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FLIGHT-TEST RESULTS FROM SUPERSONIC DEPLOYMENT OF AN 18-FOOT-DIAMETER (5.49-METER) TOWED BALLUTE DECELERATOR

by Robert J. Mayhue and Clinton V. Eckstrom

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

A ram-air-inflated, towed ballute decelerator having a maximum frontal diameter of 18 feet (5.49 meters) was deployed during free flight at a Mach number of 3.15 and a dynamic pressure of 38.5 lb/ft^2 (1843.4 N/m^2). Deployment and extraction of the test ballute were normal but inflation stopped about 1 second after mortar firing and produced an average plateau drag force of 1500 pounds (6.7 kN) for about 1 second. Approximately 30 percent of expected total frontal area was obtained.

Examination of a motion-picture film showed no unusual events during initial filling of the ballute; however, shortly after ballute growth stopped, failure of the fabric at one inlet leading edge was observed. A large aft-end rip also became evident after decay of the plateau drag forces later in the flight. It is postulated that incomplete filling of the test ballute may have been caused by prolonged whipping action of the envelope fabric which prevented sufficient inlet exposure, eventually led to inlet failure, and may have contributed to an aft-end rip during the initial inflation process.

INTRODUCTION

Aerodynamic braking of spacecraft during entry into tenuous planetary atmospheres may not be adequate to achieve subsonic terminal conditions required for initiation of soft-landing systems. One method of entry for these missions is to activate an inflatable aerodynamic decelerator system at appropriate altitudes to extract and decelerate an instrumented package to desired terminal conditions. For entry into a low-density atmosphere such as Mars, a decelerator system may be required that is capable of deployment and inflation within an environment of high Mach number and low dynamic pressure combinations. In addition, weight and packing volume restrictions for the decelerator system will dictate the use of lightweight fabrics which can be tightly packed and subsequently inflated to large drag areas.

One promising supersonic decelerator configuration for low-density operation is a ram-air-inflated cone-balloon device, commonly referred to as a ballute. Test results at dynamic pressures greater than 160 lb/ft^2 (7661 N/m^2) indicate satisfactory supersonic performance for ballute sizes up to a maximum diameter of 5 feet (1.52 meters). (See refs. 1 and 2.) For lower dynamic-pressure applications, however, no experimental information is available on the effects of scaling ballute parameters up to the larger drag areas required while maintaining a relatively lightweight structure for planetary entry missions.

In order to determine the supersonic performance characteristics of a large, lightweight ballute decelerator, the Langley Research Center has conducted an exploratory flight test of a ram-air-inflated, towed ballute having a maximum frontal diameter of 18 feet (5.49 meters). (This flight test was part of the NASA Planetary Entry Parachute Program.) Test objectives for the experiment were selected to simulate supersonic deployment of a decelerator in a Martian atmosphere, that is, Mach number of 4 at a dynamic pressure of 40 lb/ft^2 (1915 N/m^2).

The purpose of this paper is to present a description of the ballute decelerator system, flight-test techniques, and results obtained. A motion-picture supplement (L-1045) showing deployment and inflation processes is available on loan. A request card and description of the film are included at the back of this paper.

SYMBOLS

g — acceleration due to gravity (1g = 9.807 m/sec^2)

L — total length of inflated ballute including riser, feet or inches (meters)

R — maximum radius of inflated ballute profile, feet or inches (meters)

r — local radius of inflated ballute profile at station x, feet or inches (meters)

S_p — projected area of ballute from film data, feet^2 (meters^2)

$S_{p,f}$ — projected area of fully inflated ballute including burble fence, feet^2 (meters^2)

t' — time from mortar firing, sec

x — longitudinal station of inflated ballute profile from apex of keeper ring, feet or inches (meters)

ϕ — local slope of inflated ballute profile, degrees

DESCRIPTION OF TEST BALLUTE DECELERATOR

A detailed description of the design concepts and development of the test ballute is presented in reference 3. The primary characteristics and geometry of the configuration are shown in figure 1. The ballute decelerator had an inflated envelope diameter of 15 feet (4.57 meters) and an inflatable torus (called a burble fence), which gave an overall frontal diameter of 18 feet (5.49 meters). Eight ram-air inlets, comprised of 10-inch-diameter (25.4-cm) circular ducts with spring-reinforced leading edges, were attached to the ballute near the burble fence to provide full inflation within 1 to 2 seconds after deployment. Total inflated volume for the design envelope was estimated to be 2240 ft^3 (63.4 m^3).

The burble fence was incorporated to ensure uniform flow separation for stability through the subsonic and transonic speed ranges. The height of the burble fence was equal to 10 percent of the maximum diameter above the projection of a half profile, or 1.5 feet (0.46 meter). The location and height of the burble fence were selected on the basis of flow-field estimations as outlined by the principles presented in reference 4.

The ballute profile was defined by joining two curves derived to provide constant fabric stress and constant meridian tension for a particular design pressure distribution. The front and back curves had a common boundary which was the maximum equatorial diameter of 15 feet (4.57 meters). Profile coordinates for the front part of the ballute are given in figure 1. The ballute envelope was fabricated from 16 gores and 48 meridian straps which were continuous to form the ballute riser. The envelope fabric was single-ply high-temperature nylon material with an elastomeric coating. Overall material weight (mass) of the fabric was 2.55 oz/yd^2 (0.08644 kg/m^2). Estimated weights of the test ballute components (ref. 3) are presented in the following table:

Test-ballute weight breakdown		
Item	Weight	
	lb	kg
Ballute envelope	17.77	8.06
Meridians	8.36	3.79
Burble fence	6.11	2.77
8 inlets	4.00	1.81
Riser line	1.00	.45
Total	37.24	16.88

Overall packed weight of the ballute system, including the deployment bag, was 38 pounds (17.25 kg). The packed decelerator system was installed within a mortar having a volume of 1.0 ft^3 (0.03 m^3). The packed ballute and deployment bag were subjected to a heat cycle representative of part of the sterilization requirements for equipment used in interplanetary spacecraft. These test requirements were established so that the effects of heat degradation on material properties would be simulated during the flight test.

DESCRIPTION OF FLIGHT-TEST TECHNIQUE

The launch vehicle for the ballute test was an Honest John—Nike—Nike booster system with a payload configuration as illustrated in figure 2. The ballute was attached to the towing payload through a swivel and tensiometer. The fact that the ratio of decelerator diameter to overall payload base diameter (including pods) was 7.7 would indicate a negligible influence of the payload wake on the ballute flow field. (See ref. 4.) Geometry of the payload consisted of a blunt-cone—cylinder—flare combination with three aft pods housing a rearward-facing camera and two recovery parachutes. The diameter of the payload base, including the camera pods, was 28 inches (71 cm). Suspended payload weight was about 245 pounds (111 kg) including attachment bridle and tensiometer. Reference 5 presents a detailed description of the payload and onboard instrumentation (including three-axis accelerometer and gyro platform, forward- and rearward-facing cameras, and tensiometer).

Sequence of flight events is shown in figure 3. Test conditions for ballute deployment were attained on ascent after final Nike stage thrusting. Mortar firing for ballute deployment was initiated by ground command.

TEST RESULTS AND DISCUSSION

Mortar firing for ballute deployment was initiated at 55.94 seconds after launch (zero time) which gave a deployment flight environment of Mach number 3.15 at a dynamic pressure of 38.5 lb/ft^2 (1843.4 N/m^2). Figure 4 presents time histories of relative velocity and altitude after lift-off. Time histories of free-stream dynamic pressure, Mach number, and true airspeed after mortar firing are presented in figures 5 and 6.

Ballute Deployment and Inflation Results

Significant events that occurred during deployment and inflation of the test ballute are summarized in the photographs of figure 7. Time histories of the payload accelerations and tensiometer forces measured after mortar firing are shown in figures 8 and 9, respectively.

The photographs, taken with the rearward-facing camera, and corresponding tensiometer forces (fig. 7) indicated normal deployment, extraction, and filling of the test ballute up to about 1 second after mortar firing. Then ballute growth appeared to stop and an average plateau drag force of 1500 pounds (6.7 kN) was maintained during the time interval between about 1 and 2 seconds. The maximum force anticipated at full inflation was of the order of 3800 pounds (17 kN). A sudden drop in the drag force then occurred, followed by a slow decay to approximately 300 pounds (1.3 kN) for the duration of the flight.

Analysis of Ballute Inflation

The payload longitudinal accelerations shown in figure 8, as well as the comparison of time histories of tensiometer forces in figure 9 with a typical ballute inflation envelope, verified normal inflation of the ballute up to about 0.7 second after mortar firing. About this time, the rate of change of ballute growth decreased until no further filling could be observed beyond 1 second after mortar firing. (See fig. 7, photograph 6.) After ballute growth stopped, a structural failure occurred at about 1.3 seconds, as shown by photograph 7 of figure 7. This failure consisted of an inlet reinforcement spring parting from the fabric at the leading edge and flailing at the end of the inlet erection straps. Up to this time, no other structural damage could be observed from the film as illustrated by the selected photographs of figure 10.

