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AERODYNAMIC AND DEPLOYMENT CHARACTERISTICS OF SINGLE-KEEL SOLID AND SINGLE-KEEL SLOTTED PERSONNEL PARAWINGS

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16. Abstract

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SUMMARY

Wind-tunnel and free-flight tests were performed to determine the gliding-flight and deployment characteristics of single-keel solid and single-keel slotted parawings of suitable size for use in personnel recovery systems. The low-speed wind-tunnel tests of a 29.8-ft^2 (2.77-m^2) solid and a 34.3-ft^2 (3.19-m^2) slotted parawing showed that both wings had almost identical maximum lift-drag ratios and modulations of lift-drag ratio and that the slotted wing had slightly lower values and less modulation of resultant-force coefficient than the solid wing. Free-flight deployment tests of 276.5-ft^2 (25.69-m^2) solid and 375.0-ft^2 (34.84-m^2) slotted personnel parawings equipped with 235-pound (1045-newton) torso dummies showed that the maximum deployment loads were lower and the canopy inflation times were longer for the slotted wing than for the solid wing over a range of pack opening velocities from 168.8 to 337.6 ft/sec (51.5 to 103.0 m/sec). Both wings had a structural failure at a pack opening velocity of 303.8 ft/sec (92.6 m/sec). A comparison of the deployment loads of the two personnel parawings and a currently used personnel parachute showed that the parawings had much greater deployment loads than the parachute.

INTRODUCTION

The parachute deceleration and descent devices used with existing aircraft escape systems generally perform well and are quite reliable. Recently, however, there has been interest in advanced escape systems for low-altitude, high-speed egress with the added capabilities of steering and glide for high-altitude egress. Wind-tunnel and free-flight tests conducted by the National Aeronautics and Space Administration have indicated that the all-flexible parawing has good inherent stability when properly rigged, good directional control capability, and reliable opening characteristics, which make it a possible candidate for advanced personnel descent systems. Of particular interest has been the suitability of the all-flexible parawing as a replacement for the parachutes used in current aircraft escape systems. The results of several early research investigations of the glide performance and deployment characteristics of several all-flexible parawings are presented in references 1 to 5.

The present investigation was undertaken to determine the gliding-flight and deployment characteristics of two single-keel parawings of suitable size for use in personnel recovery systems. One configuration had a solid canopy, and the other had a slotted (geometrically porous) canopy. The slotted canopy was designed with the intent of lowering deployment loads without an appreciable loss in lift-drag ratio and resultant-force coefficient.

The static longitudinal aerodynamic characteristics were determined from tests of a 29.8-ft^2 (2.77-m^2) solid and a 34.3-ft^2 (3.19-m^2) slotted parawing in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel. Free-flight deployment tests of 276.5-ft^2 (25.69-m^2) solid and 375-ft^2 (34.84-m^2) slotted personnel parawings equipped with 235-pound (1045-newton) torso dummies were made at the Department of Defense Joint Parachute Test Facility at El Centro, California. The personnel parawings were tested through a deployment speed range of 168.8 to 337.6 ft/sec (51.5 to 103.0 m/sec).

SYMBOLS

The force and moment coefficients determined from the wind-tunnel tests are presented with respect to the wind axes. The positive directions of the forces, moment, and angle used in the presentation of the data are shown in figure 1. The moment reference center of the model was located at the confluence of the suspension lines held by the line clamping block, as shown in figure 2. The reference areas used in the reduction of the wind-tunnel data were the flat-pattern canopy areas of 29.8 and 34.3 ft^2 (2.77 and 3.19 m^2) for the solid and slotted wings, respectively. The reference chord lengths were taken as the flat-pattern keel lengths minus the nose cutoff lengths and were 5.74 and 5.43 feet (1.75 and 1.66 meters) for the solid and the slotted wings, respectively. Values are given in U.S. Customary Units and parenthetically in the International System of Units.

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_R resultant-force coefficient, $\sqrt{{C_L}^2 + {C_D}^2}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSc}$

c reference chord length, ft (m)

L/D lift-drag ratio

l canopy suspension-line length, ft (m)

l_k flat-pattern keel length, ft (m)

q free-stream dynamic pressure, lb/ft^2 (N/m^2)

S reference area, ft^2 (m^2)

V free-stream velocity, ft/sec (m/sec)

x_k distance along keel of canopy flat pattern, ft (m)

x_{le} distance along leading edge of canopy flat pattern, ft (m)

α_w wing angle of attack as measured from vertical to a specified keel line, deg (see fig. 1)

Subscripts:

tip wing-tip control line

keel aft-keel control line

p pack opening

DESCRIPTION OF MODELS

The flat-pattern planform details of the single-keel solid and the single-keel slotted parawings are presented in figures 3(a) and 3(b), respectively. The solid parawing had a 45° flat-pattern sweep, leading edges and keel of equal lengths, and a straight nose cut equal to one-eighth of the keel length. The flat-pattern planform of the slotted parawing was one-quarter of a circle with a rounded nose and a keel length equal to the radius of the circle. The slotted wing canopy consisted of 14 gores, each having one nose panel and five additional panels with a slot between the trailing edge of one panel and the leading edge of the next. The design philosophy of the slot was to regulate the filling progression by venting the high internal pressures within the parawing during deployment and to improve the flight performance by reducing flow separation on the upper wing surface during gliding flight. Both material and geometric (slot area) porosity varied as a function of chordwise location which provided increasing effective porosity from nose to trailing edge of each gore.

The solid parawing used in the tunnel tests had a keel length of 6.56 feet (2.00 meters) and a canopy area of 29.8 ft^2 (2.77 m^2). The slotted parawing used in the tunnel tests had a keel length of 6.79 feet (2.07 meters) and a canopy area of 34.3 ft^2 (3.19 m^2). Both wings were constructed of nonporous, 0.75 oz/yd^2 (25.4 g/m^2) nylon rip-stop material. The slotted wing was not an exact scale model of the slotted personnel parawing because it was constructed entirely of nonporous materials. The use of nonporous materials was necessary because of the nonavailability of lightweight nylon materials with the permeabilities listed in the table in figure 3(b). Both wings were rigged with 135-pound-test (600-newton) dacron line. This line had low-stretch characteristics which reduced the time required to measure and then to correct the line lengths for the effects of elongation during the tests.

The solid personnel parawings used in the free-flight tests had keel lengths of 20 feet (6.10 meters) and canopy areas of 276.5 ft^2 (25.69 m^2). The slotted personnel parawings had keel lengths of 22.5 feet (6.86 meters) and canopy areas of 375.0 ft^2 (34.84 m^2). It was more desirable to test solid and slotted personnel parawings with equal canopy areas to avoid any differences in the free-flight test results which may have been caused by a difference in wing loading. The personnel parawings tested were procured from commercially available stock which necessitated the difference in canopy area of the solid and the slotted wings. Both the solid and the slotted personnel parawings were constructed of 2.25 oz/yd^2 (76.3 g/m^2) nylon rip-stop material. Nonporous materials were used in the construction of the solid wings, and porous materials with the permeabilities listed in the table in figure 3(b) were used for the slotted wings. The solid personnel parawings were rigged with 1000-pound-test (4448-newton) nylon line except the wing-tip and aft-keel control lines which were 1500- and 2000-pound-test (6672- and 8896-newton) nylon line, respectively. The slotted personnel parawings were rigged with 1000-pound-test (4448-newton) nylon line for leading-edge suspension lines 1 to 5 and keel suspension lines 1 to 3 (leading-edge line 1 and keel line 1 are located at the attachment points nearest the wing apex), 1500-pound-test (6672-newton) nylon line for the wing-tip control lines and keel suspension lines 4 to 6, and 2000-pound-test (8896-newton) nylon line for the aft-keel control line. After each test of a personnel wing, the line lengths were measured and corrected, when necessary, to insure trim flight during the next test.

TEST PROCEDURES

Wind-Tunnel Tests

Model-size solid and slotted parawings were tested in the wind tunnel to determine their static longitudinal aerodynamic characteristics. Although models tested in free flight had a suspension system with a single confluence point, the suspension system of the models tested in the wind tunnel had to be modified to maintain the models upright in the tunnel. In order to obtain tunnel data, the single-confluence-point suspension system was modified by moving the balance attachment points of the wing-tip control lines outboard to stabilize the model in roll attitude. The attachment points of the wing-tip and aft-keel control lines were also moved rearward to augment the stability of the model in pitch attitude. Since the models were attached to a stationary force-measuring system, this type of testing is referred to as tethered testing. The dimensions of the wing-balance attachment apparatus (T-bar) are given in figure 2.

The aft-keel and the wing-tip control-line lengths were adjusted to set the model attitude relative to the wind direction. Data were taken through a wing angle-of-attack range which was usually limited at the low end (highest lift-drag ratio) by the angle for partial nose collapse and at the high end by the angle at which excessive longitudinal and lateral oscillations occurred. Tests were run on each model at several values of free-stream dynamic pressure to simulate the effects of an increase in wing loading on gliding-flight performance.

The tests were performed in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel at dynamic pressures of 0.5, 1.0, and 2.0 lb/ft^2 (23.9, 47.9, and 95.8 N/m^2). Force measurements were taken with a six-component strain-gage balance. Jet-boundary corrections to the wing angle of attack and drag coefficients, as determined from reference 6, were applied to the test data. Inasmuch as the ratio of wing area to cross-sectional area of the test section was relatively small, no blockage corrections were applied to the test data.

Free-Flight Tests

The solid and the slotted personnel parawings were tested in free flight at the Department of Defense Joint Parachute Test Facility at El Centro, California. This site was chosen for the free-flight tests because of the availability of adequate support personnel, launch facilities, and measuring, recording, and tracking equipment. (Complete descriptions of the test facilities at El Centro are given in ref. 7.) The bulk of the deployment tests were performed on the Whirl Tower, which provided a fast and economical method of testing. A photograph of the Whirl Tower is presented in figure 4. The first step in the operation of the Whirl Tower consisted of loading the parawing drop assembly into a streamlined gondola which was attached by a cable to the Whirl Tower boom. The gondola was then whirled until it had attained the precise release velocity. At a predetermined release point, the parawing drop assembly was ejected from the gondola and deployed under free-flight conditions. The drop assemblies were released from the Whirl Tower gondola at velocities that ranged from 168.8 to 337.6 ft/sec (51.5 to 103.0 m/sec).

Each wing was folded in an accordion fold from nose to trailing edge, inserted into a deployment sleeve, and then packed into a modified parachute backpack. The pack assembly was then attached to a 235-pound (1045-newton) torso dummy to form a complete drop assembly. Photographs showing the details of the packing procedure are presented in figure 5. Each drop assembly was instrumented with a strain-gage tension link in the right and left suspension-line risers. These links measured the force between the parawing and the payload during deployment. The torso dummies were instrumented with an FM/FM telemetry system that transmitted the loads data to a ground receiving station where they were recorded on magnetic tape.

Both the solid and the slotted personnel parawings were tested twice by aerial drops from a C-130 airplane at a release altitude of 1500 feet (457.2 meters) and a release velocity of 202.6 ft/sec (61.8 m/sec). In addition to loads data, five cinetheodolite cameras running at 5 frames per second were used to obtain space positioning data during both the deployment and gliding-flight phases of the aerial drop tests. The space positioning data were taken primarily to determine the horizontal and vertical velocities of the two parawings during the gliding phase of the flight. The gliding phases of the flights during the Whirl Tower tests were either very short or nonexistent, and therefore, no space positioning data were obtained. Sixteen-millimeter motion pictures were taken of both the Whirl Tower and the aerial tests and were later used to determine deployment event times and any unusual events that may have occurred during deployment.

Photographs of a typical deployment sequence and the corresponding total load time-history for a Whirl Tower drop are presented in figure 6. During the analysis of the test data, the start of canopy inflation was assumed to occur at the start of load increase after line stretch. The first full canopy inflation time was determined by visual analysis of the 16-millimeter motion-picture film by assuming that the time of full canopy inflation and maximum projected wing area occurred simultaneously. To illustrate how full opening was determined, the increase in projected wing area from frames 6 to 10 in figure 6 and the decrease from frames 11 to 15 indicates that the first full canopy inflation occurred at the time frame 10 was taken.

RESULTS AND DISCUSSION

Wind-Tunnel Tests

The results of the wind-tunnel tests of the model-size solid and slotted parawings are presented in figure 7. These test results show the effects of a variation in control-line lengths and in dynamic pressure (simulation of a variation in wing loading) on the wing performance under tethered-flight conditions in the wind tunnel. The solid parawing had a maximum lift-drag ratio of 2.27 with a corresponding resultant-force coefficient of 1.05, and the slotted parawing had an almost identical maximum lift-drag ratio of 2.24 but with a somewhat lower corresponding resultant-force coefficient of 0.78. This result indicates that for a given payload weight, the area of a slotted wing should be 1.346 times larger than the area of a solid wing to obtain a given horizontal and vertical velocity. (The ratio of the areas of the slotted and the solid personnel parawings was 1.356.) Increasing the dynamic pressure had little effect on the overall performance of both the solid and the slotted parawings other than a slight shift in the data, as shown in figures 7(b) and 7(d). It is believed that this shift in the data was a result of a combination of control-line and canopy stretching with the increase in dynamic pressure (wing loading). The slotted wing used in the tunnel tests was constructed entirely of nonporous material and therefore differed from the slotted personnel wings which had varying material permeability in the chordwise direction. It is believed that the same distribution of porous materials in the slotted wing used in the tunnel tests would result in a slight reduction in both maximum lift-drag ratio and corresponding resultant-force coefficient.

The wind-tunnel test results also showed that the slotted wing had approximately twice the range of nondimensional control-line length changes as that of the solid wing for stable flight in the wind tunnel. This result indicates that the initial control-line settings for trim flight under free-flight conditions would be less critical for a slotted wing than for a solid wing of equal keel length. The solid and the slotted parawings had almost identical modulations of lift-drag ratio; however, the slotted parawing had slightly lower values and less modulation of resultant-force coefficient than the solid wing. This result indicates that for a solid and a slotted wing with equal canopy areas and payload weights, the slotted wing would have a higher resultant velocity than the solid wing under free-flight conditions. Experience has shown that although the specific ranges in control-line lengths and modulations in lift-drag ratio and resultant-force coefficient obtainable in free flight may differ from that obtainable in tethered flight, the comparative trends of several configurations as determined from tethered-flight tests in the wind tunnel should also hold true for free-flight tests of larger models.

