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TECHNICAL REPORT

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PARACHUTE REEL-OUT REEL-IN LOW ALTITUTE AIRDROP EXPLORATORY DEVELOPMENT PROJECT NO. 1M121401D195 FINAL REPORT

by

R.R. Mills, Jr.
R.S. Payne, Jr.
J.L. Critcher
M.V. Runkles, III

AAI Corporation
Cockeysville, Md.

CONTRACT NO. DA19-129-AMC-847(N)

August 1966

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts

Airdrop Engineering
Division

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Airdrop Engineering Division
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ABSTRACT

This final report, issued by the AAI Corporation under Contract DA19-129-AMC-847(N) with the Airdrop Engineering Division of the U.S. Army Natick Laboratories, presents the results and conclusions reached during a period of evaluation from 30 November 1965 to 31 August 1966 of a low altitude airdrop system incorporating parachute reel-in/reel-out concept systems in order that cargos not now deliverable from low altitudes be capable of low altitude extraction and descent to the selected drop zone. The vertical impact velocity of the cargo is limited to 28.5 fps when dropped from altitudes of 500 feet or less. The analytical investigations conducted during this period have resulted in several candidate reel system designs that permit cargos between 2000 lbs to 35000 lbs. to meet these requirements. Estimates of the reliability, failure modes, size, cost and advantages and disadvantages of these concept systems are presented in this report, as are the assumptions and side conditions invoked during the analytical evaluations of the candidate systems.

I. INTRODUCTION

This report represents the final report issued by the AAI Corporation under Contract DA19-129-AMC-847(N) with the Airdrop Engineering Division of the U.S. Army Natick Laboratories, Natick, Massachusetts 01760. This report presents the technical aspects of a program of investigations of a low altitude airdrop system that incorporates parachute reel-in/reel-out concept devices in order that: (1) the cargo-ground impact conditions be improved over those presently achieved with standard airdrop systems, and (2) heavy cargos not now deliverable from low altitudes be capable of low altitude extraction and descent to the selected drop zone. The investigations conducted under this contract have covered the period from 30 November 1965 to 31 August 1966.

The primary objectives of this evaluation program are: (1) to analytically investigate the advantages and disadvantages of incorporating a sequence of parachute reel-in/reel-out events during the descent of a cargo after extraction from an aircraft flying at low altitude, in order to minimize the oscillatory motions experienced by the cargo during the descent, so that the cargo impacts the ground with little or no horizontal motion, at a specified vertical velocity, and (2) to evaluate devices and mechanisms capable of effecting the parachute reeling motions with respect to a series of additional requirements such as compatibility with present airdrop cargo systems and presently employed air drop procedures, etc. A secondary objective of this program is to provide a set of parameter magnitudes for use in evaluating the parachute reel-in/reel-out concept system against other systems also designed to satisfy these primary program objectives.

The performance goals, design and contract requirements applicable to this program are presented in Section II of this report in order to provide a comprehensive understanding of the program objectives. The information contained in Section II can be considered to define the envelope of conditions that must be met by the candidate parachute reel-in/reel-out devices evaluated during this program.

Section III reviews the major system parameters that have been identified during the contract investigations and the assumptions that have been incorporated into the analyses of the program. The technical discussions of this section are divided into two major parts: (1) those associated with the dynamics of extracting the cargo from the aircraft and the subsequent descent motion of the cargo-parachute(s) system, from a two-dimensional and a three-dimensional viewpoint, and (2) those associated with the concept design of the devices used to effect the reeling motions. Included in the discussions of the topics are the results of the evaluations conducted by the AAI staff during the contract investigations. In particular, the characteristics of the cargo descent trajectories are graphically presented, although the trajectory parameters that are of primary importance are presented in tabular form to aid in the evaluation of the system

Section IV of this report is reserved primarily for presentation of the items requested by Dunlap and Associates, Inc. in their report[1*] issued 22 April 1966. The parameters and discussions presented in this section are designed to aid the TIE contractor in generating the comparative evaluations of the various airdrop systems under study by AAI and others in terms of the operational scenarios selected for consideration. In addition, consideration is given in this section to both the human operational and mechanical reliability of the cargo-parachute reeling system.

Section V of this report presents the recommendations of the AAI Corporation with respect to future development of the concept parachute reel-in systems developed in Section III.

The response of the aircraft to the cargo extraction events are presented under separate cover[2] which comprises Part II of this final report.

* Superscript numbers denote references in Section VI.

II. SYSTEM PERFORMANCE GOALS, DESIGN AND CONTRACT REQUIREMENTS

A. Performance Goals

The airdrop systems evaluated during this program shall be 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 ground.
2. At aircraft speeds from 110 to 150 knots. Compatibility of the airdrop cargo system with aircraft speeds of 40 knots shall be evaluated.
3. In ground wind conditions from 0 to 15 knots.
4. In airdrop operations employing both single and mass formations (30 aircraft) of aircraft airdropping single and multiple cargo units.
5. With fewest possible restrictions on drop zone characteristics such as size, unobstructed area, flatness and texture of terrain.
6. At vertical cargo-ground impact velocities not exceeding 28.5 fps, at terrain altitudes from sea level to 5,000 feet and at ambient temperatures, between -65° F to 100°F.
7. Without modification to standard vehicles and equipment other than minor modifications which can be accomplished without special tools or equipment.
8. With a reliability of .995 and an accuracy CEP of 100 meters from the selected impact point.
9. For unit cargo weights from 2,000 to 35,000 pounds on airdrop platforms using currently standard and developmental aircraft unloading kits.
10. With a minimum of special training for 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. At night and under adverse weather conditions as outlined in AR 705-15.
14. Without complicating the rigging, loading, de-rigging and drop zone clearance of the airdrop item.
15. Without interfering with the concept of paratroopers jumping after the cargo from the same aircraft.

B. System Design Requirements

The airdrop systems must meet the following design requirements when developed. Hence, these conditions must be considered during the preliminary investigations accomplished during this program.

1. In-Flight Requirements

a. The airdrop system must be restrained until initiation of the airdrop sequence to the following minimum ultimate load factors acting independently:

(1) Forward ______________ 4.0,
(2) Aft ______________ 1.5,
(3) Lateral ______________ 1.5,
(4) Up ______________ 2.0.

b. The airdrop system must be capable of withstanding a downward load factor of 7.1, prior to initiation of the airdrop sequence, without a failure which would render the system inoperative.

c. The present rigging practice for in-flight cargo restraint should not be significantly changed.

d. Safety factors for metal components in the extraction systems shall be 1.5 for cargos weighing under 25,000 lbs., and 1.75 for cargos weighing over 25,000 lbs. The safety factor for textile components in the extraction system shall be 2.0.

e. In normal operation, the airdrop should not jeopardize flight safety and shall provide for emergency procedures and equipment for counteracting any system malfunction which would jeopardize flight safety.

2. Cargo Requirements

a. Forces applied to any single cargo suspension fitting shall not exceed 1.5 times the suspended weight. Suspension requirements are to be based on not more than four points on the airdrop item.

b. Extraction forces applied to the cargo shall not exceed 1.5 times the extracted cargo weight.

c. The system shall apply suspension and extraction forces directly to the airdrop item. The system shall also provide a means for applying extraction and suspension forces directly to the platform for cargos under 12,000 lbs.

d. The system shall be usable, within its weight limitations, for the airdrop of all Army materiel which is now air-droppable.

e. The system shall utilize standard airdrop platforms if possible. If standard platforms are not suitable, the structural design criteria for a platform compatible with the loading environment shall be determined. The system shall utilize standard and developmental aircraft unloading kits.

C. Contract Requirements

The items listed in this part are specific contract requirements that serve to define the major topics of the evaluation program. It will be noted that the investigations being conducted by the AAI staff, as outlined in Section III of this report, are aimed at satisfying these specific requirements.

1. A functional analysis of the airdrop system incorporating a sequence of parachute reel-in/reel-out events shall be conducted in order to determine the limitations and capabilities of the concept system with respect to reliability, accuracy, economy, simplicity and other goals, requirements and characteristics.

2. The system design shall aim for compatibility with C-130, C-141, CV-2, and CV-7 aircraft with respect to weight and size limitations. System analyses will be based on the characteristics of the C-130 aircraft.

3. Analysis of the system shall determine if any characteristics exist which would jeopardize flight safety in any phase of the airdrop mission.

4. In-flight system operation and drop zone size shall be determined for single, multiple consecutive and multiple intermittent cargo airdrop from single aircraft and for multiple consecutive cargo airdrop from mass formations of 30 aircraft.

5. Design criteria for equipment, and operational procedures to insure system operation for successful and accurate airdrops shall be determined.

6. The response of the aircraft to the effects of the airdrop system operation shall be determined.

7. The trajectory and body motion of typical cargos shall be examined to determine effects of the system operation.

8. Input data shall be supplied to the TIE (Technical Integration and Evaluation) contractor. Examples of such data which may be required are:

a. Weight information
b. Cost data
c. Accuracy information
d. Logistics, maintenance, training, rigging and de-rigging time data,
e. Reliability information

III. TECHNICAL ASPECTS OF PROGRAM

A. Introduction

The topics discussed in this section are divided into two primary areas: (1) those dealing with the extraction of the cargos from the C-130 aircraft and subsequent descent of the cargo to the target drop zone, and (2) those associated with the parameters leading to the selection and/or design of the component elements of the mechanisms used to achieve the reeling motions of the parachute risers and riser extensions. In general, the ultimate goal of the studies conducted in these two primary areas of investigation have been to:

1. Assure that the cargo impacts the drop zone terrain with a vertical velocity of 28.5 fps or less,
2. Minimize the horizontal motion of the cargo at terrain impact,
3. Assure that these two conditions can be achieved in a descent of 500 feet or less.

The investigations conducted with these items as goals have necessarily involved a set of qualifying assumptions and conditions that can be considered to define the overall envelope within which these analyses have been conducted for cargo weights from 2,000 to 35,000 pounds. These assumptions and conditions will be presented in detail in the next part of this section.

It is to be noted at this point, however, that the reel mechanisms that have been selected as candidate concept designs to achieve these goals are limited to a single reel-in event which is assumed to be initiated very soon after the cargo extraction tip-off event. Preliminary studies incorporating a sequence of parachute reel-in/reel-out events indicated that such a sequence of parachute riser extension motions tended to degrade the performance of the system when compared to the descent and terrain impact characteristics achieved from a single reel-in event. The primary parameter of importance in this respect is the total length of line from the cargo attachment point to the parachute; the shorter the average length of this line during the descent, the better the previously stated goals are achieved. The trajectory characteristics of systems employing a sequence of reel-in/reel-out events during the cargo descent phase have been illustrated and discussed in the 120-day Progress Report[3] issued by the AAI Corporation in March 1966. Those using only a single reel-in event have been presented in the Second Progress Report[4] issued by the AAI Corporation in July 1966.

The remainder of this section will be devoted to a discussion of the trajectory and terrain impact characteristics of parachute reel-in systems and to the mechanisms and component devices necessary to accomplish the reel-in event.

B. Cargo Descent Trajectory Studies

1. System Parameter Discussion

The topics discussed in this section will describe the assumptions made, and the conditions invoked during the course of the program studies. These assumptions and conditions can be considered to define a limiting envelope within which the major evaluations of the program were conducted. The order of this discussion will follow, as closely as possible, the sequence of events from extraction of the cargo from the aircraft to impact of the cargo with the drop zone terrain in order to logically illustrate the characteristics of this envelope of conditions.

As noted in Section II of this report, the extraction force is limited to 1.5 g's. The diameters of the G-11A parachute(s) during the extraction phase were based on this limiting force condition and were computed from the following equation:

$$1.5W = \frac{\rho}{2} V^2 C_D A_o \left(\frac{C_D A_R}{C_D A_o}\right) N f_{CL} \quad (1)$$

where: W = cargo drop weight

ρ = air density

V = cargo velocity with respect to the ground during the extraction period

$(C_D A)_o$ = drag factor of a fully inflated G-11A parachute based on the area A_o

$(C_D A)_R$ = drag factor of a reefed G-11A parachute based on the reefed area A_R

N = number of chutes

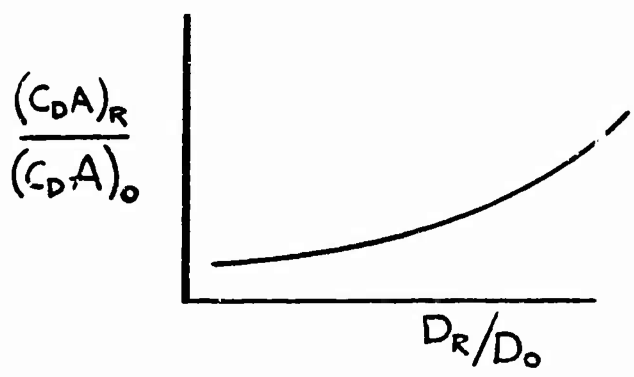
f_{CL} = cluster factor magnitude, which is a function of N as illustrated in the following table, which accounts for the modified flow field occurring with multiple parachute canopies which results in an effective drag decrease per canopy:

TABLE I

CLUSTER FACTOR MAGNITUDE

N	f_{CL}
1	1.00
2	.89
3	.86
4	.83
5	.80
6	.78
7	.75
8	.73
9	.715
10	.70
11	.69

The magnitudes of the cluster factor illustrated in Table I have been taken from the information presented in ASD-TR-61-579[5]. In addition, it has been assumed that the diameter of a disreefed parachute undergoing inflation increases linearly with time at an 11.5 fps rate. This assumption was based on viewing a series of films of an inflating G-11A parachute. The $(C_DA)_R/(C_DA)_o$ ratio magnitude was also taken from the data of reference 5, which provides data in a form similar to the following sketch:



where: D_R = diameter of reefed parachute

D_o = diameter of fully opened parachute = 67 ft. for a G-11A

For example:

Assume W = 8409 pounds,
ρ = .00238 slugs/ft^3,
V = 220 ft/sec,
N = 2,

then: $(C_D A)_o = 5880,$

$f_{CL} = .89$

Solving equation (1):

$$\frac{(C_D A)_R}{(C_D A)_o} = .021,$$

and from reference 5,

$$\frac{D_R}{D_o} = .062,$$

hence, $D_R = 4.15$ ft.

This represents the initial diameter of the parachute before motion of the cargo in the cargo compartment of the aircraft is initiated. To determine the diameter of the parachute at the next disreefing point*; an average extraction force of 1.25 g's was assumed. The distance the cargo moved before the first disreefing event occurred was generally assumed to be one-half of the distance between the initial location of the cargo in the aircraft and the end of the aircraft ramp. Denoting this distance by S, then the time it takes the cargo to move to the location at which disreefing occurs is computed from the elementary relationship:

$$S = \frac{1}{2} a t^2 \tag{2}$$

where: $a = 1.25$ g's
t = time

During this period of motion, the velocity of the cargo has decreased by an amount ΔV, given by

$$\Delta V = a t \tag{3}$$

* Generally, two disreefing points were assumed to occur during the extraction process up to the tip-off event. This was done to maintain the average extraction force as close to 1.25 g's as possible during the complete extraction period. The last disreefing event was assumed to occur approximately at cargo tip-off. At this time, the parachute was permitted to inflate at an 11.5 fps rate to a fully opened condition.

At this disreefing point, equation (1) is again used to compute the new diameter of the disreefed parachute; however, the velocity of the cargo used in this calculation was less than the initial velocity of the cargo by the increment ΔV computed from equation (3).

The number, N, of parachutes appearing in equation (1) are determined from the requirement that the vertical velocity of the cargo at terrain impact be equal to 28.5 fps. Since altitude of the drop zone terrain and the ambient temperature of the drop zone atmosphere affect the number of parachutes required to meet this condition, the following nomogram was constructed to simplify the determination of the required number of parachutes. To use this nomogram, the following procedure is employed:

1. Locate the terrain altitude of the cargo drop on the "H" scale and the cargo drop weight on the "W" scale.

2. Draw a straight line through these two points extending it to the center, or "turning" line.

3. Locate the drop zone ambient temperature on the "T" scale and construct a straight line through this point and the intersection of the previous straight line with the turning line.

4. Determine the number of chutes by locating the intersection of the second straight line with the "N" scale.

It should be noted that this nomogram does not specify the extraction altitude necessary to achieve 28.5 fps terminal velocity, it merely specifies the number of G-11A parachutes necessary to achieve this velocity as a function of terrain (drop zone) altitude and ambient temperature.

The geometrical relationship between the cargo-parachute-C-130B aircraft before initiation of motion of the cargo during the extraction phase is an important consideration, since it was determined early in the program that the shorter the average distance between the cargo and the parachutes during the descent, the better the ground impact conditions. Hence, fixing the initial distance between the cargo and the parachutes essentially determines the effectiveness of the resultant operation of the system. However, if this distance is made too short, the parachute and/or parachute risers might tend to interfere with the tail surfaces of the aircraft before initiation of cargo motion. For purposes of this program it was felt that if the confluence point of the riser extensions was assumed to be at aircraft fuselage station 90.0 before motion of the cargo was initiated, then there would be little chance of interference between the tail surfaces of the aircraft and the parachute risers, and that the operation of the system would not be penalized too severely by excessively large distances between the cargo and the parachutes during the descent phase.

NUMBER OF G-11A PARACHUTES REQUIRED
FOR VERTICAL IMPACT VELOCITY OF 28.5 fps

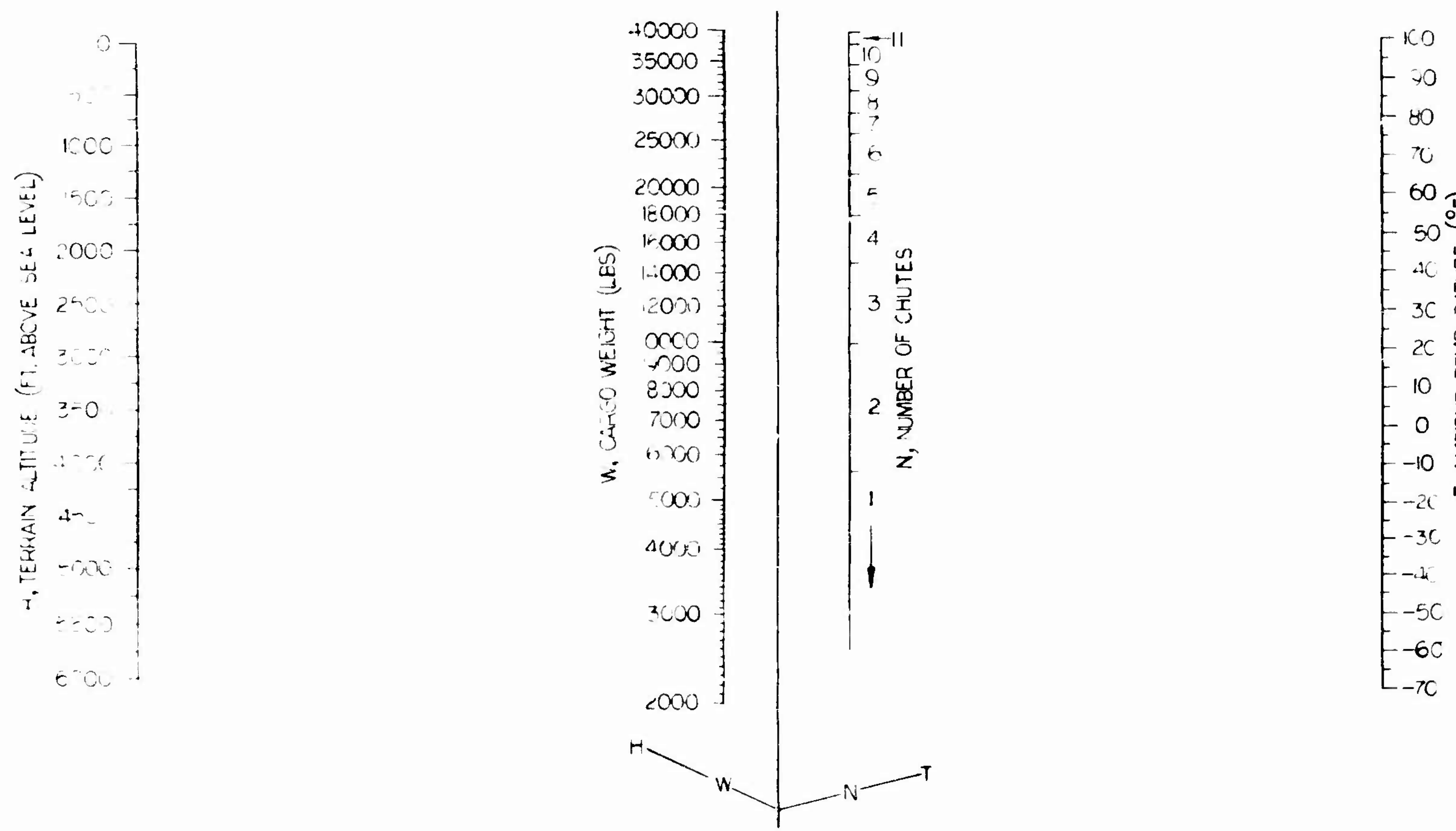


FIGURE I

The following figure illustrates the various line parameters that have been defined for use in the cargo descent trajectory analyses. These component line lengths are defined below:

L_{max} : the distance from the reefed chute (or chute cluster) c.g. to the cargo attachment point before motion of the cargo and subsequent disreefing and inflation of the chute is initiated.

L_{min} : the distance from the fully inflated chute (or chute cluster) c.g. to the cargo attachment point, following the reel-in event, if used in the specific trajectory under consideration.

ΔL_{cg} : the distance the chute (or chute cluster) c.g. is displaced as the disreefing-inflation process takes place, due to the change in geometry of the chute during the disreefing event

x_{RC} : the distance from the end of the parachute riser extensions to the c.g. of the reefed chute(s).

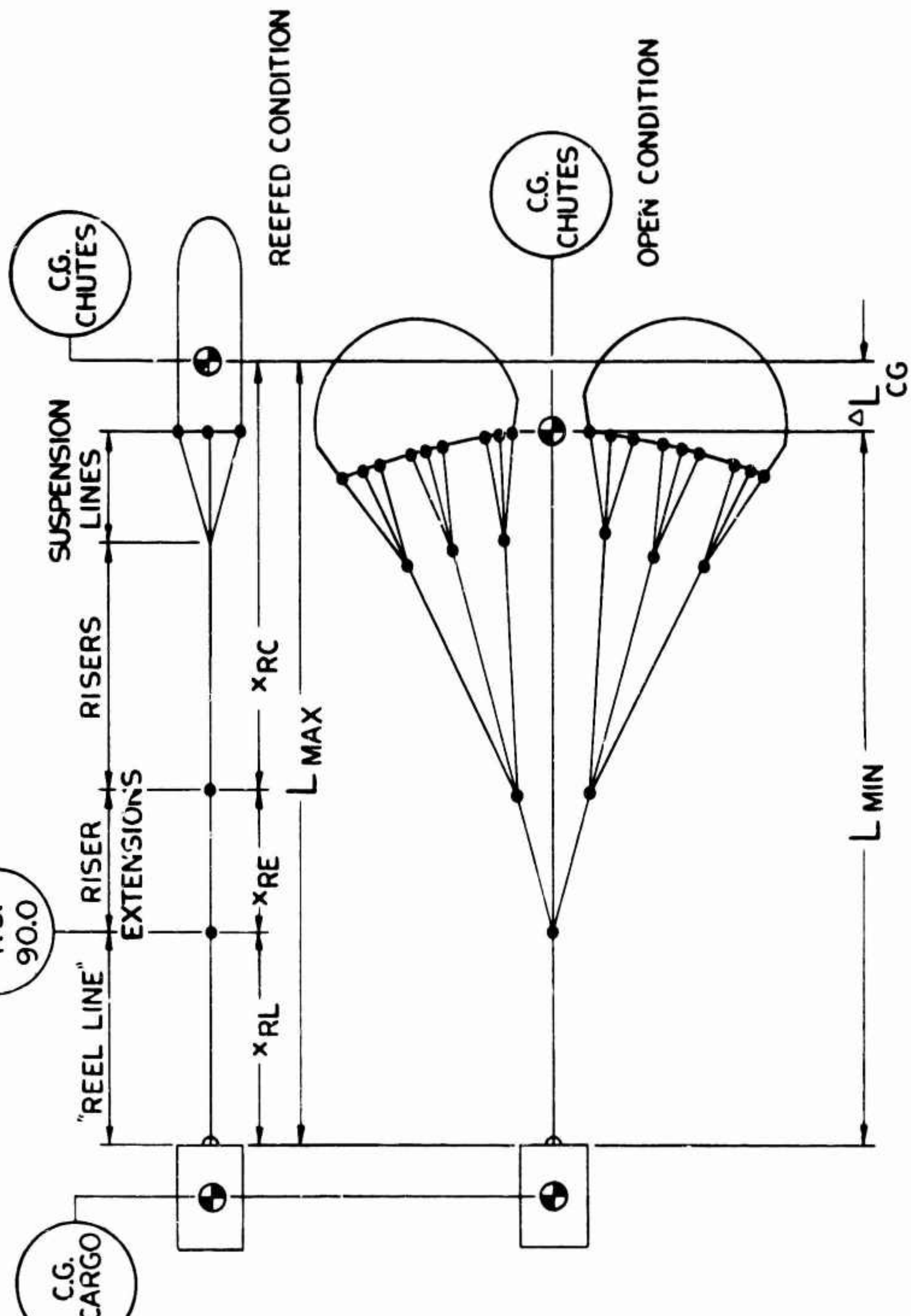
x_{RE} : the length of the riser extensions for a particular cluster of chutes.

x_{RL} : the length of the reel line employed for a particular cargo descent. The magnitude of x_{RL} is dependent on three parameters: (1) the length of the cargo pallet; (2) the location of the cargo item in the aircraft cargo compartment; (3) the location of the riser extension confluence point before motion of the cargo is initiated. As noted previously, this confluence point is assumed to be at aircraft fuselage station 90.0 ft. (1080 inches).

Table II illustrates the magnitudes of ΔL_{cg} as a function of the number of parachutes applied. In addition, magnitudes of x_{RE} corresponding to the number of parachutes used are also illustrated in this table.

TABLE II
LINE LENGTH PARAMETER MAGNITUDES

N (no. of chutes)	1	2	3	4	5	6	7	8
ΔL_{cg} (ft)	11	14	16	16	23	23	21	27
x_{RE} (ft)	20	20	40	60	80	80	100	100



CARGO PARACHUTE GEOMETRY
(WITHOUT REEL-IN)

FIGURE 2

Once the tip-off event is reached and the cargo parachute system is free of the aircraft, the allowable load applied to the cargo by the recovery parachutes is 3 g's (1.5 g's per suspension fitting, assuming a minimum of two such fittings may momentarily carry the total decelerating forces). Preliminary studies early in the program indicated that there was no sure way to assure that this limit would not be exceeded during a cargo descent trajectory that incorporated a reel-in event. However, during the development of the program analyses, it was found that for reel-in rates less than 20 fps, exceeding this limit was not likely. However, consideration was given to the effect of the air mass entrained by, and moving through the parachutes during the descent. For example, assuming a fully inflated G-11A to be a hemisphere, with a diameter of 67 feet, the weight of the air contained in the volume enclosed by the parachute can be found to be of the order of 7000 lbs. This is a significant quantity of air, and in fact, is of the same order as the weight of cargo suspended per chute under ordinary circumstances. Comparative descent trajectories for a 10,000 lb. cargo suspended from three G-11A's were computed; in one trajectory no air mass in the chute canopies was included, in the other, a weight of air was included that varied linearly from zero at tip-off to a maximum at full chute inflation. This was done to see if the air mass case would alter the line tensions from those computed in the no air mass case. However, no such effect was found; all that was noted was that the two cases were displaced somewhat in absolute time but the magnitudes of the descent parameters were not appreciably different. Hence, in all of the cargo descent trajectories described in this report, the chute air mass has been neglected.

For the cargo descent calculations, it was implicitly assumed that the G-11A parachutes are capable of developing aerodynamic loads up to 20,000 to 30,000 lbs. per canopy. This assumption was based on information received from Pioneer Parachute Company as a result of testing programs. It will be found that from the tension load plots included in the cargo descent trajectory discussions that the computed aerodynamic loads developed by the G-11A canopies do not approach these levels in most cases examined. It has been further assumed in these analyses that although the snatch loads experienced by the parachutes will exceed the 3 g limitation, the durations of these loads are so short that this effect can be safely neglected.

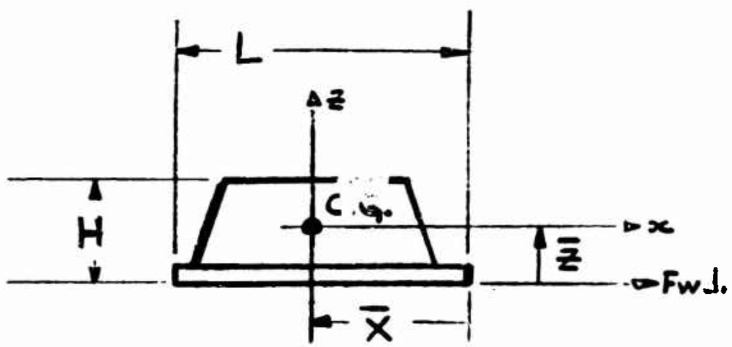
Another item for consideration is the aerodynamic characteristics of the cargos. Aerodynamic characteristics of air droppable cargos are as diverse as the cargo shapes. It is consequently of interest to determine whether or not this parameter has appreciable effect on descent trajectories. For the two dimensional analysis with cargo pitch dynamics neglected, the angle of attack of the pallet is no longer a factor and aerodynamic lift is eliminated. Thus only the drag characteristics need be considered. To obtain a reasonable value for the cargo drag coefficient, reference was made to the text by Hoerner[6]. Data is given therein for average drag coefficients of rotating cubes. The rotation gives the effect of variation in frontal area and presents the surfaces to the flow at varying angles, a situation representative of the actual case with a cargo suspended from a chute. At any rate, a value of C_D=1.0 based on the area of the cube face appears reasonable. Now to judge the effect of variation in this drag factor for various cargos, trajectories were computed for a 10,000# cargo suspended from three G-11A's and extracted at an aircraft velocity of 220 fps, first with a cargo C_D of 1.0 and then with a cargo C_D of 0.5. There was hardly a distinguishable difference between the two cases. Consequently cargo aerodynamic characteristics were not varied for the concept system evaluations in the two dimensional cases. For the three dimensional cargo descent trajectories illustrated in this report, the aerodynamic coefficient data presented in AAI Corporation Engineering Report ER-3600[7] was used. This report was submitted to the U S. Army Natick Laboratories under Contract DA19-129-QM-1850(OI 5153) in July 1964.

The two and three dimensional cargo descent trajectories have been based on the cargo items listed in the TIE contractors report.[1] Table III presents the characteristics of these cargo items. The item number designations appearing in this table will be used throughout this report to identify the particular cargo item under consideration in each of the descent trajectories illustrated. It is to be noted that the cargo weights illustrated in Table III include "rigged weight" and "drop weight" columns. The difference between these two magnitudes is merely the weight of the number of G-11A parachutes listed in the table. The drop weight is the weight of the item used in the calculation of the cargo descent trajectory characteristics, since the parachutes are inflated during the descent and are no longer attached to the cargo item. Furthermore, the drop weight magnitudes illustrated in this table do not include the component weight of the reel-in mechanisms required to effect the reel-in event applied during the cargo descent trajectory. Since the size and weight of the reel-in mechanism required for each cargo item is not known a priori, it was felt that the best approach would be to first evaluate a series of cargo descent trajectories using reel-in events without assuming a weight for the reel-in mechanism. After selection of the reel-in system, in terms of a power requirement, that generates an acceptable set of ground impact parameters, the size and weight of that system would be determined and added to the basic cargo item weight. Then a final, refined descent trajectory, with the weight of the reel-in system added to the weight of the cargo item would be evaluated. This approach has been followed in this report; however, the reel-in mechanism definition, with respect to size and weight, was not available soon enough for inclusion in this report in all cases. This restriction is not considered serious enough to invalidate the results illustrated in Section III B, since the weight of the reel-in mechanism is but a small fraction of the basic cargo item drop weights illustrated in Table III. For example, the weight of the reel-in mechanism required for item 5 is of the order of 400 lbs. for a 5 fps reel-in event. Adding 400 lbs. to the basic 8409 lbs. cargo weight will not significantly alter the ground impact parameter magnitudes presented in this report.

TABLE III

CARGO CHARACTERISTICS

Item	Cargo Geometry L (in)	W (in)	H (in)	Pallet Length (ft)	No. G-11A Chutes (S.I. Impact)	Rigged Wt. (lb)	Mom. of Inertia Ixx (slug-ft^2)	Iyy	Izz	Cent. of Mass $\bar{X}$ (in)	$\bar{Z}$ (ft)	Drop Weight (lb)
1.	96	108	72	8	1	3450	749	690	815	48	2.89	3200
2. M38A1	144	108	78	12	1	4230	969	1504	1673	84	3.06	3980
3. M274	103	108	96	8	2	6960	1751	1702	1435	46	3.98	6460
4. 105mm Howitzer	228	108	75	16	2	8376	1595	4068	4415	78	3.15	7876
5. M37	185	74	90	16	2	8909	2875	5948	6515	109	3.75	8409
6. M35	299	108	92	24	4	17864	5452	24695	24318	140	3.88	16864
7. M113	254	108	91	20	5	21900	6761	21433	21783	117	3.96	20650
8. XM551	288	108	102	24	8	34550	11337	49580	49118	144	4.35	32550



Notes:

1. Item 3-7" Cargo Overhang in Front
2. Item 4-22" Cargo Overhang in Front
   14" Cargo Overhang in Rear
3. Item 6-11" Cargo Overhang in Front
4. Item 7-14" Cargo Overhang in Rear
5. Item 8-L, W, H, $\bar{X}$ - assumed values
6. Item 1 - L, W, H, $\bar{X}$ - assumed values

The moment of inertia characteristics of the cargo items illustrated in Table III have been estimated from the Department of the Army Technical Manuals referenced in the TIE Contractors report[1]. These technical manuals describe the geometrical and component characteristics of the cargo items in detail sufficient to permit the inertia characteristics to be reliably computed.

In the cargo descent trajectory cases employing a parachute reel-in event as discussed in Part 2 of this section, it will be found that some assume that all, or a portion, of the riser extensions are reeled in. Reeling in the riser extensions will complicate the reel mechanism somewhat, since there is one riser extension per parachute used. However, this problem is classified as a detailed design problem that would be attacked during the concept development and testing program following the present contract. In addition, the analyses generated during this program assume that the recovery parachutes required to satisfy the ground impact objectives are all deployed during the extraction phase. Admittedly this is an assumption that would have to be verified as being possible from a series of actual tests. Again, this problem is recognized but is reserved for the future development-testing program.

The remainder of Part B will present and develop the characteristics of the parachute reel-in systems for the various items of cargo listed in Table III. The results obtained from the various computational programs will serve as design inputs for the reel mechanisms, the characteristics of which are reserved for discussion later in this Section III of the report.

2. Cargo Descent Trajectory Characteristics

a. Two-Dimensional Trajectories

(1) Introduction

Presented herein are the results of the computations generated for this program with respect to the characteristics of the two-dimensional descent trajectories of the prescribed cargo items identified in Table III, Part 1 of this section. These descent trajectory computations are identified in terms of two tabular listings; Table IV, titled "Cargo Descent Trajectory Log," defines the magnitudes of the various parameters used in each of the computer evaluations. In this set of tables the run number, cargo item designation, cargo weight, number of chutes, impact parameters (i.e., the altitude of the drop zone terrain and the ambient temperature); the wind conditions (applicable to three-dimensional cases only), the aircraft velocity, initial cargo center-of-gravity location (referenced to aircraft fuselage station 20.4 ft.) and the magnitudes of X_{RL}, X_{RE}, X_{RC}, L_{max} and L_{min} are given for each case examined. The column heading "Reel Inputs" is used to denote the reeling rates and time intervals over which these rates are applied for those cases involving both "natural reeling" events and the powered reel-in events. By "natural reeling" is meant the tendency for the distance between the cargo and the parachute(s) to decrease as the chutes undergo disreefing.

Table V, titled "Cargo Descent Trajectory Results," illustrates the major impact parameters achieved from each of the computer runs. These impact parameters are presented as the following items:

1. Time to descend 500 ft. in seconds - this is the time it takes the particular cargo item under consideration to impact the drop zone terrain 500 ft. below the aircraft. It is measured from the instant the cargo begins to move inside the aircraft.

2. Vertical velocity range, fps - this is the velocity of the cargo in the vertical direction at ground impact. Due to the oscillatory character of the motion of the cargo as it approaches the ground, and the uncertainty of the exact altitude of the aircraft, this vertical velocity is specified in terms of a range of magnitudes, rather than as a single value.

3. $V_{x_{max}}$ - this impact velocity parameter is the maximum value of the horizontal velocity (without regard to direction) of the cargo corresponding to the range of vertical velocities given in Item 2. The horizontal velocity of the cargo may be less than $V_{x_{max}}$ in an actual descent.

4. H_{min} - This is the minimum altitude in the Table V result sheets at which the cargo may be extracted from the aircraft and impact the ground with vertical and horizontal velocities equal to or less than the magnitudes specified in Items 2 and 3, respectively.

5. $\Phi_{500'}$ - this parameter defines the angle between the vertical and a line normal to the longitudinal dimension of the cargo after a 500 ft. descent.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS		WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0003	2	0'	60°F	none	220	-23.35	-	-	-	138.0	92.0	10: in 10: out 10: in 10: out 10: in 10: out	1.5 - 4.0 4.0 - 6.0 6.0 - 9.6 9.6 - 12.5 12.5 - 15.9 15.9 - 20.0
5.0023	2	0'	60°F	none	220	-23.35	-	-	-	138.0	138.0	-	-
5.0024	2	0'	60°F	none	220	-23.35	-	-	-	138.0	92.0	0-20 in 0-20 out 0-20 in 0-20 out 0-20 in 0-20 out	1.5 - 4.0 4.0 - 6.0 6.0 - 9.6 9.6 - 12.5 12.5 - 15.9 15.9 - 20.0
5.0028	2	0'	60°F	none	220	-23.35	-	-	-	118.0	118.0	-	-

TABLE IV 2-D PRELIMINARY CARGO DESCENT TRAJECTORY LOG
Cargo Weight: 10,000 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5 0070	1	0' 60°F	none	220	-23.35	42.25	20 0	110	172 25	161 25	Nat 2	1 2 - 6 7
5 0081	1	0' 60°F	none	220	-23.35	42.25	20.0	110	172 25	119.0	2 7 5	1 2 - 2.5 2.5 - 6.7 6.7 - 10.96
5.0084	1	0' 60°F	none	220	-23.35	42.25	20.0	110	172.25	119.0	2 12	1.2 - 2.5 2.5 - 6.7

TABLE IV 2 D CARGO DESCENT TRAJECTORY LOG
Item No 1 Cargo Weight 3200 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0108	1	0' 60°F	none	220	-23.35	41.25	20	110	171.25	160.25	Nat: 2.02	1.2 - 6.65
5.0109	1	0' 60°F	none	220	-23.35	41.25	20	110	171.25	119.0	2.02 7.02 5.0	1.2 - 2.5 2.5 - 6.65 6.65-10.76
5.0110	1	0' 60°F	none	220	-23.35	41.25	20	110	171.25	119.0	2.02 12.02	1.2 - 2.5 2.5 - 6.64

TABLE IV

2-D CARGO DESCENT TRAJECTORY LOG

Item No.: 2 Cargo Weight: 3980 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0071	2	0' 50°F	none	220	-23.35	42.08	20	110	172.08	158.08	Nat2.56	1.2 - 6.68
5.0112	2	0' 60°F	none	220	-23.35	42.08	20	110	172.08	116.0	2.56 7.56 5.0	1.2 - 2.5 2.5 - 6.68 6.68 - 10.8
5.0113	2	0' 60°F	none	220	-23.35	42.08	20	110	172.08	116.0	2.56 12.56	1.2 - 2.5 2.5 - 6.68

TABLE IV 2-D CARGO DESCENT TRAJECTORY LOG
Item No. 3 Cargo Weight: 6460 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0091	2	0' 60°F	none	220	-23.35	39.33	20	110	169.33	155.33	Nat: 2.63	1.2 - 6.54
5.0092	"	"	"	"	"	"	"	"	"	116.00	2.63 7.63 5.00	1.2 - 2.5 2.5 - 6.54 6.54-10.36
5.0093	"	"	"	"	"	"	"	"	"	"	2.63 12.63 2.63	1.2 - 2.5 2.5 - 6.43 6.43- 6.48
5.0094	"	"	"	"	- 9.90	52.8	"	"	182.8	168.8	Nat: 2.63	1.43- 6.75
5.0095	"	"	"	"	-34.10	28.6	"	"	158.6	144.6	Nat: 2.43	.92- 6.27
5.0096	3	5000'100°F	"	"	-23.35	39.33	40	"	189.33	173.33	Nat: 2.96	1.2 - 6.6
5.0097	2	0' 60°F	"	186	"	"	20	"	169.33	155.33	Nat: 2.69	1.2 - 6.4
5.0098	"	"	"	254	"	"	"	"	"	"	Nat: 2.55	1.2 - 6.7
5.0099	"	0' 60°F	"	220	-31.25	31.33	"	"	161.33	116.0	2.63 7.63 5.0	.92- 2.5 2.5 - 6.27 6.27- 8.76

TABLE IV

2-D CARGO DESCENT TRAJECTORY LOG

Item No.: 5 Cargo Weight : 8409 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X RL (ft)	X RE (ft)	X RC (ft)	L max (ft)	L min (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0100	2	0' 60°F	none	220	- 9.90	52.8	20	110	182.8	116.0	2.63 7.63 5.00	1.43- 2.5 2.5 - 6.75 6.75-13.1
5.0101	3	5000'100°F	"	"	-23.35	39.33	4	"	189.33	134.0	2.96 7.96 5.0	1.2 - 2.5 2.5 - 6.6 6.6 -10.35
5.0104	2	0' 60°F	"	203	"	"	20	"	169.33	116.0	2.66 7.66 5.0	1.2 - 2.5 2.5 - 6.47 6.47-10.36
5.0105	"	"	"	237	"	"	"	"	"	"	2.58 7.58 5.0	1.2 - 2.5 2.5 - 6.62 6.62-10.36
5.0082	"	"	"	220	"	"	"	"	"	"	2.63 6.53 5.0	1.2 - 2.5 2.5 - 6.53 6.53-10.36

TABLE IV - Continued

2-D CARGO DESCENT TRAJECTORY LOG

Item No.: 5 Cargo Weight : 8409 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0073	4	0' 60°F	none	220	-23.35	33.90	60	110	203.90	187.90	Nat: 3.02	1.2 - 6.52
5.0114	4	0' 60°F	none	220	-23.35	33.90	60	110	203.90	154.0	3.02	1.2 - 2.5
											8.02	2.5 - 6.51
											5.0	6.51 - 9.28
5.0117	4	0' 60°F	none	220	-23.35	33.90	60	110	203.90	125.4	3.02	1.2 - 2.5
											8.02	2.5 - 6.51
											5.0	6.51 - 15.0

TABLE IV

2-D CARGO DESCENT TRAJECTORY LOG

Item No. 6 Cargo Weight: 16864 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0074	5	0' 60°F	none	220	-23.35	34.85	80	110	224.85	201.85	Nat: 4.33	1.2 - 6.52
5.0089	5	0' 60°F	none	220	-23.35	34.85	80	110	224.85	167.0	4.33 9.33 5.0	1.2 - 2.5 2.5 - 6.52 6.52 - 9.48
5.0102	5	0' 60°F	none	220	-23.35	34.85	80	110	224.85	111.85	4.33 11.83 7.5	1.2 - 2.5 2.5 - 6.52 6.52 - 14.5

TABLE IV

2-D CARGO DESCENT TRAJECTORY LOG

Item No: 7 Cargo Weight: 20650 lbs.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C VEL. (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0075	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	217.25	Nat5.12	1.2 - 6.48
5.0083	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	183.0	5.12 10.12 5.0	1.2 - 2.5 2.5 - 6.48 6.48 - 9.34
5.0086	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	183.0	5.12 15.12 5.12	1.2 - 2.5 2.5 - 5.92 5.92 - 6.48
5.0087	9	0' 60°F	none	220	-23.35	34.25	100	110	244.25	183.0	5.07 10.07 5.0	1.2 - 2.5 2.5 - 6.53 6.53 - 9.34
5.0090	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	157.25	5.12 10.12 5.0	1.2 - 2.5 2.5 - 6.48 6.48 - 14.5
5.0103	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	92.25	5.12 15.12 10.0	1.2 - 2.5 2.5 - 6.48 6.48 - 15.0
5.0107	8	0' 60°F	none	220	-23.35	34.25	100	110	244.25	123.5	5.12 12.62 7.5	1.2 - 2.5 2.5 - 6.48 6.48 - 15.0
5.0118	11	5000' 100°F	none	220	-23.35	34.25	100	110	244.25	123.5	5.12 12.62 7.5	1.2 - 2.5 2.5 - 6.48 6.48 - 15.0

TABLE IV 2-D CARGO DESCENT TRAJECTORY LOG
Item No. 8 Cargo Weight: 32,550 lbs.

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HF req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0003	2	10 in 10 out 10 in 10 out 10 in 10 out	1.5 - 4.0 4.0 - 6.0 6.0 - 9.6 9.6 -12.5 12.5 -15.9 15.9 -20.0	16.52	17.9 - 39.4	6.73	11.2	471		Reel-in/Reel-out at const. rate $\Delta L_{cg} = 0$
5.0023	2	-	-	14.92	27.1 - 30.3	11.0	11.5	519		No Reel: $\Delta L_{cg} = 0$
5.0024	2	0-20: in 0-20 out 0-20: in 0-20 out 0-20: in 0-20 out	1.5 - 4.0 4.0 - 6.0 6.0 - 9.6 9.6 -12.5 12.5 -15.9 15.9 -20.0	16.42	16.4 - 46.2	5.9	9.0	476		Reel-in/Reel-out at variable rate $\Delta L_{cg} = 0$
5.0028	2	-	-	15.52	27.7 - 29.9	8.3	12.0	482		No Reel: $\Delta L_{cg} = 0$

TABLE V 2-D PRELIMINARY CARGO DESCENT TRAJECTORY RESULTS
Cargo Weight 10,000 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS Rate (fps)	Interval (sec)	IMPACT PARAMETERS Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)	HP req	COMMENTS
5.0070	1	Nat2.0	1.2 - 6.7	18.02	16.5 -26.3	20.7	20.2	458	-	No Reel-in
5.0081	1	2.0 7.0 5.0	1.2 - 2.5 2.5 - 6.7 6.7 -10.96	19.51	16.7 -26.1	18.3	4.0	390	71.5	5 fps Reel-in
5.0084	1	2.0 12.0	1.2 - 2.5 2.5 - 6.7	19.52	16.3 -26.4	18.9	7.0	381	159	10 fps Reel-in

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 1 Cargo Weight: 3200 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0108	1	Nat: 2.02	1.2 - 6.65	16.58	20.7 - 27.2	16.4	17.7	492	-	No Reel-in
5.0109	1	2.02 7.02 5.0	1.2 - 2.5 2.5 - 6.65 6.65-10.76	18.08	20.9 - 27.0	14.3	8.0	422	80	5 fps Reel-in
5.0110	1	2.02 12.02	1.2 - 2.5 2.5 - 6.64	18.08	20.9 - 27.1	14.8	5.2	415	195	10 fps Reel-in

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 2 Cargo Weight: 3980 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0071	2	Nat:2.56	1.2 - 6.68	17.26	18.9 - 27.0	18.5	20.2	474	-	No Reel-in
5.0112	2	2.56 7.56 5.0	1.2 - 2.5 2.5 - 6.68 6.68-10.8	18.74	19.2 - 26.7	16.1	1.2	404	139	5 fps Reel-in
5.0113	2	2.56 12.56	1.2 - 2.5 2.5 - 6.68	18.75	18.9 - 27.0	16.6	1.7	394	308	10 fps Reel-in

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 3 Cargo Weight: 6460 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0091	2	Nat. 2.63	1.2-6.54	15.52	22.8-29.4	20.3	14.9	499	-	No reel in
5.0092	2	2.63 7.63 5.00	1.2-2.5 2.5-6.54 6.54-10.36	17.02	23.6 27.2	13.4	13.4	444	178.5	5 fps reel in
5.0093	2	2.63 12.63 2.63	1.2-2.5 2.5-6.43 6.43-6.48	17.02	23.5 27.3	13.6	11.0	435	401	10 fps reel in.
5.0094	2	Nat. 2.63	1.43-6.75	15.30	24.4 29.8	29.7	8.5	500	--	Fwd. location, cargo c.g., no reel-in.
5.0095	2	Nat. 2.63	.92 - 6.27	15.60	23.6-28.9	14.3	16.5	495	-	Aft location, cargo c.g., no reel-in.
5.0096	2	Nat. 2.96	1.2-6.6	17.03	15.2 27.6	24.2	23.5	488	-	5000', 100°F D.Z. no reel-in.
5.0097	2	Nat. 2.69	1.2-6.4	15.5	22.7-29.4	19.5	15.5	500	--	A/C speed=166 fps no reel-in
5.0098	2	Nat. 2.55	1.2-6.7	15.4	23.1-29.2	22.2	13.2	500		A/C speed=254 fps no reel in.

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. [illegible]. Cargo Weight: 8409 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0099	2	2.63 7.63 5.0	.92-2.5 2.5-6.27 6.27-8.76	16.9	23.7-28.9	13.1	12.0	440	153	5 fps reel-in Aft location, cargo c.g. (compared to 5.0092)
5.0100	2	2.63 7.63 5.0	1.43-2.5 2.5-6.75 6.75-13.1	17.5	22 6 29.7	15.4	16.0	444	195	5 fps reel-in fwd. location, cargo c.g. (compared to 5.0092)
5.0101	3	2.96 7.96 5.0	1.2-2.5 2.5-6.6 6.6 10.35	17.6	19.2 28.9	19.0	19.5	449	185	5000', 100°F DZ 5 fps reel-in
5.0104	2	2.66 7.66 5.0	1.2-2.5 2.5 6.47 6.47-10.36	17.02	23.5 29.0	13.5	13.2	441	161	A/C speed=203 fps 5 fps reel in (compare to 5.0092)
5.0105	2	2.58 7.58 5.0	1.2-2.5 2.5 6.62 6.62-10.36	17.02	23.5-28.9	13.3	17.4	445	200	A/C speed=237 fps 5 fps reel-in (compare to 5.0092)
5.0082	2	2.63 7.63 5.0	1.2 2.5 2.5-6.53 6.53 10.36	16.3	25.7-30.1	12.0	15.7	465	199	5 fps reel-in 1000# additional wt. added to cargo item (compare to 5.0092)

TABLE V **2-D CARGO DESCENT TRAJECTORY RESULTS**
Item No. 5: Cargo Weight: 8409 lb

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0073	4	Nat. 3.02	1.2-6.52	14.19	31.3-35.0	35.3	7.4	500	--	No reel-in.
5.0114	4	3.02 8.02 5.0	1.2-2.5 2.5-6.51 6.51-9.28	15.29	23.3-31.2	28.1	13.6	500	339	5 fps reel-in
5.0017	4	3.02 8.02 5.0	1.2-2.5 2.5-6.5 6.5-15.0	16.69	21.8-31.5	17.54	23.8	482	339	5 fps reel-in; reel-in 28.6' of X_{RE}

TABLE V <u>2-D CARGO DESCENT TRAJECTORY RESULTS</u>
Item No. 6: Cargo Weight: 16864 lb.

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0074	5	Nat. 4.33	1.2-6.52	13.96	8.0-41.7	39.1	15.0	367	--	No reel-in. Insufficient time to reach 28.5 fps
5.0089	5	4.33 9.33 5.0	1.2-2.5 2.5-6.52 6.52-9.48	14.86	27.7-32.0	37.3	5.2	500	424	5 fps reel-in
5.0102	5	4.33 11.83 7.5	1.2-2.5 2.5-6.52 6.52-14.5	17.3	21.4-32.5	18.4	24.1	463	670	7.5 fps reel-in Reel-in 55.15' of X_{RE}

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 7: Cargo Weight: 20650 lb.

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0075	8	Nat: 5.12	1.2-6.48	13.57	7.3-44.0	41.9	24.0	390	--	No reel-in. Insufficient time to reach 28.5 fps.
5.0083	8	5.12 10.12 5.0	1.2-2.5 2.5-6.48 6.48-9.34	14.27	0-45.4	41.2	8.5	348	636	5 fps reel-in. Insufficient time to reach 28.5 fps
5.0086	8	5.12 15.12 5.12	1.2-2.5 2.5-5.92 5.92-6.48	14.07	6.4-44.3	39.9	6.1	341	1400	10 fps reel-in. Insufficient time to reach 28.5 fps
5.0087	9	5.07 10.07 5.0	1.2-2.5 2.5-6.525 6.525-9.34	14.51	2.5-45.7	43.0	5.1	341	683	5 fps reel-in; 9 chutes; insufficient time to reach 28.5 fps
5.0090	8	5.12 10.12 5.0	1.2-2.5 2.5-6.48 6.48-14.5	14.87	28.0-33.6	40.8	4.6	499	636	5 fps reel-in; reel-in 27.75' of X_{RE} (compare to 5.0083)
5.0103	8	5.12 15.12 10.0	1.2-2.5 2.5-6.48 6.48-15.0	17.7	18.5-33.9	18.0	20.3	437	1395	10 fps reel-in; reel-in 90.75' of X_{RE} (compare to 5.0086)

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 8: Cargo Weight: 32550 lb.

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS					HP req	COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	V_x Max. (fps)	Φ_{500} (°)	H_{min} (ft)		
5.0107	8	5.12 12.62 7.5	1.2-2.5 2.5-6.48 6.48-15.0	16.57	21.1-33.8	20.2	28.1	493	1000	7.5 fps reel-in; reel-in 59.5' of X_{RE} (compare to 5.0086, 5.0090 & 5.0103)
5.0118	11	5.12 12.62 7.5	1.2-2.5 2.5-6.48 6.48-15.0	16.90	19.4-33.9	21.8	30.5	485	1000	7.5 fps reel-in; reel-in 59.5' of X_{RE} 5000', 100°F

TABLE V 2-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 8: Cargo Weight: [illegible]550 lb.

In addition, in those descent trajectories that employ a powered reel-in event, the maximum horsepower required to effect this reel-in motion is specified in the HP_{req} column. Generally, this required horsepower is based on the product of the specified reel-in rate (velocity) and the peak line tension occurring during the descent. As such, it represents the maximum power requirement; if less power is generated, then the reel system will still be capable of reeling in the riser extensions, but during the short period of maximum line tension, the system will reel in at something less than the assumed reel rate.

The remainder of this discussion will be concerned with an analysis of the descent trajectories generated during this program. It should be noted that not all of the computer runs generated during this program are presented; rather, only the most meaningful trajectories are discussed. More specifically, preleminary investigations will be discussed first, followed by an analysis of the trajectories for the cargo items listed in Table III. Accompanying each of these analyses is a set of three curves which illustrate the following information:

1. Altitude (y) vs. Horizontal Distance (x) for each cargo descent trajectory;

2. Vertical (V_y) and Horizontal (V_x) Velocity of the cargo vs. time for each cargo item during the descent;

3. Line Tension vs. Time.

Furthermore, it should be noted that the individual trajectories are referred to by cargo item number and/or case number only. The specific input parameters may be found in the "Cargo Descent Trajectory Log" presented in this section. Similarly, the magnitudes of the principal impact parameters are not discussed in every case, but they may be found in the "Cargo Descent Trajectory Results" tables presented in this discussion. Hence, the trajectory curves are presented primarily for the sake of completeness and interest; it is not absolutely necessary to study each curve to judge the operational characteristics of the reeling systems applied to each cargo.

(2) Preliminary Trajectory Computations

The preliminary phases of this program were principally concerned with a general cargo weight of 10,000 pounds. Using this cargo, various computer calculations were generated so that general trends and conclusions could be drawn for future use in the final trajectory analyses. Initially, the length of the reel line was based solely upon the rate of reeling in (or out) and the reel time interval. Even though this initial assumption later proved to be unrealistic, it provided a means by which different reel-in/reel-out events could be compared in order to select the best system. Also, during this phase of the contract, the various line parameters listed in the "Cargo Descent Trajectory Log", Table IV, were not defined as such, hence only magnitudes of L_{max} and L_{min} appear in the charts for these preliminary studies.

Case 5.0028 provides the no-reel trajectory for a cargo weight of 10,000 pounds and two G-11A chutes. The line length was assumed to be 118 feet since, at this time, the no-reel trajectories were computed without the additional length of the reel line, and the decision to place the riser extension confluence point at fuselage station 90.0 had not yet been made. Further, since the natural line shortening effect due to disreefing was also considered to be a subordinate parameter at this time, the line length remained constant during the entire descent.

Subsequent trajectories revealed that more meaningful comparisons could be made by including the length of the reel line in no-reel cases, but Case 5.0028 is primarily presented to clearly illustrate the effect of line length on cargo trajectories. Case 5.0023 provides the no-reel trajectory for a 10,000 pound cargo with two chutes and a line length of 138 feet. Case 5.0003 is identical to 5.0023 except a reel-in/reel-out sequence of events is employed.

A comparison of these two runs reveals that, with respect to the vertical velocity range, this typical reel-in/reel-out trajectory degrades the drop system. Furthermore, neither system is better than case 5.0028 which merely employs a shorter line with no powered reel events. With respect to cargo and environmental parameters, case 5.0024 is identical to the three trajectories discussed so far. However, a variable reel rate is employed. In this particular system, the reel-in/reel-out velocities vary linearly from zero velocity to a terminal velocity of 20 fps. Once again, these reeling events tended to degrade the performance of the system when compared to the descent trajectory characteristics achieved from the no-reel case, particularly with respect to the range of V_y. These large magnitudes of V_y are caused by the fact that reeling out actually adds a vertical velocity component to the system which cannot be overcome by the chute drag force before impact. Admittedly the horizontal velocities are decreased with reel-in and reel-out but this improvement is of little benefit if the specified terminal velocity of 28.5 fps cannot be attained. Various other reel-in/reel-out computations were generated using different reel rates and/or different time intervals at which the reeling event occurred, but it would prove redundant to include these in view of the facts presented above.

Therefore, subsequent preliminary investigations revolved around a single reel-in event initiated at various times during the descent. From these results it was apparent that the primary parameter of importance was the total length of line from the cargo attachment point to the parachute; the shorter the average length of this line during the descent, the better the ground impact characteristics of the cargo. Furthermore, it was deduced that this reel-in event should occur as soon as possible in the cargo descent trajectory in order to shorten the total line length as soon as possible. If the line between the cargo and the chute(s) is considered to be a rigid rod, then the oscillatory motions of the drop system become quite analogous to the harmonic motion of a pendulum. If this assumption is valid, a decrease in the line length between the cargo and the chute(s) has the following effects on the dynamics of the system:

(1) The magnitudes of the cargo oscillation amplitudes decrease.

(2) The tangential velocities of the cargo decrease.

Consequently, it should be apparent that the sooner the line length is shortened, the better the oscillatory characteristics of the system.

(3) Final Trajectory Computations

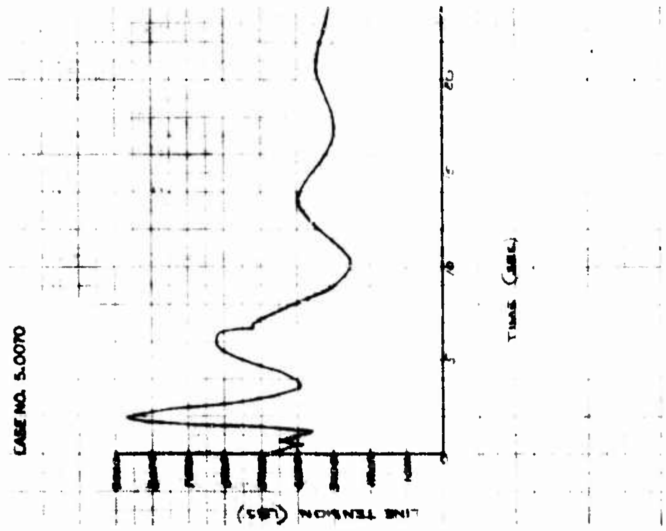
The remainder of the descent trajectory studies were primarily concerned with obtaining the optimum reel system for the cargo items listed in Table III, Part 1 of this section. It proved advantageous to include the effect of ΔL_{cg} in these analyses since this "natural" line shortening has approximately the same effect as reeling-in the chute, but no power is required for this amount of reel-in. Further, these final calculations neglected the weight of the reel-in mechanism. However, as will be illustrated in the discussion of item 5, this extra weight has very little if any effect on the descent trajectories. Consequently, power requirements are based solely upon reel-in accomplished by the reel-in device. The most recent trajectories reveal that line tensions are greatest approximately 2 seconds after extraction is initiated. Hence, reel-in events are begun at t = 2.5 seconds to miss this tension peak and lower the power requirement of the reel-in mechanism.

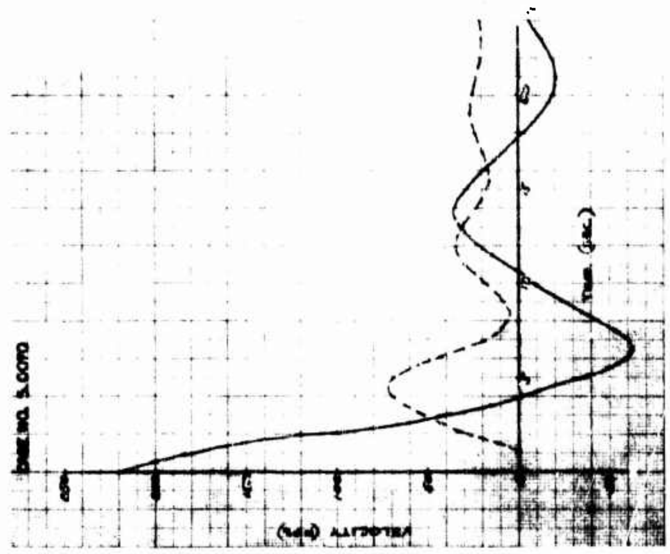
With the exception of item 4*, the following discussions will present an analysis of each cargo item listed in Table III.

* Since the drop weight of item 4 is fairly close to that of item 5, and both require 2 chutes, the trajectory characteristics of item 4 should be almost identical to those of item 5.

