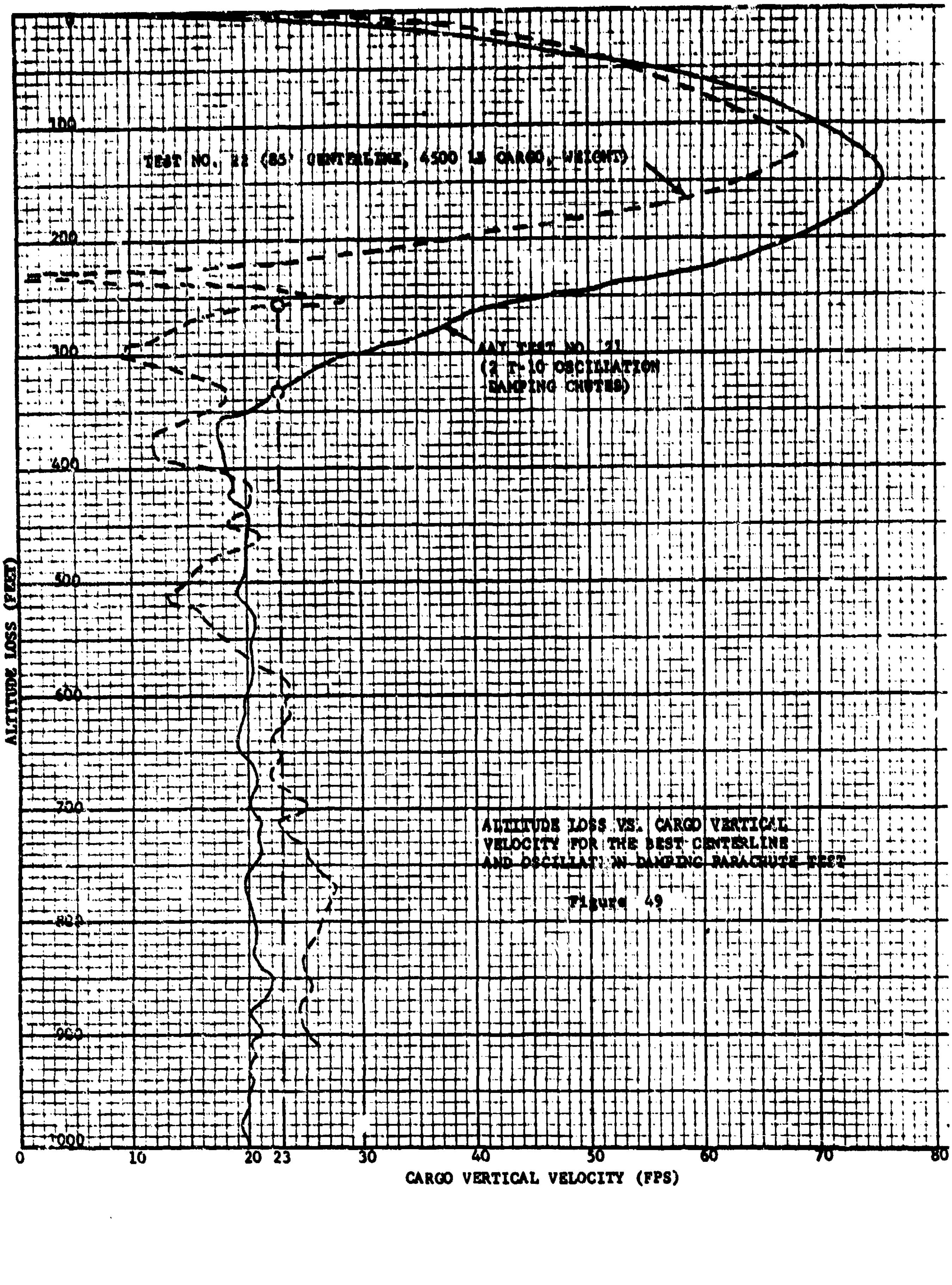


ALTITUDE LOSS VS. CARGO HORIZONTAL VELOCITY FOR THE BEST CENTERLINE AND OSCILLATION DAMPING PARACHUTE TESTS

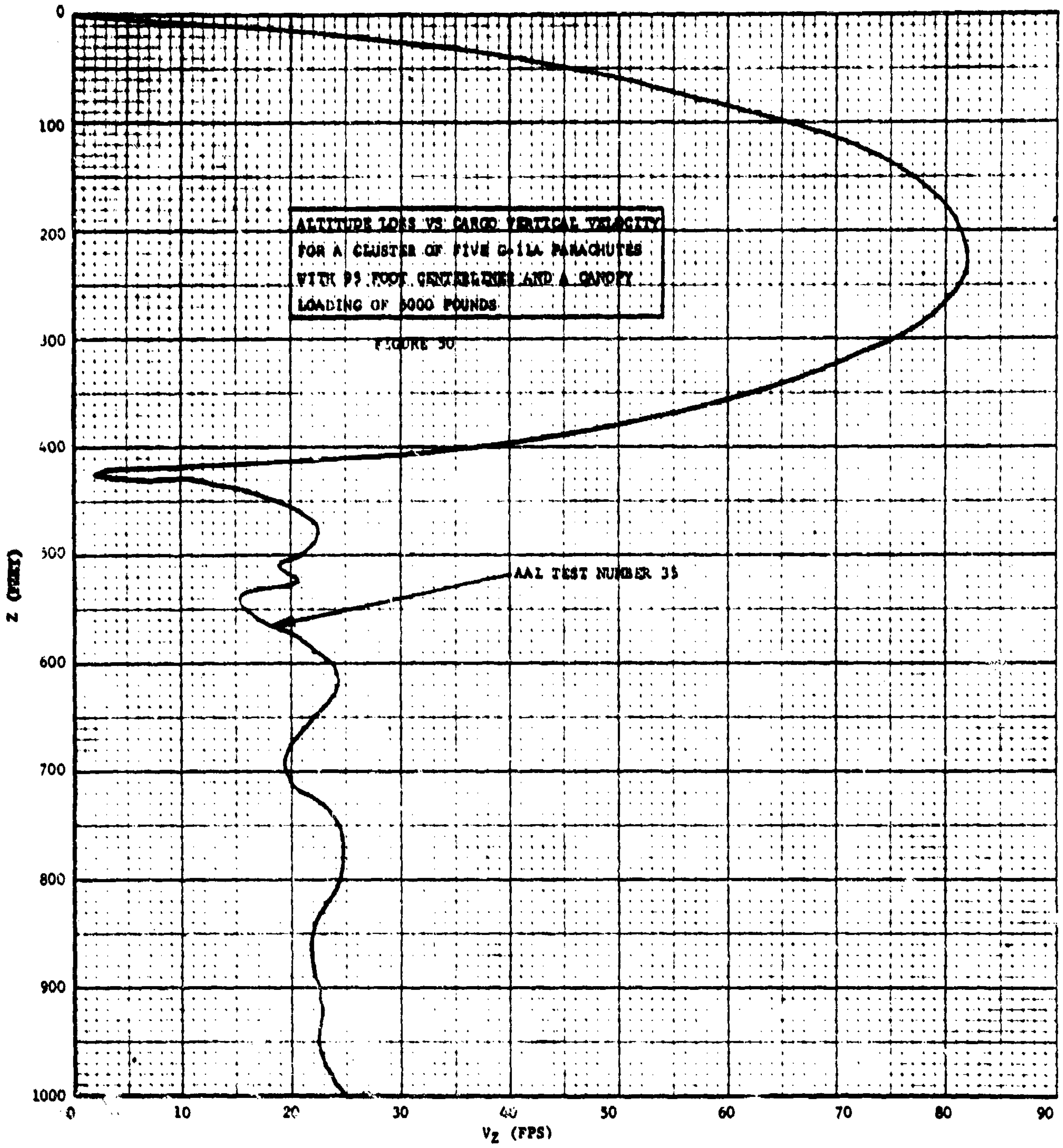
Figure 47



OSCILLATION ANGLE AND ALTITUDE LOSS COMPARISONS
FOR THE BEST CENTERLINE AND OSCILLATION DAMPENING
PARACHUTE TESTS
FIGURE 48
TEST NO. 22 (85 FT CENTERLINE)
TEST NO. 21 (2 T-10 OSC. DAMPING PARACHUTES, UNMODIFIED G-11A)
ALTITUDE LOSS
OSCILLATION ANGLE
ALTITUDE LOSS (FEET)
OSCILLATION ANGLE
0
100
200
300
400
500
600
700
800
900
1000
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
0
10
20
30
40
50
TIME (SEC)



TEST NO. 22 (85' CENTERLINE, 4500 LB CARGO WEIGHT)
AAY TEST NO. 21
(2 T-10 OSCILLATION
DAMPING CHUTES)
ALTITUDE LOSS VS. CARGO VERTICAL
VELOCITY FOR THE BEST CENTERLINE
AND OSCILLATION DAMPING PARACHUTE TEST
Figure 49
ALTITUDE LOSS (FEET)
100
200
300
400
500
600
700
800
900
1000
0
10
20 23
30
40
50
60
70
80
CARGO VERTICAL VELOCITY (FPS)


ALTITUDE LOSS VS CARGO VERTICAL VELOCITY
FOR A CLUSTER OF FIVE G-11A PARACHUTES
WITH 95 FOOT CENTERLINES AND A CANOPY
LOADING OF 5000 POUNDS
FIGURE 30
AAI TEST NUMBER 35
Z (FEET)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
V_Z (FPS)

respectively. However without specified horizontal velocity and impact angle limitations, no predication can be made that such impact conditions would be acceptable.

E. Analytical Studies

1. General

The preliminary exploratory development of low altitude airdrop system performance in Contract DA-19-129-AMC-846(N) illustrated the desirability of developing analytical techniques to predict airdrop system performance.* The development of computer programs to compute the motion of the cargo and parachute as well as other important airdrop performance parameters requires a detailed knowledge of the operation and performance of the system being investigated. AAI Corporation has written two and three dimensional equations of motion for low altitude airdrop systems and the results of these programs have shown a need to improve the input data necessary to predict the actual results obtained in airdrop operation. Therefore, the two-dimensional airdrop program was rewritten and reprogrammed for specific application to the EXIARP system. The modifications included in the computer program consisted of such items as, analyzing the stretch of the parachute lines during snatch and opening shock forces, defining the motion of the cargo during load transfer, including the apparent and included mass of the parachute canopy and improving the prediction of the line tension versus time. Also, the parachute extraction and deployment phase was added to the program to result in better prediction of the snatch force. The complex equation development and computer program description are presented in AAI Engineering Report ER-6005(12). The definition of each phase is also presented herein on the following pages. The basic assumptions made for analyzing each phase are listed on the sketches. The five major phases analyzed are:

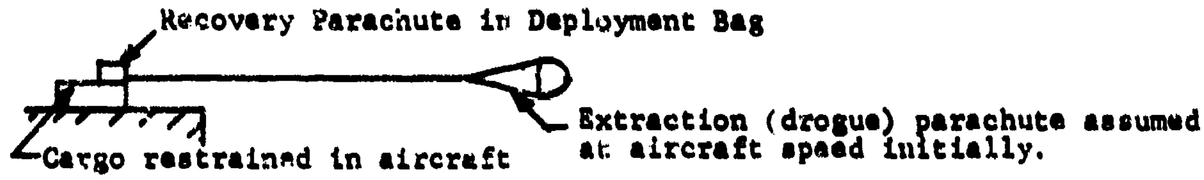
- Recovery Parachute Extraction
- Recovery Parachute Deployment
- Cargo Extraction
- Cargo Tip Off
- Descent

Several of the computer input parameters required are difficult to predict analytically, therefore, the flight test program conducted at El Centro was used to provide data for empirically predicting these parameters. Also, the theory that presently exists to predict such items as inflation time, snatch force, and other parameters was compared to the free flight results. During the test phase of the program, the two-dimensional computer program was continually modified to provide accurate airdrop predictions.

The prediction capability of the computer program is illustrated in paragraph [illegible]. The computer program was used to investigate the system performance envelope of the EXIARP system. The test program conducted could not begin to demonstrate the performance of the airdrop system for every cargo in the present airdrop inventory. Hence, the computer program was employed to analyze the performance of airdropping selected cargo. The [illegible] parameters requested by the C.I.F. [illegible] SS[illegible]-67-[illegible] for the specific cargo items were predicted using the computer program. Computer runs were also made to determine the system sensitivity and flexibility.

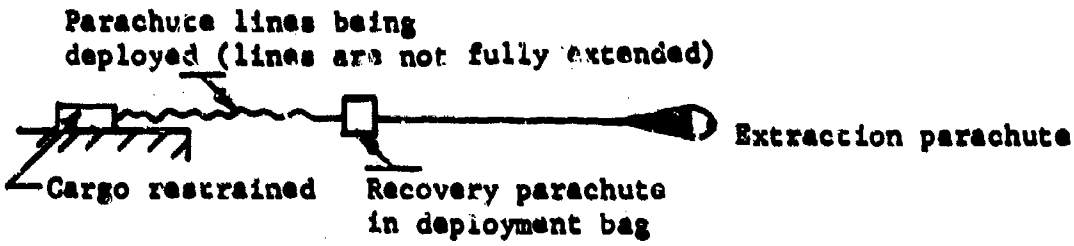
*See References 10 and 11.

RECOVERY PARACHUTE EXTRACTION PHASE
(Note: Extraction is not one-dimensional as depicted in sketches)



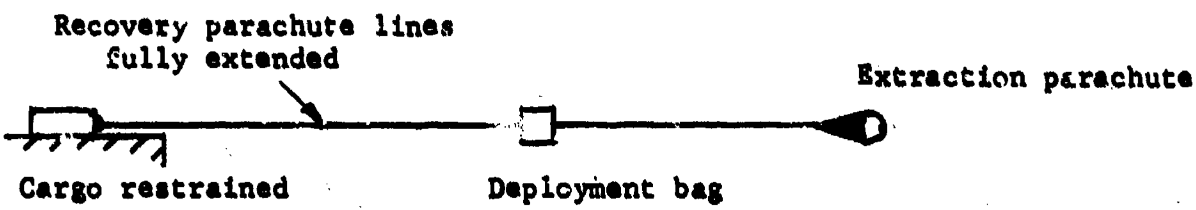
(1) Start of Recovery Parachute Extraction Phase

- extraction parachute in fully inflated state and recovery parachute located on cargo in aircraft.



(2) Deployment of Recovery Parachute Lines

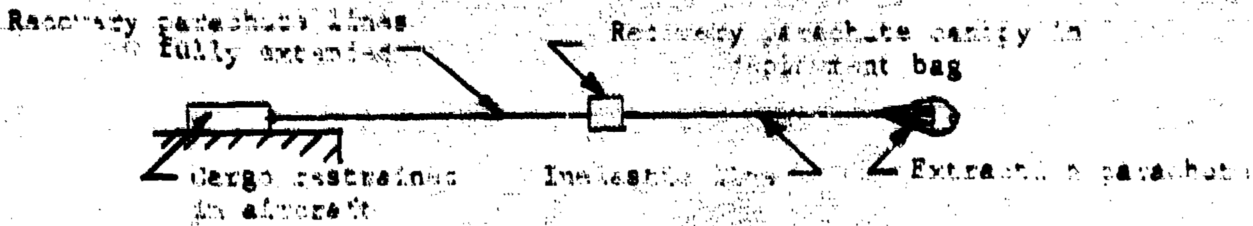
- the recovery parachute lines are assumed weightless during their deployment from the deployment bag
- the line connecting the extraction parachute and the deployment bag is assumed inelastic.



(3) End of Recovery Parachute Extraction Phase

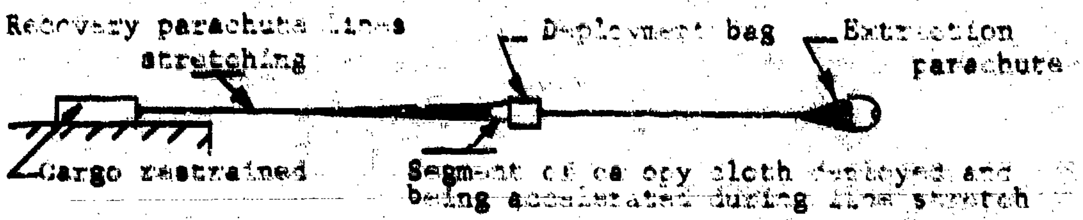
- end of this phase is defined as the full extension of the parachute lines, the lines are taut and have not begun to stretch.

RECOVERY PARACHUTE DEPLOYMENT PHASE



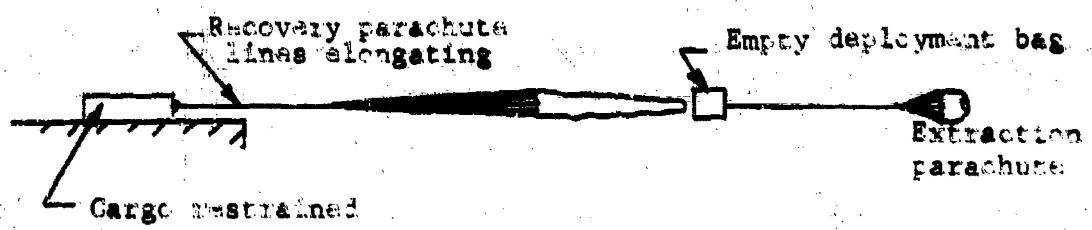
(1) Start of Recovery Parachute Deployment Phase

- recovery parachute lines are fully extended with the line tension initially zero.
- beginning of canopy inflation process (Berndt & DeWeese t=0)*



(2) Deployment of Segment of Canopy

- incremental segment of the canopy mass is deployed from the bag during elongation of recovery parachute lines.
- snatch force occurs during canopy deployment.

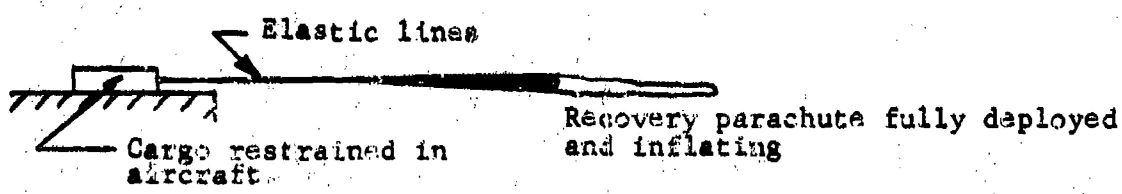


(3) End Recovery Parachute Deployment Phase

- canopy fully deployed for bag and extraction parachute no longer applies force to canopy.

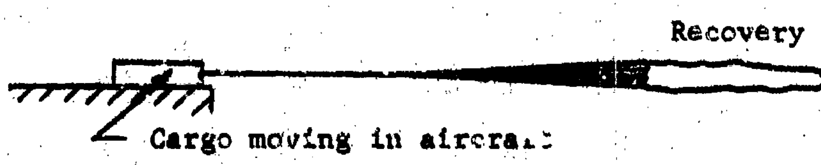
*Berndt & DeWeese describe the canopy inflation process in their article "Filling Time Prediction Approach for Solid Cloth Type Parachute Canopies," AIAA Aerodynamic Deceleration Systems Conference, Sept. 1966.

CARGO EXTRACTION PHASE



(1) Canopy Development Prior to Cargo Extraction

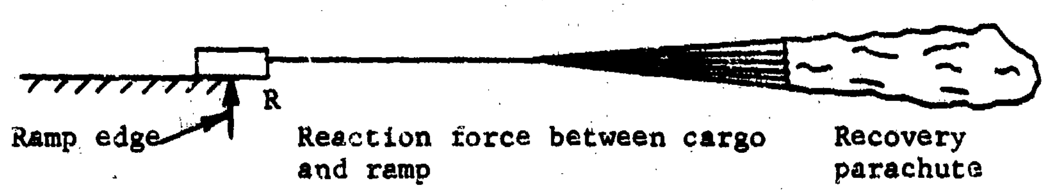
- canopy inflating and increasing force in lines.



(2) Cargo Release

- the force developed by the recovery parachute exceeds the cargo restraint force in the aircraft and begins motion of the cargo relative to the aircraft.

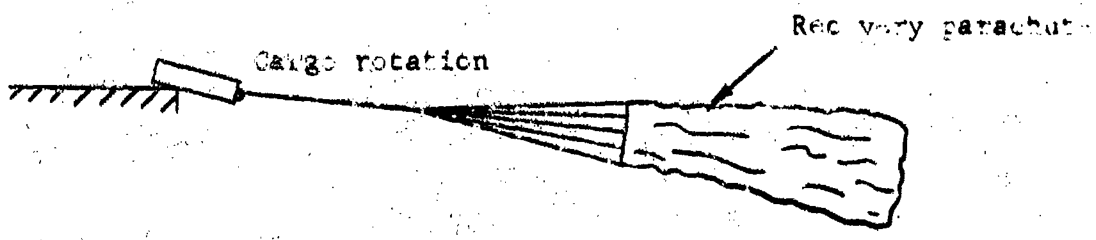
- the cargo is constrained in the aircraft from any vertical motion.



(3) End of Cargo Extraction Phase

- termination of this phase is when the center of the reaction force R between the cargo platform and the aircraft ramp reaches the end of the ramp or when the net moment about the cargo c.g. created by the reaction and extraction forces changes from zero.

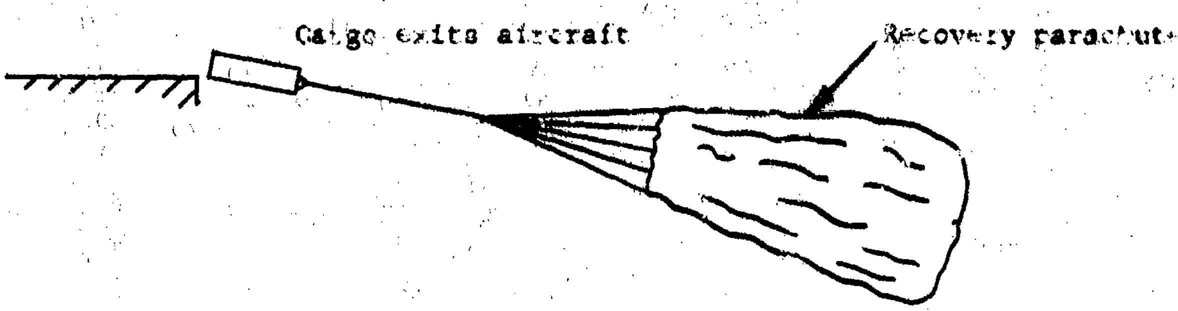
CARGO TIP-OFF PHASE



(1) Cargo Rotation During Tip-Off

- cargo rotates and translates under influence of recovery parachute force.

