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ELEVATION OF RECOVERY PARACHUTE:

LOW-ALTITUDE AIRDROP
EXPLORATORY DEVELOPMENT [PROJECT No. 1M121401D195]

FINAL REPORT

by

Edwin D. Vickery

PIONEER PARACHUTE COMPANY, INC.
Manchester, Connecticut

CONTRACT NO. DA19-129-AMC-849(N)

August 1966

U.S. Army Natick Laboratories
Natick, Massachusetts 01760

Airdrop Engineering Division

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ABSTRACT

This final report was prepared by Pioneer Parachute Company, Inc., under Contract DA19-129-AMC-849(N) with the Airdrop Engineering Division of the U.S. Army Natick Laboratories.

The report discusses the approaches pursued, and the results and conclusions reached, during this preliminary study conducted to investigate the feasibility of elevating the main recovery parachutes above the flight path of an airdrop aircraft by means of auxiliary lifting parachutes.

Preliminary analytical studies and experimental tests were conducted during the evaluation period from 30 November 1965 through 31 August 1966.

The overall objective was to determine the technical, operational, and economic feasibility of elevating the main recovery parachutes to achieve a low-altitude airdrop capability of 500 feet (absolute) altitude or less, as a basis for determining if further "in-depth" study were warranted.

The results obtained indicate that the elevation of recovery parachutes by auxiliary lifting parachutes is not feasible.

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LIST OF SYMBOLS

Symbol	Definition
C_D	drag coefficient
C_{Dr}	reefed-drag coefficient
C_L	lift coefficient
C_T	tangent-force coefficient
C_v	vertical component of lift and drag coefficients
D	drag force
d	riser separation
D_o	parachute nominal diameter, $= (4S_o/\pi)^{\frac{1}{2}}$
D_p	projected or inflated diameter of the aerodynamic decelerator, ft
F_e	extraction force
F_v	vertical force
L	lift force
q	dynamic pressure ($= 0.5\rho V^2$), lb/ft^2
R	resultant force
S_o	parachute-canopy surface area, ft^2
T	tangent force
t	time
V	velocity
V_v	vertical velocity
W	suspended weight
γ	trajectory angle
ρ	density of air at a given altitude, $slugs/ft^3$

Subscript

1	cargo
2	Para-Sail
3	recovery parachute

Additional symbols, when used, are defined in the text.

1.0 INTRODUCTION

This report is submitted in compliance with U.S. Army Natick Laboratories Contract DA19-129-AMC-849(N) (Elevation of Recovery Parachutes), dated 30 November 1965.

Three methods of cargo delivery were studied for low-level application:

(a) elevation of recovery parachutes,

(b) a lifting parachute attached to the load, and

(c) recovery parachute held at an upward angle of attack.

These studies included a qualitative analysis, trajectory sti , and model tow testing.

It is the purpose of this document to report on these findings.

This document is organized in the following manner. Section 2.0 defines the problem. Section 3.0 describes the approach to the problem. Section 4.0 presents the results of the analytical studies of the three areas of study. Section 5.0 is concerned with the operational aspects, and the conclusions and recommendations are given in Section 6.0.

2.0 STATEMENT OF PROBLEM

Cargo delivery from altitudes of 500 ft or less is desired to minimize susceptibility to enemy action and to achieve improved airdrop accuracy. Present conventional parachute recovery systems used for heavy cargo require higher altitudes for successful recovery because their physical size (length) demands relatively long deployment and filling times.

One proposed solution to the problem of low-altitude recovery is to elevate the recovery parachute(s) above the flight path of the drop aircraft in order to gain altitude and thereby decrease the altitude required of the drop aircraft at time of drop.

One of the primary objectives of this investigation was to determine the technical feasibility of the proposed elevation of recovery parachute concept

3.0 APPROACH

The approach selected for this study consisted of the following areas of consideration.

(a) Preliminary theoretical and practical analytical investigation of the entire recovery system,

(b) investigation by small-model experimentation, portions of the concept that could not be analyzed theoretically, and

(c) comparison of the results of the analytical investigation and the model experimentation with the performance goals of the contract.

Early in the investigations, an approach evolved in which a lifting parachute was attached directly to the load. This approach appeared much more effective than elevating the recovery parachutes, so a substantial work effort was applied to this new approach. However, this new approach did not conform to the principle of the airdrop concept in the contract. Therefore, Pioneer was directed to stop work on this approach and to concentrate the work effort on establishing the feasibility of the concept of elevating the recovery parachutes.

Out of this redirected effort evolved a new approach in which the recovery parachutes are elevated above the flight path, although the principle differs from that in the originally proposed concept.

Because of the foregoing turn of events, there are now three distinct principles involved, i.e., three different airdrop systems, work on which is reported in the following sections.

4.0 ANALYTICAL STUDIES

4.1 Elevation of Recovery Parachute (ERP) Concept

4.1.1 Definition of Elevation of Recovery Parachute Concept

This elevation of recovery parachute(s) concept study was based on three proposed approaches for utilizing auxiliary lifting parachutes to increase the effective airdrop altitude by elevating the recovery parachutes above the flight path of the aircraft. Pioneer investigated these three approaches, which are described below.

4.1.2 Description of Concept Approaches

4.1.2.1 Approach A

Shown in Fig. 1 (a two-page figure) is approach A, in which a lifting parachute (in this case, a Para-Sail), extracts the load, then deploys the recovery parachutes. The sequence of events is as follows. Step 1 shows the pilot chute deployed, which in turn deploys the Para-Sail, as in step 2. The next step shows the Para-Sail inflated. A Para-Sail with low L/D (inherently low, or reefed so as to be temporarily low), or a high-L/D Para-Sail restrained by means of guide-surface parachutes, is used to avoid tail interference. Step 4 shows the Para-Sail extracting the load. Step 5 shows the Para-Sail deploying the recovery parachutes while lifting them in the process. Step 6 shows the reefed recovery parachutes, and step 7 shows the fully inflated recovery parachutes, the final step of the sequence.

4.1.2.2 Approaches B and C

Shown in Fig. 2 (a two-page figure) are approaches B and C. These approaches are similar to approach A except that extraction occurs later in the sequence of events. Referring to step 4, the Para-Sail deploys the recovery parachutes to line stretch (approach B) or to canopy (system) stretch (approach C), at which point the load is extracted. The bag is held closed during extraction for approach B, then released for normal deployment. The remainder of the sequence is similar to approach A.

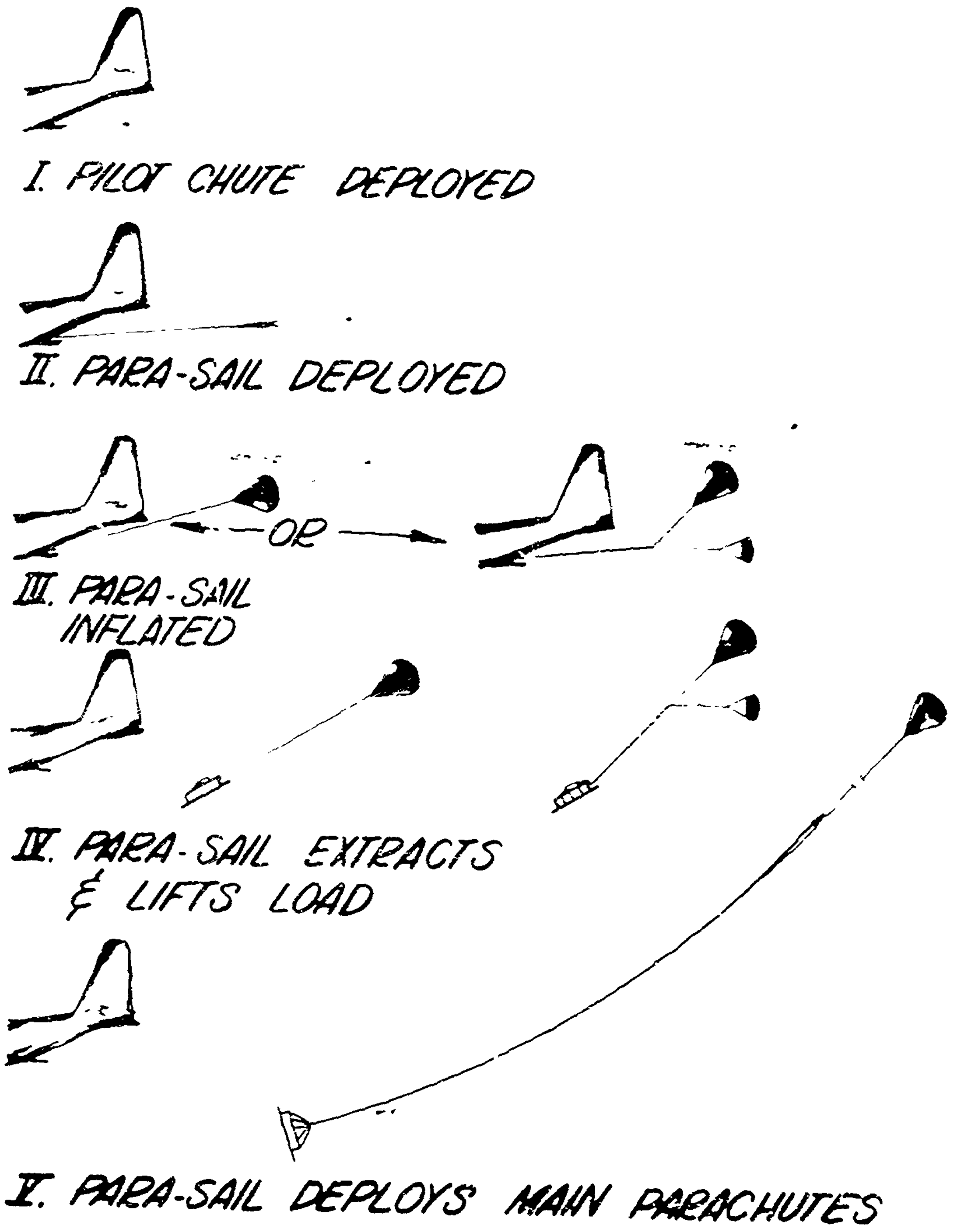


FIG. 1. APPROACH A (CONCLUDED NEXT PAGE).

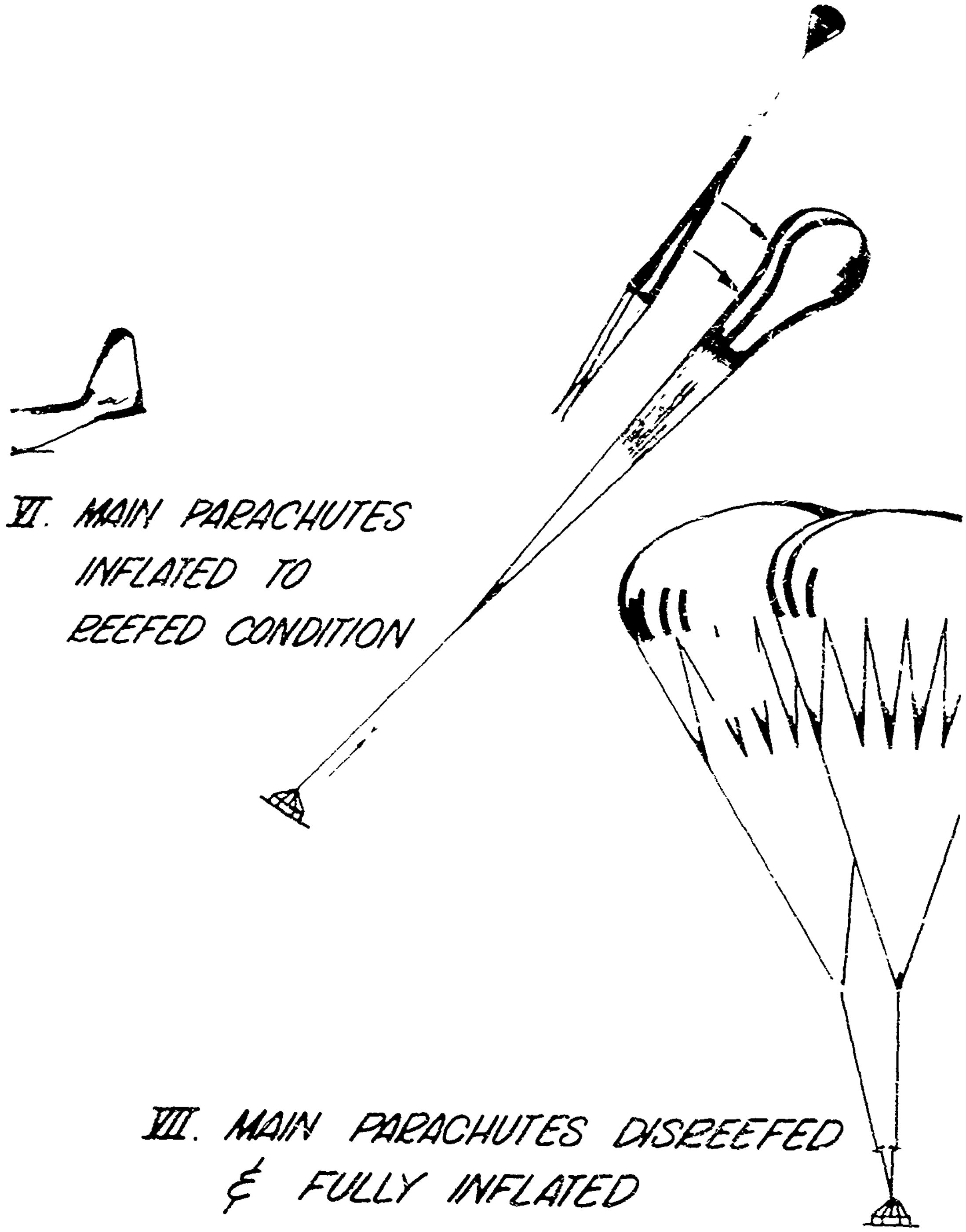


FIGURE 1 (CONCLUDED)

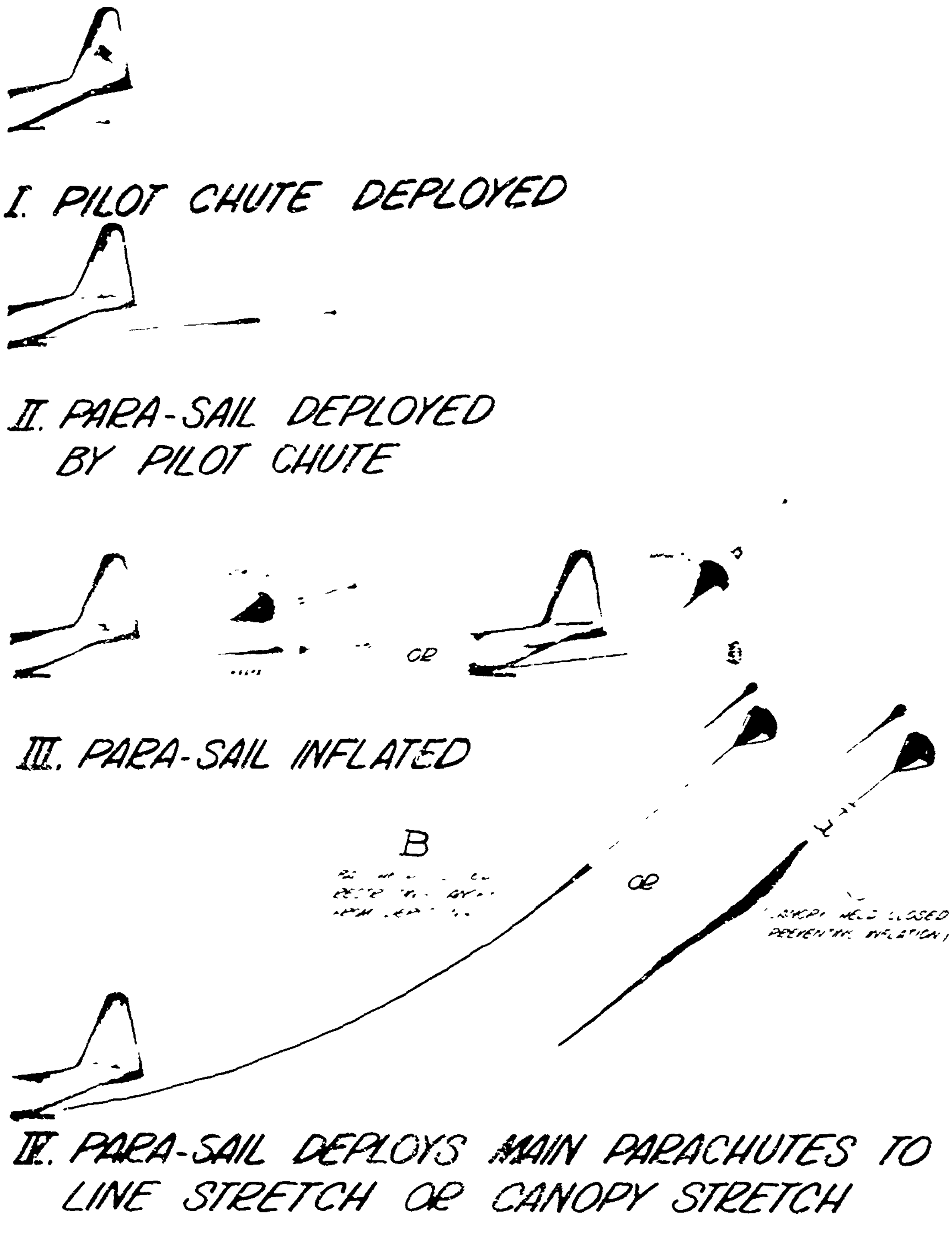


FIG. 2. APPROACHES B AND C (CONCLUDED NEXT PAGE).

