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PROGRESS REPORT ON
HIGH ALTITUDE PLASTIC BALLOONS
CONTRACT NONR-710 (01)
DECEMBER 13, 1951 to JUNE 15, 1952
VOLUME I & II
RESTRICTED SECURITY INFORMATION
Copy No. 1

PROGRESS REPORT ON RESEARCH AND DEVELOPMENT IN THE FIELD OF HIGH ALTITUDE PLASTIC BALLOONS

CONDUCTED UNDER
CONTRACT NONR-710(01), NR 320 159
FOR PERIOD DECEMBER 13, 1951 to JUNE 15, 1952
WITH THE
OFFICE OF NAVAL RESEARCH

AND SPONSORED JOINTLY
BY THE ARMY, NAVY AND AIR FORCE

Classification cancelled in accordance with Executive Order 10501 issued 5 November 1953
29 Nov 55
Document Service Center
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PREPARED BY THE
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA
MINNEAPOLIS 14, MINNESOTA

PROGRESS REPORT ON CONTRACT #710(01)

From Initiation of Contract to June 15, 1952

VOLUME I AND VOLUME II

RESTRICTED SECURITY INFORMATION

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SECTION I
Organization

A full complement of personnel has been obtained for the operation of the project. The scientific training of these people is distributed as follows:

Experienced research men (Ph.D.)	5
Assistant Scientists	2
Junior Scientists	3
Research Fellows	7
Research Assistants	2
Electronics Mechanics	4
Engineering Assistants	10
Statistical Clerks	2
Photographers	2
	37
Non-scientific, miscellaneous, etc., equivalent	5
	42

The rules governing employment of academic personnel apply to the experienced research men and to the research fellows. Four regular staff members of the University of Minnesota and one Research Associate make up the five senior researchers. The staff members remain 10% on university time during the academic year in consideration of departmental duties such as oral examinations, staff meetings, etc. Payment of salaries for time spent on the project is made at the same monthly rate (90% in the academic year) as the regular university pay for each man. The salary of the Research Associate, who came to the project from Naval Research Laboratory, is the same as that at NRL. The names and experience of the senior men are:

Charles L. Critchfield, Professor of Physics
Scientific Director of Project, Ph.D., 1939
Edward P. Ney, Associate Professor of Physics
Alternate Scientific Director, Ph.D., 1947
John R. Winckler, Associate Professor of Physics
Ph.D., 1946
Homer T. Mantis, Assistant Professor, Mechanical Engineering
Ph.D. (Meteorology), 1949
Gilbert Perlow, Research Associate, Ph.D., 1940
Raymond Maas, Consultant in Electronics and Instrumentation
B.E.E., 1948

For special work during the summer, three additional Ph.D's have been hired as Research fellows ($400/month) full-time, two half-time, and one as a consultant until July 31.

The remaining positions have been filled by the Civil Service Personnel Department of the University, which advertised for technical men and which has been most cooperative generally. A complete list of laboratory and office personnel, in addition to the five senior men listed above, is as follows:

Leland Bohl, Research Fellow (half-time)
Abraham Franck, Research Fellow (summer only)
James S. Goldhuber, Research Fellow (summer only)
John Linsley, Research Fellow (half-time)
Michael Norris, Research Fellow (summer only)
Ferdinand Ohnsorg, Research Fellow
Sophie Oleksa, Research Fellow (half-time)
Kinsey Anderson, Research Assistant (half-time)
Earl Mitchell, Research Assistant (half-time)
Robert L. Howard, Assistant Scientist
(Section Leader, Electronic Section)
Logan Gilman, Assistant Scientist
(Section Leader, Instrumentation Section)
Eugene Byrne, Junior Scientist
Willard Lewis, Junior Scientist
John Gergen, Junior Scientist (half-time)
James Bales, Electronics Mechanic
James Stoddart, Electronics Mechanic
Wilmer Kurth, Electronics Mechanic
Robert Anderson, Electronics Mechanic
Sam Brinda, Engineering Assistant
William F. Rust, Engineering Assistant
Charles K. France, Engineering Assistant
Donald F. Kruse, Engineering Assistant
Joseph LeClair, Engineering Assistant
Bernard Welinski, Engineering Assistant
Paul W. Chase, Engineering Assistant (part-time)
Robert E. Danielson, Engineering Assistant
Evan L. Day, Engineering Assistant
Robert E. Field, Engineering Assistant
Charles Wilson, Utility Man
Irwin M. Fine, Photographer
Frank Bessesen, Photography Assistant
Maxine Mandt, Senior Statistical Clerk
Shirley Whitmore, Senior Clerk
Patricia Wilkinson, Secretary

Field operations, balloon packing, etc. are assisted by a staff of general mechanics who are responsible to the foreman of the machine shop and hence do not appear under the total of 42. This arrangement is both satisfactory and economical since the demand for such service fluctuates a great deal. Furthermore, certain of these men are being trained so as to take more responsibility in the packing and launching procedures. Approximately five men are employed in this way. The following people comprise the regular crew for this work:

R. B. Thorness, Machine Shop Foreman
Donald Hansen, General Mechanic
Charles Edwards, General Mechanic
Cecil Smith, General Mechanic
Roy Lahti, General Mechanic

The working space of the project comprises four large laboratories in the Physics Building, viz: a balloon room for centralized activities prior to and subsequent to flights (54), an electronics laboratory (65), an instrumentation laboratory (62) and a combined photographic and data assembly laboratory (42). Balloon packing space has been made available, at least for the off season, in the hockey arena where there is a head room of 100 feet. A storeroom has been provided on the second floor of the Physics Building, and occasional use is made of miscellaneous hall space, the vertical shafts and the astronomical telescope in that building. Similarly, the hangar in the Department of Aeronautical Engineering is used once in a while.

Office space is primarily in the Physics Building, where two classrooms have been temporarily converted into six central offices (Rooms 157, 157A, 157B, 161, 163, 165). An adjoining office, 167, has been provided for the ONR Field Representative and his staff. The project has also two offices adjoining the instrumentation and electronics laboratories and part use of another by the stores supervisor. The meteorology group has an office in the Aeronautical Engineering Building (301) and one and one-half in the Engineering Experiment Station (204A, 205).

The working space outlined above is for the exclusive use of the Project Nonr-710 and is kept locked by special keys when not occupied. There is no recognized use of these rooms by other than project personnel with the exception implied by university staff members being 10% on university time.

In addition to specifically project space, operation of the contract has entailed expansion and modification of the physics shops. The university partly finished the uncompleted library room 260 in the new wing so that the department's electronic shop could move there and expand. The move was completed in April, 1952. The student machine shop was installed in Rooms 24 and 26 vacated by the electronics shop so as to be able to expand the floor space of the machine shop. The completion date on these moves and alterations is July 15, 1952.

Field facilities have been located primarily at the University of Minnesota airport, where there is a wind screen, a radio shack and its heating shack, power, water and telephone.

The University is abandoning the present airport site, and the buildings and services will be pulled out by August 15, 1952, and installed at the new Anoka secondary airport. At the new site the tracking and telemetering gear will be housed in the tower and one room of the administration building of the University

Plans for the wind screen are not as definite except that it must be dismantled by June, 1953, when the University plans to dispose of the property on which it stands.

Transportation necessary for flight operations is government furnished and comprises a 1 1/2-ton Reo stake truck, one Chevrolet carryall and a semi-trailer bus which is being converted into an electronics center for mobile operations. This semi will be in operation by August 10, 1952. Flight tracking is assisted by the staff of the ONR Field Representative and their radio truck.

SECTION II

A NEW METHOD OF PACKAGING AND LAUNCHING LARGE PLASTIC BALLOONS

Practically the first effort of the Minnesota Balloon Project was directed towards devising a method of condensing the large Skyhook type plastic balloons so that a vertical inflation and launching could be achieved. Early efforts are summarized in Flight #1 (see Section 7 of this report). Experience with this flight showed that the balloon must be unfolded very slowly to avoid large accelerations and consequent danger to rigging and apparatus. The following method was then adopted, and has been used on all subsequent flights with modifications and changes in equipment to improve the technique as necessary. To effect the packaging, a clamp is inserted in the balloon 1/3 of the way from the bottom, and a plastic diaphragm makes the bottom 1/3 of the balloon gas tight. The upper 2/3 of the balloon is draped over the lower third in a symmetrical manner with the apex of the balloon resting against the top of the clamp and diaphragm and the bottom of the canopy thus formed hanging level with the bottom of the balloon. The canopy is ordinarily constrained by the corset (to be described), which is subsequently removed just before launching. One thus has a balloon about 1/3 the height of the original to inflate and launch. Vertical inflations can be conducted without undue difficulty, and once the balloon and its load is clear of the ground, the gas is transferred slowly into the upper portion and lifts the canopy off the bottom. The balloon extends itself to its normal length while drifting with the wind as part of the air stream. The most essential accessory for this method of packaging is the girdle and diaphragm tube which seals off the bottom third of the balloon. This assembly must clamp the balloon fabric tightly enough so that the tension in the tapes carrying the load can be transferred across the clamp without any slipping of the fabric, which

would certainly cause damage. The most satisfactory arrangement has been found to be a girdle, which is slipped on the outside of the balloon during the packaging, and an automobile inner tube, usually strengthened with nylon tapes, which is inflated inside the balloon and clamps the balloon between the tire and the outer girdle. Tests have shown that with such an arrangement and with the tire inflated to about 10-15 pounds/square inch in pressure, no perceptible slippage of the clamped plastic occurred with total tension forces of 500-1000 pounds. In the earlier attempts, a canvas girdle was used; it was reinforced with heavy rope around the edges. This was abandoned in favor of a light aluminum girdle (see sketch #2, shop drawing, photographs in Appendix #11) with a concave inner shape and very smoothly rounded cross section to prevent abrasion of the plastic.

In the course of the work, a removable outer girdle was used (see photograph in Appendix 3) and a very large inner tire. This girdle was separated by a pressure switch and dynamite cap squib cutter a few thousand feet in the air. The present method, however, of using a closed girdle and a tube deflator has been found much simpler and equally satisfactory.

Several balloons for early flights were packaged in the Physics Department elevator shaft, but operations were then shifted to the Williams Sports Arena, which has 95 feet of head room. In this building a 73-foot-diameter cell which has a deflated length of 129 feet can just be raised far enough to insert the girdle and diaphragm tube with the balloon right side up. Two electric winches and two pulleys are used to control the balloon during packaging. The detailed steps are outlined in the balloon packaging procedure. It is possible to carry out this method in a building having as head room 1/3 the balloon length by first hanging the balloon upside down from the load ring to insert the girdle and diaphragm tube, then lowering the balloon to the floor and draping the canopy with the aid of pulleys and winches. By using this technique we have packaged 116-foot-diameter balloons (General Mills Type 1161) in Williams Arena without any difficulties.

One of the problems encountered in packaging the balloon by this method is in removing the residual air from inside the various folds and layers of the balloon after the packaging is completed. In order to accomplish this quickly, as will be noted in the details of the procedure, incisions are made through the plastic, and the air is forced out by rolling up the balloon. This involves several heat sealing and taping operations which, of course, must be done with care to avoid shortening the dimension of the balloon and producing undesirable stresses. In the early packaging operations a heat seal was not used, but polyethylene pressure-sensitive tape was applied inside the incision and also on the outside. No failures due to tapes coming loose were ever observed, but the heat seal was used as a safety measure. It is usually observed that the air escapes from the balloon without incisions if sufficient time is allowed, and that a day or so will suffice to deflate the cell to a satisfactory degree. The balloon, when packaged and rolled up in the balloon bag, is somewhat more bulky than formerly, and has been handled by carrying it on a wooden stretcher or by carrying it on a strong canvas square equipped with handling ropes. Damage may result if the balloon bag is dragged or pressed against a hard surface as this may squeeze the plastic between the hard aluminum girdle and the other surfaces and damage the balloon at this point.

The precise details of installation of the girdle and diaphragm tube are given in the packing procedure. It is most easily accomplished with the balloon hanging vertically so that the fabric of the balloon drapes naturally into position. The girdle is then placed on the outside of the balloon at a point 1/3 of the way from the bottom, a diaphragm tube assembly inserted through an opening and inflated inside the balloon into the girdle. A ripcord passes down through the balloon and falls out the

bottom so that at the moment of launching, the diaphragm which seals off the gas in the lower portion of the balloon can be broken. As will be seen in sketch #1 of this section, the diaphragm tube is equipped with a nylon harness and a suspension cord which permit the operators to hang it inside the balloon during the packaging at the correct position. This suspension cord passes out through the top of the balloon through the suspension clamp (see sketch #3) and is left in place to serve as a mooring line for the top end of the balloon during inflation. The suspension clamp, which is another of the necessary accessories, is fastened into the top of the balloon and provides a point of attachment for a winch to raise the entire balloon into a vertical position to facilitate draping the plastic. Ordinarily, a separate winch is used to control the diaphragm tube suspension cord as the lower part of the balloon is raised by this suspension cord. When the packaging has progressed to the point shown in the sketch for steps 16 to 26, cord #2 is raised and the crown of the balloon is lowered, draping the balloon as shown in sketches for steps 27 to 40. At this time an inflation thimble, shown in sketch 4 and in the photographs and engineering drawings, is inserted in the bottom of the balloon. The canopy and the bottom of the balloon are secured to this thimble by the position corset shown in sketch #5 and in the photograph. This corset is equipped with parachute type quick releases and is extended by the first pair of quick releases to permit removal of the inflation thimble after the required amount of gas has been inserted. Then just prior to launching, the corset is completely removed by pulling the second set of quick releases and the canopy then hangs free and can slide up as the gas transfers from the bottom to the top of the balloon.

As the top of the balloon extends upward, a short length of the original inside suspension cord slips through the suspension clamp hole, and a rubber packing gland closes off the opening behind it. At this time we then have the cell completely extended in the air with all of the gas in the top and the remainder of the fabric hanging straight down supporting the load. At a prescribed altitude after this time the pressure is released from the tube by a deflator (shown in sketch #7 and in the engineering drawings and photographs). The deflated tube falls down inside the balloon and is caught in the harness at the bottom where it remains throughout the flight. The girdle may stay in place on the outside of the balloon if the friction coefficient and the fabric tension is high enough and if its own weight is low enough. The exact behavior of the girdle in sliding down the outside of the balloon is discussed in a separate section of this report, and the exact behavior of the girdle under any specific set of circumstances has been calculated (see Section 4 on Balloon Physics for equations and graphs). The tube deflator consists of an aneroid bellows with a pin which presses on the tire valve and allows the air to escape at an altitude which can be determined prior to flight. The adjustment consists of screwing on the tube deflator until air begins to escape from the tire and then backing it off the required number of turns and setting the lock nut. The usual adjustment is about one turn and a quarter off for a release altitude of 15,000 feet. It should be noted that when the air pressure is released from the tire, there is no tendency for the fabric to slide as the balloon is erected and the tapes are straightened out.

THE LAUNCHING OPERATION

The procedures used in launching during the course of the 20 flights reported herein have settled into a pattern which is described in the following.

An effort is made to have all preparations completed in the laboratory with the gondola completely rigged and equipped with a snap hook to secure it to the balloon load ring. The gondola then carries the parachutes, the ripcords, the girdle catcher, and any other accessories necessary for the flight. Likewise, the balloon is completely ready in its bag, with the exception of certain kinds of appendices which, because of long, rather fragile slats, have to be completed after the balloon is rolled out on the ground. With changes in accessories and appendix design this may not be necessary.

Upon arrival at the launching site, the balloon, rolled up in its bag, is unloaded from the truck and stretched out on the ground with the load ring up-wind and the balloon top down-wind. Triple stakes or airplane-type screw-down mooring rings are set into the ground, one close to each end of the balloon. The cord from the top of the balloon is passed through a pulley with a swivel which snaps into the top tie-down, and the other end of the cord, which is 50-60 feet long, is secured to a block and tackle, which in turn is secured to another tie-down some distance from the balloon. Similarly, the load rope at the bottom of the balloon, which is secured to the load ring, passes through a pulley and swivel which is snapped onto the bottom tie-down point, and then goes to a block and tackle which, in turn, is anchored securely to the ground. The sketch (page 2-22) shows the approximate dimensions of this layout.

Two canvas ground cloths are laid out, one on each side of the balloon, and the balloon bag is unzipped and folded back on these to make a continuous ground cover. The inflation hose from the helium supply is

then connected to the short lightweight section of vacuum cleaner hose which is a part of the balloon assembly. The balloon is now ready for the inflation. During this operation the gondola has been unloaded from the truck and set to one side, and a final checkout on the gondola begins about the time that gas flows into the balloon. Normally, all of the gas is put into the balloon while both ends are secured to the ground. The proper inflation to be used is calculated out, and the balloon is weighed off on each end using the balloon lift torque wrench. This instrument is shown in the photograph (Appendix 3) and in the engineering drawing, (Appendix 11) and pictures of it in operation are given in Appendix 4. The torque wrench merely exerts a couple on the tie-down lines, and by means of the bubble level and a spring balance measures the vertical component of the tension force in the mooring lines. The torque wrenches, one on each end of the balloon, are read continuously during inflation until the proper amount of gas has been fed into the balloon. When this has been achieved, the top mooring line is disengaged from the block and tackle, and the top of the balloon is allowed to rise slowly as the line is fed through the top pulley. This line is then cut off as high above the ground as possible. An alternative procedure at this point is to cut the line close to the top of the balloon where it emerges from the top lift ring assembly and then let the balloon rise quickly under the influence of its total lift.

The balloon is now anchored by the bottom anchor line, and immediately another weigh-off is made as a check on the inflation. The balloon load ring can then be adjusted to the right height by the bottom block and tackle, the gondola is carried out and snapped into the load ring, and the balloon destruction tape, balloon antenna, or other rigging is completed. At this time, and before the inflation plug is removed, a final weigh-off

may be made which gives the exact free lift of the flight. This weigh-off may be dispensed with if weather conditions are marginal and if the balloon is in motion at this time.

The next step is to pull the first corset quick release, allowing the corset to spread and the inflation plug to fall into the load strings at the bottom of the balloon from whence it can be removed. To facilitate the removal the balloon is usually pulled back close to the ground again with the gondola still snapped on. The balloon is then let up by means of the bottom block and tackle until the gondola is lifted clear of the ground. The corset is completely removed by pulling the final quick release, the diaphragm rip-cord is pulled completely out until it falls, which means, of course, that the diaphragm at the top of the bubble is cut completely through in two directions. And finally, the tie-down rope is severed, allowing the assembly to take to the air. Gas is transferred from the bottom to the top during the launching as soon as the diaphragm is severed. As the balloon rises, gas continues to transfer, carrying the canopy off the bottom until the balloon is extended to its full size.

Appendix 5 is a series of photographs made with a telescopic lens camera and shows the behavior of the balloon as the gas transfers from the bottom to the top. Usually the canopy does not lift symmetrically off the bottom but slides one way or the other as soon as some gas has been transferred. With helium inflations the transferral of the gas takes about two minutes. A schedule is included here which is typical of a good launching. Launchings are frequently carried out in conformity with such a schedule, but in ase of difficulty in checkout of the gondola, or in case the helium manifold has to be changed during inflation, this program will require more time. With careful preparation the balloon can be put in the air in as little as 30 minutes after arrival.

at the launching site.

In most cases launchings have been made behind the large wind screen which was constructed at the University of Minnesota Airport by General Mills, Inc. under an ONR contract. While the wind shelter afforded by this screen eases the launchings, it is not essential, and launchings have been conducted on a number of occasions in winds up to eighteen knots in the open. The project schedule has not afforded very much time for windy launching tests as each flight carries instrumentation for studying various features of the balloon performance, and it was considered of prime importance to get this instrumentation launched without damage. On one occasion, however, a balloon was laid out and inflation attempted in a 45 m.p.h. wind. The layout and inflation began without difficulty, but after some gas had been put into the bubble, the wind force tore the canopy off the inflated part and the balloon was destroyed. The reason for this mishap was connected with a shortcoming of the rigging which was thereafter corrected--namely, that the top mooring rope was secured, not to the diaphragm tube clamp inside the balloon as is done now, but to the top of the balloon where the ring is attached. Therefore, any force on this tends to skin the canopy off, which is what occurred on this test.

Since control of the inflated balloon is kept until the load is in the air, chance of damage is minimized. It is also ascertained carefully that the balloon has the proper free lift so that upward motion is assured. Vertical launchings, of course, have the advantage that once the load is clear of the ground, danger of a launching mishap is terminated.

With this method of packing there is a definite limitation with a given balloon on the volume of inflation that can be obtained. With a 73-foot diameter cell this amounts to a limit of 870 pounds of displaced air, but due to the method of constraining the bottom of the balloon around the thimble,

a safe upper limit is about 700 pounds. When the balloon is erected, it is relatively stable due to the large tension in the tie-rope and the fact that the balloon is full and all of the weight of the fabric is distributed around the inflated volume. It is customary to attach the gondola and extend the tie-down rope so that the gondola is lifted clear of the ground. The assembly then becomes more subject to wind conditions as the net tension in the tie-down rope is reduced to the relatively small free lift value. Unless the wind is very low, it is necessary to support the gondola by hand at this stage to avoid having it bang on the ground. The launching procedure is carried out rapidly so that this period of time can be made short. It will be noted in photographs and drawings of the completely rigged gondola that a sufficiently long connecting line is used between the balloon and the gondola so that the gondola can rest on the ground with the balloon constrained by the tie-down rope after the gondola is attached.

Of those flights of the first 20 which were successfully launched, there is no evidence that damage to the balloon resulted specifically from this method of packaging and launching.

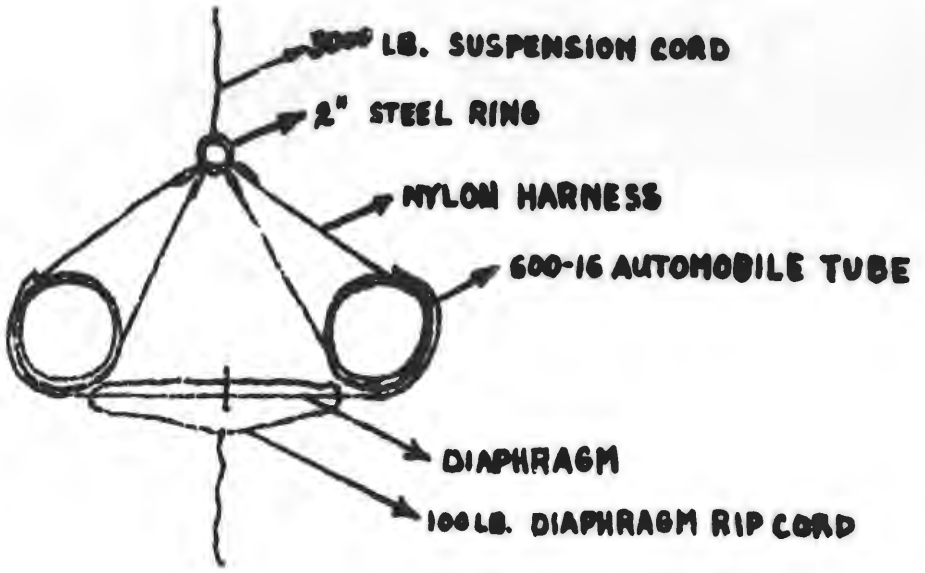
Appendix 4 shows various features of the launchings, and the titles will explain the action of each photograph.

SCHEDULE OF A VERTICAL LAUNCHING

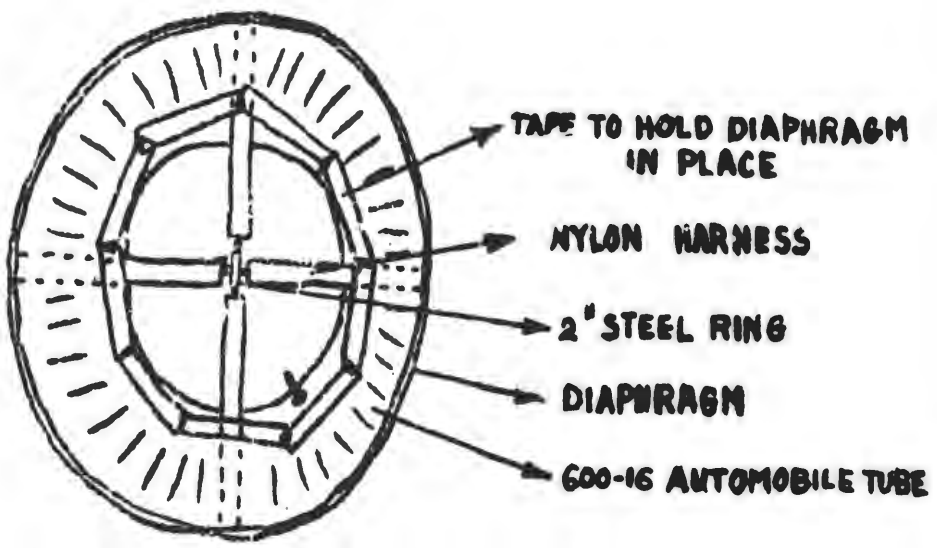
Time	Operation
0000	Arrival at radio shack. Gondola is off-loaded and balloon is carried to wind screen.
0015	Arrival at wind screen. Balloon and equipment are unloaded and balloon is laid out.
0030	Gondola arrives and receives final checkout.
0031	Inflation begins and is carried out while final steps are taken with gondola.
0051	Top of balloon is let up and gondola attached. Final weigh-off is made.
0054	Inflation plug is removed.
0056	Diaphragm is ripped, corset removed, tie line severed.
0058	Balloon is in the air.

