AD

TECHNICAL REPORT

67-66-AD

LIFTING OF AERODYNAMIC DECELERATORS

by

RONALD W. OATES
CHARLES A YOST
A.L. MARTINEZ

Stencel Aero Engineering Corporation
Asheville, N.C.

Contract No. DA19-129-AMC-350(N)

November 1966

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Airdrop Engineering Division

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Ronald W. Oates
Charles A. Yost
A. L. Martinez

Stencel Aero Engineering Corporation
Asheville, North Carolina

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U. S. Army Natick Laboratories
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INTRODUCTION

I. PURPOSE OF WORK

The strategic military mission for Army airdrop systems establishes the requirement for surprise assault through mass air transport and delivery of personnel and equipment. Ideally, such a mission demands that no foregoing preparation of the delivery zone be necessary, and the airdrop system being utilized is the most reliable, simple and economical concept possible. To improve the accuracy with which these airdrops can be made, and to reduce the vulnerability of the transport aircraft during delivery to hostile enemy interference with the mission, it is further required that the airdrops be made from delivery altitudes at or below 500 feet above the local terrain. Also, by the achievement of a low drop altitude, inherently, the least possible drop time will be realized and minimum dispersion of multiple loads will result.

Thus, the effort of the LOADS program, was to conduct a preliminary investigation of an airdrop concept which would meet the aforementioned requirements.

II. GENERAL CONCEPT AND REQUIREMENTS

The Lifting Of Aerodynamic Decelerators (LOADS) is a concept for the deceleration and safe recovery of an air droppable payload. Main recovery parachutes (G-12's or G-11's) are used, with the integration of: 1. aerodynamic assisted canopy opening in order to achieve predictable and reliable inflation of the mains and 2. an induced force vector oriented relative to, generated by, and acting on the canopy, such that the decelerator is moved upward relative to the load and ground in such a way as to impart a retarding force upon the delivered load in a direction opposing the natural accelerative effect of the earth-gravity attraction.

The LOADS system must be capable of delivering loads in range of 2,000 to 35,000 pounds from U.S.A. and U.S.A.F. aircraft at an altitude of 500 feet maximum above the terrain (drop altitudes below 500 feet are desirable if possible). Extraction force limits are 1.5 g's maximum and the retardation forces are limited to 1.5 g's per attachment point. The system will be functional at vertical cargo impact velocities not to exceed 28.5 feet per second at terrain altitudes varying from sea level to 5,000 feet and at temperatures ranging from

-65° F to 100° F.

III. METHODS OF WORK ACCOMPLISHMENT

This analytical development program for a low altitude airdrop system was dependent upon the following preliminary investigations for results and conclusions:

a. Preliminary exploration to define controlling parameters;
b. System operational analysis (computer trajectory analysis);
c. Aircraft compatibility analysis;
d. Weight and cost analysis;
e. Logistics and training analysis;
f. Functional reliability analysis;
g. Preliminary hardware design;
h. Preliminary testing of parachute concepts (runway tests and 1/10 scale dynamic trajectory tests);
i. Managerial and technical reporting;
j. Liaison with Natick Laboratories.

IV. SUMMARY OF RESULTS

1.0 LOADS Design Concept Results

The results of runway tests indicate that the most positive means of generating lift (from horizontal) in an aerodynamic decelerator is the method whereby the lower risers are allowed to extend a predetermined distance. Thus, the canopy experiences an induced angle of attack which causes it to seek a new equilibrium position at some angle above the horizontal.

2.0 Preliminary Parameter Study

This Preliminary Parameter Study had as a goal the establishment of those parameters which would determine the functional performance of LOADS.

The expected range of these parameters was desired as well as the selection of combinations of parameters to be studied under Activity 2000 - System Operational Analysis. The parameters included herein are the controlling parameters of the system's functional performance: drop load weight, airspeed of the delivery aircraft, air density at the drop zone, extraction force, position of the drop load in the aircraft, type of extraction (conventional, reefed main canopies), canopy assisted opening, parachute lift angle, reefed diameter and timing of disreef.

3.0 System Operational Analysis

The computer trajectory program helped to evaluate the effectiveness of the LOADS hardware concepts. It is based on equations that describe a two degree of freedom trajectory motion combined with a one degree of freedom system rotation.

4.0 Aircraft Compatibility, Weight, Cost, Training and Logistics Analyses

The LOADS configuration differs slightly from the conventional parachute system. For the lifting concept to operate successfully, the canopy orientation relative to the ground is of paramount concern, in order to ascertain the direction of the "anti-g" component of the parachute force. Consequently, some added hardware (parachute orientation sub-system) will be required to rig a drop load. However, the LOADS should be compatible with all aerial cargo delivery aircraft. The system will impose some weight and cost penalty when compared to the standard system. The supply of the AFOADS chutes needed for optimum system performance should present no problems. There would be some training required and manual revisions in order to rig a load to the LOADS configuration.

5.0 Functional Reliability Analysis

The reliability study followed the outline suggested in document SSD 66-30[illegible](656). The difference inherent to the LOADS systems are noted and compared with present conventional airdrop systems described in various military aircraft orders, bulletins, and load and rigging manuals. Although most of the LOADS changes fall in the areas of design and performance, a few changes are evident in extraction procedures for the case of reefed main parachute extraction. The LOADS system should improve opening reliability and performance substantially over conventional systems.

6.0 Preliminary Hardware Design

The hybrid hardware in a functional LOADS system will be that required to rig a payload for reefed main chute extraction, the necessary number of AFOADS modified cargo parachutes and the components of the parachute orientation system.

Model test sketches are found on pages 33 through 37 of this report. The bulk of the preliminary hardware design is depicted in these sketches.

V. PERFORMANCE CONCLUSIONS

Evaluation of results from the LOADS trajectory studies indicate:

1. Inflation time for the parachutes should be in the 4 to 6 second range without reefing in order to provide sufficient deceleration and oscillation damping prior to payload ground impact. LOADS assists in oscillation damping, and attitude although the AFOADS configuration is required to provide the opening time in a consistant manner and with time rate characteristics that will not impose forces in excess of 3 g's.

2. Conventional extraction and deployment, and reefing delays impose excessive altitude losses on the heavier loads. This indicates a need to avoid an extractor parachute step and to avoid a reefing stage after payload tip-off for loads heavier than 12,000 pounds. Extraction directly be reefed main parachutes coupled with AFOADS is required in most cases in the range over 12,000 pounds.

3. The parachute system transition from horizontal flight to vertical descent represents the first swing of system oscillation. In the case of heavier weights it also represents the only swing before impact. This swing is not easily damped and can develop critical horizontal velocities even though the vertical velocity is minimal. Clustered parachutes appear to be the best damping means and LOADS acts to give more rapid damping.

4 The effectiveness of LOADS would be dependent upon the rapid opening provided by AFOADS.

5. The LOADS concept has shown merit throughout this analytical investigation. However, the practical application of the concept may present so many problems that the hardware development would be extremely difficult. The paramount problem is that of parachute orientation, especially for a clustered configuration.

6. The LOADS trajectory studies assumed lift for clustered parachutes was obtainable. In actuality this may not be entirely correct. A hypothetical case of a L/D ratio of 1.0 for a cluster of seven G11A's used to decelerate a 22, 150 pound payload did show the effect of helping considerably the damping of system oscillation. Thus, the horizontal impact velocity was markedly decreased. But, a L/D of 1.0 for a cluster of seven parachutes would be very difficult, if not impossible, to achieve.

7. In essence, then, this Contractor would not recommend the use of LOADS for payloads heavier than 12,000 pounds because of the canopy orientation and cluster lifting problems. Also, for drop load weighing less than 12,000 pounds the fast opening AFOADS decelerators have been shown capable of fulfilling the contract mission requirements by themselves with the advantage of being different from the conventional drop system only by the fact that modified G-12 or G-11 canopies are used.

This preliminary investigation has shown that, at this time, LOADS does seem impractical as a means for the safe recovery of cargo from low altitudes.

REPORT TEXT

STENCEL AERO ENGINEERING CORPORATION

I. PROBLEM STATEMENT

The requirements for airdrop from altitudes of 500 feet or less present many problems to the recovery system designer, most of which are centered about the short time available to accomplish the recovery mission. During this time, certain feats must be performed which are common to the situation, regardless of the type of system utilized to execute the recovery. First, the load must be extracted safely from the mothership. It must then be decelerated horizontally at rates which do not produce excessive loading on the structures and hardware involved, to a forward velocity which will not effect tumbling of the load or excessive sliding upon reaching the ground. Furthermore, it must be decelerated vertically, again within tight structural-load limits, to a descent velocity which will not produce excessive impact forces on the cargo. Additionally, the delivery must be accomplished within a very small margin of error with respect to the accuracy of the point of impact. And, perhaps most important of all, the delivery system must in no way jeopardize the flight-safety implications surrounding the crew and aircraft responsible for the mission.

Compounding the above problems are the requirements arising from the loads which will be airdropped including allowable weights from 2,000 to 35,000 pounds, maximum extraction point forces of 1.5 times load weight, maximum suspension bridle attachment forces of 1.5 times load weight, and modification of the load of only the most minor consequence and which can be accomplished without special equipment or tools.

If an airdrop system is to be usable to the Army as its primary airdrop system then further requirements must be considered such as: no drop zone pre-preparation, compatibility with mass assault aerial delivery techniques, ground impact velocities of 28.5 feet per second at 5000 ft. altitude and -65°F to 100°F and approximately zero horizontal velocity (for zero wind conditions), the logistics problems and training of personnel for system rigging, good system reliability and adaptability to different types of aircraft.

II. BACKGROUND

There are basically four (4) academic concepts which this Contractor deemed feasible for low-level delivery, and these will be mentioned here:

These concepts which appear to provide a solution to the low-altitude delivery problem are:

1. Horizontal retardation to $V_x = 0$, with freefall to impact (delivery from very low altitude);

2. Mechanically forcing the opening of aerodynamic decelerators (ballistically, pneumatically, rigid or semi-rigid members in system);

3. Aerodynamically forcing the opening of aerodynamic decelerators;

4. The use of a lift-producing device to elevate the main recovery aerodynamic decelerator above the load-extraction level.

Additionally, an aerodynamic forced opening concept which has been tried and tested, is that wherein a parachute of reduced diameter was inflated inside the mouth of the primary. It was anticipated that an annular stagnation regime would be forced around the skirt of the inner chute, thereby forcing the skirt of the outer canopy outward radially. Test results indicate that for the canopies necessary for the cargo weight ranges of concern here, the performance is marginal.

III. LOADS APPROACH

The LOADS concept entails the induction of a force vector oriented relative to, generated by, and acting on, an aerodynamic decelerator being used to retard the motion of a load being airdropped from 500 feet or less above the terrain, such that the decelerator is moved upward relative to the load and ground in such a way as to impart a retarding force upon the delivered load in a direction opposing the natural accelerative effect of the earth-gravity attraction. For an airdrop application, the LOADS concept provides a means, integrated into the decelerator device, for elevating the decelerator above the initial altitude at which it was deployed, (at which altitude the load to be delivered is extracted from the air-carrier vehicle), inducing the upward component on the load in opposition to the gravity-vector. Since the downward pull on the load is lessened, or even temporarily negated, the load falls at a later time and at a lesser rate than when under the action of gravity alone. This "buying-off" of time permits a more efficient use of conventional, random-acting, parachute-type aerodynamic decelerators for low-level cargo delivery.

Furthermore, a means may need to be provided for cancelling the "[illegible] generating effect subsequent to the attainment of descent equilibrium by the load/decelerator combination. This would be necessary in order to eliminate the effective lateral displacement and velocity generated by the "lift-component" while the system is in the descent sequence, where velocity could well be additive to any surface-wind prevailing at the impact locale, the addition of which could result in a net lateral velocity, which would render a completely successful airdrop unachievable, either due to damages of the load or through completely missing the desired drop-zone.

Certain sequencing means must be incorporated into the system using this concept in order to ascertain that the decelerator has traveled sufficiently aft of the delivery vehicle subsequent to load extraction to preclude any contact or collision between the "lifting" decelerator and any of the aircraft's extremeties.

Concept 1: "Mid-Canopy" Reefing of Parachutes

Canopy reefing is a tried and proven method of temporarily reducing the projected diameter of a parachute, thereby reducing its effective drag-area.

Conventional reefing at the skirt (lower lateral band) of the canopy does have associated with it a relatively long period of time for total inflation subsequent to disreefing. This is true simply because the region of the canopy near the skirt is in or near radial equilibrium so that the air influx remains relatively low subsequent to disreefing because the mouth area remains relatively small. Hence, an ever-growing bubble of air is formed at the canopy's apex which pushes its way toward the skirt as it expands.

The concept of "mid-canopy" reefing merely consists of incorporating the reefing line <u>not</u> at the skirt, but rather at a distance up the canopy from the mouth, measured as a percentage of the canopy nominal diameter.

This arrangement (as depicted in Figure 7 page 36) permits an initial volume of air to build in the mouth-region of the canopy, giving the effective drag-shape desired for the time-period preceding disreefing. The inlet-area is greatly enlarged when compared to a skirt-reefed canopy rigged to give the same effective drag. The inflation to the reefed configuration is quite rapid, thereby allowing efficient utilization of extraction force limits when applied to aerial delivery systems.

When used with the configuration shown as Figure 7 this "mid-canopy" reefing has the additional associated advantage of permitting the "lift-vent" to be placed on the lower portion of the canopy, in the region of the false-apex formed during reefing, allowing hopefully, efficient operation of the vent, thereby producing canopy lift.

Runway test descriptions and results for this configuration are presented starting on page 27 .

Concept 2: Extension of Lower Risers

Another configuration which was considered feasible for the generation of canopy lift is shown by Figure 5, page 34 . This concept which appears to have some advantages in rigging simplicity and reliability utilizes the fore-shortening of the leading (or upper) parachute risers to induce a positive angle of attack of the canopy skirt. The canopy seeks a new path because a parachute is essentially a statically and dynamically stable vehicle about its longitudinal axis of symmetry, and any angular disturbances from its stable attitude will cause the canopy to seek out its stable trim position.

Test conditions and results are given beginning on page 29 for this concept.

Parachute Orientation

For both "lifting" configurations to operate successfully, the canopy orientation relative to the ground is of great concern. The direction of the anti-g component of the parachute force should never deviate more than a few degrees from vertical for efficient operation. Assuming no torsional inputs to the load itself, disturbing torques in the system, which could conceivably misorient the lift component, will likely be induced only by assymetry of the flexible canopy during the lifting phase. It is likely that such torques will be of relatively small magnitude, and will be easily countered by an anti-torsion "spreader-bar" which replaces the confluence point of the riser groups. Reference Figure 5 .

IV

ANALYTICAL STUDY

IV ANALYTICAL STUDY

The analytical study as presented in this section encompasses the areas of design concept performance, computer trajectory program descriptions and 1/10 scale dynamic testing descriptions. The general performance findings are summarized first and supported by graphical data derived from both the computer program results and the 1/10 scale model test results.

Performance Summary

Evaluation of the LOADS design concepts by both computer trajectory studies and by 1/10 scale dynamic model testing indicates that a lifting recovery system cannot be developed with only slight modifications to existing U. S. Army cargo parachutes and drop techniques. The study did determine that for LOADS to be effective it is required to:

1. Open rapidly
2. Develop high lift and lift to drag ratios in clusters
3. Maintain proper orientation

The concept modifications made to the conventional canopies in order to develop lift were not able to accommodate any of the requirements satisfactorily.

The trajectory of a typical low altitude airdrop recovery without lift and again with lift is shown in Figure 1 and Figure 2 respectively. A comparison of the two trajectories shows that parachute lift brings the system to a vertical attitude more rapidly and reduces the angular rate of the system since the parachute more nearly follows the payload trajectory.

A more comprehensive comparison of lift effect is shown in Figure 3 This figure shows an overlay of trajectories, horizontal and vertical velocity and system attitude for cases of zero, negative and positive lift. Although benefits are shown in terms of trajectory improvements when using lift, it must be pointed out that fast parachute opening is required as well as positive methods of orientation.

Standard U S. Army parachutes were given simple modifications in order to develop lift. Test results have shown that such parachutes do not provide much lift, that the inflation time is slowed considerably and that orientation remains an unresolved problem

To obtain the benefits of lift more specialized parachutes are required and concepts are required that take advantage of the dynamic energy available in such a transient recovery. So far only static lifting type parachute concepts have been applied.

Data and Analysis

The payload trajectory path for a lifting parachute shows less excursion and smaller horizontal velocities than for a no lift system. The system attitude with lift, although having no less oscillation angle does reach vertical attitudes sooner and appears to swing about a shorter center than a parachute without lift. The swinging of the payload about a shorter arm accounts for the lower horizontal velocities and smaller deviations from a ballistic trajectory path. These characteristics result from the fact that the parachute lift force tends to drive the parachute over the payload thereby reducing the payload need to swing and the development of angular momentum. A description of the computer program used in this study is given in Appendix A.

The results from 1/10 scale dynamic tests of the LOADS extended riser (canted canopy) concept indicate that entrapment and inflation is degraded such that the canopy may not open into a stable drag form. Further information regarding the 1/10 scale dynamic model tests is given in Appendix B.