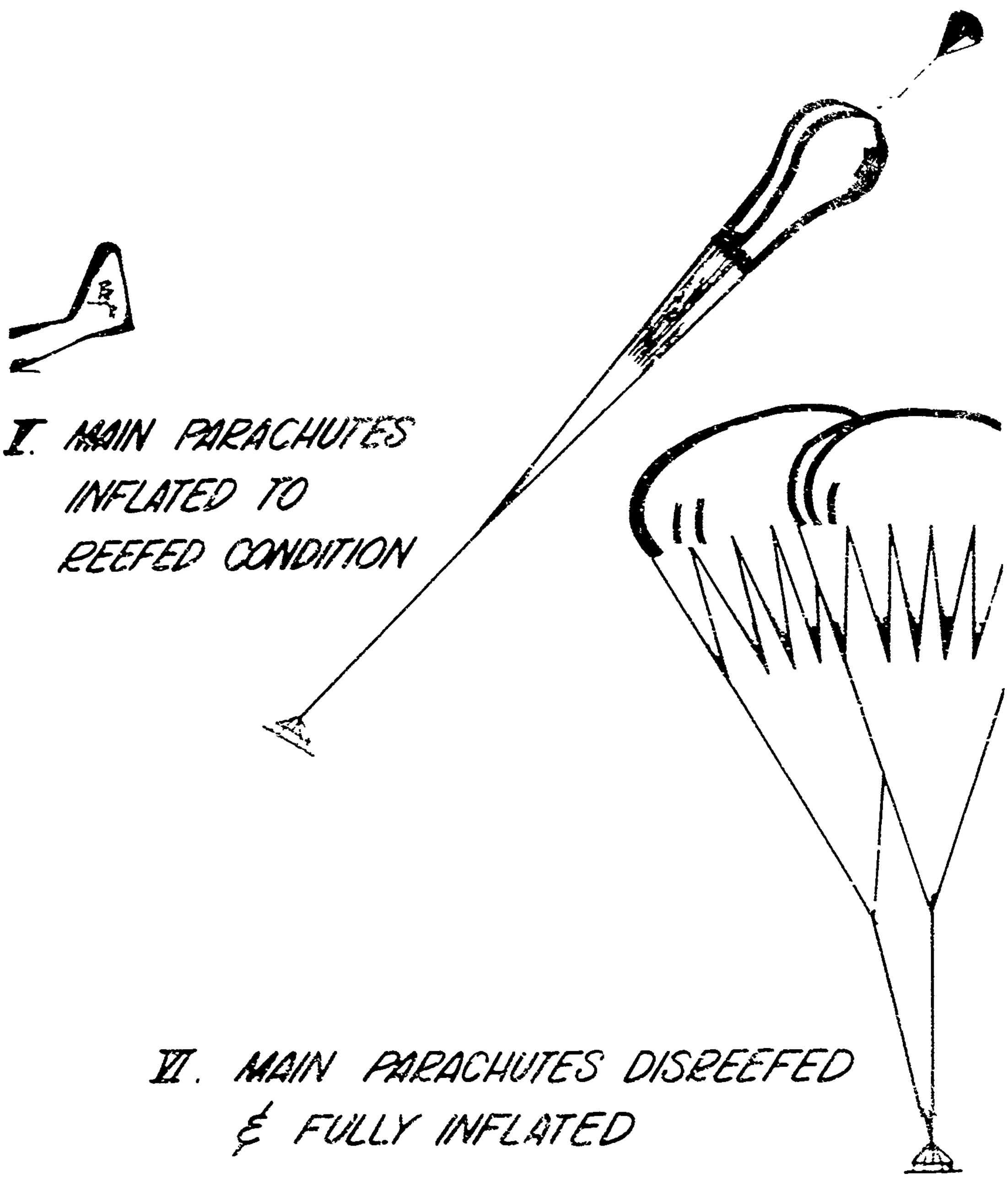


FIGURE 2 (CONCLUDED)

4.1.3 Qualitative Analysis

4.1.3.1 Para-Sail Sizes

With the ERP concept defined and described, it is desirable to determine approximate Para-Sail sizes before continuing with a qualitative analysis. Preliminary calculations were made to determine Para-Sail sizes for two conditions:

(a) A Para-Sail reefed to 8% supplying an extraction force varying from 0.8 W (heavy end of weight range) to 1.5 W (low end of weight range). For example, a Para-Sail having an 8000-lb extraction force can be used to extract loads varying from 5330 to 10,000 lb; i.e., 1.5 × 5330 = 0.8 × 10,000 = 8000.

(b) A Para-Sail guide-surface parachute combination resulting in a 20° angle of elevation.

Calculations for the first case are quite straightforward. An 0.8 extraction force for a 35,000-lb load is 28,000 lb. Equating this to $qC_{Dr}S_o$, we obtain S_o = 2040 ft^2 or D_o = 50.8 ft. This same reefed Para-Sail will extract any weight in the range from 35,000 to 18,670 lb (0.8 × 35,000 = 28,000 = 1.5 × 18,670). The limiting factor on the low end of the weight range is the 1.5-g extraction force, which is the maximum allowable force that can be applied to the cargo-extraction fittings.

The next Para-Sail size is calculated by equating 0.8 × 18,670 lb to $qC_{Dr}S_o$, which gives S_o = 950 ft^2 or D_o = 34.8 ft. The other Para-Sail sizes are calculated in like manner. The results, which are shown in Fig. 3, are applicable to approach A, to approaches B and C only if the drag on the main parachutes is neglected, and to the load deceleration concept (a concept described in a later section).

Para-Sail sizes required for the Para-Sail/guide-surface parachute combination were calculated using parachute-extraction forces determined graphically. Shown in Fig. 4 is the graphical solution. The Para-Sail tangent force is known to act at approximately 45° from the velocity vector (horizontal), and the resultant force acts along the 20° angle of elevation.

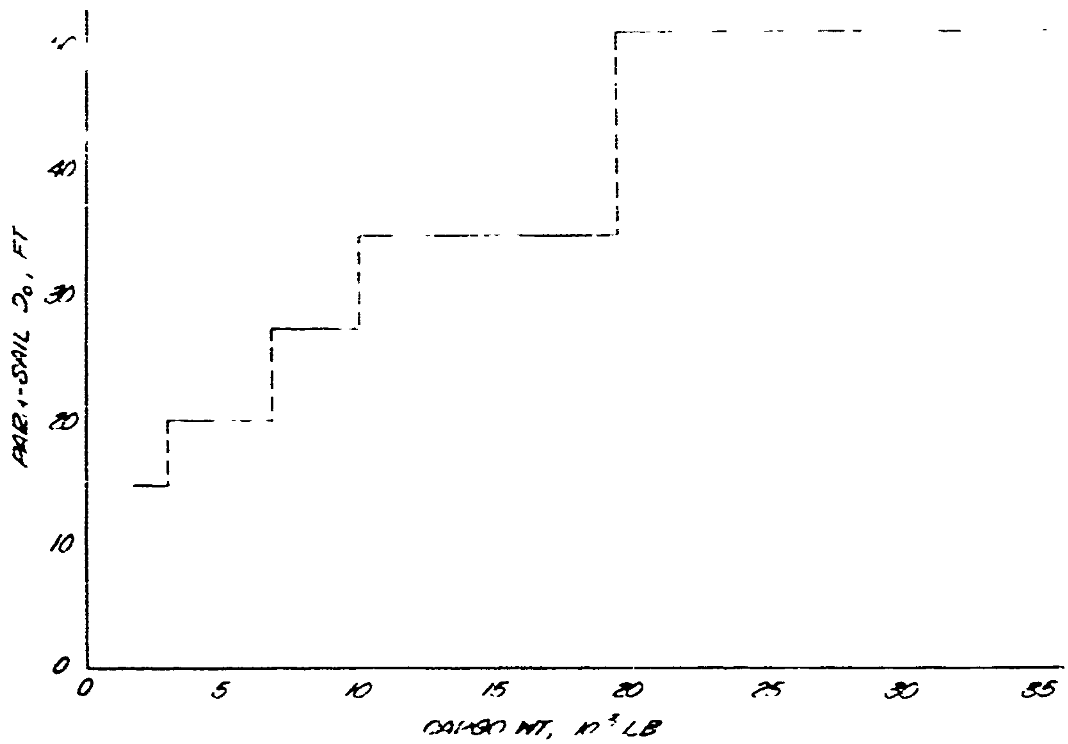


FIG. 3. PARA-SAIL REEFED TO 6% DIAMETER VS CARGO DROP WEIGHT.

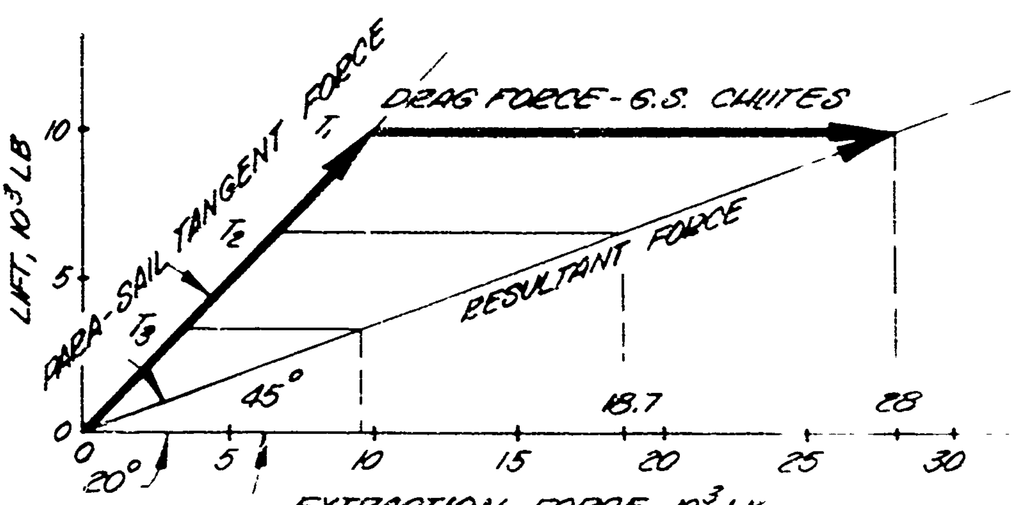


FIG. 4. GRAPHICAL METHOD OF DETERMINING PARACHUTE EXTRACTION FORCES.

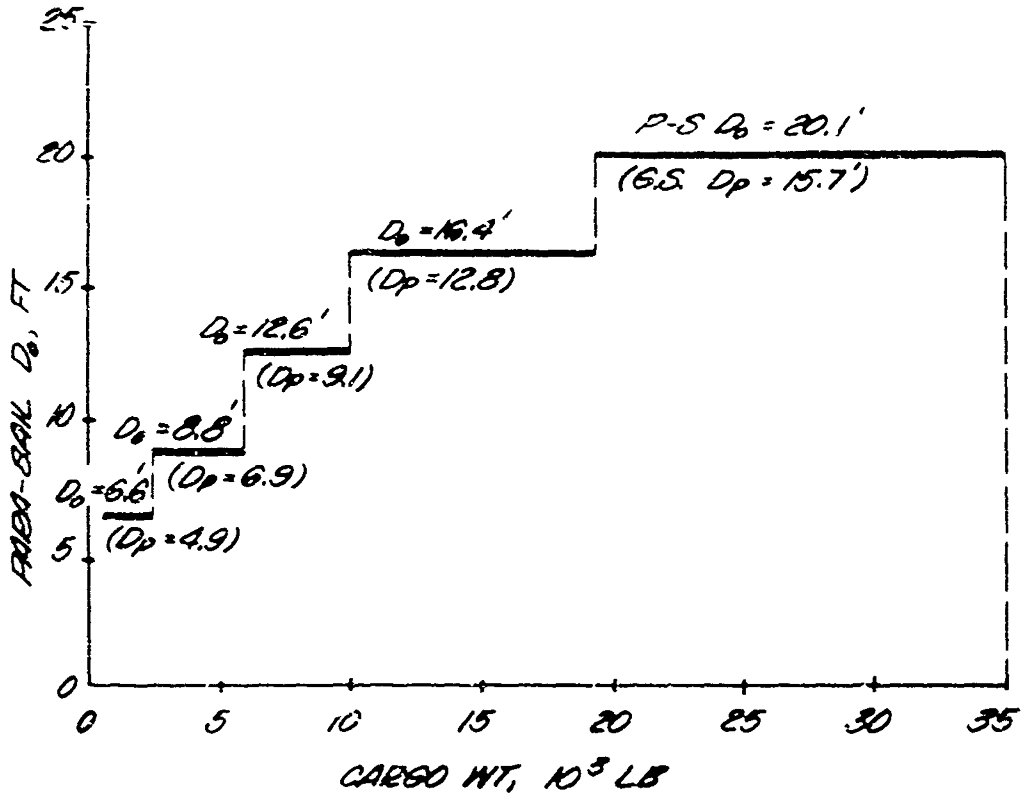


FIG. 5. PARA-SAIL DIAMETER VS CARGO DROP WEIGHT.

If an extraction force of 28,000 lb is desired, this point is marked on the resultant-force line. A horizontal line is then drawn from this point to intersect the Para-Sail tangent-force line. This then determines the drag force of the guide-surface parachutes (horizontal line of Fig. 4) and the tangent force of the Para-Sail (shown as T_1 in Fig. 4).

From these forces, the Para-Sail and guide-surface parachute sizes may be calculated in the same manner as demonstrated earlier in this section.

Shown in Fig. 5 are the results of these calculations. The calculations are made on the assumption that two guide-surface parachutes are used to orient and restrain the Para-Sail beneath the aircraft tail surfaces during load extraction. For example, to extract cargo in the weight range of from 20,000 to 35,000 lb, a Para-Sail of 20.1 ft D_o (nominal diameter) and two guide-surface parachutes of 15.7 ft D_p (projected diameter) are required.

4.1.3.2 Tail Interference

A fully open, unrestrained Para-Sail with an L/D of 1.0 might become entangled with the aircraft tail when used for load extraction with the ERP concept. Three possible solutions were considered to overcome this problem:

(a) Use a Para-Sail with a lower L/D.