1 DIAPHRAGM TUBE

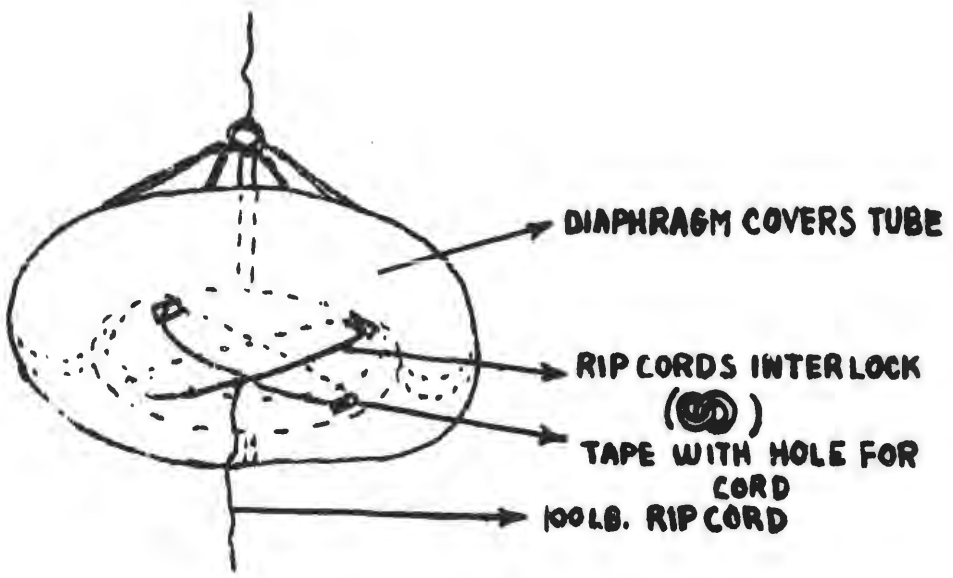
SIDE VIEW



TOP VIEW

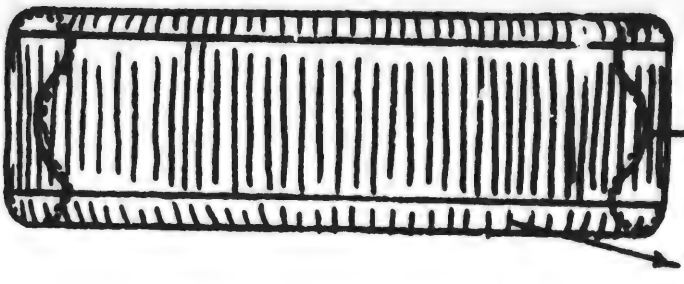


DIAGONAL



2. ALUMINUM GIRDLE

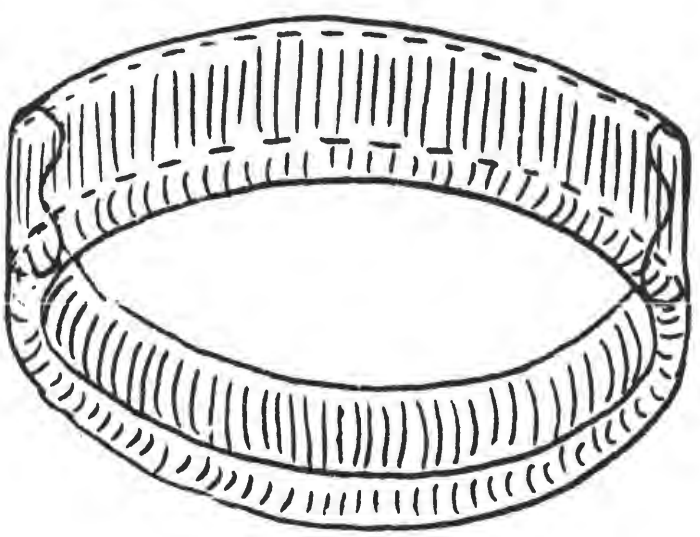
SIDE VIEW



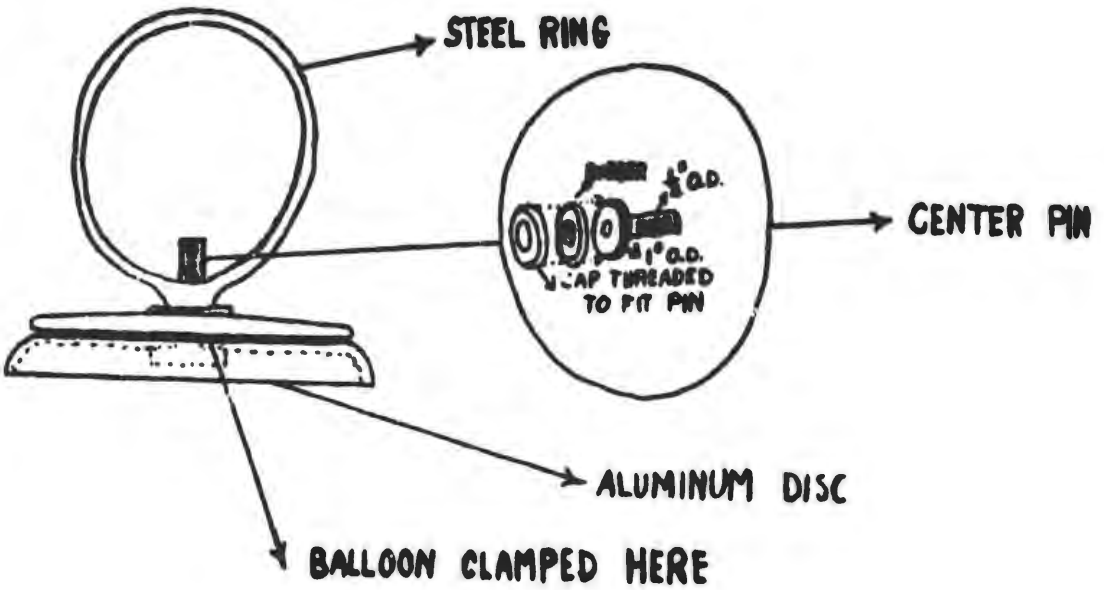
TOP VIEW

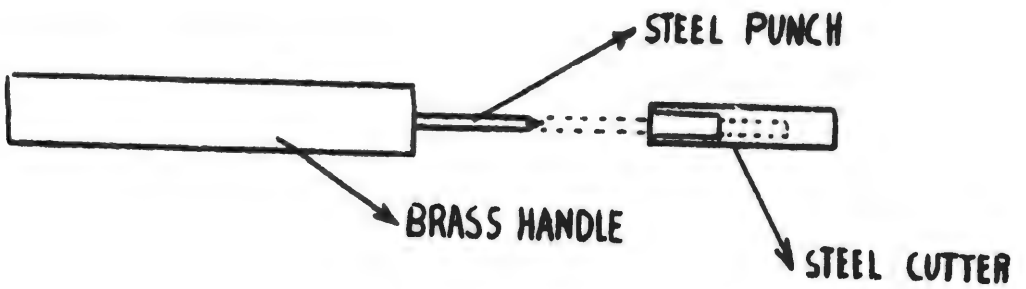


DIAGONAL

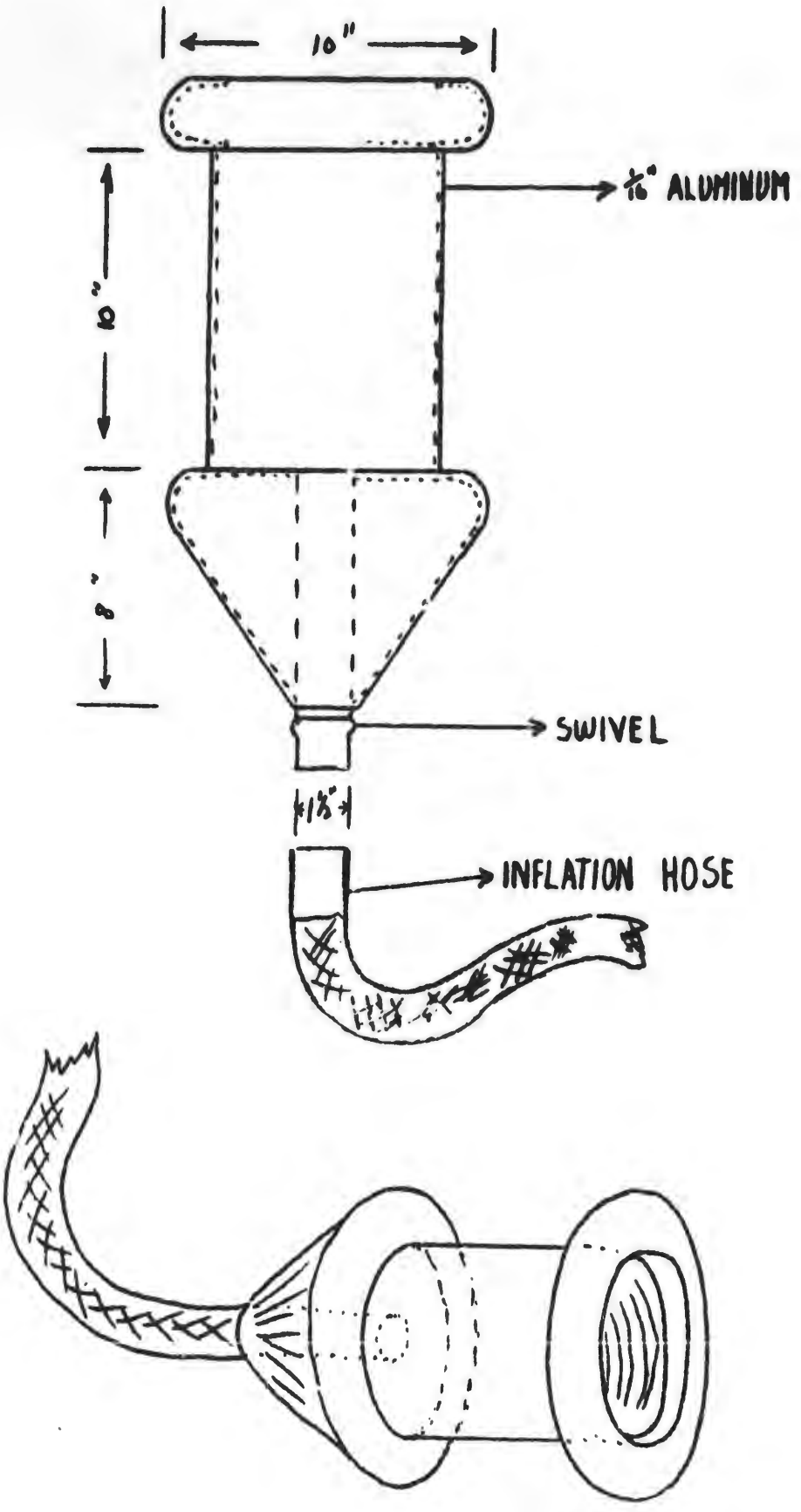


3. SUSPENSION CLAMP + PUNCH (LIFT RING)

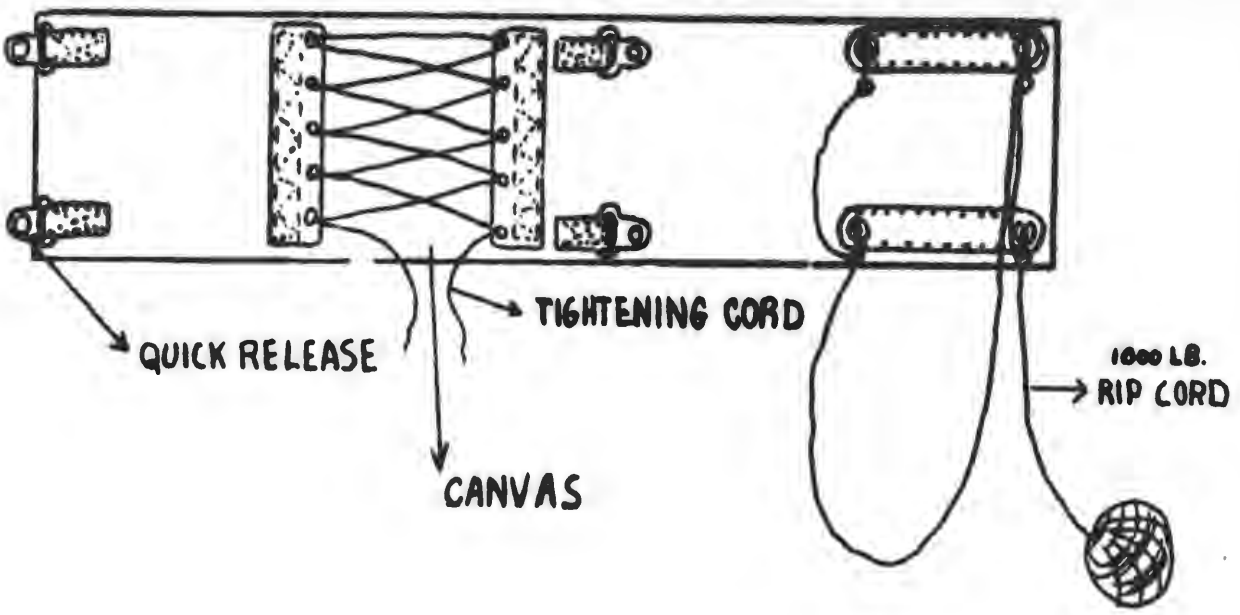


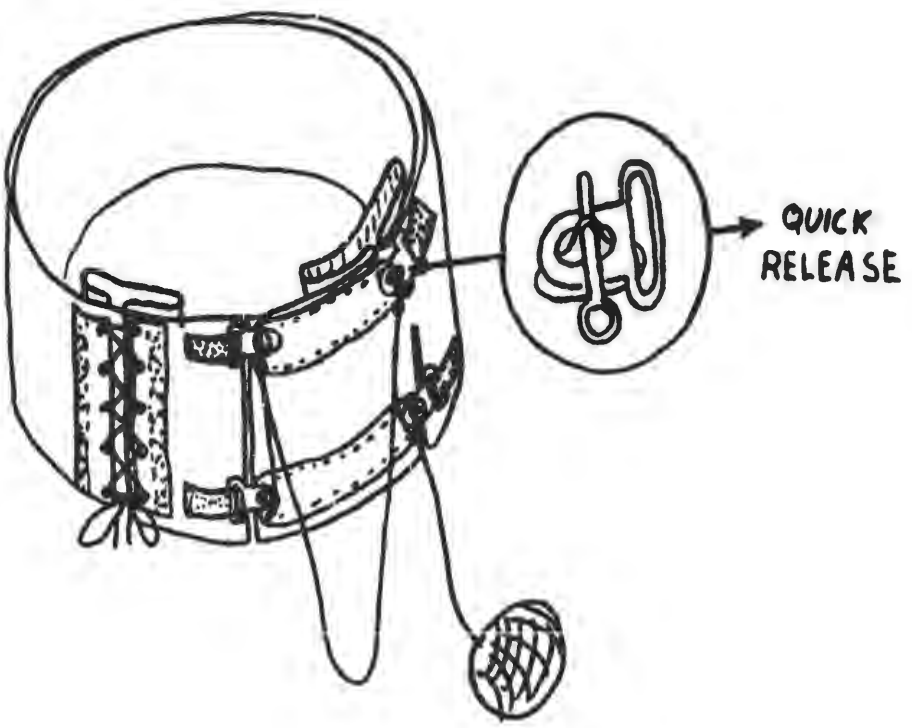


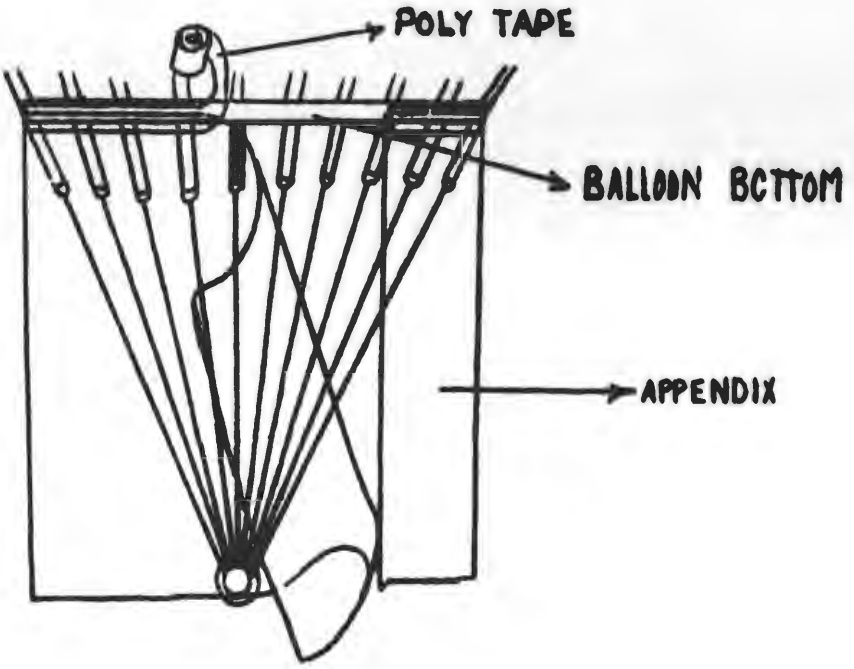
4. INFLATION THIMBLE

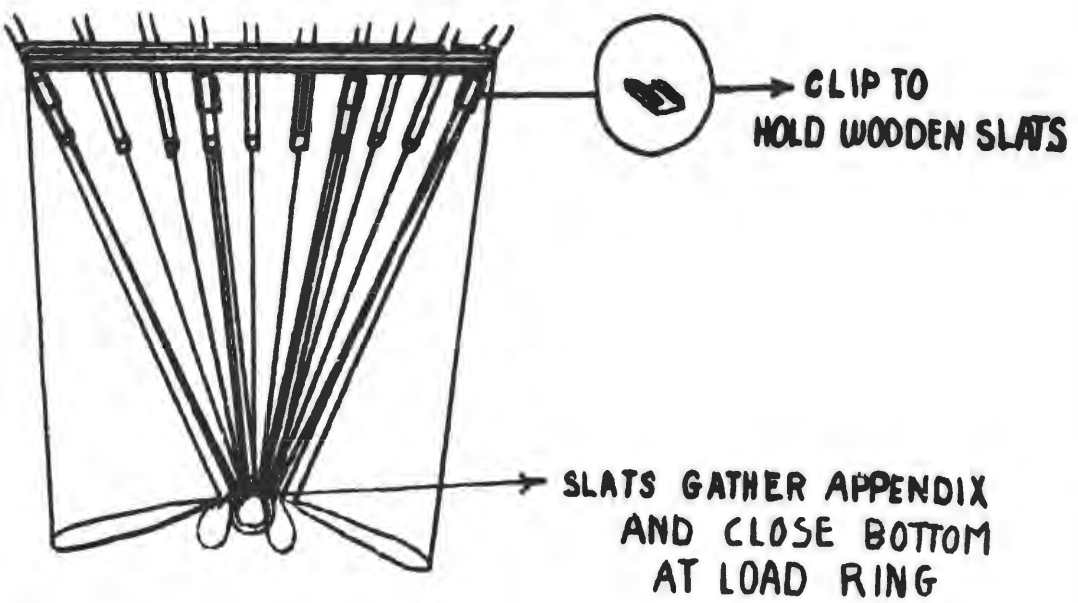


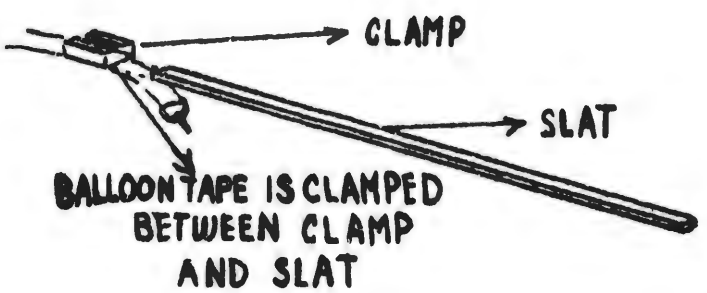
5. POSITION CORSET



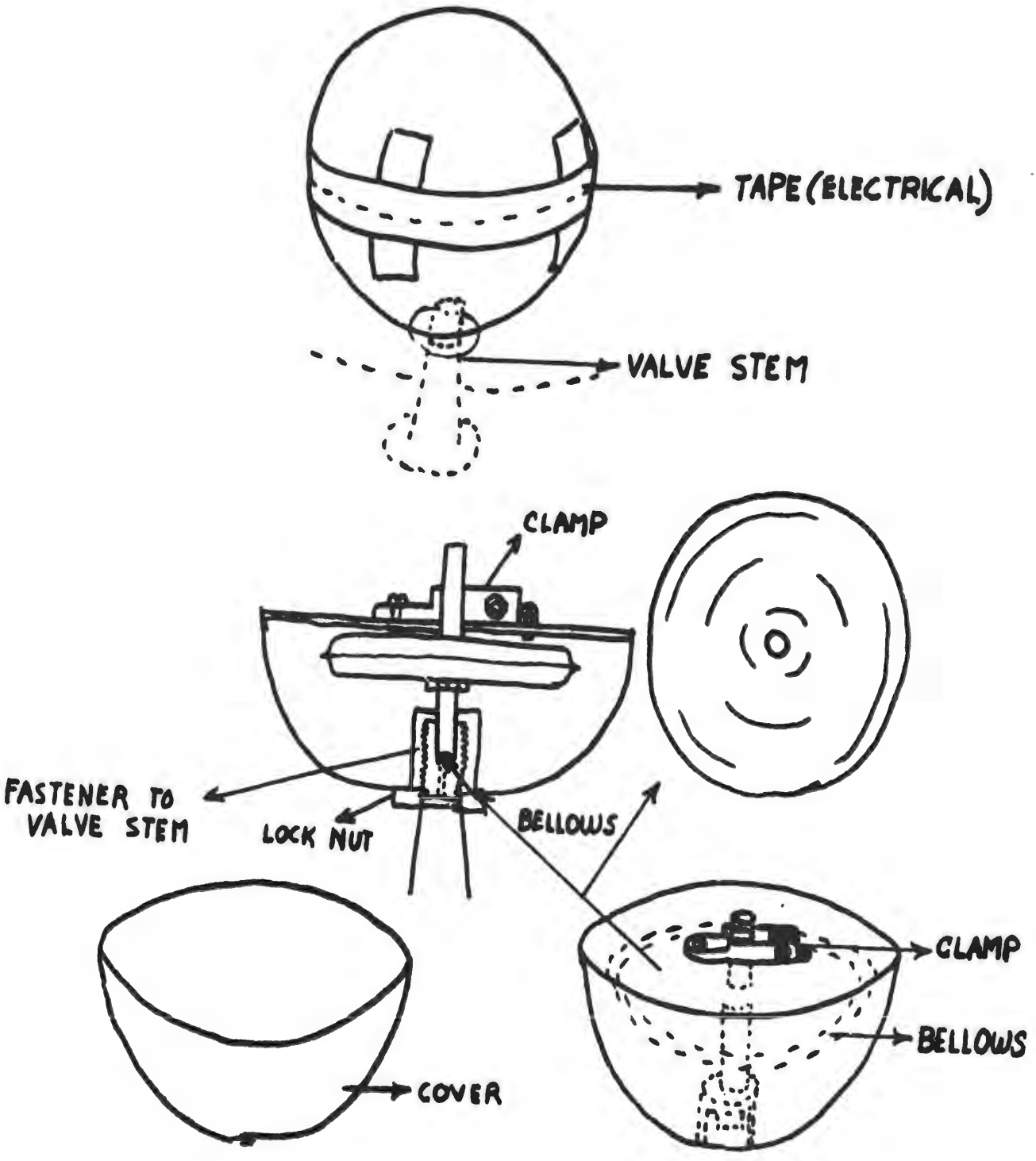


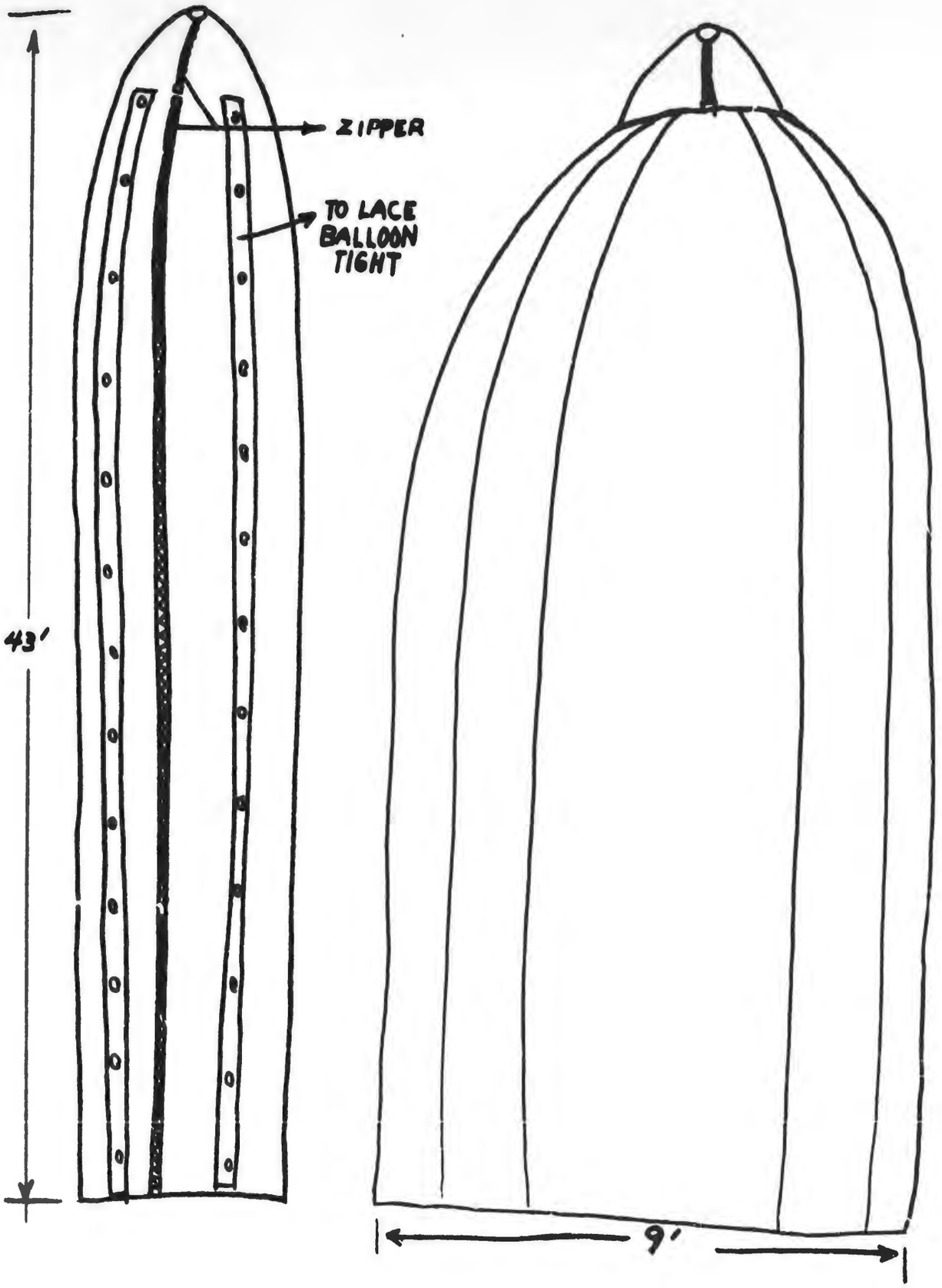

POLY TAPE
BALLOON BOTTOM
APPENDIX

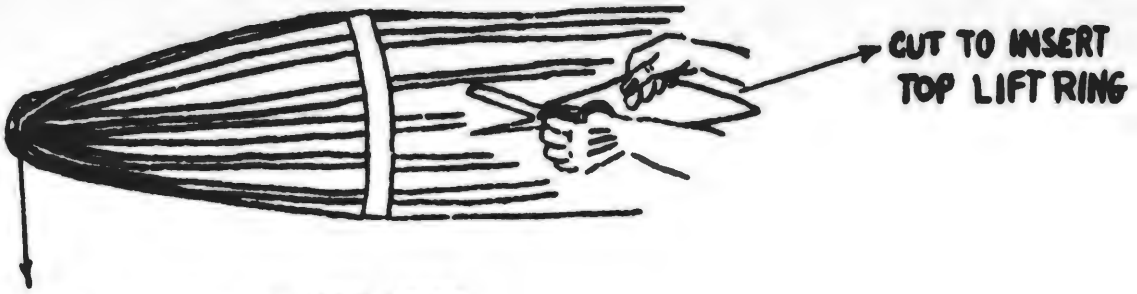

CLIP TO
HOLD WOODEN SLATS
SLATS GATHER APPENDIX
AND CLOSE BOTTOM
AT LOAD RING

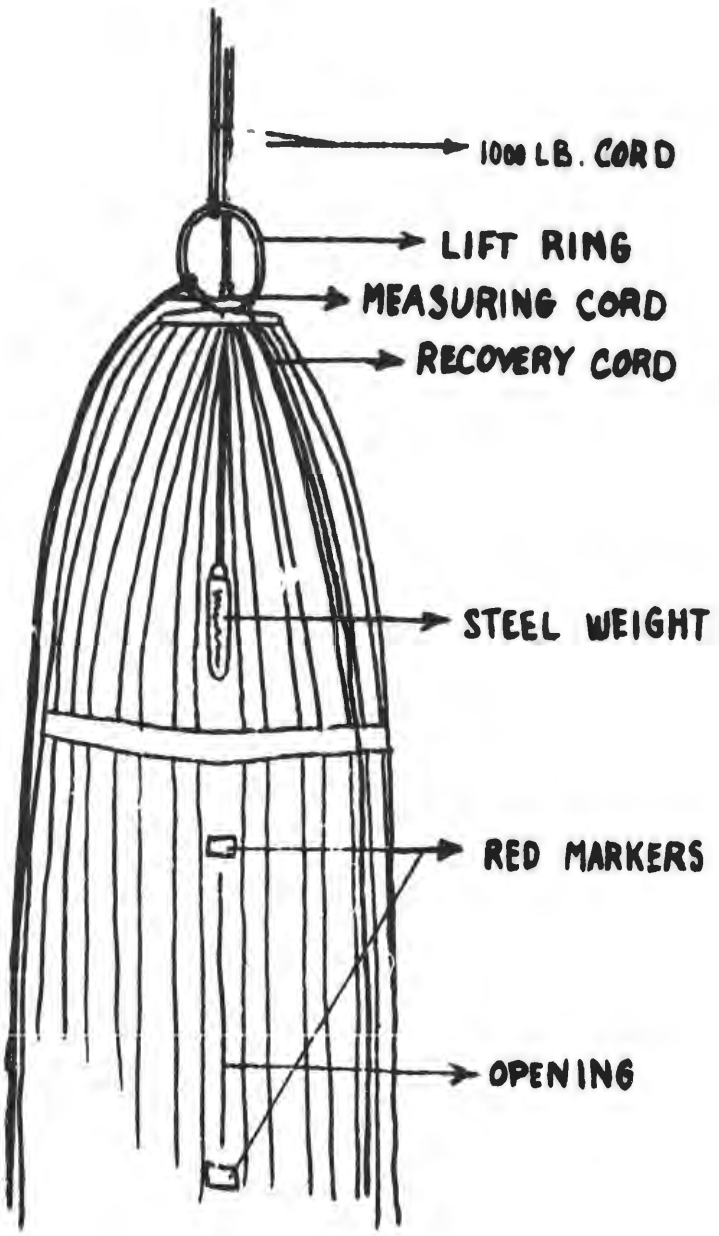

CLAMP
SLAT
BALLOON TAPE IS CLAMPED
BETWEEN CLAMP
AND SLAT

7. TUBE DEFLATOR

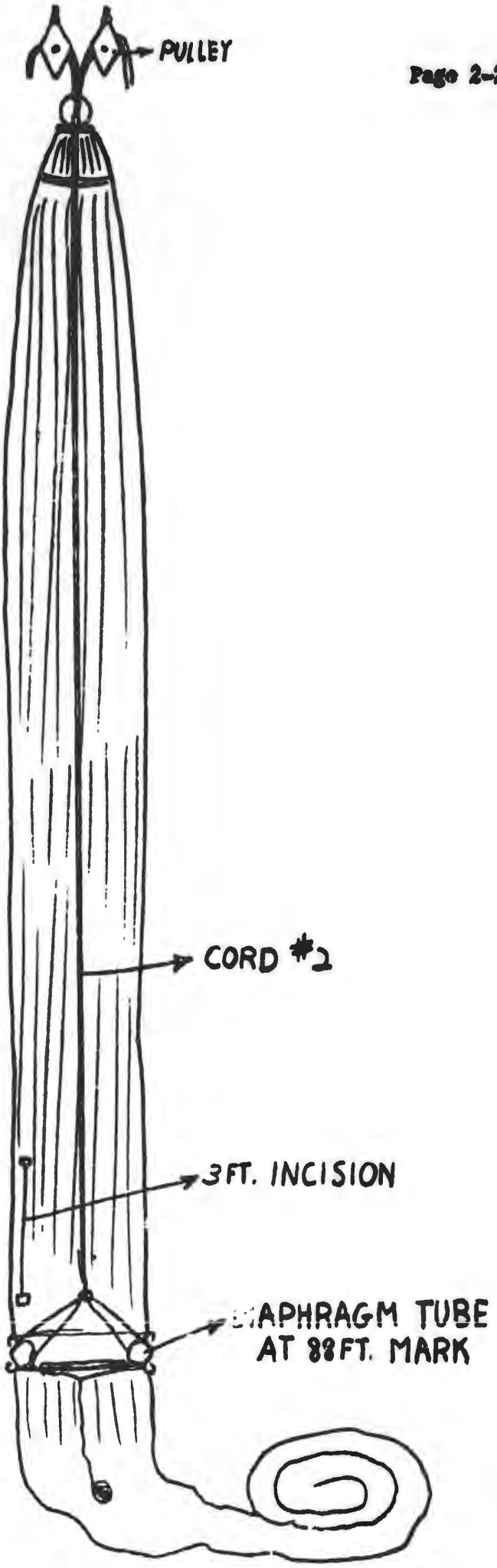


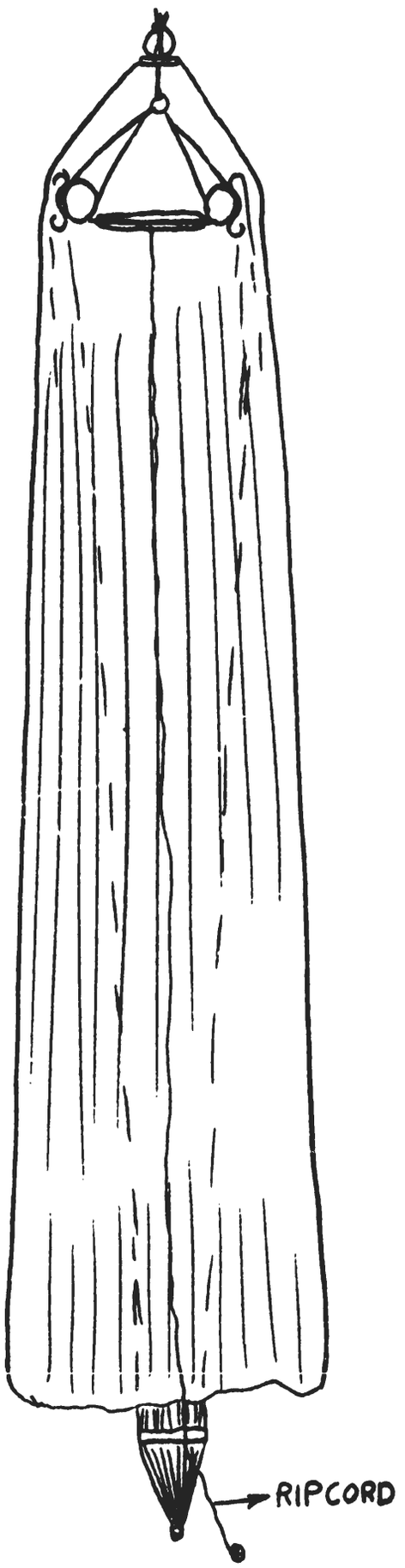

ZIPPER
TO LACE BALLOON TIGHT
43'
9'

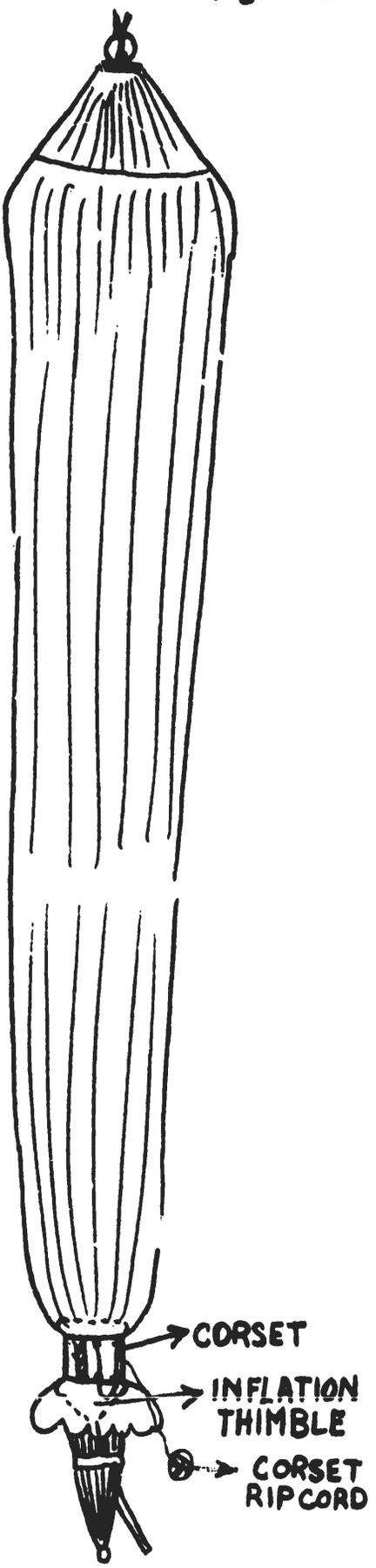

CUT TO INSERT
TOP LIFT RING
CUT HOLE WITH PUNCH HERE


1000 LB. CORD
LIFT RING
MEASURING CORD
RECOVERY CORD
STEEL WEIGHT
RED MARKERS
OPENING

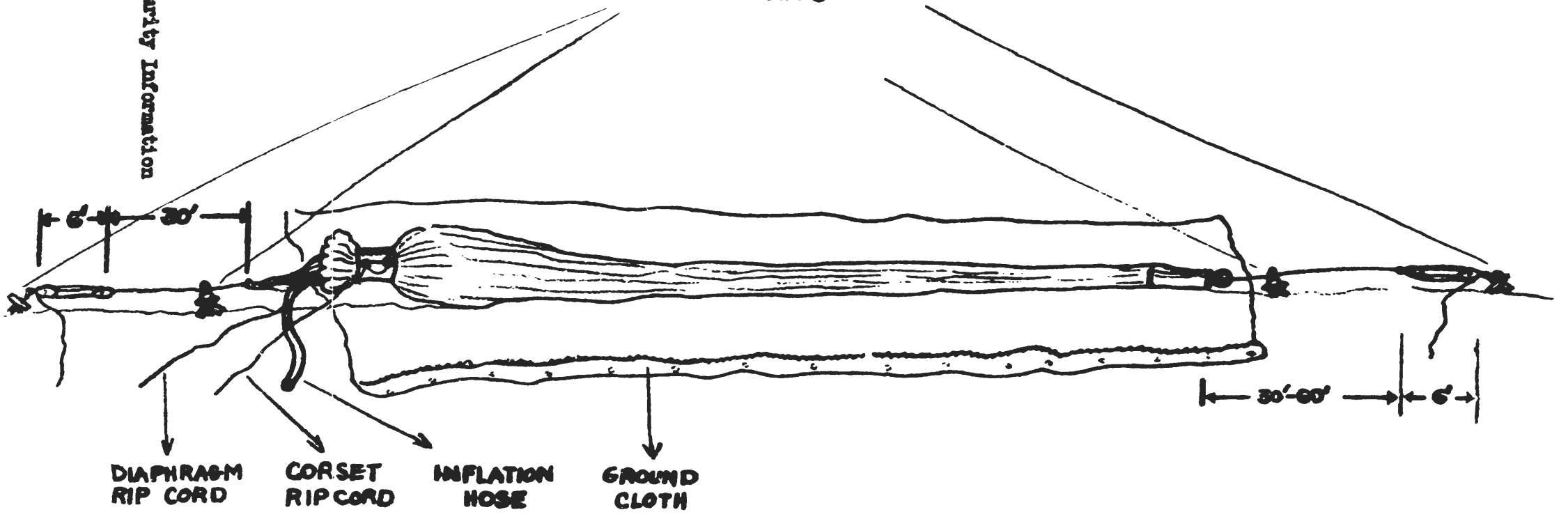
STEPS NO.16-26

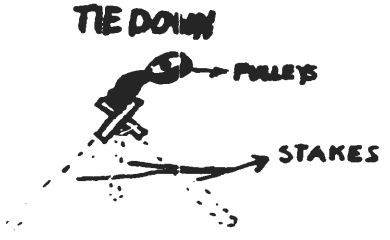



RIPCORD


CORSET
INFLATION THIMBLE
CORSET RIPCORD

READY FOR INFLATION





BALLOON PACKING PROCEDURE

Packing Equipment

A. Major equipment

1. Diaphragm and tube
2. Aluminum girdle
3. Lift ring and punch
4. Inflation thimble
5. Corset
6. Appendix
7. Tube deflator
8. Balloon Bag

B. Installation Equipment

1. Two power winches
2. Two 1000-pound pulleys
3. 1000-pound nylon cord
4. 100-pound nylon cord
5. 2-pound polished metal weight
6. 100-foot measuring tape
7. Two sharp knives
8. Two sharp scissors
9. 50-foot x 9-foot canvas
10. 3 rolls 1" polyethylene tape
11. 1 roll 2" polyethylene tape
12. Heat sealer for polyethylene material
13. Extension cords
14. Tire pump
15. Valve testing gauge
16. Vacuum cleaner

Balloon Packing Procedure

1. Secure 2 pulleys in highest point above floor in building used for balloon packing. Height of pulleys must be 90 feet or more.
2. Secure 2 power winches on floor approximately 20 feet from point directly beneath pulley.
3. String 1000-pound cord through each pulley and fasten to each winch respectively.
4. Secure opposite ends of lines to prevent slipping through pulleys.
5. All workers must realize the importance of being careful not to damage balloon in packing. Special gloves and shoes made of soft material should be used. Most of the steps in packing are done by handling the balloon, thus making this step very important. A demonstration should also be conducted showing the packers just how easily the material is abraded and explaining why they should be careful not to damage the balloon.
6. All balloons are packaged in crates and must be removed from these crates with great caution to avoid nails, sharp corners, etc.
7. Roll out canvas ground cloth directly beneath the pulleys used in hoisting the balloon.
8. Fold the balloon out on the ground cloth, ending up with top crown of balloon directly beneath pulleys. This procedure is unnecessary if balloon is folded in packing crate by manufacturer..
9. Make incision one foot beneath top crown, approximately 16 inches long. Punch center hole and insert top lift ring. Take rubber gasket out of top lift ring.

10. Pull balloon crown through aluminum girdle, allowing girdle to slide freely over the balloon.
11. Tie 1000-pound winch cord number one to top of lift ring.
12. Insert winch cord number two through center hole in top lift ring and extend inside of crown.
13. Put steel weight through incision and tie to winch cord number 2. Weight will slide freely.
14. Tie 88-foot measuring cord to top lift ring and extend it down side of balloon. (This step is unnecessary if 88-foot length is marked on balloon by manufacturer.)
15.* Tie 100-pound nylon recovery cord to top lift ring and begin taping this cord down one gore of balloon as winch #1 raises balloon. (This step unnecessary if cord is installed by manufacturer.)
16. Raise balloon to 88-foot mark, taping recovery cord as balloon raises. Continue to tape cord 3 feet past 88-foot mark.
17. Make a 3-foot incision between 2 gores upward from 87-foot mark.
18. Insert vacuum cleaner hose and reverse cleaner to pump air into balloon. Continue to pump air until gores loosen up and hang freely. (This step is essential.)
19. Hold aluminum girdle above incision, then reach in through incision and untie steel weight from winch cord #2.
20. Tie diaphragm tube harness ring to winch cord #2, allowing diaphragm rip cord to fall into the balloon. Rip cord will eventually fall through bottom of balloon as additional steps are completed.

* This step used only when camera is in top.

21. Adjust winch cord #2 so that diaphragm tube is centered at 88-foot mark.

22. Space gores of balloon equally around outside of diaphragm tube.

23. Reach through 3-foot incision and partially deflate diaphragm tube.

24. Slide aluminum girdle down over diaphragm tube and balloon to 88-foot mark.

25. Reach through incision and secure tire pump to valve step of diaphragm tube. Inflate to 13 pounds, locking balloon gores between diaphragm tube and aluminum girdle.

26. Heat seal 3-foot incision and mark clearly with red tabs for future identification of incision.

27. Raise winch #2 and lower winch #1, allowing balloon to drape freely over girdle.

28.* While draping process is being completed, continue to tape recovery cord until bottom of balloon is reached.

29. During draping process continue to raise winch #2 and lower winch #1 until diaphragm tube is approximately 3 feet from top lift ring. This will allow bottom of balloon shroud to drape approximately 1 foot above bottom of balloon.

30.* End taping process of recovery cord by tying recovery cord to load ring at bottom of balloon.

31. As balloon bottom is lifted off floor, diaphragm tube rip cord should roll out bottom.

32.**Measure circumference of bottom opening in balloon.

33.**Cut 2-mil polyethylene material the same length as circumference of bottom of balloon.

34.**Tape material to bottom of balloon with 2-inch polyethylene tape. This forms balloon appendix.

* This step used only when camera is in top.

** These steps unnecessary if balloon comes with appendix or if other appendix design is used.

35. Cut a piece of polyethylene material 8 feet long. Straighten gores at bottom of shroud and tie this material around shroud to bring center and shroud together.

36. Put balloon corset around outside of polyethylene material which protects balloon and secure quick releases, allowing corset to maintain its full diameter. Bottom of corset should be approximately 12 inches above bottom of shroud.

37. Insert inflation thimble through bottom of balloon, centering thimble with center of corset.

38. Pull corset together and secure second adjustment of quick releases, locking thimble in place.

39. Lace corset and pull together as tight as possible against thimble to lock balloon tightly between corset and thimble.

40. Put spare piece of polyethylene material over outside of corset to prevent accidentally pulling quick releases.

41. Roll out balloon bag directly beneath balloon.

42. Lower winch #1 and winch #2 simultaneously, allowing balloon to rest in balloon bag.

43. Untie 1000-pound cord from top lift ring. Reach through opening and untie cord from diaphragm tube harness ring and replace rubber gasket in top lift ring.

44. Put 60-foot cord through top lift ring and tie to diaphragm tube harness ring. This cord will be used to anchor top of balloon during inflation.

45. Start rolling balloon in balloon bag from bottom to top, leaving balloon bag unzipped until air pressure inside balloon prevents rolling farther.

46. Brace remaining opening in top of balloon with cardboard to allow air to rush out.

47. An additional incision may be made through opening in balloon crown into inner balloon section to release excess trapped air underneath canopy or inside the lower part of balloon.

48. After trapped air is released, all incisions made in the inner part of the balloon must be heat-sealed through incision near crown and taped.

49. If balloon is to be flown immediately, pressure release may be inserted and applied to valve stem of diaphragm tube. Then incision below crown must be heat sealed and taped.

50. If balloon is not going to be flown immediately, incision beneath crown may be left open, and pressure release may be insertod at a later date. (Incision must be heat sealed then.)

51. Roll balloon out once more and zip balloon bag.

52. Then re-roll balloon bag tightly, and balloon is ready for flight use.

SECTION III

BALLOON SHAPE

Design of the shape of the open-appendix balloon may be of importance in a number of ways, the most obvious one being to avoid regions in which there is more fabric than necessary to hold a stable contour. The danger in having such regions is that under the super pressure of valving at ceiling the effective volume will be larger than the stable, normal pressure volume, and an immediate ballast drop would be necessary to compensate for over valving when the material relaxes. Other objectives in design may be to minimize stress concentrations, to produce only uniaxial stress, etc. The design problem is complicated by the plastic nature of the material in such a way that ultimate dimensions of the full balloon may be several percent different from those in the unstressed envelope. Plans have been made to determine stresses and strains in inflated cells and in flat samples of polyethylene.

As of the present, the work has been of a mathematical nature and has been of two kinds. First, the fundamental differential equations for the stress along the meridian, t, and that along a horizontal circumference, t_c, have been set up for the static, axially symmetric balloon and applied to standard designs. Secondly, a number of solutions to the problem of surfaces of uniaxial stress have been obtained on the Reeves Analog Computer by Mr. Leland Bohl. The second effort is a continuation of a program initiated by Mr. Donald Melton of the Aeronautical Research Laboratory of General Mills and Dr. Ralph Upson of the University of Minnesota and has been pursued in close cooperation with them.

Let us assume that the balloon fabric is of uniform density, w pounds/feet^2, and that the stress is distributed evenly throughout a given circumferential section (i.e., ignore any inhomogeneities produced by the tapes). Then, if the difference in the densities of the gases is ρ (assumed constant over the height of the balloon) and the radius r of a section in a plane perpendicular

to the axis at z is given, $r = r(z)$, the fundamental equations are

$$\frac{d}{dz}\left(\frac{rt}{\sqrt{1+r'^2}}\right) - \beta r r'(z+\alpha) - wr\sqrt{1+r'^2} = 0 \qquad (1)$$

$$\frac{d}{dz}\left(\frac{rr't}{\sqrt{1+r'^2}}\right) + \beta r(z+\alpha) - t_c\sqrt{1+r'^2} = 0 \qquad (2)$$

where z is chosen so as to increase vertically upward. Equations (1), (2) may be combined to form

$$\frac{rr''t}{(1+r'^2)^{3/2}} + \beta r(z+\alpha) + \frac{wrr' - t_c}{\sqrt{1+r'^2}} = 0 \qquad (3)$$

$$\frac{d}{dz}(rt) - wr - r't_c = 0 \qquad (4)$$

r' means dr/dz.

The quantity α is the effective gas head at $z = 0$ which is ordinarily chosen to be the apex of the bottom cone; α may be positive if the cone is closed off or if there is a stabilized appendix hanging at $Z = 0$, or α may be negative if the balloon is not full and the "cone" is closed off. In most operations α is essentially zero.

A convenient parametric form of equations (1) and (2) can be obtained by introducing the variable s which is the distance measured along the meridian on the surface, i.e.

$$ds = \sqrt{dr^2 + dz^2} \qquad (5)$$

and

$$\frac{d}{ds}(z'rt) - \beta r r'(z+\alpha) - wr = 0 \qquad (6)$$

$$\frac{d}{ds}(r'rt) + \beta r z'(z+\alpha) - t_c = 0 \qquad (7)$$

where

$$r' = dr/ds, \quad z' = dz/ds.$$

Integrating eq. (6) (or eq. (1)) from s = 0 to the top of the balloon $s = s_\lambda$ we get

$$\left[z'rt\right]_0^\lambda = w\int_0^{s_\lambda} rds - 1/2\beta\int_0^\lambda r^2\,dz + 1/2\beta\left[r^2(z+\alpha)\right]_0^\lambda \qquad (8)$$

$$= \frac{\text{weight of fabric - bouyancy}}{2\pi}$$

The left hand side is the sum of vertical lift at the crown and the bottom of the balloon. Ordinarily the crown is flat and $(z'rt)_\lambda = 0$. The left hand side may be written $-L/2\pi = -\ell$ where L is the load carried by the balloon.

The parametric form giving r as a function of s instead of z is convenient also from the point of view of the manufacture since it is more closely related to measurements on the balloon table. Theoretically, a gore width is not exactly equal to $2\pi r(s)/n$, wherein is the number of gores equal width at s, but in practice it is very close to it. The width measured on the table is the distance along a geodesic on the balloon surface such that the intersections with the two edges of the gore are made with equal angles.

A geodesic x is related to r, s and ϕ, the azimuth angle, by

$$dx = \sqrt{ds^2 + r^2 d\phi^2} \qquad (9)$$

$$\delta\int_1^2 dx = 0$$

from which

$$\frac{d^2s}{dx^2} - r\frac{dr}{ds}\left(\frac{d\phi}{dx}\right)^2 = 0$$

$$\frac{d}{dx}\left(r^2\frac{d\phi}{dx}\right) = 0 \qquad (10)$$

integrating, we get $\frac{d\varphi}{dx} = \frac{a}{r^2}$

and from eq. (9)

$$\frac{ds}{dx} = \sqrt{1 - \frac{a^2}{r^2}}$$

$$\frac{ds}{d\varphi} = \sqrt{\frac{r^4}{a^2} - r^2} \qquad (11)$$

From eq. (11) it is evident that a is the value of the radius at the center of the gore. The width of a gore at meridian distance s_i at its center is related to the half angle of the gore $\varphi_g = \pi/n$ by

$$x = 2a\left[\varphi_g + \frac{1}{2}\varphi_g^2 \frac{d^2x}{d\varphi^2} + \frac{1}{6}\varphi_g^3 \frac{d^3x}{d\varphi^3} + \cdots\right]$$

where

$$\frac{dx}{d\varphi} = \frac{r^2}{a} = a$$

$$\frac{d^2x}{d\varphi^2} = 2\frac{r}{a}\frac{dr}{ds}\frac{ds}{d\varphi} = 0$$

$$\frac{d^3x}{d\varphi^3} = 2\frac{r}{a}\frac{dr}{ds}\frac{d^2s}{d\varphi^2} + (\cdots)\frac{ds}{d\varphi}$$

$$= 2a\dot{a}^2$$

if $\dot{a} = (dr/ds)_{r=a}$.

