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EVALUATION OF A PARACHUTE-LOAD-DISTRIBUTION MEASURING SYSTEM DURING LOW-ALTITUDE DROP TESTS

by Ira S. Hoffman

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Langley Station, Hampton, Va.

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SUMMARY

In conjunction with the low-altitude preflight drop test phase of the NASA Supersonic High-Altitude Parachute Experiments (SHAPE) program, canopy-load-distribution measurements were made on each of three types of parachute during deployment (by means of a mortar) from an aircraft-dropped payload. Loads were measured with miniature load cells at various locations on the canopies and in the suspension lines of 30- and 40-foot-diameter (9.14 and 12.19 meters) parachutes, with a total of seven measurements of this type being made on each of seven instrumented parachute drops. Out of a total of 49 such individual measurement attempts, there were six individual load-cell problems, which included one of lead-wire breakage during parachute deployment. Total parachute load measurements were also made during each test by means of a tensiometer in the main riser line. In addition, for the total parachute instrumentation program, data from approximately 40 percent of the channels were not obtained due apparently to onboard telemetry malfunction. A commercially available stretch cable was used in the hard wire data transmission link between all transducers and their corresponding telemetry channels in the payload. This cable, which required a pull of about 1 pound (4.45 newtons) for a 25-percent stretch, functioned in an excellent manner during all parachute drop tests.

INTRODUCTION

The needs for better parachute design parameters and scaling factors have been expressed by many researchers involved with flexible aerodynamic decelerators. Suitable guidelines to satisfy these needs must be established experimentally by actually obtaining load time histories and load distributions from deployed parachutes under real-use conditions. Since the low-altitude preflight drop test phase of the SHAPE program provided an opportunity for attempting such measurements, plans were made to do so. It was felt that the instrumentation scheme which had been successfully used in previous wind-tunnel tests at the Langley Research Center could be utilized if the load cells were redesigned to withstand the decelerator environment between the time of packing and deployment. For these low-altitude drop tests, packing and deployment followed the same procedure used in the NASA Planetary Entry Parachute Program (PEPP). (See ref. 1.)

An evaluation of the success of this instrumentation program is complicated by the lack of a suitable frame of reference for making such measurements and by a fairly high degree of uncertainty as to telemetry performance under the high-g mortar deployment conditions. However, in considering only the load cells and their attendant lead wires, as based on post-drop measurements, a reliability of better than 80 percent was realized in acquiring the load data.

Although the acquisition of all load data fully describing parachute performance was not achieved, the apparent ruggedness of the load cells and lead wires in surviving the severe conditions imposed by pressure packing and mortar deployment was very encouraging. It is believed that most of the difficulties encountered can be rectified and that more satisfactory data can be realized in other test programs. For this reason, procedures and results are reported herein as a basis for such efforts.

TEST SYSTEM

The test payload consisted of a cylindrical vehicle with stabilizing fins and a conical nose section. The total weight of the payload, including the parachute and its deployment system, was 400 pounds (181 kilograms) for the first five drop tests and 600 pounds (272 kilograms) for the last two drop tests. The drop tests were initiated at an altitude of 10 000 feet (3.048 kilometers) at an aircraft velocity of 150 knots indicated airspeed. The payload was released from the wing of the aircraft and allowed to free-fall for 3 seconds before a timer initiated firing of the mortar to deploy the parachute.

With the mortar-type deployment system, the entire test parachute is stowed in the mortar tube (ref. 1 and fig. 1). When the mortar fires, the parachute pack is ejected from the mortar at an exit velocity of about 120 feet per second (36.6 meters per second). The ejected parachute pack pulls the parachute risers and bridle from their stowage slots around the mortar. As these webbings are stretched full length, the first deployment load between the parachute and payload is realized. Also, when the parachute risers become taut, a knife located on the riser cuts the parachute pack tie cord and the parachute then unfolds from the pack as it travels aft from the payload. A second deployment load is generated as the parachute suspension lines are deployed full length, and a third load peak occurs as the canopy reaches its fully extended position. The largest loads are generated when the canopy inflates (fig. 2), and due to collapsing and reinflation more than one such load pulse may be realized.

The three types of parachute used in the SHAPE low-altitude drop tests were the ringsail, disk gap band, and cross. These parachute canopies have been tested previously on rocket test flights. Detailed descriptions for parachute construction, pressure packing, and mortar deployment are given in references 1, 2, and 3. Figure 3 shows the location plan for miniature load cells on the cross-type parachute used in the present series of drop tests. These locations are typical of all three parachutes.

All parachute instrumentation was developed and installed on the parachutes by Langley personnel. Parachute packing and mating to the payload functions were also handled by Langley personnel. The telemetry system was supplied and operated by drop-site personnel of the 6511th Test Group (Parachute) at the Joint Parachute Test Facility, El Centro, California, as part of an agreement with the U.S. Air Force. The telemetry was an eight-channel standard IRIG FM-FM proportional bandwidth system, with channel frequencies ranging from 3 to 52.5 kilohertz. Real-time data were recorded on magnetic tape and were later resolved into oscillograph record form for delivery to Langley. Telemetry and tracking data reduction and film processing activities were provided by the El Centro facility.

TEST PROBLEMS

Inasmuch as two of the three test parachutes had suspension lines that were 40 feet long (12.2 meters), some of the miniature-load-cell lead wires had to be about 70 feet long (21.3 meters). The parachute packing density varied from about 30 to 40 pounds per cubic foot (481 to 641 kilograms per cubic meter) and it was necessary for all parachute instrumentation and lead wires, except the total load tensiometer, to withstand the associated packing pressure. In addition, the mortar deployment process induced payload accelerations of 20g and parachute ejection velocities up to 120 feet per second (36.6 meters per second). The parachute materials stretched as much as 20 to 25 percent during deployment; thus, the hard wire signal transmission link for the miniature load cells had to be capable of performing its function under such circumstances, since it was tied or sewed directly to the parachute components.

After the miniature load cells (which had been previously calibrated under dead loads) were installed on the parachute and their lead wires were attached, the parachute was placed in a packing bag. Because of this unalterable procedure, the load cells could not again be checked either by dead load or by resistance shunt calibrations. It was therefore necessary to perform shunt calibrations at the extreme ends of the load-cell lead wires. Further, since the exact final lead lengths, hence lead-wire resistance, which would prevail at the drop site could not be predetermined at Langley, arrangement had to be made to perform this calibration function over a range of possible wire resistances from 0 to approximately 20 ohms. Correction charts were made to accommodate the estimated range, and after the as-installed lead-wire resistances were measured on site with a Wheatstone bridge, the predetermined corrections were applied by Langley personnel so that corrections would not have to be made by the El Centro personnel. Although wire resistance corrections in some instances approached 20 percent of expected full-scale load-cell output, it is believed that calibration errors from this source were limited to well under 1 percent of the full-scale output.

INSTRUMENTATION

Specific items of instrumentation supplied by the Langley Research Center, the manner in which each item was utilized, and other instrumentation considerations involved in these parachute drop tests are discussed in this section.