Figure 11 shows that 30 percent of the expected total frontal area was achieved from initial filling, and was maintained over a 1-second time interval. During this time interval, inlet failures were observed but there was no evidence of failure of the basic ballute envelope fabric. The first definite photographic evidence of envelope fabric failure was in the form of a large aft-end rip which was noted approximately 34 seconds after mortar firing, as shown in figure 12.

The factors that caused partial filling with subsequent structural failure could not be conclusively determined from the test data. It is believed, however, that the following events may have possibly occurred:

1. After initial filling, a buildup of whipping action of large areas of envelope fabric (observed in the film data, and reflected in the longitudinal measurements of figs. 8 and 9) caused the inlets to be either buried within the fabric or turned to positions of ineffective operation (fig. 10). Prolonged whipping action eventually led to failure of the fabric at the inlet leading edge and little additional filling was achieved. Plateau drag forces that were developed from initial inflation pressures were then maintained until an aft-end rip occurred, which spilled most of the volume of air present within the ballute envelope.

2. Development of an aft-end rip occurred during the initial inflation process as the result of fabric whipping action or other unknown causes. This fabric failure offset further inflation through the operating inlets by loss of pressure through the back so that plateau drag forces were maintained over a 1-second interval. Prolonged whipping action of the fabric led to enlargement of the aft-end rip, which spilled the existing volume of air within the ballute envelope.

Ballute Post-Flight Damage Inspection

An inspection of the recovered test ballute revealed three areas of major damage. The first area was the failure of six of the inlet leading-edge reinforcement springs. During flight, these springs entangled in two groups of three rings each as shown in figure 13. The second area of major damage was two parallel tears from the center of the back portion of the ballute down to the burble fence, as shown in figure 14. Four additional tears were located in the forward conical section, two of which are shown in figure 15. The tears in the forward section were not observed in the flight film and therefore probably occurred during the later descent portion of the flight.

SUMMARY OF RESULTS

An 18-foot-diameter (5.49-meter) towed ballute decelerator has been deployed in free flight at a Mach number of 3.15 and a dynamic pressure of 38.5 lb/ft^2 (1843.4 N/m^2). Photographic and tensiometer data indicated normal deployment, extraction, and inflation of the test ballute up to about 1 second after mortar firing. Ballute growth stopped about this time, however, and existing inflation pressures were maintained for about 1 second with approximately 30 percent of the total expected frontal area achieved. The average plateau drag force during this time was 1500 pounds (6.7 kN). A sudden drop in drag force then occurred, followed by a slow decay to about 300 pounds (1.3 kN) for the duration of the flight.

Structural failure of the inlets was observed from the film data at the end of ballute growth, but no photographic evidence of other fabric failure was observed until an aft-end rip became evident after decay of the plateau drag forces. The factors that caused incomplete filling and subsequent structural failure could not be conclusively determined from the available test data. It is postulated, however, that full inflation of the test ballute was not obtained because of the prolonged whipping action of the envelope fabric which prevented sufficient inlet exposure and eventually led to fabric failure at the inlet leading edge. In addition, the excessive whipping action of the ballute may have contributed to an aft-end rip during the initial inflation process which could not be observed from the film data until later in the flight.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 26, 1969,
124-07-03-20-23.

REFERENCES

1. Alexander, William C.; and Lau, Richard A.: State-of-the-Art Study for High-Speed Deceleration and Stabilization Devices. NASA CR-66141, 1966.
2. Usry, J. W.: Performance of a Towed, 48-Inch-Diameter (121.92-cm) Ballute Decelerator Tested in Free Flight at Mach Numbers From 4.2 to 0.4. NASA TN D-4943, 1969.
3. Anon.: PEPP Ballute Design and Development. NASA CR-66585, 1967.
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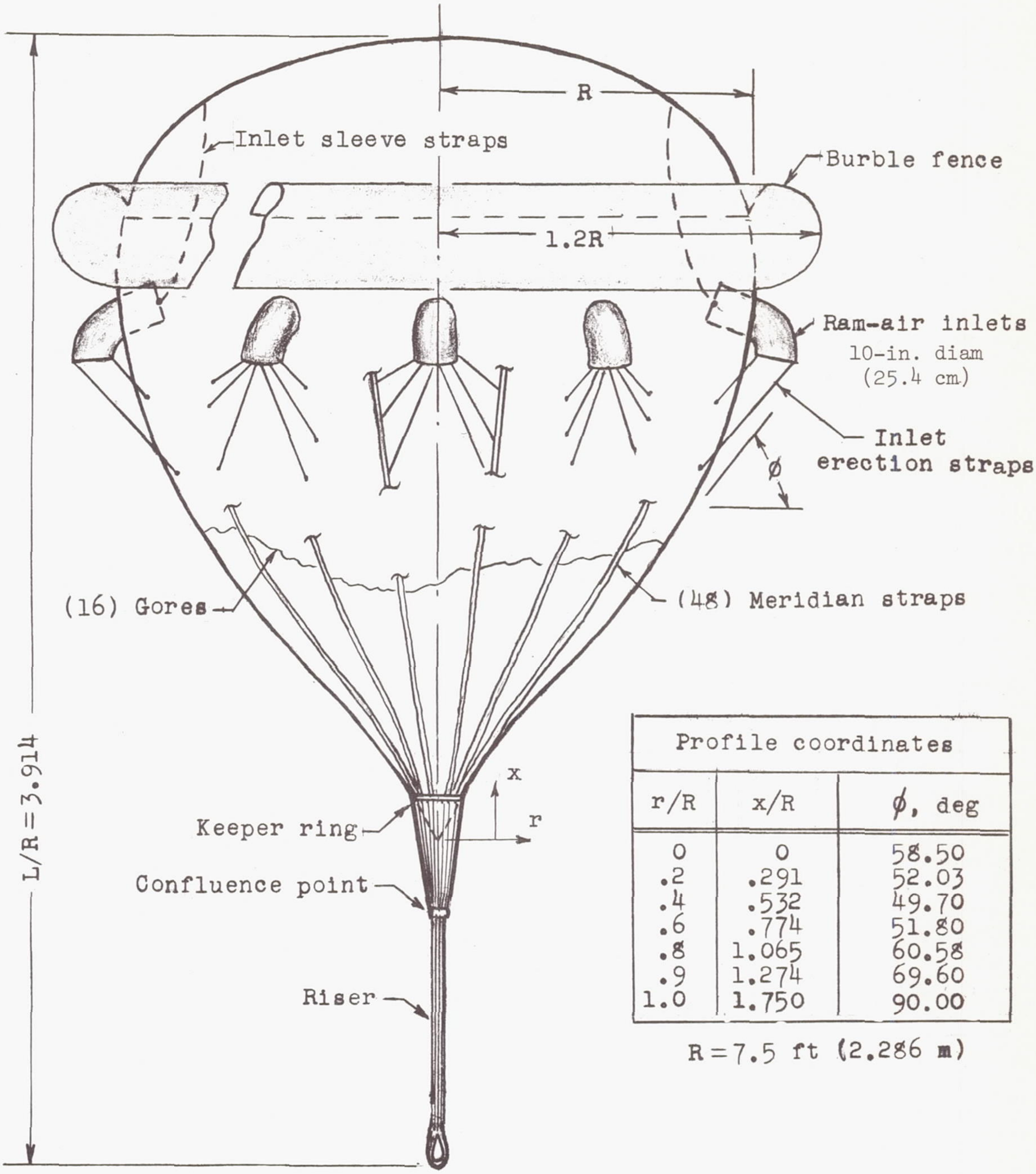
5. Preisser, John S.; Eckstrom, Clinton V.; and Murrow, Harold N.: Flight Test of a 31.2-Foot-Diameter Modified Ringsail Parachute Deployed at a Mach Number of 1.39 and a Dynamic Pressure of 11.0 Pounds Per Square Foot. NASA TM X-1414, 1967.



Profile coordinates		
r/R	x/R	ϕ, deg
0	0	58.50
.2	.291	52.03
.4	.532	49.70
.6	.774	51.80
.8	1.065	60.58
.9	1.274	69.60
1.0	1.750	90.00

R = 7.5 ft (2.286 m)

Figure 1.- Decelerator characteristics and geometry.