Free-Flight Tests

The total load time-histories obtained from the free-flight tests of the solid and the slotted personnel parawings are presented in figures 8 and 9. A summary of the pack opening conditions, deployment event times, and the maximum deployment loads shown in these figures is listed in table I. The maximum deployment loads given in table I are also presented in figure 10, in addition to comparison data of a personnel parachute used in current personnel recovery systems. The parachute data presented in this figure were taken from reference 8. This parachute had a canopy area of 612 ft^2 (56.85 m^2) and was equipped with 235-pound (1045-newton) torso dummies. The comparison showed that both the solid and the slotted personnel parawings had much greater deployment loads than the personnel parachute. The free-flight test results show also that the slotted wing had lower deployment loads and longer fill times than the solid wing over the range of pack opening velocities tested. In addition to canopy porosity, the solid and the slotted parawings had different basic planforms and areas which may account for some of the difference in deployment loads. It is reasonable to assume that an additional increase in effective canopy porosity of the slotted wing, which can be attained by increasing slot area or material permeability, would result in a reduction in deployment loads; however, an increase in porosity (not to include improved slot designs) would also result in an undesirable reduction in flight performance. Some form of canopy reefing or venting may be required to reduce the peak deployment loads of both the solid and the slotted wings and to extend the range of pack opening velocities without wing failures.

No published data were available showing the human tolerance to deceleration with the subject suspended in a harness system similar to that used in this investigation; therefore, it was not possible to determine whether or not the deployment loads of the two personnel parawings were within the limits of human tolerance. It is generally believed, however, that the deployment loads of the parawings tested were sufficiently greater than those of the personnel parachute used in the comparison to warrant the conclusion that some form of reefing or method of slowing the opening would be one of the items required for these parawings before they could be considered for use in high-speed aircraft escape systems. These parawings without reefing may be of use in low-speed aircraft escape systems or in other personnel recovery systems with low-speed deployment conditions.

The parawing data presented in table I also show considerable scatter in deployment loads and fill times at a given pack opening velocity. This type of scatter seems to be a characteristic problem associated with both parawing and parachute deployments and can possibly be attributed to small variations in packing details or deployment sequences. During several of the parawing deployment tests, the orientation of the wing to the motion-picture cameras was poor, which made it difficult to determine the full canopy inflation time accurately. This fact may account for part of the scatter in the fill times.

The cinetheodolite cameras used to obtain space positioning data during the aerial drops ran at a film speed which proved to be too slow to obtain accurate space positioning data during the deployment phase of the aerial drop tests. The frame rate was sufficient during the glide phase of the tests; however, since the flights were uncontrolled, the wings were constantly turning right or left, which resulted in random and unreliable values for the descent rate and lift-drag ratio. Although the space positioning data from the aerial drop tests were of no use, the deployment loads data were acceptable.

A summary of the structural failures that occurred during the deployment tests is presented in table II. Both wings had a structural failure at a pack opening velocity of 303.8 ft/sec (92.6 m/sec) due to either breaks at the suspension-line attachment points or tears along the canopy reinforcement tapes. Photographs of a typical structural failure are presented in figure 11.

CONCLUDING REMARKS

Wind-tunnel and free-flight tests were made to determine the gliding-flight and deployment characteristics of single-keel solid and single-keel slotted parawings of suitable size for use in personnel recovery systems. The results of low-speed wind-tunnel tests of a 29.8-ft^2 (2.77-m^2) solid and a 34.3-ft^2 (3.19-m^2) slotted parawing showed that both wings had almost identical maximum lift-drag ratios but that the slotted wing had a lower corresponding resultant-force coefficient. The slotted wing had approximately twice the range of nondimensional control-line length changes as that of the solid wing for the stable flight in the wind tunnel. Both wings had almost identical modulations of lift-drag ratio, but the slotted wing had slightly lower values and less modulation of resultant-force coefficient.

Free-flight deployment tests of 276.5-ft^2 (25.69-m^2) solid and 375.0-ft^2 (34.84-m^2) slotted personnel parawings equipped with 235-pound (1045-newton) instrumented torso dummies showed that the maximum deployment loads were lower and the canopy inflation times were longer for the slotted wing than for the solid wing over a range of pack opening velocities from 168.8 to 337.6 ft/sec (51.5 to 103.0 m/sec). Both wings had a structural failure at a pack opening velocity of 303.8 ft/sec (92.6 m/sec). A comparison of the deployment characteristics of the two personnel parawings tested and a currently used personnel parachute showed that the parawings had much greater deployment loads than the parachute. This result led to the conclusion that some form of reefing or method of slowing the opening would be one of the items required for the parawings tested before they could be considered for use in high-speed aircraft escape systems.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 3, 1970.

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TABLE I.- RESULTS OF DROP TESTS TO DETERMINE DEPLOYMENT CHARACTERISTICS OF SOLID AND SLOTTED PERSONNEL PARAWINGS

Drop	Pack opening conditions: Velocity, ft/sec (m/sec)	Pack opening conditions: Dynamic pressure, lb/ft^2 (kN/m^2)	Deployment event times: Pack opening to line stretch, sec	Deployment event times: Line stretch to start of inflation, sec	Deployment event times: Start of inflation to full opening, sec	Maximum deployment loads: Maximum right riser load, lb (kN)	Maximum deployment loads: Maximum left riser load, lb (kN)	Maximum deployment loads: Maximum total load, lb (kN)
20-foot (6.10-meter) solid parawings equipped with 235-pound (1045-newton) torso dummies								
224	168.8 (51.5)	33.88 (1.62)	0.785	0.085	0.410	2040 (9.07)	2475 (11.01)	4097 (18.22)
225	168.8 (51.5)	33.88 (1.62)	.800	.051	.409	2047 (9.11)	2172 (9.66)	4219 (18.77)
325	168.8 (51.5)	33.88 (1.62)	.840	.130	.385	1945 (8.65)	1938 (8.62)	3759 (16.72)
[a]148	174.6 (53.2)	34.60 (1.66)	.843	.065	.294	3270 (14.55)	3394 (15.10)	6524 (29.02)
[a]150	178.6 (54.4)	36.30 (1.74)	.818	.045	.371	3586 (15.95)	3038 (13.51)	6369 (28.33)
326	202.6 (61.8)	48.81 (2.34)	.580	051	.495	2700 (12.01)	3374 (15.01)	6074 (27.02)
1475	202.6 (61.8)	48.81 (2.34)	.763	045	.345	3163 (14.07)	2046 (9.10)	4425 (19.68)
1258	236.3 (72.0)	66.39 (3.18)	.420	.045	.536	3513 (15.63)	2932 (13.04)	6374 (28.35)
1270	236.3 (72.0)	66.39 (3.18)	.495	.025	.258	3680 (16.37)	4851 (21.58)	8531 (37.95)
1374	236.3 (72.0)	66.39 (3.18)	.501	.050	.320	4429 (19.70)	4373 (19.45)	8535 (37.97)
1372	270.1 (82.3)	86.74 (4.15)	.416	.040	.366	4508 (20.05)	4350 (19.35)	8715 (38.77)
1476	270.1 (82.3)	86.74 (4.15)	.426	.035	.485	3690 (16.41)	2360 (10.50)	5589 (24.86)
22.5-foot (6.86-meter) slotted parawings equipped with 235-pound (1045-newton) torso dummies								
153	168.8 (51.5)	33.88 (1.62)	0.815	0.045	0.524	1582 (7.04)	1828 (8.13)	3361 (14.95)
222	168.8 (51.5)	33.88 (1.62)	.768	.040	.451	2003 (8.91)	2339 (10.40)	4251 (18.91)
223	168.8 (51.5)	33.88 (1.62)	.755	.038	.642	1694 (7.54)	1744 (7.76)	3179 (14.14)
269	168.8 (51.5)	33.88 (1.62)	.720	.070	.440	2093 (9.31)	2195 (9.76)	4168 (18.54)
272	168.8 (51.5)	33.88 (1.62)	.918	.110	.535	1211 (5.39)	2076 (9.23)	3275 (14.57)
[a]149	176.5 (53.8)	35.40 (1.69)	.968	.040	.692	1432 (6.37)	1745 (7.76)	3039 (13.52)
[a]151	181.7 (55.4)	37.40 (1.79)	.969	.055	.512	2118 (9.42)	1944 (8.65)	4058 (18.05)
152	202.6 (61.8)	48.81 (2.34)	.729	.060	.735	2315 (10.30)	2186 (9.72)	4444 (19.77)
167	202.6 (61.8)	48.81 (2.34)	.673	.060	.542	1381 (6.14)	1957 (8.71)	3338 (14.85)
168	202.6 (61.8)	48.81 (2.34)	.948	.105	.542	1469 (6.53)	1733 (7.71)	3218 (14.31)
271	202.6 (61.8)	48.81 (2.34)	.585	.055	.605	2606 (11.59)	2217 (9.86)	4739 (21.08)
273	236.3 (72.0)	66.39 (3.18)	.664	.035	.449	2792 (12.42)	1998 (8.89)	4754 (21.15)
322	236.3 (72.0)	66.39 (3.18)	.613	.045	.452	3652 (16.24)	2601 (11.57)	6192 (27.54)
323	236.3 (72.0)	66.39 (3.18)	.650	.055	.400	2226 (9.90)	1733 (7.71)	3842 (17.09)
324	236.3 (72.0)	66.39 (3.18)	.515	.030	.490	2920 (12.99)	2958 (13.16)	5570 (24.78)
590	236.3 (72.0)	66.39 (3.18)	.577	.045	.825	3119 (13.87)	3615 (16.08)	6699 (29.80)
591	236.3 (72.0)	66.39 (3.18)	.533	.040	.503	2877 (12.80)	2749 (12.23)	5506 (24.49)
592	236.3 (72.0)	66.39 (3.18)	.558	.043	.382	3219 (14.32)	3796 (16.89)	6966 (30.99)
327	270.1 (82.3)	86.74 (4.15)	.484	.050	.386	3790 (16.86)	3807 (16.93)	7597 (33.79)
673	270.1 (82.3)	86.74 (4.15)	.470	.035	.465	3038 (13.51)	2304 (10.25)	5302 (23.58)
674	270.1 (82.3)	86.74 (4.15)	.509	.045	1.058	3471 (15.44)	2944 (13.10)	6116 (27.21)
675	270.1 (82.3)	86.74 (4.15)	.484	.040	.483	2807 (12.49)	3212 (14.29)	6007 (26.72)
723	270.1 (82.3)	86.74 (4.15)	.515	.035	.623	1567 (6.97)	2139 (9.51)	3618 (16.09)
724	270.1 (82.3)	86.74 (4.15)	.559	.045	.853	1742 (7.75)	2065 (9.19)	3802 (16.91)
725	270.1 (82.3)	86.74 (4.15)	.577	.050	.525	3168 (14.09)	3177 (14.13)	6292 (27.99)
274	303.8 (92.6)	109.74 (5.25)	.465	.035	.652	3118 (13.87)	3233 (14.38)	5717 (25.43)

[a]Release altitude was 1500 feet (457.2 meters).

TABLE II.- SUMMARY OF STRUCTURAL FAILURES DURING DEPLOYMENT TESTS OF SOLID AND SLOTTED PERSONNEL PARAWINGS

Drop	Pack opening velocity		Description of failure (a)
	ft/sec	m/sec	
20-foot (6.10-meter) solid parawings equipped with 235-pound (1045-newton) torso dummies			
1826	303.8	92.6	RLE3, RLE4, LLE3, LLE4, and LLE5 suspension lines pulled loose at attachment points. Canopy tore along spanwise tapes between K10 to LLE6 and K10 to RLE6.
1827	303.8	92.6	Stitching pulled loose at LLE5 suspension-line attachment point. Left and right connector links between risers and tension links broke at peak deployment load.
22.5-foot (6.86-meter) slotted parawings equipped with 235-pound (1045-newton) torso dummies			
1267	337.6	103.0	All suspension lines on left leading edge pulled loose at attachment points. Canopy was torn along left trailing-edge tape. (See fig. 11.)
1268	303.8	92.6	RLE2 suspension line pulled loose at attachment point.

[a]Notation: LLE Left leading edge
RLE Right leading edge
K Keel
Number after abbreviation is suspension-line number

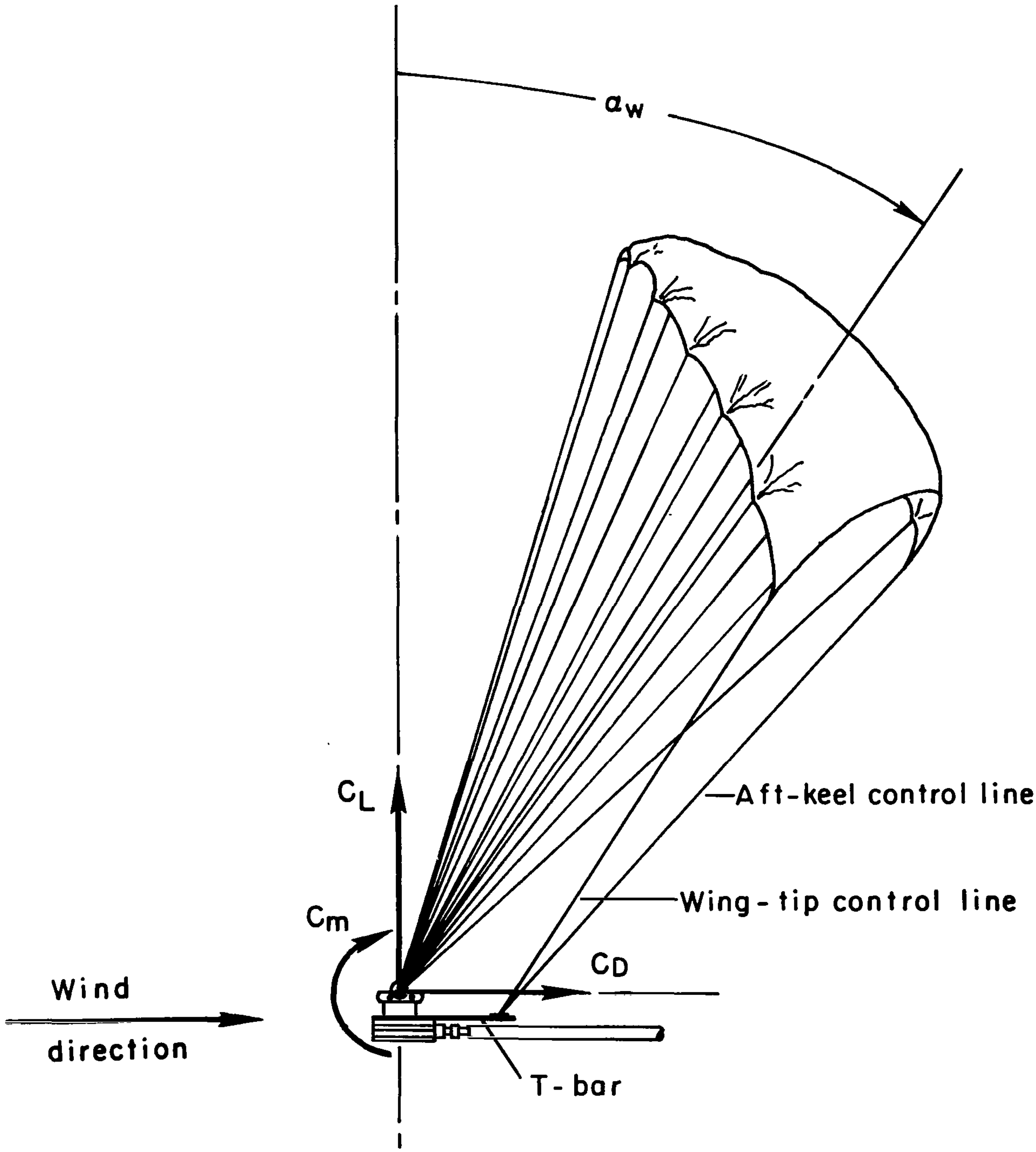


Figure 1.- Axis system used in presentation of data. Positive directions are shown with arrows.

