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MODEL WIND-TUNNEL AND FLIGHT INVESTIGATION OF A PARAWING–LIFTING-BODY LANDING SYSTEM

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16. Abstract

A parawing has been used with a model hypersonic lifting body, and landing and maneuvering capability which would be needed for the landing phase of the reentry trajectory was demonstrated. Small-scale wind-tunnel and flight-test results were used in designing the rigging and controls for an instrumented flight-test model (70 in. long (177.8 cm)). The wind-tunnel tests were made in the 17-foot (5.18 meters) test section of the Langley 300-MPH 7- by 10-foot tunnel and the flight tests were made at the NASA Wallops Station. Results of the tests showed that the rigging tightly coupled the body to the parawing so that little or no relative motion between wing and body occurred even in sharp turns. Lateral control by means of the parawing tip lines could produce turn rates of 25° per second and longitudinal control by means of the aft keel line could modulate the model in pitch from nose tuck (low angle of attack) to stall. The model was tested in a fully developed stall and was found to recover satisfactorily. Landing on the rounded bottom of the body was not satisfactory, at least in model size. Operations and safety procedures developed during the flight tests are described.

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MODEL WIND-TUNNEL AND FLIGHT INVESTIGATION OF A PARAWING—LIFTING-BODY LANDING SYSTEM

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SUMMARY

An investigation has been made of the application of an all-flexible wing (parawing) to provide the lift and maneuvering capability for a lifting body during the subsonic and landing phases of the reentry trajectory. Wind-tunnel tests were made in the 17-foot (5.18 meters) test section of the Langley 300-MPH 7- by 10-foot tunnel and radio-controlled flights were made at the NASA Wallops Station.

The procedures used for successfully rigging a parawing to a lifting body and operating the vehicle in flight tests are reported. Results of the tests showed that the rigging tightly coupled the body to the parawing so that little or no relative motion between wing and body occurred even in sharp turns. Lateral control by means of the parawing tip lines could produce turn rates of 25° per second and longitudinal control by means of the aft keel line could modulate the model in pitch from nose tuck (low angle of attack) to stall. The model was tested in a fully developed stall and was found to recover satisfactorily. Model turns lagged behind the control inputs as did return to straight flight and this characteristic required the pilot to anticipate required turning control inputs. Landing on the rounded bottom of the lifting body was not satisfactory, at least in model size, because of rollover of the body and high impact loads.

Operations and safety procedures developed during the flight tests are described, and some of the problems encountered are discussed.

INTRODUCTION

Land return of reusable spacecraft is currently of interest for many space missions. The combination of a controllable lifting body in the hypersonic phase of the reentry trajectory and a parawing that can be deployed in the subsonic and landing phases provides a land-landing system which may have many advantages.

A large ground area is accessible to an orbiting lifting body reentering the atmosphere and, therefore, the time of reentry is not as limited as that for a ballistic body. The lifting and maneuvering capability of the spacecraft reduces the number of landing sites to be prepared. Thus, for land landings, a controllable flexible wing with low wing loading permits a choice of the touchdown spot, reduces the need for surface preparation, and relieves the astronaut of the task of landing a high-speed vehicle. The low landing speed is desirable in the event of an emergency water landing. The parawing can also be considered for use in the abort situation.

Flight programs directed toward the application of flexible gliding devices to reentry vehicles have been carried out at the Manned Spacecraft Center and the Flight Research Center. The objective of the Manned Spacecraft Center study was to develop land-landing requirements, ground-based hardware, and flight procedures for an advanced landing system. The parawing was used as a representative lifting-wing system in the evaluation because it had been found to be trouble free and easy to use; that is, the landing system was being developed and evaluated, and parawing characteristics were only evaluated as needed to provide a quick turnaround flight system. Flight tests with models were made at Flight Research Center to develop a manned flight-test vehicle which could be used to obtain pilot experience and pilot opinion of flight in the speed and lift-drag-ratio regime under consideration. Again, the emphasis was not on development of the parawing but on use of an existing wing.

The purpose of the present investigation was to obtain a qualitative assessment of the flight behavior of the all-flexible parawing in combination with a lifting body during controlled gliding flight and touchdown. The flight tests were based on and supplemented by small-scale wind-tunnel tests and model-drop tests. Although the wing characteristics were of primary interest, the development of flight-test techniques, radio-control pilot displays, and ground and range equipment was necessary and was a large part of the total effort. Since the information obtained during the developmental stages of the investigation is believed to be of value for similar studies, a discussion of this information is included herein along with the discussion of the experimental results.

The wing used was the 45°-swept single-keel parawing, and the body was an ogive-shaped lifting body which was developed for Mach 7.0 flight. Small-scale model tests were made at Langley Research Center. Large-scale flight tests were made at NASA Wallops Station; excerpts from a motion picture of these tests have been incorporated in film supplement L-1014 which is available on loan. A request card and a description of the film are included at the back of this report.

SYMBOLS

The data presented in this report are referred to the wind axis system. Inasmuch as there was no well-defined reference line on the parawing, the angle of keel suspension line 7 with respect to the vertical was taken to be the wing angle of attack. The body center line was used as the body angle-of-attack reference line. Measurements for this investigation were made in the U.S. Customary Units but are also given in the International System of Units (SI). Weights given are for a location with the standard gravity value 9.80665 m/sec^2.

c	reference length, l_k minus Nose cutoff, ft (m)
C_D	drag coefficient, Drag/qS
C_L	lift coefficient, Lift/qS
C_R	resultant-force coefficient, $\sqrt{{C_L}^2 + {C_D}^2}$
C_m	pitching-moment coefficient, Pitching moment/qSc
D	drag
L	lift
q	free-stream dynamic pressure, lb/ft^2 (N/m^2)
S	area of parawing canopy flat planform, ft^2 (m^2)
t	time, sec
l	linear dimension, ft (m)
Δl	incremental linear dimension, ft (m)
x_{le}	distance from parawing theoretical apex to suspension-line attachment point, measured along leading edge, ft (m)
x_k	distance from parawing theoretical apex to suspension-line attachment point, measured along keel, ft (m)
l_k	length of keel of theoretical parawing-canopy flat planform, measured from theoretical parawing apex to trailing edge at plane of symmetry, ft (m)
l_{le}	length of parawing leading edge, measured from theoretical parawing apex to wing tip, ft (m)

α angle between relative wind and body center line, deg

α_W angle of keel suspension line 7, measured from normal to wind stream when viewed from side, deg

Suspension-line designations:

K keel

LE leading edge

DESCRIPTION OF MODELS

Single-keel all-flexible parawings (figs. 1 and 2) were used in the investigation. The shape of the model body was that of a lifting body which had been tested at hypersonic speeds to Mach 7.0. Unpublished results of these tests indicated that the body had trimmed lift-drag ratios between 1.0 and 2.0 and good static stability characteristics. The design conditions for touchdown of the body were that landing would be on soil or sand at a low speed. It was assumed that a belly landing would be made and that the relatively low landing energy would be dissipated by sliding and by rocking in pitch.

Small-Scale Models

One of the small-scale parawing-body models mounted in the tunnel is shown in figure 1, and the planform of the single-keel parawing is given in figure 2. The method of rigging the parawing to the body is discussed in appendix A. A 6.56-ft (2.0 m) keel parawing and a 7.87-ft (2.4 m) keel parawing were tested; these are 0.328-scale models, respectively, of the 20- and 24-ft (6.10 and 7.32 m) parawings to be used with the large-scale body. The wings were made from 0.75 ozm/sq yd (25.4 g/m^2) resin-impregnated rip-stop nylon cloth of essentially zero porosity. Dacron suspension lines of 135-lb (600 N) breaking force were used. Suspension-line lengths, line attachment points to the wings, and harness lengths are presented in table I. Note that these lengths will not scale to the flight vehicle values because a line-stretch factor was applied to the flight-model line lengths after they were scaled from the small-scale model lengths. Lines were tied to the connecters in the arrangements in figure 3, and the harness was attached to the body as shown in figure 4.

Two bodies (fig. 5) were used in the small-scale tests; body 1 was a model of an early version of a hypersonic lifting body and body 2 was a model of a later design. The differences in the two bodies are thought to have had no effect on the results of the small-scale tests. The bodies had thin shells cast from aluminum to provide lightweight models suitable for flight tests and also for tunnel tests. Body 1 weighed 6.0 lbf (26.7 N) and body 2 weighed 5.6 lbf (24.9 N). The canopy and suspension lines of the 6.56-ft (2.0 m) keel parawing and of the 7.87-ft (2.4 m) keel parawing weighed 0.45 lbf (2.0 N) and 0.55 lbf (2.4 N), respectively.

Large-Scale Models

The large-scale body (designated body 3) was made 70 in. (1.78 m) long because this size was large enough to contain an existing control system and gave a desired wing loading when flown. Photographs of the model attached to the helicopter ready for a drop and in gliding flight are presented as figures 6 and 7, respectively. As constructed and equipped, body 3 weighed 325 lbf (1445 N). Body 3 was used with both the 20-ft (6.10 m) keel parawing and the 24-ft (7.32 m) keel parawing to give, at its weight of 325 lbf, the approximate flight velocities of 29 ft/sec (8.8 m/sec) and 24 ft/sec (7.3 m/sec), respectively. Calculations of velocities were based on an air density at sea level and on a resultant-force coefficient of 1.00.

The parawing was scaled only in size; scaling of weight and stiffness of the lines and canopy was not considered. The canopy and line weights, however, should be considered in future flight tests because of the large effect they have on pitch and roll inertias and center-of-gravity location. For example, the flight parawing weighed about 3 percent of the total weight of the model but because of the long moment arm had about four times the inertia of the body with respect to the total system center of gravity.

The parawing—lifting-body landing system for the radio-controlled flight tests can be divided into the parawing system, body structure, control system, instrumentation system, and helicopter equipment. The essentials of the design and the construction of each system are discussed.

Parawing system.- Many parawing planforms have been studied in wind-tunnel tests (ref. 1). The single-keel parawing planform (fig. 2) utilized for the small-scale models was also used for the large-scale flight models. Commercially available single-keel parawings having keel lengths of 20 ft (6.10 m) and 24 ft (7.32 m) were selected. The parawings were constructed of 2.25 ozm/sq yd (76.3 g/m^2) coated rip-stop nylon cloth and reinforced with tape around the edges and along the keel. Details of the line attachments are shown in figure 8. Suspension-line attachment points and line lengths in table II, harness lengths in table III, and the harness arrangement of figure 4 define the wing suspension system. The method of rigging the parawing to the lifting body is described in appendix A.

Deployment bag.- Figure 9 shows details of the deployment bag, and figure 10 gives details of the deployment-bag container. The small size of body 3 and the amount and arrangement of internal equipment precluded stowing the wing pack inside the body. On the basis of experience, the packed parawing was mounted near the center of the body and positioned for a straight upward pulloff. A rectangular deployment-bag shape was chosen so that the bag would be as close as possible to the release shackle. (See fig. 6.) The deployment bag was packed in a container attached securely to the model by four 750-lbf (3340 N) ties. The deployment bag was held in the container by two 80-lbf (356 N) break cords which were broken by two loops tied into the static line. This system was used for safety reasons to contain the wing so that it would not be released accidentally and get into the helicopter blades. Any bumping or air loads on the bag were taken by the heavy ties. At release, this system functions in the following manner: The body falls away and stretches the static line which pulls the deployment bag out of the container that was attached to the body. As the body falls farther, the line bights are loosened and the suspension lines play out of the bottom of the deployment bag until, at nearly full length, the line bights holding the inner flaps are released and the parawing canopy begins to unfold. The canopy stretches to full length because it is held by the inner tie until the tightly stretched system breaks the inner tie and frees the wing for deployment and glide.

Lifting-body—parawing packing procedures are given in appendix B.

Body shell and internal equipment storage.- The body shape and center of gravity were determined from high-speed wind-tunnel tests and from some limited crew and cargo placement studies. Coordinates of the body and details of the fins are given in figure 11. Several methods of construction and materials were considered. A fiber-glass reinforced plastic shell, with ribs of the same material, was chosen as the best construction for a body which must withstand hard landings and abrasion and yet be reused many times. Easy field repair was also a consideration. The body was constructed with a removable top for access to equipment; this top was 1/4 in. (0.6 cm) thick. The bottom was 3/8 in. thick (0.95 cm). One aluminum bulkhead was used to provide a mounting for the control system and a second, to close the aft end of the model and strengthen the lower rear edge of the model. These bulkheads were tied together to strengthen the aft section of the model.

The placement of the various pieces of equipment in body 3 is shown in figure 12. The nose and ballast were removable for weight and balance adjustment. A 16-mm motion-picture camera was contained in a rack which was attached from the outside to the shell so that the film could be loaded without removing the model top. A six-channel telemetry system gave control position and some acceleration measurements. This equipment was mounted on a plate which was attached to the bottom ribs. The turn and trim control mechanism and the keel control winch were mounted on an aluminum bulkhead at the rear of the model so that the control lines entered the body aft of the rear wing harness.

Control system.- The longitudinal control system is shown in figure 13. The winch, which was mounted on the control bulkhead, had a maximum travel of 19.0 in. (48.3 cm) and had stops to reduce the travel by increments of even inches. A short length of 550-lbf (2447 N) line (not shown) was attached to the winch, and a spring sister hook was used to attach the line to the parawing control lines. The line was guided to the winch by a drilled plastic fairlead. The longitudinal control mechanism was designed to withstand deployment loads and, therefore, the wing neutral control line position could be set at midtravel for deployment.

The lateral control system is shown in figure 14. This system could vary the length of either of the parawing tip lines 10.0 in. (25.4 cm) by using two independent winches (one shown on each side of the figure) and could superimpose a differential trim by means of the centrally located trim cam. The differential line movement resulted as the cam rise acted on one or the other of the lines. All drops were made with the tip lines extended to the outstops because the lateral control system could not withstand the deployment loads unless the lines were against the outstop.

An electric motor and gear box were used with each winch and with the trim cam, and various gear ratios and motor speeds were available. Three speeds were used on the parawing tip lines for controlled flights: 2.0 in./sec (5.1 cm/sec) for flights 107 to 120, 1.3 in./sec (3.3 cm/sec) for flights 121 to 138, and 3.2 in./sec (8.1 cm/sec) for flights 139 to 169. For all controlled flights, the trim cam speed was set for 0.9 in./sec (2.3 cm/sec). Control speeds and initial settings are given for each flight in table III.

A discussion of the control system, control console, and command-system requirements and design is presented in appendix C.

Camera system.- Motion pictures of the parawing were taken by an onboard camera (fig. 12). This record was used in determining the angular and translational variations between body and wing.

HELICOPTER EQUIPMENT

A side mount attached to a utility-type-helicopter external cargo assembly was adapted for all drop tests. A bomb shackle attached to the side mount held the model at the desired attitude and released it with minimum disturbance. The drop-test equipment is shown in figure 15. A small ring held the camera lanyard and a large ring held the static line for deployment of the parawing. Both mechanical and electrical releases were available to the drop crewmen, and an electrical drop switch and a hold switch were available to the helicopter pilot.

EXPERIMENTAL PROCEDURE

Wind-tunnel and free-flight tests were made with approximately 23-in-long (58.4 cm) bodies in preparation for free-flight tests of a 70-in-long (177.8 cm) body. The tests involving the smaller bodies 1 and 2 are referred to as small-scale tests, and tests involving the larger body are referred to as large-scale tests or body 3 tests.

Small-Scale Tests

Wind-tunnel tests.- Static wind-tunnel tests of bodies 1 and 2 with the 6.56-ft (2.0 m) keel parawing and the 7.87-ft (2.4 m) keel parawing were conducted in the 17-foot (5.18 m) test section of the Langley 300-MPH 7- by 10-foot tunnel. Tests were made at a dynamic pressure of 2.0 lb/sq ft (95.8 N/m^2).

Readings were recorded from a six-component wire strain-gage balance, and the angle of keel suspension line 7 was used as reference angle of attack.

Jet-boundary corrections to the angle of attack and drag coefficient and blocking corrections to the dynamic pressure as determined from references 2 and 3 have been applied to the small-scale test results. A correction to the pitching moment has been made to account for the weight moments of the canopy material and lines.

Drop tests.- Flight tests were made with the small-scale models by dropping them from an elevated platform which was at a height of approximately 90 ft (27.4 m). The models were supported by the wing fabric. The fabric was stretched out as much as possible and the motions of the body were allowed to subside before the model was released.

Helicopter Drop Tests

Procedures used in the helicopter drop tests were range countdown (not reproduced), packing of parawing (appendix B), considerations for helicopter operational safety (appendix D), and range safety plan (appendix E). The model configurations are given in detail in table III and the date and time of each flight, the duration of the flight, and the altitude and speed of the helicopter at time of model drop are listed in table IV.

DISCUSSION

Small-Scale Wind-Tunnel and Free-Flight Tests

The small-scale wind-tunnel tests were conducted to obtain data for use in the large-scale drop tests of the flight vehicle and some of these data are presented herein. In the wind-tunnel tests, the body shape, center of gravity, and body landing attitude were changed; therefore, the effects of these changes must be taken into account when analyzing the data. The change in body shape had no significant aerodynamic effect since the body aerodynamic forces were small compared with the parawing forces, changes in the reference center of gravity were accounted for by keeping the rigging attachment points related to the center of gravity rather than to the body extremities, and no data with body landing attitude changes are included in the tunnel data.

The coefficients determined in the wind-tunnel tests are presented as a function of body angle of attack in the first part of figures 16 to 21 and as a function of resultant-force coefficient in the second part of the figures. The ranges of force coefficients and angles in these figures are similar to those presented in reference 1 and, therefore, these data are not discussed. As stated in the section entitled "Experimental Procedure," a correction to the pitching moment accounted for the weight moments of the canopy material and lines. Thus, these pitching-moment data apply directly only to a model with a weightless, or very light, parawing and a body ballasted to the center of gravity of the wind-tunnel model.

The stability and trim of the parawing-body combination were of predominant interest. The parawing when pitched to an angle of attack lower than that for maximum L/D distorts at the nose and when pitched to a higher angle goes through a short range of stable pitching-moment coefficient which is followed by an abrupt stall. The stall is usually oscillatory with rapid loss in altitude. Therefore, for tests of the inert flight vehicle, the model was rigged to fly at a low angle of attack to avoid damage at landing. To reduce the possibility of twist-up (that is, relative rotation of the wing and body which results in a nongliding condition after deployment), brace cords were used in the harness to assure that the body would be in a nearly horizontal attitude at the time of wing inflation. These cords were arranged to form a tension tripod at either the front or the rear wing-body attachment so that the body was held nearly level for either an inflation at the nose first or at the trailing edge first. The first six free-flight tests of the 6.56-ft (2.0 m) keel parawing and body 1 combination (table V(a)) were made to correct the lateral trim and to determine the body attitude in gliding flight. In these tests, the body attitude was observed to be about horizontal and, since a -5° body attitude was desired (appendix A), the control lines and rear harness straps were shortened. Observation of flight 7 confirmed that the attitude was correct. Longitudinal control tests (flights 13 to 15) indicated that the model with the basic rigging was near stall since a $0.015l_k$ shortening of all three control lines resulted in stalled flight. Good glides were obtained with the lines let out as much as $0.030l_k$. Comparable tunnel tests for a weightless canopy (fig. 16), however, showed that the model was nearly trimmed in the basic condition, was stable, and had a linear variation of pitching-moment coefficient with angle of attack on each side of the angle for trim with $-0.015l_k$ control. The model was far from trim when the control lines were extended from the basic position. Thus, for the flight tests the control lines had to be lengthened to obtain about the same range of trimmed flight as indicated by the tunnel results. Similar results have been obtained previously when riggings of models for tunnel and flight tests have been compared. The stability of the model in the tunnel with the body rigidly attached to a sting was such that it had an effect on the results so that low angles of attack could not be reached if the wing tended to roll to the side. This effect was very noticeable when the attachment point for the control lines was shifted from the ends of the rear straps to a new centered location on the body. For example, the basic configuration of figure 16 would have been trimmed if an angle of attack 1° lower than shown had been reached in the tunnel tests. Similar trends are indicated from a comparison of table V(b) (flights 15 to 23) and figure 17, although more overlap of the flight and tunnel control ranges are indicated in that the model flew with somewhat more than $-0.030l_k$ control input.

The 6.56-ft (2.0 m) wing was rigged to small-scale body 2, and the rather powerful effect of a $0.010l_k$ change in a front-strap length on trimming the model is evident in figure 19.

A study of the wind-tunnel and flight results in figures 20 and 21 and table VI for the 7.87-ft (2.4 m) keel parawing and body 2 combination indicates the same conclusions as were drawn from figures 16 and 17 and table V.

To examine the effect of the wing height on the model center of gravity, the wind-tunnel results were transferred to a combined wing-body center of gravity. There are several difficulties involved in this procedure. One is that it is hard to find the center of gravity of the wing and lines. A second is that the wing moves relative to the body as the angle of attack is varied. A photogrammetric method has been used successfully to determine the center of gravity of a wing and lines for a confluence-point rigged wing (ref. 4). Admittedly, the confluence-point data are not exactly applicable to spread rigging, and the theoretical confluence point from which the rigging was derived is not accurately located (appendix A); nevertheless, these available values were used to show the effect of wing weight on the results. A combined center of gravity was calculated for the 6.56-ft (2.0 m) keel parawing and body 1 combination; the pitching-moment data of figure 17 were transferred to this calculated center of gravity and the transferred data are presented in figure 18. The wing weight of 0.45 lbf (2.0 N) and a body weight of 6.0 lbf (26.7 N) resulted in a center-of-gravity transfer of $0.006l_k$ rearward and $0.076l_k$ upward. These distances are somewhat larger than expected in the body 3 tests because the weight of the wing used in the flight tests was a smaller part of the total vehicle weight than was the model wing in the small-scale tests. Including the parawing weight (fig. 18) resulted in a positive increment in pitching-moment coefficient and a rotation of the curves in an unstable direction. The positive increment of pitching-moment coefficient was not sufficient to trim the model for positive control movement. This transfer only partly accounts for the difference between tunnel and flight results. An examination of the curves of C_R

as a function of α_w in figure 17 indicates a considerable difference in the slope of the curves for positive control motion as compared with the slope of the curves for negative control motion. From these curves, one can conjecture that the appreciable stiffness built into the rigging by the diagonal lines had a controlling effect when the control lines are loosened. The cause of the differences in tunnel and flight results may lie in the sensitivity of either kind of test to line stretch and error in line length in some of the important lines.

The center-of-gravity range for gliding flight was not determined in the flight tests. The tunnel results indicate a static margin of 0.36c for the 6.56-ft (2.0 m) keel parawing and body combination and 0.09c for the 7.87-ft (2.4 m) keel parawing and body combination. This criterion may be only of academic interest because the center of gravity must be located well within the rigging attachment points. Therefore, large movement of the center of gravity relative to the wing would require rerigging which would likely result in a different variation of pitching-moment coefficient with lift coefficient. The difference in the slopes of the curves of C_m as a function of α for the 6.56-ft keel and 7.87-ft keel wings can perhaps be attributed to differences in rigging, especially the "rigidity" of the wing-body coupling. One wing was larger and had longer suspension lines and undoubtedly a difference in the relative tightness of the diagonal lines. Observations made during the tunnel tests were similar for the two wings, however, in that a tightening of the rear diagonal lines and a loosening of the forward running diagonal keel line 7 were noted as angle of attack was increased. Nevertheless, the α_w slope with body angle is considerably higher for the 6.56-ft keel wing than for the 7.87-ft keel wing and the movement of the wing relative to the body is likely the cause of the difference in slope.

A few free-flight tests (table V(b)) were made with lateral control movements. From the results, it appears that changes in parawing tip line control of $0.01l_k$ and $0.02l_k$ produced significant turning. Either the one tip control or the differential tip control was adequate and fully within the control capabilities of the mechanism to be used in the large-scale flight vehicle.

Rigging of Large-Scale Flight Vehicle

Drop tests were made first with an inert body to check the deployment and rigging of the parawing before beginning tests with the instrumented and controlled body. The inert body was weighted with lead sheet distributed to simulate the weight of the control and radio equipment in the instrumented shell. The parawings were rigged according to the small-scale results which were modified for line stretch and were packed according to the procedures in appendix B.

Test conditions were as given in tables III and IV. The model was released at an an altitude of 500 ft (152.4 m). The parawing deployed and glided with a fairly large amount of nose tuck inasmuch as the controls were set on the safe side, away from the stall condition. This result is more in agreement with the wind-tunnel test results than with the small-scale drop results which indicated that the model with basic rigging was near to stall. A factor which could have had a bearing on this comparison is that the large-scale rigging was altered to account for line stretch; this procedure could have changed the trim if the method used and constants were not exactly right. The wing rigging was not changed during the inert body flights, but the center of gravity was at 0.555 body length for flights 101 to 103 and at 0.568 body length for all other flights.

After controlled flights began and after some experience (just a few seconds per flight at these low altitudes) was gained, changes were made to increase the parawing angle of attack. Harness attachment points 1 and 2 were moved forward for flight 111 and again for flight 123, and the aft keel line was shortened 2 percent for flight 114.

Twist-up (that is, relative rotation of the wing and body) occurred frequently in flights 101 to 116. (See table IV.) After these flights, a refined packing procedure for the parawing (appendix B) was used and, as a result, twist-up was virtually eliminated for the rest of the tests.

Three additional parawings were used after the early development tests were completed: one 20-ft (6.10 m) keel parawing and two 24-ft (7.32 m) keel parawings. The new 20-ft keel parawing (wing 14) was checked out on the inert body in flight 118. This flight was not routine as had been expected. The wing extended normally on release but remained tightly pleated for several seconds before opening. The wing lines were twisted and the twist remained in the lines to touchdown. The reason for the slow deployment or twist-up of lines is unknown. This was the only flight in which twist-up did not clear before touchdown, possibly because of the altitude loss in deployment. The wing filled normally in flight 120 which was a repeat of flight 118.

Deployment

Since high-speed deployment techniques and deployment loads were outside the scope of the present investigation, the requirement was for a system that would put the model in steady glide easily and safely. Static line deployment was chosen for all systems investigated.

Deployment loads for flights 121 to 169 are given in table VII. The load varied from a minimum of 3.1g to a maximum of 7.1g and the average value was 5.0g. Loads of 6g had been predicted and, therefore, a design value of 10g had been used to allow a safety factor. No failures were noted in the attachment structures.

Flight Observations

Trim task.- After the deployed parawing began steady flight, the pilot was to trim in pitch until the nose was just inflated. Generally, because the wing was rigged for a low angle of attack, the keel line was pulled in until nose tuck was removed and then was let out slightly to the trim for maximum L/D. Keel control was found adequate in performing this maneuver. At this time, the wing was to be trimmed laterally before beginning maneuvering flight. In practice, this lateral trimming was rarely carried out. During low-altitude flights there was not sufficient time for trimming, and during some of the early flights the amount of trim and the effect of trim on the logic of control could not be recognized. Wing 12 required about 50 percent right trim and wing 14 required about 65 percent left trim. This much out of trim, of course, nullified the intended system of lateral control in that the vehicle did not fly straight when the control was returned to full-out position.

Control input and trajectory for flight 163.- Flight 163 was chosen to illustrate control motions and the resulting flight path inasmuch as the model was trimmed, one control was used at a time, and a significant course change took place (fig. 22). The control inputs, accelerometer reading, and altitude are presented as a function of time, and the flight times are indicated on the ground track record. The deployment load (fig. 22) was 6.3g. After deployment, the pilot trimmed the parawing and then made two left turns using about 65 percent of the available control travel. The sequence of events indicates the time to turn and to return to straight flight. The first control input was at $t = 12$ sec. Motion pictures and the ground track record (fig. 22(c)) were used to determine the turn start and stop times. The first turn began 4 sec after control was in and ended 6 sec after control was removed. The second turn began at about 39 sec, the time of full control input. Inasmuch as this control input was applied in steps, this result was to be expected. Straight flight was indicated at $t = 52$ sec which was 7 sec after control was removed. A pilot must plan to remove control well over 90° before reaching the desired heading during execution of these 25°/sec turns. The ground plot includes the effects of wind which distorts the flight path that would occur in still air. The effects of the average wind determined at drop time were removed and the data were replotted in figure 22(d). The first turn began earlier and the second turn appeared sharper in the still-air plot. This low wind velocity had not greatly distorted the flight path. Results from tests of a 72-ft (22 m) twin-keel parawing (unpublished) indicate almost immediate control response. From this result and the results of the present investigation, it appears that the tight coupling of the wing to the body which has a large amount of inertia had a significant effect on the control response.

Stall characteristics.- Flight in the stalled condition has been generally avoided because of the large loss in altitude during stall flight and the possibility of tangling or overloads on the parawing and attachments. A deliberate stall was induced in flight 137, and a portion of the record of that flight is presented in figure 23. The control motions and acceleration are shown as a function of time. The maneuver started with the tip controls extended and the keel control at about midtravel as is normal for gliding flight. All three control lines were pulled in slowly (by intermittent use of the stick) with the intent of putting the wing in a parachute flight mode (nearly vertical descent) before going into the stall. However, at about 78 sec into the flight a sharp turn was observed. The wing pitched back and oscillated. Three sec after the wing was stalled the controls were run out at full speed to effect recovery from the stall. Loads as high as those for the static line deployments were recorded after the controls were extended. Recovery was completed about 10 sec after the controls began to run out.

Final approach and landing.- The plan for each flight was greatly influenced by range safety requirements. The final range safety rules used are given in appendix E. Tables III and IV and figure 24 present many of the details of the flights. Usually landings were to be made on the grass, and landings on concrete were avoided more often than not. Some of the landings were made either with side motion or with side motion combined with turning motion relative to the ground. A roll-over and model damage usually resulted from landings made in a turn; therefore, the decision was made to neutralize the controls before landing even if it resulted in a downwind landing.

The data are not acceptable for a statistical study of landing dispersion because of the many variables. Five inexperienced pilots were used, variations in equipment and controls were made, and landing area was changed twice. Nonetheless, it is interesting to see the number of flights which terminated in each 50-ft zone (15.2 m). (See fig. 25.) All but seven flights terminated in an 800-ft-radius (243.8 m) circle. The miss distances do not appear to group according to pilot or altitude of drop but generally the largest miss distances occurred when the pilot attempted to execute a planned series of control inputs rather than just concentrate on flying.

The operating problems which were encountered were related to the test area, range safety requirements, pilot training, and pilot aids. The type of test area was found to determine the fraction of the total effort applied to operations, range safety, and piloting technique as compared with the fraction applied to study of the control, landing, and flight characteristics of the vehicle. The test range used necessarily required almost total concentration of the pilot on approach and landing. The lack of a plotting board or azimuth indication made the piloting task more difficult. The pilot was located either away from the target, at the target, or in a closed van (one flight). No particular preference was indicated by the pilots for a location of the control console either near the target or a considerable distance away. One flight was made with the pilot using the range safety plotting board and ground-to-air television. The value of the plotting board was apparent, but the effect of turn controls on the azimuth of the vehicle was difficult to detect on the ground track plot and became obvious only after the model was turned too far from the desired heading. The conclusion from this limited experience was that a plot of the vehicle location and altitude and an onboard azimuth transmitter were the minimum requirements for the pilot to fly a model by remote control at the Wallops station.

Even though the flight path includes a fair amount of turns and other maneuvers, the descent rates for the vehicle are of general interest for use, for example, in range safety plans. The descent rates are presented in table VII in feet per second and meters per second. Descent rates for the 20-ft (6.10 m) keel parawing ranged from 9.9 to 25.8 ft/sec (3.0 to 7.9 m/sec) and averaged 17.4 ft/sec (5.3 m/sec). Descent rates for the 24-ft (7.32 m) keel parawings ranged from 10.8 to 14.9 ft/sec (3.3 to 4.6 m/sec) and averaged 12.4 ft/sec (3.8 m/sec).

Landing Impact Accelerations

Mechanical accelerometers were mounted on the bottom of the body 3 shell and on the control bulkhead to obtain some values of vertical and horizontal accelerations at landing. Vertical accelerations ranged from 25g to 72g and horizontal accelerations ranged from 20g to 49g (table VII).

CONCLUDING REMARKS

Small-scale wind-tunnel and drop tests were made to obtain parawing rigging and control-range data. Use of this information to set the rigging and controls of the large-scale flight-test vehicle resulted in gliding flight for all parawings.

The procedures used for successfully operating the vehicle in flight tests are described along with the instrumentation and range equipment.

Line twist-up (that is, relative motion of the wing and body leading to loss of control and trim) had occurred frequently in some flights. This problem was solved simply by very careful attention to the orientation of the wing and lines during packing.

The helicopter drop tests showed that the rigging tightly coupled the body to the wing so that little or no relative motion between wing and body occurred in sharp turns. Lateral control by using the tip lines could produce turn rates up to 25°/sec, and longitudinal control (that is, variation in the length of the aft keel line) was capable of modulating the model in pitch from nose tuck (low angle of attack) to stall. The model was tested in a fully developed stall and was found to recover satisfactorily.

Model turns and return to straight flight lagged behind the control inputs and this characteristic required the pilot to anticipate turning control inputs.

Landing on the rounded bottom of the lifting body resulted in rollover of the body and high impact loads.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 19, 1970.

APPENDIX A

METHOD OF RIGGING PARAWING TO BODY

The information available on the parawing included results from modified confluence-point tests in the wind tunnel and generally confluence-point rigged flight tests of various sizes of parawings. A cargo box and a ballistic spacecraft shape had been rigged to the wings with the attachment points on the payload spread in a manner that coupled the payload motion to the wing in flight. The lifting body was rigged to the parawing on the basis of this experience to assure early successful flights, and the details of the procedure used to obtain the resulting rigging geometry are as follows. First, a side-view drawing (fig. 26) of a confluence-point rigging for the wing was made by utilizing data from reference 1. A line indicating the flight path was drawn with $\tan^{-1} D/L$ used to obtain the slope. Then, a scaled tracing of the lifting body was made which showed the harness attachment points, center of gravity, and body reference line. This tracing was placed over the wing drawing and positioned to put the center of gravity above the confluence point and to give a 5° nose-down landing attitude. This landing angle was chosen after some preliminary flight experience and was such that the vector sum of friction and vertical impact forces, based on still-air conditions, passed through the body center of gravity. The next step was to determine a harness length sufficient to reach from the attachment points on the body to the deployment bag near the center of the body. Thus, no individual suspension lines would be exposed to the airstream before deployment. The harness geometry (fig. 4) was based on previously successful systems, that is, cargo box and landing operations test vehicle. The split attachment at the front harness was selected to reduce fore and aft movement of the body relative to the connectors and was also useful in establishing the desired longitudinal trim of the vehicle. Both the strap length and the attachment location could be varied for the front harness. The rear harness was also split to stabilize the body in roll. The aft leading-edge lines were attached to outboard straps to reduce the inward pull on the wing tip. After the harness geometry was fixed, the suspension lines were grouped at the connecter links at the free end of the harness and a preliminary moment balance was taken about the center of gravity by using the line load coefficients of reference 1.

Experience has shown that spreading the lines from a confluence point to couple the parawing and body attitudes permits longitudinal translation of the wing relative to the body if sufficient and properly placed diagonal bracing is not used. Therefore, after the preliminary harness and rigging layouts were made, diagonal bracing for the wing rigging to the harness was designed. The diagonal lines were connected to heavily loaded points on the wing which were the fourth of six leading-edge line attachments and the seventh of 11 keel lines. Small-scale tests of body 1 and body 2 with parawings were made in the wind tunnel and from the elevated platform to define the rigging. The suspension-line lengths determined in these tests are given in table I. These values are for heavy dacron cord on a light model so that there was essentially no line stretch. The lengths were scaled up to parawings with 20-ft and 24-ft keels (6.10 m and 7.32 m) by using a line stretch factor of 0.00116 in./lbf-in. for a 750-lbf line (0.000261 cm/N-cm for a 3336-N line) used on the wing along with the tension coefficients from reference 1. The suspension-line lengths for the 20-ft (6.10 m) and 24-ft (7.32 m) keel parawings are given in table II. These lengths with the information in figures 3 and 4 define the wing-body rigging.

APPENDIX B

PARAWING—LIFTING-BODY PACKING PROCEDURES

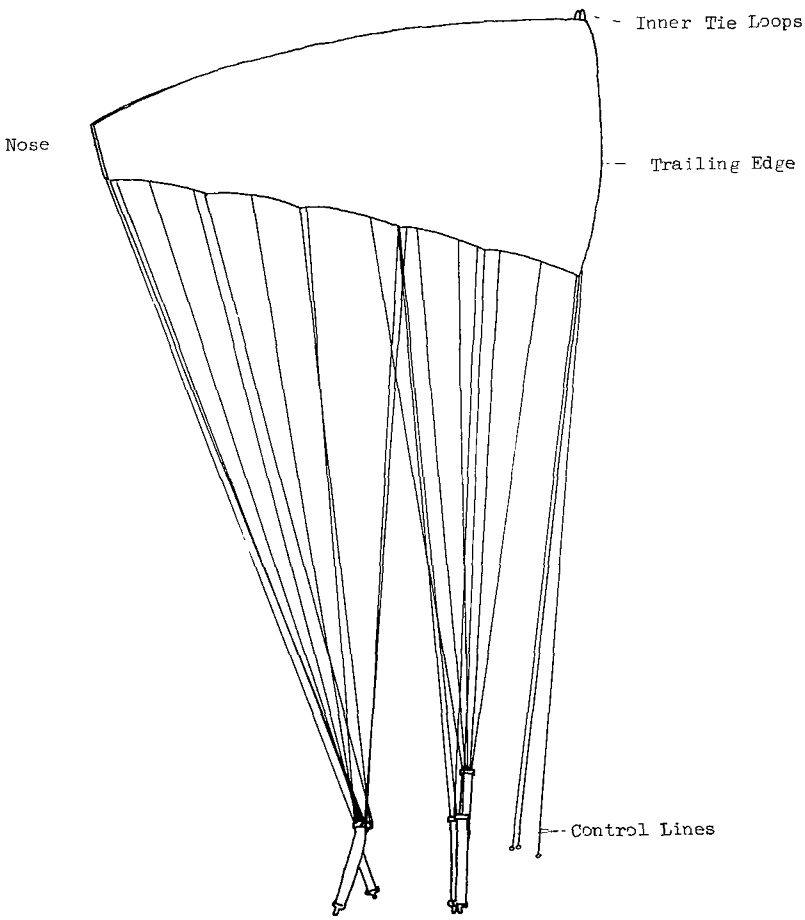
The procedure used to pack the parawing consisted of the following steps:

1. Check parawing, lines, and harness for damage.

2. Set or measure line lengths and control lengths as required by the research project engineer.

3. Update parawing history form.

4. Stretch lines out by pulling on canopy material at the top of the lobes and then stretch canopy by pulling on nose and trailing edge. Arrange with right leading edge on packing surface and left leading edge on top of right leading edge. (See sketch (a).)