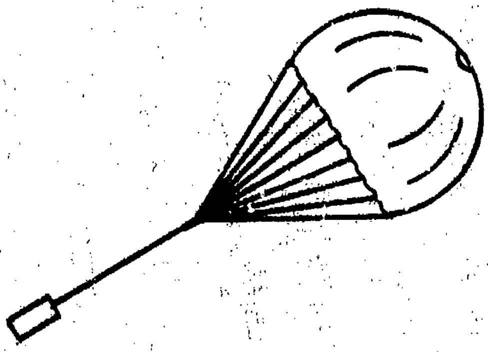
- canopy inflation continues throughout this phase.



(2) End of Tip-Off Phase

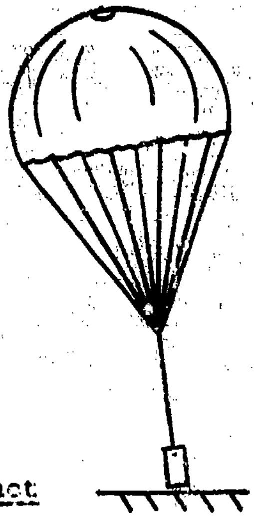
- Tip-off phase ends when the reaction force at the end of the ramp becomes zero or because the front edge of the platform moves aft of the ramp edge.

DESCENT PHASE



(1) Cargo Descent

- canopy decelerates the cargo.
- canopy inflation process ends during descent phase.



(2) Ground Impact

2. Discussion of Computer Input Data

The results of the two-dimensional airdrop computer program have revealed the importance of correct input data to accuractely predict the system results. The input data requires numerous tabular values which define the parachute diameter growth and drag charactertistics as a function of time, and the parachute lines force versus elongation. The general data required is a function of the cargo-parachute system. The nomenclature for this general input data is defined in the following table.

Nomenclature	Units	Definition
		Payload Characteristics
WL	lb	Rigged cargo weight excluding parachutes (recovery and extraction)
XIL	slugs-ft^2	Cargo tumbling moment of inertia
XKL	lb	Drag function = $q \; C_D A$
C	ft	Vertical distance from extraction point to cargo center of gravity
D	ft	Vertical distance from platform to cargo c.g.
G	ft	Pallet length
XLPAL	ft	Longitudinal distance from extraction point to c.g.
EPT1	ft	Longitudinal distance from c.g. to forward sling attachment point
FPT1	ft	Vertical distance from c.g. to forward sling attachment point
EPT2	ft	Longitudinal distance from c.g. to aft sling attachment point
FPT2	ft	Vertical distance from c.g. to aft sling attachment point
S	ft	Longitudinal distance from the initial cargo position to the ramp edge
XLO	ft	Initial X coordinate position in space

Nomenclature	Units	Definition
YLO	ft	Initial Y coordinate position in space
FRLSE	lb	Release force
		Recovery Parachute Characteristics
NPARAS	--	Number of recovery parachutes
WP	lb	Weight of single recovery parachute
DCAO	ft^2	Fully developed drag area of single recovery parachute
TFILL	sec	Filling time
CDEP	--	Cluster drag efficiency factor
		Recovery Parachute Extraction Conditions
XPLTO	ft	Initial X coordinate of extraction parachute
YPLTO	ft	Initial Y coordinate of extraction parachute
WPLT	lb	Weight of extraction parachute
WAPLT	lb	Apparent and included air weight within extraction parachute
XKPLT	lb	Extraction parachute drag function = $q \ C_D A$
XBAGO	ft	Initial X coordination of parachute bag
YBAGO	ft	Initial Y-coordinate of parachute bag
WBAG	lb	Weight of parachute and bag
XKBAG	lb	Parachute bag drag function
XLBAG	ft	Half-length of parachute bag
RC	ft	Flat (constructed) radius of canopy
WLNES	lb	Weight of parachute lines (riser and suspension) and riser extension
WCNPY	lb	Weight of recovery parachute canopy
WB	lb	Empty parachute bag weight

Nomenclature	Units	Definition
		Aircraft and Descent Conditions
VAC	ft/sec	Aircraft velocity
DEL	degrees	Ramp angle
RHO	slugs/ft^3	Air mass density
YLEND	ft	Descent distance to impact

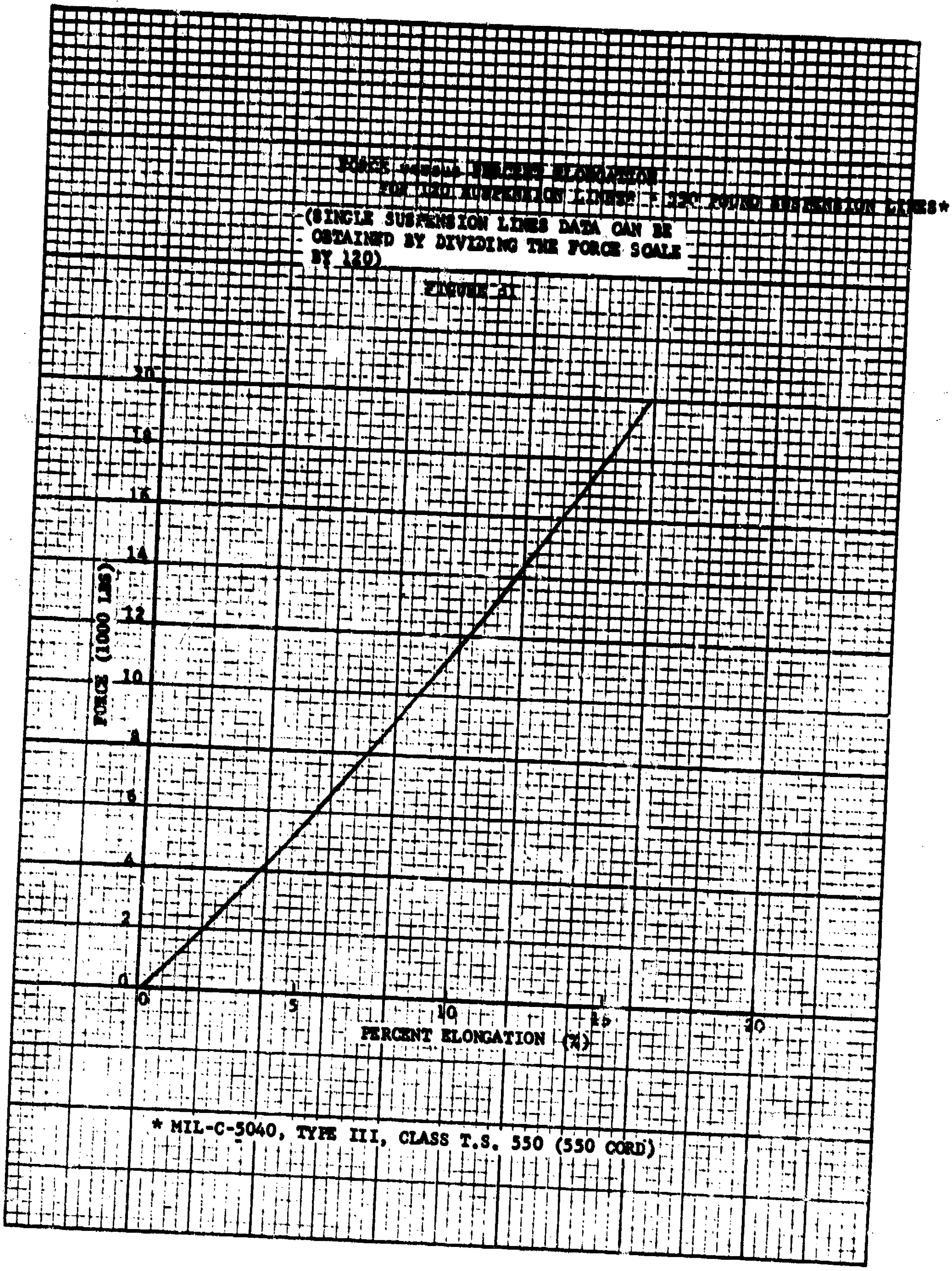
These input parameters are primarily dependent on the geometry and weight of the various components of the airdrop system. The tumbling moment of inertia for a given weight cargo can be approximated by using the curves of Reference (1).

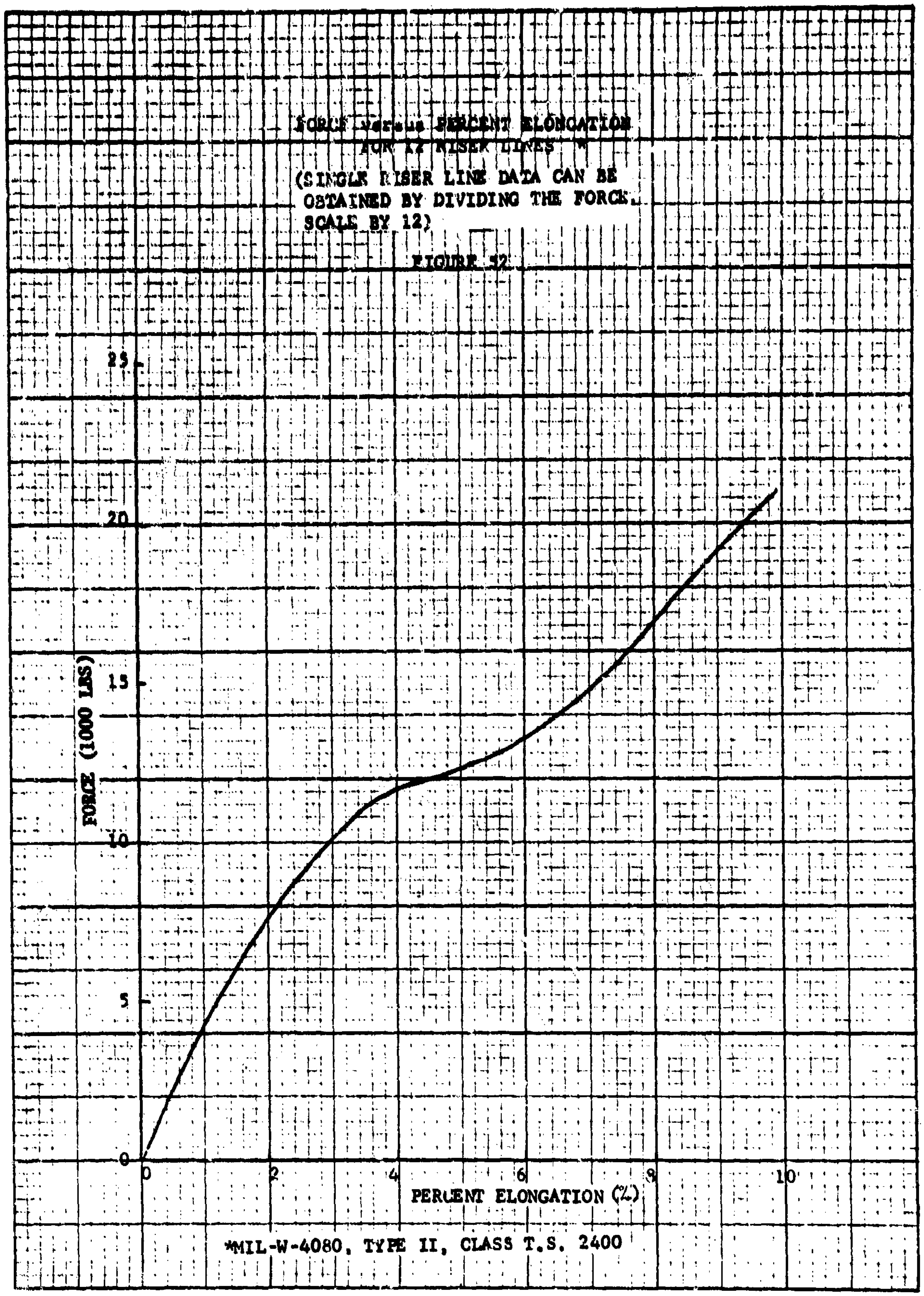
The remaining input data consist of tabular values describing the following:

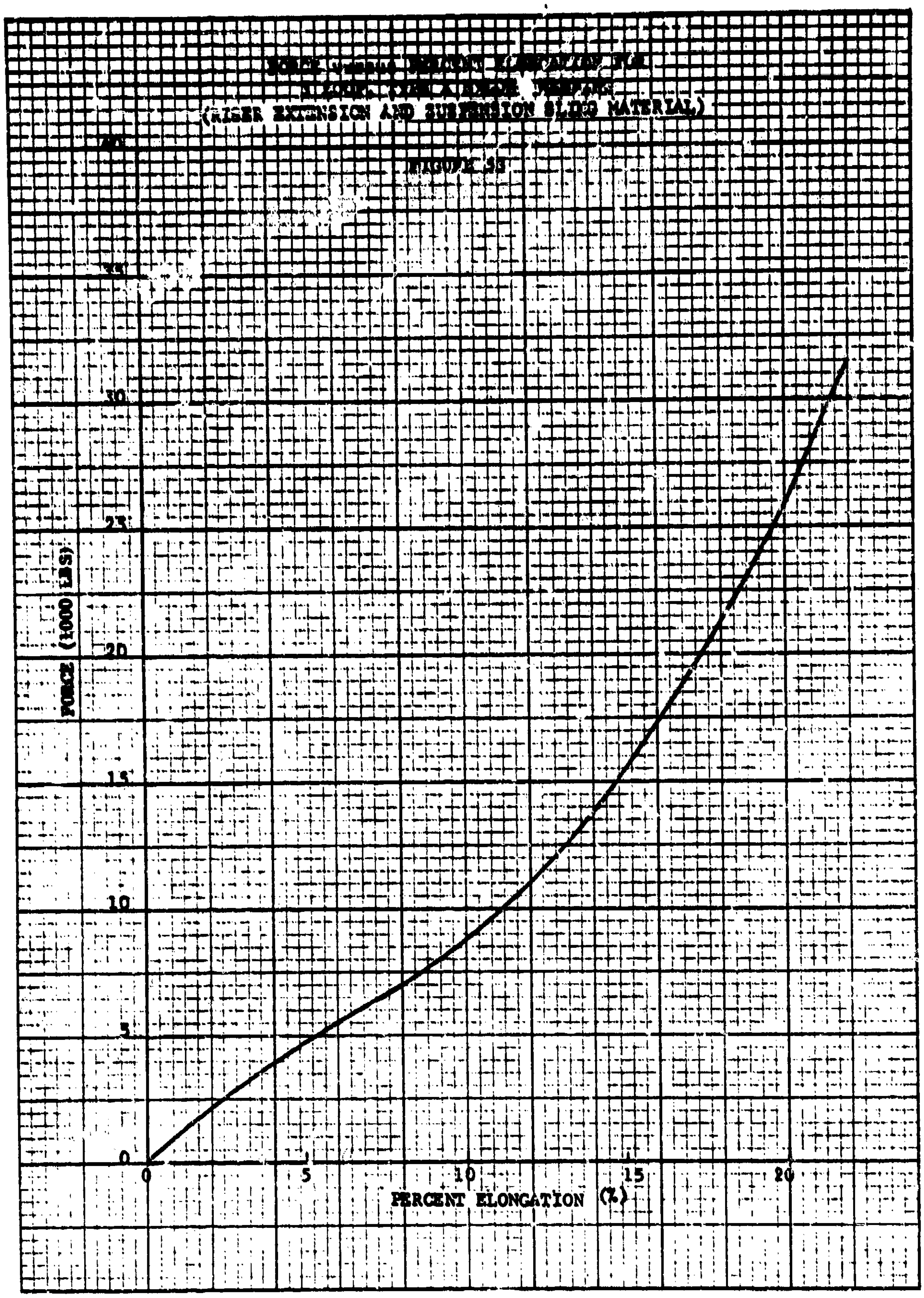
- Individual parachute line tension versus length (e.g. suspension line tension versus length). Diameter ratio versus total fill-in time ratio
- Drag area ratio, apparent air mass, rate of change of apparent air mass, included air mass and rate of change of included air mass as a function of diameter ratio.

Force versus Length

The force versus percent elongation data for each parachute line, including riser extension, riser, suspension, suspension slings and any additional lines employed such as undrawn nylon lines; is required to predict the stretching of the line during the development of the line tension force. The snatch force and opening shock are the most important forces in addition to the suspension sling forces. The computer program combines these various lines and develops a resultant line tension versus length table. This data was obtained from limited static tensile test conducted at AAI. The resulting tensile force versus elongation data has been plotted in Figures 51 through 53 for each parachute line considered. In the case of multiple lines; e.g. twelve (12) risers, e.g. 120 suspension lines; the curves reflect the total force for each set of these lines.


(SINGLE SUSPENSION LINES DATA CAN BE OBTAINED BY DIVIDING THE FORCE SCALE BY 120)
FORCE (1000 LBS)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
PERCENT ELONGATION (%)
* MIL-C-5040, TYPE III, CLASS T.S. 550 (550 CORD)


FORCE versus PERCENT ELONGATION
FOR 12 RISER LINES *
(SINGLE RISER LINE DATA CAN BE
OBTAINED BY DIVIDING THE FORCE
SCALE BY 12)
FIGURE 52
FORCE (1000 LBS)
25
20
15
10
5
0
0
2
4
6
8
10
PERCENT ELONGATION (%)
*MIL-W-4080, TYPE II, CLASS T.S. 2400


(RISER EXTENSION AND SUSPENSION SLING MATERIAL)
FORCE (1000 LBS)
30
25
20
15
10
5
0
0
5
10
15
20
PERCENT ELONGATION (%)

NOT REPRODUCIBLE

Canopy Inflation

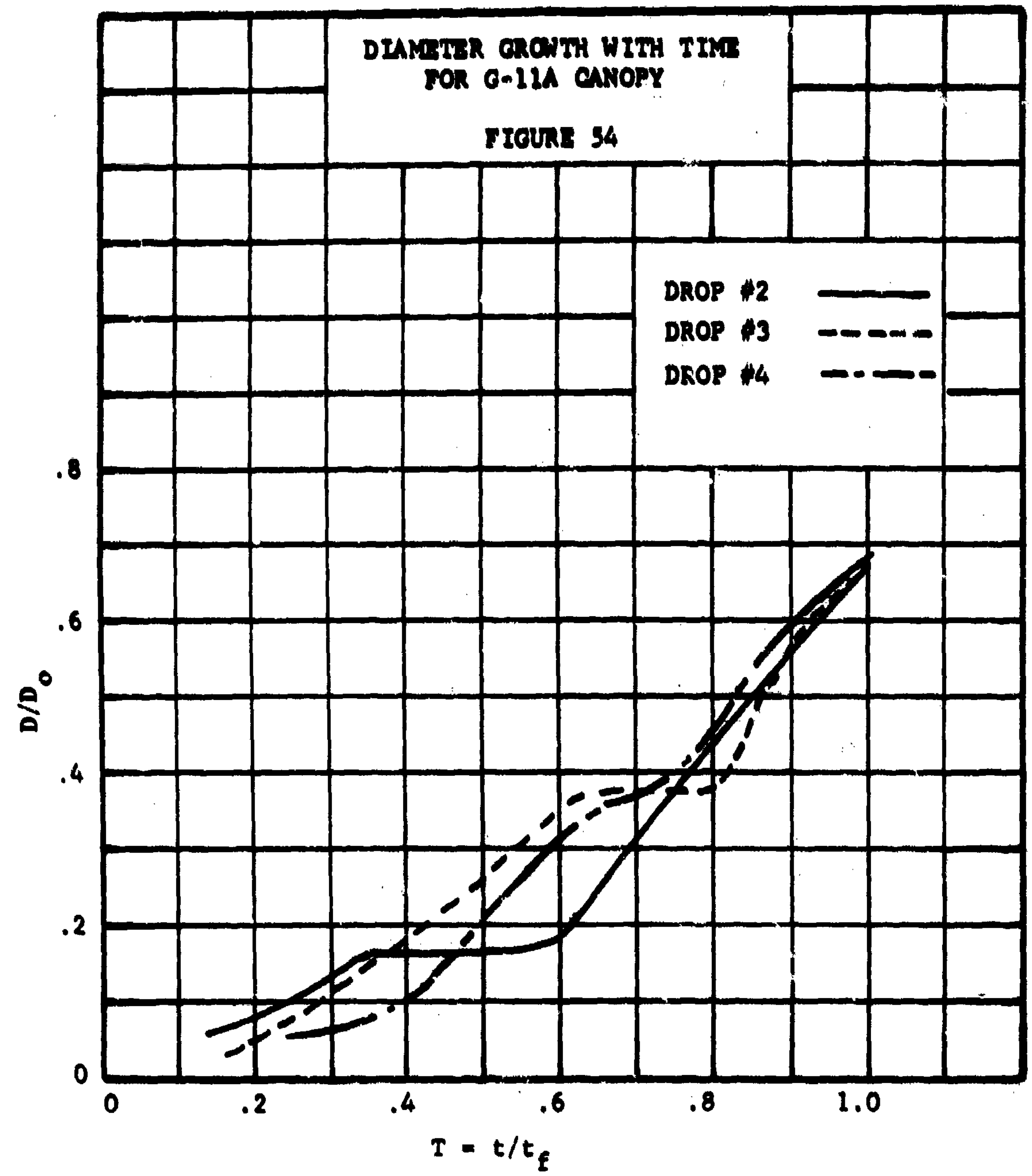
The tabular data describing the recovery parachute inflation has been defined. There exists two basic theoretical methods for describing the recovery parachute characteristics: (1) the technique discussed in Reference (1), considering the canopy diameter growth to be linear with time from a geometrically described shape, and (2) the empirical theory developed by Berndt and DeWeese (9) which describes the canopy growth based on reading test films of a [illegible] canopy. The analysis of Berndt and DeWeese is much more rigorous than that of Reference (1), and based on computer studies appears to give more acceptable results. To determine the acceptability of the method developed by Berndt and DeWeese, the canopy shapes at each of times were computed and drawn based on geometrically developed equations. Appendix B of the May 1968 Status Report (6) presents a discussion of the filling time and [illegible] Berndt and DeWeese and illustrates the canopy shapes generated. These canopy shapes were compared with film data obtained on AAI [illegible] tests, however, difficulties in scaling the 16mm film prevented an accurate comparison from being made.