Miniature Load Cells

The measuring element of the load cells consisted essentially of a simple tension-loaded rectangular beam, with strain gages mounted on the two opposite wide faces in typical T-orientation (Poisson arrangement) and wired into a conventional Wheatstone bridge type of circuit. Since 500-ohm metal-foil gages were the highest resistance type attainable, considering size and other requirements, they were used. Figure 4 shows pertinent details of the miniature-load-cell construction. The inner beam body weighed 22 grams and the outer protective sleeve weighed 20 grams, for a total of 42 grams. The outer sleeve formed a protective cover over the free end of the strain-gage beam, with sufficient overhang to virtually eliminate side loads (bending) on the beam during the time that the parachute was packed within the mortar.

Since the rectangular beam design used was found during post-drop loadings to deform permanently at torque loads in excess of only 6 inch-pounds (68 newtons-centimeter), the incorporation of torque overload stops should be considered in future designs. Some load cells were installed directly in the suspension lines, as shown in the lower part of figure 5. Other load measurements were made by installing the load cell in parallel with the parachute-canopy load-carrying member, with pleats being taken in the parachute member to compel the load to pass through the load cell. An installation of this type is also shown in figure 5 in the upper part of the photograph. These load cells were deadweight calibrated, and resistance shunts were used as load transfer standards.

Extendable Electrical Lead Wires

Since the parachute components were expected to elongate 20 percent or more during loading and since these strain levels are normally reached in a random fashion, it was necessary that electrical lead wires attached to these components have stretch capability along all portions of their length. A vendor was found who could produce a braided, stretchable, four-conductor cable in AWG No. 32 wire. From a resistance standpoint, this was believed to represent the smallest practical wire size. For the present application, teflon-insulated conductors were interwoven with stiffness-compatible strands of nylon to form the braided-rope type of construction seen in figure 5. An inner core of about 12 rubber strands supplied the elasticity and was pretensioned during construction to yield the desired elongation characteristics. Special precautions had to be taken to maintain tension in these rubber strands whenever the cable was cut to desired length. This tension was readily maintained by folding the cable back on itself and then tieing off this sharp fold-back bend, which locked the rubber strands securely in place. Such tie-offs were made approximately 1 inch (2.54 centimeters) on each side of the desired cut-off point after which the four conductors were cut and then routinely dealt with. These cables were not shielded. The specific type of wire cable used in these tests stretched 25 percent under a load of 1 pound (4.45 newtons). The cable was tied down or sewed down at about 5-inch (12.7 centimeters) intervals along its route from the bridle-payload juncture to the load transducers in the parachute (figs. 2 and 3). Low strength cotton string was used so that abnormal loads would break the cotton strings and thus release the cable. For traversing the bridle (fig. 2), the cable was overcast stitched at approximately 3/8-inch (0.95 centimeter) intervals to the narrow edge of the bridle webbing (fig. 1). It was necessary to stitch cables to both edges of the bridle, two layers high in many instances. In preparation for deployment, the bridle, with wire attached, was stuffed edgewise into an annular slot around the mortar exit lip (fig. 1), with the two-cable edge oriented to the outside whenever possible. The wire cable proved to be very durable under all normal deployment conditions; it survived the dense mortar pack and the fast play out from the predeploy slot position without measurable change in wire resistance. The unstretched cable diameter was about 0.15 inch (0.38 centimeter) and all attempts by the vendor to reduce this diameter resulted in unacceptably high spring rates. The major disadvantage of this type of cable was its high resistance. In order to accommodate a 25-percent stretch at a tolerable spring rate, between 80 percent and 100 percent additional wire length was required in the weaving process. Thus, if an unstretched cable length of 70 feet (21.3 meters) were needed, the required free length of each of the four individual conductors had to be approximately 130 feet (39.6 meters).

Tensiometers

The tensiometers used for measuring total load between the parachute and its payload were previously designed for and used in the PEPP series of tests (for example, ref. 1). These units used bonded strain gages and were designed for a nominal tension load of 10 000 pounds (44.48 kilonewtons). They had a diameter of about 1.5 inches (3.81 centimeters), were about 6 inches long (15.24 centimeters), and weighed about 1.5 pounds (0.68 kilogram). For predeployment packing, the tensiometers, which formed the connecting link between bridle and riser (fig. 2), were inserted endwise into a slot provided adjacent to the annular slot surrounding the mortar lid (fig. 1) and were oriented so as to deploy without tumbling. (The parachute deployment velocity was approximately

120 feet per second (36.6 meters per second).) All tensiometers were equipped with stretch cable (AWG No. 27 wire, vinyl insulated) and there were no cable problems on these tensiometers for any of the seven parachute drops. This larger wire did not have to pass over the parachute suspension lines or canopy.

Mechanical Scratch Gage

A Langley developed mechanical scratch gage force transducer was tested on one of the parachutes (two drops) and functioned in an acceptable manner. The scratch gage had a motion magnification ratio of about 16 to 1 and its stylus—aluminum-target recording system had a calibration sensitivity of 0.062 inch (1.575 millimeters) for the 100-pound (445 newtons) full range load. The length and diameter and other descriptive information for the scratch gage are shown in figure 6. The main body of the scratch gage was constructed from one piece of 18 Ni maraging steel, grade 300 CVM, with removable cover sleeve, stylus, and record plate. The upper body and lower body were connected through four flexures which allowed rectilinear motion between the bodies in the direction of tension load while restricting all other relative motions. The sensing beams (pair) were designed to be in parallel with the four flexures, but in series with each other, and were so arranged that tension loads on the gage induced motions in the sensing beams as indicated by the direction arrows in figure 6. These opposing motions caused a rotation about the midlength of the beams, the magnitude of which was controlled by the mechanical design of the system. The length of the stylus permitted a convenient means of motion amplification. The gage weight of 64 grams was higher than desired and possibilities of weight reductions are being considered. The device recorded maximum load only. Except for temperature sterilization, the scratch gage had been fully qualified for PEPP and SHAPE program missions.

Fabric Load Sensor

The present fabric load sensor, developed at Langley, is intended to measure forces in fabrics. Two designs of this strain-gage-based transducer have emerged; one senses two-axis bending strains and the other senses two-axis axial strains. Bending strains are induced in the transducer body by virtue of its neutral axis being slightly off-axis from the fabric load axis. With both bending and axial strains present in the transducer body, the attached strain gages can be selectively wired into a bridge circuit to be sensitive to whichever quantity is desired. The axial-type fabric load sensor utilized in the present instrumentation program is shown in figure 7. In this model, the bottom plate accommodates two active strain gages in both the x- and y-direction bridges, whereas the top plate carries two temperature compensating gages for each bridge. The top plate is intended to be completely load free and its temperature level is assumed to track closely the level of the bottom plate. The very low strain levels induced in these devices have constituted rather serious problems in real use. To overcome these low-output problems, the two devices utilized in the low-altitude SHAPE drops were instrumented with high-sensitivity semiconductor strain gages. These load sensors underwent satisfactory load calibrations after installation on the parachute fabric and appeared to be electrically stable after mortar packing, but unfortunately both gage units suffered gage-to-fabric adhesive failure during parachute inflation. Transducer lead-wire breakage followed immediately and thus rendered the load sensors completely inoperative. No further work was attempted with the load sensors during the present tests.

Fabric Strain Gages

A strong interest exists in the utilization of low-mass resistance strain gages to measure real strain directly on parachute fabrics under actual deployment conditions. However, due to the limited number of telemetry channels available for instrumentation in the El Centro tests and to insufficient confidence in such strain gages when used in previous parachute instrumentation work, fabric strain gages were not considered as active instrumentation items for this particular program. On the other hand, since reasonable success had been realized in laboratory evaluation of a particular experimental configuration, it was decided that advantage should be taken of this special opportunity to test the mechanical reaction of the gage configuration to the mortar packing and deployment conditions.