(b) Use guide-surface parachutes to restrain the Para-Sail from rising until the cargo is extracted.

(c) Reef the Para-Sail until the cargo is extracted.

A lower L/D would partially defeat the purpose of using the lifting parachute; therefore, this would be the least desirable method of providing the tail clearance. On the other hand, restraining the Para-Sail with guide-surface parachutes requires a disconnect for the guide-surface chutes, which must be actuated at the exact time the load is extracted in order to gain this optimum performance from the Para-Sail.

The third method, which is more practical, is to deploy the Para-Sail reefed (skirt constricted) until the load is extracted, then to disreef to full open. The advantage of this method is that a larger Para-Sail can be used to provide a higher lift force in the full-open state. Temporarily reefing the Para-Sail (lowering its L/D) prevents entanglement with the aircraft tail by providing the necessary clearance. Upon disreef, the Para-Sail regains its L/D of 1.0 and applies its lifting force to elevate the recovery parachutes.

To compare lift forces of solutions (b) and (c), refer to Fig. 4. It can be seen that the vertical component of the resultant force for the Para-Sail/guide-surface combination is the lift force L. The following equation applies.

$$L = R \sin 20° = 0.34R,$$

where

$$R = 1.5W\ (\max) \times f(v).$$

and f(v) is a function of velocity, or q/q_o, where q_o is the initial dynamic pressure. Substitution yields

$$L = 0.34\ (1.5W)\ f(v).$$

For the method by which a reefed parachute alone is used for extraction,

$$F_e = 1.5W \text{ (max)} = q_o C_{Dr} S_o,$$

and

$$L = qC_L S_o = \frac{qC_L \times 1.5W}{q_o C_{Dr}} = \frac{C_L}{C_{Dr}} (1.5W)\ f(v).$$

Taking the values $C_L = 0.50$ and $C_{Dr} = 0.24$, we find that

$$L = 2.08\ (1.5W)\ f(v).$$

If we now take the ratio of the lift forces of the two methods, we have

$$\frac{2.08\ (1.5W)\ f(v)}{0.34\ (1.5W)\ f(v)} = 6.1,$$

which shows that the lift force of the reefed Para-Sail system after disreef is 6 times greater than that of the Para-Sail/-guide-surface combination. This ratio would not be large later in the trajectory sequence if the two velocity histories differ. However, it is early in the deployment process that high lift forces are needed, and it is then when the ratio is highest.

4.1.3.3 Amount of Elevation

A falling cargo system during airdrop has a velocity-time history dependent on its initial velocity and on the unbalance among all the forces acting on it. To decrease the velocity of the falling cargo system relative to time, the effective aerodynamic decelerating force should be increased and effectively applied as soon as possible to potentially achieve the required 28.5-ft/sec vertical-impact velocity within a 500-ft (or less) absolute airdrop altitude.

Similar aerodynamic forces act on the cargo whether the system of cargo delivery is conventional or employs the ERP concept. If we assume that the magnitudes of the force-time histories of the recovery parachutes are likewise similar, then one possibility for changing the velocity-time history is to change the direction of the force by elevating the recovery parachutes so that the vertical component of force

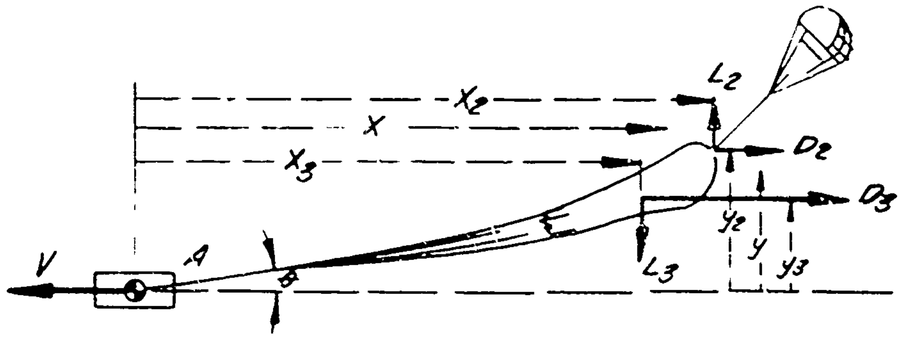


FIG. 6. AERODYNAMIC FORCES ACTING ON RECOVERY PARACHUTE, ERP CONCEPT.

is increased and applied as early in the trajectory as possible.

Figure 6 shows the aerodynamic forces acting on the recovery parachute(s) for the ERP concept. θ represents the change in direction of the external force applied to the load; i.e., θ is the angle between the line of external force for the ERP system and what the line of external force would be were a conventional system used.

The sum of the moments about A (neglecting the weight of the parachutes) is

$$\sum M_A = x_2L_2 - x_3L_3 - y_3D_3 - y_2D_2 = 0; \qquad (1a)$$

$$x_2L_2 - x_3L_3 = y_3D_3 + y_2D_2. \qquad (1b)$$

(The x's are horizontal distances from A to the line of lift force corresponding to the subscript on the x; e.g., x_2 is the horizontal distance from A to L_2. Similarly, the y's are vertical distances from A to the line of drag force corresponding to the subscript on the y.)

There is a length x such that $x_3 < x < x_2$ and such that

$$x(L_2 - L_3) = x_2L_2 - x_3L_3. \qquad (2)$$

Also, there is a height y such that $y_3 < y < y_2$ and such that

$$y(D_2 + D_3) = y_3D_3 + y_2D_2. \qquad (3)$$

Substitution of Eqs. (2) and (3) into Eq. (1b) yields

$$x(L_2 - L_3) = y(D_2 + D_3) \qquad (4a)$$

or

$$\frac{y}{x} = \frac{L_2 - L_3}{D_2 + D_3}. \tag{4b}$$

But $L_2 - L_3$ is very much smaller than $D_2 + D_3$; therefore, y will be very small in comparison with x; consequently, the angle θ of elevation of the recovery parachutes also will be very small. So no significant altitude gain would be achieved above the drop-aircraft flight path.

Analysis indicates that using the highest practical L/D Para-Sail will not provide significant elevation of the recovery parachutes because L_3 increases rapidly with a small increase in the elevation angle. Consequently, the difference between L_2 and L_3 is quickly minimized by a very small elevation of the recovery parachute(s).

At this point in the study, the concept was proposed for extracting the load with a reefed lifting chute, then disreefing and transferring the lifting chute direct to the load during deployment-inflation of the main recovery chutes. In this concept, discussed in Section 4.2, the lifting chute decelerates the load during recovery-chute deployment-inflation and damps the load oscillations.

4.1.4 Quantitative Analysis

Consideration was given to establishing a computer program whereby the ERP and conventional concepts could be compared. However, inputs for both concepts (such as C_DS_o vs time, filling and deployment times, etc.) would likely be the same, or at least not improved by the ERP concept. The only difference between the two systems is the existence of a small angle θ in the ERP concept, as mentioned in the previous section. However, this angle is dependent on an unknown, L_3. This unknown force would have to be determined experimentally, requiring testing of a sophistication beyond the scope of this contract. In addition, indications are that the angle θ is so small, and in existence for such a short time, as to be negligible. On this basis, the results of trajectory calculations would not significantly differ for the ERP concept versus the conventional system. Therefore, a computer-programmed trajectory analysis was not considered warranted and was not done.

4.1.5 Supporting Experiments

From Figs. 1 and 2 it can be seen that if the Para-Sail were to orient any way but up, the main parachutes would not be elevated; in fact, if the Para-Sail were to orient downward, the main parachutes would actually lose rather than gain altitude. Therefore, an orientation problem exists, the solution to which cannot be obtained solely by theoretical means. For this reason, tow tests were conducted early in the contract period to assay the Para-Sail orientation problems associated with the ERP concept, and to determine the degree of success or failure of the Para-Sail orientation. Because of negative results, a second group of tow tests was made at a later date using various lifting parachutes in addition to the Para-Sail. These two groups of tests are reported separately below.

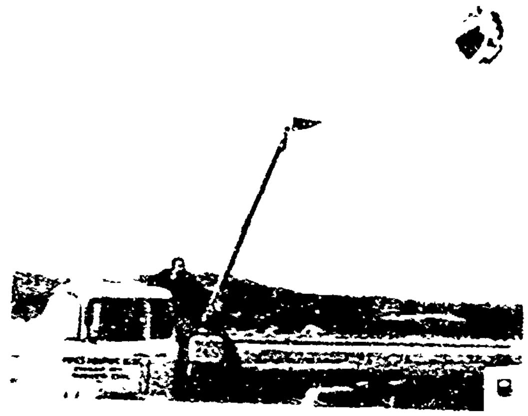
4.1.5.1 Group 1 Testing

Purpose. Tow testing of the Para-Sail was accomplished to determine what orientation problems to expect for approaches A, B, and C. The tests were to simulate the deployment procedure only and were not to consider the weight of the load or relationship of speed to size of parachute.

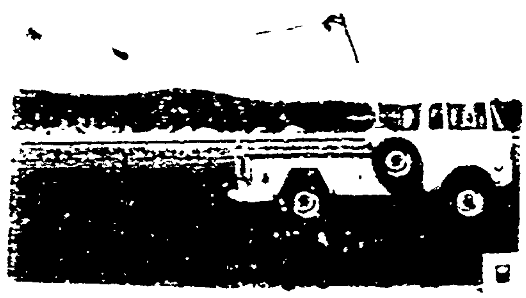
APPROACH A

Method. A specially outfitted truck was used as the tow vehicle, with the tests being performed from an extended boom as shown in Fig. 7. The simulated deployment for approach A is also shown in the referenced figure Approach A requires the Para-Sail to be attached directly to the load during extraction. The truck boom simulated the load A 4-ft-diameter Para-Sail was deployed from a deployment bag

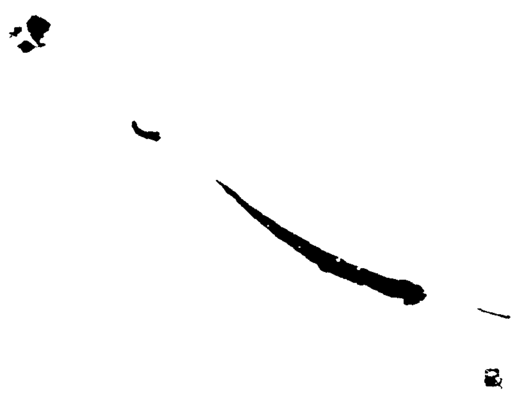
Results. Three deployment tests of approach A were conducted. A two-point riser attachment to the boom was used. The first test was a straight lines-first deployment using a guide-surface parachute as a pilot chute The second and third deployment tests of approach A were similar to the first test



APPROACH A



APPROACH B



APPROACH C

FIG. 7. TOW TESTS, ERP CONCEPT.

except that 360 and 720° twists were introduced initially to the risers. The Para-Sail in each test deployed normally and flew with proper orientation. Although, in the third test of this series, the 720° twist did not fully untwist, the Para-Sail remained properly oriented.

APPROACH B

Method. The same truck and boom were used as for the tests of approach A. The simulated deployment for approach B is shown in Fig. 7. A 4-ft-diameter Para-Sail was deployed from a deployment bag, and a 24-ft solid-flat parachute served as the main parachute. The main parachute was deployed to line stretch, but the canopy was kept within the bag throughout the test.

Results. Three deployment tests of approach B were conducted. A two-point attachment to the main-parachute deployment bag was used. The Para-Sail remained oriented to the deployment bag, but the bag proved unstable, twisting and turning during the towing and causing the Para-Sail to rotate with the deployment bag. In the last two tests of this series, the main-parachute suspension lines were separated into two groups with the thought that if the bag could be kept oriented, the Para-Sail would also remain oriented. This theory was not proven. Various methods of separating the suspension lines and attaching the Para-Sail to the main-parachute deployment bag were tried, but without success.

APPROACH C.

Method. The same truck and boom were used as for the tests of approach A. The simulated deployment for approach C is shown in Fig. 7. A 4-ft-diameter Para-Sail was deployed from a deployment bag, and a 24-ft solid-flat parachute served as the main parachute. The main parachute was deployed to canopy stretch (with the skirt held closed to prevent inflation).

Results. Three deployment tests of approach C were conducted. A one-point attachment of the Para-Sail to the vent of the main parachute was used. This approach proved more unstable than approach B. The single attachment apparently contributes to the instability of the unopened main parachute. This instability and what has been learned elsewhere concerning the drag of the unopened main chute at deployment velocities indicate that approach C is the least desirable of the three.

4.1.5.2 Group 2 Testing

Purpose. The purpose of these tests was to determine if the lifting chute would orient correctly with and without the aid of weight- and tail-orienting devices.

Method. Various lifting chutes (4-ft-D_o Para-Sail, 3-ft-length Para-Foil, and 3-ft-keel-length Paraglider) were tied to the apex of a 24-ft solid-flat chute, which in turn was attached to the boom of the tow truck The lifting chute was held oriented correctly (upward) as the truck started its run. The truck drove to speeds of 30 mph. For the Para-Foil, a tail was attached to the trailing edge for better orientation. For the Para-Sail and Paraglider, weights were hung from the trailing edge in an attempt to attain better orientation (see sketch accompanying Table 1).

Results. Neither the Paraglider nor the Para-Sail oriented satisfactorily. The Para-Foil oriented correctly; however, it could not lift the 24-ft chute off the ground at 30 mph. Therefore, for the purpose of these tests, none of the three configurations is suitable for the comparison deployment tests. However, it may be possible to rig the Para-Foil for a lower trim angle, and obtain a lift force sufficient to lift the 24-ft chute.

PARA-FOIL.

Test 1. The length of run is about a quarter of a mile, the full length of Mount Nebo Field, Manchester, Conn. We had correct orientation for about three quarters of the run, but the Para-Foil couldn't lift the 24-ft main chute. The Para-Foil dived into the ground, collapsed, reinflated, and came back up, and momentarily lifted the 24-ft chute off the ground but couldn't keep it off the ground The Para-Foil remained oriented for the rest of the run.