The tabular values necessary for the AAI two-dimensional analog program for describing the recovery parachute performance are defined as a function of a non-dimensional time ratio t/t_f, where t_f is the time to inflate the canopy from the beginning of canopy deployment. The required data as a function of this time ratio are canopy diameter, parachute drag area, apparent and included mass.

Canopy Diameter

The canopy diameter growth with time is defined in terms of a non-dimensional diameter ratio. The diameter ratio is defined for computer usage as the canopy skirt diameter at any time to the constructed diameter. Development of this relationship between canopy diameter and time is difficult to determine due to the non-uniform and extremely unsymmetrical shape of the large G-11A canopy during inflation. Determination of the canopy size by viewing films showing a profile view of the inflating canopy are in many instances misleading due to the flattening of the canopy caused by the flow around the aircraft [illegible] deployment. Assuming a circular canopy and measuring the canopy skirt size from 16mm film, taken by AAI, of single parachute tests (numbers 2, 3 and 4) resulted in an incorrect diameter growth with time. Figure 54 illustrates the results of this film reading and reveals the poor definition of the reefed size of the canopy. The reefed diameter used in each test was approximately 8 feet (a reefing line length of 25 feet was used), but the film reading results show varying sizes of reefed diameters for tests 2, 3 and 4. The results of tests [illegible] sooner because the canopy deployment occurred much sooner than in test [illegible] reason for this was the improper operation of the first snatch [illegible] used early in the Phase I tests.

Viewing of films taken from the aircraft cargo compartment [illegible] the flattening and unsymmetrical inflation of the canopy. The shape of the canopy during deployment is illustrated in the following sketch.

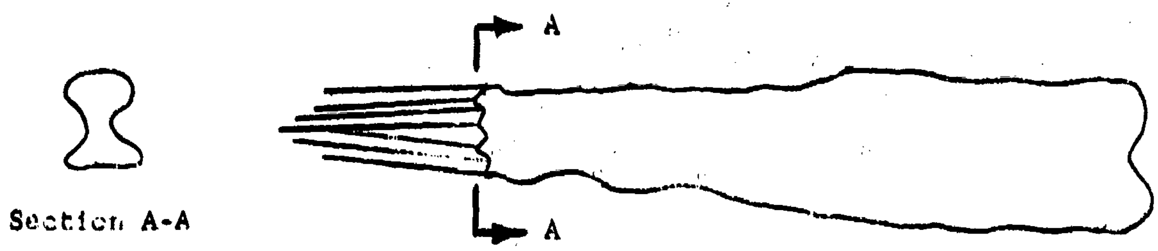


NOTE: THIS DATA WAS OBTAINED FROM READING 16MM FILMS TAKEN BY AAI.

D = SKIRT DIAMETER

D_o = CONSTRUCTED DIAMETER

t_f = CANOPY INFLATION TIME



SIDE VIEW OF PARACHUTE

One method to resolve this film reading problem is to determine the canopy area at the skirt and generate area versus time data. However, this method was not tried during the limited flight test program.

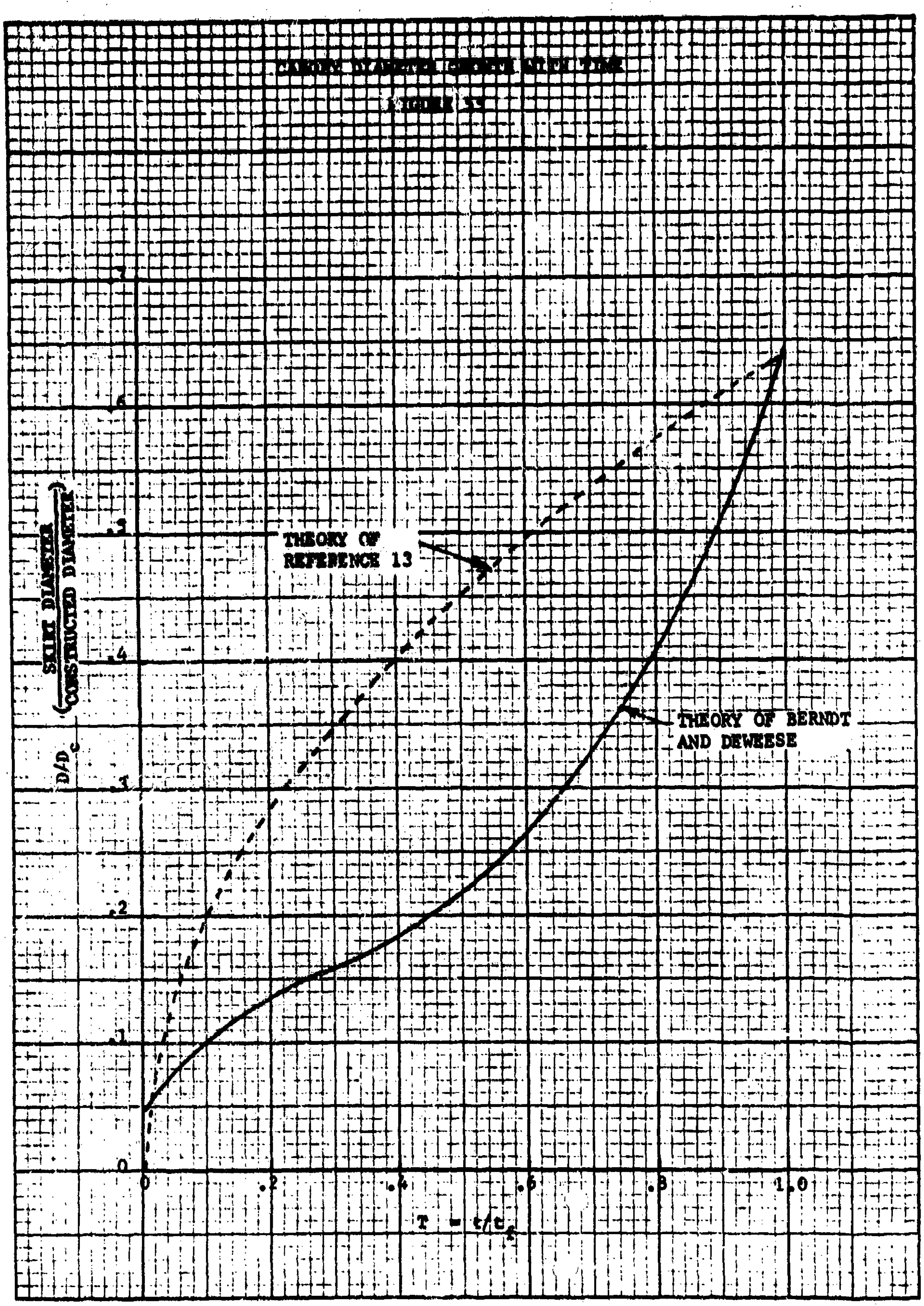
The curves of Figure 55 present the diameter growth with time for the theory of Reference (13) and Berndt and DeWeese (9) which depicts the variation of the two theoretical approaches.

Canopy Drag Area

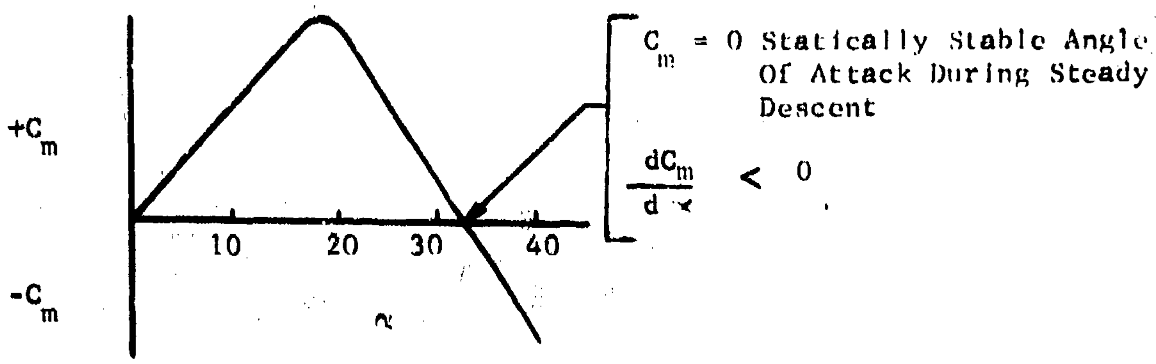
The canopy drag area is defined as the drag coefficient times the area which develops this drag coefficient. For many aerodynamic shapes, determination of this parameter is reasonably simple. A model can be inserted in a wind tunnel and the force recorded or velocity decay data can be used to compute the drag coefficient. However, canopy drag differs from solid body drag because of the problems associated with scale factors; therefore, no satisfactory experimental method has been developed to date to accurately predict the canopy drag. Drag data, therefore, is normally generated from either flight test or captive type test results.

A wide variation in the aerodynamic drag has been measured for textile canopies, especially on solid cloth canopies such as the flat circular. This drag variation is due to the instability of this type of canopy. Wind tunnel tests reveal that only one statically stable* position exists for a flat circular canopy during steady descent.

*Static stability requires $dC_m/d\alpha$ (rate of change of the pitch moment coefficient with angle of attack) to be negative.



THEORY OF
REFERENCE 13
THEORY OF BERNDT
AND DEWEESE
D/D_c (SKIRT DIAMETER / CONSTRUCTED DIAMETER)
.7
.6
.5
.4
.3
.2
.1
0
0
.2
.4
.6
.8
1.0
$T = t/t_f$



The drag area rate of growth for an inflating flat circular canopy is presented in Figure 4-85 of Reference 13 and re-plotted as Figure 56 of this report. However, these data do not agree with that obtained by Berndt. The computer results of each theory are compared and discussed in para 3 of this section. The data developed by Berndt and DeWeese were used to obtain good computer predictions of the actual test results.

Apparent and Included Mass Terms

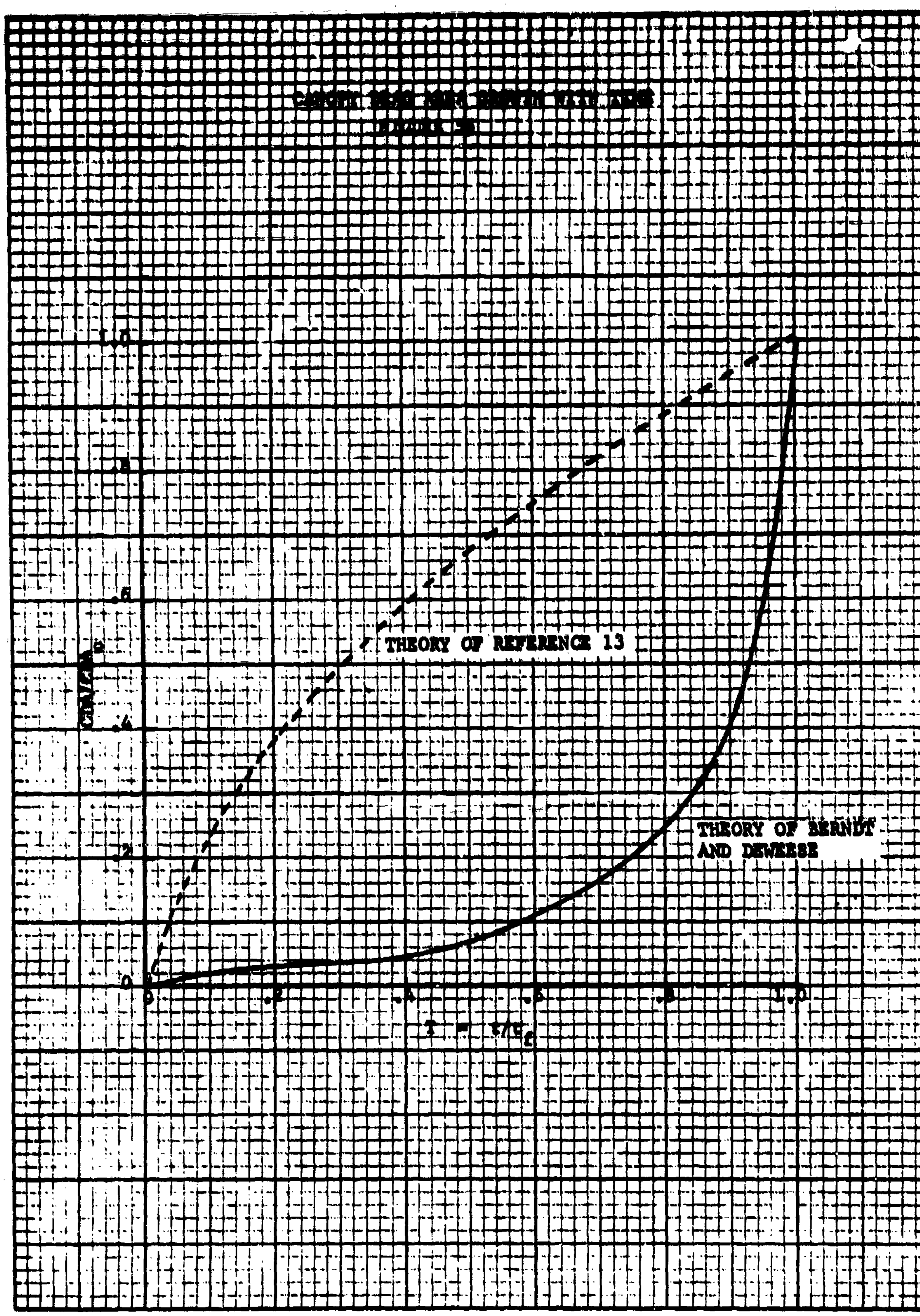
The apparent and included mass terms were discussed in the January 1968 Status Report (14) and agreement between theoretical and experimental values was illustrated for a fully inflated canopy. However, the theory differs in the prediction of these mass terms for the inflating canopy. Figures 57 through 60 illustrates the results of the present theories. Reference 13 has developed the following equations for defining the apparent and included mass.

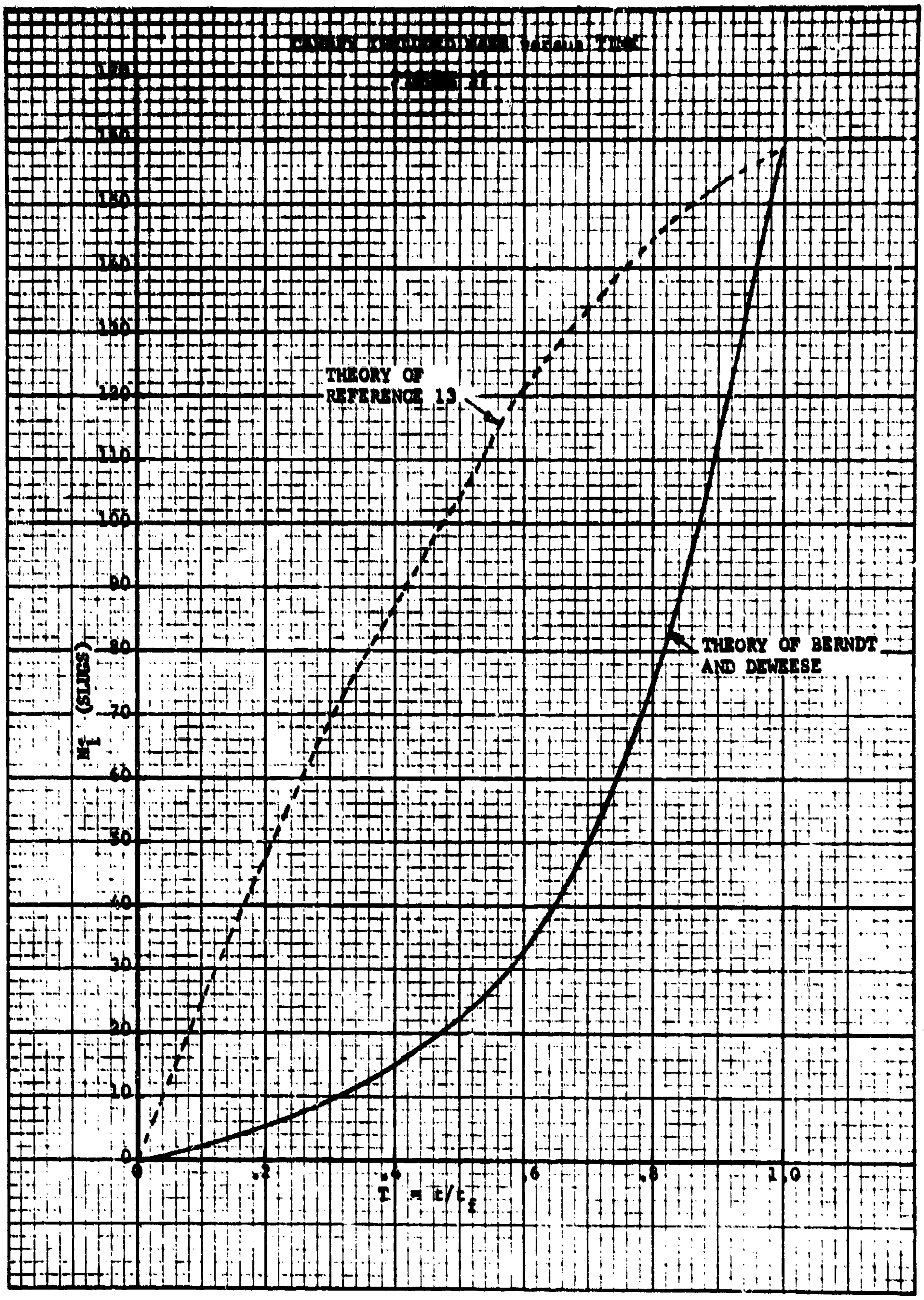
$$m_i = 99.1 \times 10^{-6}\, \sigma\, D_o^3 \left[1.71 - (T - 1.31)^2\right]$$

$$\dot{m}_i = \frac{198.2 \times 10^{-6}}{t_f}\, \sigma\, D_o^3 \left[T - 1.31\right]$$

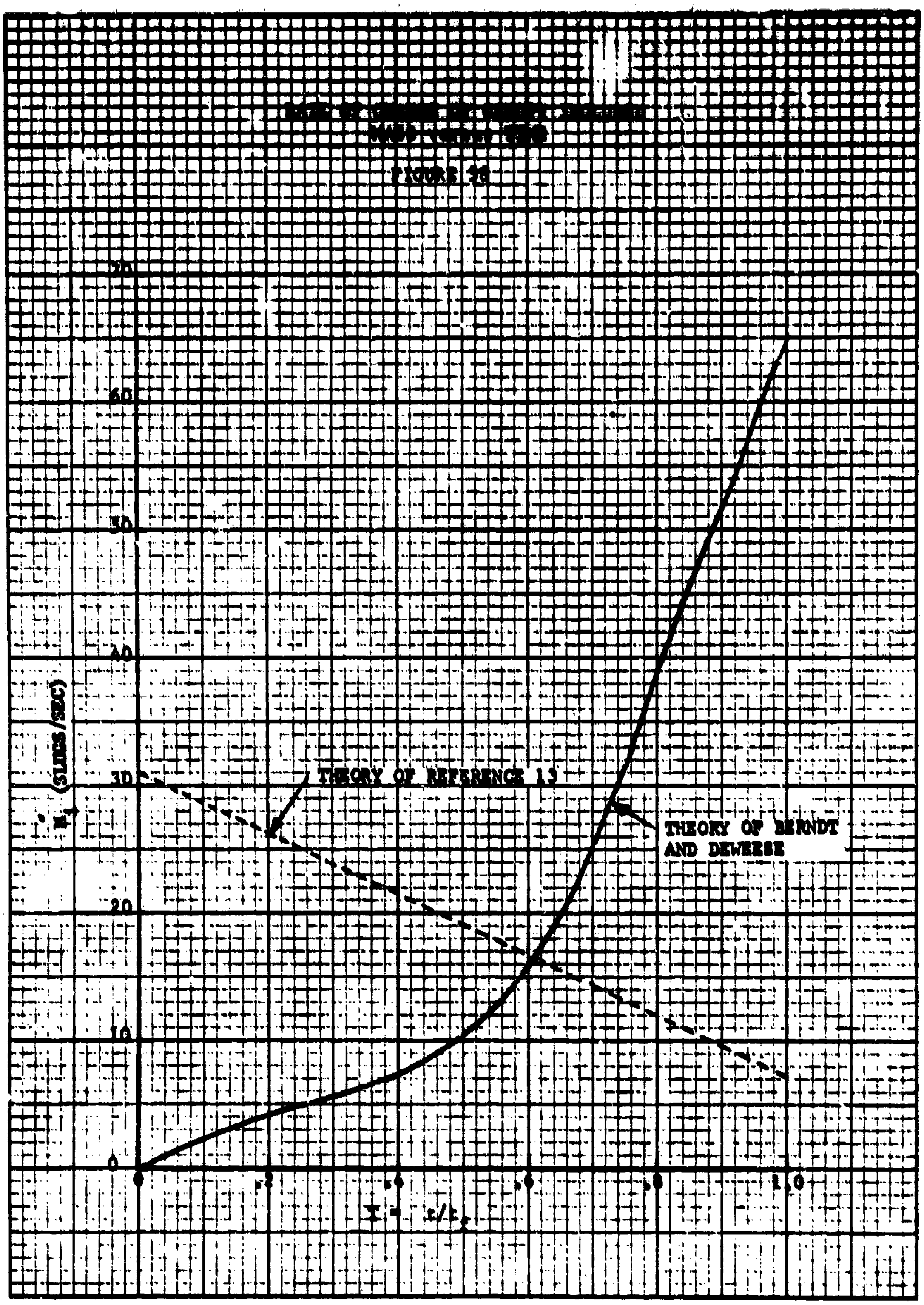
$$m_a = 60.075 \times 10^{-6}\, \sigma\, D_o^3\, T^{5/2}$$