Two strain gages were tested in each of four parachute drops, with electrical lead wires extended only about 2 feet (0.61 meter) from the gage application area and thus not connected to any readout instrumentation. The gage configuration of primary interest consisted essentially of a long U-shape 2-inch-long (5.08 centimeters) loop (4 inches (10.16 centimeters) of wire) of 0.0008-inch-diameter (0.02032 millimeter) annealed constantan wire mounted on a 0.001-inch-thick (0.0254 millimeter) nonfibrous glass paper carrier and was attached to the parachute cloth with a rubbery post-yield adhesive. Several different adhesives were used, but results were inconclusive. The most successful gage protection was realized by placing thin layers of felt on both sides of the gage after installation to reduce the severity of creasing during pressure packing of the parachute. Due to such things as wire separation where folding or creasing occurred across the gage and to patches of felt and gages being stripped away during parachute deployment, the chances of maintaining an operable gage through deployment appeared very slight. Therefore, this type of gage is not recommended for use under conditions of high-density packing and mortar deployment. It is believed that gages of this type can be used with success under certain soft-pack conditions.

RESULTS AND DISCUSSION

The limited force-distribution data which were gathered in the seven instrumented drops in the SHAPE low-altitude drop test program are not presented herein inasmuch as this is not a data report. However, sufficient information is presented to illustrate the results. Figure 8 is a copy of an oscillograph record of a parachute drop in which sequential frames of the motion-picture film of that drop were directly time correlated with the oscillograph record to verify most of the various recorded load peaks as noted. Figure 9 is a copy of the oscillograph record from the third instrumented drop of a 30-foot (9.14 meters) cross-type parachute with load magnitudes indicated on the record. This is the most complete record realized from the seven drops and it is relatively free of telemetry noise. The total load measurement was lost, however, due to telemetry malfunction. In addition, the only instance of suspension-line tangling at initial deployment occurred during this drop, and based on the onboard movie film, loads measured by load cells 1 and 2 (fig. 3) were almost surely influenced by this entanglement. Instances of rather violent motion of the suspension line load cells were observed on other drops, but the motion was always arrested when the load cell collided with the bundle of stretched out suspension lines. For the tangling pointed out, the offending load cell not only was thrust outward but also was caused to orbit two complete turns around the suspension line bundle and to cease its motion wrapped around other suspension lines in an undetermined fashion. No noticeable knotting or hard tangling was apparent when the parachute was examined after the flight test. The valuable experience gained from this drop will enable wiser load-cell-location choices to be made for future installations in suspension lines. Although there was no way in which true load magnitudes could be verified, the load data indicated in figure 9 are believed to be reasonable, except for those measured by load cells 1 and 2. Two sail panels on which miniature load cells were attached were badly torn during the ringsail-parachute deployment and there is no question that the load-cell weight aggravated the tear condition.

Through load-cell redesign and a change in the protective sleeve material, it is believed that a weight reduction of about 50 percent can be achieved. It is also felt that motion-limiting straps can be used on the load-cell bodies to limit their dynamic motions for some applications. The only load-cell damage encountered in these tests occurred as permanent twist in the measuring element of five load cells ranging from a few degrees to as much as 35°. Small amounts of twist did not appear to affect load-cell calibration.

After a drop had been made and during refurbishing of the parachute for a subsequent drop, it was noted several times that the stretch cables were actually slightly shorter in length than the suspension lines to which they were tied. This condition apparently indicates more stable elastic qualities in the stretch cable than in the suspension-line material. This is mentioned because in a close study of the 35-mm motion pictures of the descending disk-gap-band parachute, it was observed that the parachute dimpled slightly at the onboard instrumentation locations. Since this condition was noted to occur just prior to touchdown when lateral loads were light, there is a possibility that the small residual tension in the stretch cables tended to pull the parachute very slightly out of shape. The combined weight of the load cells and cables may have contributed further to the slight deformation.

Problems associated with the onboard telemetry package were very difficult to analyze by observing the parachute drop records, but it is the opinion of Langley telemetry experts who have observed these records that open-circuit conditions may have occurred intermittently. It is possible that the plug-in oscillators were not making good contact or that the wiper contacts on the circuit balancing potentiometers were not making good contact. On several occasions the data channels began to malfunction at the instant of mortar fire and never again reached normal operating conditions. Other data channels were much more random in their malfunctions. The records, in general, looked good during the period of air transport to the drop zone and during the period of payload free fall from the airplane prior to mortar fire. Nearly all records indicated a brief period of noise at mortar fire, which on most occasions subsided after a few hundredths of a second. The telemetry system was probably not fully qualified to withstand the shock load conditions encountered in a SHAPE mortar deploy. Noise levels on malfunctioning channels were frequently quite high and during bursts of high noise levels the time correlation of cross talk with other channels was readily apparent.

CONCLUDING REMARKS

One purpose of the SHAPE program low-altitude parachute drops was to evaluate the effects of pressure packing and mortar deployment on an instrumentation system which was previously used in several wind-tunnel tests for the measurement of structural load distribution in deploying parachutes. The load cells and stretch-cable wiring survived the high-density mortar packing and the severe mortar deployment conditions with only minimum damage. The effects of the instrumentation on actual parachute performance are believed to be practically negligible, except that special precautions need to be employed in the future to eliminate excessive motions of the load cells. It is felt that this same instrumentation scheme can, in general, be used for load measurements on nonrigid aerodynamic devices of reasonable size.

For application of the instrumentation scheme described herein to similar measurement problems, certain factors should be given special consideration. These factors are as follows:

1. Onboard load cells should be of minimum size and weight. However, whenever high-density packing is to be encountered, the protective sleeve should be very stiff, with

sufficient overhang to protect the free end of the measuring element. Limit stops at the free end of the measuring element should restrict sensing beam travel in the vertical and horizontal directions perpendicular to the beam axis and should also restrict beam twist. The load cell should be installed as near a heavy web or other structural member as is practical to limit the free motion of the load cell during deployment. This probably means that suspension line load cells should be installed at the top end rather than the otherwise more desirable bottom end. Some consideration should also be given to the installation of restraining straps on load-cell bodies in instances where deployment dynamics tend to forcibly move the load cell in directions not along its primary load measuring axis.

2. Strain-gage resistance should be high to minimize the effect of lead-wire resistance on gage output and shunt-calibration procedures.

3. The largest practical lead-wire size should be utilized to minimize lead-wire resistance.

4. Lead wires should not be tied to or placed directly across metal surfaces (transducer bodies) when high packing pressures are utilized.

5. Lead-wire slack requirements at the transducer should be estimated by considering any and all possible motions which the transducer might take during deployment. Then, in addition, some extra lead wire should be bunched and loosely tied down so that extra wire length can easily play out if unexpectedly severe deployment conditions occur.

6. All lead-wire tiedowns or sewdowns (at 5-inch (12.7 centimeters) intervals) should be made with low-strength cotton string to allow easy breakaway if abnormal load conditions occur at deployment.