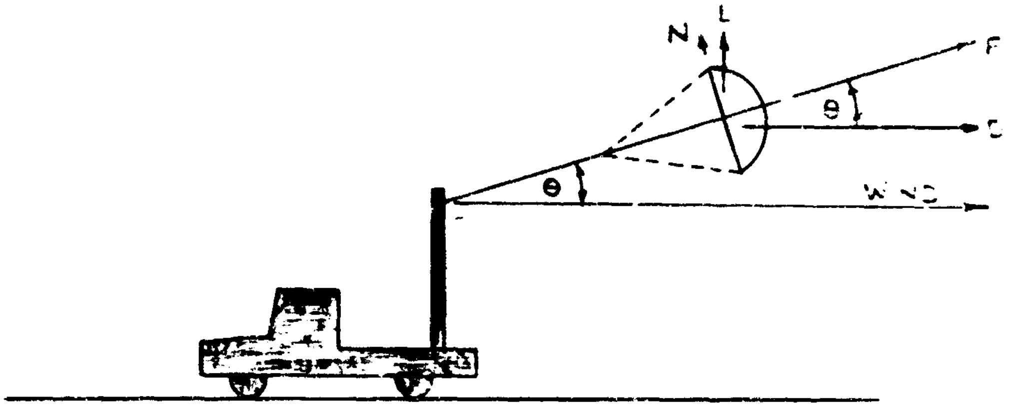
The computer study assumption of a $C_{L_P} = 1.0$ results in an L/D ratio of 0.62. Runway test data indicates that an L/D ratio of 0.64 is being achieved in practice with the canted canopy technique. This is comparable with the assumed L/D ratio; however, the actual values of C_{L_o} and C_{D_o} measured in tests are low. Based on nominal diameter canopy area, tests showed $C_{D_o} = .48$ and $C_{L_o} = .28$; as compared with an assumed $C_{D_o} = .70$ and $C_{L_o} = .44$ ($C_{L_P} = 1.0$; based on projected area, $C_{L_o} = .7$ based on cloth area), for computer studies. The lower drag coefficients derived from test data is a result of the canted canopy inefficiency.

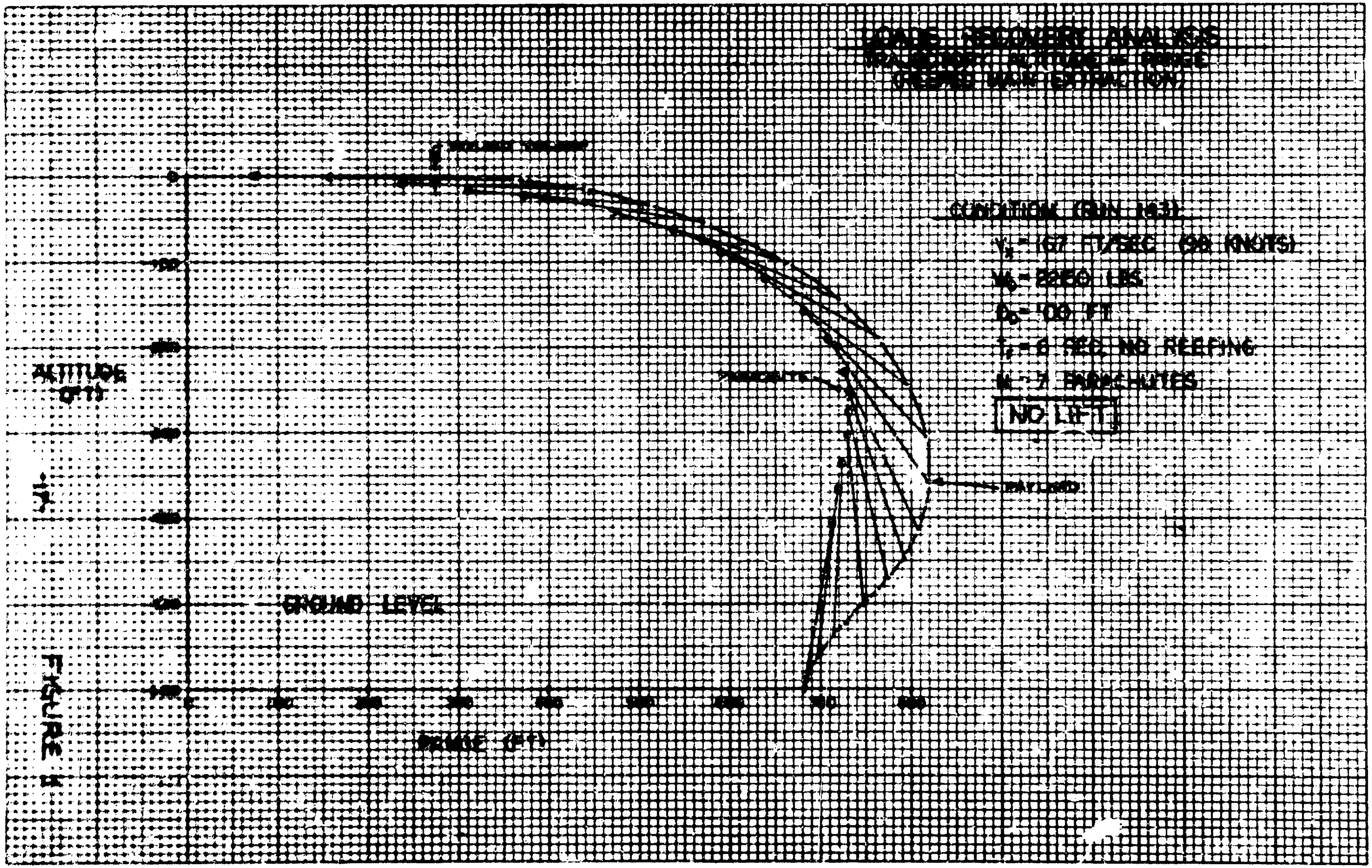
The definition of lift and drag coefficients are:

(1) $C_L = \dfrac{L}{A.q} = \dfrac{F.\sin\theta}{A.q}; \quad C_{L_P} = \dfrac{9}{4}\, C_{L_o},$

(2) $C_D = \dfrac{D}{A.q} = \dfrac{F.\cos\theta}{A.q}; \quad C_{D_P} = \dfrac{9}{4}\, C_{D_o},$

(3) $\dfrac{L}{D} = \dfrac{C_L}{C_D} = \tan\theta$





[illegible] RECOVERY ANALYSIS
TRAJECTORY: ALTITUDE vs RANGE
([illegible] EXTRACTION)
CONDITION (RUN 163)
V_A = 167 FT/SEC (99 KNOTS)
W_p = 2250 LBS
D_o = 100 FT
t_f = 6 SEC, NO REEFING
N = 7 PARACHUTES
NO LIFT
PAYLOAD
PARACHUTE
ALTITUDE (FT)
0
100
200
300
400
500
600
GROUND LEVEL
0
100
200
300
400
500
600
700
800
RANGE (FT)

FIGURE 1

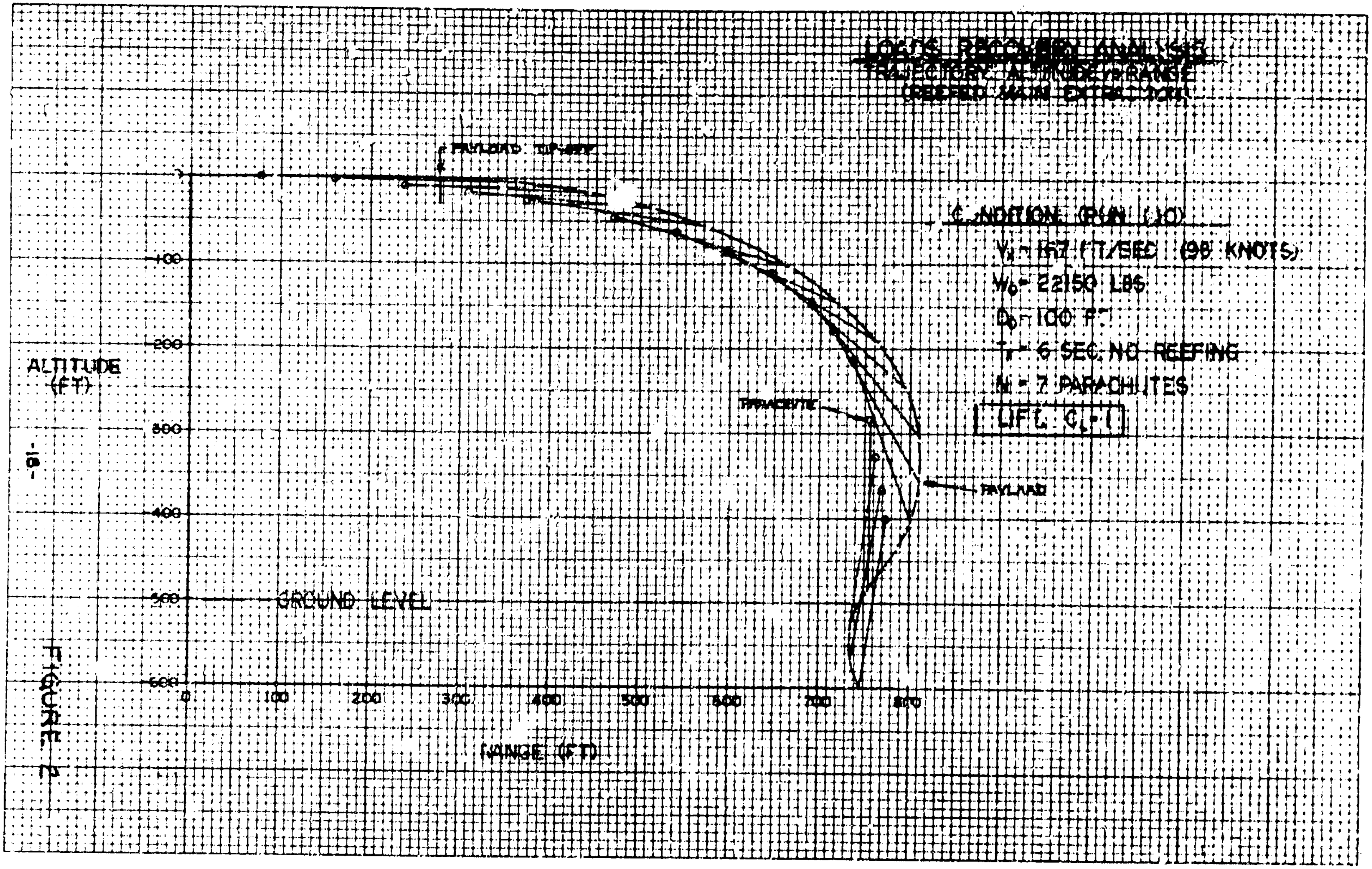

LOADS RECOVERY ANALYSIS
TRAJECTORY: ALTITUDE vs RANGE
(REEFED MAIN EXTRACTION)
CONDITION (RUN 10)
V_x = 167 FT/SEC (98 KNOTS)
W_0 = 22150 LBS
D_0 = 100 FT
T = 6 SEC. NO REEFING
N = 7 PARACHUTES
LIFT, C_L = 1
PAYLOAD TIP-OFF
PARACHUTE
PAYLOAD
GROUND LEVEL
ALTITUDE (FT)
100
200
300
400
500
600
0
100
200
300
400
500
600
700
800
RANGE (FT)

FIGURE 2

LOADS

TRAJECTORY, VELOCITY & ATTITUDE
VS
ALTITUDE

MAIN PARACHUTE EXTRACTION
PAYLOAD WT. = 28150 LB
NO. OF PARACHUTES = 7
PARACHUTE DIA. = 100 FT.
VELOCITY @ TIP-OFF = 167 FT/SEC
INFLATION TIME = 6 SEC.

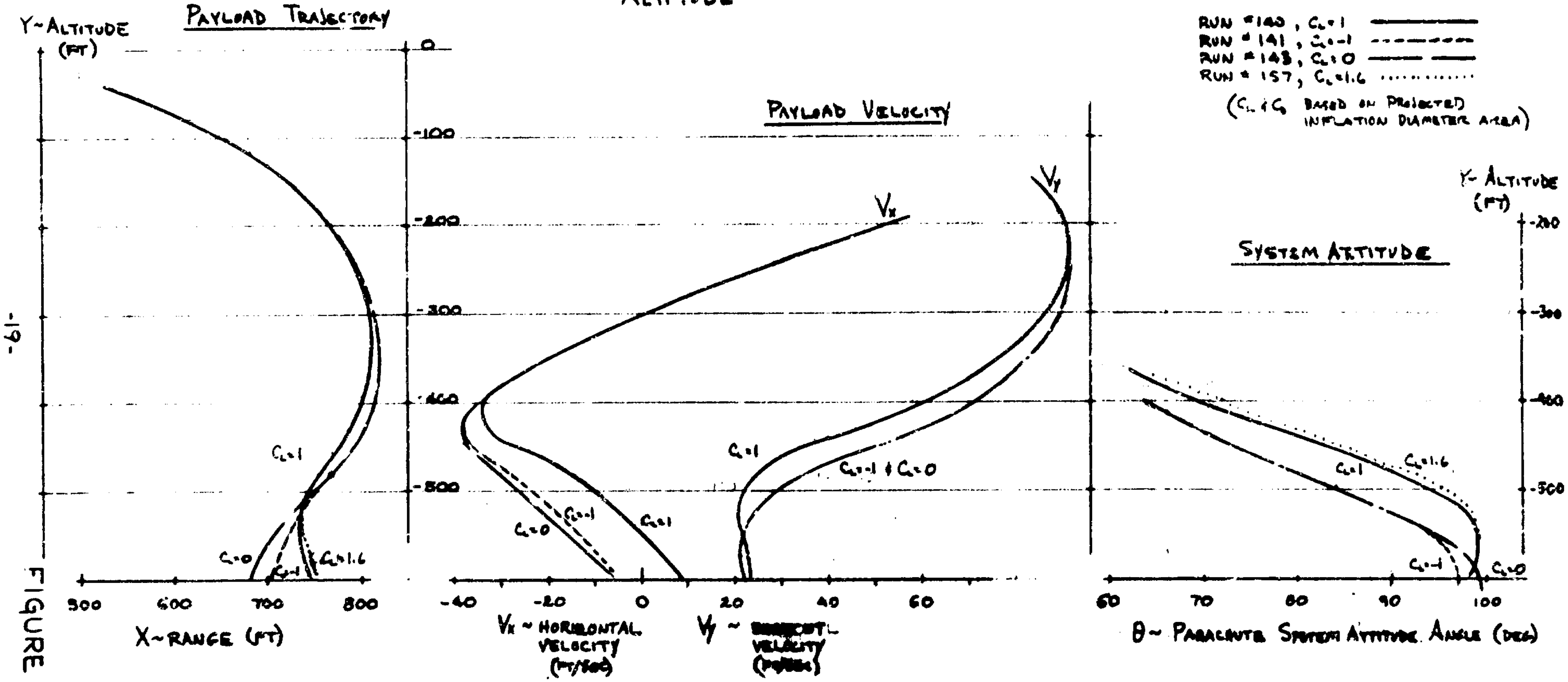


FIGURE 3

V

Runway Testing

V RUNWAY TESTING

1.0 Introduction

Because of the number of interdependent concepts to be evaluated, a comparative test program was indicated to verify or supplement evaluation of some of the more important characteristics of the proposed concepts.

There existed a capability to runway test 24' diameter parachutes up to about 45 KIAS and this satisfied the basic initial conditions requirements.

Since an important aspect of the concept involved main parachute load extraction, runway testing was devised so that the conditions for canopy performance evaluation from deployment through reefed inflation and from disreef to partial inflation approximated full scale conditions.

Through the process of elimination by testing and analysis, the results of which indicated which of the concepts showed trends which were worthy of more or less extensive development reduced the actual number of reliable tests to those enumerated at the end of this section and represent better than average performances for the configurations tested.

2.0 Objectives

The comparative runway tests series was intended to help evaluate the applicability of the proposed concepts to the solution of problems presented in meeting the airdrop system performance goals.

Those configurations which held promise were then to be subjected to tenth scale model testing, which more realistically simulates the actual dynamic conditions encountered such as cluster interference effects, finite loads, and the existence of a flight trajectory.

If for functional or practical reasons, considering also cost and availability, runway testing resulted in the elimination of all the original configurations, runway testing was also to result in the recommendation of new or alternate configurations for further consideration.

3.0 Philosophy

The need for a system that will fulfill the performance goals requires large order performance improvements of a parachute system, combined with high reliability and good repeatibility, with the best weight efficiency and cost effectiveness achievable, flexible enough to operate conventionally with and be compatible and safe with existing aircraft and perferably, minimize modification or re-design of present parachute, equipment, and associated logistics, and be readily available.

4.0 Purpose

This report is a complete reference to runway test activities and will describe facilities, test apparatus, technique, configurations, and results.

5.0 General

5.1 Background

Early analysis and testing showed that the conventional extraction and recovery technique was inadequate for the new high performance requirements involving the larger loads, which justified the concept of main chute extraction for improved time utilization, further analysis still showed that the largest loads could not be recovered without some opening augmentation and these conclusions were reached based on single chute performance. Clustered chutes with finite loads in trajectory behave differently than single chutes with finite loads in a wind tunnel, but attempts to acquire reliable data on the former floundered.

5.1.1

TM 63-104 dated 9/64 states that a 100 ft. diameter flat circular cargo chute with a load weighing 3700 lbs. released at 1500 ft. altitude at 130 KIAS without reefing will inflate in an average of 6.5 ± .06 sec. with a peak opening force of 8000 ± 610 lbs., and when reefed with a 20 ft. line averages 9.3 ± .9 sec. with a peak opening force of 7323 ± 480 lbs.

5. 1. 2

ASD-TR-61-579, Fig. 4-77 indicates that the cluster efficiency of an individual chute may be as low as 70% in the configurations now being used.

5. 1. 3

AFOADS performance analysis (12-65) and ASD-TR-61-579 both treat the way in which drag area varies with time, and if the aforementioned 70% efficiency tracks the rate of opening, a cluster may take as long as 6. 5 sec. to fully inflate from the approximate .08 D_o reefing required for main chute extraction.

LOADS performance analyses treat some of the problems associated with lift chute performance regarding attitude control, operational sequence and, performance requirements with respect to time, and the results require the application of AFOADS principles to LOADS configurations capable of moderate to high lift.

5. 1. 4

Trajectory analysis called for a worst case heavy load parachute opening time of 4 sec., so initially, for a universal system, main chute extraction, was required, and allowing for an already reefed inflated chute to tip-off, a chute opening time of 4 sec. from disreef, or roughly a minimum of 30% reduction in opening time in that mode, combined with the highest average decelerative force achievable without exceeding allowable parametric load limits.

5. 2 Approach

With a philosophy, and having established an approximate goal in mind for the reduction of opening time, peak load levels, and lift force/time requirements it was apparent that the required characteristics and order of magnitude of performance increase may not be obtained without resorting to extensive canopy modifications and/or system redesign.