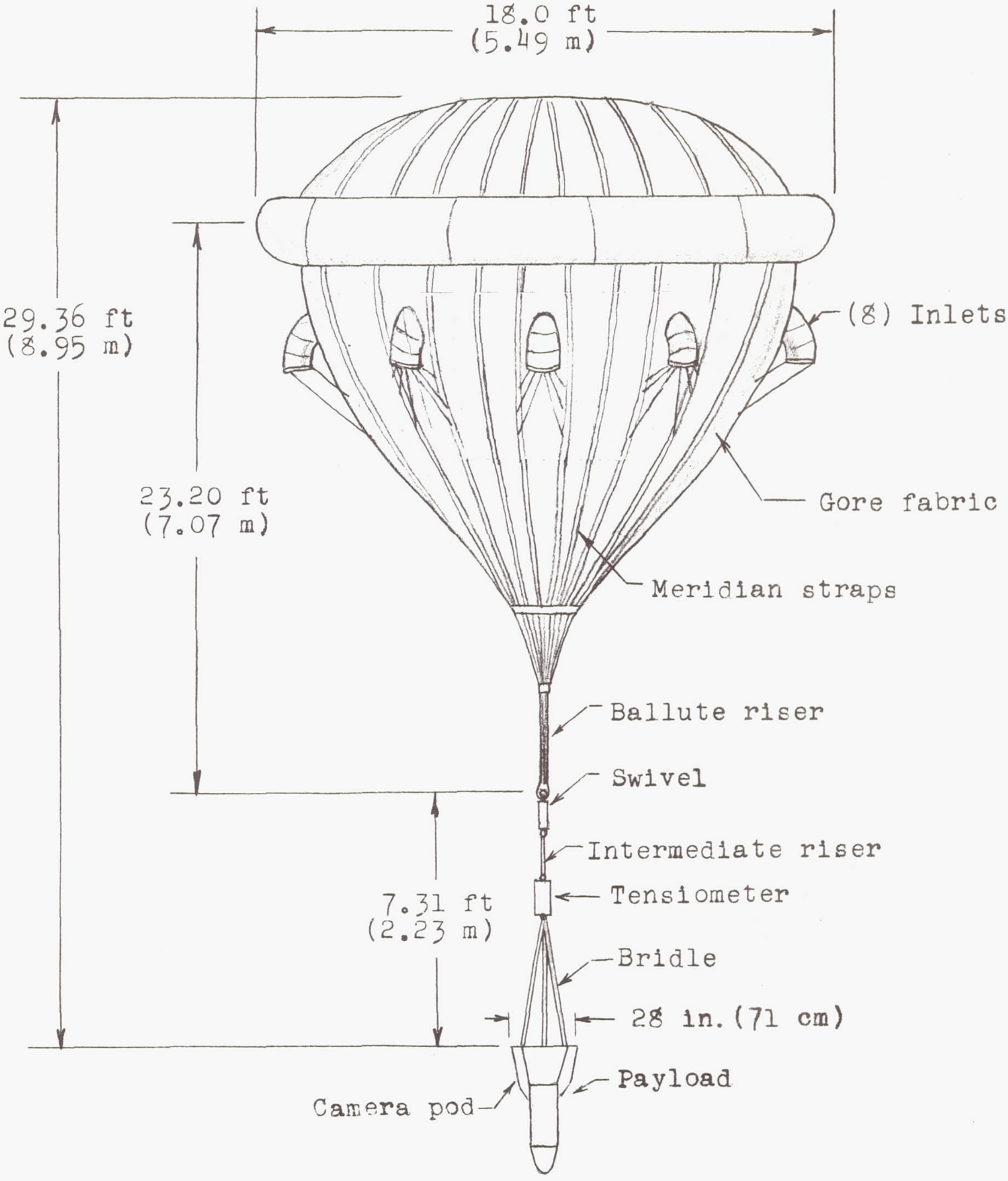
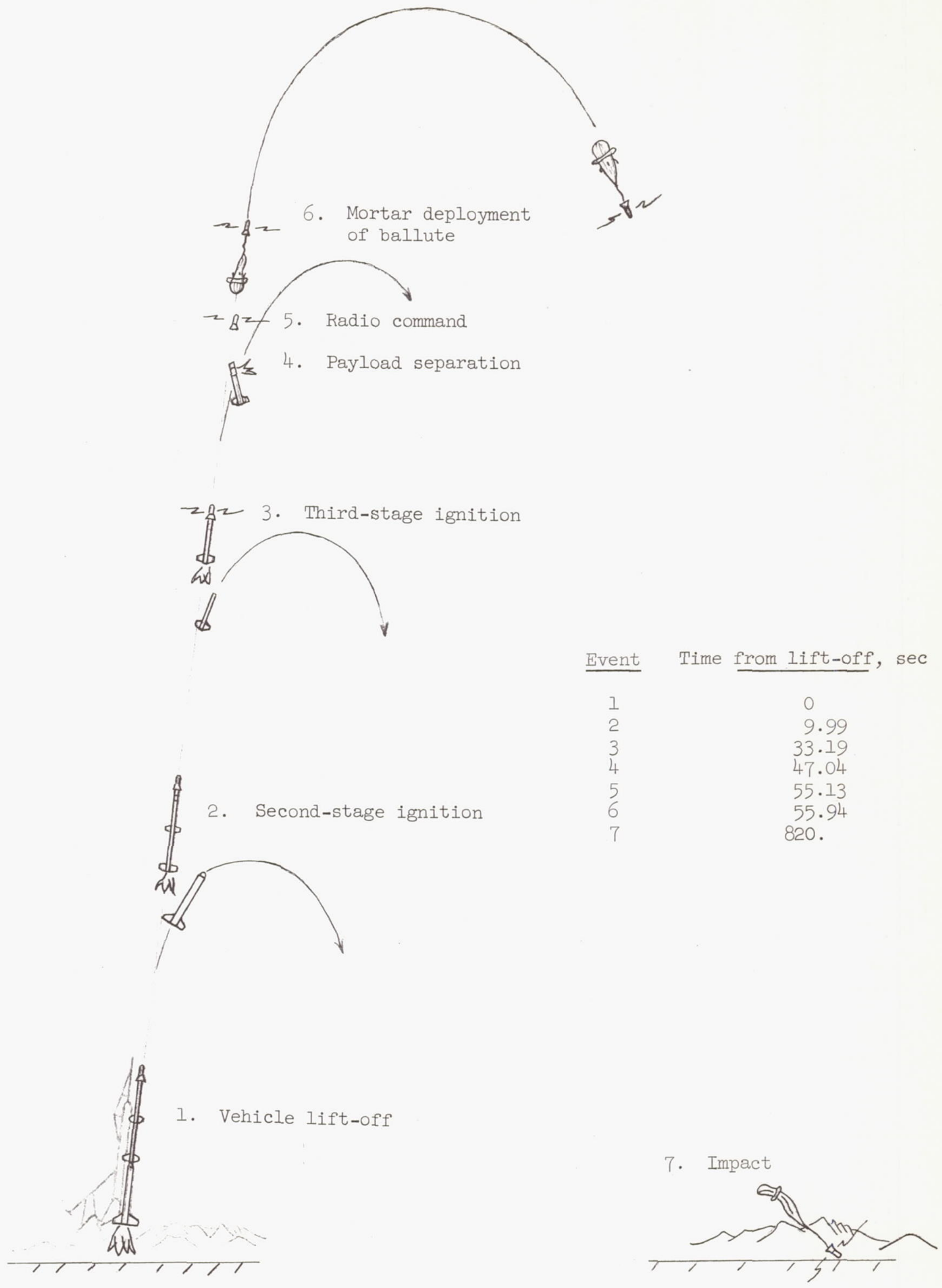


Figure 2.- Rocket-launched test configuration.



Event	Time from lift-off, sec
1	0
2	9.99
3	33.19
4	47.04
5	55.13
6	55.94
7	820.

Figure 3.- Sequence of flight events.