$$\dot{m}_a = \frac{150.2 \times 10^{-6}}{t_f}\, \sigma\, D_o^3\, T^{3/2}$$

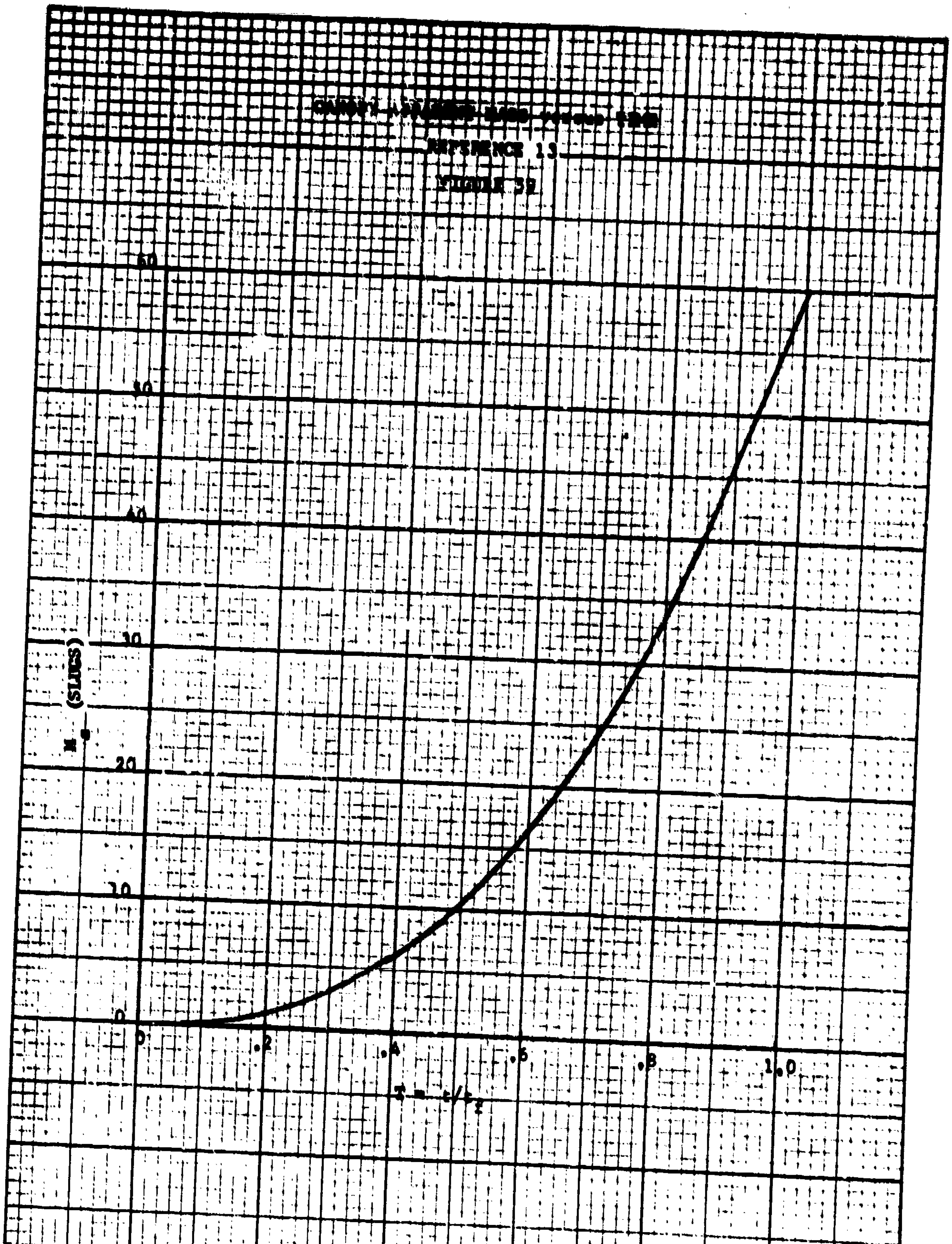

THEORY OF REFERENCE 13
THEORY OF BERNDT
AND DEWEESE
1.0
.8
.6
.4
.2
0
0
.2
.4
.6
.8
1.0

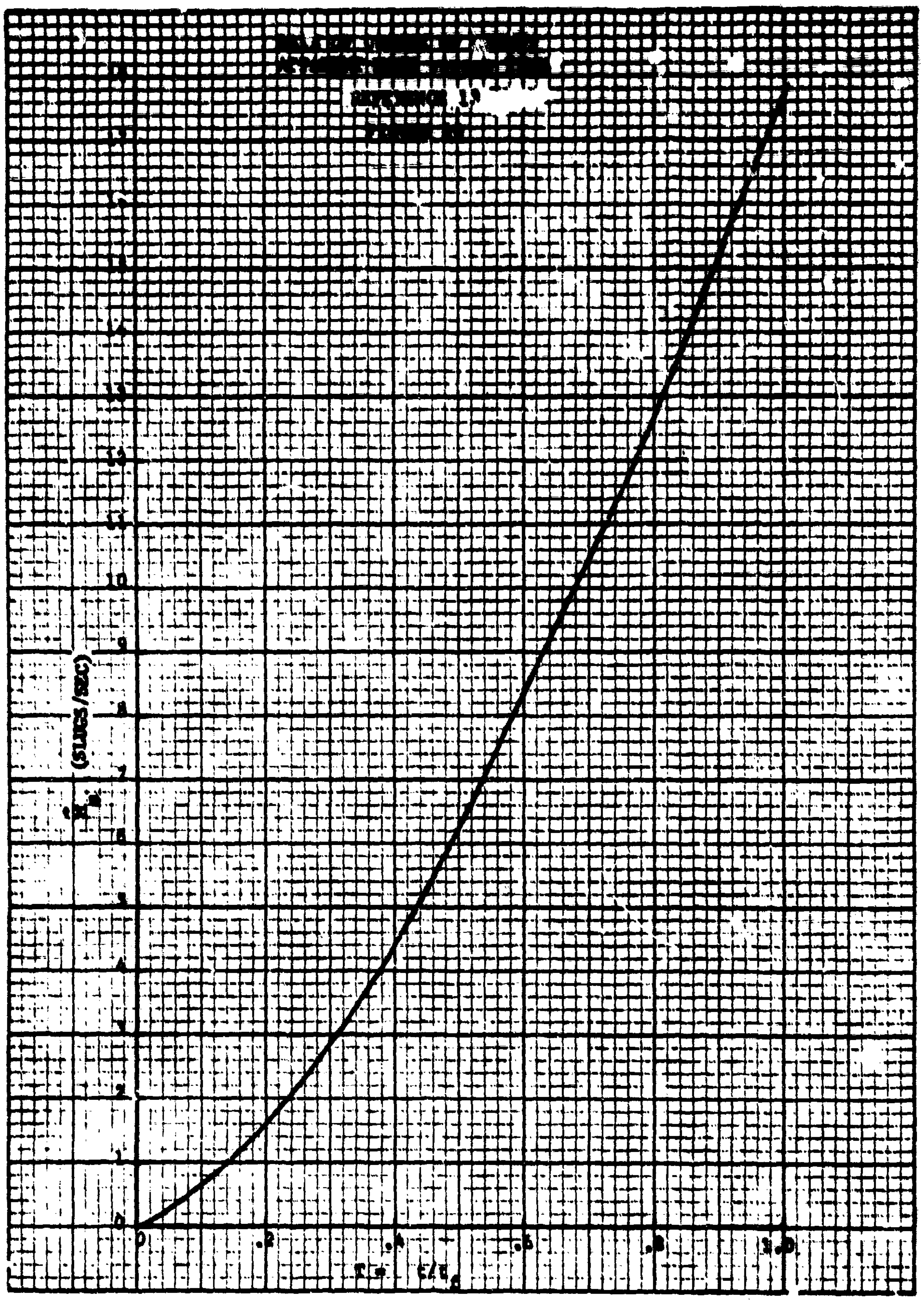


versus TIME
THEORY OF REFERENCE 13
THEORY OF BERNDT AND DEWEESE
M'I (SLUGS)
T = t/tf
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
0
.2
.4
.6
.8
1.0



70
60
50
40
30
20
10
0
(SLUGS/SEC)
THEORY OF REFERENCE 13
THEORY OF BERNDT AND DEWEESE
.2
.4
.6
.8
1.0


REFERENCE 13
FIGURE 39
60
50
40
30
20
10
0
(SLUGS)
0
.2
.4
.6
.8
1.0
t = t/t_f


(SLUGS/SEC)
0
.2
.4
.6
.8
1.0

Where:

m_i	= included canopy mass	slugs
$\dot{m}_i$	= rate of change of included mass	slugs/sec
m_a	= apparent canopy mass	slugs
$\dot{m}_a$	= rate of change of apparent mass	slugs/sec
T	= dimensionless time ratio - t/t_f	----
t_f	= time to full inflation	sec
D_o	= constructed canopy diameter	ft
σ	= air density ratio - ρ/ρ_o	----

The theory of Berndt and DeWeese (9) neglects any apparent mass and uses the geometrical equations defining the canopy shape to determine the included air mass. (The volume is computed for the geometrical shape and multiplied by the air density to determine the included mass). The resulting equations are:

for

$T < .3$

$$m_i = \rho\{.2244\ D_p^3 + 1.3348\ D_o\ T[(\frac{d_x}{2})^2 + (\frac{d_x}{2})(\frac{d_{i_{eff}}}{2}) + (\frac{d_{i_{eff}}}{2})^2]\}$$

for

$T > .3$

$$m_i = \rho\{\frac{\pi}{3}\ h[(\frac{d_x}{2})^2 + (\frac{d_x}{2})(\frac{d_i}{2}) + (\frac{d_i}{2})^2] + \pi\ a^2(\frac{2}{3}\ b + c - \frac{c^3}{3b^2})\}$$

Where:

D_p	= canopy projected diameter	ft
d_x	= .9786 D_p (see Reference 9)	ft
$d_{i_{eff}}$	= effective skirt diameter	ft
d_i	= skirt diameter	ft
h	= canopy length	ft
ρ	= air density	slugs/ft^3

a, b, c are defined in (Reference 9 , see page 17)

Experimental determination of these mass terms using flight test results is difficult, since the inertia mass (mass considered accelerated or decelerated) of the canopy is increased thereby increasing the retardation (drag) force of the canopy. Writing the equation of motion of the canopy in general form illustrates this fact.

$$\frac{d}{dt}(mv) = F$$

$$m\dot{v} + \dot{m}v = T - D$$

Where:

$$m = m_i + m_a + m_c$$

$$\dot{m} = \dot{m}_i + \dot{m}_a$$

$$\therefore (m_i + m_a + m_c)\, a = T - D - (\dot{m}_i + \dot{m}_a)v$$

and defining terms:

T = line tension force

D = canopy drag force

m_i = included mass

m_a = apparent mass

m_c = canopy cloth mass

v = canopy velocity

a = canopy acceleration

The separation of each term of the equation was performed to predict the correct values for the apparent and included mass terms for specific flight tests, however, the results were not conclusive enough to determine the actual values of these mass terms. Computer studies have revealed that the equations and assumptions of Berndt and DeWeese result in the most acceptable performance prediction.

3. Comparison Of Experimental & Theoretical Results

The two-dimensional computer programs developed for use on the EXIARP program have shown compatibility between the experimental test results and the theoretical computer results. The theory used to predict the parachute inflation and drag was that developed by Berndt and DeWeese. However, Dr. Heinrich's work presented in Reference 13 was also investigated, and the results obtained with each of these theories compared.

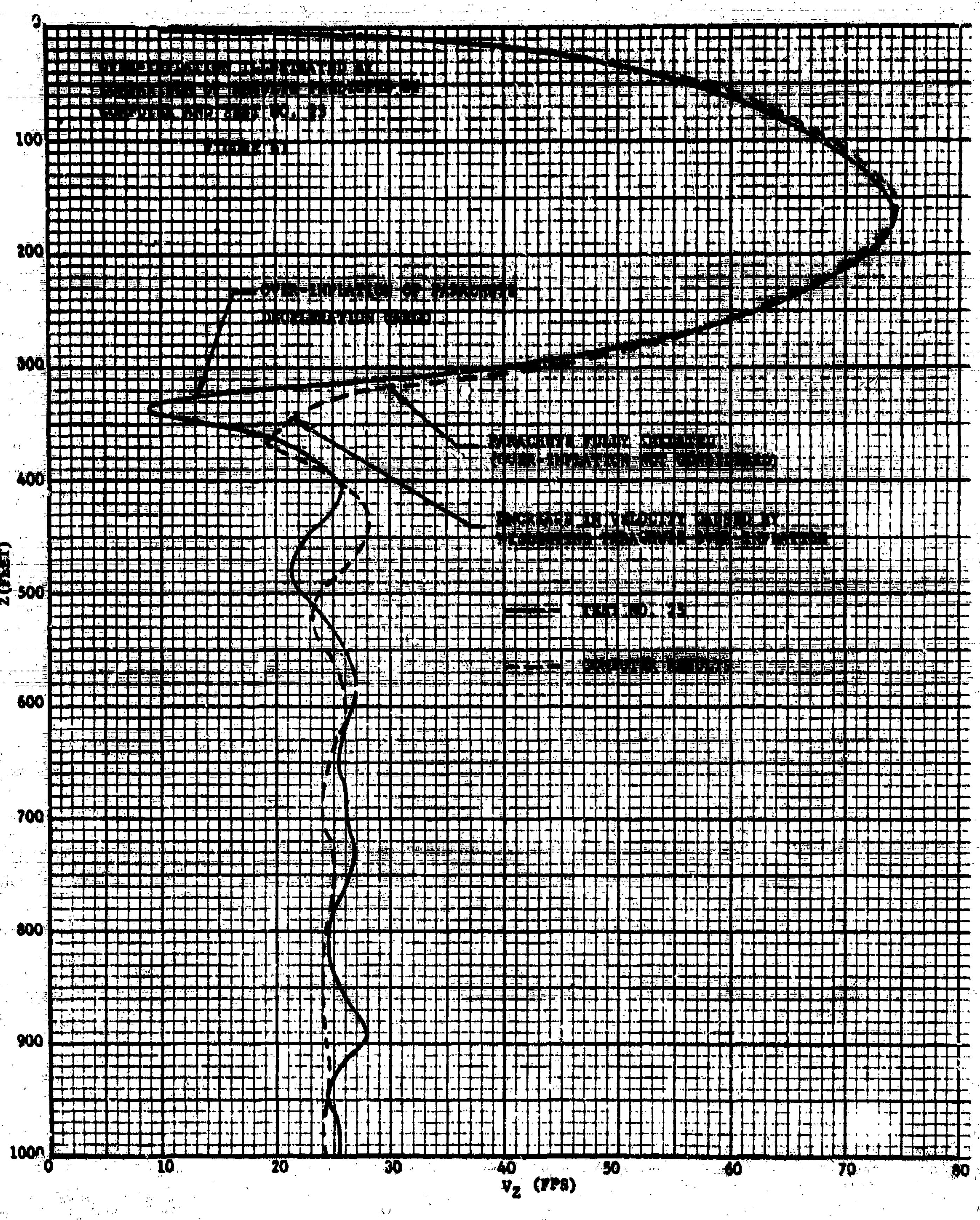
The computer program results were compared to the experimental test data by plotting the cargo trajectory, the altitude loss versus cargo vertical and horizontal velocity and the total line tension versus time. After studying several of these plots, the plot of altitude loss versus cargo vertical velocity appeared to best illustrate the compatibility of the experimental and theoretical results. Several general conclusions could be drawn from the comparisons which were made about the prediction capability of the computer program and the theory used.

a. Since the parachute cargo system was influenced by the wind, the accurate prediction of the impact point could not be obtained. This area is one which will always limit the usefulness of the computer program because the actual wind velocity must be known at the time of the airdrop if trajectory accuracy is desired.

b. The oscillatory motion of the descending parachute cargo system requires knowledge of the aerodynamic damping coefficients which has not been considered in this study. Therefore, the true descent velocity profile is not predicted accurately. The oscillations of the cargo vertical velocity as a function of altitude are not correctly predicted, but general agreement is good with only the extreme velocity values differing in value.

c. The theoretical and experimental curves for altitude loss versus cargo vertical velocity were out of phase in many cases because the parachute inflation theory of Berndt and DeWeese does not predict the over-inflation of the parachute canopy. Investigation of the vertical velocity curves reveals that the deceleration of the cargo decreases rapidly after full inflation of the canopy. This is illustrated in Figure 61.

d. The line tension versus time curves do not realistically predict the opening shock force when the parachute is reefed, or the opening shock force after force transfer occurs. The proper skirt diameter and canopy drag versus time is not available (and attempts to compute this data proved unsuccessful) for reefed parachutes. The force transfer



Z (FEET)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
V_Z (FPS)

phase was eliminated from consideration after preliminary analytical investigation showed the complexity of predicting performance in this area.

Several tests have been analyzed in detail and the compatibility of the computer and test results are illustrated in a series of figures. Test numbers 2, 3 and 4 have been studied in-depth and several other tests were analyzed to confirm the findings of these investigations. Also, considered were three separate clustered parachute-cargo tests including the 25,000 pound cargo test using five G-11A parachutes.

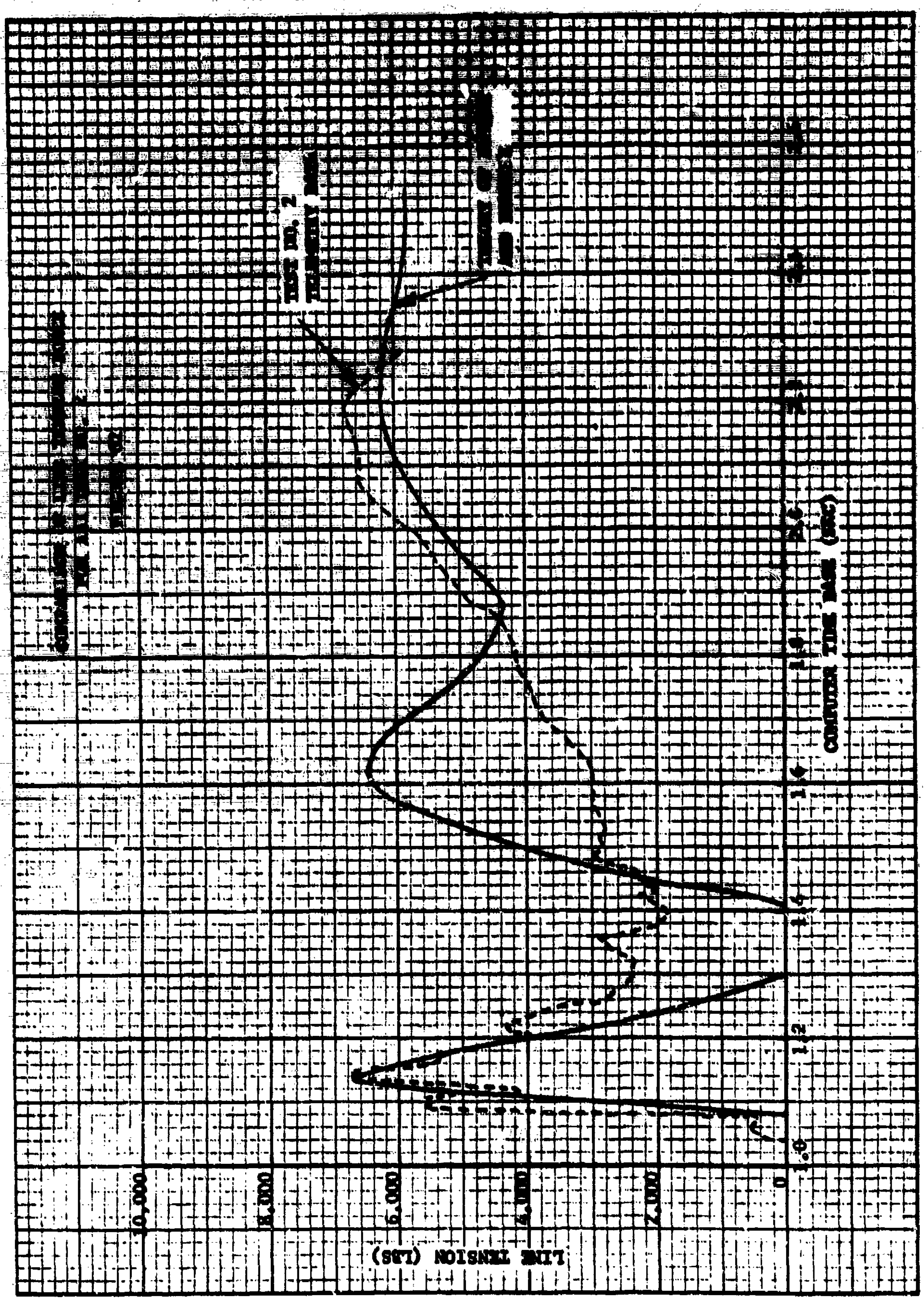
The theories of Reference 13 and Berndt and DeWeese (9) were used to generate the input data. The computer results revealed the inaccuracies of the theory developed in Reference 13. Using this theory the program generated a snatch force of 21,000 pounds compared to the 6850 pound snatch force actually developed on test number 2. Further studies revealed that the apparent and included mass terms were far too large to generate acceptable line tension forces. Therefore, the computer studies were made using the theory of Berndt and DeWeese (9).

The theory of Berndt and DeWeese has resulted in reasonable agreement between test and computer results, except that the line tension versus time curves generated from the computer program do not agree in shape. However, the magnitudes of the snatch and opening shock forces are reasonably correct. The following table compares force levels for test numbers 2 and 3. Test number 2 does not include the AAI snatch force attenuator, whereas test number 3 does consider a preliminary snatch attenuator, a single line configuration.