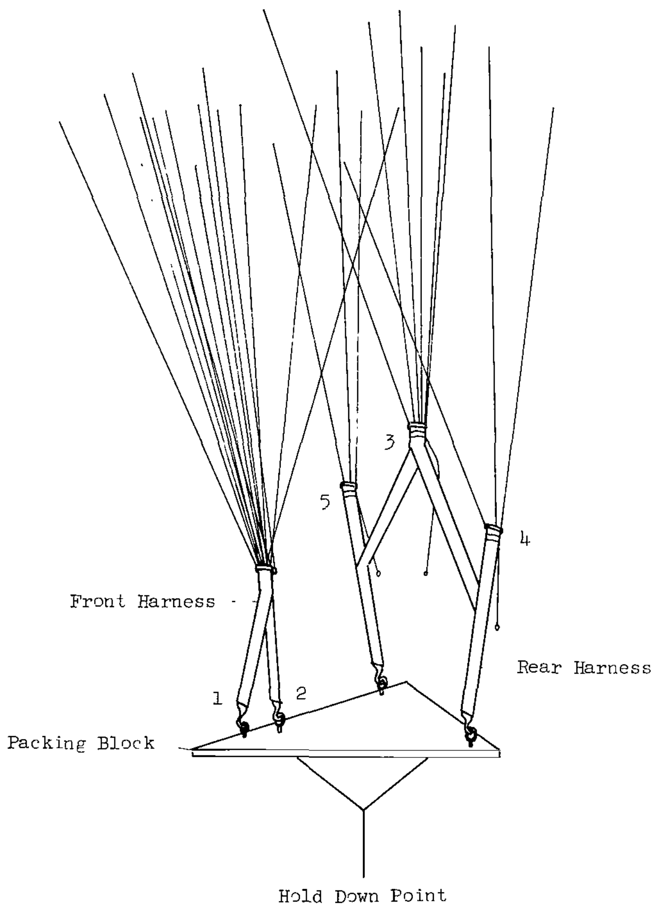


Sketch (a)

5. Check line and harness orientation and attach harness to packing block. (See sketch (b).)

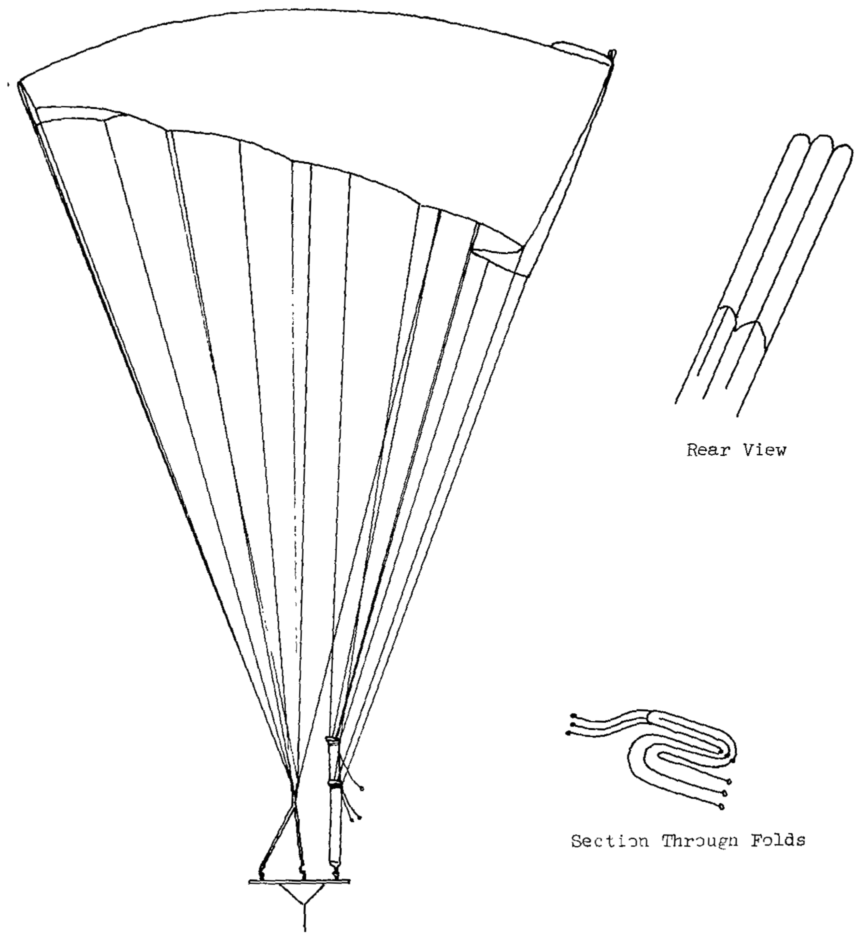
6. Attach packing block to hold-down point with block pointing in same direction as parawing nose.

7. Tape control lines to harness at the proper length.



Sketch (b)

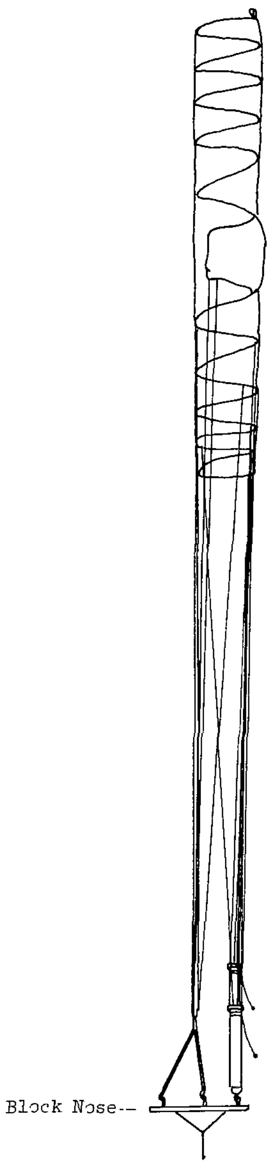
8. Start folding parawing at the trailing edge and use appropriate size accordian folds. (See sketch (c).)



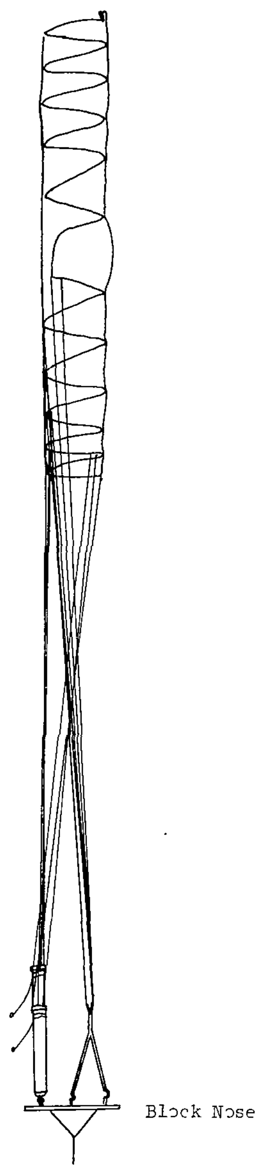
Sketch (c)

9. Pull each fold so that all lines are taut and on top of the parawing. (See sketch (d).)

10. Rotate packing block and lines 180° by lifting block nose from floor and turning so that it points in direction opposite to that in step 5. (See sketches (d) and (e).)



Sketch (d)

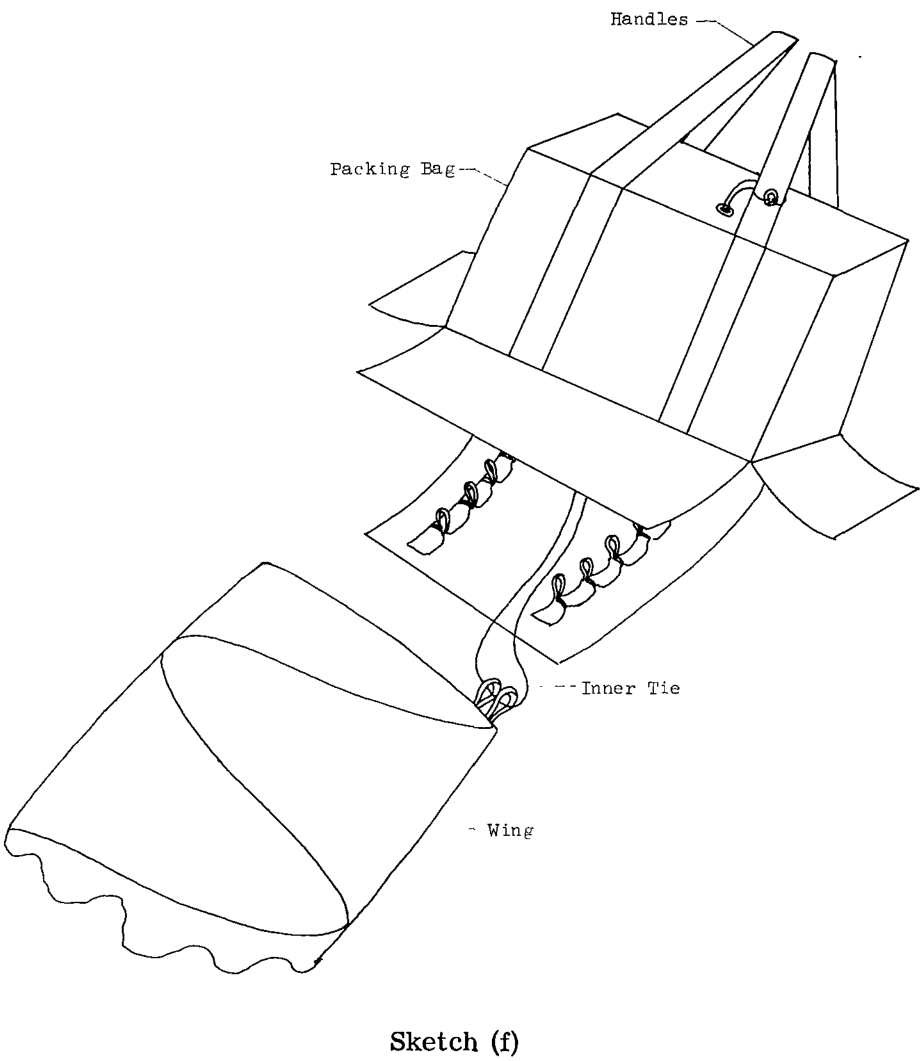


Sketch (e)

The procedure used to stow the canopy is as follows:

1. Check packing bags for damage.

2. Pass a 16-in. (40.6 cm) length of size 6 cotton cord through the loops near the top of the canopy at the trailing edge. Do not knot the two loops together. Pass free ends of cord through the bag grommet and make a temporary tie to the bag handles. (See sketch (f).)



Sketch (f)

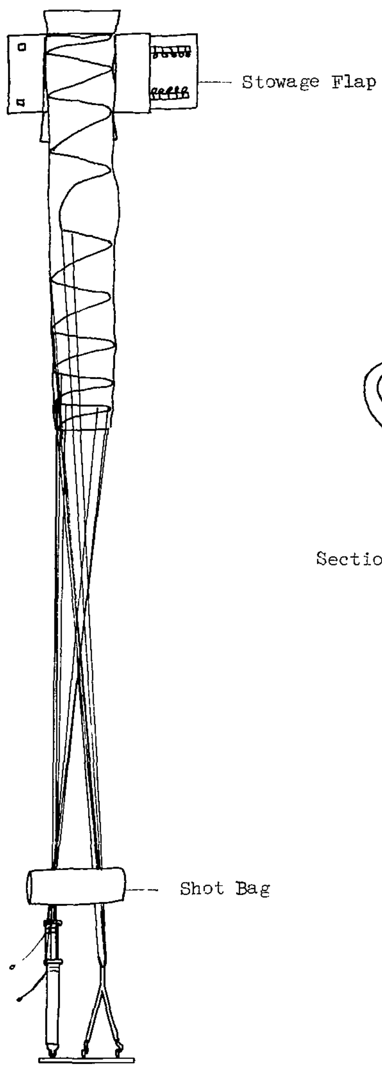
3. Orient packing bag with mouth up and with stowage flap to the left of the packer as he stands facing the hold-down point. (See sketch (g).)

4. Detach packing block from hold-down point.

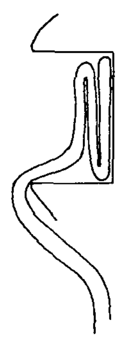
5. Place shot bags or some other weights on lines.

6. Make accordian folds as the canopy is fed into the bag. Use hand pressure only, and maintain the square shape of bag as it is filled. (See sketch (g).)

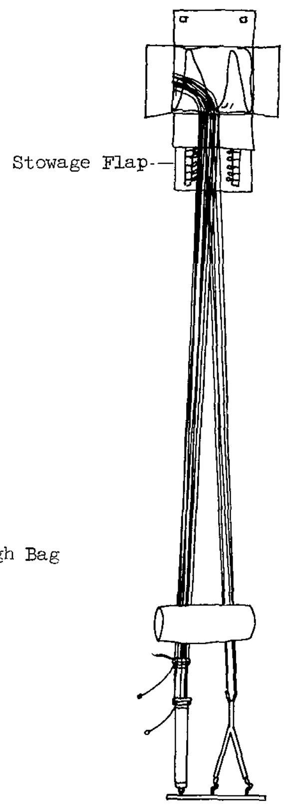
7. Rotate bag 90° clockwise. (See sketch (h).) This orientation of block and bag must be maintained until lines are transferred to the model.



Sketch (g)



Section Through Bag



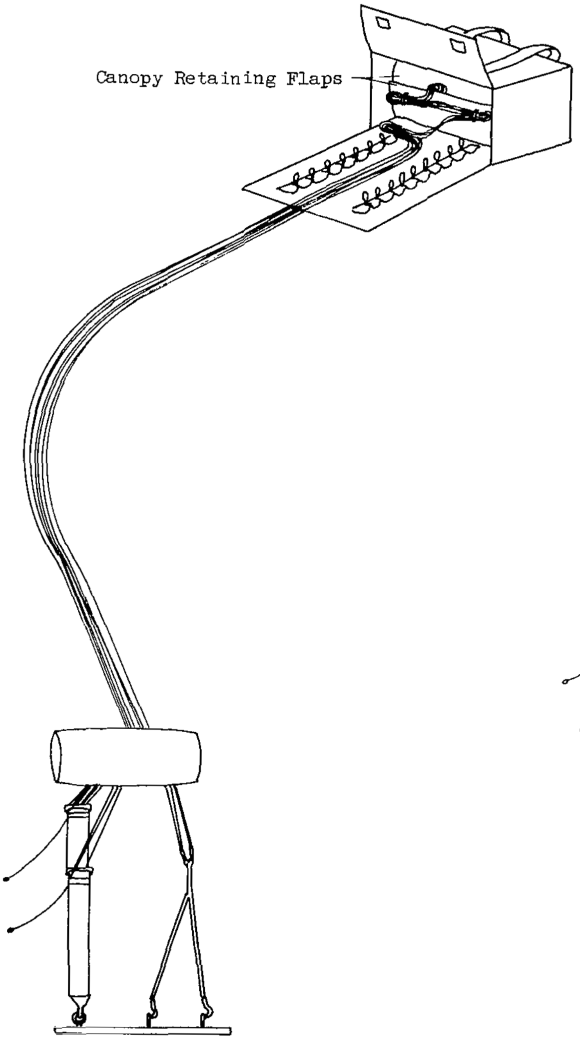
Sketch (h)

8. Close end flaps and canopy retaining flap; pull the rubber bands nearest the canopy through the flap grommets and secure with bights of lines. (See sketch (i).)

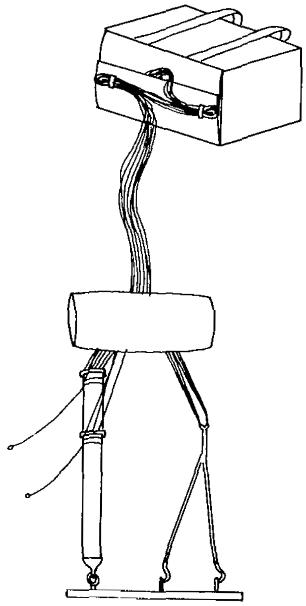
9. Start with the rubber band nearest the stowed canopy (in either row of rubber bands) and stow bights of lines.

10. When about 4 ft (1.2 m) of lines remain to be stowed, fold the line stowage flap over onto the pack and lock with a bight through the locking loops. (See sketch (j).)

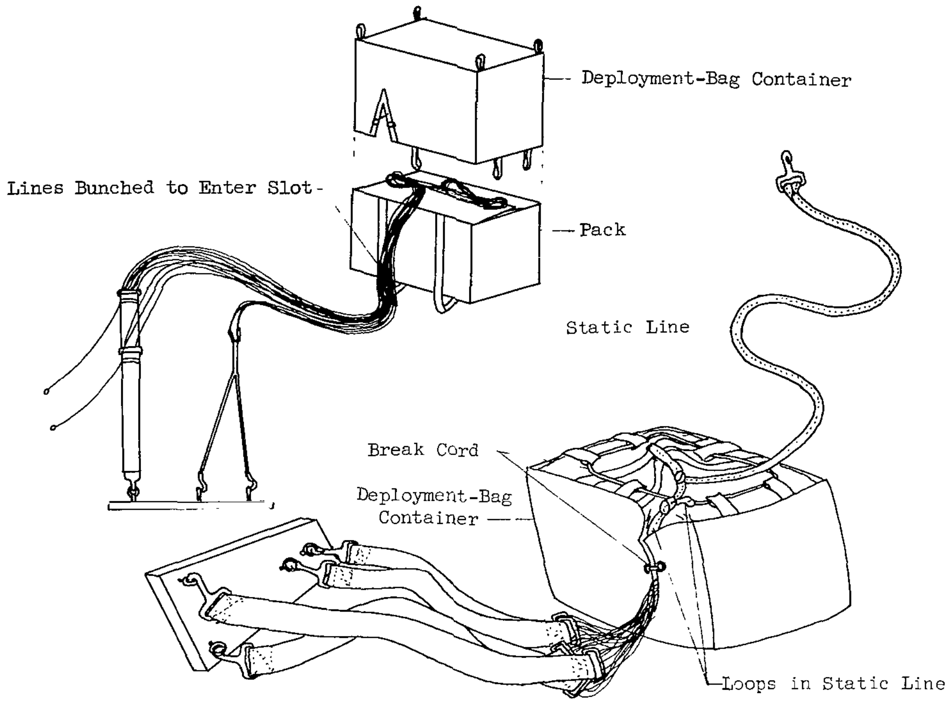
11. Make sure lines come out of loop from right side of the packer as he looks from the pack to the packing block.



Sketch (i)



Sketch (j)



Sketch (k)

12. Put deployment-bag container on from the top with slot away from the packer and put lines into slot. (See sketch (k).)

13. Take weights off lines.

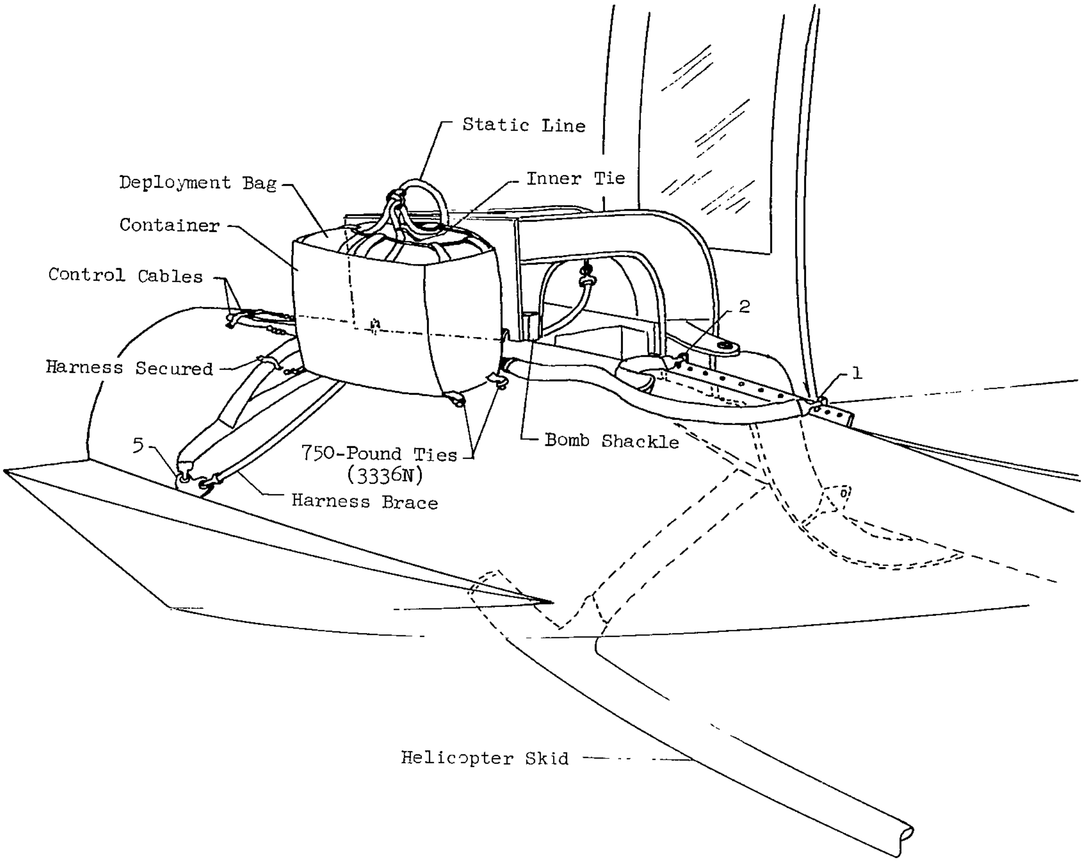
14. Invert the whole system so that the mouth of the deployment-bag container is facing up.

15. Pull the cotton cord tied to handle of inner bag tight, and retie to handle of deployment bag.

16. Attach a 2300-lbf (10.23 kN) tubular nylon static line to handle of inner bag. Knot and sew. Tie two loops 6 in. (15.2 cm) and 12 in. (30.5 cm) from handles.

17. With an 80-lbf (356 N) break cord, tie deployment-bag-container grommets together through the first loop of the static line, and tie the deployment-bag-container closing loops together through the second loop of the static line.

18. Attach a 3000-lbf (13.34 kN) butterfly snap to the other end of the static line. Knot and sew.



Sketch (1)

The parawing pack is installed as follows (sketch (1)):

1. Tie outer bag to the body with a 750-lbf (3336 N) line.

2. Match the numbers on the legs and attachment lugs, and then attach the harness legs to the vehicle.

3. Check to insure that the lines are not twisted or wrapped around another line group.

4. Record locations of front strap in front lifting brackets.

After harness leg adjustment is completed, install three harness braces (sketch (1)) and record lengths. Outer braces are attached to connectors at the confluence point of harness straps 1 and 2; inner brace is tied from point 2 to point 3. (See sketch (b).)

The harness is secured as follows (sketch (l)):

1. Arrange the harness on top of the body and secure ties.

2. If the controllable vehicle is being rigged, attach the control suspension lines to the control cables.

3. Insure that turn control is centered, tip controls are full out (100 percent), and keel control is centered (50 percent).

4. Tape control lines to body so that they will pull out and leave tape on body.

5. Recheck to be certain that the static-line knots are sewed, that loops are set to break the two break cords in proper order, and that the static line is routed under the bomb shackle but over all other lines.

6. Make a final overall inspection.

APPENDIX C

DESIGN AND OPERATION OF CONTROL AND INSTRUMENTATION SYSTEMS

A command system to control the four motors on the control system in various modes of operation, a telemetry system to transmit the control position to be displayed on the pilot's console and recorded, and a power supply were the main parts of the command and instrumentation systems. IRIG FM-FM telemetry system was used to transmit signal strength and various accelerometer outputs. A 16-mm camera actuated at drop was installed for some tests. A schematic drawing of the command and instrumentation systems is presented in figure 27. Labeled photographs and diagrams of the pilot control console and the various subsystems installed in the body are presented as figures 28 to 30.

Control System

The basic parawing is normally controlled by adjusting the lengths of the rear lines of the two leading edges (tip lines) and keel. One objective of the investigation was to determine the longitudinal control characteristics by varying the length of the rear keel line, the tip lines, or all three lines and the lateral control characteristics by varying the length of one tip line or differentially varying the tip-line lengths. A proven mechanism which could provide these functions was obtained from the Manned Spacecraft Center which developed the control systems for conducting landing-operation studies.

This system (figs. 13 and 14) was carefully designed to prevent jamming. The pulleys were machined; plastic fairleads were used; the winches turned only one turn; stops were arranged so that both electrical and mechanical stops were changed by one operation. The trim cam was inserted between the tip lines without being fastened to the lines so that each control line was continuous to the winch drums. The differential tip-line movement resulted as the cam rise acted on one or the other of the lines.

The control system provided a control deflection that was proportional to the length of time that the control stick was deflected until full travel was reached. Successful use of this type of system requires that a pilot develop many skills including a sense of timing if he is to fly a fairly slow reacting vehicle with controls that take time to activate. To aid the pilot in returning the parawing to neutral lateral control, the tests were begun with the tip lines against the outstops for good flying trim. Thus, the pilot could always return the parawing to lateral trim by running the tip lines against the outstops. This rigging also relieved the pilot of setting the tip lines to trim after deployment. Since the tip winches would have been set at the out position in any event because they could not take the deployment shock in any other position, another trim position of the tip lines would have required movement of both of the tip lines to this position immediately after deployment.

Control Console

The pilot control console (figs. 28 and 29) was designed to give considerable flexibility in parawing control. The primary method of control was by means of a single axis stick. The stick was a service-type switch set up to pivot left and right and operate a bank of switches below the panel for lateral control.

As indicated in figure 29, the switching was arranged for control by pulling in one tip line or by differential tip-line movement. For example, moving the stick to the one-half right position for a period of time pulled in the right tip line; moving the stick to neutral and squeezing the trigger let out the right tip line. After flight 148, the trigger sense was reversed so that it was necessary to depress the trigger and deflect the stick to pull in a tip line and to move the stick to neutral and release the trigger to let out the tip line. Since the stick was self-centering, in a hands-off condition both tip lines returned to the trimmed position. Movement of the stick to the stop position produced a differential control with either trigger sense. The stick thumb button was used for longitudinal control and for lateral trim control. The tip lines, keel line, or both could be selected for longitudinal control by means of the mode selector switches on the panel.

The four motors of the control system could also be controlled individually by the motor control switches on the panel if the pilot preferred. Duplicate switches were available on an extension cord if control from a position away from the console was needed or if two pilots divided the control tasks.

Antenna System

In the design of the antenna system, emphasis was placed on rigid structure and near omnidirectional radiation patterns. Initially the antennas for the four RF systems were in the fins of the lifting body. During the flight tests, however, the antennas were relocated because of frequent damage to the fins. The telemetry and command antennas were changed from thin rectangular slots to low-profile monopole antennas. The S-band antennas used were quarter-wavelength monopole antennas. Two antennas for each system were fed in parallel with the proper phase so that a near omnidirectional radiation pattern could be provided. These antennas were mounted on a ground plane and attached to the lifting body as shown in figure 30. Body 3 in position for radiation-pattern measurements is shown in figure 31. Typical radiation patterns from all antenna systems are given in figure 32.

APPENDIX D

HELICOPTER OPERATIONAL SAFETY CONSIDERATIONS

Considerable emphasis was placed on safety. Safety rules and regulations for ground and flight operation of the model and helicopter were prepared and incorporated in the operating procedures. The pilot of the helicopter was advised of all the known risks in operating with the parawing and was given its flight characteristics. The following items were discussed with the helicopter pilot:

(1) The all-flexible parawing packs like a parachute but in flight is capable of developing lift greater than the payload weight. The parawing—lifting-body vehicle could climb if the drop speed was significantly higher than the trimmed glide speed for the parawing.

(2) The lifting body is an aerodynamic shape capable of producing lift and side force in an inclined flow field; therefore, high-speed flight of the helicopter should be avoided when the test vehicle is attached to the drop rig.

(3) The static line must not be long enough to reach any of the rotating mechanism of either the main rotor or tail rotor. The deployment bag should not have metal fittings or attachments that could damage the helicopter skin.

(4) Two-way communications onboard the helicopter should be provided for the pilot and drop technician.

(5) A check should be made to confirm that the electrical and electronic systems on the test vehicle and the helicopter do not interfere with each other.

(6) The helicopter should never fly over buildings, populated areas, or ground facilities with the test vehicle attached.

(7) For an emergency condition such as power failure of the helicopter, the pilot should jettison the test vehicle without the static line connected in order to prevent parawing deployment; therefore, the static line should not be connected until the final approach to the drop point. If the flight is to be aborted, the static line should be disconnected before descent of the helicopter.

(8) Because of the gliding capability of the parawing, the helicopter should continue in level flight or climb slightly after release of the test vehicle. The helicopter pilot should not start descent until he can see the parawing.

(9) Operation of the helicopter in the avoidance zone of the height-velocity chart for the helicopter was to be avoided.

APPENDIX E

RANGE SAFETY PLAN

The range safety officer at the NASA Wallops Station prepared a range safety plan and modified it as experience was gained. Since there had been no previous experience with a gliding device of this type at Wallops, new criteria had to be worked out. The essentials of the final range safety plan are discussed in this appendix.

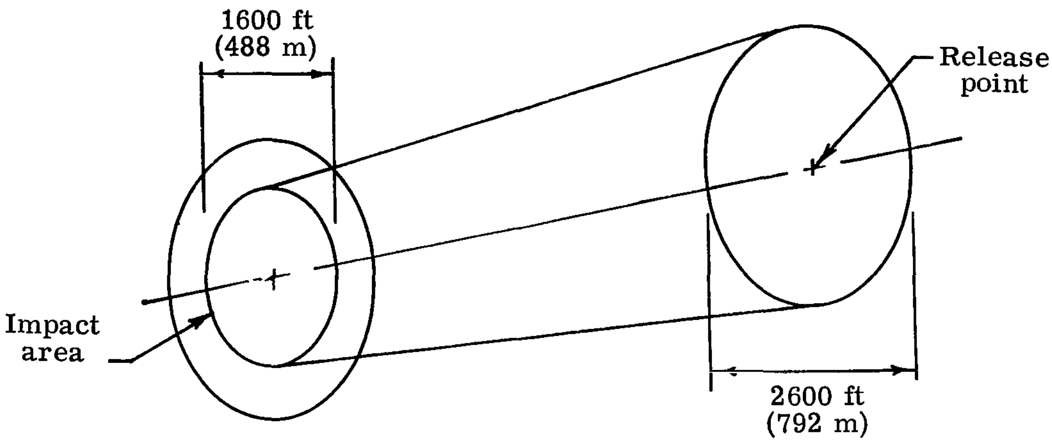
Overflight Criteria

Planned overflight of populated areas by the deployed parawing—lifting-body vehicle will not be allowed. If necessary, the helicopter pilot may jettison the system when a hazard to the flight crew exists. Because of this possibility, overflight of populated areas should be avoided by the helicopter when the parawing and lifting body are attached.

Landing Area and Impact Criteria

The designated landing area during these tests (fig. 33) is centered on a point 350 ft (107 m) due east of the airfield tetrahedron. This principal landing area is a circle whose radius is 800 ft (244 m). Predicted impact from wind drift only may be transferred anywhere in the 800-ft-radius impact area. In addition, a hazard area surrounds the principal landing area and the total area has a radius of 1300 ft (396 m). All personnel should remain clear of these areas during the flight tests with the exception of participating personnel. All private vehicles shall be removed.

The release position of each flight will be provided by range safety personnel to the test conductor and/or project engineer who will have the helicopter vectored to the proper release point. Radar will vector the helicopter to the predetermined release point and the helicopter pilot will confirm that a 500-ft-radius (152 m) area beneath the release position is clear of personnel and buildings. No drop will be allowed if personnel, buildings, or equipment are beneath the release position. Also, a corridor along the predicted drift axis to the 1300-ft-radius (396 m) circle should be cleared. The flight vehicle should be so controlled that it remains upwind and within a truncated cone 2600 ft (792 m) in diameter at the release point and 1600 ft (488 m) in diameter at the impact point, as shown in the following sketch:



Wind and Drift

A wind profile will be obtained by range safety representatives prior to the drop tests of the parawing—lifting-body vehicle. These wind data will be used for drift calculations and to determine the release position. Frequent wind profiles will be required as these data will establish displacement limits to the principal landing area. Wind data required are (a) at least one reading prior to drop, (b) at least two readings prior to the day's first drop, (c) further data readings if data are inconsistent or time between drops is long. Drift and displacement are calculated by using an approximate fall rate that would occur in a tight turn.

Displacement of the release point from the impact area of up to two times the altitude may be considered; however, it should be normally limited to 1.3 times the altitude. The needed displacement, once calculated, may not be modified.

Vectoring Helicopter and Communications

The helicopter will be tracked and positioned by radar to the calculated release position from a radar plotting board in the mobile control center. All participating activities should monitor the control-center transmissions to insure safe operations and to prevent premature drops. If communications are lost and/or radar loses track of the helicopter, the test drop will be aborted.

Additional Requirements

Several additional requirements included in the range safety plan are as follows:

(1) Complete check of controls is to be made prior to take-off and verification of operational status prior to each drop.

(2) Vehicles that are not radio controlled and have not previously been qualified or evaluated for flight must have range safety approval prior to testing.

(3) Vehicles that are radio controlled and have been approved by the range safety officer will be permitted altitude increases consistent with system reliability.

(4) The distance from predicted impact to actual impact should be determined after each drop so that the system may be evaluated for reliability and possible modifications of requirements.

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2. Gillis, Clarence L.; Polhamus, Edward C.; and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA WR L-123, 1945. (Formerly NACA ARR L5G31.)
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TABLE I.- SUSPENSION-LINE LENGTHS AND ATTACHMENT LOCATIONS FOR SMALL-SCALE PARAWINGS

Line attachment location		l/l_k for -	
x_k/l_k	x_{le}/l_k	6.56-ft model (2.0 m)	7.87-ft model (2.4 m)
0.125		1.095	1.130
.213		1.094	1.135
.300		1.084	1.128
.388		1.083	1.123
.475		1.067	1.107
.563		1.068	1.124
.650		1.050	1.095
[a].650		1.038	1.011
.738		1.027	1.069
.825		.999	1.042
.913		.965	1.005
[b]1.000		.995	1.011
	0.177	1.101	1.139
	.342	1.046	1.085
	.506	.996	1.035
	.675	.940	.981
	[a].675	.962	.883
	.835	.910	.944
	[b]1.000	.880	.883
Harness:			
Front forward		0.116	0.100
Front rear		.105	.088
Left and right rear . . .		0.111	.093
Center rear		.135	.113
Keel brace		.152	.127
Outboard brace		.192	.160

[a]Redundant-line length.

[b]Length of control line to body.

TABLE II.- SUSPENSION-LINE LENGTHS AND ATTACHMENT LOCATIONS FOR LARGE-SCALE PARAWINGS

(a) Flights 101 to 116
(Keel line shortened $0.0208l_k$ for flights 114 to 116)

x_k/l_k	l/l_k
0.125	1.0990
.208	1.0868
.292	1.0801
.375	1.0740
.458	1.0525
.540	1.0588
.646	1.0509
.750	1.0126
.833	.9895
.917	.9618
[a]1.000	.8845
[b].646	1.0286
[c]1.000	.9853

x_{le}/l_k	l/l_k
0.177	1.1010
.342	1.0364
.506	.9812
.671	.9244
.835	.8895
[a]1.000	.7973
[b].671	.9555
[c]1.000	.8704

(b) Flights 118, 120 to 125, 129, 131 to 133, 136 to 143, 145 to 148, 150 to 167

x_k/l_k	l/l_k
0.125	1.1324
.208	1.1201
.292	1.1134
.375	1.1074
.458	1.0858
.540	1.0588
.646	1.0509
.750	1.0126
.833	.9895
.917	.9618
[a]1.000	.8884
[b].646	1.0620
[c]1.000	.9978

x_{le}/l_k	l/l_k
0.177	1.343
.342	1.0697
.506	1.0145
.671	.9578
.835	.8895
[a]1.000	.7973
[b].671	.9555
[c]1.000	.9038

(c) Flights 130, 134, 135, 149, 169

x_k/l_k	l/l_k
0.125	1.1649
.208	1.1521
.292	1.1455
.375	1.1396
.458	1.1180
.540	1.0972
.646	1.0903
.750	1.0514
.833	1.0283
.917	1.0009
[a]1.000	.9272
[b].646	1.0940
[c]1.000	1.0166

x_{le}/l_k	l/l_k
0.177	1.1666
.342	1.1017
.506	1.0464
.671	.9894
.835	.9260
[a]1.000	.7926
[b].671	.9922
[c]1.000	.8938

[a]Length to reference mark.
[b]Redundant-line length.
[c]Length of control line to body.