7. In load measurements in which the transducer is placed in parallel with load-carrying structures, the load-strap connections to the transducer should be as short as possible. If these straps are allowed to be excessively long, there is a possibility that they will stretch to the extent that the load-relieving pleat in the test member will be dissipated and the transducer will no longer carry the full load as desired.

8. Continuous lengths of stretch cable should be used over flexible areas which are subjected to rather large motions during deployment. Wire splices, however, are far superior to multipin plugs for this type of application.

9. The readout system is necessarily an integral part of the overall instrumentation system and care should be exercised to insure complete compatibility with the overall mission requirements.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 25, 1969,
125-24-03-16-23.

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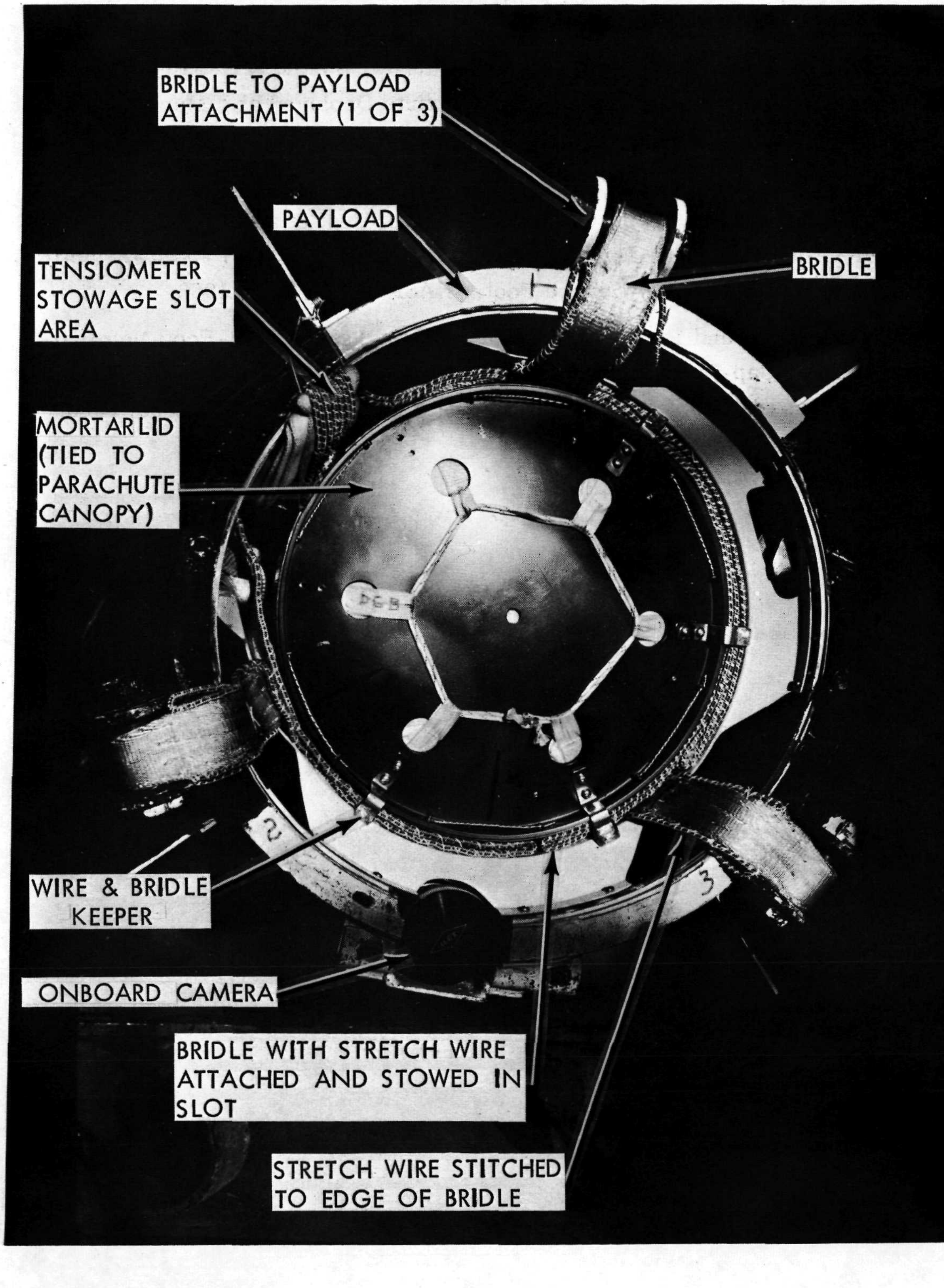


Figure 1.- Rear-end view of payload with parachute packed in mortar tube. L-69-1359

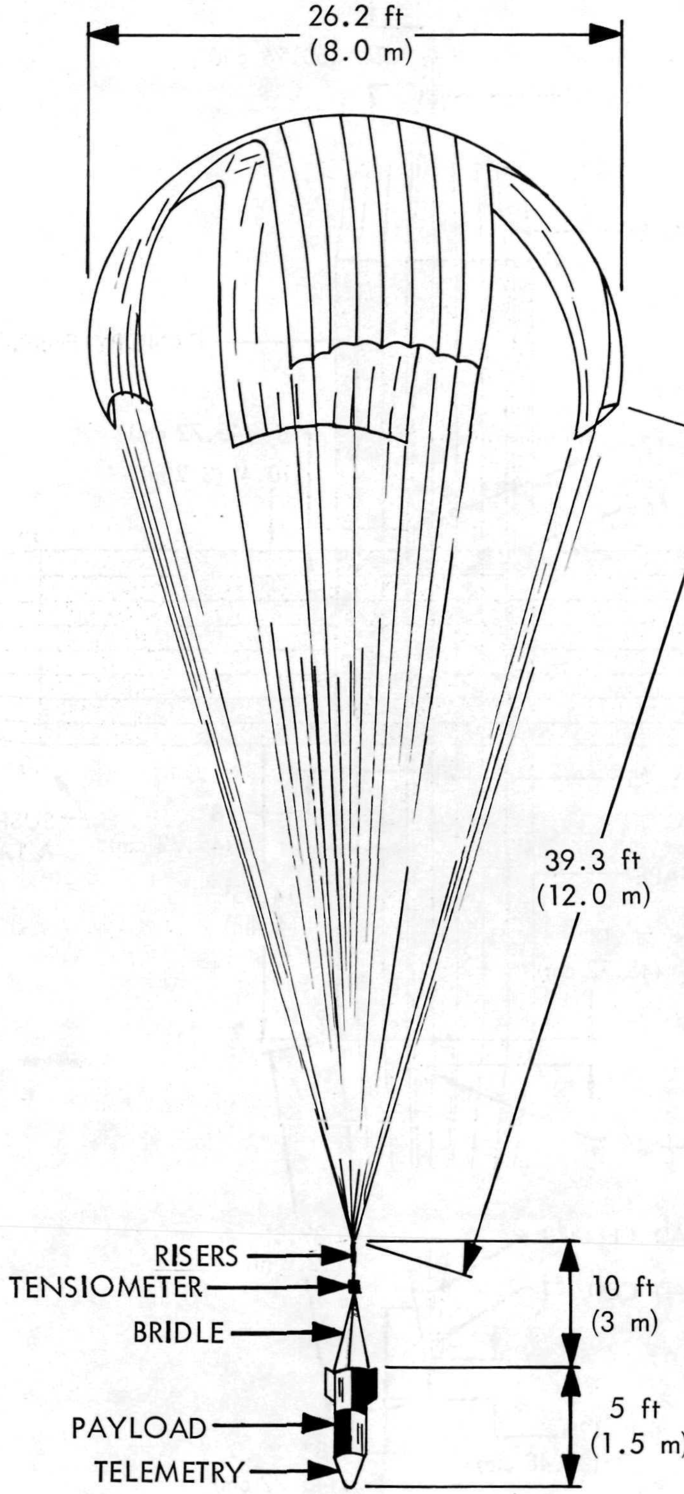


Figure 2.- General flight configuration of cross parachute.