Test No.	Snatch Force		Opening Shock	
	Test	Computer	Test	Computer
2	6850	6930	6150	7530
3	8000	7890	9000	5800

These computer runs reveal that the apparent and included mass terms are small during the initial inflation period, and that the drag force is only a small percentage of the snatch force compared to the inertia force. Further improvements to the canopy growth equations must be made to account for the variation in the line tension versus time curve which is generated from the computer program. Figures 62 and 63 compare experimental and theoretical results for tests number 2 and 3.

Plots of altitude versus cargo vertical and total horizontal velocity were made to compare test and theoretical results. The vertical


TEST NO. 2
LINE TENSION (LBS)
10,000
8,000
6,000
4,000
2,000
0
1.0
1.2
1.4
1.6
1.8
COMPUTER TIME BASE (SEC)

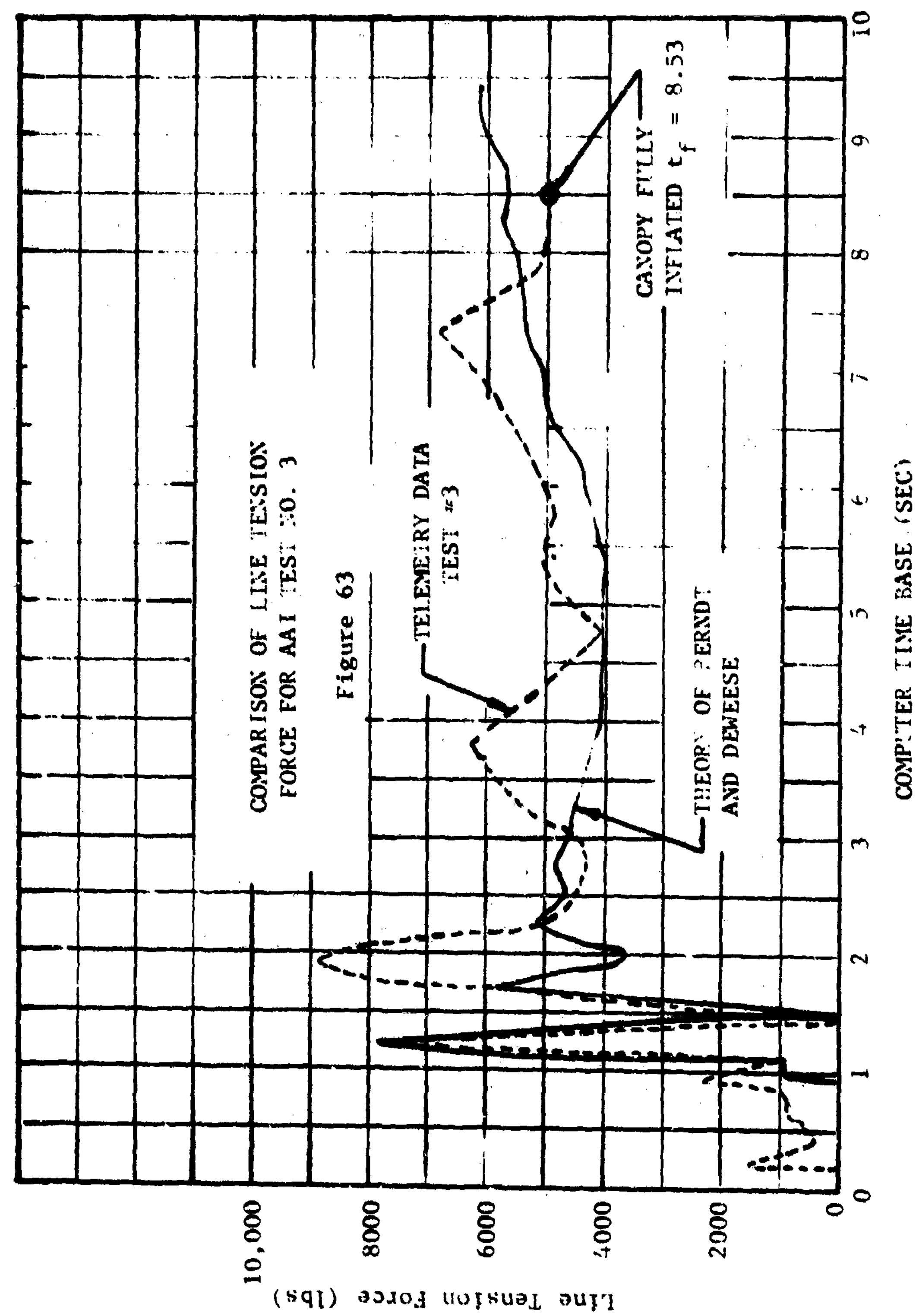


Figure 63

COMPARISON OF LINE TENSION FORCE FOR AAI TEST NO. 3

velocity curves of Figure 64 illustrate that the equilibrium velocity predicted by the computer program is high. This is attributed to either; (1) the fully inflated drag area predicted by Berndt and DeWeese is not large enough; or (2) the apparent mass at full inflation of the canopy is not zero as was initially assumed. The curve of Figure 65 reveals that more compatible results are predicted when the fully inflated canopy drag is increased.

The total cargo horizontal velocity and the descent trajectory of the cargo are the most difficult results to predict. The reason for this difficulty is the effect of the wind on the descent trajectory of the cargo parachute system and the extreme variation in the wind velocity and direction for altitudes below 2000 feet. Since the computer program is two dimensional, the effect of any wind velocity on the descent trajectory is not considered, except for the increased airspeed of the aircraft relative to the ground. This increased aircraft velocity is most important in predicting the snatch force that the cargo experiences during extraction. Plots of the test results for cargo motion in the horizontal X-Y plane, the vertical Z-X and Z-Y planes* shows the irregular drift of the cargo during descent caused by the wind variation with altitude and the instability of the descending parachute. Figures 66 through 69 compare experimental results for the cargo total horizontal velocity and trajectory with actual test results, and illustrate that the theory of Berndt and DeWeese results in a more correct prediction of the test results than the theory of Reference 13.

Possible methods of reducing the effect of the wind on a descending parachute system were studied by Talley (15). The parachute flight path is graphically illustrated to show the influence of drop altitude, rate of descent and the variation of the wind structure with time in Talley's report "The Effect of Wind on Parachute Delivery Accuracy". The results of Talley's study showed that the induced wind error due to drift was reduced by a factor of two when the descent altitude was decreased from 1200 feet to 600 feet. Also, increasing the rate of descent from 18 fps to 24 fps resulted in a 25% reduction in induced wind error. Hence, the most desirable airdrop system from a standpoint of wind drift is one which is dropped from the lowest possible altitude with the largest possible descent velocity.

The criteria for an acceptable horizontal impact velocity was initially set at 10 fps plus a maximum wind velocity of 15 knots or 35.5 fps as the maximum velocity. This criteria is questionable, since no study has been performed to determine the horizontal velocity at which tumbling occurs. The vertical velocity, the angle of the platform, and the angle and velocity of the parachute relative to the cargo are some of the parameters affecting the maximum horizontal velocity of the cargo at which tumbling will not occur. Since most test drops are conducted at 2000 feet, large horizontal velocities

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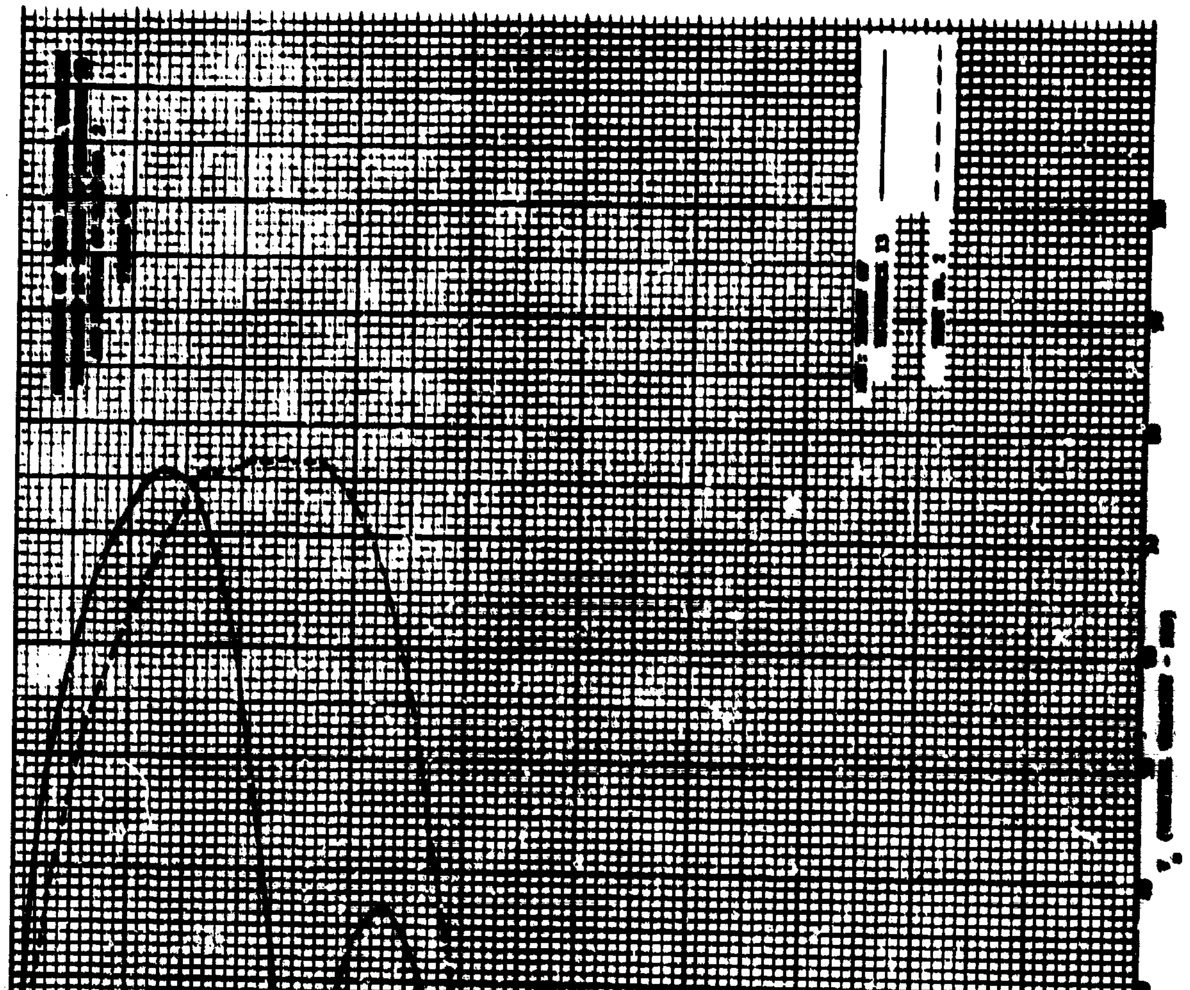
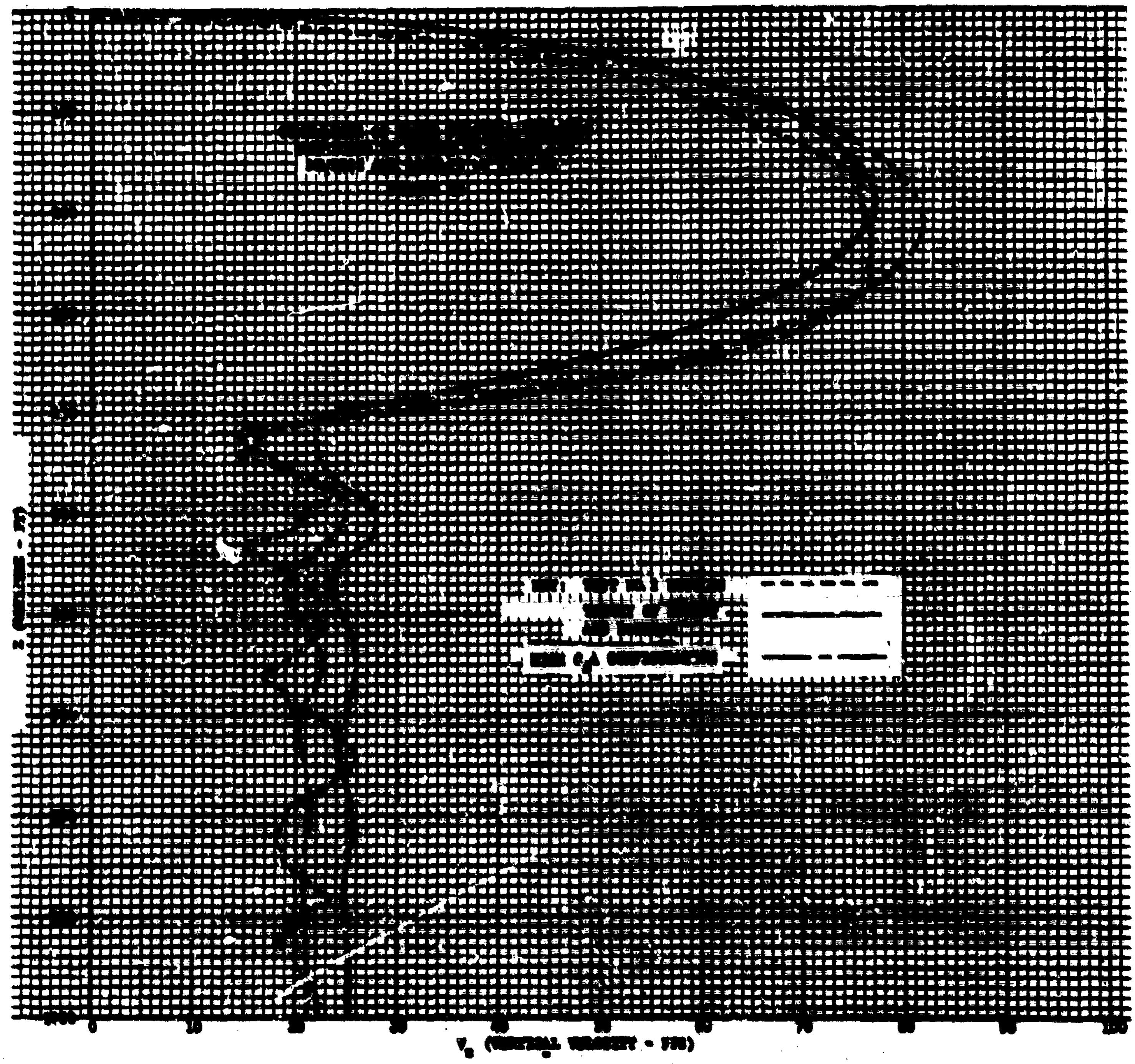
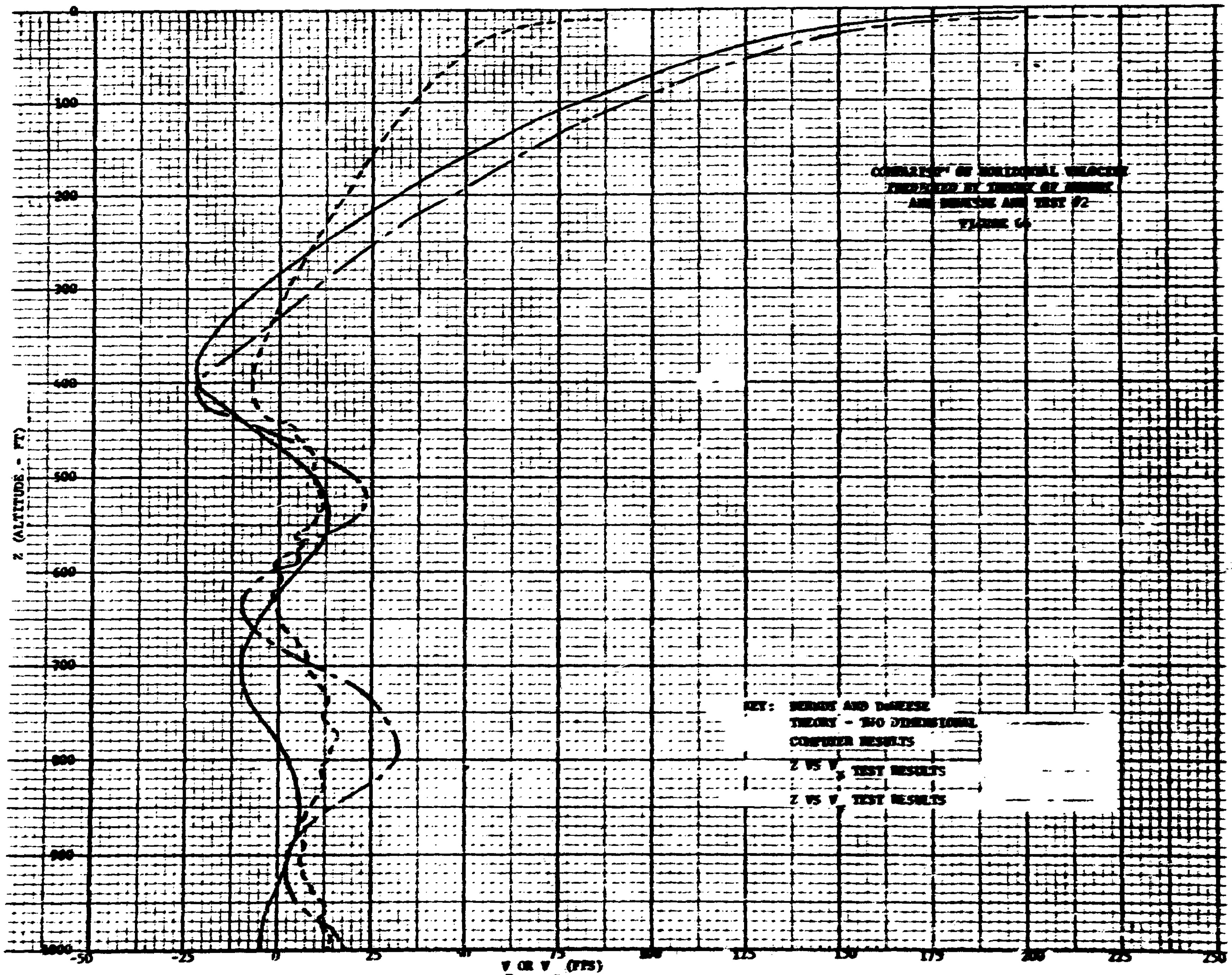
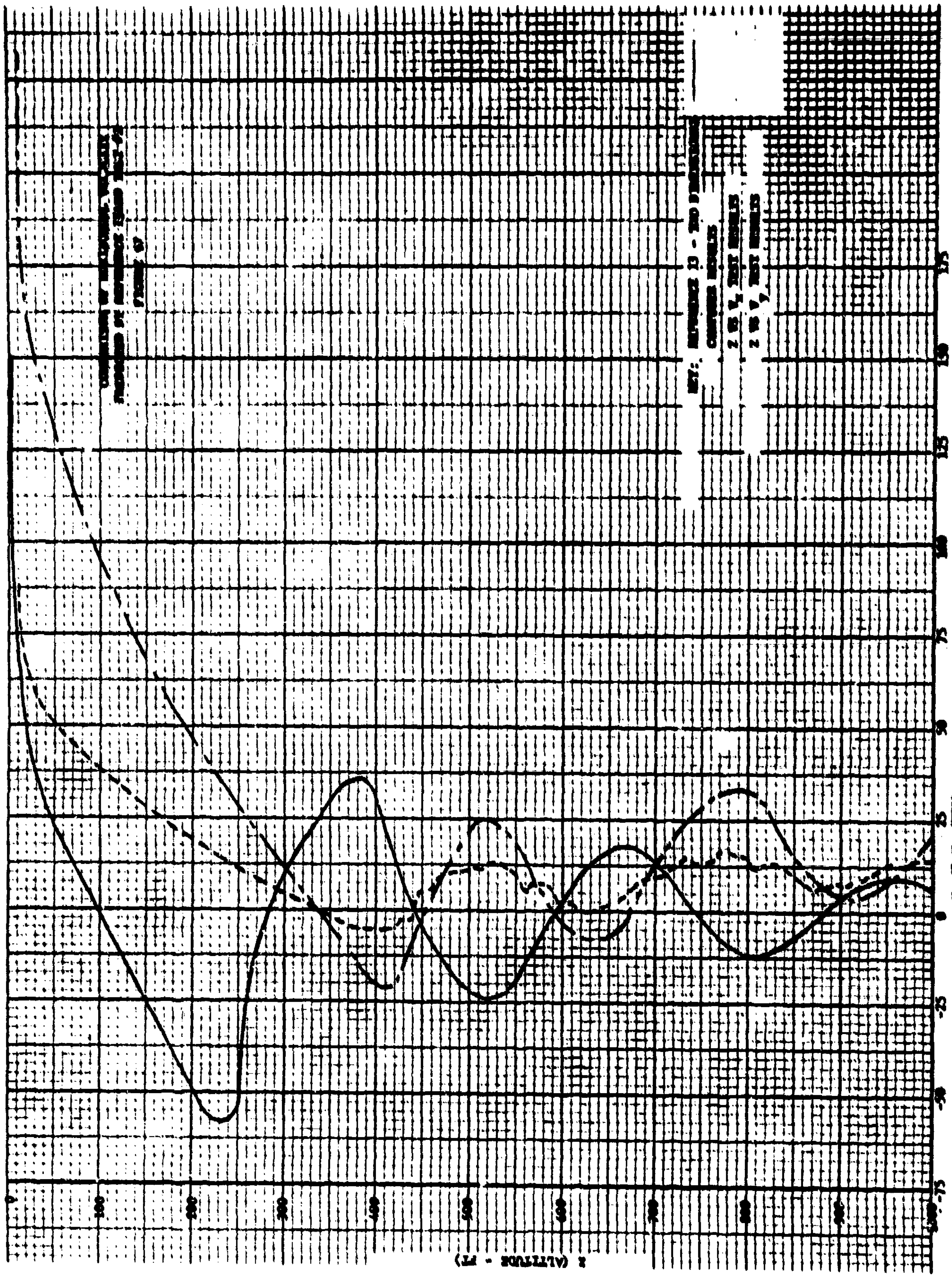
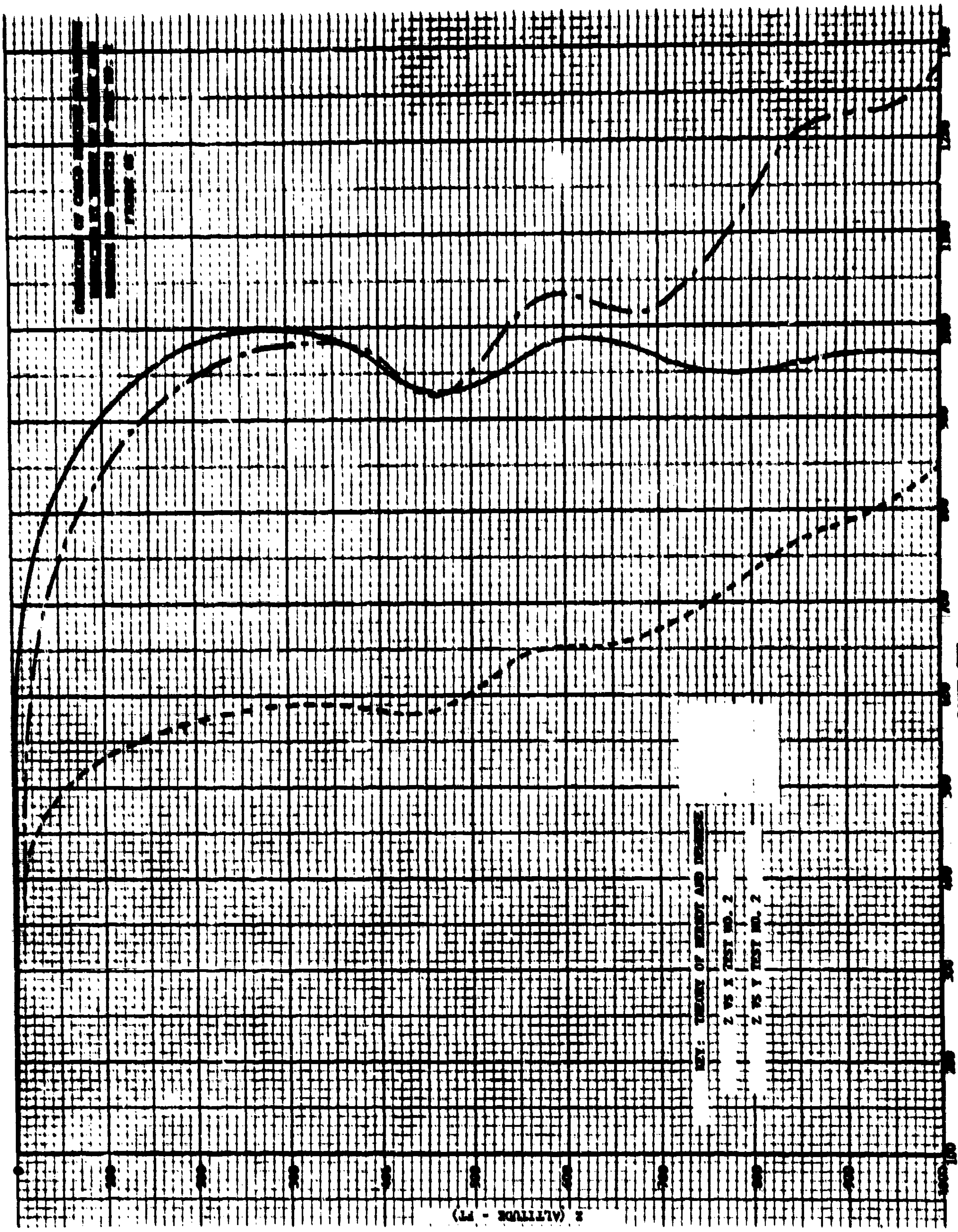
* The X, Y, Z coordinate system at the test site in which the DZ is located is used.