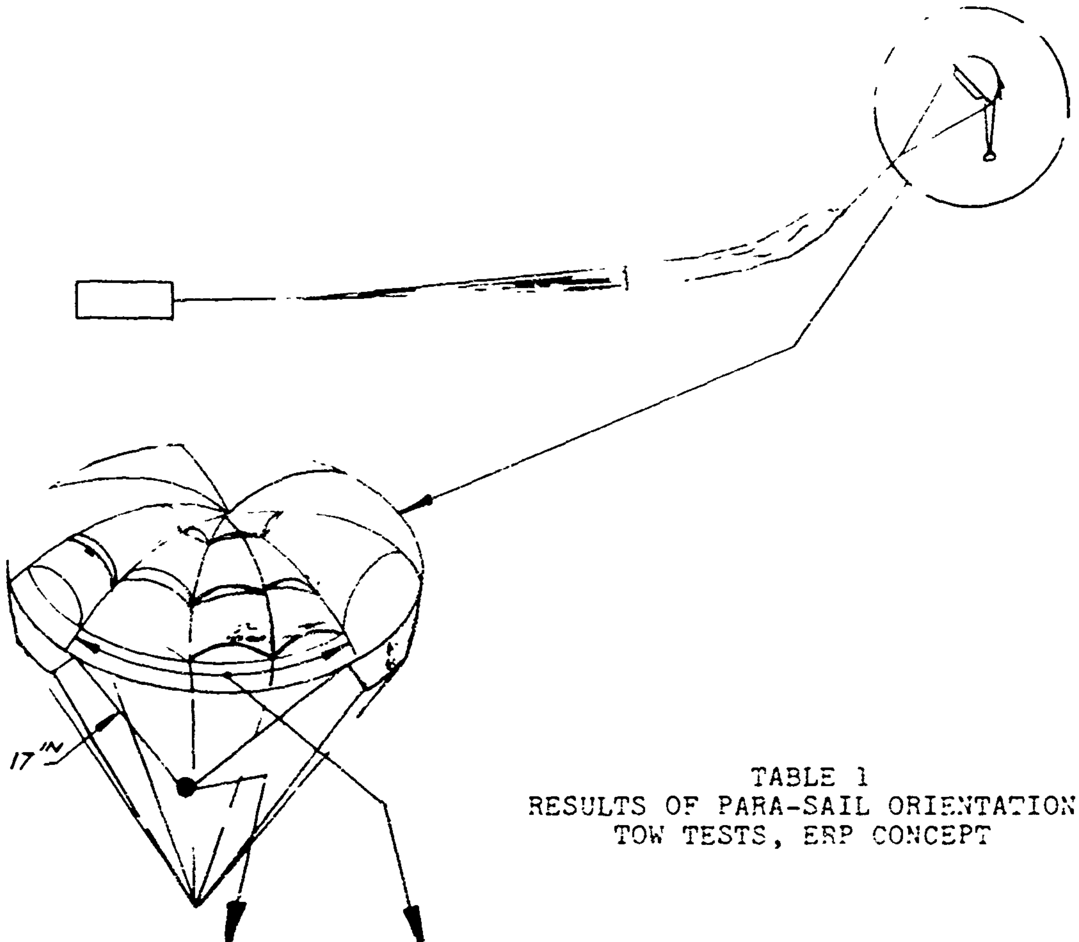


TABLE 1
RESULTS OF PARA-SAIL ORIENTATION
TOW TESTS, ERP CONCEPT

Test	Weight, oz	Gore separation, gores	Comments
1	3	5	Weight tangled in susp. lines; Para-Sail dragged ground, turning
2	3	5	Repeat of test 1; weight O.K. but results same
3	2	5	Oriented correctly for first half of run; last half poor
4	0.6	5	Oriented downward for entire run
5	0.6	3	Weight tangled in one of rear gore openings; results poor
6	0.6	3	Repeat of test 5; weight O.K. oriented up, then down, etc.
7	2	3	Oriented up, then down, etc.
8	-	-	Oriented up briefly, then down for rest of run

Test 2. Repeat of test 1. Para-Foil stayed oriented during 9/10 of the run but couldn't lift the main chute. Maximum truck speed was about 30 mph. This is the maximum speed obtainable on this length field.

Test 3. Repeat of tests 1 and 2. One side of the Para-Foil was released before the other, and it turned toward the ground and stayed there.

Test 4. Same as the other three. Oriented correctly for about half the run, then started swinging from side to side. Finally, dived into the ground and collapsed and did not reinflate.

PARAGLIDER.

Test 1. Dived into the ground immediately and stayed nose toward the ground throughout the run.

Test 2. Rotated into the ground just as in the first test and stayed in that direction.

Test 3. Repeat of tests 1 and 2 except that a 2-oz weight was hung on the rear-outside corners of the Paraglider. Dived into the ground and stayed that way for about a third of the run. Then, it started up and began rotating violently in a corkscrew path, and continued this throughout the rest of the run.

Test 4. Repeat of test 3. Turned, dived into the ground and started corkscrewing.

PARA-SAIL

See Table 1 for a tabulation of the results.

4.1.6 Conclusions

The problem of orientation for the ERP-concept lifting parachute is very formidable, as shown by the tow testing. In all probability, the difficulties would increase with a full-scale test, in view of the increased velocity, and the entire system would have to undergo deployment, rather than starting out with a fully-open correctly oriented lifting parachute. On the basis of only the tow tests already performed, the ERP concepts are infeasible.

4.2 Load Deceleration Concept

4.2.1 Definition

The basic principle of the load deceleration concept is to apply a lift force to the load during the main-parachute deployment and opening process.

4.2.2 Description

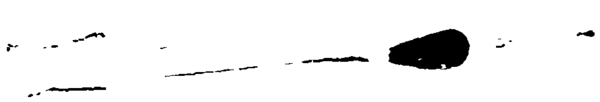
Shown in Fig. 8 (a two-page figure) is the sequence of events for the load deceleration concept. Step 1 shows the pilot chute deployed, which in turn deploys a reefed extraction chute (in this case a Para-Sail). The load is extracted in step 2. The Para-Sail disreefs immediately after extraction and transfers to the top side of the load (step 3), and the recovery parachutes begin to deploy. Note: It may be desirable to initiate recovery-parachute deployment during or just prior to extraction. As shown in step 4, the recovery parachutes inflate to a reefed condition. In the final step, the recovery parachutes are fully open and the Para-Sail remains attached to the load, aiding damping of oscillations down to ground impact.

4.2.3 Qualitative Analysis

An upward force must be applied to the load to retard vertical acceleration. Since this acceleration is at a maximum right after extraction, it is advantageous to have these forces acting as early in the recovery process as possible.

Figure 9 shows the vertical component (C_v) of the lift and drag coefficients for a Para-Sail and recovery chutes attached to the load, as a function of the trajectory angle. With recovery chutes alone attached to the load, C_v starts at zero for horizontal flight, and goes to a maximum in the vertical mode. It should be pointed out that the shapes of these curves are not necessarily accurate; only the end points and the general trends are important. With the Para-Sail attached to the load, C_v is equal to C_{L2} at launch, increases to C_{T2}, then diminishes to C_{D2} for the vertical mode. With the recovery parachute attached to the load, C_v is equal to C_{L3} (which equals zero at launch) and increases to a maximum (equal to C_{D3}) for

I. PILOT CHUTE DEPLOYED



II. PARA-SAIL DEPLOYED REEFED-
EXTRACTS LOAD

III. PARA-SAIL DISREEFS APPLYING LIFT
FORCE. MAIN PARACHUTES BEGIN
DEPLOYMENT

FIG. 8. LOAD DECELERATION CONCEPT (CONCLUDED NEXT PAGE).

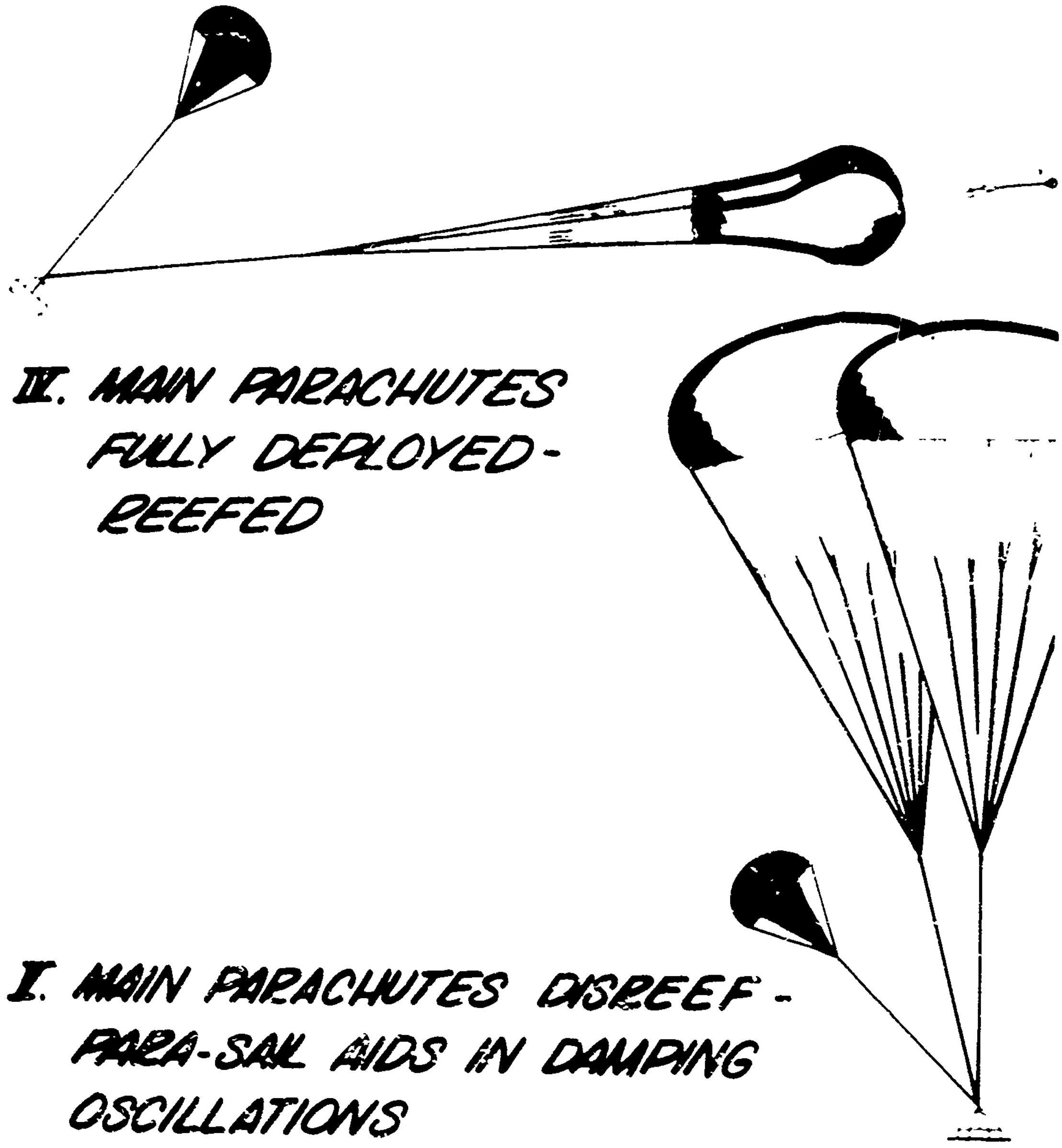


FIGURE 8 (CONCLUDED)

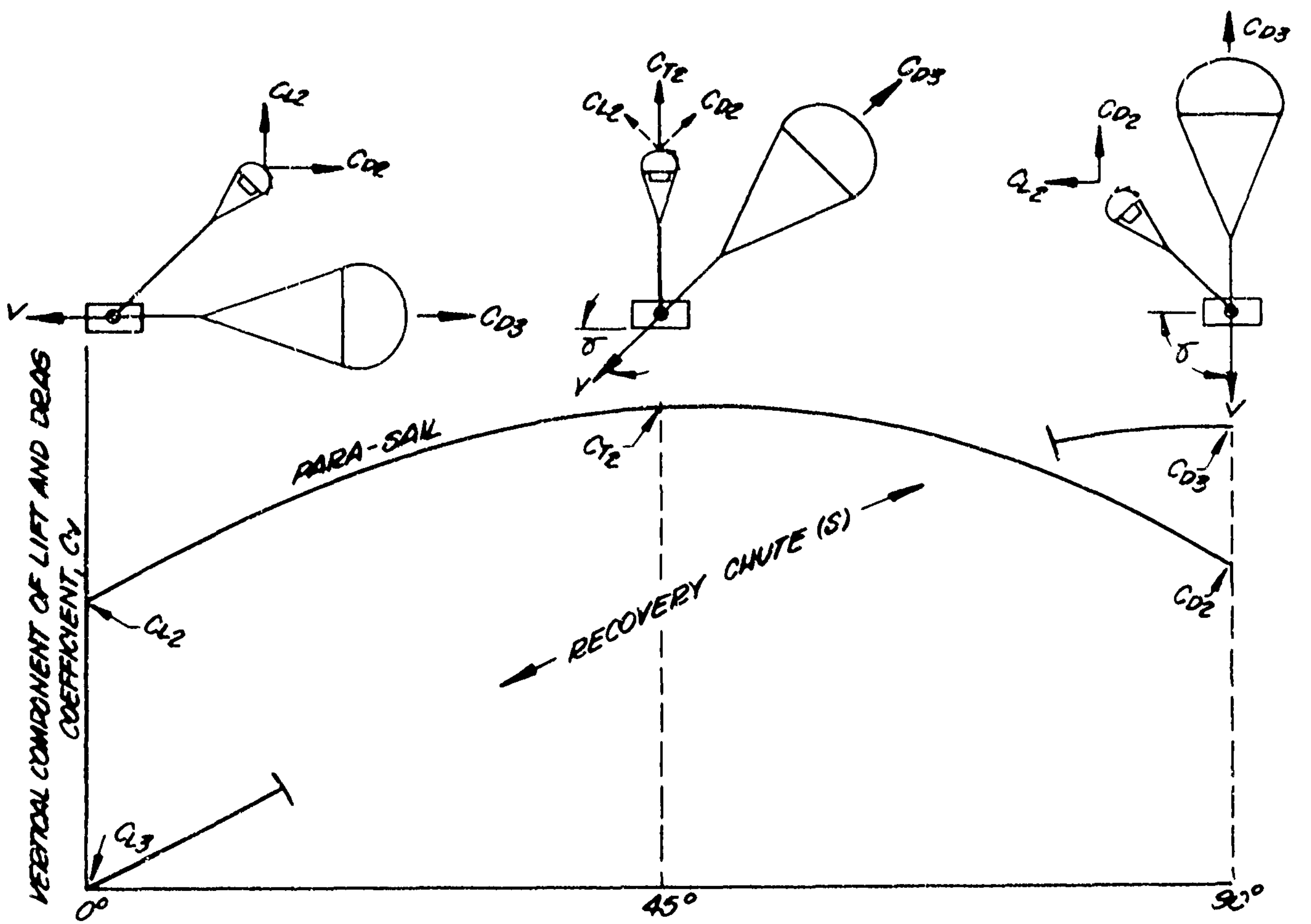


FIG. 9. VERTICAL COEFFICIENT VS TRAJECTORY ANGLE FOR PARA-SAIL ATTACHED TO LOAD, LOAD DECELERATION CONCEPT.

the vertical mode. To obtain the total vertical force acting on the load when both a Para-Sail and a recovery chute are attached to the load, the vertical coefficient (C_v) of each chute system is multiplied by the dynamic pressure (q) and the areas (S_o) of the parachutes and combined as follows.

$$F_{vP} = (qS_oC_v)_P \quad \text{and} \quad F_{vR} = (qS_oC_v)_R,$$

where the subscripts P and R refer to Para-Sail and recovery parachute respectively, and $C_v = C_L \cos \gamma + C_D \sin \gamma$;

$$(F_v)_{total} = F_{vP} + F_{vR}.$$

Figure 9 shows separately the manner in which the vertical force coefficient (C_v) varies as a function of the trajectory angle for a Para-Sail and for a recovery chute along the trajectory from launch to vertical descent.

4.2.4 Quantitative Analysis

Figure 10 shows vertical displacement of the load vs time for various Para-Sail canopy loadings (W/S_o). For a typical load of 10,000 lb, the Para-Sail diameters range from 25.2 ft (for W/S_o = 20) to 35.7 ft (for W/S_o = 10). The lowest curve is for the case in which the extraction parachute separates from the load at 0.5 sec and the load falls under its own lift and drag forces with an effectively infinite W/S_o.

Figure 11 shows vertical displacement vs horizontal displacement of the load for the same configurations used for plotting Fig. 10. Because the vertical- and horizontal-displacement scales are the same, these plots show the trajectory and flight path at various times after launch.

Both Figs. 10 and 11 have been computed for an initial velocity of 130 knots and for L/D = 1.1. For the lifting-parachute curves, the start of disreef occurs at 0.5 sec and is completed at 1.0 sec. The Para-Sails are reefed to give an extraction force of 1 g in each case.