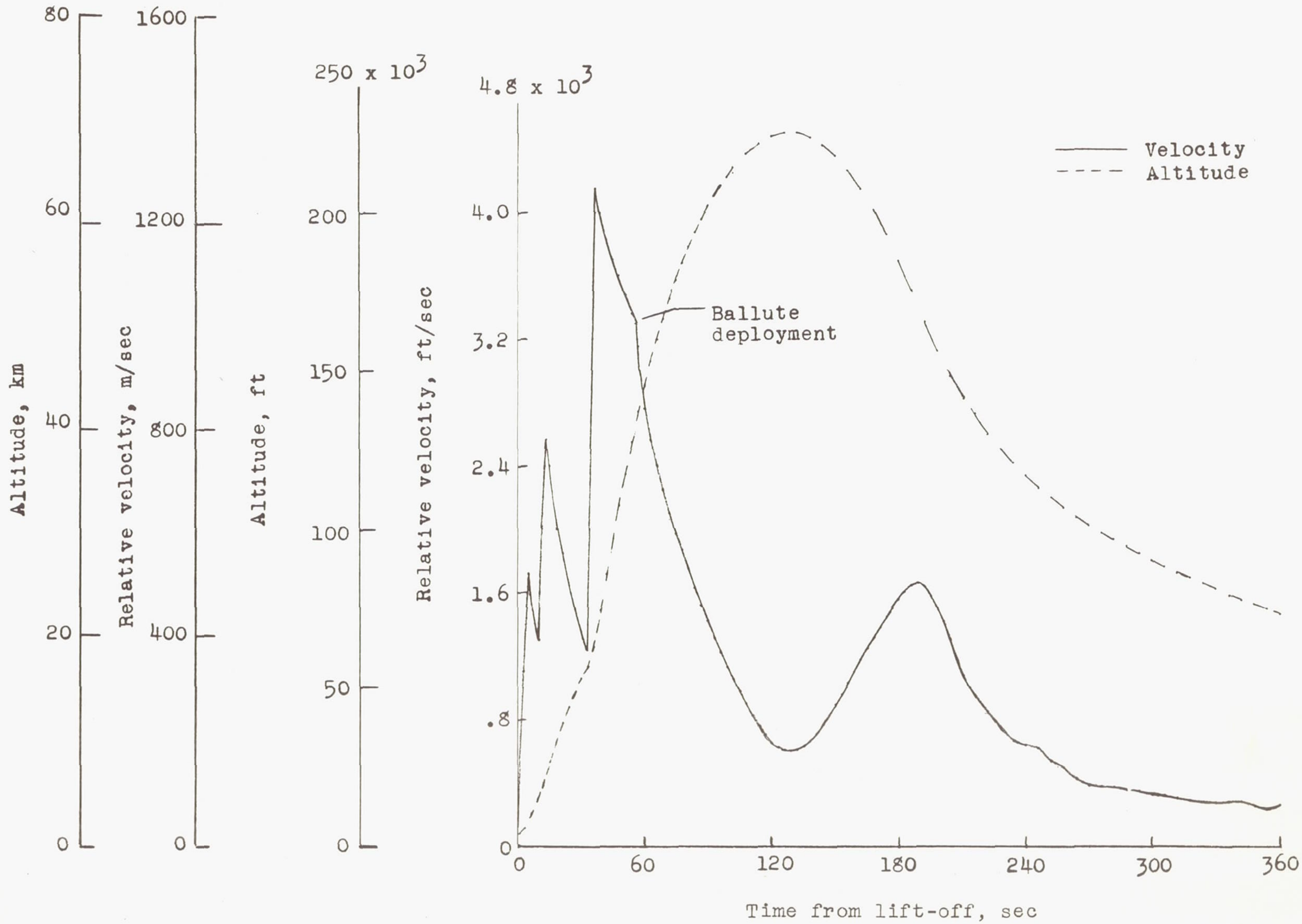


Figure 4.- Time histories of altitude and relative velocity.

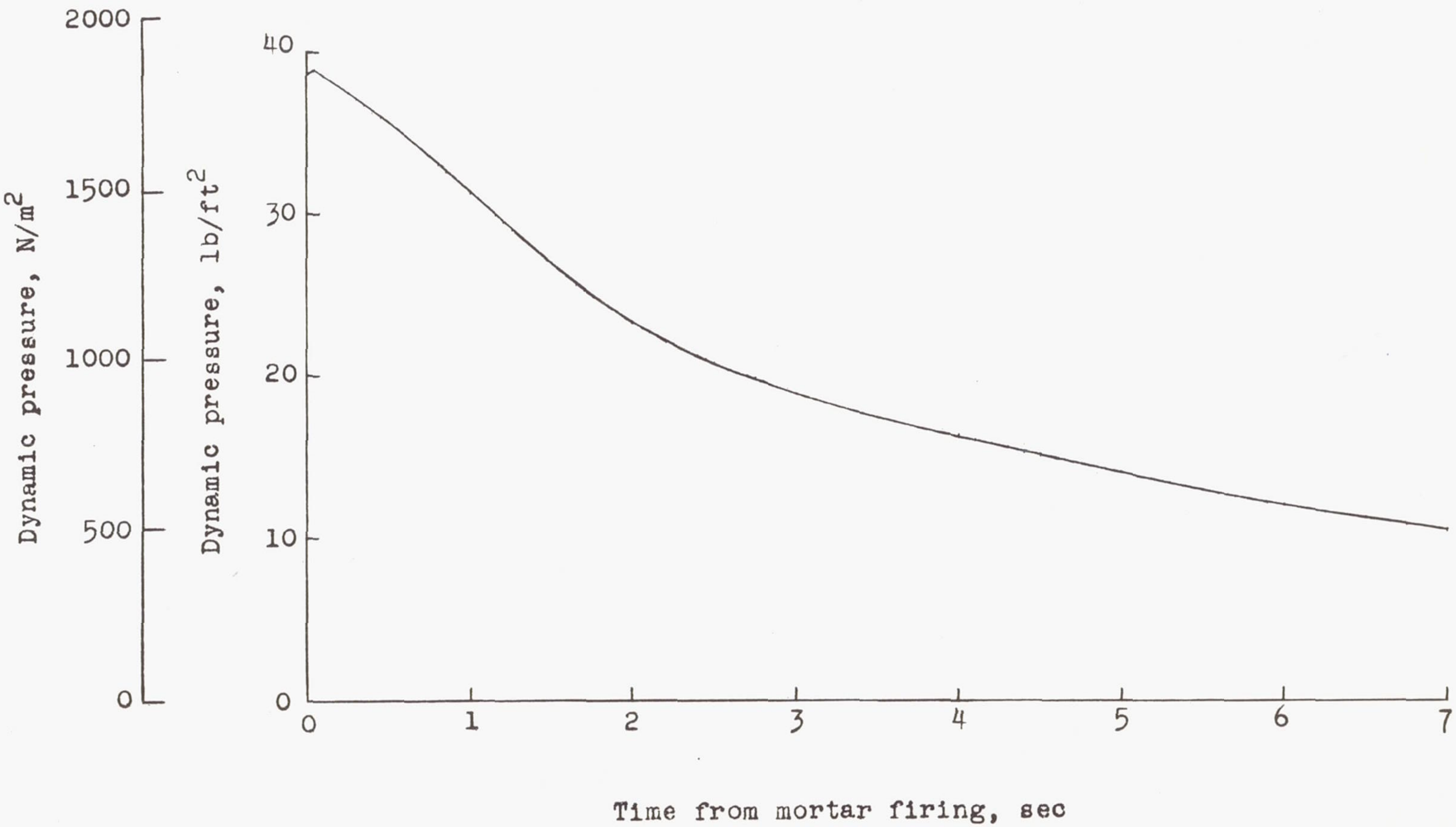


Figure 5.- Time history of free-stream dynamic pressure.