In sufficient approximation, therefore, the width at s, with $a = r(s)$ is

$$x = \frac{2\pi a}{n}\left[1 + \frac{1}{3}\frac{\pi \dot{a}^2}{n}\right]. \qquad (12)$$

Conc on Sphere Balloons

For the most part, plastic balloons have been designed to have a spherical top. In this design $t = t_c$ at the top, and each diminish with distance from the top and approaching the equator. Since t is governed

primarily by the load carried at the bottom apex, and since the curvature of a sphere does not change, the meridian stress carries more and more of the gas pressure as one approaches the bottom of the sphere. In fact, it is possible with this design for t_c to become negative in the calculations. Physically, a negative t_c corresponds to $t_c = 0$, a circumferentially slack region in the balloon, and an increase in the radius of curvature in the meridian plane. Hence, in this region the balloon will depart from design shape and approach a "natural" shape. At the junction of sphere with cone the restraint of the gas pressure is transferred from the meridian stress (since a cone has no curvature in that plane) to the circumferential stress creating a large discontinuity in t_c. Owing to the plastic properties of the material, one would expect these balloons to deform in such a way as to flare the cone and increase the radius of curvature near the bottom of the spherical portion. Evidence of such a "bump" appears in photographs of fully inflated cells. (See Appendix 8, Frame 67).

Eq. (6) can be readily integrated for t when the envelope forms a sphere. It is convenient, however, to choose the origin for $\underline{s}$ at the top of the balloon and allow $\underline{s}$ to increase downward. Further, we take the radius of the sphere, R, to be our unit of length and ρR^3 our unit of mass. The equation of the surface is then

$$r = \sin s \qquad z = 1 - \cos s \tag{13}$$

Let h be the distance between the center of the sphere and the point of zero pressure difference at the bottom of the balloon. The eq. (6) and (7) yield

$$t = \frac{1}{2} h + \frac{1}{3}\left[1 + \frac{\cos^2 s}{1 + \cos s}\right] - \frac{w}{1 + \cos s} \tag{14}$$

$$t_c = h - t + (1 - \bar{w}) \cos s \tag{15}$$

where $\bar{w}$ is the surface density of fabric in the new units. For large balloons $\bar{w}$ is of the order 0.1. The functions of s required to determine t and t_c, once h and $\bar{w}$ are given, appear in Table I.

For the cone-on-sphere design, with $\alpha = 0$, $h = \csc \theta$ (in units of R) where θ is the angle made with the axis by elements of the cone. The volume V and total area A of the balloon are

$$\begin{aligned} V &= \frac{1}{3}\pi(1 + \sin\theta)(1 + \csc\theta) \\ A &= \pi(1 + \sin\theta)(1 + \csc\theta) \\ r &= z \tan\theta \quad \text{(in conical part)} \end{aligned} \tag{16}$$

From eq. (3) we find

$$t_c = (z \sec\theta + w \tan\theta)\, z \tan\theta \tag{17}$$

and from eq. (4)

$$t = \frac{l \csc\theta}{z} + \frac{1}{3} z^2 \tan\theta \sec\theta + \frac{1}{2} \bar{w} z \sec^2\theta \tag{18}$$

In Fig. 1 are shown t and t_c as functions of s, measured from the top, for a "Skyhook", ($\theta = 31.6°$) and such that the balloon weight is 1/3 the gross load. The units are arbitrary. The sharp discontinuity in t_c will be smoothed to some extent by plastic deformation as mentioned above.

Since t_c decreases downward on the sphere, it is sufficient that $t_c \geq 0$ at the junction of cone and sphere, i.e., at $s = \frac{\pi}{2} + \theta$ in order to avoid slack regions in the design. Substituting in eq. (15) we get

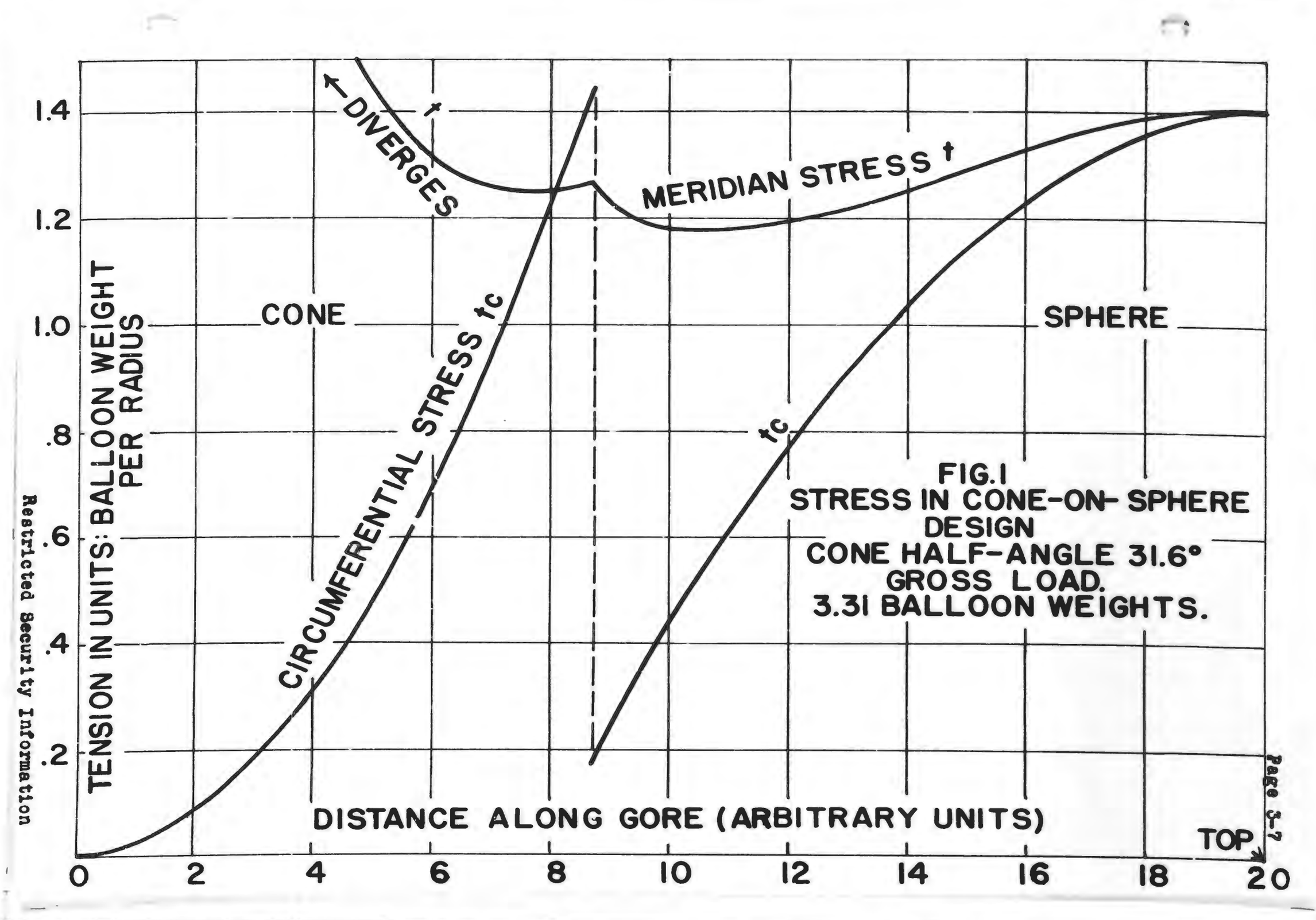
$$\min t_c = \frac{1}{2} \csc\theta - (1 - \bar{w}) \sin\theta - \frac{1}{3}\left[1 + \frac{\sin^2\theta}{1 - \sin\theta}\right] + \frac{w}{1 - \sin\theta}$$

The condition for $\min t_c \geq 0$ is then

$$\bar{w} \geq \frac{1}{6}\left[4 - \frac{3\csc\theta - 1}{\sin\theta + \cos^2\theta}\right] \tag{19}$$

In terms of weight of balloon, B, and gross lift, G

$$\bar{w} = \frac{B}{3G}$$



Restricted Security Information

Table I

Functions for Stress Computations in Spheres

s(deg)	cos s	$\frac{1}{3}\left[1+\frac{\cos^2 s}{1+\cos s}\right]$	$\frac{1}{1+\cos s}$
0	1.0000	.5000	.5000
10	.9848	.4962	.5038
20	.9397	.4851	.5155
30	.8660	.4673	.5359
40	.7660	.4441	.5663
50	.6428	.4172	.6087
60	.5000	.3889	.6667
70	.3420	.3624	.7452
80	.1736	.3419	.8521
90	.0000	.3333	1.0000
100	- .1736	.3455	1.2101
110	- .3420	.3926	1.5198
120	- .5000	.5000	2.0000
130	- .6428	.7189	2.7996
140	- .7660	1.1692	4.2735
150	- .8660	2.1990	7.4627

Fig. 2 shows the line dividing a region of B/G and θ in which (19) is satisfied from a region in which it is not. In the latter, rough estimates of the percent difference in volume between design shape and equilibrium shape are presented.

For purposes of comparison with the stresses in the cone-on-sphere design a calculation has been made for a balloon designed so that the top is a hemisphere (of unit radius) and the lower half is a sine curve.

$$r(z) = \sin z$$

The volume of the design is 4.55 (R^3) and the area 13.49 (R^2). The stresses for the case $\overline{w} = 0.1$ are shown in Fig. 3.

Natural Shape Balloons

The considerations above apply to particular designs when fully inflated. Actually, during ascent and at all times during which the balloon is not at ceiling (and the appendix remains closed) there will be regions of excess fabric. In these regions, therefore, $t_c = 0$ and the balloon will assume a 'natural' shape.

Work had been started at General Mills Aeronautical Laboratory on the natural shape as a desirable design for a full balloon since the fabric is stressed uniaxially everywhere. The project at the University took up the problem and solved the differential equations on an analog computer for a number of cases in which the weight of the fabric can be ignored. This work was done by Mr. Leland Bohl and the results transmitted through Professor Upson to General Mills, Inc.

The differential equations (3) and (4) simplify greatly when $w = t_c = 0$, viz. rt becomes a constant, $\ell \sec \theta$, and

$$\frac{r''}{(1 + r'^2)^{3/2}} + \frac{\beta r(z + \alpha)}{\ell \sec \theta} = 0 \qquad (20)$$

FIG. 2
RELATION BETWEEN θ AND B/G FOR THE ABSENCE OF SLACK ZONE IN CONE-ON-SPHERE DESIGN.

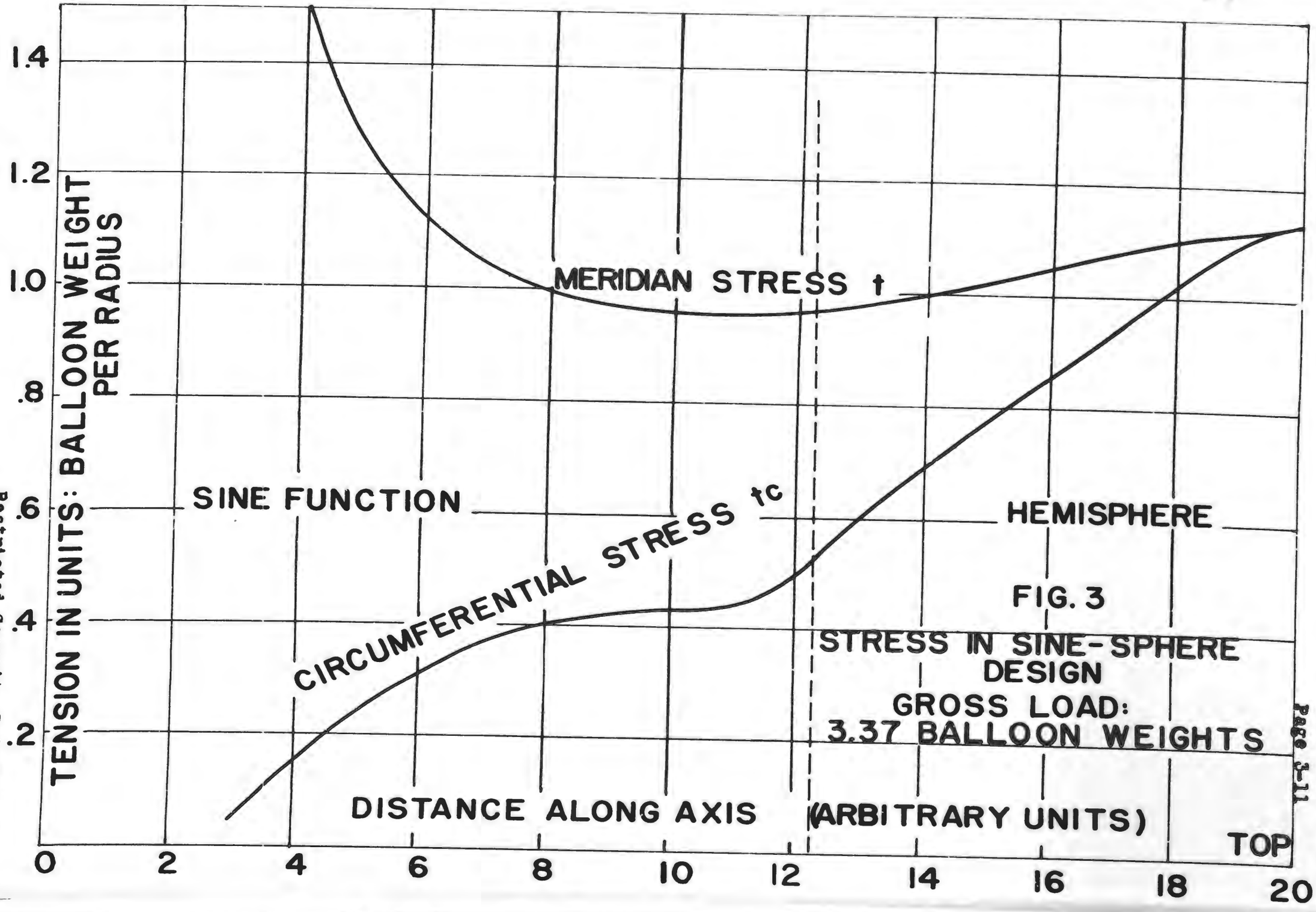


FIG. 3

STRESS IN SINE-SPHERE DESIGN

GROSS LOAD: 3.37 BALLOON WEIGHTS

Restricted Security Information

For this type of design we choose the unit of length to be

$$\left(\frac{\ell \sec \theta}{\beta}\right)^{1/3}$$

so as to eliminate it from eq. (20). Measuring r and z and α in the new units and transforming $z + \alpha \rightarrow z$ the basic differential equation becomes

$$\frac{r''}{(1 + r'^2)^{3/2}} + rz = 0 \tag{21}$$

Eq. (21) can be derived from a variational principle assuming that the length of the balloon remains fixed

$$\delta \int_0^{\lambda} \left\{ \frac{1}{2} zr^2 - \sqrt{1 + r'^2} \right\} dz = 0 \tag{22}$$

It was thought that the variational principle would be valuable as a means of introducing fabric weight as a perturbation. The present plan, however, is to solve the complete equations, with various choices for w and t_c, on the analog computer.

The parametric form of eq. (21) is the pair of equations

$$\dot{r}\ddot{z} + rz\dot{z} = 0 \tag{23}$$

$$\dot{z}\ddot{r} - \dot{z}r\dot{r} = 0 \tag{24}$$

where the dots denote differentiation by s. It may be of interest to note that eqs. (23) and (24) have solutions of form

$$r = sf(s^3) \qquad z = sg(s^3)$$

where f and g may be written as Taylor series in s^3.

It is clear from eq. (21) that if the top is flat, $z = \lambda$, $r' \rightarrow \infty$, r must approach zero as the cube root of $\lambda - z$ instead of the square root as on a sphere, for the asymptotic form of (21) is

$$-\frac{r''}{r'^3} + \lambda r = 0$$

integrating

$$\frac{1}{r'} + \frac{1}{2} \lambda r^2 = 0$$

and again

$$z - \lambda + \frac{1}{6} \lambda r^3 = 0$$

Several series of solutions to eqs. (23), (24) were produced on the analog computer. These comprise:

(a) a detailed solution for a flat topped balloon with zero pressure difference at the bottom apex,

(b) a series of curves of flattops with sub pressure at the apex,

(c) a series of curves of flattops with super pressure at the apex,

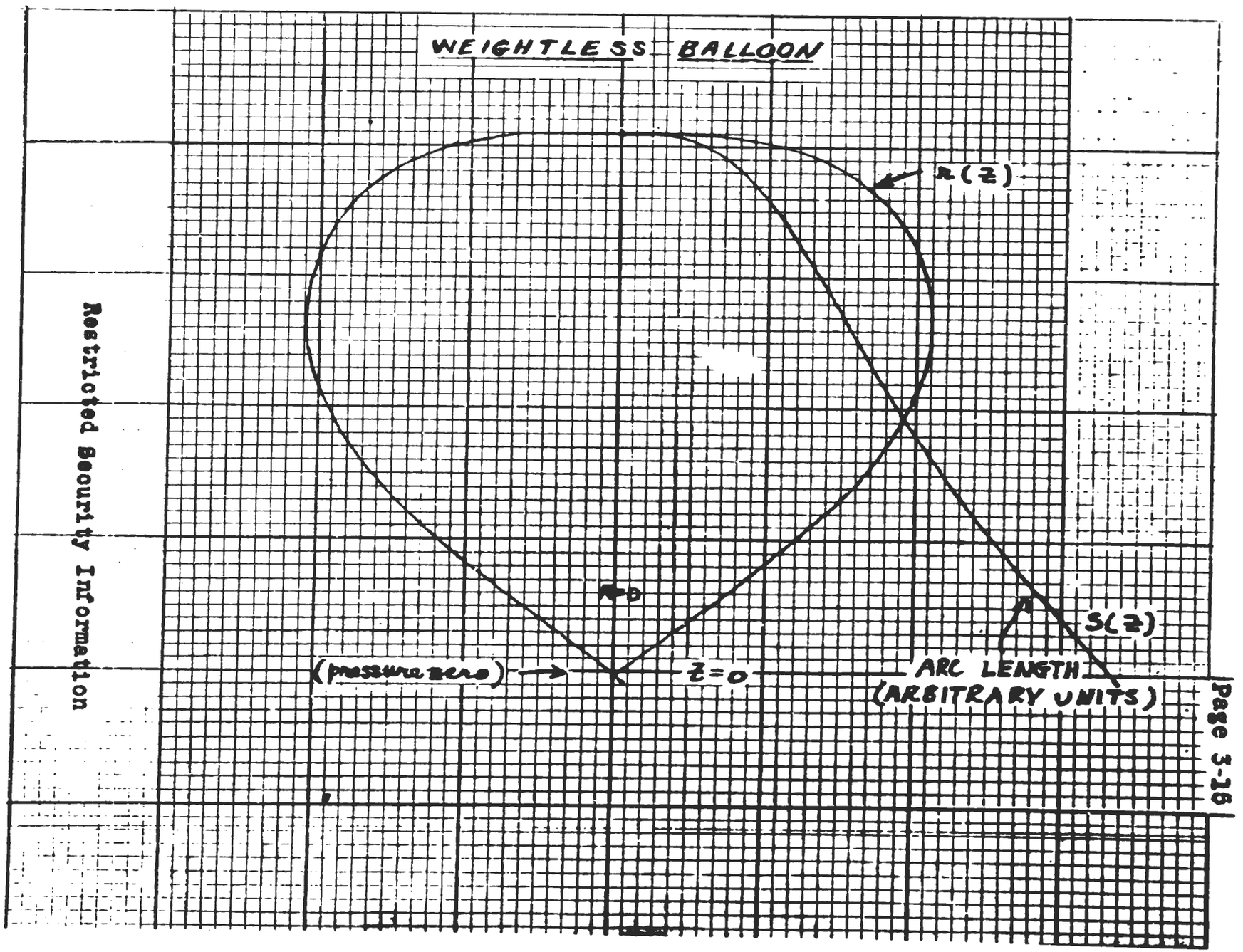
(d) a series of curves of balloons designed to carry part of the load on the crown (valentines).

The method of finding solution (a) was to start solutions to the equations with zero pressure difference at the apex but with different apex angles θ and have the computer plot r and $\dot{z}$, in appropriate units. By trial it was found that when $\theta = 50.5^{\circ}$, r and $\dot{z}$ became zero simultaneous, thus forming a flattop balloon. An axial cross section is shown in Fig. 4, and values of r and z read from the computer are presented in Table II. This is the natural shape for a flattop, weightless balloon, and the numbers appearing in Table II were supplied to General Mills for their 116-foot new design.

A second flattop solution was found at $\theta = 44.5^{\circ}$ for which the natural shape comprises two cells in tandem with the pressure at the bottom of the upper cell equal to that at the top of the lower one. The axial cross section is shown in Fig. 5.

FIG. 4 SINGLE CELL FIG. 5 DOUBLE CELL

AXIAL SECTIONS OF NATURAL BALLOON DESIGNS WITH FLAT TOPS AND WITH APEX AT ATMOSPHERIC PRESSURE (LOCAL)



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Table II

Radius vs Axial Distance, Natural Balloon Shape

r	z	r	z
0	0	.907	1.48
.168	.142	.843	1.59
.352	.293	.753	1.68
.528	.451	.633	1.76
.652	.578	.487	1.83
.750	.692	.350	1.88
.823	.798	.252	1.89
.892	.928	.151	1.90
.935	1.06	.085	1.90
.958	1.19	.020	1.90
.940	1.38	-.119	1.90

Series (b) and (c) form a general study of single cell, flat-top balloons. The integrations were started at the top at different pressures; the pressure difference leading to the shape in (a) being 105 arbitrary units. At 105 on the crown the natural shape comes to r = 0 at Δ p = 0 at the bottom. In (b) lower pressures were assumed at the crown, and such solutions reach Δp = 0 before r = 0 so that the lower part of the balloon is a lower than atmospheric pressure. These sub pressure cells are shown in Fig. 6 together with the crown pressure of each. Between 92.5 and 90 the r curve osculates the axis at infinity, and the shape obtained would be the ideal one for the flabby infinitely long balloon (weightless). At still lower pressures on the crown the design does not close at the bottom.

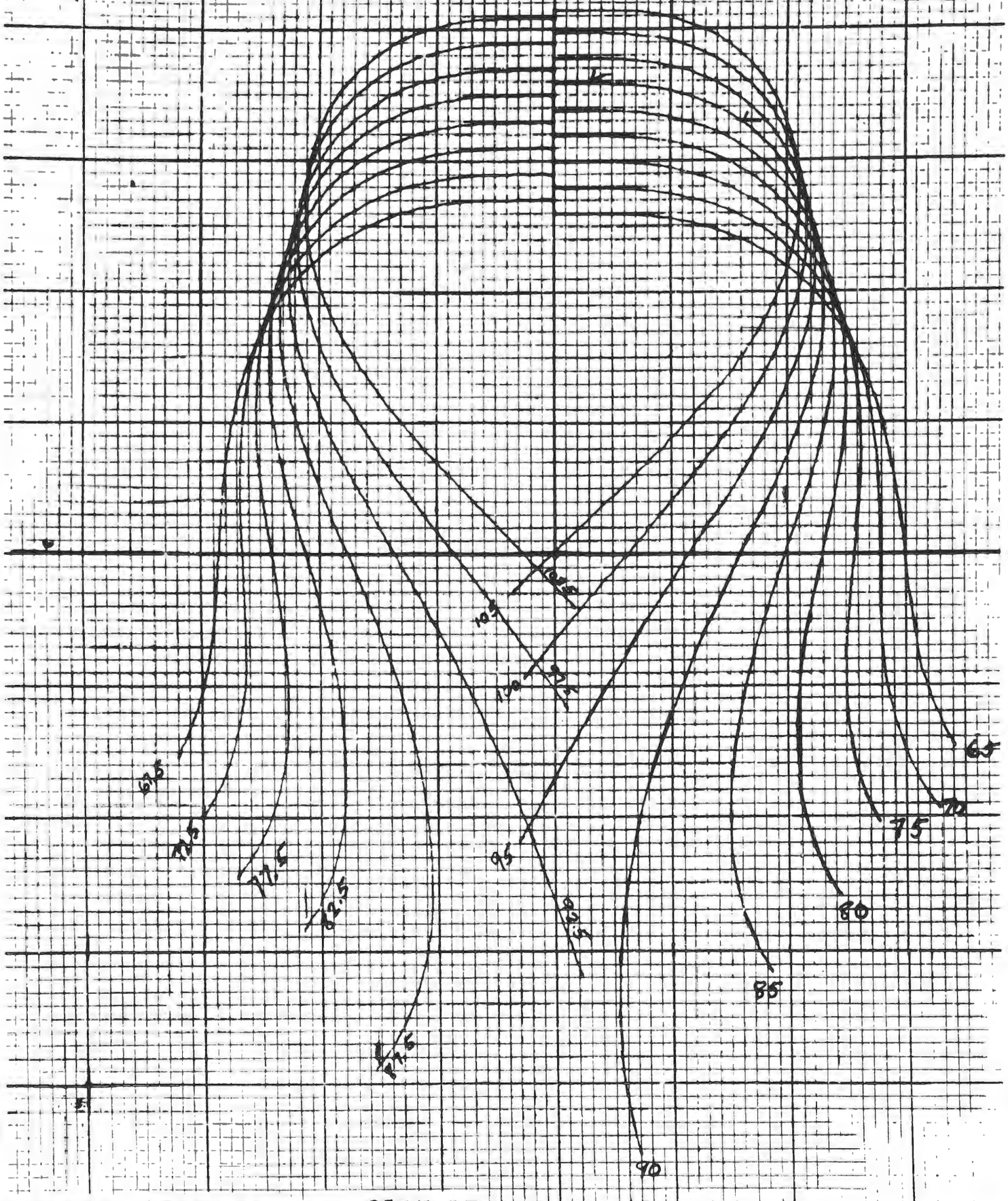
In Fig. 7 is shown the series of super pressure balloons in which the crown pressure is greater than 105. In all such cases the bottom closes also at a positive Δp.

If part of the load is attached to the crown of the balloon, it will sink in forming a "heart shape." Such a loading scheme may be advisable for certain types of measurements or of ballast systems although it has its inconvenient side. A theoretical advantage is that more efficient use is made of the meridian tension rt, i.e. the ratio ℓ/rt increases as more load is put on the head. In the study (d) a series of axial sections for the weightless cells of uniaxial stress was obtained by assuming $\theta > 50.5^\circ$ and Δ p = 0 at the lower apex. Some of the shapes are shown in Fig. 8 where the value of ℓ/rt vs θ bottom is plotted.

As mentioned above, plans have been made to find series of natural shapes with finite weight and t_c. A rough, hand calculation has shown that the effect of fabric weight will be to increase the bottom cone angle in order to obtain t_c = 0. In fact, one sees immediately (from eq. (1) e.g.) that the force owing to fabric will act like additional gas pressure in the

FIG. 6

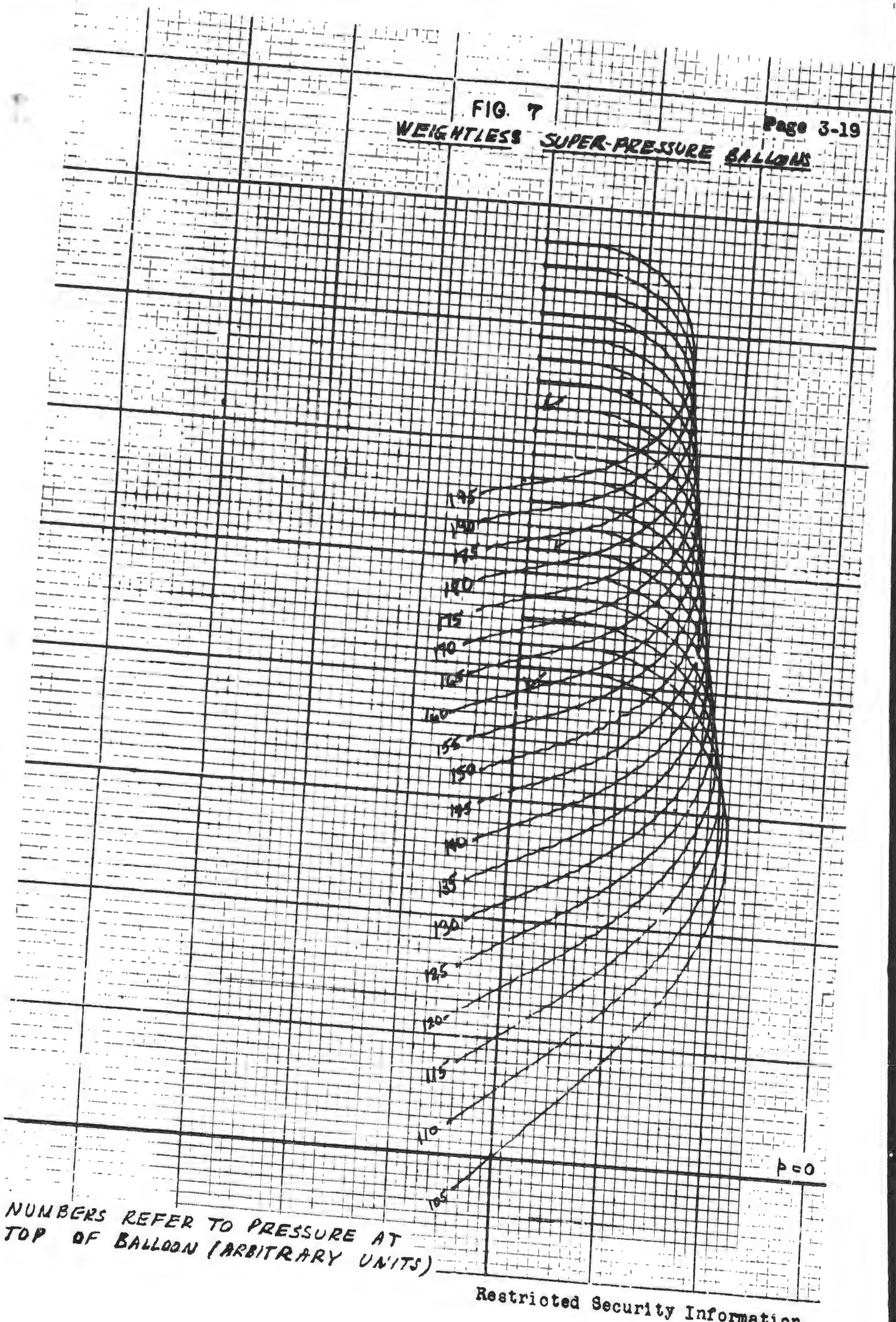
WEIGHTLESS SUB-PRESSURE BALLOONS



NUMBERS REFER TO THE PRESSURE AT THE TOP OF THE BALLOON (IN ARBITRARY UNITS)

FIG. 7

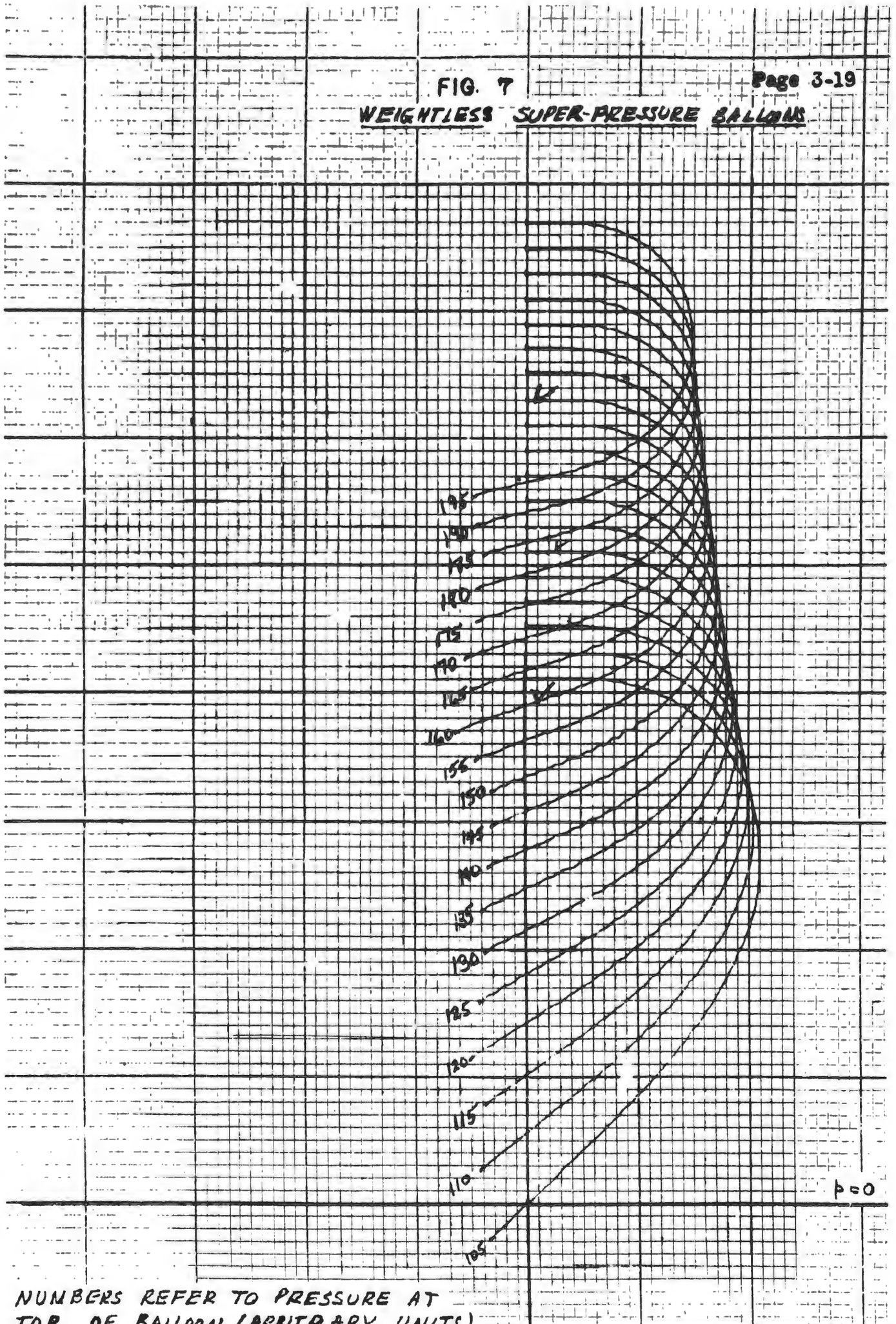
WEIGHTLESS SUPER-PRESSURE BALLOONS



NUMBERS REFER TO PRESSURE AT TOP OF BALLOON (ARBITRARY UNITS)

FIG. 7

WEIGHTLESS SUPER-PRESSURE BALLOONS



NUMBERS REFER TO PRESSURE AT TOP OF BALLOON (ARBITRARY UNITS)

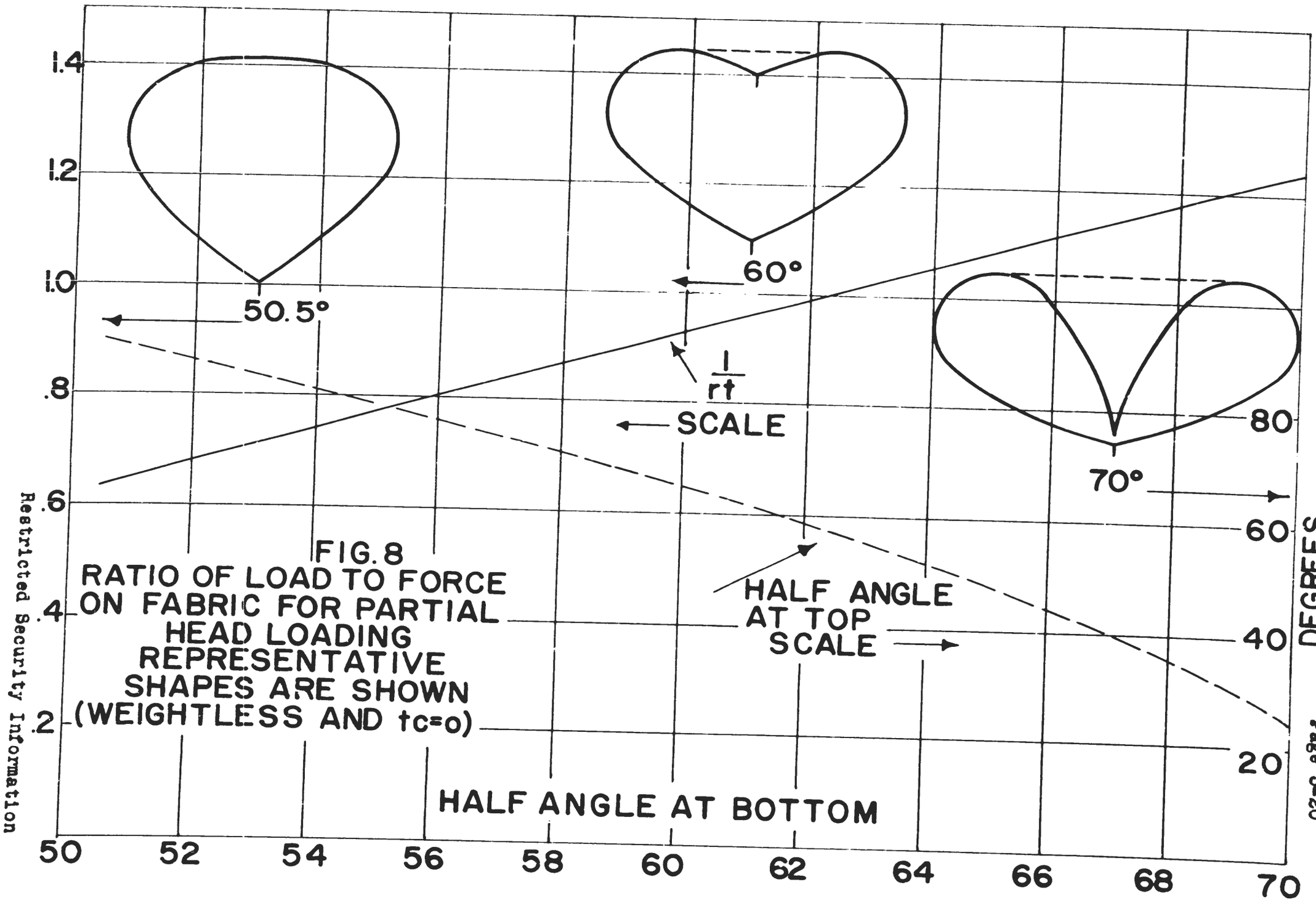


FIG. 8
RATIO OF LOAD TO FORCE ON FABRIC FOR PARTIAL HEAD LOADING REPRESENTATIVE SHAPES ARE SHOWN (WEIGHTLESS AND tc=o)

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lower portion of the balloon and like a reduction in the upper. The general character of the solution near the bottom should be like those in series (c). An inherent difficulty with shapes of $t_c = 0$ for given β and w is that when used at other β, i.e. other pay loads, their ceiling shape will have regions of positive and negative t_c. The basis for a suitable compromise is being sought.

BALLOON SHAPE MEASUREMENTS

Measurements have been made on four balloons to investigate any change in size that may occur during flight. The balloons which were measured were all of Winzen manufacture. The measurement that was taken was the circumference of the balloon at its equator. In order to measure the equator, the balloons were hung from the crown and marked at a distance of 57 1/2' and measured down the gores. This distance is $\frac{\pi}{2}$ $36\frac{1}{2}$', which should determine the equator on a nominal 73' diameter balloon. In one case of a recovered balloon, it was possible actually to cut the equator out of the balloon and lay it down on the floor for this measurement.

The information that we have on balloons which have not been flown is the following:

1. Winzen's design circumference at the equator.

   This circumference was obtained from Winzen on July 17 and is 229'. This circumference corresponds to a design diameter of 72.9'.

   Design circumference: 229 feet.