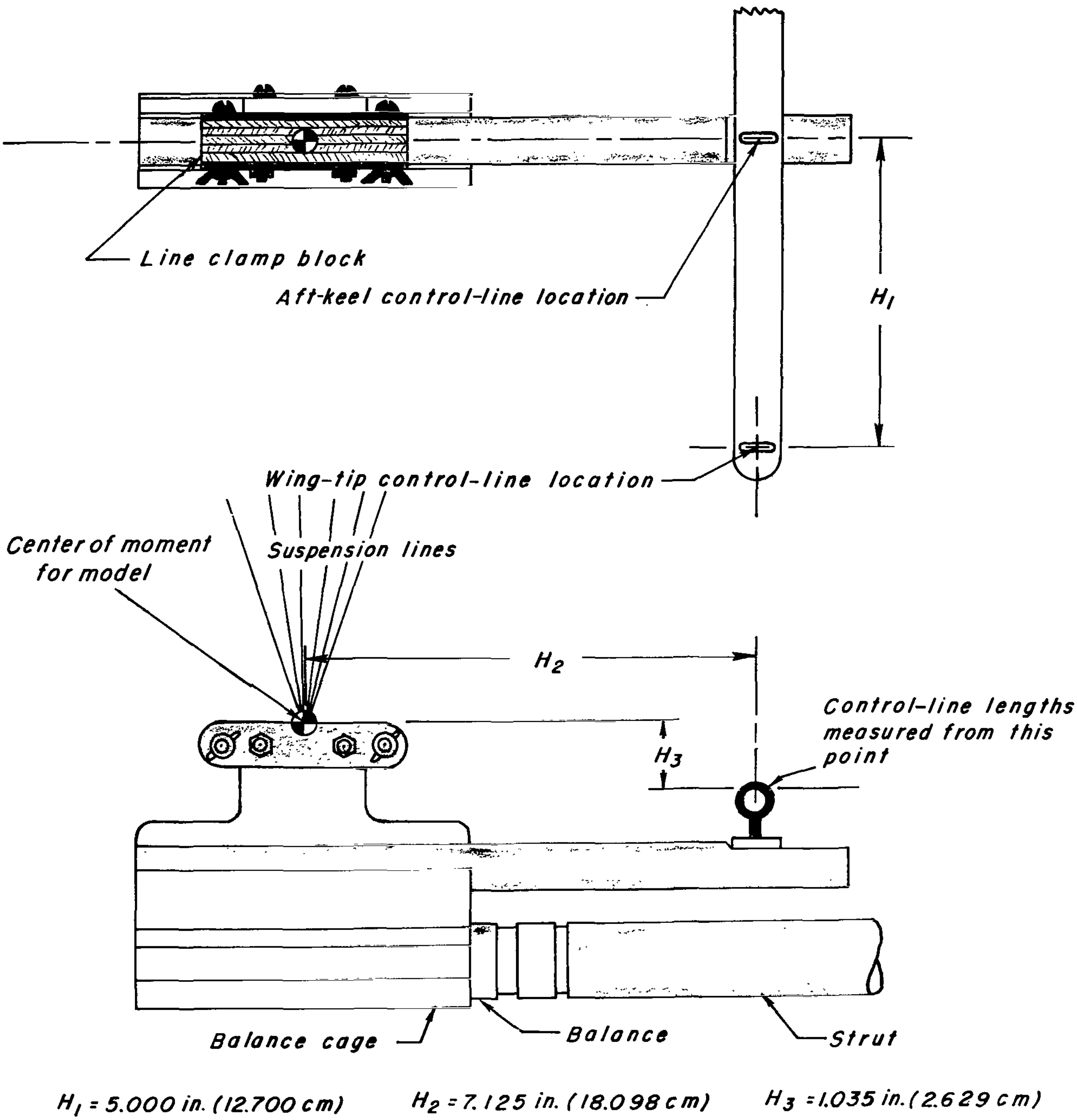
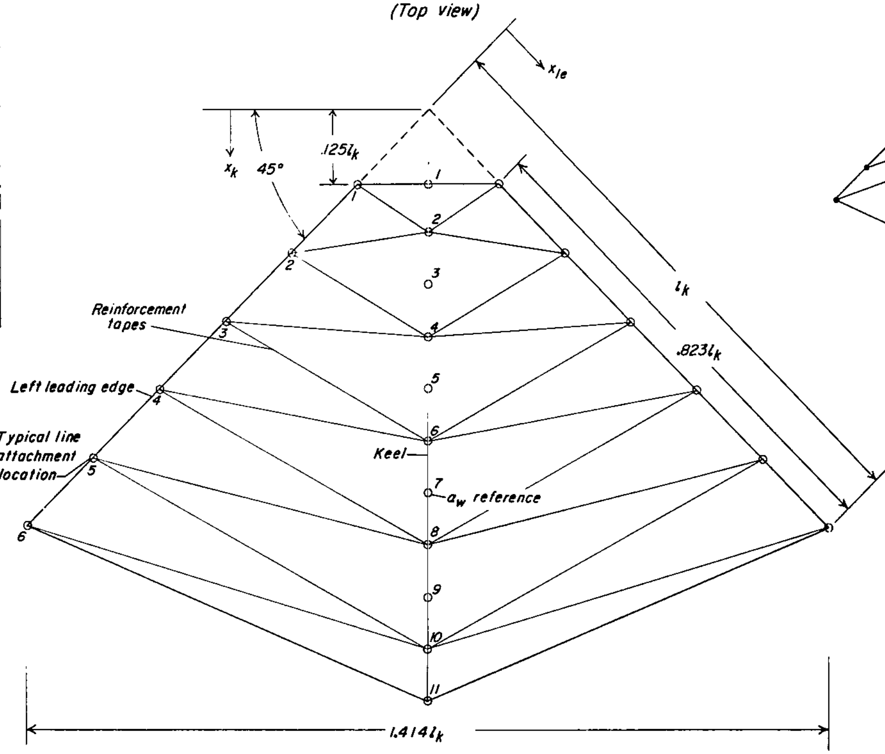
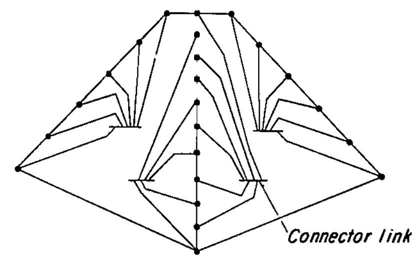


Figure 2.- Details of wing-balance attachment apparatus (T-bar).

Line attachment locations

Line	Keel x_k/l_k	Leading edge x_{le}/l_k
1	.1250	.1768
2	.2125	.3414
3	.3000	.5061
4	.3875	.6707
5	.4750	.8354
6	.5625	1.0000
7	.6500	—
8	.7375	—
9	.8250	—
10	.9125	—
11	1.0000	—





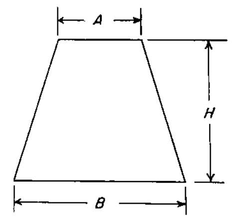
Line lengths

Line	Keel l/l_k	Leading edge l/l_k
1	1.2883	1.3317
2	1.3133	1.2983
3	1.3213	1.2375
4	1.3000	1.1667
5	1.2783	1.1192
6	1.2683	1.0354
7	1.2683	—
8	1.2683	—
9	1.2521	—
10	1.1783	—
11	1.1025	—

(a) Single-keel solid parawing.

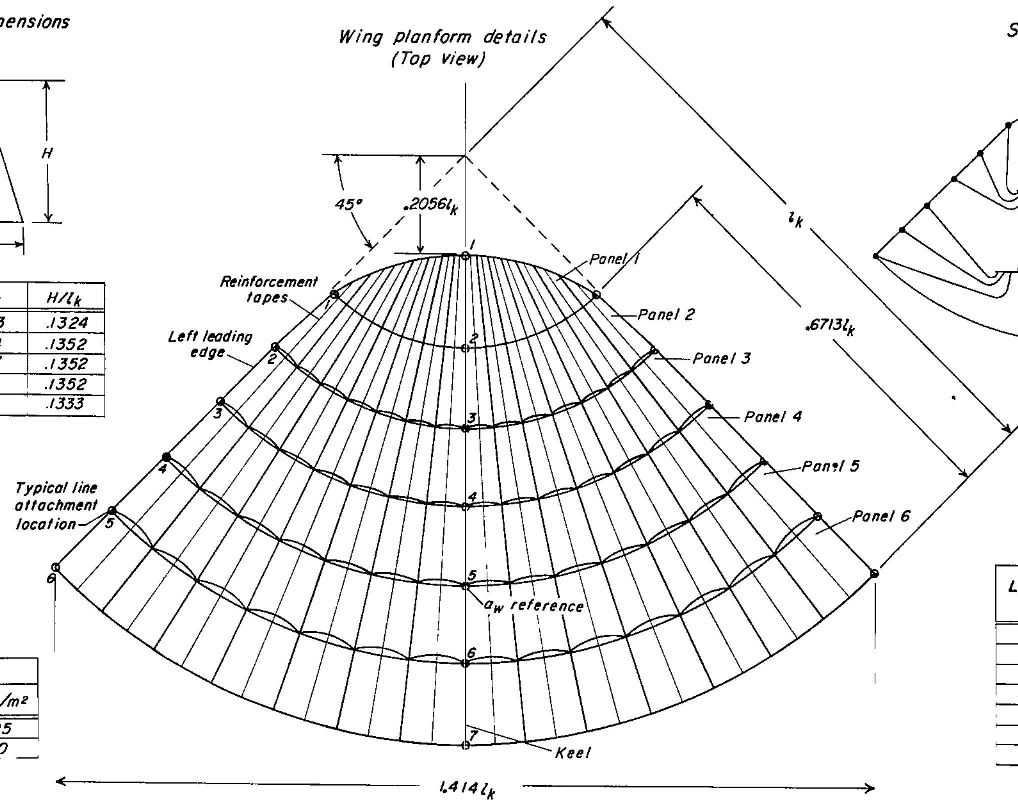
Figure 3.- Planform details of single-keel solid and single-keel slotted parawings.

Panel dimensions

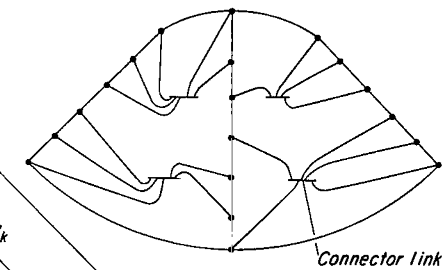


Panel	A/l_k	B/l_k	H/l_k
2	.0371	.0523	.1324
3	.0520	.0684	.1352
4	.0671	.0847	.1352
5	.0823	.1016	.1352
6	.0977	.1124	.1333

Wing planform details (Top view)



Suspension-line routing diagram (Bottom view)



Panel permeability at 1/2 inch (1.27cm) of water*

Panel	Permeability	
	$ft^3/min/ft^2$	$m^3/sec/m^2$
1–2	1.0	0.005
3–6	25.7	0.130

*Applies to personnel wings only.

Line lengths

Line	Keel l/l_k	Leading edge l/l_k
1	1.2667	1.2111
2	1.2593	1.1815
3	1.2519	1.1426
4	1.2667	1.0963
5	1.2444	1.0204
6	1.1704	0.9370
7	1.0667	—

(b) Single-keel slotted parawing.

Figure 3.- Concluded.