Note that all these curves ignore any drag or lift of the load itself and exclude drag forces resulting from deployment of the main canopies. If deployment of the extraction

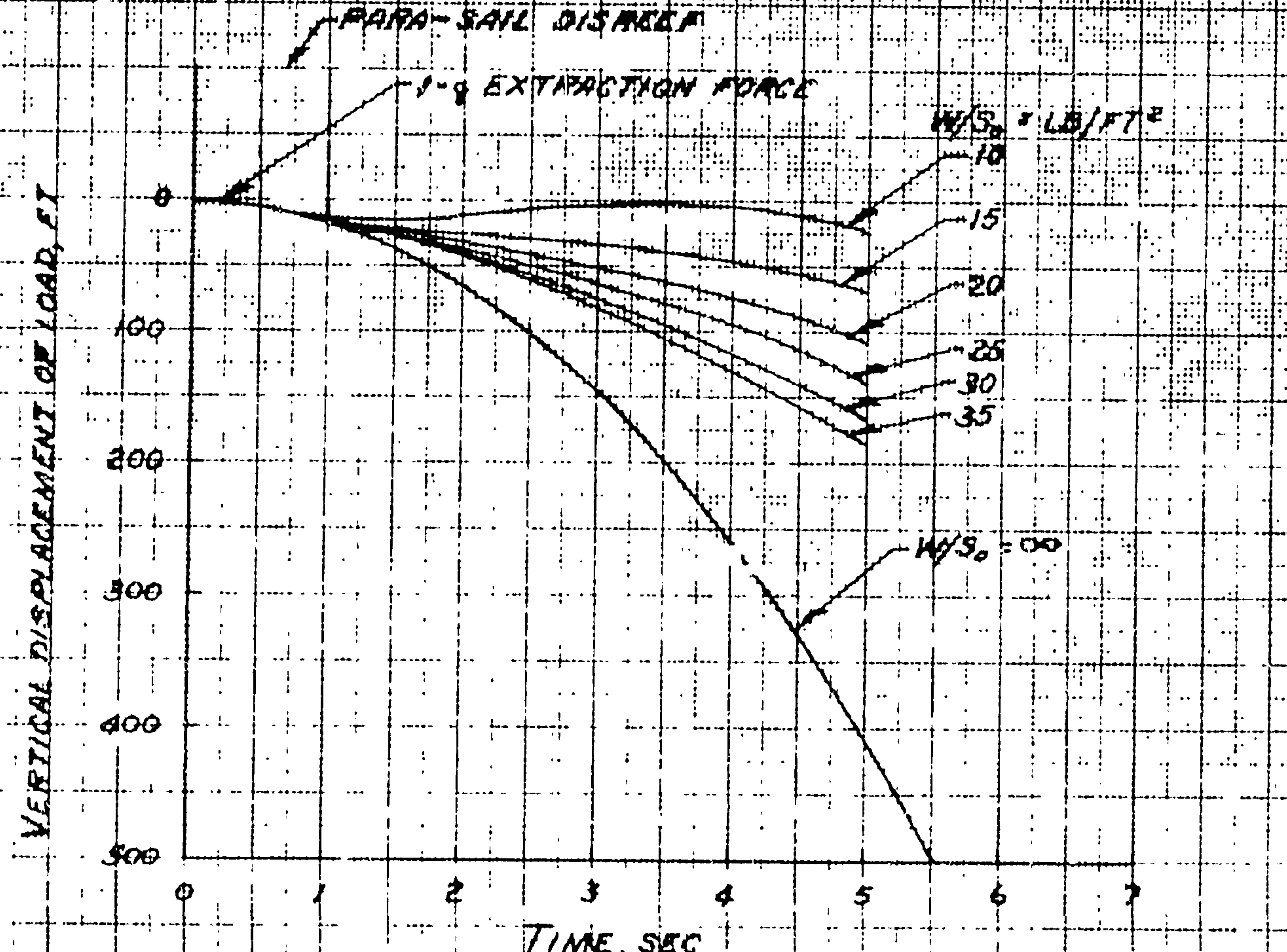


FIG. 10. VERTICAL DISPLACEMENT VS. TIME WITH VARIOUS LIFT FORCES APPLIED TO LOAD. LOAD DECELERATION CONCEPT.

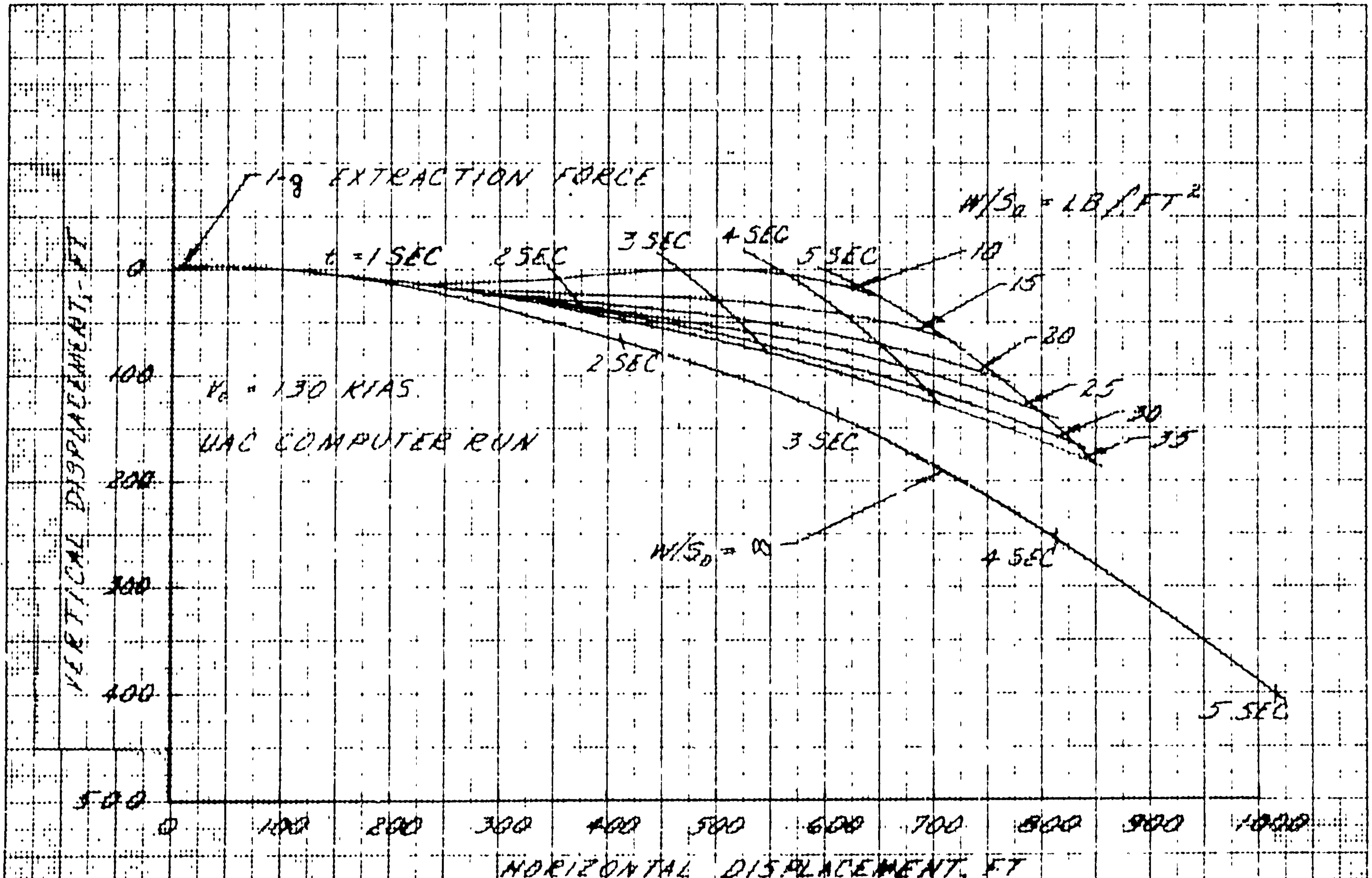


FIG. 11. VERTICAL VS HORIZONTAL DISPLACEMENTS WITH VARIOUS LIFT FORCES APPLIED TO LOAD, LOAD DECELERATION CONCEPT.

TABLE 2
TRAJECTORY CONDITIONS FOR THREE DIFFERENT CANOPIES,
LOAD DECELERATION CONCEPT

Main-chute deployment time, sec*	Para-Sail W/S_o (L/D = 1.1)	Conditions at main-chute canopy stretch†		
		s, ft	γ, deg	V, ft/sec
	¶	145	-25	255
2	20	47	-8	139
	10	1	+3	100
	¶	258	-32	240
3	20	70	-13	127
	10	2	-6	83

*Add 1 sec to obtain time after launch.
†s, vertical displacement; γ, flight-path angle; V, velocity.
¶Nonlifting extraction parachute.

parachute is considered to occur at 1 sec, the main canopies may be considered to be fully deployed at between 3 and 4 sec after launch (requiring from 2 to 3 sec for deployment).

Table 2 shows the different trajectory conditions encountered when the load is extracted by a nonlifting extraction parachute and by two sizes of Para-Sail (i.e., the same three configurations considered in Figs. 10 and 11) for main-canopy deployment times of 2 and 3 sec. The savings in altitude afforded by the Para-Sail is evident from Table 2: for 3 sec deployment time, the larger Para-Sail (whose $W/S_o = 10$, or whose $S_o = W/10$) is 256 ft higher at main-parachute canopy stretch than a nonlifting extraction parachute would be. Moreover, the more nearly horizontal flight-path angle of the load at this point is cause for less altitude loss during subsequent inflation of the main canopies. Although a relatively horizontal flight path tends to increase the pendulum effect during and after main-canopy inflation, the "trailing" parachute will tend to damp the oscillation significantly. Finally, either Para-Sail's total velocity at main-canopy stretch is significantly lower than that of a nonlifting parachute, and this may result in longer filling times for the main canopies.

4.2.5 Supporting Experiments

Two types of tow testing were performed to represent certain aspects of the load deceleration concept. The first type was not intended to produce quantitative results, but rather to afford an opportunity to observe the overall deployment process.

The problem of correct Para-Sail orientation is not unique to the ERP concept. In order that the lift force applied to the load in the load deceleration concept be vertical, the Para-Sail must orient so that the front is in an upward direction. With approach-A testing, the Para-Sail oriented correctly when attached to the load; however, the Para-Sail was not reefed. Therefore, there were two questions that must be answered with the second type of load deceleration concept tow testing:

(a) Will the Para-Sail orient correctly when deployed reefed?

(b) What is the amount of riser separation necessary for optimum orientation performance?

The results of the two types of tow testing are reported below.

4.2.5.1 Load Deceleration Concept Deployment

Purpose. The purpose of this tow testing was to observe the performance of the extraction and deployment scheme for the deceleration concept.

Method. A 4-ft (diameter) Para-Sail was attached to a simulated weight which sat on a platform at the end of the boom of the tow truck. A bag containing a 24-ft flat-circular parachute was attached to the platform in such a way that the 24-ft parachute was allowed to commence deployment as soon as the weight was released from the platform.

Test site was the Windham Airport, Willimantic, Conn. The tow truck was driven at 40 mph with the Para-Sail and main

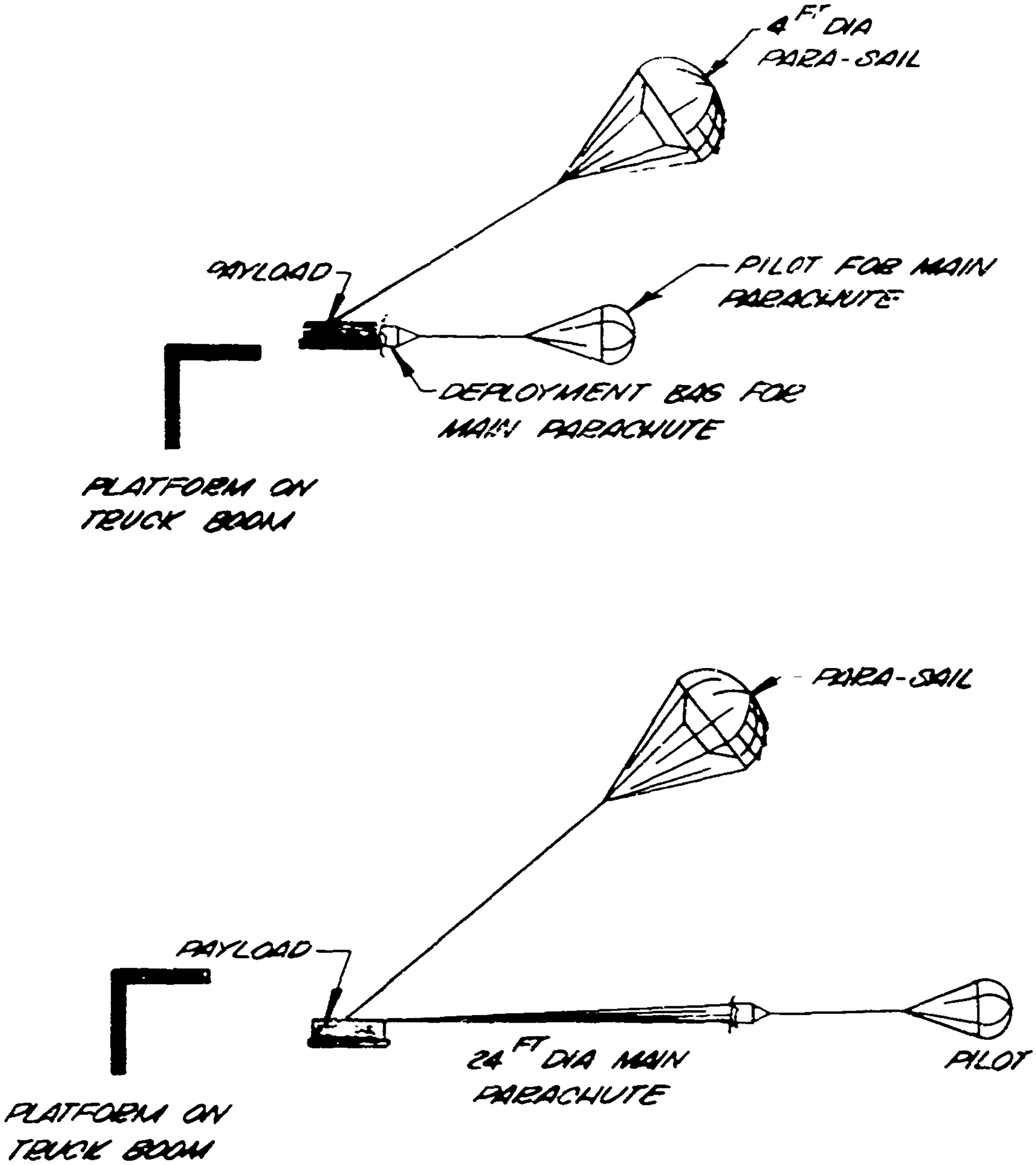


FIG. 12. TOW-TEST DEPLOYMENT SEQUENCE, LOAD DECELERATION CONCEPT.

pilot parachute fully open. A ripcord was pulled, and the deployment sequence was as shown in Fig. 12.

Movie coverage consisted of a 16-mm gun camera mounted on the boom and a 16-mm hand-held camera used alternately from t e truck bed and from alongside the truck as it drove by.

Results. Four runs were made with the following results.

Run 1. The weight rolled to the left (about a horizontal axis) after release, foreshortening the left Para-Sail riser. The 24-ft parachute did not have enough time to deploy before the weight hit the ground. Stopwatch time was missed. In general, the test looked good It appeared that there was time gained (i.e. altitude saved) by having a lifting parachute attached to the load. It was observed that the Para-Sail became more stable with truck speed (while being towed, prior to release).

Run 2. This run looked even better than the first. The weight did not turn as much. Stopwatch time was missed again. The main-parachute suspension lines did not have enough time to deploy.

Run 3 Vibration caused the release mechanism to actuate prematurely, allowing early deployment initiation of the 24-ft parachute. The lines started to deploy, and then the weight was released as in the previous tests. This test actually looked better than any of the others, indicating that deployment of the main parachute(s) should be initiated prior to cargo extraction

The time from the weight release to ground impact was 2.7 sec. The 24-ft parachute lines deployed up to the last locking flap near the skirt.

Run 4. This run looked much like run 1. The weight rolled about 45° about a horizontal axis so that the left side of the weight hit the ground first. About 3 ft of the 24-ft parachute lines deployed before hitting the ground. The time to impact was 1 2 sec However, because the events occurred rapidly, these times were very difficult to measure and, therefore, the accuracy of the times is no doubt very poor.