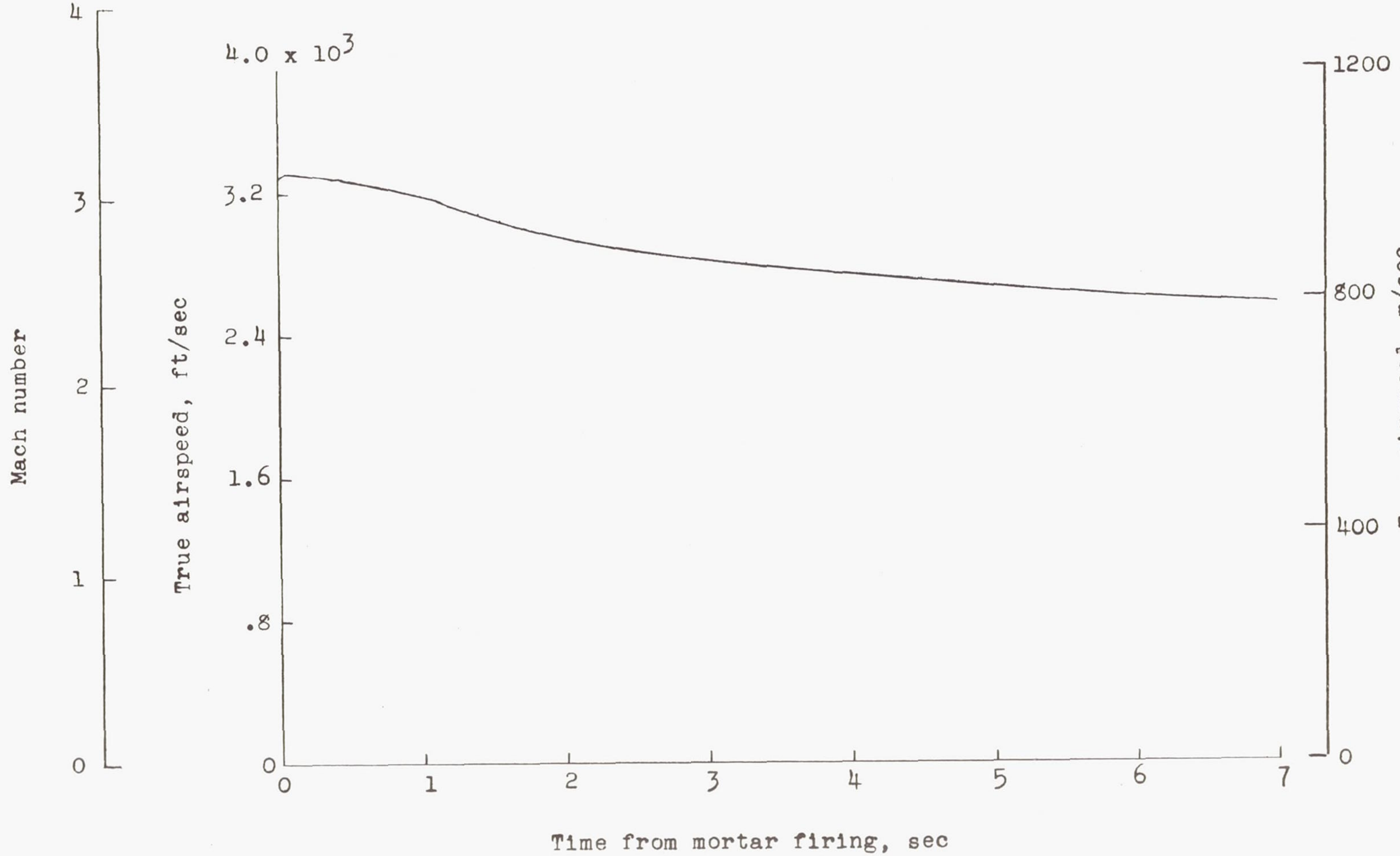


Figure 6.- Time histories of Mach number and true airspeed.

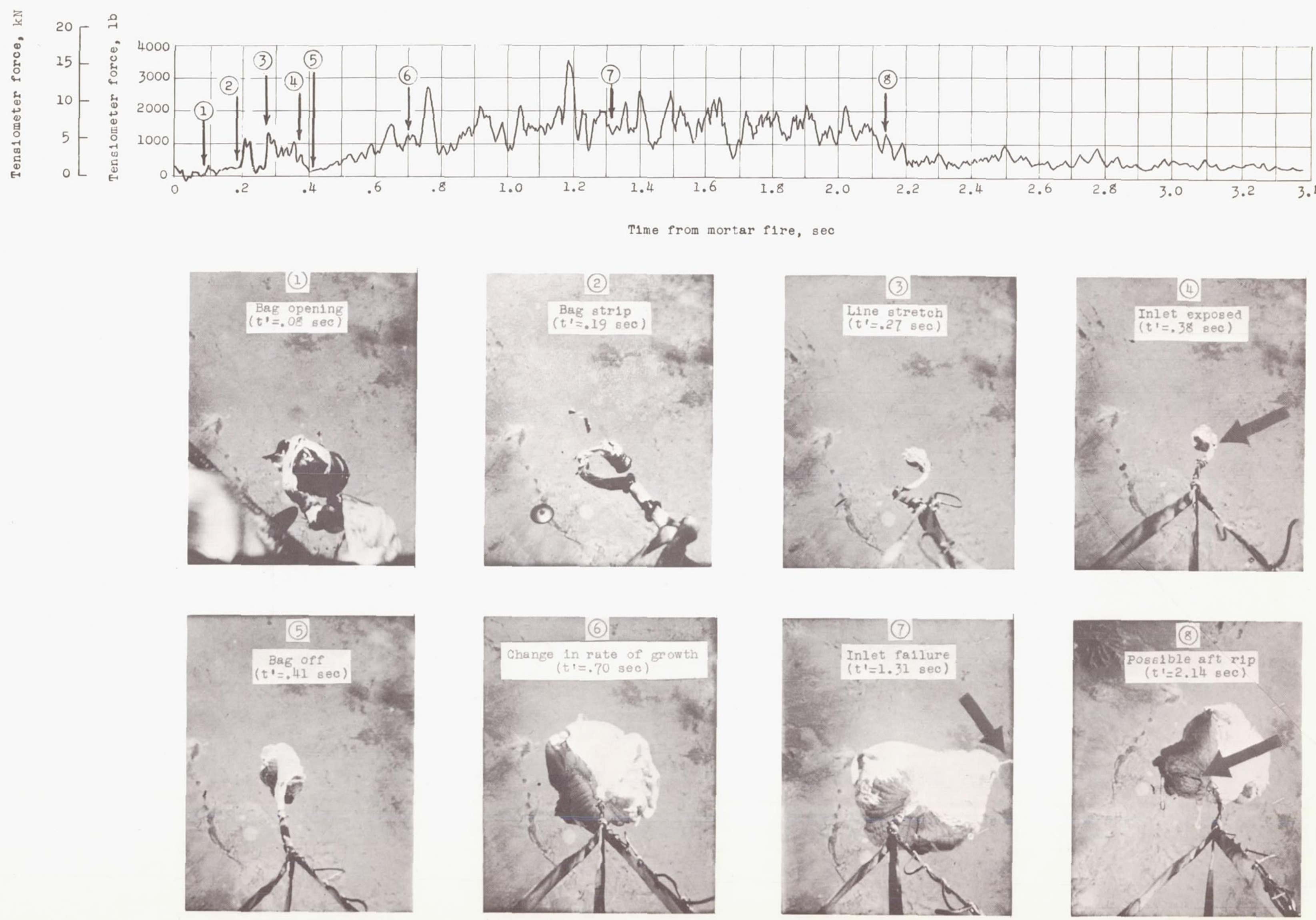


Figure 7.- Photographs of deployment and inflation with tensiometer forces.

L-69-1256

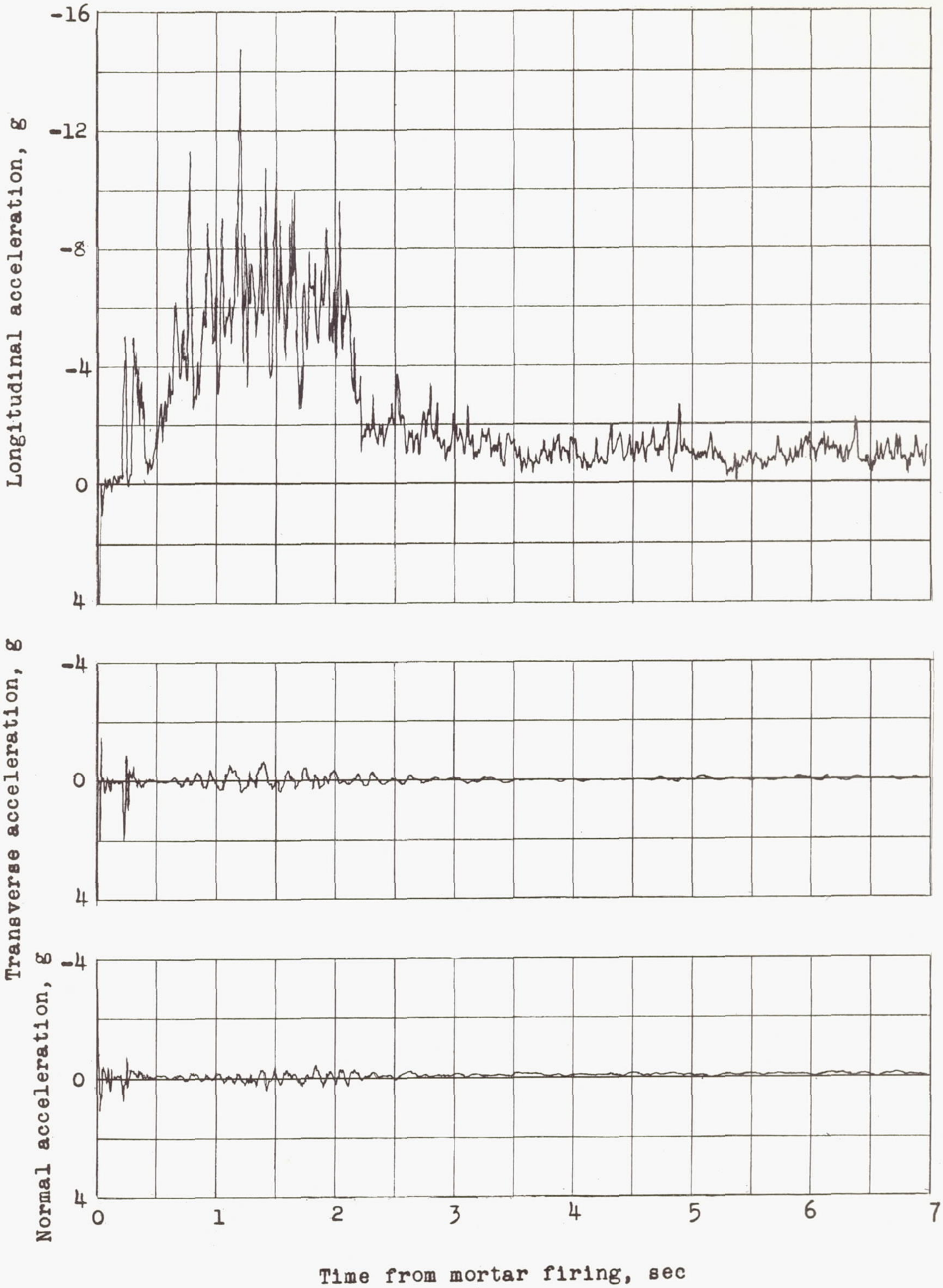


Figure 8.- Time histories of payload accelerations.