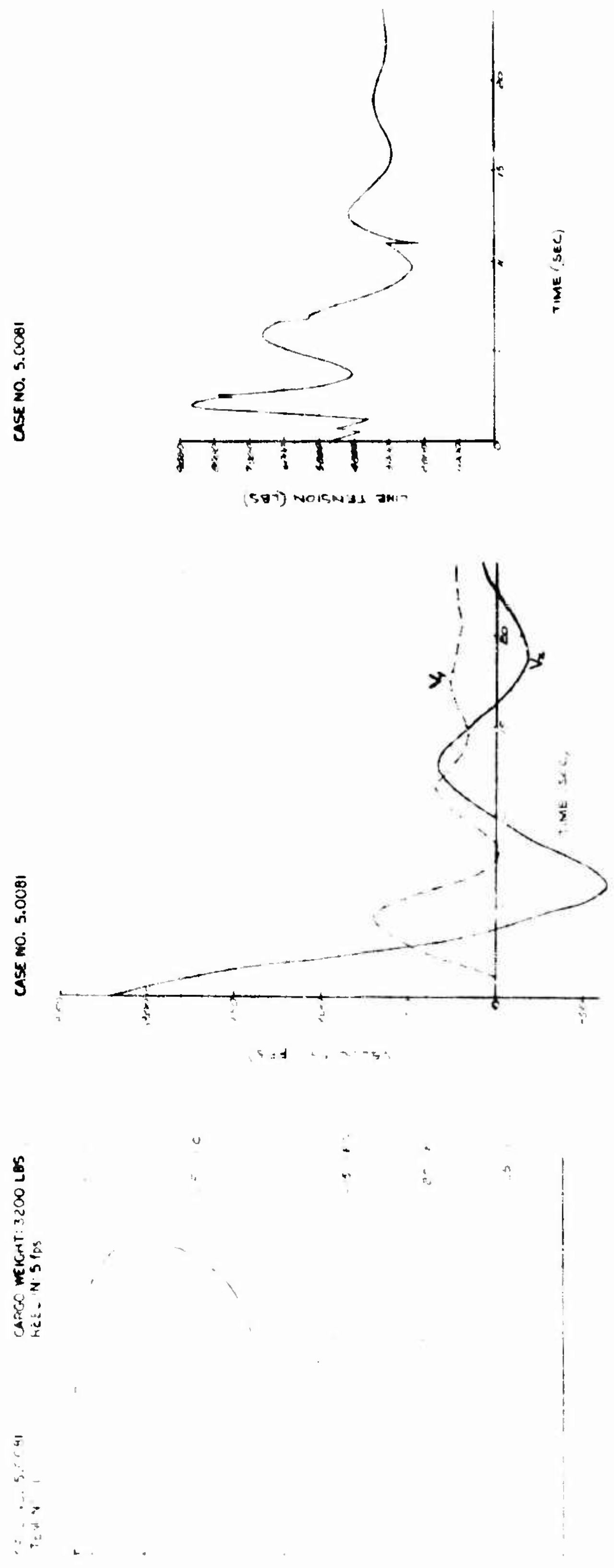
(a) Item 1:

Case 5.0070 provides the basic trajectory for item 1 with 1 chute and no reel-in, other than the natural line shortening effect due to disreefing. Cases 5.0081 and 5.0084 are identical to 5.0070 except that reel-in rates of 5 fps and 10 fps are used, respectively. Comparison of these three trajectories reveals that although there is no major change in the impact velocities, the magnitude of H_{min} is effectively reduced from 458 feet with no reel-in to 390 feet with 5 fps reel-in and 381.1 feet with 10 fps reel-in. An examination of the altitude (y) vs. horizontal distance (x) plots of these trajectories discloses no effective change in the maximum horizontal amplitudes of the oscillations with reel-in; rather, these "knees" occur earlier on the time scale producing similar impact parameters for lower extraction altitudes. Furthermore, the impact conditions achieved with a 10 fps reel-in velocity are not significantly better than those achieved with a 5 fps reel rate. Consequently, since the only significant change in the impact parameters is the magnitude of H_{min}, it is suggested that a reel-in device not be used on this particular item.


CASE NO. 5.0070
LINE TENSION (LBS)
TIME (SEC.)

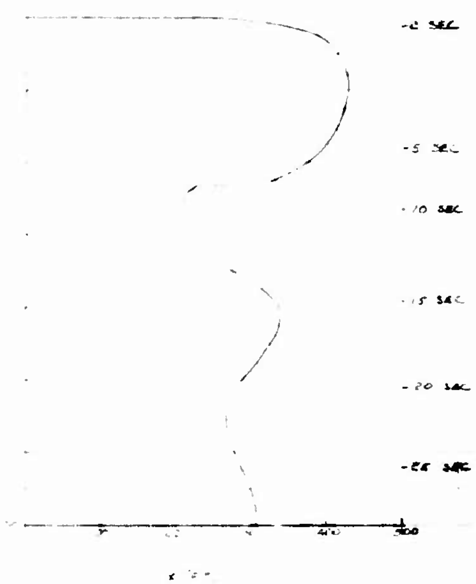

VELOCITY (FPS)
TIME (SEC.)


CASE NO. 5.00
ITEM NO.1
x (FT)

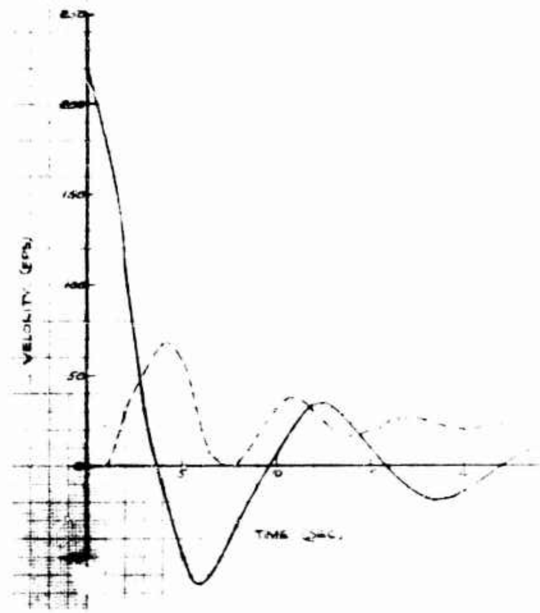

CASE NO. 5.0081
LINE TENSION (LBS)
TIME (SEC)
CASE NO. 5.0081
V
TIME (SEC)
CARGO WEIGHT: 3200 LBS

CASE NO. 5.0084
ITEM NO. 1

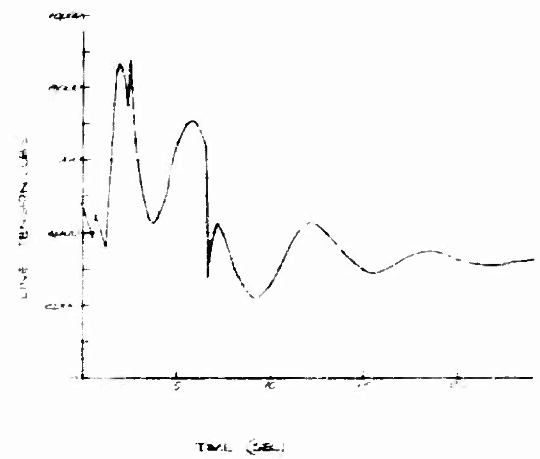
CARGO WEIGHT: 3200 LBS
REEL IN: 10 fps



CASE NO. 5.0084



CASE NO. 5.0084

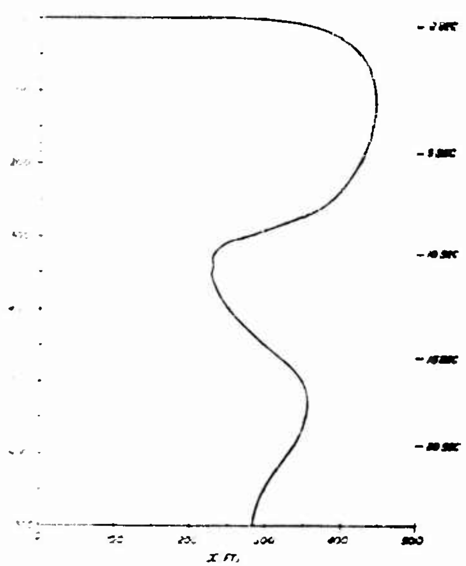


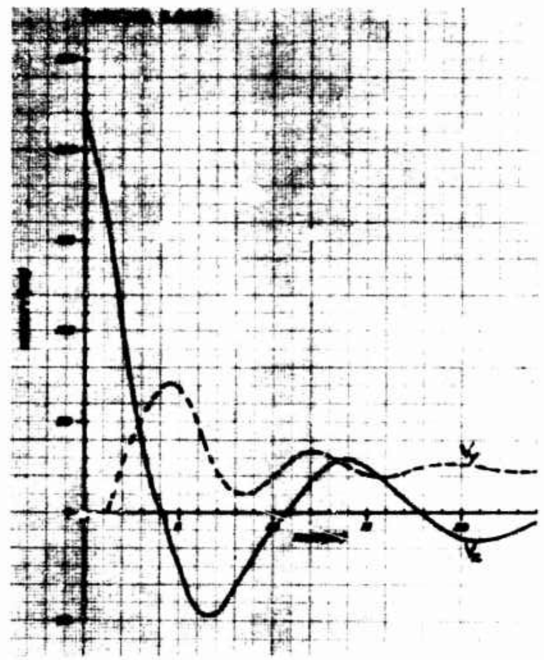
(b) Item 2:

Case 5.0108 provides the basic no-reel trajectory for item 2. Cases 5.0109 and 5.0110 are identical to 5.0108 except for reel-in rates of 5 fps and 10 fps, respectively. As with item 1, the only impact parameter that is effectively improved is that of H_{min} being reduced from 492 ft. to 414 ft. with a 10 fps reel-in system. However, since the impact velocities remain relatively stable for all three cases, the AAI staff feels that a reel system should be neglected for this drop item.

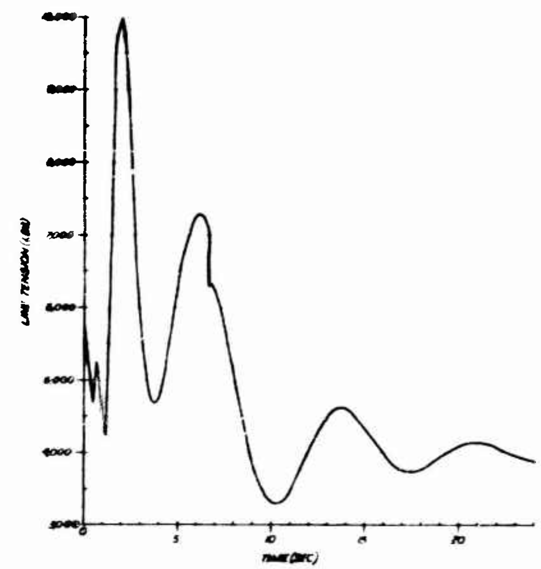
CASE NO. 5 0108
ITEM NO. 2

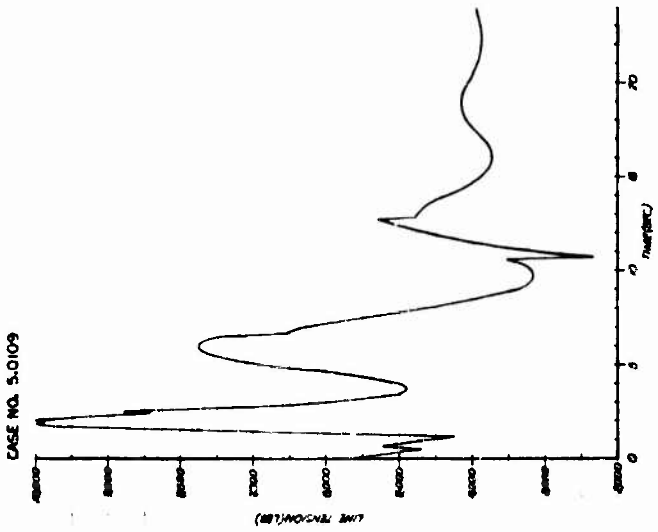
CARGO WEIGHT: 3980 LBS
NO REEL IN

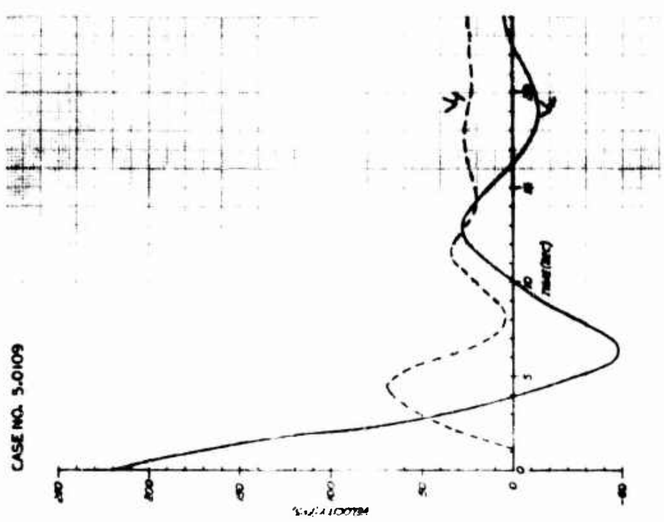


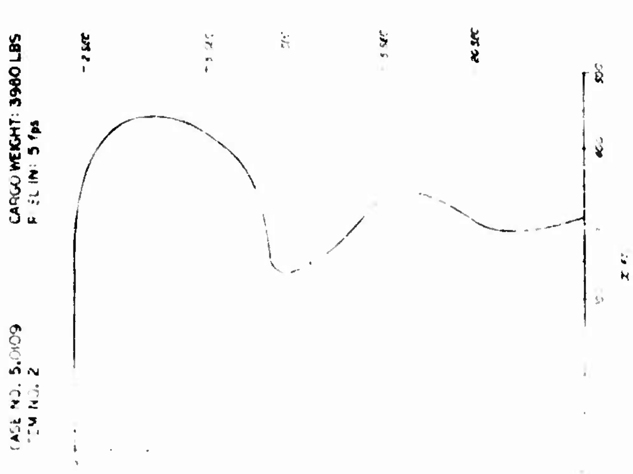


CASE NO. 5.0:08

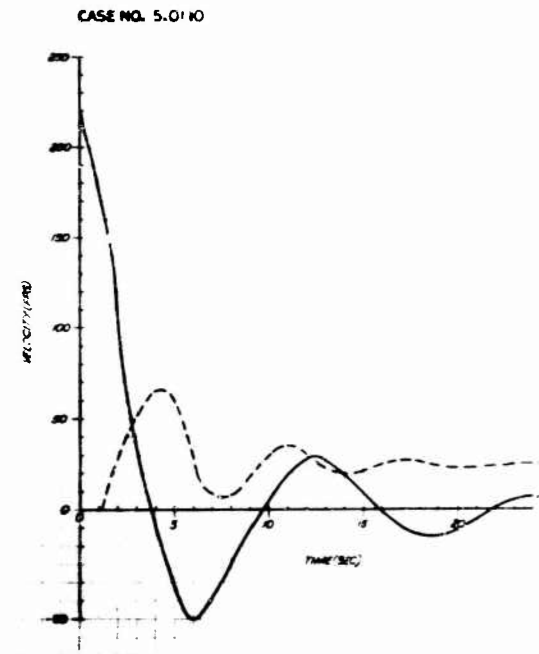


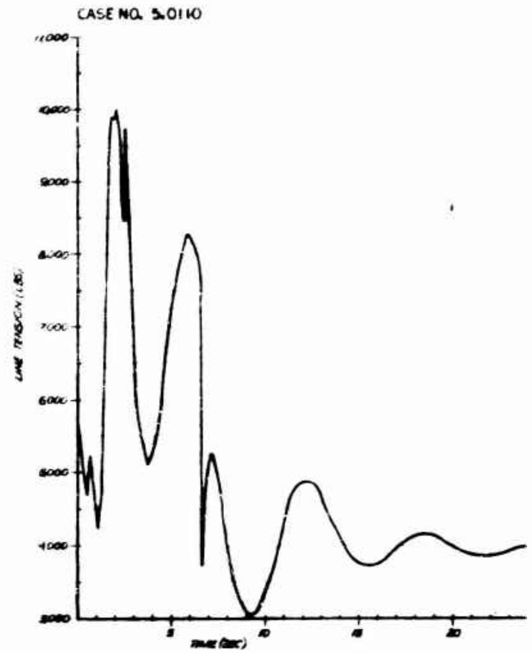

CASE NO. 5.0109
LINE TENSION (LBS)
TIME (SEC)


CASE NO. 5.0109
TIME (SEC)


CARGO WEIGHT: 3980 LBS

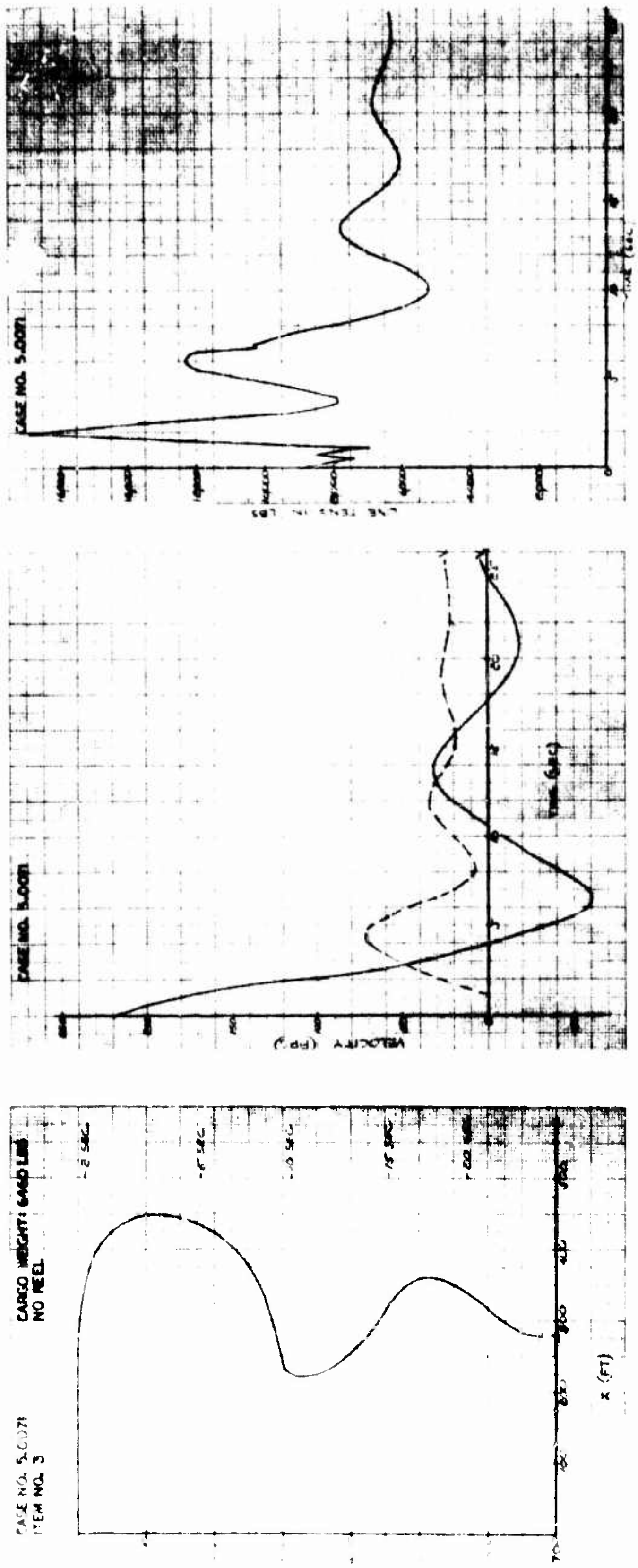

CASE NO. 5.0110
ITEM NO. 2
CARGO WEIGHT 3980 LBS
REEL IN 10 fps
-2 SEC
-5 SEC
-10 SEC
-15 SEC
-20 SEC
100
200
300
400
500

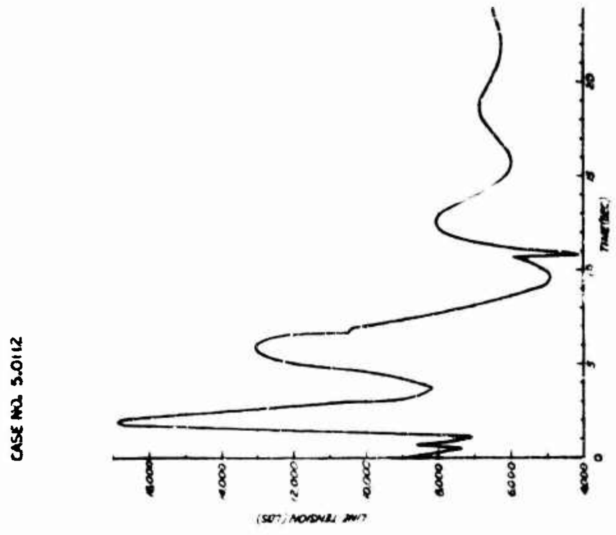

CASE NO. 5.0110
VELOCITY (FPS)
TIME (SEC)
250
200
150
100
50
0
-50
5
10
15
20

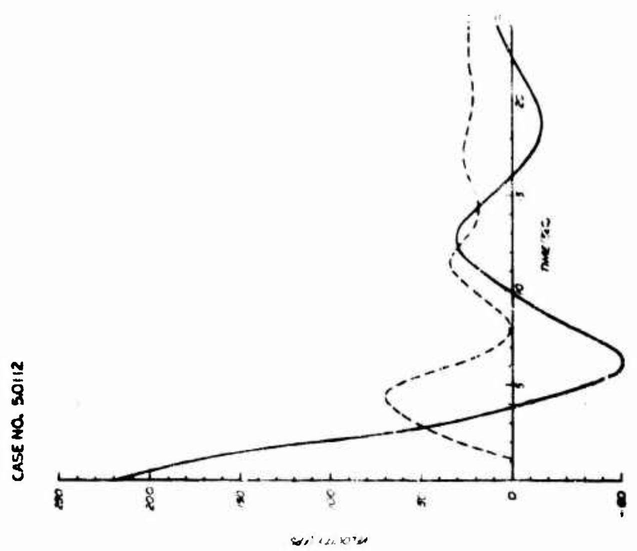

CASE NO. 5.0110
LINE TENSION (LBS)
TIME (SEC)
11000
10000
9000
8000
7000
6000
5000
4000
3000
5
10
15
20

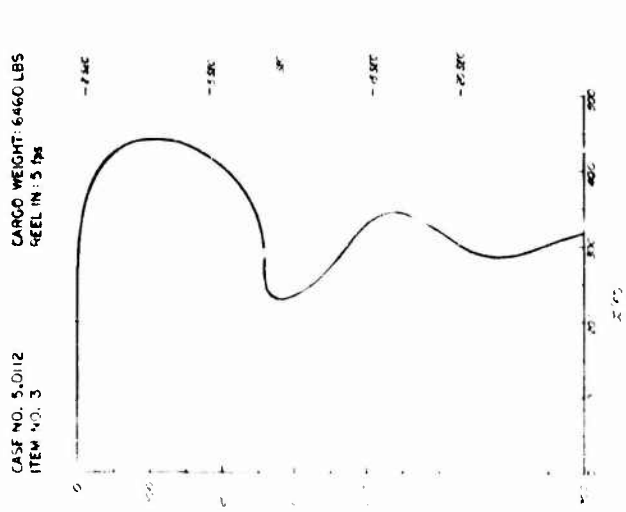
(c) Item 3:

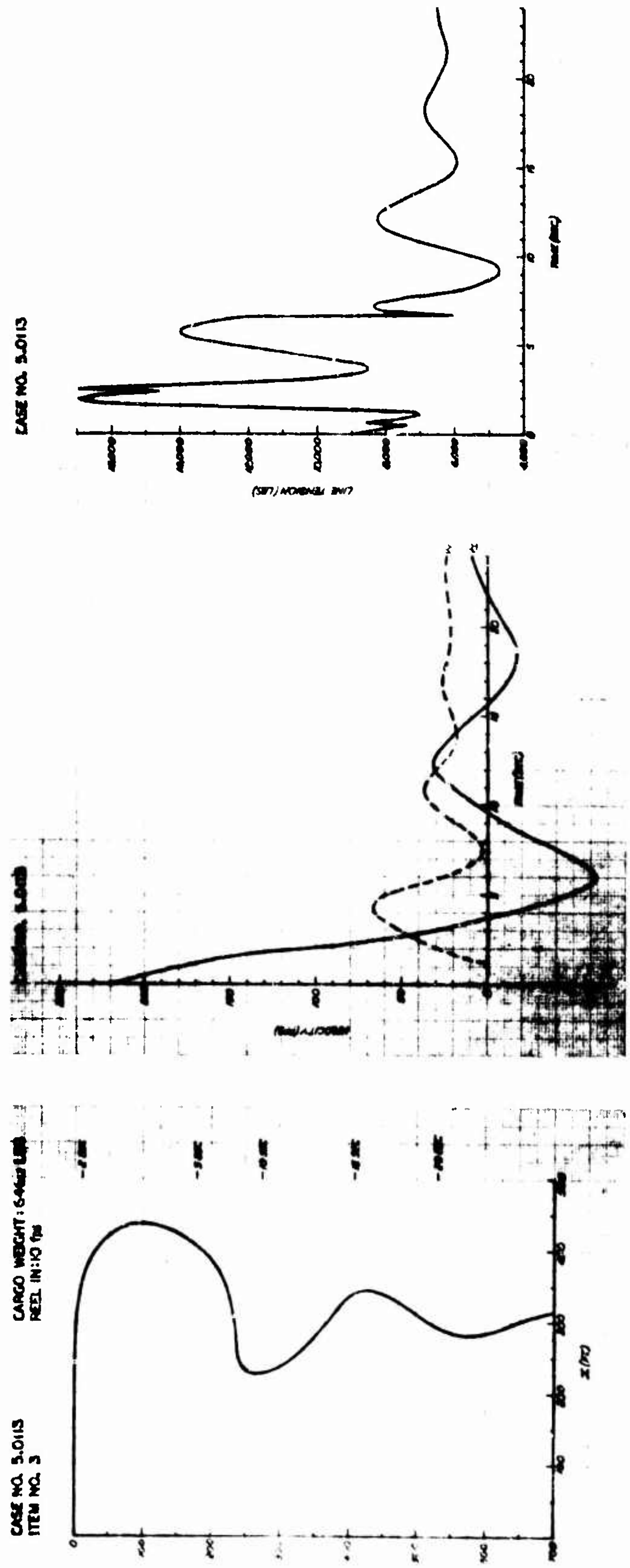
Case 5.0071 provides the basic no-reel trajectory for item 3. The vertical velocity (V_y) range is relatively good but the magnitude of $V_{x_{max}}$ is probably higher than desired. Cases 5.0112 and 5.0113 provide reel-in trajectories for item 3 reeling-in at rates of 5 fps and 10 fps, respectively. $V_{x_{max}}$ is decreased slightly in both cases but the V_y range remains fairly stable. However, H_{min} is effectively reduced from 474 ft. with no reel to 404 ft. and 394 ft. with 5 fps and 10 fps reel rates, respectively. Similarly, the value of $\Phi_{500'}$ goes from 20.2° with no reel-in to approximately 1.5° with reel-in inputs. The results of these analyses show that reel-in for item 3 affects only the values of H_{min} and $\Phi_{500'}$. Hence, if the improvement in these two parameters justifies the use of a reel-in device, the reel-in mechanism should be used. Furthermore, if a reel system is employed, the 5 fps reel system should be the one chosen for future development since the 5 fps reel rate horsepower requirement (139 HP) is less than half that required for the 10 fps reel system.


CASE NO. 5.0071
ITEM NO. 3
NO REEL
x (FT)
CASE NO. 5.0071
VELOCITY (FPS)
TIME (SEC)
CASE NO. 5.0071
LINE TENSION (LBS)
TIME (SEC)


CASE NO. 5.0112
LINE TENSION (LBS)
TIME (SEC)


CASE NO. 5.0112
TIME (SEC)


CASE NO. 5.0112
ITEM NO. 3
CARGO WEIGHT: 6460 LBS
REEL IN: 5 fps


CASE NO. 5.0113
ITEM NO. 3
CARGO WEIGHT: 646
REEL IN: 10 fps
CASE NO. 5.0113
LINE TENSION (LBS)
TIME (SEC)

(d) Item 5:

Most of the effort expended during this program has been concentrated on computing trajectories for item 5 (M37). Case 5.0091 provides the no-reel (other than the natural line shortening effect due to disreefing) trajectory with 2 chutes, while case 5.0092 reels-in at 5 fps and case 5.0093 reels-in at 10 fps. This series of runs discloses the fact that a reel-in system actually delays impact thereby improving impact conditions over no-reel trajectories. The absolute value of $V_{x\,max}$ is effectively decreased while the V_y range remains about the same. And, as with item 1, it should be apparent that a reel rate of 5 fps produces the best solution since the power requirement is significantly lower than the 10 fps reel system while the impact conditions remain relatively unchanged with the faster reel rate.

Runs 5.0097 and 5.0098 show the effect of aircraft velocity on cargo trajectories. Again, item 5 is the drop cargo, and there is no mechanical reel-in. The results show that there is no significant effect upon the impact parameters, even over an aircraft speed range of 186 fps to 254 fps. There is a slight change in $V_{x\,max}$ but this is quite compatible with the initial velocities. Cases 5.0104 and 5.105 show the effect of aircraft velocity on trajectories with reel-in. When compared with the results of case 5.0092 it becomes evident that the specified aircraft velocity range is a relatively unimportant parameter with respect to impact conditions. However, there is an increase in the power requirement for the system with the faster aircraft velocity. Hence, for the same reel rate, a change in the aircraft velocity results in a change in the power requirement.

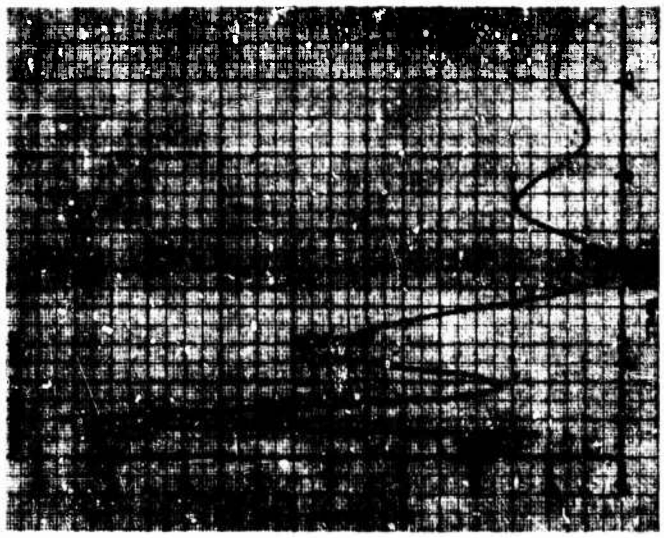
Case 5.0096 provides the no reel trajectory for a terrain altitude of 5000 feet at an ambient temperature of 100°F. Three chutes are required in this case because of the decrease in air density. Case 5.0101 is identical to 5.0096 except a reel rate of 5 fps is used. The reel system increases the time to reach 500 feet, thereby decreasing the value of H_{min}, while the remaining impact parameters stay about the same as with the no-reel system. Of further interest is the fact that the addition of a chute has relatively little effect on the impact parameters of the reel system in the given environment when compared to the similar two-chute system at sea -level.

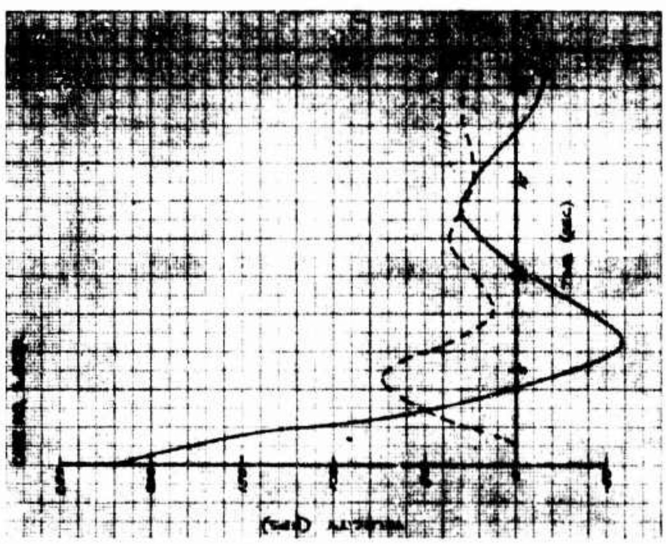
Cases 5.0094 and 5.0095 show the effect of relocating the cargo in the aircraft cargo compartment. In case 5.0094, item 5 is placed at the forward end of the cargo compartment while it is placed at the aft end in case 5.0095. Neither case employs reel-in other than the natural line shortening due to disreefing. The results are quite interesting. Even while the vertical velocity range for both remains within reason, the magnitude of $V_{x\,max}$ is more than halved when the cargo is located at the aft end of the cargo compartment. This is due to the shortening of X_{RL}

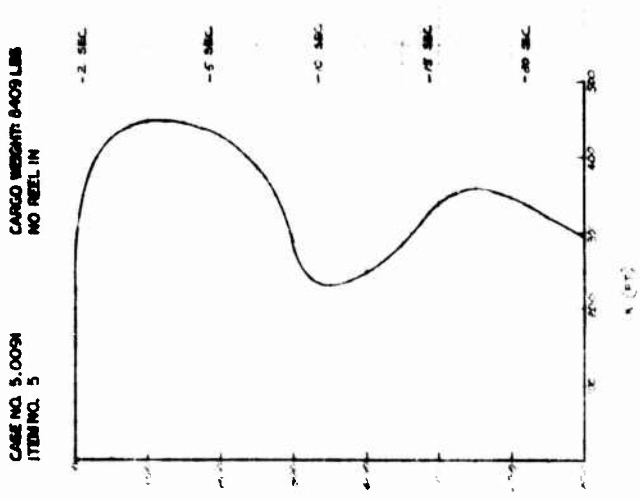
when the cargo is further back in the aircraft. When the cargo is placed at the forward end of the cargo compartment, X_{RL} is nearly 25 feet longer than it is when the cargo is at the aft end giving rise to much larger descent oscillations. Cases 5.0099 and 5.0100 show the effect of a 5 fps reel-in on cases 5.0095 and 5.0094 respectively. Case 5.0099(cargo at aft location) appears to have the most desirable trajectory characteristics, particularly from the standpoint of required power. In fact, the power requirement for 5.0099 is even somewhat lower than that of 5.0092 where the cargo c.g. is located on the aircraft c.g.

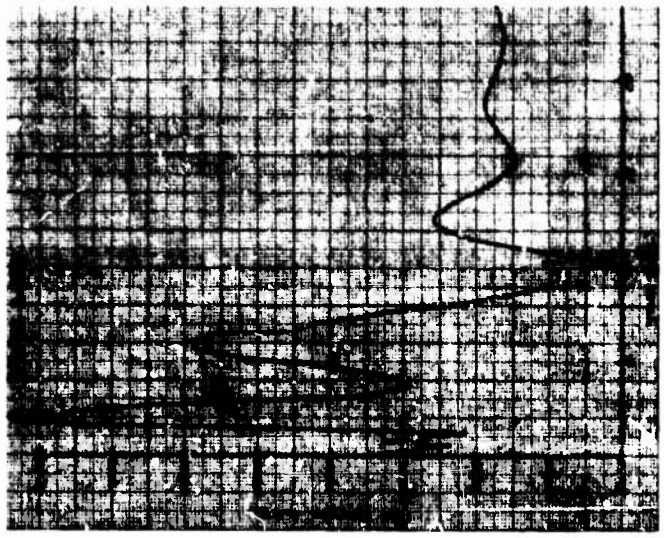
An analysis of this series of trajectories for item 5 shows that more satisfactory impact conditions may be obtained with a reel system than without, and that the distance between the chute (chute cluster) c.g. and the cargo c.g. is the principal governing factor in drop trajectories. Further, the closer the cargo c.g. is placed towards the aft end of the cargo compartment, the better the impact parameters since the line length is shortened. However, it should be noted that as the individual cargo weights increase, the distance the cargo may be displaced from the aircraft c.g. decreases. Otherwise, adverse moments are placed upon the aircraft structure. Therefore, this method of line shortening should be neglected for single drops involving very heavy cargoes. Furthermore, a reel system with a reel rate of 5 fps seems to be the best system to use for this cargo and, if the cargo is initially located towards the aft end of the cargo compartment the power requirement will be at its lowest.

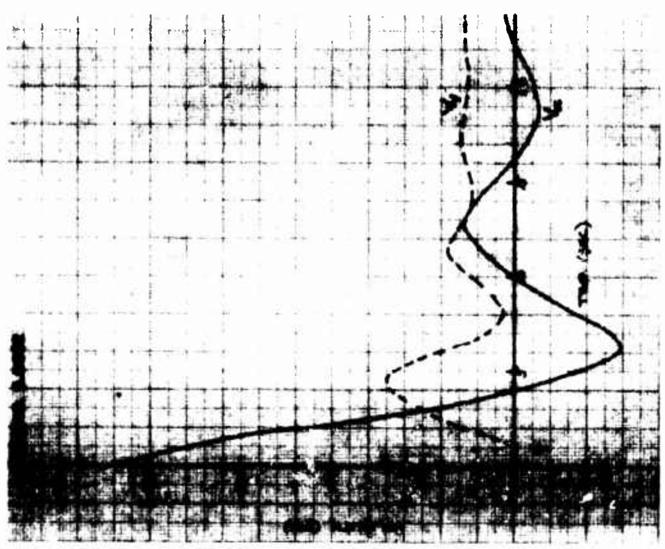
Run 5.0082 is illustrated in this discussion of cargo item 5 in order to illustrate the effect of adding weight to the basic cargo weight of 8409 lb. In this case, 1000 lb. of weight was arbitrarily added to the cargo, in order to simulate the effect of the additional weight imposed on the system due to the reel-in mechanism. (Actually, the approximately 200 HP reel-in mechanism required for item 5 weighs only about 400 lb. as noted in Part 3 of this section.) Comparing the impact parameters achieved from Run 5.0082 to those of Run 5.0092 indicates that the addition of 1000 lb. to the cargo item did not significantly change the magnitude of the impact parameters. Hence, the addition of the reel mechanism components to the various items of cargo is not expected to invalidate the results illustrated in this report, which do not, as noted previously, include the reel system weight.

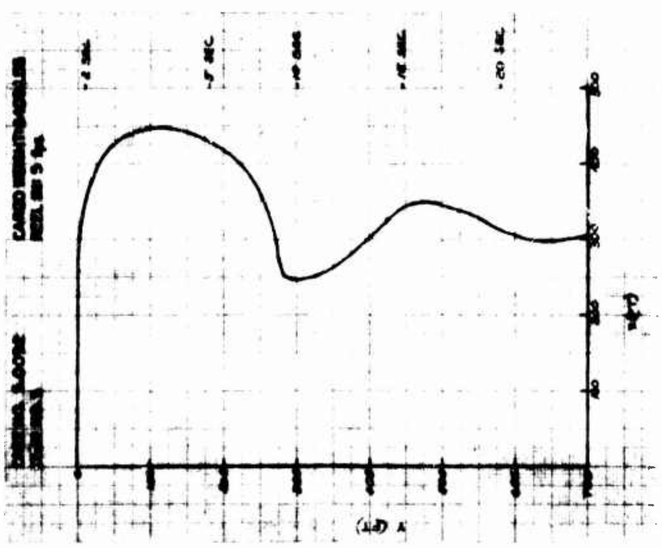


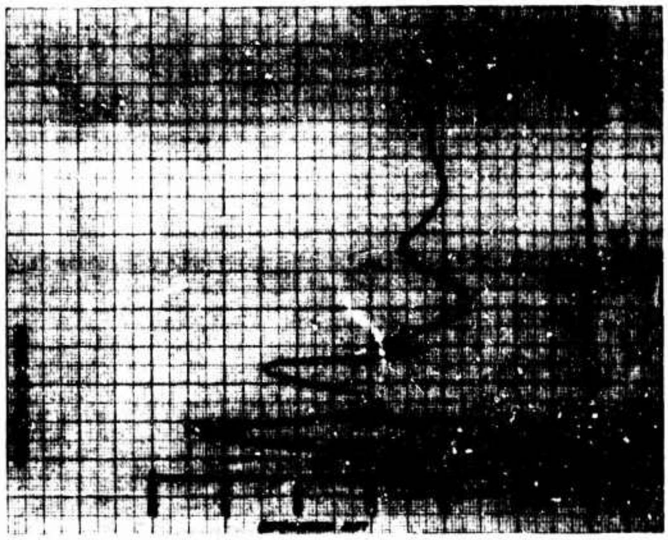


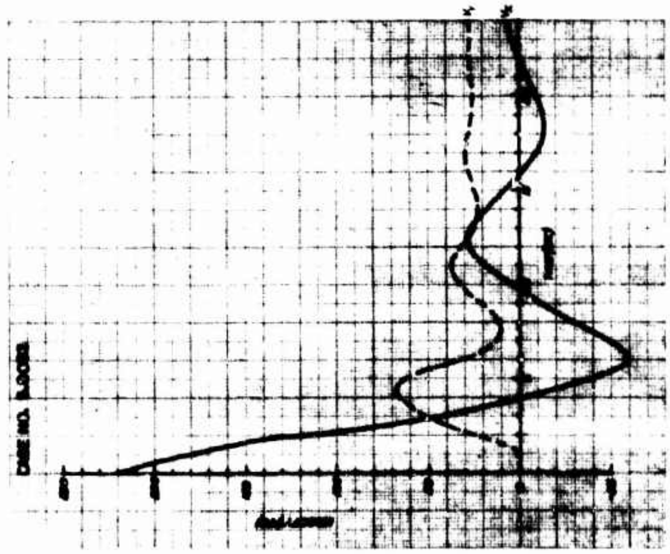

CASE NO. 5.0091
ITEM NO. 5
CARGO WEIGHT: 8409 LBS
NO REEL IN

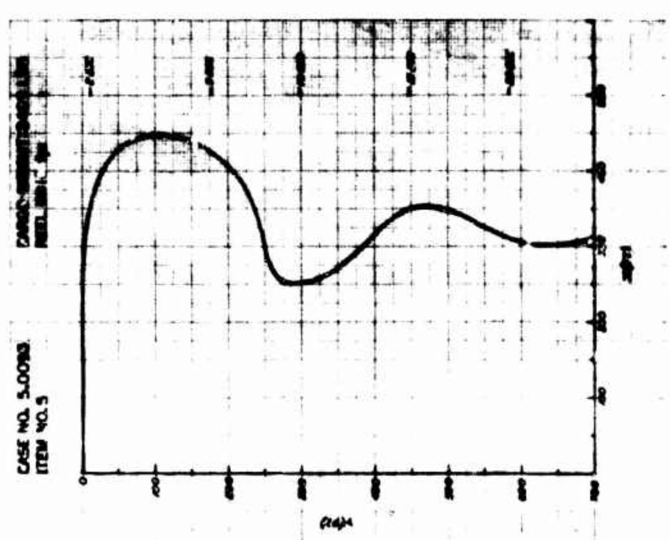


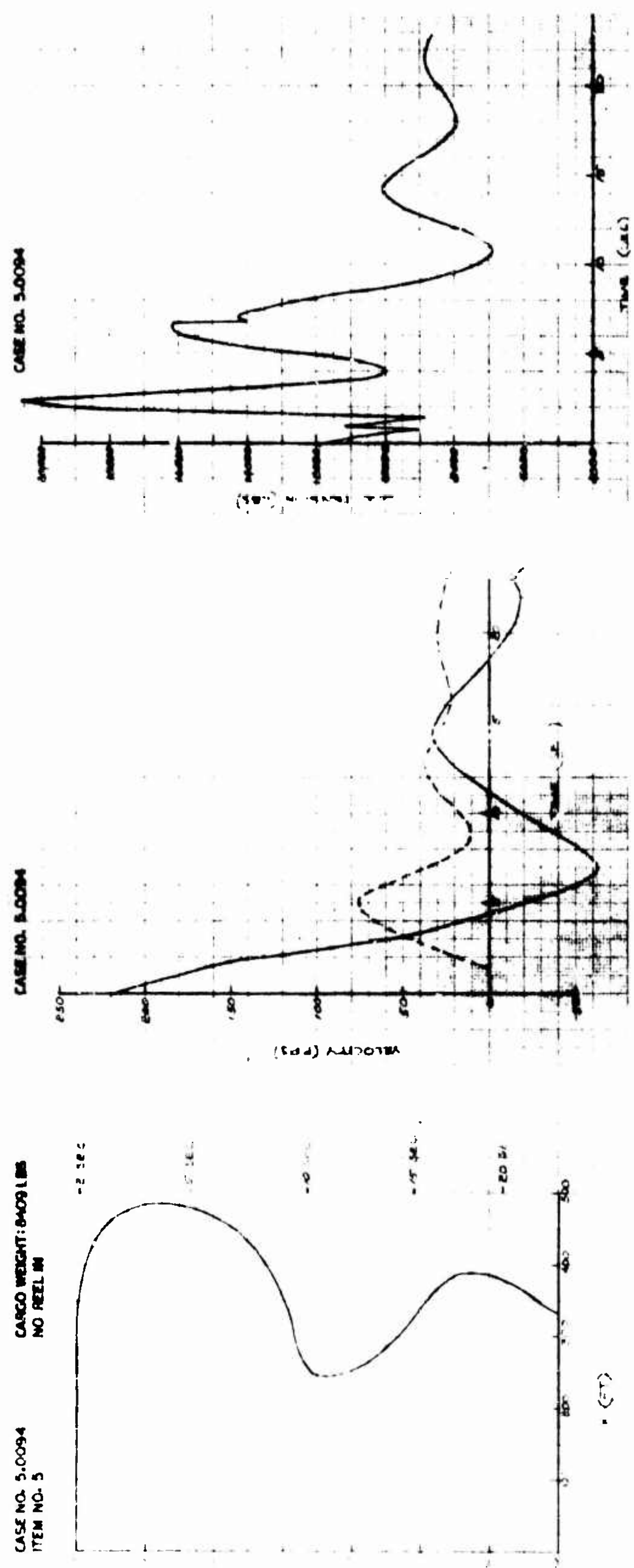


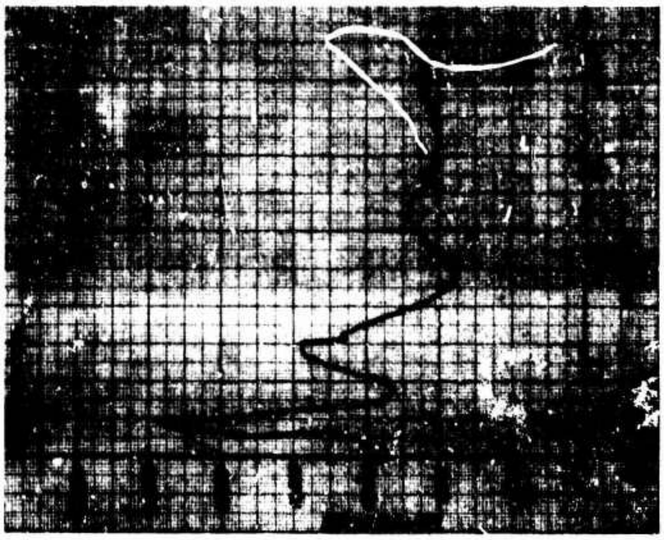


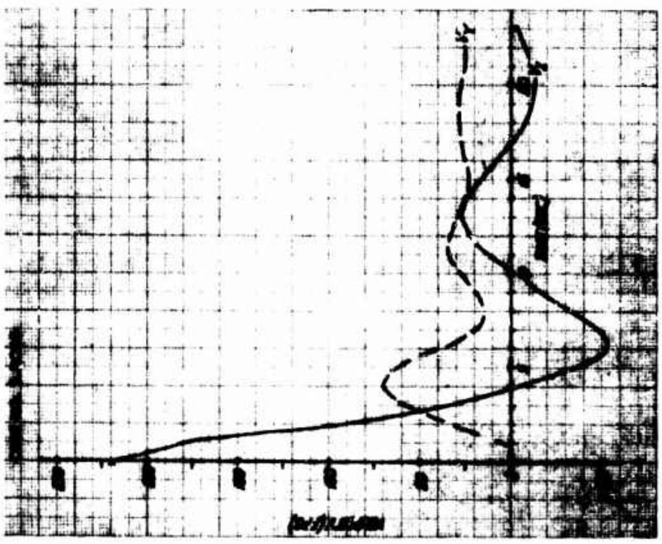


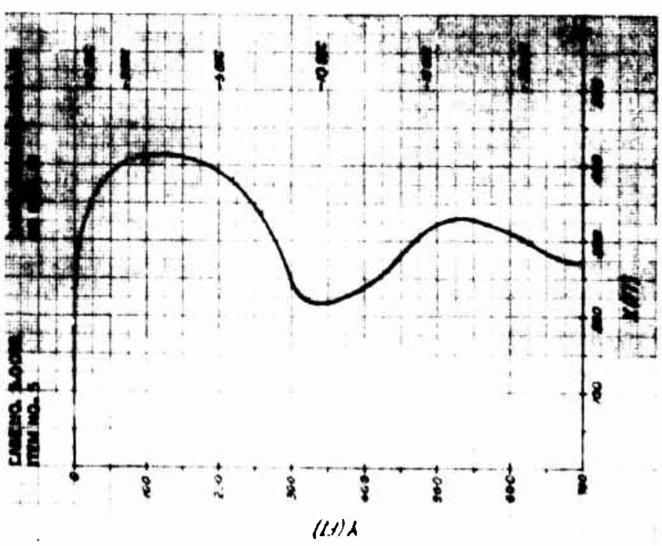


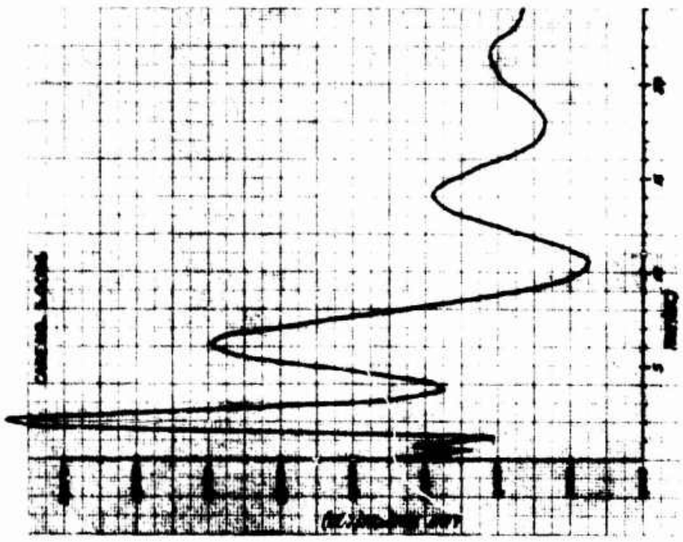


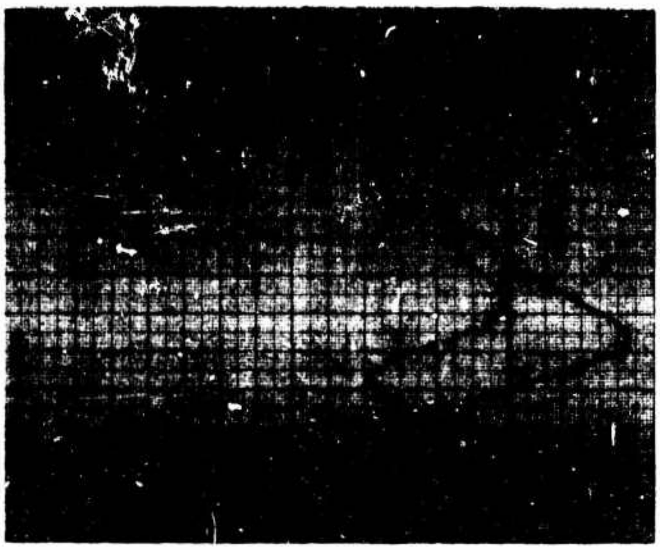

CASE NO. 5.0094
TIME (SEC)
CASE NO. 5.0094
VELOCITY (FPS)
CASE NO. 5.0094
ITEM NO. 5
CARGO WEIGHT: 8409 LBS
NO REEL IN

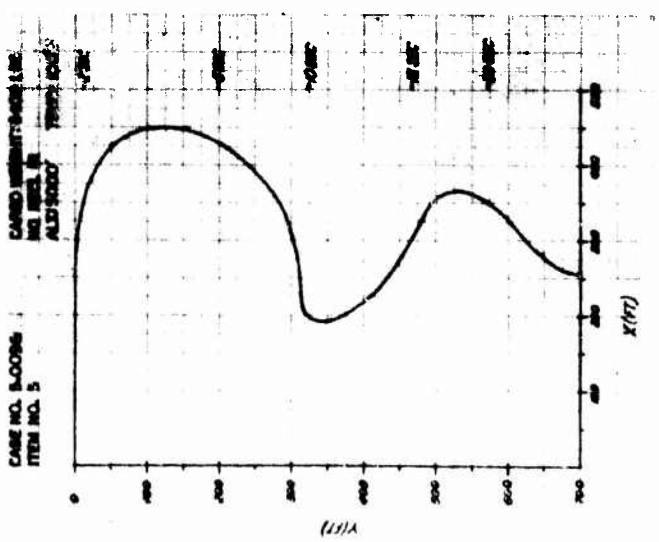


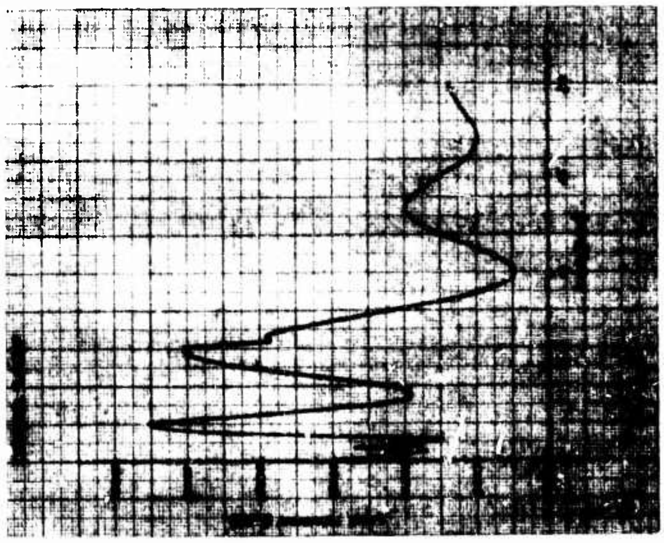


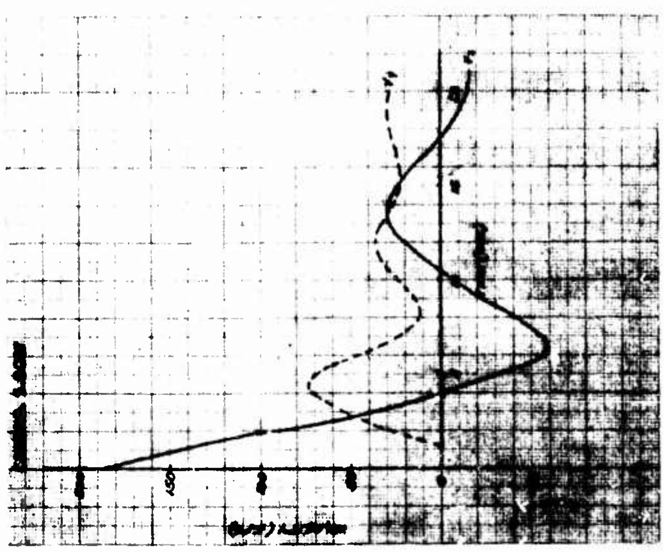


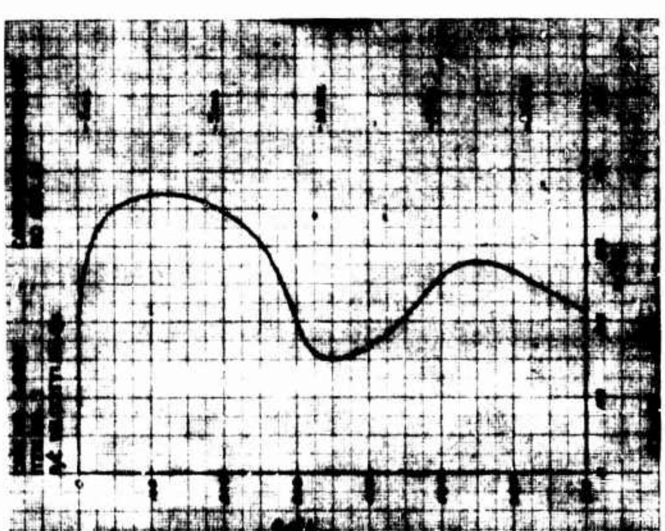


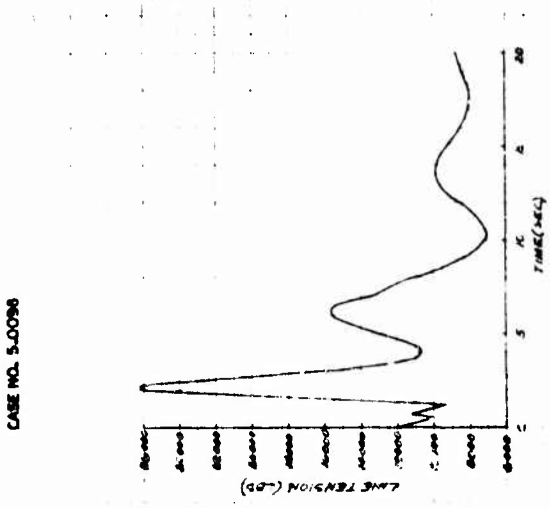


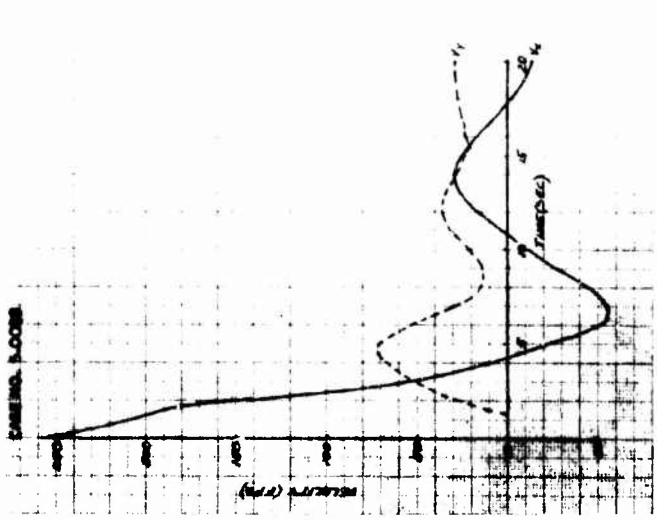


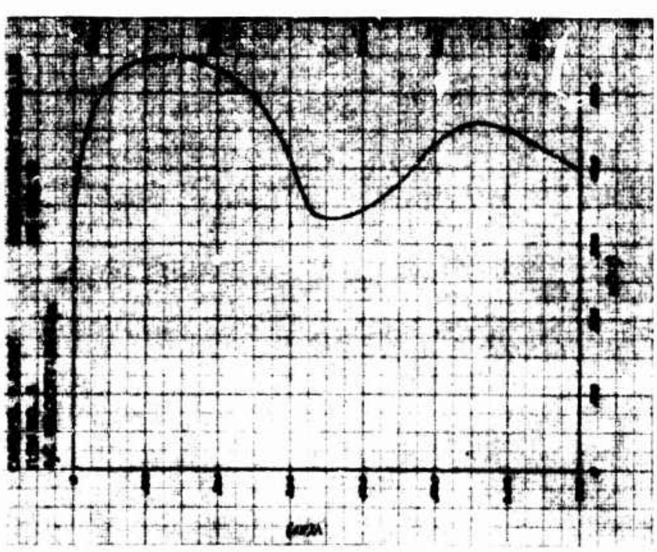


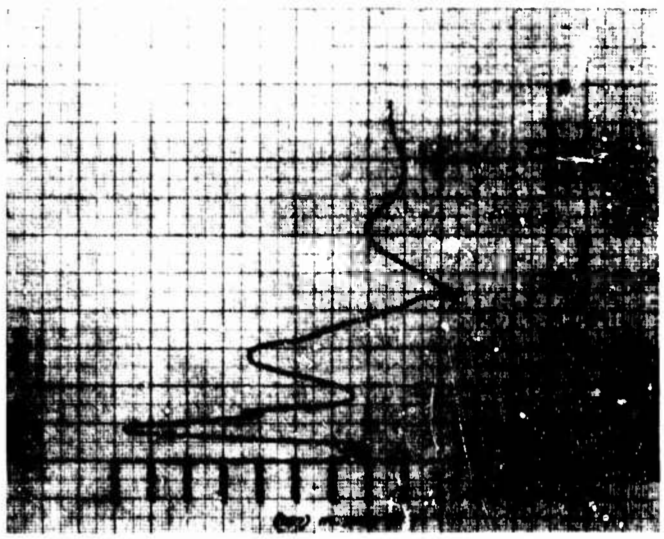


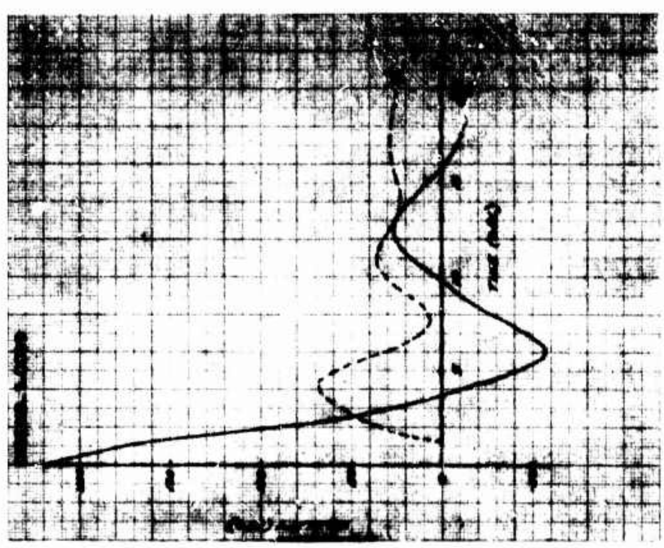


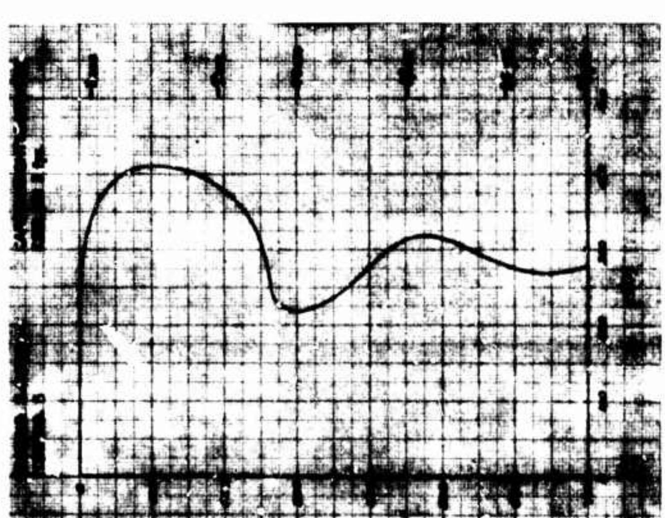

CASE NO. 5.0098
LINE TENSION (LBS)
TIME(SEC)