4.2.5.2 Load Deceleration Concept Orientation

Purpose. Tests were conducted with a reefed Para-Sail to determine the percentage of properly oriented Para-Sail deployments as a function of riser separation.

Method. A 4-ft (diameter) Para-Sail, reefed to 20% (i.e., the length of the reefing line was equal to 0.2 times the parachute circumference) at the skirt, was packed into the deployment bag and attached to a specially designed platform. The platform was rigged on the boom of the truck. A 16-mm gun camera was mounted on the launch platform. Still shots and movies were also taken from the side during the tests.

The truck was moving at 30 mph directly into the wind. The wind speed was between 30 and 35 mph. Before the Para-Sail was deployed, a 16-mm gun camera was activated to cover deployment and orientation of the canopy.

The launch platform was built so that the separation between the risers could be adjusted from 2 to 10 in. by 1-in. increments.

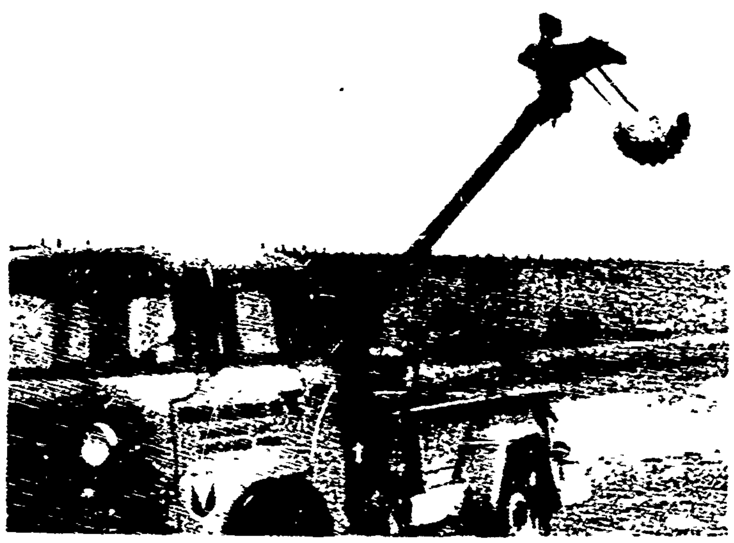
Results. The risers were placed in position 1 (2 in. apart), and five runs were made. The first run was without film coverage. The second run was unacceptable because the canopy was hooked on with a 180° turn. During the third run, the truck moved about 60° off the wind line, which probably caused an approximately 90° turn in the canopy. The fourth and fifth runs were directly into the wind, and both were successful.

The risers were placed in position 2 (3 in. apart), and five runs were made. The first run was successful. On the second run, the canopy deployed with a twist on the risers. The remaining runs were successful.

The risers were placed in position 3 (4 in. apart), and six runs were made. The first three runs were successful: the canopy oriented up after deployment. During the fourth and fifth runs, the canopy rotated and oriented up. The

TABLE 3
RESULTS OF TOW TESTS, LOAD DECELERATION CONCEPT

Position	Riser separation d, in.	d/D_o	Run	Orientation	Remarks
1	2	0.04	1	Up	No film coverage
			2	-	Improper rigging
			3	Down	90° twist: truck moving 60° off wind line
			4	Down	
			5	Up	
2	3	0.06	1	Up	Twist on risers lasting 1.5 sec
			2	Up	Same as pos. 2, run 1
			3	Up	
			4	Up	
			5	Up	
3	4	0.08	1	Up	
			2	Up	
			3	Up	
			4	Down	Twist on risers lasting 3.5 sec
			5	Up	Twist on risers lasting 2 sec
			6	Up	
4	5	0.10	1	Up	
			2	Up	
			3	Up	
			4	Up	
			5	Up	
5	6	0.125	1	-	Canopy jammed in bag
			2	Up	
			3	Up	
			4	Up	
			5	Down	Canopy rotated 180° to right, untwisted and went 180° to left
			6	Up	
			7	Up	



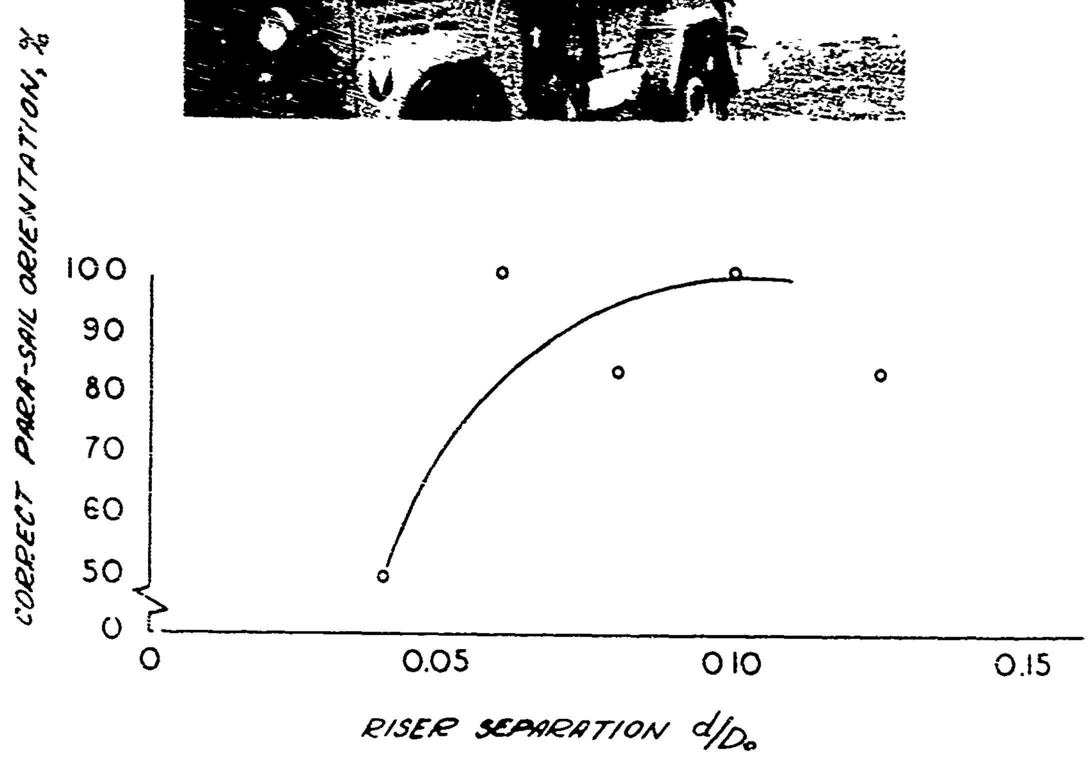


FIG. 13. PERCENTAGE OF CORRECT PARA-SAIL ORIENTATION VS DIMENSIONLESS RISER SEPARATION.

sixth run was successful: the canopy oriented up after deployment.

The risers were placed in position 4 (5 in. apart), and five runs were made, all successful.

The risers were placed in position 5 (6 in. apart), and seven runs were made. The first run was unacceptable because of improper deployment of the parachute. The canopy jammed inside the deployment bag for about 5 sec. Only the fifth run was questionable: the canopy rotated once to the left and once to the right before stabilization.

Table 3 summarizes the results of the test, and Fig. 13 shows the results plotted. For a riser separation of 5 in. (d/D_o = 0.10), the Para-Sail oriented correctly for all five tests. At this separation, the orientation was quicker and more positive than for any other separation.

4.2.6 Conclusions

The studies performed on the load deceleration concept showed promise, at least to the extent they were carried out.

The qualitative analysis showed that the lift force is very advantageous in the load deceleration concept since it can be applied to the load early in the recovery process.

The quantitative analysis showed that the altitude saved is substantial (at least from a theoretical standpoint).

The deployment tow tests showed promise strictly from an observational standpoint.

The orientation tow tests showed that good orientation performance could be achieved, at least at the relatively slow tow and deployment velocities.

Based on the above conclusions, the load deceleration concept looks promising. However, it should be pointed out that these conclusions were arrived at through a limited amount of theoretical and experimental analysis and, as such, are susceptible to question.

4.3 TILT Concept

4.3.1 Definition

The TILT (Trim Introducing LifT) concept is a low-level delivery concept whereby the recovery parachute is "tilted" (lifted) to its trim angle by a Para-Sail. As such, the recovery parachute acts as a lifting parachute possessing its own lift coefficient.

4.3.2 Description

Shown in Fig. 14 is the TILT concept. A Para-Sail is

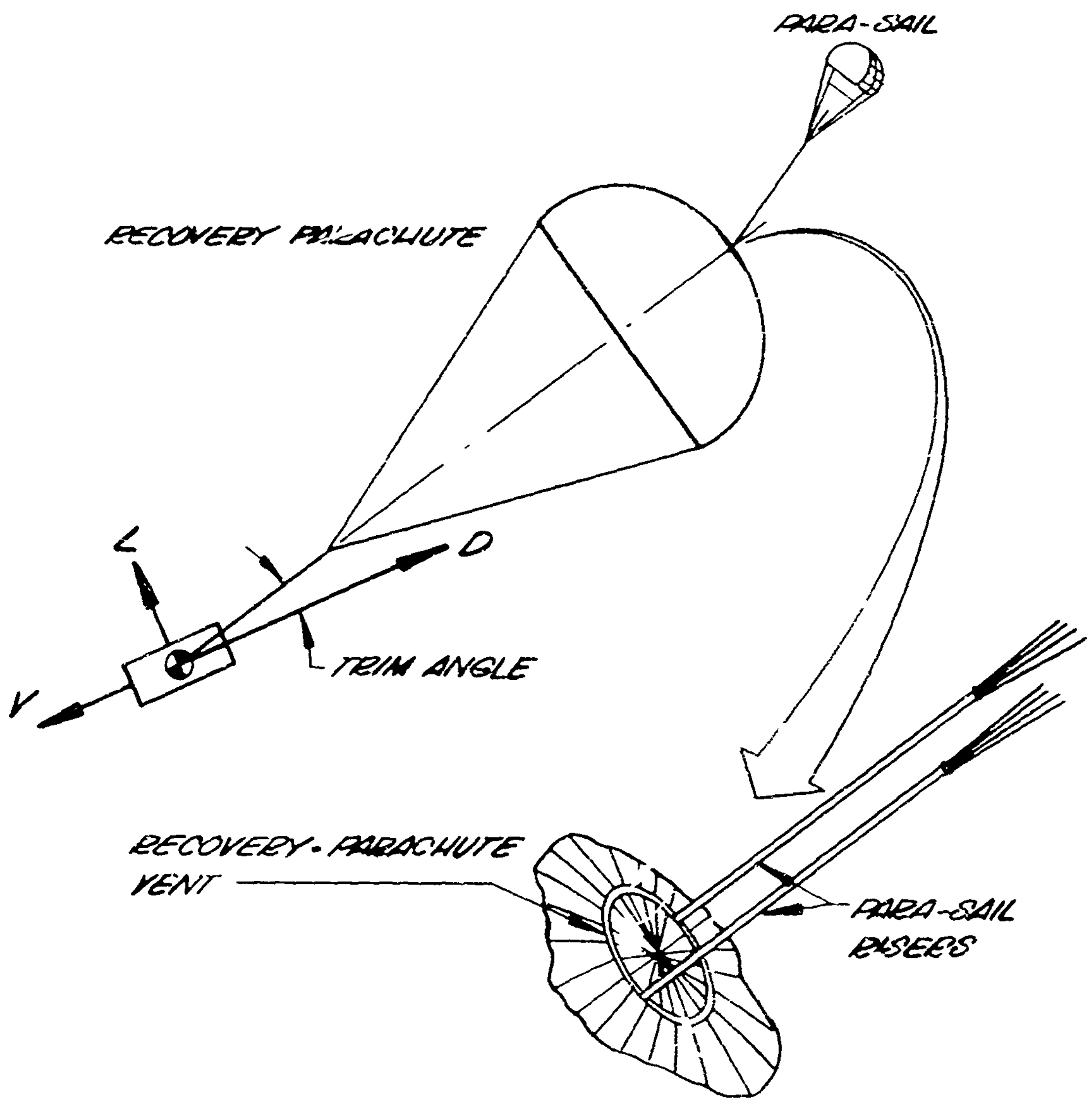


FIG. 14. TILT CONCEPT.

attached to the vent of the recovery parachute with risers separated as shown in the blown-up sketch. After a conventional deployment, the recovery parachute begins a filling process and is lifted to its trim angle--or slightly beyond--by the time it is opened, or at least shortly afterward. It is at this point that the recovery parachute applies a lift force to the load. Prior to this, the TILT concept has no significance.

4.3.3 Qualitative Analysis

Upon its inception, the TILT concept was considered to conform to the principle of the ERP concept. However, the original version of the ERP concept was that altitude could be gained over the aircraft absolute drop altitude by approximately the amount that the recovery parachute(s) are elevated above the flight path, whereas the TILT concept attempts to affect the cargo trajectory by elevating the recovery parachute to an angle of attack at which a lift force is produced.

Solid-flat parachutes with effective porosity similar to that of the G-11 have a trim angle of about 20° (measured between the parachute center line and the relative-velocity vector). It is this phenomenon that allows a parachute of this type to produce a lift force in addition to the drag force. Since the trim angle has no directional orientation, the lift force is likewise random in orientation. However, if the recovery parachute were to be oriented upward, by means of a Para-Sail attached to the vent, the lift force would be oriented upward also. This upward force would tend to increase the instantaneous radius of curvature of the flight path. thus possibly reducing the altitude necessary for successful recovery.

4.3.4 Quantitative Analysis

The effectiveness of the TILT type of flight-path control was studied by means of a 2-degree-of-freedom trajectory program which computed the trajectory of a point mass having up to four parachutes attached. The aerodynamic coefficients of the load and parachutes were input to the program as functions of time and were based on known characteristics of canopies of the size under consideration. The program considered lift, drag, weight, and inertial forces acting in a plane normal to the earth's surface. The assumed sequence of events was as follows.

T = 0 sec. Extraction of payload begins, utilizing a normally lifting parachute that is reefed or otherwise temporarily altered to provide a 1.5-g pure-drag extraction force.

T = 1.0 sec. The extraction chute is disconnected from the payload and initiates the deployment of a G-11 cargo chute.

T = 2.2 sec. Line stretch of the cargo chute occurs, and disreefing of the extraction deployment chute begins.

T = 2.6 sec. Disreefing of the extraction deplovment chute completed, maximum lift force is applied to main parachute.

T = 6.2 sec. Disreefing of main canopy commences.

T = 13 to 15.3 sec. Main canopy full open and oriented near its stable angle of attack of about 20°, stabilized at this angle by the applied force of the lifting deployment parachute.