TABLE III.- TEST RECORD

Flight	Parawing	Keel length, ft	Keel length, m	Length l/l_k of harness leg[a], 1	Length l/l_k of harness leg[a], 2	Length l/l_k of harness leg[a], 3	Length l/l_k of harness leg[a], 4 & 5	Location l/l_k of harness leg, 1	Location l/l_k of harness leg, 2	Location l/l_k of harness leg, 4 & 5	Radio control	Center of gravity,[b] percent body length	Tip lines control, Max. l/l_k	Tip lines control, l/l_k at drop	Tip lines control, Speed, l/l_k/sec	Keel line control, Max. l/l_k	Keel line control, l/l_k at drop	Keel line control, Speed, l/l_k/sec	Trim control, Max. l/l_k	Trim control, l/l_k at drop	Trim control, Speed, l/l_k/sec	Body weight, lbf	Body weight, N	Brace length[a] l/l_k, Outboard	Brace length[a] l/l_k, Keel
101	13	20.0	6.10	0.1192	0.1062	0.1367	0.1095	0.0612	0.1182	0.2281	No	55.5	-----	------	-----	-----	-----	-----	-----	------	-----	300.00	1334.4	0.1917	0.1521
102	12					.1367						55.5	-----	------	-----	-----	-----	-----	-----	------	-----	300.00	1334.4		
103	13					.1267						55.5	-----	------	-----	-----	-----	-----	-----	------	-----	300.00	1334.4		
104	12					.1267						56.8	-----	------	-----	-----	-----	-----	-----	------	-----	320.00	1423.4		
105	13					.1367							-----	------	-----	-----	-----	-----	-----	------	-----				
106	13												-----	------	-----	-----	-----	-----	-----	------	-----				
107	12										Yes		0.0406	Outstop	0.0083	0.0760	0.0375	0.0079	0.0167	Neutral	0.0042				
108	13																								
109	12																								
110	13																								
111	12							.0572	.1143															.1958	.1562
112	13																			0.0083	.0041				
113	12																.0188								
114	13																.0375								
115	12																.0375								
116	13																.0375								
118	14					.1700	.1429				No				-----	-----	-----	-----	-----	------	-----	323.20	1437.6	.1510	.1667
120	14										No				-----	-----	-----	-----	-----	------	-----	323.20	1437.6	.1510	.1667
121	12										Yes				.0054	.0760	.0375	.0079	.0296	0	.0042	323.60	1439.4	.1510	.1667
122	13																							.1510	.1667
123	12							.0531	.1102															.1896	.2083
124	13																								
125	12																								
129	14										No		-----	-0.0110 Right	-----	-----	-----	-----	-----	------	-----	323.20	1437.6		
130	2	24.0	7.32	.0993	.0885	.1417	.1191	.0443	.0919	.1901	No		-----	-.0110 Right	-----	-----	-----	-----	-----	------	-----	323.20	1437.6		
131	12	20.0	6.10	.1192	.1062	.1700	.1429	.0531	.1102	.2281	Yes		.0406	------	.0054	.0760	.0375	.0079	.0296	0	.0042	323.60	1439.4		
132	13	20.0	6.10	.1192	.1062	.1700	.1429	.0531	.1102	.2281			.0406	------	.0054	.0760	.0375	.0079	.0296	0	.0042	323.60	1439.4		
133	14	20.0	6.10	.1192	.1062	.1700	.1429	.0531	.1102	.2281			.0406	------	.0054	.0760	.0375	.0079	.0296	0	.0042	323.60	1439.4		
134	1	24.0	7.32	.0993	.0885	.1417	.1191	.0443	.0919	.1901	No		-----	Right -.0104	-----	-----	-----	-----	-----	------	-----	323.20	1437.6		
135	2	24.0	7.32	.0993	.0885	.1417	.1191	.0443	.0919	.1901	No		-----	-.0104	-----	-----	-----	-----	-----	------	-----	323.20	1437.6		
136	12	20.0	6.10	.1192	.1062	.1700	.1429	.0531	.1103	.2281	Yes		.0406	Outstop	.0054	.0760	.0375	.0079	.0296	0	.0042	323.60	1439.4	.2000	.2188
137	13														.0054										
138	12														.0054										
139	13														.0092										
140	14																								
141	12																								
142	13																								
143	14																								
145	12																								
146	13																								
147	14																								
148	12																								
149	2	24.0	7.32	.0977	.0873	.1411	.1168	.0443	.0919	.1901	No		-----	Right -.0208	-----	-----	-----	-----	-----	------	-----	325.20	1446.5	.1660	.1823
150	13	20.0	6.10	.1188	.1062	.1682	.1388	.0531	.1102	.2281	Yes		.0432	Outstop	.0133	.0760	.0380	.0079	.0296	0	.0042	339.20	1508.8	.1933	.2062
151	14			.1177	.1042	.1688	.1396																	.1958	
152	12			.1167	.1052	.1698	.1391																	.1932	
153	13			.1188	.1062	.1682	.1388																		
154	12			.1167	.1073	.1698	.1391																		
155	13			.1188	.1063	.1682	.1388																		
156	12			.1167	.1073	.1698	.1390										.0375								
157	13			.1188	.1062	.1682	.1390																		
158	14			.1177	.1042	.1688	.1396																		
159	12			.1167	.1052	.1698	.1390																		
160	14			.1177	.1042	.1688	.1396																	.1958	
161	12			.1167	.1052	.1698	.1390																	.1932	
162	14			.1177	.1042	.1688	.1396																	.1958	
163	12			.1167	.1052	.1688	.1390																	.1932	
164	13			.1188	.1062	.1682	.1390																	.1933	
165	14			.1177	.1042	.1688	.1396																	.1958	
166	14			.1177	.1042	.1688	.1396																	.1958	
167	13			.1188	.1062	.1390	.1682																	.1933	
169	2	24.0	7.32	.099	.088	.1402	.1154	.0443	.919	.1901			.0360		.0111	.0634	.0312	.0066	.0248		.0035			.1611	.1719

[a]See figure 4.

[b]Measured from nose.

TABLE IV.- TEST CONDITIONS AND RESULTS

(a) Numerical data

Flight	Test conditions: Date	Time, GMT	Flight duration, sec	Altitude, ft	Altitude, m	Helicopter speed, knots	Radio control pilot	Wing	Keel length, ft	Keel length, m	Wind, Surface: Velocity, ft/sec	Velocity, m/sec	Direction, deg	Wind, Average: Velocity, ft/sec	Velocity, m/sec	Direction, deg	Calculated displacement, ft	Calculated displacement, m	Drop point: Displacement, ft	Displacement, m	Direction, deg	Touchdown point: Error, ft	Error, m	Direction, deg
101	2/27/68	1703:25	20.0	500.0	152.4	20	---	13	20.0	6.10	13.2	4.02	140	18.7	5.70	157	693.00	211.23	375	114.30	180	30	9.14	255
102	2/27/68	2003:30	35.0	500.0	152.4	20	---	12	20.0	6.10	14.7	4.48	130	16.1	4.91	151.3	597.00	181.97	250	76.20	215	250	76.20	030
103	2/28/68	1619:13	5.0	500.0	152.4	25	---	13	20.0	6.10	14.7	4.48	140	14.5	4.42	148.8	536.00	163.37	380	115.82	150	150	45.72	140
104	3/5/68	1408:38	24.0	500.0	152.4	25	---	12	20.0	6.10	13.2	4.02	290	17.4	5.30	281.4	643.00	195.99	600	182.88	280	675	205.74	230
105	3/5/68	1624:20	21.0	500.0	152.4	30	---	13	20.0	6.10	19.1	5.82	335	28.6	8.72	323.5	1060.00	323.09	600	182.88	270	600	182.88	268
106	3/5/68	2102:55	35.0	500.0	152.4	30	---	13	20.0	6.10	10.3	3.14	160	13.1	3.99	159	483.00	147.22	517	157.58	196	190	57.91	200
107	3/6/68	1504:33	30.0	500.0	152.4	25	A	12	20.0	6.10	8.8	2.68	341	---	----	328.9	391.00	119.18	483	147.22	347	285	86.87	320
108	3/6/68	1622:41	34.7	700.0	213.4	20	B	13	20.0	6.10	5.9	1.80	013	6.2	1.89	331.9	331.00	100.89	211	64.31	342	720	219.46	340
109	3/6/68	1843:07	30.7	700.0	213.4	20	A	12	20.0	6.10	23.5	7.16	020	31.4	9.57	009.8	942.00	287.12	1080	329.18	020	190	57.91	350
110	3/6/68	2012:39	37.0	700.0	213.4	20	B	13	20.0	6.10	30.8	9.39	028	21.9	6.68	027.6	768.00	234.09	600	182.88	018	770	234.70	250
111	3/7/68	1445:35	33.0	700.0	213.4	20	A	12	20.0	6.10	26.4	8.05	352	27.0	8.23	007.7	1000.00	304.80	1000	304.80	005	700	213.36	020
112	3/7/68	2058:30	36.0	700.0	213.4	20	B	13	20.0	6.10	11.7	3.57	085	10.9	3.32	055.9	405.00	123.44	400	121.92	050	750	228.60	340
113	3/7/68	1428:16	29.0	700.0	213.4	20	A	12	20.0	6.10	10.3	3.14	215	25.9	7.89	240.0	960.00	292.61	600	182.88	240	96	29.26	248
114	3/8/68	1509:27	45.0	700.0	213.4	20	B	13	20.0	6.10	17.6	5.36	215	16.8	5.12	221.6	621.00	189.28	600	182.88	240	490	149.35	310
115	3/8/68	1554:05	33.2	700.0	213.4	20	A	12	20.0	6.10	20.5	6.25	170	14.6	4.45	221.6	540.00	164.59	300	91.44	220	125	38.10	240
116	3/8/68	1659:58	34.3	700.0	213.4	20	B	13	20.0	6.10	26.4	8.05	172	28.1	8.56	190.5	1040.00	316.99	500	152.40	180	415	126.49	070
118	4/23/68	1194:33	25.0	500.0	152.4	20	---	14	20.0	6.10	26.4	8.05	070	14.9	4.54	061.9	377.00	114.91	1050	320.04	074	500	152.40	079
120	4/23/68	2120:33	20.0	500.0	152.4	20	---	14	20.0	6.10	24.9	7.59	060	10.2	3.11	068.3	408.00	124.36	1083	330.10	128	530	161.54	155
121	4/25/68	1554:00	26.7	700.0	213.4	20	B	12	20.0	6.10	17.0	5.18	135	17.4	5.30	273.0	643.00	195.99	825	251.46	236	515	156.97	216
122	4/25/68	1715:00	36.3	700.0	213.4	20	A	13	20.0	6.10	20.4	6.22	240	19.9	6.07	244.0	736.00	224.33	860	262.13	224	330	100.58	111
123	4/26/68	1533:00	62.1	1000.0	304.8	15	B	12	20.0	6.10	17.6	5.36	133	17.0	5.18	154.0	900.00	274.32	265	80.77	285	590	179.83	147
124	4/26/68	1649:00	82.1	1200.0	365.8	10	B	13	20.0	6.10	14.7	4.48	162	14.2	4.33	171.0	923.00	281.33	980	298.70	152	605	184.40	139
125	4/29/68	2201.25	65.0	1200.0	365.8	20	B	12	20.0	6.10	16.1	4.91	175	16.1	4.91	174.0	1046.00	318.82	690	210.31	161	380	115.82	307
129	4/30/68	1916:00	25.0	500.0	152.4	20	---	14	20.0	6.10	---	---	---	17.3	5.27	305.0	640.00	195.07	803	244.75	282	451	137.46	188
130	4/30/68	2010:00	18.2	500.0	152.4	20	---	2	24.0	7.32	---	---	---	3.9	1.19	329.0	146.00	44.50	490	149.35	211	290	88.39	186
131	5/2/68	1137:00	64.8	1200.0	365.8	20	C, A	12	20.0	6.10	8.8	2.68	305	23.3	7.10	349.0	1514.00	461.0	1060	323.09	304	1020	310.90	188
132	5/2/68	1238:38	67.8	1200.0	365.8	20	C	13	20.0	6.10	10.3	3.14	290	15.8	4.82	333.0	1026.00	312.72	1050	320.04	302	1020	310.90	207
133	5/2/68	1330:15	62.3	1000.0	304.8	20	C	14	20.0	6.10	13.0	3.96	290	21.0	6.40	303.0	1135.00	345.95	915	278.89	298	115	35.05	148
134	5/2/68	1701:00	19.8	300.0	91.4	20	---	1	24.0	7.32	17.6	5.36	295	17.3	5.27	296.0	346.00	105.46	719	219.15	274	540	164.59	260
135	5/2/68	1754:00	23.3	300.0	91.4	20	---	2	24.0	7.32	20.5	6.25	260	11.5	3.51	270	230.00	70.10	712	217.02	266	380	115.82	348
136	5/3/68	1219:54	76.4	1200.0	365.8	20	C, A	12	20.0	6.10	19.1	5.82	234	33.2	10.12	245	1943.00	592.23	1068	325.53	246	290	88.39	305
137	5/3/68	1310:35	74.8	1200.0	365.8	20	C	13	20.0	6.10	22.0	6.71	232	26.5	8.08	250	1548.00	471.83	830	252.98	263	620	188.98	024
138	5/6/68	1344:55	66.5	1500.0	457.2	20	B	12	20.0	6.10	23.5	7.16	310	34.2	10.42	342	2584.00	787.60	1400	426.72	333	533	162.46	232
139	5/7/68	1535:13	113.7	2000.0	609.6	20	B	13	20.0	6.10	22.0	6.71	350	9.4	2.87	037	1068.00	325.53	1430	435.86	356	514	156.67	260
140	5/7/68	2030:53	81.9	1500.0	457.2	20	C	14	20.0	6.10	19.1	5.82	150	18.5	5.64	177	1399.00	426.42	1080	329.18	143	035	10.67	180
141	5/7/68	2114:16	120.1	2000.0	609.6	20	C	12	20.0	6.10	22.0	6.71	173	15.5	4.72	239	243.00	74.07	1350	411.48	193	192	58.52	333
142	5/7/68	2145:12	185.4	3000.0	914.4	20	B	13	20.0	6.10	22.0	6.71	178	12.6	3.84	267	2186.00	666.29	3230	984.50	274	448	136.55	294
143	5/8/68	1817:42	171.5	3000.0	914.4	20	C	14	20.0	6.10	19.1	5.82	138	12.1	3.69	184	1896.00	577.90	1930	588.26	174	987	300.84	357
145	5/8/68	2049:33	265.3	4000.0	1219.2	20	B	12	20.0	6.10	23.5	7.16	160	16.6	5.06	185	3510.00	1069.85	3880	1182.62	199	530	161.54	291
146	5/8/68	2129:32	284.4	4000.0	1219.2	20	C	13	20.0	6.10	22.0	6.71	169	16.6	5.06	183	3273.00	997.61	3660	1115.57	196	400	121.92	285
147	5/8/68	2206:45	217.6	4000.0	1219.2	20	B	14	20.0	6.10	22.0	6.71	173	25.6	7.80	186	5405.00	1647.44	3615	1101.85	199	400	121.92	234
148	5/8/68	2237:18	277.5	4000.0	1219.2	20	C	12	20.0	6.10	19.1	5.82	172	20.5	6.25	180	4334.00	1321.00	3530	1075.94	199	682	207.87	338
149	7/17/68	1421:55	36.5	500.0	152.4	20	---	2	24.0	7.32	5.9	1.80	231	9.3	2.83	219	400.00	121.92	470	143.26	222	560	170.69	195
150	7/17/68	1550:30	57.0	1000.0	304.8	20	C	13	20.0	6.10	7.3	2.23	356	12.6	3.84	231	755.00	230.12	945	288.04	246	60	18.29	129.
151	7/17/68	1803:22	45.0	1000.0	304.8	20	D	14	20.0	6.10	11.7	3.57	247	11.7	3.57	265	703.00	214.27	960	292.61	248	470	143.26	235
152	7/17/68	1913:31	73.6	1100.0	335.3	20	D	12	20.0	6.10	16.1	4.91	182	6.1	1.86	241	364.00	110.95	900	274.32	231	150	45.72	253
153	7/17/68	1956:40	61.0	1200.0	365.8	20	D	13	20.0	6.10	14.7	4.48	183	8.1	2.47	249	585.00	178.31	570	173.74	243	680	207.26	360
154	7/18/68	1401:48	72.4	1200.0	365.8	20	D	12	20.0	6.10	Calm	---	---	8.9	2.71	212	638.00	194.46	385	117.35	212	335	102.11	208
155	7/18/68	1500:30	147.0	1500.0	457.2	20	D	13	20.0	6.10	5.9	1.80	240	13.5	4.11	221	1214.00	370.03	530	161.54	199	690	210.31	211
156	7/18/68	1704:07	129.0	2000.0	609.6	20	D	12	20.0	6.10	14.7	4.48	156	16.1	4.91	172	1610.00	490.73	1440	438.91	158	1340	408.43	068
157	7/18/68	1913:07	60.0	1200.0	365.8	20	D	13	20.0	6.10	20.3	6.19	170	27.7	8.44	167	1997.00	608.69	975	297.18	190	240	73.15	240
158	7/19/68	1506:01	71.0	1200.0	365.8	20	D	14	20.0	6.10	30.0	9.14	190	25.6	7.80	201	1848.00	563.27	960	292.61	192	305	92.96	117
159	7/19/68	1540:45	106.3	1500.0	457.2	20	D	12	20.0	6.10	20.5	6.25	170	16.0	4.88	197	1438.00	438.30	1585	483.11	183	560	170.69	244
160	7/22/68	1541:20	117.0	2000.0	609.6	20	C	14	20.0	6.10	16.1	4.91	175	16.0	4.88	185	1822.00	555.35	1380	420.62	184	210	64.01	068
161	7/22/68	1735:45	198.0	3000.0	914.4	20	C	12	20.0	6.10	24.9	7.59	170	19.2	5.85	190	3451.00	1051.86	1660	505.97	174	460	140.21	024
162	7/23/68	1337:49	131.0	2000.0	609.6	20	C	14	20.0	6.10	13.2	4.02	245	---	---	260	------	------	910	277.37	228	1270	387.10	133
163	7/23/68	1448:18	57.0	800.0	243.8	20	E	12	20.0	6.10	10.3	3.14	300	3.5	1.07	272	128.00	39.01	440	134.11	270	450	137.16	251
164	7/23/68	1527:43	66.0	700.0	213.4	20	E	13	20.0	6.10	7.3	2.23	215	4.2	1.28	252	150.00	45.72	450	137.16	276	430	131.06	298
165	7/23/68	1734:22	56.0	1000.0	304.8	20	E	14	20.0	6.10	17.6	5.36	170	18.5	5.64	179	1000.00	304.80	505	153.92	169	400	121.92	022
166	7/25/68	1601:20	68.5	1200.0	365.8	20	C	14	20.0	6.10	7.3	2.23	280	12.6	3.84	264	829.00	252.68	825	251.46	295	440	134.11	220
167	7/25/68	1750:59	66.0	1200.0	365.8	20	C, E	13	20.0	6.10	10.3	3.14	230	17.3	5.27	268	1139.00	347.17	985	300.23	277	195	59.44	045
169	7/25/68	1913:37	90.0	1000.0	304.8	20	C	2	24.0	7.32	7.3	2.23	260	8.1	2.47	263	607.00	185.01	840	256.03	264	935	284.99	161

TABLE IV.- TEST CONDITIONS AND RESULTS – Concluded

(b) Observational data

Flight	Deployment: Blow back	Deployment: Body transients: Pitching	Deployment: Body transients: Yawing	Deployment: Wing flight direction relative to predrop direction	Deployment: Twist-up	Landing: Body direction at touchdown relative to wind	Landing: Flight condition at touchdown	Landing: Body angle at touchdown	Landing: Body motions after touchdown	Landing: Touchdown surface	Landing: Body roll after touchdown	Landing: Damage	Remarks
101	No	---	Large angles	90^{o} left	Yes	---	Straight	---	Slide	Grass	No	None	
102	---	High $+\alpha$	---	---	Yes	Into wind	Turn	Level right roll	---	Grass	---	None	
103	---	---	---	---	No	---	---	Nose-down 60^{o}	---	Grass	---	Heavy	Static line came loose.
104	Yes	$+\alpha$	Large rotation	30^{o} left	Yes	Crosswind	---	Level	Slide	Grass	---	None	
105	Yes	---	About 90^{o}	0^{o}	No	---	Straight	---	---	Grass	---	None	Ring connector broke at left parawing tip line.
106	---	---	---	90^{o} left	No	---	Right turn	---	---	Grass	---	None	
107	Yes	$+\alpha$	$\pm45^{o}$ oscillation	45^{o} left	No	---	Straight	Nose-down	Slide	Grass	No	None	
108	Yes	$+\alpha$	$\pm30^{o}$ oscillation	0^{o}	No	---	Right turn	Right roll	---	---	---	None	
109	Yes	$+\alpha$, -90^{o}	Large $\pm$ rotation	90^{o} left	Yes	Crosswind	Straight	Level	Bounced, no slide	Grass	Wing induced	---	Worst deployment of all.
110	Yes	$+\alpha$	45^{o} left	45^{o} left	Yes	---	Right turn	---	---	Grass	---	---	Wing yaw more than body yaw.
111	---	---	One turn	0^{o}	Yes	---	Right turn	Nose-down 20^{o} right roll	Slide	Grass	Yes	Fin broken	
112	Yes	None	None	0^{o}	No	Crosswind	Straight	Nose-down	Slid, rocked in pitch	Grass	---	None	Clean opening.
113	Yes	$-\alpha$	Small	45^{o} left	No	Downwind	Straight	Nose-down	Slid, rolled, and yawed	Grass	Yes	Fin cracked	No large disturbances.
114	Yes	$-\alpha$	Small	30^{o} left	No	Downwind	---	---	---	Grass	---	None	Fairly clean opening.
115	---	Small $-\alpha$	---	45^{o} left	No	Into wind	Straight	Nose-up 10^{o}	Rocked in pitch	Grass	No	None	
116	Yes	$-\alpha$	---	90^{o} left	No	Crosswind	Straight	---	---	Grass	Wing induced	None	Trimmed quickly.
118	---	High $+\alpha$	Reversed	---	Yes	---	Straight	Level	Body reversed	Grass	Yes	Scratched	Lines twisted; body reversed.
120	Yes	$+\alpha$	---	90^{o} left	No	Into wind	Straight	Level	---	Grass	---	None	
121	Yes	---	Large angles	45^{o} left		Crosswind	Right turn	Right roll	Bounced and rolled	Grass	Yes	---	Clean opening
122	Yes	$-\alpha$	180^{o}	0^{o}		---	Left turn	Nose-down left roll	Tumbled and skidded	Concrete	Yes	Heavy to nose and fin	Easy opening
123	---	---	---	*Left*		---	*Straight*	*Level*	*Slide*	*Grass*	---	*None*	
124	---	---	---	20^{o} left		Into wind	Straight	---	No slide	Concrete	Wing induced	None	Very little disturbance at deployment
125	---	---	---	30^{o} left		Into wind	Straight	Nose-up	Rearward contact	Grass	Yes	Antennas and fin	
129	Yes	---	---	0^{o}		Downwind	Right turn	---	Slide	Grass	No	---	
130	---	---	---	90^{o} left		---	Straight	Nose-up	Rocked in pitch and roll	Grass	No	None	Clean deployment; packing error looped rear keel line around group.
131	Yes	---	---	0^{o}		Crosswind	Left turn	---	---	Grass	---	None	
132	Yes	---	---	0^{o}		Crosswind	Straight	Level	Slide	Concrete	Wing induced	None	
133	Yes	---	---	45^{o} left		Crosswind	Straight	---	Bounced to nose	Grass	Wing induced	None	
134	Yes	---	---	0^{o}		Crosswind	Right turn	Nose-up	Hit base, rocked	Grass	Wing induced	---	Disorganized appearing deployment; wing collapsed and recovered.
135	Yes	$+\alpha$	---	90^{o} left		Crosswind	Straight	---	Bounced, rocked in pitch	Concrete	Yes	---	
136	---	$-\alpha$	---	45^{o} left		Crosswind	Straight	Level	Bounced, rolled, and rocked	Grass	No	---	
137	Yes	$-\alpha$	$\pm45^{o}$ oscillation	45^{o} left		Crosswind	Straight	Level	Rocked	Grass	Wing induced	---	Fairly good deployment.
138	Yes	---	90^{o} yaw	45^{o} left		Crosswind	Straight	Level	Rocked and yawed	Grass	Wing induced	---	
139	Yes	None	$\pm30^{o}$	60^{o} left		Crosswind	Straight	Level	Rocked to nose	Grass	Yes	---	
140	---	Fill and dive	---	10^{o} left		Downwind	Straight	Level	Rocked to nose	Grass	Yes	Fin damage	
141	---	$-\alpha$	---	*20^{o} right*		*Upwind*	*Right turn*	*Level*	*Rocked to nose*	*Grass*	*No*	*None*	*Collapse and fill cycle at least twice; disorganized deployment.*
142	Yes	---	---	45^{o} left		---	Straight	Level	Bounced and rocked	Grass	No	None	Very clean deployment.
143	Yes	---	---	90^{o} left		Crosswind	Turn	Level	Bounced	Grass	Yes	Broken fins	Smooth opening; little transient opening
145	---	---	---	90^{o} left to 45^{o} left		Crosswind	Straight	Level	Rocked to nose	Grass	Yes	None	Fairly smooth opening; few transient disturbances.
146	---	---	90^{o} yaw	120^{o} right		Crosswind	Right turn	Level	Rocked to base	Grass	Wing induced	None	Large canopy disturbance at opening.
147	---	---	---	---		Crosswind	*Straight*	Level	Rocked to nose	Grass	Yes	None	
148	---	---	---	---		Crosswind	---	---	---	Grass	---	None	
149	---	---	---	---		Crosswind	Right turn	Level	Slid and yawed	Concrete	No	Fin damage	
150	Yes	$-\alpha$	---	45^{o} left		Downwind	Straight	Level	Rocked to nose	Grass	No	None	
151	Yes	---	$\pm45^{o}$	30^{o} left		Crosswind	Right turn	Right roll	Bounced and slid	Grass	Yes	Fin and camera	
152	---	$+\alpha$, $-\alpha$	---	0^{o}		Crosswind	Straight	---	Rocked to nose	Grass	---	---	Body yaw 90^{o} to left; pulled wing around in yaw; collapse and fill cycle.
153	Yes	---	---	0^{o}		---	Right turn	Nose-down	Slid backwards	Concrete	No	---	Smooth, rapid fill; no significant transients
154	Yes	---	---	0^{o}		No wind	Straight	Level	Rocked to nose	Grass	Yes	---	Very clean deployment; trimmed quickly.
155	Yes	---	---	0^{o}		Crosswind	Straight	Level	Rocked to nose	Grass	Yes	---	Very smooth opening; minor disturbances.
156	---	---	---	---		Crosswind	Left turn	Turn	Rolled and yawed	Concrete	Yes	Hook and switch	Hard, disorganized deployment.
157	---	---	None	90^{o} left		Crosswind	Straight	Level	Rolled and slid	Grass	No	---	Filling appeared to be delayed; start of fill almost twice as long as normal; trimmed quickly.
158	---	---	---	10^{o} right		Crosswind	Right turn	Nose-down	Rocked to nose	Grass	Yes	---	Clean deployment after initial transient.
159	Yes	None	None	10^{o} left		Crosswind	Straight	Level	Rolled	Concrete	Yes	---	Very clean deployment.
160	Yes	Shallow dive	None	30^{o} left		---	Straight	Level	Rocked to nose	Concrete	Yes	---	Clean opening; trimmed quickly.
161	---	$+\alpha$ and dive	---	0^{o}		Crosswind	Straight	Level	Rolled and rocked	Grass	Yes	Broken fin	Rapid fill and high angle, nose collapse and trim.
162	Yes	$+\alpha$, then dive	---	45^{o} left		---	Right turn	Nose-down	Bounced and rolled	Grass	Yes	---	
163	Yes	Very small	None	90^{o} left		---	Straight	Level	Rocked to nose	Grass	Yes	None	Very clean deployment.
164	Yes	$+\alpha$, then dive	---	45^{o} left		Crosswind	Straight	Level	Rocked to nose	Concrete	Yes	---	
165	Yes	Slight	None	0^{o} to 90^{o} right		Downwind	Straight	Level	Rocked to nose	Grass	Yes	---	Clean deployment.
166	Yes	Dive after high $+\alpha$	70^{o} right to 45^{o} left	30^{o} right		---	Straight	Level	Rocked to base	Grass	No	None	
167	Yes	None	None	10^{o} left		Crosswind	Straight	Level	Slide	Concrete	Yes	Minor	Very clean, stable deployment.
169	Yes	$+\alpha$, then *dive*	---	45^{o} left		Crosswind	Straight	Level	Rocked to nose	Grass	---	---	Trimmed quickly following pitch-up and *dive disturbance.*

TABLE V.- DROPS FROM ELEVATED PLATFORM OF SMALL-SCALE BODY 1 AND 6.56-FOOT (2.0 METER) KEEL PARAWING

Drop test	Keel control, $\Delta l/l_k$	Parawing tip control, $\Delta l/l_k$		Remarks
		Left	Right	
(a) Longitudinal control and twist-up				
1	0	0	0	Trial rigging. Good gliding flight, some turn.
2	0	-.005	0	Lateral trimming. Good gliding flight, some turn.
3	0	-.005	0	Wing loading doubled. Fast gliding flight.
4	0	-.005	0	Lateral trimming. Fast gliding flight.
5	0	-.005	0	Repeat of drop 4. Body attitude, nose-up.
6	0	-.005	0	Repeat of drop 4.
7	-.025	-.025	-.025	Attitude correction.[a]
8	-.025	-.025	-.025	Tests of rear point confluence rigging on body (riser connectors tied together). Several wings deployed quickly and flew.
9	-.025	-.025	-.025	
10	-.025	-.025	-.025	
11	-.025	-.025	-.025	
12	-.025	-.025	-.025	
13	-.015	-.015	[b]-.015	Tight spiral flight indication near stall.
14	.015	.015	.015	Good glide.
15	.030	.030	.030	Good glide, but wing tips loose and flapping.
(b) Longitudinal and lateral control				
1 to 6	0	0	0	Basic rigging, table I.
7 and 8	0	0	.010	180° right turn.
9	0	0	.020	Tight turn approximately 270°.
10	0	-.010	0	Slight left turn 45°, long glide.
11	0	-.020	0	Left turn approximately 270°.
12	0	-.005	.005	Differential control. 180° left turn.
13	0	-.010	.010	Differential control. 270° left turn.
14	0	-.010	.010	Differential control. 180° left turn.
15	0	0	0	Basic rigging. Good glide and landing.
16	-.015	0	0	Good gliding flight, possibly slower than drop 15.
17	-.030	0	0	Good gliding flight, possibly slower than drop 16.
18	-.045	0	0	Vertical flight parachutelike.
19	-.040	0	0	Near vertical flight, oscillating.
20	-.040	0	0	Steady parachutelike drop.
21	-.035	0	0	Vertical flight.
22	-.030	0	0	Slow gliding flight.
23	.060	0	0	Gliding flight keel line loose but no nose collapse.

[a]Rear straps and control lines shortened $0.025 l_k$ to obtain the desired nose-down attitude of -5°. Basic rigging, table I.

[b]From new attitude.

TABLE VI.- DROPS FROM ELEVATED PLATFORM OF SMALL-SCALE BODY 2 AND 7.87-FOOT (2.4 METER) KEEL PARAWING

Drop test	Keel control, $\Delta l/l_k$	Parawing tip control, $\Delta l/l_k$		Remarks
		Left	Right	
1	0	0	0	Basic rigging, table I. Gliding flight
2	0	0	0	Basic rigging, table I. Gliding flight.
3	0	0	0	Basic rigging, table I. Gliding flight.
4	0	0	0	Basic rigging, table I. Gliding flight.
5	-.020	0	0	Stalled flight with pitch oscillations.
6	-.010	0	0	Parachute mode.
7	.010	0	0	Gliding flight.
8	.020	0	0	Gliding flight.
9	.030	0	0	Gliding flight.
10	.040	0	0	Gliding flight.
11	.060	0	0	Gliding flight.
12	0	0	0	Basic rigging, table I. Gliding flight.
13	0	-.020	-.020	Stalled flight.
14	0	-.020	-.020	Stalled flight.
15	0	-.010	-.010	Stalled flight.
16	0	.010	.010	Gliding flight.
17	0	.020	.020	Gliding flight.
18	0	.040	.040	Gliding flight but tips loose and flapping.

TABLE VII.- FLIGHT-TEST DATA

(a) Landing impact accelerations obtained from mechanical accelerometer readings

Flight	Acceleration, g units	
	Vertical axis	Horizontal axis
101	25	49
102	65	20
106	72	--
[a]107, 108	55	25
[a]111 to 115	55	23

[a]Mechanical accelerometers not reset between flights.

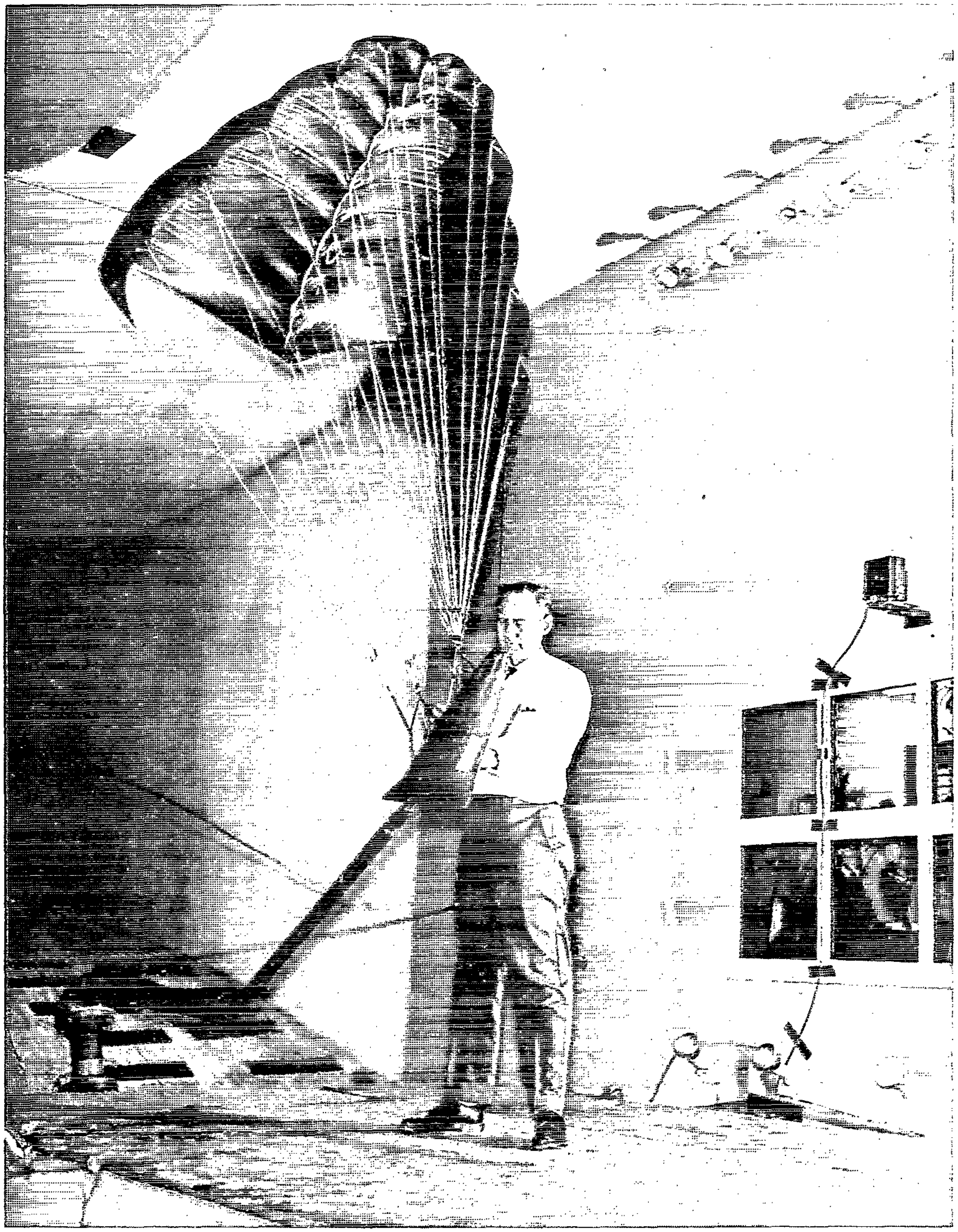
(b) Deployment loads along vertical axis of the body obtained from telemetrical data

Flight	Deployment load, g units	Flight	Deployment load, g units
121	4.7	150	4.9
122	4.6	151	4.5
123	3.1	152	4.6
125	4.1	153	3.9
131	5.1	154	4.3
132	5.3	155	5.7
133	5.7	156	3.9
136	4.8	157	5.7
137	4.7	158	5.7
138	3.5	159	4.7
139	---	160	---
140	4.2	161	---
141	5.3	162	5.6
142	5.9	163	6.4
143	5.0	164	4.8
145	6.1	165	7.1
146	3.2	166	6.2
147	6.2	167	5.4
148	5.9	169	5.8

Minimum load 3.1g
Maximum load 7.1g
Average load 5.0g

(c) Maximum, minimum, and average descent rates

Wing keel length		Maximum descent rate		Minimum descent rate		Average descent rate	
ft	m	ft/sec	m/sec	ft/sec	m/sec	ft/sec	m/sec
20	6.10	25.8	7.9	9.9	3.0	17.4	5.3
24	7.32	14.9	4.6	10.8	3.3	12.4	3.8



L-67-6069

Figure 1.- Small-scale body I and the 6.56-ft (2 m) single-keel parawing mounted in the 17-ft (5.18 m) test section of the Langley 300-MPH 7- by 10-foot tunnel.