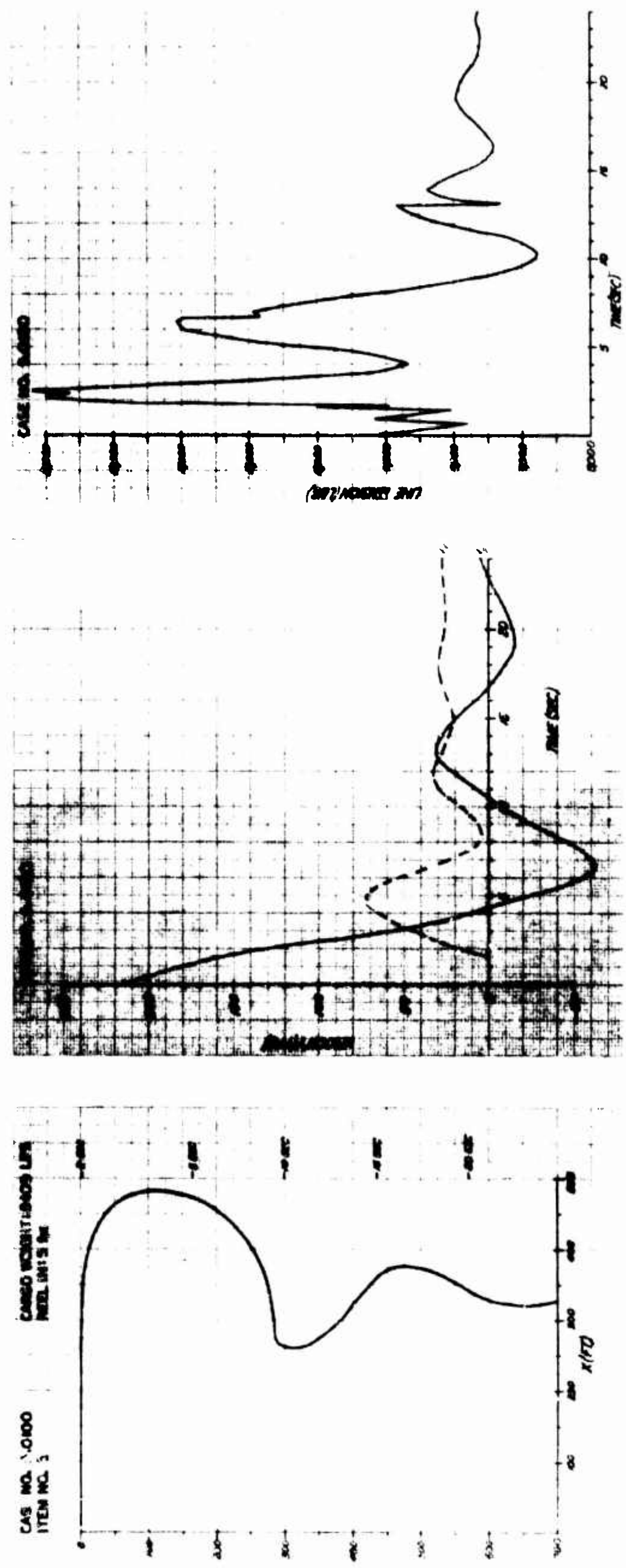

TIME(SEC)

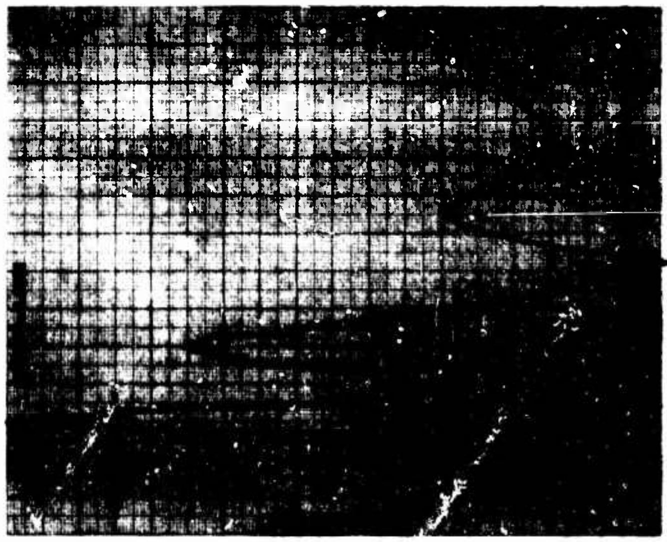


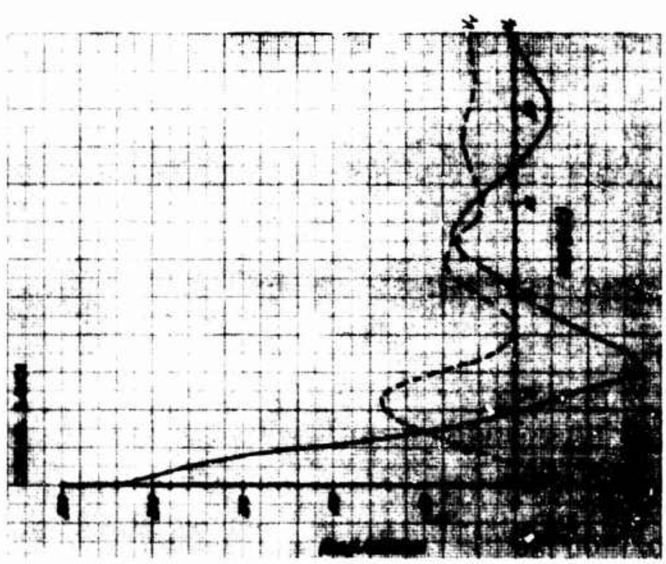


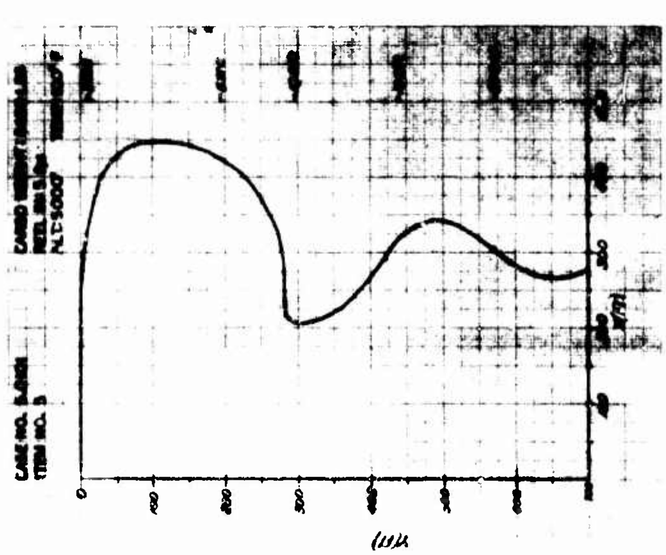


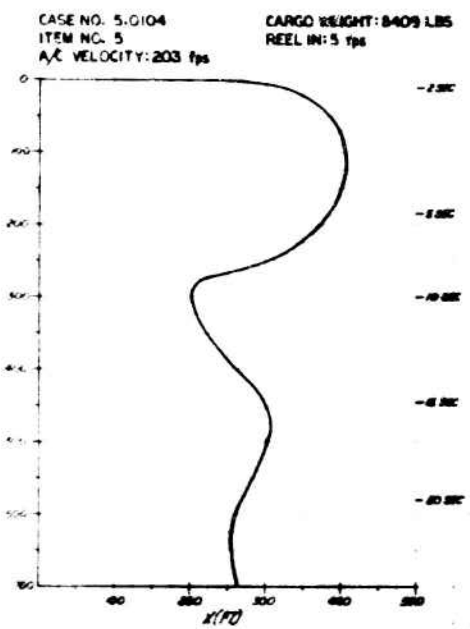


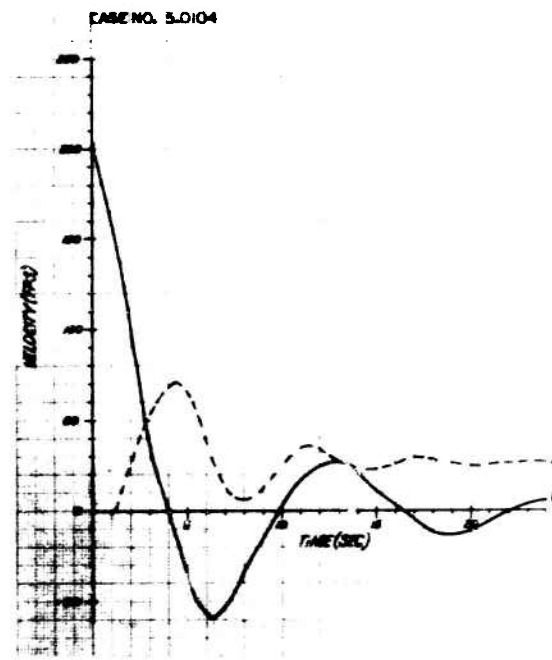


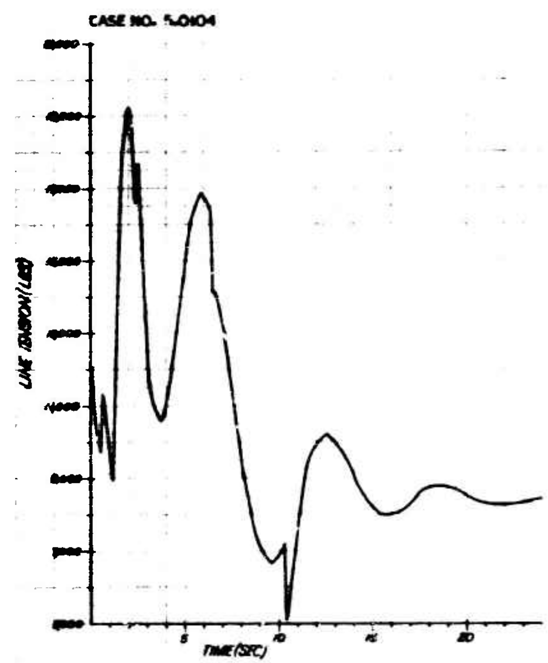


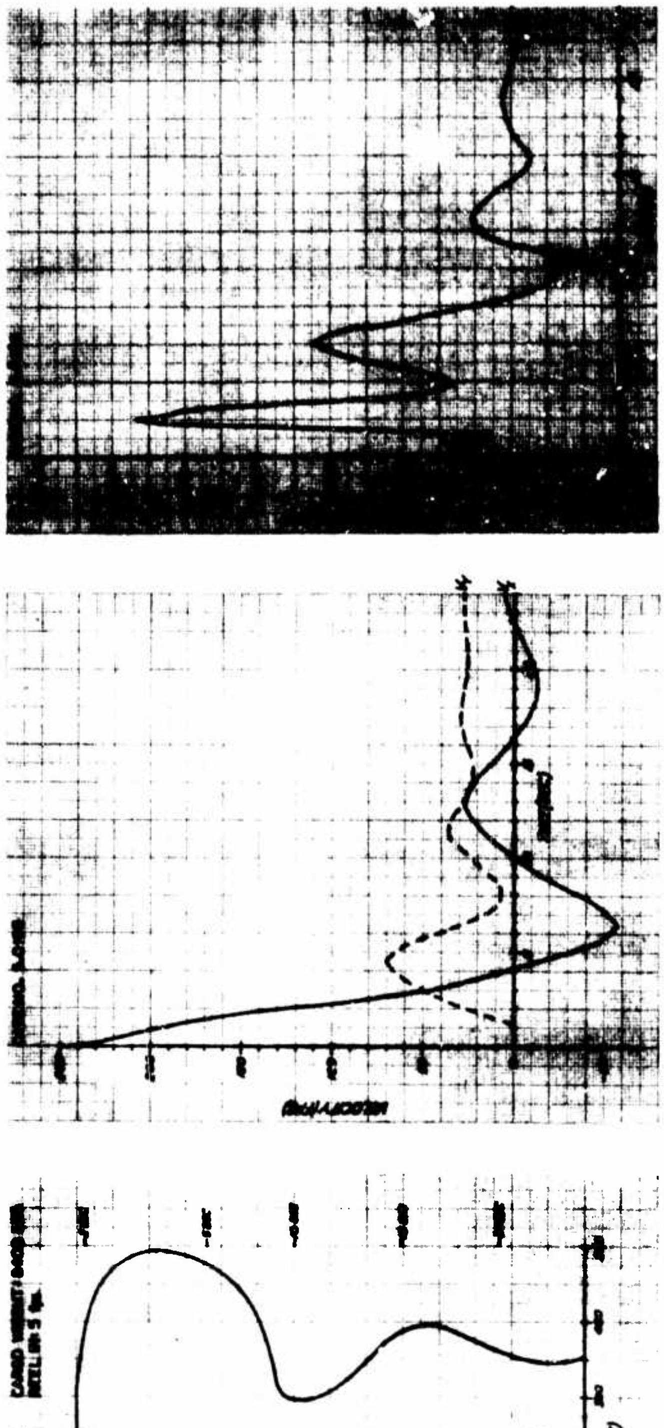


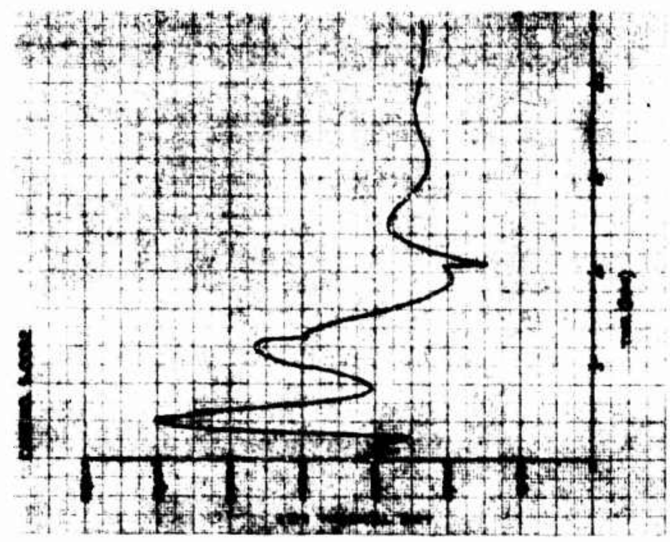


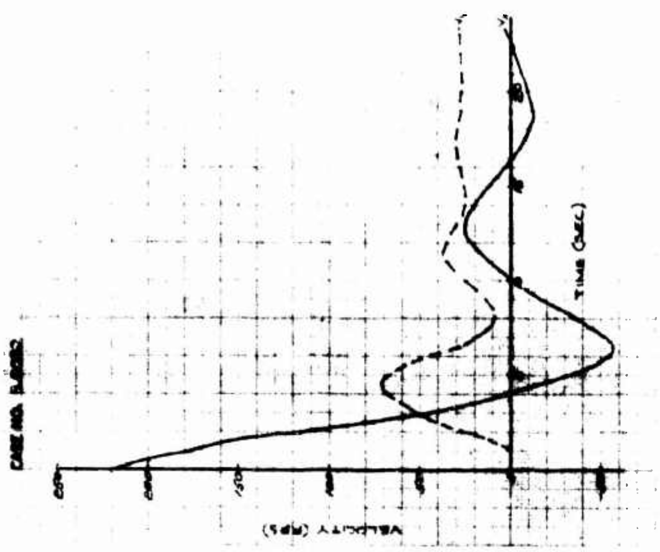

CASE NO. 5.0104
ITEM NO. 5
A/C VELOCITY: 203 fps
CARGO WEIGHT: 8409 LBS
REEL IN: 5 fps
X(FT)

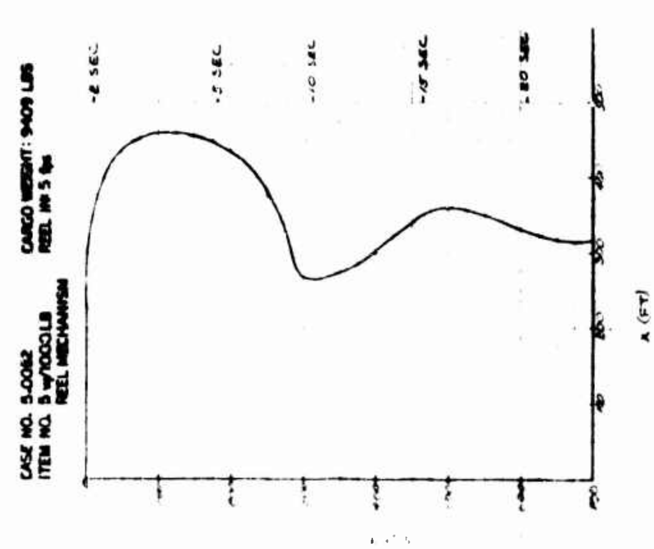

CASE NO. 5.0104
VELOCITY(FPS)
TIME(SEC)


CASE NO. 5.0104
LINE TENSION (LBS)
TIME(SEC)



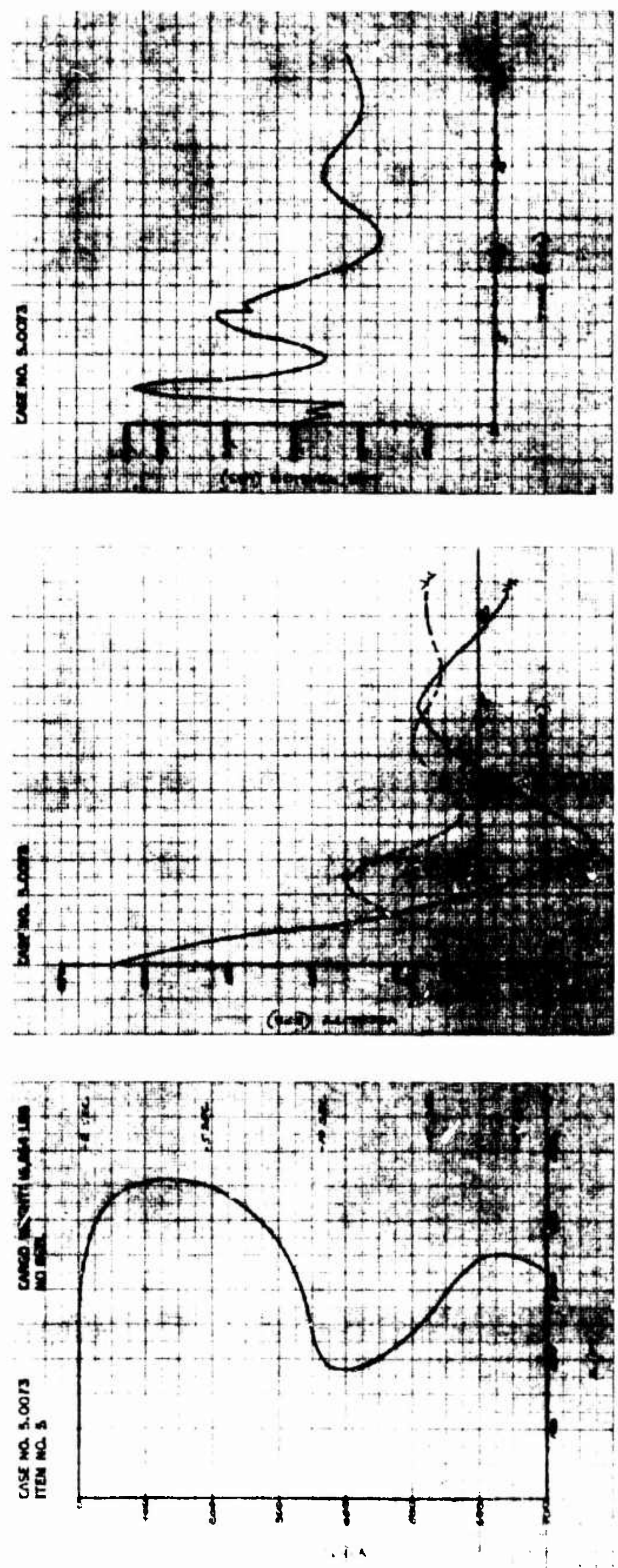


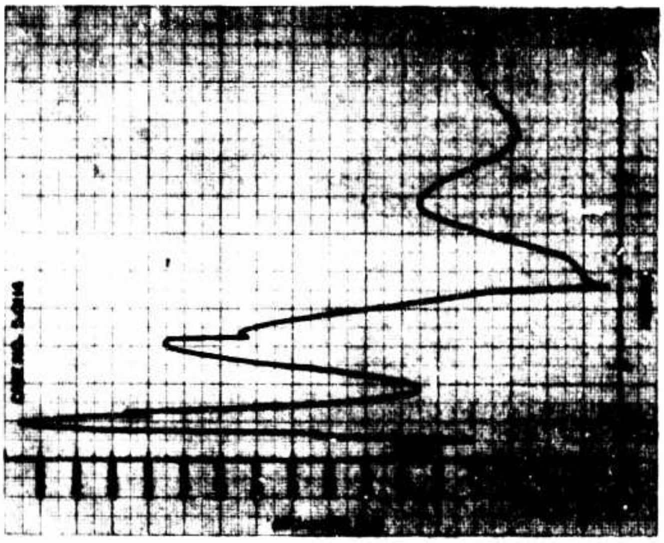

CASE NO. 5-0062
VELOCITY (FPS)
TIME (SEC)

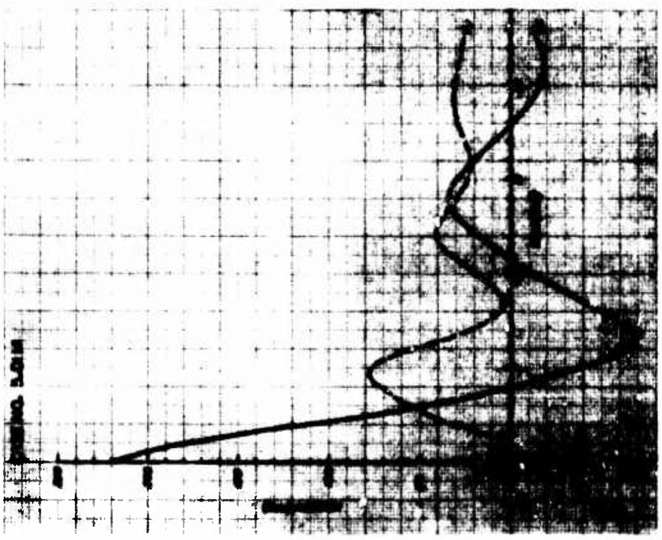

CASE NO. 5-0062
CARGO WEIGHT: 9409 LBS
REEL MECHANISM
X (FT)

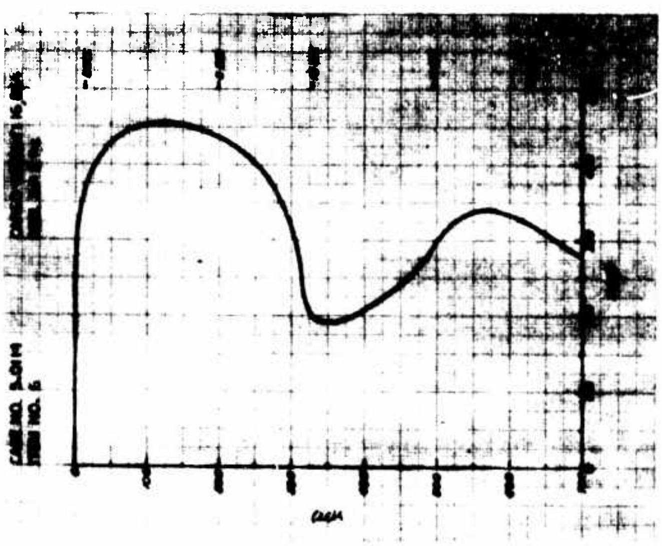
(d) Item 6

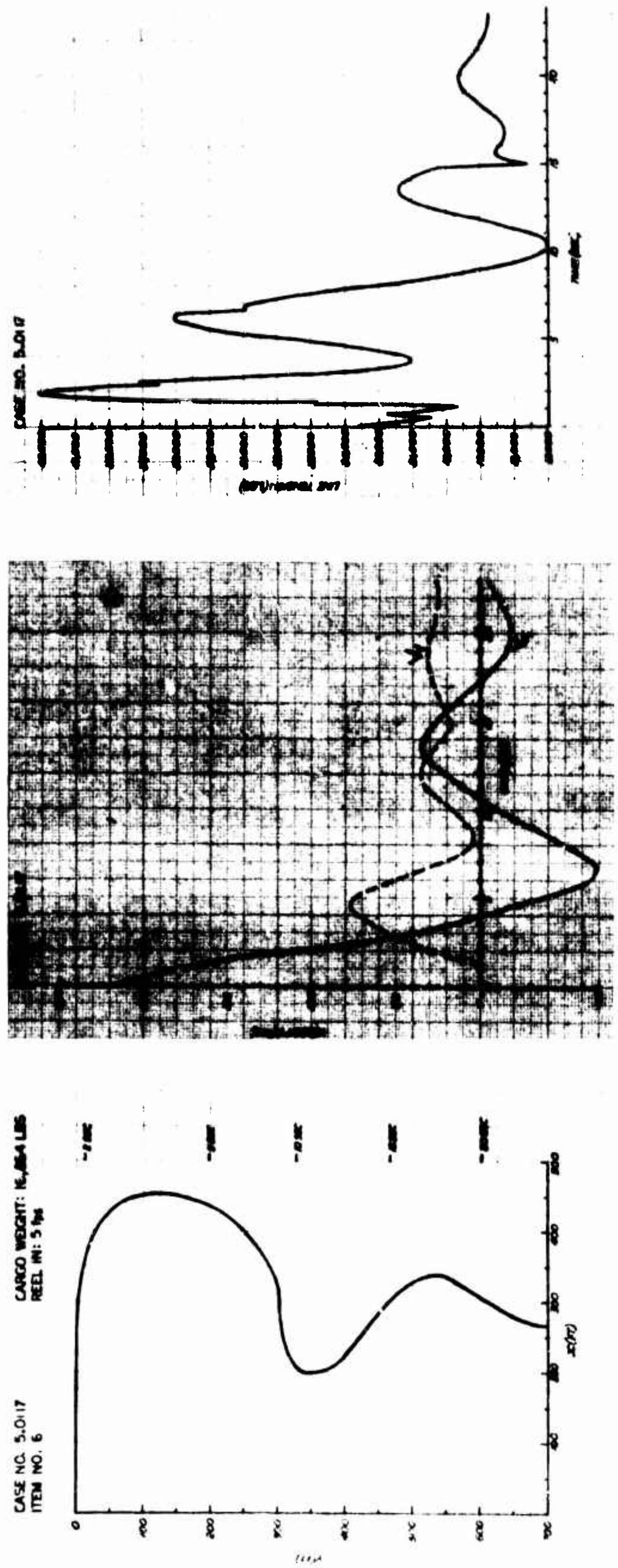
Case 5.0073 provides the no-reel trajectory for item 6 while cases 5.0114 and 5.0117 show the effects of reeling in at 5 fps. Case 5.0114 reels-in only X_{RL} while case 5.0117 reels-in X_{RL} and 28.6 ft. of X_{RE}. Obviously, the latter provides the best results, particularly with respect to the magnitude of $V_{x\ max}$ and H_{min}. It seems probable that even more favorable results could be obtained using a reel-in rate of 7.5 fps and reeling in more of X_{RE}, but when compared with the results obtained for a 7.5 fps reel system used with item 7 (the drop weights of items 6 and 7 are fairly close) it can be seen that the horsepower requirement for item 6 is about half that required for item 7 while the impact parameters are about the same. Hence, a 5 fps reel-in system reeling-in part of the riser extensions should be chosen for future development for this item.


CASE NO. 5.0073
CASE NO. 5.0073
ITEM NO. 5







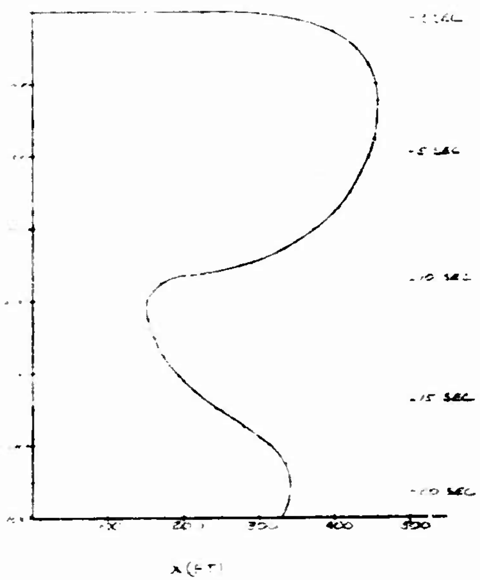


(f) Item 7:

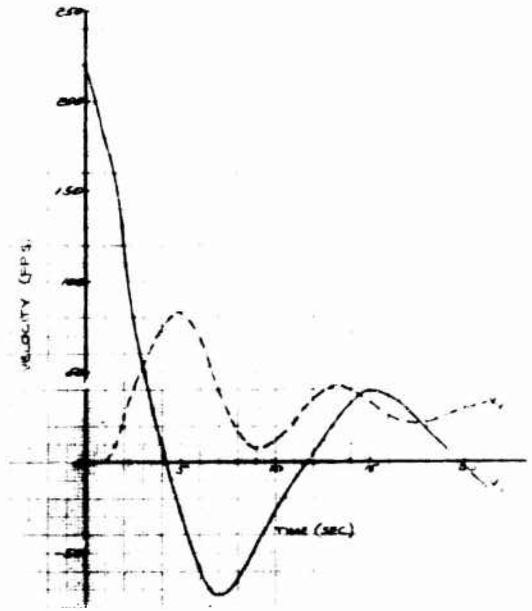
Case 5.0074 provides the basic trajectory for this cargo, with 5 chutes and no powered reel-in. Examination of the trajectory results shows that this particular drop item does not attain a terminal velocity of 28.5 fps at the desired extraction altitude. Also, the horizontal velocities at impact are relatively high. Case 5.0089 is identical to 5.0074 except a 5 fps reel rate is used to shorten the line. The V_y range is significantly improved, even though the maximum value of this range is still higher than desired. Because of this, it was felt that reeling in part of the riser extensions would further decrease impact velocities. Case 5.0102 provides the trajectory for this extra reel-in at a rate of 7.5 fps. Admittedly, the V_y range is not significantly improved, but the magnitude of $V_{x\ max}$ is roughly halved. Furthermore, this system permits lower extraction altitudes than the 5 fps reel-in system. Also, the power requirement goes significantly upward in case 5.0102 but this increase in power seems small when compared to the improved impact parameters. Hence, the 7.5 fps reel system is the suggested system to be chosen for future development.

CASE NO. 5.0074
ITEM NO. 7

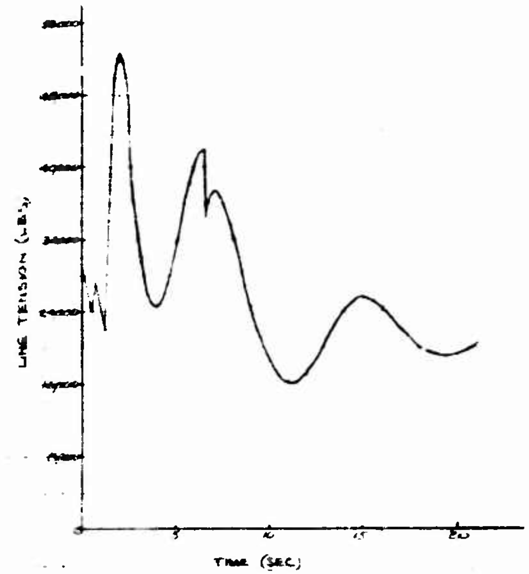
CARGO WEIGHT: 20,650 LBS
NO REEL IN

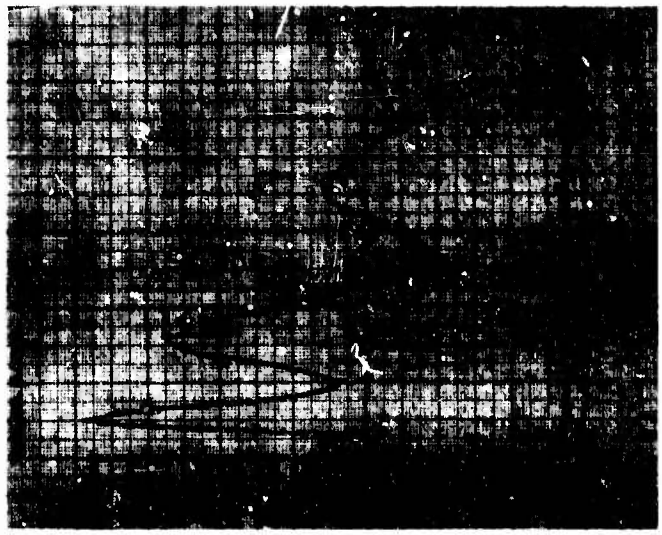


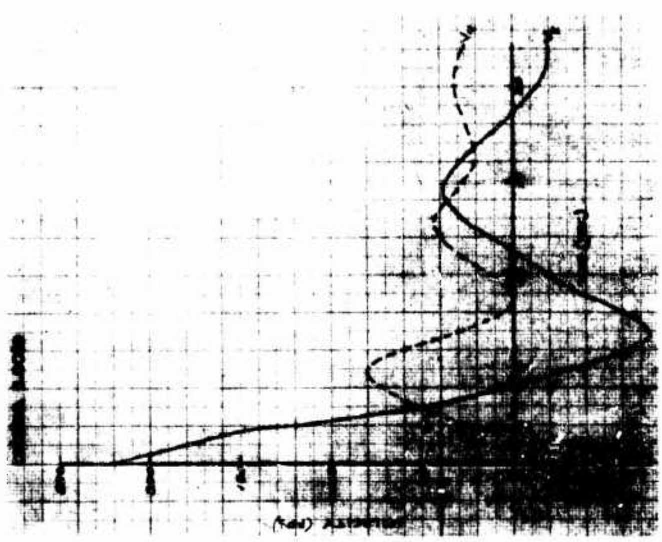
CASE NO. 5.0074

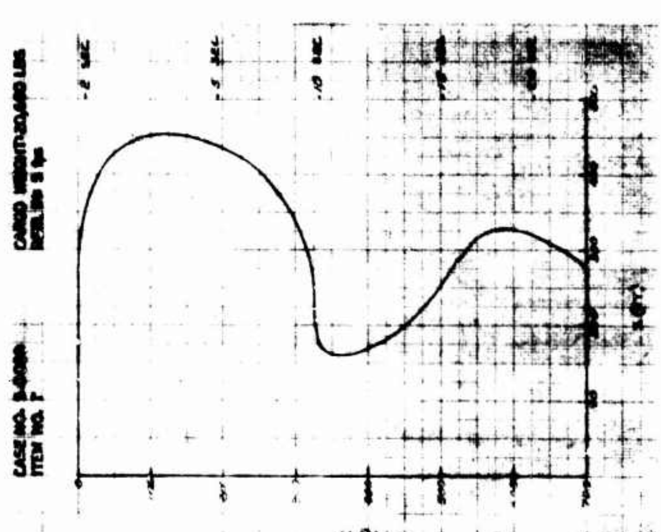


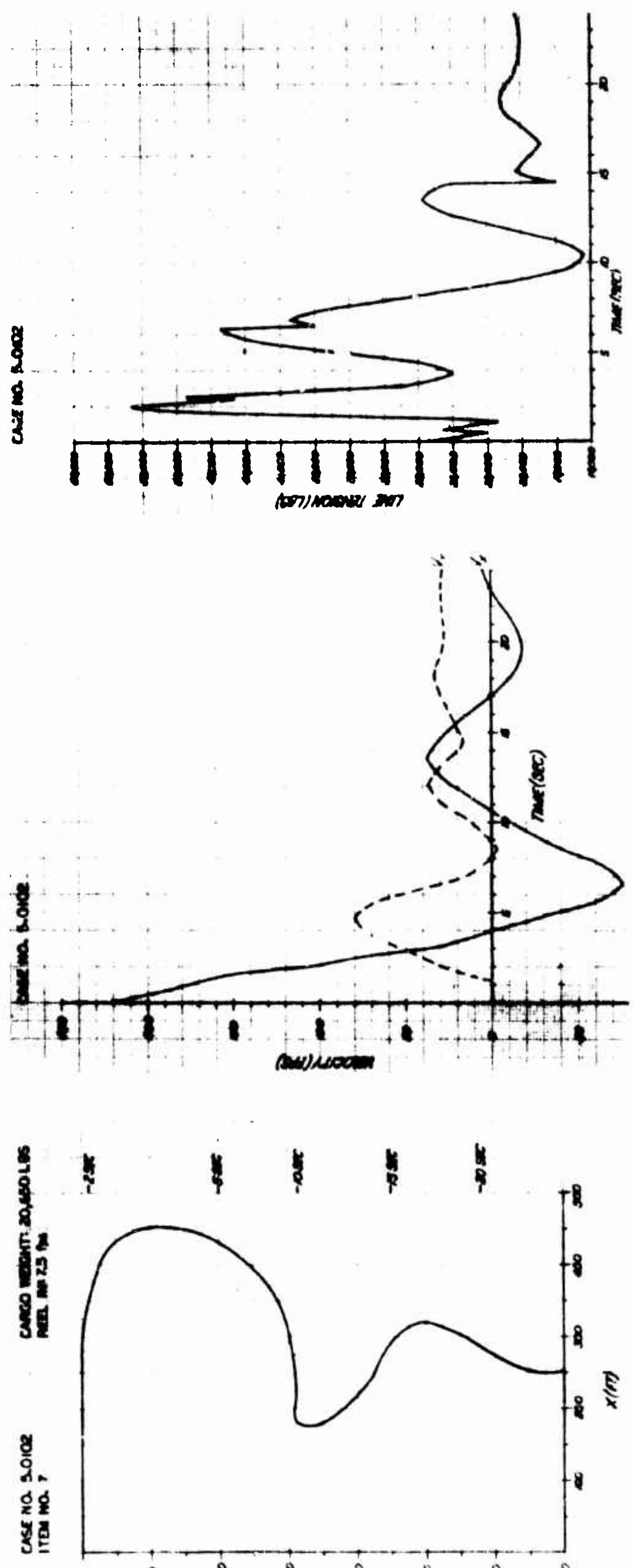
CASE NO. 5.0074









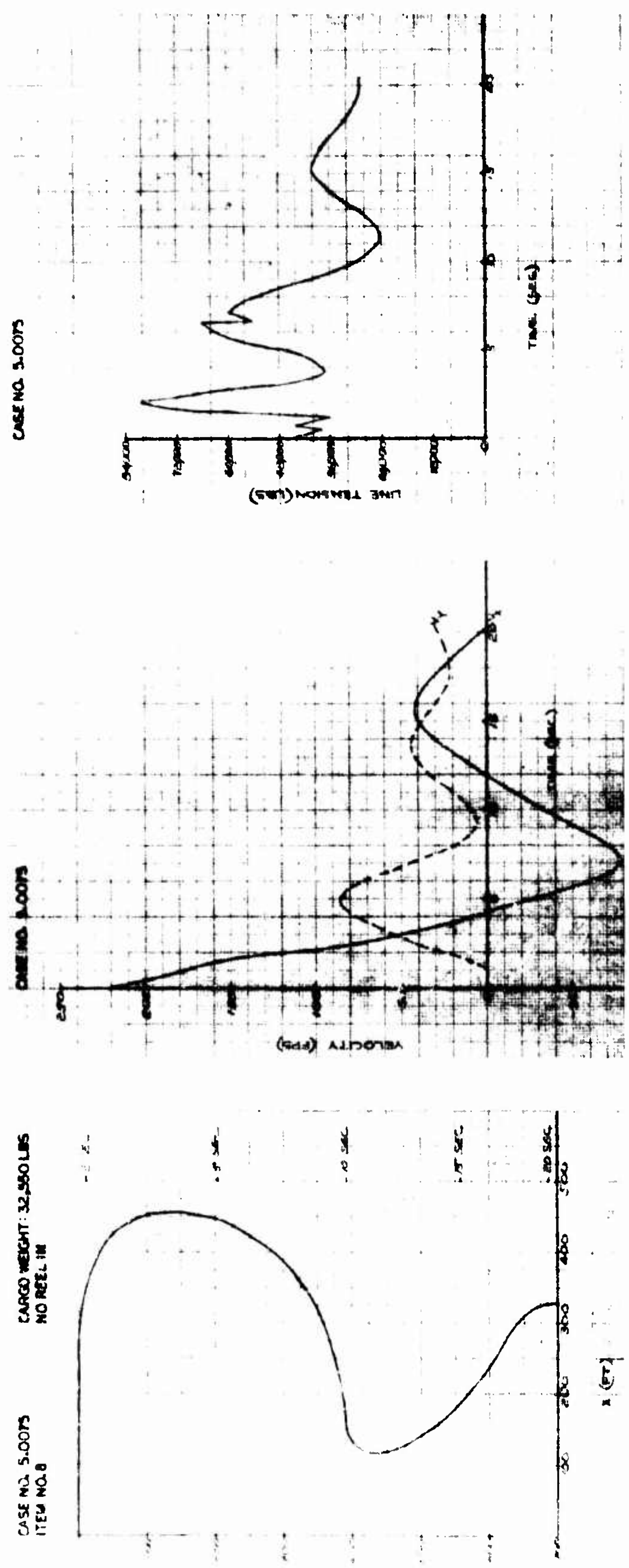

CASE NO. 5.0102
CASE NO. 5.0102
TIME (SEC)
LINE TENSION (LBS)
CASE NO. 5.0102
TIME (SEC)
VELOCITY (FPS)
CASE NO. 5.0102
ITEM NO. 7
CARGO WEIGHT: 20,450 LBS
REEL IN 7.5 fps
X (FT)

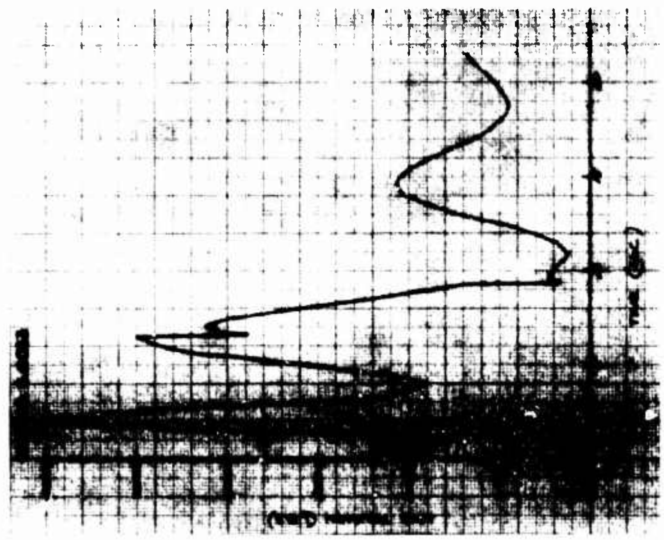
(g) Item 8:

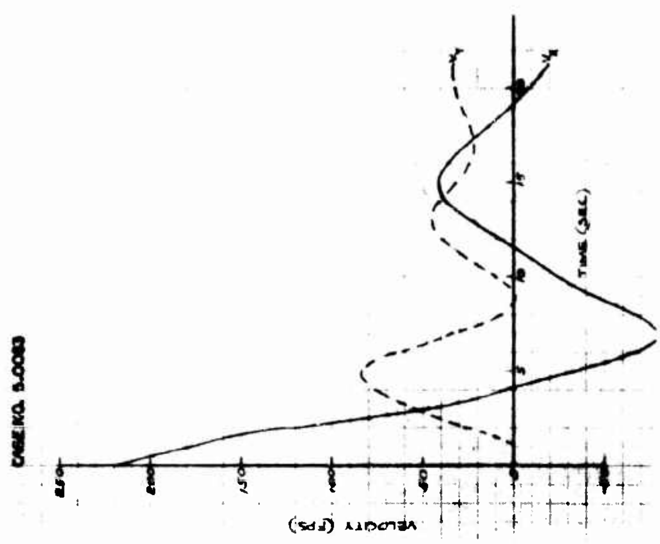
Case 5.0075 provides the basic no powered reel-in trajectory for item 8. As with item 7, a satisfactory terminal velocity is not attained within the specified drop height. Consequently, subsequent trajectories employed various reel rates and more chutes in an attempt to overcome this condition. Case 5.0083 reels in at 5 fps and case 5.0086 uses a 10 fps reel rate. In both cases it is apparent that the mere reel-in of X_{RL} is insufficient to achieve satisfactory impact conditions, even though the values of H_{min} are relatively good. Case 5.0087 is identical to 5.0083 except 9 chutes are used instead of eight. Once again, the impact conditions remain relatively unchanged from the three runs above. Case 5.0090 reels in part of the riser extensions and it becomes evident that this is the correct approach to use. A comparison of the velocity plots of 5.0075 and 5.0090 reveals a time lag between the two with the reel-in case lagging the no-reel case. This small time differential appears to be sufficient for the vertical velocity to fall off to satisfactory magnitudes at impact. Case 5.0103 reels in almost all of the riser extensions and, as suspected, the results are quite favorable. The vertical velocity range is quite good when compared with the no-reel case and the magnitude of $V_{x\,max}$ is more than halved. Since a reel rate of 10 fps was used in this case, there is quite a large power requirement, but apparently this is necessary for a reasonable drop. The final distance between cargo and chute cluster c.g. is approximately 90 feet and even though this may prove to be quite unrealistic in an actual drop, it should be apparent that this case provides a very good example of the effect of line length on impact parameters.

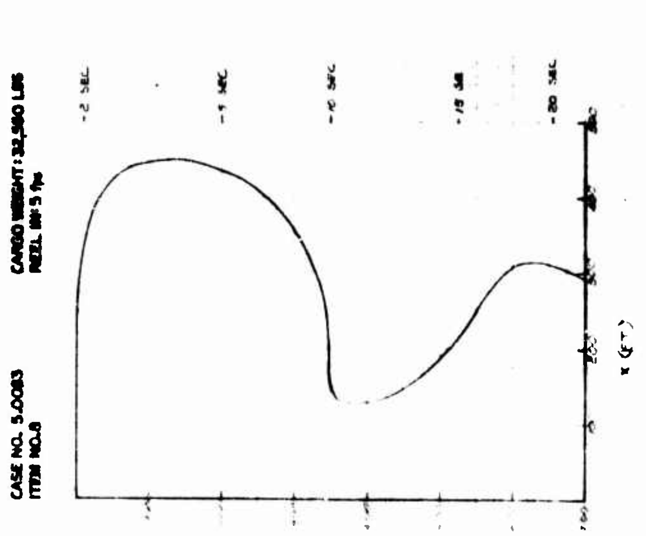
Case 5.0107 reels in approximately 60 feet of the riser extensions at a rate of 7.5 fps. When compared to 5.0103, the only significant difference in the impact parameters is the value of H_{min}; but when compared with the decrease in the power requirement, this difference seems negligible. The V_y range is still reasonable and there is just a slight increase in $V_{x\,max}$. Consequently, a 7.5 fps reel system would be the suggested system selected for future development with respect to item 8.

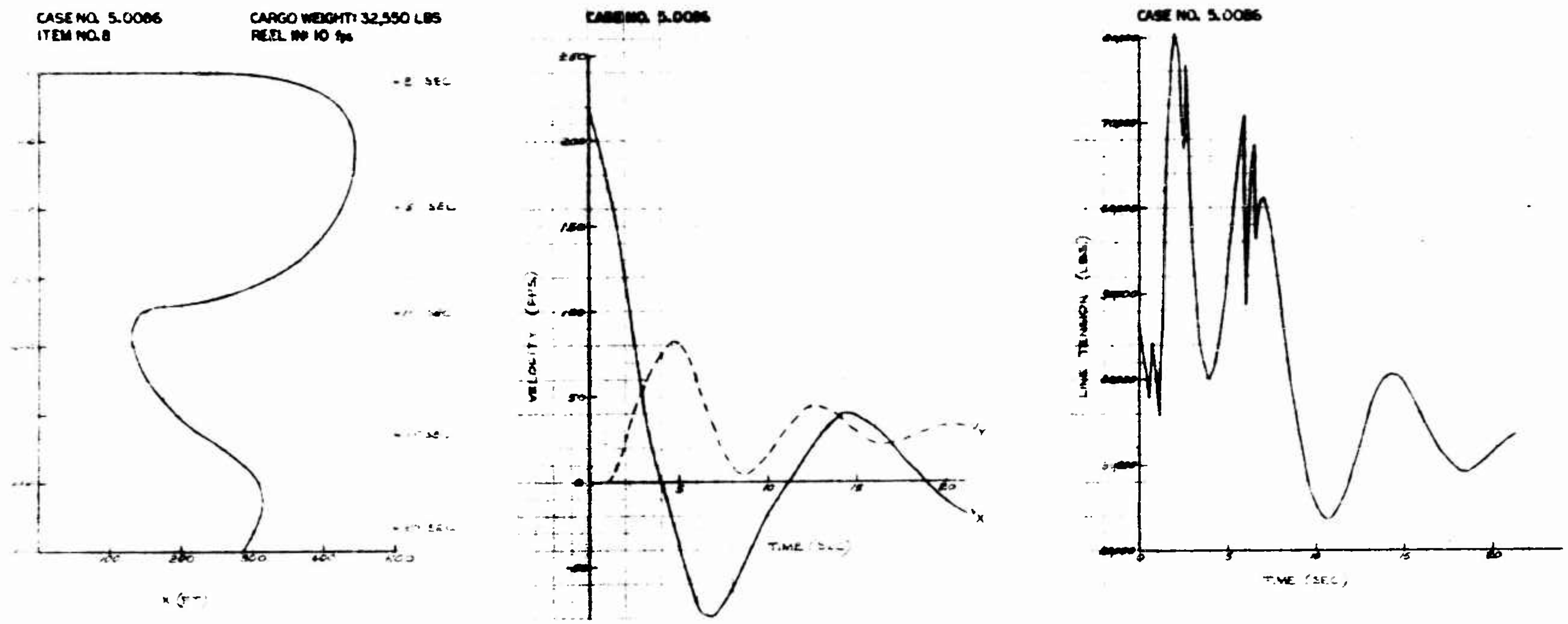
Case 5.0118 examines cargo item 8 when airdropped over a drop zone terrain altitude of 5000 feet at an ambient temperature of 100°F. In this case, eleven G-11A parachutes are required to meet the terminal velocity condition of 28.5 fps. A reel-in velocity of 7.5 fps is applied in this run as was done in case 5.0107.

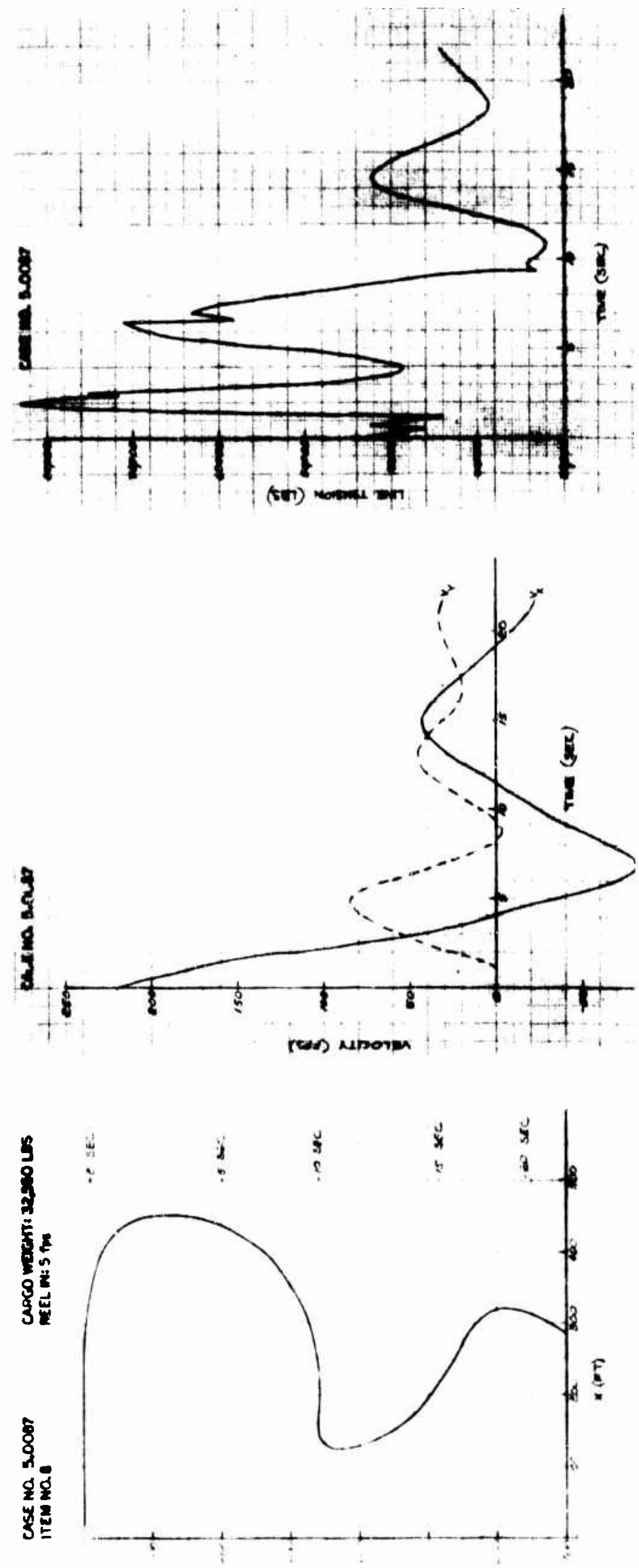

CASE NO. 5.007S
ITEM NO. 8
CARGO WEIGHT: 32,550 LBS
VELOCITY (FPS)
LINE TENSION (LBS)
TIME (SEC)



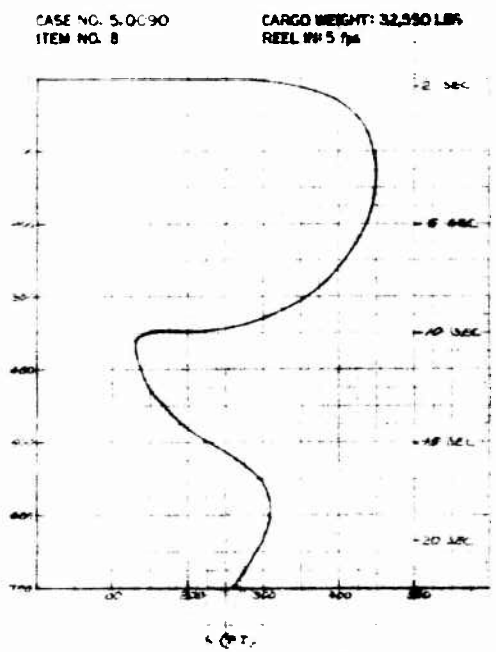

CASE NO. 5.0083
VELOCITY (FPS)
TIME (SEC)

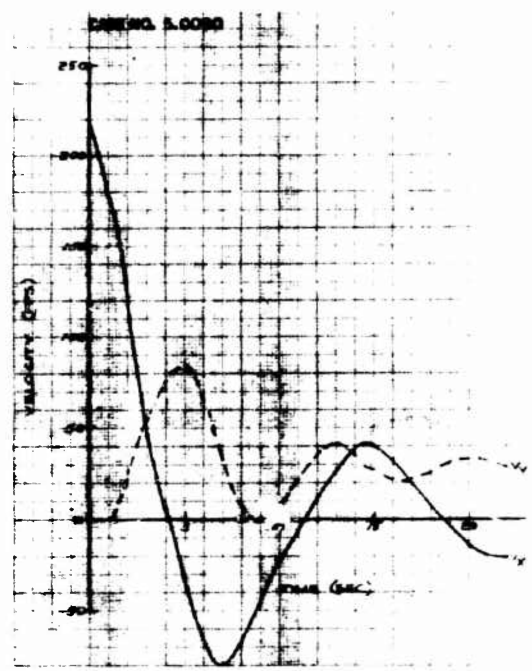

CASE NO. 5.0083
ITEM NO.8
CARGO WEIGHT : 32,580 LBS
X (FT)

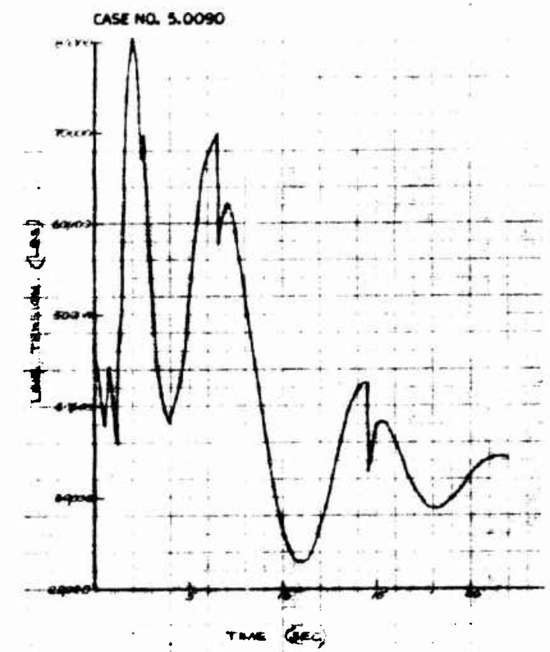

CASE NO. 5.0086
ITEM NO. 8
CARGO WEIGHT: 32,550 LBS
REEL IN: 10 fps
X (FT)
CASE NO. 5.0086
VELOCITY (FPS)
TIME (SEC)
CASE NO. 5.0086
LINE TENSION (LBS.)
TIME (SEC)

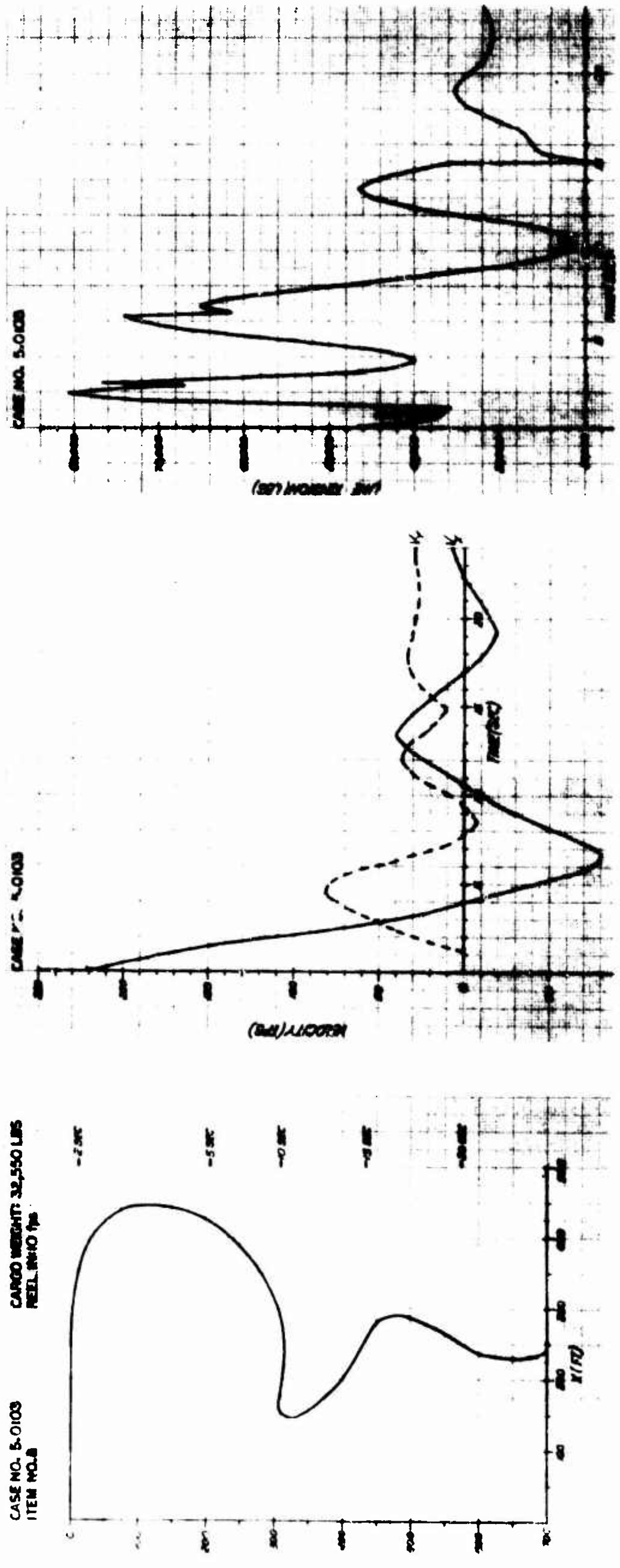


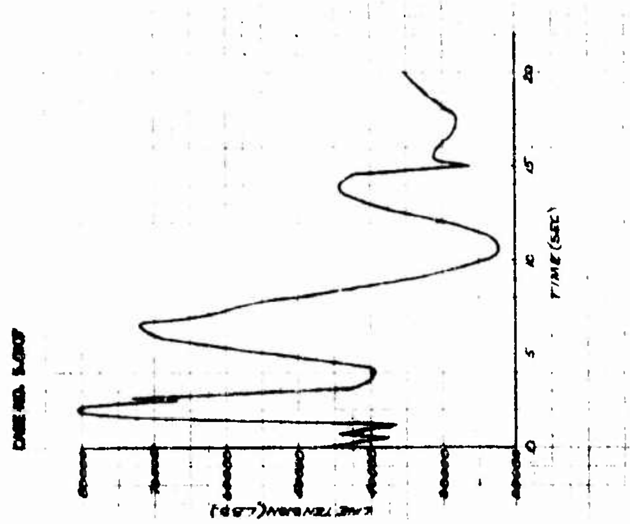
CASE NO. 5.D087
ITEM NO. 8
CARGO WEIGHT: 32,980 LBS
X (FT)
VELOCITY (FPS)
TIME (SEC)
LINE TENSION (LBS)
TIME (SEC)

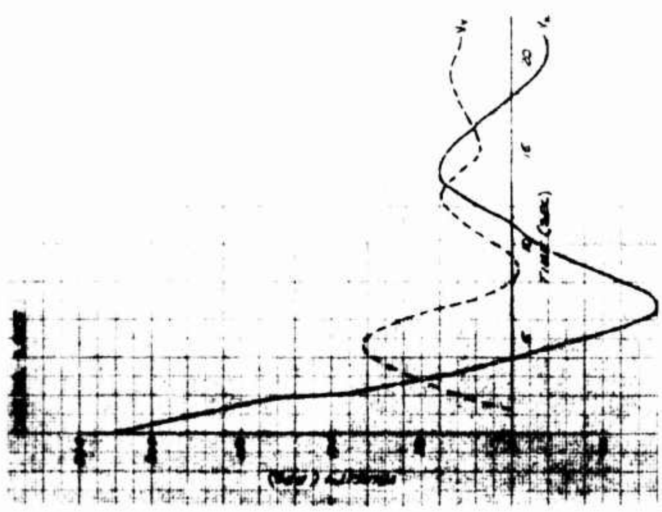

CASE NO. 5.0090
ITEM NO. 8
CARGO WEIGHT: 32,550 LBS
REEL IN 5 fps
2 SEC
6 SEC
10 SEC
14 SEC
20 SEC

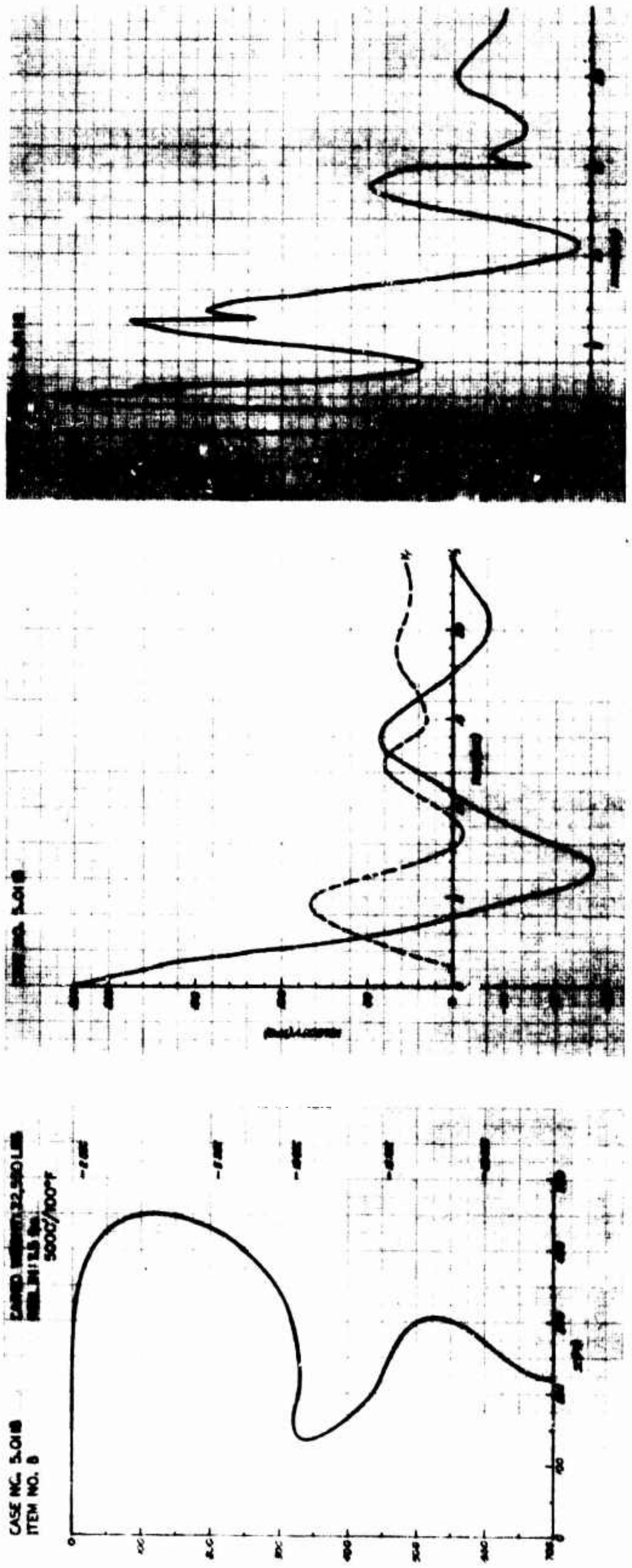

CASE NO. 5.0090
250
200
VELOCITY (FPS)
TIME (SEC)


CASE NO. 5.0090
LINE TENSION (LBS)
TIME (SEC)


CASE NO. 5-0103
CARGO WEIGHT: 32,550 LBS
CASE NO. 5-0103
ITEM NO. 8






CASE NO. 5.018
ITEM NO. 8
5000/100°F

b. Three Dimensional Trajectories

(1) Introduction

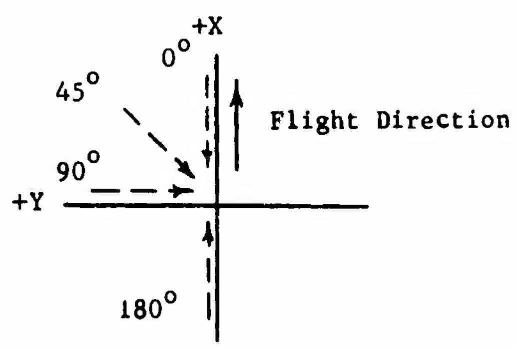
The following three dimensional drop simulation runs were compiled primarily for informative purposes, and other than a few required environmental characteristics, the data portrayed was not specifically required by the contract item.