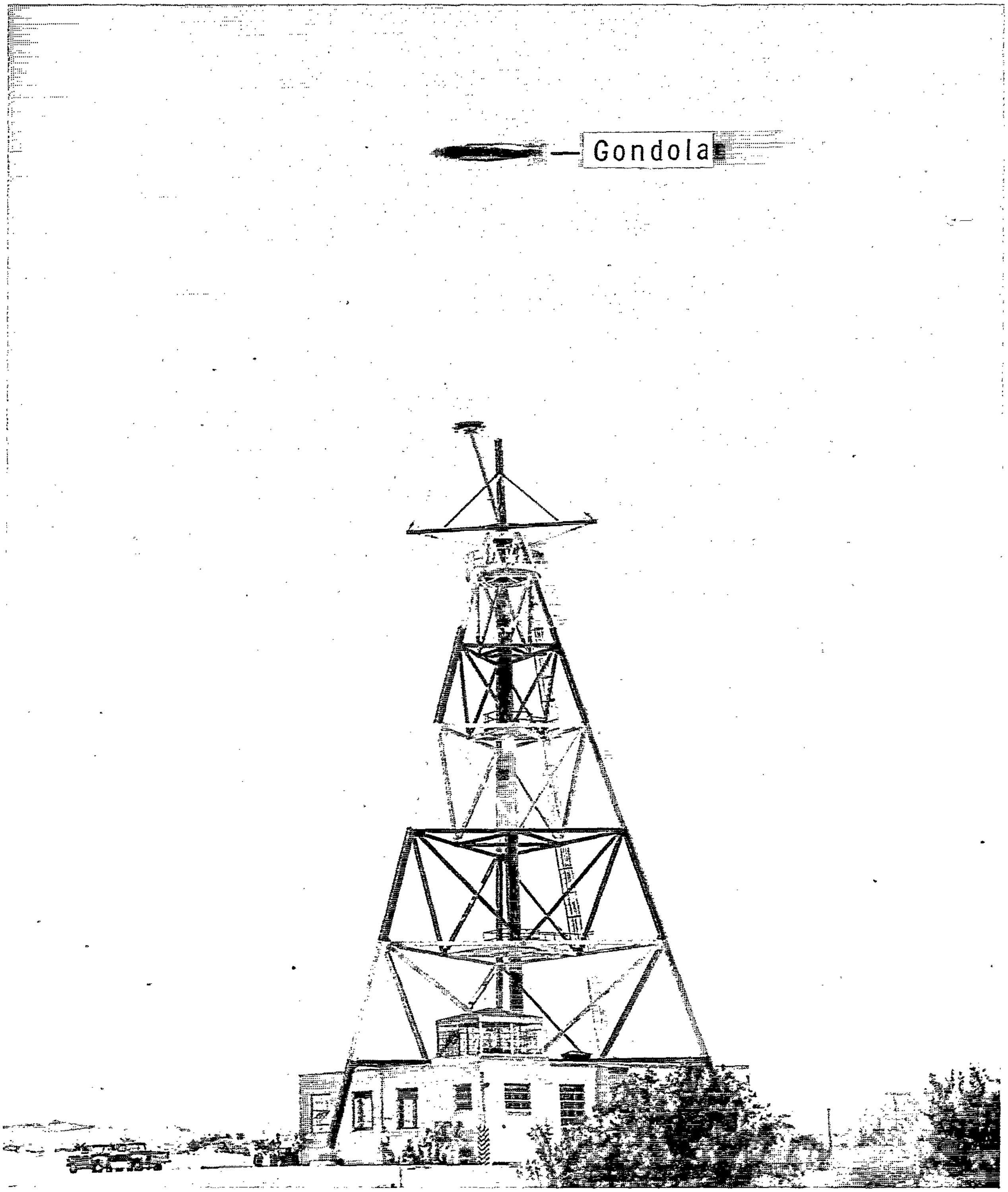


Figure 4.- Whirl Tower at Department of Defense Joint Parachute Test Facility at El Centro, California. L-70-1640

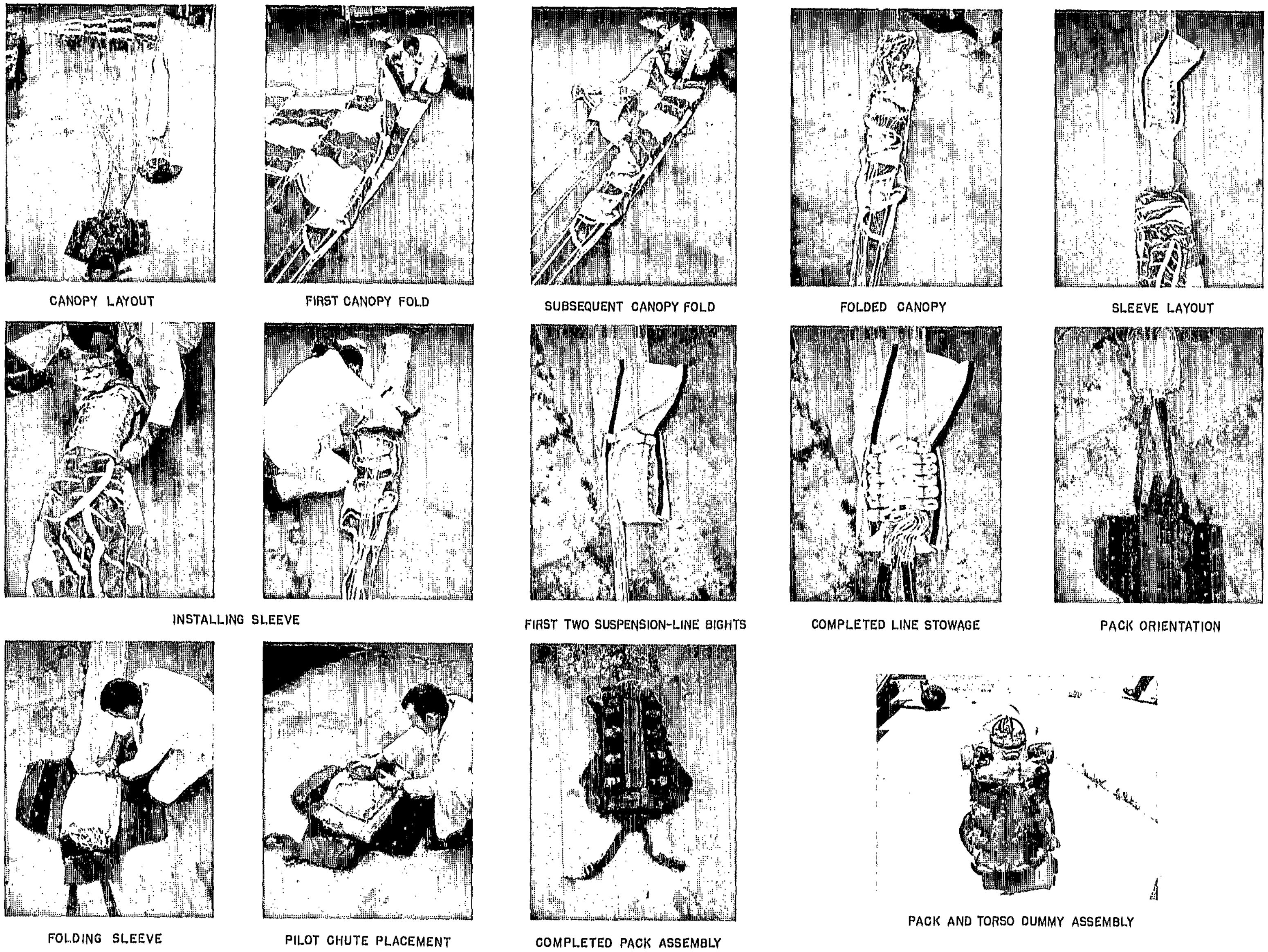


Figure 5.- Photographs of packing procedure for a single-keel all-flexible parawing. L-70-1641

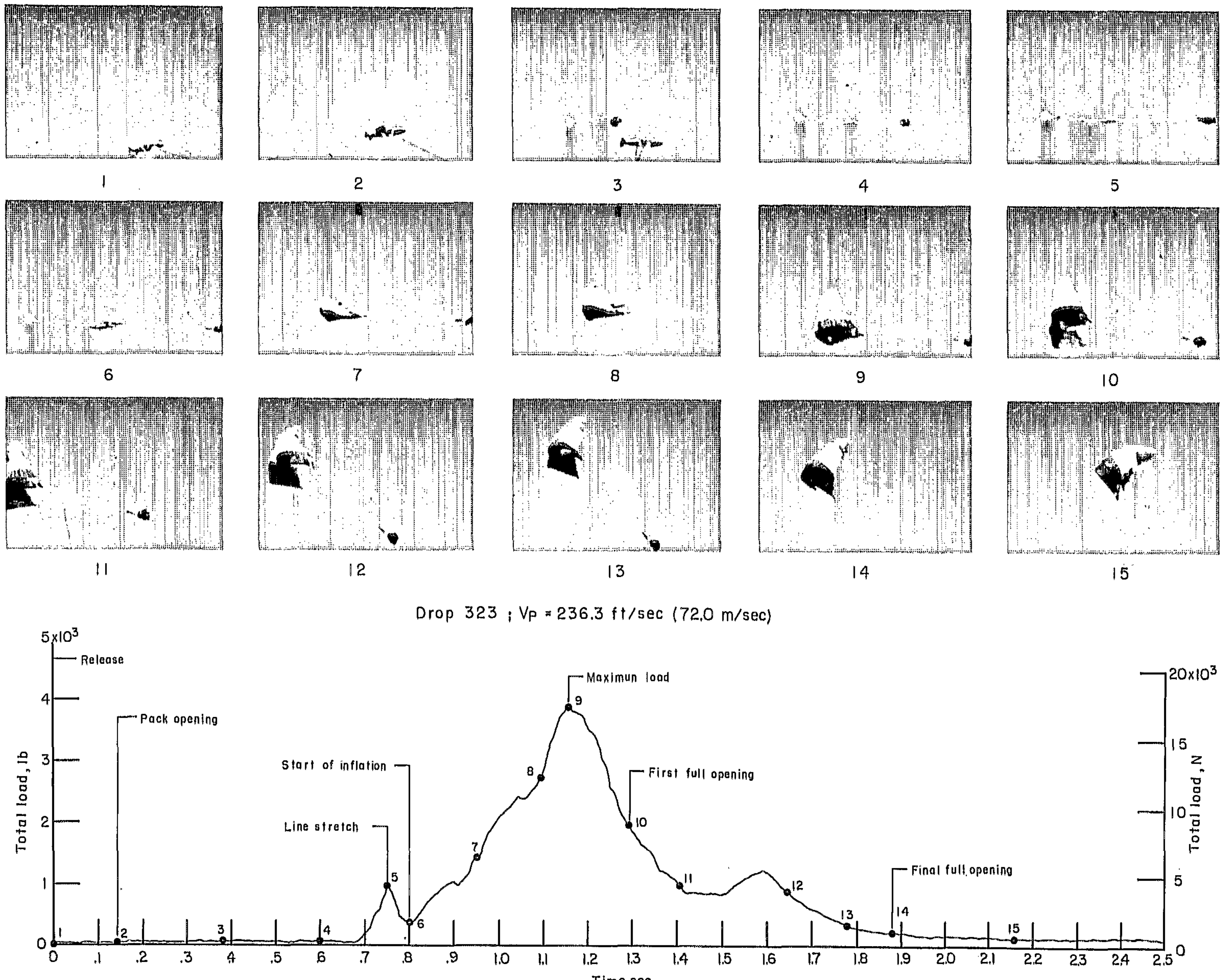
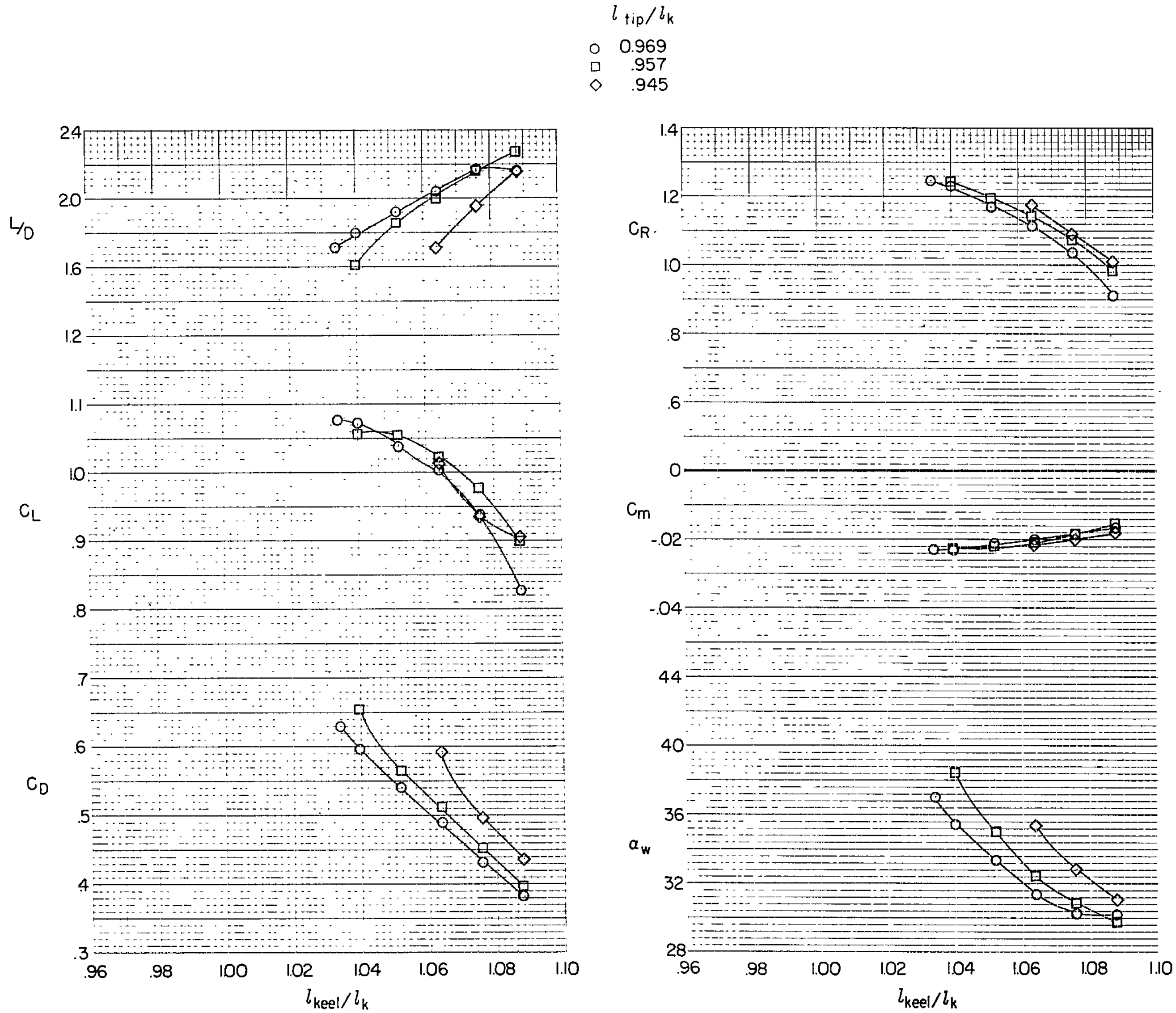
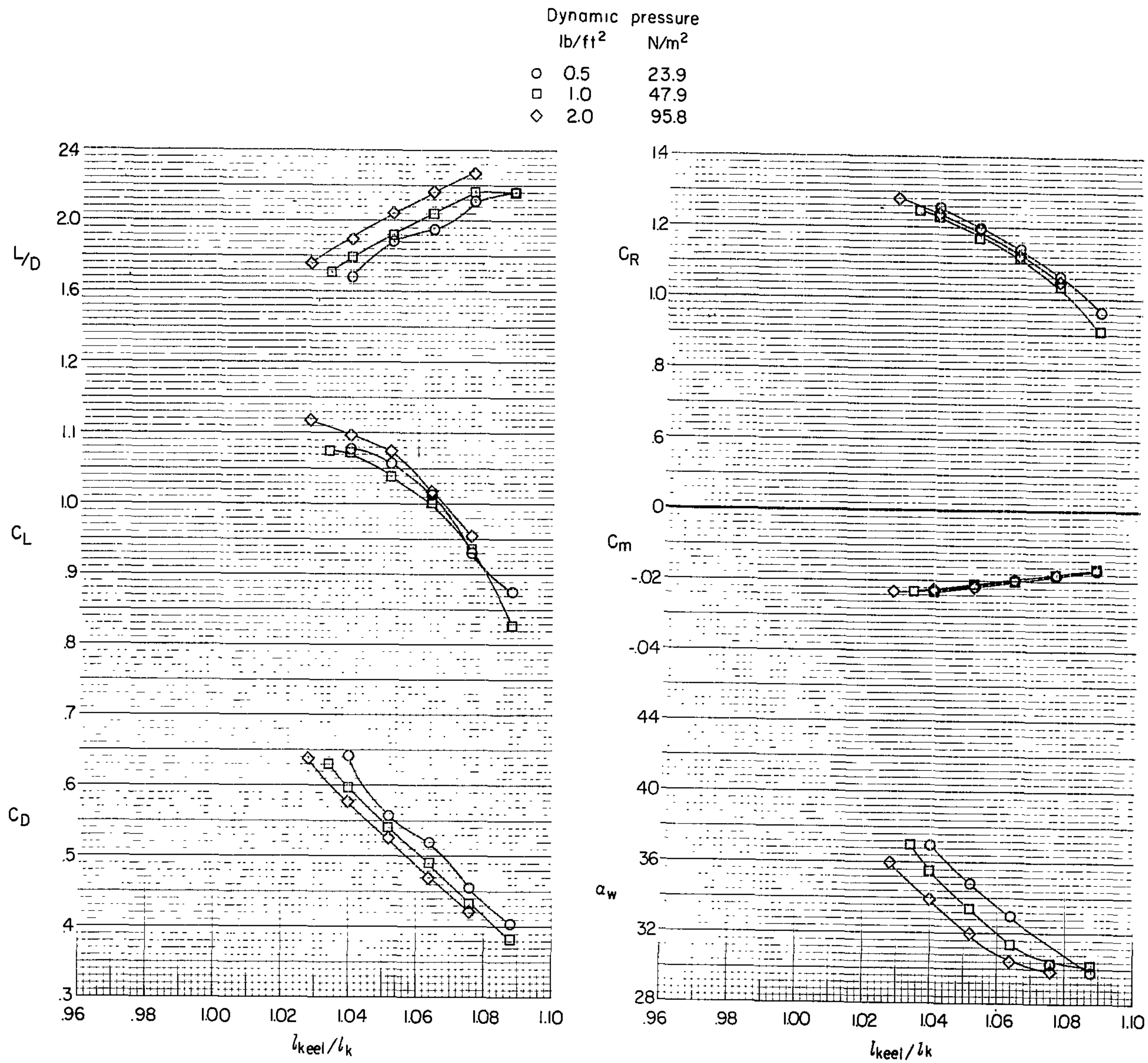