Therefore, a concurrent program was undertaken to develop the highest performing system within the scope of the study and then re-evaluate the system based on subsequent testing of tenth scale or full scale clusters.

The alternate system should also allow for design flexibility, to adjust later if required.

5.3 Facility

Old Municipal Airport, "A" shaped, with 3500 feet long runways.

Apparatus (Ref. Fig. 4)

5.3.1

6,500 pound truck with 22 feet long tubular triangle tower section mounted and guyed to structure.

5.3.2

C.E.C. type 5-116 Multichannel Oscillograph with 120 cycle reference and calibration unit.

5.3.3

One Keystone type A-9 and two Milliken type DBM 4A high speed cameras with timing.

5.3.4

B-L-H Type U 10-2000 pound load cells.

5.3.5

Airspeed indicator and pitot installation.

5.3.6

Miscellaneous: interlocked fire control unit, flashbulb holder, electrically fired re-usable line cutters.

5.4 Controls

In order to compare the series tests with one another and with other data, some qualifications with regard to the basis for comparison must be elaborated on.

5.4.1

Because 24' diameter parachutes were to be used, airspeeds of 30 and 35 KIAS were employed, which are .24 scale of 60 and 70 KIAS, or approximately the lowest speed at which tip-off occurs, yielding the slowest inflating or worst case system.

This parameter obtains from the following simularity factor determination for model design:

(1) Scale velocity = full scale velocity X $L^{1/2}$,

(2) Where $L = \text{scale factor ratio} = \dfrac{\text{model scale}}{\text{full scale}}$

So, in our case:

(3) $60 \text{ or } 70 \times .24^{1/2} = 60 \text{ or } 70 \times .49 = @\ 30 \text{ or } 35$

This technique has been dependable for model parachutes in incompressible, or low subsonic velocities. And, of course, other reliable simularity factors for evaluation of other parameters exist and were employed during analysis of the results.

5.4.2

Although the 24' test parachutes have 24 gores instead of the 64 and 120 as in full scale, when attention is directed toward overall performance characteristics, comparatively reliable results obtain and establish trends which are true at any scale.

Other differences such as suspension line layouts are effectively equivalent and are of lesser importance.

5.4.3

Wind and ground effects were minimized and/or accounted for as well as possible under the circumstances and there was always the wake effects of the truck, but since the tests were comparative, the emphasis was on control, that is, running each test under as nearly the same conditions as possible.

5.4.4 Technique (Ref. Fig. 5)

To simulate actual conditions and to facilitate field test preparation, 21' long riser extensions to simulate quarter scale main chute extraction riser extension requirements are attached to the load cells at the top of the tower. The other ends attach to the parachute suspension lines.

Two surplus 24' dia., 24 gore, 1.6 oz. Nylon canopies with 18" diameter vents, 550 pound 16'-10" long suspension lines, and rolled self-edged skirts without any other modifications such as pocket bands were purchased.

These parachutes, whether flown as is or variously modified as required for a test, were long-folded conventionally and drawn into the deployment sleeve depicted in Figure 6 except for center line equipped configurations which were long folded then the apex drawn through to the skirt, then drawn into the sleeve.

The sleeve is tailed with a 12 foot diameter flat circular chute with its suspension line confluence point attached to the end of the sleeve through a swivel to prevent wind up.

The drag of the 12 foot chute combined with the way in which the drogue load is transmitted through the sleeve to the skirt and suspension lines of the test canopy provides for a taut system prior to deployment and fast reliable deployment free from sleeve interference effects.

Other details of construction are interesting and important to efficient operation but are relatively unimportant from the standpoint of comparative canopy performance testing and are omitted here in the interest of brevity. It may be said, however, that actual testing was under the surveillance of an FAA designated parachute rigger examiner, and that all hardware and materials were suitable for the purpose and workmanship was of the best.

A typical run was accomplished as follows:

The truck is accelerated then stabilized at 35 KIAS (approximately .25 scale main P/C extraction tip-off speed), passes a reference marker and a flashbulb signal is fired to start the oscillograph and all cameras. It passes another marker and the canopy is de-sleeved by the 12 foot diameter drogue chute, passes other markers for subsequent disreefing as required. Markers are far enough apart to allow a configuration to reach stabilization and/or stage of inflation before subsequent operations, and to locate field emplaced cameras for predictable parallax. All equipment is operated till drag slows the truck to about half its original speed.

6.0 Configurations and Comparisons

6.1

The first tests, then, involved the unmodified, or control, chutes to establish a basis for comparison with other configurations.

6.1.1

High speed film analysis showed that: a plain chute has idiosyncrasies, particularly, the way in which the gore panels blow - in or out - and how many of each, during early inflation, and may vary in lift characteristics.

6.2

The above tests formed the basis of comparison for all subsequent testing and when a configuration was compared with its control, the control was the chute which was modified into the concept being evaluated.

6.3

The LOADS chute tests used plain unmodified chutes for comparisons. Refer to 62T-100, 62T-101, 62T-115 and 62T-116 for typical test mode performance of the basic parachute system.

6.3.1

Mid-canopy reefed chute with vent: Ref. Figure 7
This configureation utilized the special riser arrangement shown in Figure 5 and was oriented with the vent down when attached to the truck tower and when conventionally long folded, sleeved, and deployed. The geometry of the special riser pair simulates the quarter scale requirements of the minimum 60 ft. long extraction line currently used with the C-130, and makes up for the .95 D_0 suspension line length which was not provided in the 24 ft. diameter chutes.

This configuration requires additional skirt reefing to be useful for main chute load extraction, the filling characteristics of which configuration are unknown. Negative functional behavior was observed since the mid-canopy reefed configuration drags or lifts downward, when it was supposed to lift upward, and lifts upward when disreefed and is not supposed to lift. Steady state drag force was reduced.

6.3.1.1

No lift till fully inflated: achievable lift may be insufficient for required effect, trajectory analysis will decide applicability of this concept. The LOADS concept requires the application of AFOADS principles to inflate in time. Severe deployment problems plagued this concept as reliable lift vector orientation at deployment was difficult to achieve even when tests were rigged to work for lift data. The horizontal bar (2 ft. long, 8 ft. full scale) was inadequate to restore lift vector in acceptable time, and was totally useless if the chute inflated when in a roll attitude exceeding 90°. Cluster behavior of this lift configuration is a gray area also, aerodynamically and mechanically because of multitudinous risers and torque bars and the need to restore the system to a no lift, no horizontal velocity condition.

6. 3. 2

Extended lower riser chute which induces angle of attack and chute lifts: this concept was tested utilizing an unmodified parachute and the special riser arrangement shown in Figure 5. The characteristics mentioned in paragraph 6. 3. 1. 1 apply to this configuration also. With all risers 21 ft. long the configuration inflated in 1. 66 seconds average with a peak opening force of 1535 lbs. average, a final drag of 1042 lbs. average, and oscillated between +30° and -18° of horizontal with a period of 4. 68 seconds average.

The steadiest and highest lift was achieved by extending the lower risers 2 ft. This configuration was steady at 33° average angle of attack. Opening characteristics were anywhere from the same to slightly worse than the unextended configuration. At 1 ft. extension, lift was reduced to oscillation between +24° and +7° of horizontal, otherwise, characteristics were the same as the control. With 3 ft. and 4 ft. lower riser extensions, all characteristics are degraded. Opening time is slower, and upon full inflation, oscillation from horizontal to +30° is coupled with leading edge cave in and large roll forces; repeatability, opening characteristics, lift and stability were so bad that the data is not considered useful or applicable and will not be presented.

The coincidence of the 2 ft. lower riser extension was interesting, considering the 2 ft. separation of left and right riser pairs, and at that point, a centerline, designed to hold the chute apex in the skirt plane when inflated was installed (torachute), and the system was tested once. Opening time was almost halved, and except for slight tendency of leading edge to cave in initially, the canopy was stable at 33°. Opening characteristics were comparable with a standard torachute. The significance of this experiment was that lower riser extensions may be reduced if AFOADS (torachute) principles are applied, and additional testing will be required to evaluate the condition, as this single experiment seems to show.

6.4

Up to this point then, the two LOADS concepts had been tested but the quality and quantity of change in performance appeared not to coincide with the requirements.

An alternate design was indicated. But the concurrent back up program to develop the alternate concept(s) was not fruitful.

Analysis failed to result in practical solutions to the following basic problems:

(a) Lift vector orientation (deployment).
(b) Lift vector restoration (correction).
(c) No lift till fully inflated.
(d) Unknown cluster behavior.
(e) Riser complexity.

6.5

Reefing Techniques

Common to the total effort was the need for a configuration to provide reduced drag for main chute load extraction, and at the same time to speed up inflation processes without exceeding force limits.

6.5.1

Mid-Canopy: (Ref. Figure 8)

The illustration shows a technique that was investigated for applicability to the LOADS program. A plain chute was used.

The reefing technique requires additional skirt reefing to be useful for main chute load extraction with a 1.5 g limit, because upon mid-canopy reefed inflation the steady state drag forces are too high; and even with additional skirt reefing peak opening force factors are high, further limiting its applicability. Peak opening force factors are higher for disreef to full inflation modes, even though the configuration is slower to full inflation than a conventional skirt reefed chute, and when used with the inflector equipped chute to reduce cumulative opening times to a point comparable with the inflector chute itself, peak opening forces went up even more.

This configuration inflates to a mid-canopy reefed condition like a parachute of reduced proportions, with an inflated ball on the end and is fast to that condition as would be expected of a smaller chute, the inflated ball slowing the inflation but little, although giving distinct rough, pumping oscillation to the system in an axial direction when mid-canopy inflation is reached. Testing showed that any interruptive event that occurs during the inflation process will slow the process, even if it may be intended to speed the process, such as a mid-canopy reefed stage, and this is at odds with our best interest. Also, it looks like disreef timing sequences in cluster operation could be complicated if staged disreefing is pursued.

Early testing of a mid-canopy chute located the mid-canopy reefing line 72 inches up from the skirt instead of 48 inches (Ref. Figure 8), and inflation times in various modes was proportionately different, due, apparently to difference in volumetric efficiency. At that time, time from disreef to full inflation was faster than conventional skirt reefed chute. To lower steady state drag forces, then, the reefing rings were relocated as shown in Figure 8, but that attempt to approximate the drag of a comparable skirt reefed chute missed. It is obvious that as the mid-canopy reefing line is located closer to the skirt, it begins to look and behave just like skirt reefing, especially with the effects of the inflated dragging ball to consider.

The reefing line was always 51 inches long which is the same periphery as the vent.

The reefing line was also tested on the outside of the chute, with no different results, and cumulative burning damage was evident, as expected.

The above remarks all apply to the mid-canopy reefing technique when applied to the LOADS concept, and in addition, useful lift was not produced when the configuration was tested inducing an angle of attack.

7.0 Conclusions

Analysis of runway test data shows that of the configurations tested, that the extended lower riser chute which induces an angle of attack and lifts, was the only one worthy of further study. However, functional or practical considerations seem to relegate even that idea to a category of not being applicable to the solution of the job at hand because achievable lift is inadequate for the time allowed in trajectory.

8.0 Recommendations

Runway testing has indicated that the lift configurations suffer badly from their own problems, need the AFOADS principle to work, so if AFOADS holds promise alone, lift is not required, even if it may be beneficial to performance.

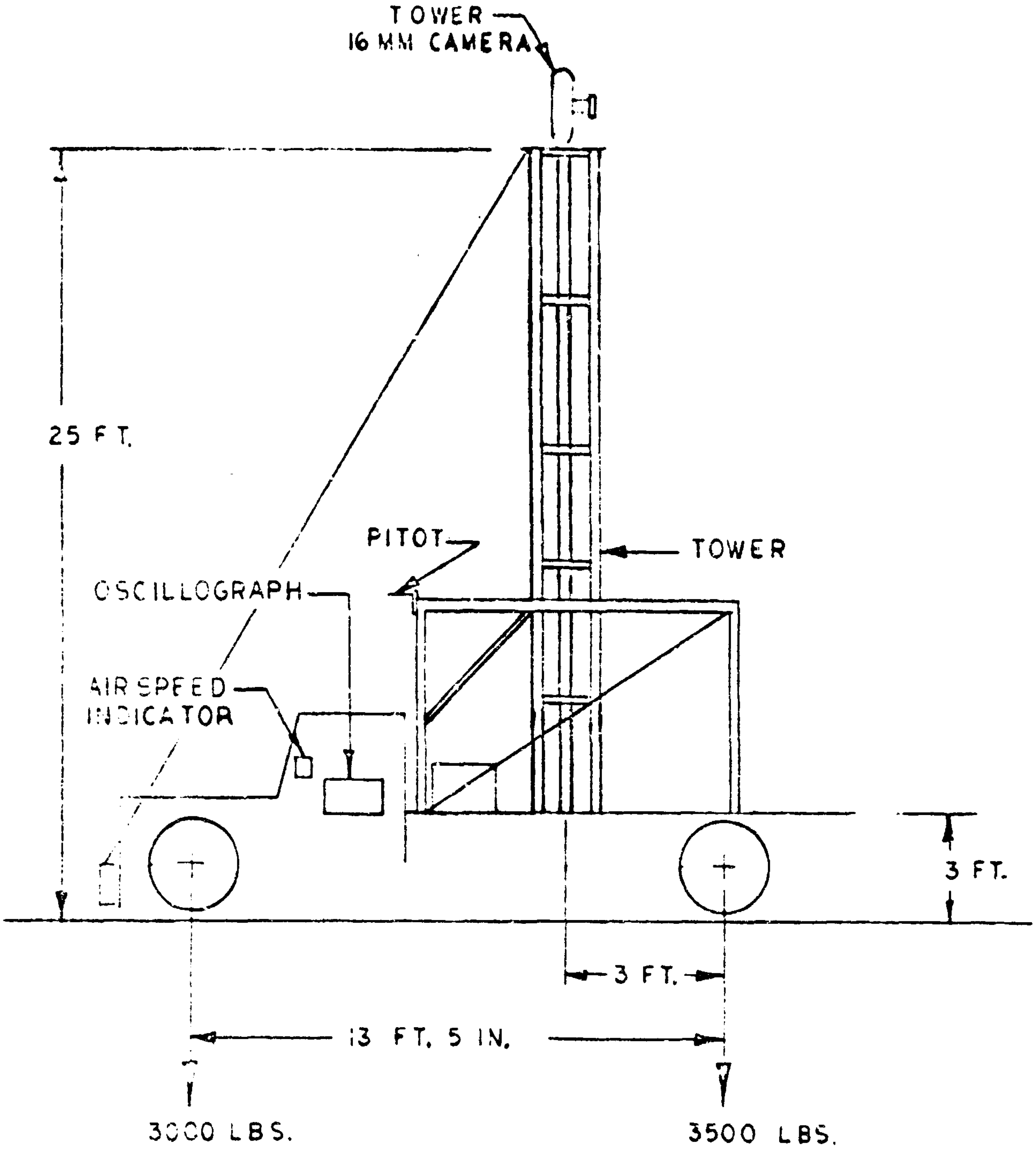

TOWER 16 MM CAMERA
25 FT.
PITOT
TOWER
OSCILLOGRAPH
AIR SPEED INDICATOR
3 FT.
3 FT.
13 FT. 5 IN.
3000 LBS.
3500 LBS.

FIGURE 4.

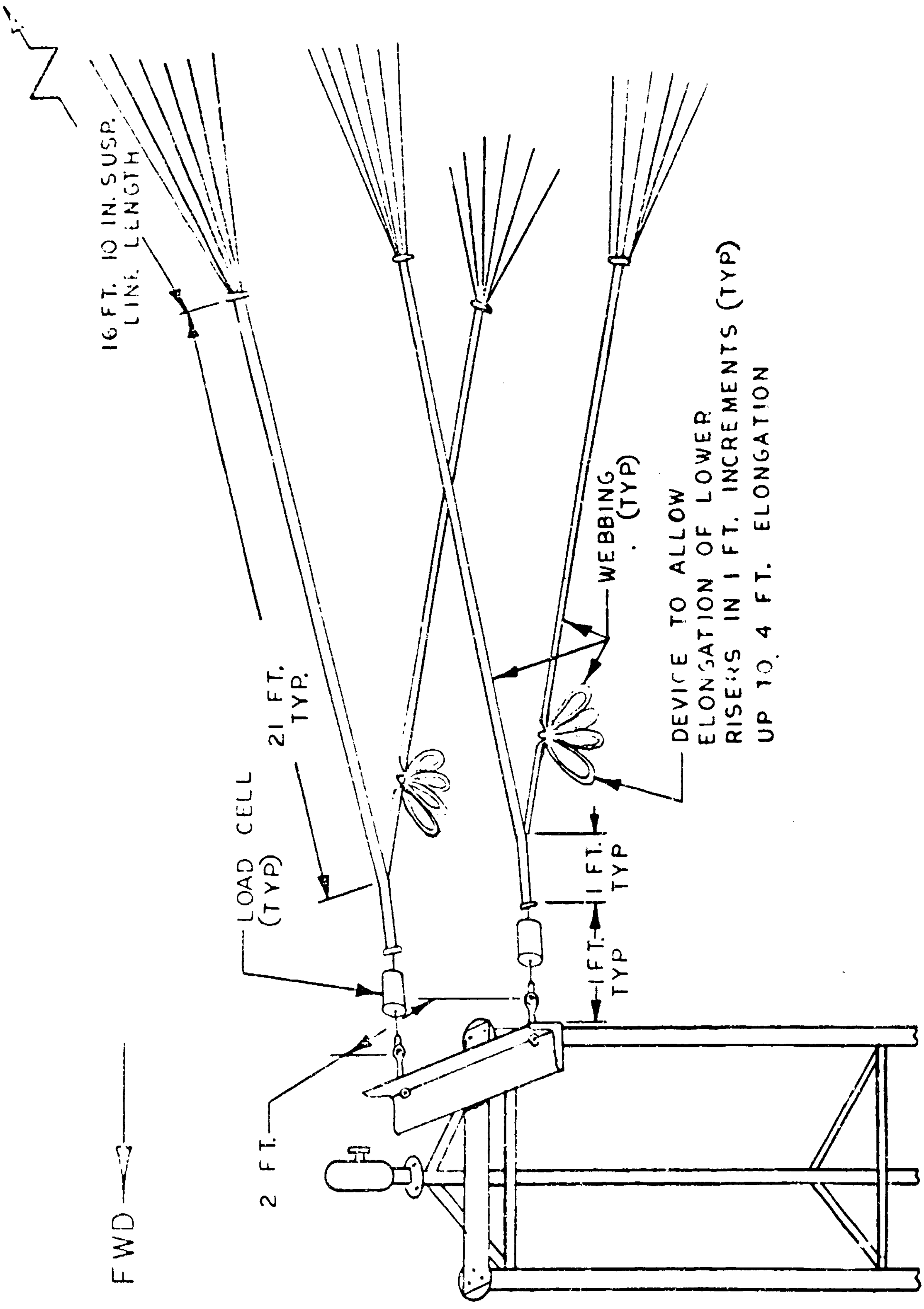

16 FT. 10 IN. SUSP. LINE LENGTH
21 FT. TYP.
LOAD CELL (TYP)
2 FT.
FWD
1 FT. TYP
1 FT. TYP
WEBBING (TYP)
DEVICE TO ALLOW ELONGATION OF LOWER RISERS IN 1 FT. INCREMENTS (TYP) UP TO 4 FT. ELONGATION

FIGURE 5.