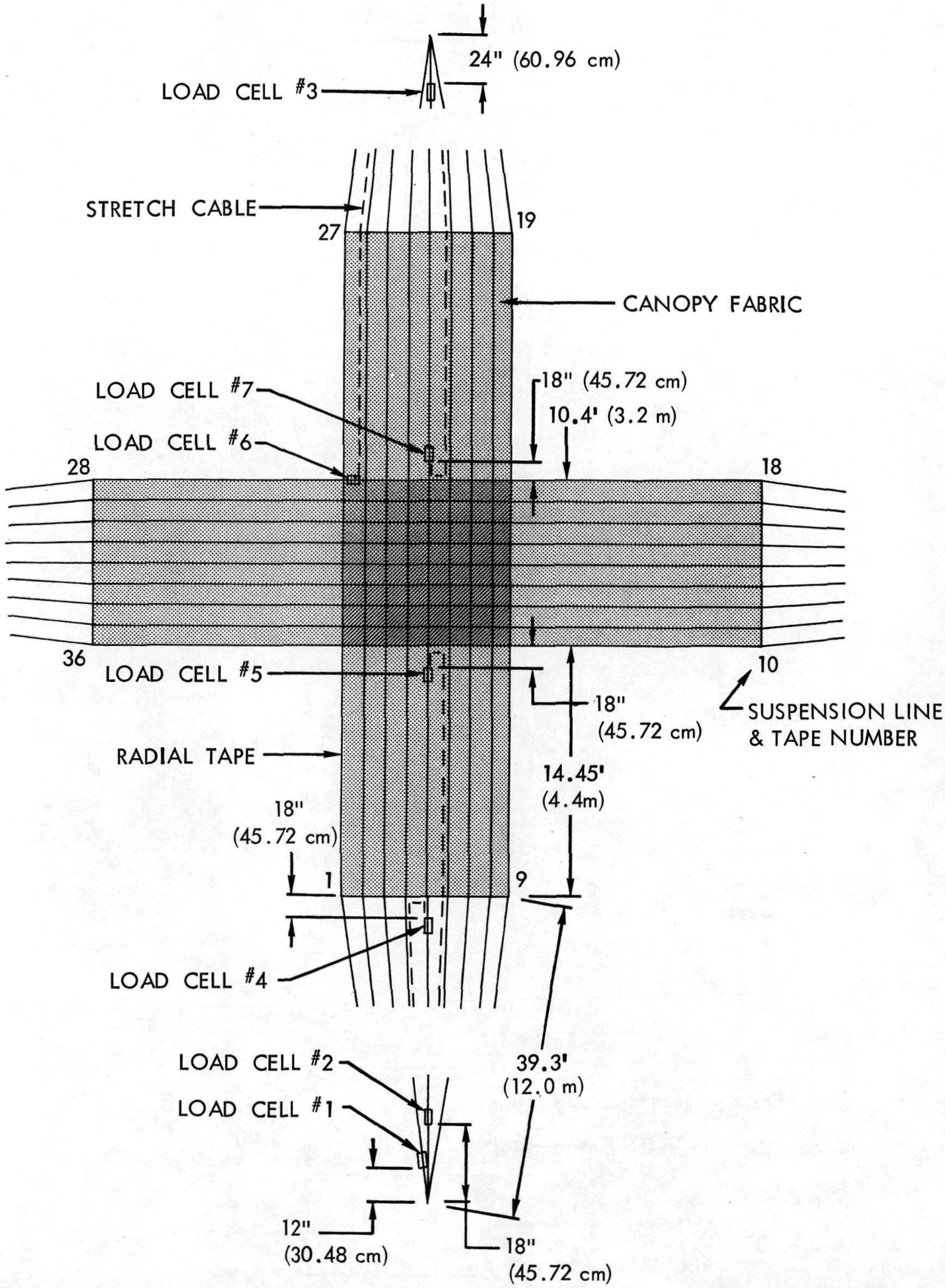
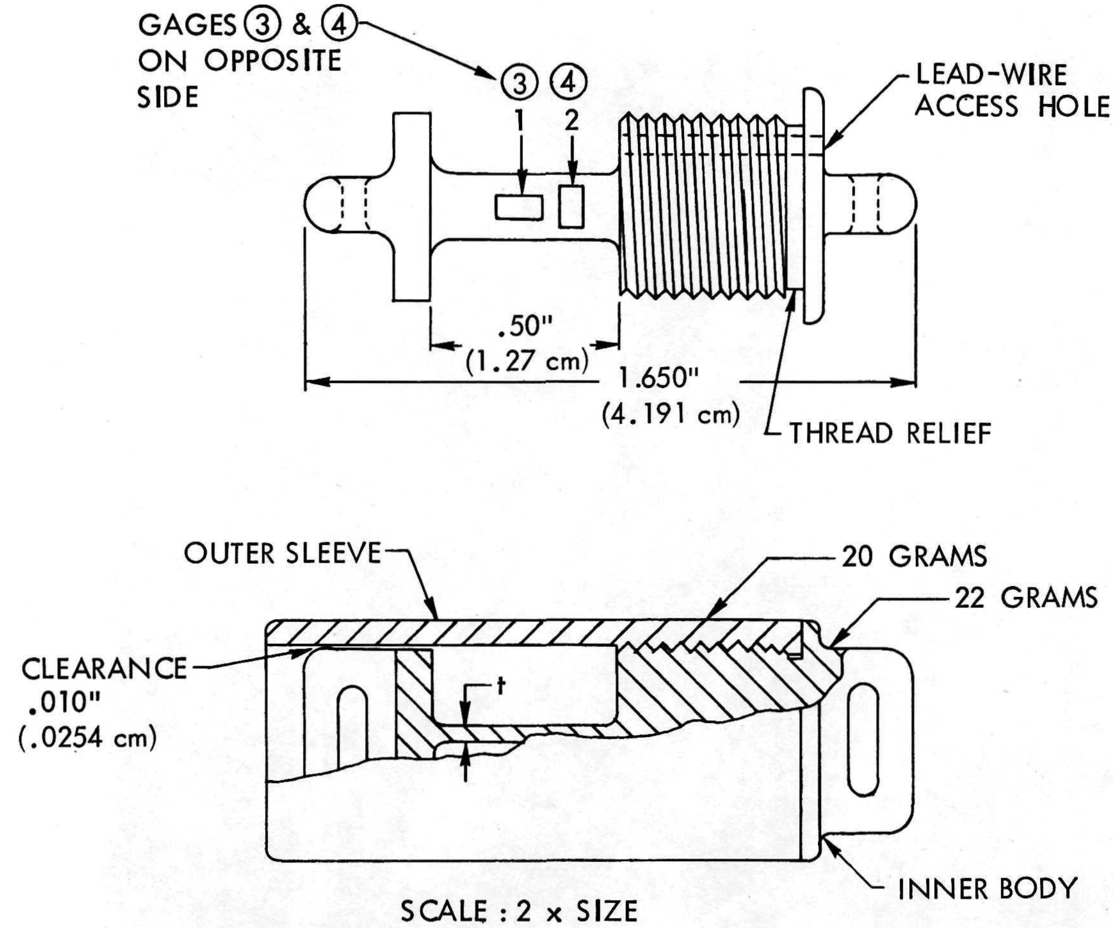
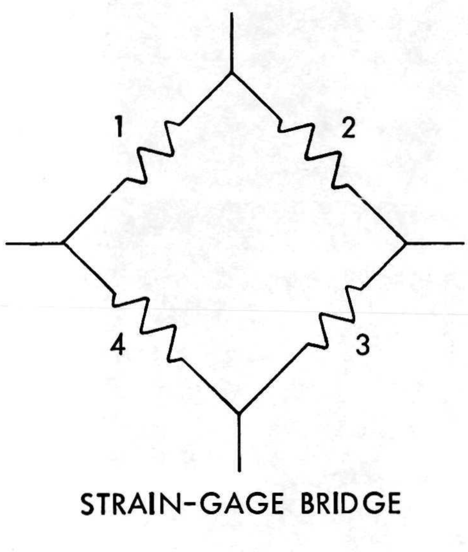