2. Actual measurement of the equator ring from the balloon used on Flight 7.

   This balloon was damaged on the ground and never launched, and it was possible to cut the equator out of it and measure it in one piece. The balloon was a 1-mil DE 2500 #100-V-66. With the fabric stretched just enough to take the wrinkles out, it measured 229.3'.

   Measured circumference of balloon #100-V-66: 229.3'. (Not flown)

   Rough measurements were made to determine the extension of the equator when placed under stress. With a tension exerted of 2 lbs.

per linear foot, the circumference increased by 15"; with 4 lbs. per linear foot, the extension was 44"; with 6 lbs. per linear foot, one of the heat seals tore apart.

3. Measurements taken on a Winzen double-wall balloon during packing.

This balloon was #2-100-V-128. During packing, the balloon was measured gore by gore at the equator point, determined in the way previously described. The measurement yielded the value 229.3' in exact agreement with the balloon from Flight 7.

Measurement of circumference of balloon #2-100-V128, not flown: 229.3'.

Two balloons have been available for measurement after flight. They were recovered in unusually good shape, and when they were hung up, it was possible to go around and measure all of the gores. One of these balloons was from Flight #19, which had a duration of 10 hours total, of which approximately 35 minutes were at level ceiling. The other balloon was the balloon flown in Flight #27. This was a 48 hour flight, and the balloon spent on the order of 20 hours at an altitude at which it would be completely full. The measurements on these two balloons are as follows:

1. Balloon from Flight #19, #2-100-V-89, was a double-wall Air Force balloon with glass filament tapes. As previously mentioned, this balloon spent an hour or less at altitudes at which it would be completely full. The equator strip from the balloon was cut out of the balloon, laid out on the floor, and pulled tight. With the balloon definitely taut,

the measured length of the equator strip was 232.3".

Equator circumference after flight for balloon #2-100-V-89: 232.3".

2. The balloon from Flight #27 was recovered after spending 102 hours in the air. The equator was measured by pulling the balloon up and measuring it gore by gore. The equator circumference was found to be 231.4".

Equator circumference for balloon #2-100-V-127 after flight: 231.4".

Conclusions:

It appears that Winzen s design circumference is well maintained in practice and that balloons before flight have a circumference of 229.3". After flight, the balloon circumference is between 231.4" and 232.3". The larger circumference was measured on a flight which stayed at ceiling a shorter time, and therefore, the indications are that this change in size takes place rather rapidly. The average change in length obtained is 2.5" out of 230", or about 1% change in length. The measurements on the force required to elastically stretch a balloon this far indicate a force of about 5 lbs. per linear foot. However, the elastic stretch would disappear after the force was removed if the force was applied for a short time. It is believed that the increase in size of the balloon takes place quite slowly through the mechanism of plastic creep. Rough laboratory experiments have been performed at room temperature and at dry ice temperature, and they confirm the existence of this property. It is very possible that in spite of the bad stresses existing in the cone-on-sphere balloon, plastic creep may allow the balloon to alter its shape during flight and approach more nearly the natural shape balloon.

SECTION IV

BALLOON PHYSICS

The Dynamics of Balloons

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Introduction

The balloon is an important tool in the study of cosmic rays. In the earliest experiments on cosmic rays by Hess and Kolhoerster, balloons were used to transport the ionization chambers sufficiently high above the earth to show that the rays must have an extra-terrestrial origin. Today, balloons can rise above 99% of the earth's atmosphere and can carry equipment for the study of the primary component of cosmic rays.

Of particular importance to the cosmic-ray experimenter are polyethylene balloons, sometimes known as "Skyhooks". The flight of these balloons is characterized by a rapid rise after take-off with roughly constant velocity followed by a sharp leveling off at "ceiling" altitude. This level flight provides a convenient platform to keep cosmic-ray equipment at the "top" of the atmosphere. The Skyhook balloon is inflated on the ground only enough to provide a slight net buoyancy. The gas fills out the balloon to perhaps only one percent of its possible content, the excess fabric lying in folds under the bubble of gas. As the balloon rises, the mass of gas in the balloon remains constant while its volume increases, filling out the limp balloon. The pressure inside the balloon is the same as that outside. Finally, the balloon becomes taut and the volume of gas can no longer increase by expanding the balloon. At this "valving" altitude, the balloon tends to develop an excess internal pressure which opens an appendix in the bottom of the balloon, allowing gas to escape. The balloon continues to rise until the escape of gas renders the net buoyancy zero. The balloon is now in neutral equilibrium

with respect to lowering its altitude, since the collapse of the balloon on descent to greater pressure is compensated for by the increase of outside air density. Moreover, tendency to descend is resisted by both the "aero-dynamic" and "thermal" drag described in later sections.

Unfortunately, should one of these balloons once lose lift (e.g. through leakage of gas), the balloon will descend to the ground without reaching equilibrium. All balloons leak to some extent, and the resulting rate of downward drift is determined by the nature and magnitude of the "drags" on the balloon.

For some cosmic-ray experiments, one would like to keep equipment aloft for long periods. Here one is faced with the situation that the balloon rises during the day until the net lift is zero, and then at night the balloon cools more than the outside air with the resulting establishment of a negative (downward) net lift. Thus the radiation equilibrium of the balloon becomes of practical importance.

To ensure a successful flight, one must use care in the amount of inflation given a balloon on the ground. Too great an initial net lift will cause it to rise too fast. Many balloons are believed to have broken on this account (reference 1). On the other hand, too slow an initial rate of rise might reduce the time available for flight at ceiling or make more difficult the recovery of the equipment because of prolonged flight. To calculate the proper inflation, the relation between lift and rate of rise must be known.

In general, then, one would like to be able to write an equation of motion for the balloon and to be able to say as much as possible about the various terms entering the equation.

Equation of Motion of Vertical Flight

To obtain a solution to the equations of motion for a balloon in vertical flight, one must determine what forces are exerted on the balloon by the atmosphere and gravity. These forces then determine the motion and, except in the case of a fully taut non-extensible balloon, the size and shape of the balloon. The vertical component of the forces determines the motion by

$$m \cdot \frac{dv}{dt} = \sum \text{vertical forces} \qquad (1)$$

where m is the total mass of the balloon. Inasmuch as the rate of rise of balloons is observed to be a slowly varying function of altitude, one is most interested in the solution

$$\sum \text{vertical forces} = 0. \qquad (2)$$

The external forces acting on the balloon would be:

(a) The downward force of gravity on the fabric and load.

(b) The vertical component of the pressure difference across the fabric, integrated over the fabric.

(c) The vertical component of the tangential shearing stress of the moving air on the fabric, integrated over the fabric.

In (b) one would include both the static pressure difference (due to the forces of hydrostatic equilibrium) and that due to the dynamic (or impact) pressure. Thus the forces of both (b) and (c) depend on the velocity of the balloon with respect to the air. Moreover, all these forces, acting directly and through the tensions in the fabric, determine the shape that

the ascending balloon will assume.

The problem of determining the rate of rise, v, from Eq. (2), using the forces of (a), (b), and (c) above, would involve a very detailed knowledge of these forces. A considerable simplification can be achieved by the approximation of grouping the forces into "static" forces and "dynamic" forces in such a way that the size and shape of the balloon are assumed to depend only on the static forces. For the vertical component of the static force one has W (the weight of the fabric and load), and the vertical component of the pressure difference across the fabric due to the forces of hydrostatic equilibrium integrated over the surface of the balloon. The latter force can be evaluated by applying Archimedes' law on assuming that the pressure inside the balloon is to first order the same as that of the outside air and that the density of the air and balloon gas do not change appreciably over the length of the balloon. Then if F is the net upward static force

$$F = V (\rho_{air} - \rho_{gas}) - W \qquad (3)$$

where V is the volume of the balloon gas. When thus defined, F is called the "free lift", the "gross lift" being

$$G = V (\rho_{air} - \rho_{gas}) = F + W \qquad (4)$$

Let

$$\sigma = \frac{\text{Molecular weight of air}}{\text{Molecular weight of balloon gas}}, \qquad (5)$$

ther, since [illegible] same [illegible] outside [illegible] balloon,

$$\frac{\rho_{air}}{\rho_{gas}} = \sigma \quad \frac{T_{[illegible]}}{T_{[illegible]}} \qquad (6)$$

Defining the "superheat", Θ, by

$$T_{gas} = T_{air} + \Theta \qquad (7)$$

and calling $T_{[illegible]} = T$, and M = [illegible] of balloon gas, one obtains

$$G = V \rho_{gas} \left(\frac{\rho_{air}}{\rho_{gas}} - 1\right) = \sigma \frac{T + \Theta}{T} - 1 \qquad (8)$$

Hence

$$F = M \left(\sigma - 1 + \sigma \frac{\Theta}{T}\right) - \ldots \qquad (9)$$

This shows that the free lift of an ascending balloon (M = constant) depends only on the superheat, Θ, which, however, might depend on the rate of rise, v, through the "thermal drag" effect.

The "dynamic" force or "aerodynamic drag" is best determined empirically. This is treated in a later section. The drag will be a function of v and perhaps of the altitude through changes of shape and density of the medium, ρ. In general the drag will be

$$D = D\ (v, \rho) \qquad (10)$$

and the equation of motion (2) will now read

$$F - D = 0. \qquad (11)$$

Equation (11) can then be solved for v, once the thermal and aerodynamic drag are known.

Thermal Drag and Balloon-Gas Superheat

Thermal drag gets its name from the fact that the free lift depends upon the superheat θ, which in turn depends upon the velocity of the balloon. The dependence of the free lift upon the superheat of the lifting gas is

$$F = G - W = M \left(\sigma - 1 + \sigma \frac{\theta}{T} \right) - W. \tag{12}$$

If the gas is not at a uniform temperature, θ would be that corresponding to the mean density of the gas at the pressure of the outside air.

The gas in a rising balloon will be expanding at a rate determined by the upward velocity of the balloon, thus tending to cool the gas. In competition with this is the convection of heat into the gas from the surrounding fabric of the balloon. Let $-q_o$ be the rate of convection of heat from the fabric into the balloon gas. The complete determination of q_o will involve finding the temperature of the fabric.

Applying the first law of thermodynamics to the gas

$$- q_o = M c_v \frac{d}{dt} (T + \theta) + p \frac{dV}{dt} . \tag{13}$$

Using the ideal gas law in the form $V = M \sigma \frac{R (T + \theta)}{p}$, (14)

$$- q_o = M c_p \frac{d}{dt} (T + \theta) - M \sigma R (T + \theta) \frac{1}{p} \cdot \frac{dp}{dt} \tag{15}$$

where $C_p = C_v + \sigma R$, $R = 2.88 \times 10^6$ ergs/gm-degree.

But from the equation of hydrostatic equilibrium

$$\frac{1}{p}\frac{dp}{dt} = -\frac{g}{RT} \cdot \frac{dZ}{dt} = -\frac{gv}{RT} \quad (16)$$

Moreover, since the atmosphere is such that the "lapse rate", $-\frac{dT}{dZ}$, is constant over relatively large regions, it is convenient to write

$$\frac{dT}{dt} = \frac{dT}{dZ} \cdot \frac{dZ}{dt} = v\frac{dT}{dZ} \quad (17)$$

Putting (16) and (17) in (15) and solving for the rate of change of superheat:

$$\frac{d\theta}{dt} = -v\left[\frac{dT}{dZ} + \frac{g\sigma}{C_p}\left(1 + \frac{\theta}{T}\right)\right] - \frac{q_o}{C_p M} \quad (18)$$

The solution of (18) $\theta = \theta(v)$ when taken with Eq. (12) will give the "thermal drag". In order to solve Eq. (18) it is necessary to know how q_o depends on θ. In general, q_o will depend strongly on the temperature difference between the gas and the fabric, $\theta - \theta_1$, where $T + \theta_1$ is the temperature of the fabric. The determination of q_o is essentially a problem of natural convection (as opposed to "forced" convection) of a gas near a wall (i.e., the balloon fabric).

Experiments on convection are correlated by expressing the results as functional relations among various dimensionless combinations of the physical quantities on which the convection can depend. Using an analysis of this type, Jakob[2] gives for the heat gain per unit area by convection from a surface to a gas at a temperature ϑ °C warmer

$$\frac{dq_o}{dS} = K \cdot (\gamma\vartheta^4)^{1/3} \quad (19)$$

where

$$\zeta = \frac{k^2 \rho^2 C_p g}{\eta T} \quad . \qquad (20)^*$$

and K is a dimensionless constant that depends on the orientation of the surface. The results of the experiment of Griffiths and Davis as quoted by Jakob give K as shown in Table I.

TABLE I.

orientation of surface	gas-to-surface temperature difference	K
horizontal, gas above	$\vartheta > 0$	0.159
horizontal, gas below	$\vartheta > 0$	0.080
horizontal, gas above	$\vartheta < 0$	0.080
horizontal, gas below	$\vartheta < 0$	0.159
vertical, gas on one side	$\vartheta \lesseqgtr 0$	0.125

To arrive at the heat transfer from gas to fabric one would have to integrate Eq. (19) over the inside surface of the balloon, taking into account the orientation of the fabric surface. One might guess that such a procedure would overestimate the efficiency of the convection by failing to take into account that the finiteness of the volume of gas enclosed tends to restrict the flow of gas past the surface of the fabric. Accordingly, one could take the value of K in Eq. (19)

*In Eq. (20), g = acceleration of gravity, T = mean temperature of the gas, k = conductivity of the gas, ρ = density of the gas, η = viscosity of the gas, and C_p = specific heat of the gas at constant pressure.

to be that corresponding to vertical orientation of the fabric surface and leaving a parameter, C_c, to be determined by a suitable experiment:

$$q_o = \pm 0.125\, C_c \left[\frac{k^2 \rho^2 C_p g}{\eta T}\right]^{1/3} (\theta - \theta_1)^{4/3} S \qquad (21)$$

where $q_o \gtrless 0$ according as $\theta \gtrless \theta_1$, and $C_c \approx 1$.

One can notice here that the convection is essentially independent of the altitude of the balloon: the only quantities depending strongly on the pressure of the gas are ρ and S and they occur as the product

$$\rho^{2/3} S \sim \rho^{2/3} V^{2/3} \sim M^{2/3} = \begin{cases}\text{independent} \\ \text{of altitude}\end{cases} \qquad (22)$$

As will be shown later, the thermal drag becomes important in determining the rate of rise only when that rate is slow. Many authors neglect the thermal drag effect entirely and assume that the balloon gas temperature is that of the fabric. Poncelet[2] calculates the rate of cooling and the resultant effect upon the rate of rise only for the case where the cooling is adiabatic ($q_o = 0$). He shows that in two kilometers of ascension the superheat has changed $\Delta\theta = -20^{\circ}C$ with a resulting change in rate of rise of $\Delta v = -0.026\ v$. He uses this result to show that the cooling in actual cases is not adiabatic ($q_o \neq 0$), but he does no more with it, since he is considering rubber balloons with rates of rise of about 700 feet/minute, where the thermal drag could be expected to be negligible.

In efforts to maintain a balloon at constant altitude, the thermal drag may be expected to play an important role. In particular, the setting of the sun on a floating balloon removes an important source of heat from the fabric (see next section), with the result that the fabric, and thus the gas, cools and the balloon starts down. The thermal drag acts here to slow down this rate of descent by restoring part of the lost superheat to the gas. This effect is mentioned by Prandtl.[4]

An example of the effect of thermal drag is given by Anderson[5] in "Report of the Pilot" when he tells of making the descent from an altitude of 65,000 feet in the balloon, Explorer II:

> "At 12:20 p.m. the balloon was valved to start the return to earth. A very generous release of gas was needed to start a positive descent, and very frequent valving thereafter to keep the balloon descending at a rate of about 300 feet per minute for the first 30,000 feet. During periods when the valves were closed the rate of descent would slowly decrease. With more time available for descent through the stratosphere this descent could be made with less loss of gas.
>
> "The valves were opened for the last time around 40,000 feet. After passing this altitude the balloon, now entering the troposphere, began to lose superheat and, for about 5000 feet, maintained a uniform rate of descent of about 400 feet per minute and then began losing lift at an ever-increasing rate."

A balloon with a constant vertical velocity must develop a greater superheat in the stratosphere in order to dissipate the greater energy q_o. From Eq. (18) with $d\theta/dt = 0$ for equilibrium condition

$$\frac{q_o \text{ stratosphere}}{q_o \text{ troposphere}} = \frac{v_{st}\left[\left(\frac{dT}{dZ}\right)_{st} + \frac{g\sigma}{C_p}\right]}{v_{tr}\left[\left(\frac{dT}{dZ}\right)_{tr} + \frac{g\sigma}{C_p}\right]} . \qquad (23)$$

Since $dT/dZ \approx 0$ in the stratosphere and $dT/dZ = -2^{\circ}C/1000$ feet in the troposphere, and since for helium $g\sigma/C_p = 4^{\circ}C/1000$ feet, we have, with $v_{st} = v_{tr}$

$$\frac{q_o \text{ stratosphere}}{q_o \text{ troposphere}} = 2, \tag{24}$$

or, conversely, to work with the same superheat ($q_{ost} = q_{otr}$) one would have to valve gas such that

$$\frac{v \text{ stratosphere}}{v \text{ troposphere}} = \frac{1}{2}. \tag{25}$$

Balloon-Fabric Superheat

The heat balance equation for the superheat, θ_1, of the balloon fabric will involve not only a problem of natural and forced convection but also a consideration of the radiation equilibrium. For a helium-filled balloon, one may consider that the balloon interacts with the radiation from the sun, earth, and ambient atmosphere only by absorption of the radiation in the fabric and re-radiation by the fabric. The balloon gas contributes to the heat balance of the fabric only through the convection term, q_0.

If the specific heat of t fabric is C_f and the mass of the fabric is m, then the heat balance equation will be

$$C_f\, m \frac{d}{dt} (T + \theta_1) = q_0 + q_1 - q_2 + q_3 - q_4 \qquad (26)$$

where

q_0 = heat convected per second from the gas to the fabric.

q_1 = power absorbed by the fabric from the solar radiation ($\lambda \approx 0.5\,\mu$).

q_2 = power radiated by the fabric because of its temperature ($\lambda \approx 10\,\mu$).

q_3 = power absorbed by the fabric from the terrestrial and atmospheric radiation ($\lambda \approx 10\,\mu$).

q_4 = heat convected per second from the fabric to the outside air.

Most literature on the heat balance of balloon fabric is concerned with either rubber or rubber-covered cloth balloons. As a

result, not all of the terms in Eq. (26) are even considered.

For example, Edwards and Long[6] consider only the terms q_1, q_2, and q_4. A typical fabric with which they were concerned reflected 50% and absorbed 50% of the visible light incident on it, thus giving a large value for q_1 as compared, say, with the value of q_1 which one obtains for a one-mil thick piece of polyethylene, which is virtually transparent. For the term q_2, they consider that the balloon radiates as a "gray" body with a certain emissivity characterizing the radiation near a wavelength of 10μ. It is not clear why they neglect the term q_3 which must be of the same order of magnitude as q_2. For the outside convection term they assume "forced" convection and take

$$q_4 = \text{const} \cdot v^n \cdot \theta_1 \qquad (27)$$

where v is the air-speed of the balloon and n is some parameter characteristic of the shape of the balloon. The dependence of q_4 on the properties of the air (particularly its density) is not indicated. The possible importance of free convection for small values of v is not mentioned. For an opaque balloon, the fabric will not, in general, have everywhere the same temperature. Edwards and Long introduce a further term to account for the radiation transferred within the balloon.

The report of Poncelet[3] does not consider directly the various terms in Eq. (26). However, by comparing the rate of rise of a day flight and night flight, respectively, he calculates (assuming $\theta \approx \theta_1$) how much warmer the fabric is during the day than at night.

$$\theta_1 = \theta_1 \text{ day} - \theta_1 \text{ night} \qquad (28)$$

His results are shown in Table II.

TABLE II.

Altitude	0	2	4	6	8	10	12	14 km.
$\Delta\,\theta_1$	6.9	5.9	5.6	7.0	10.0	17.8	29.8	33.8°C

This information can be related to the terms in Eq. (1) by assuming that $\theta = \theta_1$ (hence $q_0 = 0$) and that the term

$$C_f\, m \left[\left(\frac{dT}{dt}\right)_{day} - \left(\frac{dT}{dt}\right)_{night}\right]$$

is small. Then, since q_3 day $= q_3$ night, we have for the equilibrium condition

$$\left[q_2\ (\theta_1 \text{ day}) - q_2\ (\theta_1 \text{ night})\right] + \left[q_4\ (\theta_1 \text{ day}) - q_4(\theta_1 \text{ night})\right] = 0 \qquad (29)$$

If S is the total area of the balloon, and E_s is the solar flux, then

$$q_1 = A_s \cdot E_s \cdot \frac{S}{4} \qquad (30)$$

where A_s = emissivity of the fabric for $\lambda = 0.5\mu$. Similarly, if A_ϵ is the emissivity for the fabric near $\lambda = 10\mu$, then

$$q_4 = A_\epsilon \cdot b \cdot (T + \theta_1)^4 \cdot S \qquad (31)$$

where b is the radiation constant $b = 5.672 \times 10^{-12}$ watts/cm^2-deg^4.

Finally, if we put

$$q_4 = H\,\theta_1 \qquad (32)$$

where H indicates the effectiveness of the convection, Eq. (29) becomes

$$A_\varepsilon \; b \; S \left[(T + \theta_{1\ \text{day}})^4 - (T + \theta_{1\ \text{night}})^4 \right] + H \cdot \Delta\theta_1 = A_s \; E_s \; \frac{S}{4} \qquad (33)$$

Assuming $\theta_1 \ll T$, Eq. (33) becomes

$$\Delta\theta_1 = \frac{\frac{1}{4} \; A_s \cdot E_s \cdot S}{4 \; T^3 \; A_\varepsilon \cdot b \cdot S + H} \qquad (34)$$

In order to evaluate H from Eq. (34) one would have to know both A_s and A_ε for the particular rubber used in the flights. Poncelet considers H to be of the form

$$H = \text{const} \cdot \gamma^{\frac{1}{2}} \cdot \rho^{3/4} \cdot \eta^{-3/4} . \qquad (35)$$

Since, for his cases, H is small, it is not possible to use an equation like (34) to verify Eq. (35).

In computing the ballast requirements for the balloon 'Explorer II', Tuckerman, Swan, and Hamberd[5] took for the terms in Eq. (26)

$$q_1 = A_s \cdot E_s \cdot S \qquad (36)$$

$$q_2 = A_\varepsilon \cdot b \cdot (T + \theta_1)^4 \cdot S \qquad (37)$$

$$q_3 = A_\varepsilon \cdot b \cdot T^4 \cdot S \qquad (38)$$

The convection terms were neglected. In effect, then, they assumed that in absence of solar radiation ($E_s = 0$) the fabric was clamped to the out-

side air temperature by the infrared radiation, that is

$$-C_f\, m\, \frac{d\theta_1}{dt} = q_2 - q_3 = A_\xi\, b\, S\left[(T + \theta_1)^2 + T^2\right]\left[2T + \theta_1\right] \cdot \theta_1$$

with the equilibrium condition being thus $\theta_1 = 0$. Their assumption would be plausible in the case where the outside air could radiate near $\lambda = 10\,\mu$, which in turn would require that the air not be transparent in this region. However, dry air is transparent in the infrared, the infrared absorption of moist air being just proportional to its water vapor content.[7] Moreover, even the water vapor in the air is transparent in the region $8 < \lambda < 13\,\mu$, the vibrational absorption line lying $\lambda < 8\,\mu$ and the rotational bands lying $\lambda > 13\,\mu$, though the "tail" of these bands extends down into the $\lambda = 10\,\mu$ region. The "window" region, $8 < \lambda < 13\,\mu$, contains roughly one-third of the energy radiant from a black body at 15°C. Humphreys[8] has pointed out that ozone has an absorption in this "window" region, and thus the ozone layers above the balloon* might be expected to radiate back energy that would otherwise have been lost. Both the ozone and water-vapor content of the air vary from day to day. Another variable element is the presence of low-lying clouds which doubtless absorb all terrestrial radiation.

In considering the q_1 term, one should probably take account of the fact that the solar constant, $E_s = 1.34 \times 10^{-1}$ watts/cm^2, does not fully describe the total flux of visible radiation falling on the balloon. At great altitudes, the balloon receives, in addition to E_s,

*O'Brien, Mohler and Stewart[5] find that approximately one-half of the atmospheric ozone lies above 25 kilometers altitude.

the visible radiation that is scattered back up from the denser part of the atmosphere and the surface of the earth. Humphreys[8] estimates this to average 38%, but reaching 78% for a dense cloud. On the other hand, near the surface of the earth, the balloon fails to receive as visible radiation that part of the incident solar energy that is reflected away or absorbed by the atmosphere above (including clouds). Humphreys estimates the atmospheric absorption of visible radiation to be roughly 20%, while the portion reflected varies greatly with cloud conditions.

As we have seen, both the terms q_1 and q_3 may be expected to vary with the altitude of the balloon and prevailing atmospheric conditions. However, as will be argued later, the effect of the resulting superheat is small for the case of reasonable ascension velocities. Where one would be most interested in knowing the superheat θ_1 that results from the solution of Eq. (26) is for the case of a balloon floating at its ceiling altitude. Here one could calculate the so-called "sunset effect", $\Delta\theta_1$, once the relative size of the terms in Eq. (26) is known.

For thin polyethylene balloons, one must take into account that the fabric (exclusive of "load-bearing" tapes) is essentially transparent. Although the radiation on the balloon will now pass through at least two thicknesses of fabric, little will be absorbed and thus the convection terms, q_0 and q_4, will be relatively more important. The "emissivity" of the fabric will be correspondingly less also. The absorption of a piece of standard polyethylene balloon material (thickness 10^{-3} inches) is 0.017 in the visible and 0.06 in the infrared near 10 μ wavelength.

Using a value for the solar constant of 2 calories/cm^2 - minute, the power absorbed in the fabric from the sun would be

$$q_1 = 2.4 \times 10^{-3} \text{ watts/cm}^2 \tag{39}$$

for a one-mil thick section of polyethylene fabric. One could estimate the thermal radiation from the balloon (assuming a fabric temperature of -55°C) to be

$$q_2 = 8 \times 10^{-4} \text{ watts/cm}^2. \tag{40}$$

The value of q_2 would be three times larger for a fabric temperature of +15°C. If Eq. (21) is used to estimate the convection terms at an altitude of say 100,000 feet, the power convected to the fabric from the balloon gas would be

$$q_0 = 1.6 \cdot 10^{-5} \cdot C_c \cdot (\theta - \theta_1)^{4/3} \text{ watts/cm}^2. \tag{41}$$

Floating at ceiling, the balloon would have the same "superheat" in the gas as in the fabric ($\theta = \theta_1$) and so for this case $q_0 = 0$. Similarly, for the power convected from the fabric to the outside air

$$q_4 = 1.1 \cdot 10^{-5} \cdot C_c' \cdot \theta_1^{4/3} \text{ watts/cm}^2 \tag{42}$$

where the prime indicates that perhaps a different parameter C'_c is applicable here. Finally, one can write the power absorbed in the infrared region as

$$q_4 = 0.06 f$$

where f is the flux of infrared incident on the balloon.

Because the term q_o is usually quite small, one can consider that the superheat of the fabric, θ_1, is nearly independent of the superheat of the gas inside, θ. In a practical case, this would simplify the estimation of the fabric superheat.

For polyethylene thickness greater than one mil, the radiation terms would be correspondingly greater.

Aerodynamic Drag

We take the point of view here that it is the "static" forces that determine the shape of the balloon, and we ask for the resistance offered by still air to the motion of a body of this shape. Actually, the resistance of the air will act on the balloon in such a way as to make it more oblate, but this effect is observed to be small. Also, the air is not perfectly still. However, large movements of air will tend just to superimpose their velocity upon that of the balloon, and though there might be small scale turbulences in the air, this turbulence will be much less than for example in the best wind tunnel.

In the usual presentation of data on wind resistance, one writes the drag as proportional to the impact pressure and cross-sectional area of the body:

$$D = \tfrac{1}{2} \rho v^2 \cdot A \cdot C_D \qquad (43)$$

where the dimensionless quantity C_D (the drag coefficient) is determined experimentally. In general, C_D is a function of the shape of a body, the size of the body (as expressed by some characteristic length l), the relative velocity v, and the fluid properties of the medium characterized by ρ, the density, and η, the viscosity. Since C_D is dimensionless, it can depend on v, l, ρ, and η only in the combination

$$Rn = \frac{\rho v l}{\eta} \qquad (44)$$

where Rn is the so-called Reynolds number. Thus for a given shape of

body one writes

$$C_D = C_D\,(Rn). \tag{45}$$

Once this drag coefficient is known for a particular body, the drag can be found for all geometrically-similar bodies. In principle, the form of the function $C_D(Rn)$ should depend only on the shape of the body. In regions where $C_D(Rn)$ = constant, the drag varies as the square of the velocity of the body.

Unfortunately, in the case of an ascending non-extensible type balloon, the shape is not constant with altitude, varying from the shape of a small sphere with long depending folds of fabric at take-off to roughly a spherical shape at altitude. It is not possible therefore to use a single function $C_D(Rn)$ to predict the drag at all altitudes.

In the case of sealed-off rubber balloons of the meteorological type, the shape of the balloon is at all altitudes nearly spherical, the rubber fabric extending easily enough that the pressure of the gas within the balloon is little greater than the outside air pressure. The volume of the balloon will then vary inversely as the density of the outside air (neglecting superheat effects). Under these conditions one may write the drag as proportional to a single function $C_D(Rn)$ holding for all altitudes. The equation of motion (11) may be written, using (43), as

$$F - \tfrac{1}{2}\rho v^2 \cdot A \cdot C_D\,(Rn) = 0. \tag{46}$$

But the cross-sectional area of the balloon will be

$$A = \pi r^2. \tag{47}$$

Using Eqs. (4), (5), and (6) one can evaluate the radius of the balloon from the gross lift by neglecting the superheat and equating pressure inside and out:

$$G = V\rho\left(1 - \frac{\rho_{gas}}{\rho}\right) = \rho\frac{4}{3}\pi r^3\left(1 - \frac{1}{\sigma}\right) \tag{48}$$

(the subscript on ρ air has been suppressed). Solving (48) for r and using (47), Eq. (46) now contains only F, ρ, G, C_D, and v, and can be solved to give

$$v = 0.434\left[\frac{\sigma - 1}{\sigma}\right]^{1/3} \cdot \frac{F^{1/2}}{G^{1/3}} \cdot \left[C_D\,(Rn)\right]^{-1/2} \cdot \rho^{-1/6}. \tag{49}$$

Since the superheat has been neglected in the above equation, F and G are constant with altitude. On the other hand, the Reynolds number will decrease by roughly an order of magnitude during the flight. Thus v as a function of altitude (or air density) will depend on the nature of the function C_D (Rn). If, in the region of Reynolds numbers considered, C_D is a constant, then the drag is proportional to the square of the velocity and Eq. (49) yields Hergesell's law:[10]

$$v = \text{constant} \cdot \rho^{-1/6}. \tag{50}$$

Observations on the ascent of spherical pilot balloons indicate departures from this law. In particular, at great heights, Eq. (50) would predict velocities considerably greater than those at sea level, which is not observed. Rather, the rate of rise is more nearly the same at the two altitudes.

Clark and Korff[9] attributed this discrepancy to the fact that the drag coefficient $C_D(Rn)$ is not constant in the region applicable to balloons. In effect, they assumed that the rate of rise was constant with altitude, and asked what this requires of the function $C_D(Rn)$. One can see from Eq. (49) that a constant rate of rise would necessitate that $C_D(Rn) \cdot \rho^{1/3}$ be constant with altitude, i.e., independent of ρ. Since the Reynolds number of the balloon rising with constant velocity is proportional to $\rho^{2/3}$

$$Rn = \frac{v \rho l}{\eta} \sim \rho l \sim \rho v^{1/3} \sim \rho \left(\frac{1}{\rho}\right)^{1/3} \sim \rho^{2/3} \qquad (51)$$

assuming η and v independent of ρ, it follows that a constant rate of rise implies that

$$C_D (Rn) \sim Rn^{-1/2}. \qquad (52)$$

This result is in rough agreement with wind tunnel data on spheres for Reynolds numbers of order 10^5. The wind tunnel data are, however, not themselves consistent, depending on the texture of the sphere and the turbulence of the air stream. On the basis of flight tests of spheres (in still air), Millikan[11] reports a more critical dependence of C_D on Rn. For Rn of order 10^5, he gives

$$\begin{aligned} C_D &= 0.5, \quad Rn < Rn_{critical} \\ C_D &= 0.08, \quad Rn > Rn_{critical} \end{aligned} \qquad (53)$$

where $Rn_{critical} = 3.7 \times 10^5$.

Careful measurements on pilot balloons by Poncelet,[3] using double theodolites, give still a different result. He finds that the

result of flights of balloons of various diameters and rates of rise indicate a drag coefficient satisfying the relation

$$(C_D - 0.16)\, Rn = 7 \times 10^4, \tag{54}$$

for Rn of order 10^5.

Unfortunately, these results cannot be applied directly to the case of polyethylene balloons, since the shape of these balloons is not constant with altitude. At great altitudes, however, the balloons are nearly spherical and the results of the studies on pilot balloons might be carried over. In fact, the workers on the N.Y.U. balloon project[1] even applied Eq. (49), in the form

$$v = \text{constant} \cdot \frac{F^{1/2}}{G^{1/3}} \tag{55}$$

to the case of 20-foot polyethylene balloons near sea level (i.e., where the balloons are not spherical) in order to calculate the inflation necessary to produce a given rate of rise. Their results, as indicated in a plot of altitude vs. time for each flight, show that (55) is not very well satisfied, though the discrepancies might come from the difficulty of inflating the balloon to just the free lift given by (55). However, the time-altitude curves do indicate the surprising fact that the rate of rise of a 20-foot polyethylene balloon is independent of altitude.

Flight records on 73-foot and 85-foot polyethylene balloons also indicate a constant rate of rise. Measurements on the free lift at take-off and rate of rise obtained show that if one takes A to be the cross-sectional area of the balloon as calculated from the gross lift and assumes the drag

to equal the free lift, the drag equation (43) can be written

$$F = D = \tfrac{1}{2} \rho \, v^2 \, A,$$

that is, $C_D=1$. This is the same drag one would get on a disk of area A moving normal to its plane, and shows that the balloon should not be considered "stream-lined". Because of the possible change of superheat during ascension, and the resulting effect on F, one cannot assume that (56) will hold at great altitudes.

Velocity and Initial Free Lift

Equation (11), which equates the free lift to the aerodynamic drag, in principle gives a complete description of the vertical velocity of the balloon in its dependence on such factors as the inflation, the superheats and the density of the outside air.

A practical question one might ask is, "Given an initial free lift, what velocity will the balloon establish?" The complication here is, that while the velocity depends on the actual free lift in a direct way which, from Eqs. (11) and (43) is

$$F = D = C_D \frac{A}{2} \rho v^2 , \tag{57}$$

the actual free lift F is not the initial free lift. Though the initial free lift (call it F_o) might be measured, the actual free lift F is unavailable for measurement except by measuring θ and calculating from Eq. (12)

$$F = M \left(\sigma - 1 + \sigma \frac{\theta}{T}\right) - W_o$$

In this equation the gas superheat θ depends again on the velocity by Eq. (18)

$$\frac{d\theta}{dt} = - v \left[\frac{dT}{dZ} + \frac{g\sigma}{c_p}\left(1 + \frac{\theta}{T}\right)\right] - \frac{q_o}{C_p M}$$

where, finally, the term q_o depends upon both the gas and fabric superheat by some relation such as Eq. (21):

$$q_o = 0.125 \cdot C_c \cdot S \cdot \zeta \cdot (\theta - \theta_1)^{4/3}, \tag{58}$$

where ζ depends on the properties of the balloon gas as defined in Eq. (20). By making some simplifying assumptions it is possible to relate the initial free lift directly to the velocity that obtain. To do this we assume that initially the fabric had a certain superheat θ_1, (e.g., the balloon might have been sitting in the sun prior to take-off). If the gas inside had come to equilibrium, $d\theta/dt = 0$ and, since initially $v = 0$, Eqs. (18) and (21) yield

$$(\theta - \theta_1)^{4/3} \sim q_o \sim v = 0 \tag{59}$$

or $\theta = \theta_1$ initially, giving

$$F_o = M\left(\sigma - 1 + \frac{\theta_1}{T}\right) - W. \tag{60}$$

In a previous section it was shown that radiation plays a large part in determining the fabric superheat, and that the velocity-dependent convection terms might be small. It will be convenient to assume that the fabric superheat is determined entirely by radiation conditions, or at least that the fabric superheat does not depend on the velocity of the balloon (i.e., θ_1 = constant).

The balloon had free lift F_o and superheat $\theta = \theta_1$ before release. After release, the balloon reaches some velocity v and the gas in the balloon comes to some superheat θ. The fabric superheat is still θ_1, but the actual free lift is now

$$F = M\left(\sigma \quad 1 + \sigma\,\frac{\theta}{T}\right) - W = F_o + \frac{M\sigma}{T}(\theta - \theta_1) \tag{61}$$

taking F_o from Eq. (59). The term $(\theta - \theta_1)$ is still velocity dependent,

but we notice that we can evaluate it in terms of the convection transfer of heat from the gas to the fabric; from Eq. (58) we have

$$q_o \sim C_c \quad (\theta - \theta_1)^{4/3} \tag{62}$$

where it has been assumed that the superheat θ is established in sufficiently short distance of balloon travel that it is not necessary to consider any change of convection with altitude. When equilibrium is reached (i.e., when $d\theta/dt$ is negligible), the convection has become, according to Eq. (18) with the assumption $\theta << T$,

$$q_o = v M c_p \left[\frac{dT}{dZ} + \frac{g\sigma}{c_p}\right] \sim v. \tag{63}$$

Combining (63) and (62)

$$(\theta - \theta_1) \sim (\frac{v}{C_c})^{3/4}. \tag{64}$$

From the drag equation (43), the dependence of the drag upon the velocity can be expressed as

$$D \sim C_D v^2. \tag{65}$$

Knowing the dependence of F on the velocity from (60) and (64), and using the equation of motion F = D we can solve for F_o as a function of v, getting

$$F_o = B_1 C_D v^2 + B_2 (\frac{v}{C_c}) 3/4 \tag{66}$$

where B_1 and B_2 are independent of v and C_D and C_c are the coefficients of drag and convection, respectively. The coefficient C_D might depend slightly on velocity through the relation $C_D = C_D\,(Rn)$, but C_c is velocity independent. Calling both these coefficients really constants, the relation between initial free lift before release and rate of rise after release becomes

$$F_o \cdot C_1 v^2 + C_2 v^{3/4} \,. \qquad (67)$$

FIGURE I

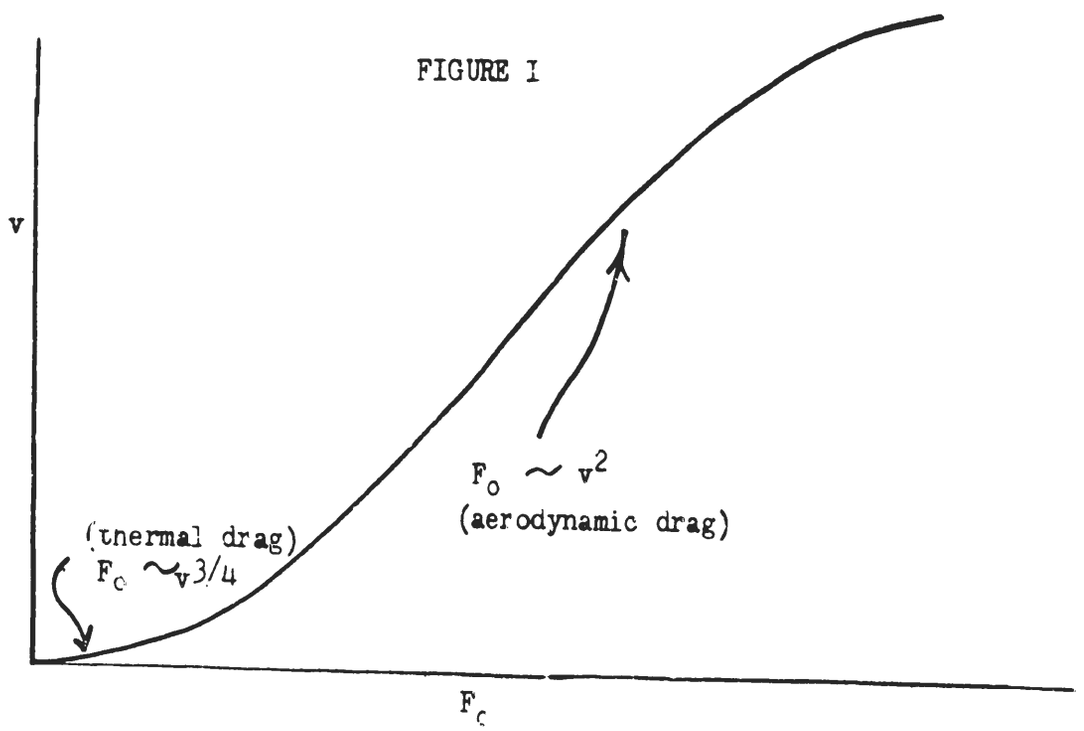


Figure 1 shows a rough plot of Eq. (67). For large values of initial free lift, the dependence is $F_c \sim v^2$ which one could get by neglecting the superheat problem and considering only the aerodynamic drag. For small values of F_o (very small values of v) the relation is $F_o \sim v^{3/4}$. In this region the aerodynamic drag could be neglected with the rate of rise determined only by the convection of heat from the gas. Hence the name "thermal

drag". This suggests writing (67) in the form

$$F_o = D_{aerodynamic} + D_{thermal} \tag{68}$$

where $D_{aerodynamic} \sim v^2$ and $D_{thermal} \sim v^{3/4}$.