The results presented in this section were generated from the characteristics of Item 5 (Table III, Part 1) of this section, with various wind conditions added. The "Cargo Trajectory Log" appearing on the following pages describes concisely what flight-wind conditions were selected for examination.

After the addition of the cross wind velocity vectors, a new coordinate designation was of necessity instituted. It was basically as follows: Positive X would be parallel to and in the same direction as aircraft travel. Positive Y would be exactly 90° counter clockwise from positive X. The Z axis would now be the vertical axis and would be considered positive with increasing altitude.

All wind angles originated with the positive X direction of the aircraft and rotated in a counter clockwise direction from there. The wind was assumed to always blow in toward the aircraft, and the aircraft velocity was always assumed to remain constant with the ground fixed frame of reference, and was assumed independent of the direction of the wind vector.

Four wind positions were proposed, as shown in the following sketch, which was felt would represent all critical positions. Naturally, it was assumed that a wind of 15 knots in a positive 90° direction would have the same effect on the aircraft as a wind in the positive 270° direction; hence, the obvious elimination of superfluous runs.



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RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0130	2	0' 60°F	15K at 45°	220	-23.35	39.33	20	110	169.33	155.33	Nat. 2.63	1.2 - 6.34
5.0131	2	0' 60°F	15K at 45°	220	-23.35	39.33	20	110	169.33	116	2.63 7.63 5.	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0132	2	0' 60°F	15K at 0°	220	-23.35	39.33	20	110	169.33	155.33	Nat. 2.63	1.2 - 6.34
5.0133	2	0' 60°F	15K at 0°	220	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0134	2	0' 60°F	15K at 90°	220	-23.35	39.33	20	110	169.33	155.33	Nat. 2.63	1.2 - 6.34
5.0135	2	0' 60°F	15K at 90°	220	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0136	2	0' 60°F	15K at 180°	220	-23.35	39.33	20	110	169.33	155.33	Nat. 2.63	1.2 - 6.34
5.0137	2	0' 60°F	15K at 180°	220	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0138	2	0' 60°F	15K at 0°	203	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36

TABLE VI 3-D CARGO DESCENT TRAJECTORY LOG
Item No. 5: Cargo Weight 8409 lb.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0139	2	0' 60° F	15K at 180°	203	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0140	2	0' 60° F	15K at 0°	237	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0141	2	0' 60° F	15K at 180°	237	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0142	2	0' 60° F	15K at 90°	203	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36
5.0143	2	0' 60° F	15K at 90°	237	-23.35	39.33	20	110	169.33	116	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 - 10.36

TABLE VI 3-D CARGO DESCENT TRAJECTORY LOG
Item No. 5 Cargo Weight 34[illegible] lb.

RUN NO.	NO. CHUTES	IMPACT PARAMETERS	WIND COND.	A/C (fps)	INITIAL CARGO C.G. LOCATION (ft)	X_{RL} (ft)	X_{RE} (ft)	X_{RC} (ft)	L_{max} (ft)	L_{min} (ft)	REEL INPUTS RATE (fps)	REEL INPUTS INTERVAL (Seconds)
5.0144	8	0' 60°F	15K at 45°	220	-23.35	34.25	100	110	244.25	123.5	5.12 12.62 7.5	1.2 - 2.5 2.5 - 6.40 6.40-15.0

TABLE VI 3-D CARGO DESCENT TRAJECTORY LOG
Item No. 8: Cargo Weight 32,550 lbs.

Much of the data for the three dimensional runs was identical to that used in the two dimensional programs; however, because of the addition of the wind vectors, a completely new computer program was required since the limitations of the two dimensional program were such that it could not be merely modified to reflect the three dimensional problem.

As an example of the correspondence between the two dimensional and three dimensional programs, a typical two dimensional run (5.0092) was written in terms of the three dimensional inputs with all wind velocity vectors given a value of zero. These "three dimensional" curves were plotted on the same chart with the two dimensional curves from run 5.0092 in order to objectively judge the relative merits of the two programs. These curves are shown directly following this page.

As is readily seen, the difference between the two separate programs is negligible, thereby completely vouching for the validity of the three dimensional program.

The "Cargo Descent Trajectory Results", Table VII, gives a synopsis of the most important impact parameters from each computer run in the same terms applied in the two dimensional cases illustrated in Part 1 of this section. Most of the impact parameters were identical to the two dimensional impact parameters save for the addition of a lateral velocity, which was needed for the few cases dealing with crosswind conditions.

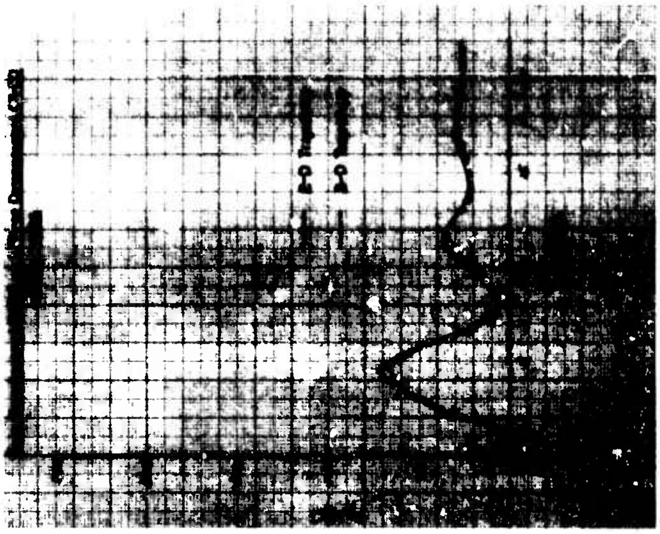
Horsepower was not computed for the three dimensional runs since the extra programming necessary for line tension in the runs was not completed in time. It was felt that since the general agreement between the two dimensional and three dimensional systems was so similar, that line tension could be neglected in lieu of stressing other more important aspects, and by doing such, the overall validity of the outputs would not be adversely affected.

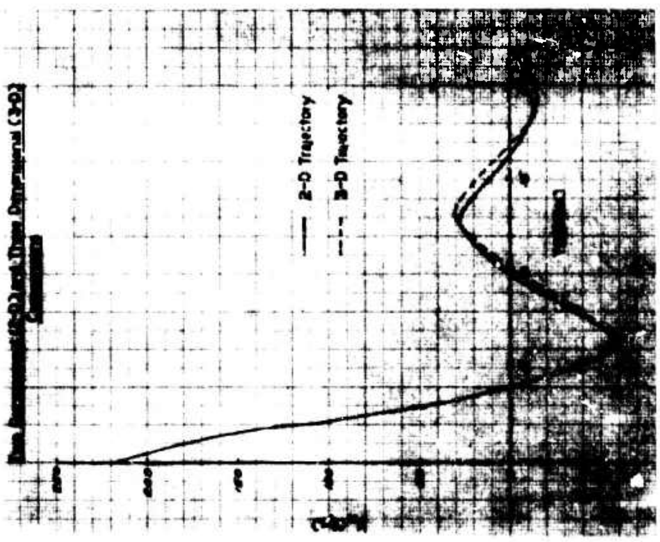
(2). Results

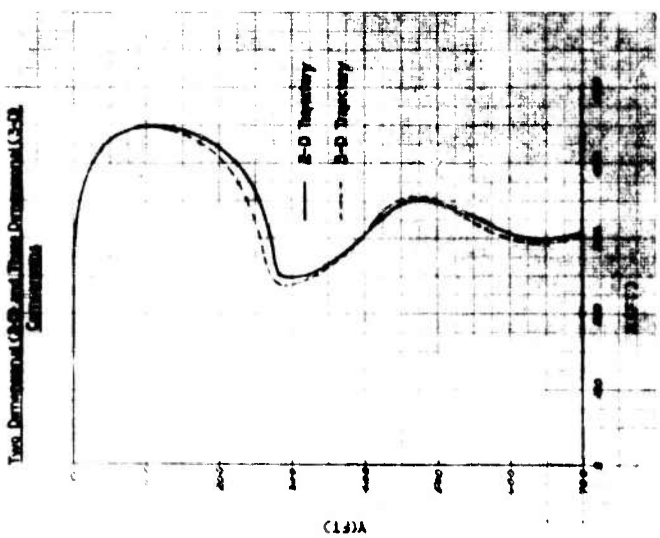
The graphs of the computer outputs follow in order of case number and consist of the horizontal and vertical displacement curves and a plot of the velocities versus time - all for the complete descent trajectory of the cargo.

From the displacement curves, the effect of the various wind vectors can be readily noted and compared with a similar two dimensional run such as 5.0092, where powered reel-in was applied, or 5.0091, where no mechanical reel-in was used. The crosswind did have quite an effect on the cargo impact locations of the cargo, as would be expected.

The velocity versus time curves show no great deviation from the similar two dimensional curves, and the discussion would therefore be essentially identical.


2-D Trajectory
3-D Trajectory


2-D Trajectory
3-D Trajectory


2-D Trajectory
3-D Trajectory

RUN NO.	NO. CHUTES	REEL-IN INPUTS Rate (fps)	Interval (sec)	IMPACT PARAMETERS Time to Descend 500' (sec)	Vert. Vel. (fps)	Max. Long. Vel. (fps)	Max. Lat. Vel. (fps)	$\Phi_{500'}$ (°)	H_{min} (ft)	COMMENTS
5.0130	2	Nat. 2.63	1.2 - 6.34	16.73	28.5 29.0	36.22	19.0	10.3°	430	
5.0131	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54 -10.36	18.08	21 30	33.71	18.9	3.8°	372	
5.0132	2	Nat. 2.63	1.2 - 6.34	16.20	21.2 29.7	42.68		20.65	433	
5.0133	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	17.75	21 29	40		3.5°	375	
5.0134	2	Nat. 2.63	1.2 - 6.34	16.4	25 30	18	28	4.6°	495	
5.0135	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.5-10.36	17.8	24 29	15	26	-1.7°	433	
5.0136	2	Nat. 2.63	1.2 - 6.34	16.7	25 30	41		23.[illegible]	500	
5.0137	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	18.0	24 29	15		14.5°	500	

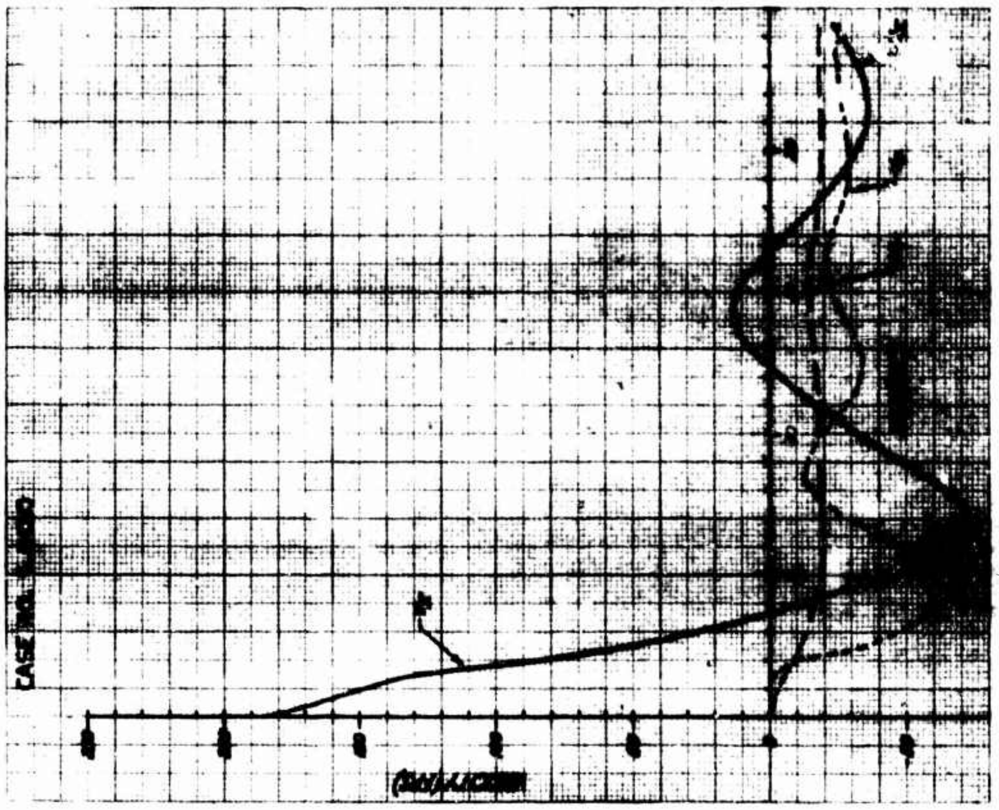
TABLE VII **3-D CARGO DESCENT TRAJECTORY RESULTS**
Item No. 5: Cargo Weight 8409 lbs.

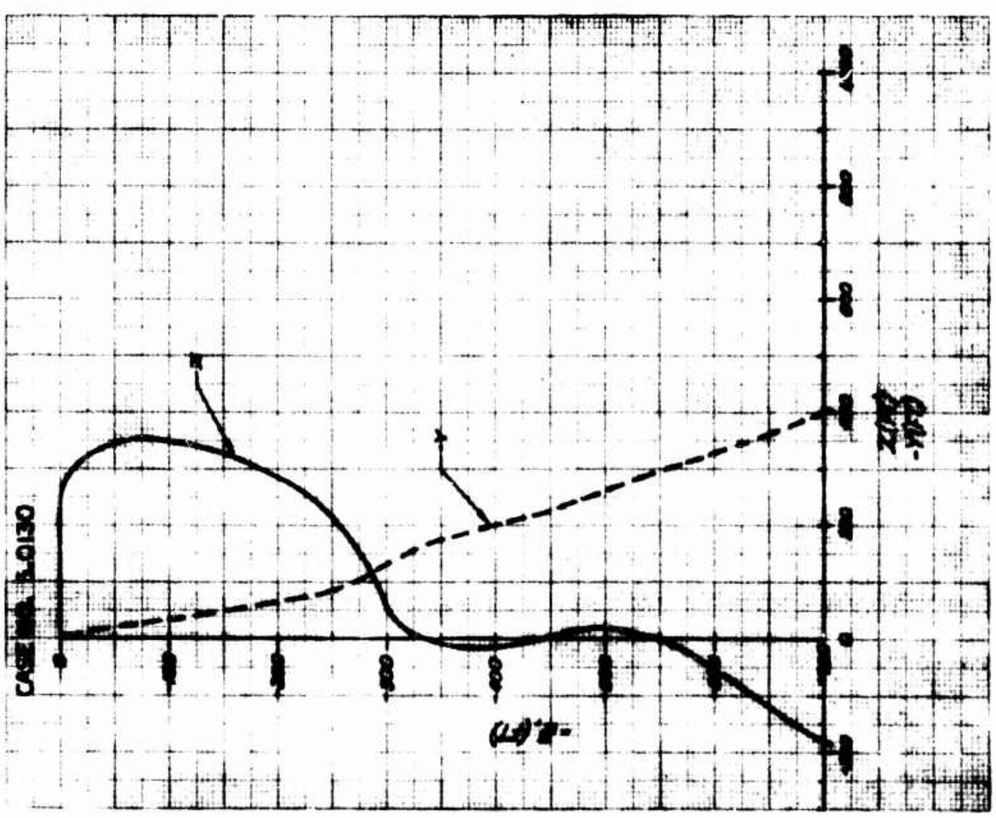
RUN NO.	NO. CHUTES	REEL-IN INPUTS Rate (fps)	Interval (sec)	IMPACT PARAMETERS Time to Descend 500' (sec)	Vert. Vel. (fps)	Max. Long. Vel. (fps)	Max. Lat. Vel. (fps)	$\Phi_{500'}$ (°)	H_{min} (ft)	COMMENTS
5.0138	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.5-10.36	17.7	20 29	39		18.9	380	
5.0139	2	2.63 7.63 5	1,2 -2.5 2.5 - 6.54 6.54-10.36	18.3	25 29	13		12.1°	500	
5.0140	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	17.7	21 29	40		17.8°	314	
5.0141	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	17.9	26 30	11		16.6°	380	
5.0142	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	17.8	22 30	28	27	-4.0	380	
5.0143	2	2.63 7.63 5	1.2 - 2.5 2.5 - 6.54 6.54-10.36	18.0	23 27	14	28	14.6°	436	

TABLE VII 3-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 5: Cargo Weight 8409 lbs.

RUN NO.	NO. CHUTES	REEL-IN INPUTS		IMPACT PARAMETERS						COMMENTS
		Rate (fps)	Interval (sec)	Time to Descend 500' (sec)	Vert. Vel. (fps)	Max. Long. Vel. (fps)	Max. Lat. Vel. (fps)	$\Phi_{500'}$ (°)	H_{min} (ft)	
5.0144	8	5.12 12.62 7.5	1.2 - 2.5 2.5 - 6.48 6.48-15.0	16.4	18.34	39	19	24.6°	420	

TABLE VII 3-D CARGO DESCENT TRAJECTORY RESULTS
Item No. 8: Cargo Weight 32550 lbs.

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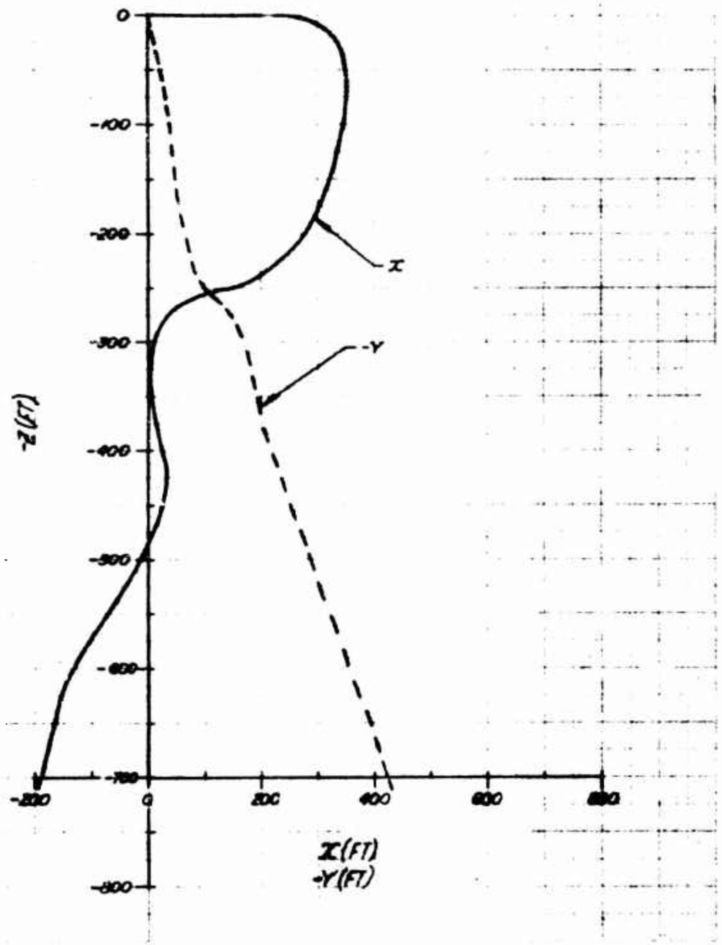
CASE NO. 5.0131



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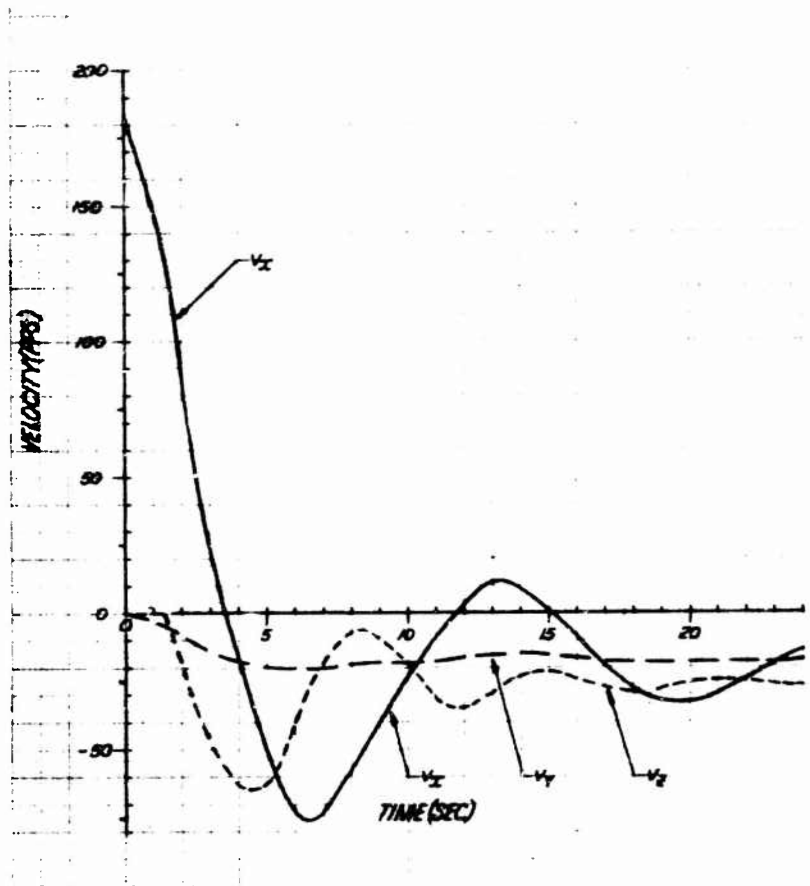

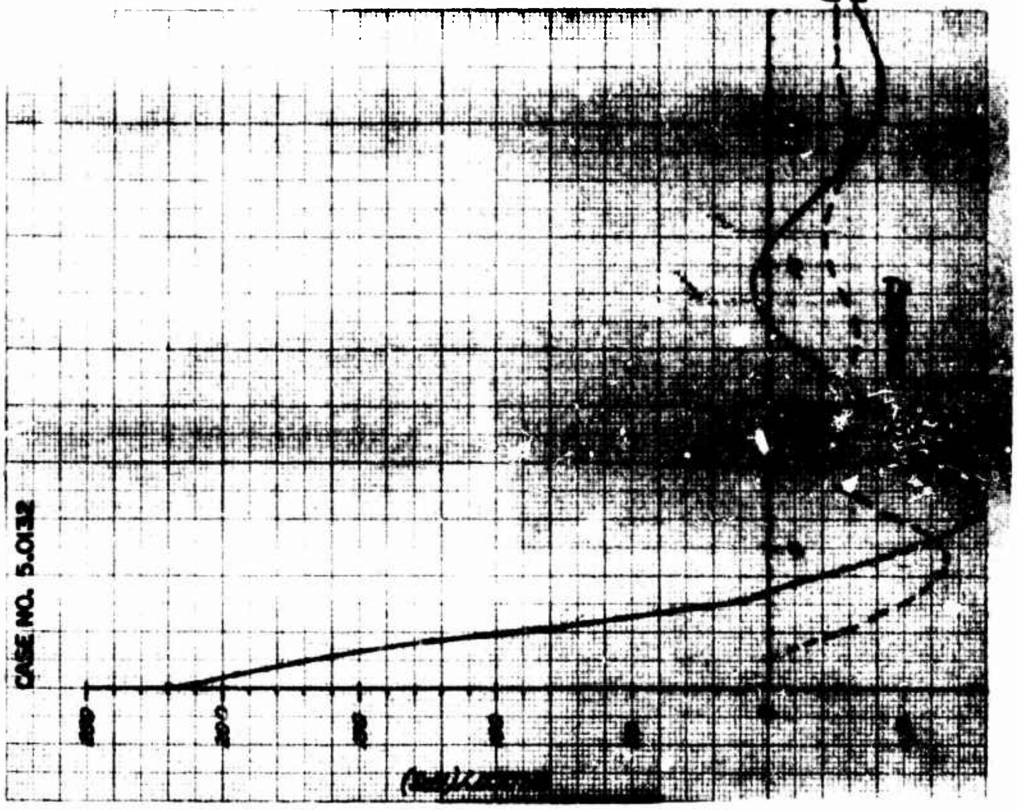
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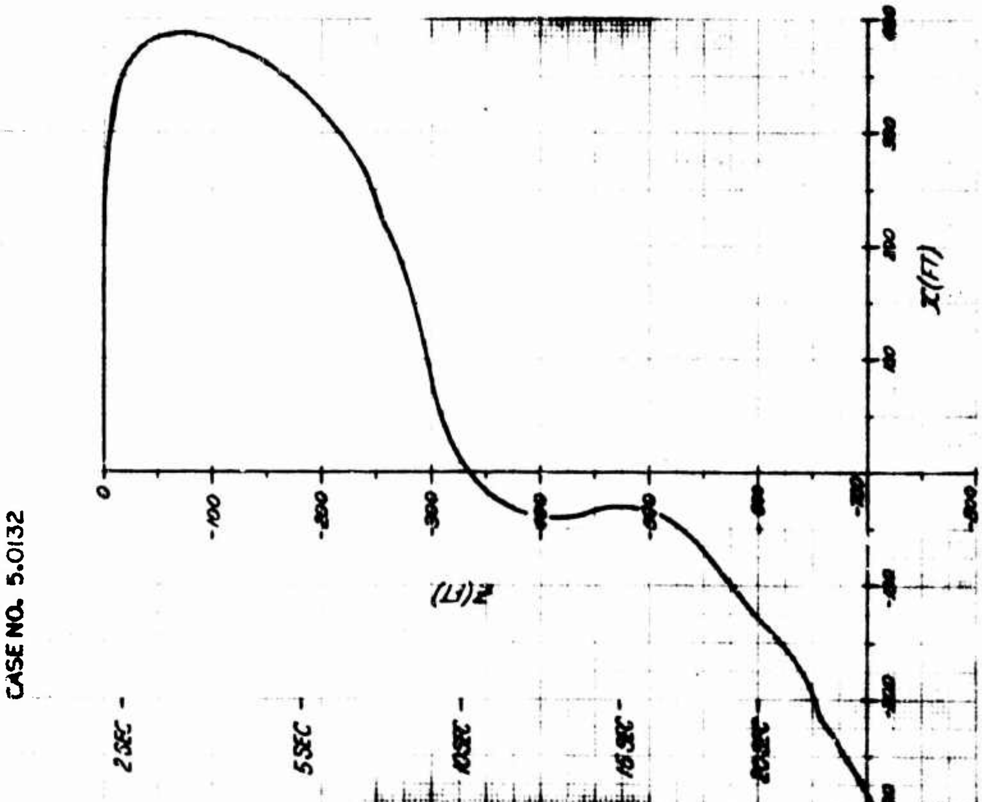
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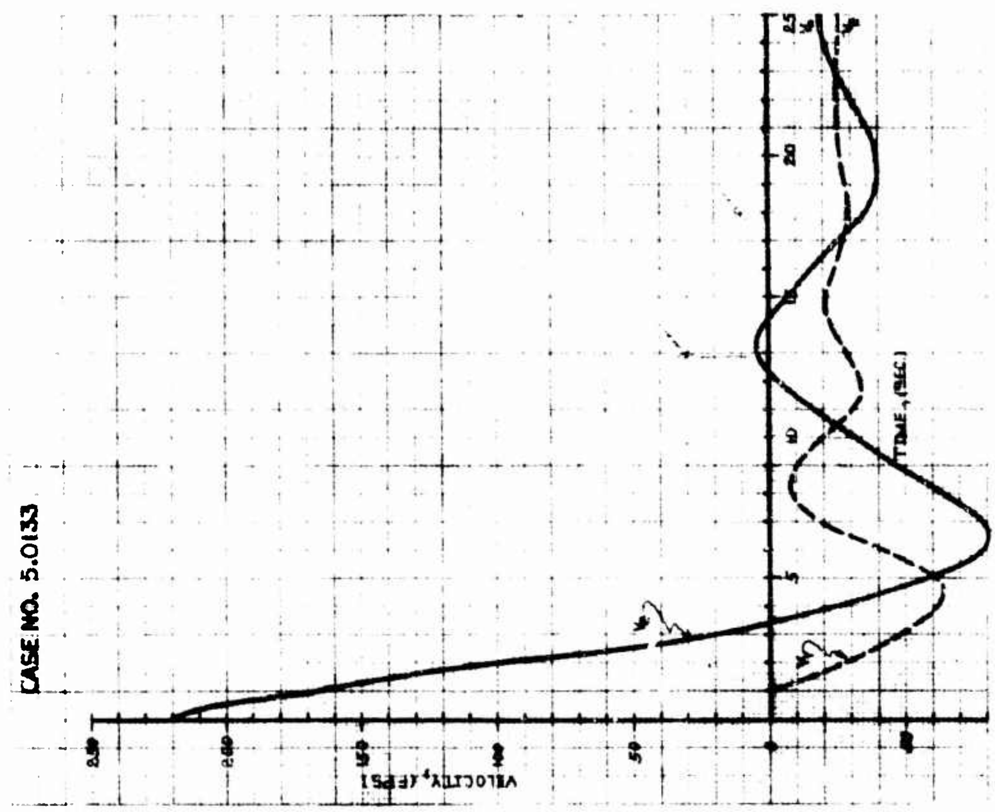
2 SEC
5 SEC
10 SEC
15 SEC
20 SEC
Z(FT)
X(FT)


CASE NO. 5.0133
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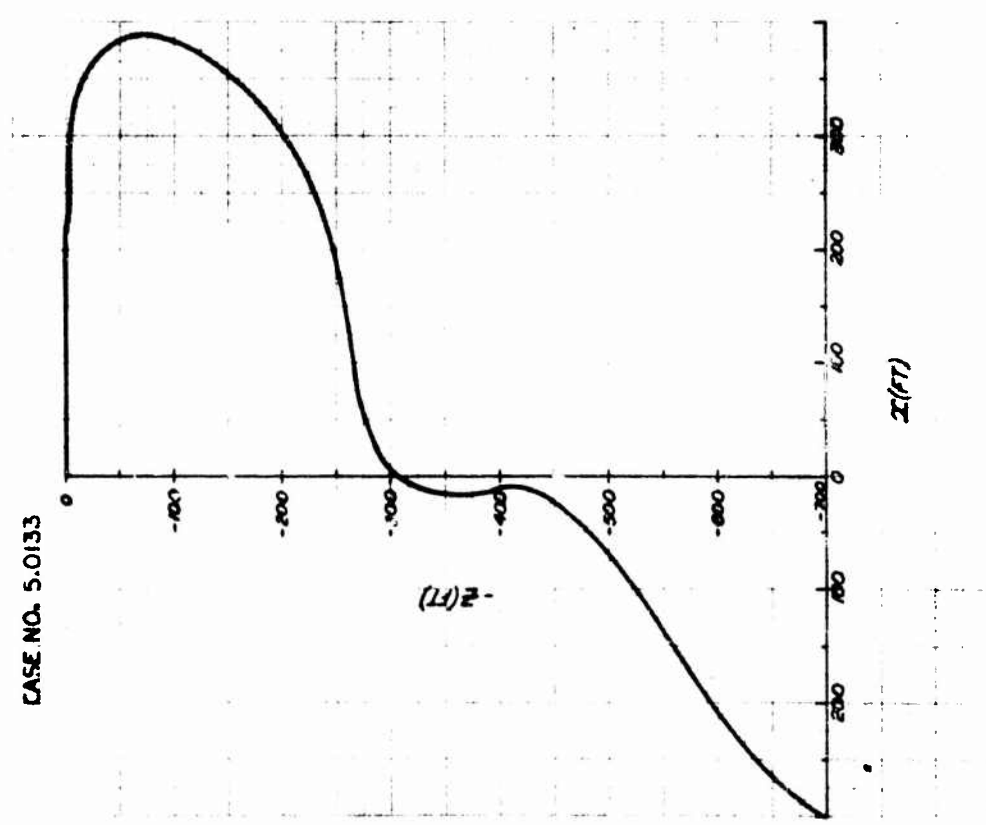
TIME, (SEC)
250
200
150
100
50
0
5
10
15
20
25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X(FT)
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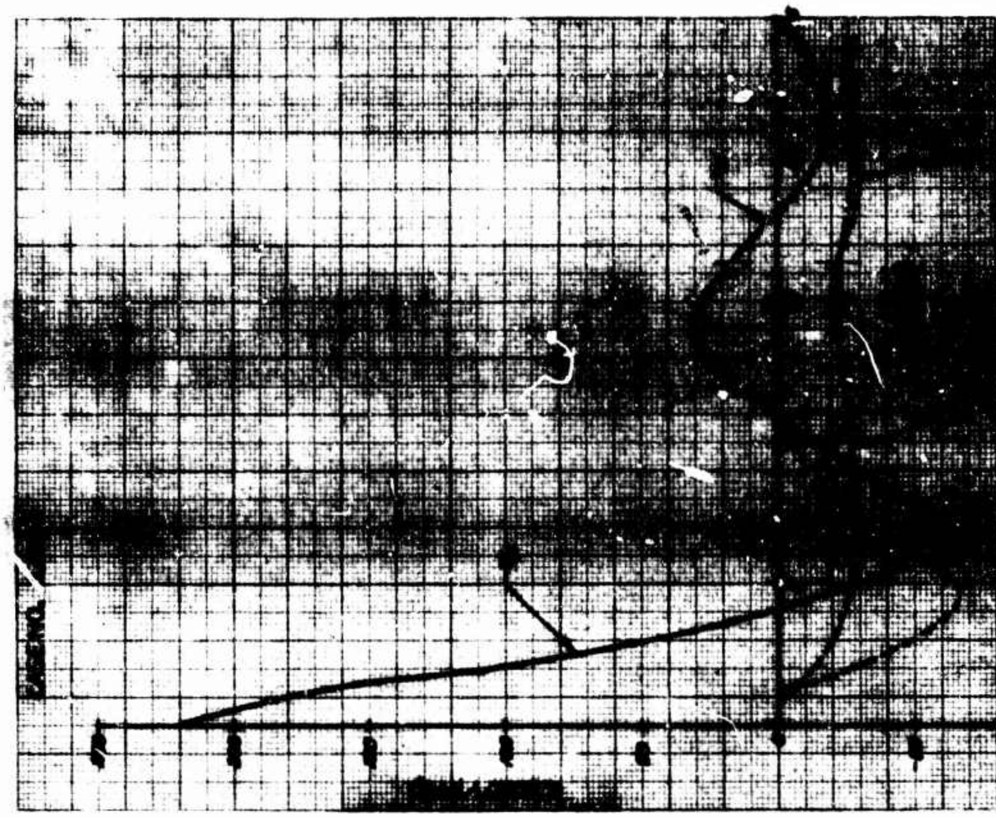
-100
-200
-300
-400
-500
-600
-700
100
200
300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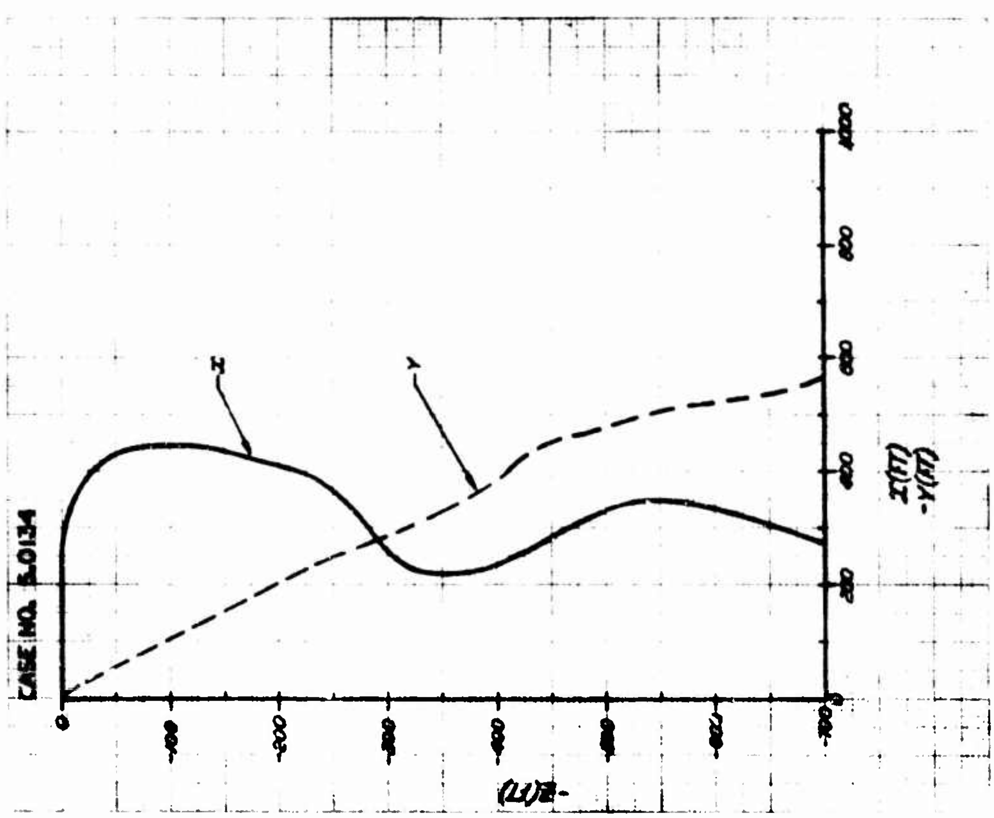
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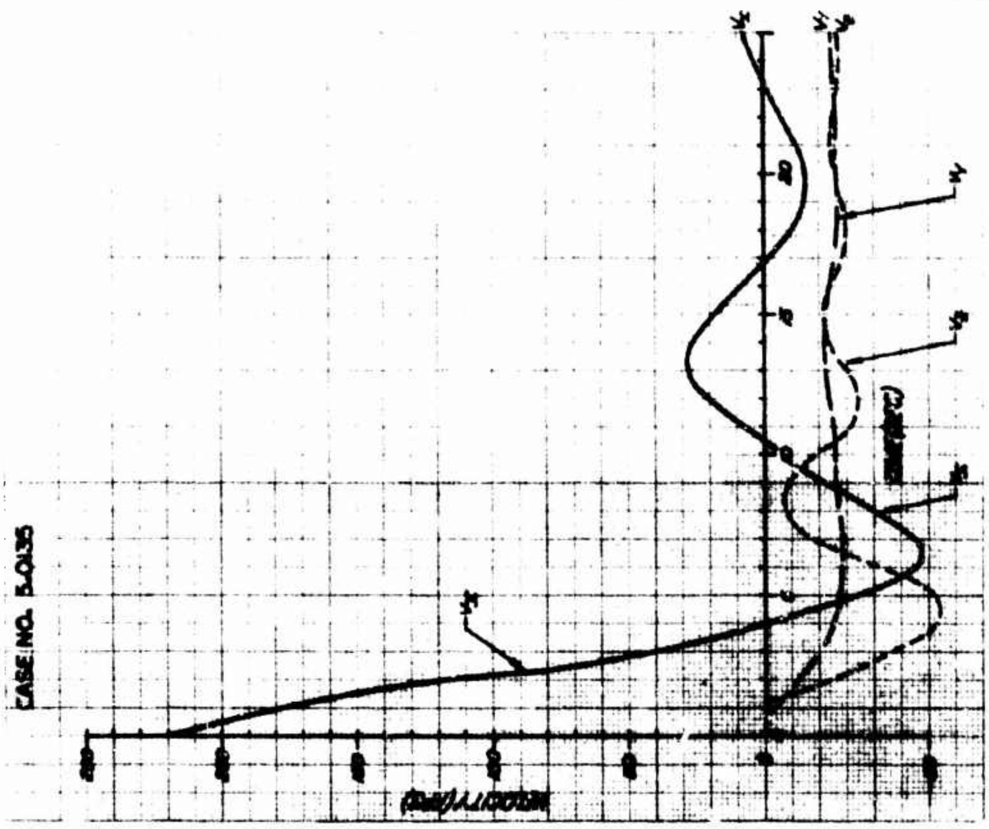
H
V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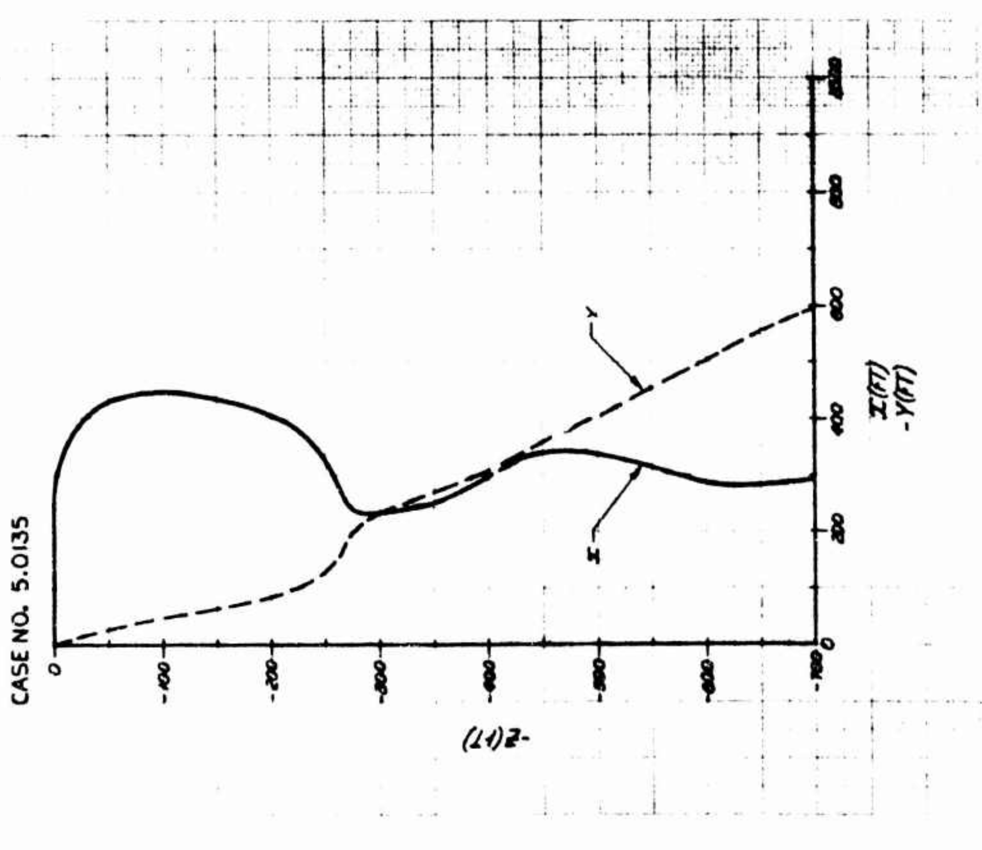
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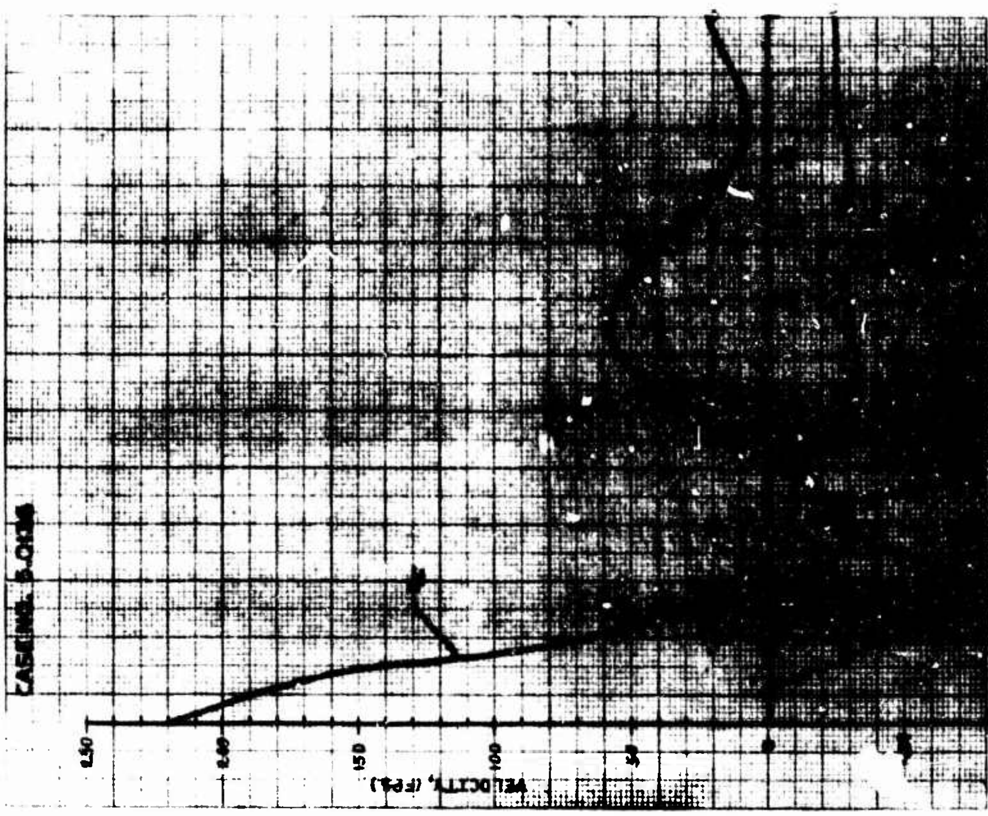
X(FT)
-Y(FT)
X
Y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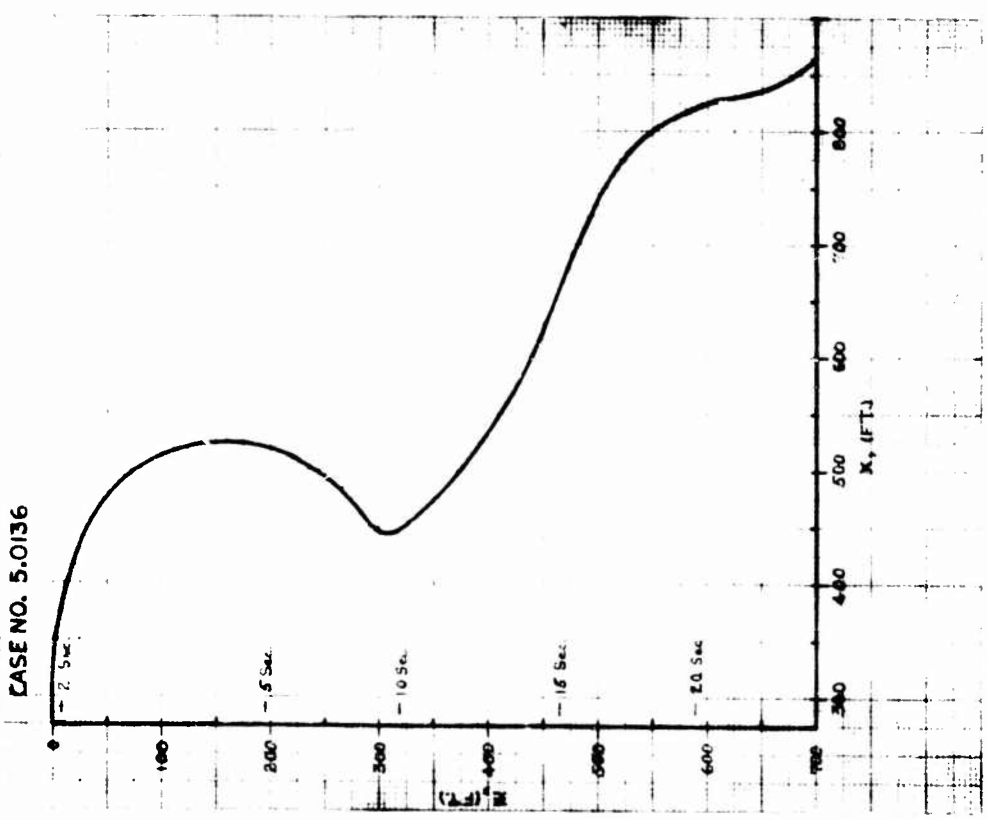
200
150
100
50
0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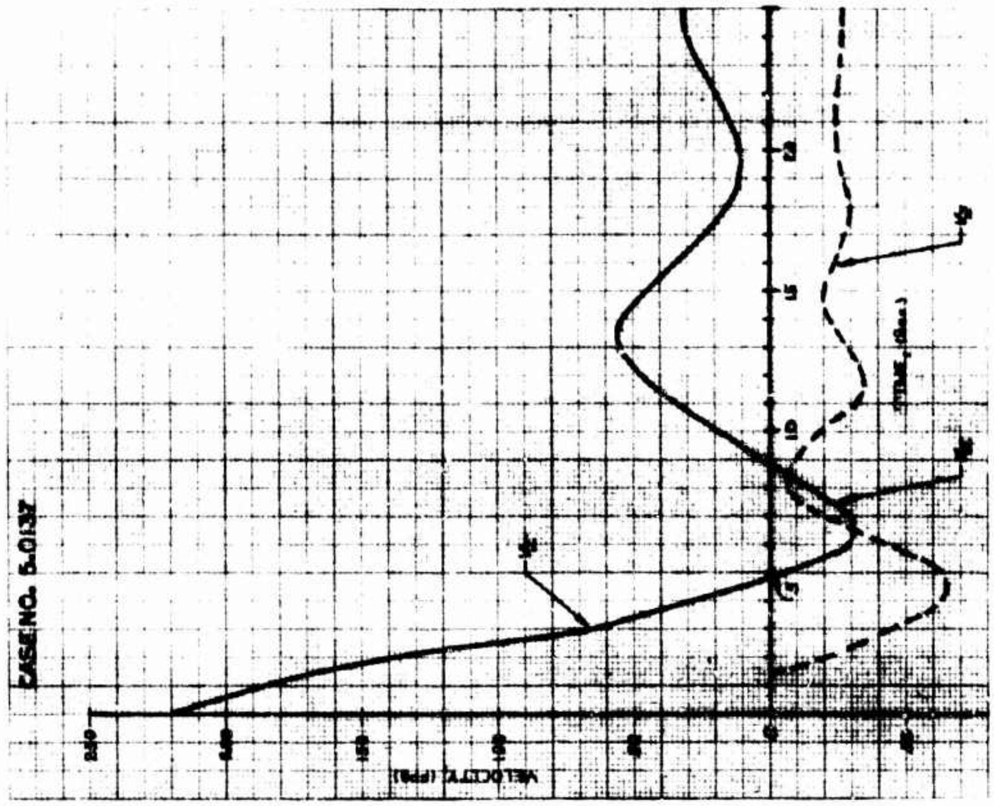
5 Sec.
10 Sec.
15 Sec.
20 Sec.
0
100
200
300
400
500
600
700
300
400
500
600
700
800
X, (FT.)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VELOCITY (FPS)
TIME (Sec.)
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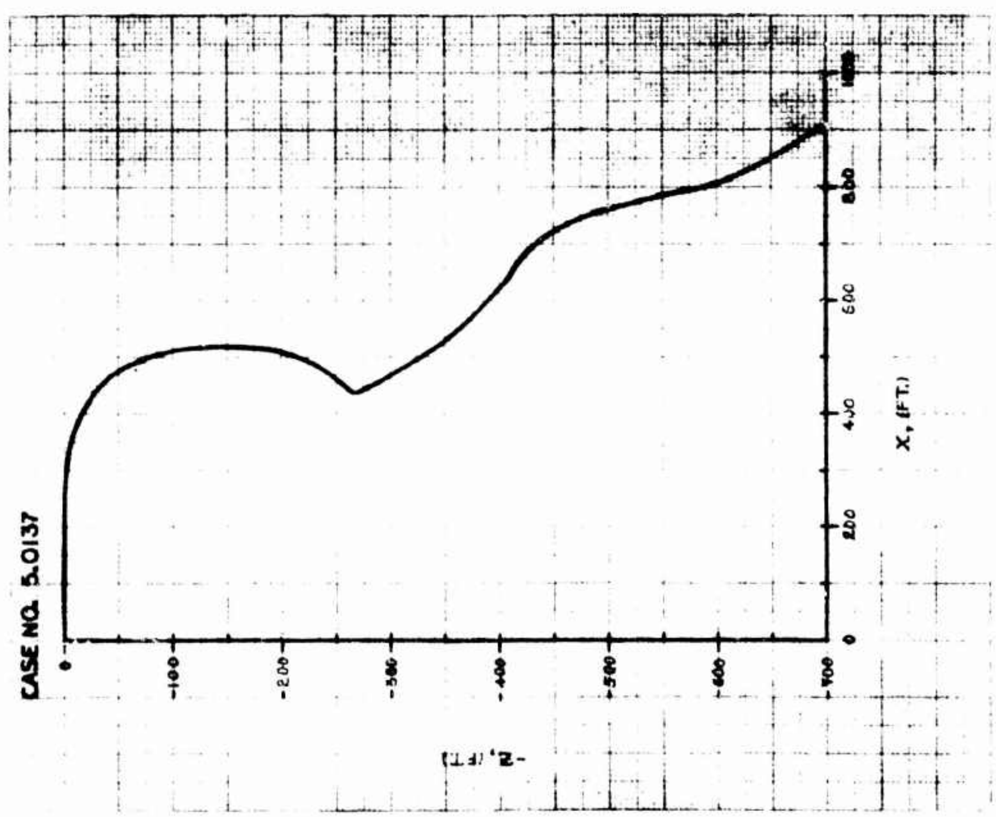
150
100
50
0
-50
5
10
15
20