Figure 3.- Location of miniature load cells on 30-foot-diameter (9.14 meters) cross parachute.





NOTES:

1. MATERIAL 17-4 PH VAC. REMELT
   HARDNESS: R/C 44
2. LOAD BEAM DESIGN STRESS=50 000 PSI
   (3.45×10^8 N/m^2)
3. LOAD BEAM THICKNESS = 0.020"
   (.0508 cm)
4. STRAIN-GAGE RESISTANCE= 500 Ω

Figure 4.- Miniature load cell.

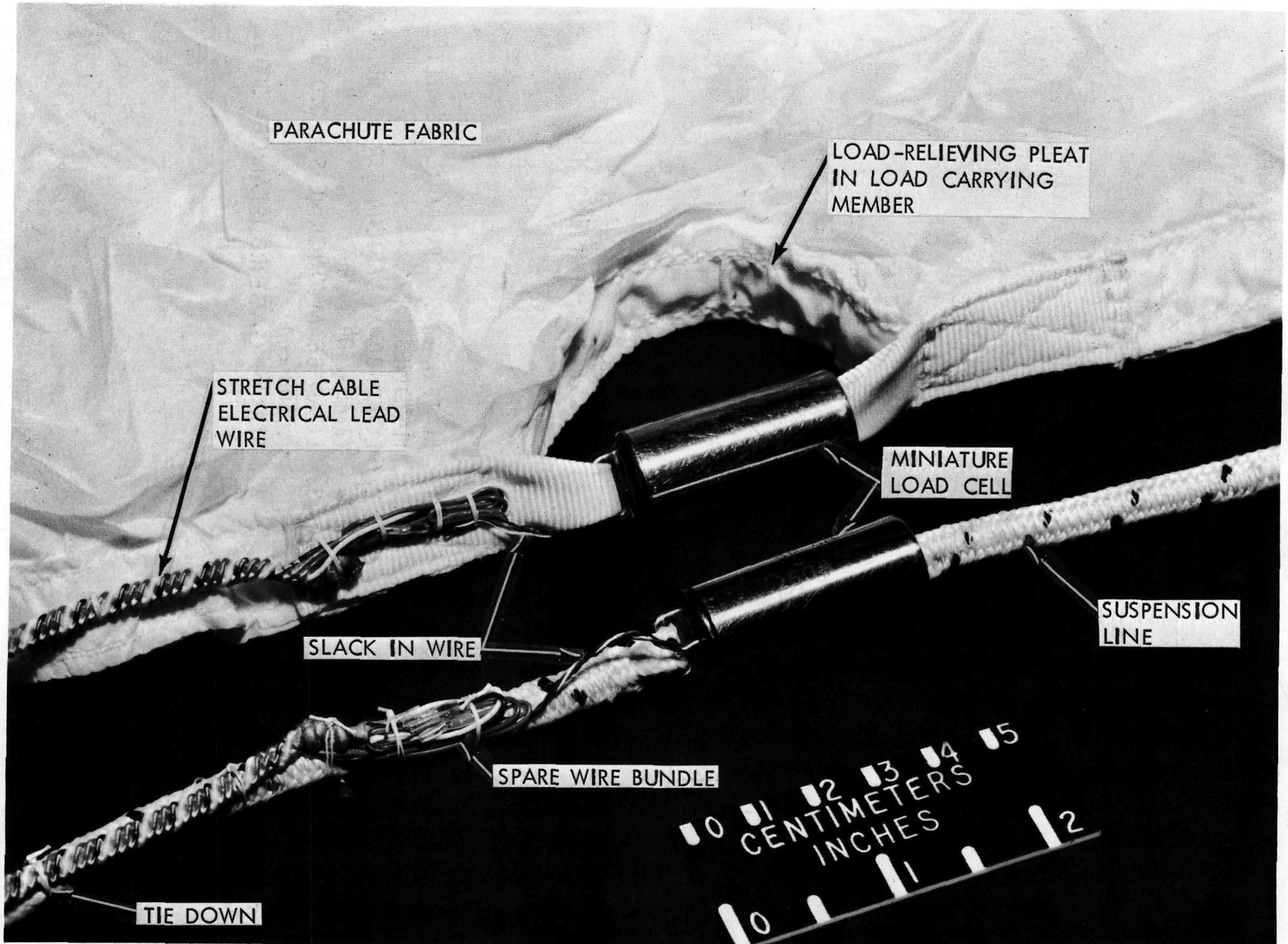


Figure 5.- Installation of miniature load cell on parachute. L-68-8956

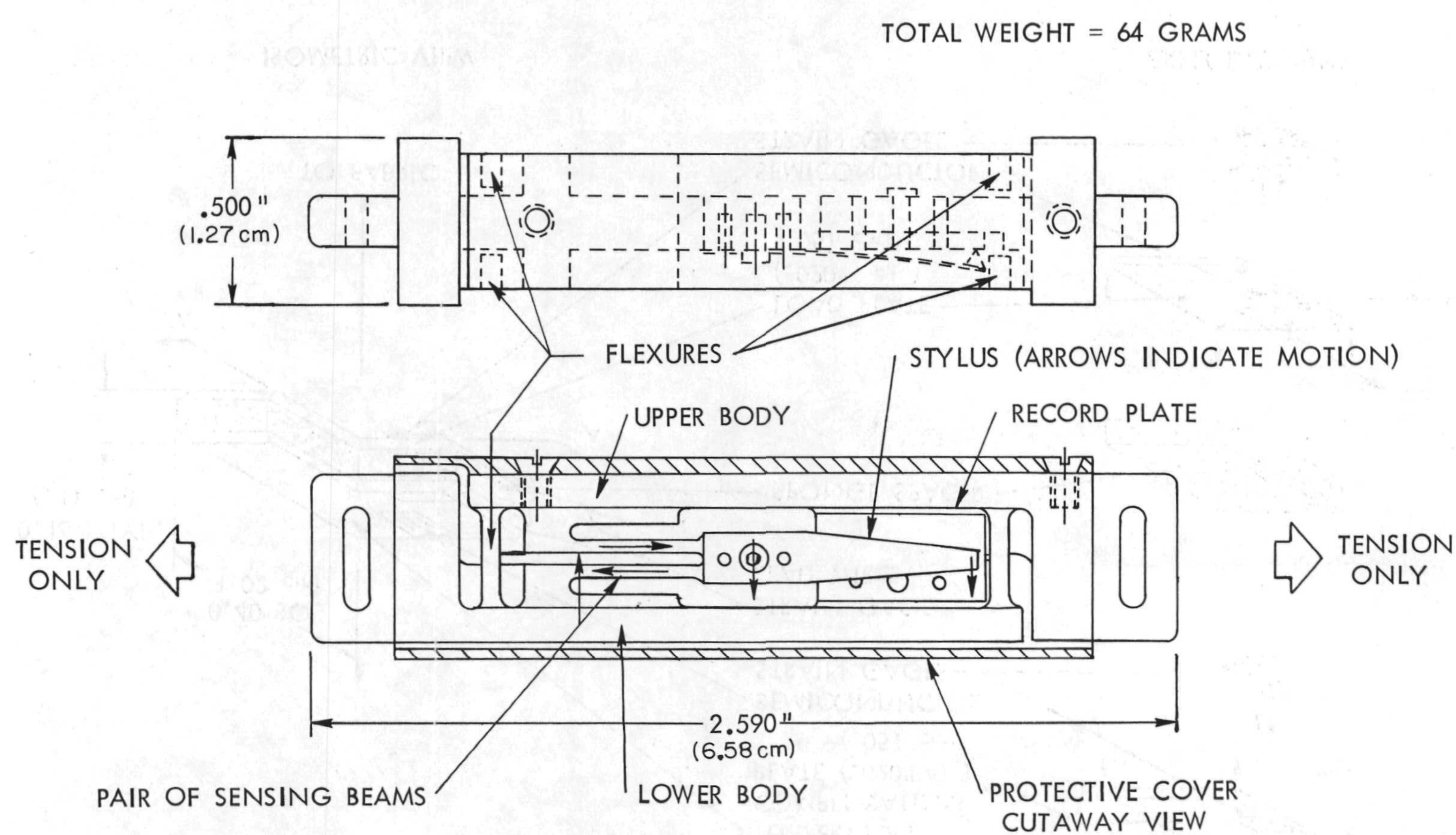


Figure 6.- Mechanical scratch gage.

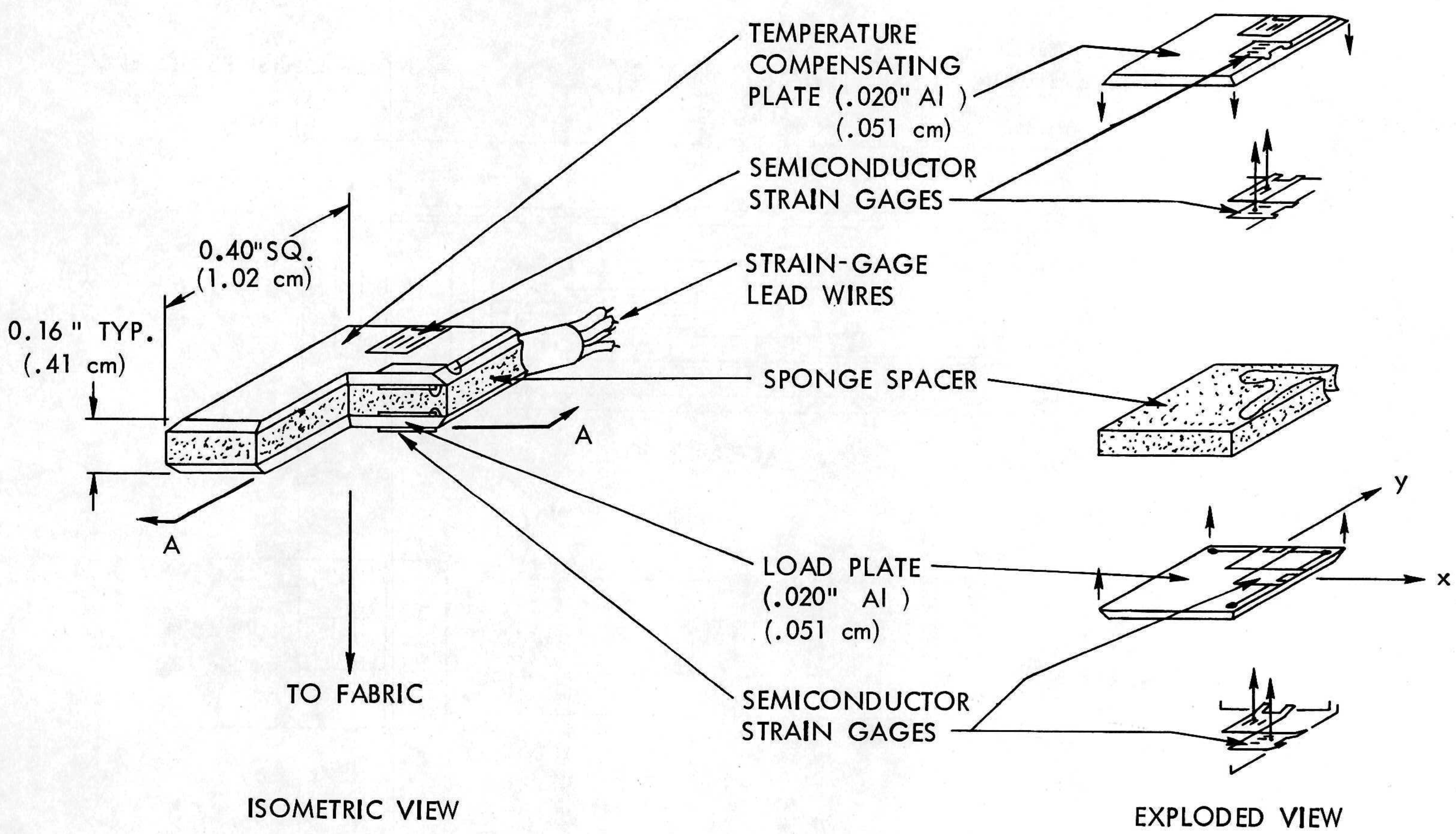


Figure 7.- Axial-type fabric load sensor.