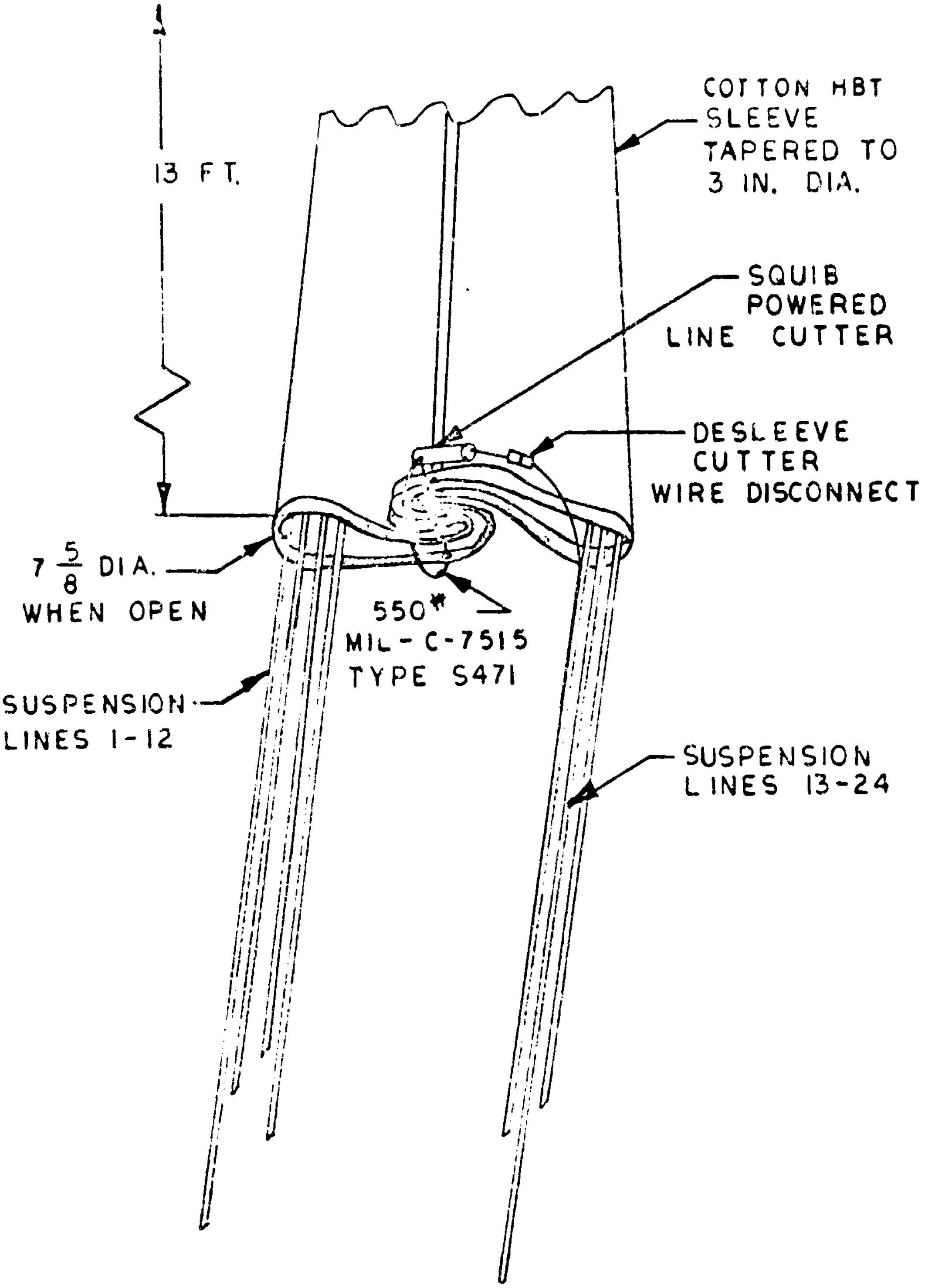
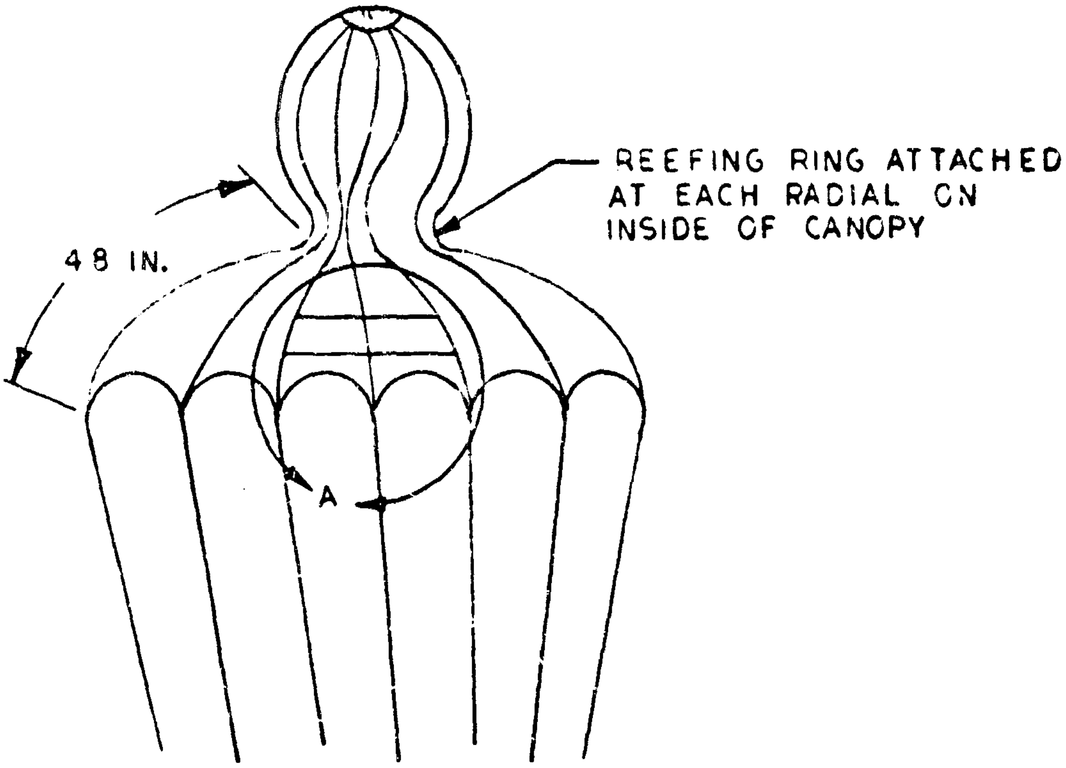
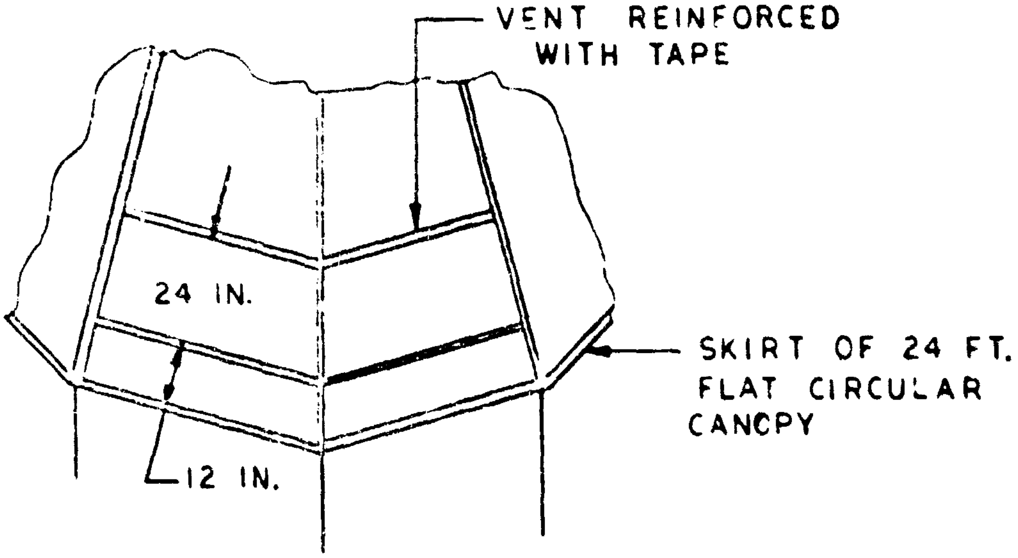

COTTON HBT SLEEVE TAPERED TO 3 IN. DIA.
13 FT.
SQUIB POWERED LINE CUTTER
DESLEEVE CUTTER WIRE DISCONNECT
7 5/8 DIA. WHEN OPEN
550# MIL-C-7515 TYPE S471
SUSPENSION LINES 1-12
SUSPENSION LINES 13-24

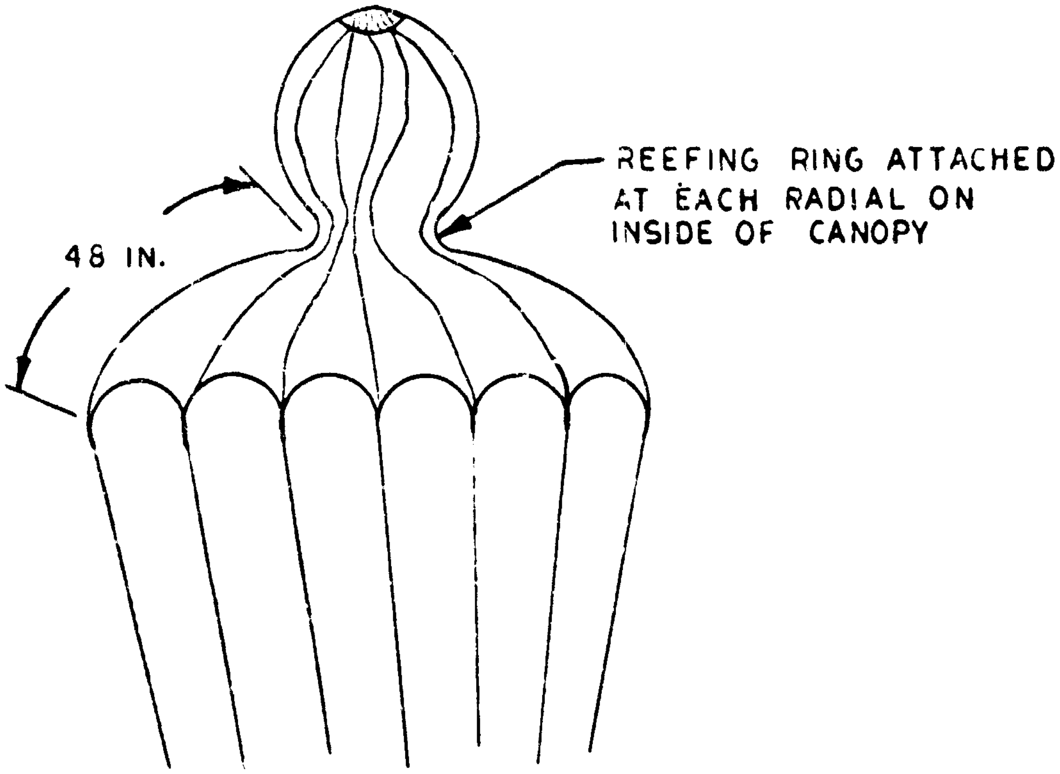
FIGURE 6.





DETAIL A

FIGURE 7.



48 IN.
REEFING RING ATTACHED AT EACH RADIAL ON INSIDE OF CANOPY

FIGURE 8.

TEST NO.	TEST DESCRIPTION	KIAS	t_f	Fo(Lbs)	Fc(Lbs)	$\Delta\alpha°$		Period(sec)
						from	to	
62T-100	Individual P/C idiosyncracy test, without reefing or modification, to full inflation (for vent mod. P/C)	35	3.96	1440	1040	+10	-12.5	3.88
62T-101		35	3.80	1351	910	+12.5	-16	3.04
62T-103	Sleeve deployed with 1 ft. additional length of lower risers and without reefing to full inflation	35	1.72	1580	1030	+23.8	+7	2.44
62T-104		35	2.18	1670	1090	+22.6	+10	4.46
62T-106	Same as above except with 2 ft additional lower riser length	35	2.26	1546	1125	+40	+33	Stable
62T-107		35	2.27	1465	1000	+32	+26	Stable
62T-108B	Same as above except with addition of centerline	35	1.21	1200	775	+35	+32	Stable
62T-109	Same as 62T-103 and 62T-104 except with 3 ft. additional lower riser length	35	1.77	1337	927	+30	0	1.17
62T-112	Same as 62T-103 and 62T-104 except with 4 ft. additional lower riser length	35	Unstable inflation no data			+18	0	1.17
62T-113		35	(Same unstable performance as 62T-112)					
62T-115	Individual P/C idiosyncracy test, sleeve deployed without reefing or modification, to full inflation (for extended lower riser mod. (P/C)	35	1.46	1510	960	+28	-18	5.27
62T-116		35	1.86	1560	1124	+30	-12	4.08
62T-118	Sleeve Deployed without reefing to full inflation with vent modification.	35	3.04	1500	1000	+35	+28	Stable
62T-119		35	5.39	1510	1100	+33	0	2.54

TEST NO.	TEST DESCRIPTION	KIAS	t_f	Fo(Lbs)	Fc(Lbs)	$\Delta\alpha$°		Period(sec)
						from	to	
61T-121	Sleeve deployed with mid-canopy reefing to reefed inflation with vent modification.	35	1.16	240	200	-20		Stable
61T-122		35	0.85	280	270	-22		Stable
61T-124	Sleeve deployed with mid-canopy reefing, reefed inflation to full inflation with vent modification.	35	0.50	1770	1100	+25	-16	2.50