In a normal launching F_o is quite large, giving v of the order of a thousand feet per minute. Under these conditions, the thermal drag is negligible in determining the rate of rise.

The thermal drag becomes important for slow velocities, that is, when the initial free lift is small. Such a case occurs when the solar radiation on a balloon floating at altitude is removed by the setting of the sun. The fabric will change its superheat by an amount $\Delta\theta_1$ (see Eq. (28). Assuming that the gas in the balloon comes again into equilibrium with the fabric before the balloon actually starts down, the change of gas superheat will be $\Delta\theta = \Delta\theta_1$ and thus from Eq. (9) since the free lift was zero before sunset

$$\Delta F = F_o = \frac{M\sigma}{T} \Delta\theta_1 \tag{69}$$

This F_o lies usually in the thermal drag region and so the rate of fall of the balloon is small compared to ascension velocities. It is interesting to note that, whereas leakage before sunset would give a free lift of

$$F_L = (\sigma - 1) \cdot \Delta M \tag{70}$$

which might not result in a very great rate of fall because of thermal drag, a subsequent sunset effect would give a total free lift loss of

$$F_o = (\sigma - 1) \cdot \Delta M + \frac{M\sigma}{T} \cdot \Delta\theta \tag{71}$$

which might lie beyond the thermal drag region. Thus the resulting rate of fall might be considerably larger than the sum of the rates with the sunset effect and leakage acting separately. In this way, the effect of the leakage might show up most strongly as an increased rate of fall of the balloon at sunset.

In deriving Eq. (68) it was assumed that the fabric superheat θ_1 does not change. Equation (68) will thus predict the velocity only until the balloon has gone far enough for θ_1 to change. The equation would continue to hold only if amended to read

$$F_o + \frac{M\sigma}{T}\left(\theta_1^{\circ} - \theta_1\right) = D_{aerodynamic} + D_{thermal} \qquad (72)$$

where θ_1° is the fabric superheat when the free lift was F_o, and θ_1 is the superheat at the time in question.

The superheat of the fabric is probably determined mostly by the radiation equilibrium. With changes in altitude, the flux of radiation on the balloon changes (particularly in the infrared region) and hence the superheat also. Even if the radiation flux were constant, the superheat could change since even if the fabric temperature, $T + \theta_1$, is constant, θ_1 is not constant with altitude in those regions where the lapse rate, $-dT/dZ$, is not zero.

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BALLOON FLIGHT ANALOGY ON ELECTRONIC ANALOGUE COMPUTER

Mechanization

In Technical Report No. 1 an effort was made to set forth the various physical considerations involved in finding a solution of the equation of motion of a balloon in vertical flight. Some of these considerations are as follows:

aerodynamic drag relation

static lift relation

heat balance of the fabric

heat balance of the lifting gas

characterization of the atmosphere

(by lapse-rate)

equation of hydrostatic equilibrium

A discussion of these factors and how they enter the equation of motion is given in Technical Report No. 1, and frequent reference will be made to that report.

The physical considerations given in Technical Report No. 1 lead to a set of simultaneous algebraic and differential equations. When these equations are mechanized on the Reeves analogue computer, one has the physical quantities available as voltages, potentiometer settings and switch positions. The physical equations to be mechanized are computed for a particular size and type of balloon. (In this case it was an 85-foot diameter polyethylene helium-filled balloon, weighing 200 pounds, carrying a variable load of about 150 pounds.) Some of the physical quantities were left adjustable. These were of two types. Of the first type were such quantities as initial load and initial inflation (given by initial free lift or by initial

rate of rise) and those quantities that must be set in, such as ballast control. The atmospheric lapse rate was set manually during the flight. The second type of adjustable element includes quantities such as drag coefficient, solar flux, infra-red flux, and radiation absorption characteristics of the fabric. While these quantities were known roughly, it was hoped that the could in some way be determined from comparison of the results of the computer flights with actual flight data. This comparison would, of course, also serve as a check on the physical assumptions discussed in the next section.

In the mechanization, a time scale was employed such that one second computer time was equivalent to four minutes of actual balloon time. On the time plot of the various physical quantities one inch represented forty minutes of actual balloon time.

Physical Assumptions

The equations used were taken for the most part directly from Technical Report No. 1 and specialized to this particular case given above. Some simplifying assumptions were made -- for instance the convection terms q_0 and q_4 were assumed to depend on the first power and the temperature difference rather than the 4/3 power. In the equation of motion the forces of acceleration were neglected.

In equation (26) of Technical Report No. 1, q_1 was taken as the cross-sectional area of the balloon times some absorption coefficient, "A_s". For the terms q_2 and q_3, it was assumed that the balloon fabric was approaching radiation equilibrium with a surrounding black body of the same temperature as the ambient atmosphere. The emissivity A_ε of the fabric was taken to equal the

absorption coefficient for infra-red radiation. The validity of this assumption is discussed in the section on results.

In the aerodynamic drag relation, the drag coefficient C_D was determined by analysis of what data was available at that time from flights in which both the initial rate of rise and the initial free lift were measured. The value of C_D thus determined from an equation such as (46) in Technical Report No. 1 was taken to apply near the ground. No data was available that would give an indication of what the drag coefficient should be for a balloon near its ceiling. The assumption was made that the drag coefficient varied as the minus 1/3 power of the atmospheric density. This assumption is consistent with a constant rate of rise in the absence of any variation of the free lift with altitude. The difficulty in predicting the value of C_D in advance lies in the fact that the shape of the balloon is not constant with altitude, and thus one cannot carry over the results of wind-tunnel experiments on any particular shape of model.

The static lift of the balloon was computed continuously taking account of the variation of the temperature of the lifting gas and the temperature of the atmosphere. The gross load was computed with provision for dropping ballast. The weakest assumptions are perhaps that of the value of the drag coefficient and the nature of radiation balance in the infra-red.

Computer Flights

Several types of runs were made on the computer. In one group were ascensions, both at night and during the day (that is, with the solar

flux turned off and on), and ascensions in which the sun rises on the balloon or sets on the balloon during flight. In another group of flights the balloon is initially floating at ceiling with the sun on. The sun is turned off to simulate sunset and the effect of various ballast drops is noted. Examples of the records from some typical flights are included at the end of this report. The record plots time on the abscissa with scale one inch equals forty minutes. Four ordinants are plotted: These are altitude, temperature of the outside air, rate of rise of the balloon, and lifting gas superheat.

Flight No. 2 is a typical ascension at night. The balloon has an initial free lift of 92 pounds and initial rate of rise of 750 feet per minute and an initial superheat of zero (i.e., the lifting gas is initially at the temperature of the outside air). On release, the balloon rises with essentially a constant velocity somewhat less than the initial 750 feet per minute. This is due to the small negative superheat that is developed. At about 35,000 foot altitude the lapse rate of the atmosphere changes and the balloon develops a greater negative superheat, resulting in a somewhat decreased rate of rise.

Flight No. 6 is a balloon flight launched under the same conditions as in flight No. 2, except that the sun is shining. The effect here is that the solar flux gradually diminishes the negative superheat and the balloon rises somewhat faster, as shown in the record.

Flight No. 19-a is a dawn flight in which the sun rises when the balloon is at about 60,000 feet. The effect of sunrise is to spped up the balloon's rate of rise, as shown in the record.

Flight No. 6-a is a twilight flight in which the sun sets on the balloon during flight.

In Flight No. 4-a, the setting of the sun on a slowly rising balloon is seen to be sufficient to actually cause it to fall.

Flight No. 2-b shows the effect of sunset on a balloon floating at ceiling. The rate of fall after sunset is seen to be very rapid.

Flight No. 4-b shows the effect of dropping ballast. In this case enough ballast was dropped to slow the rate of descent by 1/2, so that at sunrise the next day the balloon would rise at essentially this same rate. However, the balloon in this particular flight reached the ground before sunrise.

Discussion of Results

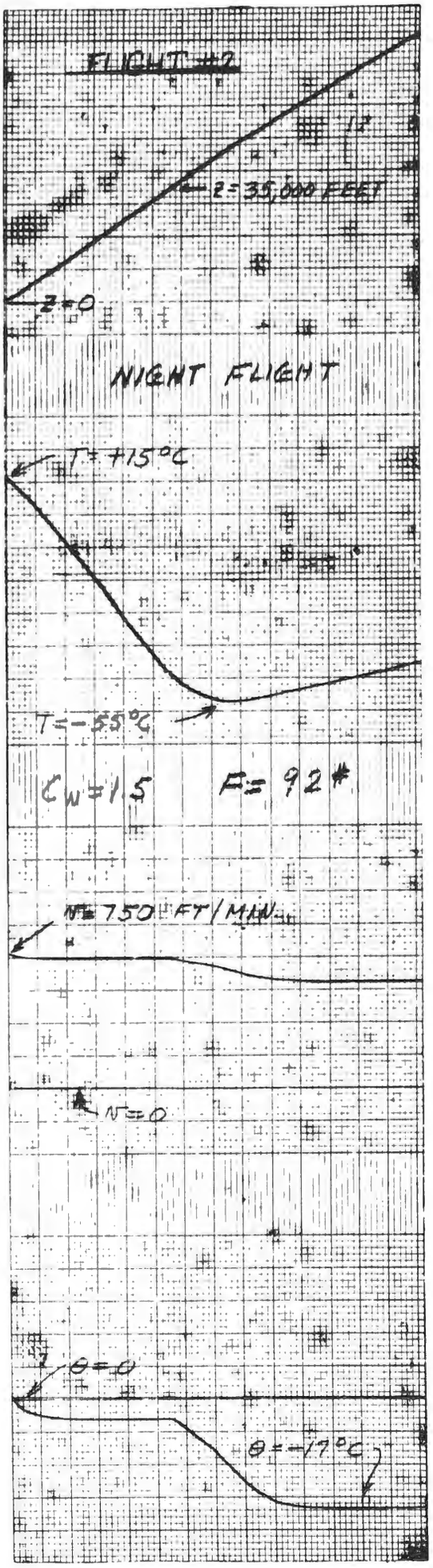
In general the ascensions on the computer correspond to actual flights. However, this does not five a very good check on the assumptions involving heat balance because the effect of superheat in helium-filled balloons is small during ascensions where the free lift is relatively very large. In the flights where the sun set on the floating balloon, the rate of fall indicated by the computer flights is greater than that observed in actual flights. Probacly the fault lies in the assumption that the balloon receives infra-red radiation from an equivalent black body at the temperature of the outside air. A better assumption would be to use in the q_{33} term the infra-red flux as computed from the concentration of the absorbing water vapor throughout the atmosphere. Roughly speaking the upward infra-red flux falls off with altitude reaching

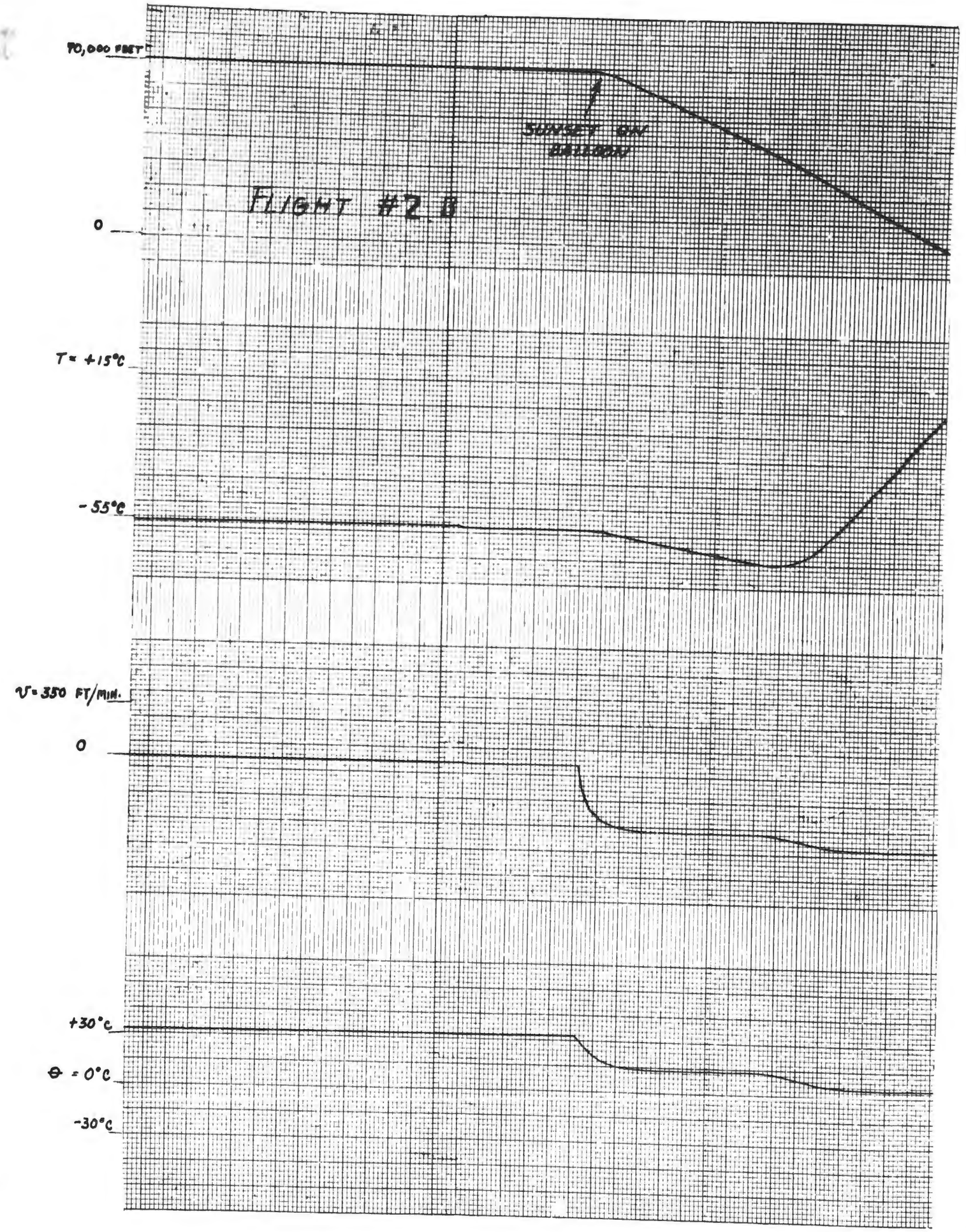
about 2/3 of its sea-level value at the tropopause.

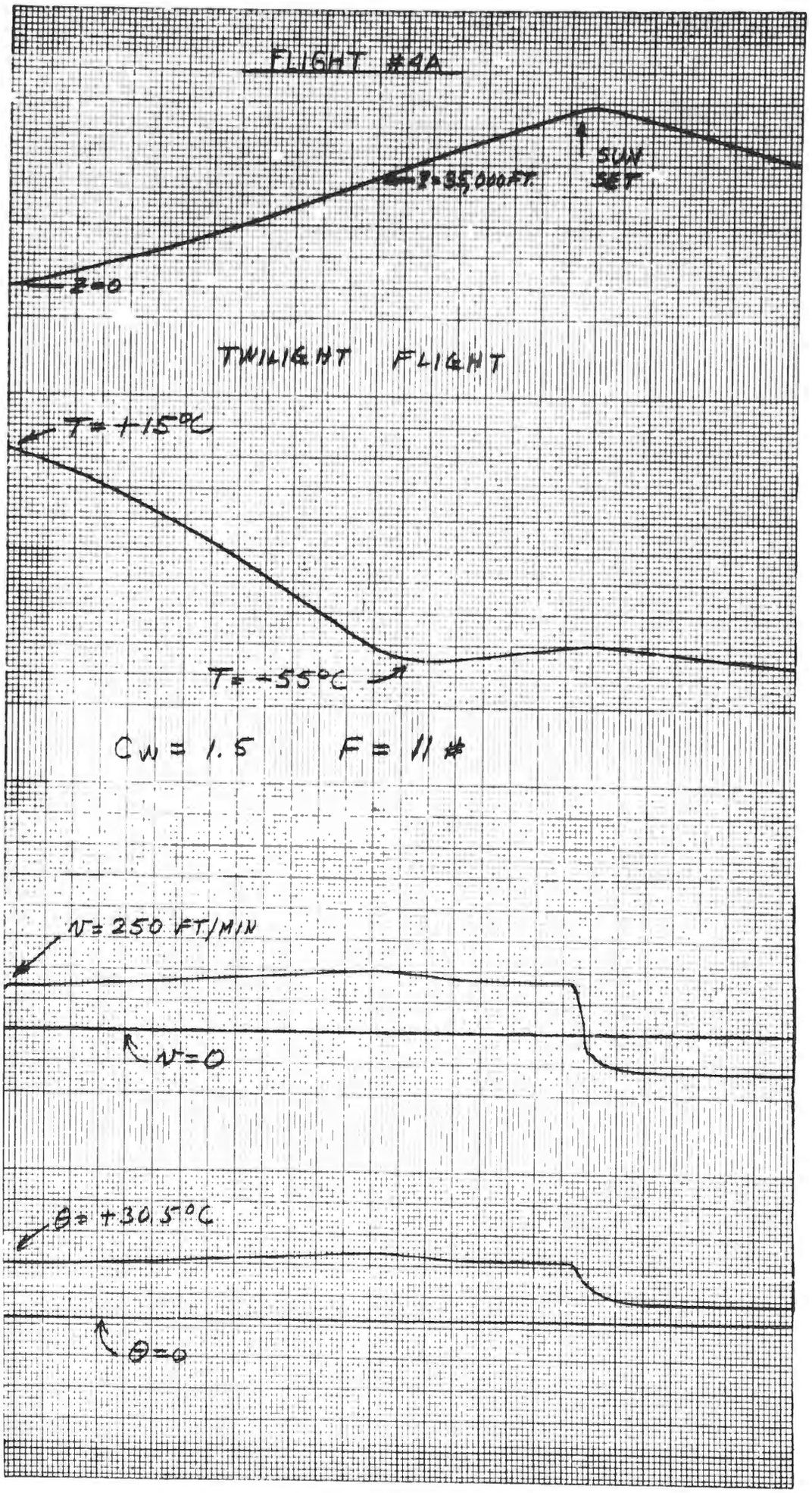
How strongly this might be affected by local cloud conditions is not known. Some runs were made on the computer in which partial radiative clamping to the earth's surface was introduced. The results are shown in the records of Flights 12 and 13.

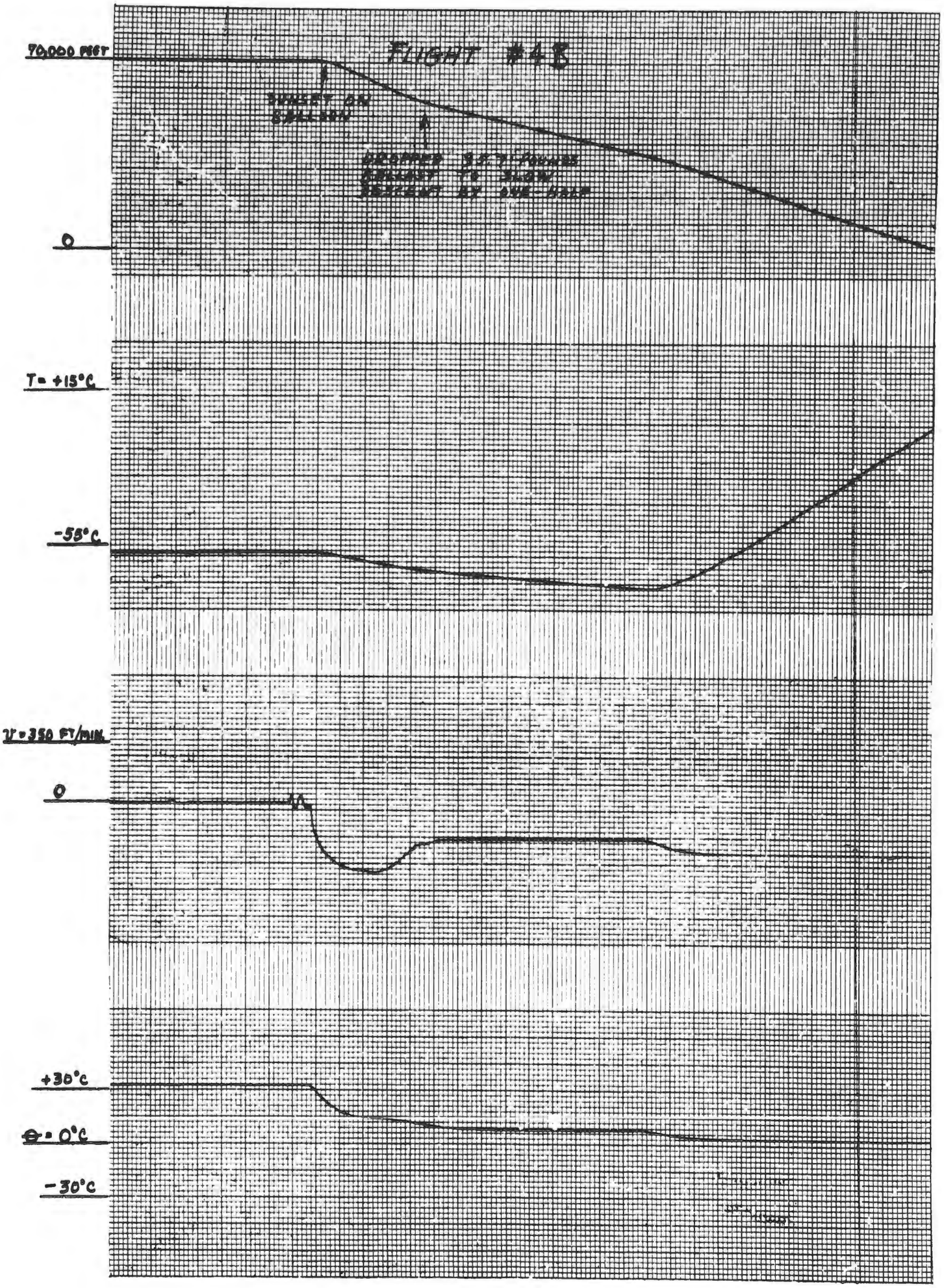
Proposed Modifications

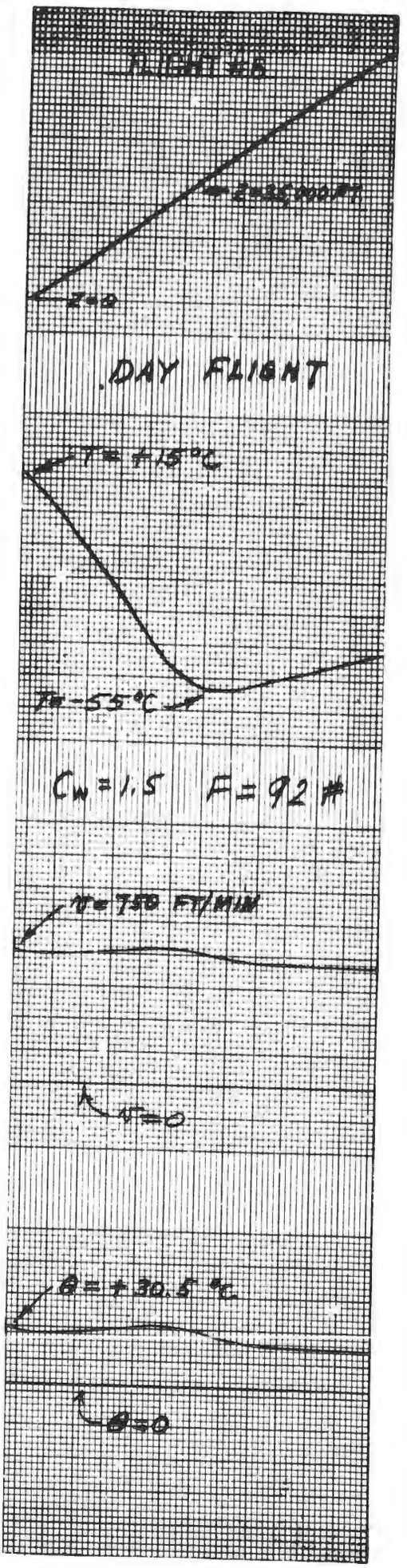
Using the results of recent balloon flights, it should be possible to refine considerably the balloon flight analogy. In particular, one would want to put in a more realistic value for the drag coefficient. One would also want to include as detailed as possible a value for the infra-red flux.

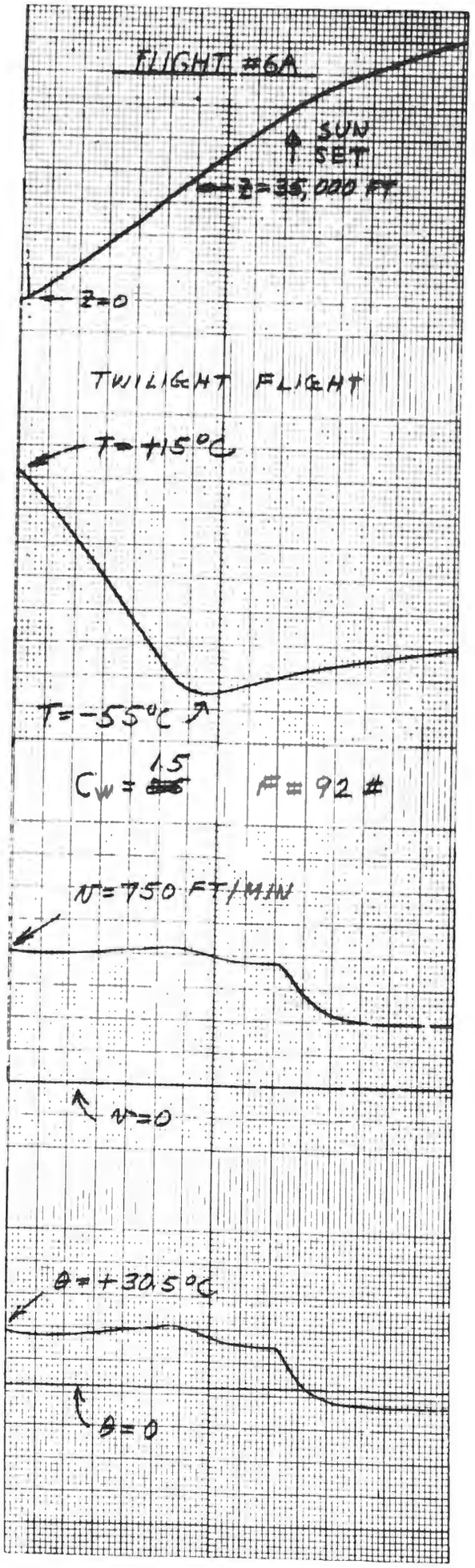

FLIGHT #2
Z=35,000 FEET
Z=0
NIGHT FLIGHT
T=+15°C
T=-55°C
C_W=1.5
F= 92#
V=750 FT/MIN
V=0
θ=0
θ=-17°C


70,000 FEET
SUNSET ON BALLOON
FLIGHT #2.8
0
T = +15°C
-55°C
V = 350 FT/MIN.
0
+30°C
θ = 0°C
-30°C

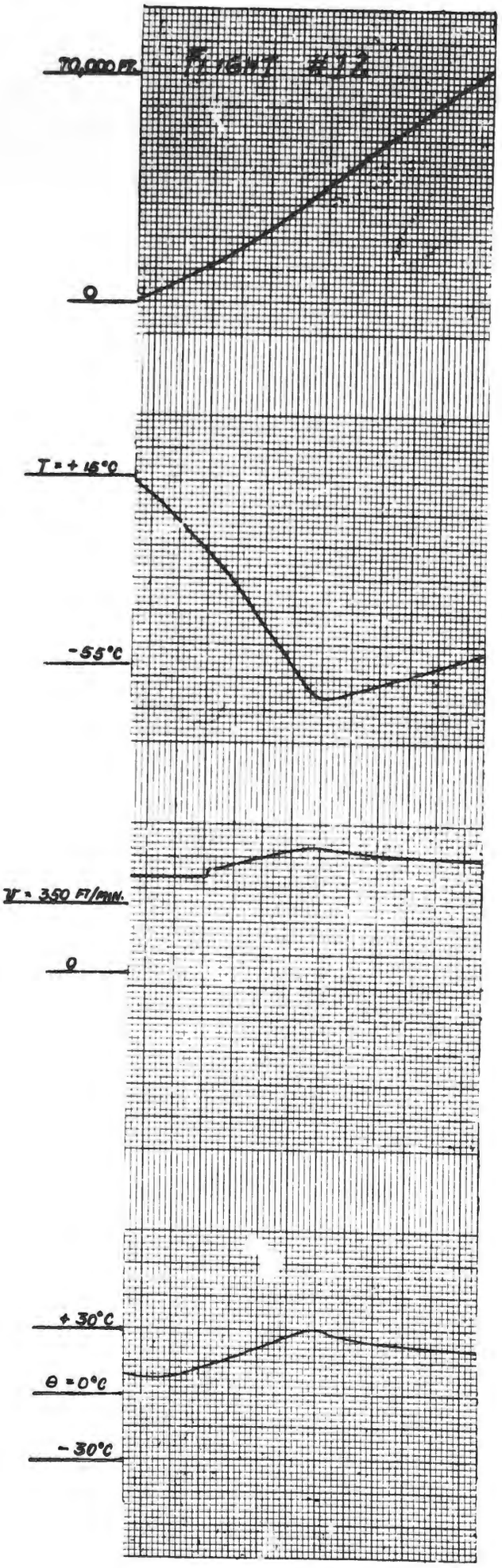

FLIGHT #4A
SUN SET
Z=0
TWILIGHT FLIGHT
T=+15°C
T=-55°C
Cw = 1.5
F = 11 #
V=250 FT/MIN
V=0
θ=+30.5°C
θ=0


FLIGHT #45
70,000 FEET
SUBJECT ON BALLOON
PROPPED 3.5 G'S POSITIVE
ERRATIC TO 3.2 G'S
RECOVERY AT 40K FEET
0
T = +15°C
-55°C
V = 350 FT/MIN.
0
+30°C
Θ = 0°C
-30°C

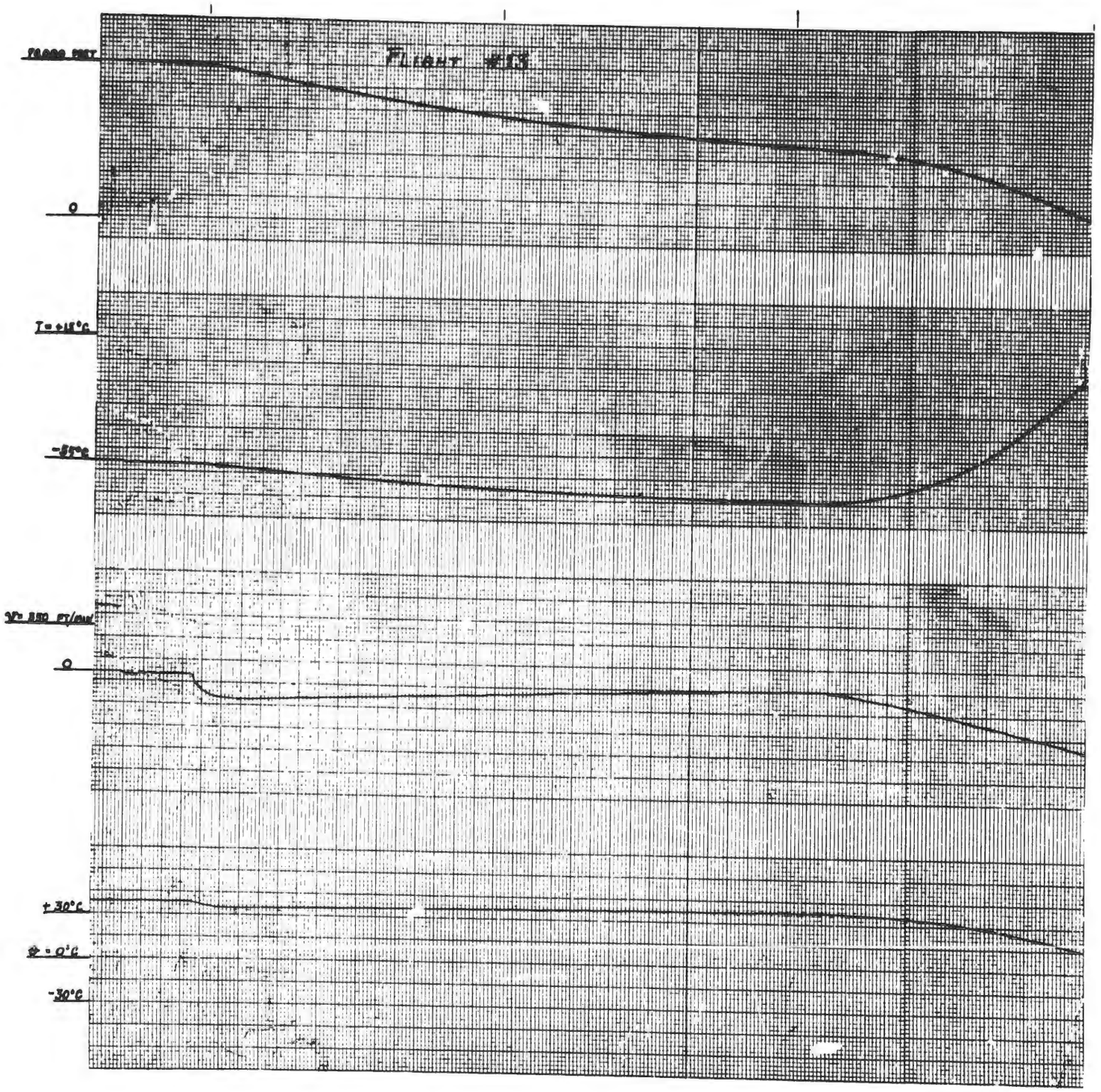

FLIGHT #5
2 SEC/INCH
z=0
DAY FLIGHT
T= +15°C
T= -55°C
C_W = 1.5 F = 92 #
V= 750 FT/MIN
V=0
θ= +30.5 °C
θ=0

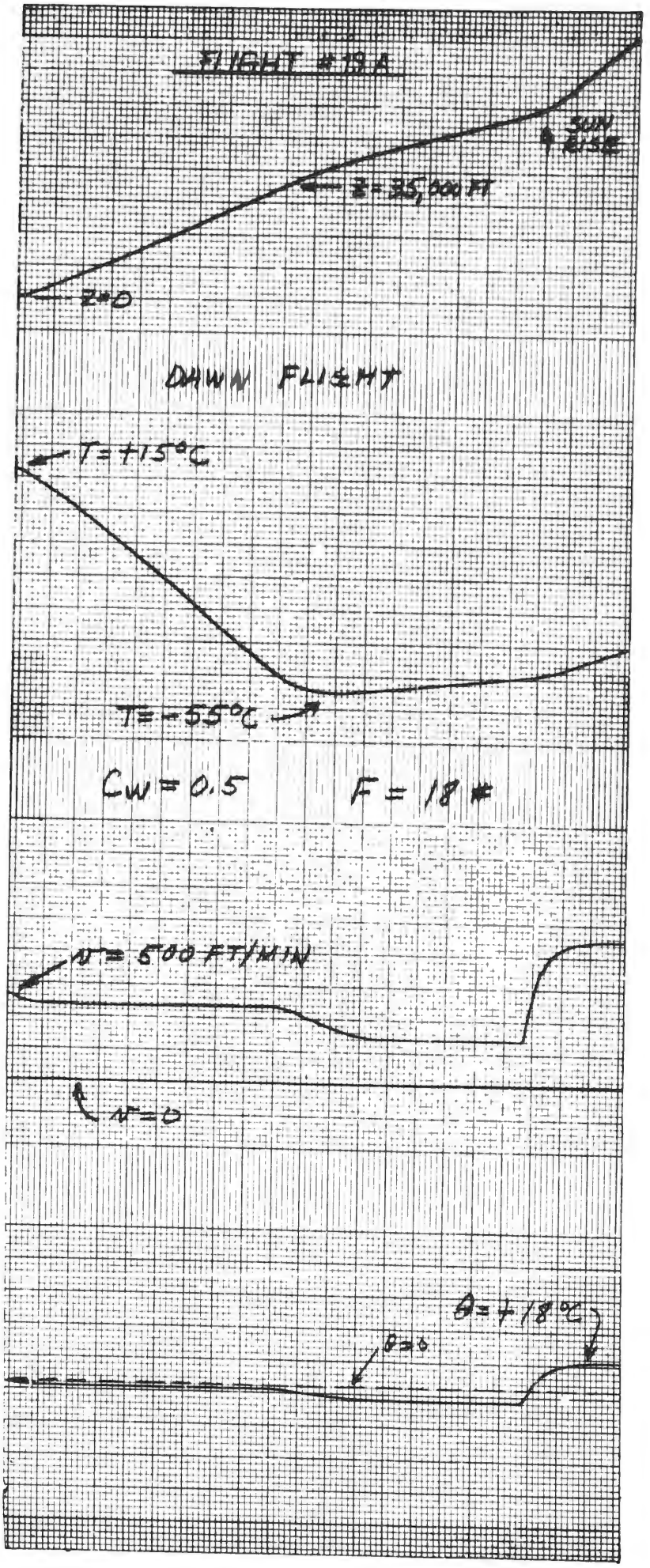

FLIGHT #6A
SUN SET
Z=35,000 FT
Z=0
TWILIGHT FLIGHT
T=+15°C
T=-55°C
$C_w = \frac{15}{}$
F=92 #
V=750 FT/MIN
V=0
θ=+30.5°C
θ=0

Day Flight With Partial Radiative Clamping to Earth's Surface



IDENTICAL WITH FLIGHT 12 EXCEPT DESCENT AT NIGHT




FLIGHT #19A
SUNRISE
Z = 35,000 FT
Z = 0
DAWN FLIGHT
T = +15°C
T = -55°C
Cw = 0.5
F = 18 #
V = 500 FT/MIN
V = 0
θ = +18°C
θ = 0

MISCELLANEOUS CALCULATIONS

1. Performance Nomographs

A series of nomographs has been constructed to assist in rapidly determining balloon performance characteristics.