CASE NO. 5.0137
-Z, (FT.)
X, (FT.)
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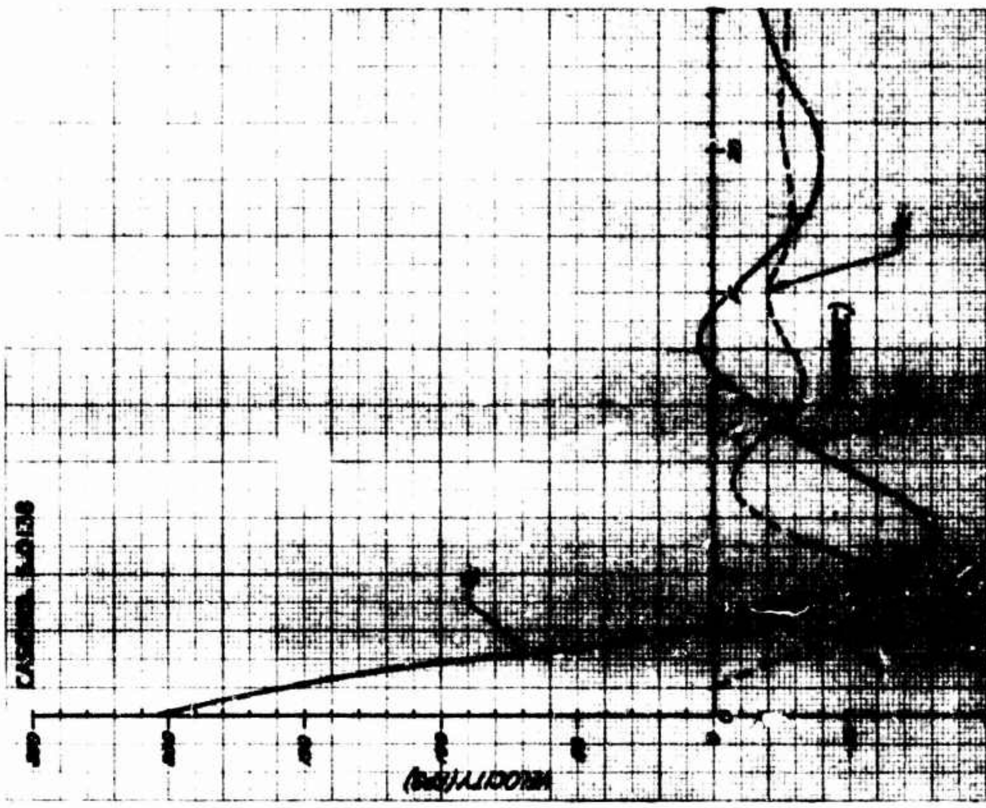
-100
-200
-300
-400
-500
-600
-700
200
400
600
800
1000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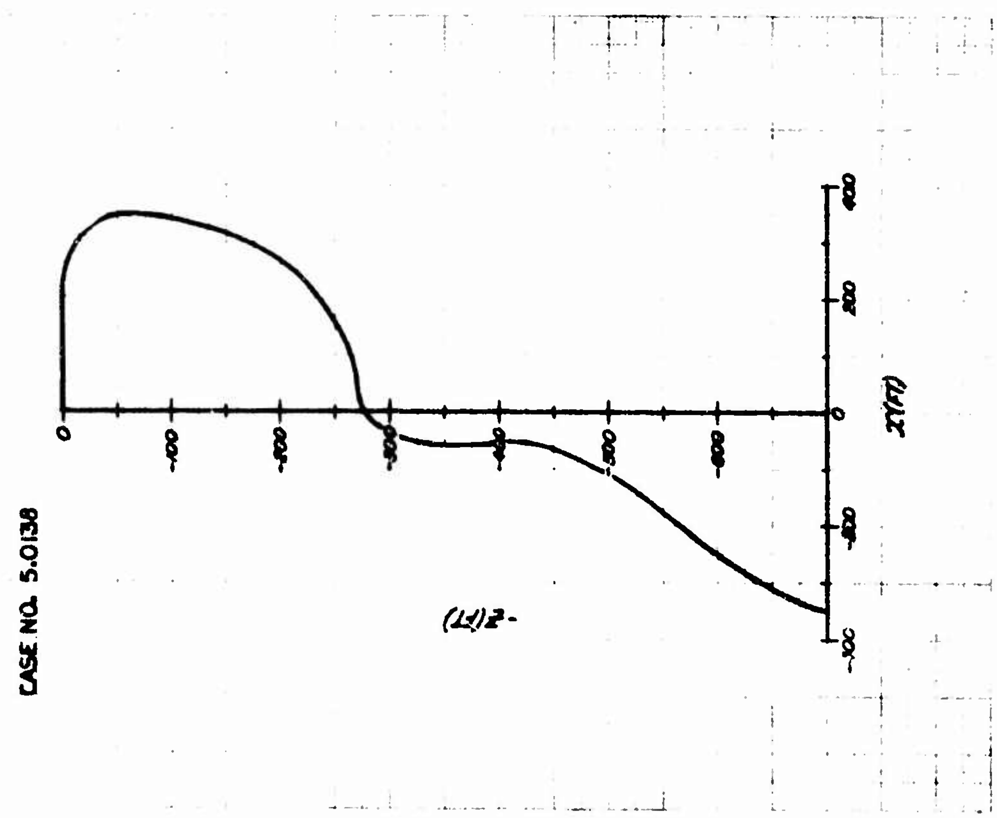
VELOCITY (FPS)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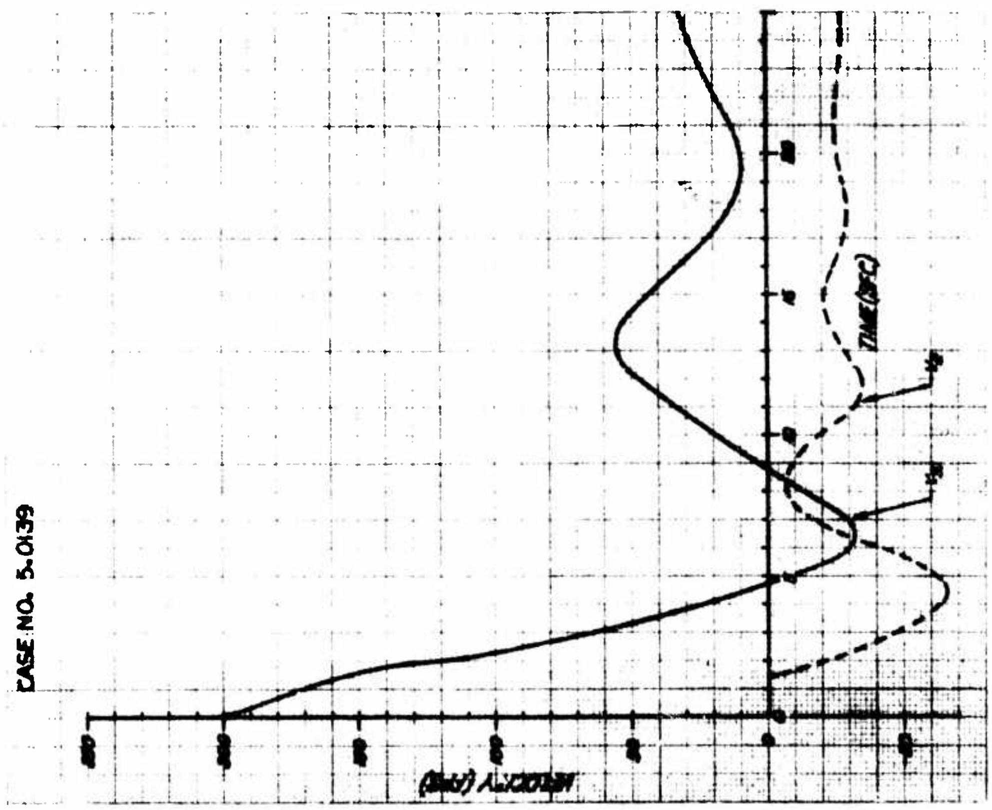
-Z(FT)
X(FT)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TIME (SEC)
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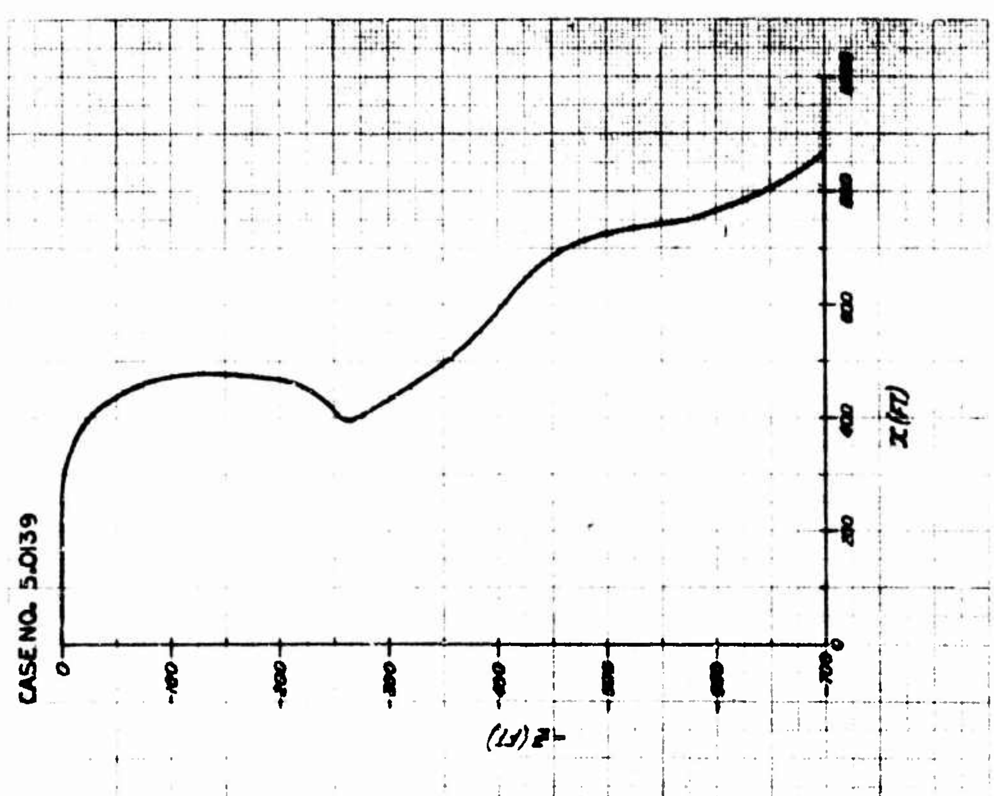
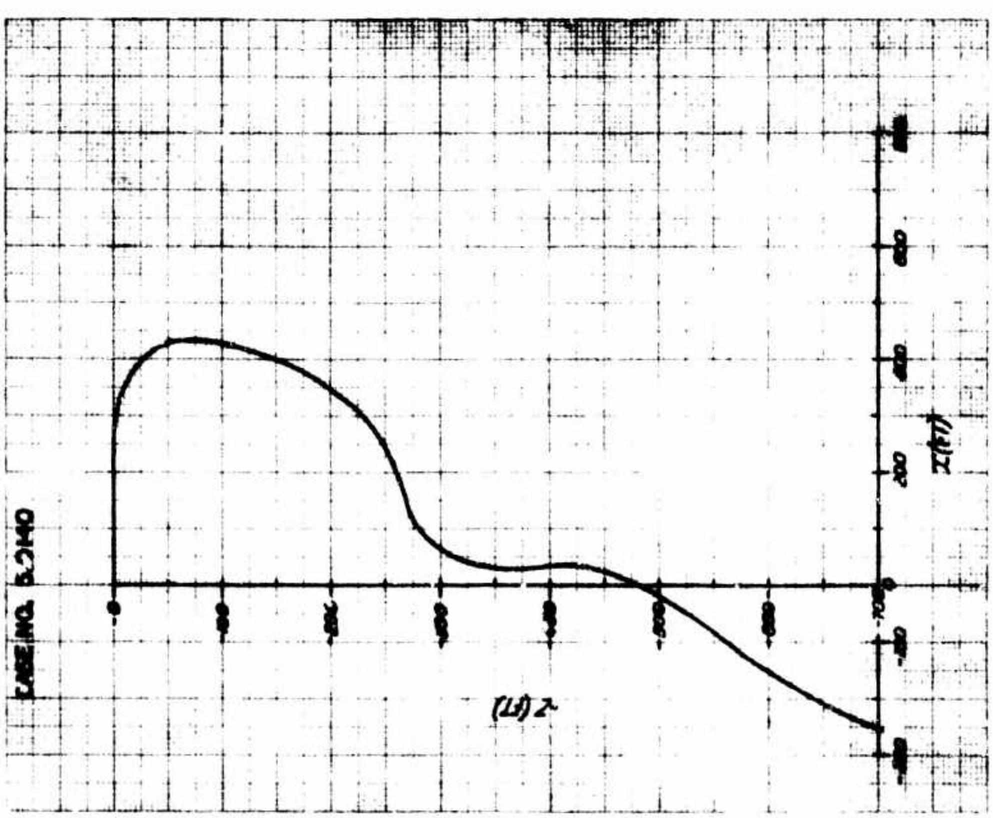
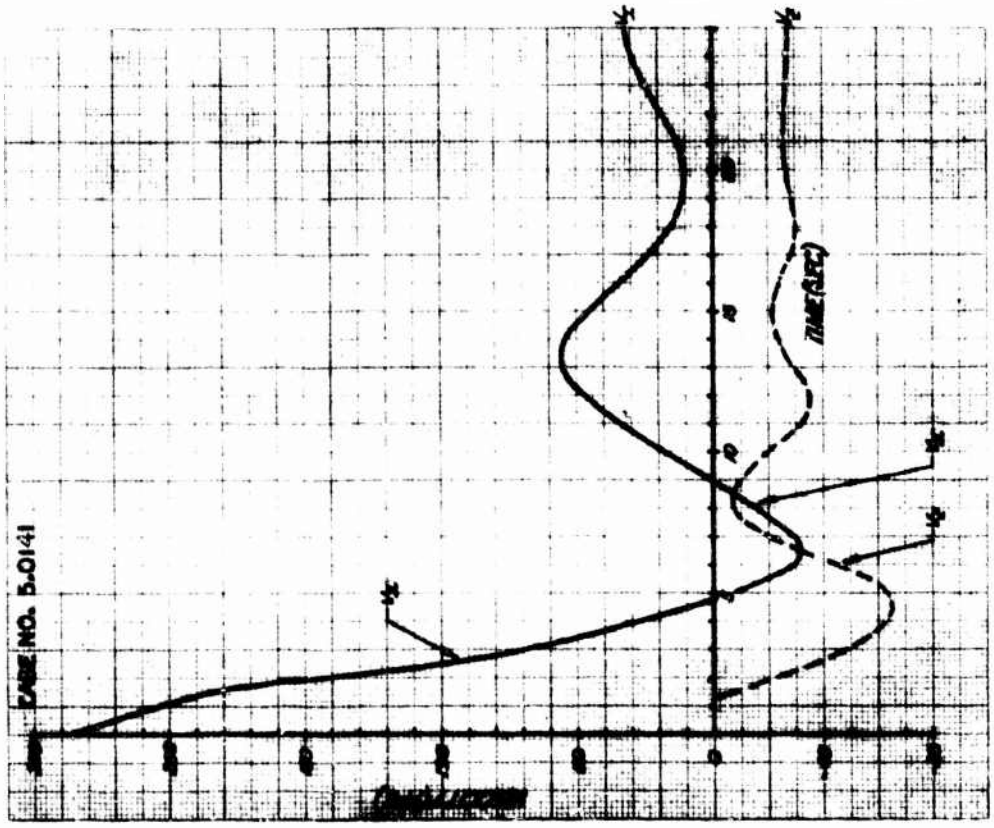
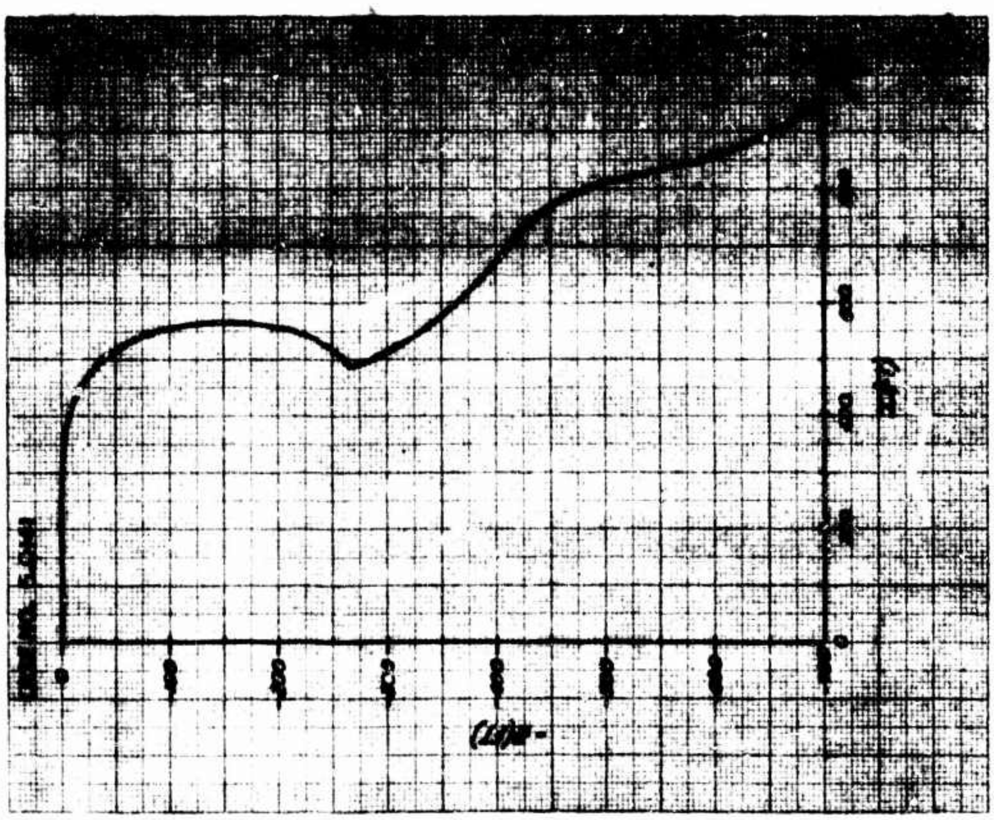
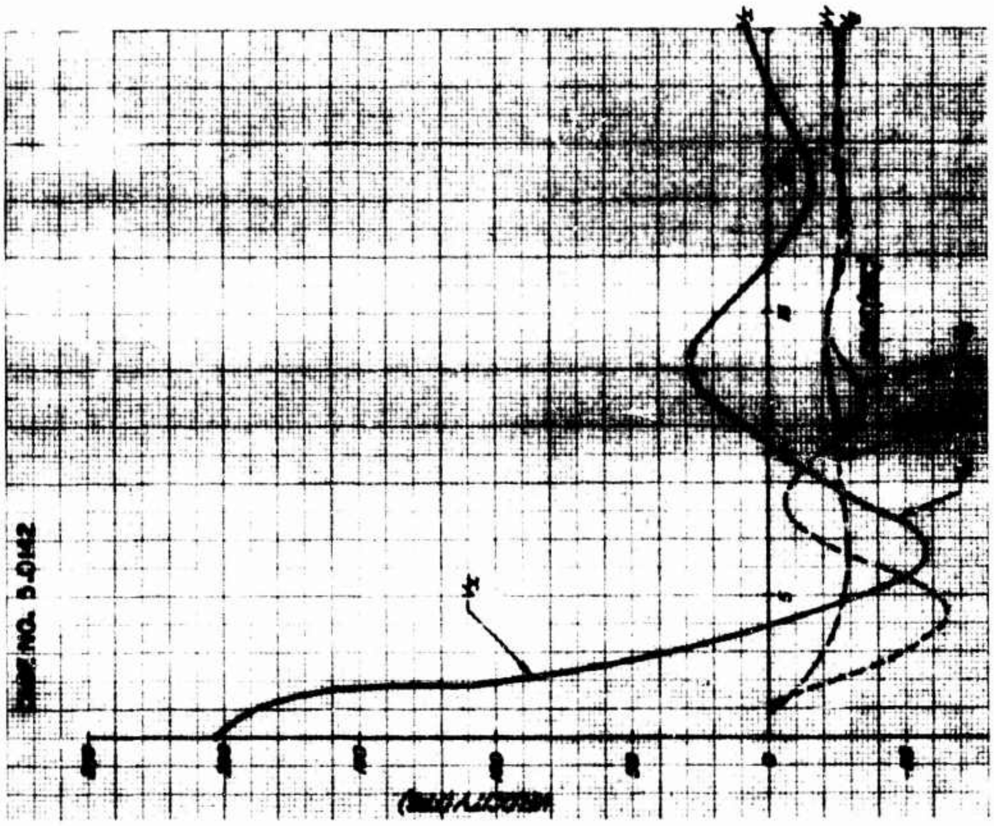

CASE NO. 5.0139
-Z (FT)
X (FT)
0
200
400
600

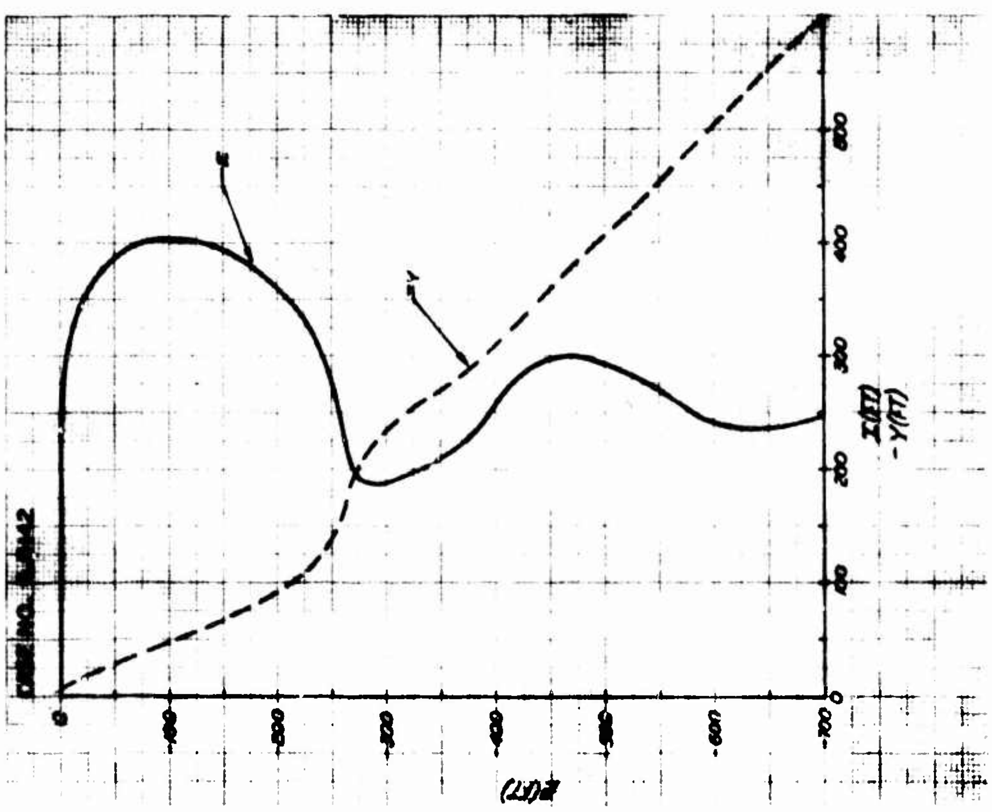

CASE NO. 5.0140

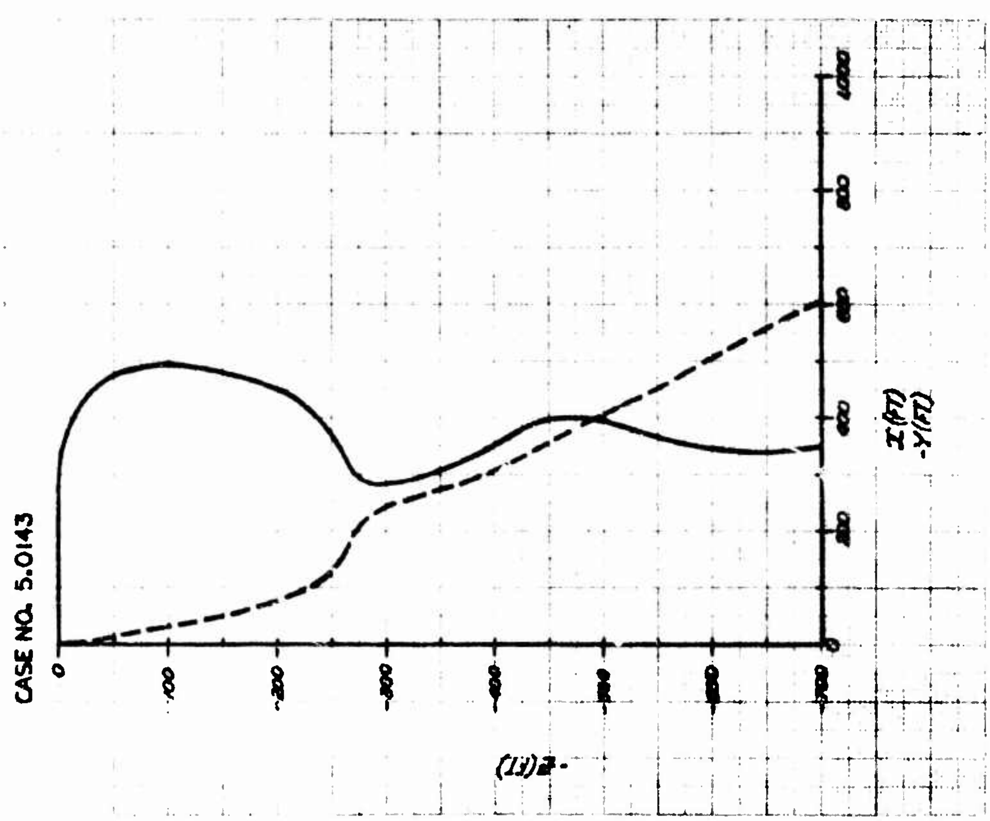



CABLE NO. 5.0141
TIME(SEC)




CASE NO. 5.0142

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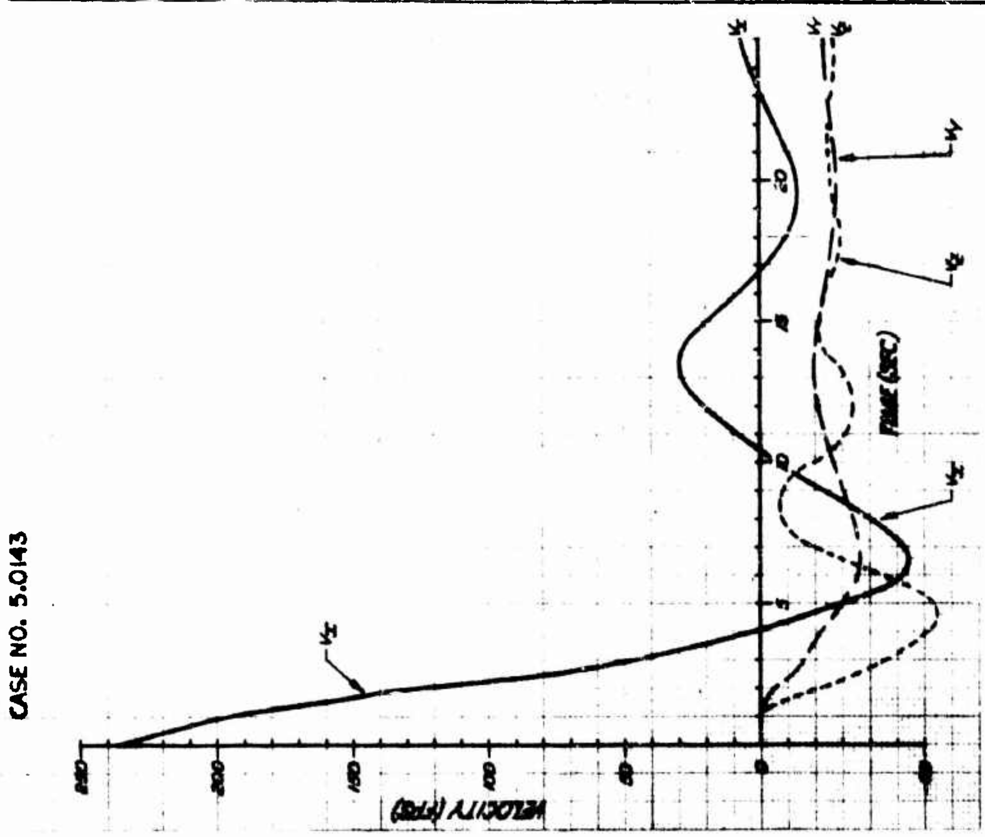
-Y (FT)
-Z (FT)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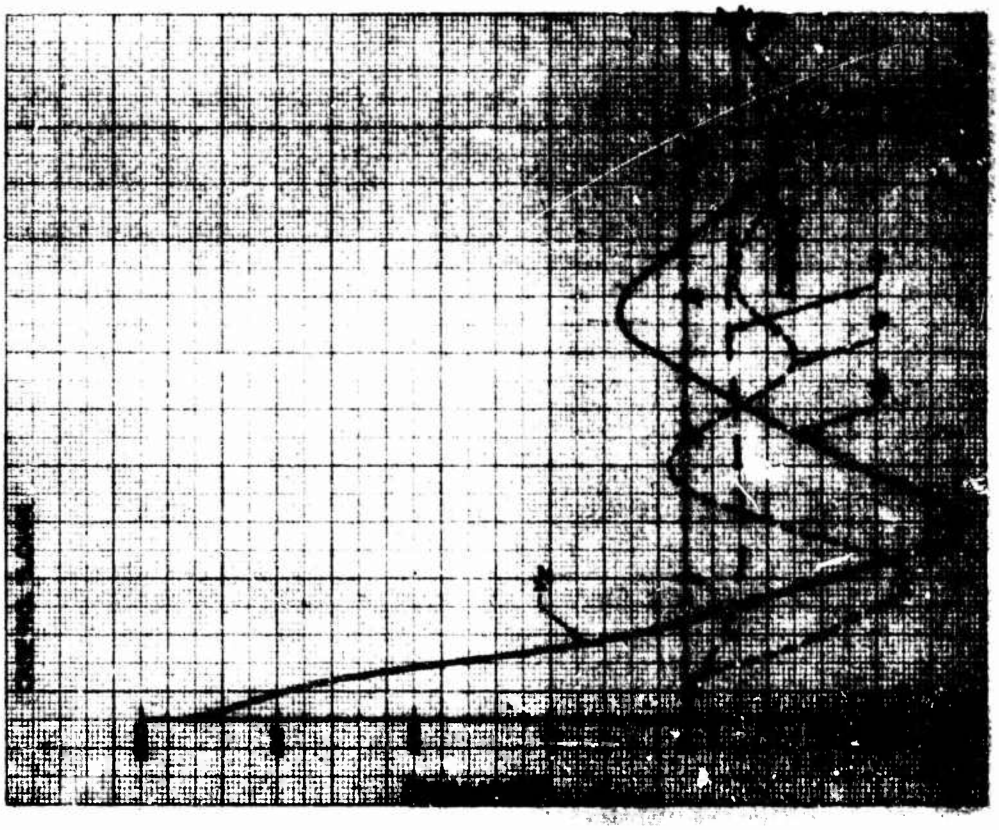
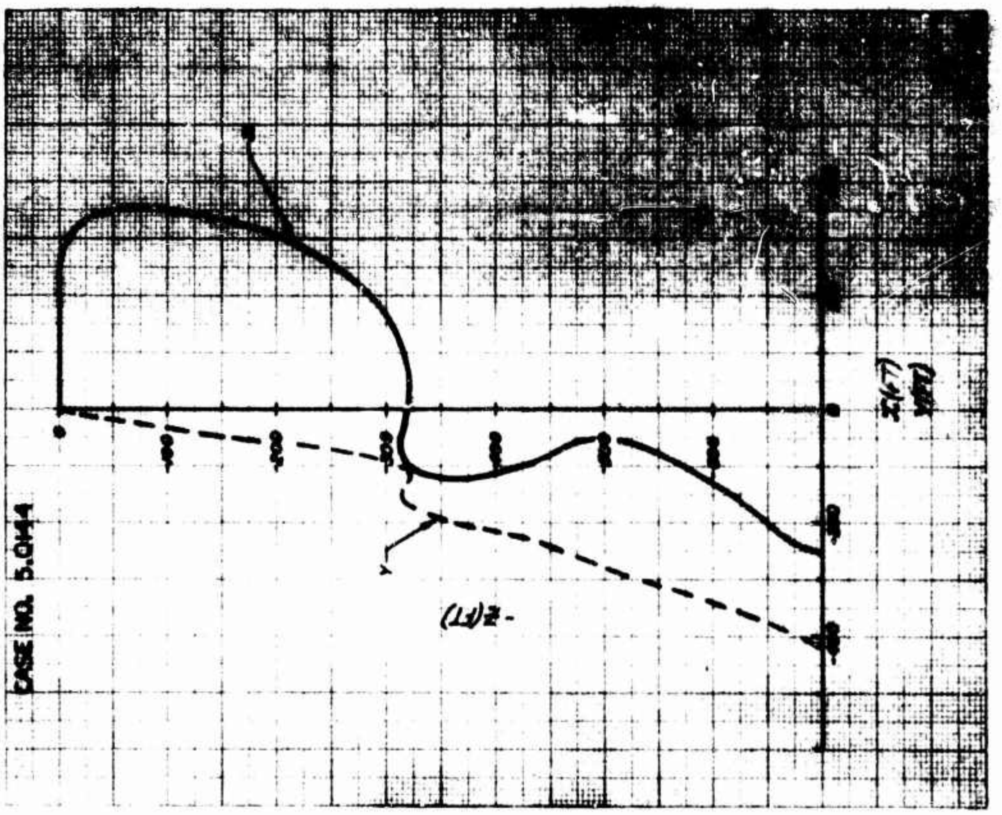
VELOCITY (FPS)
TIME (SEC)

AAI Corporation





Finally, a plot of the various impact locations from an assumed fixed air release point is shown. It is to be noted that these impact locations assume that the drop zone is 700 feet below the aircraft altitude. This was done primarily to illustrate the maximum expected variations in cargo impact locations as a function of wind conditions, since the x coordinate of each of the cargo impact locations tends to be close to zero for a descent of only 500 feet and a wind condition from 0° to $\pm 90^{\circ}$. As was mentioned in the introduction, it must be remembered that a crosswind approaching from the positive 90° direction would give identical numerical results as one from the positive 270° direction; hence, the impact locations may be considered to be symmetrical about the X axis, thus eliminating the necessity of duplicating runs. The numbers given in this plot correspond to the last two digits of the run numbers listed in Tables VI and VII.

From this plot, the effects of the given wind conditions may be readily discerned, with the most extreme case being that of a tail wind acting longitudinally along the direction of flight of the aircraft. Headwind conditions, on the other hand, enable the cargo to impact the ground with the least deviation of the impact point from the point of cargo release in the aircraft.

C. Reel System Characteristics

1. Introduction

The discussions of the characteristics of the reel systems presented in this section are based on the investigations reported in the previous progress reports[3,4] issued by AAI during the contract period 31 November 1965 through 31 July 1966. However, the concept reel system designs have been extended in this report to a more complete level of hardware feasibility, both in terms of subsystem component selection and mating of these components into a workable, overall unit. In addition to the discussion of the technical characteristics of these candidate systems, data is presented in this section that provides preliminary estimates of system development costs for use in the evaluation program. It is to be noted that in Section IV.E. of this report, the airdrop gear cost estimates have been listed in terms of an appropriate gas turbine power source. The tabular data presented in Part 3. of this section can be used to estimate the airdrop gear costs for systems that employ a power source other than a gas turbine.

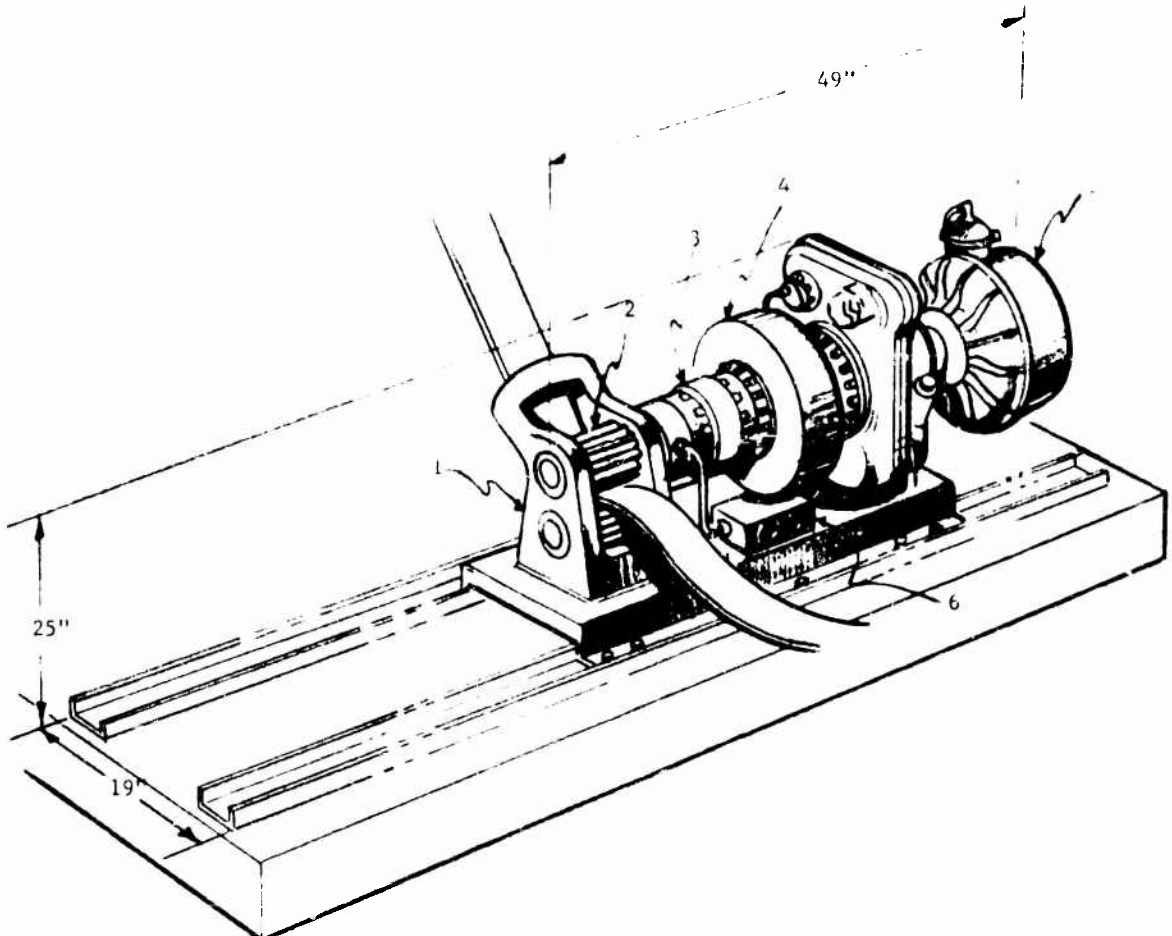
As a quick review of the two most promising power candidate systems, the designs that have been discussed in previous progress reports[3,4] are summarized here.

a. Gas Turbine Reel-In Systems

This system employs an existing, "off-the-shelf" gas turbine for the power source to drive the reel-in mechanism. Figure 3 illustrates the fundamental subsystem components of a 200 H.P. system designed to perform within a cargo weight range up to 10,000 lbs. approximately. It is to be noted that Figure 3 illustrates a reel system employing "pull-through" reels rotating at constant speed. The design parameters for this type of system were presented in the Second Progress Report[4]. A modified and improved design for thi concept will be presented later in this section.

b. Spiral Actuator Concept Power System

This power system concept is illustrated in Figure 4. This device was studied during the early phases of the program in which basic prime movers were evaluated in general, and has been discussed in the 120-Day Progress Report[3]. It is to be noted that a reel-out brake drum has been included in this illustration; at the time this concept was undergoing evaluation, a reel-out sequence of events were being used during the cargo descent trajectory. Since reel-out is no longer a requirement, this element of the system would not be necessary, except for lock-up of the system after completion of the reel-in event.



Item	Weight
1 Mounting Frame	40
2 Reel Drums	26
3 Clutch Mechanism	78
4 Speed Reductor	80
5 Gas Turbine	138
6 Clutch Control System	10
Total	372 lbs.

Figure No. 3 200 H.P. REEL-IN MECHANISM

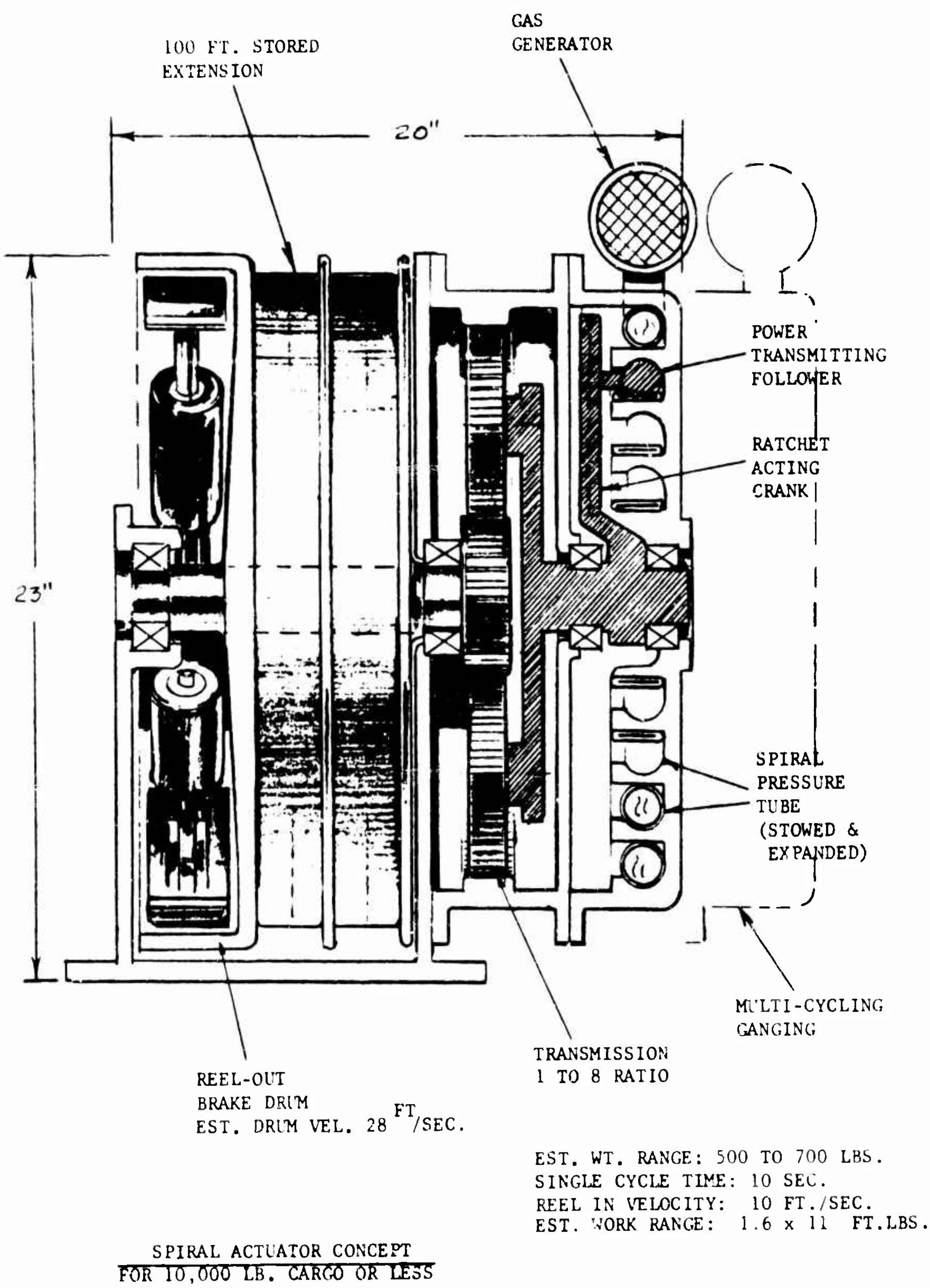


Figure No. 4 SPIRAL ACTUATOR CONCEPT
10,000 LB. CARGO OR LESS

The spiral actuator power unit derives its motion from a pyrotechnically inflated "Bourdon Tube" cartridge that generates torque as it expands by driving a crank follower around the spiral tube. The crank drives a speed-increase transmission and finally the reel-in drum. Due to the newness of the concept, the gas turbine powered concept has been followed in more detail during this program; however, the spiral actuator concept has been evaluated with respect to physical and economic characteristics in this report in order to provide a more complete basis for evaluation of these concepts. The compactness and non-venting propellant characteristics of the spiral actuator are worthy of further consideration, as is the fact that the spiral actuator could be "custom-designed" for direct application to a short duration reel-in event rather than using a turbine system designed for a continuous operation envelope.

In addition to the gas turbine and spiral actuator power systems, aircraft engines have been evaluated in terms applicable to this program. These power generating components appear to offer a reasonable alternative to the developed gas turbine system, which is costly, while still providing a reasonable "off-the-shelf" characteristic in contrast to the yet undeveloped spiral actuator concept.*

Previous evaluation effort expended in this program has concentrated on a pull-through type of reel drum, as illustrated in Figure 5. The major problem with such a concept is the tendency of the pull-through drums to deform the fibers of the reel line, thus reducing the load capacity of these lines and perhaps introducing requirements for metal-strand reinforcement of these lines. It was felt that a more reliable, less complex reel system could be evolved from consideration of a wrap-type reel drum. For this reason, extensive design analyses of a wrap-type reel drum are presented in this section in order to assure feasibility of such a component. As illustrated in the following figure, both the wrapping type reel and the pull-through reel operate with the same suspension system components.

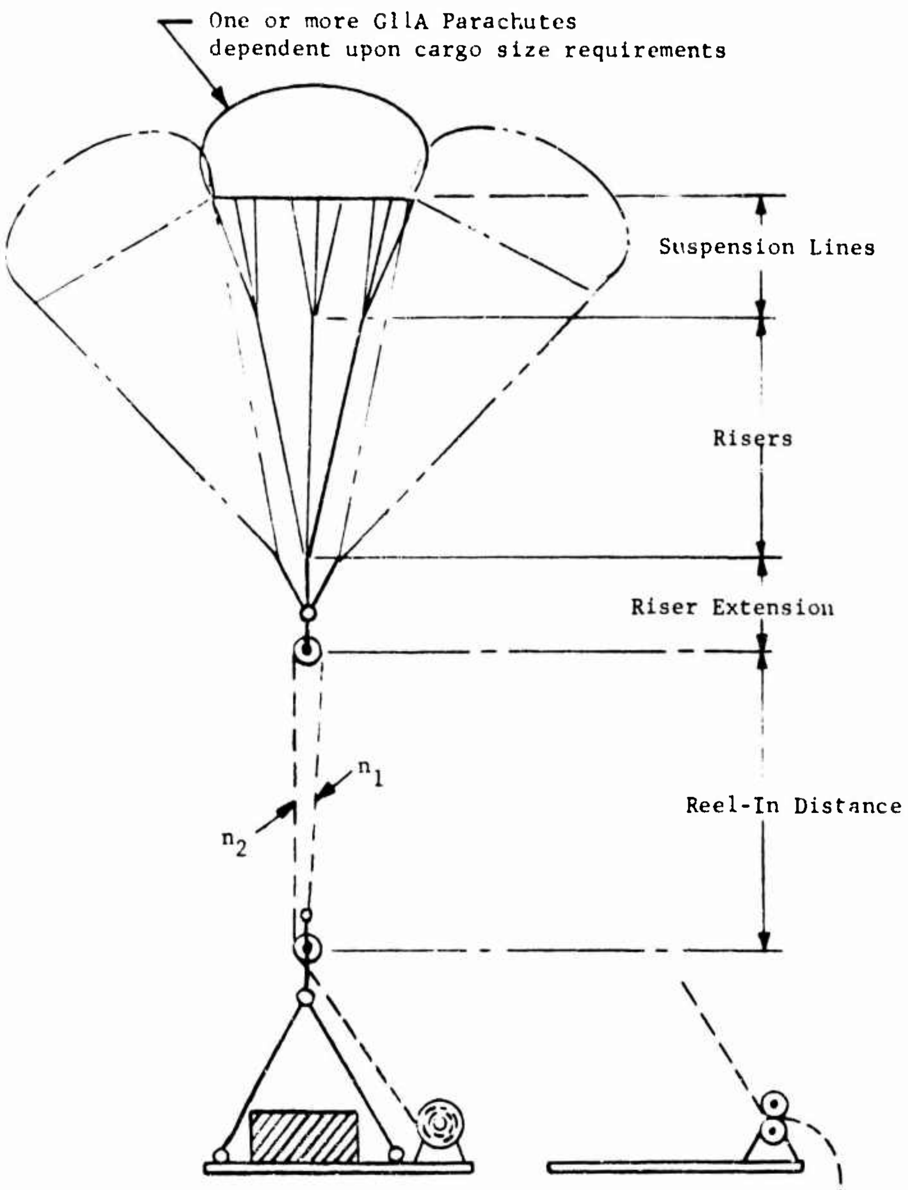
An analysis of the suspension system dynamics is developed in this section in order to define the geometric restrictions imposed on the system to maintain stability of the cargo during the descent trajectory. Discussions of the elements of the reel-in control system are also presented in this section. The use of available hardware appear promising, particularly since components with high reliability are considered.

2. Technical Discussion of the Design Concepts

a. Overall Sequence of Events During Cargo Airdrop

The restraint, extraction (recovery) chute deployment and reefing control systems remain conventional. Approximately 30 seconds prior to initiation of the cargo extraction event, the reel-in system power unit must be started and brought to full output rpm. The engine starting event is accomplished from available aircraft electrical systems.

* As noted in detail in later parts of this section, the aircraft engine concept requires a reorientation of the engine from that presently used, which in turn may necessitate a revision in the engine cooling and lubrication systems.



Type A. Wrapping Type Reel

Performance Conditions

(a) High to low torque output with low to high speed reel-in velocities, respectively.

Type B. Pull-Thru Reel

(a) Constant torque output.

(b) Constant reel-in velocity.

Figure No. 5 CARGO-PARACHUTE GEOMETRY SCHEMATIC (WITH REEL-IN SYSTEM COMPONENTS)

(1) Extraction of Cargo (refer to Figure 6)

The reefed recovery chutes will forcibly extract the cargo. The extraction coupling will remain conventional. Static break-away initiating lines will start the load transfer delay device.

(2) Load Transfer (refer to Figure 6)

Completion of the load transfer event would result in cutting of the extraction coupling straps, plus the additional feature of starting the reel-in clutch delay. This insures that the reel-in event cannot occur if there is a load transfer malfunction; consequently a reliability characteristic is employed.

(3) Reel-In Starts (refer to Figure 6)

This event begins when the reel-in clutch delay device permits. Upon completion of this pyrotechnic delay phase, a cartridge actuated valve permits hydraulic pressure to be applied to the reel-in clutch. The reel-in process continues for a predetermined time. A typical reel-in pulley system arrangement is illustrated in Figure 7, which also indicates a possible method of isolating the cargo pallet from the deceleration forces during the descent.

(4) Reel-In Completed (refer to Figure 6)

This event occurs when the uppermost pulley in the reel-in suspension approaches the lower sheave. A mechanical sensor located in the reel drum is actuated by the growth of the wrapped reel-in webbing causing a second cartridge actuated valve to transfer the hydraulic pressure from the clutch mode to the lock-up mode. The latter has a check valve-accumulator in its hydraulic circuit to insure lock-up continuation. This feature allows the gas turbine to be stopped by the same cartridge actuated valve and, the same lock-up hydraulic pressure would actuate a circuit breaker in the ignition circuit. Consequently, the possibility of a fuel ignition fire during a rough landing would be minimized.

(5) Balance of Descent to Ground Contact (refer to Figure 6)

This segment exists only for the required deceleration to reach equilibrium velocity. There are no other functions occurring during this period if a conventional canopy disconnect is used in the system. In the case where an improved canopy disconnect is desirable, the uppermost sheave axle could be designed to perform this task, as illustrated in Figure 8. In this device, the pyrotechnic cartridge that is fired to destroy the axle of the sheave is not armed until completion of the reel-in event. This is accomplished as the arming lug passes over the firing pin arming lever and is not accomplished until the end of reel-in for obvious safety reasons. Once armed, the cartridge is fixed upon relaxation of the suspension forces in the riser extensions as the cargo impacts the ground.

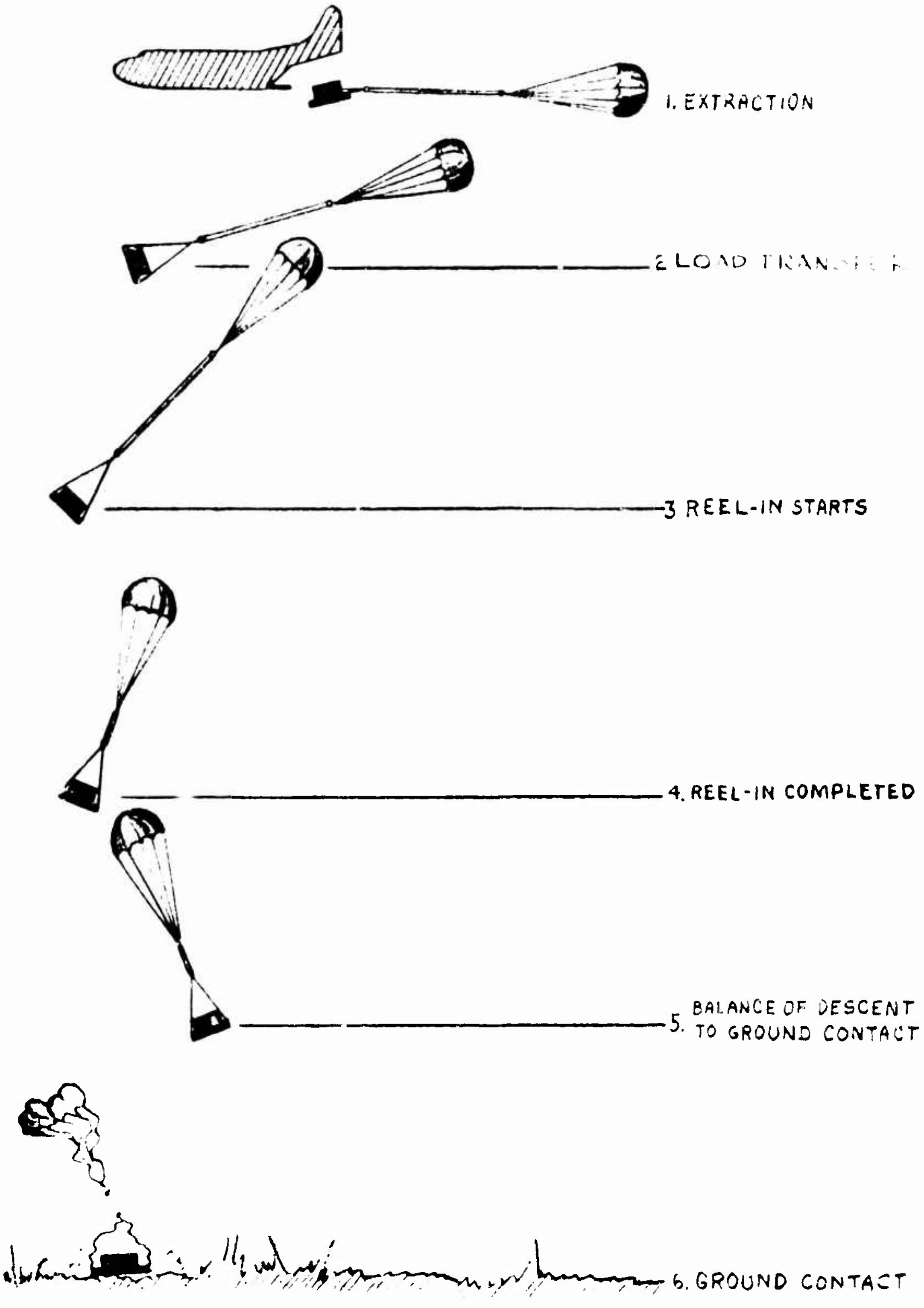


Figure No. 6 REEL-IN SYSTEM: SEQUENCE OF EVENTS

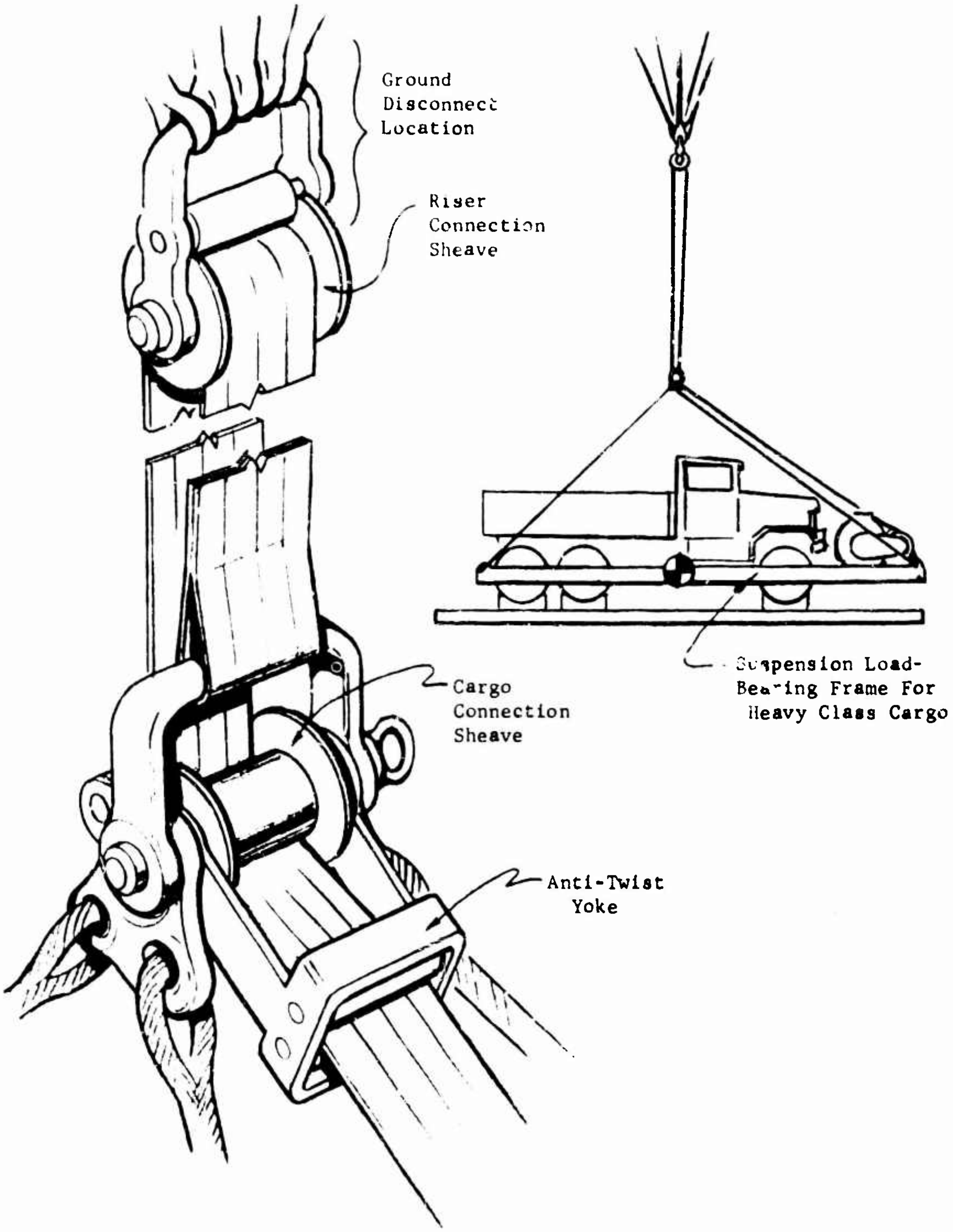


Figure No. 7 TYPICAL REEL-IN PULLEY SYSTEM

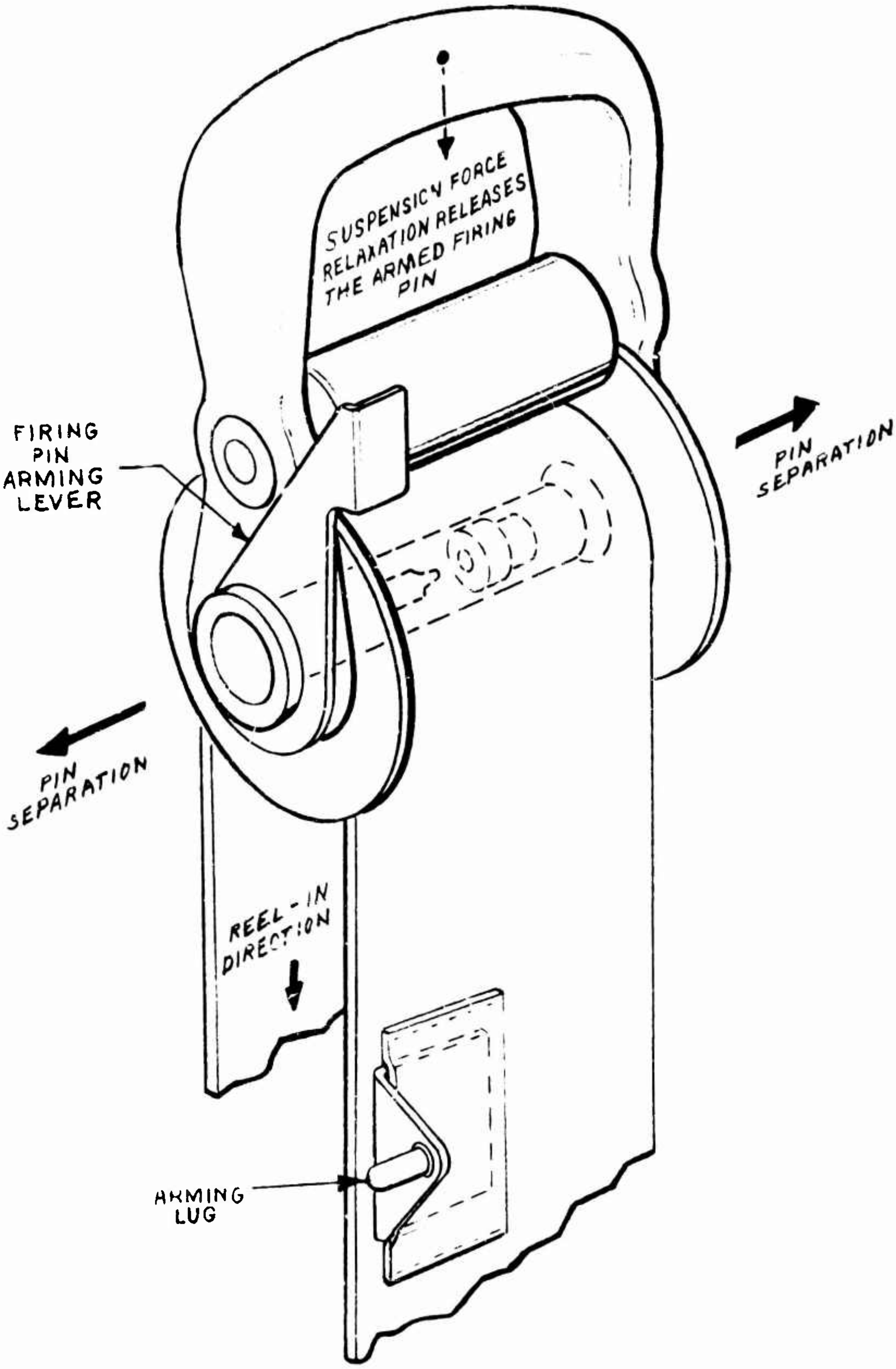


Figure No. 8 <u>CARTRIDGE ACTUATED CANOPY RELEASE CONCEPT</u>

(6) Ground Contact (refer to Figure 6)

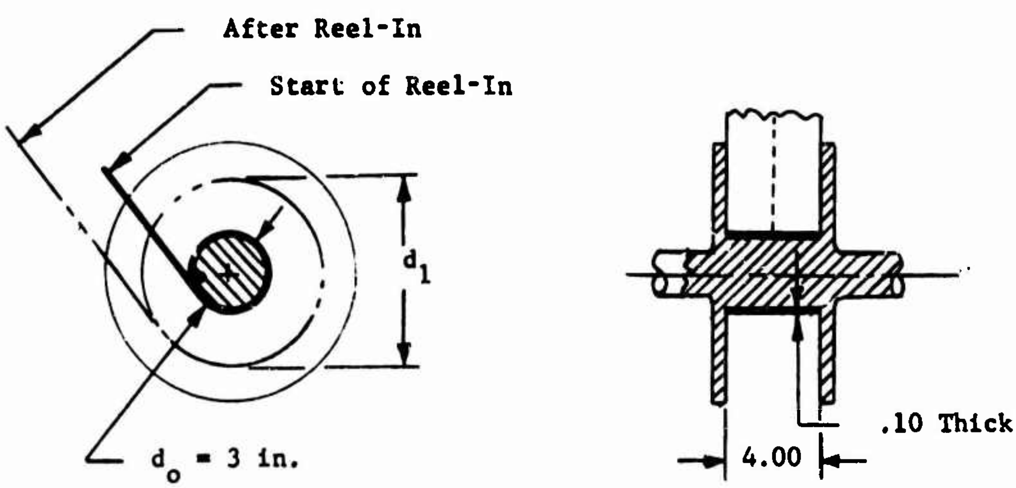
The cargo lands at a safe velocity where upon the tension forces in the suspension system relax. This phenomena allows the standard canopy release to function. Consequently, the cargo is safe-guarded from being towed hazardously by ground winds.

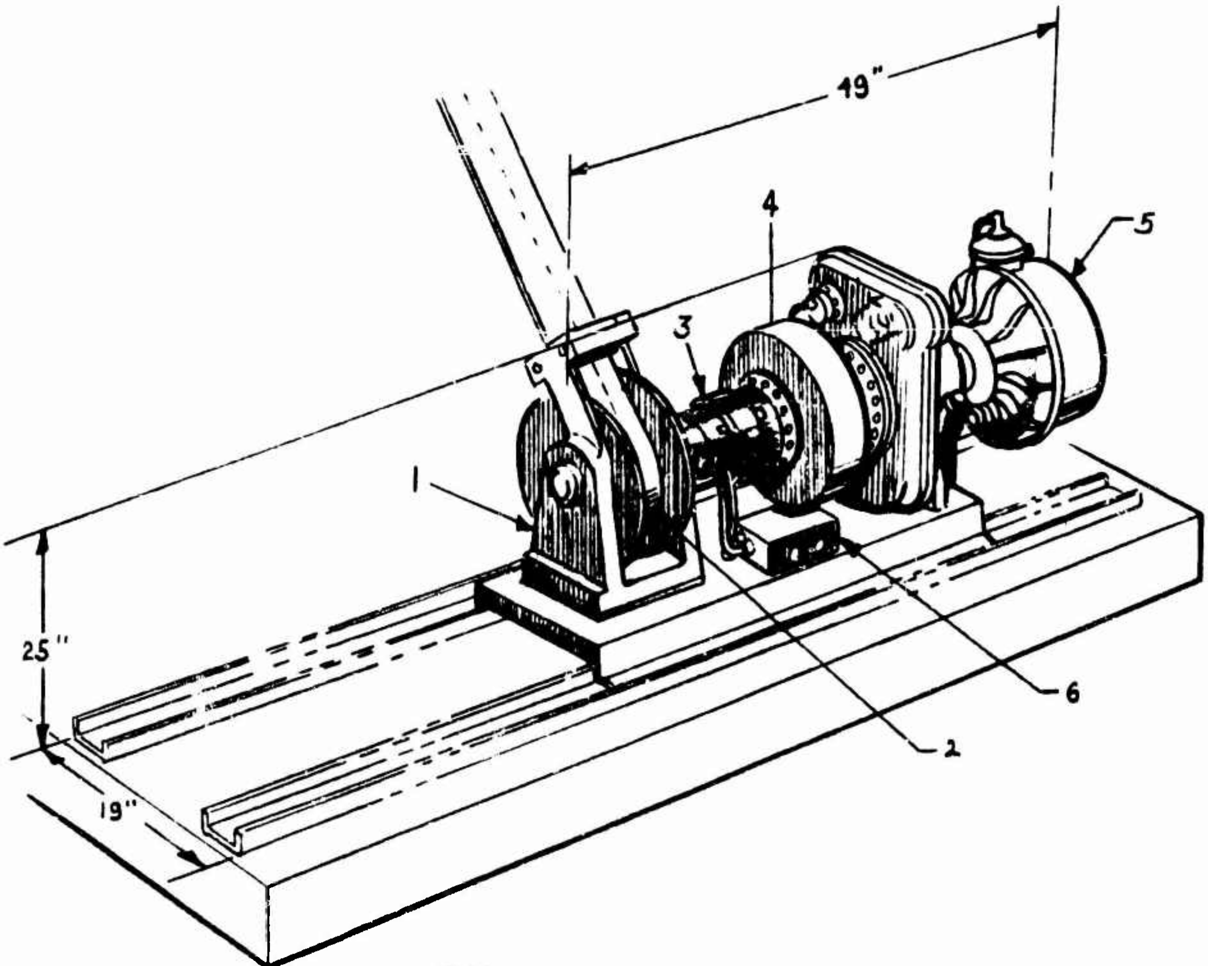
b. Reel-In Drum Design

Previous design considerations have been primarily concerned with a constant reel-in rate, pull-through type reel drum[4]. Further research disclosed the fact that the application of a "wrapping-type" reel drum (i.e., the reeled-in line is actually wound upon a drum) proved more favorable than the pull-through drum, particularly from the stand-points of (1), wear and tear on the reel-line, and (2), efficient utilization of the available power. The first of these two advantages should be apparent since the wrapping-type drum merely winds the reel line about a drum instead of pulling it through two toothed drums. The second of these two benefits is not so apparent, hence the following discussion will present a description of the drum design followed by analytical support as to why the available power is effectively utilized. Two examples will be developed in this discussion: one for the 200 H.P. system required for Case 5.0092 (Cargo Item 5, 8409 lb), and the other for Case 5.0107 (Cargo Item 8, 32550 lb).