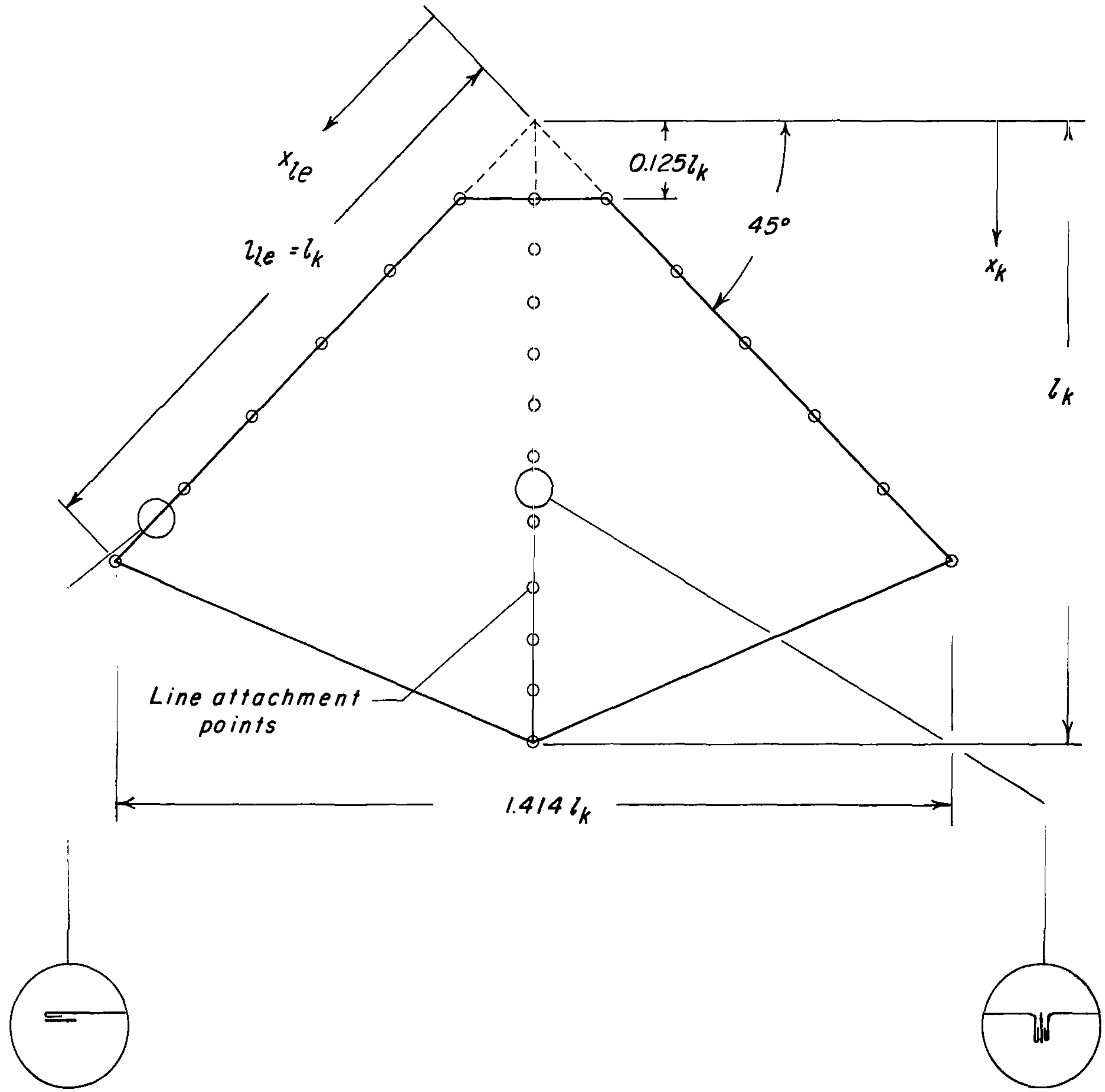
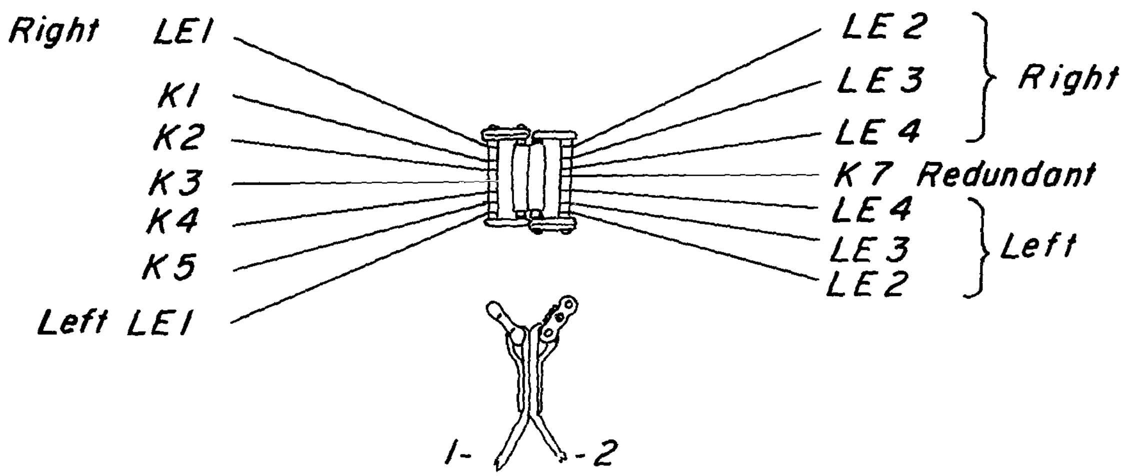
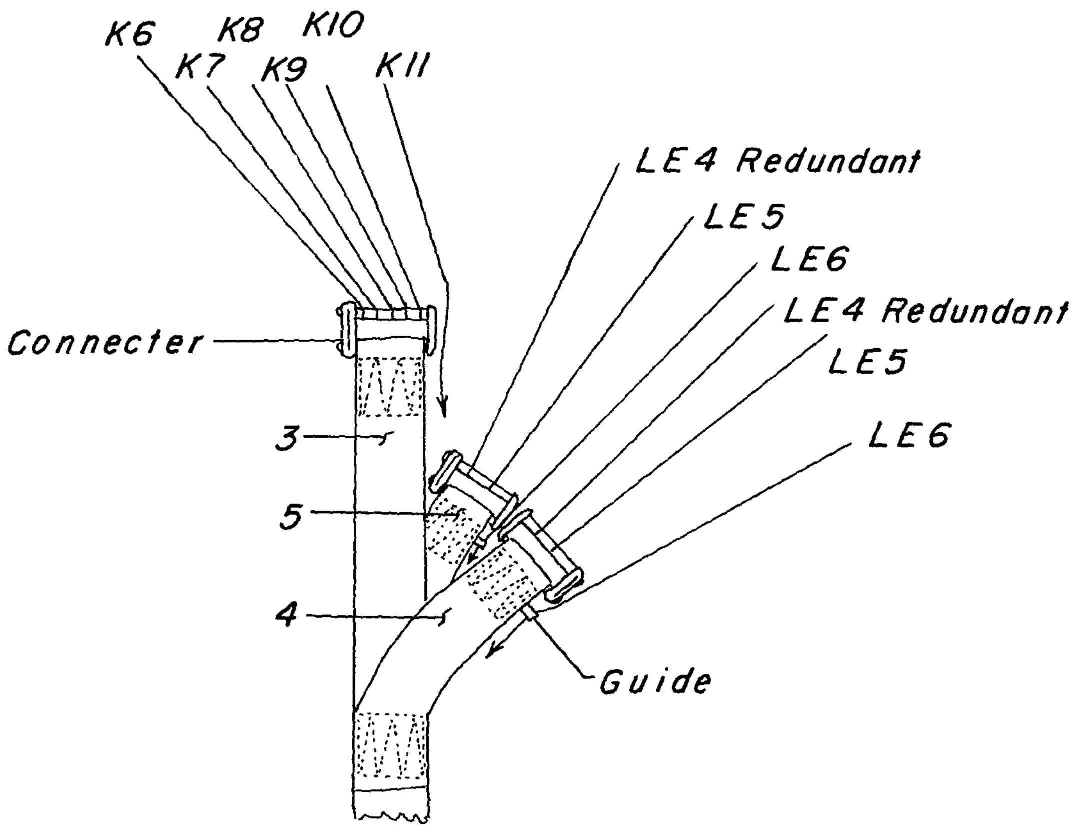


Figure 2.- Details of the single-keel-parawing planform.



(a) Front strap.



(b) Rear strap.

Figure 3.- Line grouping at the connecter link for a single-keel parawing.

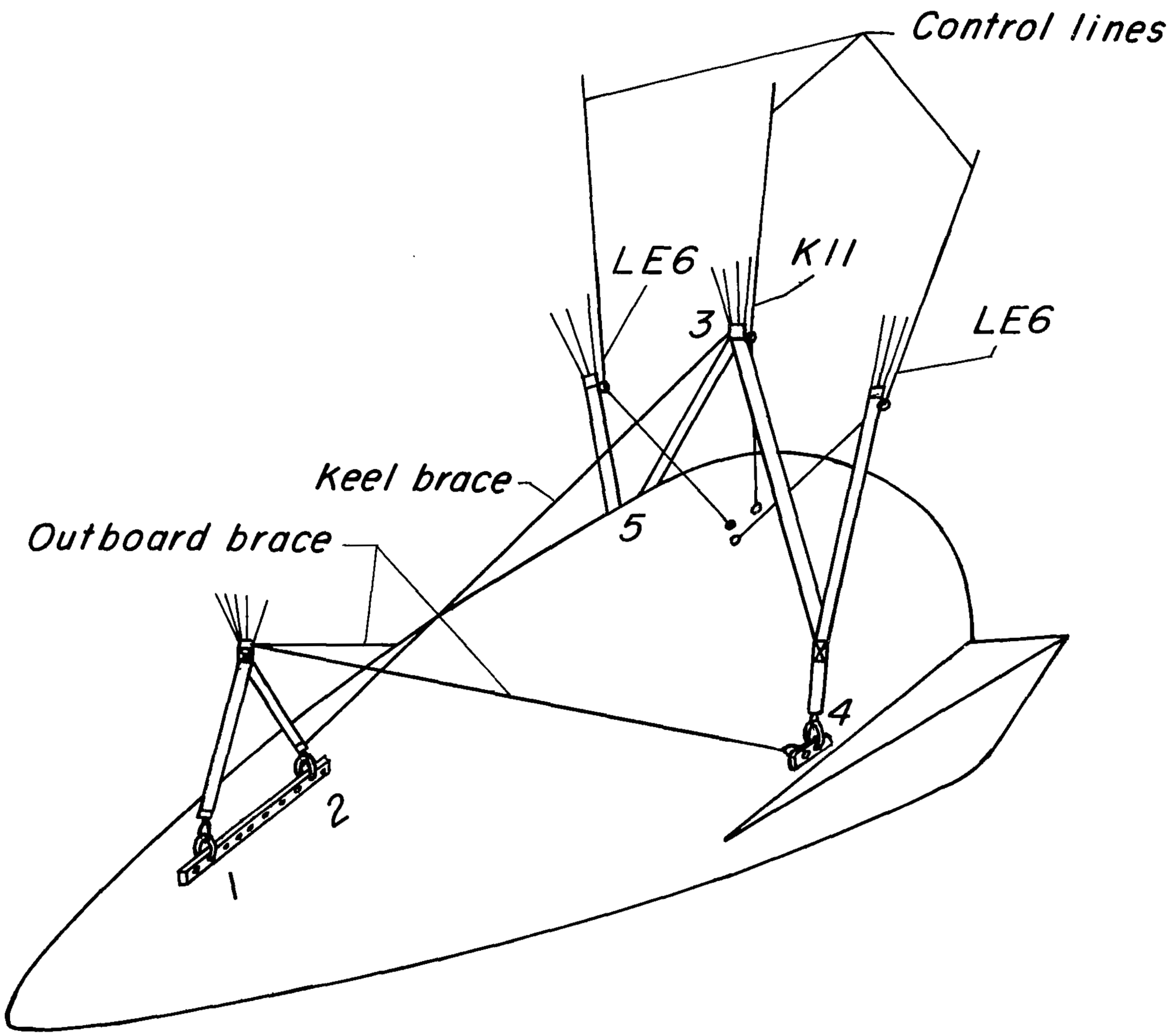


Figure 4.- Harness and brace cords.

Dimension	Body 1	Body 2
A	22.25 in. (56.52 cm)	22.97 in. (58.34 cm)
B	0.550A	0.568A
C	.040A	.040A
D	.180A	.221A
E	.378A	.408A
F	.790A	.836A
G	.781A	.783A
H	.016A	.016A

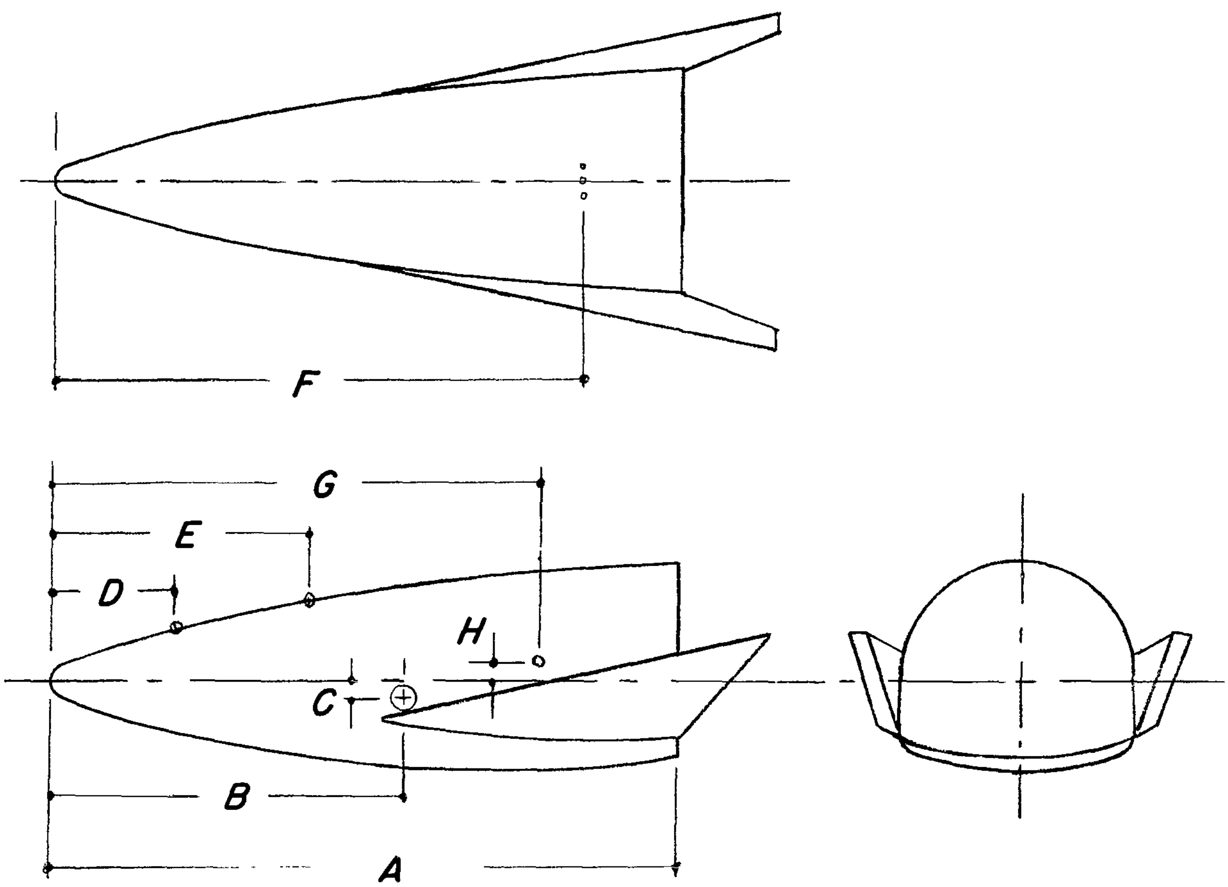


Figure 5.- Details of bodies 1 and 2 used in small-scale tests.

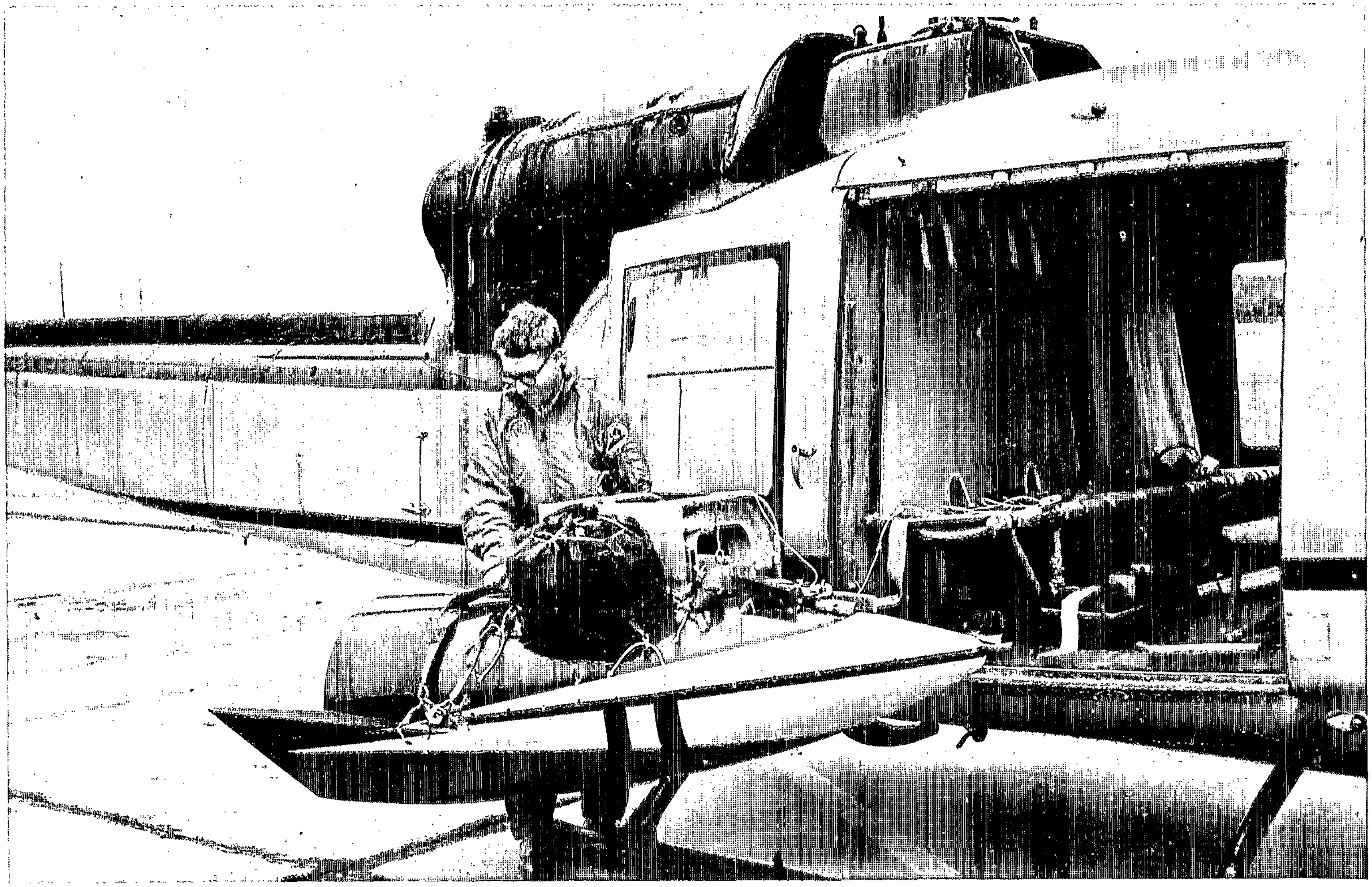
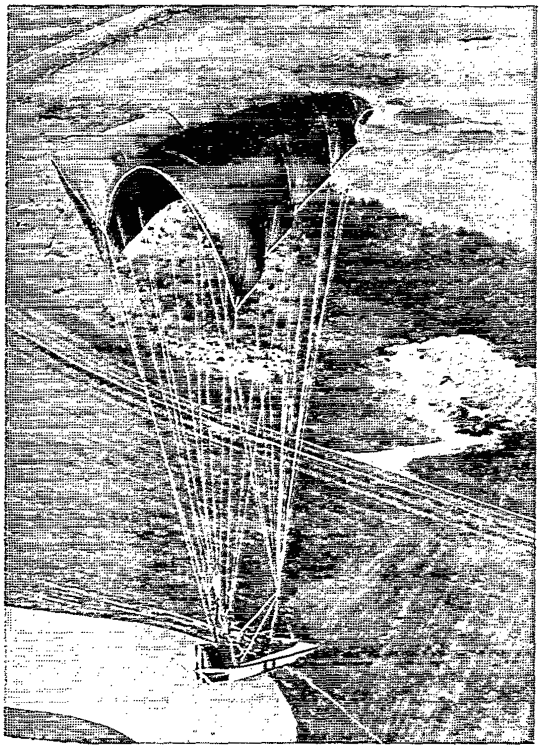
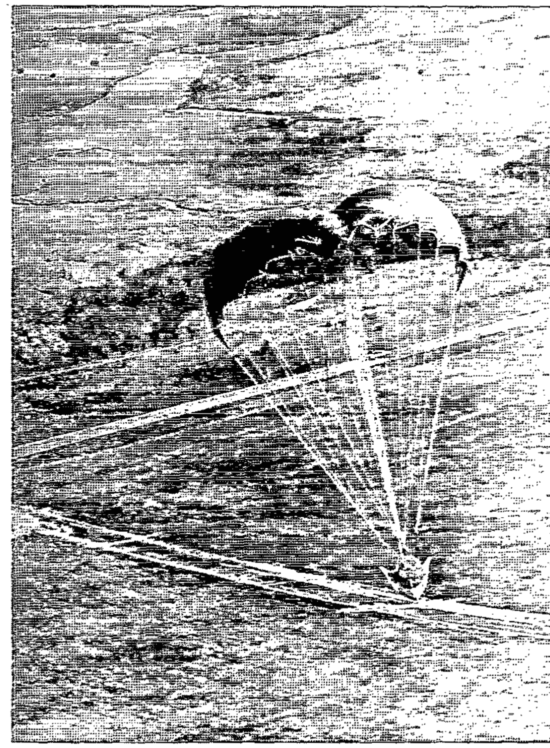


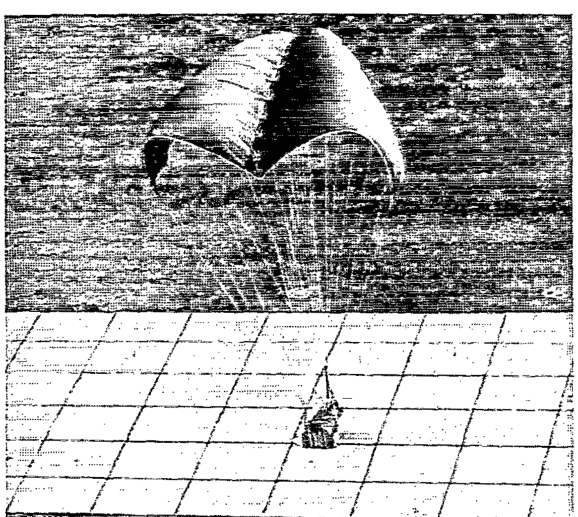
Figure 6.- Radio-controlled body 3 and parawing mounted on the helicopter. L-68-81.1



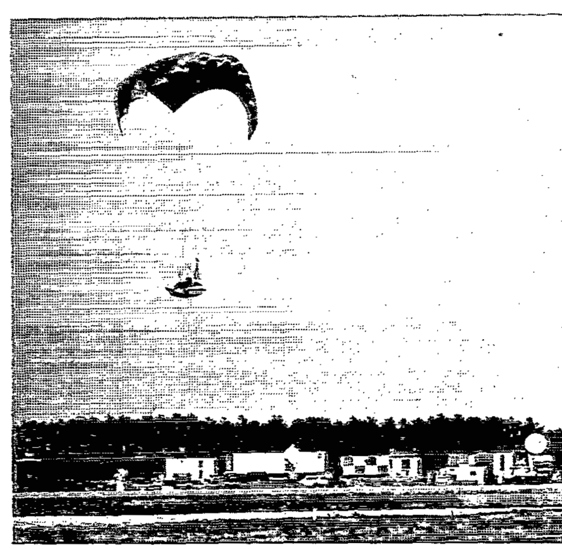
(a) Side view. L-68-5884



(b) Front view. L-68-5888



(c) Rear view. L-68-5887



(d) Landing approach. L-68-3509

Figure 7.- Body 3 and 20-ft (6.10 m) single-keel parawing in flight.

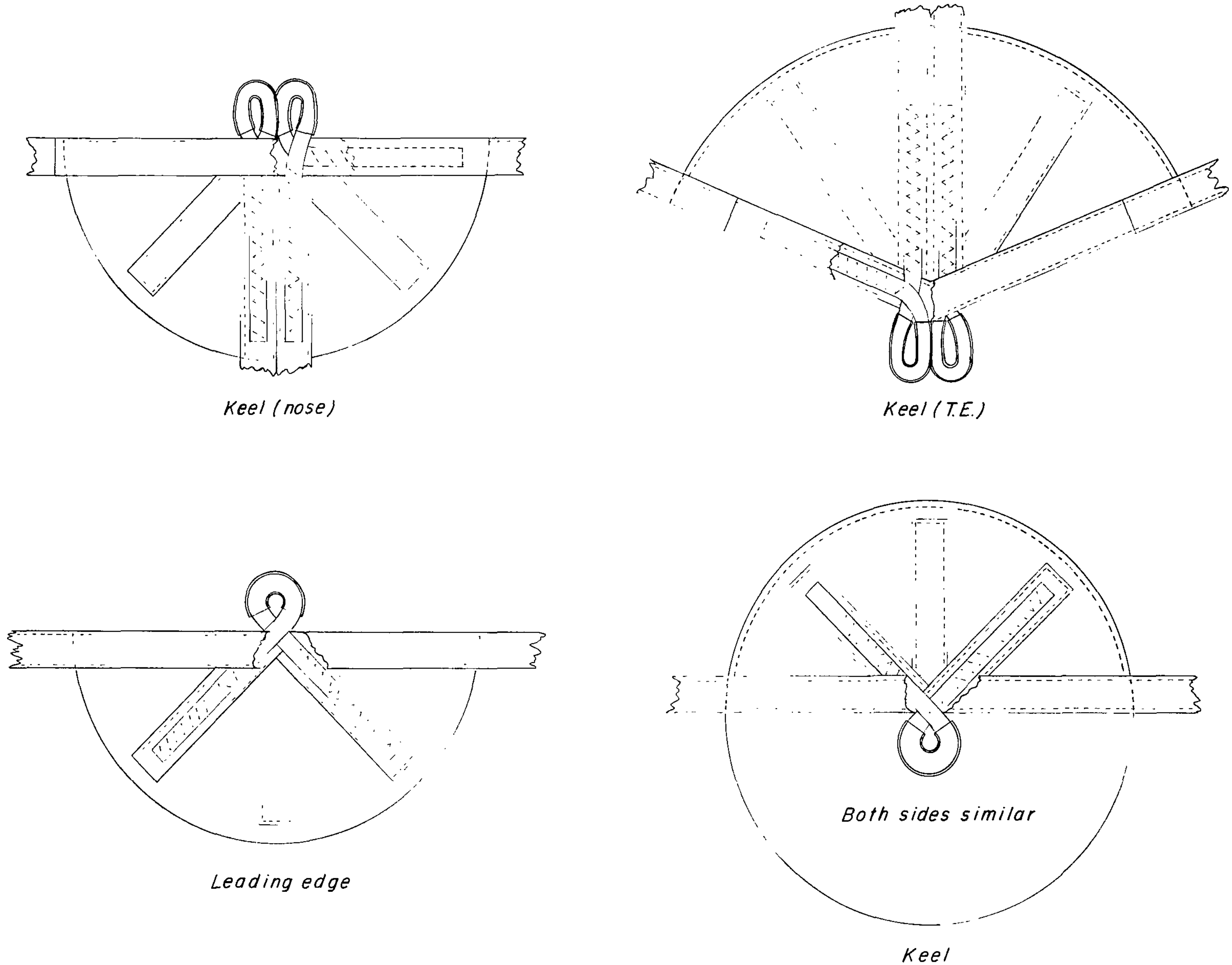
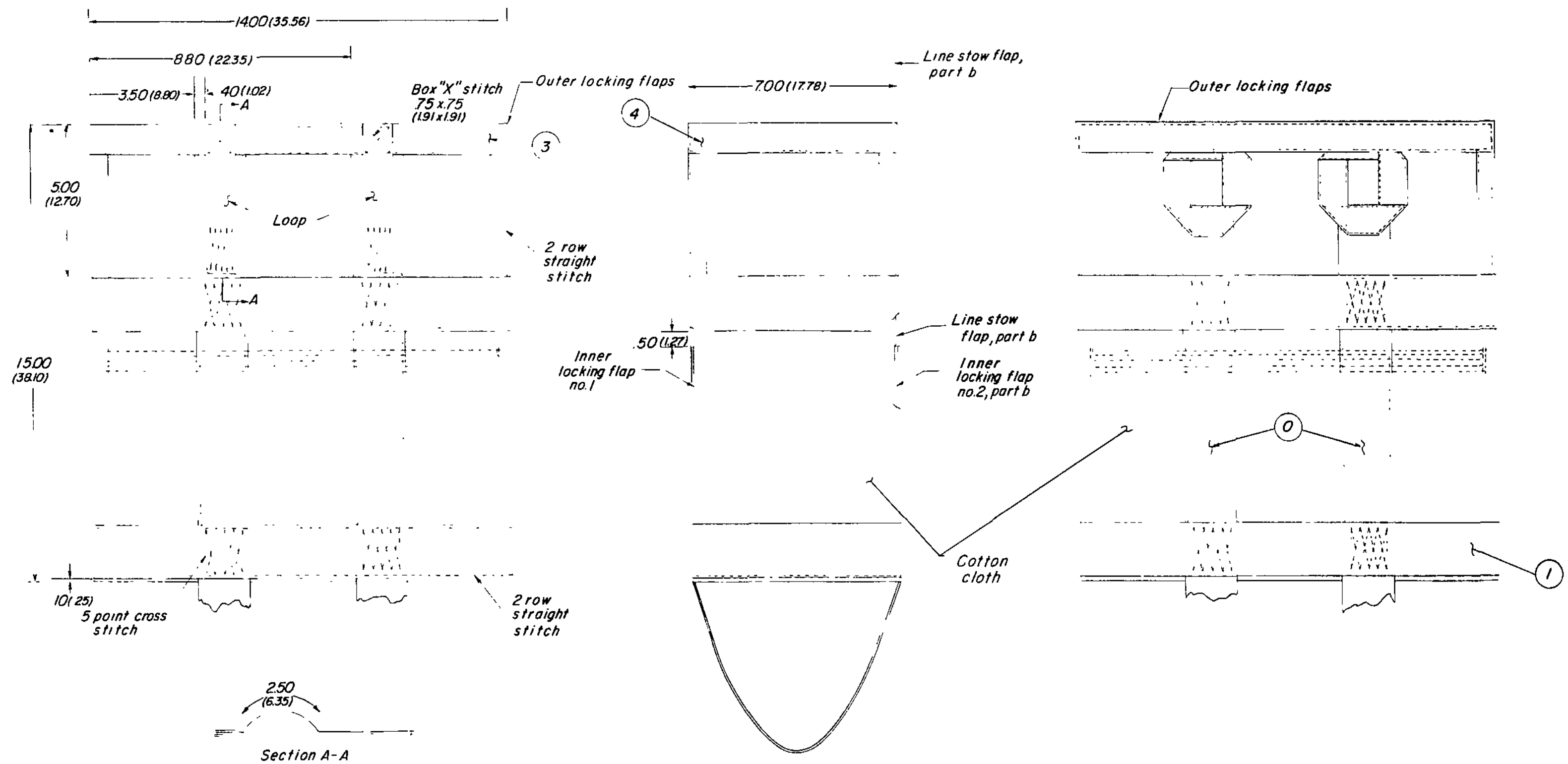


Figure 8.- Details of construction of line attachments.

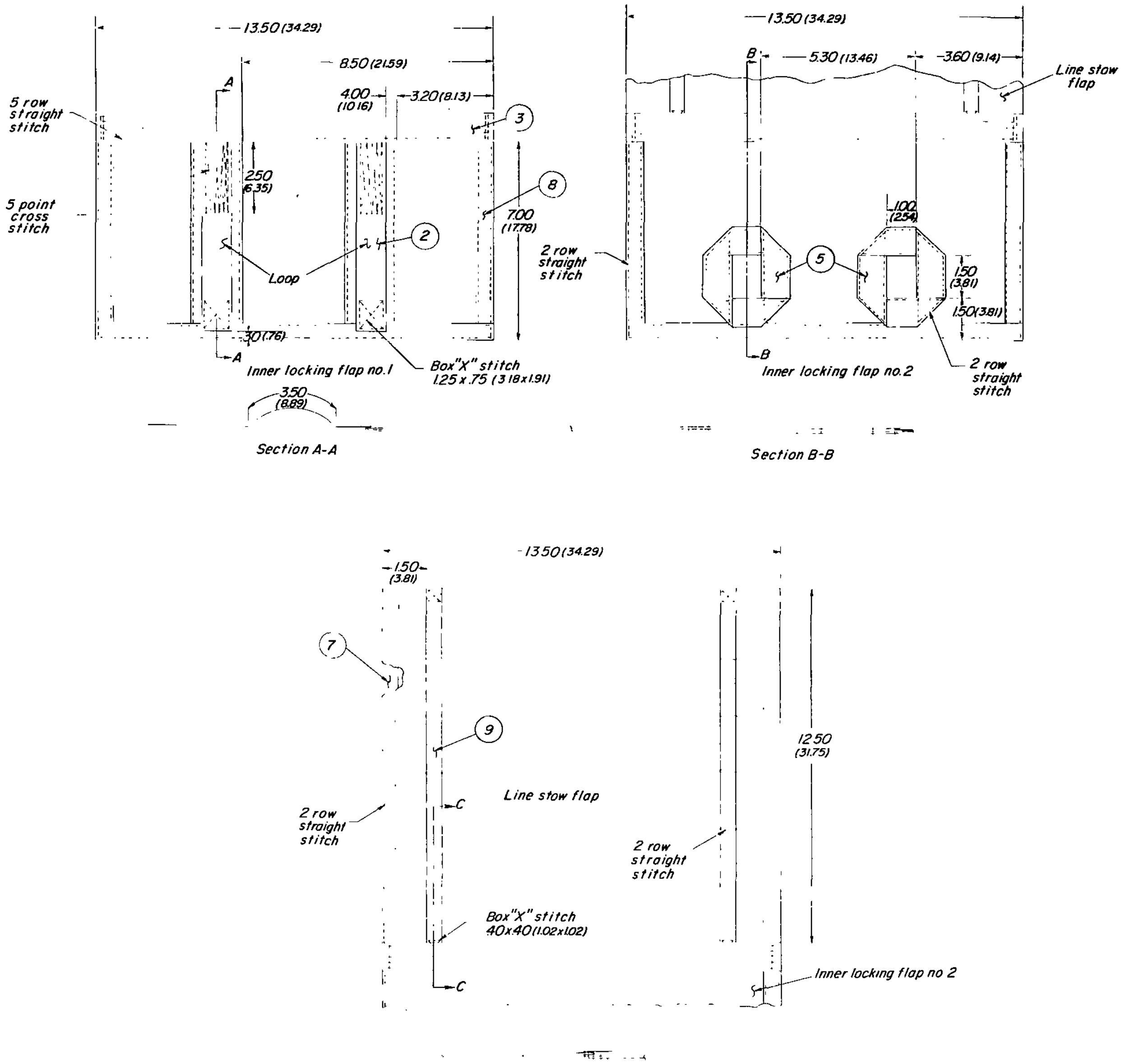


DESCRIPTION

Item	No.	Part	Size inches (cm)	Material
0	2	Strap	1.75 x 54.00 (4.45 x 137.16)	Nylon web
1	2	Reinforcing strap	1.75 x 42.00 (4.45 x 106.68)	Nylon web
2	4	Loop	1.00 x 9.00 (2.54 x 22.86)	Nylon tape
3	4	Edge reinforcing	1.00 x 14.00 (2.54 x 35.56)	Nylon tape
4	2	Edge reinforcing	1.00 x 7.00 (2.54 x 17.78)	Nylon tape
5	8	Loop reinforcing	1.00 x 8.00 (2.54 x 20.32)	Nylon tape
6	2	Edge reinforcing	.56 x 14.00 (1.42 x 35.56)	Nylon tape
7	2	Edge reinforcing	.56 x 13.00 (1.42 x 33.02)	Nylon tape
8	8	Edge reinforcing	.56 x 7.00 (1.42 x 17.78)	Nylon tape
9	2	Loop	.56 x 14.00 (1.42 x 35.56)	Nylon tape

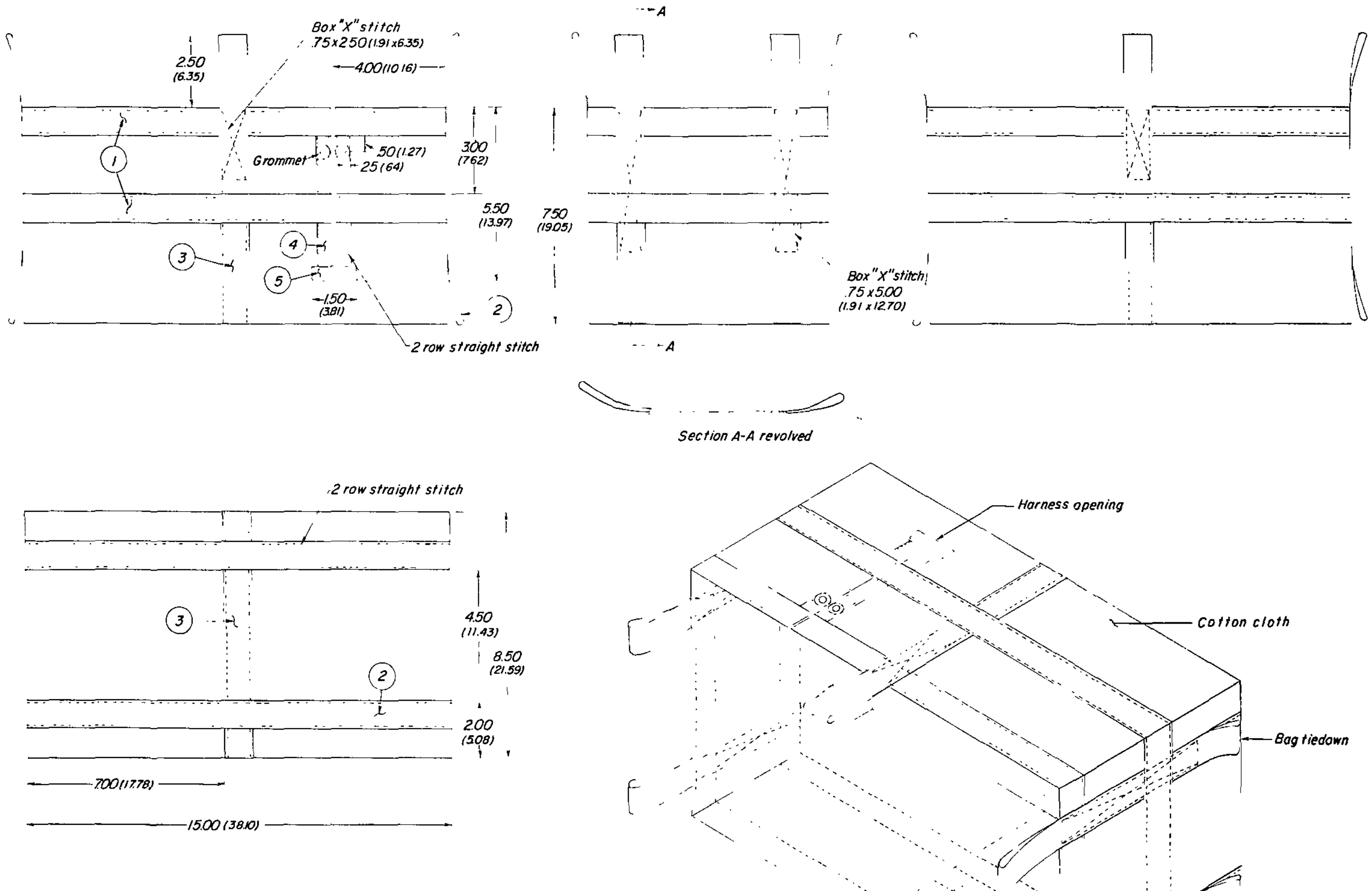
(a) Bag assembly.