A. Nomographs 1 and 2.

The first and second nomographs are used to determine the ceiling altitude of a balloon, given its volume, the gross load, and the inflation medium. Because of the uncertainty in the atmospheric temperature assumed by the NACA standard atmosphere, our time-altitude graphs in the flight performance section are plotted in terms of pressure rather than altitude. The altitude can then be determined from these time-altitude curves by assuming an appropriate average temperature. The nomographs were constructed, however, to allow easy determination of the approximate altitude based on the NACA temperature distributions. The first two nomographs were designed to solve the equation

$$K_G = V \rho_A$$

V = balloon volume

ρ_A = density of the air

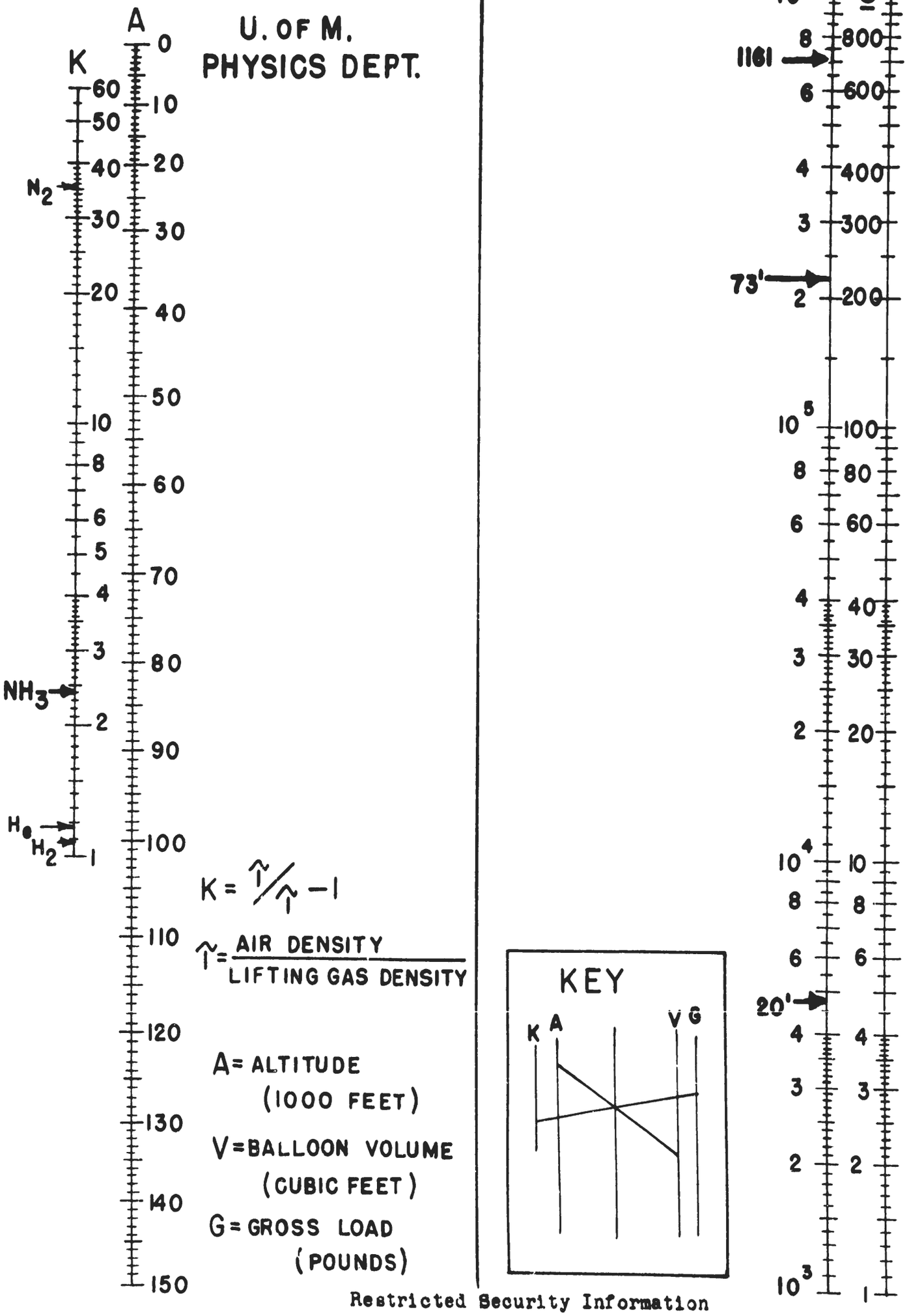
G = gross load

$K = \frac{\tau}{\tau - 1}$ where τ is the ratio of the density of air to the density of the lifting gas. (For example, if hydrogen were the lifting gas, τ would equal 14.4 and K would equal 1.075.)

ARCHIMEDES NOMOGRAPH (I)

FOR NACA STANDARD ATMOSPHERE

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$K = \frac{\sim}{\uparrow} / \frac{\sim}{\uparrow} - 1$

$\frac{\sim}{\uparrow} = \frac{\text{AIR DENSITY}}{\text{LIFTING GAS DENSITY}}$

A = ALTITUDE (1000 FEET)

V = BALLOON VOLUME (CUBIC FEET)

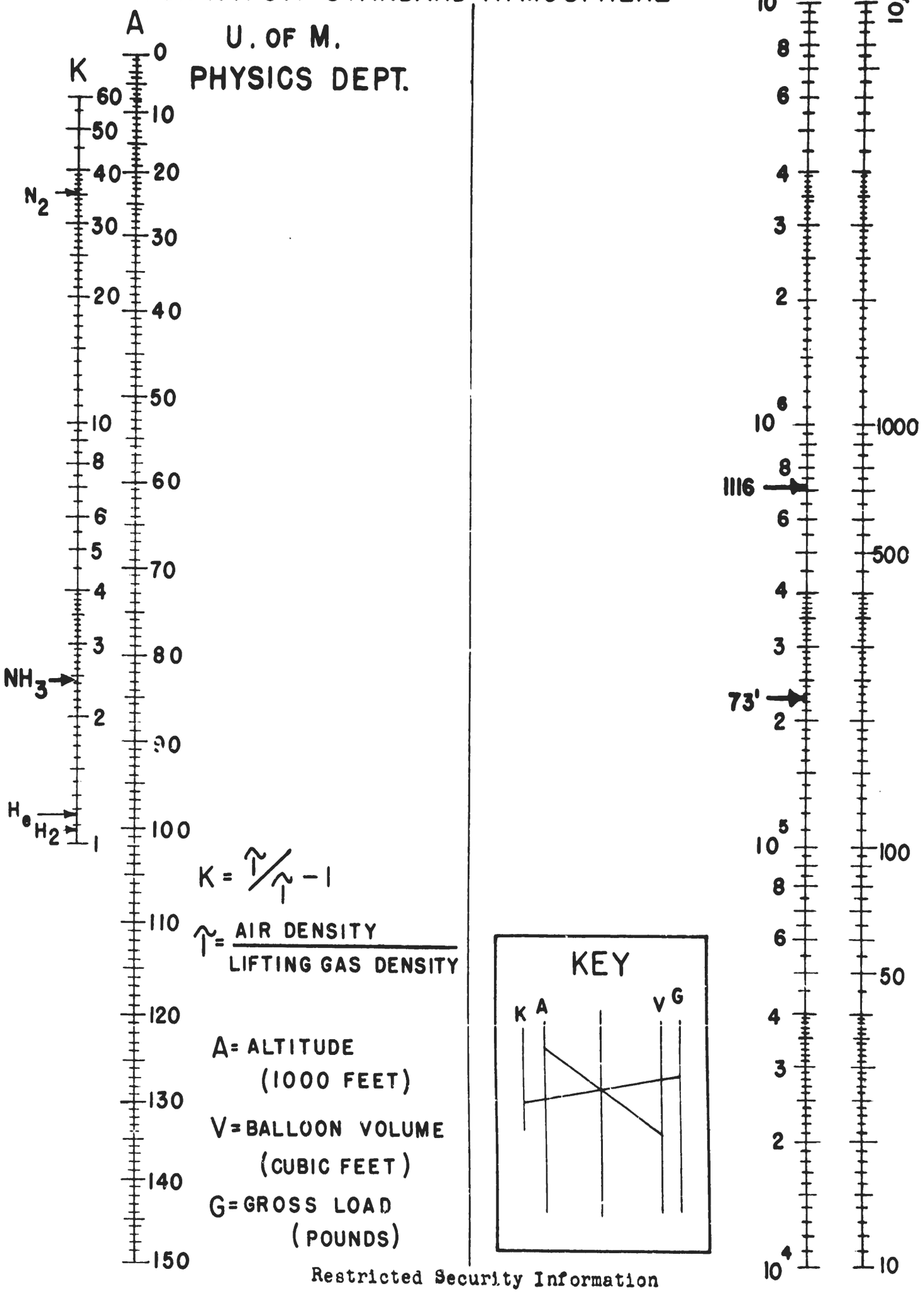
G = GROSS LOAD (POUNDS)

KEY

ARCHIMEDES NOMOGRAPH (II)

FOR N A C A STANDARD ATMOSPHERE

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$$K = \frac{\sigma}{\sigma'} - 1$$

$\sigma' = \frac{\text{AIR DENSITY}}{\text{LIFTING GAS DENSITY}}$

A = ALTITUDE (1000 FEET)

V = BALLOON VOLUME (CUBIC FEET)

G = GROSS LOAD (POUNDS)

KEY

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It will be noted on these nomographs that ρ_A is not plotted, but rather the altitude of the balloon in thousands of feet. Because of the way in which the nomograph is constructed, this scale of altitude comes out linear. The volume is given in cubic feet and the gross load in pounds. The calculated volumes of the Winzen 73-foot diameter balloon, the Winzen 20-foot diameter balloon, and the General Mills 1161 are indicated by arrows. On the K scale, arrows indicate the values of the following lifting gases: hydrogen, helium, ammonia and pure nitrogen. The key at the bottom right corner of these nomographs shows the manner in which they are used. To give a numerical example, consider helium as the lifting gas with a gross load of 400 pounds; the nomograph gives the theoretical ceiling altitude of a 73-foot diameter balloon to be 86,000. The reason for designating these Archimedes' nomographs is evident since they numerically solve the problem of equating the gross load of the balloon and its contained gas to the weight of the displaced air.

B. Nomographs 3 and 4.

Nomographs 3 and 4 allow one to determine the fractional loss of lift per unit time for a balloon, due to porosity leakage. If leakage through small holes were the only effect tending to bring a balloon down, and if one continually dropped off just the proper amount of ballast to keep the balloon floating at its full volume ceiling, then the total weight of the balloon and load would be an exponential function of time. The time constant of this exponential will depend on the magnitude of the leakage and will determine the time in which the total mass of the system will have to be reduced to $\frac{1}{e}$ of its initial weight. The weight is a function

of time as given by the equation

$$G = G_0 o - \frac{t}{T}$$

G = weight at the time t

G_0 = weight at the time of first reaching altitude

T = time constant given by: $T = \dfrac{V^{1/6}}{3.07 \times 10^6 (\tau - 1)^{1/2} f}$

where τ is the ratio of the molecular weight of air to the molecular weight of lifting gas, V the volume of the balloon in cubic feet, and f the fraction of the surface area which is covered by holes.

For a balloon that leaks enough to lose 10% of its lift per day with helium, the time constant T would be 10 days. 10% per day leakage with helium is a rather large figure, and most properly handled balloons exhibit leakages of the order of 2% per day or less when inflated with helium.

Nomograph 3 relates the total area occupied by holes, the radius of the balloon (or its volume), the lifting gas, and the fractional loss of lift per day. The example that is shown indicates that a 0.4 square-inch hole in a 3/4-million cubic foot balloon inflated with helium will cause it to lose 5.7% of its lift per day. The lines on the nomograph used to solve this example illustrate the way in which it is used.

Nomograph 4 relates the quantity T, previously defined, the volume in cubic feet, the fraction of the surface area covered by holes, and the fractional loss of lift per day. Again, the construction lines demonstrate the use of the nomograph. The example taken is a 1/4-million cubic foot balloon inflated with helium, and shows that if one part in ten million of the surface is represented by holes, such a balloon will lose 10% of its lift per day. It should be indicated that both nomographs 3 and 4 apply to holes at the position of average pressure in the balloon (approximately at the equator) and are strictly true only when the balloon is floating at its theoretical ceiling.

C. Nomograph 5.

Polyethylene will allow a certain amount of helium to pass through it by diffusion. Even in the absence of holes in the surface, this diffusion of helium produces leakage. The magnitude of the effect has been measured by Dr. Karl Kammermeyer of the University of Iowa, working on a sub-contract from General Mills. The magnitude of the diffusion measured sets a lower limit on the leakage of a polyethylene balloon. Fortunately, this limit is well below the actual leakage encountered in balloon flights. The equation which governs the diffusion through films is

$$F = \frac{PA\ (P_1 - P_2)}{d}$$

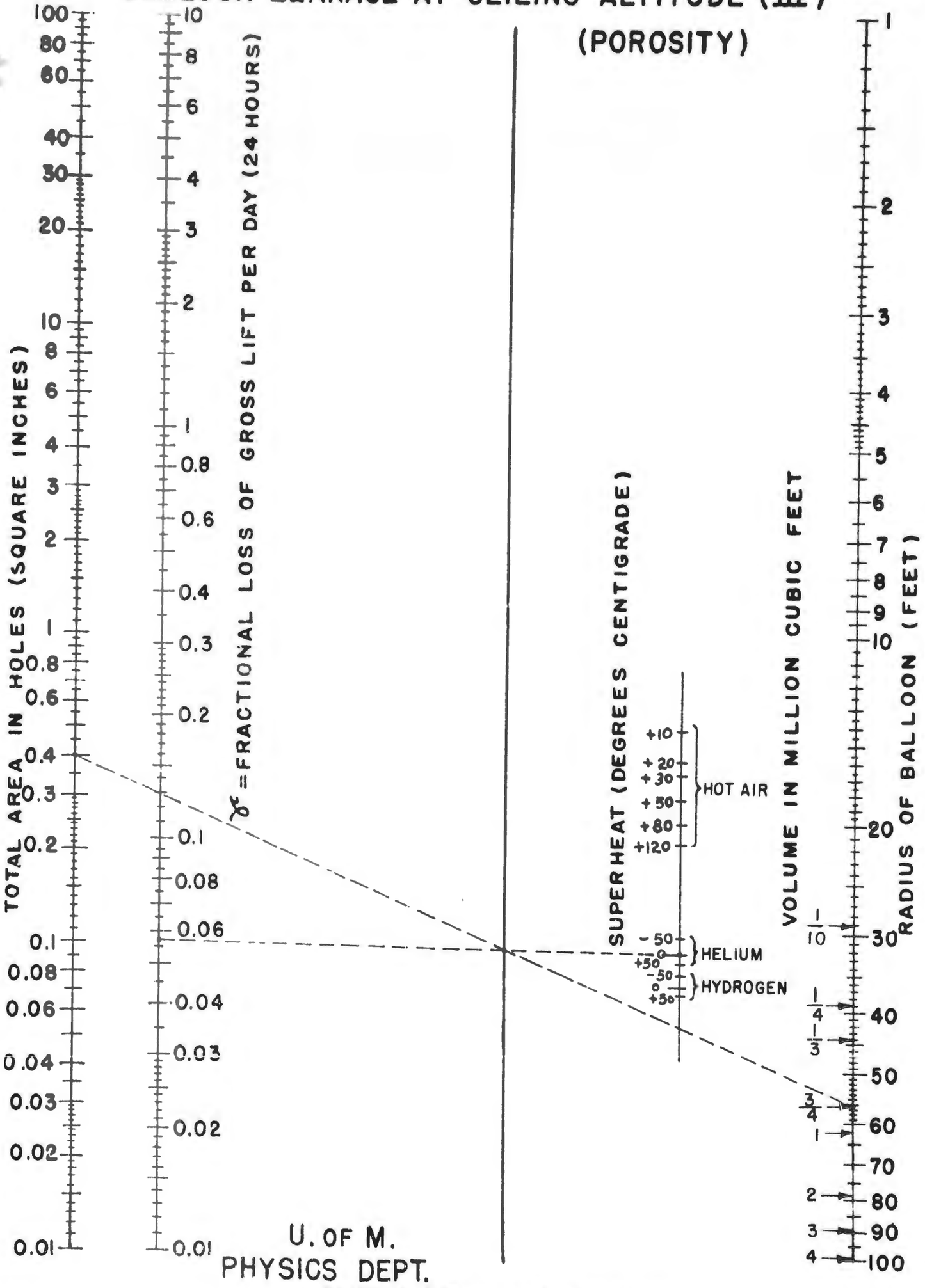
F = volume flow in cc per second

P = constant, characteristic of the material. Its units are

cm^2/second/cm of mercury pressure

BALLOON LEAKAGE AT CEILING ALTITUDE (III)

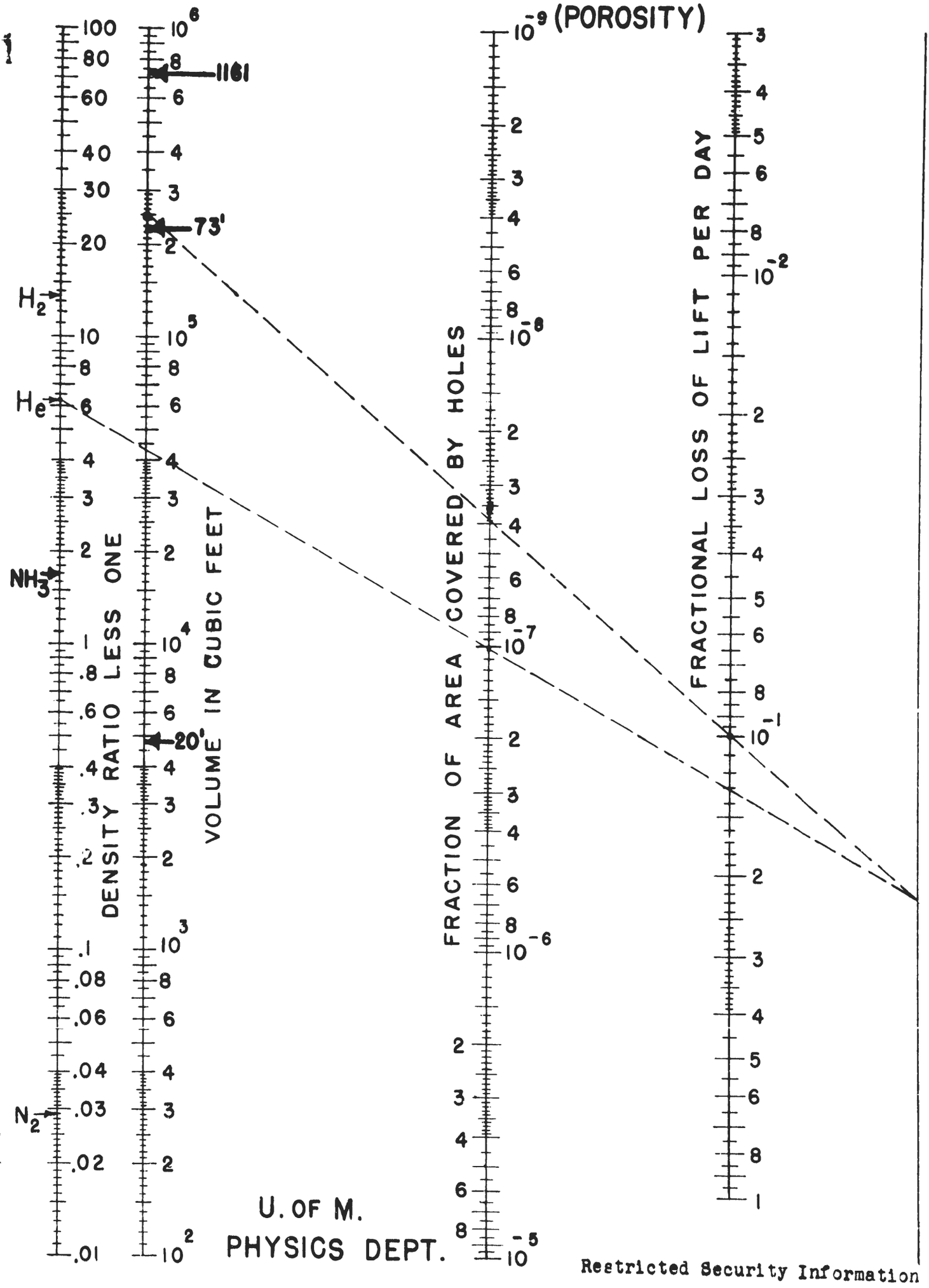
(POROSITY)



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BALLOON LEAKAGE AT CEILING ALTITUDE IV



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p_1 and p_2 = partial pressures of the gas on both sides of the film

d = thickness of the film in cm

The diffusion equation was solved in terms of the fractional loss of lift per day, and in nomograph 5 it was constructed to represent this equation

$$\delta = 3.79 \frac{G}{V^{4/3}} \frac{1}{d}$$

δ = the fractional loss of lift per day

G = gross load in pounds

V = volume in cubic feet

d = thickness of balloon in thousandths of an inch.

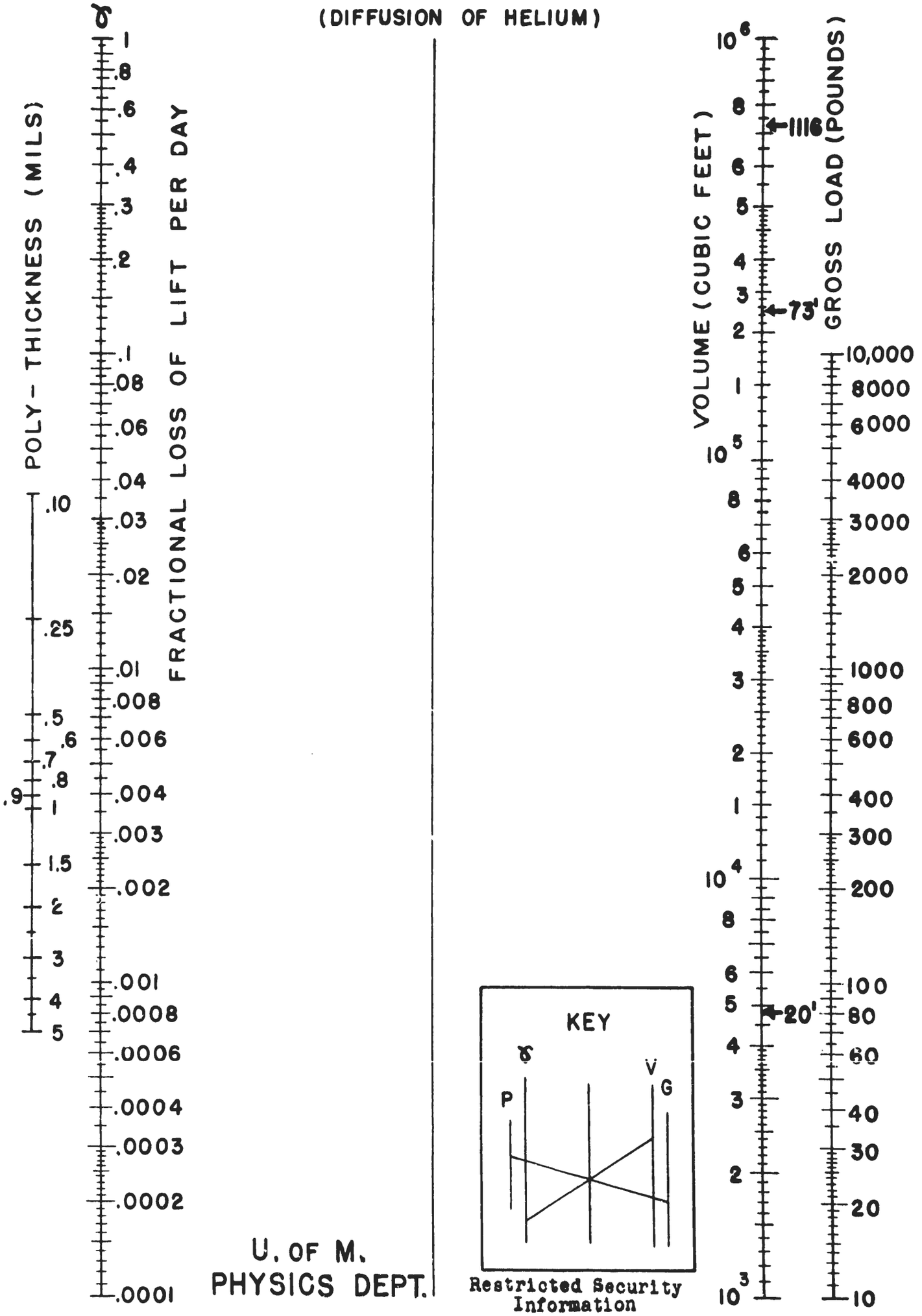
To give a numerical example, consider a 1-mil thick 73-foot diameter balloon carrying a gross load of 600 pounds. The nomograph indicates a fractional loss of 0.00015 per day, or fifteen thousandths of a percent per day. The nomograph applies to the diffusion of helium. The diffusion of hydrogen is approximately the square root of two times greater at the same temperature. It turns out in Kammermeyer's work that the diffusion is much slower at lower temperatures. It is clear from the example that was chosen that the diffusion leakage of a balloon is essentially negligible.

D. Nomograph 6.

The sixth nomograph allows one to calculate the amount of power in kilowatts which must be transferred into a rising balloon in order to keep it ascending at various rates of rise. The amount of power is naturally a function of the atmospheric lapse rate, which is indicated in the nomograph. The philosophy behing this type of calculation is the following. If a balloon is considered as a heat engine, then a constant volume balloon which is sufficiently inflated at sea level to be in

BALLOON LEAKAGE AT CEILING ALTITUDE V

(DIFFUSION OF HELIUM)



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equilibrium can also be in equilibrium at any altitude in an isothermal atmosphere below the altitude at which the balloon becomes full. If one asks about the energy relations in moving the balloon from sea level to some higher altitude, then it is relatively easy to show that the change in gravitational potential in lifting the weight must just be balanced by a flow of energy into the balloon, exactly equal in the proper units to the work done in raising the weight. If the atmospheric lapse rate is not zero, a different quantity of heat will flow into the balloon since the balloon can change its temperature and thereby use some of its internal energy store to assist in raising the weight. The following discussion shows quantitatively this result:

Thermodynamics of a Balloon

These symbols are used in the following equations:

dQ = heat transferred into system

C_p = specific heat at constant pressure

R = gas constant

V = balloon volume

P = atmospheric pressure

n = number of moles of gas

T = atmospheric temperature

g = acceleration of gravity

$$dQ = C_p dT - V dP$$

$$Q = \int C_p dT - \int V dP$$

Simple case isothermal atmosphere

$$Q = \int V dP$$

$$PV = nRT$$

$$Q = \int \frac{nRT}{P} dP$$

From the atmosphere

$$dP = \rho g \, dh$$

$$PV = \frac{n}{M} RT$$

$$P = \frac{\rho}{M} RT$$

$$dP = \frac{PM}{RT} g \, dh$$

$$\frac{dP}{P} = \frac{M}{RT} g \, dh$$

$$Q = \int \frac{nRTM}{RT} g \, dh = n \, Mg \, h$$

nM = the mass of displaced air m

$$\boxed{Q = mgh}$$

In an isothermal atmosphere the heat transferred into the balloon is equal to the work done in raising the gross weight of the system against gravity.

The work done in inflating a balloon is PV no matter what altitude it is inflated at. You would do as much work inflating it at 1 cm as at 100 cm because the volume has changed in the same ratio. This work is done in raising the atmosphere.

$$PV = nRT$$

In terms of potential energy and heat we ask how much heat is required to correspond to RT or what h in mgh is required.

$$Q = \int nRT \frac{dp}{p} = nMgh$$

if

$$Q = RT = Mgh$$

$$h = \frac{RT}{Mg} = ho$$

Since

$$\frac{dp}{p} = \frac{Mg}{RT} dh$$

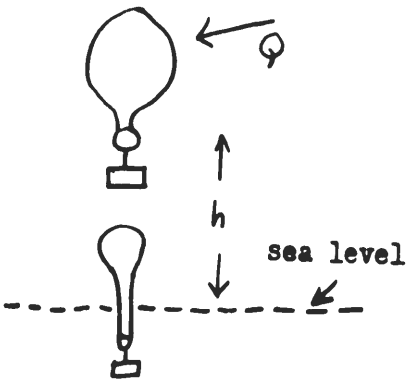
or

$$\frac{dp}{p} = \frac{dh}{ho} \quad ,$$

ho is the "e folding" height in the isothermal atmosphere.

The work done in inflating a balloon against the atmosphere is just equal to the work the atmosphere must do on the total mass to raise it an e-folding distance in an isothermal atmosphere.

Since the same work must be done on the atmosphere in order to inflate the balloon to the same gross load at any stable altitude, we prefer to take the zero of energy for the system when the balloon is inflated at sea level. An amount of work nRT is done, but it is not possible for this work to be recovered as kinetic or potential energy except in the ideal adiabatic case where no heat is transferred into the balloon.



Q flows into the system to do the work in raising the weight.

Condition	Heat added to balloon	Change in internal energy of balloon
Isothermal atmosphere	mgh	0
Adiabatic with lapse equal to balloon gas	0	mgh
Adiabatic with lapse rate less than balloon	$mgh - C_p \Delta T$	
Adiabatic with lapse rate greater than balloon	$mgh + C_p \Delta T$	

When the equation for the power is expressed in terms of the lapse rate, the gross load, and the velocity, the equation obtained is the following for helium:

$$P = (.65L + 2.6)GV$$

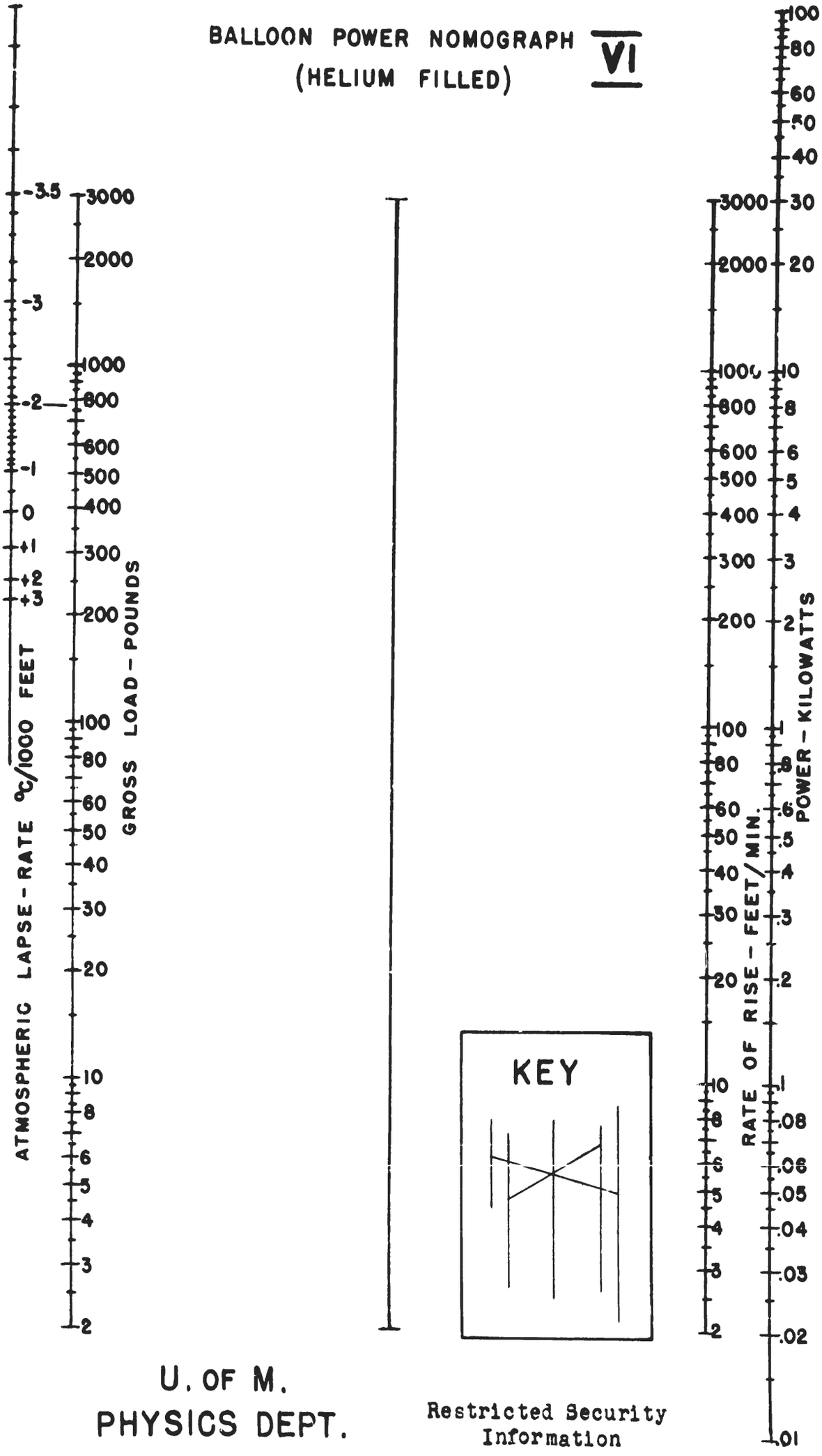
L = lapse rate in degrees per thousand feet

G = gross load expressed in units of 100 pounds

V = velocity in 1000 feet per minute.

The power then comes out in kilowatts. To take a numerical example, consider the normal tropospheric lapse rate of 2 degrees per thousand feet, a gross load of 500 pounds, and a rate of rise 1000 feet a minute. The nomograph gives 6.2 kilowatts as the power required to maintain this rate of rise. The key at the lower right of the nomographs shows the way in which they are used.

BALLOON POWER NOMOGRAPH VI
(HELIUM FILLED)



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Ground and Balloon Sunset

The sunrise and sunset tables are copied from The British Nautical Almanac for 1945. The references to twilight are to be ignored. These tables give the local civil time of sunrise (left half of the page) and sunset (right half of the page) for each day of the year and from 0° to 60° north latitude. To convert the local civil time to standard time, one must add four minutes for each degree west of the standard meridian (i.e., 75°, 90°, 105°, 120°, etc.), and subtract four minutes for each degree east of the standard meridian.

These tables are accurate for non-leap years. They are identical with the tables given for 1953. For leap years such as 1952, the sunrise tables will be as given in the tables for 1952 or one minute slow. The sunset tables will correspondingly be accurate or one minute fast. If the values are desired accurate to the nearest minute at high latitudes (i.e., 60°), it is best to consult the current British Nautical Almanac or the American Ephemeris and Nautical Almanac. The latter, however, requires interpolation between five day intervals.