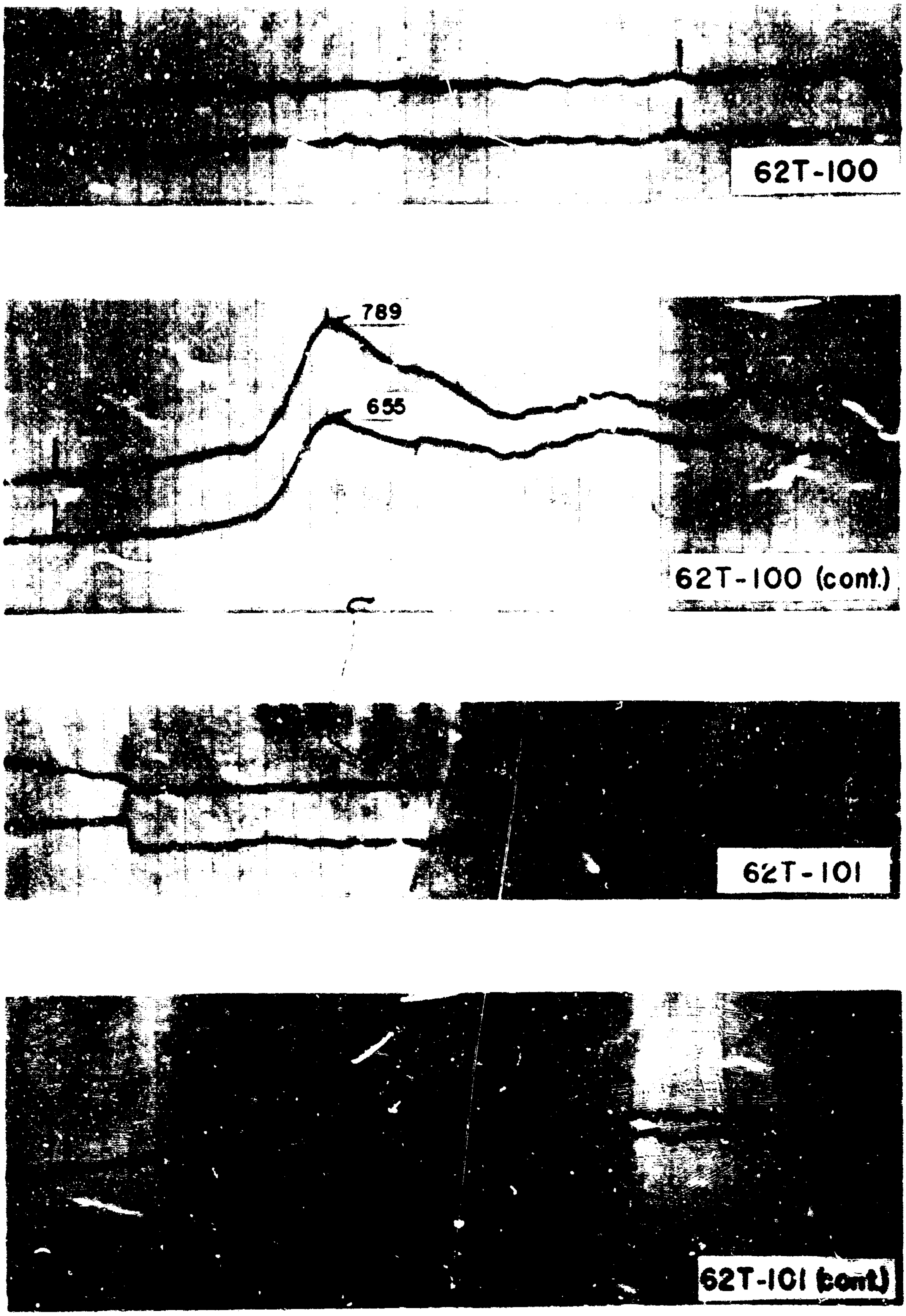


FIG. 9

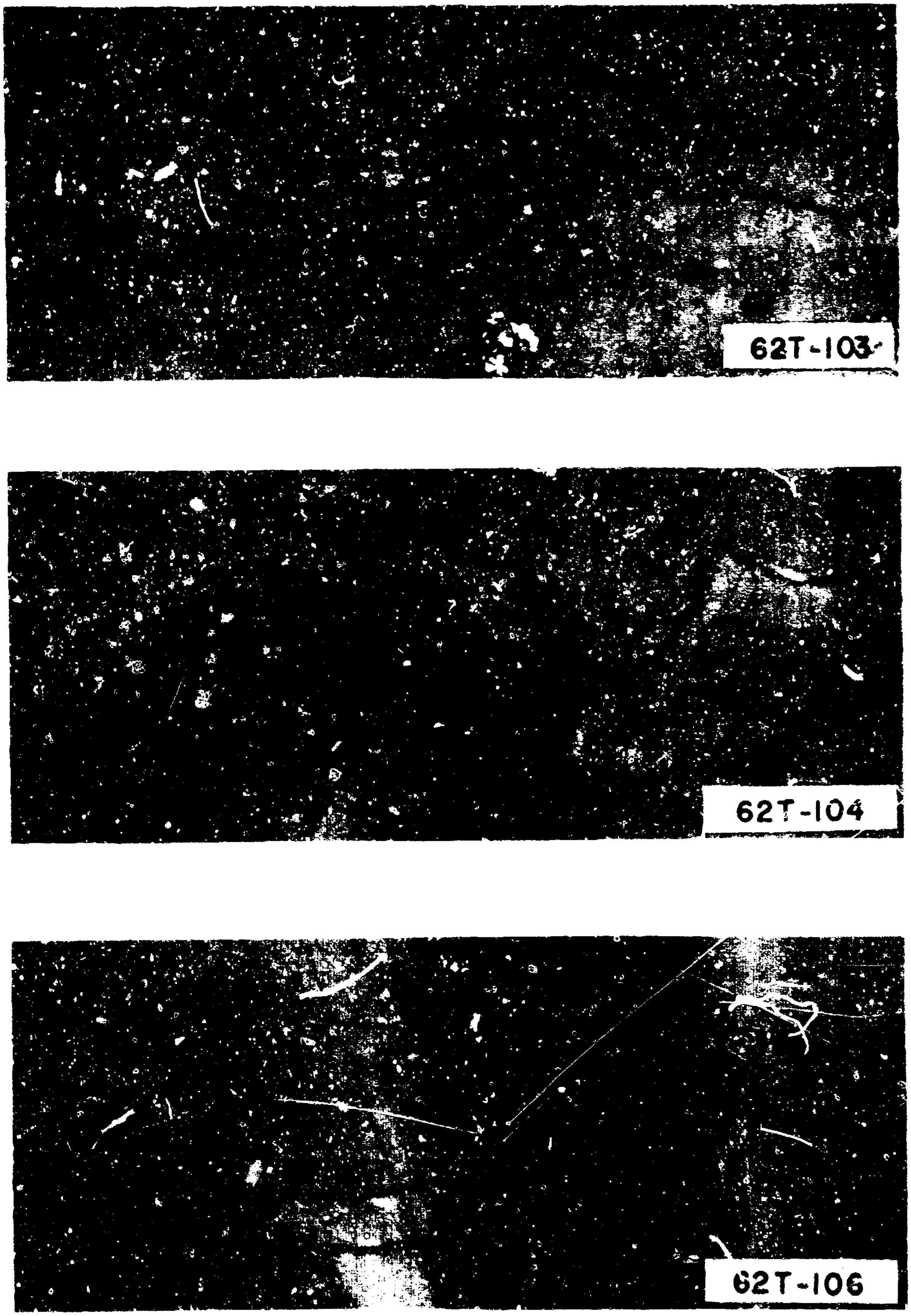


FIG. 10

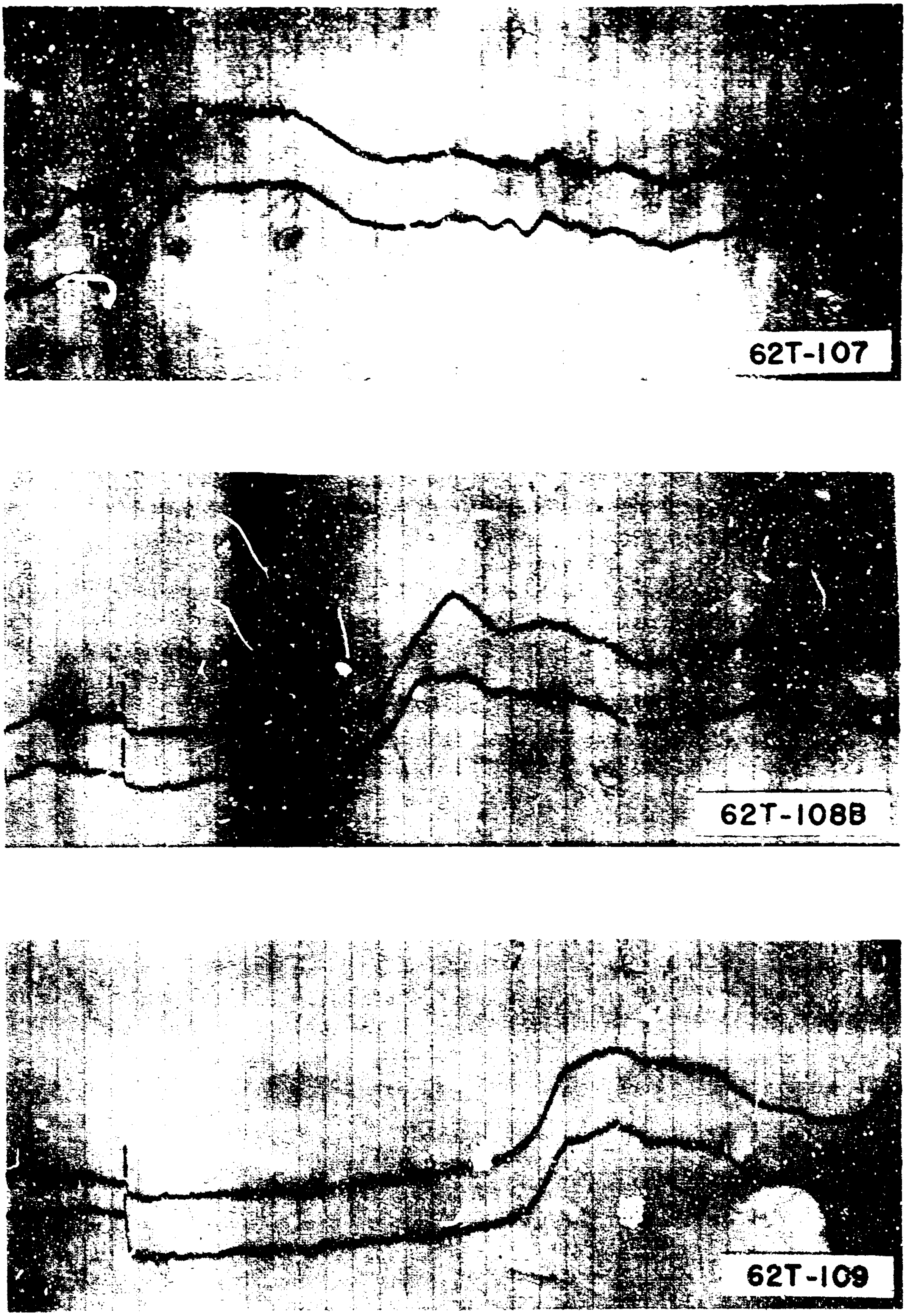


FIG. 11

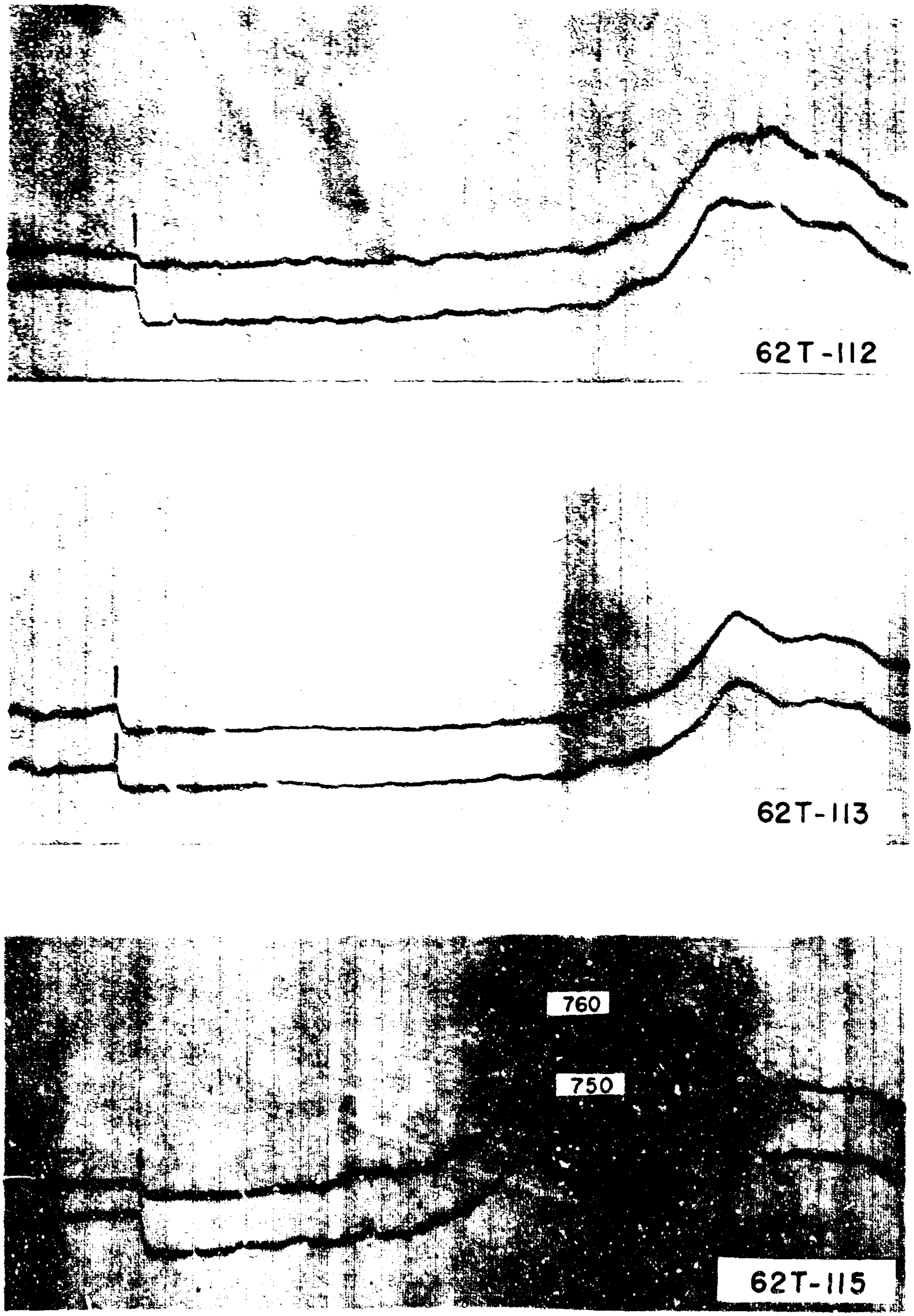
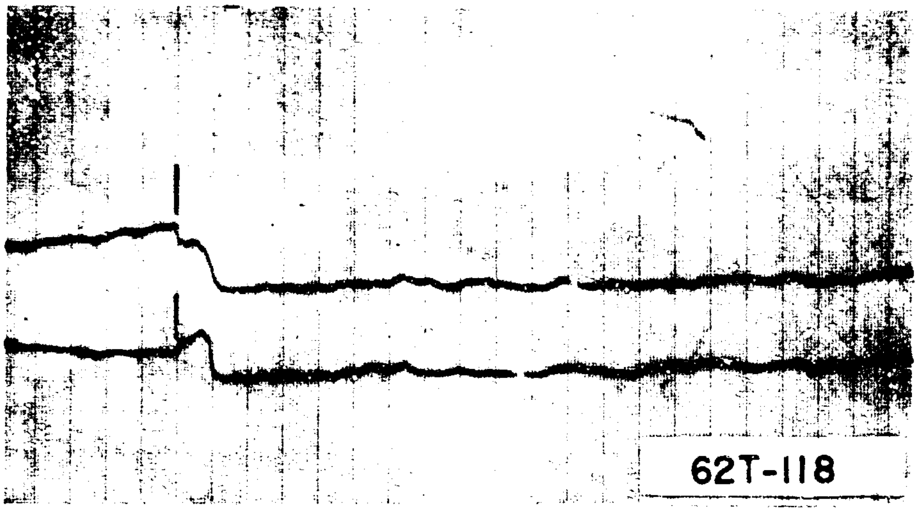
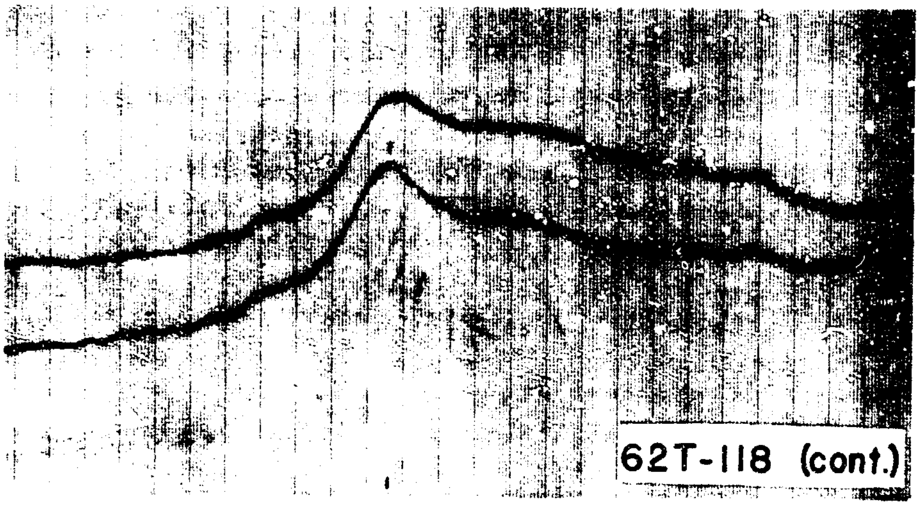


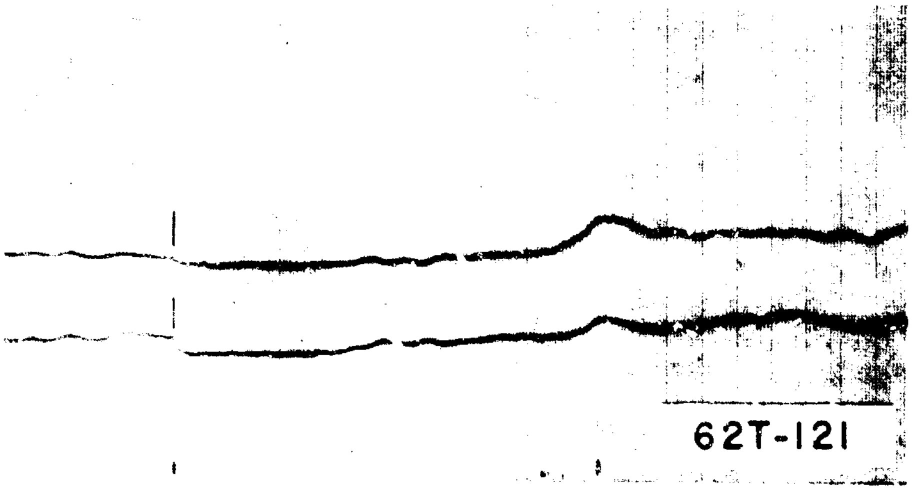
FIG. 12



62T-118

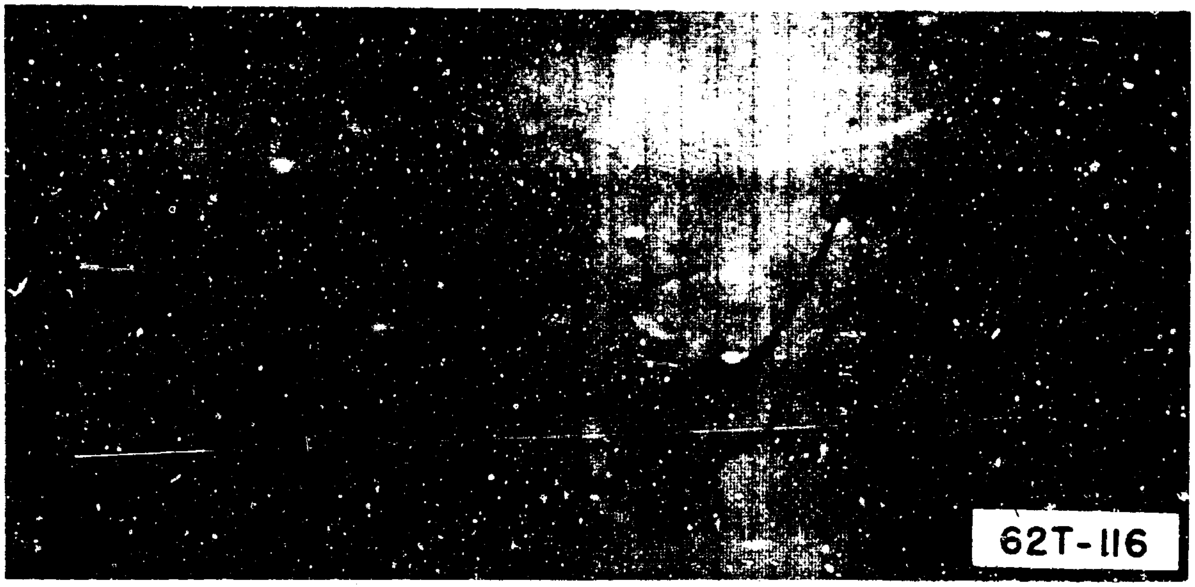


62T-118 (cont.)