The concept was studied parametrically by considering launch velocities from 110 to 150 KIAS and extraction/-deployment canopy sizes from the smallest which provided the 1.5-g extraction force to the largest that could be sufficiently reefed to prevent exceeding the 1.5-g extraction force. Since lift forces do not become significant until the main parachute is near full open, the time required to assume the full-open configuration must be considered. The inflation rate of a 100-ft-dia. cargo parachute is plotted in Figs. 15 and 16 for the slowest and fastest rates taken from the data available. These curves were prepared from full-scale drop-test data by dividing the instantaneous total parachute load by the instantaneous dynamic pressure. These curves were then faired and used as input data for the trajectory program. The results of this study were compared with the trajectory of an equivalent payload extracted and deployed in the conventional

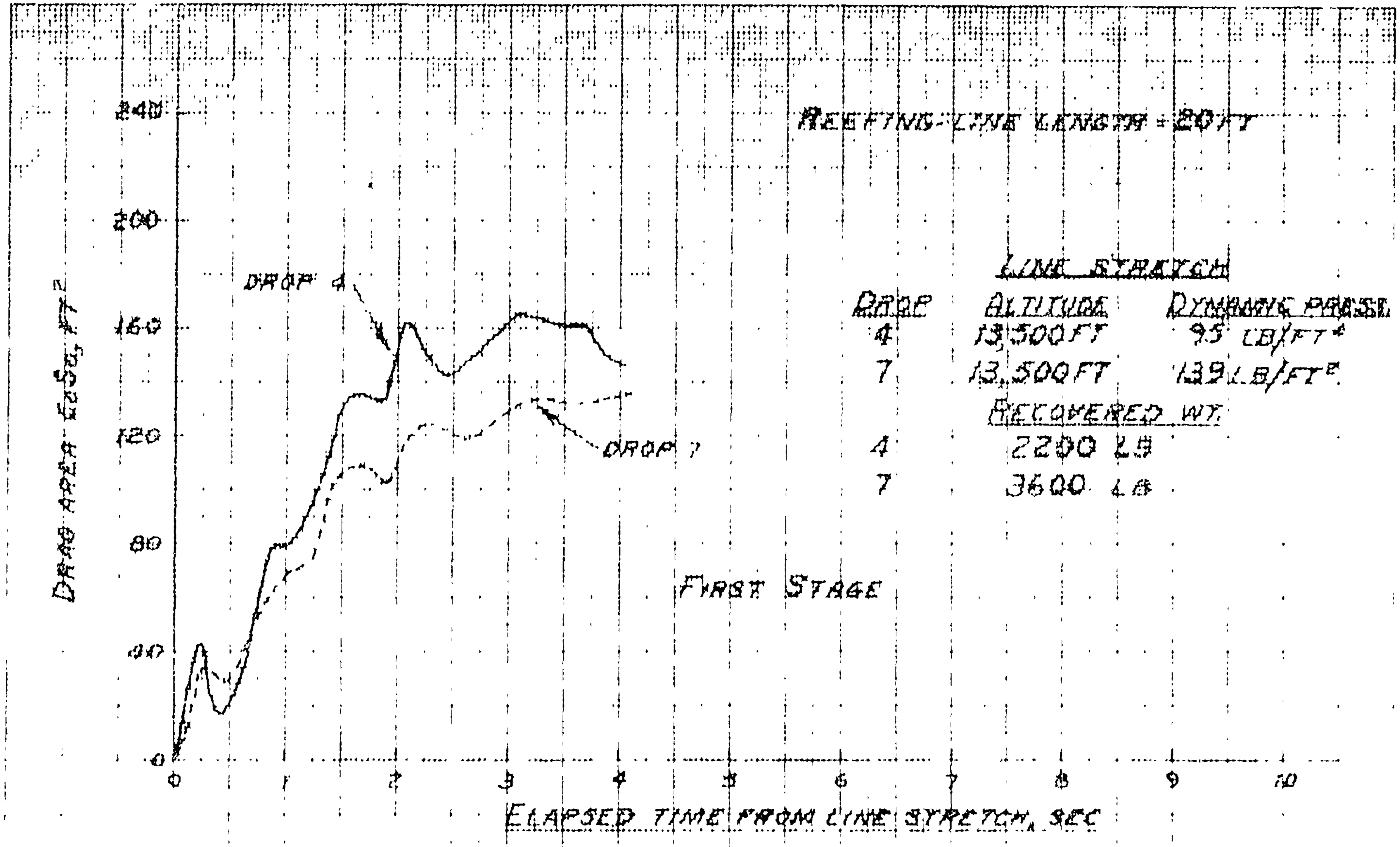


FIG 15. 100-FT-D_0 TRICONICAL PARACHUTE, DRAG AREA VS TIME, LINE STRETCH TO REEFED DIAMETER.

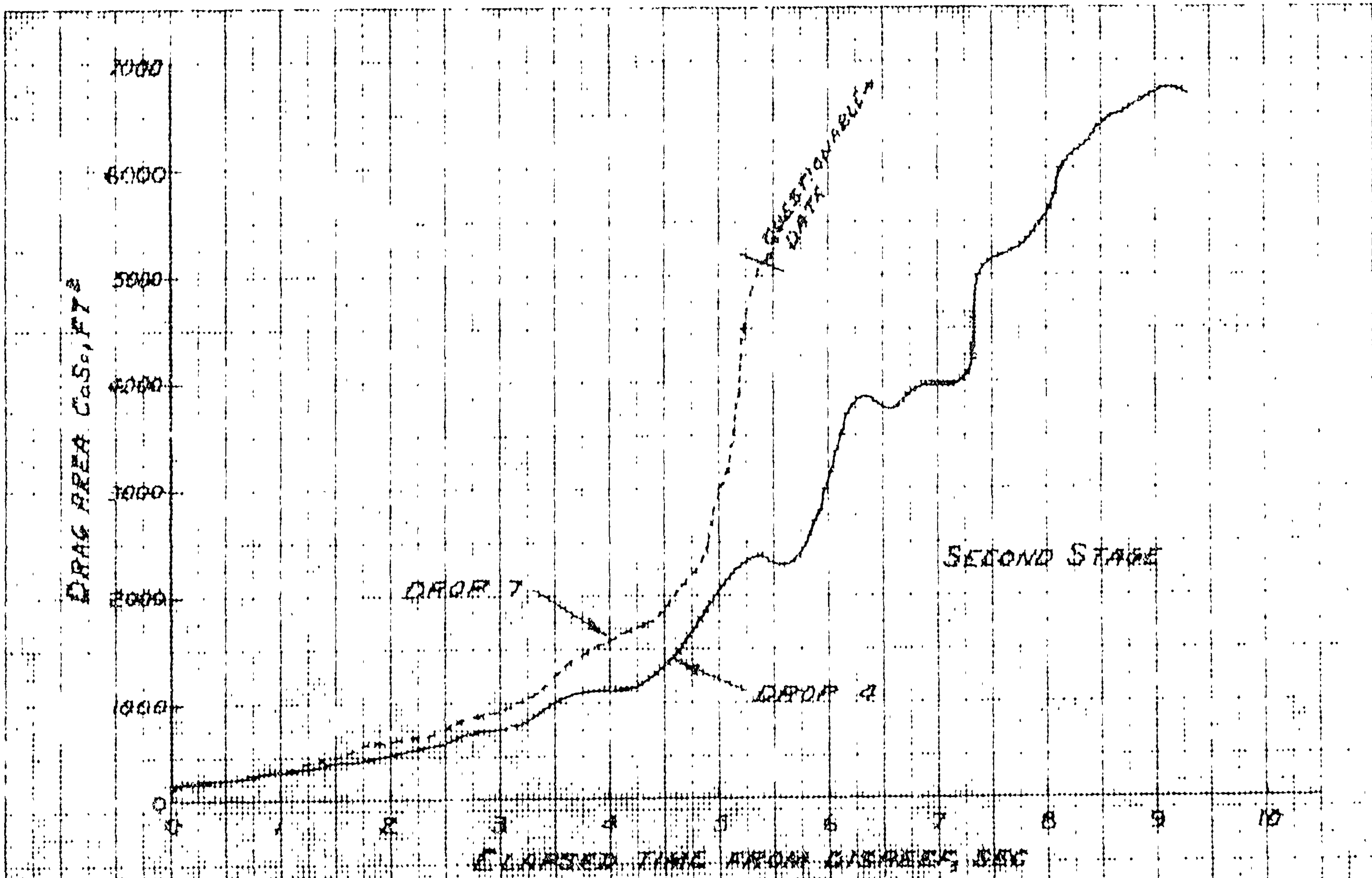


FIG 16 100-FT DIA TRICONICAL PARACHUTE
DRAG AREA VS TIME, DISREEF TO FULL OPEN

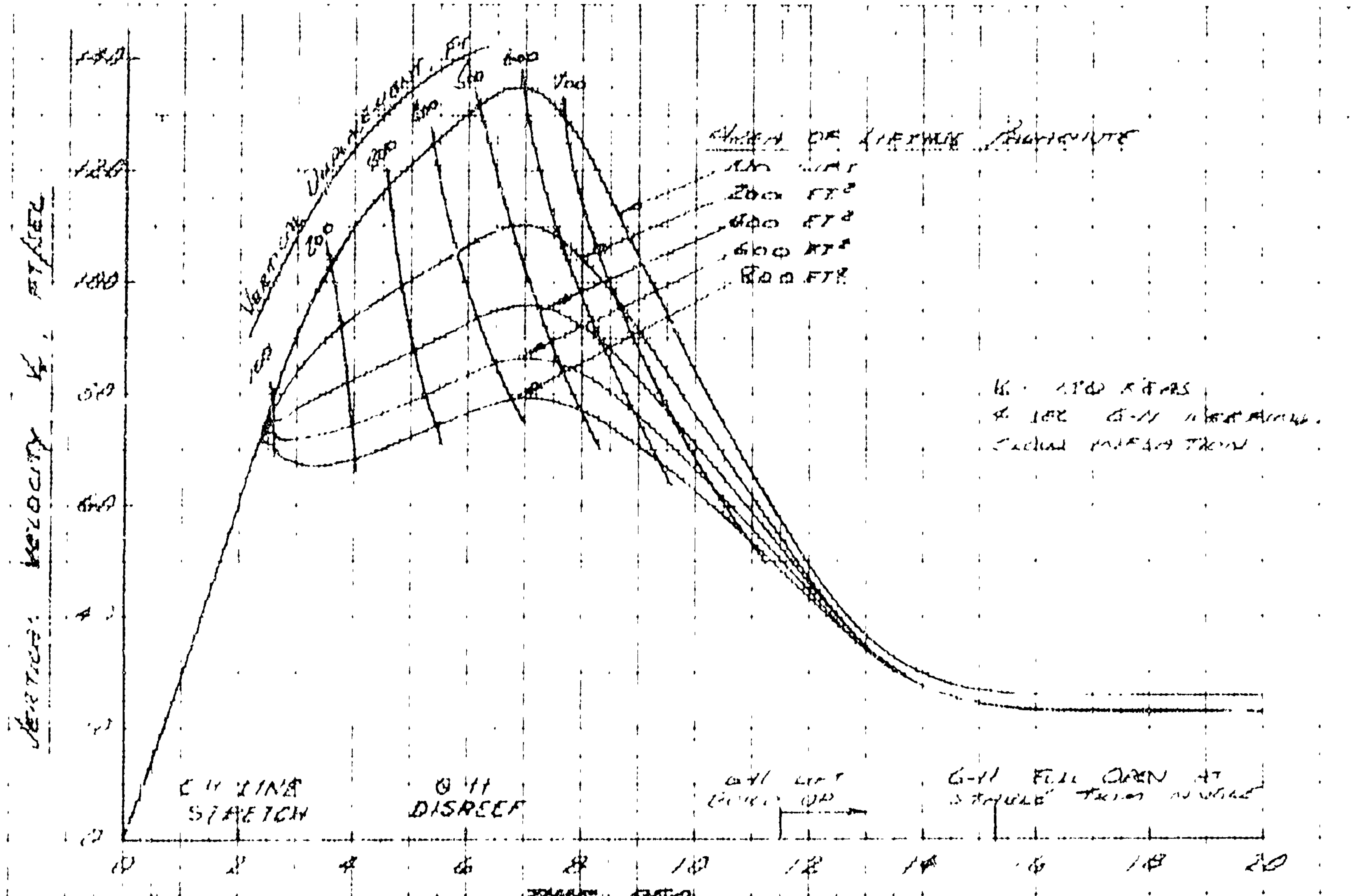
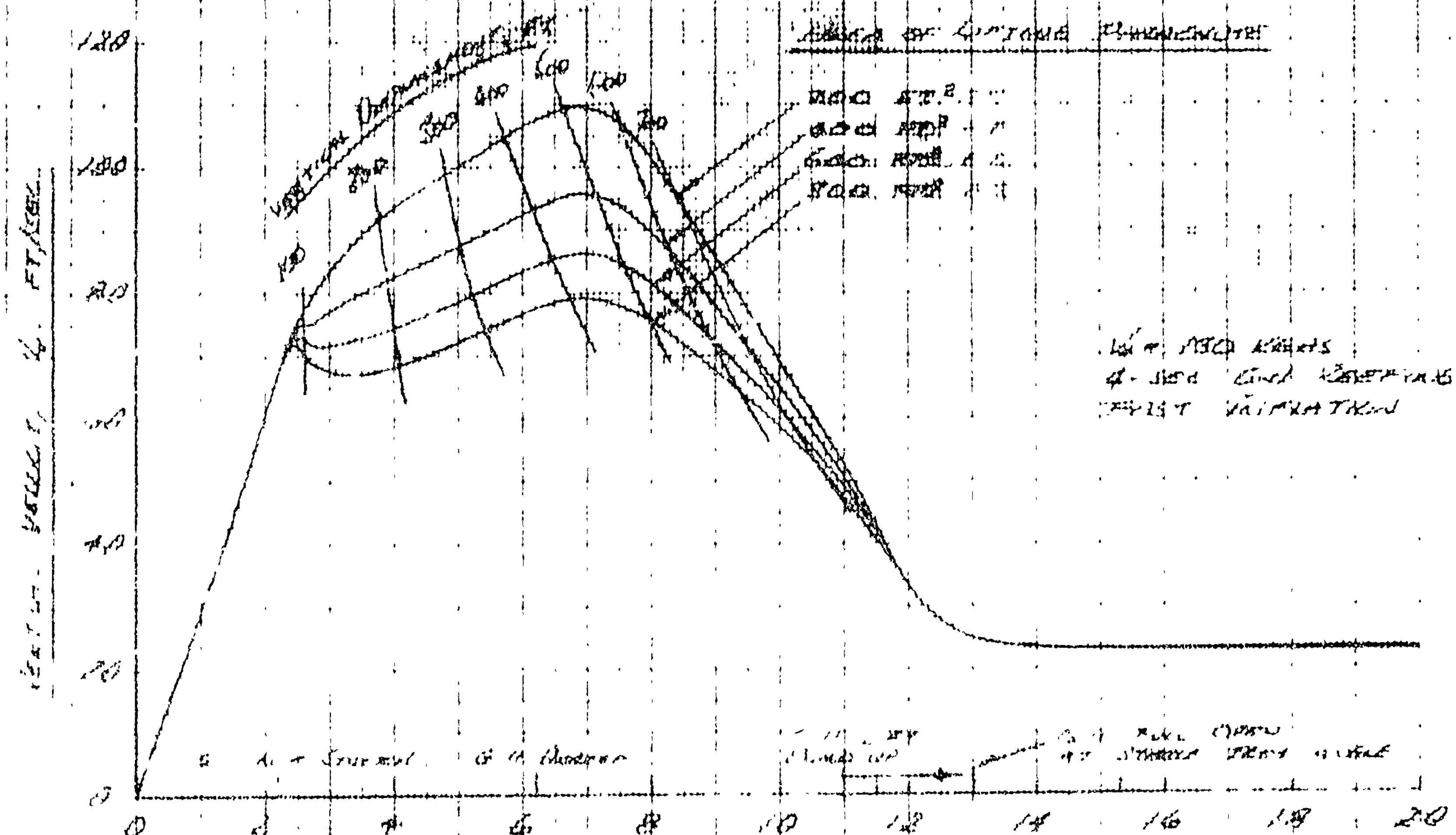