Figure 6.- Typical deployment sequence of 22.5-foot (6.86-meter) slotted personnel parawing equipped with a 235-pound (1045-newton) torso dummy. L-70-1642



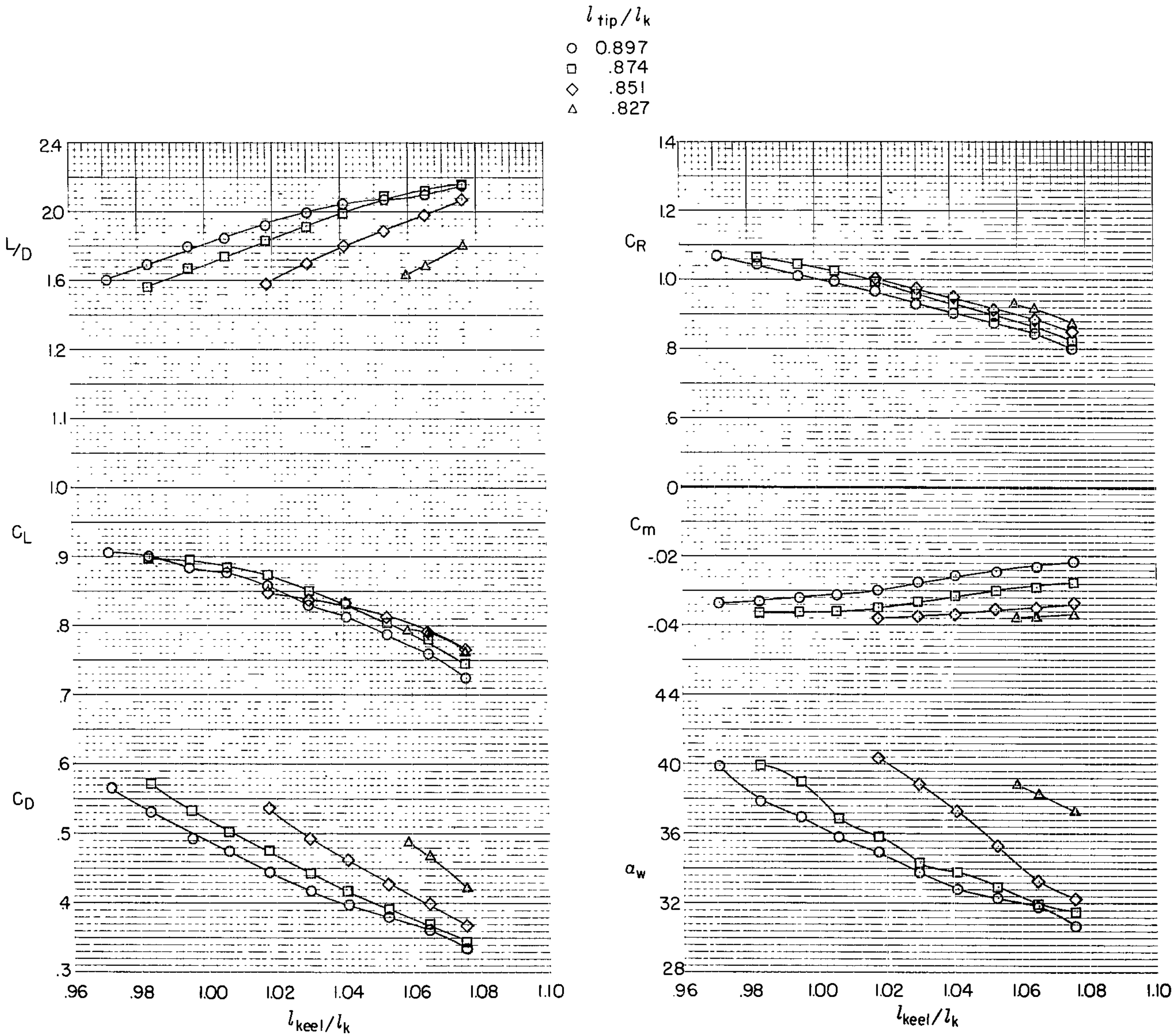
(a) 6.56-foot (2.00-meter) solid parawing; q = 1.0 lb/ft^2 $(47.9\ N/m^2)$.

Figure 7.- Longitudinal aerodynamic characteristics obtained from wind-tunnel tests of model-size solid and slotted parawings.



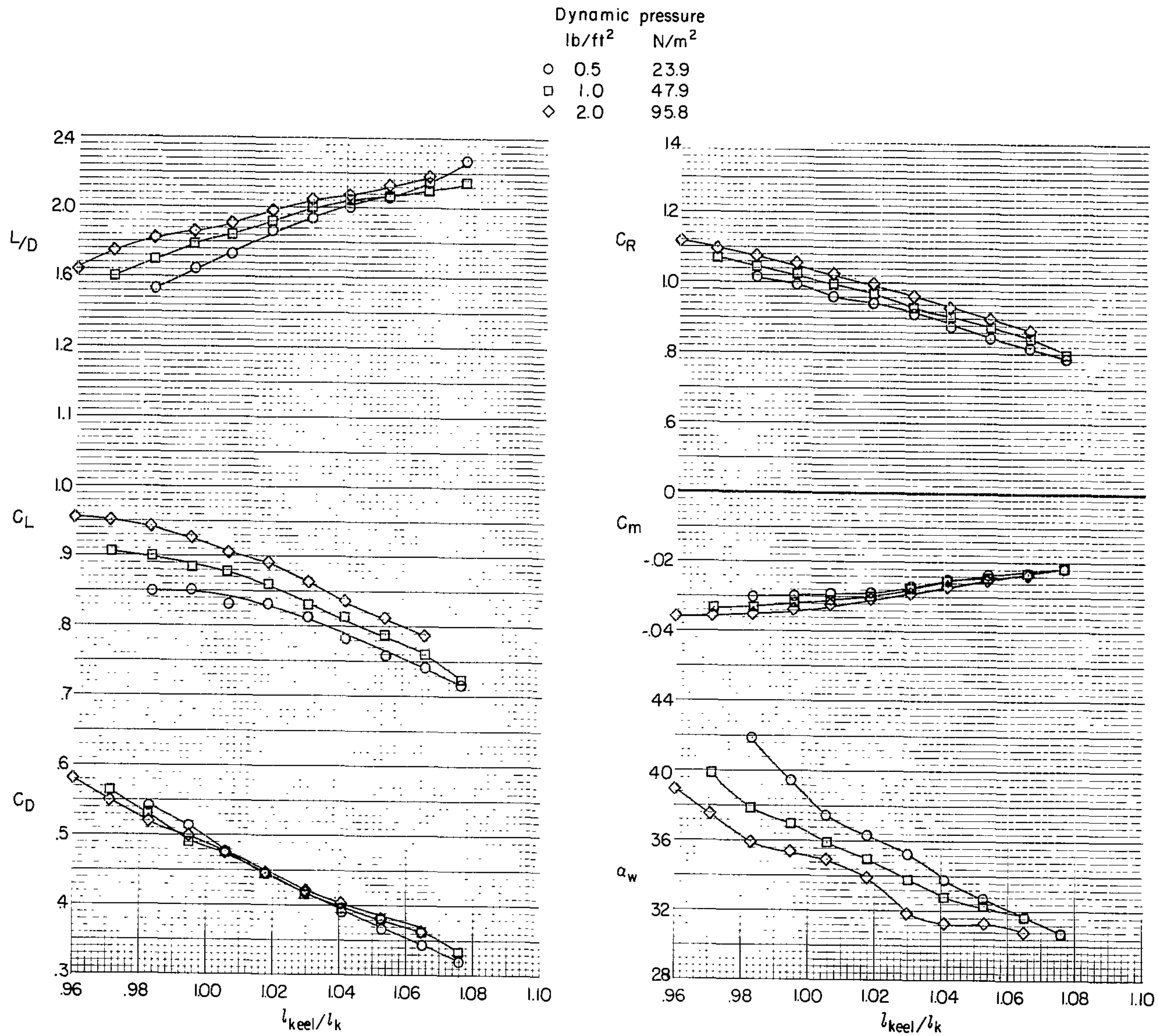
(b) 6.56-foot (2.00-meter) solid parawing; $l_{tip}/l_k = 0.969$.

Figure 7.- Continued.



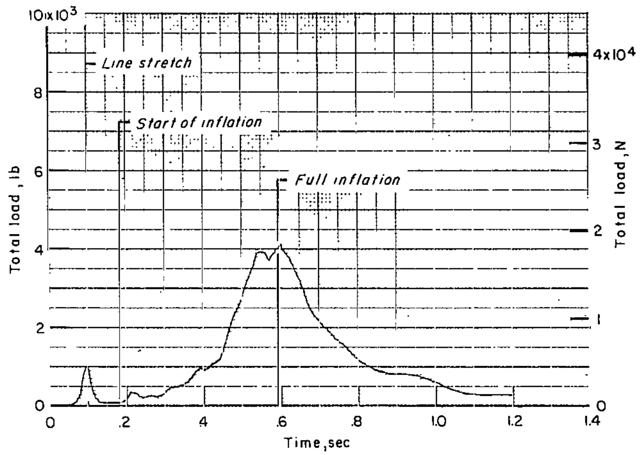
(c) 6.79-foot (2.07-meter) slotted parawing; q = 1.0 lb/ft^2 (47.9 N/m^2).

Figure 7.- Continued.

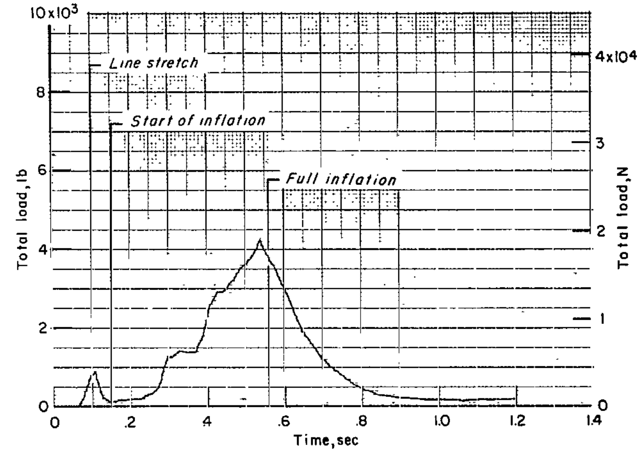


(d) 6.79-foot (2.07-meter) slotted parawing; $l_{tip}/l_k = 0.897$.

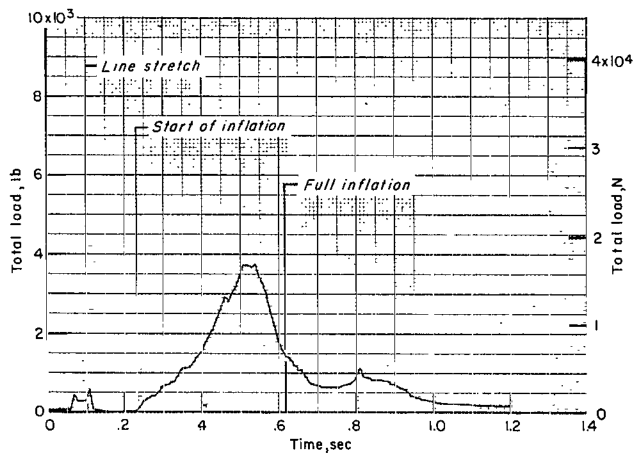
Figure 7.- Concluded.