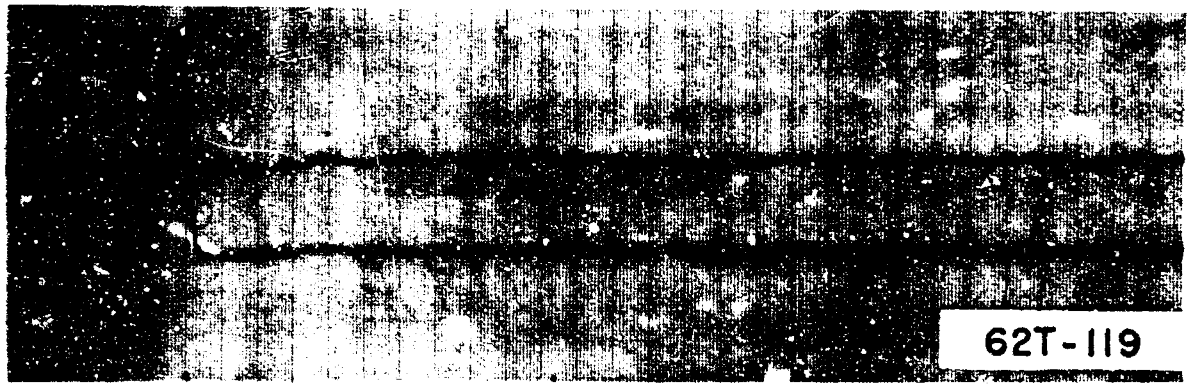


62T-121

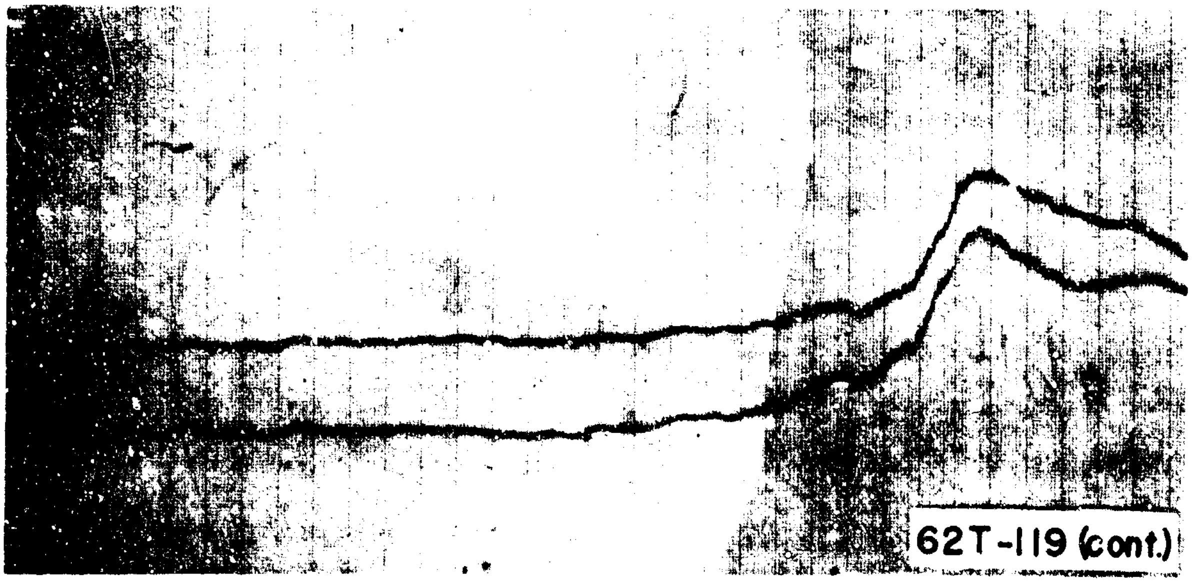
FIG. 13



62T-116



62T-119



62T-119 (cont.)

FIG. 14

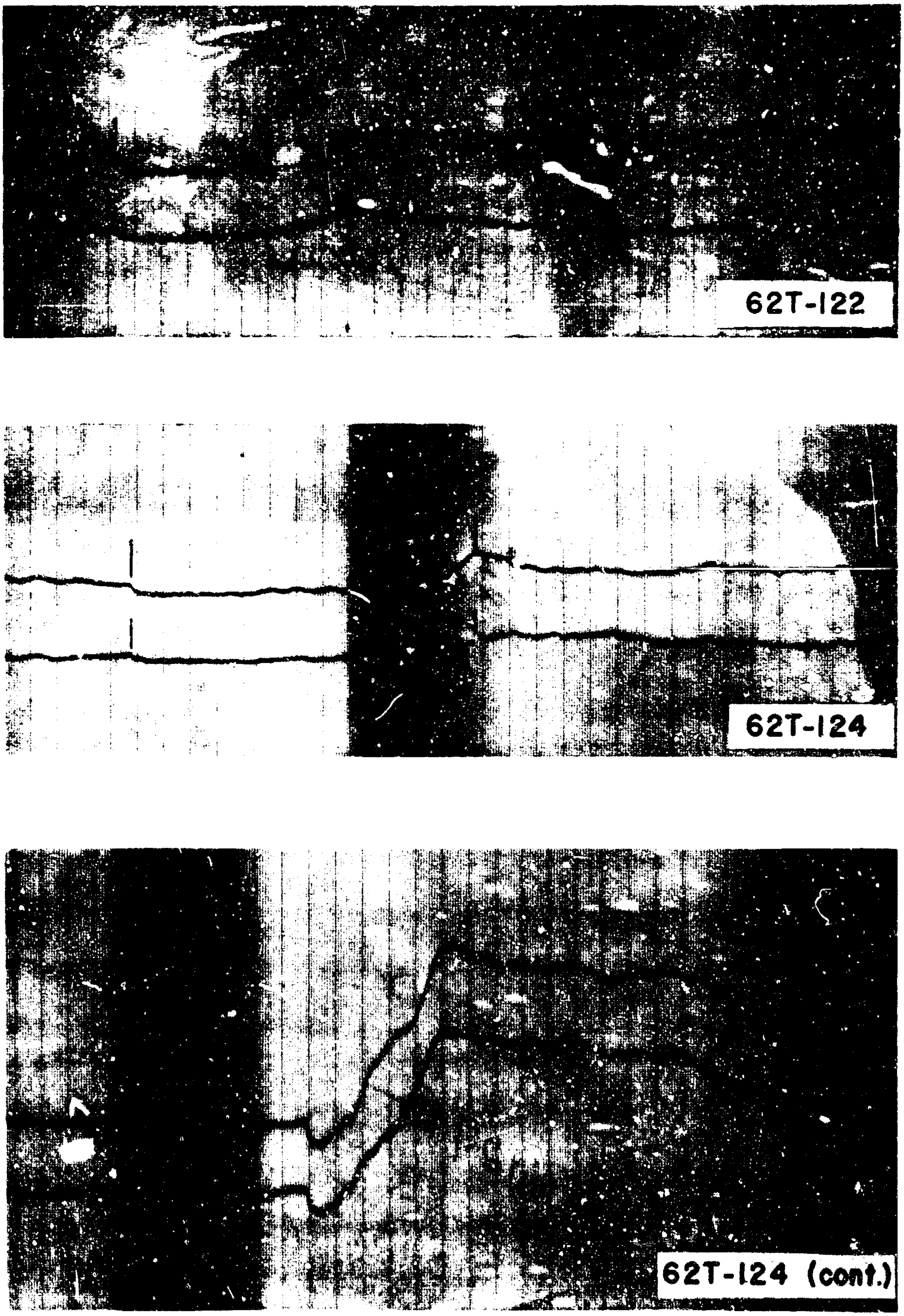


FIG. 15

VI

Compatibility Analysis

Weight and Size Limits

Flight Safety Analysis

Weight and Cost Analysis

Logistics and Training Analysis

VI 1.0 Introduction

Consideration of the conclusions reached and the recommendations made pertaining to the two LOADS configurations that were studied makes any subsequent analyses of the impracticable equipment seem superfluous, and the following discussion may help to explain why.

2.0 Discussion

New and serious problems continued to present themselves right up till the termination of tenth scale pendulum tests, of types for which there were no forthcoming practical solutions.

A sample reiteration of some problems are:

(a) Concepts required opening augmentation (which concept can perform job alone) to inflate in time.

(b) No effective lift till inflated.

(c) Lift vector orientation (deployment) problems.

(d) Destabilizing effects of lift mechanisms.

(e) Increased riser complexity.

(f) Failure to inflate in time, if at all when tenth scale pendulum tested.

(g) Unknown cluster behavior.

(h) Lift achievable with configurations tested would not make significant contribution to performances.

When the above problems compound, the ideas appear even less applicable.

Therefore, without knowing what the actual basic mechanism of a workable lift configuration might be, the compatibility of such a system with the aircraft system, the safety involved with its use, and its weight and cost are inestimable.

3.0 Findings

If, however, the proposed configurations were functional, the aircraft compatibility analysis, size and weight limits safety analysis, and logistics and training analysis would have resulted in the same findings as for the AFOADS concepts and reference to the Stencel Aero Engineering Corporation report dated November, 1966, is recommended.

System weight and cost would have been higher though, based on the requirement for the additional application of AFOADS principles.

X

FUNCTIONAL RELIABILITY ANALYSIS

X Functional Reliability Analysis

The LOADS parachute configuration found to be most successful was the tilted canopy (extended lower risers) modification. Unfortunately, this and other LOADS configurations did not perform efficiently and as such could not be considered as final lifting parachute configurations. The functional reliability described herein therefore assumes a sequence of events that is likely even though adequate lift capability has not been shown.

The proposed procedure for payload extraction by reefed main parachutes is a significant change. The need for main parachute inflation immediately after payload tip-off physically requires that the main parachute also be deployed and used to extract the payload. The current procedure of using an extractor parachute to deploy the main parachute packs would be maintained. To avoid main extraction of the payload at rates in excess of 1.5 g's it would be necessary to reef the main parachutes until they brought the payload to aircraft tip-off. The use of main parachutes to extract the payload causes two new events to occur with the payload in the aircraft. Namely, main parachute deployment, and reefed main inflation. The occurrence of these two events increase the chance of functional failure in close proximity with the aircraft; however, failures in main deployment and reefed inflation can be separated from the aircraft by cutting away of the parachutes, thus also saving the payload. The physical process of payload extraction would not be any different whether a large extraction or reefed main parachute applied the moving force. The functional reliability of extraction by reefed main parachutes is not expected to be significantly different from the conventional system methods.

A comparison of conventional and reefed main extraction functional reliability is given in Figure 16. Air drop events are divided into three categories; A, no drop; B, aircraft loss; and C, payload loss.

Referring to Figure 16, the overall sequence reliability from extractor deployment is:

Conventional. $R_c = A. A. B. C. C. C.$

LOADS. $R_L = A. A. A. A. B. C. C. C.$

The greater number of (A) events for LOADS indicate the increased chance for trouble while the payload is still in the aircraft, however, the (A) events can be negated by cutting the parachutes away from the payload before payload release. The same number of (B) and (C) events would indicate similar chances of success after payload release for both conventional and LOADS Overall, the LOADS system sequence does not show as high a reliability potential as the conventional sequence.

FUNCTIONAL RELIABILITY COMPARISON

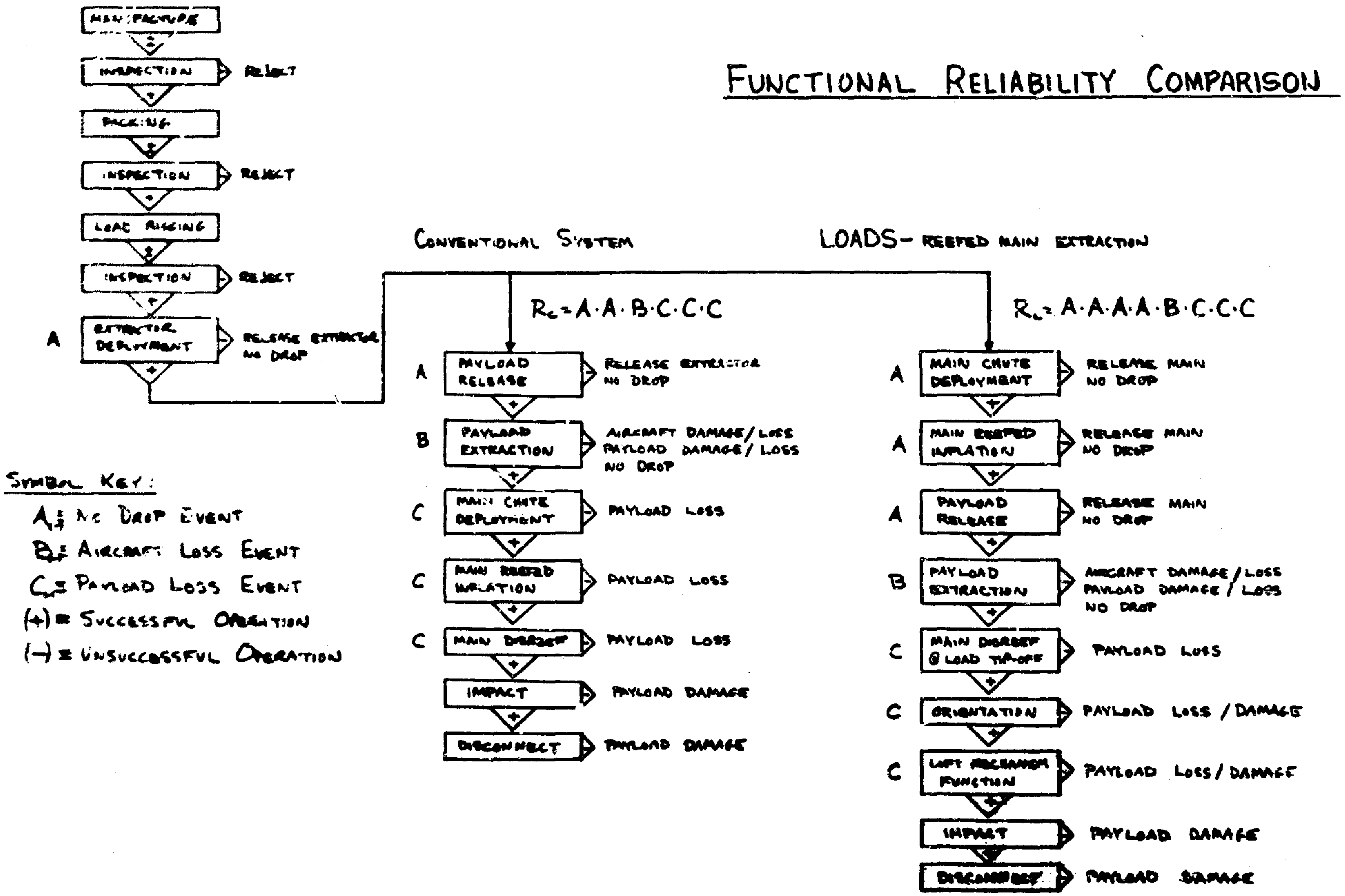


FIGURE 16

CONCLUSIONS AND RECOMMENDATIONS

STENCEL AERO ENGINEERING CORPORATION

After a thorough preliminary investigation of the LOADS concepts as proposed, this Contractor can only conclude that either of the conceived lifting parachute systems alone cannot meet the requirements of a low altitude cargo delivery system.

Theoretically, the initiation of lift of the parachutes above the horizontal at the time of payload tip-off does help in damping system oscillation. In reality, however, lift would not be realized until the parachutes are fully inflated, and the short time remaining (4 to 5 seconds maximum) before impact, after inflation, would not be sufficient for the lifting chutes to be very beneficial to system performance.

Correct orientation for the decelerators remains as an unresolved problem.

With the cognizance of these and other conclusions reported in the text, the only recommendations Stencel Aero Engineering Corporation can make would be to study extensions of the LOADS design concepts in order to analytically develop a low altitude delivery system capable of conforming to the mission requirements.

APPENDIX A

APPENDIX (A)

COMPUTER TRAJECTORY PROGRAM

The purpose of the computer trajectory program was to evaluate the effectiveness of the LOADS hardware concepts. It is based on equations that describe a two degree of freedom trajectory motion combined with a one degree of freedom system rotation.

Because of the transient nature of low altitude airdrop specific attention has been given to mathematical expression of the system oscillation and attitude factors. Forces acting on both the payload and the parachute are described separately and combined to define both trajectory motion forces and system rotational moments. A diagram of the physical model and basic equations are shown in Figure A-1.

The equations were written and programmed for application on the IBM 1620 Computer and function in a manner as shown by the flow chart of Figure A-2.