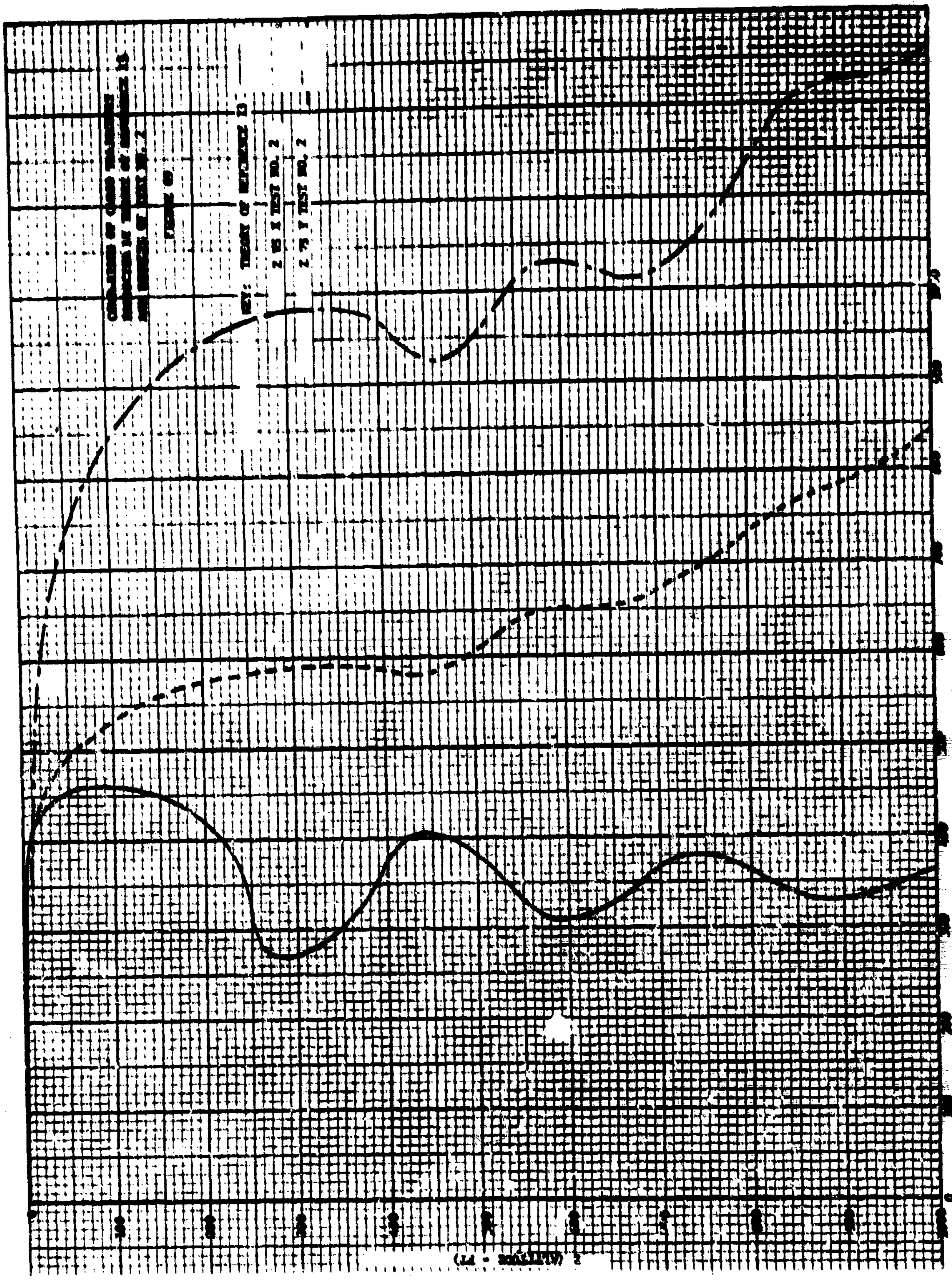





KEY:
THEORY - TWO DIMENSIONAL
COMPUTER RESULTS
Z VS V TEST RESULTS
Z VS V TEST RESULTS
Z (ALTITUDE - FT)
0
100
200
300
400
500
600
700
800
900
1000
-50
-25
0
25
75
100
125
150
175
200
225
250




Z VS X TEST NO. 2
Z VS Y TEST NO. 2
RANGE (FT)
Z (ALTITUDE - FT)


KEY: THEORY OF REFERENCE 13
Z VS X TEST NO. 2
Z VS Y TEST NO. 2

of the cargo and/or high angles of impact do not exist, and hence, no tumbling of the load results. However, at lower descent altitude this problem is more pronounced and must be investigated in detail since no exact criteria other than "the load did not overturn" exist for determining acceptable horizontal velocities.

The compatibility of the computer results with actual test results is illustrated for three and five G-11A parachute clusters in Figure 70 and 71 . In Figure 70 the sudden change in the velocity occurs at the time of full inflation clearly illustrating the need to predict the parachute over-inflation. However, the results of both figures are most encouraging, and reveal that the performance of different parachute clusters can be predicted with reasonable accuracy.

The results in this section have been presented to indicate the degree of compatibility which presently exists between the theoretical and experimental results. The computer program and the accompanying input data defined in the preceeding sections has been used to predict the results for the detailed system performance study of part 4 .

PAGES 132 133

ARE

MISSING

IN

ORIGINAL

DOCUMENT

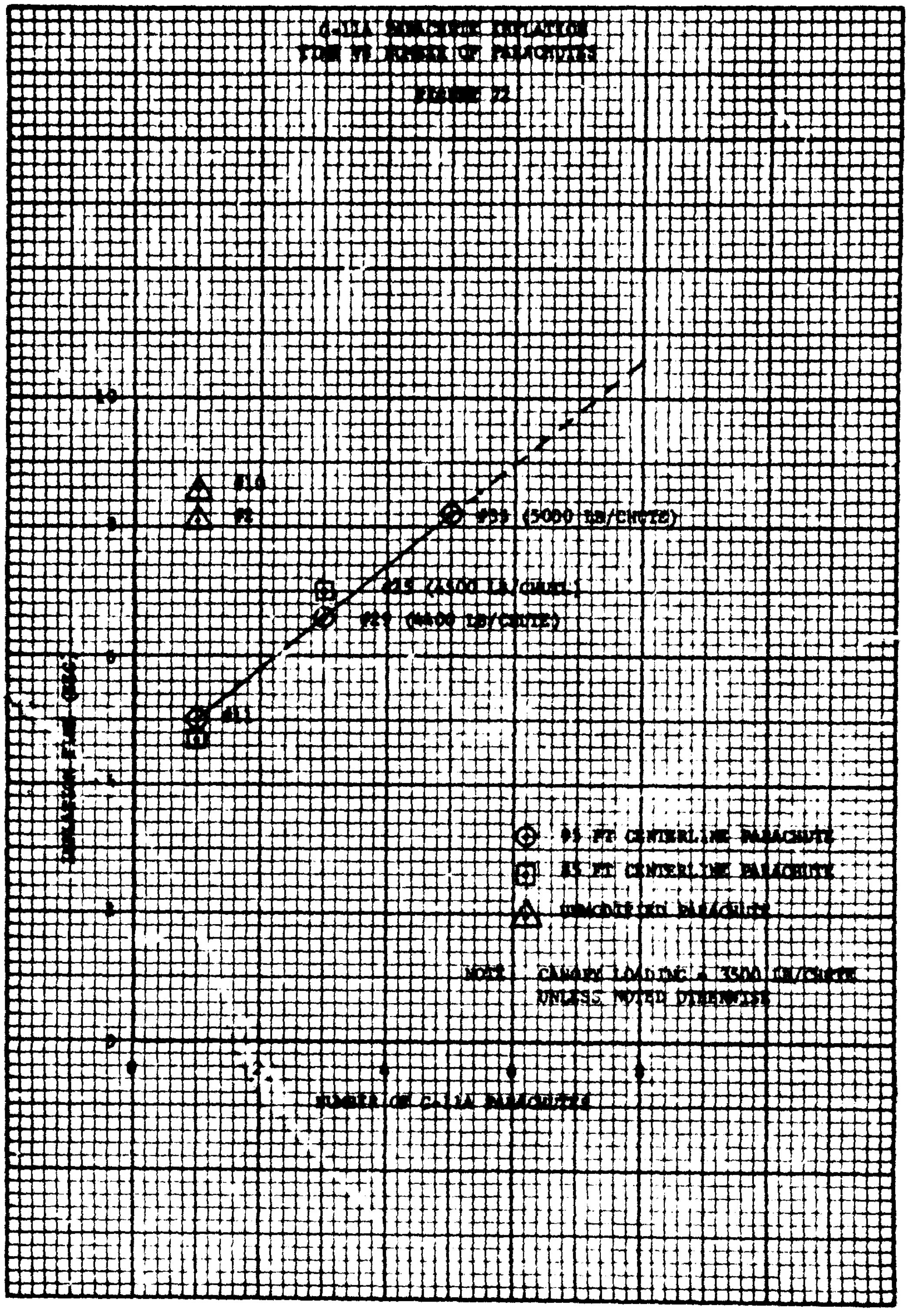
4. System Performance Envelope Study

a. Background

The objectives of the system performance envelope study was to analyze the trajectory and body motion of typical cargoes to determine the effects of the system operation. Therefore, numerous computer programs were developed in an attempt to accurately predict the performance of the EXIARP system. The acceptability of the computer program results was illustrated in the preceding part of this section. However, several computer input parameters values were determined empirically to arrive at acceptable theoretical solutions. These parameters were the canopy inflation time and the parachute drag area. For the single parachute airdrops the inflation time obtained from reading the 16mm films resulted in good correlation of the experimental and theoretical results. Also, by determining the average vertical rate of descent from investigating the cinetheodolite data, the parachute drag area for the steady state descent segment of the trajectory was computed by equating the aerodynamic drag to the system weight.

The determination of the inflation time of G-11A parachutes in cluster configuration was much more complex. The use of motion pictures to obtain inflation times was impossible because of the difficulty in distinguishing the individual canopy skirts in the pictures. This is illustrated by the inflation times read by the film readers at El Centro for the test requiring five G-11A parachutes. The average time read was 9.05 seconds but the range of times was 4.76 to 15.2 seconds. Hence, another method was developed to determine the inflation time of clustered parachute configuration. Using the proper computer program to analyze the parachute cluster and cargo performance, the inflation time was varied until the computer results matched those of the flight tests. Care was taken to use the correct initial conditions for each flight test analyzed in this manner with special consideration given to the line length and total system weight parameters. This trial-and-error solution for determining the inflation time worked very well for the flight tests which were successful.

To predict the system performance over the entire cargo weight range, test data was needed for the final EXIARP system selected for each individual parachute configuration. Unfortunately, this data was not obtained for several parachute configurations because; (1) the test program was terminated prior to running flight tests using more than five parachutes; and (2) the final system components were modified as a result of the cluster parachute tests which were conducted. As a result of these occurrences only three tests could be used to empirically compute the canopy inflation times. These tests used a 95 foot centerline and the inflation time versus number of parachutes is plotted in Figure 72. Extrapolation of the data beyond five parachutes is questionable, however, this method is the best which presently exists and consequently was used. The resulting curve is a straight line defined by the following equation.


#33 (5000 LB/CHUTE)
#11
NOTE: CANOPY LOADING = 3500 LB/CHUTE
UNLESS NOTED OTHERWISE
NUMBER OF C-11A PARACHUTES

$$t_f = 4.2 + 0.3 N$$

Where:

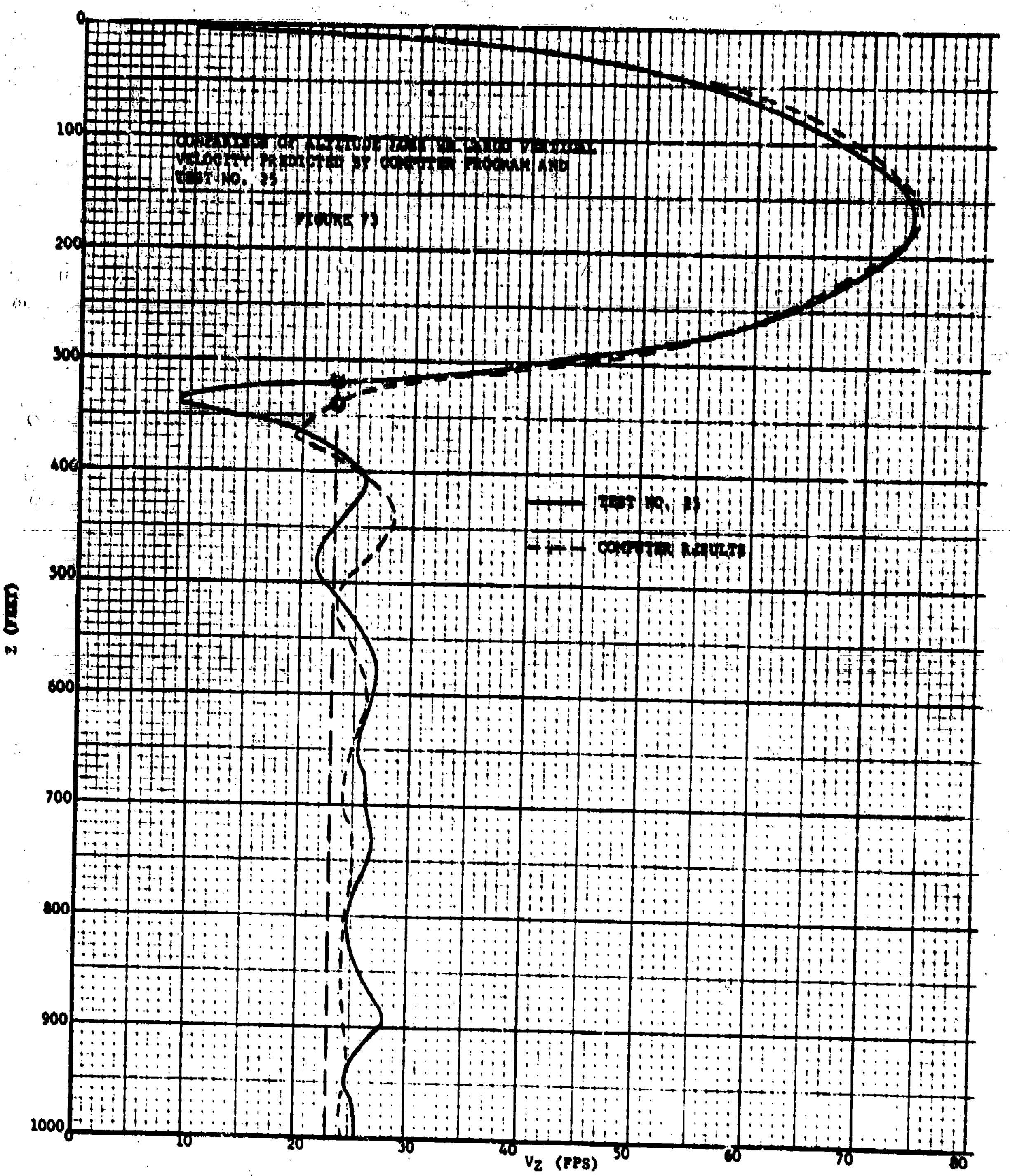
t_f = canopy inflation time as defined by Berndt and DeWeese (time interval from skirt exiting the deployment bag to the first development of the steady-state canopy diameter).

N = number of G-11A parachutes.

Computation of the drag area of the various parachute clusters tested was complicated by the fact that the vertical rate of descent of the cargo did not reach a steady state value until the last 100 feet of descent in the 2000 foot airdrops when using a 95 foot centerline and hence, steady state conditions were not achieved in the 500 foot drops. It was hoped that a cluster efficiency factor for each clustered parachute configuration could be obtained by ratioing the cluster parachute drag area to the single parachute drag area. Though this computation proved fruitless, the effect of the cluster efficiency factor on the inflation time computation was insignificant and hence, the inflation time equation developed previously could be used for this study.

Because of the complexity of describing the parachute and cargo performance, a single performance parameter has been selected to present the results predicted by the computer programs for the system performance envelope. This parameter is the cargo vertical velocity. Comparisons of experimental and theoretical results have shown that the cargo vertical velocity is not sensitive to the wind (with the exception of thermals). Other parameters such as cargo trajectory and horizontal velocity are important but the correlation between test and computer run is good only when the test was conducted in a zero wind environment.

In using the cargo vertical velocity parameter for this study, the limiting value has been defined in the contract scope and the acceptability of each airdrop (from a vertical impact standpoint) can be ascertained immediately. Studies have shown that the curves of altitude loss versus cargo vertical velocity for the experimental and theoretical results agree extremely well until the second knee in the cargo trajectory occurs. After this point the effect of parachute over inflation especially with the centerline installed in the parachute causes variations in the vertical velocity predicted by the computer programs and test results. Figure 73 illustrates this variation. Therefore, the point at which the cargo vertical velocity reaches 23 fps, between first and second knees of the descent trajectory, has been used to present and compare the expected system performance. This point is shown in Figure 73.


VELOCITY PREDICTED BY COMPUTER PROGRAM AND
FIGURE 73
COMPUTER RESULTS
Z (FEET)
VZ (FPS)
0
100
200
300
400
500
600
700
800
900
1000
10
20
30
40
50
60
70
80

b. Results

There are numerous parameters which could be investigated in a study of this type with an infinite number of combinations if the interaction of all these parameters were studied. Therefore only those parameters have been selected which are the most important based on past experience. Previous parameter studies have used a general case which had a known set of initial conditions to analyze the effect of varying different parameters. In this program two such general cases have been used to evaluate the system performance envelope. These cases will be refered to as Cases I and II for discussion purposes and the pertinent computer input data for these cases is summarized below.

Parameter	Case I	Case II
Number of parachute	1	3
Type of parachute	G-11A	G-11A
Cargo weight (rigged)	3500 lbs.	12,000 lbs.
Drop zone elevation	Sea Level	Sea Level
Aircraft speed	130 knots	130 knots
Wind condition	No Wind	No Wind
Platform length	8 ft.	20 ft.
Position of cargo in aircraft	At A/C c.g.	At A/C c.g.
Line length	138.5 ft.	138.5 ft.
Canopy inflation time	8.62 sec.	5.0 sec.
Fully inflated canopy drag area	7242 ft^2	7242 ft^2
Cluster efficiency factor	1.0	1.0
Drogue parachute size	15 ft ring slot	28 ft. ring slot

Since these studies were performed earlier in the program several input values have changed. For example, the cargo weight per parachute has been increased to 5000 pounds from 3500 pounds. However, these general case studies illustrate the effect on system performance of varying any given parameter. To illustrate the expected system performance, the actual EXLARP system has been analyzed over the entire cargo weight range of 2000 to 35,000 pounds. The expected parameter values have been used for this investigation.