Figure 9.- Two-compartment deployment bag. Dimensions are in inches (centimeters) unless otherwise indicated.



(b) Inner flaps.

Figure 9.- Concluded.



DESCRIPTION				
Item	No.	Part	Size inches, (cm)	Material
1	2	Strap	1.00 x 47.00 (2.54 x 119.38)	Nylon web
2	2	Loop strap	1.00 x 65.00 (2.54 x 165.10)	Nylon web
3	1	Loop strap	1.00 x 38.50 (2.54 x 97.79)	Nylon web
4	2	Reinforcing	.50 x 5.50 (1.27 x 13.97)	Nylon tape
5	1	Reinforcing	.50 x 1.50 (1.27 x 3.81)	Nylon tape

Figure 10.- Deployment-bag container. Dimensions are in inches (centimeters).

COORDINATES

Station	Y_1 Lateral and upper	Y_1 Lower	Y_2 To ℄ ellipse	a Axis	b Axis
0	Nose radius = 2.70				
5.71	4.03	4.03			
11.43	5.74	5.74			
17.14	7.31	7.31			
22.86	8.74	8.74			
28.57	10.10	10.10			
34.29	11.26	11.26			
40.00	12.41	11.94	1.57	12.41	10.37
45.71	13.46	12.63	3.23	13.46	9.40
51.43	14.27	13.11	4.64	14.27	8.49
57.14	14.94	13.51	5.83	14.94	7.69
62.86	15.56	13.87	7.24	15.56	6.63
68.57	16.09	14.01	8.57	16.09	5.46
74.29	16.74	14.01	9.26	16.74	4.76
80.00	17.17	13.94	9.70	17.17	4.26
85.71	17.60	13.70	10.14	17.60	3.57
91.43	18.01	13.11	10.07	18.01	3.03
97.14	18.37	12.43	9.41	18.37	3.01
100.00	18.50	12.00	9.00	18.50	3.00

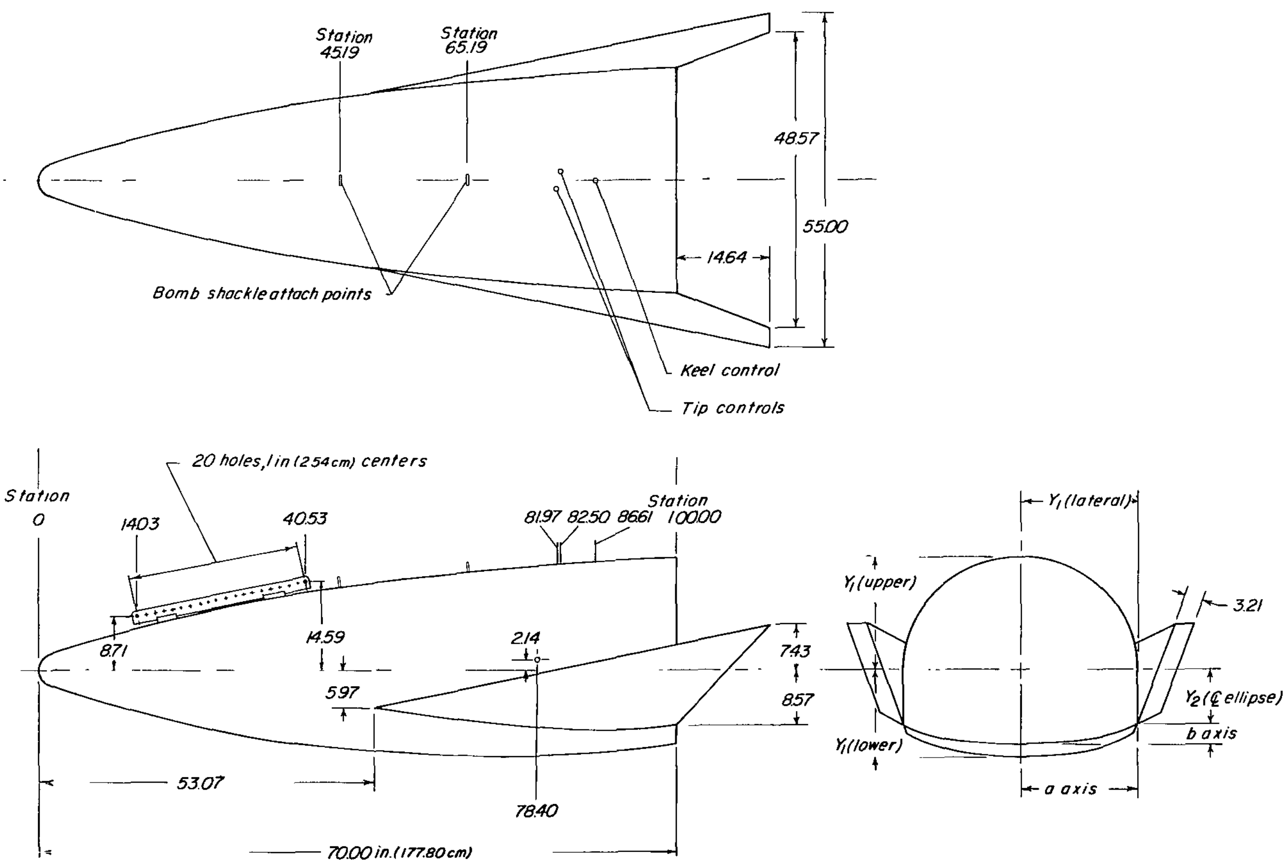


Figure 11.- Details of body 3. All dimensions are in percent body length unless otherwise indicated.

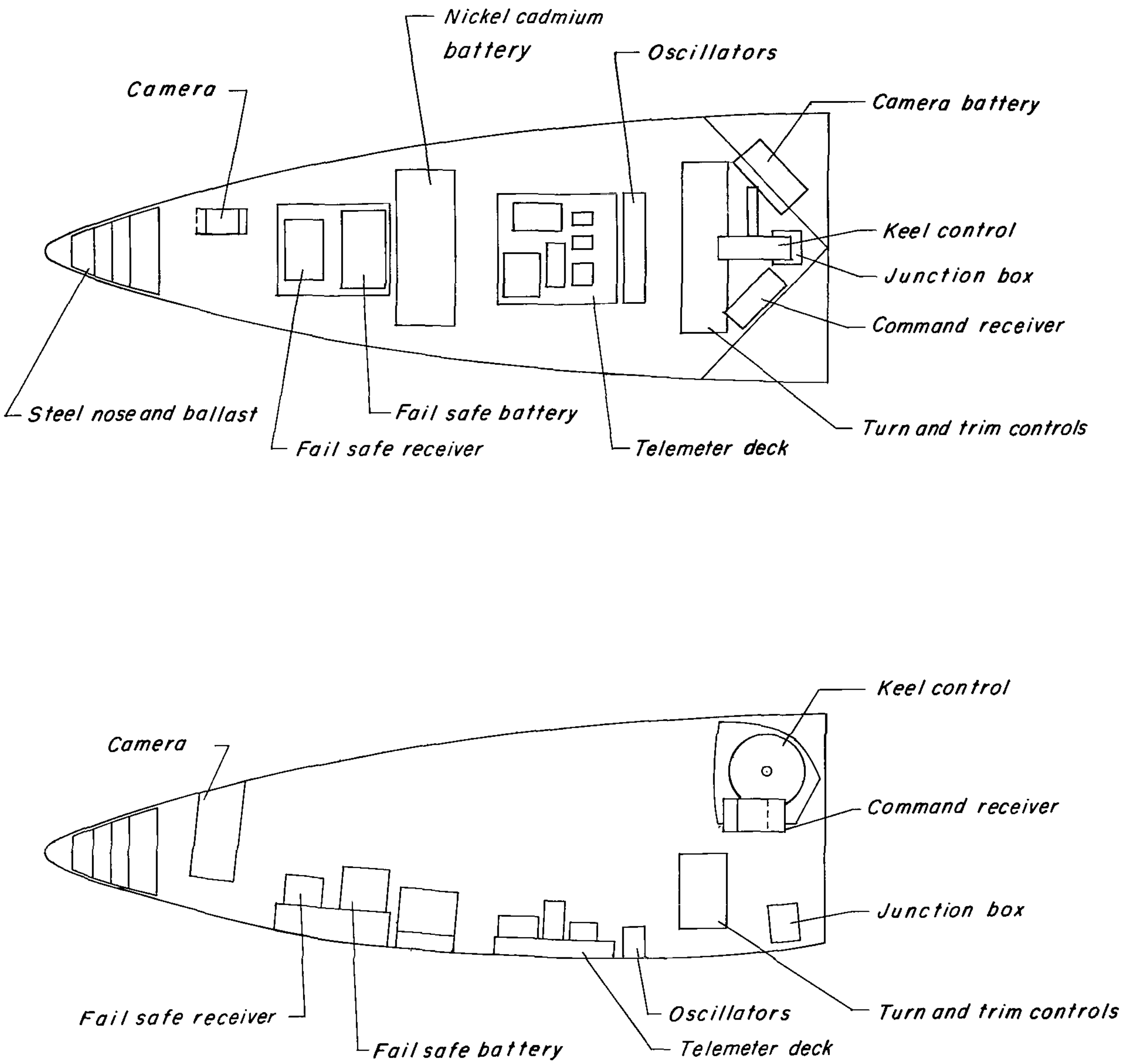


Figure 12.- Internal arrangement and identification of equipment used in body 3.

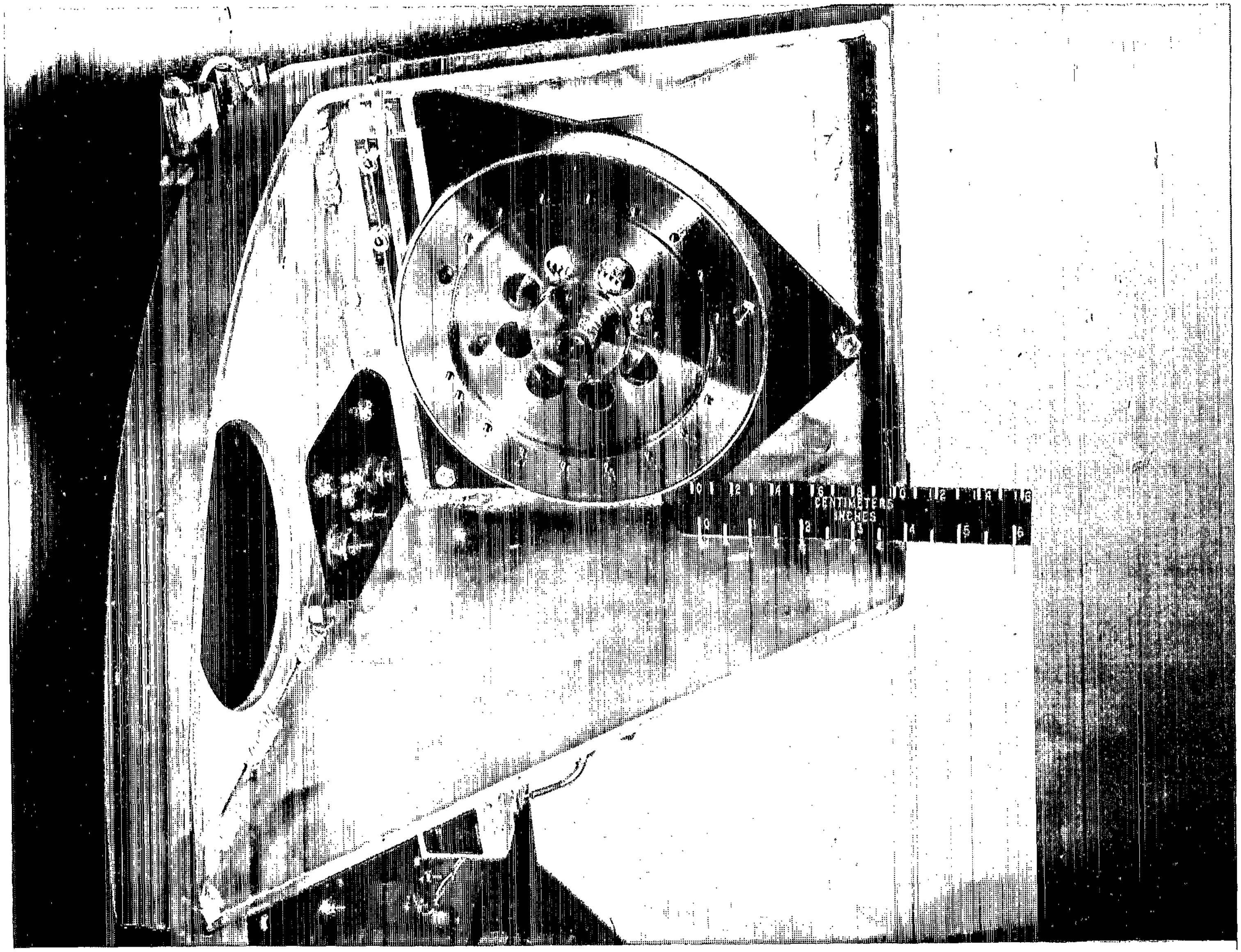


Figure 13.- Longitudinal control winch mounted on a body bulkhead. L-67-7467

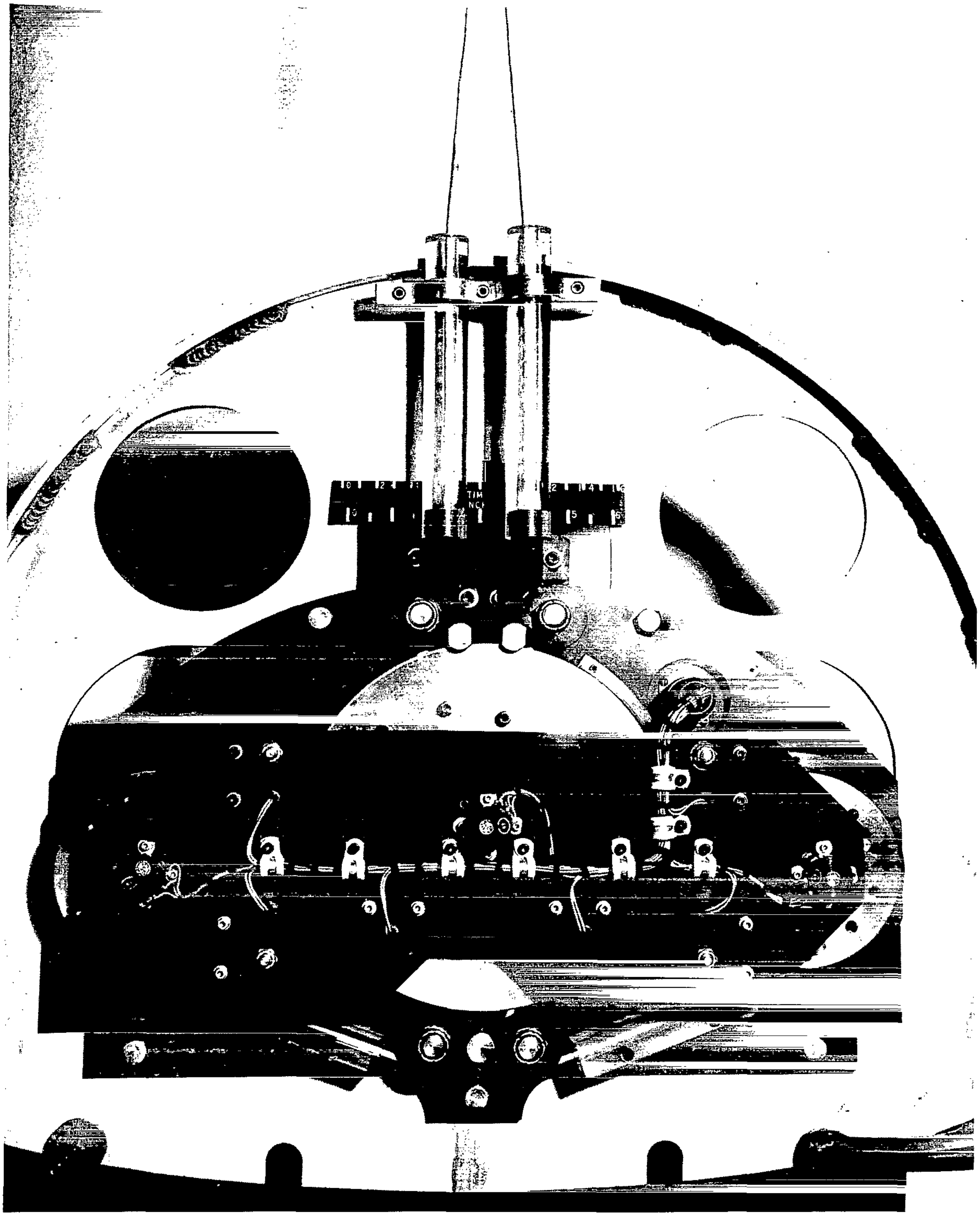


Figure 14.- Lateral control mechanism. L-67-7466

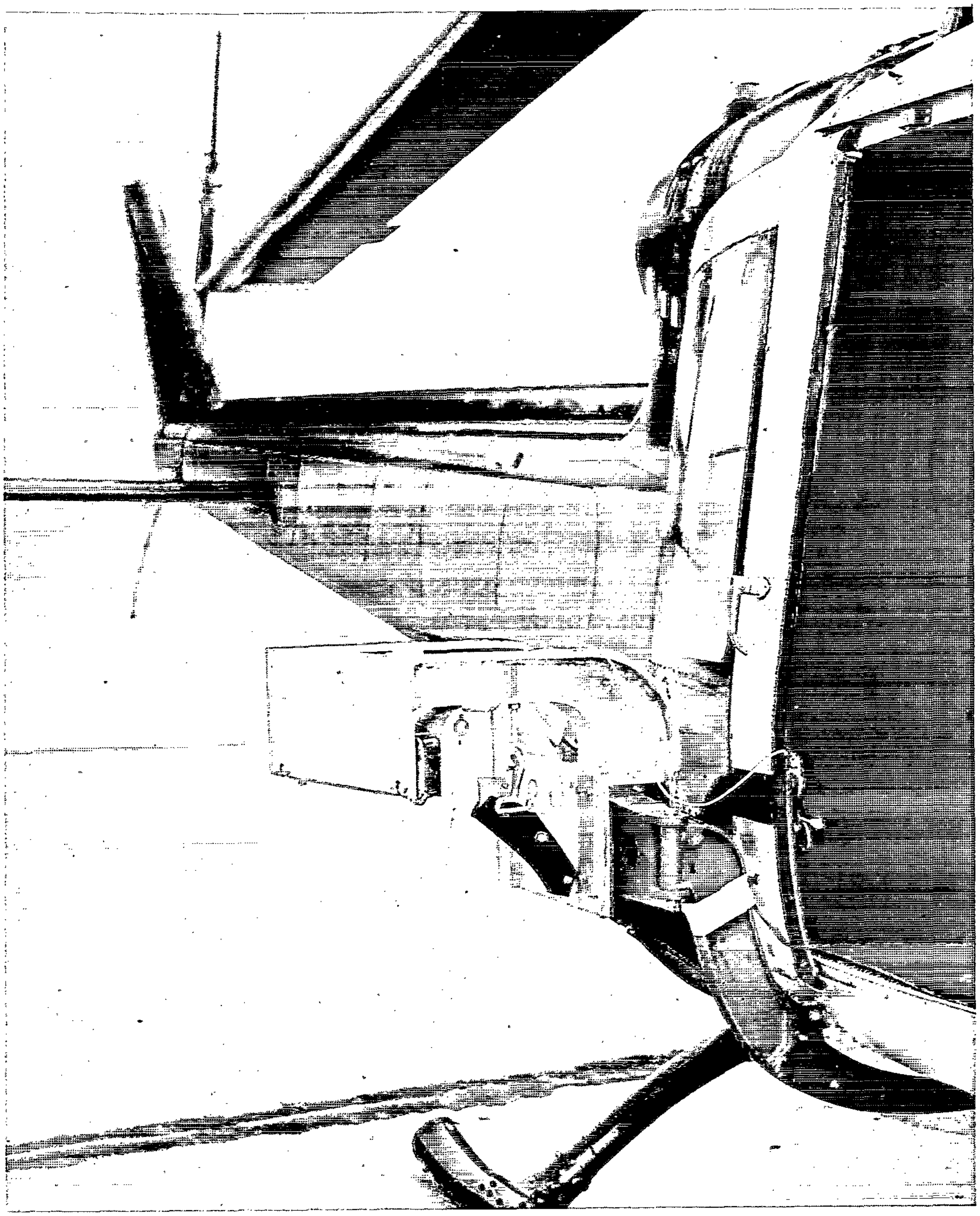


Figure 15.- Model support mounted on the drop helicopter. L-68-58.1

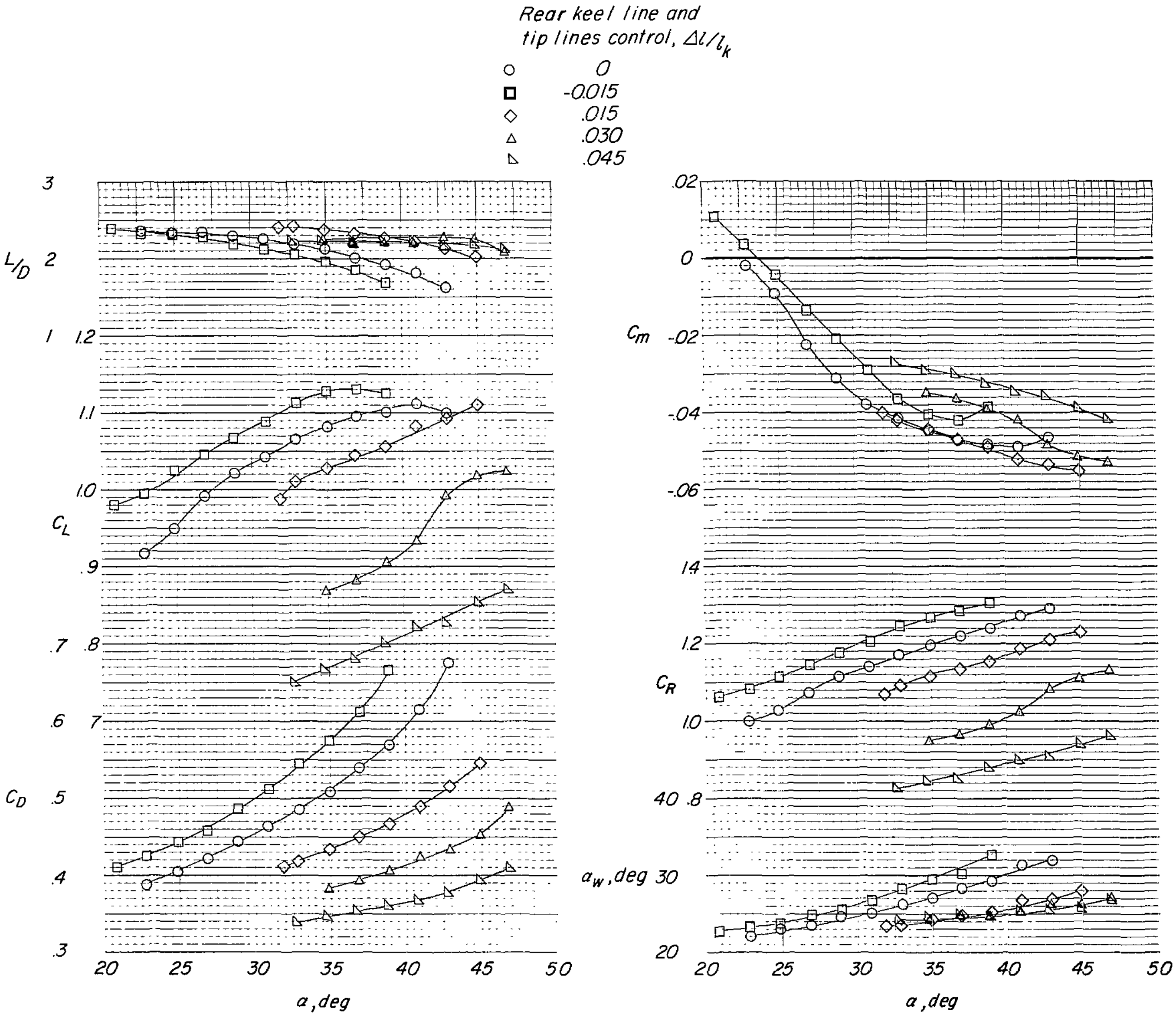


Figure 16.- Effect of rear keel line and tip lines control on the longitudinal aerodynamic characteristics of body 1 and the 6.56-ft (2.0 m) 45° swept parawing.

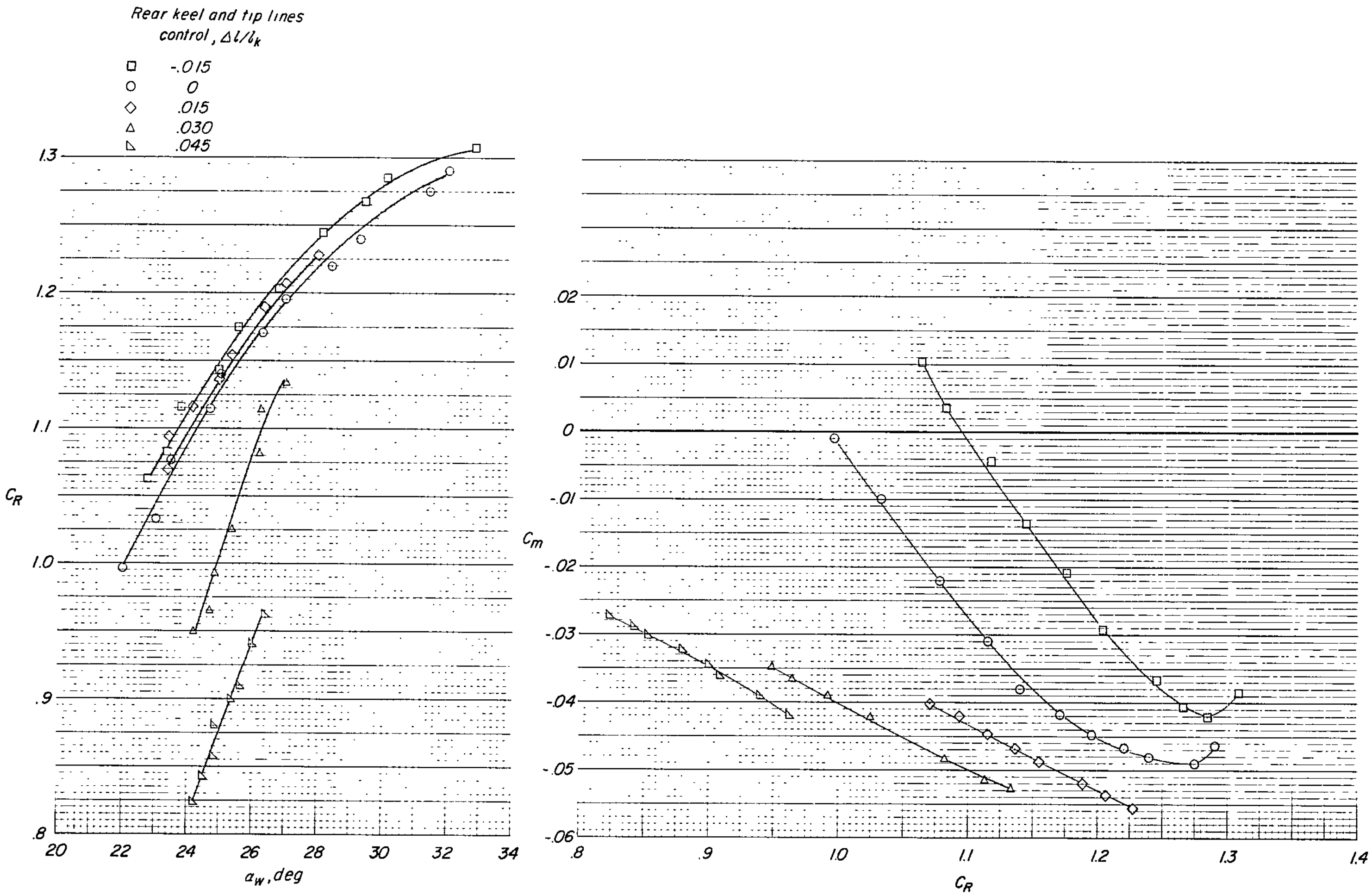


Figure 16.- Concluded.

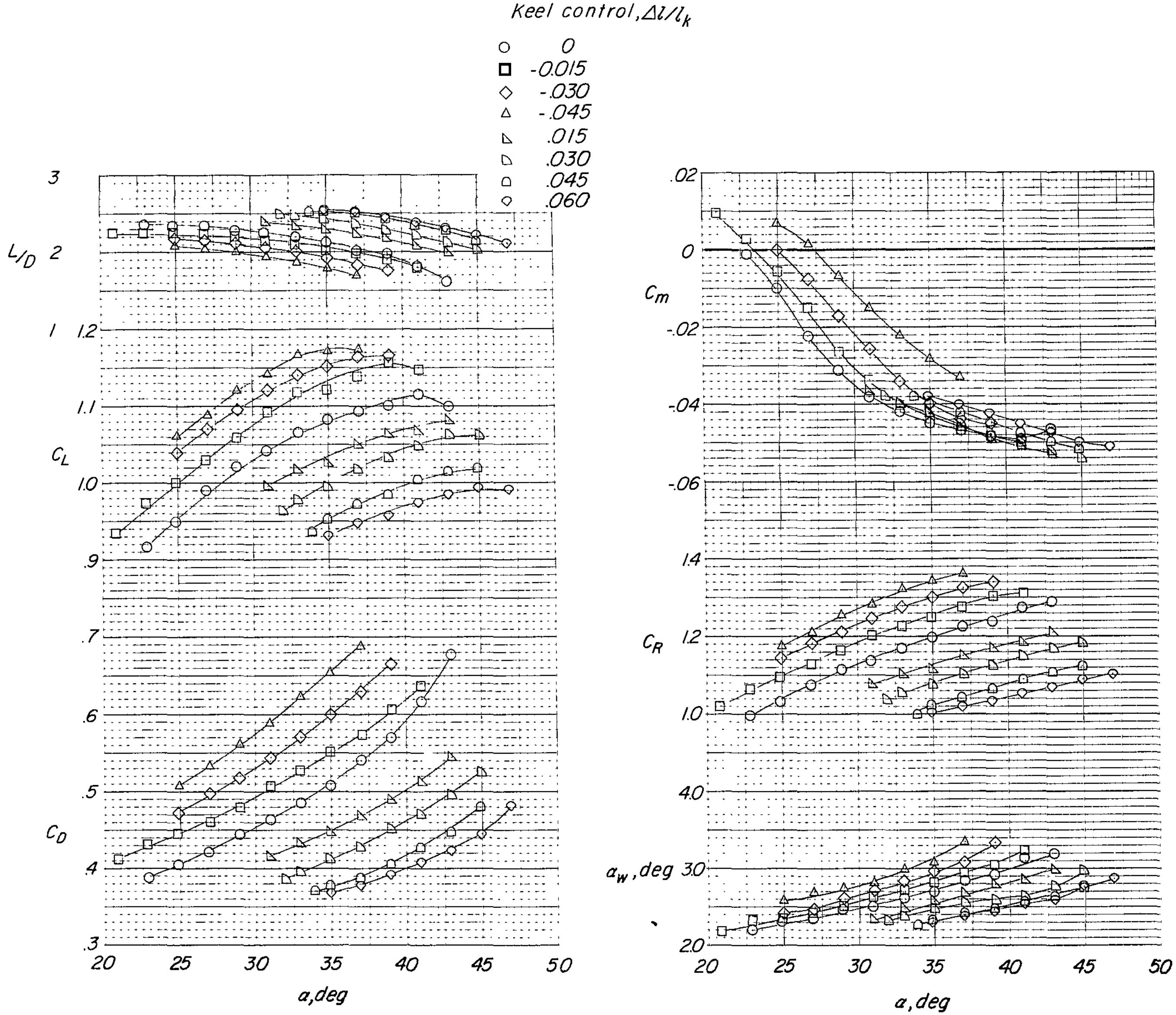


Figure 17.- Effect of keel control on the longitudinal aerodynamic characteristics of body 1 and the 6.56-ft (2.0 m) 45° swept parawing.

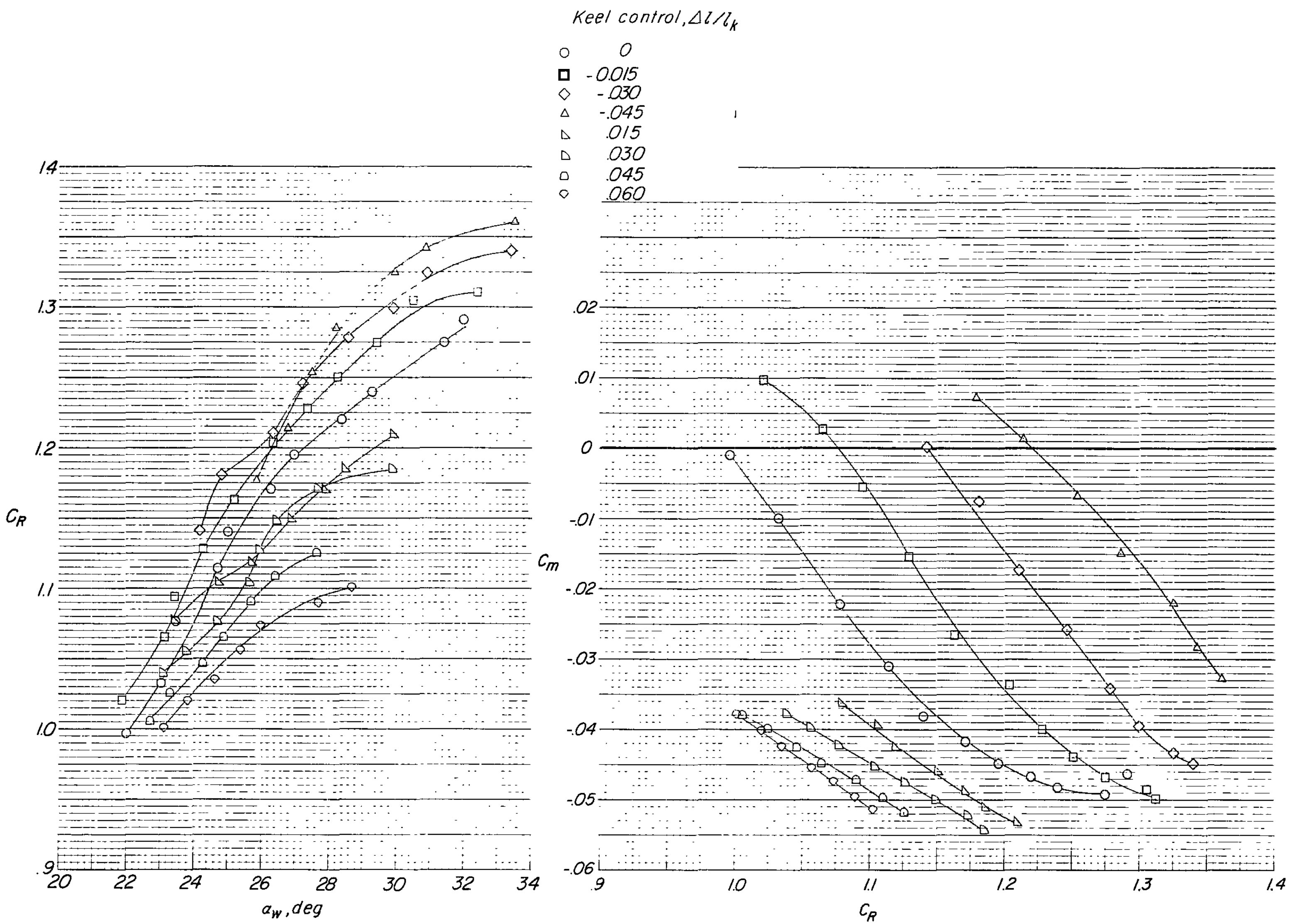


Figure 17.- Concluded.