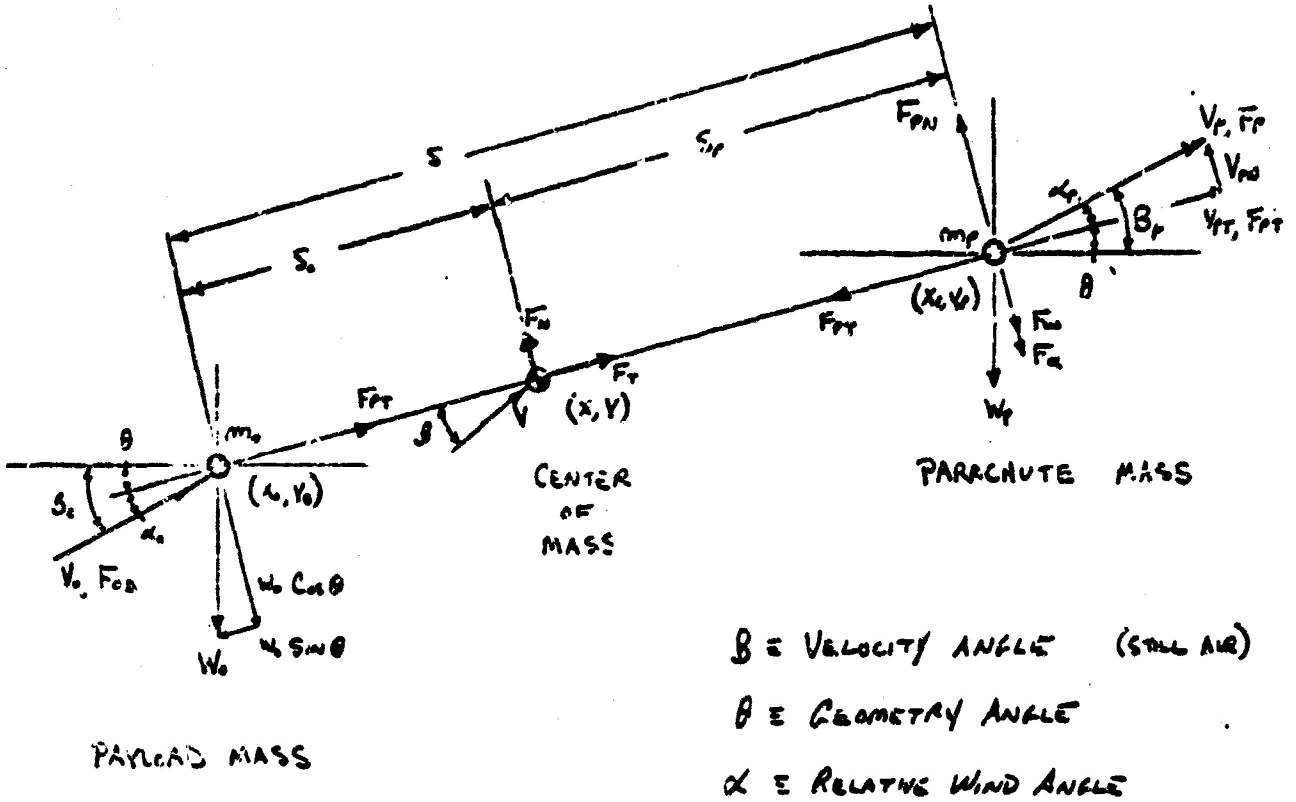
The input data, constants and program options have been made flexible in order that various inflation concepts can be evaluated and so that the oscillation attitude factors can be varied. The program permits variations in parachute lift, drag, opening rate, effective air mass, damping, force limit, weight, system length, number of parachutes and other initial input conditions. The mathematical symbols are defined by Figure A-3. Figure A-4 presents an example of the input data format used to define each trajectory computer run. The resultant data is tabulated as shown by the example of Figure A-5.

Two options for parachute inflation have been provided in this program. Referring to the Figure A-2 flow chart; one option (+205) provides that the parachute inflate in proportion to the instantaneous diameter and a chosen force limit. This option permits the simulation of controlled opening without exceeding specified g-limits. The other option, (-205), uses a table input in which the opening characteristics of the conventional G-12 and G-11A can be specified either as typical data indicates or as modified to represent AFOADS. Typical data for the table input is derived from Figure A-6. Both option forms have been used throughout the analysis.

The choice of reasonable damping coefficients ($C_D W$) was made after a parametric study of maximum oscillation angles under different degrees of damping. (Ref. Fig. A-7). Other forms entering into the oscillation damping analysis were the effective apparent air mass term and the effective moment of inertia about the system mass center.

SUBJECT AFOADS/LOADS
TRAJECTORY PROGRAM #2
MATHEMATICAL MODEL

FIGURE A-1



$\beta \equiv$ VELOCITY ANGLE (STILL AIR)

$\theta \equiv$ GEOMETRY ANGLE

$\alpha \equiv$ RELATIVE WIND ANGLE

$$a_T = \frac{F_T}{m_o+m_p} \; ; \quad a_N = \frac{F_N}{m_o+m_p} \; , \quad \ddot{\theta} = \frac{M}{I}$$

$$F_T = F_P \cos\alpha_P - (W_P + W_o)\sin\theta + F_{oD}\cos\alpha_o$$

$$F_N = F_P \sin\alpha_P - (W_P + W_o)\cos\theta + F_a + F_{oD}\sin\alpha_o$$

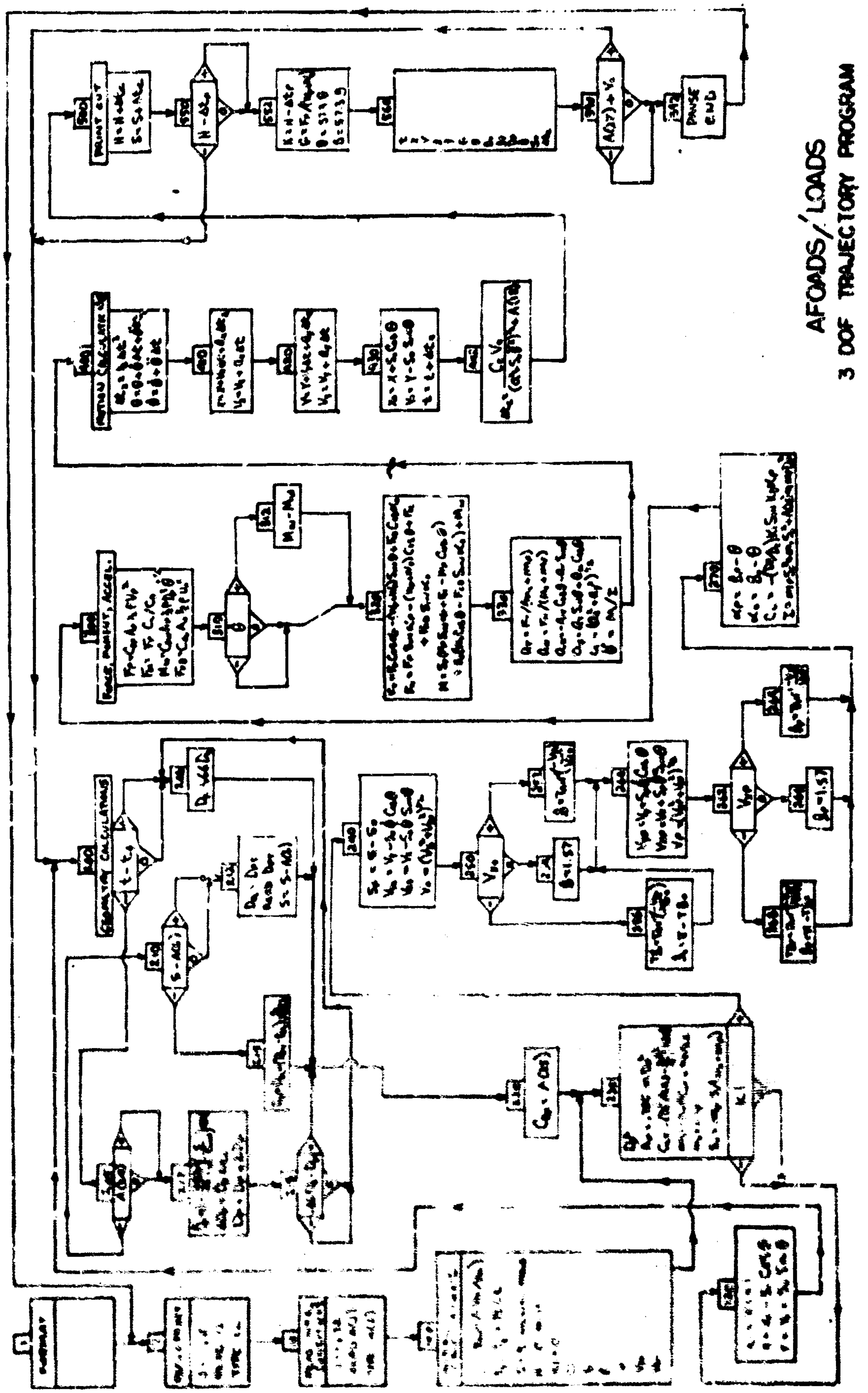
$$M = S_P(F_P \sin\alpha_P + F_a - W_P\cos\theta) + S_o(W_o\cos\theta - F_{oD}\sin\alpha_o) + M_w$$

$$F_P = C_{DP} A_P \tfrac{1}{2}\rho V_P^2$$

$$F_a = F_P (C_L / C_{DP})$$

$$F_{oD} = C_{Do} A_o \tfrac{1}{2}\rho V_o^2$$

$$M_w = C_{Dw} A_P \tfrac{1}{2}\rho D_P^3 \dot{\theta}^2$$



AFOADS/LOADS
3 DOF TRAJECTORY PROGRAM

FIGURE A-2

SUBJECT AFOADS/LOADS
PROGRAM #2 INPUT

FIGURE A-3

A(1)	W_o	PAYLOAD WEIGHT (LBS)
A(2)	D_o	NOMINAL PARACHUTE DIAMETER (FT)
A(3)	m	NUMBER OF PARACHUTES
A(4)	C_{DW}	DAMPING DRAG COEFFICIENT
A(5)	S	RISER LENGTH (PAYLOAD TO SKIRT) (FT)
A(6)	Δt_t	D_p TABLE INPUT TIME INTERVAL (SEC)
A(7)	σ	RATIO STD TO ACTUAL AIR DENSITY
A(8)	Δt_c	COMPUTING TIME INTERVAL (SEC)
A(9)	t_i	INITIAL TIME VALVE (RUN START) (SEC)
A(10)	x_o	LOAD HORIZONTAL POSITION (FT)
A(11)	Y_o	LOAD VERTICAL POSITION (FT)
A(12)	$\dot{x}_o$	LOAD HORIZONTAL VELOCITY (FT/SEC)
A(13)	$\dot{Y}_o$	LOAD VERTICAL VELOCITY (FT/SEC)
A(14)	θ	PARACHUTE AXIS (RISER) ANGLE (DEG)
A(15)	$\dot{\theta}$	PARACHUTE AXIS ANGULAR RATE (DEG/SEC)
A(16)	C_{Do}	PAYLOAD DRAG COEFFICIENT
A(17)	A_o	PAYLOAD DRAG-AREA (FT^2)
A(18)	b	Δt_c CONTROL FACTOR —
A(19)	C_e	Δt_c COMPUTATION ALLOWABLE ERROR CONSTANT
A(20)	K_{L1}	MAXIMUM LIFT COEFFICIENT CONSTANT
A(21)	K_{L2}	LIFT COEFFICIENT PERIOD CONSTANT
A(22)	Δt_p	PRINT-OUT TIME INTERVAL
A(23)	t_f	TIME TO FULL INFLATION OR RUN END -(SEC)
A(24)	W_p	PARACHUTE WEIGHT (LBS)
A(25)	C_{DP}	PARACHUTE PROJECTED AREA DRAG COEFFICIENT
A(26)	KI	EFFECTIVE AIR MASS INERTIA CONSTANT
A(27)	h	DISTANCE ABOVE GROUND (FT)
A(28)	K_m	EFFECTIVE AIR MASS VOLUME CONSTANT
A(29)	—	D_p MODE - DECISION OPERATOR
A(30)	G_{max}	MAXIMUM SYSTEM LOADING (g's)
A(31)	$\dot{D}_p$	PARACHUTE DIAMETER OPENING RATE (FT/SEC)
A(32)	—	D_p INFLATION RATE CONTROL OPERATOR (0 or 1)

BY________ DATE________ SUBJECT PROGRAM #2 INPUT DATA SHEET NO.____ OF____

CHKD. BY________ DATE________ LOADS JOB NO. FIGURE A-4

INPUT	I.D.	140	143	157
A(1)	W_0	22150	22150	22150
A(2)	D_0	100	100	100
A(3)	n_1	7	7	7
A(4)	C_{DW}	15	15	15
A(5)	S	210	2.10	210
A(6)	ct_c	1	1	1
A(7)	σ	1	1	1
A(8)	Δt_c	0.01	0.01	0.01
A(9)	t_2	0	0	0
A(10)	X_0	276	276	276
A(11)	Y_0	0	0	0
A(12)	V_x	167	167	167
A(13)	V_y	0	0	0
A(14)	θ	0	0	0
A(15)	$\dot{\theta}$	0	0	0
A(16)	C_{D0}	0.8	0.8	0.8
A(17)	A_0	10	10	10
A(18)	b_t	1	1	1
A(19)	C_t	0.05	0.05	0.05
A(20)	K_{L1}	1	0	1.6
A(21)	K_{L2}	9	9	9
A(22)	Δt_p	0.5	0.5	0.5
A(23)	t_f	9	6	6
A(24)	W_p	700	700	700
A(25)	C_{DP}	1.6	1.6	1.6
A(26)	KI	0.2	0.2	0.2
A(27)	h	600	600	600
A(28)	K_m	0.7	0.7	0.7
A(29)	$\dot{D}_p(+)$	−1	−1	−1
A(30)	G_{max}	5	5	5
A(31)	D_p	30	30	30
A(32)	$(\frac{D}{D_0})_c$	0	0	0
		$t_f=6$	$t_f=6$	$t_f=6$
		D_p	D_p-t	D_p
		4	4	4
		6	6	6
		10.7	10.7	10.7
		19	19	19
		30.7	30.7	30.7
		46	46	46
		66	66	66
		66	66	66
		66	66	66

BY ________ DATE ______ SUBJECT 1620 COMPUTER DATA
CHKD BY ________ DATE ______ TRAJECTORY ANALYSIS
LOADS

FIGURE A-5

PAYLOAD WT. 22150 LBS

RUN NO. 140

PARACHUTE DIA. 100 FT.

PARACHUTE NO. 7

INFLATION DIAMETER (TABLE @ 1 SEC INTERVALS)
4, 6, 10.7, 18.0, 30.7, 46, 66.

$C_L = 1$

t (SEC)	X (FT)	Y (FT)	V_x (FT/SEC)	V_y (FT/SEC)	G (g's)	θ (DEG)	B_o (DEG)	B_p (DEG)	D_p (FT)	$\dot{\theta}$ (RAD/SEC)	S (FT)
0	276	0	167	0	—	0	0	0	4	0	—
.50	360	-4.09	164.8	-8.3	.31	.37	2.89	2.07	4.98	.029	9.32
.98	437.7	-15.6	159.4	-24.0	.41	1.85	8.57	4.55	5.95	.081	10.5
1.44	510	-33.5	152.0	-39.3	.70	4.75	14.5	5.96	8.0	.139	13.7
1.64	571	-55	141.5	-53.0	.97	8.53	26.5	7.35	9.9	.185	17.3
2.50	663	-102	114	-73.7	1.68	16.7	32.7	11.4	14.7	.250	29.1
3.00	720	-147	85.9	-84.6	2.08	24.5	44.5	14.9	18.9	.296	40.8
3.42	762	-191	57.9	-90.4	2.48	32.2	57.3	19.2	23.8	.327	55.6
3.91	793	-246	26.2	-90.9	2.61	41.7	73.9	26.1	29.6	.345	72.6
4.43	810	-305	-3.4	-86.0	2.72	52.0	92.2	35.9	37.2	.351	92.5
4.90	810	-355	-23.6	-75.9	2.66	61.4	107.3	45.2	44.4	.338	108
5.43	800	-403	-35.6	-59.9	2.60	70.9	120.7	56.8	54.4	.288	124
5.98	784	-439	-31.9	-41.5	2.31	78.8	127.5	67.5	65.5	.204	135
6.40	772	-454	-24.9	-32.9	1.80	83.1	127.2	70.8	66.7	.156	135.5
6.95	762	-470	-19.0	-27.1	1.43	87.4	125.0	73.1	↑	.119	↑
7.46	753	-483	-15.1	-24.2	1.25	90.5	121.9	75.1		.095	
7.85	748	-492	-12.6	-22.9	1.17	92.4	118.9	76.5		.080	
8.28	744	-501	-10.4	-22.0	1.12	94.2	115.2	77.9		.066	
8.98	738	-516	-7.1	-21.4	1.07	96.5	108.3	79.9		.047	
9.47	736	-527	-5.0	-21.3	1.05	97.7	103.1	81.0		.035	
9.97	735	-537	-2.9	-21.4	1.03	98.5	97.7	81.9		.029	
10.49	734	-549	-.83	-21.7	1.02	99.0	92.2	82.5		.012	
10.75	734	-554	.21	-21.8	1.02	99.1	89.4	82.7		.007	
11.29	736	-566	2.35	-22.2	1.02	99.2	83.9	83.1		-.004	
11.85	738	-579	4.57	-22.5	1.02	98.9	78.5	83.1	↓	-.014	↓
12.45	742	-593	6.8	-22.9	1.02	98.3	73.4	82.8		-.024	
12.78	745	-600	7.9	-23.0	1.03	97.8	70.9	82.5	66.7	-.028	135.5