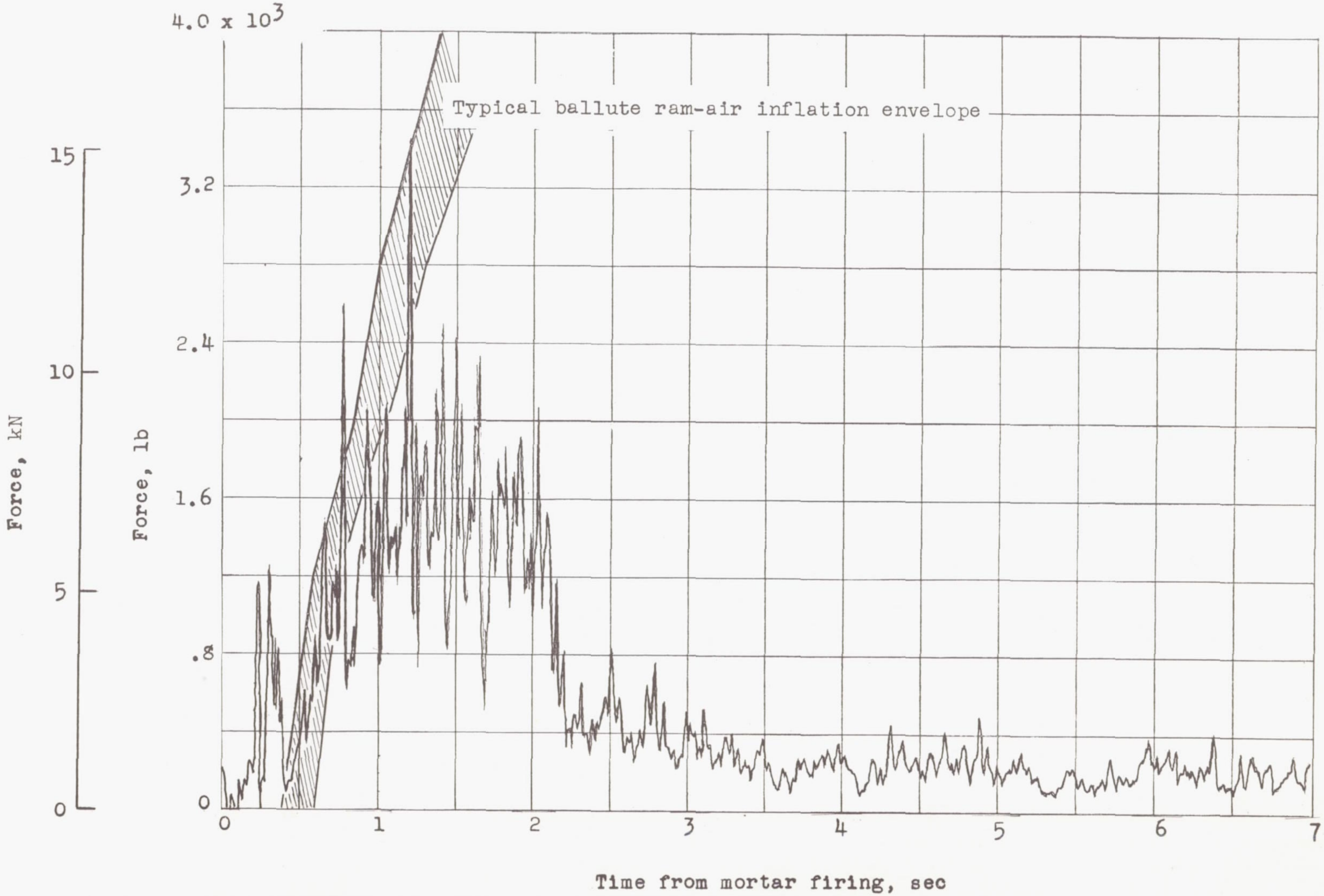
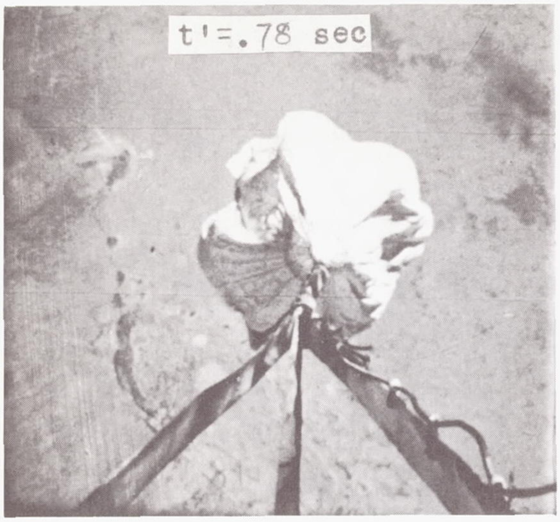
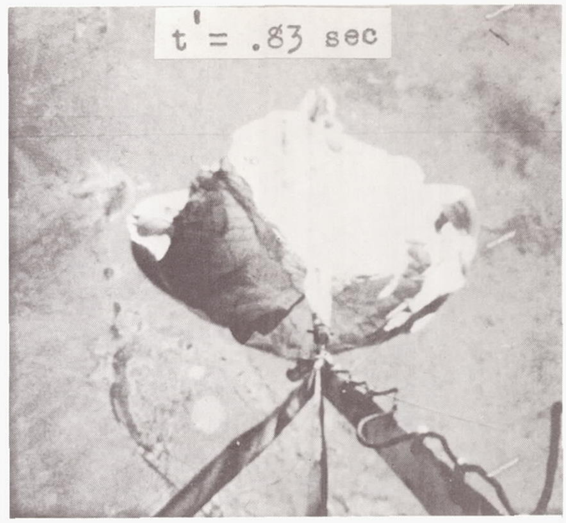


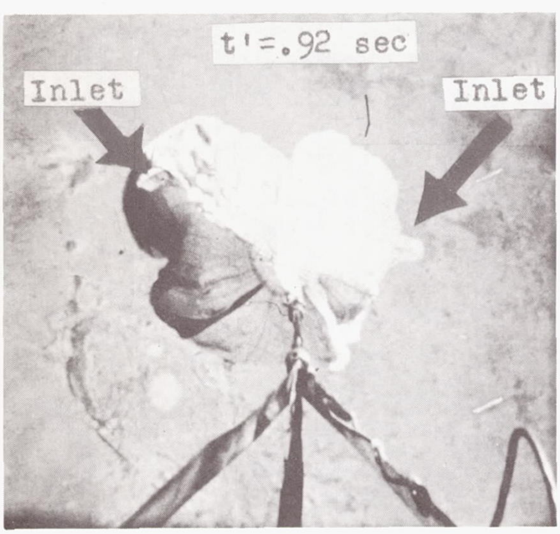
Figure 9.- Time history of tensiometer force measurements.



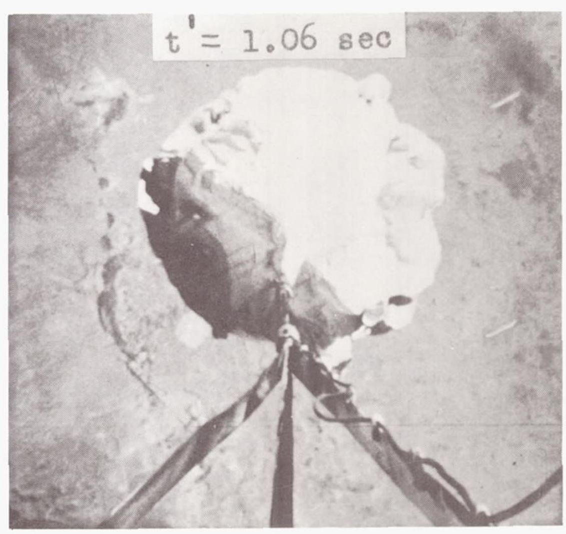
(a) Maximum force, 2600 lb (11.56 kN).