(1) Wrap Type Reel-In Design for Case 5.0092

The typical geometry for this system is illustrated in Figure 9. Choosing two 11,000 lb reel line components, a system mechanical advantage of 2:1 (as noted on p.317 of AAI ER-4473[4]) will be denoted by the factor Kp. The starting configuration appears as follows:





ITEM		WEIGHT
1 MOUNTING FRAME		40
2 REEL DRUM		34
3 CLUTCH MECHANISM		78
4 SPEED REDUCTOR		80
5 GAS TURBINE		138
6 CLUTCH CONTROL SYSTEM		10
	TOTAL	380 LBS

Figure No. 9 200 H.P. REEL-IN MECHANISM WRAPPING TYPE REEL

The envelope of d_o to d_1 is established by satisfying the required reel-in length, in this case, a pulley multiplication of 2 must be applied to the reel-in length of the chutes. The initial diameter d_o is determined by the structural size that will satisfy the expected peak parachute forces during the cargo descent. This force is readily available from the computer case run no. 5.0092, and indicates a peak tension force of 22,000 lbs. The reel shaft will experience this load even when not running; and, dependent upon its mode of attachment to the shaft, will probably produce a torsional load. Since a minimum value of d_o will produce the smallest reel envelope, this structural criteria is a sound basis for this parameter.

Using the torsional stress equation

$$\gamma = \frac{n\ 16\ T}{\pi\ d_o^3} \quad \text{PSI}$$

and transposing,

$$d = \sqrt[3]{n\ \frac{16T}{\pi\gamma}} \quad \text{inches}$$

where T = in. lbs. torque = $\dfrac{F_p d_o}{2\ K_p}$

F_p = 22,000 pounds

K_p = 2 factor of load reduction by the suspension pulley system

γ = 50,000 PSI selected torsional stress

n = 5 factor of safety

then $d_o = \sqrt[3]{n\ \dfrac{16T}{\pi\gamma}}$ inches minimum diameter of reel drum shaft

$$= \sqrt[3]{n\ \frac{16\ F_p d_o}{\pi\gamma 2K_p}}$$

and reducing,

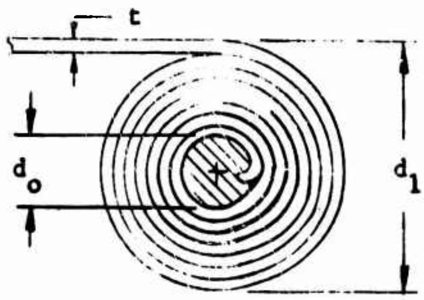
$$d_o = \left[\frac{n\ 16\ F_p}{\pi\gamma 2K_p}\right]^{1/2}$$

$$= \left(\frac{5(16)2200}{\pi\ 50,000(2)2}\right)^{1/2}$$

$$= (2.82)^{1/2}$$

d_o = 1.68 inches minimum diameter of the reel drum shaft

An allowance for fastening the reel-in strap to this diameter will necessarily enlarge it; to expedite the remaining computations a 3.0 inch diameter will be used as d_o. The maximum diameter (d_1) can now be established for a specified reel-in length. The conditions of this envelope become:



Using the webb area equation $A_w = 12\ LtK_p = \frac{\pi}{4}(d_1^2 - d_o^2)$ and transposing :

$$d_1 = \left(\frac{4(12)LtK_p}{\pi} + d_o^2\right)^{1/2}$$

where

L_{RI} = 39.33 feet of reel-in distance between the cargo and chutes

K_p = 2, factor required to allow for the 2:1 advantage of the suspension pulley system.

t = .1 inches, webb thickness

d_o = 3 inches diameter

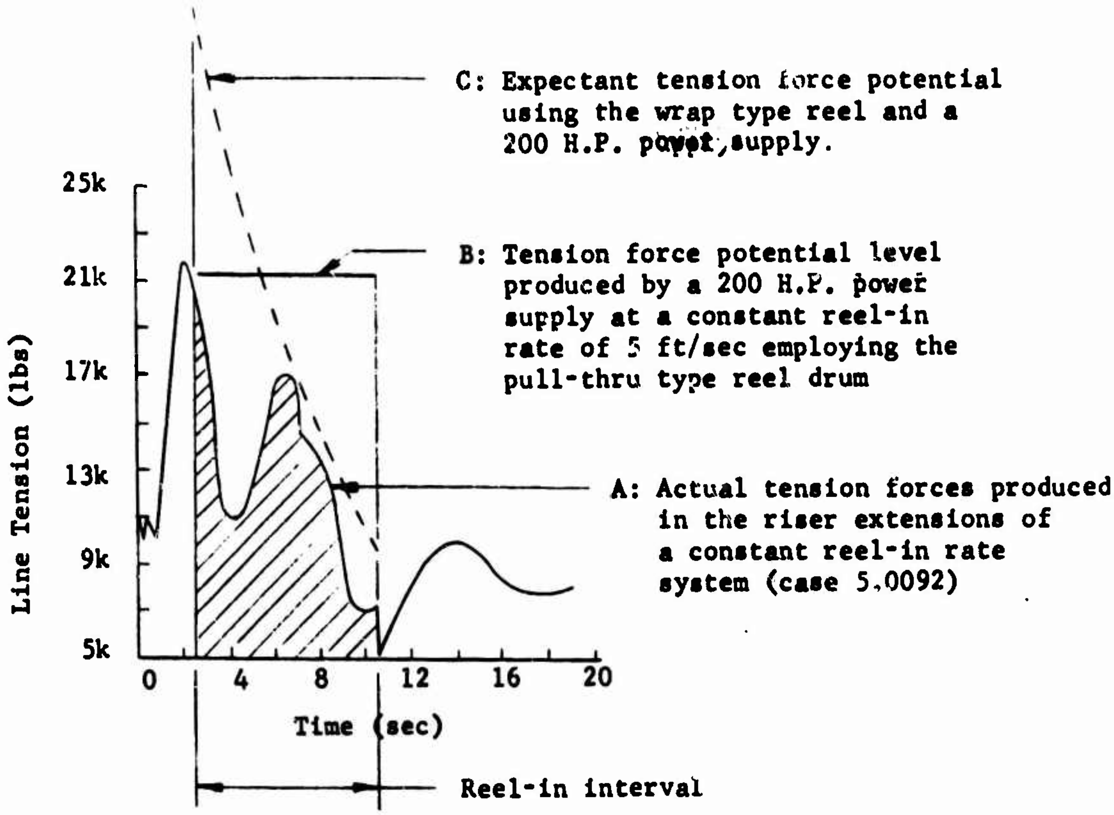
then,

$$d_1 = \left(\frac{4(12)(39.33)(.1)(2)}{\pi} + 3^2\right)^{1/2}$$

$$= (129.3)^{1/2}$$

d_1 = 11.36 inches

Now that the envelope is defined, the next design parameter deals with selecting its performance. Computer Case Run No. 5.0092 defined the tension force during a constant reel-in rate that was necessary to achieve that low altitude drop successfully. Replotting this line tension force versus time curve and observing the conditions during the reel-in interval, definite performance parameters for the wrap type reel can be selected.



It is important to note that the force potential B is a consequence of the method of determining H.P. requirements which were based on the max. force during reel-in. The constant reel-in rate (RPM) is a kinematic condition that effectively contributes to force conditions A. The speed droop of the reel-in mechanism is negligible with respect to force A variations. The speed droop of a wrap type reel can likewise be considered negligible as long as the force potential C is greater than the force level A throughout the reel-in interval. Therefore, the most efficient use of the wrap type reel is approached by designing this force slope C as close to the force A curve as possible; the consequence of doing this produces the maximum reel-in rate for a selected power (in this case 200 H.P.). It is obvious that the greater the reel-in rate, the greater the effect of decelerating the cargo. This approach must be taken to at least achieve the success that the constant reel-in rate produced in computer case no. 5.0092. In order to do this, the moment arm change of the wrap drum must be considered. Any point on the force slope C is determined by the following equation.

$$\Delta F_c = \frac{Q}{M} K_p$$

where Q = inch-lbs. torque produced by the power plant which is equal to

$$Q = \frac{NP}{R.P.M.}$$

where N = 63025 Conversion factor for in-lbs. torque

P = 200 H.P.

K_p = 2 factor of allowance for the suspension pulley system

RPM = Drum Speed

and $M = \frac{\Delta D}{2}$

where

ΔD = selected wrapping diameter at any selected point during the reel-in interval; in this computation it is desirable to check the terminal diameter d_1 where the slope C will be lowest. d_1 = 11.36 inches

and finally

ΔF_{CT} = 11,000 lbs. this is an arbritary force selection, a reasonable level above the 7200 lbs. terminal force of slope A indicated in the 5.0092 run, at the end of the reel-in event.

Restating the equation

$$\Delta F_{CT} = \frac{Q K_p}{M}$$

$$\Delta F_{CT} = \frac{2N P K_p}{(RPM)\Delta D}$$

and transposing ,

$$RPM = \frac{2N P K_p}{\Delta F_C \Delta D}$$

$$= \frac{2(63025)200(2)}{11,100\ (11.36)}$$

RPM = 400 Drum Speed

Now that the RPM (consequently the torque level) has been selected on the basis of satisfying the terminal area of force slopes A with force slope C, the initial end of slope C can be checked for its margin of performance to avoid stalling the power system. Again, restating the equations, the initial force of slope C $\Delta F_{CI} = \frac{2 N P K_p}{(RPM)\ \Delta D}$ lbs.

where the only variation here is

ΔD = 3 inches initial diameter of the reel drum at the beginning of the reel-in interval the potential force of the initial reel-in power becomes:

$$\Delta F_{CI} = \frac{2(63025)200(2)}{400(3)}$$

$$\Delta F_{CI} = 39{,}500 \text{ lbs.}$$

Comparing this force to the starting force on the slope A (18,000 lbs), a great margin of safety exists. The next region of concern is the slope C force level throughout the reel-in event; the rise and fall of slope A must still remain under slope C throughout this reel-in event. In order to plot the potential force slope C completely, it is necessary to conduct a tabulation of incremental changes that occur primarily to the moment M which varies as ΔD, the drum diameter. Precomputing the reel-in velocity of the drum as a function of changes in the diameter of the drum as the webbing is wrapped around it, provides the input conditions necessary to verify the operational characteristics of the system. Computer Case 5.0119 was programmed for computation with the precomputed reel velocities as inputs. Figure 10 illustrates the results of this computation. The tension-time characteristics illustrated in the set of graphs comprising Figure 10 confirm that the utilization of a wrap-type reel drum is within the capabilities of the power system. Figure 11 illustrates the tension time characteristic of a pull-through reel system for convenient comparison. This latter graph was extracted from p. 3.21 of AAI ER-4473[4].

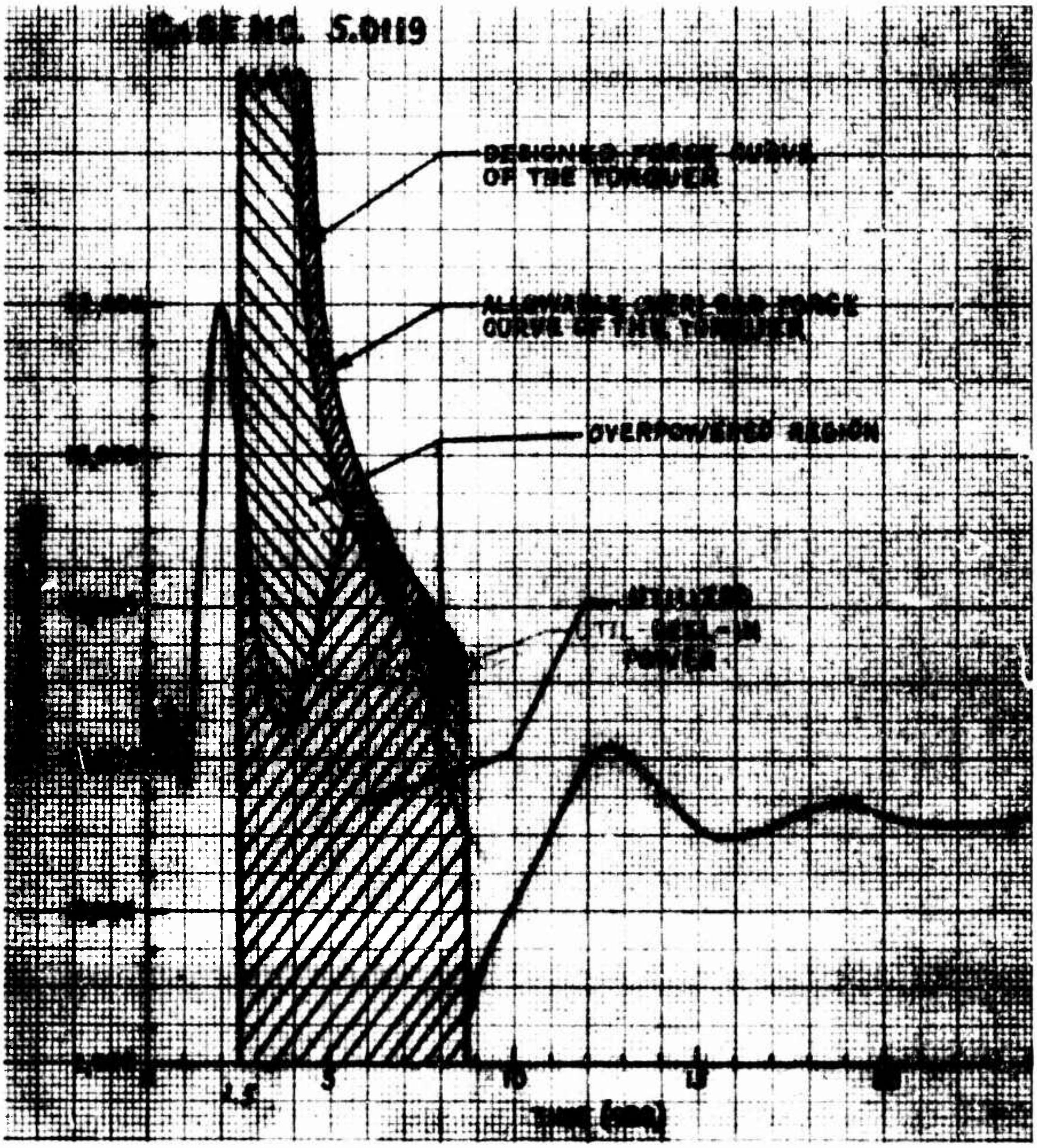


Figure No. 10 200 H.P. WRAPPING REEL DRUM (ACCELERATED REEL-IN)
400 R.P.M. DRUM SPEED CARGO WT: 8409 LBS.

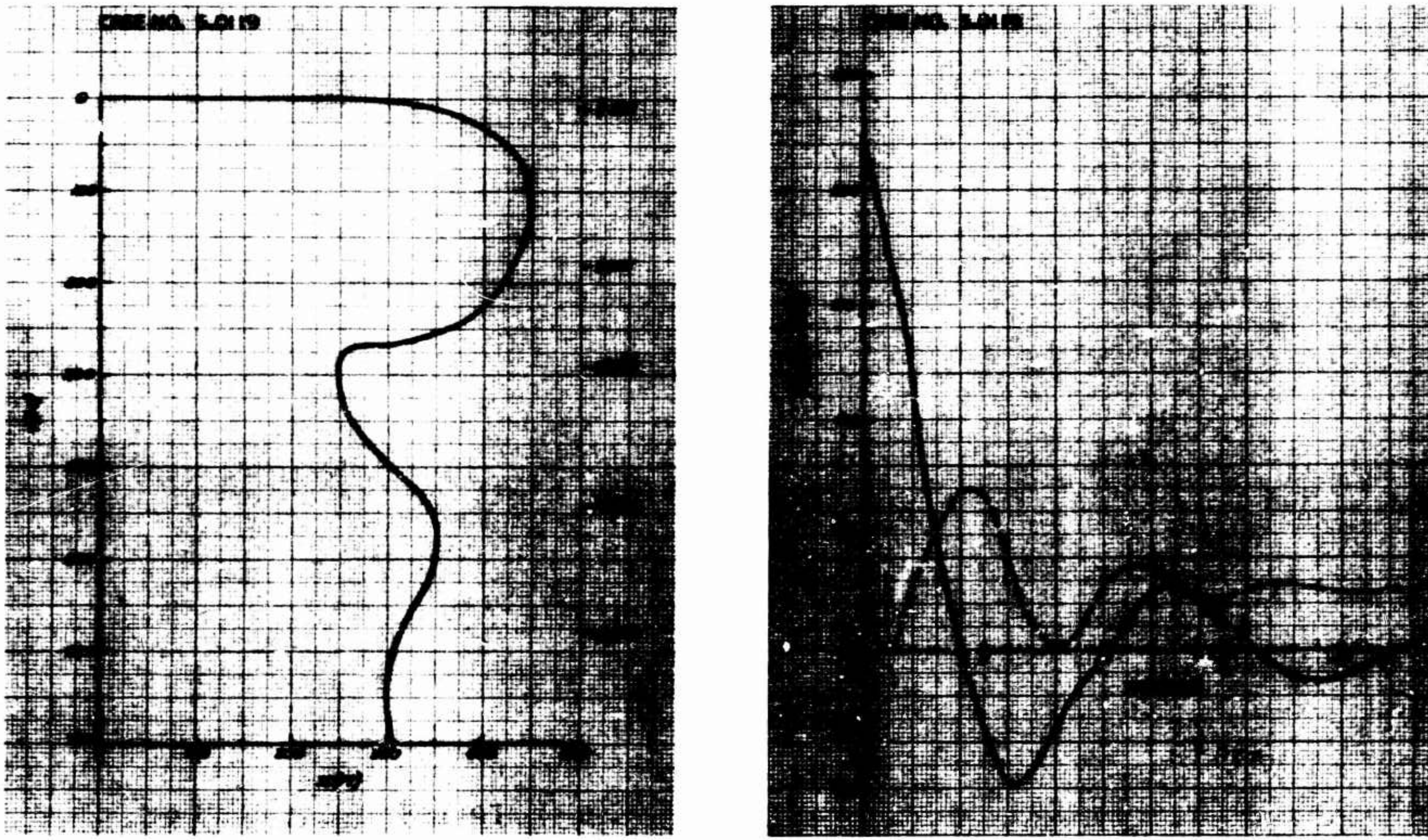


Figure No. 10 (CONTINUED)

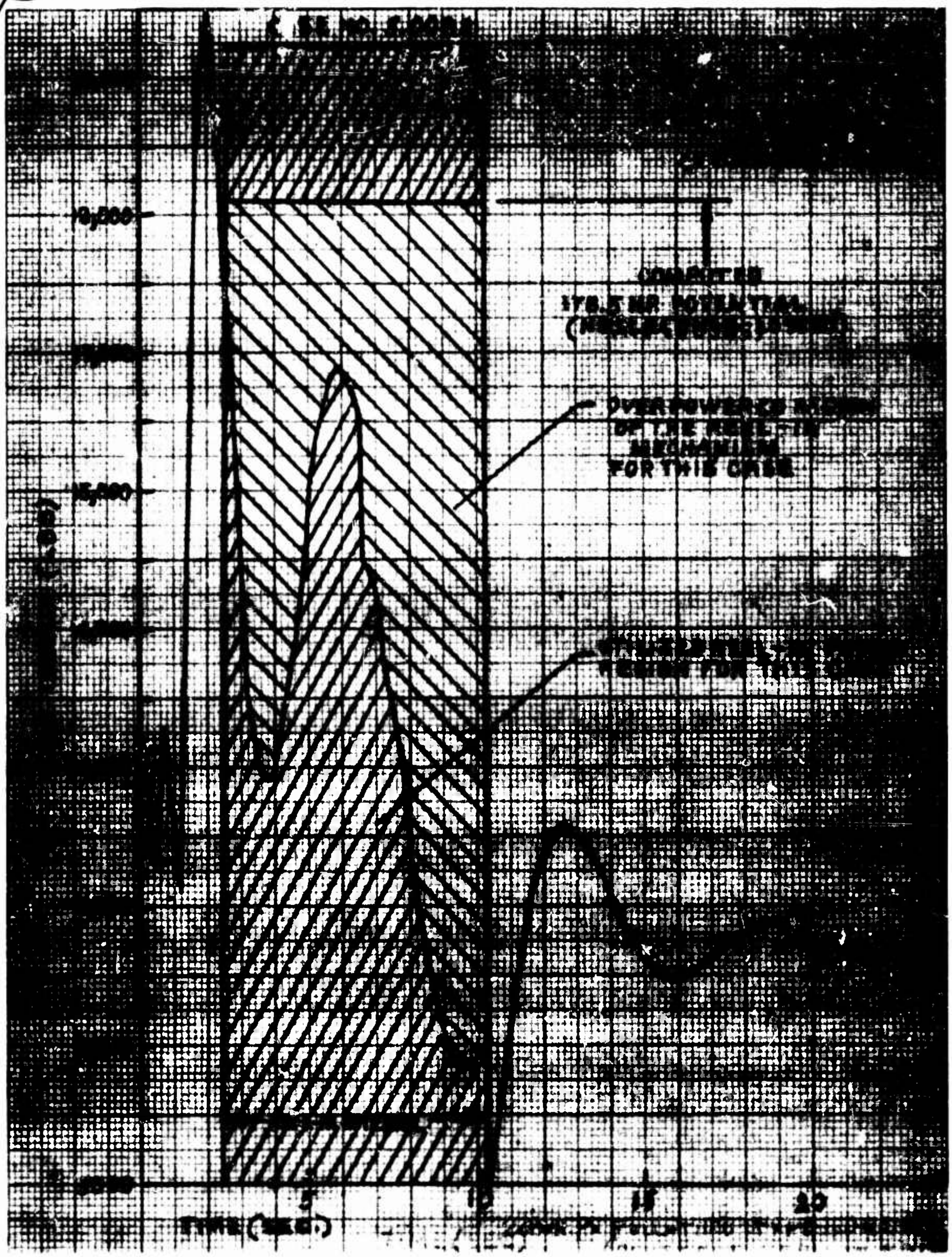


Figure No. 11 200 H.P. PULL-THRU TYPE DRUM (CONSTANT REEL-IN RATE)
600 R.P.M. DRUM SPEED CARGO WT: 8409 LBS.

(2) Wrap Type Reel-In Design for Case 5.0107

Using the same techniques as in the preceeding example, Computer Case 5.0120 was programmed in order to verify the characteristics of the reel system for the 32550 lb. cargo (Item 8). The three graphs comprising Figure 12 illustrate the results of this computation, again confirming that the power system is capable of achieving the desired operational characteristics.

Figure 13 shows a preliminary rigging concept of the XM551 Cargo (32,500 lbs.), utilizing the 1070 H.P. reel-in system. Since suspension system attachments to cargo weights over 10,000 pounds must be attached to the cargo, rigging the XM551 is as follows:

The suspension system shows attachment to cargo lugs which are imaginary, and a frame to support the reel system. It is felt that a frame support of this type or similar configuration will be necessary to allow for the load bearing performance of the reel system itself. A conventional suspension attachment would normally only require the slings to be attached but, in this case, the reel system must also support the load. This is defined in the cargo suspension system geometry section of this report.

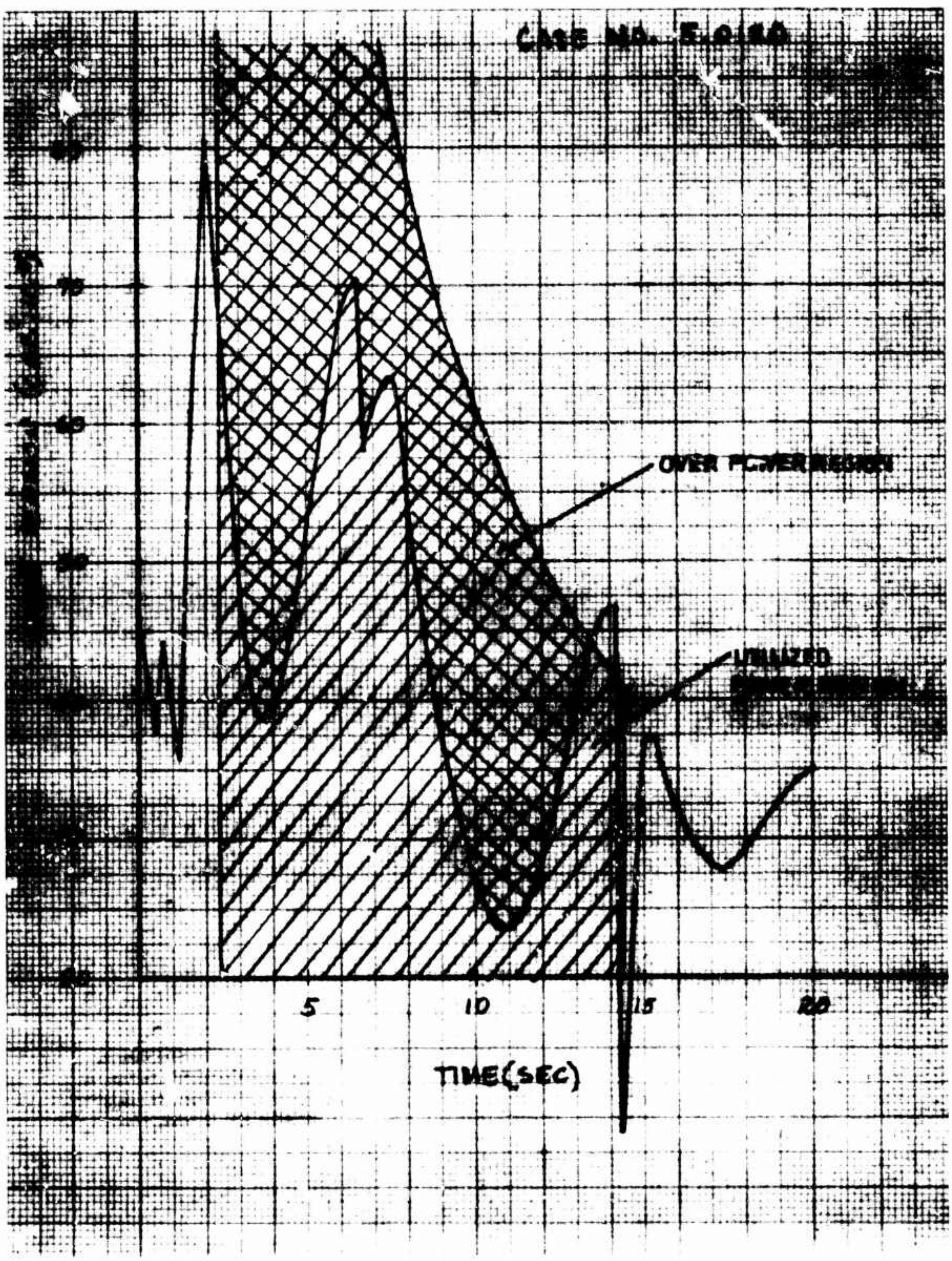
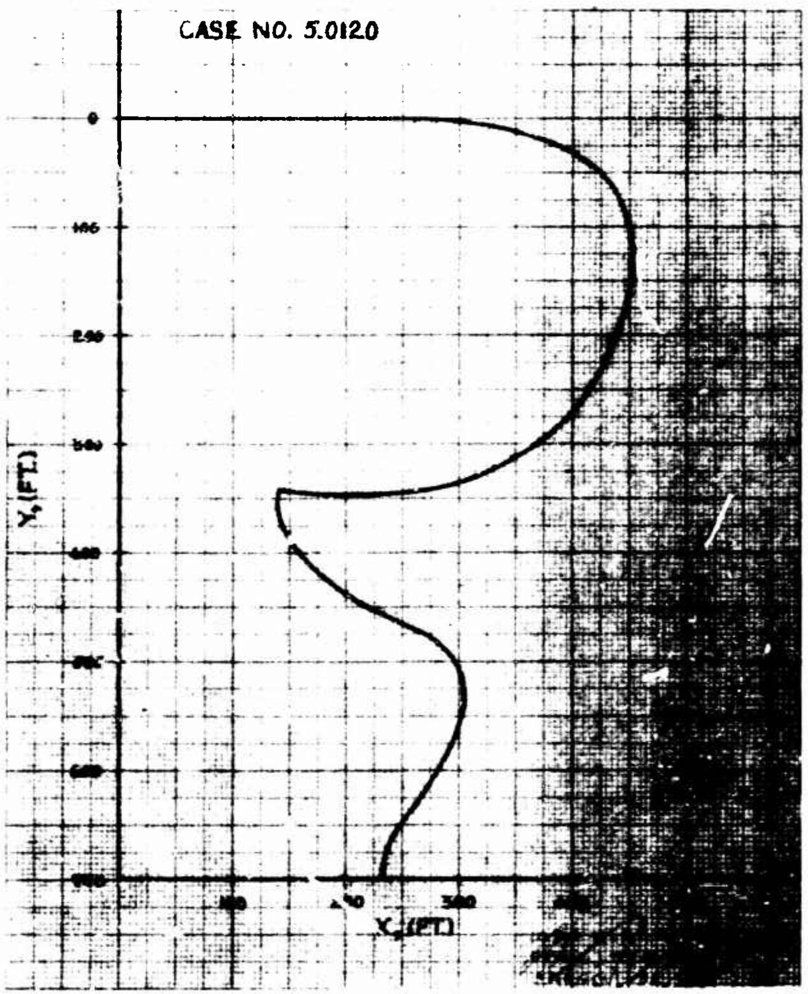


Figure No. 12 1070 H.P. WRAPPING REEL DRUM (ACCELERATED REEL-IN)
270 R.P.M. DRUM SPEED CARGO WT: 32550 LBS.



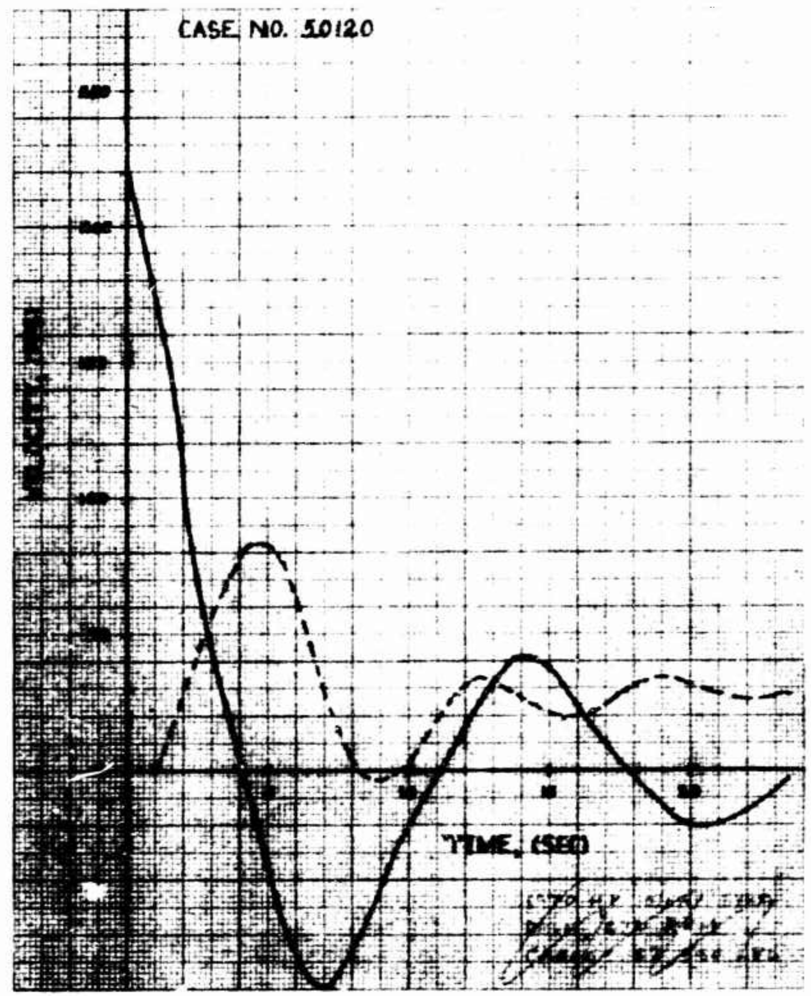


Figure No. 12 (CONTINUED)

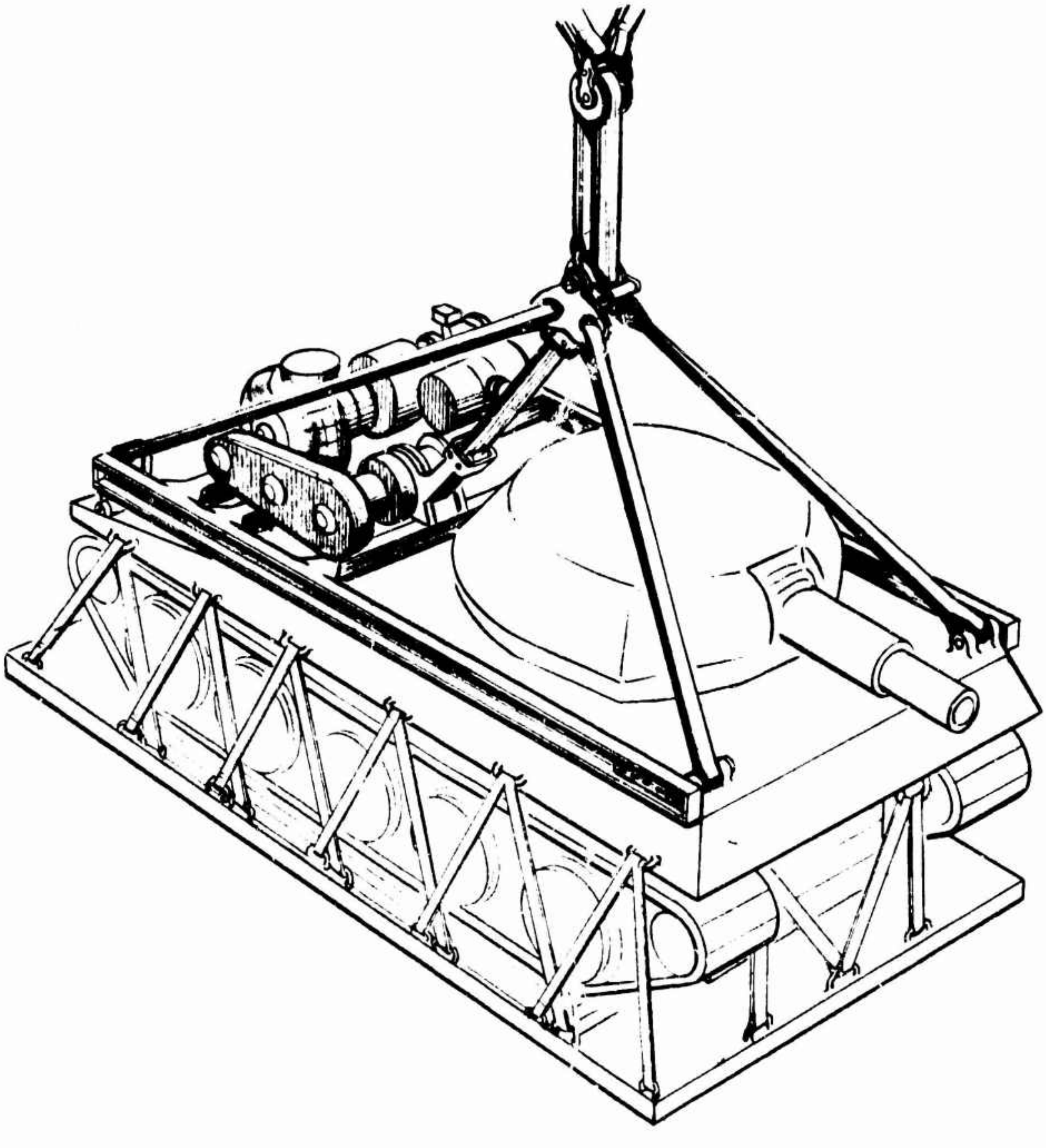
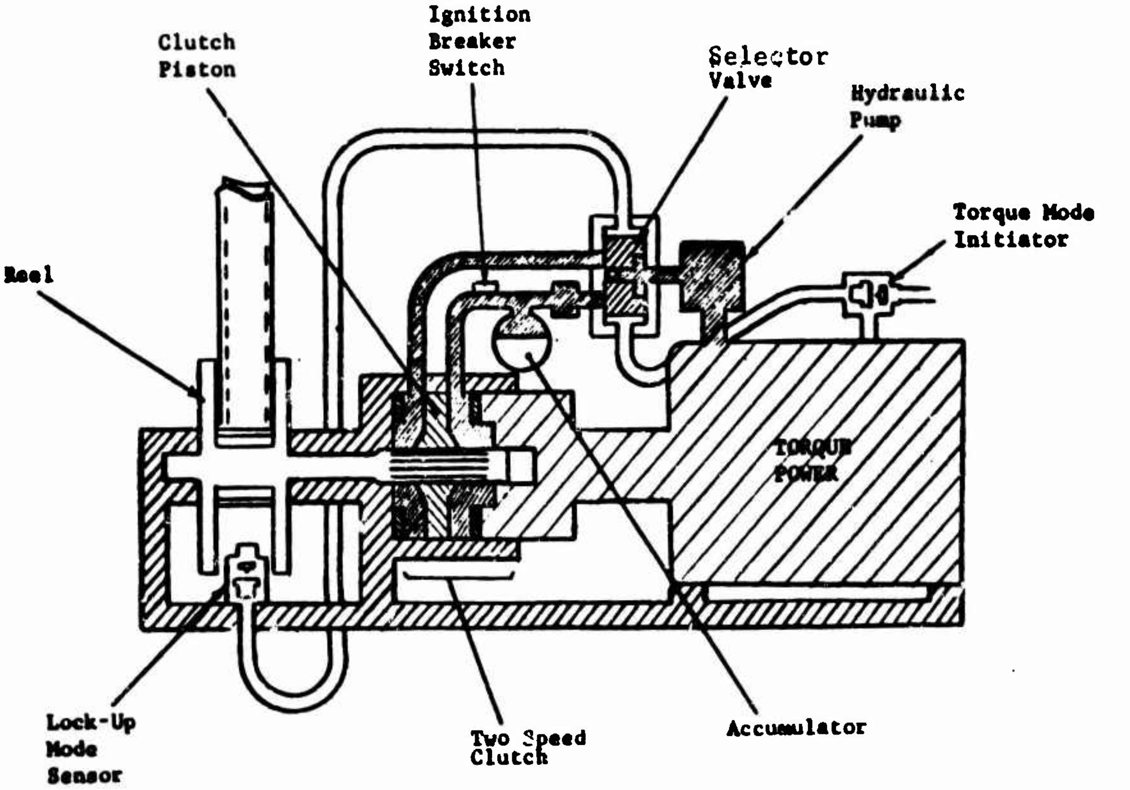
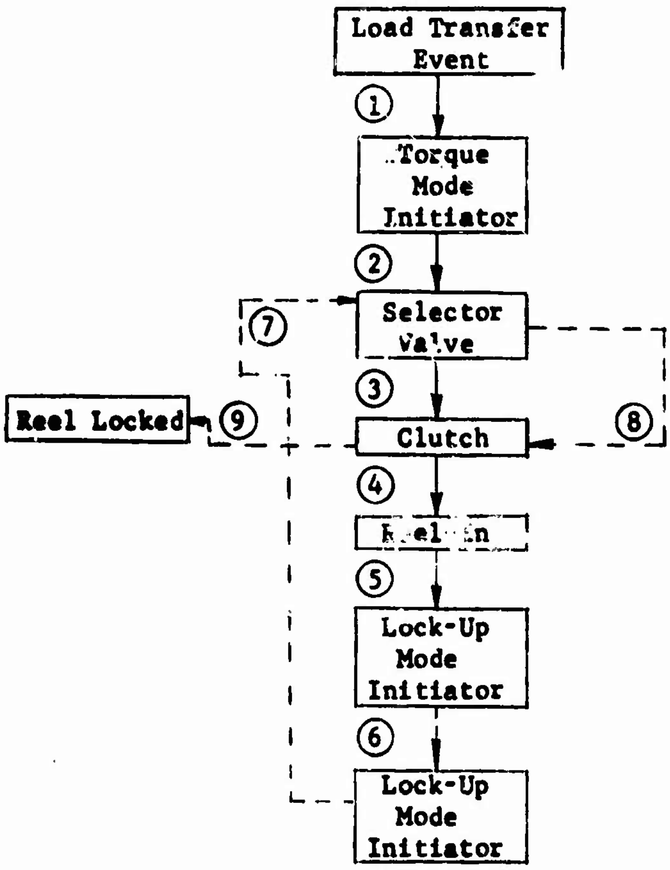


Figure No. 13 REEL-IN DROP SYSTEM
CARGO: ITEM 8 (XM551) 32550 LBS.
1070 H.P. REEL MECHANISM

c. Control System Design

The control system required for the events throughout the reel-in interval of the drop system, as described in the preceding section begins with a presentation of the control system semi-schematic and its accompanying diagram of operation sequence. This diagram is the result of compiling specific operations based on the use of selected types of hardware.





CONTROL SYSTEM
REEL OPERATION SEQUENCE DIAGRAM

The numbered event points illustrated in this diagram are described in the following statements:

Reel Control Event No. 1

A static line, connected to the extraction coupling and the torque mode initiator, is actuated during the load transfer event. The end attached to the torque mode initiator extracts a pull-pin which fires a delay and actuating cartridge. The delay portion insures that load transfer has been accomplished; and that the suspension system is oriented properly under the influence of deceleration forces. This delay will probably be in the order of .5 seconds duration.

Reel Control Event No. 2

The actuating portion of the torque mode initiating cartridge is ignited by the terminal burning of the delay segment. This generates an abundant gas pressure which impinges on the piston face of the selector valve slide, the initial movement of the slide shears a shear pin which normally captivates the slide to a neutral position for obvious safety reasons. The slide is forced over a fixed stroke whereupon the terminal position aligns the hydraulic port that allows passage of pump-pressurized fluid to the torque mode section of the clutch. A locking detent insures that the slide cannot return when the propellant gases have been vented.

Reel Control Event No. 3

Fluid pressure is transmitted to the torque-mode section of the clutch. This pressure forces the clutch piston against the friction plates which produces a mechanical coupling between the power system and reel-drum shafts.

Reel Control Event No. 4

Torque is transmitted to the reel-drum which wraps the reel-in webbing onto the drum.

Reel Control Event No. 5

When the reel drum wraps the required amount of length in, a lock-up mode sensor is mechanically actuated by the maximum diameter that corresponds to that specific reel-in length. (A protruding attachment to the reel-in webbing may be an improved actuating method to obtain a closer reel-in length tolerance.) Actuation of the lock-up mode sensor transmits a mechanical force to the lock-up mode initiator.

Reel Control Event No. 6

The mechanical force emanating from the lock-up mode sensor extracts a pull-pin which fires on actuating cartridge. The propellant gases generated by this cartridge impinge on the opposite side of the selector valve slide.

Reel Control Event No. 7

The initial pressure that emanates from the lock-up mode initiator forces the slide-locking detent free; the impinging pressure on the slide causes it to translate to the extreme opposite side of the selector valve. This action performs two hydraulic functions; the torque-mode circuit is interrupted and relieved (drum torque is released), and the terminal position aligns the pressurized fluid supply with the lock-up port of the hydraulic circuit.

Reel Control Event No. 8

Hydraulic pressure is pumped to the lock-up mode section of the clutch. This pressure forces the clutch piston against the friction plates that produce a mechanical coupling of the reel-drum shaft to the mounting frame.

Reel Control Event No. 9

This portion of the hydraulic circuit has three additional components in it. A check valve, small hydraulic accumulator, and a pressure switch. Reel lock-up mode is assured by the loading pressure of the accumulator (clutch lock-up pressure is reasonably lower). Upon loading the accumulator to full pressure, the pressure switch is actuated which stops the ignition of the reel power system. Even though engine power stops and consequently the hydraulic pump, lock-up pressure is maintained by the check valve which is upstream in the circuit.

Control Component Discussion

Clutch Selection

The preceding description of clutch operation is based on the performance of available clutch hardware. The previous report[4] on this program listed several sizes of "Rockford" clutches that are applicable to requirements of these drop systems. The two-sided clutch is a standard design that represents an improved mode of performance over the first designs presented in this study program. They are reasonably compact, lightweight, and economical; consequently, development requirements would be minimized in this area.

Mode Initiators

These are pyrotechnic devices with broad history in airborne applications. Many sizes are available as off-the-shelf designs that have broad acceptance history for safety-systems on aircraft. They are compact, highly reliable, and enjoy an unequalled energy source capability.

High pressure hosing allows them to be placed where desired. Mechanical firing is described in the control system even though electric squib counterparts are available; the latter type are used extensively in the space development field where the slight weight saving features are gained by an electric firing system. The merits of the electrical system would have to be evaluated further, including reliability and safety features, before a preference could be presented.

Selector Valve

The described selector valve bears many features that sound familiar to available hardware but, the reservation must be stated that some custom feature. may be necessary for this particular application.

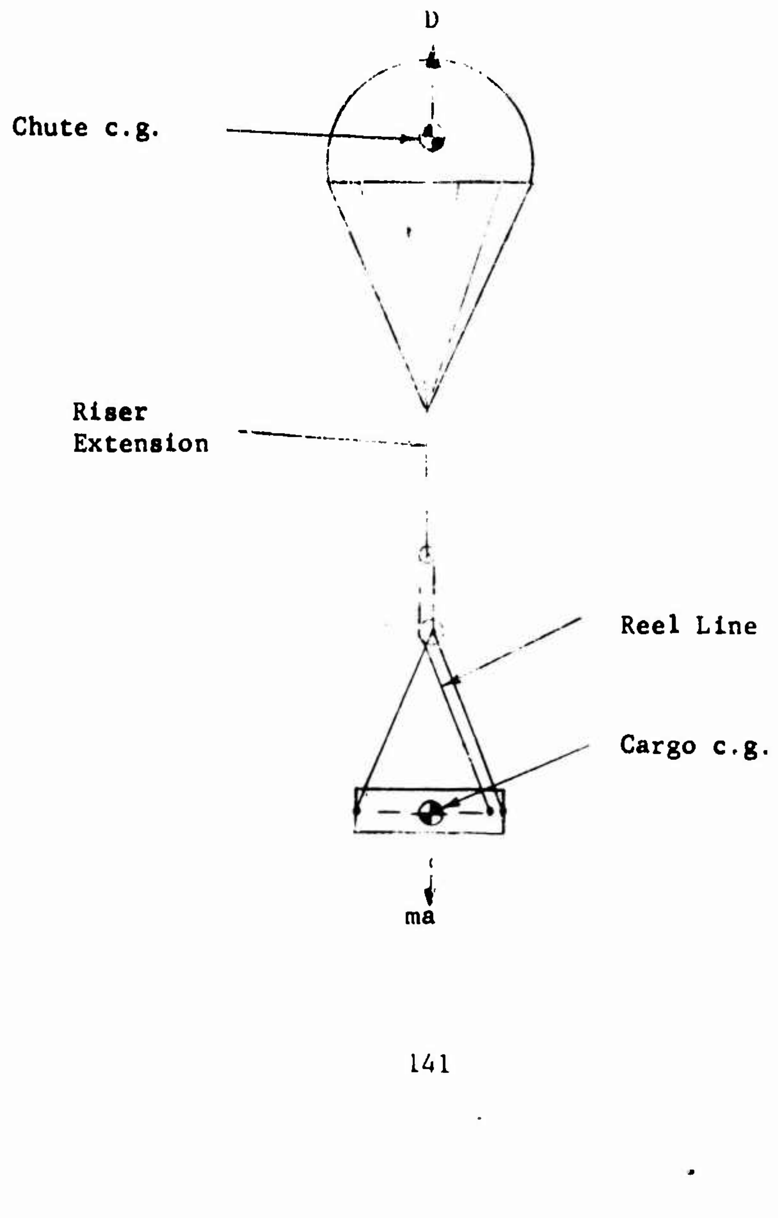
Accumulator, Pressure Switch, Check Valve

It is felt that no problem of selecting these components from available stock would exist, including the accessory components.

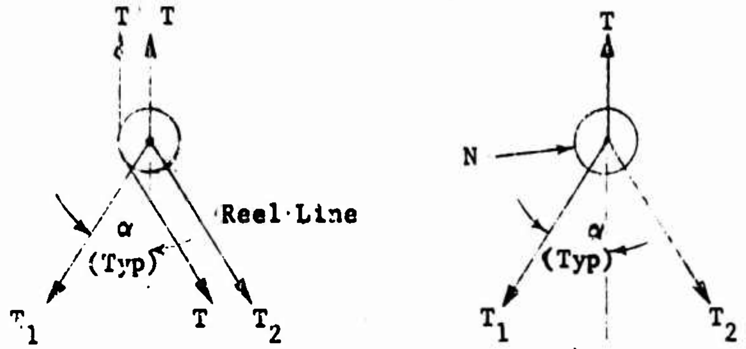
d. Cargo Suspension System Geometry

Due to the unconventional mode of cargo suspension rigging employed in the proposed reel-in drop system, it is necessary to investigate the stability of the cargo during the descent. In particular, if the cargo suspension lines which are parallel to the reel line go slack, there could be a tendency for the cargo to tip over and impact upside-down or at some adverse angle. Scale model reel systems have been constructed by the AAI staff and, based on preliminary tests, the aforementioned tipping characteristic actually occurred under certain test conditions. The following discussion will attempt to show why tipping occurs and how the problem may be overcome or effectively reduced. It should be noted that this analysis does not attempt to provide conclusive evidence as to why this characteristic is present, instead it is presented to provide analytical support for the tests performed with the scale models.

First, consider a cargo-chute reel system illustrated in the following diagram.



Assuming the system to be in dynamic equilibrium, the following free body diagram may be drawn at the cargo suspension line confluence point.



where: T = 1/2 of the tension in the riser extension

N = the normal force created by the reel line on the pulley

T_1 = the tension in one pair (2) of the cargo suspension lines

T_2 = the tension in the pair of cargo suspension lines parallel to the reel line

α = the angle between the riser extensions and the cargo suspension and reel lines.

After solving for N in terms of T, there are only two unknowns, T_1 and T_2 which may be found by summing forces. This calculation yields:

$$T_1 = T/\cos\alpha \text{ , and} \tag{1}$$

$$T_2 = T(1/\cos\alpha - 1) \tag{2}$$

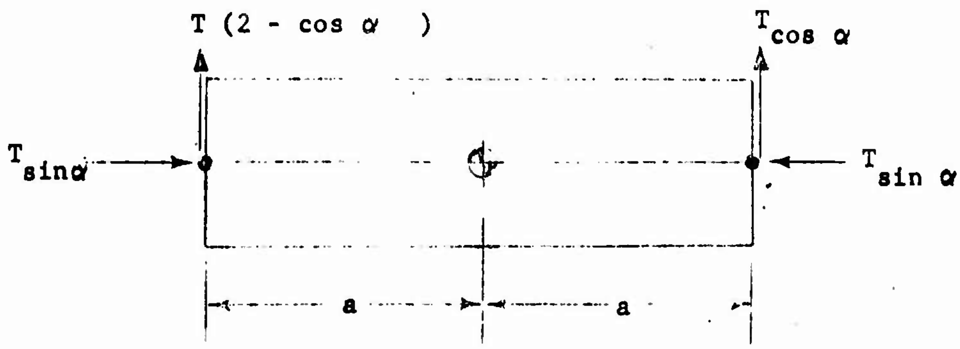
Now, suppose that for some reason the suspension lines parallel to the reel line go slack. At the very instant this happens there is no appreciable change in the suspension geometry, hence the line tensions may be calculated just as before giving:

$$T_{1_H} = T \sin\alpha \tag{3}$$

$$T_{1_V} = T\,(2 - \cos\alpha) \quad \text{and} \tag{4}$$

$$T_2 = 0$$

where the subscripts H and V refer to the horizontal and vertical components of T_1 respectively. Further, the tension in the reel line does not change and is equal to T. Referring to the following diagram and summing moments about the cargo C.G., we have:

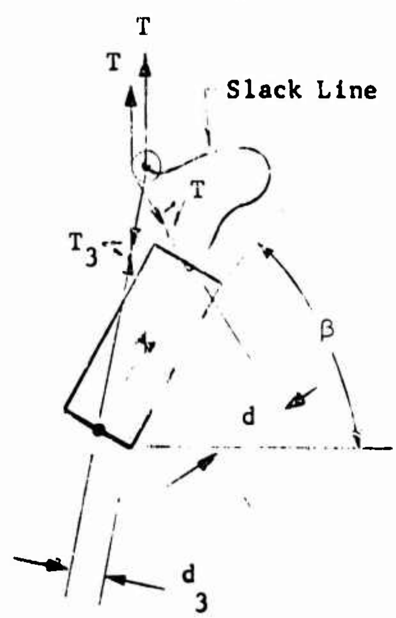


$$\Sigma M^{\curvearrowright +}_{C.G.} = T(2 - \cos\alpha) \cdot a - T\cos\alpha \cdot a$$

$$\text{or} \quad M = 2\,Ta\,(1 - \cos\alpha) \qquad (5)$$

Since α is acute, this moment is always positive and referring to the diagram, clockwise. Therefore, for very small angles of cargo rotation resulting in $T_2 = 0$ there is a moment about the cargo C.G. which tends to restore the cargo to dynamic equilibrium. This is by no means any startling discovery, but it should be evident that this restoring moment is less than that produced by present day suspension systems since there is no reel line to create a counterclockwise torque with the conventional suspension system. Further, an examination of equation 5 reveals the fact that as α approaches zero, M, the restoring torque, becomes small.

Next, suppose that the cargo happens to rotate through some very large acute angle, β, during the reel-in event. The following exaggerated diagram illustrates what effect this phenomenon could possibly have on the geometry of the system.



Where:

T_3 = some new tension in the cargo suspension lines

d and d_3 = moment arms to T and T_3, respectively

Notice that the moment arm of the torque $T_3 d_3$ has decreased considerably from its value when the system was in equilibrium, while the moment arm of the torque $T d$ changes very little. It is assumed without proof that as β increases from zero, the moment of Td approaches $T_n d_n$. Then, there is some angle, β', where $T_n d_n$ = Td where there is no resultant moment about the cargo c.g. Further if β > β' the resultant torque will be counter-clockwise and the cargo will tip over. To prevent this situation, it is suggested that the angle, α, in equation 5 be made as large as possible to create a greater restoring moment, M.

The above analysis has been simplified to say the least, since angular accelerations have been neglected. Actually, the inertial torque effects decrease the restoring moment, M, which in turn, tend to decrease the value of β' for a given geometry.

Once again, it should be noted that the above is merely analytical support of experimental evidence obtained from scale model reel system tests. Although not entirely conclusive, the tests seemd to indicate that values of α greater than 45^o would prohibit unrestored tipping. Now that a reasonable suspension geometry has been established, it is of interest to note what effect the suggested configuration has upon the cargo suspension fittings. Since T_1 will be greater when the lines parallel to the reel line go slack, the related reaction at the suspension fittings will be greater. Hence, for a 3-g force on the system, the tension components in the two non-slack cargo suspension lines will be given by equations 3 and 4.

Then, letting:

$\alpha = 45^{o}$

Cargo Weight = 10,000 lbs.

T_{1_V} = 15,000 lbs $(2 - \cos 45^{o})$

= 19,400 lbs

T_{1_H} = 15,000 lbs $(\sin 45^{o})$

= 10,600 lbs.

then,

$$T_1 = \sqrt{T_{1_V}{}^2 + T_{1_H}{}^2}$$

$\therefore$ = 22,100 lbs

Since this is the tension in both lines, the tension in one line will be 11,050 lbs. which is well within the 1-1/2 - g limitation specified in this contract. This value is somewhat conservative since the actual angle the suspension lines make with the vertical is somewhat larger than 45^{o} when one considers the system from a three-dimensional point of view. Hence, 11,050 is a low value but a three-dimensional analysis would not tend to increase this tension significantly.

e. Power Plants

Gas Turbines

Additional information has been obtained about this type of engine. Representatives of "Solar" gas turbines have provided to following items of interest to this program:

(1) Stalling Criteria (All Models)

Overload up to 15% for 1 to 10 seconds duration is an allowable and normal design critieria for these engines.

(2) Output R.P.M. Reduction Limits

Reductions to the 300 R.P.M. region have been made successfully. If weight is of great concern, belt drive reduction is recommended over use of gearing.

(3) Fuel Supply System

5 psi fuel pump pressure is recommended; this is no problem for the thicker fuels but, thin fuels such as gasoline could have vapor pressure problems that must be solved.

(4) Starting with 28 V.D.C. Voltage Supplied by the Aircraft

This can be done; the voltage is standard practice on their starters but, inital current requirements are very high as a result of low resistance in the starting system for gas turbines. The current requirements for a specific turbine would have to be checked against the available supply in specific aircraft. An addition to the aircraft supply may be necessary.

(5) Effects of Inertial Forces on a Running Turbine

The units are qualified for 100 g, 15 milisecond shock loading but, extended "g" forces, even of low order, may upset the efficiency of the lubricating oil-sump system. No effects on other performance aspects are expected.

(6) Thrust Effects from the Exhaust

Negligible; can be modified easily to "none".

(7) Extended Price Projection

95% learning curve is applicable but, stated price ranges are based on current production rates of 30 to 65 units per month. The nearest price reduction objective is 20% on all units; improved fabrication techniques at no loss in quality are being sought. A large expansion program to increase production is in the planning stage; this facility will cover 90 acres. No additional data available about that at this time.

Aircraft Engines

Some effort has been made to reconsider the use of aircraft engines as candidate reel power plants. This has been stimulated by the unappealing costs of gas turbines. An investigation of two helicopter engine systems that approach favorable consideration resulted in the following comparison of critical evaluation characteristics.

Type	Gas Turbines (Including Accessories)		Aircraft Engines (Helicopter Sys. Incl. Acces.)	
Mf'r.	Solar	Solar	Franklin	Wright
Model No.	T220 Series	T1000 Series	6VS 335 A	R 1820 series 9
Rated Power	200 H.P.	1070 H.P.	240 H.P.	1200 H.P.
Output R.P.M.	6000	1200	3200	2000
RPM Reduction Required	(400 RPM Reel) 15:1	(270 RPM Reel) 4.44:1	(400 RPM Reel) 8:1	(270 RPM Reel) 7.4:1
Envelope	$7.4ft^3$ 19x24x28 inches	$53.5ft^3$ 40x30x77 inches	$28.9ft^3$ 40x32x39 inches	$57.8ft^3$ 55 in. dia. x 42 in. long
Weight	154 lbs(avg)	1500 lbs(avg)	400 lbs	2000 lbs
Cost	$13,500(avg)	$50,000	$4000	$15,000

The cost advantages of the compared helicopter engine systems above appear to be reduced only slightly from a weight and envelope criteria.

In evaluating this alternate power plant system, certain performance features were investigated which would affect their acceptance as reel-system candidates. The performance history is broad on both engines. Other engine sizes are available but, knowledge of their background cannot be presented at this time.

The 240 H.P., 6VS335A is currently used on an in-service helicopter; this basic "Franklin" engine is also currently used on six other airborne applications. The "Wright" R1820 Series 9, 1200 H.P. engine is also used on a current helicopter. Many "versions" of this engine (accessory, power, and aircraft variations) have been used dating back to its original application on the B17 bomber aircraft of World War II.

The comparison table values are based on these engines with subsystems including items such as starter, generator, lubrication components and, most importantly, a self contained, air cooling system.

Previous evaluation of aircraft engines as candidates encountered some deficiency from a cooling criteria. The relatively non cooling conditions of the reel-in drop system posed what was thought of as a serious modification or addition to conventional aircraft engines. The increased bulk and weight deterred further investigation at that time. The air cooling system incorporated on the helicopter applications of these power plants present a compact accessory added to the engine system.

If application of the helicopter power plants to reel-in mechanisms is considered seriously, the reel-control system would remain unchanged. A thirty-second warm up period prior to drop would also remain good practice.

Some drawback features result when comparing the helicopter engines to gas turbines that should be mentioned. The overall rigged cargo system will be slightly longer due to the increase in power plant envelope; however, length additions of approximately one to two feet are not expected to seriously limit the use. The 240 H.P. engine listed is used with the crankshaft in the vertical position in its helicopter application. The lubrication system is designed to perform accordingly; horizontal models of this engine are used in conventional aircraft but, the self contained air cooling system is not incorporated on them. This would be a custom modification requirement for the reel-in system application but, no serious problems in doing this are expected. The production price would be expected to remain the same based on some authoritive information.

Considering the previous discussion of evaluating the helicopter power plants or candidates for the reel-in system, there seems to be sufficient reason to include them in the total reel-system evaluation charts in the next section.

3. Summary of Candidate Reel Systems

The following tables presents data applicable to the various topics of evaluation for the three basic powered reel-in systems that have been discussed in this section. Table VIII illustrates the characteristics of the gas turbine reel-in system; Tables IX and X illustrate the same data for the aircraft engine and spiral actuator power systems respectively. It is to be noted that each table is divided into two parts; one for a 200 H.P. system, and one for a 1000 H.P. system, in order to generate a range of data that applies for a fairly wide range of cargo items. The development costs, given in terms of hours in these tables, and the dollars spent in fabricating the particular unit under consideration are provided with realistic tolerance ranges so that these estimated figures will be of more value in the system evaluation program.

In Tables VIII, IX, and X, the identifying characteristic of each component of the reel system is provided; for example, with respect to the transmission unit, it is identified either as a speed reducing or a speed increasing unit in terms of the listed ratio. The control system in most cases is a combination of cartridge actuated devices (CAD) and hydraulic units. The dimensions, volume displacements, and weights given in these tables represent data supplied by the unit manufacturers or, in the case of the spiral actuator unit which is undeveloped, these parameters are best estimates.

The Estimated System Development Costs provided in the series of charts comprising Table XI have been developed from the data displayed in Tables VIII, IX and X. The "Hi" and "Low" costs illustrated in Table XI are obtained by adding the appropriate tolerance to the basic item in the "Hi" figure; the tolerance is subtracted from the basic item to provide the "Low" figure. The estimated total system costs provided in Table XI are obtained by combining all of the "Hi" and "Low" dollar sums given in the last column of this table.