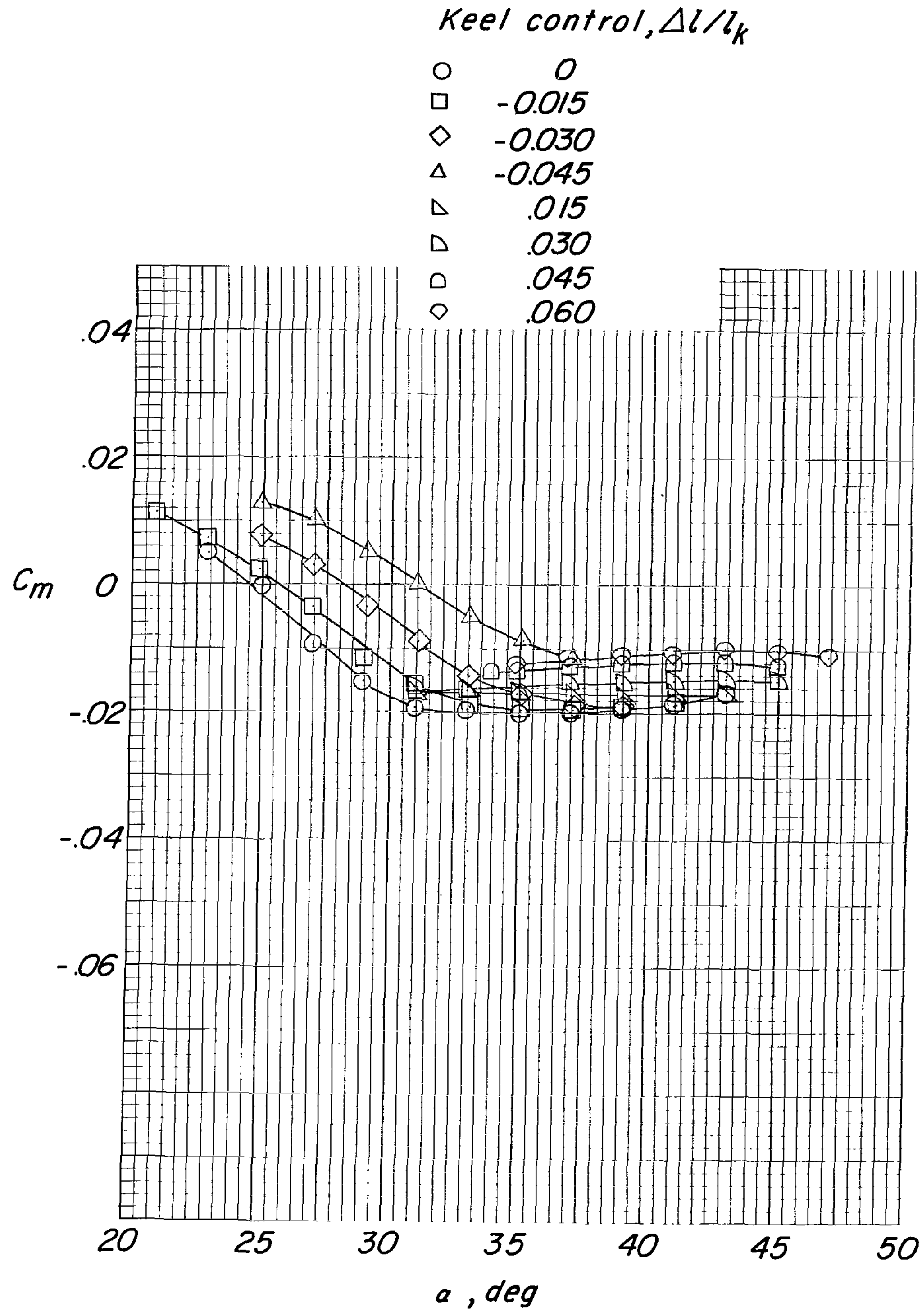


Figure 18.- Pitching-moment coefficients of figure 17 transferred from body center of gravity (weightless parawing condition) to small-scale parawing-body center of gravity.

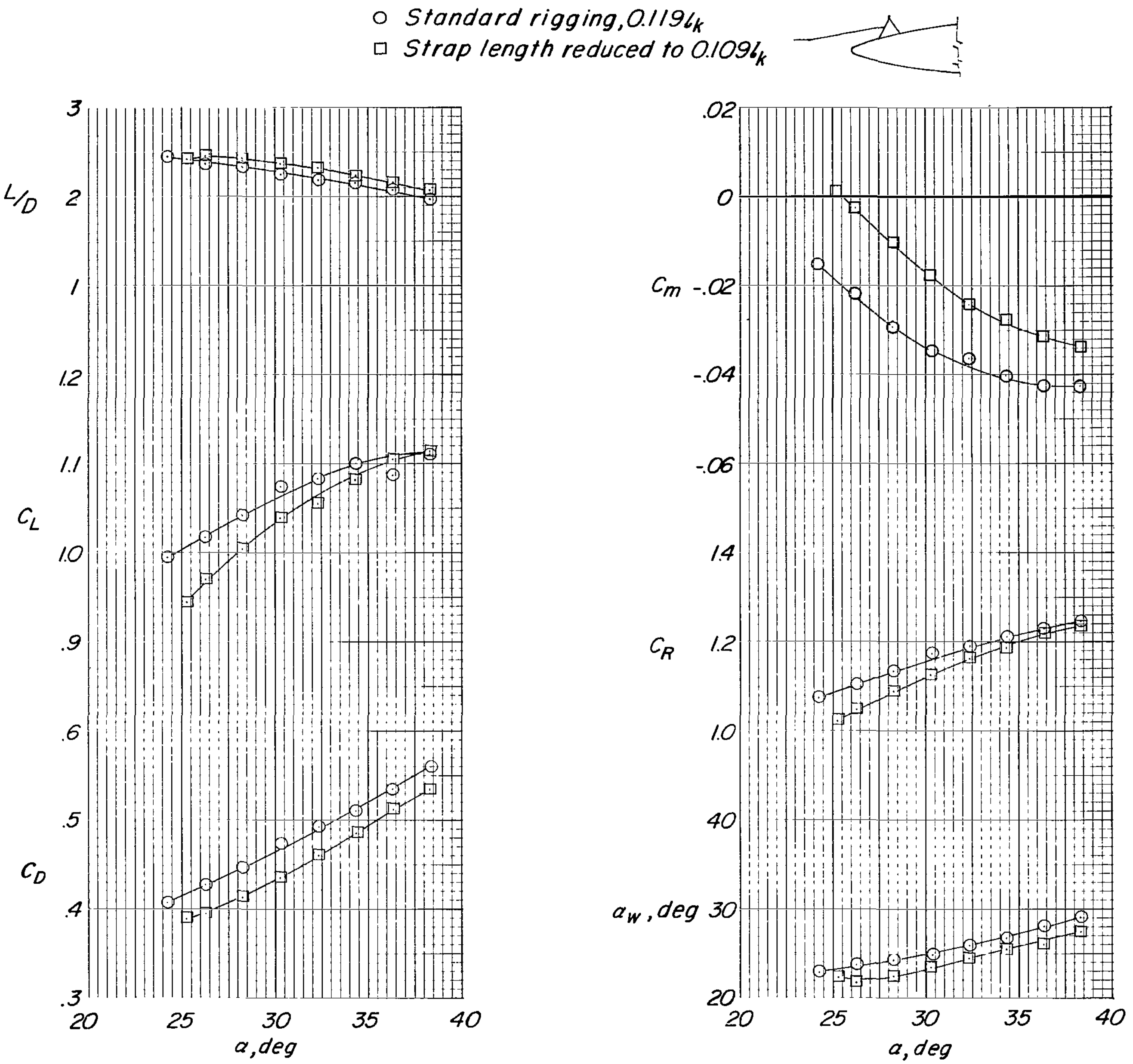


Figure 19.- Effect of forward attachment rigging on the longitudinal aerodynamic characteristics of body 2 and the 6.56-ft (2.0 m) 45° swept parawing.

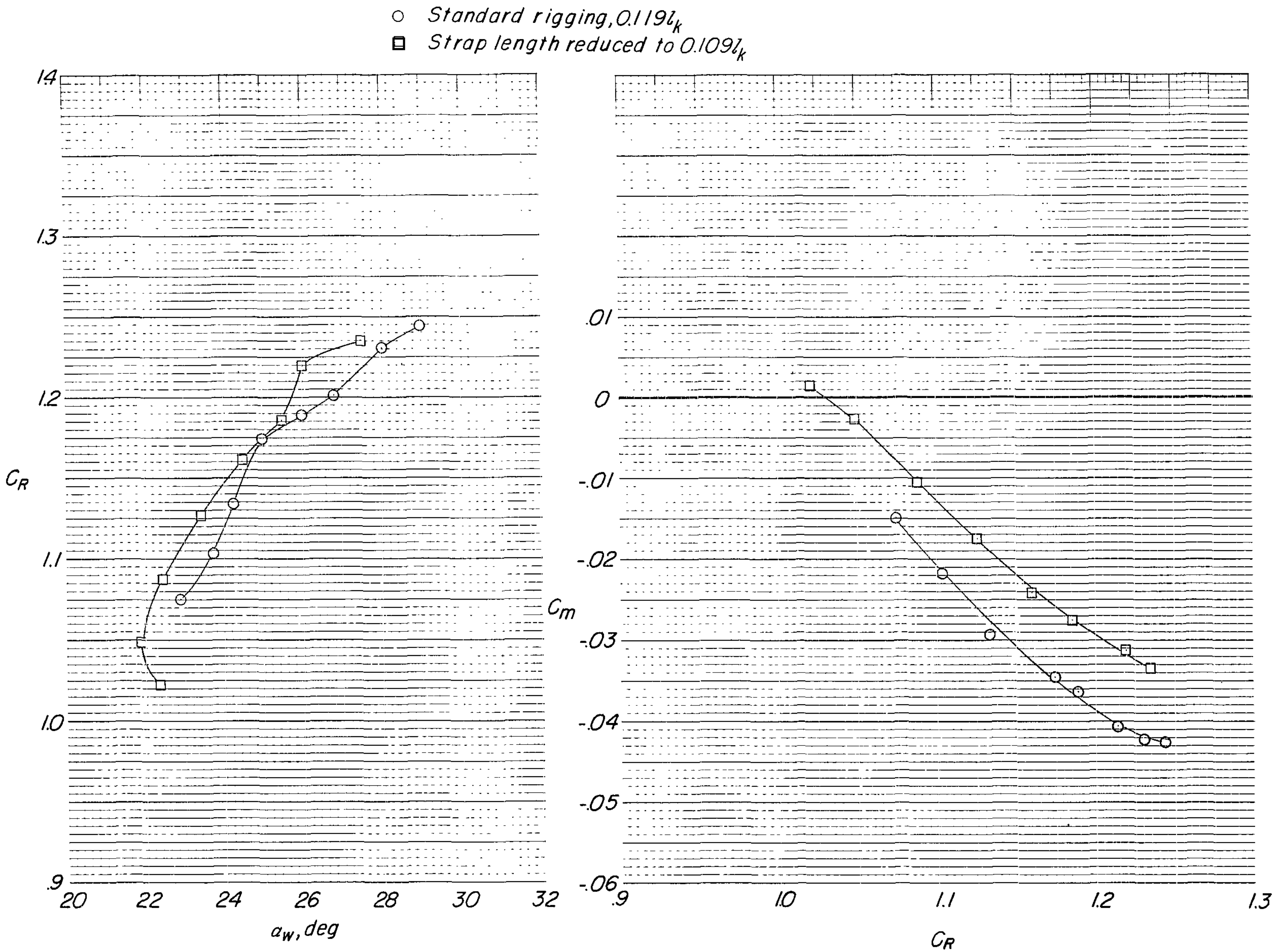


Figure 19.- Concluded.

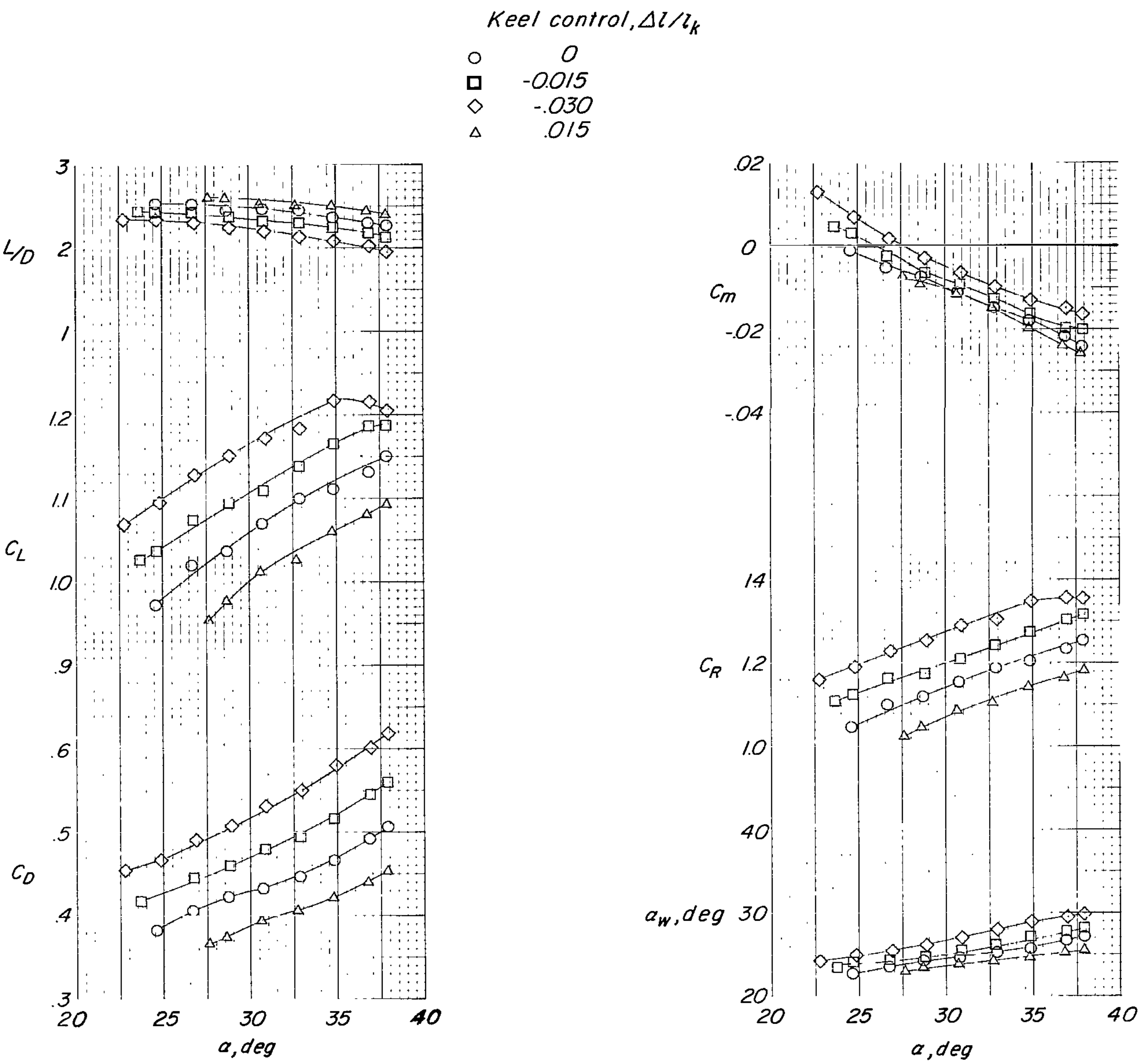


Figure 20.- Effect of keel control on the longitudinal aerodynamic characteristics of body 2 and the 7.87-ft (2.4 m) 45° swept parawing.

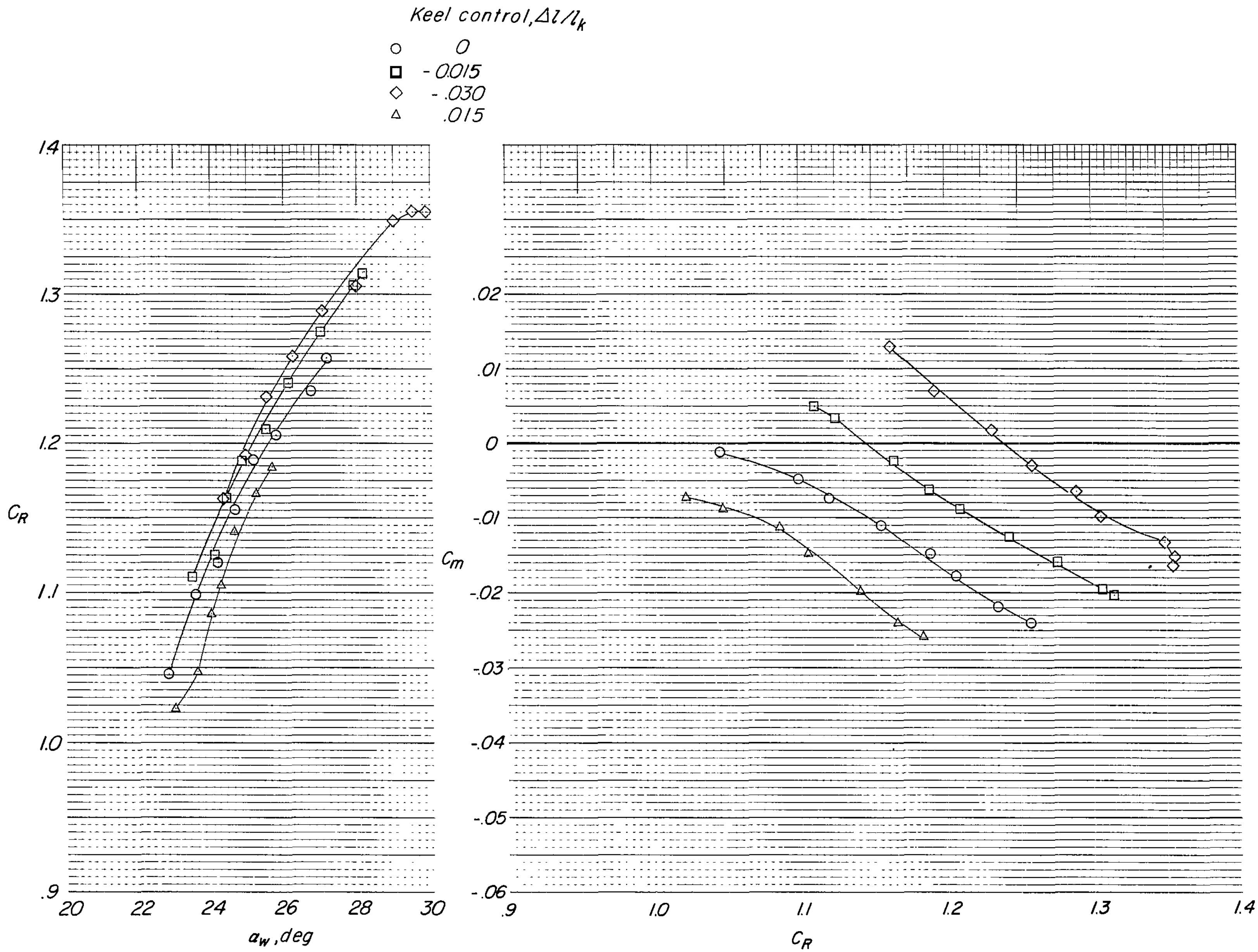


Figure 20.- Concluded.

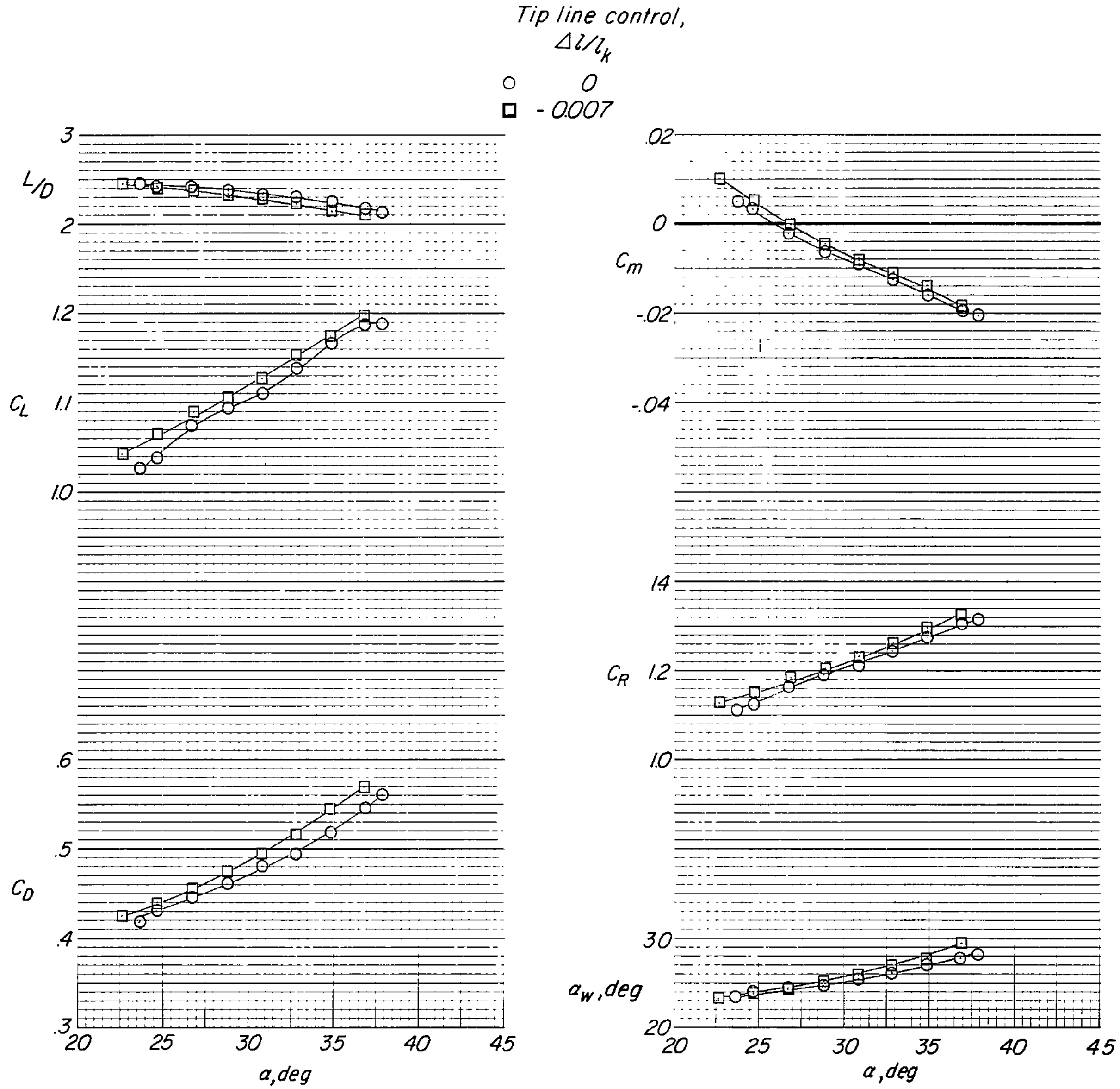


Figure 21.- Effect of tip-line control on the longitudinal aerodynamic characteristics of body 2 and the 7.87-ft (2.4 m) 45° swept parawing. Keel line shortened $0.015l_k$.

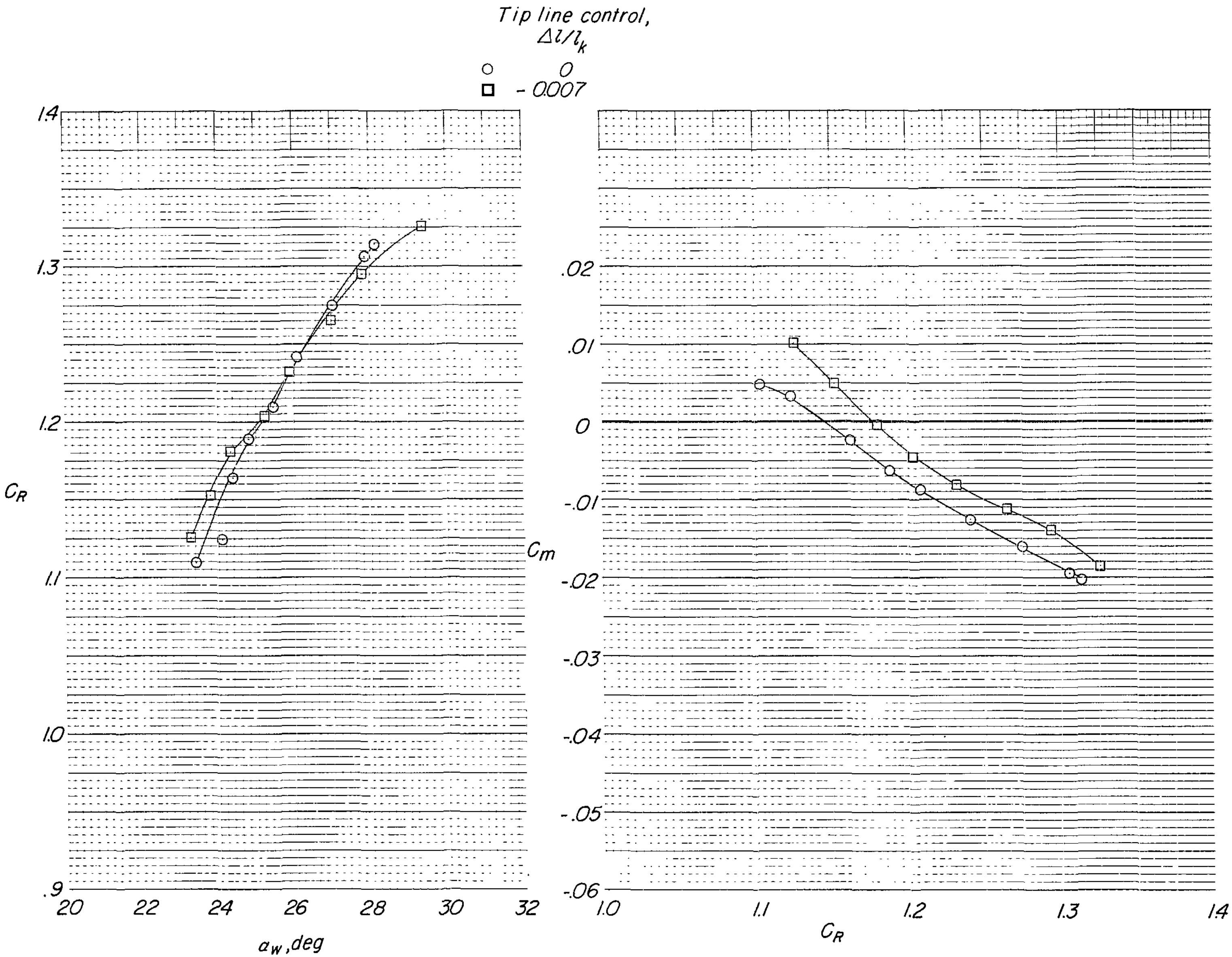
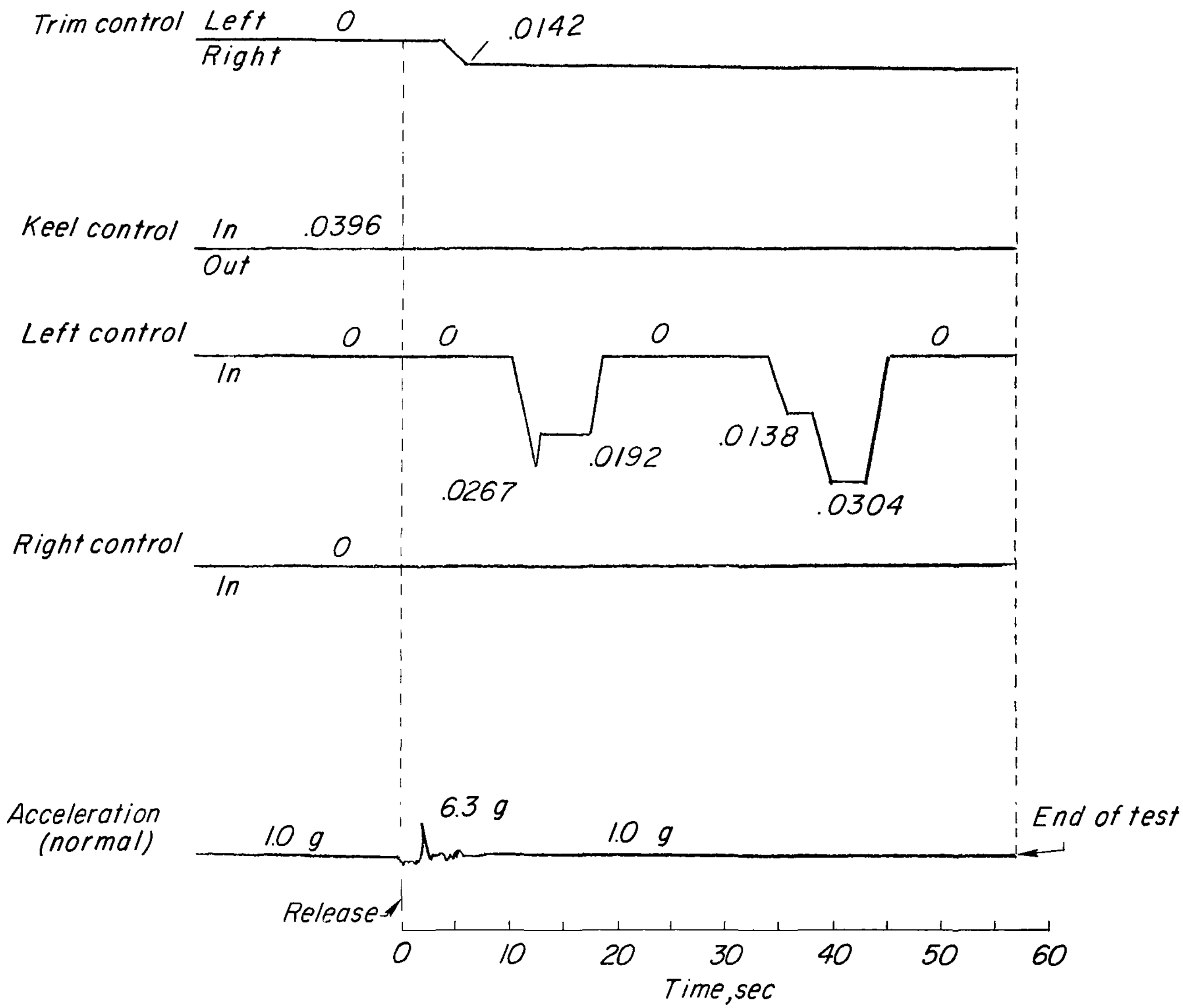
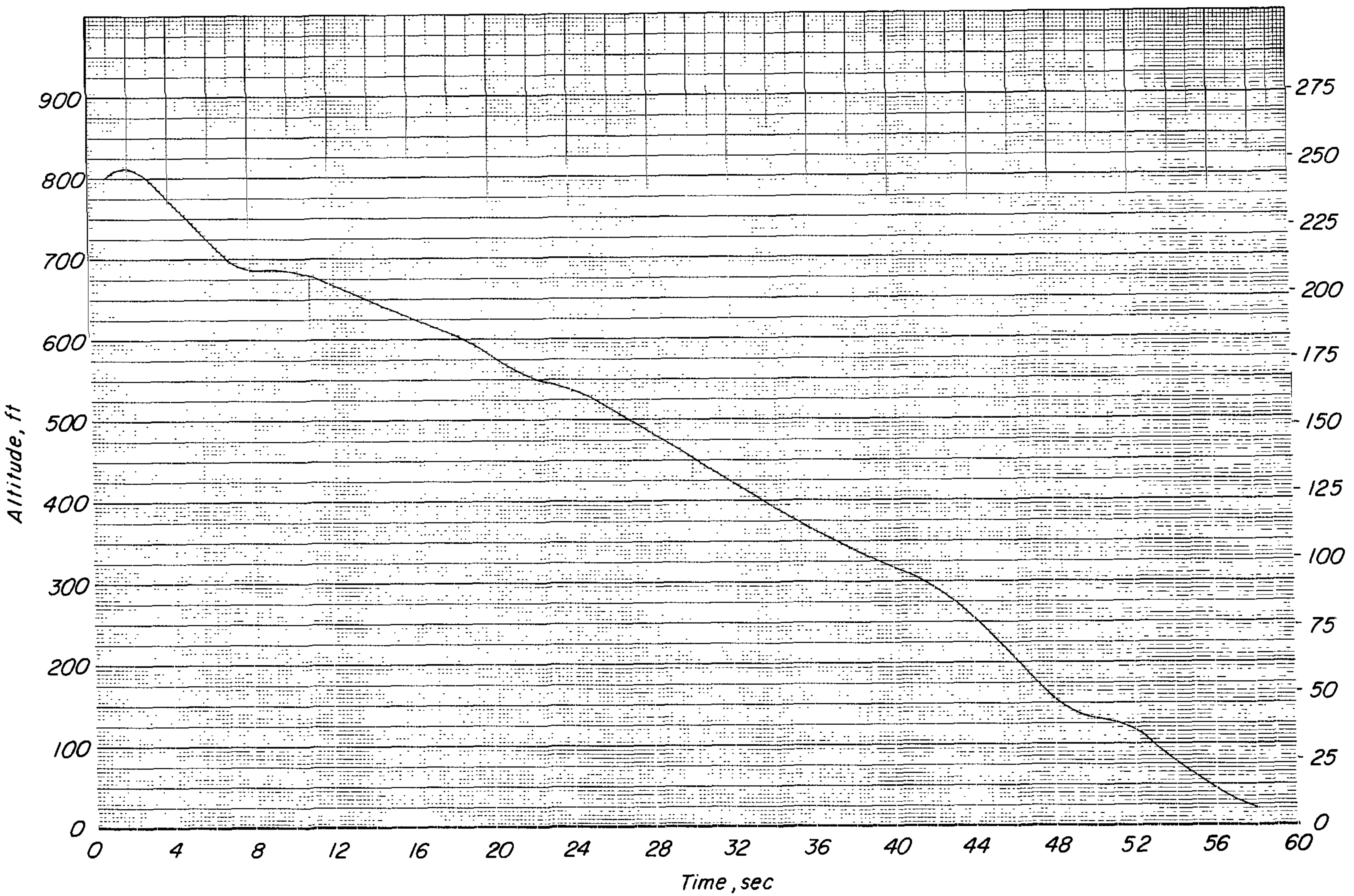


Figure 21.- Concluded.