(b) Minimum force, 600 lb (2.67 kN).



(c) Maximum force, 2100 lb (9.34 kN).



(d) Maximum force, 2150 lb (9.56 kN).

Figure 10.- Photographs of ballute inflation prior to inlet failure. L-69-1257

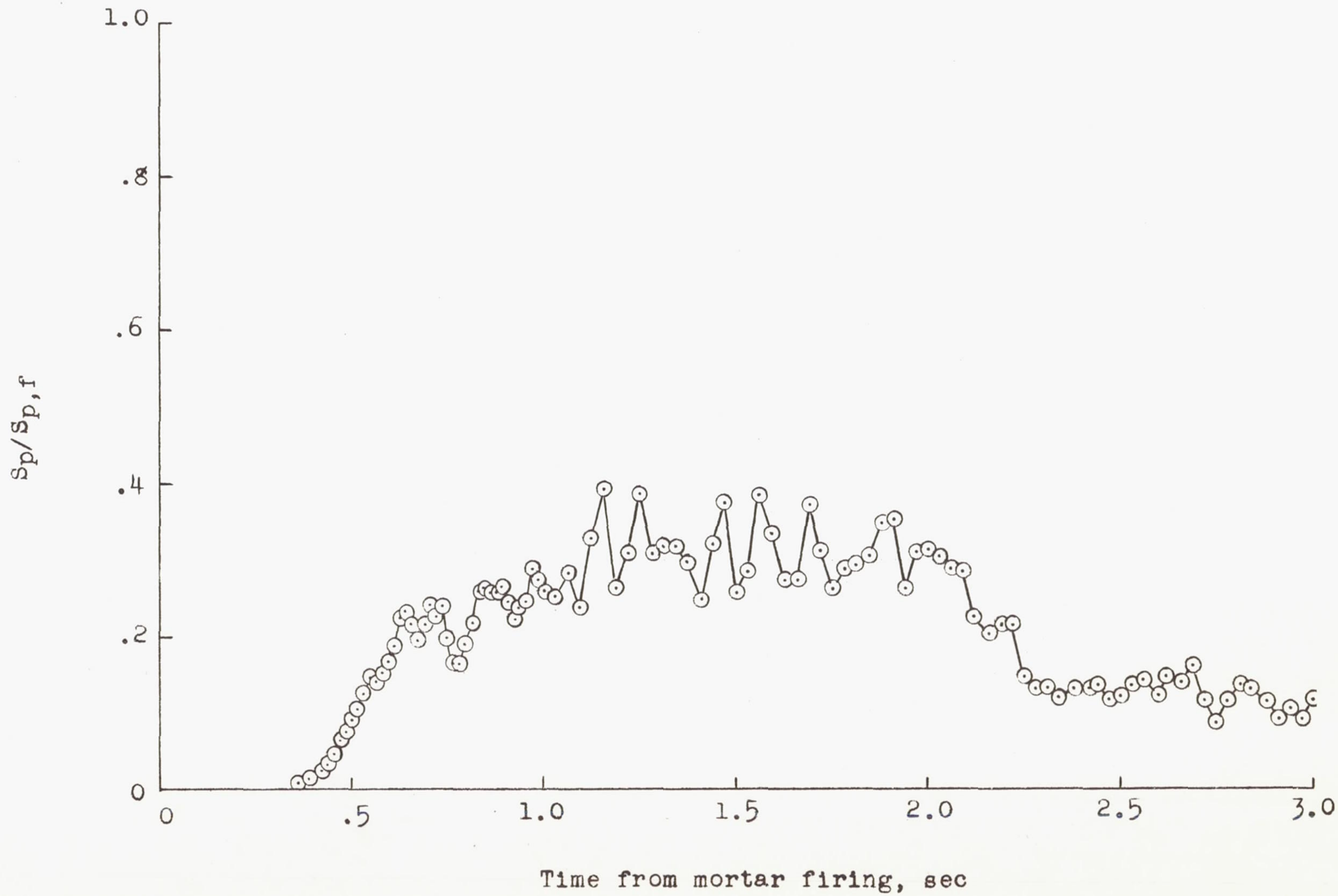


Figure 11.- Time history of projected-area ratio.