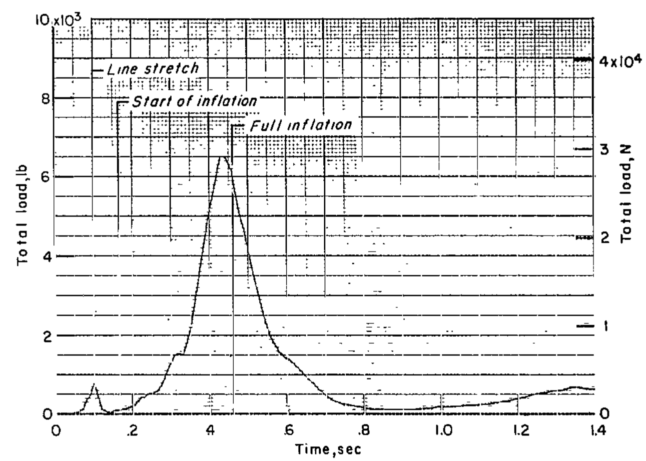
(a) Drop 224; V_p = 168.8 ft/sec (51.5 m/sec).



(b) Drop 225; V_p = 168.8 ft/sec (51.5 m/sec).

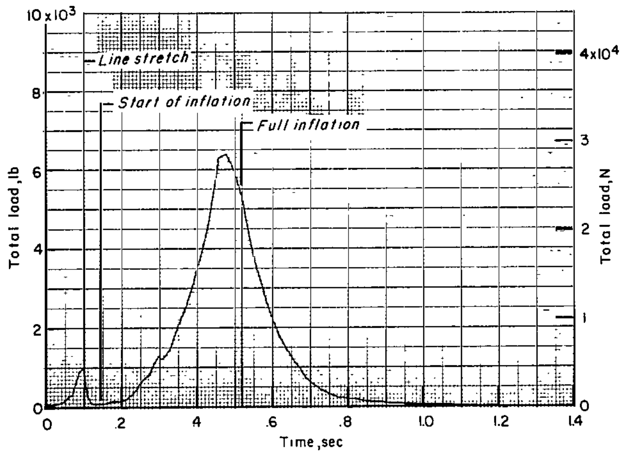


(c) Drop 325; V_p = 168.8 ft/sec (51.5 m/sec).

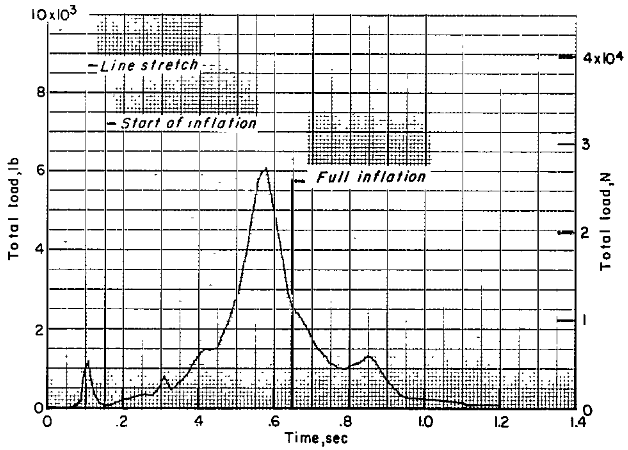


(d) Drop 148; V_p = 174.6 ft/sec (53.2 m/sec).

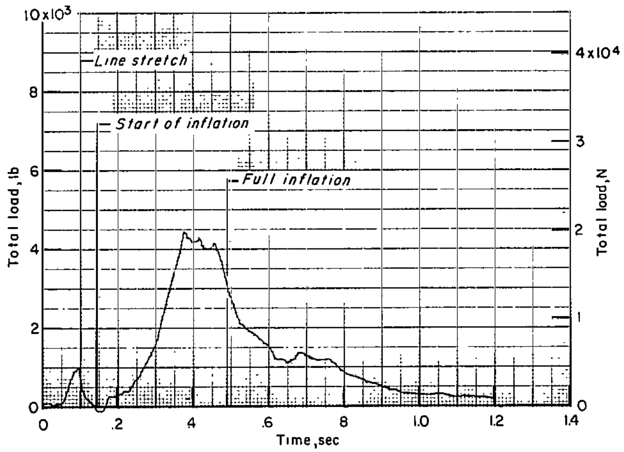
Figure 8.- Total load time histories from drop tests of 20-foot (6.10-meter) solid personnel parawings equipped with 235-pound (1045-newton) torso dummies.



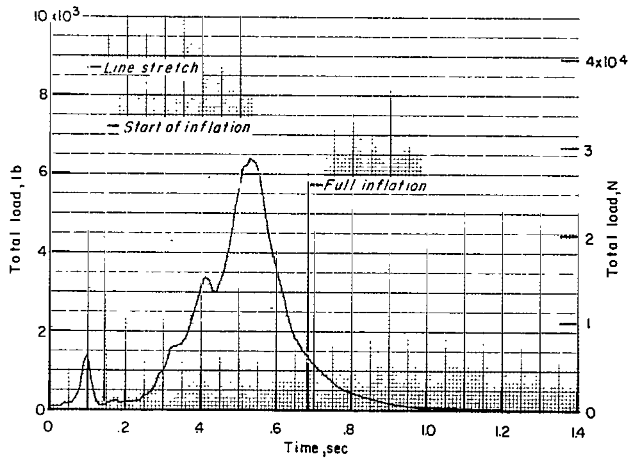
(e) Drop 150; V_p = 178.6 ft/sec (54.4 m/sec).



(f) Drop 326; V_p = 202.6 ft/sec (61.8 m/sec).

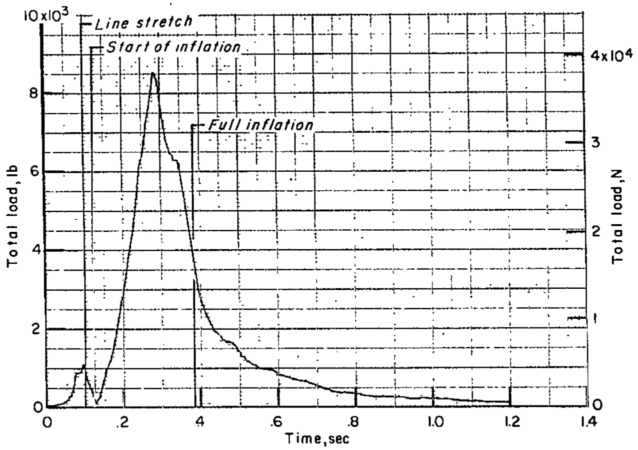


(g) Drop 1475; V_p = 202.6 ft/sec (61.8 m/sec).

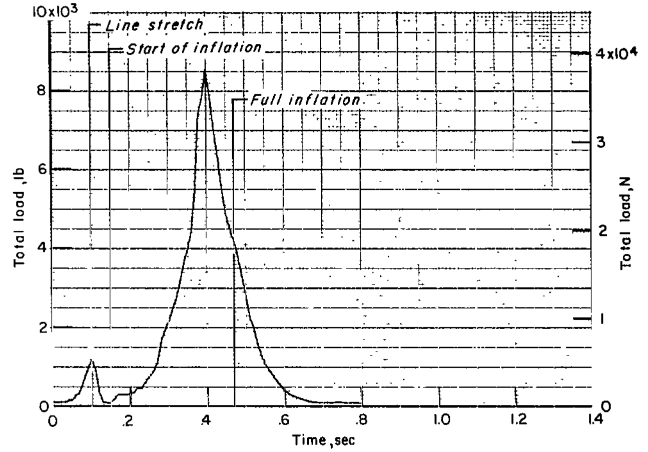


(h) Drop 1258; V_p = 236.3 ft/sec (72.0 m/sec).

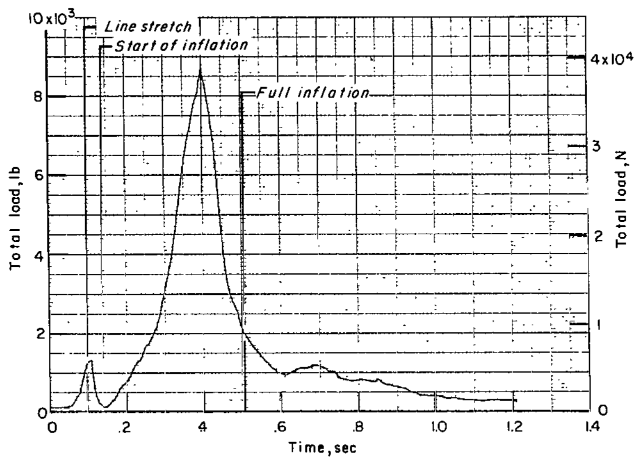
Figure 8.- Continued.



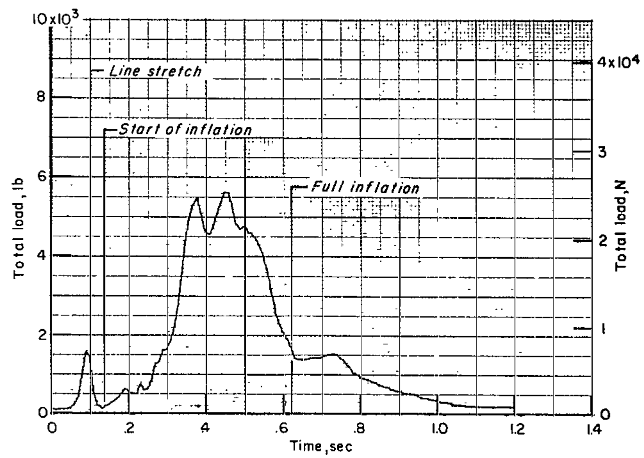
(i) Drop 1270; V_p = 236.3 ft/sec (72.0 m/sec).



(j) Drop 1374; V_p = 236.3 ft/sec (72.0 m/sec).

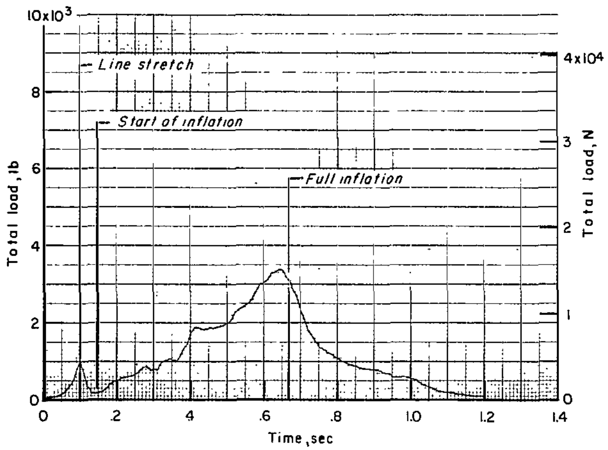


(k) Drop 1372; V_p = 270.1 ft/sec (82.3 m/sec).

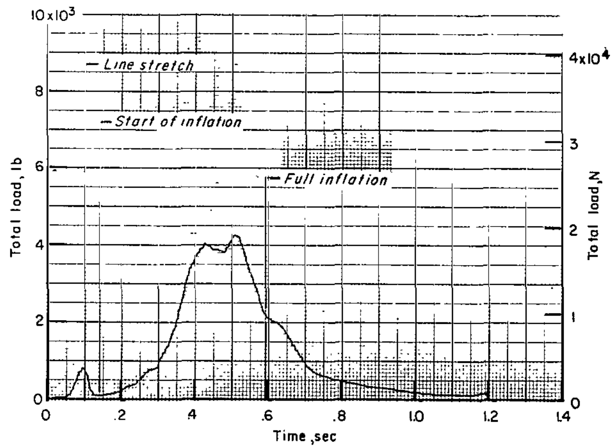


(l) Drop 1476; V_p = 270.1 ft/sec (82.3 m/sec).

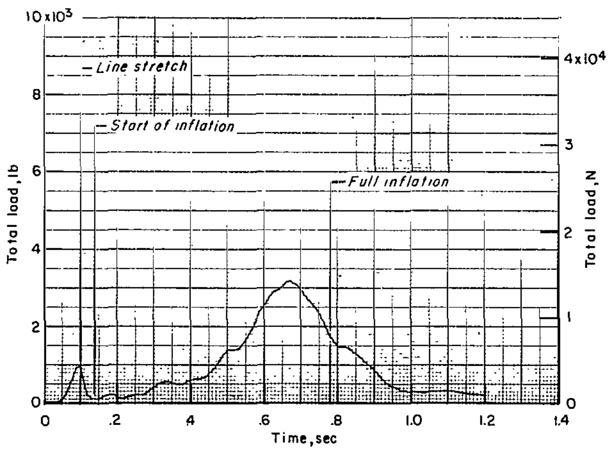
Figure 8.- Concluded.



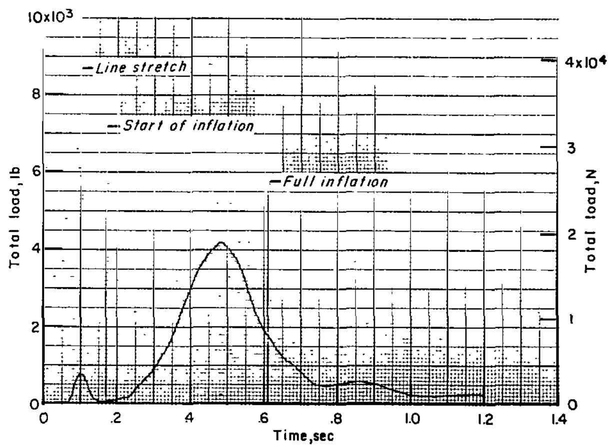
(a) Drop 153; V_p = 168.8 ft/sec (51.5 m/sec).



(b) Drop 222; V_p = 168.8 ft/sec (51.5 m/sec).

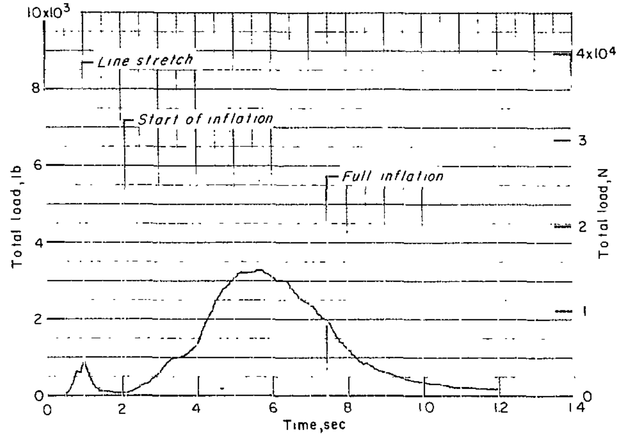


(c) Drop 223; V_p = 168.8 ft/sec (51.5 m/sec).