464 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date \ Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	5 59	6 17	6 35	6 56	7 08	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 03
1	6 00	6 17	6 35	6 56	7 08	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 03
2	6 00	6 17	6 35	6 56	7 08	7 22	7 39	7 59	8 08	8 19	8 31	8 46	9 02
3	6 01	6 18	6 36	6 56	7 08	7 22	7 39	7 59	8 08	8 19	8 31	8 45	9 02
4	6 01	6 18	6 36	6 57	7 09	7 22	7 38	7 58	8 08	8 19	8 31	8 45	9 01
5	6 02	6 18	6 36	6 57	7 09	7 22	7 38	7 58	8 08	8 18	8 30	8 44	9 00
6	6 02	6 19	6 36	6 57	7 09	7 22	7 38	7 58	8 08	8 18	8 30	8 44	9 00
7	6 02	6 19	6 37	6 57	7 09	7 22	7 38	7 58	8 07	8 17	8 29	8 43	8 59
8	6 03	6 19	6 37	6 57	7 09	7 22	7 38	7 57	8 06	8 17	8 28	8 42	8 58
9	6 03	6 20	6 37	6 57	7 09	7 22	7 38	7 57	8 06	8 16	8 28	8 41	8 57
10	6 04	6 20	6 37	6 57	7 09	7 22	7 37	7 56	8 06	8 16	8 27	8 40	8 56
11	6 04	6 20	6 38	6 57	7 09	7 22	7 37	7 56	8 05	8 15	8 26	8 39	8 54
12	6 05	6 21	6 38	6 57	7 09	7 22	7 37	7 55	8 04	8 14	8 25	8 38	8 53
13	6 05	6 21	6 38	6 57	7 08	7 21	7 36	7 55	8 04	8 13	8 24	8 37	8 52
14	6 05	6 21	6 38	6 57	7 08	7 21	7 36	7 54	8 03	8 12	8 23	8 36	8 50
15	6 06	6 21	6 38	6 57	7 08	7 20	7 35	7 53	8 02	8 11	8 22	8 34	8 49
16	6 06	6 22	6 38	6 57	7 08	7 20	7 35	7 53	8 01	8 10	8 21	8 33	8 47
17	6 06	6 22	6 38	6 57	7 08	7 20	7 34	7 52	8 00	8 09	8 20	8 32	8 46
18	6 07	6 22	6 38	6 56	7 07	7 19	7 34	7 51	7 59	8 08	8 19	8 30	8 44
19	6 07	6 22	6 38	6 56	7 07	7 19	7 33	7 50	7 58	8 07	8 17	8 29	8 42
20	6 07	6 22	6 38	6 56	7 06	7 18	7 32	7 49	7 57	8 06	8 16	8 27	8 41
21	6 08	6 22	6 38	6 56	7 06	7 18	7 31	7 48	7 56	8 05	8 15	8 26	8 39
22	6 08	6 22	6 38	6 55	7 06	7 17	7 31	7 47	7 55	8 03	8 13	8 24	8 37
23	6 08	6 23	6 38	6 55	7 05	7 16	7 30	7 46	7 54	8 02	8 12	8 22	8 35
24	6 08	6 23	6 38	6 55	7 04	7 16	7 29	7 45	7 52	8 01	8 10	8 21	8 33

SUNSET AND TWILIGHT, 1945 465

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date \ Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	18 07	17 50	17 31	17 10	16 58	16 44	16 28	16 08	15 58	15 47	15 34	15 20	15 03
1	18 07	17 50	17 32	17 11	16 59	16 45	16 29	16 09	15 59	15 48	15 36	15 21	15 05
2	18 08	17 51	17 33	17 12	17 00	16 46	16 30	16 10	16 00	15 49	15 37	15 23	15 06
3	18 08	17 51	17 33	17 13	17 01	16 47	16 31	16 11	16 01	15 50	15 38	15 24	15 08
4	18 09	17 52	17 34	17 13	17 01	16 48	16 32	16 12	16 02	15 52	15 40	15 25	15 09
5	18 09	17 52	17 35	17 14	17 02	16 49	16 33	16 13	16 03	15 53	15 41	15 27	15 11
6	18 10	17 53	17 35	17 15	17 03	16 50	16 34	16 14	16 04	15 54	15 42	15 29	15 13
7	18 10	17 54	17 36	17 16	17 04	16 50	16 35	16 15	16 06	15 56	15 44	15 30	15 14
8	18 10	17 54	17 36	17 16	17 05	16 51	16 36	16 16	16 07	15 57	15 45	15 32	15 16
9	18 11	17 55	17 37	17 17	17 06	16 52	16 37	16 18	16 09	15 59	15 47	15 34	15 18
10	18 11	17 55	17 38	17 18	17 07	16 54	16 38	16 19	16 10	16 00	15 49	15 36	15 20
11	18 12	17 56	17 38	17 19	17 08	16 55	16 39	16 20	16 12	16 02	15 50	15 37	15 22
12	18 12	17 56	17 39	17 20	17 08	16 56	16 40	16 22	16 13	16 03	15 52	15 39	15 24
13	18 12	17 57	17 40	17 20	17 09	16 57	16 42	16 23	16 14	16 05	15 54	15 41	15 26
14	18 13	17 57	17 40	17 21	17 10	16 58	16 43	16 25	16 16	16 06	15 56	15 43	15 29
15	18 13	17 58	17 41	17 22	17 11	16 59	16 44	16 26	16 18	16 08	15 57	15 45	15 31
16	18 14	17 58	17 42	17 23	17 12	17 00	16 45	16 28	16 19	16 10	15 59	15 47	15 33
17	18 14	17 58	17 42	17 24	17 13	17 01	16 46	16 29	16 21	16 12	16 01	15 49	15 35
18	18 14	17 59	17 43	17 25	17 14	17 02	16 48	16 31	16 22	16 13	16 03	15 51	15 38
19	18 14	18 00	17 44	17 26	17 15	17 03	16 49	16 32	16 24	16 15	16 05	15 53	15 40
20	18 15	18 00	17 44	17 26	17 16	17 04	16 50	16 34	16 26	16 17	16 07	15 56	15 42
21	18 15	18 00	17 45	17 27	17 17	17 06	16 52	16 35	16 27	16 19	16 09	15 58	15 45
22	18 15	18 01	17 46	17 28	17 18	17 07	16 53	16 37	16 29	16 21	16 11	16 00	15 47
23	18 16	18 01	17 46	17 29	17 19	17 08	16 55	16 38	16 31	16 22	16 13	16 02	15 50
24	18 16	18 02	17 47	17 30	17 20	17 09	16 56	16 40	16 33	16 24	16 15	16 05	15 52

466 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west and subtract if east
For further explanation see page 502. For southern latitudes see page 503

Date \ Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 23	6 08	6 23	6 38	6 55	7 05	7 16	7 30	7 46	7 54	8 02	8 12	8 22	8 35
24	6 08	6 23	6 38	6 55	7 04	7 16	7 29	7 45	7 52	8 01	8 10	8 21	8 33
25	6 09	6 23	6 37	6 54	7 04	7 15	7 28	7 44	7 51	7 59	8 08	8 19	8 31
26	6 09	6 23	6 37	6 54	7 04	7 14	7 27	7 43	7 50	7 58	8 07	8 17	8 29
27	6 09	6 23	6 37	6 53	7 03	7 14	7 26	7 41	7 48	7 56	8 05	8 15	8 27
28	6 09	6 23	6 37	6 53	7 02	7 13	7 25	7 40	7 47	7 55	8 04	8 13	8 25
29	6 10	6 23	6 37	6 52	7 02	7 12	7 24	7 39	7 46	7 53	8 02	8 11	8 22
30	6 10	6 23	6 36	6 52	7 01	7 11	7 23	7 37	7 44	7 52	8 00	8 09	8 20
31	6 10	6 23	6 36	6 51	7 00	7 10	7 22	7 36	7 43	7 50	7 58	8 07	8 18
Feb. 1	6 10	6 23	6 36	6 51	7 00	7 09	7 21	7 35	7 41	7 48	7 56	8 05	8 16
2	6 10	6 22	6 36	6 50	6 59	7 08	7 20	7 33	7 40	7 46	7 54	8 03	8 13
3	6 10	6 22	6 35	6 50	6 58	7 07	7 18	7 32	7 38	7 45	7 52	8 01	8 11
4	6 10	6 22	6 35	6 49	6 57	7 06	7 17	7 30	7 36	7 43	7 50	7 59	8 08
5	6 10	6 22	6 34	6 48	6 56	7 05	7 16	7 29	7 35	7 41	7 48	7 57	8 06
6	6 10	6 22	6 34	6 48	6 55	7 04	7 15	7 27	7 33	7 39	7 46	7 54	8 03
7	6 11	6 22	6 34	6 47	6 55	7 03	7 13	7 26	7 31	7 37	7 44	7 52	8 01
8	6 11	6 22	6 33	6 46	6 54	7 02	7 12	7 24	7 30	7 36	7 42	7 50	7 58
9	6 11	6 21	6 33	6 46	6 53	7 01	7 11	7 22	7 28	7 34	7 40	7 48	7 56
10	6 11	6 21	6 32	6 45	6 52	7 00	7 09	7 21	7 26	7 32	7 38	7 45	7 53
11	6 11	6 21	6 32	6 44	6 51	6 59	7 08	7 19	7 24	7 30	7 36	7 43	7 51
12	6 11	6 21	6 31	6 43	6 50	6 58	7 06	7 17	7 22	7 28	7 34	7 40	7 48
13	6 11	6 20	6 31	6 42	6 49	6 56	7 05	7 16	7 20	7 26	7 31	7 38	7 45
14	6 11	6 20	6 30	6 42	6 48	6 55	7 04	7 14	7 18	7 24	7 29	7 36	7 43
15	6 11	6 20	6 30	6 41	6 47	6 54	7 02	7 12	7 16	7 21	7 27	7 33	7 40
16	6 11	6 20	6 29	6 40	6 46	6 53	7 01	7 10	7 14	7 19	7 25	7 31	7 37

SUNSET AND TWILIGHT, 1945 467

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east
For further explanation see page 502. For southern latitudes see page 503.

Date \ Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 23	18 10	18 01	17 46	17 29	17 19	17 08	16 55	16 38	16 31	16 22	16 13	16 02	15 50
24	18 16	18 02	17 47	17 30	17 20	17 09	16 56	16 40	16 33	16 24	16 15	16 05	15 52
25	18 16	18 02	17 48	17 31	17 21	17 10	16 57	16 42	16 34	16 26	16 17	16 07	15 55
26	18 16	18 03	17 48	17 32	17 22	17 12	16 59	16 43	16 36	16 28	16 19	16 09	15 58
27	18 16	18 03	17 49	17 33	17 23	17 13	17 00	16 45	16 38	16 30	16 21	16 11	16 00
28	18 17	18 04	17 49	17 34	17 24	17 14	17 02	16 47	16 40	16 32	16 24	16 14	16 03
29	18 17	18 04	17 50	17 34	17 25	17 15	17 03	16 48	16 42	16 34	16 26	16 16	16 05
30	18 17	18 04	17 51	17 35	17 26	17 16	17 04	16 50	16 43	16 36	16 28	16 18	16 08
31	18 17	18 04	17 51	17 36	17 27	17 17	17 06	16 52	16 45	16 38	16 30	16 21	16 10
Feb. 1	18 18	18 05	17 52	17 37	17 28	17 19	17 07	16 53	16 47	16 40	16 32	16 23	16 13
2	18 18	18 05	17 52	17 38	17 29	17 20	17 09	16 55	16 49	16 42	16 34	16 26	16 16
3	18 18	18 06	17 53	17 38	17 30	17 21	17 10	16 57	16 51	16 44	16 36	16 28	16 18
4	18 18	18 06	17 54	17 39	17 31	17 22	17 12	16 59	16 53	16 46	16 39	16 30	16 21
5	18 18	18 06	17 54	17 40	17 32	17 23	17 13	17 00	16 54	16 48	16 41	16 33	16 24
6	18 18	18 07	17 55	17 41	17 33	17 25	17 14	17 02	16 56	16 50	16 43	16 35	16 26
7	18 18	18 07	17 55	17 42	17 34	17 26	17 16	17 04	16 58	16 52	16 45	16 38	16 29
8	18 18	18 07	17 56	17 43	17 35	17 27	17 17	17 05	17 00	16 54	16 47	16 40	16 31
9	18 18	18 07	17 56	17 44	17 36	17 28	17 19	17 07	17 02	16 56	16 50	16 42	16 34
10	18 18	18 08	17 57	17 44	17 37	17 29	17 20	17 09	17 04	16 58	16 52	16 45	16 37
11	18 18	18 08	17 57	17 45	17 38	17 31	17 22	17 11	17 06	17 00	16 54	16 47	16 39
12	18 18	18 08	17 58	17 46	17 39	17 32	17 23	17 12	17 08	17 02	16 56	16 50	16 42
13	18 18	18 08	17 58	17 47	17 40	17 33	17 24	17 14	17 09	17 04	16 58	16 52	16 45
14	18 18	18 08	17 59	17 48	17 41	17 34	17 26	17 16	17 11	17 06	17 00	16 54	16 47
15	18 18	18 09	17 59	17 48	17 42	17 35	17 27	17 18	17 13	17 08	17 03	16 57	16 50
16	18 18	18 09	18 00	17 49	17 43	17 36	17 29	17 19	17 15	17 10	17 05	16 59	16 52

468 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east

For further explanation see page 502 For southern latitudes see page 503

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Feb	15	6 11	6 20	6 30	6 41	6 47	6 54	7 02	7 12	7 16	7 21	7 27	7 33	7 40
	16	6 11	6 20	6 29	6 40	6 46	6 53	7 01	7 10	7 14	7 19	7 25	7 31	7 37
	17	6 11	6 19	6 28	6 39	6 45	6 51	6 59	7 08	7 12	7 17	7 22	7 28	7 34
	18	6 11	6 19	6 28	6 38	6 44	6 50	6 57	7 06	7 10	7 15	7 20	7 26	7 32
	19	6 11	6 19	6 27	6 37	6 42	6 49	6 56	7 04	7 08	7 13	7 18	7 23	7 29
	20	6 10	6 18	6 27	6 36	6 41	6 47	6 54	7 03	7 06	7 11	7 15	7 20	7 26
	21	6 10	6 18	6 26	6 35	6 40	6 46	6 53	7 01	7 04	7 08	7 13	7 18	7 23
	22	6 10	6 18	6 25	6 34	6 39	6 44	6 51	6 59	7 02	7 06	7 10	7 15	7 20
	23	6 10	6 17	6 25	6 33	6 38	6 43	6 49	6 57	7 00	7 04	7 08	7 13	7 18
	24	6 10	6 17	6 24	6 32	6 37	6 42	6 [illegible]	6 55	6 58	7 02	7 06	7 10	7 15
	25	6 10	6 16	6 23	6 31	6 35	6 40	6 46	6 53	6 56	6 59	7 03	7 07	7 12
	26	6 10	6 16	6 22	6 30	6 34	6 39	6 44	6 51	6 54	6 57	7 01	7 05	7 09
	27	6 10	6 16	6 22	6 29	6 33	6 37	6 43	6 49	6 52	6 55	6 58	7 02	7 06
	28	6 09	6 15	6 21	6 28	6 32	6 36	6 41	6 47	6 50	6 52	6 56	6 59	7 03
Mar.	1	6 09	6 15	6 20	6 27	6 30	6 34	6 39	6 45	6 47	6 50	6 53	6 57	7 00
	2	6 09	6 14	6 20	6 26	6 29	6 33	6 37	6 43	6 45	6 48	6 51	6 54	6 58
	3	6 09	6 14	6 19	6 25	6 28	6 32	6 36	6 41	6 43	6 45	6 48	6 51	6 55
	4	6 09	6 13	6 18	6 23	6 27	6 30	6 34	6 39	6 41	6 43	6 46	6 48	6 52
	5	6 08	6 13	6 17	6 22	6 25	6 28	6 32	6 37	6 38	6 41	6 43	6 46	6 49
	6	6 08	6 12	6 16	6 21	6 24	6 27	6 30	6 34	6 36	6 38	6 40	6 43	6 46
	7	6 08	6 12	6 16	6 20	6 22	6 25	6 28	6 32	6 34	6 36	6 38	6 40	6 43
	8	6 08	6 11	6 15	6 19	6 21	6 24	6 27	6 30	6 32	6 34	6 35	6 37	6 40
	9	6 07	6 11	6 14	6 18	6 20	6 22	6 25	6 28	6 29	6 31	6 33	6 35	6 37
	10	6 07	6 10	6 13	6 17	6 19	6 21	6 23	6 26	6 27	6 29	6 30	6 32	6 34
	11	6 07	6 10	6 12	6 16	6 17	6 19	6 21	6 24	6 25	6 26	6 28	6 29	6 31

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.

For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Feb.	15	18 18	18 09	17 59	17 48	17 42	17 35	17 27	17 18	17 13	17 08	17 03	16 57	16 50
	16	18 18	18 09	18 00	17 49	17 43	17 36	17 29	17 19	17 15	17 10	17 05	16 59	16 52
	17	18 18	18 09	18 00	17 50	17 44	17 38	17 30	17 21	17 17	17 12	17 07	17 01	16 55
	18	18 18	18 09	18 00	17 51	17 45	17 39	17 31	17 23	17 19	17 14	17 09	17 04	16 58
	19	18 17	18 09	18 01	17 51	17 46	17 40	17 33	17 24	17 20	17 16	17 11	17 06	17 00
	20	18 17	18 10	18 01	17 52	17 47	17 41	17 34	17 26	17 22	17 18	17 14	17 08	17 03
	21	18 17	18 10	18 02	17 53	17 48	17 42	17 36	17 28	17 24	17 20	17 16	17 11	17 06
	22	18 17	18 10	18 02	17 54	17 49	17 43	17 37	17 30	17 26	17 22	17 18	17 13	17 08
	23	18 17	18 10	18 03	17 54	17 50	17 45	17 38	17 31	17 28	17 24	17 20	17 16	17 11
	24	18 17	18 10	18 03	17 55	17 51	17 46	17 40	17 33	17 30	17 26	17 22	17 18	17 13
	25	18 17	18 10	18 04	17 56	17 52	17 47	17 41	17 35	17 32	17 28	17 24	17 20	17 16
	26	18 16	18 10	18 04	17 57	17 53	17 48	17 43	17 36	17 33	17 30	17 27	17 23	17 18
	27	18 16	18 10	18 04	17 57	17 53	17 49	17 44	17 38	17 35	17 32	17 29	17 25	17 21
	28	18 16	18 10	18 05	17 58	17 54	17 50	17 45	17 40	17 37	17 34	17 31	17 27	17 23
Mar.	1	18 16	18 10	18 05	17 59	17 55	17 51	17 47	17 41	17 39	17 36	17 33	17 30	17 26
	2	18 16	18 11	18 05	18 00	17 56	17 52	17 48	17 43	17 41	17 38	17 35	17 32	17 28
	3	18 15	18 11	18 06	18 00	17 57	17 53	17 49	17 44	17 42	17 40	17 37	17 34	17 31
	4	18 15	18 11	18 06	18 01	17 58	17 55	17 51	17 46	17 44	17 42	17 39	17 37	17 34
	5	18 15	18 11	18 06	18 02	17 59	17 56	17 52	17 48	17 46	17 44	17 42	17 39	17 36
	6	18 15	18 11	18 07	18 02	18 00	17 57	17 53	17 49	17 48	17 46	17 44	17 41	17 38
	7	18 15	18 11	18 07	18 03	18 00	17 58	17 55	17 51	17 50	17 48	17 46	17 44	17 41
	8	18 14	18 11	18 07	18 04	18 01	17 59	17 56	17 53	17 51	17 50	17 48	17 46	17 44
	9	18 14	18 11	18 08	18 04	18 02	18 00	17 57	17 54	17 53	17 52	17 50	17 48	17 46
	10	18 14	18 11	18 08	18 05	18 03	18 01	17 59	17 56	17 55	17 53	17 52	17 50	17 48
	11	18 14	18 11	18 08	18 05	18 04	18 02	18 00	17 58	17 56	17 55	17 54	17 52	17 51

470 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.

For further explanation see page 502 For southern latitudes see page 503

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Mar.	10	6 07	6 10	6 13	6 17	6 19	6 21	6 23	6 26	6 27	6 29	6 30	6 32	6 34
	11	6 07	6 10	6 12	6 16	6 17	6 19	6 21	6 24	6 25	6 26	6 28	6 29	6 31
	12	6 07	6 09	6 12	6 14	6 16	6 18	6 19	6 22	6 23	6 24	6 25	6 26	6 28
	13	6 06	6 09	6 11	6 13	6 14	6 16	6 18	6 20	6 20	6 21	6 22	6 24	6 25
	14	6 06	6 08	6 10	6 12	6 13	6 14	6 16	6 17	6 18	6 19	6 20	6 21	6 22
	15	6 06	6 07	6 09	6 11	6 12	6 13	6 14	6 15	6 16	6 16	6 17	6 18	6 19
	16	6 06	6 07	6 08	6 10	6 10	6 11	6 12	6 13	6 13	6 14	6 14	6 15	6 16
	17	6 05	6 06	6 07	6 08	6 09	6 10	6 10	6 11	6 11	6 12	6 12	6 12	6 13
	18	6 05	6 06	6 06	6 07	6 08	6 08	6 08	6 09	6 09	6 09	6 09	6 10	6 10
	19	6 05	6 05	6 06	6 06	6 06	6 06	6 06	6 06	6 06	6 06	6 07	6 07	6 07
	20	6 04	6 05	6 05	6 05	6 05	6 05	6 04	6 04	6 04	6 04	6 04	6 04	6 04
	21	6 04	6 04	6 04	6 04	6 03	6 03	6 03	6 02	6 02	6 02	6 01	6 01	6 01
	22	6 04	6 03	6 03	6 02	6 02	6 01	6 01	6 00	6 00	5 59	5 59	5 58	5 58
	23	6 04	6 03	6 02	6 01	6 00	6 00	5 59	5 58	5 58	5 57	5 56	5 55	5 55
	24	6 03	6 02	6 01	6 00	5 59	5 58	5 57	5 56	5 55	5 54	5 53	5 53	5 52
	25	6 03	6 02	6 00	5 59	5 58	5 57	5 55	5 53	5 53	5 52	5 51	5 50	5 49
	26	6 02	6 01	5 59	5 57	5 56	5 55	5 53	5 51	5 50	5 49	5 48	5 47	5 46
	27	6 02	6 00	5 58	5 56	5 55	5 53	5 51	5 49	5 48	5 47	5 45	5 44	5 42
	28	6 02	6 00	5 58	5 55	5 54	5 52	5 50	5 47	5 46	5 44	5 43	5 41	5 39
	29	6 02	5 59	5 57	5 54	5 52	5 50	5 48	5 45	5 43	5 42	5 40	5 38	5 36
	30	6 01	5 59	5 56	5 53	5 51	5 48	5 46	5 42	5 41	5 39	5 38	5 36	5 33
	31	6 01	5 58	5 55	5 51	5 49	5 47	5 44	5 40	5 39	5 37	5 35	5 33	5 30
Apr.	1	6 01	5 58	5 54	5 50	5 48	5 45	5 42	5 38	5 36	5 34	5 32	5 30	5 27
	2	6 00	5 57	5 53	5 49	5 46	5 44	5 40	5 36	5 34	5 32	5 30	5 27	5 24
	3	6 00	5 57	5 52	5 48	5 45	5 42	5 38	5 34	5 32	5 30	5 27	5 24	5 21

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.

For further explanation see page 502 For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Mar.	10	18 14	18 11	18 08	18 05	18 03	18 01	17 59	17 56	17 55	17 53	17 52	17 50	17 48
	11	18 14	18 11	18 08	18 05	18 04	18 02	18 00	17 58	17 56	17 55	17 54	17 52	17 51
	12	18 13	18 11	18 09	18 06	18 05	18 03	18 01	17 59	17 58	17 57	17 56	17 55	17 53
	13	18 13	18 11	18 09	18 07	18 05	18 04	18 03	18 01	18 00	17 59	17 58	17 57	17 56
	14	18 13	18 11	18 09	18 07	18 06	18 05	18 04	18 02	18 02	18 01	18 00	17 59	17 58
	15	18 12	18 11	18 10	18 08	18 07	18 06	18 05	18 04	18 04	18 03	18 02	18 02	18 01
	16	18 12	18 11	18 10	18 09	18 08	18 07	18 06	18 06	18 05	18 05	18 04	18 04	18 03
	17	18 12	18 11	18 10	18 09	18 09	18 08	18 08	18 07	18 07	18 07	18 06	18 06	18 06
	18	18 12	18 11	18 10	18 10	18 10	18 09	18 09	18 09	18 09	18 09	18 08	18 08	18 08
	19	18 11	18 11	18 11	18 10	18 10	18 10	18 10	18 10	18 10	18 10	18 10	18 11	18 11
	20	18 11	18 11	18 11	18 11	18 11	18 11	18 12	18 12	18 12	18 12	18 12	18 13	18 13
	21	18 11	18 11	18 11	18 12	18 12	18 12	18 13	18 14	18 14	18 14	18 14	18 15	18 15
	22	18 10	18 11	18 12	18 13	18 13	18 13	18 14	18 15	18 16	18 16	18 17	18 17	18 18
	23	18 10	18 11	18 12	18 13	18 14	18 14	18 16	18 17	18 17	18 18	18 19	18 20	18 20
	24	18 10	18 11	18 12	18 14	18 14	18 16	18 17	18 18	18 19	18 20	18 21	18 22	18 23
	25	18 09	18 11	18 12	18 14	18 15	18 17	18 18	18 20	18 21	18 22	18 23	18 24	18 25
	26	18 09	18 11	18 13	18 15	18 16	18 18	18 19	18 22	18 22	18 24	18 25	18 26	18 28
	27	18 09	18 11	18 13	18 15	18 17	18 19	18 21	18 23	18 24	18 26	18 27	18 28	18 30
	28	18 08	18 11	18 13	18 16	18 18	18 20	18 22	18 25	18 26	18 27	18 29	18 31	18 32
	29	18 08	18 11	18 13	18 17	18 18	18 21	18 23	18 26	18 28	18 29	18 31	18 33	18 35
	30	18 08	18 11	18 14	18 17	18 19	18 22	18 24	18 28	18 29	18 31	18 33	18 35	18 37
	31	18 08	18 11	18 14	18 18	18 20	18 23	18 26	18 29	18 31	18 33	18 35	18 37	18 40
Apr.	1	18 07	18 11	18 14	18 18	18 21	18 24	18 27	18 31	18 33	18 35	18 37	18 40	18 42
	2	18 07	18 10	18 14	18 19	18 22	18 25	18 28	18 32	18 34	18 37	18 39	18 42	18 45
	3	18 07	18 10	18 15	18 20	18 22	18 26	18 29	18 34	18 36	18 38	18 41	18 44	18 47

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472 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
Apr.	1	6 01	5 58	5 54	5 50	5 48	5 45	5 42	5 38	5 36	5 34	5 32	5 30	5 27
	2	6 00	5 57	5 53	5 49	5 46	5 44	5 40	5 36	5 34	5 32	5 30	5 27	5 24
	3	6 00	5 57	5 52	5 48	5 45	5 42	5 38	5 34	5 32	5 30	5 27	5 24	5 21
	4	6 00	5 56	5 52	5 47	5 44	5 40	5 36	5 32	5 30	5 27	5 24	5 21	5 18
	5	6 00	5 56	5 51	5 45	5 42	5 39	5 34	5 30	5 27	5 25	5 22	5 19	5 15
	6	5 59	5 55	5 50	5 44	5 41	5 37	5 33	5 27	5 25	5 22	5 19	5 16	5 12
	7	5 59	5 54	5 49	5 43	5 40	5 36	5 31	5 25	5 23	5 20	5 16	5 13	5 09
	8	5 59	5 54	5 48	5 42	5 38	5 34	5 29	5 23	5 20	5 17	5 14	5 10	5 06
	9	5 58	5 53	5 48	5 41	5 37	5 32	5 27	5 21	5 18	5 15	5 11	5 08	5 03
	10	5 58	5 52	5 47	5 40	5 36	5 31	5 25	5 19	5 16	5 12	5 09	5 05	5 00
	11	5 58	5 52	5 46	5 38	5 34	5 29	5 24	5 17	5 14	5 10	5 06	5 02	4 57
	12	5 58	5 52	5 45	5 37	5 33	5 28	5 22	5 15	5 11	5 08	5 04	4 59	4 54
	13	5 57	5 51	5 44	5 36	5 32	5 26	5 20	5 13	5 09	5 05	5 01	4 56	4 51
	14	5 57	5 50	5 43	5 35	5 30	5 25	5 18	5 11	5 07	5 03	4 59	4 54	4 48
	15	5 57	5 50	5 42	5 34	5 29	5 23	5 16	5 08	5 05	5 01	4 56	4 51	4 45
	16	5 57	5 50	5 42	5 33	5 28	5 22	5 15	5 06	5 02	4 58	4 54	4 48	4 42
	17	5 56	5 49	5 41	5 32	5 26	5 20	5 13	5 04	5 00	4 56	4 51	4 45	4 39
	18	5 56	5 48	5 40	5 31	5 25	5 19	5 11	5 02	4 58	4 53	4 48	4 43	4 36
	19	5 56	5 48	5 39	5 30	5 24	5 17	5 10	5 00	4 56	4 51	4 46	4 40	4 33
	20	5 56	5 47	5 39	5 29	5 23	5 16	5 08	4 58	4 54	4 49	4 44	4 38	4 30
	21	5 55	5 47	5 38	5 28	5 21	5 14	5 06	4 56	4 52	4 47	4 41	4 35	4 28
	22	5 55	5 46	5 37	5 26	5 20	5 13	5 04	4 54	4 50	4 44	4 39	4 32	4 25
	23	5 55	5 46	5 36	5 25	5 19	5 12	5 03	4 52	4 48	4 42	4 36	4 29	4 22
	24	5 55	5 46	5 36	5 24	5 18	5 10	5 01	4 50	4 46	4 40	4 34	4 27	4 19
	25	5 55	5 45	5 35	5 23	5 17	5 09	5 00	4 49	4 43	4 38	4 31	4 24	4 16

SUNSET AND TWILIGHT, 1945 473

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
Apr.	1	18 07	18 11	18 14	18 18	18 21	18 24	18 27	18 31	18 33	18 35	18 37	18 40	18 42
	2	18 07	18 10	18 14	18 19	18 22	18 25	18 28	18 32	18 34	18 37	18 39	18 42	18 45
	3	18 07	18 10	18 15	18 20	18 22	18 26	18 29	18 34	18 36	18 38	18 41	18 44	18 47
	4	18 06	18 10	18 15	18 20	18 23	18 27	18 31	18 36	18 38	18 40	18 43	18 46	18 50
	5	18 06	18 10	18 15	18 21	18 24	18 28	18 32	18 37	18 40	18 42	18 45	18 48	18 52
	6	18 06	18 10	18 16	18 21	18 25	18 29	18 33	18 39	18 41	18 44	18 47	18 51	18 54
	7	18 06	18 10	18 16	18 22	18 25	18 30	18 34	18 40	18 43	18 46	18 49	18 53	18 57
	8	18 05	18 10	18 16	18 23	18 26	18 31	18 36	18 42	18 45	18 48	18 51	18 55	18 59
	9	18 05	18 10	18 16	18 23	18 27	18 32	18 37	18 43	18 46	18 50	18 53	18 57	19 02
	10	18 05	18 10	18 17	18 24	18 28	18 33	18 38	18 45	18 48	18 51	18 55	18 59	19 04
	11	18 05	18 10	18 17	18 24	18 29	18 34	18 40	18 46	18 50	18 53	18 57	19 02	19 07
	12	18 04	18 10	18 17	18 25	18 29	18 35	18 41	18 48	18 51	18 55	18 59	19 04	19 09
	13	18 04	18 10	18 17	18 26	18 30	18 36	18 42	18 50	18 53	18 57	19 01	19 06	19 12
	14	18 04	18 10	18 18	18 26	18 31	18 37	18 43	18 51	18 55	18 59	19 03	19 08	19 14
	15	18 04	18 10	18 18	18 27	18 32	18 38	18 45	18 53	18 57	19 01	19 05	19 10	19 16
	16	18 03	18 10	18 18	18 27	18 33	18 39	18 46	18 54	18 58	19 03	19 07	19 13	19 19
	17	18 03	18 10	18 19	18 28	18 33	18 40	18 47	18 56	19 00	19 04	19 09	19 15	19 21
	18	18 03	18 10	18 19	18 29	18 34	18 41	18 4	18 57	19 02	19 06	19 12	19 17	19 24
	19	18 03	18 11	18 19	18 29	18 35	18 42	18 50	18 59	19 03	19 08	19 14	19 20	19 26
	20	18 02	18 11	18 20	18 30	18 36	18 43	18 51	19 00	19 05	19 10	19 16	19 22	19 29
	21	18 02	18 11	18 20	18 30	18 37	18 44	18 52	19 02	19 07	19 12	19 18	19 24	19 31
	22	18 02	18 11	18 20	18 31	18 38	18 45	18 53	19 04	19 08	19 14	19 20	19 26	19 34
	23	18 02	18 11	18 20	18 32	18 38	18 46	18 55	19 05	19 10	19 16	19 22	19 28	19 36
	24	18 02	18 11	18 21	18 32	18 39	18 47	18 56	19 07	19 12	19 18	19 24	19 31	19 39
	25	18 02	18 11	18 21	18 33	18 40	18 48	18 57	19 08	19 14	19 19	19 26	19 33	19 41

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L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
Apr.	24	5 55	5 46	5 36	5 24	5 18	5 10	5 01	4 50	4 46	4 40	4 34	4 27	4 19
	25	5 55	5 45	5 35	5 23	5 17	5 09	5 00	4 49	4 43	4 38	4 31	4 24	4 16
	26	5 54	5 45	5 34	5 22	5 15	5 07	4 58	4 47	4 41	4 35	4 29	4 22	4 13
	27	5 54	5 44	5 34	5 21	5 14	5 06	4 56	4 45	4 39	4 33	4 26	4 19	4 10
	28	5 54	5 44	5 33	5 20	5 13	5 05	4 55	4 43	4 37	4 31	4 24	4 17	4 08
	29	5 54	5 44	5 32	5 20	5 12	5 03	4 53	4 41	4 35	4 29	4 22	4 14	4 05
	30	5 54	5 43	5 32	5 19	5 11	5 02	4 52	4 39	4 33	4 27	4 20	4 12	4 02
May	1	5 54	5 43	5 31	5 18	5 10	5 01	4 50	4 38	4 31	4 25	4 17	4 09	3 59
	2	5 54	5 42	5 31	5 17	5 09	5 00	4 49	4 36	4 30	4 23	4 15	4 06	3 57
	3	5 53	5 42	5 30	5 16	5 08	4 58	4 47	4 34	4 28	4 21	4 13	4 04	3 54
	4	5 53	5 42	5 29	5 15	5 07	4 57	4 46	4 32	4 26	4 19	4 11	4 02	3 51
	5	5 53	5 42	5 29	5 14	5 06	4 56	4 44	4 30	4 24	4 17	4 08	3 59	3 49
	6	5 53	5 41	5 28	5 13	5 05	4 55	4 43	4 29	4 22	4 15	4 06	3 57	3 46
	7	5 53	5 41	5 28	5 12	5 04	4 54	4 42	4 27	4 20	4 13	4 04	3 54	3 43
	8	5 53	5 40	5 27	5 11	5 03	4 52	4 40	4 25	4 18	4 11	4 02	3 52	3 41
	9	5 53	5 40	5 27	5 11	5 02	4 51	4 39	4 24	4 17	4 09	4 00	3 50	3 38
	10	5 53	5 40	5 26	5 10	5 01	4 50	4 38	4 22	4 15	4 07	3 58	3 48	3 36
	11	5 53	5 40	5 26	5 10	5 00	4 49	4 36	4 21	4 13	4 05	3 56	3 45	3 33
	12	5 53	5 40	5 25	5 09	4 59	4 48	4 35	4 19	4 12	4 03	3 54	3 43	3 31
	13	5 53	5 39	5 25	5 08	4 58	4 47	4 34	4 18	4 10	4 02	3 52	3 41	3 28
	14	5 53	5 39	5 24	5 08	4 58	4 46	4 33	4 16	4 08	4 00	3 50	3 39	3 26
	15	5 53	5 39	5 24	5 07	4 57	4 45	4 32	4 15	4 07	3 58	3 48	3 37	3 24
	16	5 53	5 39	5 24	5 06	4 56	4 44	4 30	4 13	4 05	3 56	3 46	3 35	3 21
	17	5 53	5 39	5 23	5 06	4 55	4 44	4 29	4 12	4 04	3 55	3 44	3 33	3 19
	18	5 53	5 38	5 23	5 05	4 54	4 43	4 28	4 11	4 02	3 53	3 43	3 31	3 17

SUNSET AND TWILIGHT, 1945 475

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
Apr.	24	18 02	18 11	18 21	18 32	18 39	18 47	18 56	19 07	19 12	19 18	19 24	19 31	19 39
	25	18 02	18 11	18 21	18 33	18 40	18 48	18 57	19 08	19 14	19 19	19 26	19 33	19 41
	26	18 01	18 11	18 22	18 34	18 41	18 49	18 58	19 10	19 15	19 21	19 28	19 35	19 44
	27	18 01	18 11	18 22	18 34	18 42	18 50	19 00	19 11	19 17	19 23	19 30	19 38	19 46
	28	18 01	18 11	18 22	18 35	18 42	18 51	19 01	19 13	19 19	19 25	19 32	19 40	19 49
	29	18 01	18 11	18 22	18 36	18 43	18 52	19 02	19 14	19 20	19 27	19 34	19 42	19 51
	30	18 01	18 11	18 23	18 36	18 44	18 53	19 03	19 16	19 22	19 29	19 36	19 44	19 54
May	1	18 00	18 11	18 23	18 37	18 45	18 54	19 05	19 18	19 24	19 30	19 38	19 46	19 56
	2	18 00	18 12	18 24	18 38	18 46	18 55	19 06	19 19	19 25	19 32	19 40	19 49	19 58
	3	18 00	18 12	18 24	18 38	18 46	18 56	19 07	19 21	19 27	19 34	19 42	19 51	20 01
	4	18 00	18 12	18 24	18 39	18 47	18 57	19 08	19 22	19 29	19 36	19 44	19 53	20 04
	5	18 00	18 12	18 25	18 40	18 48	18 58	19 10	19 24	19 30	19 38	19 46	19 55	20 06
	6	18 00	18 12	18 25	18 40	18 49	18 59	19 11	19 25	19 32	19 40	19 48	19 57	20 08
	7	18 00	18 12	18 26	18 41	18 50	19 00	19 12	19 27	19 34	19 41	19 50	20 00	20 11
	8	18 00	18 12	18 26	18 41	18 50	19 01	19 13	19 28	19 35	19 43	19 52	20 02	20 13
	9	18 00	18 13	18 26	18 42	18 51	19 02	19 14	19 30	19 37	19 45	19 54	20 04	20 16
	10	18 00	18 13	18 27	18 43	18 52	19 03	19 16	19 31	19 38	19 47	19 56	20 06	20 18
	11	18 00	18 13	18 27	18 43	18 53	19 04	19 17	19 33	19 40	19 48	19 58	20 08	20 21
	12	18 00	18 13	18 28	18 44	18 54	19 05	19 18	19 34	19 42	19 50	20 00	20 10	20 23
	13	18 00	18 13	18 28	18 45	18 54	19 06	19 19	19 36	19 43	19 52	20 02	20 13	20 25
	14	18 00	18 13	18 28	18 45	18 55	19 07	19 20	19 37	19 45	19 54	20 03	20 15	20 28
	15	18 00	18 14	18 29	18 46	18 56	19 08	19 22	19 38	19 46	19 55	20 05	20 17	20 30
	16	18 00	18 14	18 29	18 46	18 57	19 09	19 23	19 40	19 48	19 57	20 07	20 19	20 32
	17	18 00	18 14	18 29	18 47	18 58	19 10	19 24	19 41	19 49	19 58	20 09	20 21	20 35
	18	18 00	18 14	18 30	18 48	18 58	19 10	19 25	19 42	19 51	20 00	20 11	20 23	20 37

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
May	17	5 53	5 39	5 23	5 06	4 55	4 44	4 29	4 12	4 04	3 55	3 44	3 33	3 19
	18	5 53	5 38	5 23	5 05	4 54	4 43	4 28	4 11	4 02	3 53	3 43	3 31	3 17
	19	5 53	5 38	5 23	5 04	4 54	4 42	4 27	4 10	4 01	3 52	3 41	3 29	3 14
	20	5 53	5 38	5 22	5 04	4 53	4 41	4 26	4 08	4 00	3 50	3 39	3 27	3 12
	21	5 53	5 38	5 22	5 04	4 53	4 40	4 25	4 07	3 58	3 49	3 38	3 25	3 10
	22	5 53	5 38	5 22	5 03	4 52	4 39	4 24	4 06	3 57	3 47	3 36	3 23	3 08
	23	5 53	5 38	5 21	5 02	4 51	4 38	4 23	4 05	3 56	3 46	3 34	3 21	3 06
	24	5 53	5 38	5 21	5 02	4 51	4 38	4 23	4 04	3 54	3 44	3 33	3 20	3 04
	25	5 53	5 38	5 21	5 02	4 50	4 37	4 22	4 02	3 53	3 43	3 31	3 18	3 02
	26	5 53	5 38	5 21	5 01	4 50	4 37	4 21	4 01	3 52	3 42	3 30	3 16	3 00
	27	5 53	5 38	5 21	5 01	4 49	4 36	4 20	4 00	3 51	3 41	3 28	3 15	2 58
	28	5 54	5 38	5 20	5 00	4 49	4 35	4 19	4 00	3 50	3 40	3 27	3 13	2 56
	29	5 54	5 37	5 20	5 00	4 48	4 35	4 19	3 59	3 49	3 38	3 26	3 12	2 55
	30	5 54	5 37	5 20	5 00	4 48	4 34	4 18	3 58	3 48	3 37	3 25	3 10	2 53
	31	5 54	5 38	5 20	5 00	4 48	4 34	4 17	3 57	3 47	3 36	3 24	3 09	2 51
June	1	5 54	5 38	5 20	4 59	4 47	4 33	4 17	3 56	3 46	3 35	3 22	3 08	2 50
	2	5 54	5 38	5 20	4 59	4 47	4 33	4 16	3 55	3 45	3 34	3 21	3 06	2 48
	3	5 54	5 38	5 20	4 59	4 47	4 32	4 16	3 55	3 45	3 33	3 20	3 05	2 47
	4	5 54	5 38	5 20	4 59	4 46	4 32	4 15	3 54	3 44	3 32	3 19	3 04	2 46
	5	5 55	5 38	5 20	4 58	4 46	4 32	4 15	3 53	3 43	3 32	3 18	3 03	2 44
	6	5 55	5 38	5 20	4 58	4 46	4 32	4 14	3 53	3 42	3 31	3 18	3 02	2 43
	7	5 55	5 38	5 20	4 58	4 46	4 31	4 14	3 52	3 42	3 30	3 17	3 01	2 42
	8	5 55	5 38	5 20	4 58	4 46	4 31	4 14	3 52	3 41	3 30	3 16	3 00	2 41
	9	5 55	5 38	5 20	4 58	4 46	4 31	4 13	3 52	3 41	3 29	3 15	2 59	2 40
	10	5 56	5 38	5 20	4 58	4 45	4 31	4 13	3 51	3 40	3 29	3 15	2 59	2 39