The following list of parameters has been investigated to determine their effect on system performance,

General Case I was used to investigate the .....

- canopy loading, W/C_DA
- cargo release force
- drogue parachute reefing

and General Case II was used to study the .....

- canopy inflation time
- line length
- cluster efficiency factor
- cargo location in the aircraft prior to release
- platform length
- aircraft velocity
- cargo weight

The results presented reveal that the cargo weight, the line length, and the canopy inflation time are the parameters which effect the cargo descent and impact performance the most. The extraction force is effected primarily by the aircraft speed, the drogue parachute size, and the canopy loading. A discussion of each of the above parameters is presented as follows.

(1) Canopy Loading

The rigged cargo weight was increased from 3550 pounds to 4500 pounds for a single G-11A canopy to obtain the variations in performance which results when using extraction by recovery parachutes. The following results were obtained:

- The snatch force in pounds was the same for both weights, and the opening shock increased by only a small amount (several hundred pounds), however, the g loading of both forces increased by the weight ratio (4500/3550) for the lighter weight.
- The altitude loss to an acceptable vertical velocity value increased for the high weight case, however, acceptable velocities were obtained at an altitude loss less than 500 ft.
- The increased weight case caused small reductions in the horizontal velocity and trajectory oscillations.

In general, the results appeared acceptable for descent altitude of 400' or more for an unmodified G-11A. Some concern exists as to the acceptability of the impact angle, which is as high as 50° between 400 to 600 feet of altitude loss, and whether the cargo will overturn at impact.

(2) Cargo Release Force

The computer results illustrate that the cargo release force has a small effect on the magnitude of the snatch and opening shock forces. The following table illustrates these results.

Release Force (lb)	Snatch Force (lb)	Opening Shock (lb)
2000	6450	6470
3500	6460	6480
6000	6490	6520

(3) Drogue Parachute Reefing

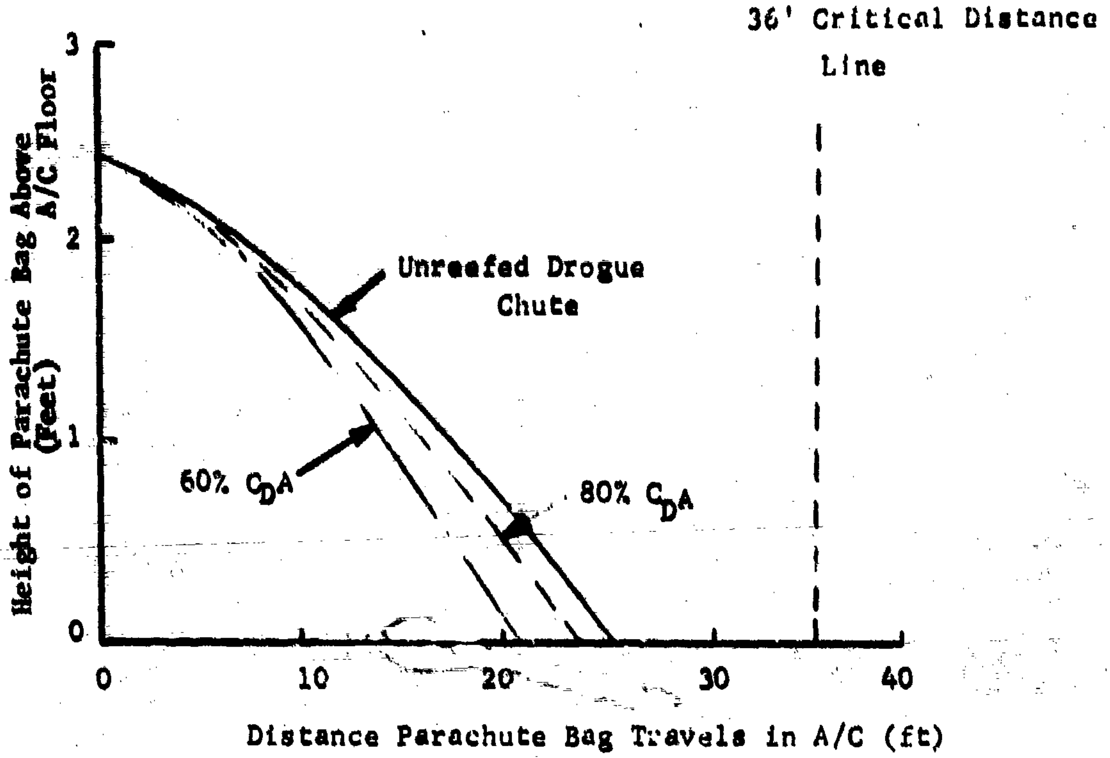
In the EXIARP system the drogue parachute is used to extract the recovery parachute(s) and not the cargo. Therefore, the requirement of the drogue parachute is to extract the recovery parachute(s) in its deployment bag(s) such that the bag does not hit the ramp during extraction. The drag area of a 15-foot ring slot parachute was reduced to determine the effect of drogue parachute size on the snatch force. The following results were obtained from the computer program.

15' RS Drogue C_DA	Reefing Line Length (ft)	Parachute Snatch Force (lb)	Parachute Opening Shock (lb)
100%	None	6450	6480
80%	42.0	6280	6400
60%	36.4	6010	6295

The above results were obtained by reducing the C_DA of the drogue parachute only and not changing the apparent and included mass of the drogue parachute, which are reduced due to the reduction in canopy volume associated with a C_DA reduction. The decrease of these mass terms will tend to further reduce the snatch force.

To obtain a reduction in C_DA the ring slot parachute must be reefed. The resulting reduction in force developed by a reefed canopy causes a decrease in the relative velocity between the recovery parachute in its deployment bag (when extracted by the drogue parachute) and the cargo in the aircraft. This results in a decrease in the snatch force.

One problem associated with reefing the drogue parachute is the drop of the recovery parachute, in its deployment bag, along its trajectory in the aircraft during extraction. The height of the bag above the aircraft floor versus the distance the bag travels is plotted in the following sketch.



The curves above are conservative in nature, since the initial restraint (ties) of the bag to the cargo has been neglected. This restraint causes higher accelerations than those associated with a no-restraint situation, and will tend to reduce the bag height loss with horizontal travel.

(4) Canopy Inflation Time

In analyzing the effects of the canopy inflation time on the system performance, general case II described previously in this section was employed and the inflation time was the only parameter varied. Inflation times from 4 to 10 seconds were investigated, since this range covers the expected inflation time of a G-11A recovery parachute using the vent pull down technique. (Phase I test results indicate inflation times less than 5.0 seconds for the 85' centerline vent pull down system, and 8.5 seconds for an unmodified G-11A parachute).

By plotting the altitude loss when the cargo vertical velocity never exceeds 23 fps versus inflation time, the increase in altitude loss with inflation time is clearly illustrated, see Figure 74. Though the curve is non linear, a transition in the curve occurs at approximately 6.5 seconds, with the inflation times lower than this value being less sensitive to time variation than those values greater than 6.5 seconds. Hence, inflation times for three parachute clusters (which is being investigated in Case II) should be less than 6.5 seconds for minimum sensitivity to inflation time. The change in altitude loss in this time region being 22 feet/second of inflation time.

Selection of shortest time for optimum performance is implied by the results presented in Figure 74, however, to select the optimum time the horizontal velocity and oscillation angle must be considered. These parameters increase in value as the inflation time decreases, and could cause unacceptable impact conditions. However, for the three tests conducted at 500 foot altitude the cargo impact was acceptable. The maximum weight dropped from this altitude was 15,000 pounds.

(5) Line Length

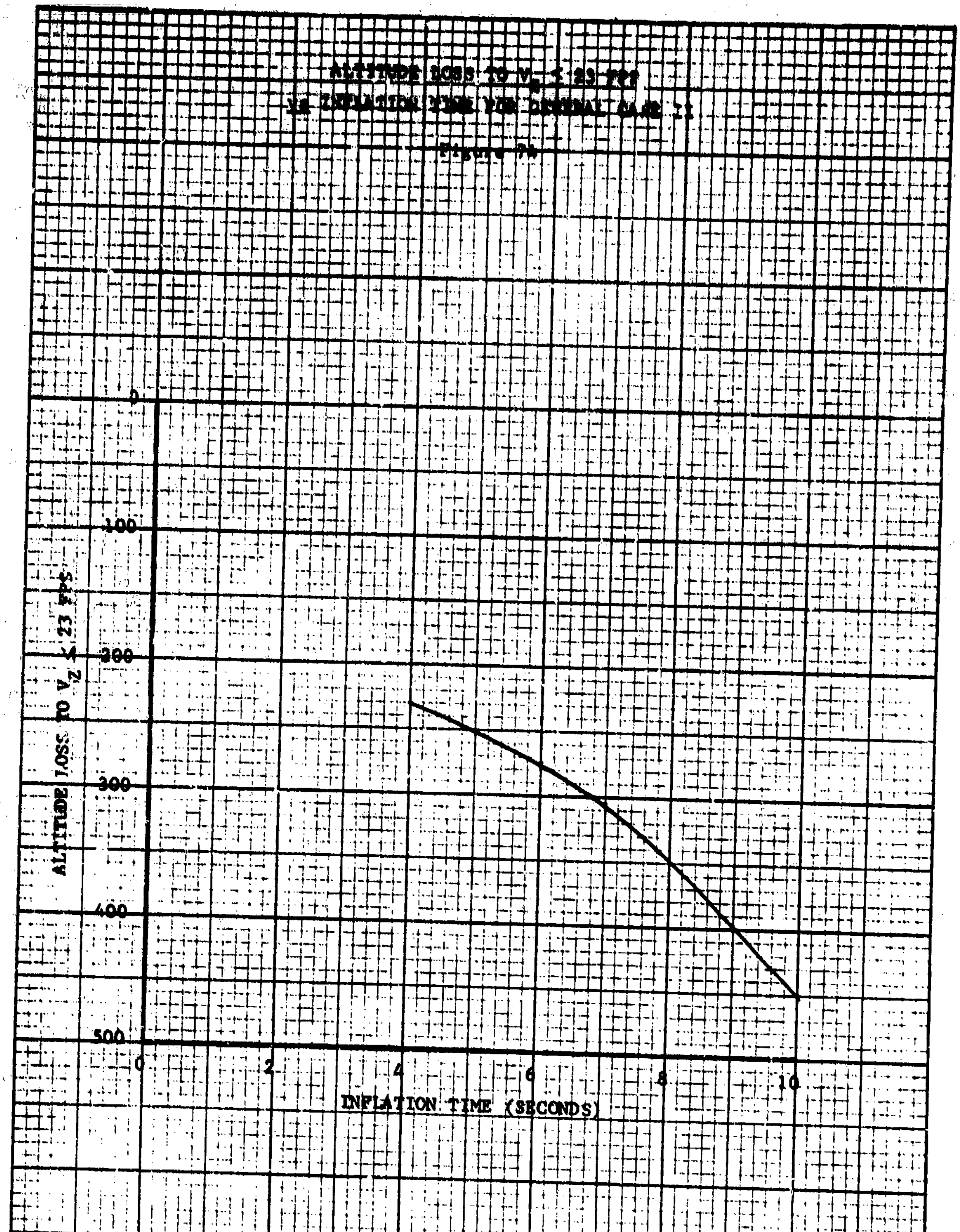
The line length of the general three-parachute cluster case II was varied for different filling times to determine effect of varying the line length. The line length variation was kept within a realistic operating range for the extraction by recovery parachutes system. The case studied, included filling times of 5 and 7 seconds and line lengths ranging from 118.5 to 158.5 feet. The acceptability of the 118.5 feet line length is questionable from a flight safety standpoint, however, it was run to determine its desirability, if any.

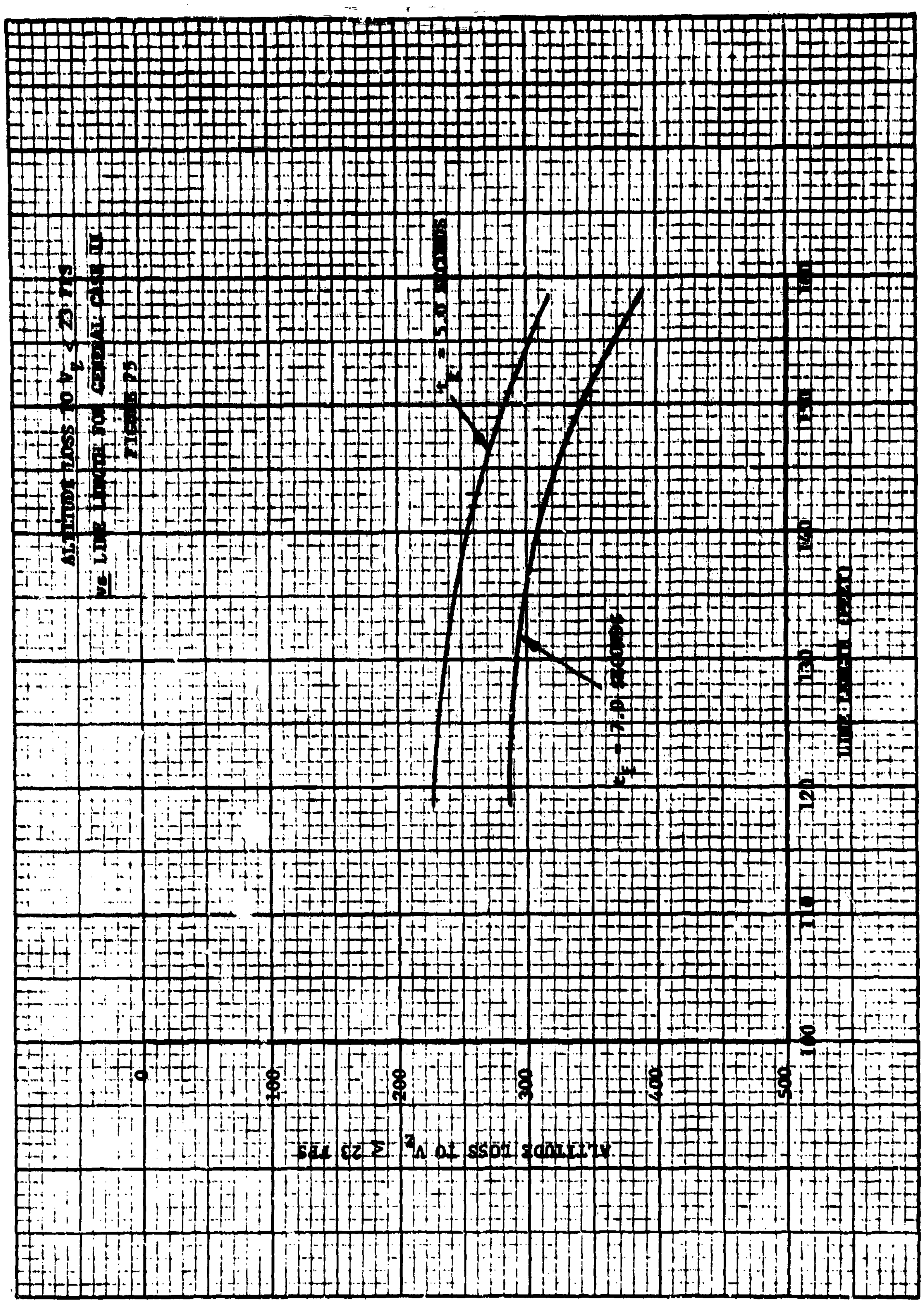
Figure 75 illustrates that the lowest altitude loss occurs for the shortest line length and the shortest inflation time. However, very little reduction in altitude loss is developed by shortening the line length below 135 feet.

(6) Cluster Efficiency Factor

The three-parachute, 12,000 pound cargo case was used to analyze the effect of reducing the cluster efficiency factor or total cluster parachute drag on system performance. Three differenct cluster factors were studied, 1.0, .95 and .85 and the results plotted. These results showed very little change in the shape of the plotted curves for the cargo descent trajectory and the altitude loss versus cargo horizontal and vertical velocities. The altitude loss increased slightly for decreasing cluster factor; however, the major parameter variation was the cargo-parachute equilibrium descent velocity. The equilibrium velocity varies as the square root of the cluster efficiency factor and for values less than one the equilibrium velocity increases.

For low altitude airdrops of heavy cargoes the development of steady state descent of the parachute-cargo system is unlikely, and


ALTITUDE LOSS TO $V_Z \leq$ 23 FPS
0
100
200
300
400
500
ALTITUDE LOSS TO $V_Z \leq$ 23 FPS
0
2
4
6
8
10
INFLATION TIME (SECONDS)


ALTITUDE LOSS TO $V_z \leq 23$ FPS
vs LINE LENGTH FOR GENERAL CASE III
FIGURE 75
t_f = 5.0 INCHES
t_f = 7.0 INCHES
ALTITUDE LOSS TO $V_z \leq 23$ FPS
0
100
200
300
400
500
LINE LENGTH (FEET)
100
110
120
130
140
150
160

the loss in performance caused by clusters will not be significant enough to warrant the use of additional parachutes which would reduce the equilibrium velocity of the system during descent, provided acceptable impact velocities are developed.

(7) Cargo Location in Aircraft

A 12,000 pound cargo was positioned at the aircraft center of gravity, and the most aft and most forward positions in the compartment of the C-130 aircraft. The most aft and most forward cargo position were determined so that the resulting aircraft and cargo center of gravity always remained within the center of gravity envelope of the C-130 airplane.

The computer program results illustrate that the snatch and opening shock forces were not affected by the cargo position variation. These results occurred because the same line length was used for each case, however, for aircrafts such as the C-141 and C-5A the most forward position of the cargo will require a longer line length and may cause significant variations to the extraction forces and the cargo descent velocities. As previously discussed, increasing line lengths may cause increased altitude losses and horizontal impact velocities. The future of low altitude air delivery from oversize cargo aircraft may hinge on the solution for this cargo extraction problem. Computer studies such as those presently being performed by AAI would greatly reduce the work required to determine the system performance for the extraction of cargoes from aircraft such as the C-141 and C-5A.

Investigation of the computer results for the cargo locations studied revealed that the system performance was not affected by the variation in cargo position. The difference in altitude loss was less than 10 feet for the cases studied.

(8) Platform Length

The platform length using the same weight cargo was varied from 12 to 20 feet. The results showed very little variation in performance.

(9) Aircraft Velocity

The operational aircraft speed range studied was 110 to 150 knots for airdrop of a 12,000 pound cargo. The effect of the aircraft velocity on the cargo descent trajectory and cargo velocity is negligible for this speed range. The most significant effect of the variation in aircraft speed is that the snatch and opening shock forces are increased by a factor of 1.7 when the speed increases from 110 to 150 knots. To assure acceptable extraction forces, the snatch force attenuator system has been overdesigned at the aircraft speed of 130 knots. Preliminary computer results indicate a 25% increase in the extraction forces caused by increasing the aircraft speed from 130 knots to the maximum of 150 knots.

(10) Cargo Weight

The cargo weight parameter is used to indicate the expected performance of the EXIARP system. Actual flight tests have demonstrated system feasibility for cargoes weighing up to 15,000 pounds, and have indicated that acceptable low altitude performance may be developed for cargoes weighing up to 25,000 pounds. This study has been used to extend this investigation to the maximum cargo weight of 35,000 pounds to be airdropped at low atlitude.

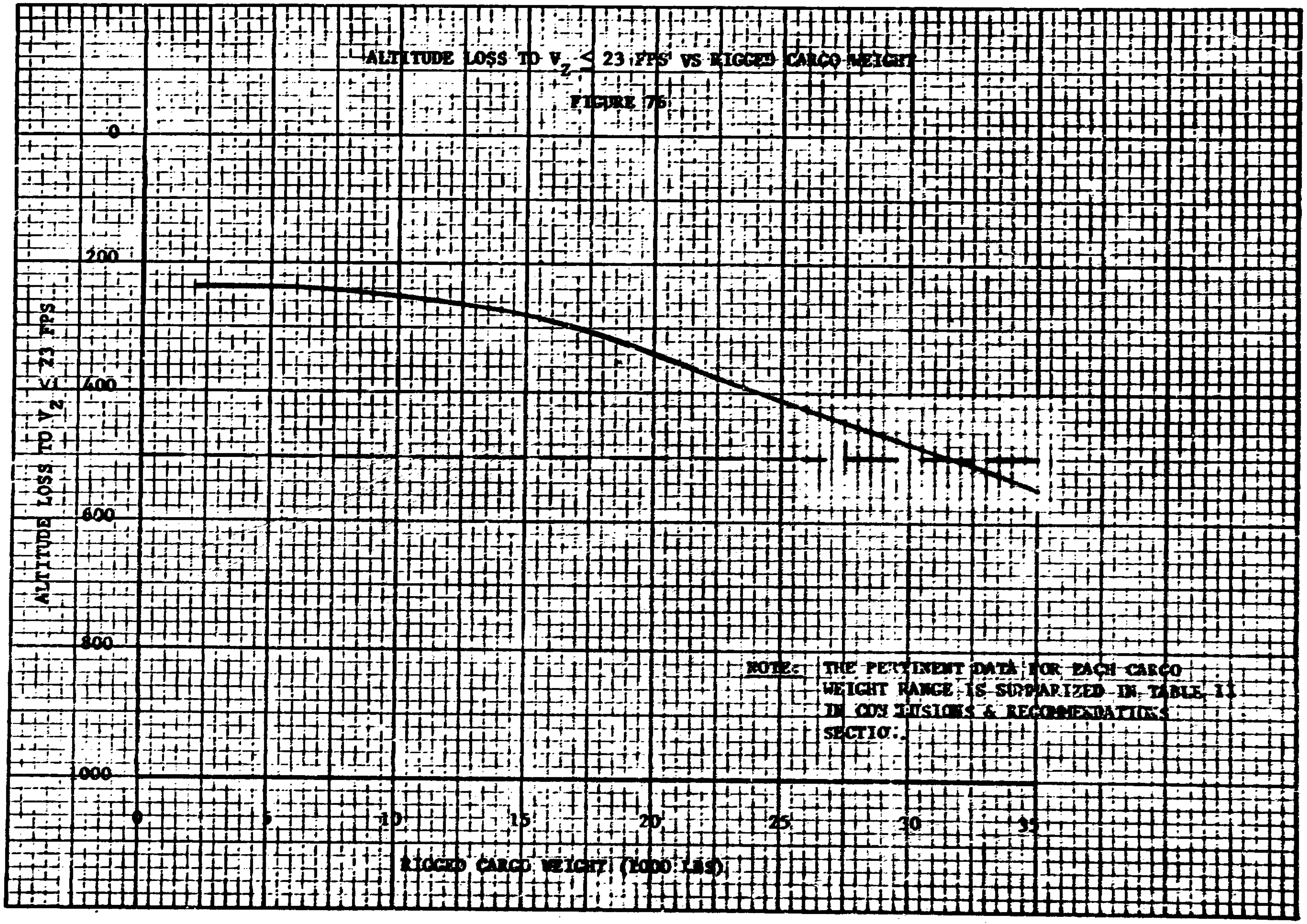
Based on flight test results and computer analyses the following cargo weight range as a function of the number of parachutes was developed. The maximum cargo weight in each weight range was analyzed in this study.