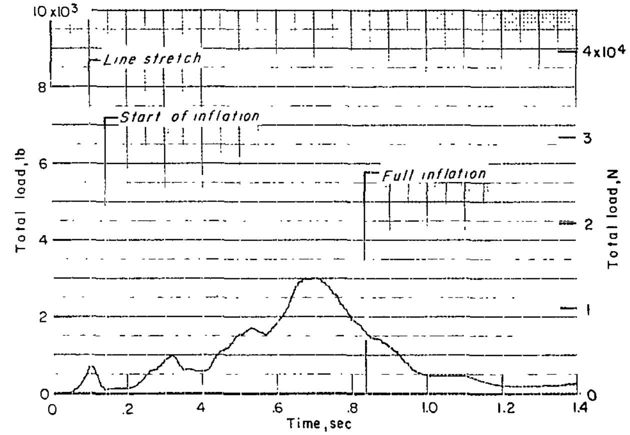


(d) Drop 269; V_p = 168.8 ft/sec (51.5 m/sec).

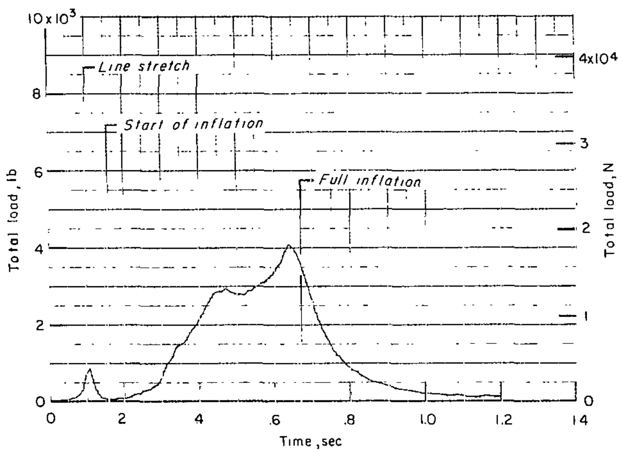
Figure 9.- Total load time histories from drop tests of 22.5-foot (6.86-meter) slotted personnel parawings equipped with 235-pound (1045-newton) torso dummies.



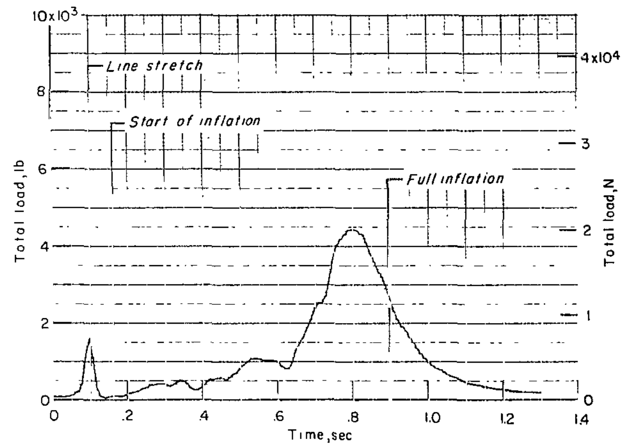
(e) Drop 272; V_p = 168.8 ft/sec (51.5 m/sec).



(f) Drop 149; V_p = 176.5 ft/sec (53.8 m/sec).

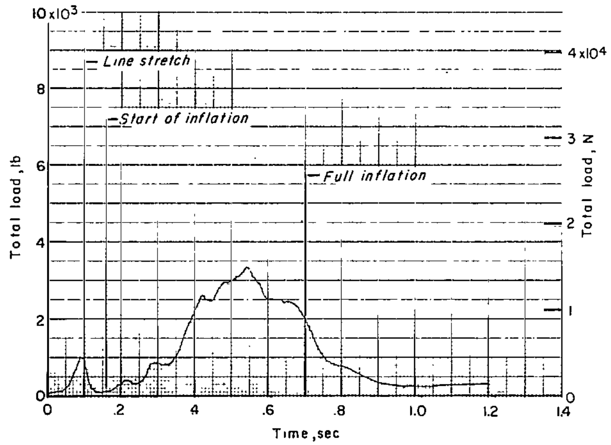


(g) Drop 151; V_p = 181.7 ft/sec (55.4 m/sec).

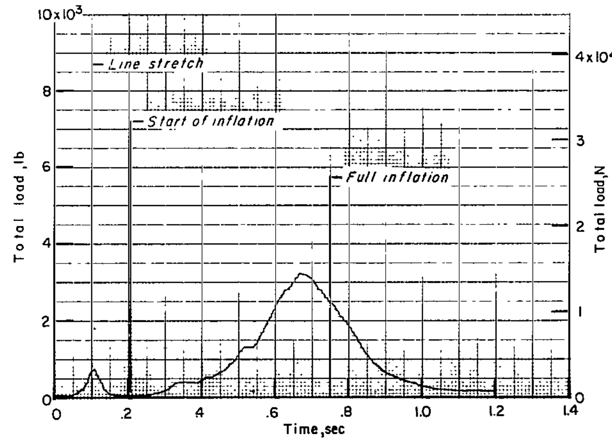


(h) Drop 152; V_p = 202.6 ft/sec (61.8 m/sec).

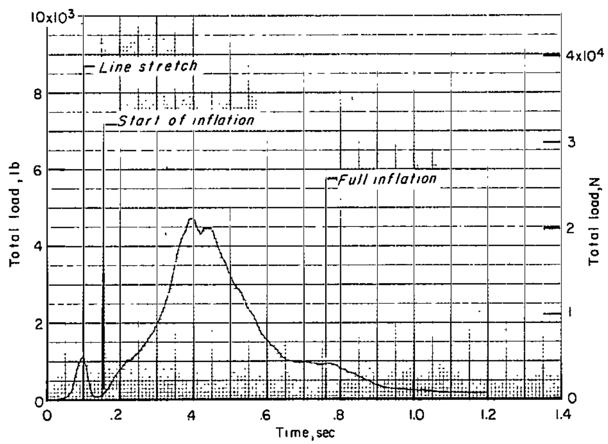
Figure 9.- Continued.



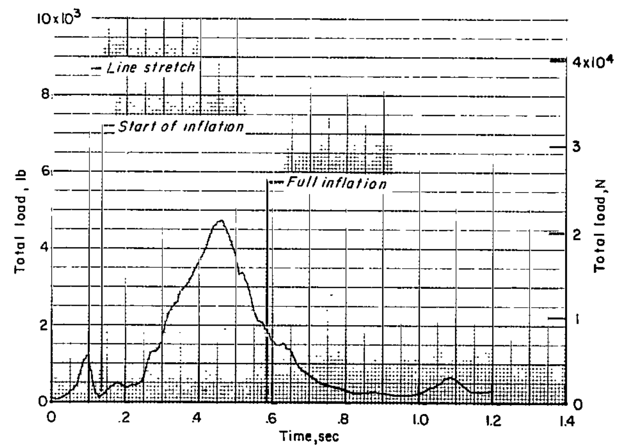
(i) Drop 167; V_p = 202.6 ft/sec (61.8 m/sec).



(j) Drop 168; V_p = 202.6 ft/sec (61.8 m/sec).

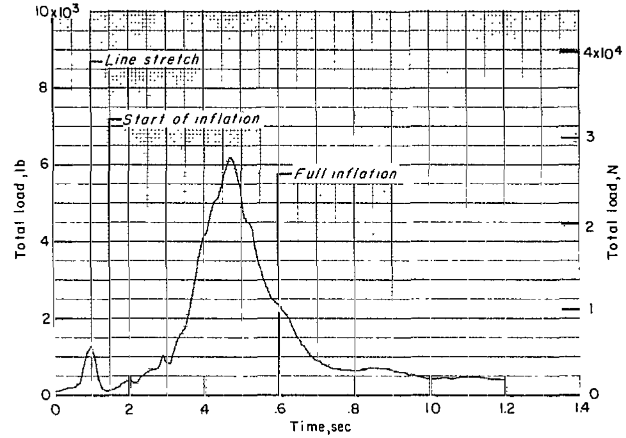


(k) Drop 271; V_p = 202.6 ft/sec (61.8 m/sec).

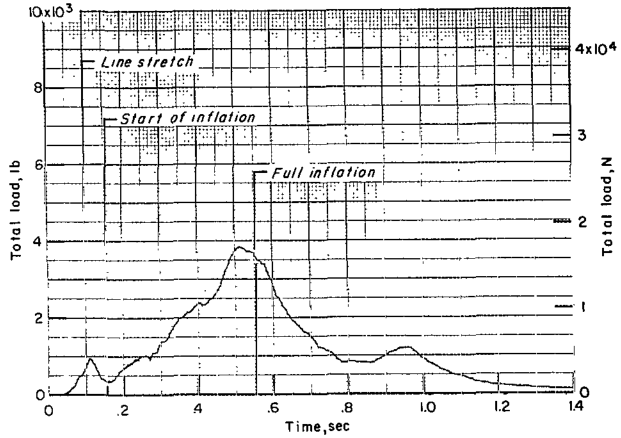


(l) Drop 273; V_p = 236.3 ft/sec (72.0 m/sec).

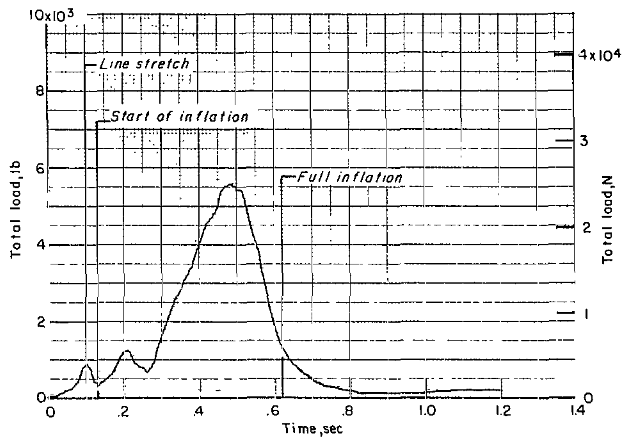
Figure 9.- Continued.



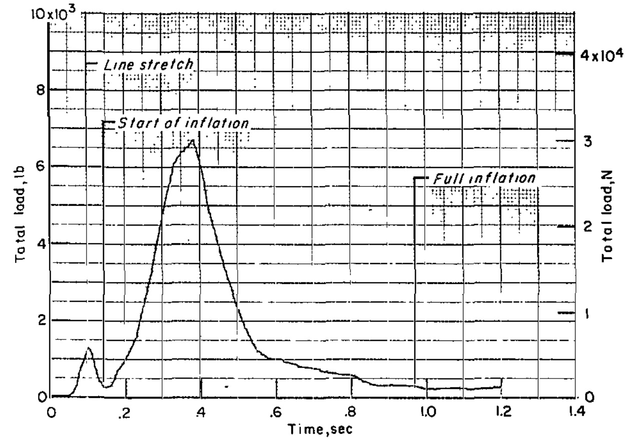
(m) Drop 322; V_p = 236.3 ft/sec (72.0 m/sec).



(n) Drop 323; V_p = 236.3 ft/sec (72.0 m/sec).

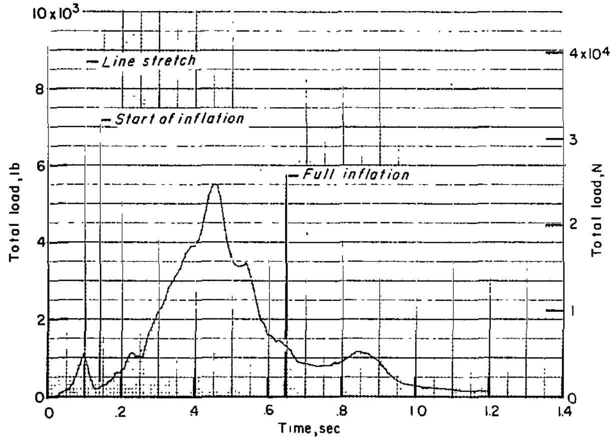


(o) Drop 324; V_p = 236.3 ft/sec (72.0 m/sec).

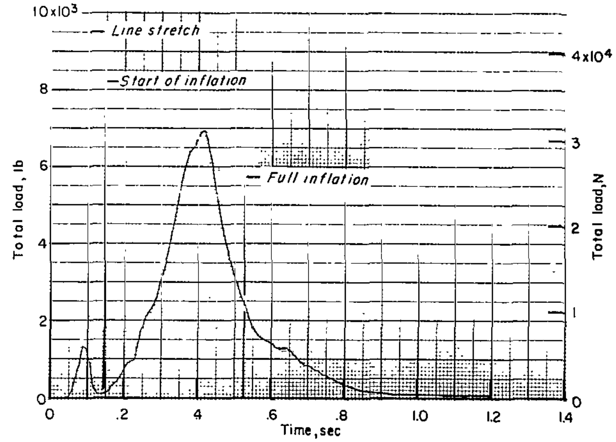


(p) Drop 590; V_p = 236.3 ft/sec (72.0 m/sec).

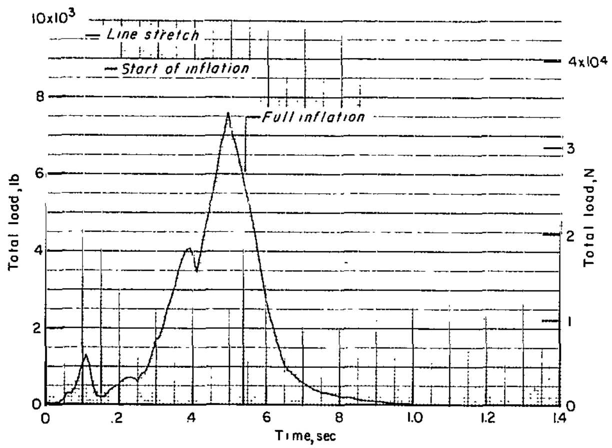
Figure 9.- Continued.



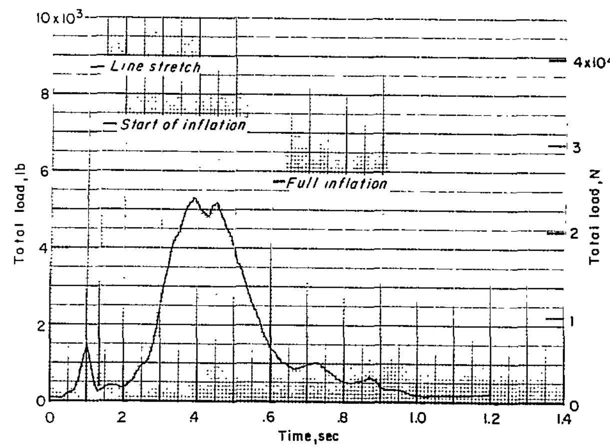
(q) Drop 591; V_p = 236.3 ft/sec (72.0 m/sec).