FIG 17. VERTICAL VELOCITY VS TIME, SLOW FILL, TILT CONCEPT



TIME, SEC

FIG. 48. VERTICAL VELOCITY VS TIME, FIRST FALL,

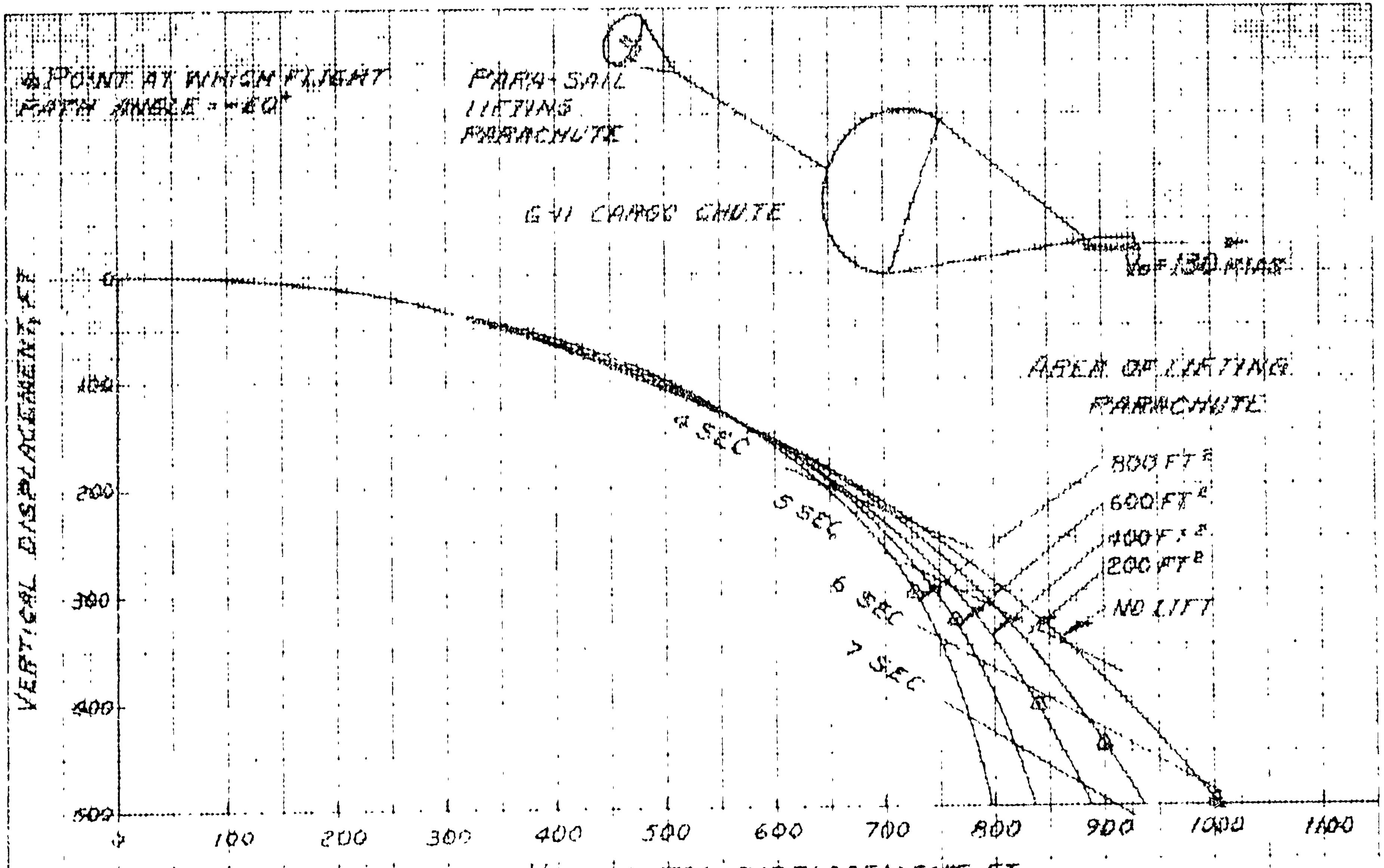


FIG.19 VERTICAL VS HORIZONTAL DISPLACEMENTS, TILT CONCEPT

manner under the same conditions.

Figures 17 and 18 are plots of vertical velocity vs time for slow and fast G-11 filling rates. The upper curves represent the conventional system. The lower curves represent various sizes of Para-Sails being utilized in the TILT concept.

In the conventional system, the cargo has fallen 500 ft in the first 6 sec and the vertical velocity is more than 130 ft/sec and still increasing. For the largest-size Para-Sail, with the TILT system, the cargo takes 8 sec to fall 500 ft, and the vertical velocity is 75 ft/sec and beginning to decrease. But since lift forces are not produced until the G-11 approaches full open, it becomes obvious that, in the time required to descend 500 ft, the lifting capability of the tilted main canopy is not utilized. It requires approximately 15 sec for the system to reach terminal rate of descent regardless of any tilting force applied to the G-11. The fact that the altitude required to reach terminal becomes less as the size of the lifting parachute is increased is due primarily to the added drag of the larger Para-Sail.

Figure 19 shows the actual payload trajectory from extraction at 500 ft to touchdown. Note that the flight-path angle (i.e., the slope of the curve) reaches -60° in from 5 to 7 sec; the effect of lift forces, even if available this soon in the sequence, diminishes rapidly after this point.

4.3.5 Supporting Experiments

As mentioned earlier, the trim angle of a flat-circular canopy of the G-11 type has a random directional orientation while in free flight. If this type of canopy were placed in a wind tunnel and tethered at the confluence point, the moment about the confluence point would, by definition, go to zero when the canopy was rotated to its trim angle. In effect, this means that the normal force at the vent would average to zero. Based on this, it was theorized that a flat-circular canopy in tow could be held at (or just beyond) its trim angle (in the desired upward direction) by means of a lifting parachute attached to the vent or skirt of the towed canopy. It was this theory (prediction) that led to the tow testing reported below.

4.3.6 Orientation Tow Testing

Purpose. The purpose of these tests was to determine if a flat-circular canopy could be stabilized in an upward direction at its trim angle by means of a lifting parachute attached in such a way as to produce a lift force in the direction of desired orientation.

Method. The risers of an 18-ft flat-circular 1.1-oz parachute were attached to the boom of a tow truck, with the risers being separated by 1 ft to avoid rotation about the center line. The parachute was then towed, fully open, without any lifting parachute attached. This was necessary to determine if ground effect by itself was sufficient to cause correct orientation, for if it were, the results of subsequent tests with a lifting parachute attached would be questionable.

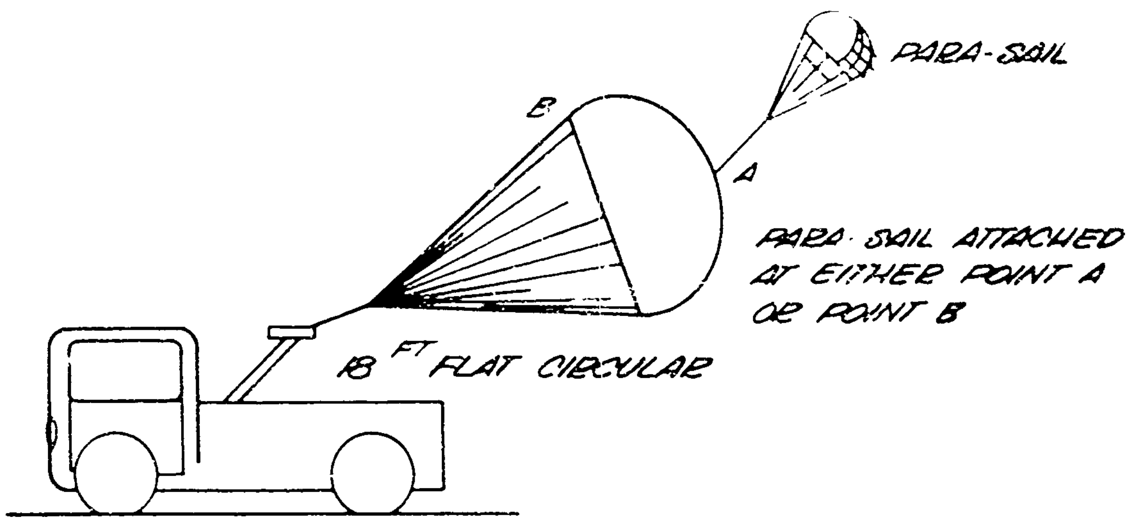
After determining that the ground effect did not cause upward orientation, a 4-ft Para-Sail was attached to the vent of the 18-ft parachute as shown in Fig. 20. Before the truck started moving, the Para-Sail was hand-held in an open oriented-upward position with the 18-ft parachute in a fully extended unopen position. As the truck gained speed, the Para-Sail was allowed to rise (in manner similar to that shown in Fig. 21a), and the 18-ft parachute opened soon afterward (in manner similar to that shown in Fig. 21b).

Runs were made for various Para-Sail riser lengths, with an attachment point at the vent, then at the skirt (as shown in Fig. 20).

Runs were also made in the same manner except that an 8-ft instead of a 4-ft Para-Sail was used.

Results.

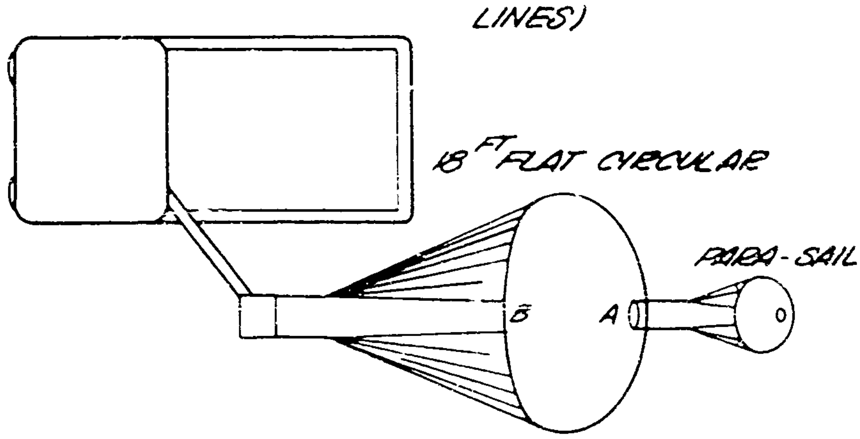
Run 1. The parachute tried to seek its trim angle in random directions: up, then to one side, then down, then up, etc., etc. The ground did not appear to cause any upward-orientation tendencies.



SIDE VIEW

POINT A IS RISER SEPARATION
POINT STRADDLING VENT

POINT B IS AT SKIRT OF 18 FT
FLAT CIRCULAR (2 FRONT ADJ.
LINES)



TOP VIEW

FIG. 20. ORIENTATION TOW TESTING, TILT CONCEPT.

(a)

(b)

FIG. 21. SUCCESSFUL TOW-TEST CONFIGURATION, TILT CONCEPT.

Run 2. A 4-ft Para-Sail was attached to the vent by a 4½-ft riser. The Para-Sail was blanketed out when the main parachute (18-ft) inflated.

Run 3. A 4-ft Para-Sail was attached to the vent by a 20-ft riser. The system worked well at the beginning of the run, but the Para-Sail risers twisted, and the main parachute did not orient correctly throughout the rest of the run. Apparently, 20-ft risers were too long.

Run 4. A 4-ft Para-Sail was attached to the vent by a 16-ft riser. The Para-Sail was blanketed out by the main parachute. The 16-ft risers were too short to avoid the wake of the main parachute.

Run 5. A 4-ft Para-Sail was attached to the skirt by a 4½-ft riser. The main parachute opened so fast that the ensuing jerking motion caused the Para-Sail to collapse. Therefore, the test was repeated.

Run 6. Repeat of run 5. The Para-Sail collapsed again on this run. One probable cause was the relatively short risers.

Run 7. A 4-ft Para-Sail was attached to the skirt by a 16-ft riser. The Para-Sail was slow in rising high enough to apply a lift force to the main parachute. Correct orientation was obtained, but there was an unstable oscillating motion of the main parachute.

Run 8. A 4-ft Para-Sail was attached to the skirt by a 20-ft riser. The Para-Sail risers twisted, again indicating that 20 ft is too long.

Run 9. An 8-ft Para-Sail was attached to the skirt by a 16-ft riser. The Para-Sail oriented correctly for this run, but the main parachute oscillated up and down through its trim angle.

Run 10. An 8-ft Para-Sail was attached to the vent by a 16-ft riser. For the entire run, the Para-Sail was above the main parachute, and the main parachute was oriented upward at a positive and stable angle. The results were very good.

TABLE 4
RESULTS OF TOW TESTS, TILT CONCEPT

Run	Para-Sail			Orientation results
	Attach. point	Riser length, ft	D_o, ft	
1	-	-	-	Random
2	Vent	4½	4	Poor
3	Vent	20	4	Poor
4	Vent	16	4	Poor
5	Skirt	4½	4	Poor
6	Skirt	4½	4	Poor
7	Skirt	16	4	Fair
8	Skirt	20	4	Poor
9	Skirt	16	8	Fair
10	Vent	16	8	Good
11	Vent	16	8	Good
12-15	Vent	16	8	Good

Run 11. An 8-ft Para-Sail was attached to the vent by a 16-ft riser. The main parachute was oriented correctly for the length of the field being used. However, as the truck made a 180° turn, the Para-Sail swung out and turned upside down. The main parachute then oriented downward.

Runs 12 through 15. An 8-ft Para-Sail was attached to the vent by a 16-ft riser. The main parachute oriented upward at a positive stable trim angle for all these runs. The results were very good.

Data for runs 1 through 15 are tabulated in Table 4.

4.3.7 Conclusions

Tow testing has shown that a flat-circular parachute can be made to orient in an upward direction and remain stable at (or slightly beyond) its trim angle while being towed at relatively slow velocities. There is no assurance that the same would be true for much higher velocities.

However, trajectory analysis indicated that the TILT effect cannot be utilized until something more than 500 ft of altitude has been used. Therefore, the TILT concept would be beneficial only for cargo dropped at altitudes higher than 500 ft. Even then, the altitude savings would be minimal because by the time the canopy approaches full open, where the TILT concept becomes effective, the velocity would have decreased cosiderably, and the trajectory angle would fast approach the vertical. Both factors minimize the TILT effect. Therefore, it is concluded that the TILT concept is not feasible for use at absolute drop altitudes of 500 ft or less.

5.0 OPERATIONAL ANALYSIS

The aspects concerned with operational use of the delivery system studied in this program have not been explored. As the result of the initial phases of study, the concept of elevating the recovery parachute to a position above the aircraft flight path, and thereby providing the increased vertical displacement required to reach terminal velocity, was determined not to be feasible. This conclusion applies to each approach to parachute elevation studied, including orienting the main parachutes to a position where they would apply lift directly to the load (TILT). On this basis, the expense of time and effort to further study operational problems was not justified. Although the approach of applying lift directly to the load, as in the load deceleration concept, did appear to have potential, effort along this line was stopped before analysis of the operational aspects was undertaken.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the theoretical analysis and experimental tow tests made under this contract, conclusions and recommendations are made on (a) the elevation of recovery parachutes, (b) the load deceleration concept, and (c) the TILT concept.

6.1 Elevation of Recovery Parachutes Concept

The concept of elevating the recovery parachutes as a means of gaining the additional altitude required above the absolute 500-ft drop altitude for cargo delivery is not practical. Lift forces applied to the recovery parachute as it deploys and begins to inflate produce insufficient elevation of the parachute in the desired upward direction to significantly improve the system performance. Therefore, additional studies of this concept are not recommended.

6.2 Load Deceleration Concept

The nominal cargo-delivery trajectory may be influenced by use of lifting extraction parachutes which, after extraction, transfer to the payload during deployment-inflation of the main parachutes and remain attached to the load during descent to ground impact. It is recommended that further studies be made of this concept.

6.3 TILT Concept

Orienting the recovery parachutes to an angle such that lift forces are generated as the canopy approaches full open is not practical due to the time period required for deployment and inflation of existing cargo parachutes. Further studies of this concept are warranted only if utilization of faster-opening cargo parachutes is considered.

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13. ABSTRACT

The report discusses the approaches pursued, and the results and conclusions reached, during this preliminary study conducted to investigate the feasibility of elevating the main recovery parachutes above the flight path of an airdrop aircraft by means of auxiliary lifting parachutes.

Preliminary analytical studies and experimental tests were conducted during the evaluation period from 30 Nov 65 through 31 Aug 66.

The overall objective was to determine the technical, operational, and economic feasibility of elevating the main recovery parachute to achieve a low-altitude airdrop capability of 500 ft (absolute) altitude or less, as a basis for determining if further "in-depth" study were warranted.

The results indicate that the elevation of recovery parachutes by auxiliary lifting parachutes is not feasible.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Auxiliary	0					
Lifting parachutes	10					
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Low altitude	4					