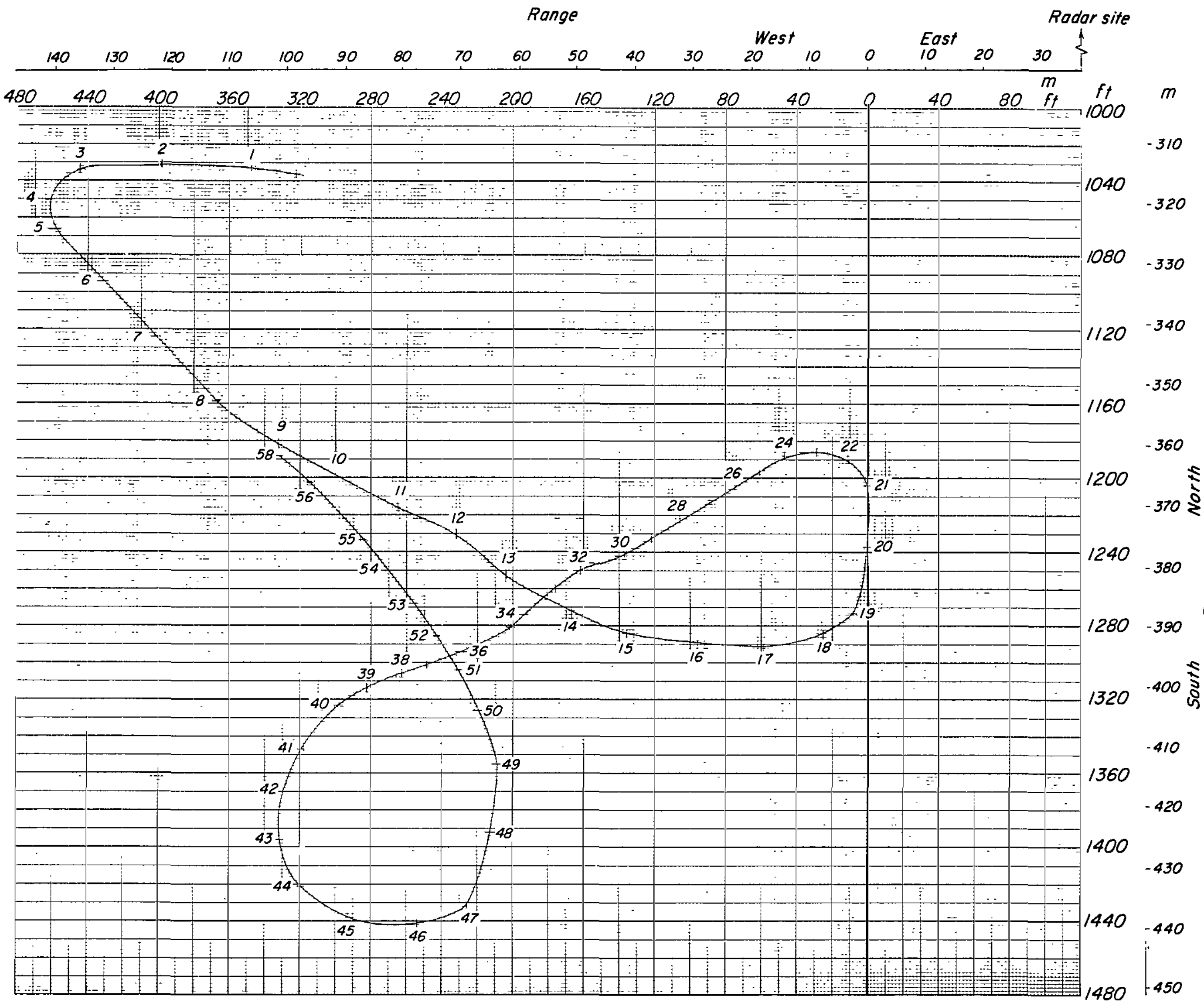
(a) Variation of control position, $\Delta l/l_k$, and vertical acceleration with time.

Figure 22.- Control inputs and trajectory for flight 163.



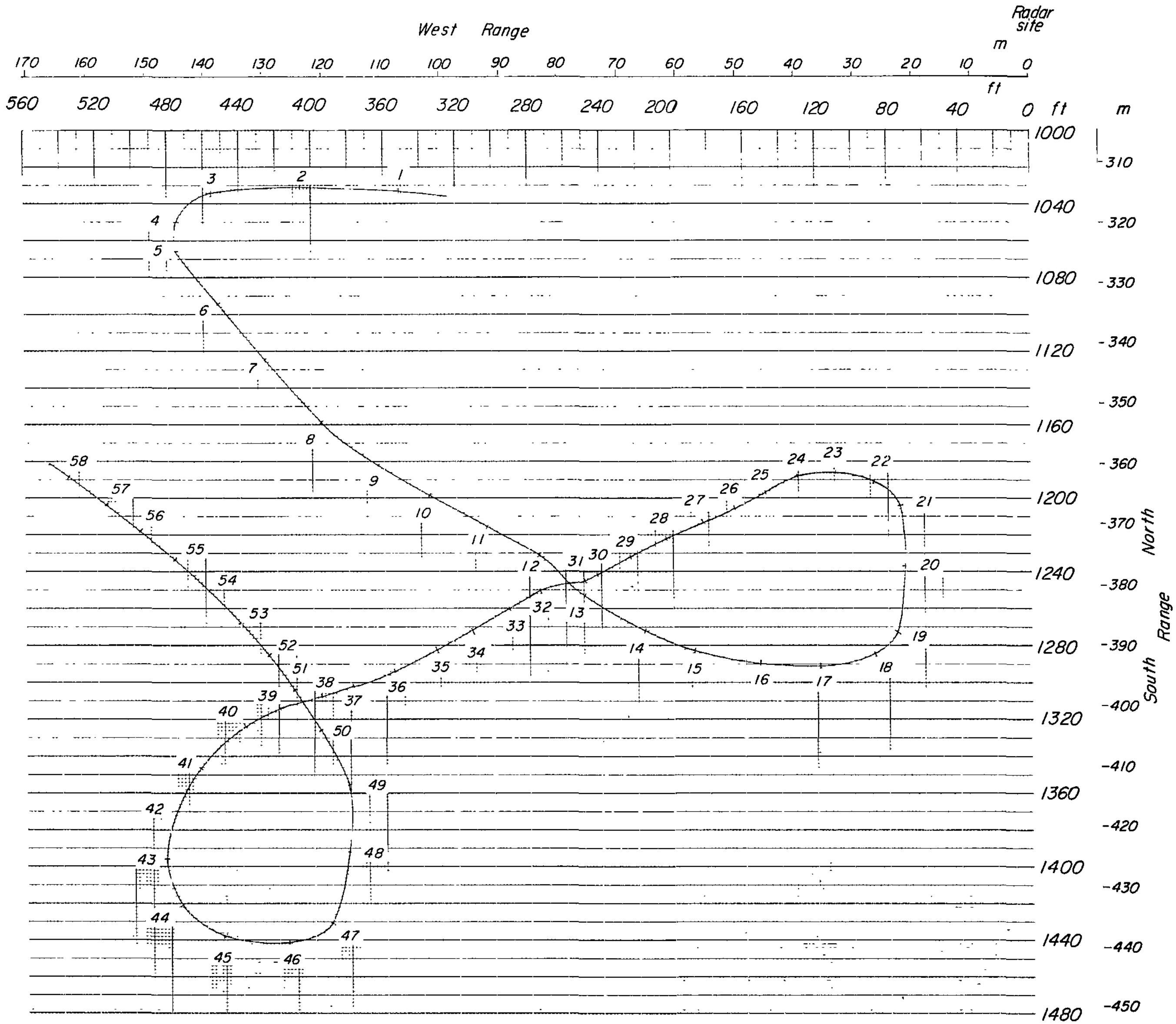
(b) Altitude as a function of time.

Figure 22.- Continued.



(c) Ground track. Flight time in seconds indicated on the curve.

Figure 22.- Continued.



(d) Ground track with the drift due to a 3.5-ft/sec (1.07 m/sec) west wind removed. Time in seconds indicated on the curve.

Figure 22.- Concluded.

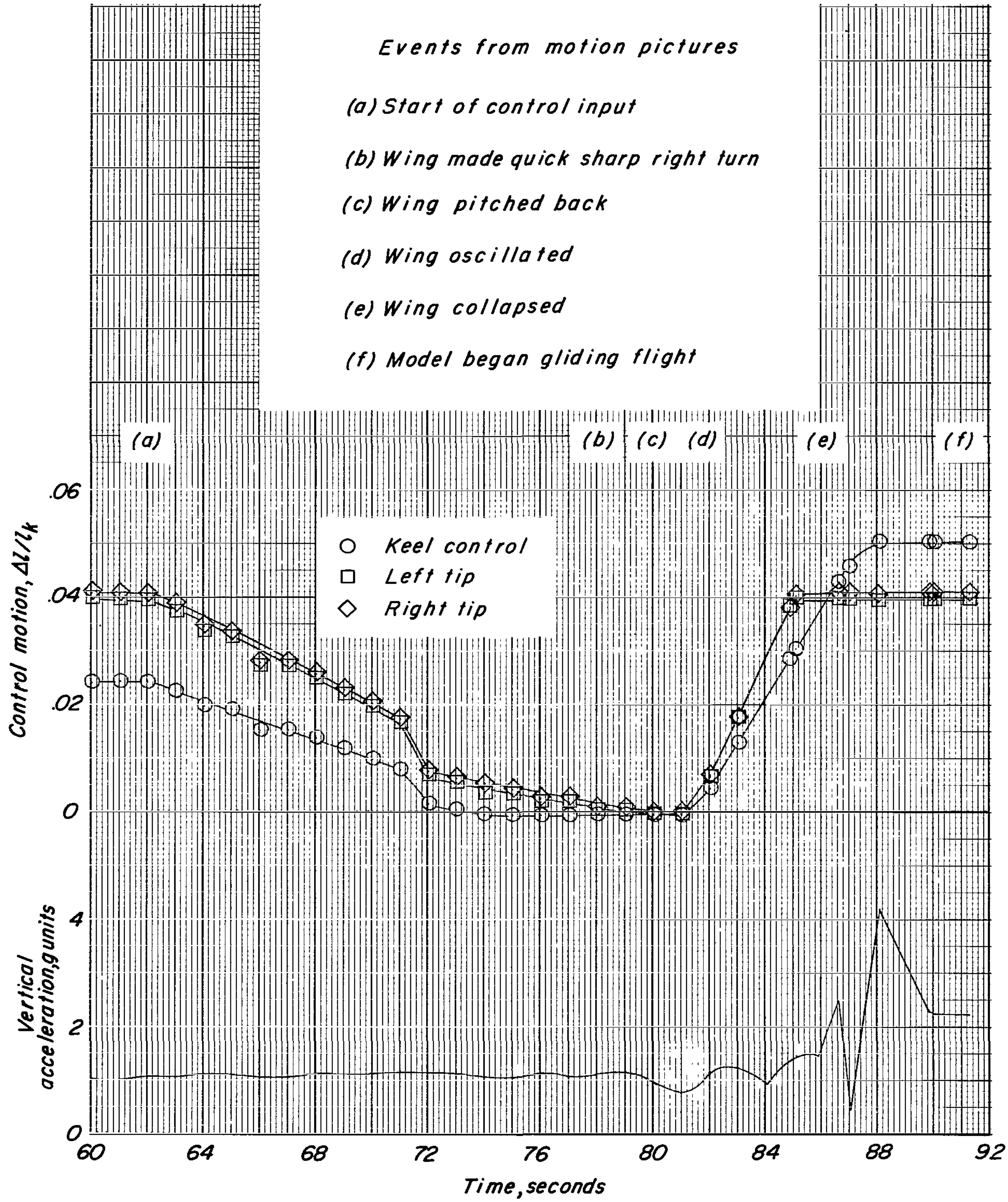


Figure 23.- Record of intentional stall induced in flight 137.

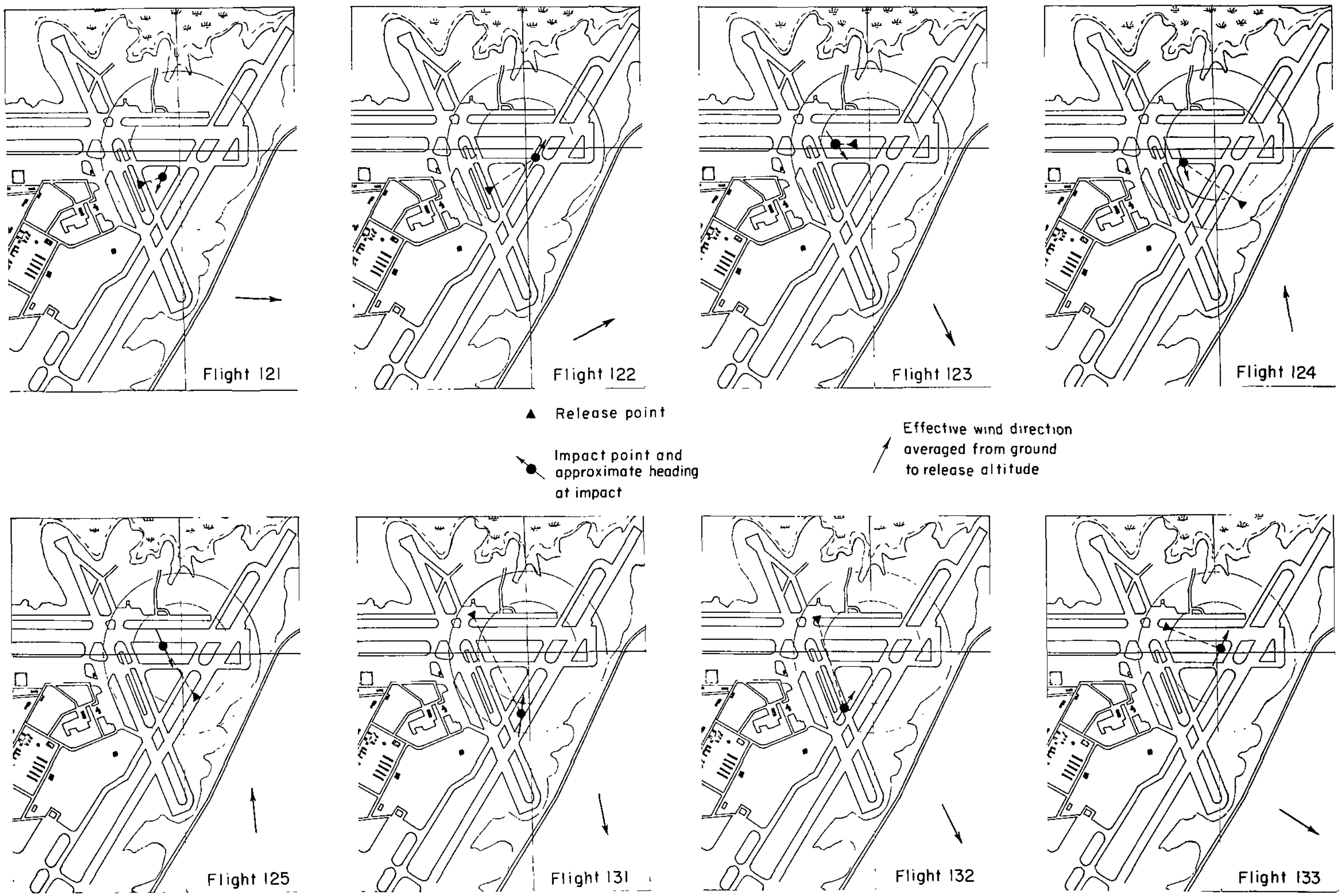


Figure 24.- Release and impact points for radio-controlled flights.

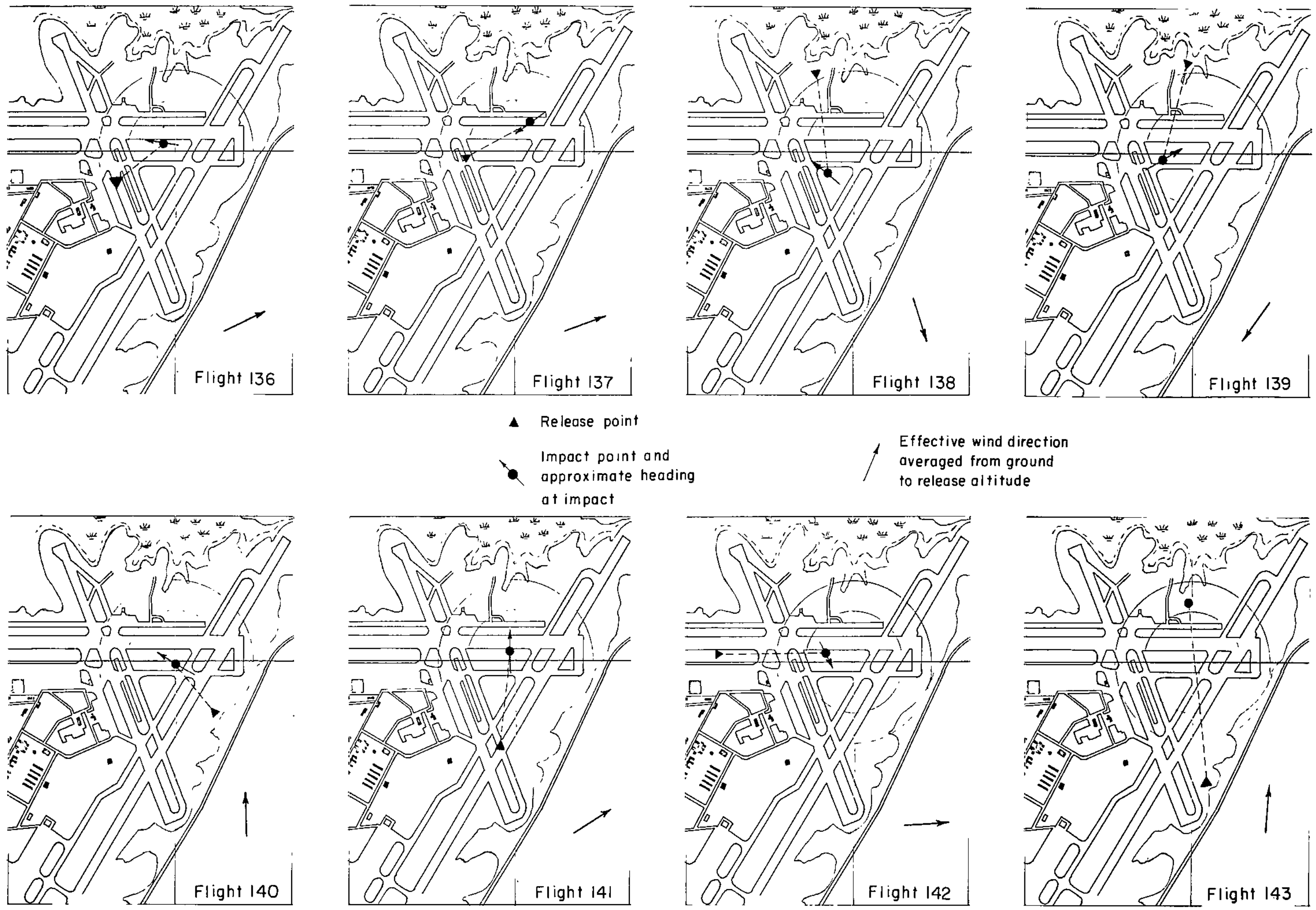


Figure 24.- Continued.

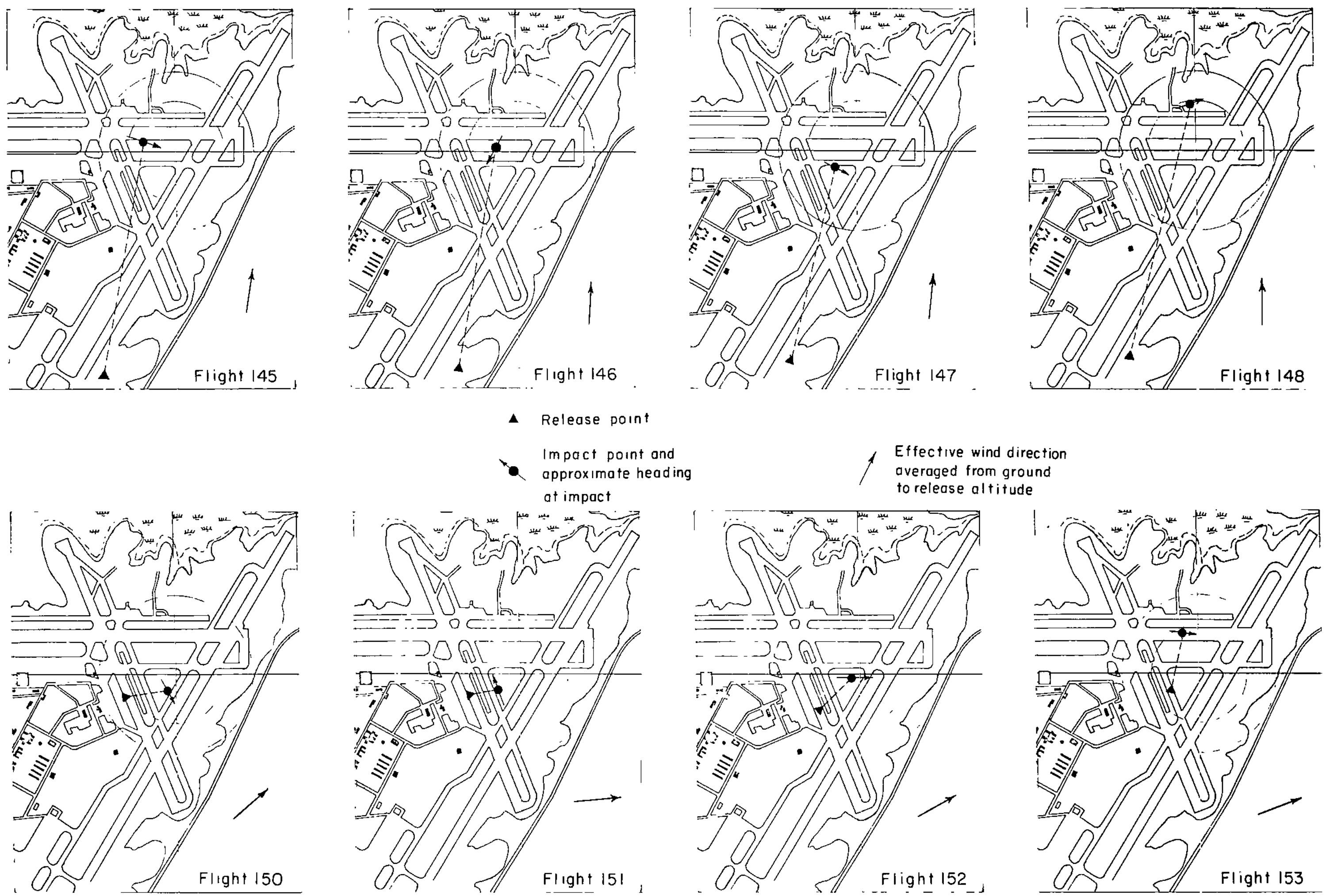


Figure 24.- Continued.

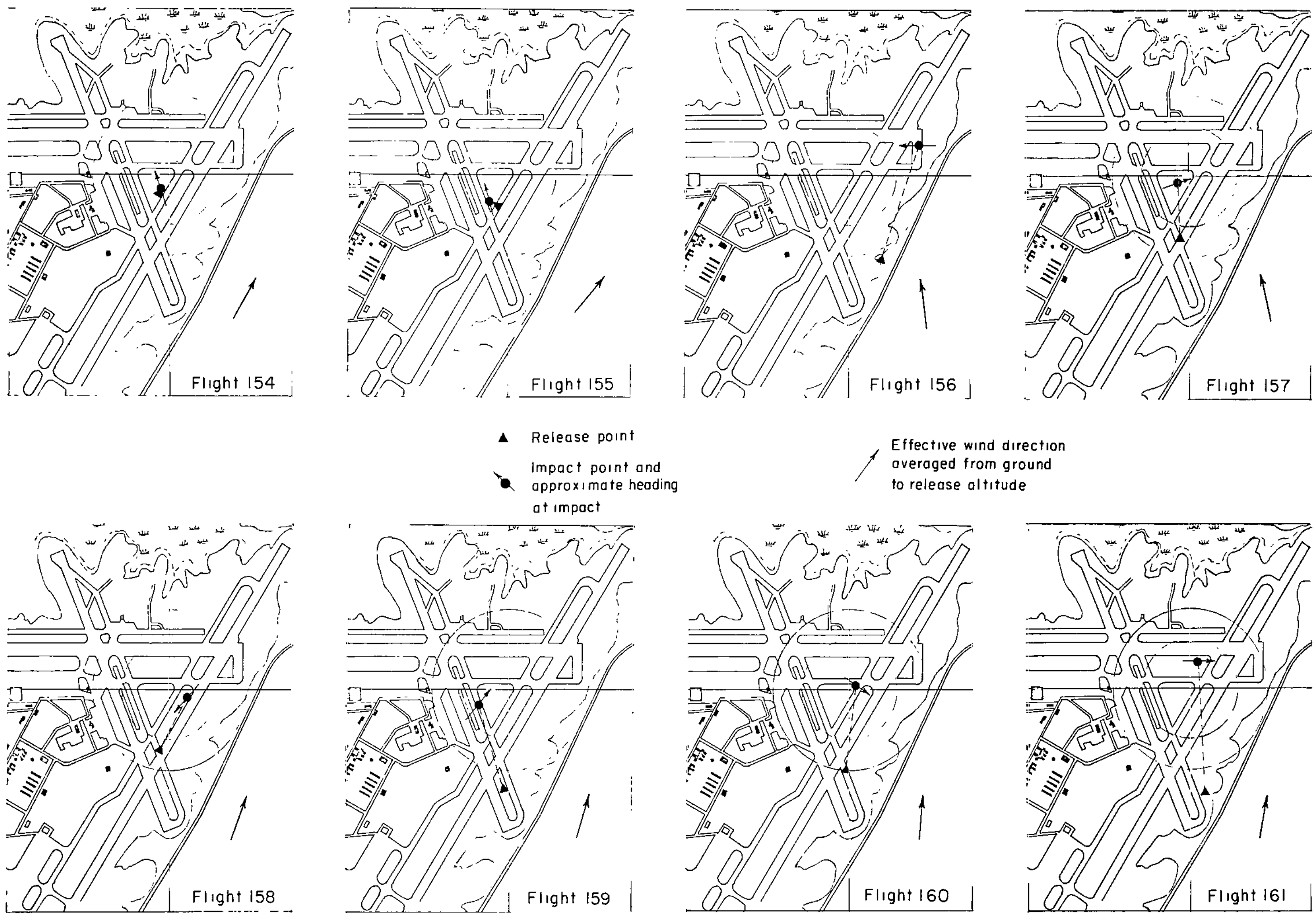


Figure 24.- Continued.

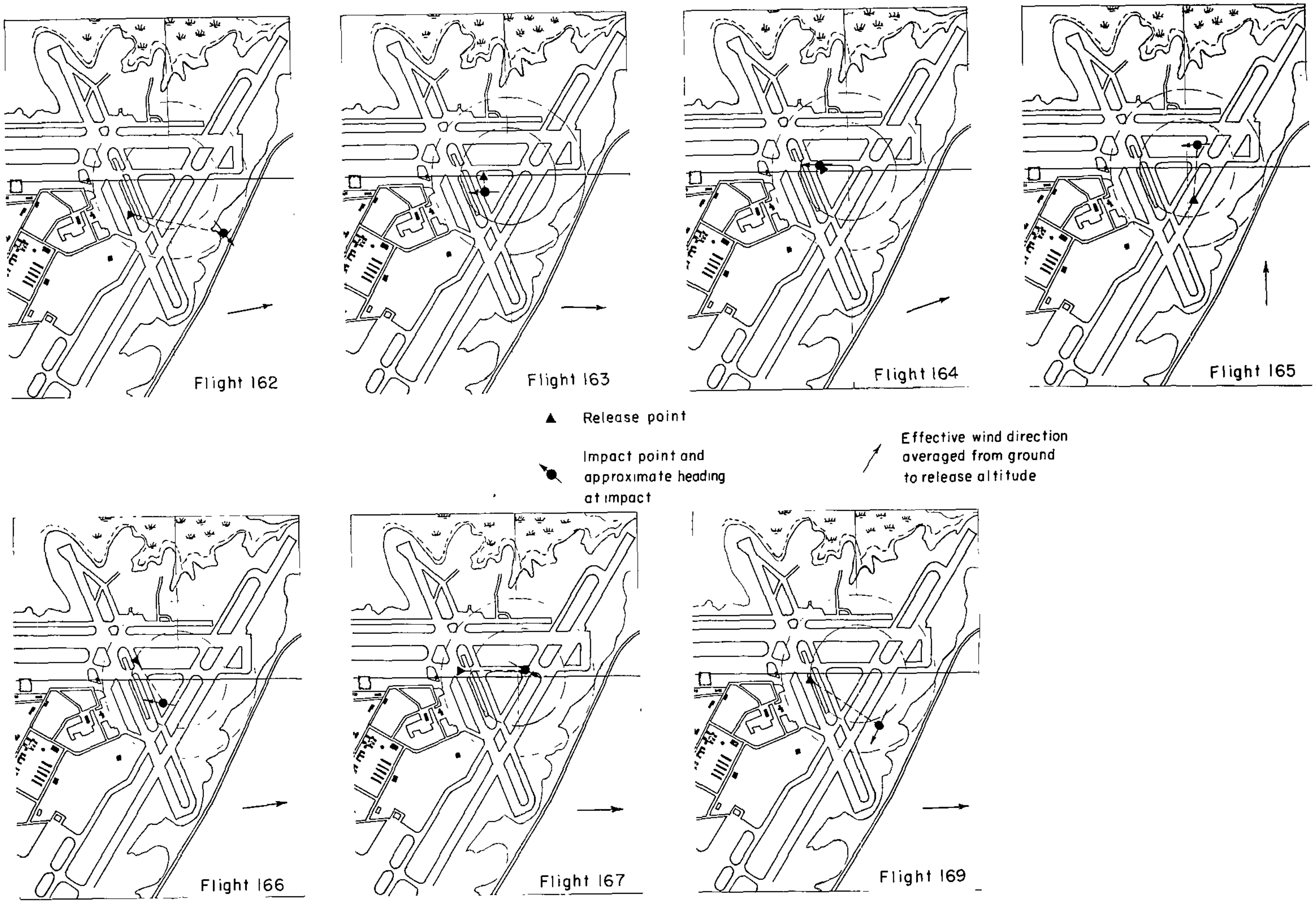


Figure 24.- Concluded.

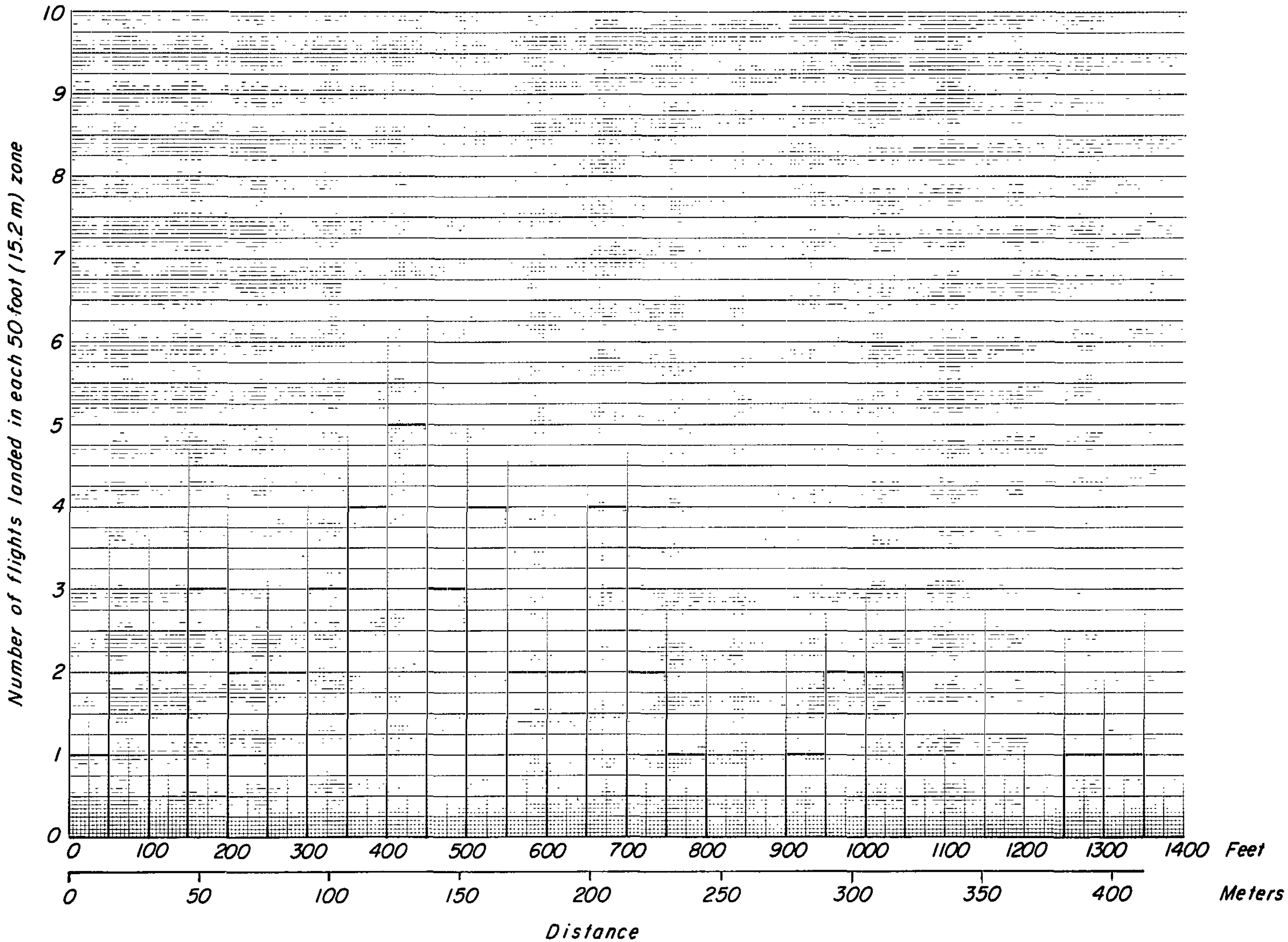


Figure 25.- Distribution of landings of the radio-controlled flight vehicle about the selected impact point.

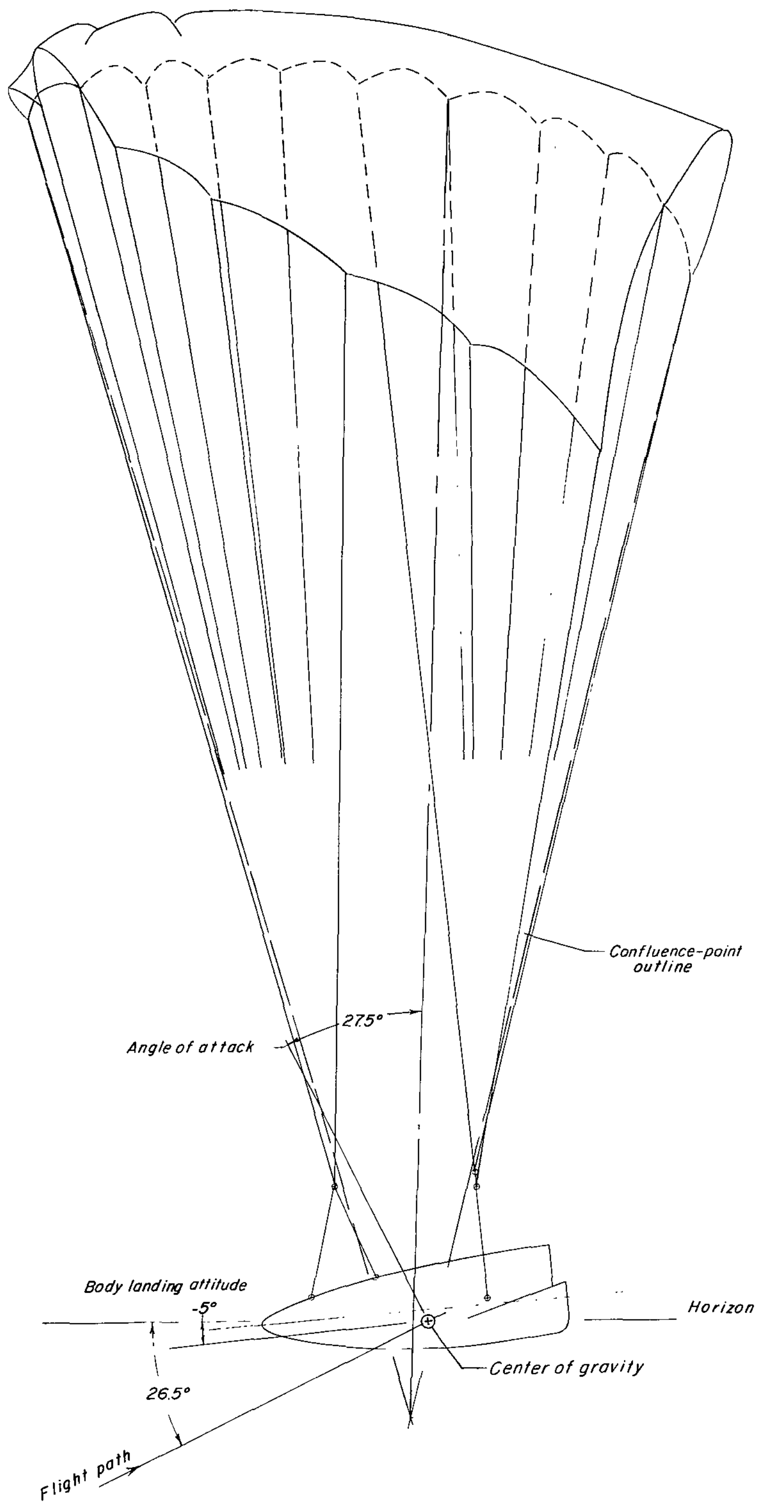


Figure 26.- Trial layout to adapt a confluence-point wing rigging to a body.