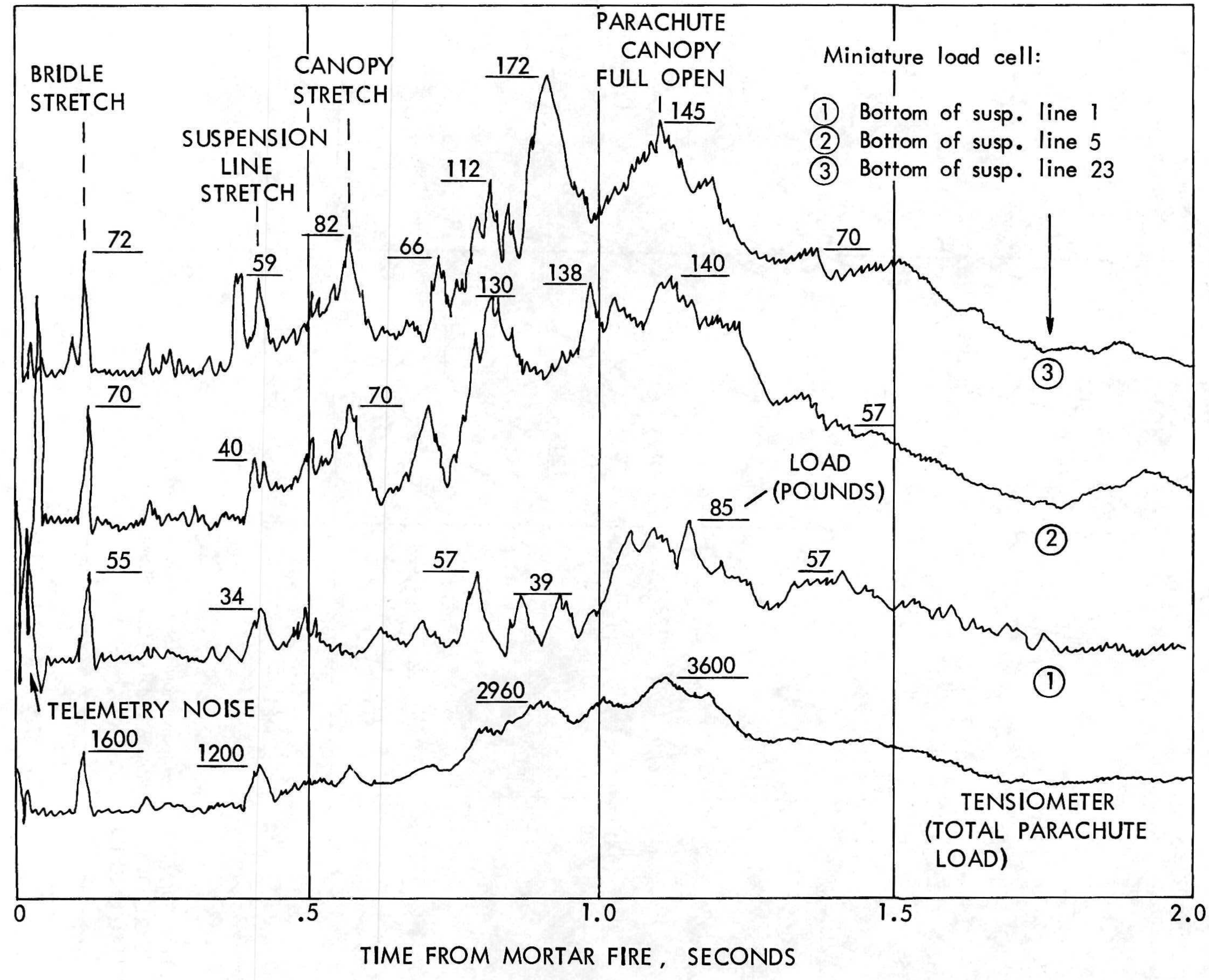


Figure 8.- Correlation of oscillograph miniature-load-cell data with motion-picture film. Light payload; cross parachute; location of miniature load cells given in figure 3. (1 pound = 4.448 newtons.)

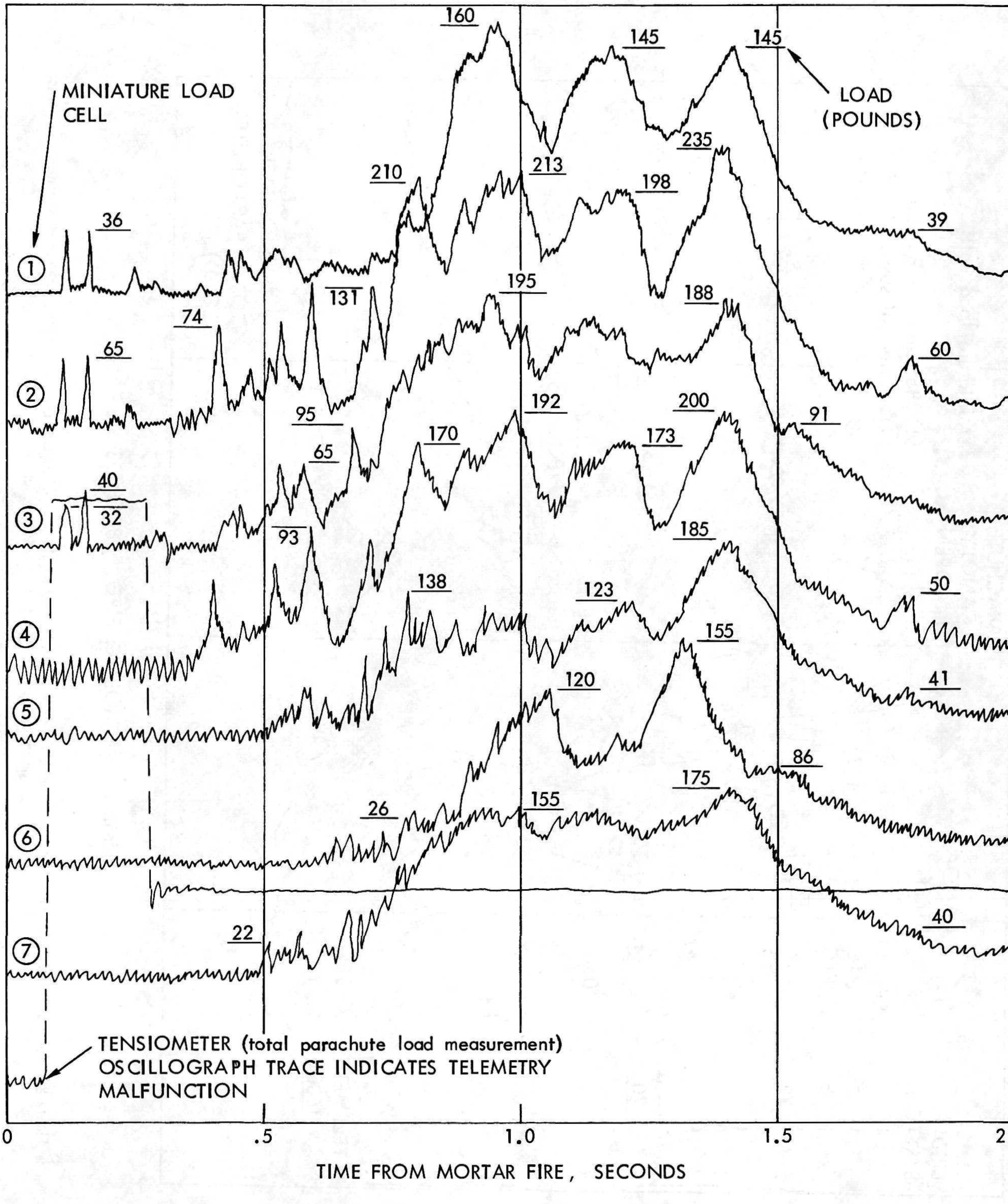


Figure 9.- Oscillograph record of load-cell output with time for a 600-pound-payload cross-parachute drop. Location of miniature load cells given in figure 3. (1 pound = 4.448 newtons.)

NASA-Langley, 1969 — 14 L-6575

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