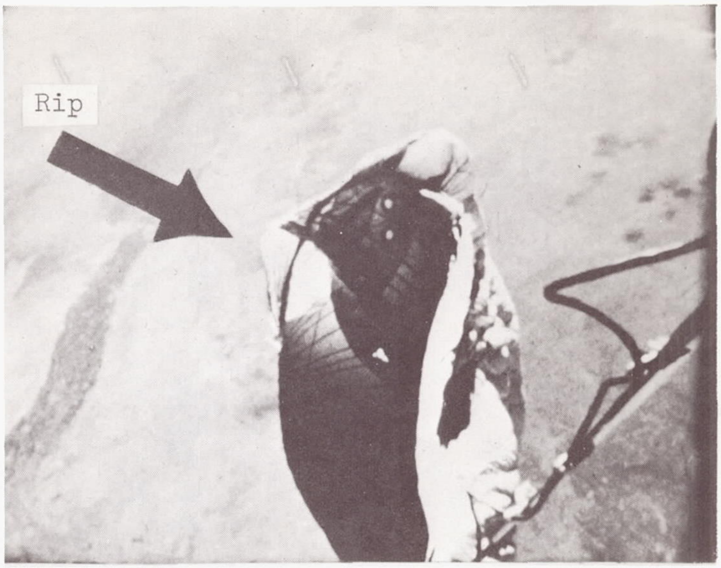


Figure 12.- Photographs of aft-end rips (t' ≈ 34 sec). L-69-1258

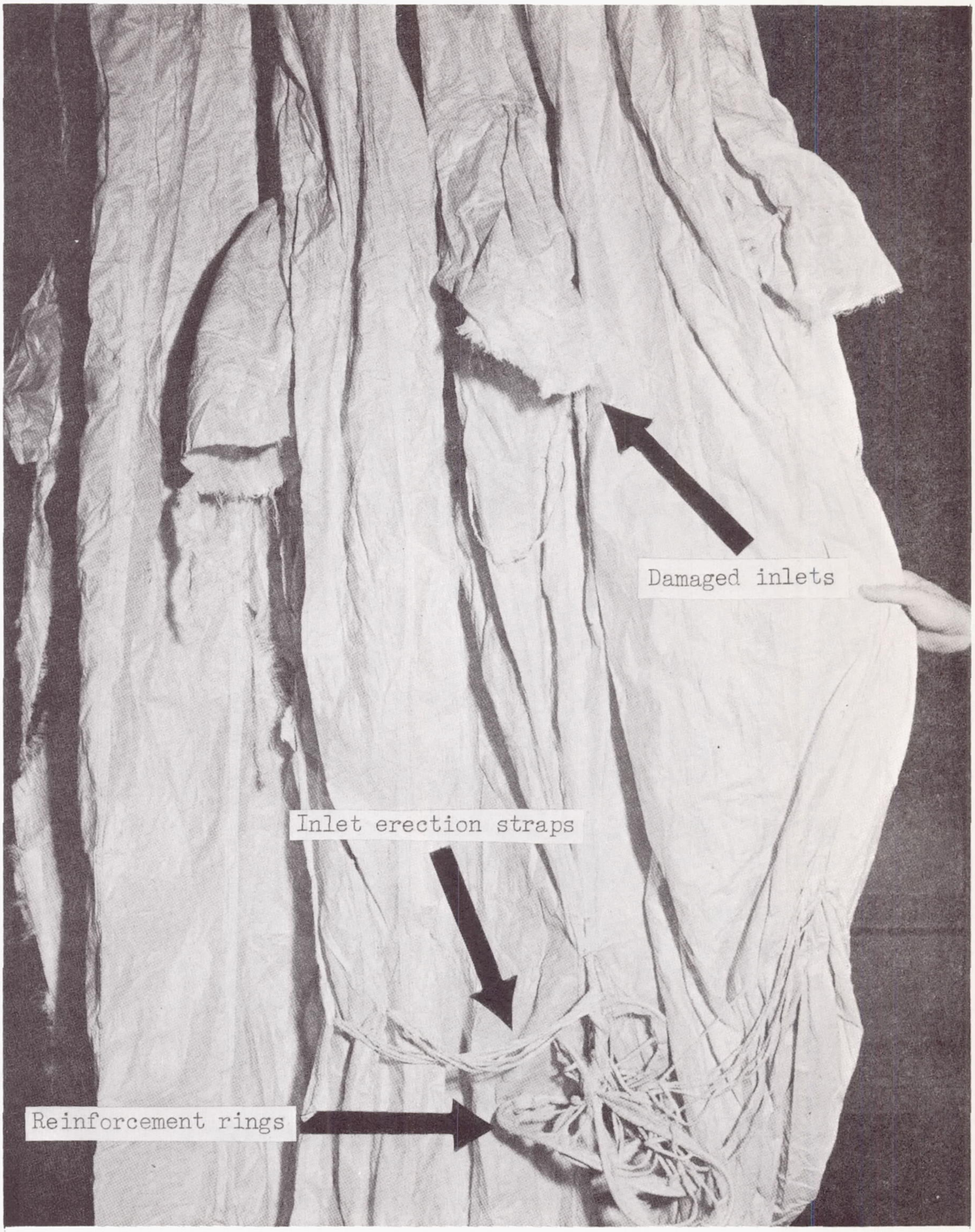


Figure 13.- Failure and entanglement of inlet reinforcement rings. L-69-1259

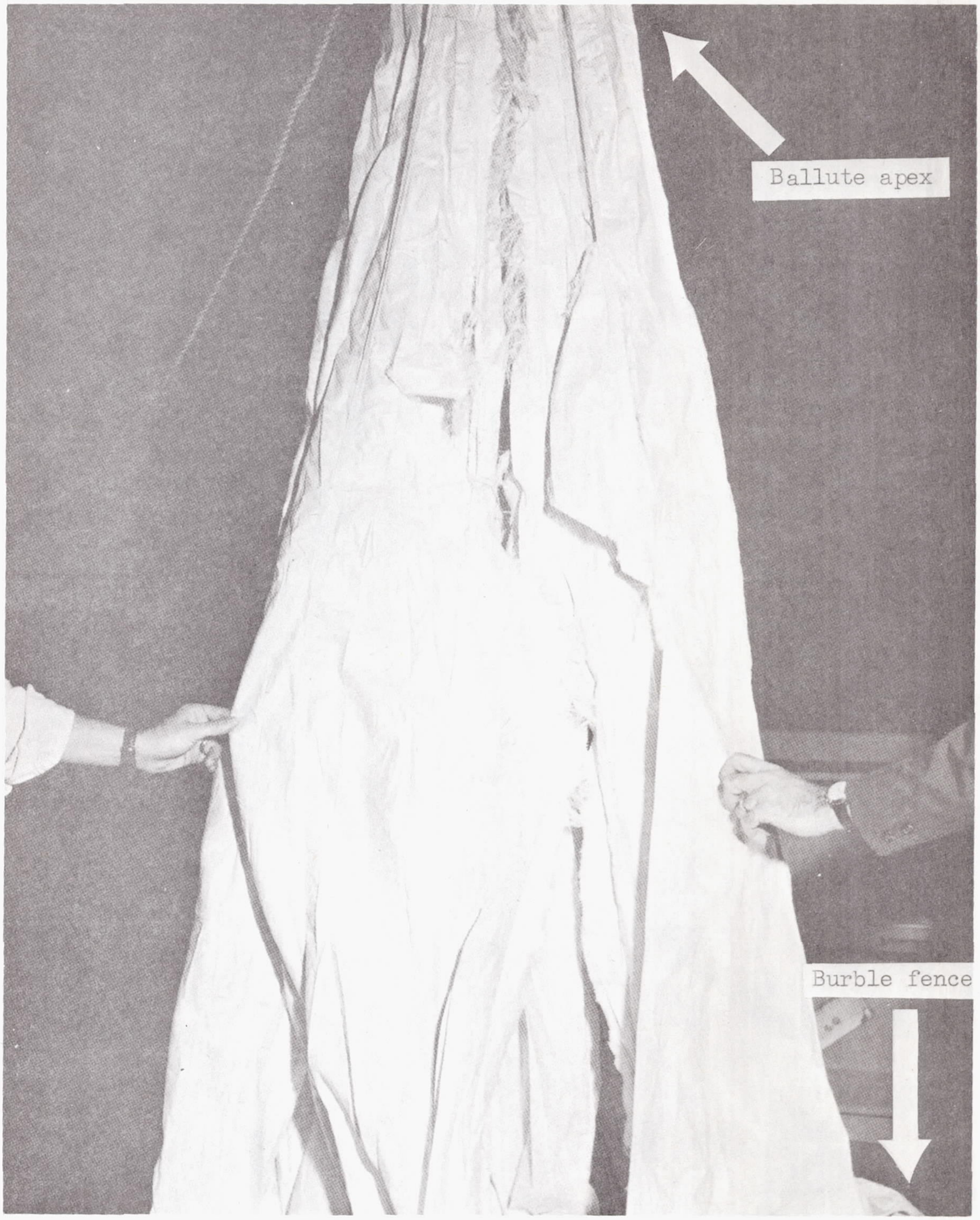


Figure 14.- Tears in back portion of ballute down from apex to burble fence. L-69-1260

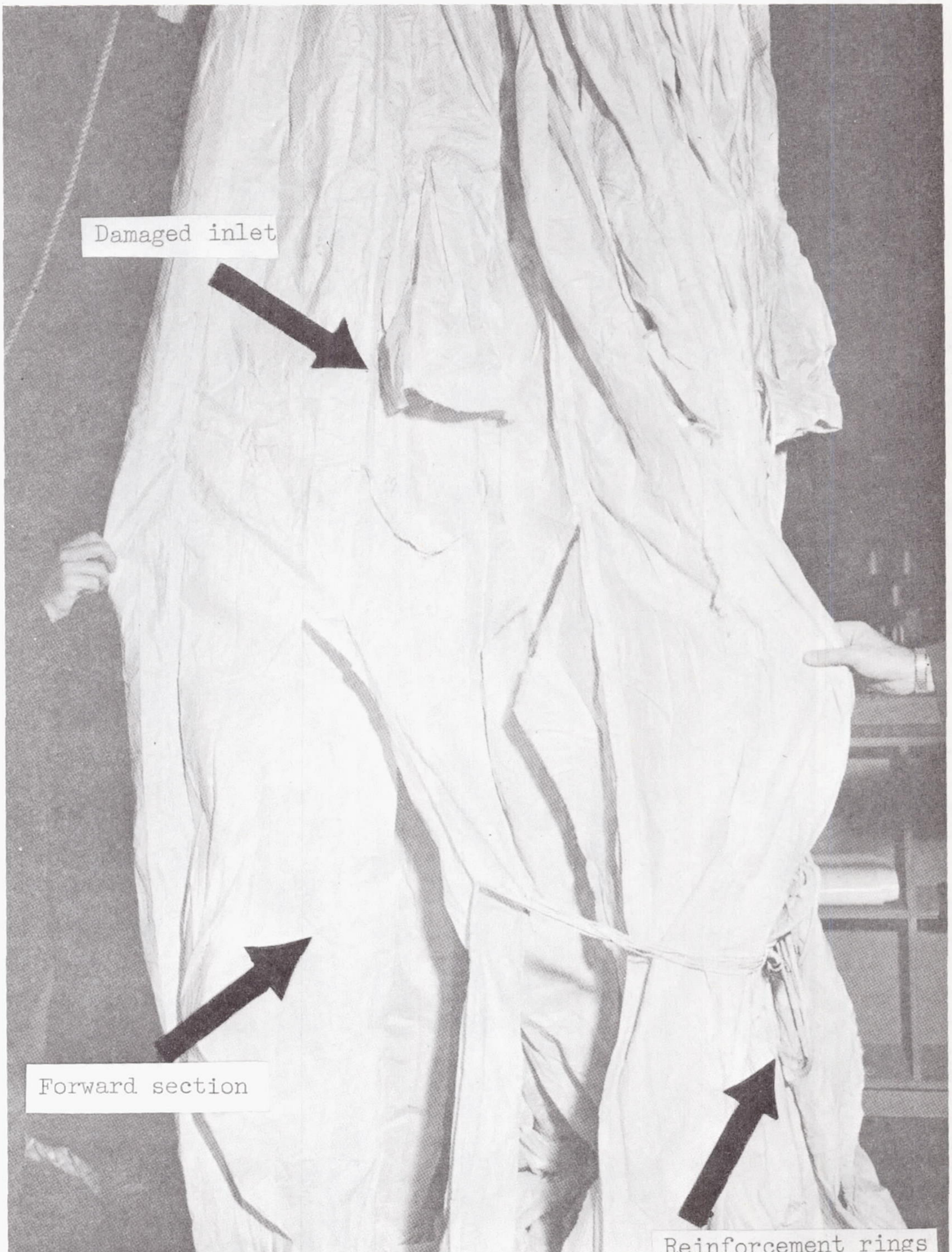


Figure 15.- Tears in forward section. L-69-1261

NASA-Langley, 1969 —— 31 L-6199