Subsystem Component	Identifying Character-istics	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	(F) Dev. Costs (hrs x 10^{-3})	(G) Mfg. Costs ($)
Power Plant System	200 HP T-220	19x24x28	7.40	154	1-5	13500
Supporting Frame	pallet mounted			40	.5-1	200
Transmission	15:1 Red.	19 dia x 6	.99	80	.5-1	500
Clutch	2500 ft lb	9 dia x 10	.37	78	.5-1	150
Control System	CAD-Hyd			15	.5-1	450
Reel Drum Assem.	80' wrap	12 dia x 5	.33	34	.2-.4	340
Reel-In Strap	11000 lb max			30	.2-.4	100
Upper Sheave Group				20	.2-.4	100
Lower Sheave Group				30	.2-.4	150
TOTAL % TOLERANCE		19x25x49	9.09	481 ±10%	3.8-10.6 +100%	15490 ± 20%

TABLE VIII CONCEPT REEL SYSTEM EVALUATION DATA
200 H.P. Gas Turbine Reel-In System

Subsystem Component	Identifying Character-istics	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	(L) Dev. Costs (hrs $x10^{-3}$)	(M) Mfg. Costs ($)
Power Plant System	1070 HP T-1000	35 Dia x77	42.8	1500	2-10	50000
Supporting Frame	Cargo Mounted			300	1-2	1500
Transmission	4.4:1 Red.	20x40x10	4.63	200	1-2	2000
Clutch	12000 ft lb	12 Dia x5	.98	250	1-2	350
Control System	CAD-Hyd			15	1-2	450
Reel Drum Assem.	160' wrap	22 Dia x9	1.97	50	.5-1	500
Reel-In Strap	40000 lbmax			100	.5-1	333
Upper Sheave Group				30	.5-1	150
Lower Sheave Group				40	.5-1	200
TOTAL % TOLERANCE		45x64x87	50.38	2485 ± 10%	8-22 +100%	55483 ± 20%

TABLE VIII CONCEPT REEL SYSTEM EVALUATION DATA
1000 H.P. Gas Turbine Reel-In System

Subsystem Component	Identifying Characteristics	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	(F) Dev. Costs (hrs x 10^{-3})	(G) Mfg. Costs ($)
Power Plant System	240 HP 6V5335A	40x32x39	28.9	400	Same as 200 H.P. Turbine	4000
Supporting Frame	pallet mounted			60		300
Transmission	8:1 Red.	15 Dia x6	1.06	70		500
Clutch	2500 ft lb	9 Dia x10	.37	78		150
Control System	CAD-Hyd			15		450
Reel Drum Assem.	80' wrap	12 Dia x5	.33	34		340
Reel-In Strap	11000 lb max			30		100
Upper Sheave Group				20		100
Lower Sheave Group				30		150
TOTAL % TOLERANCE		40x32x55	30.66	737 ±10%		6090 ± 20%

TABLE IX CONCEPT REEL SYSTEM EVALUATION DATA
200 H.P. Aircraft Engine Reel-In System

Subsystem Component	Identifying Character-istics	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	(L) Dev. Costs (hrs x 10^{-3})	(M) Mfg. Costs ($)
Power Plant System	1200 HP R 1820	55 Dia x42	57.8	2000	Same as 1000 H. P. Turbine	15000
Supporting Frame	cargo mounted			400		2000
Transmission	7.4:1 Red.	25x40x12	6.95	300		2500
Clutch	12000 ft lb	12 Dia x15	.98	250		350
Control System	CAD-Hyd			15		450
Reel Drum Assem.	160' wrap	22 Dia x 9	1.97	50		500
Reel-In Strap	40000 lb max			100		333
Upper Sheave Group				30		150
Lower Sheave Group				40		200
TOTAL % TOLERANCE			67.70	3185 ± 10%		21483 ± 20%

TABLE IX CONCEPT REEL SYSTEM EVALUATION DATA
1000 HP Aircraft Engine Reel-In System

Subsystem Component	Identifying Character-istics	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	(F) Dev. Costs (hrs x 10^{-3})	(G) Mfg. Costs ($)
Power Plant System	300 HP	23 Dia x5	1.20	100	5-10	1000
Supporting Frame	pallet mounted			40	.5-1	200
Transmission	1:8 Increase	15 Dia x10	1.02	100	2-4	1000
Clutch	Lock-Up Pawl Only			25	.3-.6	100
Control System	CAD			10	.5-1	300
Reel Drum Assem.	80' wrap	12 Dia x7	.46	34	.2-.4	340
Reel-In Strap	11000 lbmax			30	.2-.4	100
Upper Sheave Group				20	.2-.4	100
Lower Sheave Group				30	.2-.4	100
TOTAL % TOLERANCE			2.68	389 ±10%	9.1-18.2 +100%	3290 ± 20%

TABLE X CONCEPT REEL SYSTEM EVALUATION DATA
200 H.P. Spiral Actuator Reel-In System

Subsystem Component	Identifying Character-istic	Dimensions (inches)	Displacement (ft^3)	Weight (lb)	Dev.Costs (hrs x 10^{-3})	Mfg.Costs ($)
Power Plant System	1500 HP	48 Dia x8	8.40	500	10-20	5000
Supporting Frame	cargo mounted			300	1-2	1500
Transmission	1:8 Increase	30 Dia x20	4.10	500	4-8	3500
Clutch	Lock-Up Pawl Only			75	.6-1.2	350
Control System	CAD			10	1-2	300
Reel Drum Assem.	160' wrap	22 Dia x11	2.41	50	.5-1	500
Reel-In Strap	40000 lb max			100	.5-1	333
Upper Sheave Group				30	.5-1	150
Lower Sheave Group				40	.5-1	200
TOTAL % TOLERANCE			14.91	1605 ±10%	18.6-37.2 +100%	11833 ± 20%

TABLE X CONCEPT REEL SYSTEM EVALUATION DATA
1000 H.P. Spiral Actuator Reel-In System

Item	Program Type	No. Tests	Cost Range	R & D		Prototype		Field Tests			$ Sum
								Proto	Pilot	Field	
		N		F x $10	L x $10	G x 2	M x 2	Nor 2N	As Shown	N or 2N	
200 H.P. Turbine	Feasibility .90 Rel. .50 Conf.	7	Hi	76		37.2		14	2G 37.2	14	179.0
			Low	38		24.8		7	2G 24.8	7	101.6
	In Service .995 Rel. .50 Conf.	139	Hi	212					10G 186	139	537.0
			Low	106					10G 124	139	369.0
1000 H.P. Turbine	Feasibility .90 Rel. .50 Conf.	7	Hi		160		133	14	M 66.5	14	387.5
			Low		80		88.7	7	M 44.4	7	227.1
	In Service .995 Rel. .50 Conf.	139	Hi		440				4M 266.0	139	845.0
			Low		220				4M 177.6	139	536.4

Estimated Total System Costs — Hi - $1,943.5; Low - $1,234.1

TABLE XI - ESTIMATED SYSTEM DEVELOPMENT COSTS ($ x 10^{-3})
Gas Turbine Reel-In System

Item	Program Type	No. Tests	Cost Range	R & D		Prototype		Field Tests			$ Sum
								Proto	Pilot	Field	
		N		F x $10	L x $10	G x 2	M x 2	N or 2N	As Shown	N or 2N	
200 H.P. A/C Engine	Feasibility .90 Rel. .50 Conf.	7	Hi	76		14.6		14	4G 29.2	14	147.8
			Low	38		9.8		7	4G 19.6	7	81.4
	In Service .995 Rel. .50 Conf.	139	Hi	212					20G 146.0	139	497.0
			Low	106					20G 98.0	139	343.0
1000 H.P. A/C Engine	Feasibility .90 Rel. .50 Conf.	7	Hi		160		51.6	14	2M 51.6	14	291.2
			Low		80		34.4	7	2M 34.4	7	162.8
	In Service .995 Rel. .50 Conf.	139	Hi		440				8M 206.4	139	785.4
			Low		220				8M 137.6	139	496.6

Estimated Total System Costs

Hi - $1,721.4

Low - $1,083.8

TABLE XI - ESTIMATED SYSTEM DEVELOPMENT COSTS ($ x 10^{-3})
Aircraft Engine Reel-In System

Item	Program Type	No. Tests	Cost Range	R & D		Prototype		Field Tests			$ Sum
								Proto	Pilot	Field	
		N		F x $10	L x $10	G x 2	M x 2	N or2N	As Shown	N or2N	
200 H.P. Spiral Actuator	Feasibility .90 Rel. .50 Conf.	7	Hi	182		7.9		14	6G 23.7	14	241.6
			Low	91		5.3		7	6G 15.9	7	126.2
	In Service .995 Rel. .50 Conf.	139	Hi	292					30G 118.5	139	549.5
			Low	146					30G 79.0	139	364.0
1000 H.P. Spiral Actuator	Feasibility .90 Rel. .50 Conf.	7	Hi		372		28.4	14	4M 56.8	14	435.2
			Low		186		13.0	7	4M 38.0	7	257.0
	In Service .995 Rel. .50 Conf.	139	Hi		744				20M 284.0	139	1167.0
			Low		372				20M 190.0	139	701.0

Estimated Total System Costs   Hi - $2,443.3   Low - $1,448.2

TABLE XI - ESTIMATED SYSTEM DEVELOPMENT COSTS ($ x 10^{-3})
Spiral Actuator Reel-In System

4. Recommendations

The following recommendations are referenced specifically to the topics that have been discussed in this section. These recommendations are intended to aid in the formulation and definition of a future development program of the powered parachute reel-in system, and, as such, are suggestions that could be incorporated in the detailed study phases of the development program.

a. The dynamic stability of the cargo pallet during the reel-in event should be evaluated both from an analytical viewpoint, similar to that presented in Part 2.d. of this section, and from an experimental approach using a "breadboard" reel-in system.

b. If development of the spiral actuator power system appears warranted, there are several areas of investigation that must be completed before a workable system of this type can be effected:

(1) An evaluation of the stress levels in the expandable "bourdon" tube must be conducted in order to arrive at a feasible tube design.

(2) The gas generator component must be defined in terms sufficient to provide power for the full duration of the reel-in event and still not generate an impulse level sufficient to rupture the expandable tube.

(3) The efficiency of transmitting torque from the expanding spiral tube to the crank-follower must be identified.

c. The basis for the cost estimate figures, for the various power generation systems presented in this section, should be carefully reviewed and verified. In particular, realistic time frame development schedules for the entire reel-in component should be established. In addition, the logistical problems associated with recovery of these systems after an airdrop event should be defined and evaluated.

IV. SYSTEM EVALUATION PARAMETERS

A. Introduction

The majority of information presented in this section is designed to satisfy the requests of the TIE Contractor listed in reference 1. It is emphasized that these evaluation parameters are not available for all of the cargo items listed in Table III of Section III. B. 1 of this report. Most of the parametric variation of these data have been prepared for cargo item 5 (8409 lb.). Fortunately, the variation in the magnitudes of the evaluation parameters has been found to be small for the parachute reel system of interest in this report. Furthermore, there is no reason to suspect that the magnitudes of these variations would be an order of magnitude different for any of the other cargos evaluated in this study. Hence, the unavailability of these parameters in some cases is not a serious defect in the system results presented in this section.

Part B of this section is arranged to provide the data and evaluation parameters discussed in the TIE Contractor's report[1], although other items of interest that are required by the Contract Statement of Work have been included in Part B also. This has been done since much of the information requested by the TIE Contractor compliments, or dovetails with the items listed in the Contract Statement of Work.

Part C of this section provides a comprehensive discussion of the mechanical and human-operational reliability aspects of the overall system that incorporates the parachute reel-in event. It is to be recognized that the mechanical reliability characteristics of the system are estimates at best, since there is little, if any, accumulated background reliability data for general mechanical devices as there is for typical electronic components.

Part D of this section provides data on other parameters listed in the TIE Contractors Report[1] and the Contract Statement of Work. Included in this section are discussions of the effects of variation in environmental conditions, sensitivity and flexibility, signature, and CEP characteristics.

The last part of this section, Part E, provides a listing of the cost estimates of the airdrop gear required for each load item listed in Table III of the TIE Contractors Report[1]. Where necessary, modifications to the standard set of items are indicated in these lists, together with an estimated cost of such modifications.

B. Evaluation Parameters

The following series of tables present the magnitudes of the various parameters requested in the TIE Contractors report[1]. It is to be noted that these tables present data for the various items of cargo as functions of the initial location of the center of gravity of the cargo in the aircraft, denoted by CG_o*, the aircraft velocity, denoted by $V_{A/C}$, and the reel-in rate, if used, in the particular run under consideration. The following nomenclature list defines the remaining quantities appearing in this table.

t_e - time interval between initiation of cargo motion and the end of the extraction phase. The end of the extraction phase occurs when the reaction between the cargo and the aircraft floor reaches the edge of the extraction ramp**.

t_t - time interval between initiation of cargo motion and the end of the tip-off event. The tip-off event is concluded when the cargo-aircraft floor reaction force becomes zero**.

t_i - time interval between initiation of motion of the cargo and touch-down (impact) of the cargo after a 500' descent.

F_e - maximum extraction force (in g units) experienced by the cargo during the extraction event.

F_r - maximum retardation force (in g units) exerted on the cargo during the descent phase of the cargo trajectory.

* These magnitudes are referenced to the forward end of the C-130B cargo compartment, which is aircraft fuselage station 20.4'.

** See Patterson and Foster[8] for a comprehensive discussion of the extraction tip-off, and subsequent descent phases of the cargo.

$V_{V_{500}}$ - vertical component of cargo velocity at ground impact after a descent of exactly 500 feet*.

V_{h500} - horizontal component of cargo velocity at ground impact after a descent of exactly 500 feet*.

$\overline{\mathcal{P}}_{500}$ - angle between a line normal to the cargo platform and the vertical, after a descent of 500 feet.

It is to be noted that the only factors that affect the magnitudes of the time parameters are the aircraft speed and the initial location of the cargo in the aircraft cargo compartment. Although these effects are available for cargo item 5 only, the time variations due to changes in aircraft speed and initial cargo location for the other cargo items are expected to be similar. These variations are illustrated in the following listing for a 5 fps reel-in system applied to cargo item 5. (see p. 165).

* These magnitudes correspond to a descent of exactly 500 feet, and are to be contrasted to the velocity component data provided in Table V, Section III.B. 2, which have been previously defined in a somewhat different manner.

AAI Corporation

EVALUATION PARAMETERS

ITEM NO.	RUN NO.	CG_o (ft)	$V_{A/C}$ (fps)	REEL RATE (fps)	t_e (sec)	t_t (sec)	t_i (sec)	F_e (g)	F_r (g)	V_v 500' (fps)	V_h 500' (fps)	Φ 500' (o)
1	5.0070	-23.35	220	0	1.14	1.22	18.02	1.50	2.70	24.0	2.9	20.2
1	5.0081	-23.35	220	5	1.14	1.22	19.51	1.50	2.70	21.7	17.6	18.3
2	5.0108	-23.35	220	0	1.15	1.28	16.57	1.45	2.51	21.4	12.5	17.7
2	5.0109	-23.35	220	5	1.15	1.28	18.08	1.45	2.51	26.8	12.1	8.0
2	5.0110	-23.35	220	10	1.15	1.28	18.08	1.45	2.51	26.4	14.0	5.2
3	5.0071	-23.35	220	0	1.17	1.26	17.26	1.39	2.62	22.7	5.5	20.2
3	5.0112	-23.35	220	5	1.17	1.26	18.74	1.39	2.62	24.6	16.1	1.2
3	5.0113	-23.35	220	10	1.17	1.26	18.75	1.39	2.62	23.7	16.4	1.7
5	5.0091	-23.35	220	0	1.15	1.32	15.52	1.41	2.65	22.8	20.2	14.9
5	5.0092	-23.35	220	5	1.15	1.32	17.02	1.41	2.65	28.8	6.2	13.4
5	5.0093	-23.35	220	10	1.15	1.32	17.02	1.41	2.65	29.1	9.0	11.0
5	5.0100	- 9.90	220	5	1.46	1.61	17.50	1.31	2.54	29.3	6.9	16.0
5	5.0099	-31.25	220	5	.95	1.15	16.90	1.43	2.79	28.8	7.2	12.0
5	5.0104	-23.35	203	5	1.15	1.32	17.02	1.43	2.28	28.8	6.6	13.2
5	5.0105	-23.35	237	5	1.15	1.32	17.02	1.37	2.80	28.7	5.7	17.4
6	5.0073	-23.35	220	0	1.14	1.39	14.19	1.42	2.54	35.0	33.9	7.4
6	5.0114	-23.35	220	5	1.14	1.39	15.29	1.44	2.56	23.3	28.1	13.8
6	5.0117	-23.35	220	5	1.14	1.39	16.69	1.42	2.54	25.4	8.4	23.8
7	5.0074	-23.35	220	0	1.15	1.36	13.96	1.41	2.60	40.0	32.9	15.0
7	5.0089	-23.35	220	5	1.15	1.36	14.86	1.41	2.57	27.7	37.3	5.2

TABLE XII EVALUATION PARAMETERS

EVALUATION PARAMETERS

ITEM NO.	RUN NO.	CG_o (ft)	$V_{A/C}$ (fps)	REEL RATE (fps)	t_e (sec)	t_t (sec)	t_i (sec)	F_e (g)	F_r (g)	V_v 500' (fps)	V_h 500' (fps)	Φ 500' (o)
7	5.0102	-23.35	220	7.5	1.16	1.38	17.30	1.41	2.62	30.0	1.6	24.1
8	5.0075	-23.35	220	0	1.12	1.37	13.57	1.42	2.46	43.9	25.5	24.0
8	5.0083	-23.35	220	5	1.12	1.37	14.27	1.42	2.54	39.7	38.7	8.5
8	5.0086	-23.35	220	10	1.12	1.37	14.07	1.42	2.54	36.8	38.8	6.1
8	5.0090	-23.35	220	5	1.12	1.37	14.87	1.42	2.51	28.0	40.8	4.6
8	5.0103	-23.35	220	10	1.12	1.37	17.70	1.41	2.48	33.6	8.7	20.3
8	5.0107	-23.35	220	7.5	1.12	1.37	16.57	1.43	2.47	22.7	15.9	28.1

TABLE XII EVALUATION PARAMETERS (cont'd.)

Run No.	CG_o (ft)	$V_{A/C}$ (fps)	t_e (sec)	t_t (sec)	t_i (sec)
5.0092	-23.35	200	1.15	1.32	17.02
5.0100	- 9.90	200	1.46	1.61	17.50
5.0099	-31.25	200	.95	1.15	16.90
5.0104	-23.35	203	1.15	1.32	17.02
5.0105	-23.35	237	1.15	1.32	17.02

It is seen that a 7% (approximately) variation in aircraft speed has no effect on these time parameters. Moreover, the variation in location of the cargo in the aircraft does not generate a very significant difference in these times as shown in the next listing, which illustrates changes in the time parameters as functions of change in cargo location:

ΔCG_o (ft)	Δt_e (sec)	Δt_t (sec)	Δt_i (sec)
+13.45	+.31	+.29	+.48
- 7.90	-.20	-.17	-.12

Thus, for cargo item 5, the minimum, maximum, and expected values for these times can be found to be:

	Minimum	Maximum	Expected
t_e(sec)	.95	1.46	1.15
t_t(sec)	1.15	1.61	1.32
t_i(sec)	16.90	17.50	17.02

Similar variations in these time parameters can be expected for the other items of cargo listed in Table III, Section III. B. 1 of this report. The magnitudes of these time parameters listed in Table XII of this section are the "expected" values for each of these times.

It is to be noted that the maximum extraction and maximum retardation f ces experienced by the cargo items are all less than the allowable 1.5 g extraction force and 3.0 g retardation force. Since the forces achieved during the extraction phase are directly a function of the diameters of the parachutes during the disreefing events, a small discrepancy in reading the curves for the drag factor of a reefed parachute from the data of ASD-TR-61-579[5] will result in extraction forces that either exceed or are less than the allowable 1.5 g limitation. During this program of studies, an attempt was made to assure that the computed extraction forces would be less than, or equal to this limitation, in order to introduce an element of conservatism into the analyses. That is, the performance of the system as illustrated in this report could be improved somewhat in an actual airdrop; however, the analyses of this report still provide a very reasonable estimate of the operation of an actual system.

The magnitudes of the maximum retardation force illustrated in Table XII are less than the allowable maximum of 3 g since there is no way apriori to assure that the combined effects of cargo-parachute aerodynamic deceleration and reel induced deceleration load will be equal to exactly 3 g's. Actually, a second iteration of the descent phase characteristics of the system should be conducted, using the retardation force level given in Table XII as first approximations, in order to better approach the 3 g limitation. However, the operation of the system based on the listed magnitudes of these forces is somewhat conservative; i.e., an actual system could be made to exceed somewhat the operational characteristics of the systems illustrated in this report.

As noted previously in Section III.B.2.a of this report, the AAI staff recommends that a powered reel-in system be applied to cargo items 4, 5, 6, 7, and 8, as listed in Table III of Section III.B.1*. A powered reel system would be applied to cargo items 1, 2, and 3 only if a relatively small magnitude of impact attitude angle is desirable. Hence, the results for no reel systems for items 1, 2, and 3, and the results for the other cargo items, as tabulated in the following list in terms of V_{V500}, V_{h500}, and Φ_{500} applicable to the system evaluation are presented.

* Item 4, although not examined in detail in this report, is very close in weight to cargo item 5. Hence, a powered reel-in system would be required to achieve acceptable impact characteristics with this item.

TABLE XIII

IMPACT VELOCITIES AND ANGLES

Item	Run	V_{V500} (fps)	V_{h500} (fps)	Φ_{500} (o)	Reel Rate (fps)	Cargo Wt. (lbs.)
1	5.0070	24.0	2.9	20.2	0	3200
2	5.0108	21.4	12.5	17.7	0	3980
3	5.0071	22.7	5.5	20.2	0	6560
5	5.0092	28.8	6.2	13.4	5	8409
6	5.0117	25.4	8.4	23.8	5	16864
7	5.0102	30.0	1.6	24.1	7.5	20650
8	5.0107	22.7	15.9	28.1	7.5	32550

From this listing, the maximum and minimum values for the tabulated parameters are:

	Maximum	Minimum
V_{V500} (fps)	30.0	21.4
V_{h500} (fps)	15.9	1.6
Φ_{500} (o)	28.1	13.4

The following list defines the number of C-130 aircraft required to airdrop the various cargo mixtures identified as items 9, 10, and 11, in Table II, p. 9, of the TIE Contractor's report[1].

Mixture Item	No. C-130 Aircraft Required (NA (I))
9	3
10	7
11	59

There is no constraint imposed on formation flying of these numbers of aircraft due to the use of a powered reel-in system on the various cargo pallets other than those normally exercised in a standard airdrop system.

The next table illustrates the cargo items dropped from each aircraft for each of the mixture items 9, 10, and 11. The values of exp CT* illustrated in this table incorporate a 2.5 second interval between the tip-off event of one cargo and the initiation of motion of the next cargo in the extraction sequence, to account for the time involved in ejection and inflating the small extraction parachute used to deploy the main G11A extraction-recovery parachutes. The magnitudes of F_e, F_r, V_{V500}, V_{h500}, and $\bar{\Phi}_{500}$ for each of the cargo items can be found in Table XII of this section. It is to be recognized that the cargoes are not all at the same aircraft station in Table XII. Hence, there will be some variation in the forces, velocities, and impact attitude angle as a function of initial location of the cargo in the aircraft. Such variations can be seen for item 5 in Table XIII, by comparing Runs 5.0092, 5.0100 and 5.0099.

The reel-in system presented in this report does not introduce any constraints which would interfere with the presently used mode of operation for cargo-personnel airdrop missions. Moreover, all of these parachute reel systems, although sized to a particular cargo (or range of cargo weights) are compatible with the various aircraft specified in the contract Statement of Work (See Part C, Section II). There is nothing in the parachute reel-in system that would be incompatible with these aircraft, other than the size-weight envelope of the basic cargo. Moreover, the parachute reel-in systems do not have any unique characteristics that would jeopardize flight safety in any phase of the airdrop mission, other than what could be expected to jeopardize flight safety in any airdrop mission. The response of the C-130 aircraft to the cargo extraction events has been found to be reasonable in that no violent, uncontrollable aircraft oscillations are induced by the extraction of the cargos. It is to be noted, however, that if a cargo item would "hang-up" during the cargo extraction process, it is possible that the configuration center of gravity would violate the permissible center of gravity envelope for the aircraft under consideration. This could result in a flight emergency that would necessitate abandonment of the aircraft by the flight crew. However, this could occur with any system; the parachute reel concept does not have any unique characteristics that make occurrence of such an event more likely.

There are no special procedures that must be followed by the airdrop crew to assure success of the mission, other than a standard set of operations applicable to all airdrop missions. The only unique event with respect to the parachute reel-in system is the starting of the reel power system to assure that the reel-in event will be accomplished. However, if this event fails to occur, the controlled descent of cargo will still take place since the disreefing and inflation events of the recovery parachutes do not depend on the operation of the reel power system. Of course, the impact velocities of the cargo, particularly the larger items of cargo, will be excessive in this case. Consequently, the cargo would no doubt suffer some degree of damage in the case of a power source failure that takes place before the reel-in event

* exp CT is the expected value of the cumulative drop time as defined in Table I, p. 5, of Reference 1.

TABLE XIV

PARAMETRIC DATA FOR MULTIPLE LOADS

Mixture Item	Aircraft Number	Cargo Items	exp CT
9	1	2,2,2	23.99
	2	1,2,1	25.50
	3	3,3	21.00
10	1-4*	5,4	20.65
	5-6	2,2,1	25.50
	7*	1,1,1,1	29.15
11	1-3	8	16.57
	4-5	3,3,2,1	29.37
	6-18	2,5,1	24.59
	19-33	6,1	22.07
	34	5,5	20.51
	35-39	1,7,1	24.54

* Also used in Mixture Item 11.

is accomplished. Failure of the power source after the reel-in event is accomplished is inconsequental, since the system is in a "locked" condition after reel-in.

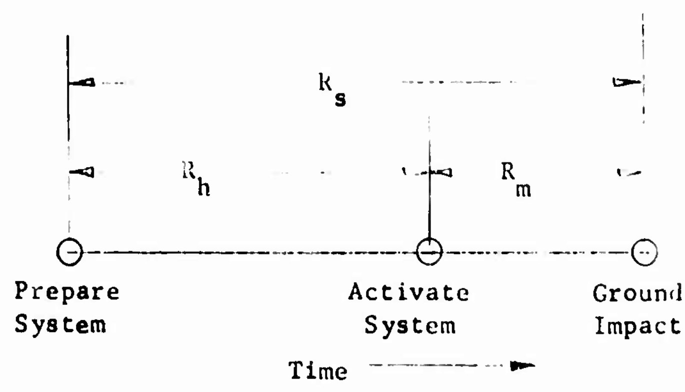
It is to be noted that, in particular, the cargo handling capacity and speed range of a C-141 aircraft are applicable to the cargo descent systems discussed in this report. However, the larger cargo compartment of the C-141 aircraft would probably necessitate that the length of line between the cargo and the recovery parachutes be increased over the magnitudes used in this report, in order to minimize interference effects. This increase in line length would tend to degrade the performance of the system as discussed previously.

C. Reliability Considerations

1. Introduction

The purpose of this section is to describe the results of the reliability analyses that were completed during this program. Reliability, as the term applies to this program, is defined as the probability of successfully completing a cargo airdrop mission under specified conditions. The primary cargo delivery mission of concern was a heavy cargo airdrop with the aircraft at a nominal altitude of 500 feet. However, secondary missions involving drops from higher altitudes, up to 1500 feet, were also considered. Conditional parameters such as aircraft performance, pilot performance, environmental conditions, etc., were considered to be optimum for the purpose of these analyses. Only those equipment or manual parameters directly associated with airdrop operations were considered. Airdrop operations are defined as the series of operations beginning with cargo preparation and terminating when the cargo impacts with the ground.

System reliability (R_s) is a function of two variables, mechanical reliability (R_m) and human reliability (R_h). R_m is defined as the probability that no equipment malfunctions that will degrade mission success will occur during an airdrop operation. R_h is defined as the probability that no human errors that will degrade mission success will occur during an airdrop operation. System reliability, then, may be defined as: $R_s = (R_m)(R_h)$. Although this is a suitable working definition for the purpose of this program, it should be realized that these two variables are not completely independent. For example, inappropriate manual operations, such as overstressing a mechanical component, can increase the probability of equipment failures. In establishing the working definition of system reliability, R_m and R_h were treated as totally independent factors. On a mission time base, we assume that R_m begins affecting an overall system reliability when the pendelum release mechanism is activated. Also, at this point (system activation) the operator is no longer an integral part of the system and R_h is no longer considered a factor of system reliability. In graphic form, this subdivision of system reliability is:



The tenor of the reliability analyses completed during this program was dictated by several issues. One paramount issue was that the absolute value of system reliability is not required by the nature of this program. Rather, the relationship between the R_s for existing airdrop systems and the R_s for the Reel-In Airdrop System studies during this program is required for evaluation purposes. Therefore, the analyses attempted to establish this relative relationship instead of attempting to define the absolute value of R_s. This approach was adopted because numerical failure rate information for many of the components, including the human, involved in the Reel-In Airdrop System operations is not available. However, relative judgments regarding the probability of failure for different components and procedures could be made. These judgements were based on the results of preliminary "rough-cut" analyses in some cases and engineering experience in other cases. It should also be noted that this system is in the concept stage and refinements of these preliminary reliability asessments will be available (and more valid) after equipment definition. The description of the results of the reliability analyses is divided into two principle parts: one part describes the results of the mechanical reliability analyses and the second describes the results of the human reliability analyses. In general, the combined results of these analyses, reflecting R_s, indicate that the Reel-In Airdrop System, performing its primary mission, favorably compares with the R_s of conventional systems performing their primary missions.

2. Mechanical Reliability

As stated in SectionIV.B.1, this portion of reliability evaluation will deal with only those failures directly attributed to mechanical malfunctions. All human dependent operations are considered to have been performed correctly and not contributing to the resultant consequences.

In performing a reliability study on the Reel-In Airdrop System, (RIAS), the fact that there is a lack of applicable failure rate date on system components makes it difficult to assign a numerical value to system reliability. Some failure rate data are available on parachutes and reefing cutters. However, since the conditions and applications in the RIAS are not the same as those specified in this analyses, the use of these data is questionable. The only way to obtain valid failure rate data would be through extensive system tests. The mechanical reliability study will therefore limit itself to a failure mode analysis of the system.

The introduction defined Mechanical Reliability (R_M) as the probability of all mechanical elements performing properly, thus enabling the cargo to be delivered, on the ground, with no damage. The inability of various components to function as required causes various degrees of consequences, ranging from complete loss of aircraft or cargo to minor cargo damage on impact. The proper functioning of some components are dependent upon others performing correctly. The study of system failures must assume that sufficient development and test have been undertaken to assure that any failures which occur are random in nature and not due to improper design or utilization of the components. The consequences of various system component failures will be listed under the following categories:

a. Loss or major damage to aircraft;

b. Loss of load;

c Inability to deliver load;

d. Damage to load to a degree affecting its usefulness in combat or increased probability of such damage (i.e., due to increased rate of descent); and

e. Damage to elements of airdrop system or minor damage to aircraft.

The failure mode analysis for the Reel-In Airdrop System is presented in Table XV . The events are placed in their normal order of occurrence. The failures listed are considered to be the most logical type which would occur with any given element in the system. Failures are also considered as independent of occurrences prior to and following the event. Resultant failures of dependent components are not considered since the chain of events may take many routes following a malfunction.

Most elements presented for use in the RIAS have been used in other airdrop systems. Their reliability has been tested and proven for a given application. However, when they are used under different circumstances, the reliability may be altered.

The ringslot parachute used to extract the main load carrying parachute(s) is selected to give a wide margin of safety for any overloads due to variation in packing of main chutes. The pendulum release system used to deploy the ringslot chute is presently in use and has proven its dependability in this application. Previously, the ringslot has been used to extract the cargo prior to deployment of the main parachute(s). The use of a ringslot parachute to deploy the main cargo parachutes should induce no major change in the performance of this element.

The standard G-11A Cargo Parachute has been employed for cargo extraction in the past with good results. However, extensive testing information in this mode is not available. The reliability of the G-11A used as a main cargo chute has been proven in the normal cargo drop configuration.

The extraction coupler, which was developed by AAI in a prior study, will be used as the load point during extraction and as the load transfer device. This unit utilizes a pyrotechnic time delay and ballistic

TABLE XV FAILURE MODES FOR THE REEL-IN DROP SYSTEM

	EVENT	FAILURE DESCRIPTION	CONSEQUENCE CATEGORY	REDUNDANCY OR FAIL SAFE FEATURES	COMMENTS
1	Start Turbine	Will not start	3	-	The mission will have to be aborted. If slow starting is encountered aircraft will have to make a second pass over drop area
2	Extraction Parachute Release	Does not deploy	3	-	Main parachute(s) may be extracted and mission could continue. In operation involving multiple parachute deployment the undeployed parachute may entangle the remaining parachutes.
		Parachute blows	3 or 5	-	Damaged parachute trailing behind aircraft could come in contact with the empennage and foul the control surfaces.
3	Extraction of Main Parachute(s)	Reefing cutters not activated	2	Total of 4 cutters used in 2 pairs for each parachute	At line stretch, static lines pull firing pins from reefing cutters to initiate the time delay. 4 pins must be pulled from each parachute to insure proper reefing sequence
4	Deployment of Main Parachute(s)	Squidding	2	-	Parachute does not inflate properly resulting in very low drag. Load loss is quite probable even where multiple chutes are being deployed due to high loading from increased velocities, on remaining parachutes as they deploy.
5	Load Extraction	Rail lock system jams and cargo is not released	1-3-5	-	Failure or rail lock system to release load after main parachute(s) have deployed will place severe loading upon the airframe with resultant loss of airspeed and altitude. Parachutes should blow thereby reducing drag.
6	Tip Off	Static lines to extraction coupler break	2 or 4	2 lines used	Static lines must activate cutters for [illegible] transfer.
		Static line to reel-in programmer breaks	2 or 4		Reel in sequence will not be initiated and increased rate of descent and horizontal motion will result. Damage to cargo on impact will result.
7	Load Transfer	Cutters do not fire	2	2 cutters utilized	Failure of cutters to release risers from extraction coupler will cause load to impact on end. Reel-in functioning will be prevented since riser will pass over load to reel-in device.
8	Reefing Cutters Fire	Both cutters fail	2	2 cutters	Failure of both will result in chute being unable to inflate fully. Reduced drag will cause severe impact damage due to high rate of descent.
		Only 1 cutter fires	4	-	With 1 cutter operating the chute will inflate at a slower rate. Impact damage may be experienced but to a much lesser degree than with no disreefing at all.
9	Development of main Parachute(s) and final trajectory	Ruptured gore	4	-	Loss of one gore should not seriously effect the system provided that the parachute does not collapse. Some horizontal force will result from air exiting from rupture.
		Suspension line failure		120 lines per chute	Failure of single suspension line should not seriously effect performance.
		Riser failure	2 or 4	-	Failure of riser will result in loss of associated parachute configuration, with multiple chutes possibility of drop completion but at increased impact velocity
		Connecting link failure	2 or 4	-	Loss of link will mean loss of chute. As with riser failure some possibility of drop completion exists but at higher rate of descent
10	Reel In	Programmer, valve, clutch, or reduction gear failure	2 or 4	-	Reel in sequence will not be started. Higher impact velocity and horizontal motion results
		Turbine [illegible]	2 or 4	-	Reel in will stop. Extent of consequences dependent upon how much line has been reeled in prior to malfunction. Line will not pay out due to high reverse torque inherent in high-ratio reduction gearing
		Failure of end of line sensor	-	Slip clutch	Clutch will slip as no more reeling line is available and will hold line until impact with no degradation of system performance
11	Impact	Failure of cargo restraints	4		Cargo restraints may be overstressed. Should pallet strike ground in a non-horizontal attitude, the load may break loose from pallet and be damaged
12	Ground activation	Premature activation	2 or 4	-	Parachute will be released from the suspension and the cargo will free fall or with multiple chutes possibility of completion at higher rate of descent

line cutter, similar to the reefing line cutters. It can be expected that the same high degree of reliability inherent in these devices will be achieved in this application. The use of dual cutters to provide redundance should assure operation under all load conditions.

The reel-in drive system has inherent features which protect the system in the event of a malfunction. The high gearing ratio prevents the line from playing out should a premature shutdown occur. The clutch will provide override protection should the reeling line become jammed. In the lock-up mode, braking will be maintained (in event of hydraulic pressure loss) by an accumulator and check value system.

The reefing cutters are used in redundant pairs to insure that normal reefing takes place. When only one of a pair of cutters functions, reefing takes place but at a slower rate. The cutters are to be the same standard type currently in use.

It can be seen in Table XV that most failures which occur will cause serious consequences. The system, in general, must be considered as a serial one, with parallel elements provided in critical areas. In most instances, the failure of a major component will result in the load being destroyed or seriously damaged upon impact. In the cases where insufficient drag is the factor, the extent of damage will vary depending upon the amount of increase in the rate of descent and the susceptibility of various loads to damage.

As stated in the beginning of this reliability section, no attempt has been made to determine a numerical value for R_m. However, one of the System Performance Goals is a Reliability of .995. No confidence level has been specified for this goal, so a confidence coefficient of 90% has been assumed for the following discussion. Utilizing numerical values from WADD TR 60-200, a reliability of .995 at a confidence level of 90% will be difficult to achieve. The conditions under which these data were obtained are not the same for the RIAS. Therefore, the numerical values should not be associated with the RIAS until such testing has been done to determine applicable values.

The reliability of a serial model is defined as:

$$R_m = R_{e_1} \cdot R_{e_2} \cdot R_{e_3} \cdots R_{e_n}$$

R_m = mechanical reliability of the system.

$R_{e_1} \ldots R_{e_n}$ = Reliability of individual elements.

ELEMENT	RELIABILITY @ 90% CONFIDENCE
E1 Parachute (G11A)	.9980
E2 Risers	.9999
E3 Reefing cutters (M2A1)	.9900 (.9999 in pairs)
E4 Load Transfer Device (Pair M2A1)	.9999
E5 Disconnect (Pair of M2A1)	.9999
E6 Packing	.9962

The reliability for a single parachute system excluding factors for extraction parachutes, rigging, rail locks, and reel-in elements would be:

$$R_m = R_{e_1} \cdot R_{e_2} \cdot (R_{e_3})^2 \cdot R_{e_4} \cdot R_{e_5} \cdot R_{e_6}$$

$$R_m = .9980 \text{ X } .9999 \text{ X } (.9999 \text{ X } .9999) \text{ X } .9999 \text{ X } .9999 \text{ X } .9962$$

$$R_m = .9937$$

NOTE: R_{e_3} is for 2 pairs of M2A1 cutters.

The reliability factor for a system as described above is .9937. This was determined based on a confidence coefficient of 90%. It may be more likely that a reliability factor of .995 could be achieved at a reduced confidence level. For a system such as the RIAS the other factors (e.g. extraction chutes, reel-in unit, etc.) must be added to the equation. These factors would make R_m even lower.

Testing of the Reel-In Airdrop System to prove a R_m of .995 with a confidence level of 90% would involve 460 tests with no failures occuring. However, if a lower confidence coefficient could be tolerated, substantially fewer tests could be performed. For example, lowering the confidence level to 70% would involve only 241 tests. In setting up a reliability demonstration both a confidence coefficient and accept-reject criteria must be specified.

3. Reliability of Human Operation

a. General

In recent years, human reliability has emerged as a distinct area of investigation. The utility and potential impact of human reliability investigation on system designs is illustrated in a pioneering study by Shapero[10], et. al. Although various procedures for quantifying human reliability have been proposed (THERP, for example) a universally applicable and widely acceptable methodology for human reliability analyses has not been established. Therefore, it is necessary to formulate an approach which is more-or-less tailored to the particular system under design. The terms used in defining the analytical approach must also be clearly defined.

With respect to the Reel-In Airdrop System, human reliability (R_h) is defined as the probability that the airdrop system will successfully complete cargo delivery when all equipment components function properly. The probability that a critical human error would result in an unsuccessful airdrop then, is $1-R_h$. In this study, we have limited our consideration of human errors to operations concerned with assembling, rigging, and using the airdrop unit and have not considered prior operator errors, i.e. those associated with design, manufacturing or shipping actions. Also, as defined here, R_h does not include those human actions associated with aircraft control and/or drop zone selection. The purpose of the human reliability analysis for this program was to isolate those operator-equipment interactions which could adversely affect airdrops, and to minimize the probability of occurrence of a critical human error.

A critical human error is classified as an error of omission or an error of commission which reduced R_h. An error of omission is defined as the failure of an operator to perform a specified or required task. An error of commission can be categorized as: (1) the incorrect performance of a specified or required task; (2) the performance of a task out of the specified or proper sequence; or (3) the performance of a task that is not specified or required under the system operational procedures. The occurrence of a human error of omission or commission does not necessarily result in the degradation of the overall human reliability (R_h). To be of consequence in determining human reliability, the error must have some effect on system performance. For example, if an installation procedure specified a tie-down bolt is to be torqued to 150 ft-lbs, and the operator torques the bolt to 160 ft-lbs, he has, in effect, committed an error. However, if his action has no effect whatsoever on system performance, (i.e. the system will operate within its performance specifications whether the tie-down bolt is torqued to 150 ft-lbs or 160 ft-lbs) he has not reduced the probability of system success and the error is considered non-critical. On the other hand, if an operator error causes, or has the potential to cause, a reduction in the probability of success of an airdrop that error must be considered as having an adverse effect on system performance and is classified as a critical human error.

Another facet of human error, associated with criticality that must be considered in discussing the reliability of human operations is the reversibility of the error. By reversibility we mean that the occurrence of an error can be detected and subsequently negated before it influences system performance. The operator may detect the error himself, particularly if the error consequence acts as a task interferent in other system operational events; or, the error may be detected in the performance of test and/or inspection routines. The probability of reversing or negating an error, with the potential to affect R_h, is a function of the equipment design concepts that facilitate operator detection, and the effectiveness of the scheduled inspections.

The use of equipment configuration (e.g. the use of mechanical interferents to task completion when an error has been committed), rather than inspections, appears to enhance the detection and reversibility of human errors. The inspection process, by nature, is susceptible to personnel considerations that could influence the effectivity of inspections. That is, the inspector could commit a critical human error in failing to detect a rigging or assembly error that could affect R_h. However, the inspection process is considered a complementary factor to equipment configuration in the reversibility of potential critical human errors.

As stated previously, the operator reliability portion of the Reel-In Airdrop System program was concerned with the minimization of human errors that adversely affect airdrop operations. A human error can be viewed as having two error sources -- individual produced errors and situation produced errors. The individual produced errors are related to the characteristics of the operating personnel. These personnel attributes include such factors as individual motivation, skill level, background, and experience. The variability associated with human performance that is conducive to human errors is both intra-individual and inter-individual. The intra-individual variability is a factor of the day-to-day variations of an individual's performance and is, largely, an uncontrollable system characteristic. The inter-individual variability is a factor of the variations between individuals and is a factor of the individual training, background, and experience of the operating personnel. The inter-individual variability has been considered as a design constraint; i.e. the expected range of personnel capabilities and limitations has influenced design complexity, equipment configurations, component selection, etc. By assuring the compatibility of the Reel-In Airdrop System and the expected user personnel, we have minimized one of the causal elements of human error sources.

Situation produced errors are primarily induced by equipment and/or procedure characteristics and are the primary cause of human errors. Although no specific equipments or procedures are required under this phase of the program, design concepts that are compatible with the minimization of situation produced errors have been developed. Equipment and procedure characteristics such as fail/safe devices, assemblies that can only be done correctly, warning notes in procedures and on equipment, and judicious use of inspection and test are under consideration for incorporation in the Reel-In Airdrop System.

As an indication of the inherent reliability of human operations in the low level airdrop concept, the following system characteristics will be discussed:

(1) Section IV.C.3.b:
The Operational Events Required for System Operation.

(2) Section IV.C.3.c:
Failure Source Analysis Data.

(3) Section IV.C.3.d:
An Index of System Reliability Relative To Present Operational Systems.

b. Operational Events

An operational event is defined as a manual operation required during assembly and rigging of the airdrop system from platform preparation through system activation. The operational events that comprise the Reel-In Airdrop System can be grouped into three main categories:

1.0 Component Preparation;

2.0 Delivery Unit Assembly; and

3.0 Preparation for Airdrop.

The operational events contained in each of these categories, and their sequence of occurrence, where applicable, are shown in Figure 14 . As seen in this flow diagram, the events of the first category, Component Preparation, are not sequentially related. However, the events required to complete the Delivery Unit Assembly and the Preparation for Airdrop operations are to be performed in a prescribed sequence. It is inherent in the assembly and rigging of an airdrop system that each major component must be prepared prior to mating with other system components or assemblies. The sequence in which the components are prepared is not defined, i.e., the preparation of one prime component is not a prerequisite for the preparation of another. In fact, it is highly probable that the components will be pre-prepared and treated as "shelf-items" in assembling the delivery unit.

The summary of the operational events, how they relate to previous systems and the number of man-hours required to prepare for the delivery of the M37 3/4-ton Cargo Truck (Reference item 5 of Table III), is presented in Table XVI . As an indication of human error potential, the task content, requisite personnel skill levels, estimated man-hours, and

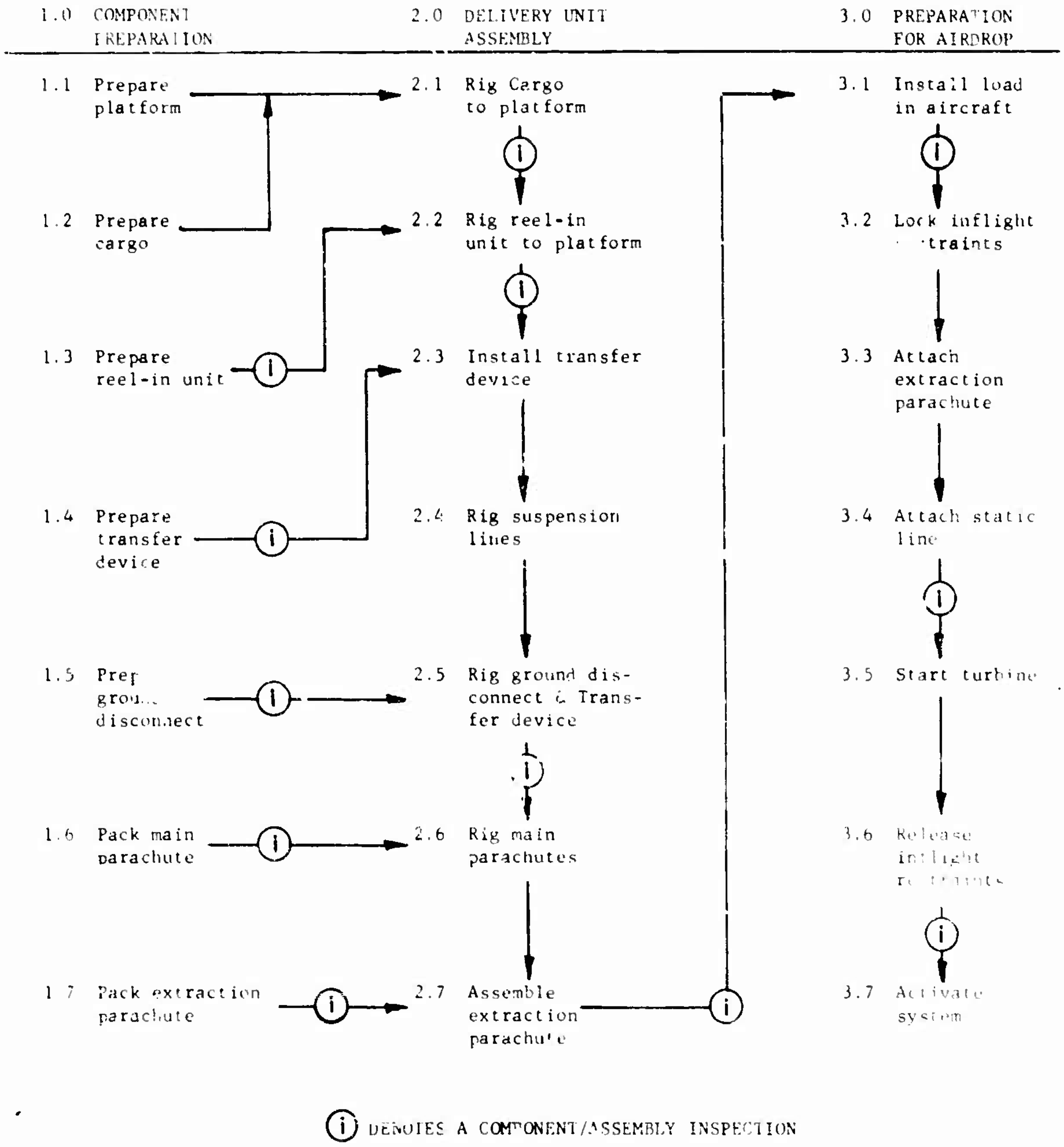


Figure No. 14 SEQUENCE OF EVENTS IN OPERATION OF THE REEL-IN AIRDROP SYSTEM

TABLE XVI SUMMARY OF OPERATIONAL EVENTS FOR AIRDROP OF AN M37 3/4-TON CARGO TRUCK

REF NO.	OPERATIONAL EVENTS	RELATION TO PRESENT DAY SYSTEMS	ESTIMATED MAN HOURS
1.0	Component Preparation		
1.1	Prepare 16-foot Platform	Same Event	2.0
1.2	Prepare Cargo	Same Event	1.0
1.3	Prepare Reel-In Unit *	New Event	1.0
1.4	Prepare Transfer Device *	New Event	0.5
1.5	Prepare Ground Disconnect *	Same Event	0.2
1.6	Pack Main Parachutes (1.5mh each)*	Changed Event	3.0
1.7	Pack Extraction Parachute *	Same Event	0.2
2.0	Delivery Unit Assembly		
2.1	Rig Cargo to Platform *	Same Event	2.0
2.2	Rig Reel-In Unit to Platform*	New Event	0.5
2.3	Install Transfer Device	Changed Event	0.2
2.4	Rig Suspension Lines	New Event	0.5
2.5	Rig Ground Disconnect & Transfer Device *	Changed Event	0.5
2.6	Rig Main Parachutes (0.2mh each)	Changed Event	0.4
2.7	Assemble Extraction Parachute *	Changed Event	0.1
3.0	Preparation for Airdrop		
3.1	Install Load in Aircraft *	Changed Event	1.5
3.2	Lock In-Flight Restraints	Same Event	0.2
3.3	Attach Extraction Parachute	Same Event	0.1
3.4	Attach Static Lines *	Changed Event	0.2
3.5	Start Turbine	New Event	0.1
3.6	Release In-Flight Restraints *	Same Event	0.1
3.7	Activate System	Same Event	- -

* Denotes an inspection associated with the operational event. Time estimates for performing inspections have not been included in this summary.

variation in operational events as a function of selected cargo, are discussed by operational event reference number as follows:

1.1 Prepare Platform - This event is identical to platform preparation used in present airdrop systems. Paper honeycomb energy dissipators are mated to standard Army modular-platforms and standard tie-down hardware, webbing, and load binders are secured to the platform. The event can be done by untrained enlisted men supervised by a Rigger (MOS Code 464) in approximately 2 man-hours. The man-hours estimate will vary depending on the size of platform being prepared.

1.2 Prepare Cargo - The cargo is prepared in a manner identical to that used in present systems. Cargo preparation can be done by a Rigger (or by untrained enlisted men supervised by a Rigger if necessary). The man-hours expended for cargo preparation will vary with respect to load complexity, taking about 1 man-hour to prepare an M37 3/4-ton Cargo Truck up to two man-hours to prepare an M-551 ARAAV.

1.3 Prepare Reel-In Unit - This event includes the inspection and checkout of the reel-in unit. Moving parts are checked for alignment, the clutch operation is checked, the timer is programmed for the proper delay, the turbine starting circuits are checked, and the turbine motor oil and hydraulic fluid reservoirs are filled. This event can be done by a specially trained enlisted man in 1.0 man-hours. After event completion, the reel-in unit is inspected by the Project NCO Inspector.

1.4 Prepare Transfer Device - Preparation of the transfer device will consist of installing the cutter elements. Similar transfer devices are used on present airdrop systems, but this is considered a new event because of the new function performed. This event can be done by a Rigger, or an enlisted man specially trained to perform this task. It is estimated that 0.5 man-hours will be expended to complete this task. The time to perform this event will not vary with the load complexity. After completion of the event, the transfe device will be inspected by the Project NCO Inspector.

1.5 Prepare Ground Disconnect - This event is identical to ground disconnect preparation procedure used in present systems. It will consist of the installation of the cutter elements. A Rigger, or a specially trained enlisted man, can perform this task in about 0.2 man-hours. This event will not vary with respect to load complexity. The prepared ground disconnect device is inspected by the Project NCO Inspector.

1.6 Pack Main Parachutes - The packing of the G-11A parachutes will take approximately 1.5 man-hours per parachute. Multi-man teams of Riggers will perform this event. The packing operation is changed fr. present airdrop systems in that the reel-in line and associated hardware are packed as an integral part of the G-11A package. The parachute bag will be modified to permit this change. The parachutes are inspected by the Project NCO Inspector during and after packing.

1.7 Pack Extraction Parachute - The packing of the ringslot parachute is the same as that used in present systems. This task, performed by a Rigger, will take approximately 0.1 man-hours and will be inspected by the Project NCO Inspector during and after packing.

2.1 Rig Cargo to Platform - The cargo is rigged to the platform using standard webbing, tie-downs, and load binders, just as in present airdrop systems. This event can be done in two man-hours (or more, depending on load complexity) by Riggers and/or supervised untrained enlisted personnel. The cargo-platform assembly is inspected by the Project NCO Inspector.

2.2 Rig Reel-In Unit to Platform - This is a new event that can be performed by specially trained enlisted personnel in approximately 0.5 man-hours. The task consists of bolting the unit to the platform and fueling the turbine system. The Project NCO Inspector verifies the appropriate performance of this event.

2.3 Install Transfer Device - This event is changed from present airdrop systems. Present systems cut the extraction (ringslot) parachute free of the cargo and use it to deploy the main recovery parachute. The Reel-In Airdrop System uses the same parachute for extraction and recovery. This task consisists of attaching the transfer device (or extraction coupler) to the platform and attaching the static line. It is estimated that a Rigger can install this device in 0.2 man-hours.

2.4 Rig Suspension Lines - Rigging of the suspension lines is modified from present airdrop systems. The modification concerns the positioning of the suspension sling on the load to enable a main parachute to be used for both extraction and recovery; and the connection of the lines to the reel-in device. This task can be done by a Rigger in 0.6 man-hours.

2.5 Rig Ground Disconnect and Transfer Device This event is changed from present airdrop systems because of the change in function of the extraction coupler (transfer device). This task consists of rigging the extraction line and riser extension through the transfer device and the ground disconnect cutters. The task can be done by a Rigger in approximately 0.5 man-hours. This event does not vary with load complexity. Upon completion, the rigging is inspected by the Project NCO Inspector.

2.6 Rig Main Parachutes - This event is slightly modified from present airdrop systems, primarily in the area of tie-downs to prevent cargo lash during parachute deployment and to facilitate transfer from the extraction to the recovery mode of operation. This task would be done by Riggers. Event time is approximately 0.2 man-hours per parachute.

2.7 Assemble Extraction Parachute - This event concerns the attachment of the ringslot extraction parachute to the main parachutes. The task is slightly changed from present airdrop systems in that the ringslot parachute is used to deploy the G-11A parachutes, not cargo extraction. This event can be performed by a Rigger in approximately 0.1 man-hours. The rigging of the extraction parachute to the main parachutes is inspected by the Project Officer Inspector.

3.1 Install Load in Aircraft - The installation of the load into the aircraft is slightly modified (the rail indent-detent values may vary), but very similar and no more complex than installation procedures for present airdrop systems. This task can be accomplished by Riggers and supervised untrained enlisted men in approximately 1.5 man-hours. Task time does not vary appreciably with load complexity. After installation, the complete load is inspected by the Project Officer Inspector and the Aircraft Safety Officer.

3.2 Lock In-Flight Restraints - This task is identical to locking in-flight restraints in present airdrop systems. It can be performed by the Aircraft Load Master in 0.2 man-hours.

3.3 Attach Extraction Parachute - This task concerns the attachment of the extraction parachute to the pendulum release system. It can be done by a Rigger in 0.1 man-hours. The event is unchanged from present systems.

3.4 Attach Static Lines - Attachment of the static lines is basically the same as in present systems. The task is slightly changed by the addition of the static line used to activate the reel-in unit timer. Attachment can be done by a Rigger in 0.2 man-hours. After this task, the static line installations are inspected by the Project Officer Inspector and the Aircraft Safety Officer.

3.5 Start Turbine - This event, not done on present systems, consists of activating the turbine starter circuit. The time span associated with this action is 0.1 man-hours. The event is performed by the Aircraft Load-Master.

3.6 Release In-Flight Restraints - This task is identical to the release of In-Flight restraints in present airdrop systems. It can be done by the Aircraft Load-Master in approximately 0.1 man-hours. Verification of restraint release is made by the Aircraft Safety Officer.

3.7 Activate System - As in existing systems, the Aircraft Load-Master activates the airdrop system (trips the pendulum release) upon command from the pilot. No time span is associated with system activation.

The estimated total man-hour requirement for performing the operational events associated with the airdrop of an M37 Cargo Truck is 16.7 man-hours. This estimate can be subdivided by personnel as follows:

(1). Riggers - 10.4 man-hours

(2). Specially trained enlisted men - 1.5 man-hours

(3). Supervised untrained enlisted men - 2.0 man-hours

(4). Aircraft load-master - 0.4 man-hours

(5). Inspection (based on 0.2 man-hours per inspection) - 2.4 man-hours

These estimates would vary depending on load complexity -- platform size, number of parachutes, cargo tie-down requirements, etc.

Of the twenty-one operational events required for system preparation, five are considered new, seven are changed from present airdrop systems, and nine are considered the same as present systems. The new and changed events are easily performed and are no more complex than similar events on standard systems.

The task content of the operational events, in conjunction with the sequence of events, constitute an operational environment that can be considered relatively non-conducive to the occurrence of critical human errors. Such situational factors as performance time stress, operator task overload (fatigue), complex operator interactions, and potential personnel hazard and risk of equipment damage, which are expected to increase the probability of human error are not evidenced in the rigging and assembly of the Reel-In Airdrop System.

c. Failure Source Analysis

Failure source analysis data, reflecting the consequence of critical human errors in the assembly and rigging of the Reel-In Airdrop System, are presented in Table XVII .

These data indicate the effect of a given class of error on overall system reliability, the ease of detection (reversibility) of a particular error, and a gross estimate of the frequency of occurrence (relative to present airdrop systems) of the human error. Failure source analysis data are presented only for changed or new operational events; when the event is the same as for standard systems, error source information has not been presented.

d. Index of Human Reliability

As an index of the reliability of human operations, we can compare the operational events of the Reel-In Airdrop System with the operational events of present airdrop systems. Although the primary missions

TABLE XVII REEL-IN AIRDROP SYSTEM FAILURE SOURCE DATA FOR HUMAN OPERATIONS

OPERATIONAL EVENT	ERROR SOURCE	EST. FREQ W RESPECT TO PRESENT SYSTEMS	CONSEQUENCE OF ERROR	INSPECTION PROCESS: EASE OF DETECTION	INSPECTION PROCESS: TIMES INSPECTED	INSPECTION PROCESS: INSPECTED BY	DESIGN FAIL SAFE FEATURES	REMARKS
1.1 Prepare Reel-in Unit	Improper verification of mechanical integrity or improper timer programming	New event, estimated freq. is minimal	Damage to load due to rate of oscillatory motion if unit does not operate	Somewhat difficult without testing or hand operating the turbine	1	Project NCO Inspector		A pre-drop test of the Reel-in unit to verify its operation may be desirable
	Failure to put oil or hydraulic fluid in turbine reservoirs	Minimal (new event)	Damage to load due to inoperable unit	Readily detected through visual check	1	Project NCO Inspector	Visual indicators or dipsticks to check reservoir levels will be supplied.	
1.6 Prepare Transfer Device	Improper installation of cutter devices	Minimal (new event)	Loss of load	Readily detected due to mechanical incompatabilities	1	Project NCO Inspector	Device will have mechanical interferences to prevent improper assy	No operator problems have been encountered with experimental models of this device
1.7 Pack Main Chutes	Improper pack	Same as present system	Gross errors could cause loss of load; minor errors could cause damage to load	Somewhat difficult after task completion, in-process inspection is recommended	1	Project NCO Inspector	A detailed investigation of packing processes & procedures may provide areas where fail/safe design features could be incorporated	Standard packing devices are used in performing this event
	Improper installation or wrong length of reel-in line	Increase freq. over present system due to increased task content	Increased probability of load damage because of faulty reel-in	Impossible after task completion; recommend in-process inspection	1	Project NCO Inspector		
2.2 Rig Reel-in Unit to Platform	Improper attachment	Minimal (new event)	Loss of load due to loss of reel-in unit	Readily detected by manual & visual checks	1	Project Officer Inspector	Self-locking tie-down hardware can be used to assure attachment	No problems are expected in the performance of this task due to its inherent simplicity
	Failure to fuel turbine	Minimal (new event)	Damage or loss of load due to failure of reel-in device	Readily detected through visual monitor of fuel indicator	1	Project Officer Inspector	Visual indication of fuel level can be provided.	
2.3 Install Transfer Device	Improper attachment of static line	Same as present systems	Loss of load due to inability to transfer	Readily detected through visual & manual checks	3	Project NCO & Officer Inspectors, Aircraft Safety Officer	Provisions will be made so the static line can only be attached correctly	Basic hardware and techniques for this event are standard
2.4 Rig Suspension Lines	Improper positioning of lines	Same as present systems	Increased probability of load damage due to rate of descent or oscillatory motion	Readily detected through visual cues	3	Project NCO & Officer Inspectors, Aircraft Safety Officer		As evidenced on the LAAS Program Army Riggers becomes quickly skilled in preparing all parachute systems. The inspection process should detect critical errors

TABLE XVII REEL-IN AIRDROP SYSTEM FAILURE SOURCE DATA FOR HUMAN OPERATIONS (CONT'D.)