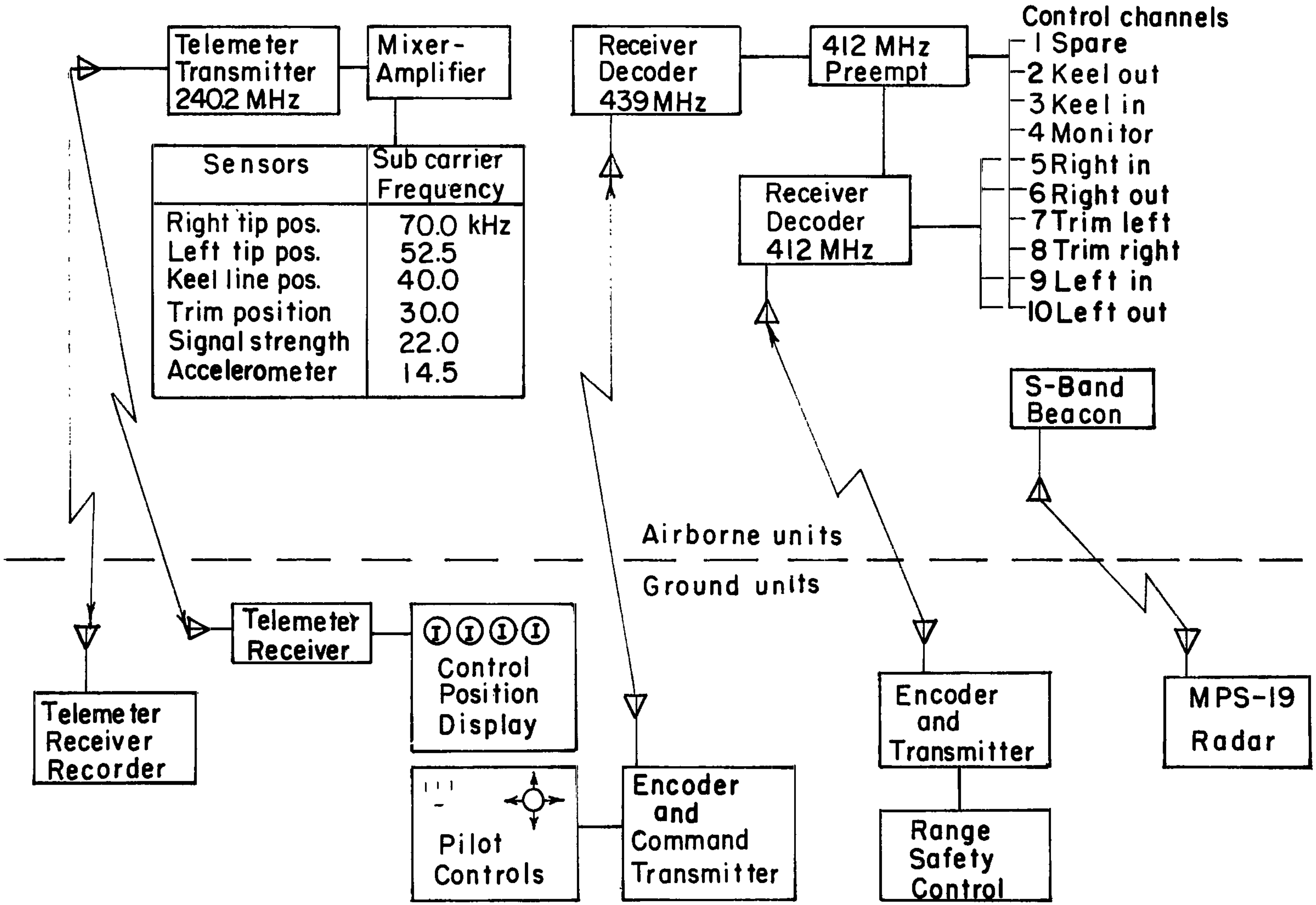


Figure 27.- Command and instrumentation schematic.

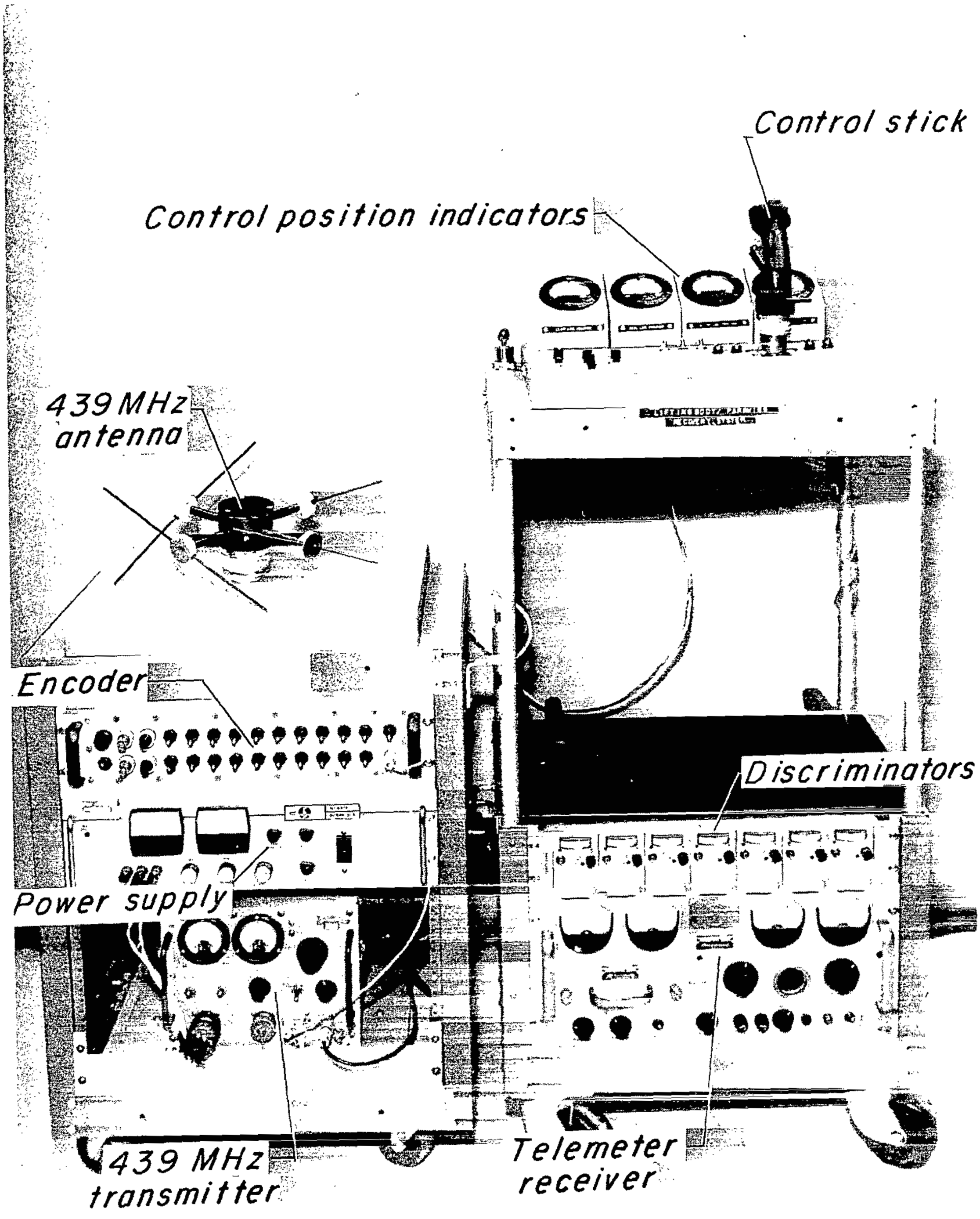
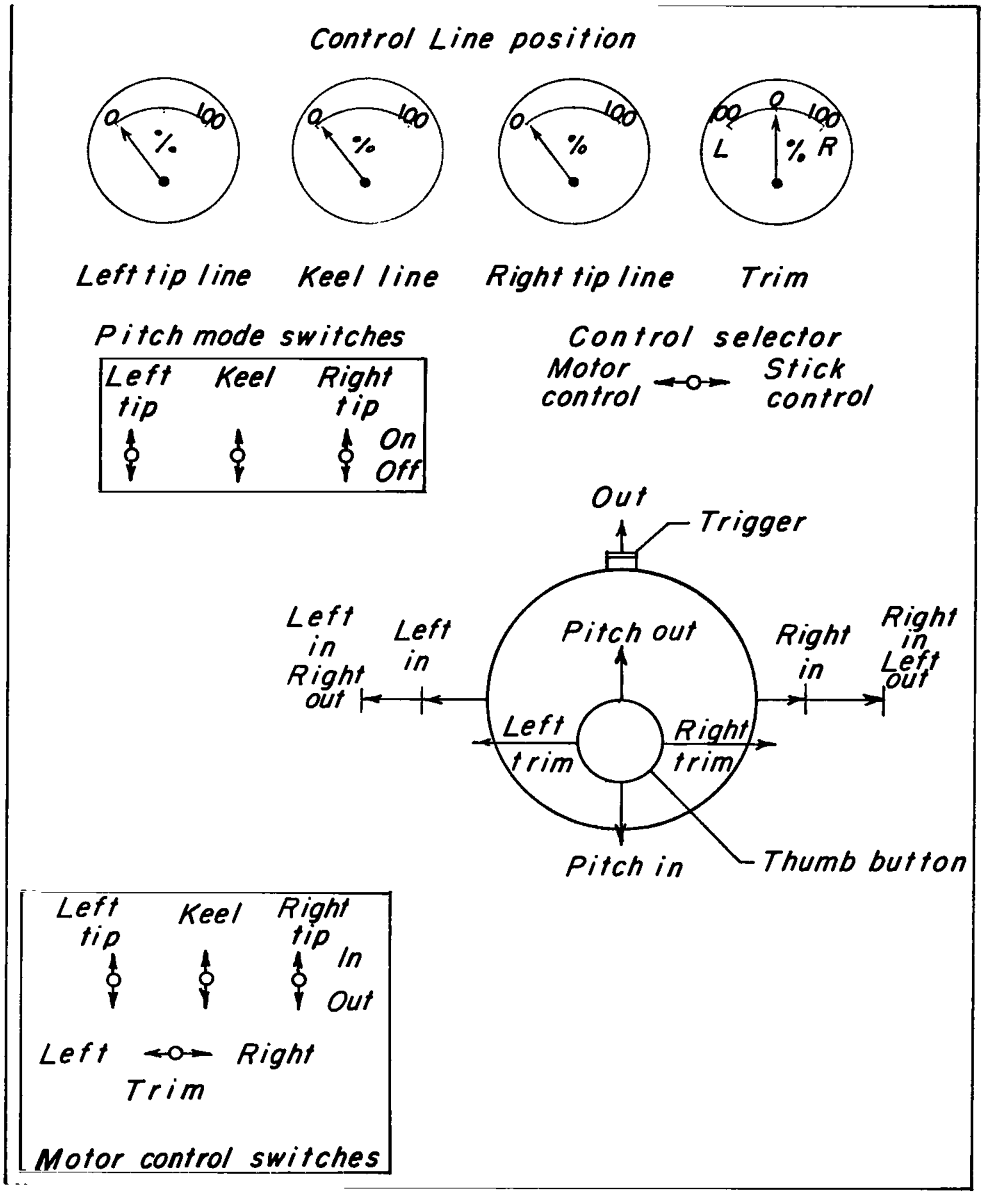


Figure 28.- Pilot control console for flight-vehicle tests. L-68-5761.1

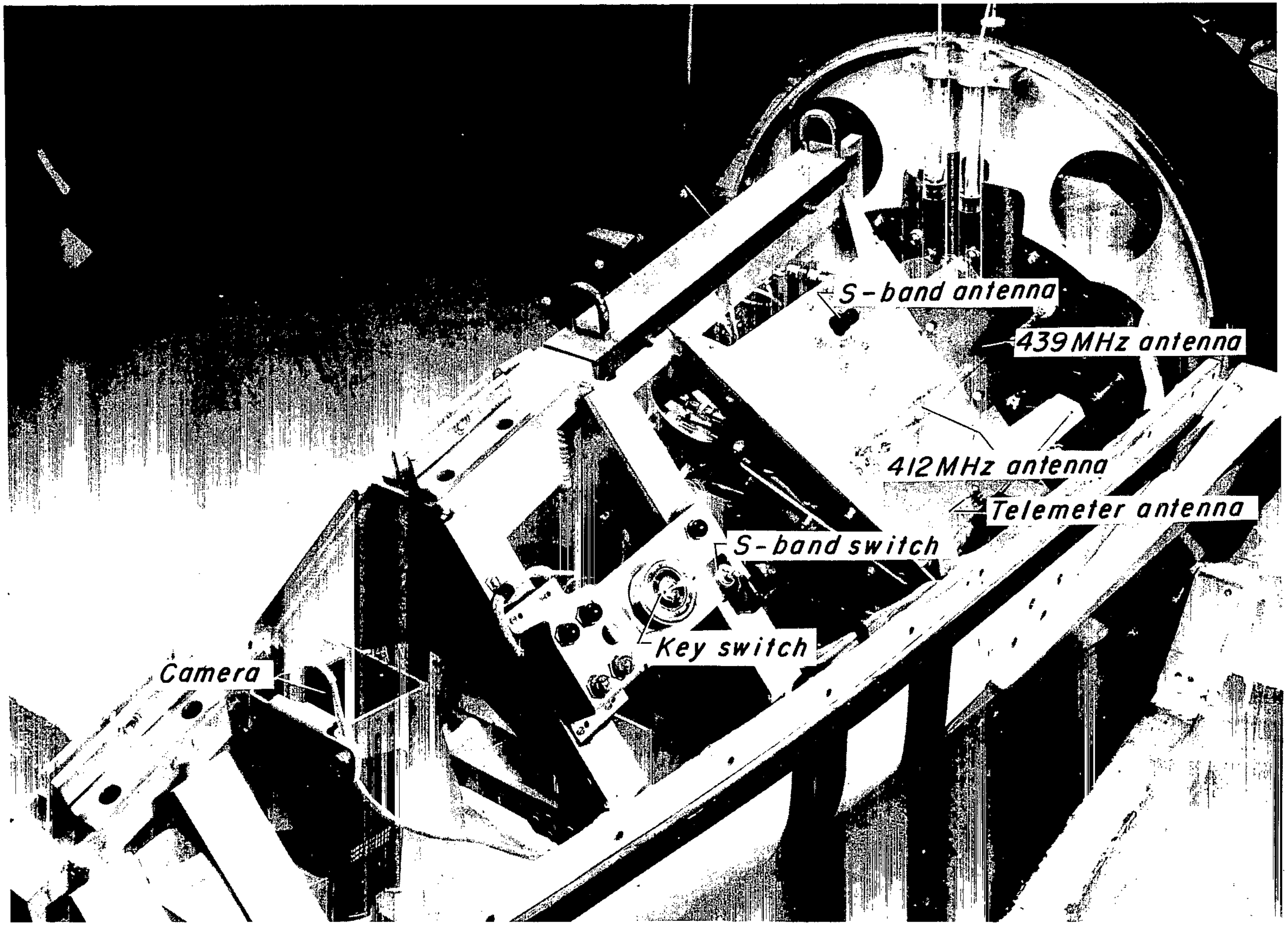


Notes: 1. Stick controls tip motors and moves only laterally.

2. Motors selected by mode switches are controlled by pitch switches on thumb button.

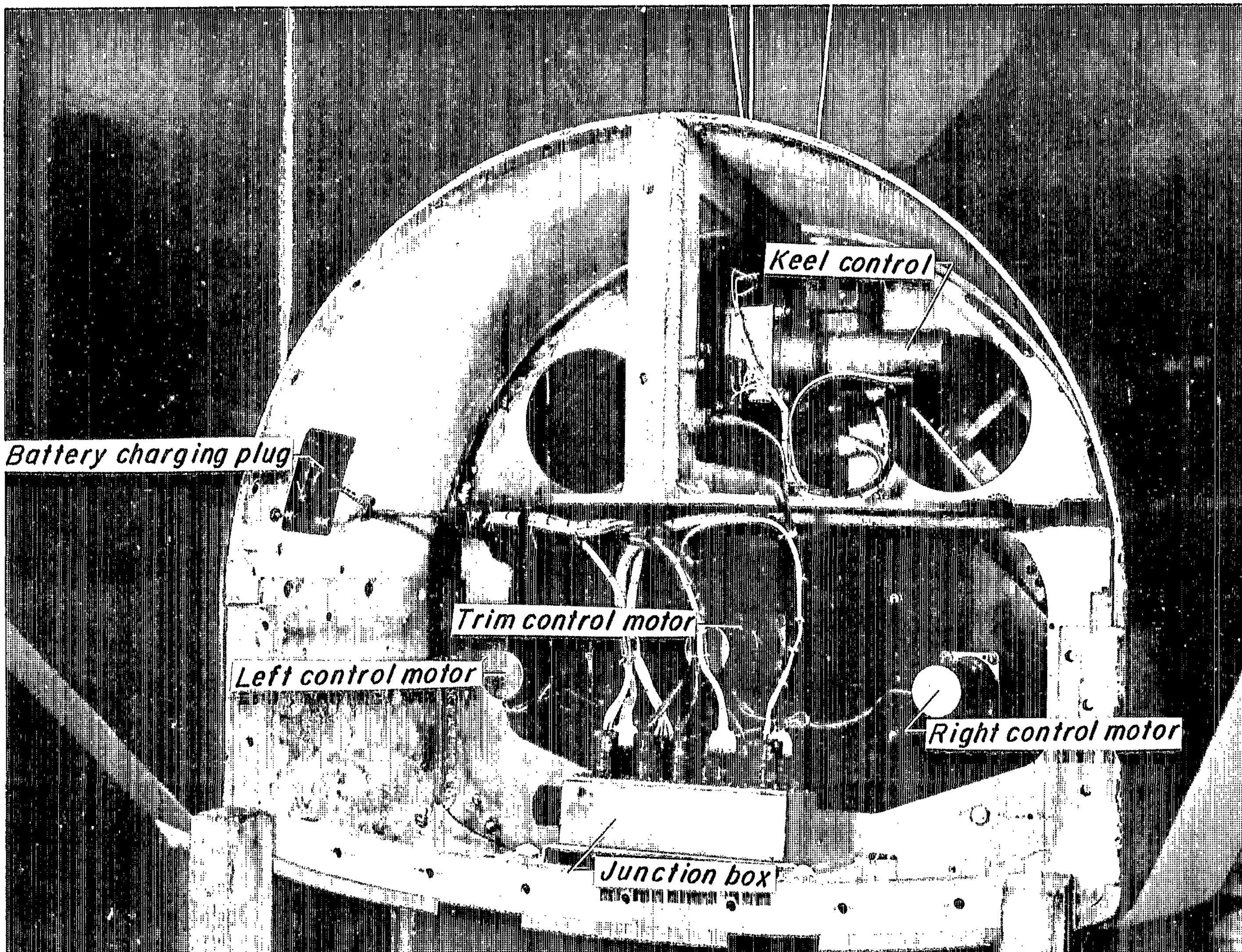
3. Squeezing trigger at neutral stick position returns tip lines to out stops. Sense of switch reversed after flight 148.

Figure 29.- Diagram of control console.



(a) Left side view. L-68-6812.1

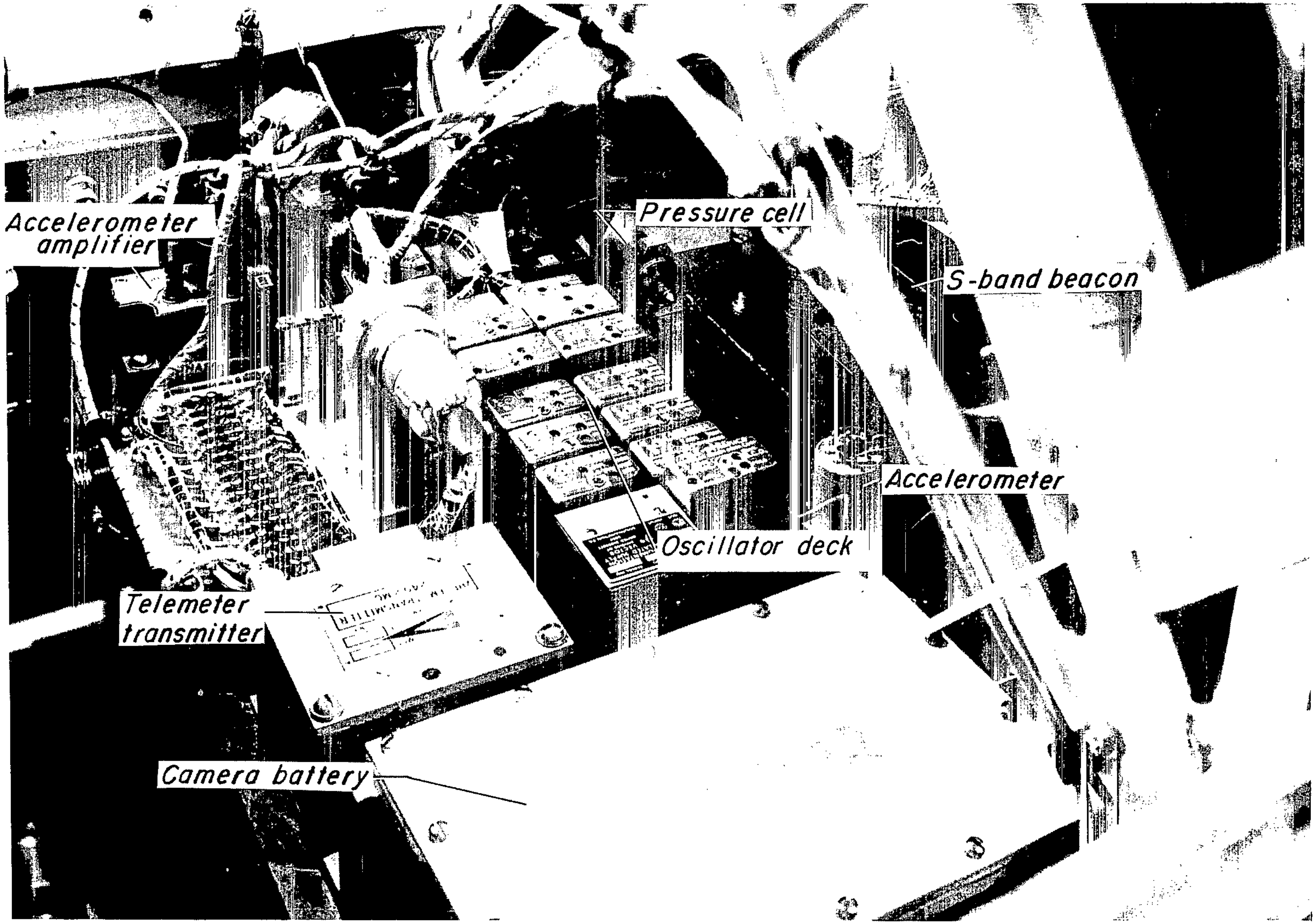
Figure 30.- Interior of body 3.



(b) Rear view.

L-68-6817 .1

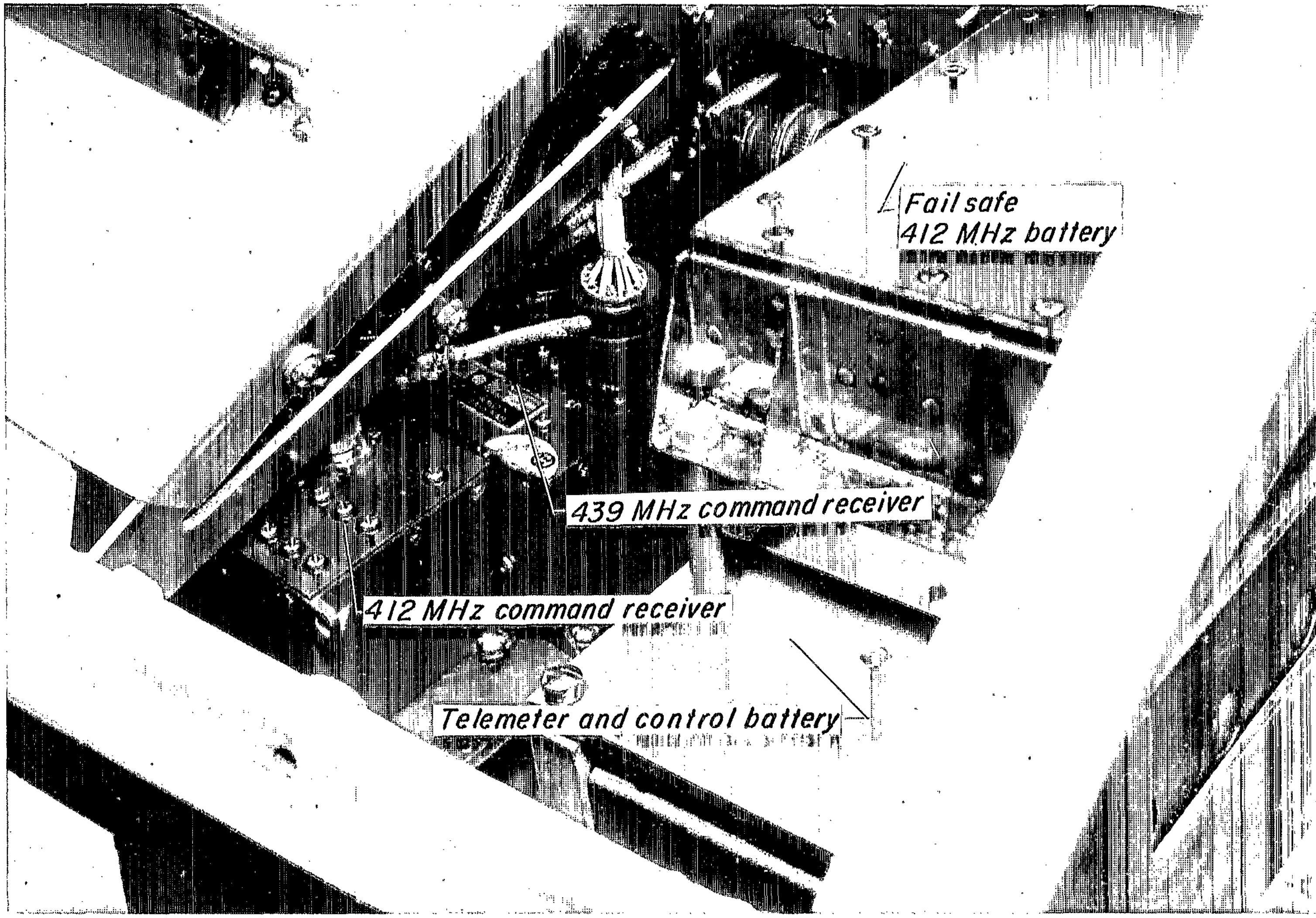
Figure 30.- Continued.



(c) Partial top view.

L-68-6816.1

Figure 30.- Continued.



(d) Partial side view. L-68-6813.1

Figure 30.- Concluded.

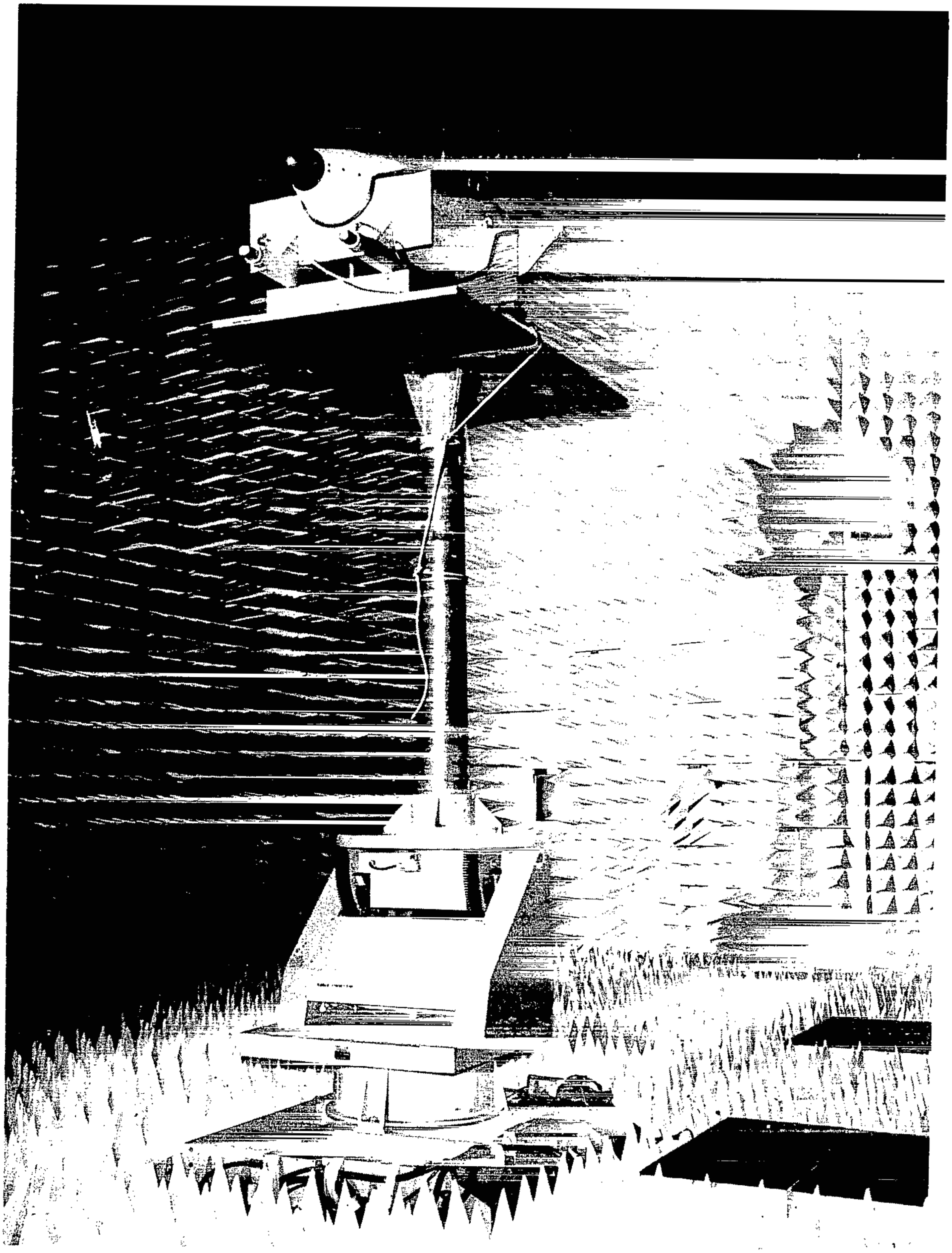
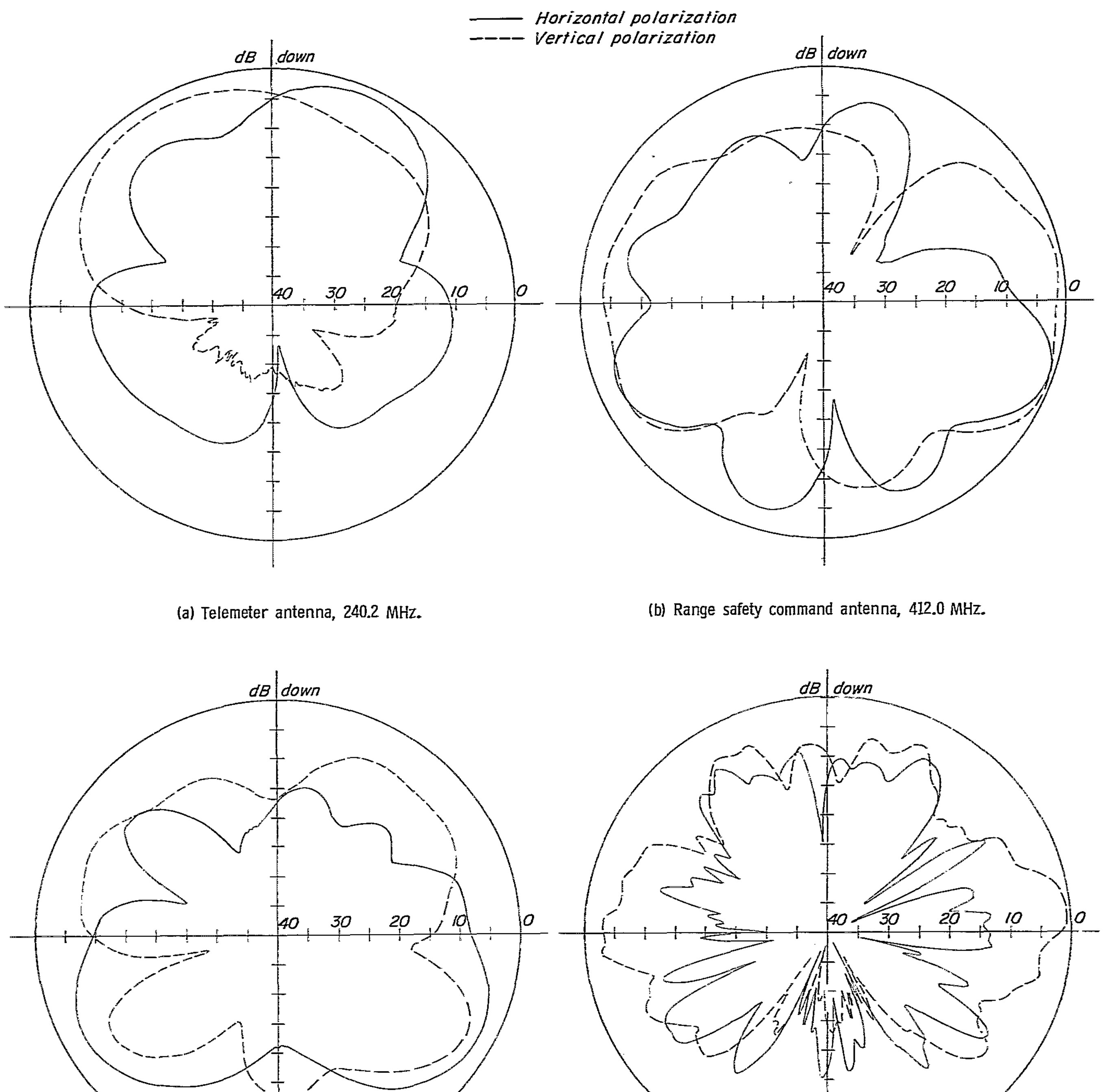


Figure 31.- Body 3 in position for radiation-pattern measurements. L-67-9801.1



(a) Telemeter antenna, 240.2 MHz.

(b) Range safety command antenna, 412.0 MHz.

(c) Radio control antenna, 439.0 MHz.

(d) Beacon antenna, 2800.0 MHz.

Figure 32.- Body 3 antenna radiation patterns. Isotropic level at 0 dB.

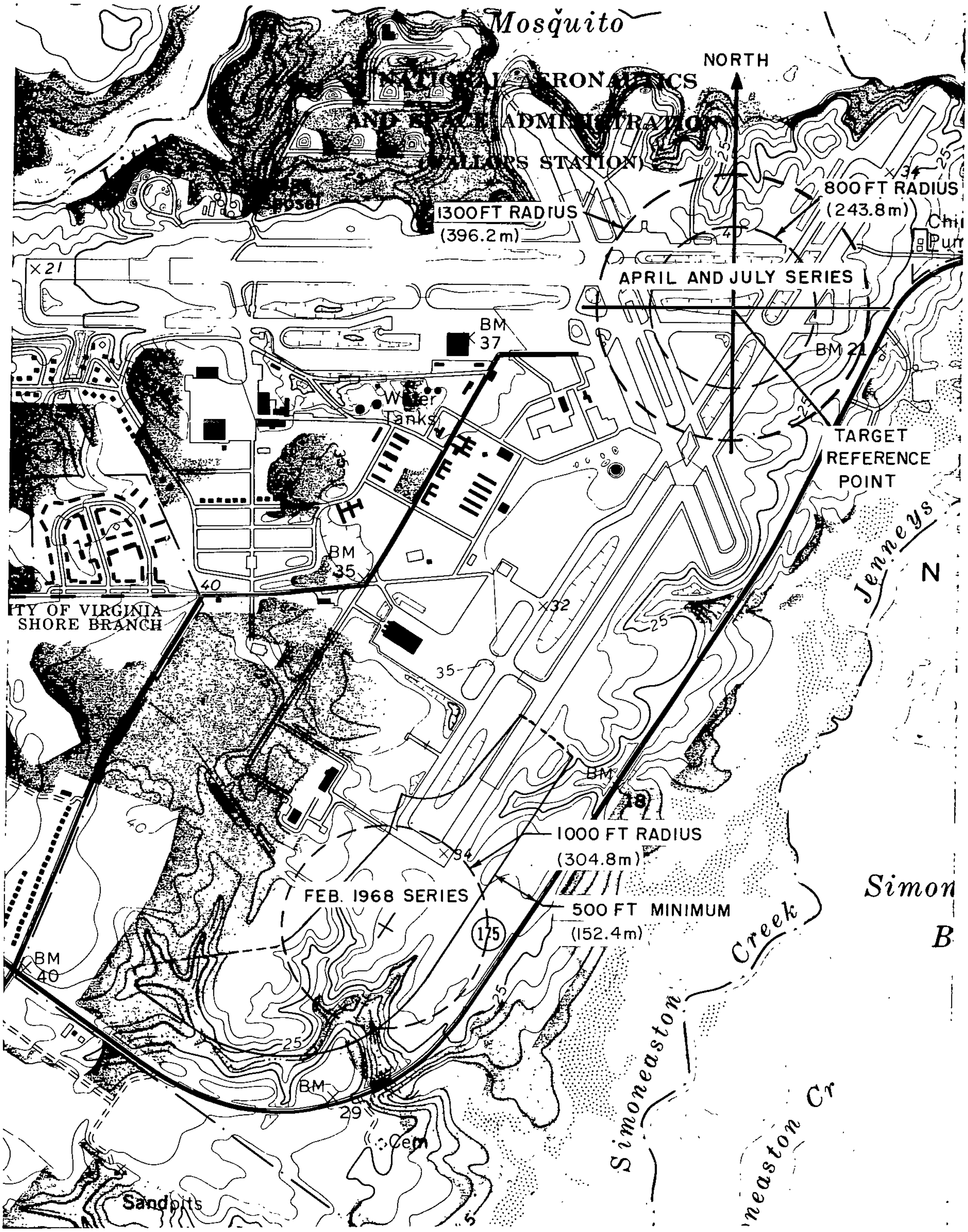


Figure 33.- Lifting-body parawing drop zones.

NASA-Langley, 1970 —— 2 L-6995

A motion-picture film supplement L-1014 is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The motion picture (16 mm, 15 min, color, silent) shows excerpts from the technical data film made at NASA Wallops Station. Types of parawing deployments after release of the body from the helicopter, flight maneuvers including turns and stall, and a selection of landings showing the body motions are presented. Deployment and stall are shown on film taken at a ground camera station and onboard the helicopter or the body model.

Requests for the film should be addressed to:

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Att: Photographic Branch, Mail Stop 171
Hampton, Va. 23365

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