Number of G-11A Recovery Parachutes	Cargo Weight Range (Pounds)
1	2,000 - 5,000
2	5,000 - 10,000
3	10,000 - 15,000
4	15,000 - 20,000
5	20,000 - 25,000
6	25,000 - 30,000
7	30,000 - 35,000

Since numerous other parameters are dependent on the cargo weight, the value of these parameters was varied as the cargo weight changed. These parameters include:

- cargo tumbling moment of inertia
- platform length
- longitudinal and vertical distances from the extraction point of the cargo center of gravity
- cargo release force (rail lock setting)
- drogue parachute size, weight and initial position
- parachute bag drag function

The results predicted by the two-dimensional computer program using the empirically determined parachute inflation times are presented in Figure 76. The curve for altitude loss to $V_z \leq 23$ fps versus rigged cargo weight does not clearly indicate the minimum altitude loss for a successful low altitude airdrop since the horizontal velocity and impact angle of the cargo must be considered. The curve intersects the 500 feet altitude loss value just prior to 35,000 pounds for the cargo weight. To achieve a successful airdrop for this maximum cargo weight the altitude would in all probability have to be increased possibly to the 550-600 foot region to achieve an acceptable rate of descent.



ALTITUDE LOSS TO $V_z \leq$ 23 FPS VS RIGGED CARGO WEIGHT

FIGURE 76

5. High Altitude Drop Zone Study

Since the EXIARP system used aerodynamic decelerators (parachutes) for recovery of airdrop cargoes, any reduction in air density will tend to degrade the system performance. For this reason AAI has attempted to overdesign the deceleration capabilities of the EXIARP system for operation at sea level drop zones (standard day conditions). The criterion of never exceeding 28.5 fps for the cargo vertical velocity after 500 feet of descent at a 5000 foot drop zone and 100°F temperature has been used for determining the acceptability of an airdrop. Therefore, most cargoes in the U. S. Army airdrop inventory will not require additional decelerators or an increased altitude above the terrain for operations carried out to drop zones of 5000 feet elevation and 100°F temperatures.

To illustrate the degradation in system performance caused by a reduction in air density, a 12,000 pound cargo (general Case II) has been analyzed for drop zones at 5000 feet and 41°F, 10,000 feet and 23°F and 15,000 feet and 6°F.

Figures 77 and 78 indicate the system performance variation for air densities from a minimum value of .0015 to a maximum value of .00313 slugs/ft^3. The figures illustrate that decreasing air density causes the extraction forces and altitude loss to acceptable vertical velocity to increase and the cargo horizontal velocity to decrease. The altitude loss differs by only 80 feet for the air density range, illustrating little sensitivity, whereas the extraction forces are significantly affected by the air density.

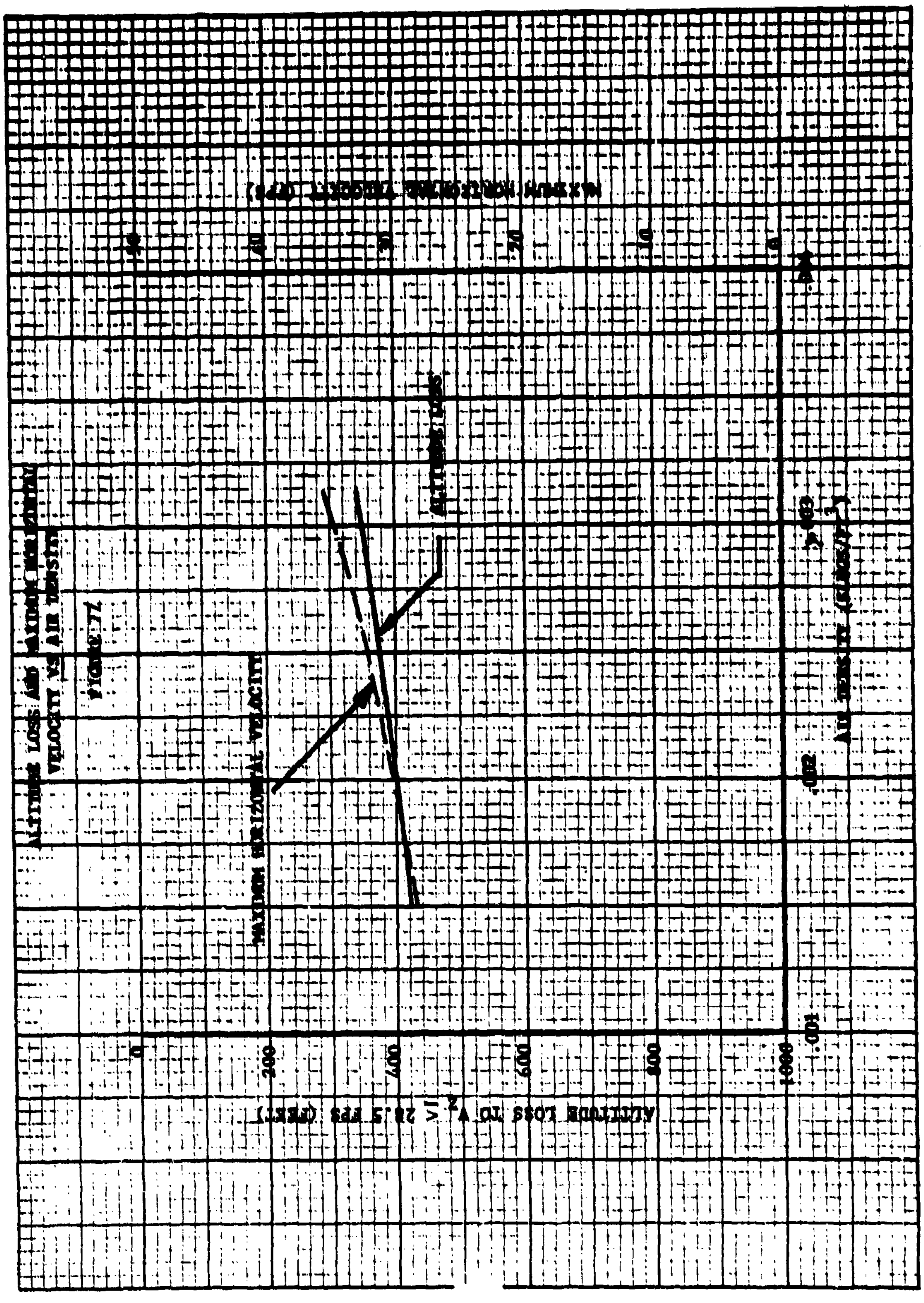
The snatch force is dependent on the true air speed, which, in turn, is inversely affected by the air density. The following equation relates the indicated airspeed, true airspeed and the air density,

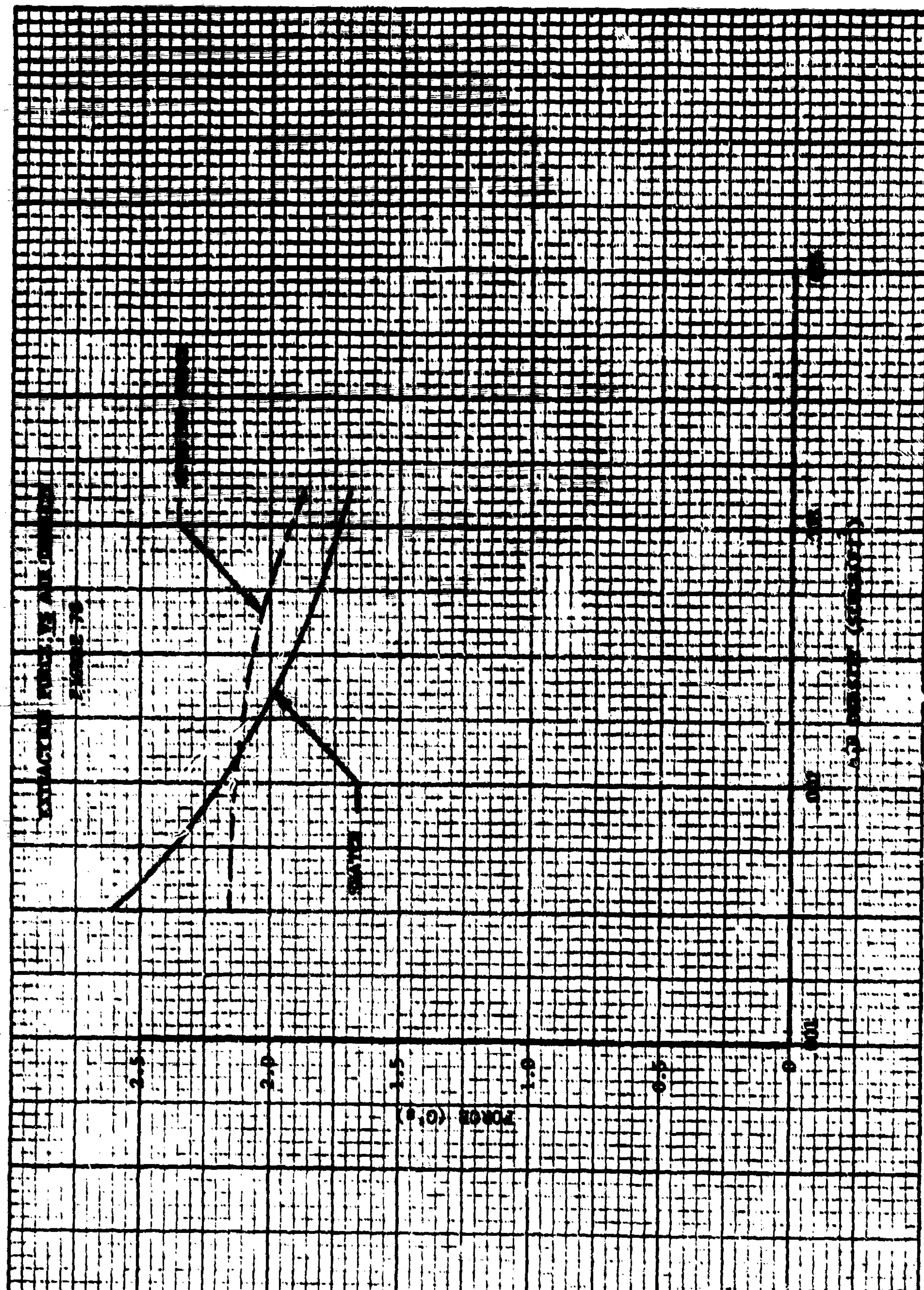
$$V_T = \frac{V_{IAS}}{\sqrt{\frac{\rho}{\rho_o}}}$$

where

V_{IAS}	=	indicated airspeed
V_T	=	true airspeed
ρ	=	air density
ρ_o	=	sea level air density

Therefore, for a constant indicated airspeed and decreasing air density (increasing altitude), the true airspeed increases causing the snatch force to increase.


ALTITUDE LOSS AND MAXIMUM HORIZONTAL
VELOCITY VS AIR DENSITY
FIGURE 77
MAXIMUM HORIZONTAL VELOCITY
ALTITUDE LOSS
0
200
400
600
800
1000
ALTITUDE LOSS TO $V_z \leq 28.5$ FPS (FEET)
.001
.002
.003
.004
AIR DENSITY (SLUGS/FT^3)
0
10
20
30
40
50
MAXIMUM HORIZONTAL VELOCITY (FPS)


FORCE (G's)
2.5
2.0
1.5
1.0
0.5
0
100

F. T.I.E. (Technical Integration and Evaluation) Study

1. Introduction

The data required by Dunlap and Associates, Inc., as set forth in their report entitled "Information Requirements for Technical Integration and Evaluation of Low Altitude Cargo Airdrop Systems" (16) has been presented in AAI Report No. ER-6055 and is summarized in this section. The data requirements set forth in the above report include evaluation parameters for specific loads in the U. S. Army airdrop inventory, performance of specific airdrop cargoes in various environmental and aircraft drop conditions and additional supplementary considerations including reliability, sensitivity, flexibility, signature, residue and cost data.

The most desirable source of data is from actual airdrop tests. However, the number of airdrop tests were limited and tests could not be conducted for the specific load items set forth in the T.I.E. requirements. Therefore, the majority of the information required for the T.I.E. report was generated from computational techniques. AAI developed a mathematical model in the form of a computer program to predict expected results for cargo airdrops using recovery parachutes for extraction. The theoretical results obtained from this computer program agree very well with the test results with the exception of predicting the correct oscillation angles.

2. Effectiveness Parameters

In order to evaluate the effectiveness of a system, it is necessary to examine the effects on performance of the variances in the more important system parameters. The T.I.E. contractor provided a list of these parameters and a dual approach has been taken to generate the desired effectiveness values. First, emperical data from the airdrop tests were used, wherever possible, to establish these values; and second, mathematical models were developed, checked against the emperical data, and then used to predict expected effectiveness in those regions where emperical data was lacking. Due to the limited nature of the emperical data this second approach, the use of the mathematical model, was the technique most generally employed.

The following is a list of parameters for which effectiveness studies were made.

- Drop sequence and times
- Accuracy measurements
- Maximum forces and force histories
- Impact characteristics
- Minimum drop altitudes
- Multiple load restrictions
- Cumulative drop times
- Compatibility with existing personnel system
- Aircraft utilization

In addition to the above parameters, several specific conditions were evaluated which included environmental conditions and high altitude drop zones.

3. Supplementary Considerations

In addition to the presentation of the results of investigations of the effectiveness parameters in the aforementioned report, several supplementary considerations are presented. These considerations include,

- Reliability
- Sensitivity and flexibility
- Signature and residue
- Costs

The reliability considerations presented include both mechanical and human reliability. For mechanical reliability, a listing of the failure sources and associated information such as numerical reliability estimates, failure effects, detectability and failsafe features is given. The human reliability analyses are made through comparison of the human operations of the EXIARP system and the standard system.

Sensitivity, for analysis purposes, was considered to be the deviation of operational parameters such as aircraft speed and altitude, and load weight caused by human and instrumentation errors. A range of variation was assigned to each parameter and the effect of these variations considered. Flexibility was considered to be a large planned change in parameter values. Again a set range of variation was considered.

The signature, residue, and cost of the EXIARP system was compared to the standard system and the results presented in the T.I.E. report.

V. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this program was to conduct an in-depth exploratory development investigation of the EXIARP concept with the objective being the establishment of feasible and practical designs for a low altitude airdrop system which uses inflation-aided recovery parachutes for extraction. To attain the objectives, a plan employing a combination of design, analysis and testing was pursued wherein the tests were a dominant factor since by this means feasibility and practicality was determined. Originally it had been planned to conclude the program with a series of demonstration airdrops from a 500 foot altitude. Circumstances, however, led to termination of the test program before this could be achieved and demonstration airdrops employing a 15,000 pound cargo were the only tests conducted at low altitude. Development tests, however, from a 2000 foot altitude for cargoes weighing up to 25,000 pounds were completed before termination of the test program, and analysis of the results indicate, that satisfactory performance from a 500 foot altitude for cargoes up to this weight value may be expected. Mathematical models simulating the functioning of the system were checked against experimental data from the test program and refined, where necessary, so that generally good correlation of predicted and actual performance was obtained. These mathematical models were then used to obtain predicted performance in the cargo weight ranges, and for the equipment combinations, where test results were not available. The major findings of this program are summarized in the following list:

1. The inflation time for parachutes equipped with inflector type inflation aids was reduced somewhat. However, for both single and cluster parachute configurations these inflectors induced high system oscillations and their use in the EXIARP system is not recommended.

2. Oscillation damping parachutes in the low cargo weight range results in optimum performance, i.e., very low oscillation with acceptable altitude losses. However, the added cost, additional rigging time, and the complexity it adds to the system is not warranted since the system without these oscillation parachutes gives acceptable (but not optimum) performance.

3. The 95 foot centerline increased the drag characteristic of the G-11A canopy significantly. Acceptable cargo vertical velocities were obtained with canopy loadings of 5000 pounds/parachute where this length centerline was installed.

4. Centerlines are highly effective in reducing the inflation time of both the G-12D and G-11A parachutes. Inflation times in the order of 5 seconds were obtained on the G-11A parachute using a 95 foot centerline as compared to 8.5 seconds for a standard parachute.

5. Undrawn nylon force attenuators were used in conjunction with parachute reefing techniques to control the peak forces during extraction, and the forces in the suspension lines after force transfer. This technique proved to be very effective and its development is considered to be a major program accomplishment. The peak forces were limited to values below the 1.5 g goal. The force attenuators are the key elements in this system. They, acting alone, limit the snatch force to acceptable values, and work in conjunction with skirt reefing of the parachutes to control the opening shock forces. The attenuator configurations developed during the course of the test program are simple to fabricate and easy to install and are recommended for this type of problem.

6. The following reefing line arrangements proved effective for reefing the G-11A parachute and are recommended where this parachute is used in the EXTARP system.

Parachutes	Reefing Line Length And Cutter
1 or 2	19 feet/2 second cutter
3 or 4	23 feet/2 second cutter
5 thru 7	23 feet/2 second cutter * 60 feet/4 second cutter

* Not Tested

7. The two and four second reefing cutter delay times are not optimum from a systems standpoint. However, they are standard items and the improvement of system performance realized by optimizing their design does not warrant the development costs.

8. The variance in the delay times of the reefing cutters was a major source of trouble in multiple parachute airdrops. When the functioning times for these cutters is staggered, the parachute which is first to be disreefed, inflates much more rapidly than the others and in some instances was damaged or destroyed. The use of a secondary reefing line (60 feet with a 4 second delay) was proposed as a control for this problem but termination of the test program occurred before it was tested.

This similarity to the standard airdrop system would minimize retraining requirements and simplify the problems of introducing the EXIARP concept as an operational system.

9. In the long cargo compartments of the C-141 and C-5A airplanes and at particular cargo configurations consisting of several units of light cargo, the EXIARP concept would be subject to some decrement in aircraft utilization when compared to the standard system. This problem is also a function of operational procedures, i.e., whether the cargoes are airdropped sequentially or individually. This utilization factor diminishes in importance as the weight of the individual cargoes increases and the loading becomes weight limited rather than space limited.

10. Further understanding leading to a definition of the limits that can be tolerated in the horizontal oscillations of the cargo-parachute system is needed. The EXIARP, and other systems as well, are subject to these oscillations. It can be corrected by the use of oscillation parachutes, but these complicate the system somewhat and the desire is to avoid their use if possible.

11. The feasibility and practicality of the EXIARP concept has been demonstrated by actual airdrop from 500 feet for a 15,000 pound cargo only. Due to the similarity of design plus the results of the 2000 foot altitude developmental airdrops, it seems reasonable to project this property of feasibility to the range of cargo weights from 2000 through 20,000 pounds. One airdrop was performed on a 25,000 pound cargo and the trajectory data obtained encourages the possibility of including this cargo in the feasible set. The probabilities, however, do not favor the extension of this 500 foot altitude airdrop capability to include the 35,000 pound cargoes. The theoretical studies indicate that feasibility is lost somewhere between 30,000 and 35,000 pounds and that these cargoes must be airdropped from an increased altitude in order to satisfy acceptable cargo impact conditions.

12. A good understanding of the probable composition of a practical EXIARP system emerged from this program. Recommendations as to the composition of the equipment as a function of cargo weight is presented in Table II.

TABLE II. RECOMMENDED EXTARP SYSTEM DESCRIPTION

Cargo Weight Range	Recovery Parachute System		Extraction System		
	Number Of Parachutes	Riser Extension Length	Drogue Parachute Size & Type	Break-Web Strength Or Platform Rail Setting	Reefing Line Length And Cutter Delay Time
2,000 - 5,000	1	30	15' Ring Slot Reefed w/144" Reefing Line	2400 pound	19' / 2 Seconds
5,000 - 10,000	2	30	15' Ring Slot	4800 pound	19' / 2 Seconds
10,000 - 15,000	3	30	22' Ring Slot	8000 pound	23' / 2 Seconds
15,000 - 20,000	4	40	28' Ring Slot	12,000 pound	23' / 2 Seconds
20,000 - 25,000	5	70	28' Ring Slot	4000 Lb Rail Setting	23' / 2 Seconds and 60' / 4 Seconds
25,000 - 30,000	6	90	28' Ring Slot	4000 Lb Rail Setting	23' / 2 Seconds and 60' / 4 Seconds
30,000 - 35,000	7	90	28' Ring Slot	4000 Lb Rail Setting	23' / 2 Seconds and 60' / 4 Seconds

NOTES:
1. All Recovery Parachutes G-11A Type W/95' Centerline
2. Cargo Release Force Set At 1/2 g (see T.O. 1C-130A-9)
3. One Multi-Line Snatch Attenuator/Parachute
4. Two Undrawn Nylon Lines Rigged Parallel to Aft Suspension Slings/Parachute
   One Undrawn Nylon Line Rigged Parallel To Foward Suspension Slings/Parachute

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