(r) Drop 592; V_p = 236.3 ft/sec (72.0 m/sec).

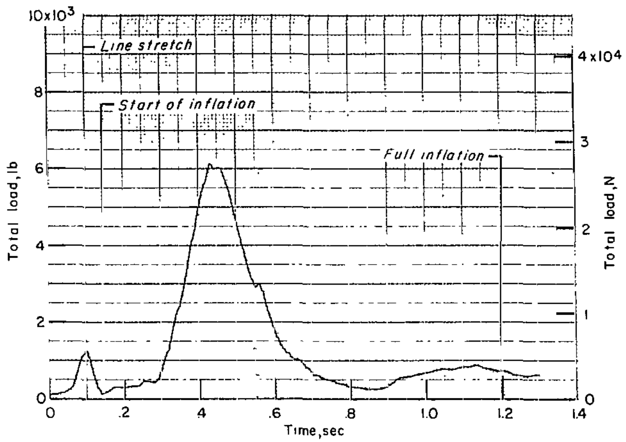


(s) Drop 327; V_p = 270.1 ft/sec (82.3 m/sec).

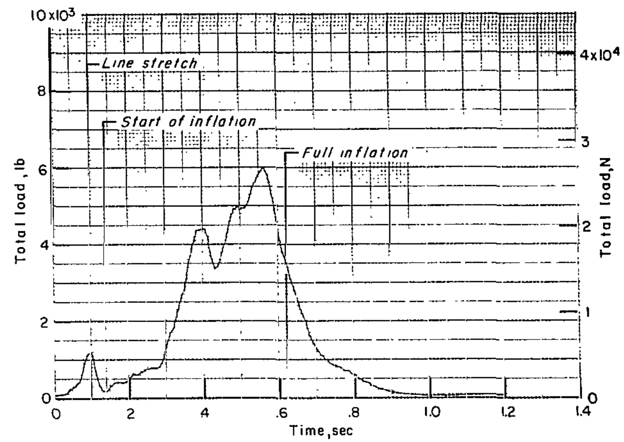


(t) Drop 673; V_p = 270.1 ft/sec (82.3 m/sec).

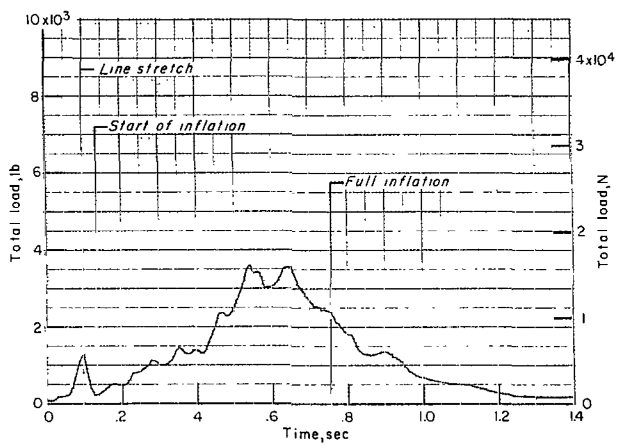
Figure 9.- Continued.



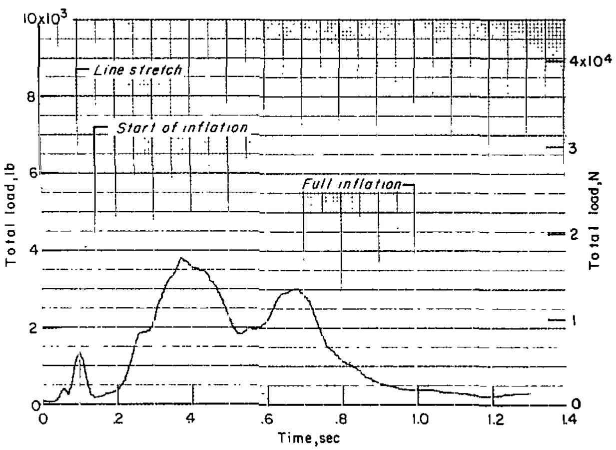
(u) Drop 674; V_p = 270.1 ft/sec (82.3 m/sec).



(v) Drop 675; V_p = 270.1 ft/sec (82.3 m/sec).

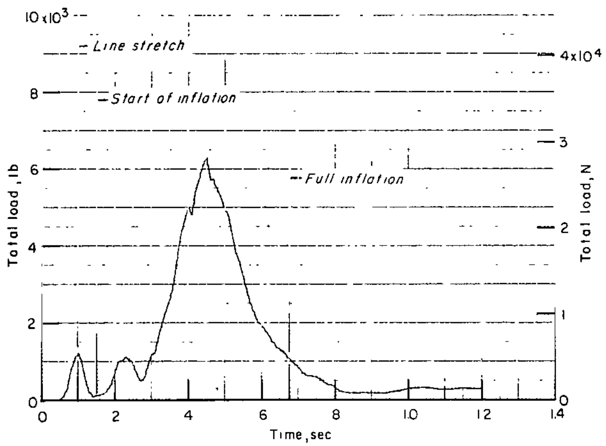


(w) Drop 723; V_p = 270.1 ft/sec (82.3 m/sec).

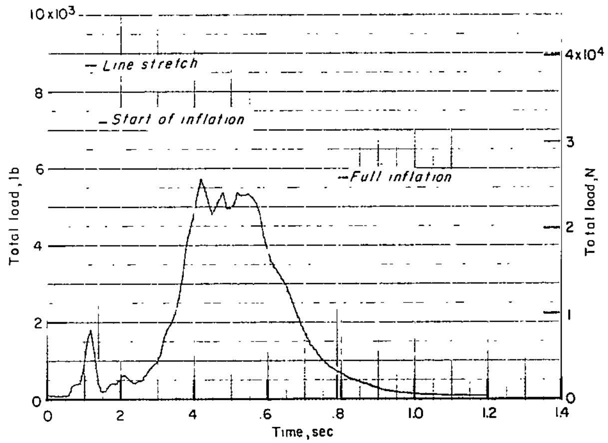


(x) Drop 724; V_p = 270.1 ft/sec (82.3 m/sec).

Figure 9.- Continued.



(y) Drop 725; V_p = 270.1 ft/sec (82.3 m/sec).



(z) Drop 274; V_p = 303.8 ft/sec (92.6 m/sec).

Figure 9.- Concluded.

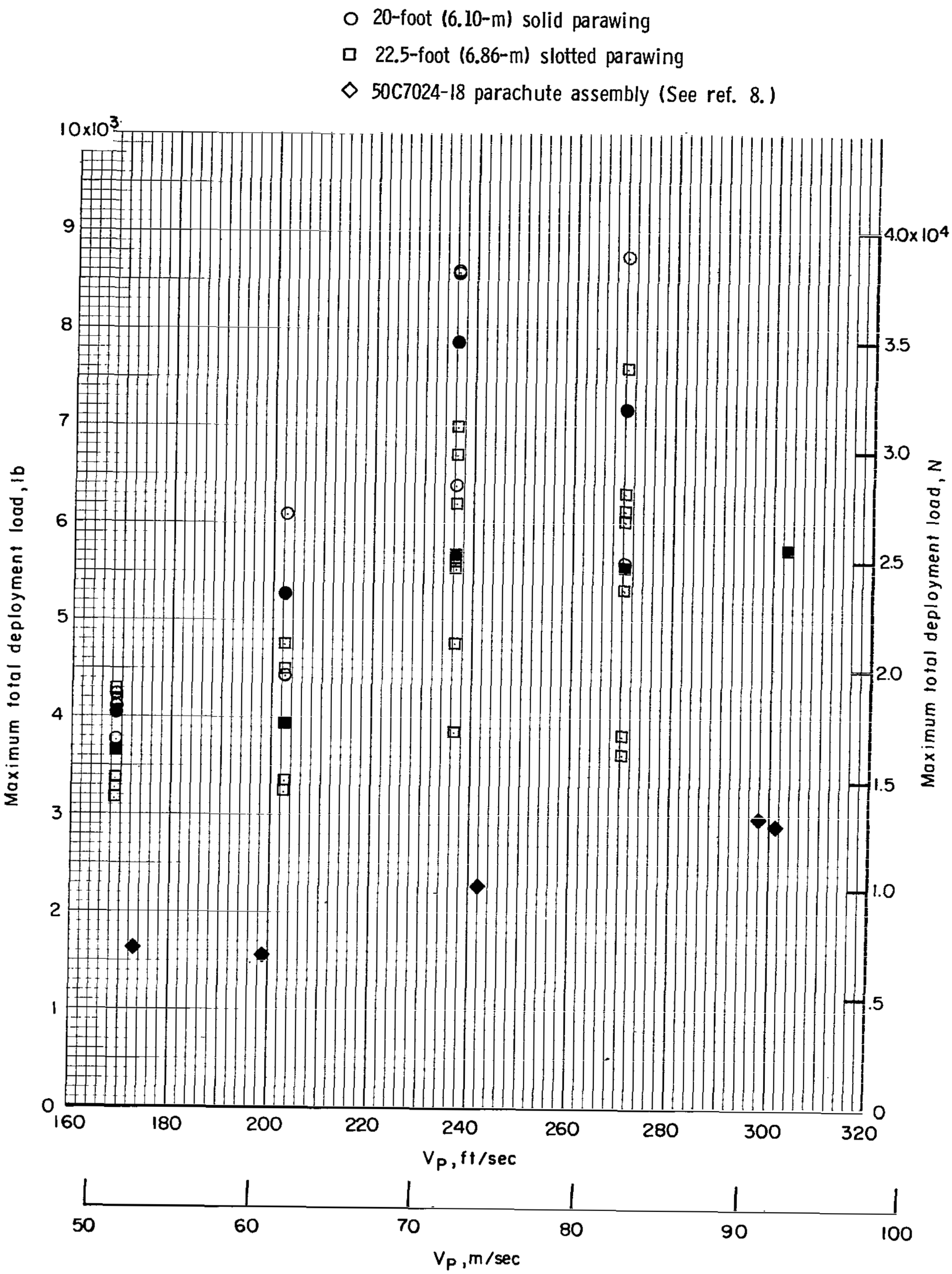
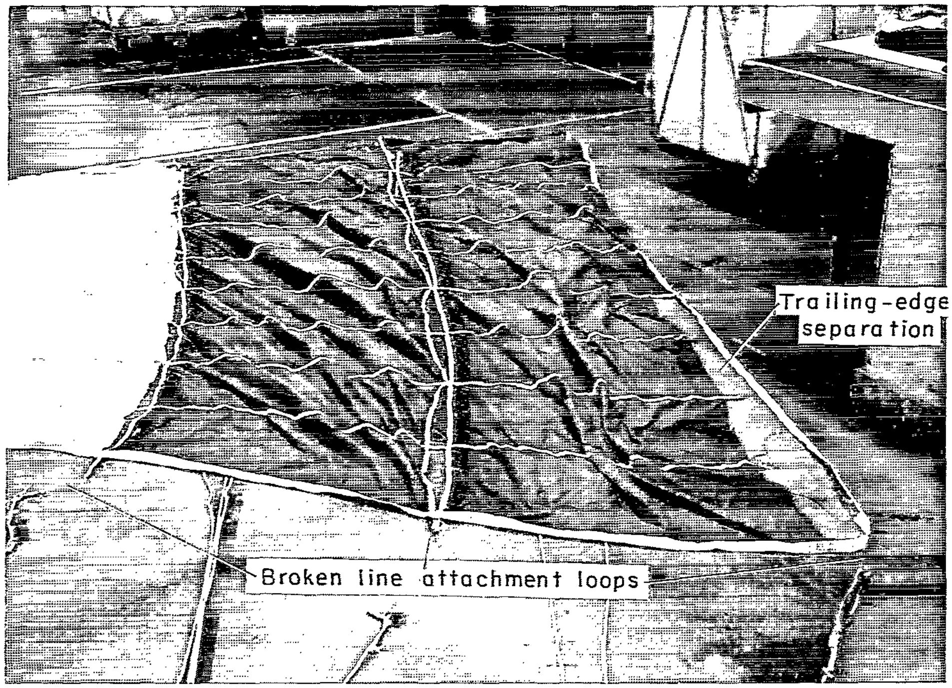
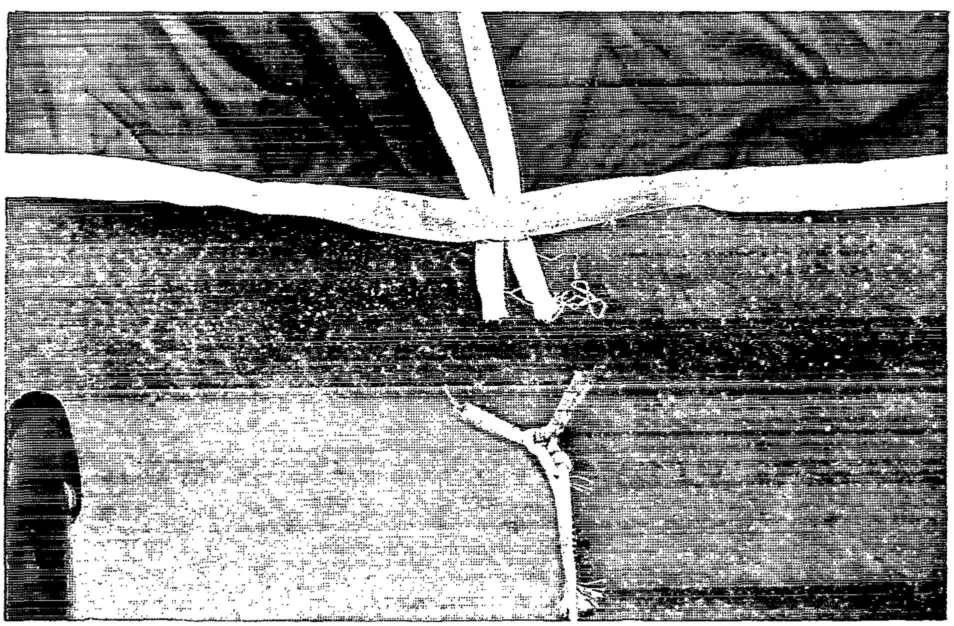


Figure 10.- Comparison of deployment loads of solid and slotted personnel parawings and a personnel parachute. (Solid symbols are averaged values.)



(a) Overall view of the wing damage.



(b) Enlargement of a broken line attachment loop.

L-70-1643

Figure 11.- Photographs of damaged 22.5-foot (6.86-meter) slotted personnel parawing after drop 1267 where V_p = 337.6 ft/sec (103.0 m/sec).

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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