OPERATIONAL EVENT	ERROR SOURCE	EST. FREQ. W/RESPECT TO PRESENT SYSTEMS	CONSEQUENCE OF ERROR	INSPECTION PROCESS			DESIGN FAIL/SAFE FEATURES	REMARKS
				EASE OF DETECTION	TIMES INSPECTED	INSPECTED BY		
2.5 Rig Ground Disconnect & Transfer Device	Improper rigging	Less than present systems due to a simpler transfer device	Loss or damage to the load	Readily detected through visual cues	3	Project NCO & Officer Inspectors, Aircraft Safety Officer	Design will provide for exposed rigging	Rigging is exposed for visual inspection, errors will be visually detectable.
2.6 Rig Main Chutes	Risers not connected	Same as present systems	Load cannot be extracted if it is in extraction bag; loss or damage to load or other bags.	Readily detected by manual check	3	Project NCO Inspector, Aircraft Safety Officer	Rigging attachment points can be positioned to be visible for inspection.	Army Riggers had no problems performing the rigging assemblies of the LAAS Program, and since LAAS rigging was more complex than this system, no problems are envisioned. The multiple inspections should detect critical human errors.
	Risers improperly installed	Same as present systems	Loss or damage to load due to	Readily detected by visual check	2	Project NCO Inspector, Aircraft		
	Bag improperly attached to load	Same as present systems	Load cannot be delivered due to failure to deploy bag.	Readily detected in visual-manual checks	2	Project NCO Inspector, Aircraft Safety Officer	Attachment points will be exposed for visual check	
2.7 Assemble Extraction Chute	Improper Attachment to main chute	Less than present systems due to less complex rigging	Load cannot be delivered due to failure to deploy bag.	Readily detected in visual-manual checks	2	Project Officer Inspector, Aircraft Safety Officer	Attachment points will be exposed for visual check.	This event is less complex than present systems in that the ring-slot is used only for deployment of the G11A, not extraction
3.1 Install Load in Aircraft	Fail restraints are set to improper resisting value	Same as present system	Load cannot be delivered, or premature release of load	Detected only by verification during inspection	2	Project Officer Inspector, Aircraft Safety Officer		This event is identical to present systems except for the resisting value of restraint. No problems are expected.
3.4 Attach Static Lines	Improper attachment of static line to reel-in timer	Same as present system static line attachments	Damage or loss of load due to inoperation of reel-in unit	Readily detected by visual inspection	[illegible]	Project Officer Inspector, Aircraft Safety Officer	Provisions will be made so the static line can only be attached correctly	Failure to attach the static line will be obvious during visual checkout.
3.5 Start Turbine	Failure to start turbine before load release	Minimal (new event)	Damage or loss of load due to inoperation of reel-in unit	Readily detected by visual and auditory cues	1	Aircraft Safety Officer		Proper start of the turbine is a pre-requisite to Operational Event 3.6 - Release of Inflight Restraints.

of present airdrop systems and the Reel-In Airdrop System differ in some respects, there is a large degree of commonality in the operational events required to assemble and rig the systems. Because failure or error rate data are not available for the individual events, we have estimated the human reliability of the Reel-In Airdrop System on a relative basis. Also, because we do not have human reliability data for the present airdrop system, we have assumed the probability of failure to correctly perform a present day operational event to be an arbitrary value, K. We then made relative judgments, based primarily on task complexity as defined by preliminary analyses and/or engineering experience, to obtain a probability of failure for Reel-In Airdrop System operational events expressed in terms of some percentage of K, e.g., 0.95K, 1.00K, 1.20K, etc. In this manner, each operational event was assigned a relative estimate of human reliability. The operational events associated with the Reel-In Unit, and thus not performed in present systems, were considered to have a base value of 100% K to which was added a percent value based on task complexity and the average complexity of other operational events. For example, preparing the Reel-In Unit (Event 1.3) was assumed to be of the same approximate complexity as other operational events so its estimated reliability factor was 100% base plus 100% complexity, or 2.00K. On the other hand, starting the Reel-In Unit turbine was adjudged to be only one-quarter as complex as other operational tasks so the estimated reliability factor was 100% base plus 25% complexity or 1.25K.

These estimates were summed and the resultant mean was considered as an index of human reliability. The estimates are shown in Table XVIII . As seen in this table, the mean estimate of human reliability for the Reel-In Airdrop System is 1.13K. This index indicates that we may expect the Reel-In Airdrop System to be 13% more "unreliable" than present day systems in the performance of assembly and rigging operations. This slight increase in the probability of human error is due to the addition of the three operational events associated with the Reel-In Unit.

TABLE XVIII ESTIMATE OF RELIABILITY OF HUMAN OPERATIONS

OPERATIONAL EVENT	PRESENT SYSTEM	RIAS	COMMENT
1.1 Prepare Platform	K	1.00K	Identical to present systems
1.2 Prepare Cargo	K	1.00K	Identical to present systems
1.3 Prepare Reel-in Unit	-	2.00K	200% factor added because event is not in present systems but is no more complex than other system operations
1.4 Prepare Transfer Device	K	1.00K	No more complex than present systems
1.5 Prepare Ground Disconnect	K	1.00K	Identical to present systems
1.6 Pack Main Chutes	K	1.20K	20% more complex due to addition of reel-in line to chute pack
1.7 Pack Extraction Chute	K	1.00K	Identical to present systems
2.1 Rig Cargo to Platform	K	1.00K	Identical to present systems
2.2 Rig Reel-in Unit to Platform	-	1.75K	175% factor is added because event is not in present system but is not as complex as most system functions
2.3 Install Transfer Device	K	1.00K	No more complex than present systems
2.4 Rig Suspension Lines	K	1.25K	25% more complex due to changes in rigging for reel-in operation
2.5 Rig Ground Disconnect and Transfer Device	K	1.10K	10% more complex due to rigging changes required for transfer operations
2.6 Rig Main Chutes	K	1.10K	10% more complex due to positioning and rigging required for transfer
2.7 Assemble Extraction Chute	K	1.00K	No more complex than present systems
3.1 Install Load in Aircraft	K	1.00K	No more complex than present systems
3.2 Lock In-Flight Restraints	K	1.00K	Identical to present systems
3.3 Attach Extraction Chute	K	1.00K	Identical to present systems
3.4 Attach Static Lines	K	1.05K	5% more complex due to additional static line for reel-in unit
3.5 Start Turbine	-	1.25K	125% factor added because event is not in present systems but task is very straight forward and simple
3.6 Release In-Flight Restraints	K	1.00K	Identical to present systems
3.7 Activate System	K	1.00K	Identical to present systems
Mean Reliability Factor	K	1.13K	

D. Supplementary Considerations

1. Environmental Considerations

Three environmental conditions have been applied to cargo items 5 and 8. These are:

a. Standard Conditions, defined as a sea level drop zone at 60°F, with no winds aloft,

b. Sea Level drop zone at 60°F, with a 15 knot wind at 45° with respect to the flight path of the aircraft,

c. Drop zone 5000 feet above sea level with an ambient temperature of 100°F and a no wind condition.

Table XIX defines run numbers and input conditions used to examine these environmental variations for items 5 and 8. Included in this table are the resultant impact parameters of the cargo defined in terms that have been used in Tables V and VII of Section III. The next tabular listing provides the magnitudes of the times, forces, velocities, etc. as previously used and defined in Table XX of this section. The plots of the trajectory characteristics of the computer evaluations shown in these tables will be found in the appropriate parts of Section III B of this report. As noted previously, the line tension characteristics were not computed in the three dimensional cases; hence, values of Fe and Fr are not presented for Runs 5.0131 and 5.0144. However, these line tensions would parallel those presented for cases 5.0092 and 5.0107 respectively.

From a consideration of the parameters listed in these tables, it is seen that changes in the terrain altitude and ambient temperature, (Runs 5.0092 and 5.0101 for item 5 and Runs 5.0107 and 5.0118 for item 8), do not alter the cargo impact characteristics significantly. Moreover, the effect of a 15 knot wind condition does not alter these parameters by a significant magnitude. Hence, the reel-in system discussed in this report is not very sensitive to variations in environmental conditions.

ENVIRONMENTAL EFFECTS

ITEM NO.	RUN NO.	DROP ZONE PARAMETERS	WIND COND.	REEL RATE (fps)	IMPACT PARAMETERS					
					TIME TO DESCEND 500' (sec)	VERTICAL VELOCITY (fps)	LONG. VEL. (fps)	LAT. VEL. (MAX.) (fps)	Φ 500 (o)	H_{min} (ft)
5	5.0092	0' 60°F	none	5	17.02	23.6-27.2	13.4	--	13.4	444
5	5.0101	5000' 100°	none	5	17.6	19.2-28.9	19.0	--	19.5	449
5	5.0131	0' 60°F	15K/45°	5	18.08	21.0-30.0	33.7	18.9	3.8	372
8	5.0107	0' 60°F	none	7.5	16.57	21.1-33.8	20.2	--	28.1	493
8	5.0118	5000' 100°	none	7.5	16.90	19.4-33.9	21.8	--	30.5	485
8	5.0144	0' 60°F	15K/45°	7.5	16.4	17.6-34.0	39.0	19.0	24.6	420

TABLE XIX ENVIRONMENTAL EFFECTS

EVALUATION PARAMETERS

ITEM NO.	RUN NO.	CG_o (ft)	$V_{A/C}$ (fps)	REEL RATE (fps)	t_e (sec)	t_t (sec)	t_1 (sec)	F_e (g)	F_r (g)	V_v 500' (fps)	V_h 500' (fps)	Φ 500' (o)
5	5.0092	-23.35	220	5	1.15	1.32	17.02	1.41	2.65	28.8	6.2	13.4
5	5.0101	-23.35	220	5	1.17	1.35	17.55	1.35	2.74	27.8	5.7	19.5
5	5.0131	-23.35	220	5	1.33	1.48	18.08	--	--	29.4	27.7	3.8
8	5.0107	-23.35	220	7.5	1.12	1.37	16.57	1.43	2.47	21.7	15.9	28.1
8	5.0118	-23.35	220	7.5	1.14	1.40	16.9	1.35	2.54	23.9	11.3	30.5
8	5.0144	-23.35	220	7.5	1.31	1.56	16.4	--	--	17.6	5.5	24.6

TABLE XX ENVIRONMENTAL PARAMETERS

2. Sensitivity and Flexibility

The effects of variations in aircraft speed and altitude on the impact locations of cargo item 5 are presented in this discussion, in which tolerances of ± 10 knots in speed and ± 100 feet in altitude have been imposed. The computer evaluations used in this discussion are:

Run 5.0092 - Item 5, 5 fps reel-in, A/C speed = 130 kts
Run 5.0104 - Item 5, 5 fps reel-in, A/C speed = 120 kts
Run 5.0105 - Item 5, 5 fps reel-in, A/C speed = 140 kts

It has been previously noted that variations in aircraft speed of this magnitude do not alter the values of the time parameters t_e, t_t, and t_i for a descent of exactly 500 feet. However, altitude variations of ± 100 feet will change the magnitude of t_i, which is the time it takes the cargo to impact the ground measured from incipient motion of the item in the aircraft. The next table summarizes the trajectory and impact parameters associated with the listed computer evaluations for cargo item 5 chosen to illustrate the sensitivity characteristics of the reel-in system. Although data is available for item 5 only, the other cargo items are expected to exhibit similar characteristics.

Examination of this table indicates that:

a. Variations in aircraft speed do not affect the time parameters associated with the cargo descent trajectory.

b. Increases in aircraft speed tend to increase slightly the maximum retardation force (F_r) experienced by the cargo as expected.*

c. Over the range of altitude considered, the vertical impact velocity (V_v) of the cargo is within desirable limits.

d. The horizontal impact velocity (V_h) undergoes a wide variation in magnitude as a function of changes in altitude. This is to be expected from the oscillatory character of the horizontal velocities of the cargo as illustrated in the curves presented in Section III B 2

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*The variations in F_e illustrated in this table are primarily a function of the reeled diameters of the parachutes and as such, do not exhibit any direct relation to aircraft speed.

TABLE XXI

SENSITIVITY-FLEXIBILITY CHARACTERISTICS

Run		5.0104			5.0092			5.0105	
A/C Speed (fps)		203			220			237	
t_e (sec)		1.15			1.15			1.15	
t_t (sec)		1.32			1.32			1.32	
t_i at 500' (sec)		17.02			17.02			17.02	
F_e (g's)		1.43			1.41			1.37	
F_r (g's)		2.28			2.65			2.80	
Altitude (ft.)	400	500	600	400	500	600	400	500	600
V_v (fps)	26.9	28.8	25.8	27.2	28.8	25.8	27.6	28.7	25.8
V_h (fps)	26.9	6.6	8.1	26.8	6.2	8.2	26.7	5.7	8.5
Φ (degrees)	5.0	13.2	8.5	4.0	13.4	8.0	3.5	17.4	2.0
t_i (sec)	13.12	17.02	20.72	13.12	17.02	20.72	13.12	17.02	20.72

of this report. Since no defined limit was placed on V_h, there is no way to judge these variations, other than to state that the smaller the magnitude of V_h, the better the cargo touchdown event. The same is true for the impact altitude angle Φ illustrated in this table.

It is clear that the parachute reel-in system is quite insensitive to variations in aircraft speed, and exhibits only a relatively small sensitivity to variations in altitude.

3. CEP Characteristics

The CEP characteristics of the systems evaluated in this report have been examined on the basis of the analyses developed by Culpepper.[11] This examination is restricted to cargo item 5, but is considered to be representative of the other items of cargo of interest in this program. Several cases have been evaluated by assuming that the pilot of the aircraft cannot maintain a command altitude any closer than ± 100 feet and a command speed any closer than ± 7%. Under these assumptions, the CEP magnitude for cargo item 5 without a reel-in system applied to the item is 36.2 ft. (11.04 meters). Under the same conditions, but with a reel-in event of 5 fps as specified in Run 5.0092, the CEP magnitude is 30.4 ft. (9.27 meters).

4. Signature

The signature of the parachute reel-in system is similar to the existing airdrop system now in use. However, there are several important characteristics of the reel-in system that distinguish it from other airdrop systems. First, the parachute reel-in system is designed to permit airdrops to be executed from altitudes of 500 feet (less in some cases as noted in this report). Hence, the descent time for the powered reel-in system is much less than the presently used airdrop system, which is designed for operation at 1500 feet or above. Reducing the time taken in the air descent phase tends to reduce the chance of enemy observation of the cargo airdrop event. Of course, the signature characteristics of a heavy cargo airdrop operation is poor, at best, due to the large number of parachute canopies deployed during the descent. In general, the signature of the lighter weight cargoes is better in this respect, since a fewer number of parachute canopies are required to effect a successful descent of the cargo item.

In addition, the powered reel-in system does exhibit one poor signature characteristic; the exhaust flow from the gas turbine unit is both visible and noisy, and could easily be detected by an infrared heat seeker device. The spiral actuator power unit, described in Section III C of this report does not exhibit this characteristic, however, since the operation of the device is accomplished without any exhaust flow.

E. Cost Estimates of Airdrop Gear

The data and information presented in this discussion are keyed to the cargo items identified in Table III, pages 25-27, of the TIE Contractors report.[1] It is to be noted that this list of cargo items includes the eight cargo items presented in Table III, Section III.B.1 of this report. In addition, there are seven other cargo items identified in Table III of the TIE Contractors report. For convenient reference, this table is summarized in the listing on the following page.

The format followed in presenting the costs of the gear required to airdrop these items parallels that suggested in the TIE Contractors report. That is, the existing airdrop equipment now used to airdrop each load item, and still applicable without change or modification to the parachute reel-in concept airdrop system is presented as an equipment list that provides the Federal Stock No., Part No. (where applicable), Description and Quantity required of the component equipment items. Following this listing is a tabluation of the new or modified equipment items that must be provided for use with the parachute reel-in airdrop system. Estimated costs of these particular items are included in this second tabulation.

As noted in the preceding sections of this report, the general cargo identified as item 1 in Table III of Section III.B.1, the M38A1 (item 2), and the M274 (item 3), do not experience a dramatic improvement in impact characteristics when a reel-in event is applied during the cargo descent trajectory. About the only change between a no reel descent and a reel-in descent for these items is a decrease in the impact attitude angle magnitude in the powered reel cases. Assuming that this angle change is not a particularly important characteristic, it is recommended that items 1, 2, and 3 of Table III not be supplied with a powered reel-in system, at least for sea level airdrop missions.

However, since the effect of an increase in terrain altitude is to degrade the performance of the system, a powered reel-in event would probably be necessary during the descent of even these items to a drop zone at altitudes above sea level and with elevated ambient temperatures. Hence, the equipment lists provided in this section include a reel-in system for these items, even though the use of the reel system is not required for sea level airdrop missions.

The following equipment list is referenced to the "List Item No." designation used in Table XXII. Moreover, the sections of this list that present the new or modified components of the airdrop gear all incorporate a modification to the G-11A parachute riser extensions that includes the "reel line" and associated pulleys used to accomplish the reel-in event. In addition, the bag in which these parachutes are packed will require additional flaps to enclose these components when the system is rigged to the cargo item. In the modification part of the equipment lists, these modifications are assumed to be included in the item denoted

TABLE XXII

REPRESENTATIVE LOADS TO BE RIGGED FOR AIRDROP
(Reference: Table III, pp. 25-27, Ref. 1)

LIST ITEM NO.	MILITARY DESIGNATION	ITEM NO. DESIGNATION FROM TABLE III, SECTION III.3.1 (if applicable)	SUMMARY DESCRIPTION OF LOAD ITEM
1	M38A1	2	¼-ton truck
2	M37	5	3/4-ton truck
3	-	-	gasoline containers
4	M101	-	3/4-ton trailer
5	M170	-	¼-ton ambulance
6	105mm Howitzer	4	Howitzer
7	M274	3	Weapons carriers
8	M151	-	¼-ton utility Truck
9	M416	-	¼-ton cargo trailer
10	M35	6	2½-ton truck
11	-	-	repair shop truck
12	-	-	2 Honest John rockets
13	M113	7	personnel carrier
14	XM551	8	ARAAV
15	-	-	gasoline cans

by "Modified G-11A". This part of the equipment list also includes the gas turbine required to power the reel-in event. It is assumed that the item denoted by "Power Package" includes the entire power package, i.e., the power turbine, transmission, take-up reel, etc., and associated structure required to make up a self contained power system that is attached to the cargo pallet. Furthermore, the number of G-11A parachutes referenced in these lists are based on a sea level drop zone at normal ambient temperature. The required number of parachutes has been based on the nomogram presented in Figure 1, Section III.B.1 of this report, and the weight of the cargo item provided in Table III of the TIE Contractors report.[1]

Corporation

1. Item No. 1 (M38A1)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste, 1 gal (ENG) ------	As required
3990-360-0248	AF 50C6777	Binder, load ---------------------	16
		Bolt Assembly:	
1670-317-3022	AN 8-11A	Aircraft --------------------	2
1670-360-0272	QM 11-1-210	U-frame suspension -----------	2
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction. (Required only when using a fixed-pin restraint system.)	1
		Clevis Assembly, suspension:	
1670-090-5354	QM 11-1-20	Large -----------------------	5
1670-360-0304	QM 11-1-67	Small -----------------------	2
4020-240-2146	----------	Cord, nylon, type III, 550-lb	As required
1670-360-0328	AF 50C7406	Cover, clevis large --------------	2
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -----------------------	16
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV -----------------------------	1
1670-799-8596	QM 11-1-66	Load Coupler, 8-spool ------------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 10- by 12-in -----------	12
		3- by 11- by 56-in -----------	1
		3- by 12- by 12-in -----------	10
		3- by 12- by 18-in -----------	14
		3- by 12- by 96-in -----------	8
		3- by 16- by 20-in -----------	2
1670-851-4574	AF 61A4312	Parachute, cargo extraction, 22 ft, nylon canopy --------------------	1
		Platform, air delivery, modular, dual-rail system, 12-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	6
1670-893-1630	QM 11-1-320	Fitting, restraing pin assembly (Required only when using a fixed-pin restraint system.)--	2
1670-893-1624	QM 11-1-318	Panel -----------------------	3
1670-893-1626	QM 11-1-321	Rail, platform side, 12-ft ---	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia. (ORD) ------------	48

Federal Stock No.	Part. No.	Item (QM unless otherwise indicated)	Quantity
1670-709-8494	QM 11-1-71	Release, cargo prachute, 5,000-lb capacity ----------------------------	2
		Sling, cargo, A/D:	
1670-753-3788	----------	3-foot ----------------------	3
1670-753-3789	----------	8-foot (2-loop) --------------	2
1670-753-3790	----------	9-foot (2-loop) --------------	2
1670-753-3794	----------	20-foot (2-loop) (riser extension)	1
1670-473-5115	QM 11-1-134	Static line, cargo parachute, break-away type w/release knife and clevis-	2
1670-301-5698	AF 54C6056	Strap, restraint, engine ¼-ton, M38A1 ----------------------------	1
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft -------------	19
1670-368-7486	AF 51C6109-1	Strap, webbing, nylon, 60-in. (shear strap) ---------------------	2
8135-266-5016	----------	Tape, adhesive, 2-in --------------	As required
8305-268-2411	----------	Webbing, cotton, 80-lb ------------	As required
		ITEMS FOR FABRICATION	
		Battery Box Support Assembly:	
5315-010-4657	----------	Nail, wire, steel, common, 6d, (ENG) --------------------	As required
NSN	----------	Plywood (ENG):	
		3/4- by 1½- by 7-in ---------	2
		3/4- by 7- by 10-in ---------	2
		3/4- by 7- by 14 3/4in ------	1
		3/4 - by 9- by 16-3/4-in ----	1
NSN	----------	Lumber, 2- by 4- by 12-in (brace) (ENG) -----------------	1
NSN	----------	Plywood (ENG):	
		3/4- by 12- by 60-in. (windshield protector --------	1
		3/4- by 48- by 60-in. (stowage platform) ----------	1
NSN	----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details see TM 10-500/TO 13C7-1-5.) ------------------	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	1	$170 + basic cost of parachute
Transfer Device	1	$70.00
Power Package	1	$10,000.00

2. Item No. 2 (M37)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, past, 1 gal (ENG) -------	As required
3990-360-0248	AF 50C6777	Binder, load ---------------------	20
1670-897-4459	QM 11-1-149	Cable, release parachute extraction. (Required when fixed-pin restraint system is used.) ----------------	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large-	5
8305-170-5879	----------	Cloth, cotton duck, 72-in. --------	As required
4020-240-2146	----------	Cord, nylon, type III, 550-lb.-----	As required
1670-360-0328	AF 50C7406	Cover, clevis, large -------------	2
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
2510-508-1086	----------	Extension, right side rail, 3/4-ton truck (ORD). (Not required for truck with winch.) --------------------	1
2510-508-1087	----------	Extension, left side rail, 3/4-ton truck (ORD). (Not required for truck with winch.) --------------------	1
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -----------------------	20
1670-783-5988	QM 11-1-58	Link Assembly, single suspension or extraction, quick release, type IV.	1
1670-799-8596	QM 11-1-66	Load coupler, 8-spool ------------	1
5310-012-0371	----------	Nut, plain, hexagon, ½-in. (ORD). (Not required for truck with winch.)	6
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 12- by 12-in -----------	10
		3- by 12- by 14-in -----------	2
		3- by 12- by 24-in -----------	3
		3- by 12- by 30-in -----------	2
		3- by 12- by 36-in -----------	1
		3- by 12- by 40-in -----------	11
		3- by 12- by 48-in -----------	2
		3- by 12- by 54-in -----------	14
		3- by 20- by 60-in -----------	1
		3- by 23- by 36-in -----------	1
		3- by 24- by 48-in -----------	6
1670-687-5458	AF 52K6329	Parachute, cargo extraction, 22-ft-	1
		Platform, air delivery, modular, dual-rail system, 16-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	14
1670-893-1630	QM 11-1-320	Fitting, restraing pin assembly. (Required when fixed-pin restraint system is used). ------------	2

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-893-1624	QM 11-1-318	Panel -----------------------	4
1670-893-1627	QM 11-1-321	Rail, platform side, 16-ft ---	2
5320-893-1632	----------	Rivet, blind drive type, ¼-in dia -------------------------	64
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000lb capabity --------------------	2
5310-012-0424	----------	Screw, cap, ½-in. (ORD). (Not required for truck with winch).	12
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft ------------------------	2
1670-753-3789	----------	8-ft (2-loop) ----------------	1
1670-753-3791	----------	11-ft (2-loop) ---------------	4
1670-753-3794	----------	20-ft (2-loop) (riser extension)	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft ------------	27
8135-266-5016	----------	Tape, adhesive,2-in --------------	As required
5310-012-0384	----------	Washer, lock, ½-in (ORD). (Not required for truck with winch.) ------------	12
8305-268-2411	----------	Webbing, cotton, 80-lb ------------	As required

ITEMS FOR FABRICATION

NSN	----------	Plywood, (ENG):	
		3/4- by 14½- by 60-in (windshield support) ---------	1
		3/4- by 48- by 52-in (stowage platform) -----------	1
NSN	----------	Strap, connector, type X nylon webbing -------------------------	1
		(For fabrication details see TM 10-500/TO 13C7-1-5):	
		60-in for loads under 8,000-lb	1
		120-in for loads over 8,000-lb	0

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated
Modified G-11A	2	$200 + basic cost of parachutes.
Transfer Device	1	$70.00
Power Package	1	$13,000.00

3. Item No. 3

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
3990-360-0248	AF 50C6777	Binder, load ----------------------	17
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large	5
4020-240-2146	-----------	Cord, nylon, natural, type III, 550-lb. --------------------------	14 yd.
		Cover, cargo:	
1670-360-0323	AF 51C6175	End --------------------------	2
1670-360-0324	AF 51C6174	Side -------------------------	2
1670-360-0328	AF 50C7406	Cover, clevis, large --------------	2
1375-862-6923	OA-A2-20	Cartridge, time delay, 20-sec. (ORD)	2
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit ------------------------	34
8305-191-1097	-----------	Felt Sheet, ½ by 36-inch ----------	1 ft.
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV.	1
1670-799-8596	QM 11-1-66	Load Coupler, 8-spool	1
1670-753-3928	-----------	Pad, energy dissipating, honeycomb:	
		3- by 17- by 96-in -----------	1
		3- by 28- by 91-in -----------	1
		3- by 36- by 91-in -----------	2
		3- by 36- by 96-in -----------	2
1670-687-5458	AF 61A4312	Parachute, cargo extraction, 22-ft., nylon canopy (reefed or unreefed). Parachute, cargo, extraction, 15-ft., FSN 1670-691-1117 or FSN 1670-375-9131 may be used when properly reefed. (See par. 22 for requirements.)	1
		Platform, air delivery, modular, dual-rail system, 8-ft.:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ----------	28
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly	2
1670-893-1624	QM 11-1-318	Panel ------------------------	2
1670-893-1625	QM 11-1-321	Rail, platform side, 8-ft.-----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in dia.	32
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb. capacity	2

3. Item No. 3

a. Existing Airdrop Equipment Required (Continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft ------------------------	6
1670-753-3790	----------	9-ft (2-loop) ----------------	4
1670-753-3792	----------	12-ft (2-loop) ---------------	3
1670-753-3794	----------	20-ft (2-loop) (riser extension)	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft ------------	34
8135-266-5016	----------	Tape, adhesive, 2-in -------------	1 roll
8305-268-2411	----------	Webbing, cotton, 80-lb -----------	4 yd
		ITEMS FOR FABRICATION	
NSN	----------	Strap, connector, type X nylon webbing 60-inch (For fabrication details see TM 10-500/TO 13C7-1-5).	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	2	$200 + basic cost of parachutes
Transfer Device	1	$70
Power Package	1	$13,000

4. Item No. 4 (M101)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	-----------	Adhesive, paste, 1 gal. (ENG) ------	As required
3990-360-0248	AF 50C6777	Binder, load ----------------------	14
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large	3
4020-240-2146	-----------	Cord, nylon, type III, 550-lb ------	As required
1670-360-0328	AF 50C7406	Cover, clevis, large --------------	2
8135-558-0823	-----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit ------------------------------	14
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV.	1
1670-799-8596	QM 11-1-66	Load Coupler, 8-spool -------------	1
1670-753-3928	-----------	Pad, energy dissipating, honeycomb:	
		3- by 12- by 12-in -----------	12
		3- by 12- by 32-in -----------	18
		3- by 12- by 36-in -----------	10
		3- by 12- by 42-in -----------	1
		3- by 12- by 50-in -----------	1
		3- by 12- by 53-in -----------	1
		3- by 36- by 36-in. (parachute stowage platform) ------------	1
1670-687-5458	-----------	Parachute, cargo extraction, 22-ft nylon canopy ----------------------	1
		Platform, air delivery, modular, dual-rail system, 12-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	10
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly	2
1670-893-1624	QM 11-1-318	Panel -----------------------	3
1670-893-1626	QM 11-1-321	Rail, platform side, 12-ft ----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia.	48
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb capacity	1
		Sling, cargo, A/D:	
1670-753-3788	-----------	3-ft ------------------------	2
1670-753-3790	-----------	9-ft (2-loop) ----------------	1
1670-753-3792	-----------	12-ft (2-loop) ---------------	2
1670-753-3794	-----------	20-ft (2-loop) (riser extension)	1

4. Item No. 4 (M101)

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft --------------	14
8135-266-5016	-----------	Tape, adhesive, 2-in --------------	As required
8305-268-2411	-----------	Webbing, cotton, 80-lb ------------	As required
		ITEMS FOR FABRICATION	
NSN	-----------	Lumber (ENG), 2- by 12- by 46-in ---	2
NSN	-----------	Plywood (ENG), 3/4- by 2-3/4 by 14-in	1
NSN	-----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details, see TM 10-500/TO 13C7-1-5.)	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	1	$170 + basic cost of parachute
Transfer Device	1	$70
Power Package	1	$10,000

5. Item No. 5 (M170)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste, 1 gal (ENG) -------	As required
3990-360-0248	AF 50C6777	Binder, load ----------------------	17
		Bolt Assembly:	
1670-317-3022	AN 8-11A	Aircraft ---------------------	2
1670-360-0272	QM 11-1-210	U-frame ---------------------	2
		Clevis Assembly, suspension:	
1670-090-5354	AM 11-1-20	Large -----------------------	5
1670-360-0304	QM 11-1-67	Small -----------------------	2
4020-240-2146	----------	Cord, nylon, type III 550-lb -------	As required
1670-360-0328	AF 50C7406	Cover, clevis, large --------------	2
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding -----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit ------------------------	17
1670-738-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV -	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 6- by 12-in ------------	4
		3- by 10- by 12-in -----------	18
		3- by 12- by 12-in -----------	10
		3- by 12- by 16-in -----------	4
		3- by 12- by 112-in ----------	8
		3- by 6- by 20-in ------------	2
		3- by 20- by 56-in -----------	1
1670-687-5854	----------	Parachute, cargo extraction, 22-ft nylon canopy ---------------------	1
		Platform, air delivery, modular, dual-rail system, 12-ft:	
1670-893-1631	QM 11-1-332	Clevis, load tiedown ----------	12
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly. (Required only when using a fixed-pin restraint system). ---	2
1670-893-1624	QM 11-1-318	Panel------------------------	3
1670-893-1626	QM 11-1-321	Rail, plarform side, 12-ft -----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in dia. ------------------------	48
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb. capacity -------------------------	2

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft ----------------------	3
1670-753-3789	----------	8-ft (2-loop) -------------	2
1670-753-3790	----------	9-ft (2-loop) ---------- --	2
1670-753-3794	----------	20-ft (2-loop) (riser Extension)	1
1670-473-5115	QM 11-1-134	Static line, cargo parachute, break-away type, w/release knife and clevis-	2
1670-473-5116	QM 11-1-129	Strap, parachute release, w/fastener and release knife ----------------------	1
1670-301-5698	AF 54C6056	Strap, restraint, engine, ¼-ton, M38A1 --------------------------------	1
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft ---------------	20
1670-368-7486	AF 51C6109-1	Strap, webbing, nylon, 60-in (shear strap)	2
8135-266-5016	----------	Tape, adhesive, 2-in ---------------	As required
8305-268-2411	----------	Webbing, cotton, 80-lb -------------	As required
		ITEMS OF FABRICATION	
		Battery Box Support Assembly:	
5315-010-4657	----------	Nail, wire, steel, common, 6d (ENG)	As required
NSN	----------	Plywood, (ENG)	
		3/4- by 1½- by 7-in -----------	2
		3/4- by 7- by 10-in -----------	2
		3/4- by 7- by 14 3/4-in -------	1
		3/4- by 9- by 16 3/4-in -------	1
NSN	----------	Lumber, 2- by 4- by 12-in (brace) (ENG) -----------------------------	1
NSN	----------	Plywood, (ENG):	
		3/4- by 12- by 60-in (windshield support) ----------	1
		3/4- by 48- by 60-in (stowage platform) ------------	1
NSN	----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details see TM 10-500/TO 13C7-1-5.)	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	1	$170.00 + basic cost of parachute
Transfer Device	1	$70.00
Power Package	1	$10,000.00

6. Item No. 6 (105 mm Howitzer)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	---------	Adhesive, paste, 1 gal. (ENG) -----	As required
3990-360-0248	AF 50C6777	Binder, load ---------------------	21
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large	7
4020-240-2146	----------	Cord, nylon, type III, 550-lb. ----	As required
1670-360-0328	AF 50C7406	Cover, clevis, large -------------	3
1670-360-0330	AF 50C7401	Cover, link, single --------------	3
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -----------------------	21
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV -------------------------	4
1670-799-8596	QM 11-1-66	Load Coupler, 8-spool -----------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 36- by 84-in. ---------	2
		3- by 18- by 36-in. ---------	12
		3- by 36- by 64-in. (sight mount protector) ------------	1
		3- by 36- by 72-in. (accompanying load) ------------------	2
1670-687-5458	AF 52K6329	Parachute, cargo extraction, 22-ft.	1
1670-360-0427	AF 48D7264	Plate, suspension, wheel ---------	2
		Platform, air delivery, modular, dual-rail system, 16-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	24
1670-893-1624	QM 11-1-318	Panel ----------------------	4
1670-893-1627	QM 11-1-321	Rail, platform side, 16-ft. --	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia. (ORD) -----------------	64
1670-799-8494	QM 11-1-71	Release Assembly, parachute, 5,000-lb. capacity --------------	3
		Sling, cargo, A/D (2-loop):	
1670-753-3789	----------	8-ft. ----------------------	3
1670-753-3790	----------	9-ft. ----------------------	2
1670-753-3791	----------	11-ft. ---------------------	1
1670-753-3794	----------	20-ft. ---------------------	2
1670-753-3788	----------	Sling, cargo, A/D, 3-ft. ---------	5

6. Item No. 6 (105 mm Howitzer)

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-473-5115	QM 11-1-134	Static Line, cargo parachute, break-away type, w/release knife and clevis	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft. -------------	21
8135-266-5016	-----------	Tape, adhesive, 2-in. --------------	As required
8305-268-2411	-----------	Webbing, cotton, 80-lb. ------------	As required
		ITEMS FOR FABRICATION	
		Platform, stowage, parachute:	
		Plywood (ENG) 3/4- by 48- by 60-in. -----------------------	1
		Lumber (ENG) 2- by 4- by 60-in.	2
		Nail, wire, steel, common (ENG) 6d ---------------------------	As required
		Strap, connector, type X nylon webbing, 120-in.	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	2	$200 + basic cost of parachutes
Transfer Device	1	$70
Power Package	1	$13,000

7. Item No. 7 (M 274)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste 1 gal. (ENG) ------	1
3990-360-0248	AF 50C6777	Binder, load ----------------------	34
1670-897-4459	QM 11-1-149	Cable, release parachute extraction	1
		Clevis Assembly, suspension:	
1670-090-5354	QM 11-1-20	large ----------------------	7
1670-360-0304	QM 11-1-67	small (used for wheel suspension)	4
8305-170-5879	----------	Cloth, cotton duck, 72-in. --------	3 yd.
4020-240-2146	----------	Cord, nylon, type III, 550-lb -----	40 yd.
1670-360-0328	AF 50C7406	Cover, clevis, large -------------	3
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	4 yd.
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -----------------------	42
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release type IV	3
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 5- by 10-in. -----------	8
		3- by 5- by 12-in. -----------	4
		3- by 5- by 25-in. -----------	18
		3- by 8- by 25-in. -----------	8
		3- by 8- by 27-in. -----------	8
		3- by 12- by 29-in. ----------	36
		3- by 18- by 18-in. ----------	4
		3- by 33- by 36-in. ----------	4
1670-687-5458	AF 61A4312	Parachute, cargo extraction, 22-ft, nylon canopy (unreefed) -----------	1
		Platform, air delivery, modular, dual-rail system 8-ft.	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	12
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly	2
1670-893-1624	QM 11-1-318	Panel ----------------------	2
1670-893-1625	QM 11-1-321	Rail, platform side, 8-ft. ---	2
1670-893-1632	QM 11-1-317	Rivet, blind drive type, ½-in. dia. (use SM 10-1-1600 for requisitioning rivets until SM 9-1-C5320-SL is available)	32
1670-543-3731	AF 50C6814	Release Assembly, parachute, single w/ejector springs	2

7. Item No. 7 (M 274)

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-251-1153	AF 51C6716	Sling, cargo, 500-lb. capacity, 188-in. long, (A-7A) ---------------	1
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft. ------------------------	9
1670-753-3789	----------	8-ft. (2-loop) ---------------	3
1670-753-3791	----------	11-ft. (2-loop) --------------	4
1670-753-3792	----------	12-ft. (2-loop) --------------	4
1670-753-3793	----------	16-ft. (2-loop) --------------	2
1670-753-3794	----------	20-ft. (2-loop) (riser extension)	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft. ------------	34
1670-368-7486	AF 51C6109-1	Strap, webbing, nylon, 60-in. (shear strap) ---------------------------	1
8135-266-5016	----------	Tape, adhesive, 2-in. -------------	1 roll
8305-268-2411	----------	Webbing, cotton, 80-lb. -----------	9 yd.
		ITEMS FOR FABRICATION	
NSN	----------	Lumber (ENG):	
		2- by 6- by 36-in. (braces) ---	3
		2- by 6- by 106½-in. (load spreader) --------------------	2
5315-164-5121	----------	Nail, wire, steel, common, 20d (ENG)	1 lb.
		Platform, combat-expendable, 96-in. by 107-in. ------------------------	
NSN	----------	Lumber (ENG):	
		2- by 6- by 12-in. -------	24
		2- by 6- by 28-in. -------	4
		2- by 6- by 84-in. -------	4
		2- by 6- by 106½-in. -----	3
		Nail, wire, steel, common (ENG):	
5315-010-4657	----------	6d ----------------------	2 lb.
5315-010-4659	----------	8d ----------------------	2 lb.
5315-164-5121	----------	20d ---------------------	5 lb.
NSN	----------	Plywood (ENG):	
		3/4- by 11- by 96-in. ---------	1
		3/4- by 48- by 96-in. ---------	2
NSN	----------	Plywood (ENG):	
		3/4- by 6- by 36-in. (braces)	3
		1/2- by 6- by 36-in. (braces)	3

7. Item No. 7 (M 274)

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
NSN	----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details see TM 10-500/TO 13C7-1-5.)	1
8305-260-6890	----------	Webbing, nylon, type X -----------	23 yd.

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	2	$200 + basic cost of parachutes
Transfer Device	1	$70
Power Package	1	$13,000

8. Item No. 8 (M151)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
8040-273-8713	----------	Adhesive, paste, 1 gal. (ENG) -----	As required
3990-360-0248	AF 50C6777	Binder, load ---------------------	15
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction. (Required only when using a fixed-pin restraint system.)	1
		Clevis Assembly, suspension:	
1670-090-5354	QM 11-1-20	Large -------------------------	4
1670-360-0304	QM 11-1-67	Small -------------------------	4
8305-170-5879	----------	Cloth, cotton duck, 72-in. ---------	3 yd.
4020-240-2146	----------	Cord, nylon, type III, 550-lb. -----	As required
1670-360-0330	AF 50C7401	Cover, link, single ---------------	1
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding -----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -------------------------	15
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV.	2
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 6- by 8-in --------------	28
		3- by 12- by 12-in ------------	6
		3- by 12- by 18-in ------------	1
		3- by 18- by 20-in ------------	6
		3- by 18- by 61-in ------------	2
		3- by 20- by 50-in ------------	1
		3- by 24- by 48-in ------------	3
1670-887-5458	AF 61A4312	Parachute, cargo extraction, 22 ft. nylon canopy ---------------------	1
		Platform, A/D, modular, dual-rail system, 8-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown -----------	12
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly Required only when using a fixed-pin restraint system.) ---------	2
1670-893-1624	QM 11-1-318	Panel -------------------------	2
1670-893-1625	QM 11-1-321	Rail, platform side, 8-ft. -----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in, dia ---------------------------	32
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb. capacity -------------------------	1
		Sling, A/D:	
1670-753-3788	----------	3-ft --------------------------	4
1670-753-3790	----------	9-ft. (2-loop) ----------------	4
1670-753-3794	----------	20-ft. (2-loop) (riser extension)	1

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-473-5115	QM 11-1-134	Static Line, cargo parachute, breakaway type w/release knife and clevis.	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft. -------------	15
8135-266-5016	----------	Tape, adhesive, 2-in ---------------	As required
8305-268-2411	----------	Webbing, cotton, 80-lb -------------	As required
		ITEMS FOR FABRICATION	
NSN	----------	Lumber, 2- by 4- by 96-in. (ENG) ---	2
NSN	----------	Plywood (ENG):	
		3/4- by 18- by 20-in -----------	1
		3/4- by 24- by 48-in ----------	1
NSN	----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details see TM 10-500/TO 13C7-1-5.)	1

b. New of Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	1	$170.00 + basic cost of parachute
Transfer Device	1	$70.00
Power Package	1	$10,000.00

9. Item No. 9 (M416)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste, 1 gal (ENG) -------	1
3990-360-0248	AF 50C6777	Binder, load ----------------------	10
1670-897-4459	QM 11-1-149	Cable, release, parachute, extraction	1
1375-862-6923	OA-A2-20	Cartridge, time delay, 20-sec (ORD)-	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large--	3
4020-240-2146	----------	Cord, nylon, type III, 550-lb ------	4 yd.
1670-360-0329	AF 50C7496	Cover, link, dual cluster ----------	1
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	4 yd.
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit -----------------------	10
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV--	2
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 12- by 42-in ------------	18
		3- by 36- by 72-in ------------	As required
1670-851-4574	AF 61A4312	Parachute, cargo extraction, 15-ft. nylon canopy (reefed with 260-in reefing line). Parachute, cargo extraction, 15-ft, FSN 1670-691-1117 or FSN 1670-375-9131 may be used when properly reefed. ------------------	1
		Platform, air delivery, modular, dual-rail system, 8-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown -----------	20
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly-	2
1670-893-1624	QM 11-1-318	Panel --------------------------	2
1670-893-1625	QM 11-1-321	Rail, platform side, 8-ft ------	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia. -------------------------	32
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb capacity ------------------------	1
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft --------------------------	7
1670-753-3789	----------	8-ft (2-loop) -----------------	4
1670-753-3794	----------	20-ft Riser Extension ----------	1
1670-473-5115	QM 11-1-134	Static line, cargo parachute, break-away type, w/release knife and clevis	2
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft -------------	10
8135-266-5016	----------	Tape, adhesive, 2-in --------------	1 roll

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS FOR FABRICATION	
NSN	----------	Strap, connector, type X nylon webbing, 60-in. (For fabrication details, see TM 10-500/TO 13C7-1-5.)	

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	1	$170.00 + basic cost of parachute
Transfer Device	1	$70.00
Power Package	1	$10,000.00

10. Item No. 10 (M 35)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste, 1 gal. (ENG) ------	1
3990-360-0248	AF 50C6777	Binder, load ----------------------	30
1670-630-9013	QM 11-1-119	Bracket Assembly, suspension, 2½-ton truck, M35 ------------------------	2
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction (required only with fixed-pin restraint system)	1
1375-862-6923	OA-A2-20	Cartridge, time delay, 20-sec. (ORD)	6
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large --	15
1670-360-0308	AF 51B6245	Clevis, suspension, cargo (link assembly, dual, suspension may be used) ----------------------------	2
4020-240-2146	----------	Cord, nylon, type III, 550-lb. ------	10 yd.
1670-360-0328	AF 50C7406	Cover, clevis, large ---------------	6
1670-360-0329	AF 50C7496	Cover, link, dual cluster ----------	18
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------------	4 yd.
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit --------------------------------	30
1670-573-6790	AF 53C7171	Frame Extension Assembly (required only when vehicle is not equipped with winch)	1
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV --	19
1670-799-8597	QM 11-1-66	Load Coupler, 12-spool -------------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 6- by 12-in. ------------	6
		3- by 6- by 30-in. ------------	6
		3- by 12- by 12-in. -----------	5
		3- by 12- by 18-in. -----------	1
		3- by 12- by 20-in. -----------	7
		3- by 12- by 30-in. -----------	5
		3- by 12- by 36-in. -----------	13
		3- by 12- by 40-in. -----------	1
		3- by 12- by 42-in. -----------	12
		3- by 12- by 54-in. -----------	12
		3- by 12- by 60-in. -----------	12
		3- by 18- by 18-in. -----------	18
		3- by 19- by 65-in. -----------	1
		3- by 20- by 30-in. ---------- -	5
		Parachute, cargo extraction, 35 ft.	1

10. Item No. 10 (M 35)

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		Platform, air delivery, modular, dual-rail system, 24-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ----------	18
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly ----- (required only with fixed-pin restraint system)	2
1670-893-1624	QM 11-1-318	Panel ------------------------------	6
1670-893-1629	QM 11-1-321	Rail, platform side, 24-ft. ---------	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia. (ORD) -------------------------------	96
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb. capacity (if not available, use release assembly, parachute, multiple)	6
		Sling, cargo, A/D:	
1670-753-3788	-----------	3-ft. ------------------------	9
1670-753-3789	-----------	8-ft. (2-loop) ----------------	1
1670-753-3791	-----------	11-ft. (2-loop) ---------------	4
1670-753-3793	-----------	16-ft. (2-loop) ---------------	4
1670-753-3794	-----------	20-ft. (2-loop) ---------------	12
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft. -------------	37
8135-266-5016	-----------	Tape, adhesive, 2-in. --------------	1 roll
8305-268-2411	-----------	Webbing, cotton, 80-lb. ------------	9 yd.
		ITEMS FOR FABRICATION	
NSN	-----------	Lumber, 3-1/8- by 4- by 9-in. (ENG) (required only when M34 truck is rigged with M35 suspension brackets)	2
NSN	-----------	Plywood, 3/4- by 19- by 65-in. (ENG)	1
NSN	-----------	Strap, connector, type X nylon webbing, 120-in. (For fabrication details see TM 10-500/TO 13C7-1-5)	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	4	$250 + cost of parachutes
Transfer Device	1	$70
Power Package	1	$16,000

11. Item No. 11

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		ITEMS OF ISSUE	
8040-273-8713	----------	Adhesive, paste, 1 gal (ENG) ------	As required
3990-360-0248	AF 50C6777	Binder, load ------------------------	31
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction (Required when fixed-pin restraint system is ued.)	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large	8
4020-240-2146	----------	Cord, nylon, type III, 550-lb.	As required
1670-360-0329	AF 50C7496	Cover, link, dual ----------------	8
1670-360-0328	AF 50C7406	Cover, clevis, large ---------------	4
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit ------------------------	31
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV	9
1670-799-8596	QM 11-1-66	Load Coupler, 8-spool ------------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 12- by 12-in. ----------	28
		3- by 12- by 22-in. ----------	3
		3- by 12- by 24-in. ----------	2
		3- by 12- by 36-in. ----------	1
		3- by 12- by 40-in. ----------	10
		3- by 12- by 43-in. ----------	2
		3- by 12- by 48-in. ----------	17
		3- by 18- by 12-in. ----------	1
		3- by 18- by 22-in. ----------	1
		3- by 18- by 48-in. ----------	6
		3- by 20- by 22-in. (under gasoline cans) ----------------	1
		3- by 22- by 48-in. ----------	7
		3- by 36- by 52-in. (hood protector) -------------------	1
1670-687-5459	AF 52K6329	Parachute, cargo extraction, 28 ft.	1
		Platform, air delivery, modular, dual-rail system, 20-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown -------------	20

11. Item No. 11

a. Existing Airdrop Equipment Required (continued)

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly ---- (Required when fixed-pin restraint system is used.)	2
1670-893-1624	QM 11-1-318	Panel ------------------------	5
1670-893-1628	QM 11-1-321	Rail, platform side, 20-ft ----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type ¼-in.dia.	80
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb capacity -------------------------	4
		Sling, cargo, A/D:	
1670-753-3788	-----------	3-ft -------------------------	6
1670-823-5042	-----------	16-ft (3-loop) ---------------	4
1670-753-3794	-----------	20-ft (2-loop) (riser extension)	6
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft -------------	31
8135-266-5016	-----------	Tape, adhesive, 2-in --------------	As required
8305-268-2411	-----------	Webbing, cotton, 80-lb ------------	As required
8305-263-3591	-----------	Webbing, nylon, type VIII (parachute restraint strap)	10 yd
		ITEMS FOR FABRICATION	
		Platform, stowage, parachute:	
NSN	-----------	Lumber, 4- by 4- by 53-in (ENG)	1
5315-010-4659	-----------	Nail, steel wire, common, 8d (ENG)	As required
NSN	-----------	Plywood, 3/4- by 48- by 60-in. (ENG)	1
		Roof Support	
NSN	-----------	Lumber (ENG):	
		2- by 4- by 19-in -------	1
		2- by 4- by 26-in -------	1
		2- by 4- by 49½-in ------	2
		2- by 12- by 50½ in -----	1
5315-010-4659	-----------	Nail, steel wire, common, 8d (ENG)	As required
NSN	-----------	Strap, connector, type X nylon webbing, 120-in. (For fabrication details see TM 10-500/TO 13C7-1-5.)	1

11. Item No. 11 (continued)

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	3	$230 + basic cost of parachutes
Transfer Device	1	$70
Power Package	1	$14,000

12. Item No. 12

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
8040-273-8713	----------	Adhesive, paste, 1 gal (ENG) -------	As required
3990-360-0248	AF 50C6777	Binder, load ----------------------	28
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction (used only with fixed-pin restraint system). ----------------------	1
1670-090-5354	QM 11-1-20	Clevis Assembly, suspension, large-	10
4020-240-2146	----------	Cord, nylon, type III, 550-lb -----	As required
1670-360-0328	AF 50C7406	Cover, clevis, large -------------	5
1670-360-0329	AF 50C7496	Cover, link, dual cluster ---------	27
8135-558-0823	----------	Cushioning Material, packaging, cellulose wadding ----------------	As required
1670-360-0340	AN 6508-1	Fastener, strap, quick-fit --------	47
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV.	28
1670-799-8597	QM 11-1-66	Load Coupler, 12-spool -----------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 8- by 50-in ------------	1
		3- by 8- by 86-in ------------	5
		3- by 12- by 18-in -----------	13
		3- by 12- by 24-in -----------	2
		3- by 16- by 18-in -----------	2
		3- by 16- by 36-in -----------	1
		3- by 18- by 18-in -----------	6
		3- by 18- by 32-in -----------	36
		3- by 18- by 50-in -----------	1
		3- by 18- by 70-in -----------	2
		3- by 18- by 86-in -----------	10
1670-687-5459	----------	Parachute, cargo extraction, 28-ft	1
		Platform, air delivery, modular, dual-rail system, 24-ft:	
1670-893-1631	QM 11-1-322	Clevis, load tiedown ---------	20
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly (used only with fixed-pin restraint system). --------------------	2
1670-893-1624	QM 11-1-318	Panel -----------------------	6
1670-893-1629	QM 11-1-321	Rail, platform side, 24-ft ----	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in dia. -----------------------	96
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb capacity -----------------------	5

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		Sling, cargo, A/D:	
1670-753-3788	----------	3-ft	10
1670-753-3789	----------	8-ft (2-loop)	6
1670-753-3790	----------	9-ft (2-loop)	14
1670-753-3791	----------	11-ft (2-loop)	4
1670-823-5040	----------	11-ft (3-loop)	2
1670-753-3794	----------	20-ft (2-loop) (riser extension)	6
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft	29
8135-266-5016	----------	Tape, adhesive, 2-in	As required
8305-268-2411	----------	Webbing, cotton, 80-lb	As required
8305-263-3591	----------	Webbing, nylon, type VIII (parachute restraint strap)	10 yd
		ITEMS FOR FABRICATION	
		Platform, stowage, parachute:	
NSN	----------	Lumber, 2- by 6- by 96-in (ENG)	3
5315-010-4659	----------	Nail, wire, steel, common, 8d (ENG)	As required
NSN	----------	Plywood, 3/4- by 48- by 96-in (ENG)	1
NSN	----------	Strap, connector, type X nylon webbing, 120-in. (For fabrication details see TM 10-500/TO 13C7-1-5).	1

5. New or Modified Items

Item Description	Quantity	Average Unit Cost (Estimated)
Modified G-11A	3	$230.00 + basic cost of parachute
Transfer Device	1	$70.00
Power Package	1	$15,000.00

13. Item No. 13 (M113)

a. Existing Airdrop Equipment Required

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity)
8040-273-8713	----------	Adhesive, paste, 1 gal. (ENG) -----	As required
3990-360-0248	AF 50C6777	Binder, load ----------------------	39
1670-897-4459	QM 11-1-149	Cable, release, parachute extraction (Required only when using a fixed-pin restraint system). ------------	1
1670-090-5354	QM 11-1-20	Clevis, Assembly, suspension, large	21
8305-170-5879	----------	Cloth, cotton duck, 72-in ---------	As required
4020-240-2146	----------	Cord, nylon, type III, 550-lb -----	As required
1670-360-0328	AF 50C7406	Cover, clevis, large -------------	6
1670-360-0329	AF 50C7496	Cover, link, dual ----------------	18
1670-360-0340	AN 6508-1	Fastener, strap, cargo tiedown, quick-fit ------------------------	39
1670-783-5988	QM 11-1-58	Link Assembly, single, suspension or extraction, quick-release, type IV-	19
1670-799-8597	QM 11-1-66	Load Coupler, 12-spool -----------	1
1670-753-3928	----------	Pad, energy dissipating, honeycomb:	
		3- by 12- by 12-in ------------	11
		3- by 12- by 16-in ------------	10
		3- by 12- by 18-in ------------	3
		3- by 12- by 22-in ------------	6
		3- by 12- by 36-in ------------	20
		3- by 12- by 60-in ------------	7
		3- by 16- by 144-in -----------	2
		3- by 18- by 60-in ------------	7
		3- by 18- by 72-in ------------	1
		3- by 22- by 60-in ------------	14
		Platform, air delivery, modular, dual-rail system, 20-ft:	
1670-893-163	QM 11-1-322	Clevis, load tiedown ----------	32
1670-893-1630	QM 11-1-320	Fitting, restraint pin assembly (Required only when using a fixed-pin restraint system).----	2
1670-893-1624	QM 11-1-318	Panel -------------------------	5
1670-893-1628	QM 11-1-321	Rail,platform side, 20-ft ------	2
5320-893-1632	QM 11-1-317	Rivet, blind drive type, ¼-in. dia -------------------------	80
1670-799-8494	QM 11-1-71	Release, cargo parachute, 5,000-lb. capacity ----------------------	6

Federal Stock No.	Part No.	Item (QM unless otherwise indicated)	Quantity
		Sling, cargo, A/D:	
1670-753-3788	--------	3-ft ----------------------------	9
1670-753-3794	--------	20-ft (2-loop) (riser extension)	20
1670-753-3630	--------	8-ft (3-loop) ------------------	5
1670-753-3631	--------	9-ft (3-loop) ------------------	4
1670-473-5115	QM 11-1-134	Static line, cargo parachute, breakaway type w/release knife and clevis	
1670-473-5116	QM 11-1-129	Strap, parachute release, w/fastener	
1670-360-0540	AF 50C7421-1	Strap, tiedown, 15-ft. --------------	39
8135-266-5016	--------	Tape, adhesive, 2-in ----------------	As required
8305-268-2411	--------	Webbing, cotton, 80-lb --------------	As required
8305-263-3591	--------	Webbing, nylon, type VIII (parachute restraint strap)--------------------	10 yd.
		ITEMS FOR FABRICATION	
NSN	--------	Lumber, 2- by 4- by 14¼-in. (ENG) -----	3
NSN	--------	Plywood, 3/4- by 11- by 37-in. (ENG)	2
		Platform, stowage, parachute:	
NSN	--------	Lumber, 2- by 6- by 96-in. (ENG)	3
5315-010-4659	--------	Nail, wire, steel, common, 8d (ENG)	As required
NSN	--------	Plywood, 3/4- by 48- by 96-in. (ENG)	1
NSN	--------	Strap, connector, type X nylon webbing, 120-in. (For fabrication details see TM 10-500/TO 13C7-1-5 ------------------	1

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (estimated)
Modified G-11A	5	$ 270 + basic cost of parachutes
Transfer Device	1	$ 70
Power Package	1	$ 50,000

14. Item No. 14 (XM 551)

a. Existing Airdrop Equipment

Federal Stock No.	Part No.	Item
		Extraction Parachute Subsystem
NSN	AF58J6098	Deployment Bag, 28-ft dia., Cargo Extraction Parachute
NSN	NLABS-T65-1	Deployment Bag Retaining Line, Nylon Webbing, 4,000 lb, width 1-in, cut length-48 in (canopy-deployment bag) MIL-W-5625
NSN	AF58K6326	Canopy, Parachute, cargo extraction, 28-ft dia.
NSN	AF57D6300	Web, Adapter for 28-ft dia. cargo extraction parachute
NSN	AF(X64B2173)	Link, 3-point (extraction line to extraction parachute adapter web)
NSN	AF(X65D1511) NLABST65-2	Line, extraction, 60', 5 loop, type XXVI Nylon Webbing for C-130 aircraft
		Extraction Force Transfer Subsystem
NSN	AF(X64B2174)	Link, 2 point (extraction line to connector strap, connector strap to load)
NSN	NLABS-T65-1	Strap, connector type XXVI Nylon, 20-ft long (extraction line - load)
1670-783-5988	QM-11-1-58	Link, quick release, type IV (joining ends of connector strap)
NSN	QM-11-1-20 (modified)	Clevis, Suspension, large (spread) (2 point link to deployment line)
NSN	--------	Bolt for clevis, suspension, large (spread)
NSN	NLABS-T63-1 AF(X63J4301) (modified)	Line, deployment, 8-ft., 4 loop, type XXVI Nylon
1670-090-5354	QM-11-1-20	Clevis Assembly, suspension, large, G-11
1670-753-3788	MIL-S-25963	Sling, cargo, air delivery, 3 loop, 3-ft., type nylon
		Recovery Parachute Subsystem
1670-823-5043	MIL-S-25963	Sling Cargo,air delivery, 3 loop, 20-ft, type X nylon (riser extension)
1670-783-5988	QM-11-1-58	Link, quick release, type IV (joining riser extensions)
		Suspension Subsystem
1670-799-8494	MIL-R-43003(QMC)	Release Cargo Parachute, 5,000 lb. capacity
1375-862-6923	--------	Cartridge, time delay, 20 seconds
1670-753-3788	MIL-S-25963	Sling, cargo, air delivery, 3 loop, 3 point type X nylon
NSN	NLABS-SK-143	Load Coupler, 8/4 spool
NSN	NLABS-T63-1 AF(X63J4301) (modified)	Sling, suspension, 4 loop, 16-ft., type XXVI nylon
NSN	RR-C-271a	Shackle, suspension, screw-pin, type IV, class 2

Federal Stock No.	Part No.	Item
		Platform Subsystem
NSN	XM-551	Load (XM551 vehicle)
---------------	--------	Plywood
1670-753-3928	MIL-H-9889	Pad, energy dissipating, aerial delivery honeycomb
1670-893-1624	QM-11-1-318	Panel, platform
1670-893-1629	QM-11-1-321	Rail, platform, side, notched, 24-ft
1670-893-1631	QM-11-1-322	Clevis, load tiedown, platform
NSN	--------	Tiedown, cargo, aircraft, 10,000 lab. 15-ft dacron strap and dee ring
NSN	NLABS-SK-161	Binder, load, 10,000 lb . capacity (used with tiedown above)
NSN	NLABS-SK-181	Dee ring, heavy duty (used with tiedown above)

b. New or Modified Items

Item Description	Quantity	Average Unit Cost (estimated)
Modified G-11A	8	$ 330 + basic cost of parachutes
Transfer Device	1	$ 70
Power Package	1	$ 50,000

V. CONCLUSIONS AND RECOMMENDATIONS

The following table summarizes the characteristics of the reel-in system required by each of the cargo items listed in Table III of this report.

TABLE XXIII
REEL-IN SYSTEM CHARACTERISTICS

Item	No. G-11A Parachutes	Reel System Power Requirement	"Solar" Gas Turbine Designation	
			Name	Model No.
1	1	80 (71.5)	Titan	T-62 series
2	1	" (80)	"	" "
3	2	200 (139)	-	T-220 series
5	2	200 (179)	-	" "
6	4	400 (339)	-	T-350 series
7	5	1000 (670)	Saturn	T-1000 series
8	8	1000 (1000)	"	" "

The power system characteristics given in this table have been rounded-off to the figure corresponding to an available gas turbine unit, (the magnitudes in parenthesis are the computed power requirements), and are based on a sea level drop zone altitude at normal ambient temperature. However, as noted in Table V, Section III B 2 of this report, for cargo items 5 and 8, the required power output of the reel system does not increase significantly with an increase in both drop zone altitude and ambient temperature. Hence, the magnitudes given in Table XXI can be considered effective for a wide range of drop zone environments. In addition, as noted previously, cargo items 1, 2, and 3 do not require a powered reel-in system for sea level drop zone conditions. However, power systems are listed for these cargo items, since higher altitude and temperature drop zones may necessitate that a power system be used with these items. The validity of this statement should, of course, be verified by computation of the trajectory characteristics of these cargo items for other drop zone altitude and temperature conditions.

With reel-in systems powered by the designated gas turbine system*, all of these cargo items can be airdropped from extraction altitudes of 500 feet or less and will impact the ground at approximately 28.5 fps with a minimum of horizontal motion. Hence, it can be concluded that the primary objectives of this concept study program have been satisfied. It is recognized that the most costly item associated with the reel-in airdrop system is the basic power package. Although this particular component cost is high, the

* In this report, power systems based on gas turbine units have been emphasized primarily because of the approximate "off-the-shelf" availability of these systems. However, as noted in Part 3 of Section III 3 of this report, there are other power unit concepts that, while undeveloped and untested at this point, could provide the required system power

re-use of the system must be considered in evaluating the effective cost-use envelope of the system. Since the addition of the reel-in event assures that even the heaviest cargo items can be safely airdropped, the cargo, cargo pallet, and power package should not be damaged by the touchdown event. Hence, the pallet-power package components should be reuseable, thus lowering the total system cost per airdrop.

On the basis of the results that have been generated during this evaluation program, it is recommended that the reel-in airdrop system be programmed for future development by the Natick Laboratories. The reel-in concept is applicable to a wide range of cargo weights (2000 to 35000 lbs.) and does not require a great deal of modification to the existing gear used in a standard airdrop system. Of course, the power package and associated modifications of the cargo suspension lines will involve some familiarization and retraining on the part of the rigging and airdrop crew, but the inherent simplicity of the operation of the system coupled with the capability of assuring safe airdrops from altitudes of 500 feet or less far outweigh these negative factors.

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13. ABSTRACT

Results and conclusions are reported for work accomplished on the program, during the period 30 November 1965 through 31 August 1966, of evaluating parachute reel in/reel out systems designed to permit airdrops to be made from altitudes of 500 feet or less and with vertical velocities of the cargo at ground impact not exceeding 28.5 fps, with as little horizontal motion as possible. The weight range of the cargos of interest is between 2000 and 35000 lb. Cargo descent trajectory data and candidate reel system designs are presented and discussed in this report. A review of the program requirements is also included.

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Low altitude	4		4			