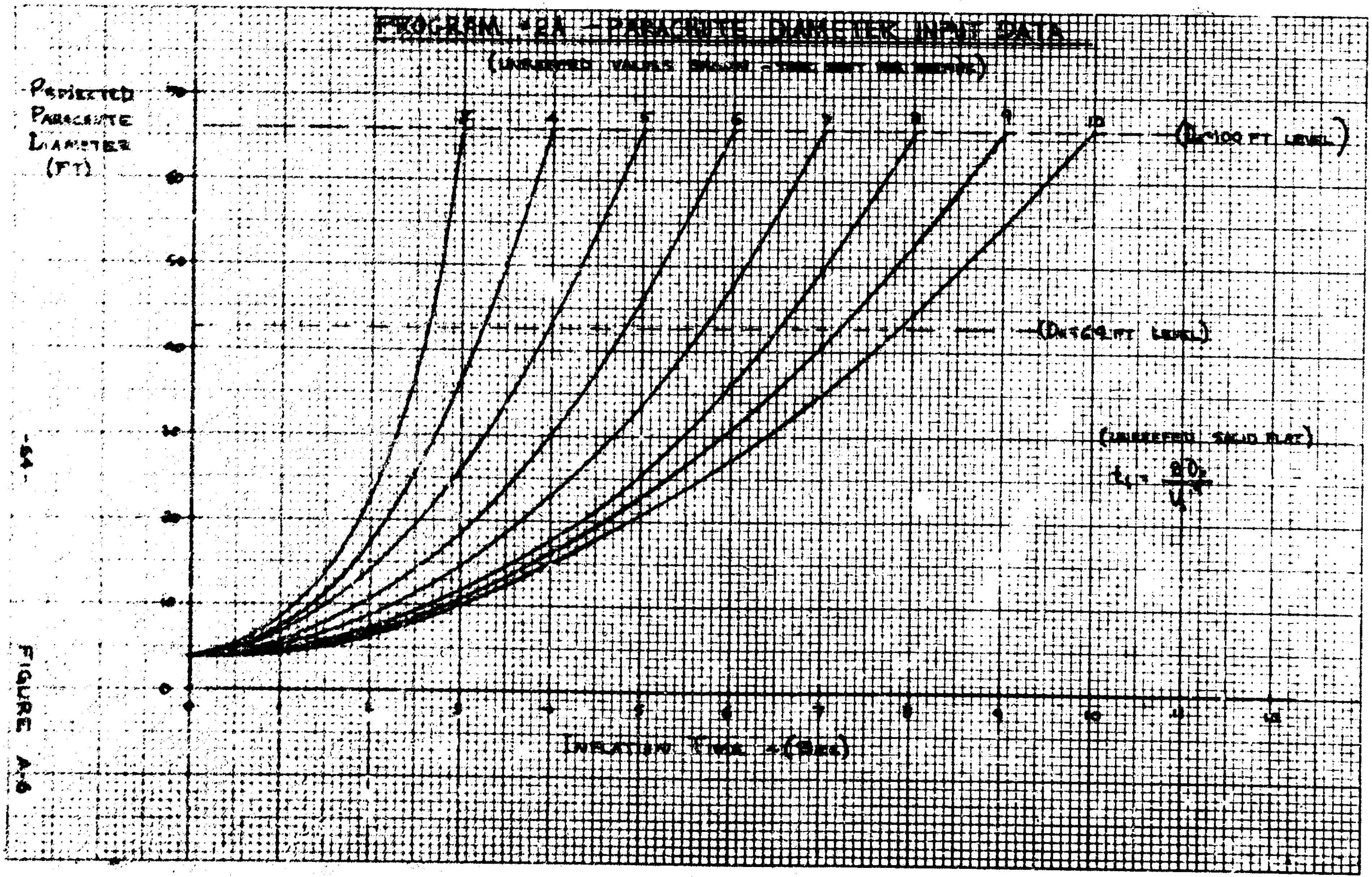

PROGRAM #2A — PARACHUTE DIAMETER INPUT DATA
(UNREEFED VALUES SHOWN — [illegible])
PROJECTED PARACHUTE DIAMETER (FT)
70
60
50
40
30
20
10
0
3
4
5
6
7
8
9
10
(D₀=100 FT LEVEL)
(D₀=64 FT LEVEL)
(UNREEFED SOLID FLAT)
$t_i = \frac{8D_0}{V_1}$
0
1
2
3
4
5
6
7
8
9
10
11
12
INFLATION TIME — (SEC)

FIGURE A-6

DAMPING COEFFICIENT EFFECT ON OSCILLATION

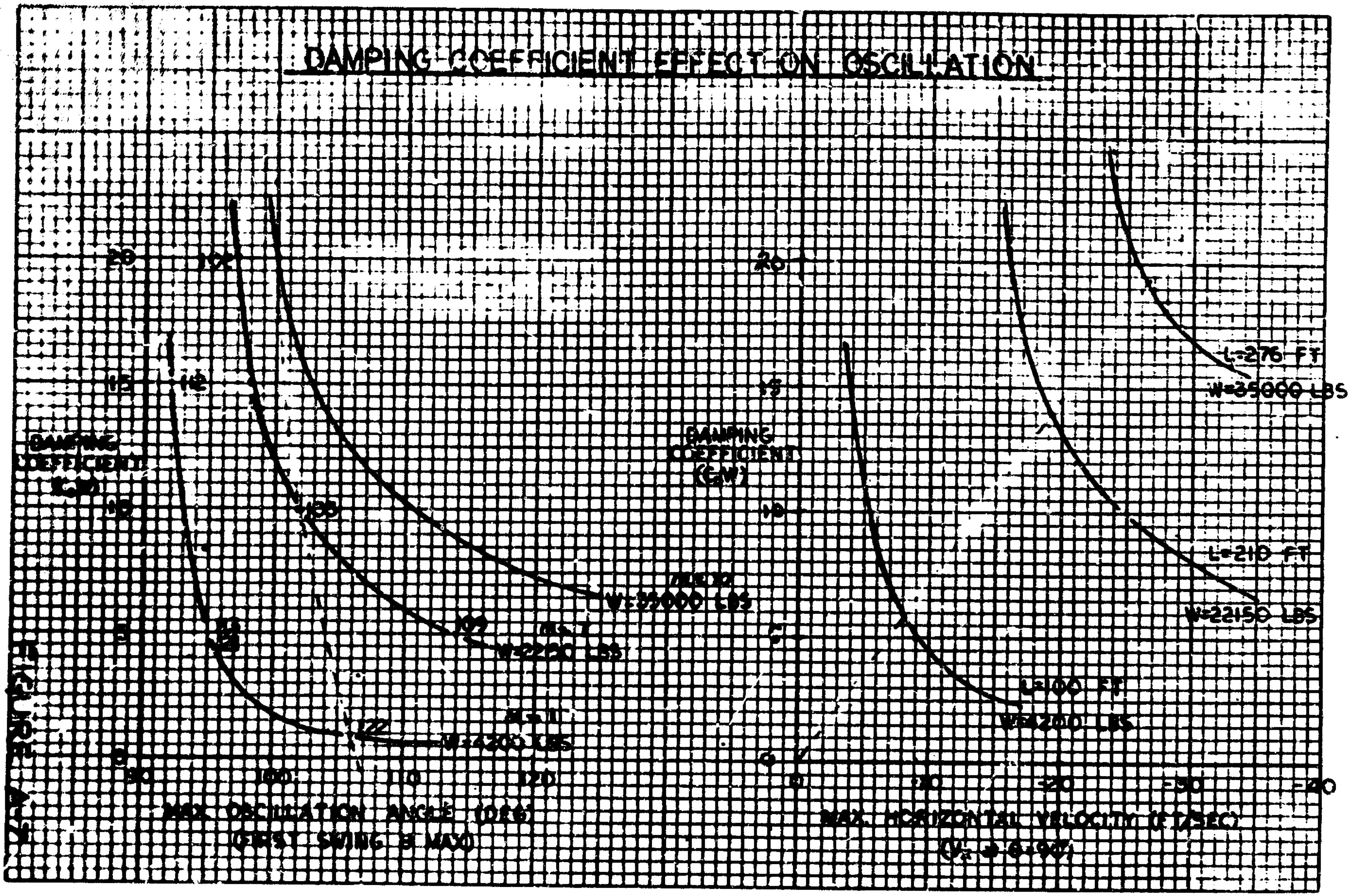


FIGURE A-7

APPENDIX B

APPENDIX (B)

1/10 SCALE TRAJECTORY DYNAMIC MODEL TESTS

The purpose of 1/10 scale model testing the LOADS concept was to obtain rapid and realistic indications of full scale performance. The G-11A parachute models were scaled as accurately as possible in order to provide similar inflation time and inflation characteristic data. The tests were performed with the goal of obtaining cluster interference data, inflation time under transient dynamics data, oscillation damping factor data and for trajectory data to compare with the computer results.

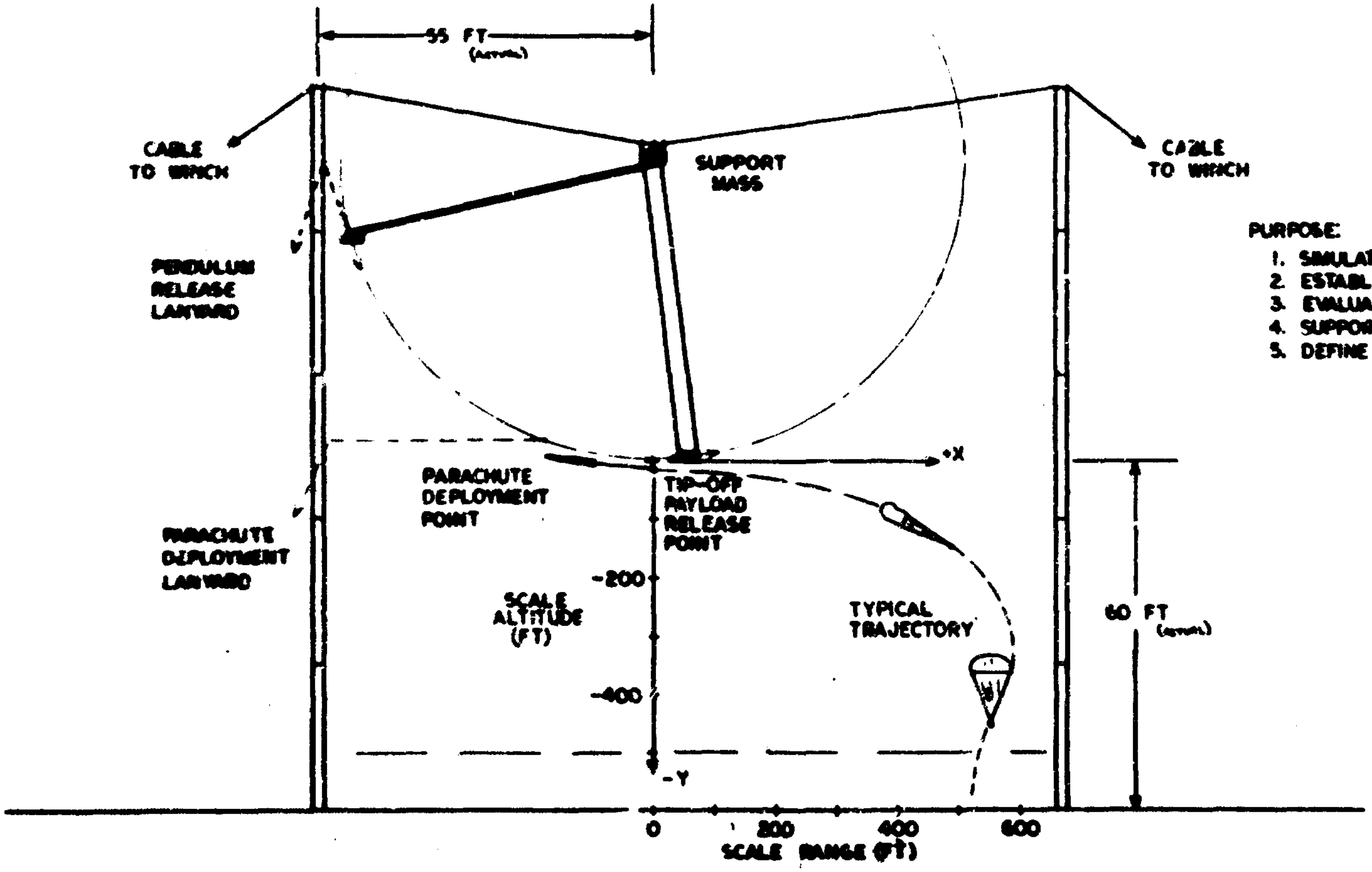
Validity of the 1/10 scale model data was established by a series of conventional model G-11A parachute drop tests in which the data was compared with actual full scale results on hand. The model data compared favorably in both inflation time and inflation characteristics after suitable scaling law corrections were performed. The test set-up and procedure is illustrated in Figure B-1. Approximately 60 drop tests were performed. The tip-off condition simulated a scaled weight of 4,200 pounds, air speed of 105 KIAS, and altitude of 550 feet.

Figure B-2 shows a trajectory comparison of the 1/10 scale results with that of a similar computer run. This figure shows a close agreement in trajectory when the inflation diameter time is in close agreement. Drop test #44 compares well with the computer assumptions in this respect. The fact that the oscillation modes are similar indicate a satisfactory computer model.

AFOADS/LOADS

$\frac{1}{10}$ SCALE CLUSTER PERFORMANCE TEST

HARDWARE & PROCEDURE



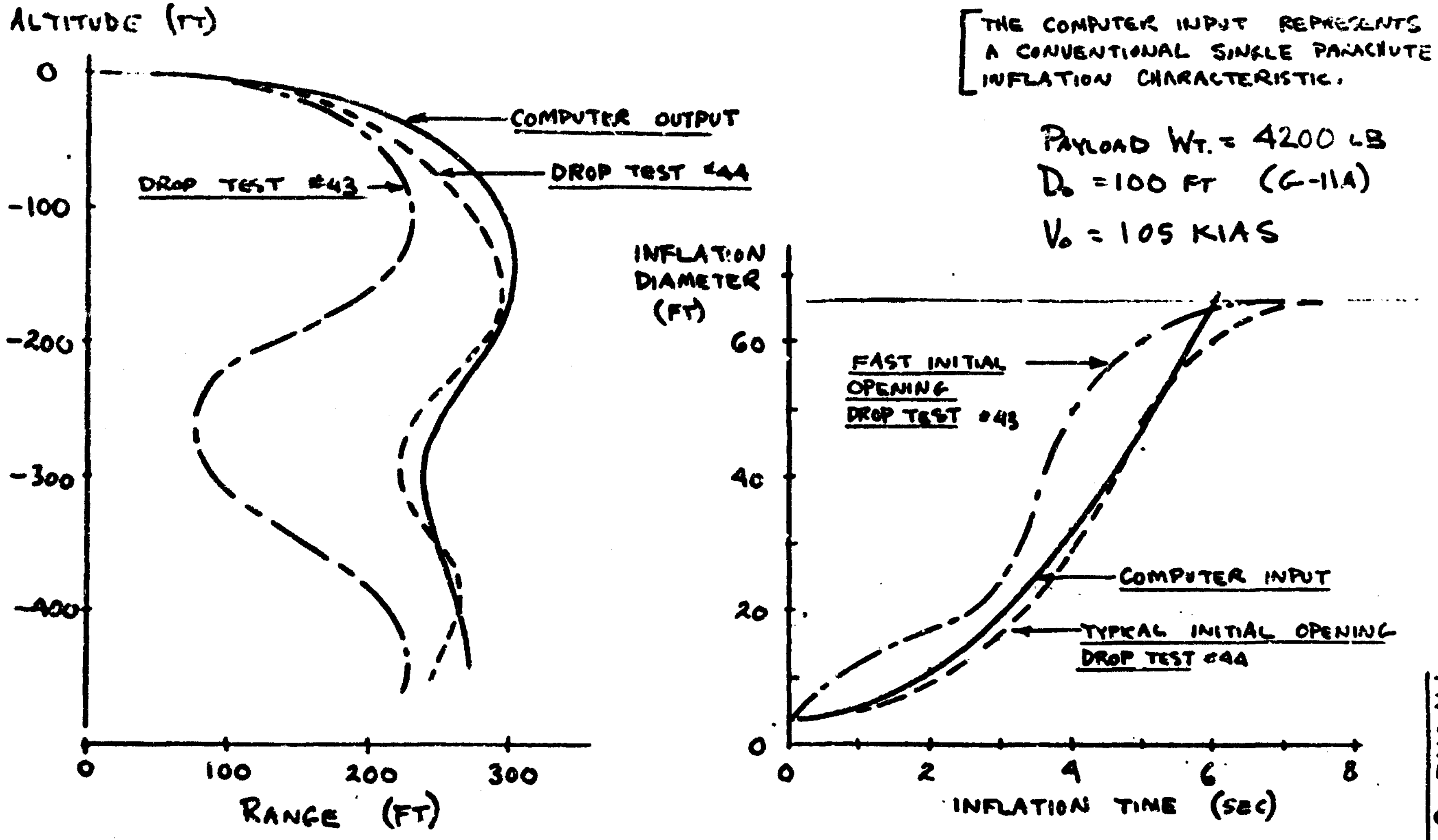
PURPOSE:

1. SIMULATE TRANSIENT DYNAMICS
2. ESTABLISH G-11A AFOADS/LOADS MARGIN
3. EVALUATE CLUSTER INTERFERENCE
4. SUPPORT COMPUTER TRAJECTORY DATA
5. DEFINE OSCILLATION DAMPING FACTOR

FIGURE B-1

TRAJECTORY COMPARISON

($\frac{1}{10}$ Scale Test Data with Computer Data)
(Data Corrected to Full Scale)



[THE COMPUTER INPUT REPRESENTS A CONVENTIONAL SINGLE PARACHUTE INFLATION CHARACTERISTIC.

PAYLOAD WT. = 4200 LB
D_o = 100 FT (G-11A)
V_o = 105 KIAS

FIGURE B-2

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Natick, Massachusetts

13. ABSTRACT

Progress is reported for all work accomplished on the following activities: (1) analytical studies-parachute dynamics, parachute performance required for low level cargo delivery; computer trajectory program, performance summary and conclusions; (2) runway level test results of parachute inflation and force-time histories with aerodynamic assistance and lifting canopies; (3) weight and size limits, flight safety, system weight and cost, logistics and training; (4) functional reliability.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
LOAD (Lifting of Aerodynamic Decelerators)	6,8		10			
Cargo	7		9			
Delivery	7		8			
Low altitude	7,4		8,4			
Air-drop operations	7,4		4			

Unclassified

Security Classification