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
May	17	18 00	18 14	18 29	18 47	18 58	19 10	19 24	19 41	19 49	19 58	20 09	20 21	20 35
	18	18 00	18 14	18 30	18 48	18 58	19 10	19 25	19 42	19 51	20 00	20 11	20 23	20 37
	19	18 00	18 14	18 30	18 48	18 59	19 11	19 26	19 44	19 52	20 02	20 13	20 25	20 39
	20	18 00	18 15	18 31	18 49	19 00	19 12	19 27	19 45	19 54	20 03	20 14	20 27	20 42
	21	18 00	18 15	18 31	18 50	19 01	19 13	19 28	19 46	19 55	20 05	20 16	20 29	20 44
	22	18 00	18 15	18 31	18 50	19 01	19 14	19 29	19 48	19 57	20 06	20 18	20 31	20 46
	23	18 00	18 15	18 32	18 51	19 02	19 15	19 30	19 49	19 58	20 08	20 20	20 33	20 48
	24	18 00	18 16	18 32	18 52	19 03	19 16	19 31	19 50	19 59	20 10	20 21	20 35	20 50
	25	18 00	18 16	18 33	18 52	19 04	19 17	19 32	19 52	20 01	20 11	20 23	20 36	20 52
	26	18 00	18 16	18 33	18 53	19 04	19 17	19 33	19 53	20 02	20 12	20 24	20 38	20 55
	27	18 00	18 16	18 34	18 53	19 05	19 18	19 34	19 54	20 03	20 14	20 26	20 40	20 57
	28	18 01	18 17	18 34	18 54	19 06	19 19	19 35	19 55	20 05	20 15	20 28	20 42	20 59
	29	18 01	18 17	18 34	18 54	19 06	19 20	19 36	19 56	20 06	20 17	20 29	20 44	21 01
	30	18 01	18 17	18 35	18 55	19 07	19 21	19 37	19 57	20 07	20 18	20 31	20 45	21 03
	31	18 01	18 17	18 35	18 56	19 08	19 21	19 38	19 58	20 08	20 19	20 32	20 47	21 04
June	1	18 01	18 18	18 35	18 56	19 08	19 22	19 39	19 59	20 09	20 20	20 34	20 48	21 06
	2	18 01	18 18	18 36	18 57	19 09	19 23	19 40	20 00	20 10	20 22	20 35	20 50	21 08
	3	18 02	18 18	18 36	18 57	19 09	19 24	19 40	20 01	20 12	20 23	20 36	20 51	21 10
	4	18 02	18 18	18 37	18 58	19 10	19 24	19 41	20 02	20 13	20 24	20 37	20 53	21 11
	5	18 02	18 19	18 37	18 58	19 10	19 25	19 42	20 03	20 14	20 25	20 39	20 54	21 13
	6	18 02	18 19	18 37	18 59	19 11	19 26	19 43	20 04	20 15	20 26	20 40	20 55	21 14
	7	18 02	18 19	18 38	18 59	19 12	19 26	19 43	20 05	20 16	20 27	20 41	20 56	21 16
	8	18 02	18 20	18 38	19 00	19 12	19 27	19 44	20 06	20 16	20 28	20 42	20 58	21 17
	9	18 03	18 20	18 38	19 00	19 13	19 27	19 45	20 07	20 17	20 29	20 43	20 59	21 18
	10	18 03	18 20	18 39	19 00	19 13	19 28	19 45	20 07	20 18	20 30	20 44	21 00	21 20

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
June	9	5 55	5 38	5 20	4 58	4 46	4 32	4 13	3 52	3 41	3 29	3 15	2 59	2 40
	10	5 56	5 38	5 20	4 58	4 45	4 31	4 13	3 51	3 40	3 29	3 15	2 59	2 39
	11	5 56	5 38	5 20	4 58	4 45	4 30	4 13	3 51	3 40	3 28	3 14	2 58	2 38
	12	5 56	5 38	5 20	4 58	4 45	4 30	4 13	3 50	3 40	3 28	3 14	2 57	2 38
	13	5 56	5 39	5 20	4 58	4 45	4 30	4 12	3 50	3 40	3 27	3 13	2 57	2 37
	14	5 56	5 39	5 20	4 58	4 45	4 30	4 12	3 50	3 39	3 27	3 13	2 56	2 36
	15	5 56	5 39	5 20	4 58	4 45	4 30	4 12	3 50	3 39	3 27	3 13	2 56	2 36
	16	5 57	5 39	5 20	4 58	4 45	4 30	4 12	3 50	3 39	3 27	3 13	2 56	2 36
	17	5 57	5 39	5 20	4 58	4 45	4 30	4 12	3 50	3 39	3 27	3 12	2 56	2 35
	18	5 57	5 40	5 20	4 59	4 45	4 30	4 12	3 50	3 39	3 27	3 12	2 56	2 35
	19	5 57	5 40	5 21	4 59	4 46	4 30	4 12	3 50	3 39	3 27	3 12	2 56	2 35
	20	5 58	5 40	5 21	4 59	4 46	4 31	4 13	3 50	3 39	3 27	3 12	2 56	2 35
	21	5 58	5 40	5 21	4 59	4 46	4 31	4 13	3 50	3 39	3 27	3 13	2 56	2 35
	22	5 58	5 40	5 21	4 59	4 46	4 31	4 13	3 50	3 40	3 27	3 13	2 56	2 36
	23	5 58	5 41	5 22	5 00	4 46	4 31	4 13	3 51	3 40	3 27	3 13	2 56	2 36
	24	5 58	5 41	5 22	5 00	4 47	4 32	4 14	3 51	3 40	3 28	3 14	2 57	2 36
	25	5 59	5 41	5 22	5 00	4 47	4 32	4 14	3 51	3 40	3 28	3 14	2 57	2 37
	26	5 59	5 41	5 22	5 00	4 47	4 32	4 14	3 52	3 41	3 29	3 14	2 58	2 37
	27	5 59	5 41	5 22	5 00	4 48	4 33	4 15	3 52	3 41	3 29	3 15	2 58	2 38
	28	5 59	5 42	5 23	5 01	4 48	4 33	4 15	3 53	3 42	3 30	3 15	2 59	2 38
	29	5 59	5 42	5 23	5 01	4 48	4 33	4 16	3 53	3 42	3 30	3 16	3 00	2 39
	30	6 00	5 42	5 23	5 02	4 49	4 34	4 16	3 54	3 43	3 31	3 17	3 00	2 40
July	1	6 00	5 42	5 24	5 02	4 49	4 34	4 16	3 54	3 44	3 32	3 18	3 01	2 41
	2	6 00	5 43	5 24	5 02	4 50	4 35	4 17	3 55	3 44	3 32	3 18	3 02	2 42
	3	6 00	5 43	5 24	5 03	4 50	4 35	4 18	3 56	3 45	3 33	3 19	3 03	2 43

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
June	9	18 03	18 20	18 38	19 00	19 13	19 27	19 45	20 07	20 17	20 29	20 43	20 59	21 18
	10	18 03	18 20	18 39	19 00	19 13	19 28	19 45	20 07	20 18	20 30	20 44	21 00	21 20
	11	18 03	18 20	18 39	19 01	19 14	19 28	19 46	20 08	20 19	20 31	20 45	21 01	21 21
	12	18 03	18 21	18 39	19 01	19 14	19 29	19 46	20 09	20 19	20 32	20 46	21 02	21 22
	13	18 04	18 21	18 40	19 02	19 14	19 29	19 47	20 09	20 20	20 32	20 46	21 03	21 23
	14	18 04	18 21	18 40	19 02	19 15	19 30	19 48	20 10	20 21	20 33	20 47	21 04	21 24
	15	18 04	18 21	18 40	19 02	19 15	19 30	19 48	20 10	20 21	20 34	20 48	21 04	21 25
	16	18 04	18 22	18 41	19 02	19 16	19 31	19 48	20 11	20 22	20 34	20 48	21 05	21 25
	17	18 04	18 22	18 41	19 03	19 16	19 31	19 49	20 11	20 22	20 34	20 49	21 06	21 26
	18	18 04	18 22	18 41	19 03	19 16	19 31	19 49	20 12	20 23	20 35	20 49	21 06	21 26
	19	18 05	18 22	18 41	19 04	19 16	19 32	19 50	20 12	20 23	20 35	20 50	21 06	21 27
	20	18 05	18 22	18 42	19 04	19 17	19 32	19 50	20 12	20 23	20 36	20 50	21 07	21 27
	21	18 05	18 23	18 42	19 04	19 17	19 32	19 50	20 13	20 24	20 36	20 50	21 07	21 28
	22	18 05	18 23	18 42	19 04	19 17	19 32	19 50	20 13	20 24	20 36	20 50	21 07	21 28
	23	18 06	18 23	18 42	19 04	19 17	19 32	19 50	20 13	20 24	20 36	20 51	21 07	21 28
	24	18 06	18 23	18 42	19 04	19 18	19 33	19 50	20 13	20 24	20 36	20 51	21 08	21 28
	25	18 06	18 24	18 43	19 05	19 18	19 33	19 51	20 13	20 24	20 36	20 51	21 08	21 28
	26	18 06	18 24	18 43	19 05	19 18	19 33	19 51	20 13	20 24	20 36	20 51	21 07	21 28
	27	18 06	18 24	18 43	19 05	19 18	19 33	19 51	20 13	20 24	20 36	20 50	21 07	21 27
	28	18 07	18 24	18 43	19 05	19 18	19 33	19 51	20 13	20 24	20 36	20 50	21 07	21 27
	29	18 07	18 24	18 43	19 05	19 18	19 33	19 50	20 13	20 24	20 36	20 50	21 07	21 27
	30	18 07	18 24	18 43	19 05	19 18	19 33	19 50	20 13	20 24	20 36	20 50	21 06	21 26
July	1	18 07	18 25	18 43	19 05	19 18	19 33	19 50	20 13	20 23	20 35	20 49	21 06	21 26
	2	18 08	18 25	18 43	19 05	19 18	19 33	19 50	20 12	20 23	20 35	20 49	21 05	21 25
	3	18 08	18 25	18 43	19 05	19 18	19 32	19 50	20 12	20 22	20 34	20 48	21 04	21 24

Restricted Security Information

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
July	1	h m 6 00	h m 5 42	h m 5 24	h m 5 02	h m 4 49	h m 4 34	h m 4 16	h m 3 54	h m 3 44	h m 3 32	h m 3 18	h m 3 01	h m 2 41
	2	6 00	5 43	5 24	5 02	4 50	4 35	4 17	3 55	3 44	3 32	3 18	3 02	2 42
	3	6 00	5 43	5 24	5 03	4 50	4 35	4 18	3 56	3 45	3 33	3 19	3 03	2 43
	4	6 00	5 43	5 25	5 03	4 50	4 36	4 18	3 56	3 46	3 34	3 20	3 04	2 44
	5	6 01	5 44	5 25	5 04	4 51	4 36	4 19	3 57	3 47	3 35	3 21	3 05	2 46
	6	6 01	5 44	5 25	5 04	4 51	4 37	4 20	3 58	3 47	3 36	3 22	3 06	2 47
	7	6 01	5 44	5 26	5 04	4 52	4 38	4 20	3 59	3 48	3 37	3 23	3 08	2 49
	8	6 01	5 44	5 26	5 05	4 52	4 38	4 21	4 00	3 49	3 38	3 24	3 09	2 50
	9	6 01	5 44	5 26	5 05	4 53	4 39	4 22	4 00	3 50	3 39	3 26	3 10	2 52
	10	6 02	5 45	5 27	5 06	4 54	4 40	4 22	4 01	3 51	3 40	3 27	3 12	2 53
	11	6 02	5 45	5 27	5 06	4 54	4 40	4 23	4 02	3 52	3 41	3 28	3 13	2 55
	12	6 02	5 45	5 28	5 07	4 55	4 41	4 24	4 03	3 53	3 42	3 30	3 14	2 57
	13	6 02	5 46	5 28	5 08	4 55	4 42	4 25	4 04	3 55	3 44	3 31	3 16	2 58
	14	6 02	5 46	5 28	5 08	4 56	4 42	4 26	4 05	3 56	3 45	3 32	3 18	3 00
	15	6 02	5 46	5 29	5 08	4 57	4 43	4 27	4 06	3 57	3 46	3 34	3 19	3 02
	16	6 02	5 46	5 29	5 09	4 57	4 44	4 28	4 08	3 58	3 47	3 35	3 21	3 04
	17	6 02	5 46	5 29	5 10	4 58	4 44	4 28	4 09	3 59	3 49	3 37	3 23	3 06
	18	6 02	5 47	5 30	5 10	4 59	4 45	4 29	4 10	4 00	3 50	3 38	3 24	3 08
	19	6 02	5 47	5 30	5 11	4 59	4 46	4 30	4 11	4 02	3 52	3 40	3 26	3 10
	20	6 03	5 47	5 30	5 11	5 00	4 47	4 31	4 12	4 03	3 53	3 41	3 28	3 12
	21	6 03	5 47	5 31	5 12	5 01	4 48	4 32	4 14	4 04	3 54	3 43	3 30	3 14
	22	6 03	5 48	5 31	5 12	5 01	4 49	4 33	4 15	4 06	3 56	3 45	3 32	3 16
	23	6 03	5 48	5 32	5 13	5 02	4 49	4 34	4 16	4 07	3 58	3 46	3 34	3 18
	24	6 03	5 48	5 32	5 14	5 03	4 50	4 36	4 17	4 09	3 59	3 48	3 36	3 21
	25	6 03	5 48	5 32	5 14	5 04	4 51	4 37	4 19	4 10	4 01	3 50	3 38	3 23

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
July	1	h m 18 07	h m 18 25	h m 18 43	h m 19 05	h m 19 18	h m 19 33	h m 19 50	h m 20 13	h m 20 23	h m 20 35	h m 20 49	h m 21 06	h m 21 26
	2	18 08	18 25	18 43	19 05	19 18	19 33	19 50	20 12	20 23	20 35	20 49	21 05	21 25
	3	18 08	18 25	18 43	19 05	19 18	19 32	19 50	20 12	20 22	20 34	20 48	21 04	21 24
	4	18 08	18 25	18 43	19 05	19 18	19 32	19 50	20 12	20 22	20 34	20 48	21 04	21 23
	5	18 08	18 25	18 43	19 05	19 18	19 32	19 49	20 11	20 22	20 33	20 47	21 03	21 22
	6	18 08	18 25	18 43	19 05	19 17	19 32	19 49	20 11	20 21	20 33	20 46	21 02	21 21
	7	18 08	18 25	18 43	19 05	19 17	19 32	19 49	20 10	20 20	20 32	20 46	21 01	21 20
	8	18 08	18 25	18 43	19 04	19 17	19 31	19 48	20 10	20 20	20 31	20 45	21 00	21 19
	9	18 08	18 25	18 43	19 04	19 16	19 31	19 48	20 09	20 19	20 30	20 44	20 59	21 18
	10	18 09	18 25	18 43	19 04	19 16	19 30	19 47	20 08	20 18	20 30	20 43	20 58	21 16
	11	18 09	18 25	18 43	19 04	19 16	19 30	19 47	20 08	20 18	20 29	20 42	20 57	21 15
	12	18 09	18 25	18 43	19 04	19 16	19 30	19 46	20 07	20 17	20 28	20 41	20 56	21 13
	13	18 09	18 25	18 43	19 03	19 15	19 29	19 46	20 06	20 16	20 27	20 39	20 54	21 12
	14	18 09	18 25	18 43	19 03	19 15	19 29	19 45	20 05	20 15	20 26	20 38	20 53	21 10
	15	18 09	18 25	18 43	19 03	19 15	19 28	19 44	20 04	20 14	20 25	20 37	20 51	21 08
	16	18 09	18 25	18 42	19 02	19 14	19 28	19 44	20 03	20 13	20 24	20 36	20 50	21 07
	17	18 09	18 25	18 42	19 02	19 14	19 27	19 43	20 02	20 12	20 22	20 34	20 48	21 05
	18	18 10	18 25	18 42	19 02	19 13	19 26	19 42	20 01	20 11	20 21	20 33	20 47	21 03
	19	18 10	18 25	18 42	19 01	19 12	19 26	19 41	20 00	20 10	20 20	20 32	20 45	21 01
	20	18 10	18 25	18 42	19 01	19 12	19 25	19 40	19 59	20 08	20 18	20 30	20 43	20 59
	21	18 10	18 25	18 41	19 00	19 11	19 24	19 39	19 58	20 07	20 17	20 28	20 42	20 57
	22	18 10	18 25	18 41	19 00	19 11	19 23	19 38	19 57	20 06	20 16	20 27	20 40	20 55
	23	18 10	18 25	18 41	18 59	19 10	19 23	19 38	19 56	20 05	20 14	20 25	20 38	20 53
	24	18 10	18 24	18 40	18 59	19 10	19 22	19 37	19 55	20 03	20 13	20 24	20 36	20 51
	25	18 10	18 24	18 40	18 58	19 09	19 21	19 36	19 53	20 02	20 11	20 22	20 34	20 49

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
July	24	h m 6 03	h m 5 48	h m 5 32	h m 5 14	h m 5 03	h m 4 50	h m 4 36	h m 4 17	h m 4 09	h m 3 59	h m 3 48	h m 3 36	h m 3 21
	25	6 03	5 48	5 32	5 14	5 04	4 51	4 37	4 19	4 10	4 01	3 50	3 38	3 23
	26	6 03	5 48	5 33	5 15	5 04	4 52	4 38	4 20	4 12	4 02	3 52	3 39	3 25
	27	6 03	5 49	5 34	5 16	5 06	4 54	4 40	4 22	4 14	4 05	3 55	3 43	3 27
	28	6 03	5 49	5 34	5 17	5 06	4 55	4 41	4 24	4 16	4 07	3 57	3 45	3 30
	29	6 03	5 49	5 34	5 17	5 07	4 56	4 42	4 25	4 17	4 09	3 58	3 47	3 32
	30	6 03	5 49	5 35	5 18	5 08	4 56	4 43	4 27	4 19	4 10	4 00	3 50	3 34
	31	6 03	5 49	5 35	5 18	5 09	4 57	4 44	4 28	4 20	4 12	4 02	3 52	3 37
Aug.	1	6 03	5 50	5 35	5 19	5 09	4 58	4 46	4 30	4 22	4 14	4 04	3 54	3 39
	2	6 03	5 50	5 36	5 20	5 10	4 59	4 47	4 31	4 24	4 15	4 06	3 56	3 41
	3	6 02	5 50	5 36	5 20	5 11	5 00	4 48	4 32	4 25	4 17	4 08	3 58	3 44
	4	6 02	5 50	5 36	5 21	5 12	5 01	4 49	4 34	4 27	4 19	4 10	4 00	3 46
	5	6 02	5 50	5 37	5 21	5 12	5 02	4 50	4 35	4 28	4 20	4 12	4 02	3 48
	6	6 02	5 50	5 37	5 22	5 13	5 03	4 51	4 37	4 30	4 22	4 14	4 04	3 51
	7	6 02	5 50	5 37	5 23	5 14	5 04	4 52	4 38	4 31	4 24	4 16	4 06	3 53
	8	6 02	5 50	5 38	5 23	5 15	5 05	4 54	4 40	4 33	4 26	4 18	4 09	3 56
	9	6 02	5 50	5 38	5 24	5 16	5 06	4 55	4 41	4 35	4 28	4 20	4 11	4 00
	10	6 02	5 50	5 38	5 24	5 16	5 07	4 56	4 42	4 36	4 29	4 22	4 13	4 03
	11	6 02	5 51	5 39	5 25	5 17	5 08	4 57	4 44	4 38	4 31	4 24	4 15	4 05
	12	6 02	5 51	5 39	5 26	5 18	5 09	4 58	4 45	4 40	4 33	4 26	4 17	4 08
	13	6 01	5 51	5 39	5 26	5 18	5 10	5 00	4 47	4 41	4 35	4 27	4 19	4 10
	14	6 01	5 51	5 40	5 27	5 19	5 11	5 01	4 48	4 43	4 36	4 29	4 21	4 12
	15	6 01	5 51	5 40	5 27	5 20	5 12	5 02	4 50	4 44	4 38	4 31	4 24	4 15
	16	6 01	5 51	5 40	5 28	5 21	5 13	5 03	4 51	4 46	4 40	4 33	4 26	4 17
	17	6 01	5 51	5 40	5 28	5 21	5 13	5 03	4 51	4 46	4 40	4 33	4 26	4 17

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
July	24	h m 18 10	h m 18 24	h m 18 40	h m 18 59	h m 19 10	h m 19 22	h m 19 37	h m 19 55	h m 20 03	h m 20 13	h m 20 24	h m 20 36	h m 20 51
	25	18 10	18 24	18 40	18 58	19 09	19 21	19 36	19 53	20 02	20 11	20 22	20 34	20 49
	26	18 10	18 24	18 40	18 58	19 08	19 20	19 34	19 52	20 00	20 10	20 20	20 32	20 46
	27	18 10	18 24	18 39	18 57	19 07	19 19	19 33	19 51	19 59	20 08	20 18	20 30	20 44
	28	18 10	18 24	18 39	18 56	19 07	19 18	19 32	19 49	19 57	20 06	20 17	20 28	20 42
	29	18 10	18 24	18 38	18 56	19 06	19 17	19 31	19 48	19 56	20 05	20 15	20 26	20 39
	30	18 10	18 23	18 38	18 55	19 05	19 16	19 30	19 46	19 54	20 03	20 13	20 24	20 37
	31	18 10	18 23	18 37	18 54	19 04	19 15	19 29	19 45	19 53	20 01	20 11	20 22	20 35
Aug.	1	18 10	18 23	18 37	18 54	19 03	19 14	19 27	19 44	19 51	19 59	20 09	20 20	20 32
	2	18 09	18 22	18 37	18 53	19 02	19 13	19 26	19 42	19 49	19 58	20 07	20 17	20 30
	3	18 09	18 22	18 36	18 52	19 02	19 12	19 25	19 40	19 48	19 56	20 05	20 15	20 27
	4	18 09	18 22	18 36	18 51	19 01	19 11	19 24	19 39	19 46	19 54	20 03	20 13	20 25
	5	18 09	18 22	18 35	18 50	19 00	19 10	19 22	19 37	19 44	19 52	20 01	20 11	20 22
	6	18 09	18 21	18 35	18 50	18 59	19 09	19 21	19 36	19 43	19 50	19 59	20 08	20 19
	7	18 09	18 21	18 34	18 49	18 58	19 08	19 19	19 34	19 40	19 48	19 56	20 06	20 17
	8	18 09	18 21	18 33	18 48	18 57	19 06	19 18	19 32	19 39	19 46	19 54	20 03	20 14
	9	18 09	18 20	18 33	18 47	18 56	19 05	19 16	19 30	19 37	19 44	19 52	20 01	20 11
	10	18 08	18 20	18 32	18 46	18 55	19 04	19 15	19 28	19 35	19 42	19 50	19 59	20 09
	11	18 08	18 20	18 32	18 45	18 54	19 03	19 14	19 27	19 33	19 40	19 48	19 56	20 06
	12	18 08	18 19	18 31	18 44	18 54	19 02	19 12	19 25	19 31	19 38	19 45	19 54	20 03
	13	18 08	18 19	18 30	18 44	18 51	19 00	19 10	19 23	19 29	19 36	19 43	19 51	20 00
	14	18 08	18 18	18 30	18 43	18 50	18 59	19 09	19 21	19 27	19 34	19 41	19 48	19 58
	15	18 08	18 18	18 29	18 42	18 49	18 58	19 07	19 20	19 25	19 31	19 38	19 46	19 55
	16	18 08	18 18	18 28	18 41	18 48	18 56	19 06	19 18	19 23	19 29	19 36	19 44	19 52
	17	18 07	18 17	18 27	18 40	18 47	18 55	19 04	19 16	19 21	19 27	19 34	19 41	19 49

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
July	1	6 00	5 42	5 24	5 02	4 49	4 34	4 16	3 54	3 44	3 32	3 18	3 01	2 41
	2	6 00	5 43	5 24	5 02	4 50	4 35	4 17	3 55	3 44	3 32	3 18	3 02	2 42
	3	6 00	5 43	5 24	5 03	4 50	4 35	4 18	3 56	3 45	3 33	3 19	3 03	2 43
	4	6 00	5 43	5 25	5 03	4 50	4 36	4 18	3 56	3 46	3 34	3 20	3 04	2 44
	5	6 01	5 44	5 25	5 04	4 51	4 36	4 19	3 57	3 47	3 35	3 21	3 05	2 46
	6	6 01	5 44	5 25	5 04	4 51	4 37	4 20	3 58	3 47	3 36	3 22	3 06	2 47
	7	6 01	5 44	5 26	5 04	4 52	4 38	4 20	3 59	3 48	3 37	3 23	3 08	2 49
	8	6 01	5 44	5 26	5 05	4 52	4 38	4 21	4 00	3 49	3 38	3 24	3 09	2 50
	9	6 01	5 44	5 26	5 05	4 53	4 39	4 22	4 00	3 50	3 39	3 26	3 10	2 52
	10	6 02	5 45	5 27	5 06	4 54	4 40	4 22	4 01	3 51	3 40	3 27	3 12	2 53
	11	6 02	5 45	5 27	5 06	4 54	4 40	4 23	4 02	3 52	3 41	3 28	3 13	2 55
	12	6 02	5 45	5 28	5 07	4 55	4 41	4 24	4 03	3 53	3 42	3 30	3 14	2 57
	13	6 02	5 46	5 28	5 08	4 55	4 42	4 25	4 04	3 55	3 44	3 31	3 16	2 58
	14	6 02	5 46	5 28	5 08	4 56	4 42	4 26	4 05	3 56	3 45	3 32	3 18	3 00
	15	6 02	5 46	5 29	5 08	4 57	4 43	4 27	4 06	3 57	3 46	3 34	3 19	3 02
	16	6 02	5 46	5 29	5 09	4 57	4 44	4 28	4 08	3 58	3 47	3 35	3 21	3 04
	17	6 02	5 46	5 29	5 10	4 58	4 44	4 28	4 09	3 59	3 49	3 37	3 23	3 06
	18	6 02	5 47	5 30	5 10	4 59	4 45	4 29	4 10	4 00	3 50	3 38	3 24	3 08
	19	6 02	5 47	5 30	5 11	4 59	4 46	4 30	4 11	4 02	3 52	3 40	3 26	3 10
	20	6 03	5 47	5 30	5 11	5 00	4 47	4 31	4 12	4 03	3 53	3 41	3 28	3 12
	21	6 03	5 47	5 31	5 12	5 01	4 48	4 32	4 14	4 04	3 54	3 43	3 30	3 14
	22	6 03	5 48	5 31	5 12	5 01	4 49	4 33	4 15	4 06	3 56	3 45	3 32	3 16
	23	6 03	5 48	5 32	5 13	5 02	4 49	4 34	4 16	4 07	3 58	3 46	3 34	3 18
	24	6 03	5 48	5 32	5 14	5 03	4 50	4 36	4 17	4 09	3 59	3 48	3 36	3 21
	25	6 03	5 48	5 32	5 14	5 04	4 51	4 37	4 19	4 10	4 01	3 50	3 38	3 23

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
July	1	18 07	18 25	18 43	19 05	19 18	19 33	19 50	20 13	20 23	20 35	20 49	21 06	21 26
	2	18 08	18 25	18 43	19 05	19 18	19 33	19 50	20 12	20 23	20 35	20 49	21 05	21 25
	3	18 08	18 25	18 43	19 05	19 18	19 32	19 50	20 12	20 22	20 34	20 48	21 04	21 24
	4	18 08	18 25	18 43	19 05	19 18	19 32	19 50	20 12	20 22	20 34	20 48	21 04	21 23
	5	18 08	18 25	18 43	19 05	19 18	19 32	19 49	20 11	20 22	20 33	20 47	21 03	21 22
	6	18 08	18 25	18 43	19 05	19 17	19 32	19 49	20 11	20 21	20 33	20 46	21 02	21 21
	7	18 08	18 25	18 43	19 05	19 17	19 32	19 49	20 10	20 20	20 32	20 46	21 01	21 20
	8	18 08	18 25	18 43	19 04	19 17	19 31	19 48	20 10	20 20	20 31	20 45	21 00	21 19
	9	18 08	18 25	18 43	19 04	19 16	19 31	19 48	20 09	20 19	20 30	20 44	20 59	21 18
	10	18 09	18 25	18 43	19 04	19 16	19 30	19 47	20 08	20 18	20 30	20 43	20 58	21 16
	11	18 09	18 25	18 43	19 04	19 16	19 30	19 47	20 08	20 18	20 29	20 42	20 57	21 15
	12	18 09	18 25	18 43	19 04	19 16	19 30	19 46	20 07	20 17	20 28	20 41	20 56	21 13
	13	18 09	18 25	18 43	19 03	19 15	19 29	19 46	20 06	20 16	20 27	20 39	20 54	21 12
	14	18 09	18 25	18 43	19 03	19 15	19 29	19 45	20 05	20 15	20 26	20 38	20 53	21 10
	15	18 09	18 25	18 43	19 03	19 15	19 28	19 44	20 04	20 14	20 25	20 37	20 51	21 08
	16	18 09	18 25	18 42	19 02	19 14	19 28	19 44	20 03	20 13	20 24	20 36	20 50	21 07
	17	18 09	18 25	18 42	19 02	19 14	19 27	19 43	20 02	20 12	20 22	20 34	20 48	21 05
	18	18 10	18 25	18 42	19 02	19 13	19 26	19 42	20 01	20 11	20 21	20 33	20 47	21 03
	19	18 10	18 25	18 42	19 01	19 12	19 26	19 41	20 00	20 10	20 20	20 32	20 45	21 01
	20	18 10	18 25	18 42	19 01	19 12	19 25	19 40	19 59	20 08	20 18	20 30	20 43	20 59
	21	18 10	18 25	18 41	19 00	19 11	19 24	19 39	19 58	20 07	20 17	20 28	20 42	20 57
	22	18 10	18 25	18 41	19 00	19 11	19 23	19 38	19 57	20 06	20 16	20 27	20 40	20 55
	23	18 10	18 25	18 41	18 59	19 10	19 23	19 38	19 56	20 05	20 14	20 25	20 38	20 53
	24	18 10	18 24	18 40	18 59	19 10	19 22	19 37	19 55	20 03	20 13	20 24	20 36	20 51
	25	18 10	18 24	18 40	18 58	19 09	19 21	19 36	19 53	20 02	20 11	20 22	20 34	20 49

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
July	24	6 03	5 48	5 32	5 14	5 03	4 50	4 36	4 17	4 09	3 59	3 48	3 36	3 21
	25	6 03	5 48	5 32	5 14	5 04	4 51	4 37	4 19	4 10	4 01	3 50	3 38	3 23
	26	6 03	5 48	5 33	5 15	5 04	4 52	4 38	4 20	4 12	4 02	3 52	3 39	3 25
	27	6 03	5 48	5 33	5 15	5 05	4 53	4 39	4 21	4 13	4 04	3 53	3 41	3 27
	28	6 03	5 49	5 34	5 16	5 06	4 54	4 40	4 22	4 14	4 05	3 55	3 43	3 30
	29	6 03	5 49	5 34	5 17	5 06	4 55	4 41	4 24	4 16	4 07	3 57	3 45	3 32
	30	6 03	5 49	5 34	5 17	5 07	4 56	4 42	4 25	4 17	4 09	3 58	3 47	3 34
	31	6 03	5 49	5 35	5 18	5 08	4 56	4 43	4 27	4 19	4 10	4 00	3 50	3 37
Aug.	1	6 03	5 49	5 35	5 18	5 09	4 57	4 44	4 28	4 20	4 12	4 02	3 52	3 39
	2	6 03	5 50	5 35	5 19	5 09	4 58	4 46	4 30	4 22	4 14	4 04	3 54	3 41
	3	6 03	5 50	5 36	5 20	5 10	4 59	4 47	4 31	4 24	4 15	4 06	3 56	3 44
	4	6 02	5 50	5 36	5 20	5 11	5 00	4 48	4 32	4 25	4 17	4 08	3 58	3 46
	5	6 02	5 50	5 36	5 21	5 12	5 01	4 49	4 34	4 27	4 19	4 10	4 00	3 48
	6	6 02	5 50	5 37	5 21	5 12	5 02	4 50	4 35	4 28	4 20	4 12	4 02	3 51
	7	6 02	5 50	5 37	5 22	5 13	5 03	4 52	4 37	4 30	4 22	4 14	4 04	3 53
	8	6 02	5 50	5 37	5 23	5 14	5 04	4 52	4 38	4 31	4 24	4 16	4 06	3 56
	9	6 02	5 50	5 38	5 23	5 15	5 05	4 54	4 40	4 33	4 26	4 18	4 09	3 58
	10	6 02	5 50	5 38	5 24	5 16	5 06	4 55	4 41	4 35	4 28	4 20	4 11	4 00
	11	6 02	5 50	5 38	5 24	5 16	5 07	4 56	4 42	4 36	4 29	4 22	4 13	4 03
	12	6 02	5 51	5 39	5 25	5 17	5 08	4 57	4 44	4 38	4 31	4 24	4 15	4 05
	13	6 02	5 51	5 39	5 26	5 18	5 09	4 58	4 45	4 40	4 33	4 26	4 17	4 08
	14	6 01	5 51	5 39	5 26	5 18	5 10	5 00	4 47	4 41	4 35	4 27	4 19	4 10
	15	6 01	5 51	5 40	5 27	5 19	5 11	5 01	4 48	4 43	4 36	4 29	4 21	4 12
	16	6 01	5 51	5 40	5 27	5 20	5 12	5 02	4 50	4 44	4 38	4 31	4 24	4 15
	17	6 01	5 51	5 40	5 28	5 21	5 13	5 03	4 51	4 46	4 40	4 33	4 26	4 17

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
July	24	18 10	18 24	18 40	18 59	19 10	19 22	19 37	19 55	20 03	20 13	20 24	20 36	20 51
	25	18 10	18 24	18 40	18 58	19 09	19 21	19 36	19 53	20 02	20 11	20 22	20 34	20 49
	26	18 10	18 24	18 40	18 58	19 08	19 20	19 34	19 52	20 00	20 10	20 20	20 32	20 46
	27	18 10	18 24	18 39	18 57	19 07	19 19	19 33	19 51	19 59	20 08	20 18	20 30	20 44
	28	18 10	18 24	18 39	18 56	19 07	19 18	19 32	19 49	19 57	20 06	20 17	20 28	20 42
	29	18 10	18 24	18 38	18 56	19 06	19 17	19 31	19 48	19 56	20 05	20 15	20 26	20 39
	30	18 10	18 23	18 38	18 55	19 05	19 16	19 30	19 46	19 54	20 03	20 13	20 24	20 37
	31	18 10	18 23	18 37	18 54	19 04	19 15	19 29	19 45	19 53	20 01	20 11	20 22	20 35
Aug.	1	18 10	18 23	18 37	18 54	19 03	19 14	19 27	19 44	19 51	19 59	20 09	20 20	20 32
	2	18 09	18 22	18 37	18 53	19 02	19 13	19 26	19 42	19 49	19 58	20 07	20 17	20 30
	3	18 09	18 22	18 36	18 52	19 02	19 12	19 25	19 40	19 48	19 56	20 05	20 15	20 27
	4	18 09	18 22	18 36	18 51	19 01	19 11	19 24	19 39	19 46	19 54	20 03	20 13	20 25
	5	18 09	18 22	18 35	18 50	19 00	19 10	19 22	19 37	19 44	19 52	20 01	20 11	20 22
	6	18 09	18 21	18 35	18 50	18 59	19 09	19 21	19 36	19 42	19 50	19 59	20 08	20 19
	7	18 09	18 21	18 34	18 49	18 58	19 08	19 19	19 34	19 40	19 48	19 56	20 06	20 17
	8	18 09	18 21	18 33	18 48	18 57	19 06	19 18	19 32	19 39	19 46	19 54	20 03	20 14
	9	18 09	18 20	18 33	18 47	18 56	19 05	19 16	19 30	19 37	19 44	19 52	20 01	20 11
	10	18 08	18 20	18 32	18 46	18 55	19 04	19 15	19 28	19 35	19 42	19 50	19 59	20 09
	11	18 08	18 20	18 32	18 45	18 54	19 03	19 14	19 27	19 33	19 40	19 48	19 56	20 06
	12	18 08	18 19	18 31	18 44	18 52	19 02	19 12	19 25	19 31	19 38	19 45	19 54	20 03
	13	18 08	18 19	18 30	18 44	18 51	19 00	19 10	19 23	19 29	19 36	19 43	19 51	[illegible]
	14	18 08	18 18	18 30	18 43	18 50	18 59	19 09	19 21	19 27	19 34	19 41	19 48	[illegible]
	15	18 08	18 18	18 29	18 42	18 49	18 58	19 07	19 20	19 25	19 31	19 38	19 46	[illegible]
	16	18 08	18 18	18 28	18 41	18 48	18 56	19 06	19 18	19 23	19 29	19 36	19 44	[illegible]
	17	18 07	18 17	18 27	18 40	18 47	18 55	19 04	19 16	19 21	19 27	19 34	19 41	19 49

Restricted Security Information

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Aug.	16	6 01	5 51	5 40	5 27	5 20	5 12	5 02	4 50	4 44	4 38	4 31	4 24	4 15
	17	6 01	5 51	5 40	5 28	5 21	5 13	5 03	4 51	4 46	4 40	4 33	4 26	4 17
	18	6 00	5 51	5 41	5 28	5 22	5 14	5 04	4 53	4 48	4 42	4 35	4 28	4 20
	19	6 00	5 51	5 41	5 29	5 22	5 14	5 06	4 54	4 49	4 44	4 37	4 30	4 22
	20	6 00	5 51	5 41	5 30	5 23	5 15	5 07	4 56	4 51	4 45	4 39	4 32	4 25
	21	6 00	5 51	5 41	5 30	5 24	5 16	5 08	4 57	4 52	4 47	4 41	4 34	4 27
	22	6 00	5 51	5 42	5 31	5 24	5 17	5 09	4 59	4 54	4 49	4 43	4 37	4 29
	23	5 59	5 51	5 42	5 31	5 25	5 18	5 10	5 00	4 56	4 51	4 45	4 39	4 32
	24	5 59	5 51	5 42	5 32	5 26	5 19	5 11	5 02	4 57	4 52	4 47	4 41	4 34
	25	5 59	5 51	5 42	5 33	5 27	5 20	5 13	5 03	4 59	4 54	4 49	4 43	4 36
	26	5 58	5 51	5 43	5 33	5 28	5 21	5 14	5 05	5 01	4 56	4 51	4 45	4 39
	27	5 58	5 51	5 43	5 34	5 28	5 22	5 15	5 06	5 02	4 58	4 53	4 47	4 41
	28	5 58	5 51	5 43	5 34	5 29	5 23	5 16	5 08	5 04	5 00	4 55	4 50	4 44
	29	5 58	5 51	5 43	5 35	5 30	5 24	5 17	5 09	5 06	5 01	4 57	4 52	4 46
	30	5 57	5 51	5 44	5 35	5 30	5 25	5 18	5 11	5 07	5 03	4 59	4 54	4 48
	31	5 57	5 51	5 44	5 36	5 31	5 26	5 20	5 12	5 09	5 05	5 01	4 56	4 51
Sept	1	5 57	5 51	5 44	5 36	5 32	5 27	5 21	5 14	5 10	5 07	5 03	4 58	4 53
	2	5 56	5 51	5 44	5 37	5 33	5 28	5 22	5 15	5 12	5 08	5 05	5 00	4 56
	3	5 56	5 51	5 45	5 38	5 33	5 29	5 23	5 17	5 14	5 10	5 07	5 02	4 58
	4	5 56	5 50	5 45	5 38	5 34	5 30	5 24	5 18	5 15	5 12	5 09	5 05	5 00
	5	5 56	5 50	5 45	5 39	5 35	5 31	5 26	5 20	5 17	5 14	5 10	5 07	5 03
	6	5 55	5 50	5 45	5 39	5 36	5 32	5 27	5 21	5 19	5 16	5 12	5 09	5 05
	7	5 55	5 50	5 46	5 40	5 36	5 33	5 28	5 23	5 20	5 18	5 14	5 11	5 07
	8	5 54	5 50	5 46	5 40	5 37	5 34	5 29	5 24	5 22	5 19	5 16	5 13	5 10
	9	5 54	5 50	5 46	5 41	5 38	5 34	5 30	5 26	5 24	5 21	5 18	5 15	5 12

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Aug.	16	18 08	18 18	18 28	18 41	18 48	18 56	19 06	19 18	19 23	19 29	19 36	19 44	19 52
	17	18 07	18 17	18 27	18 40	18 47	18 55	19 04	19 16	19 21	19 27	19 34	19 41	19 49
	18	18 07	18 16	18 27	18 39	18 46	18 53	19 03	19 14	19 19	19 25	19 31	19 38	19 46
	19	18 07	18 16	18 26	18 38	18 44	18 52	19 01	19 12	19 17	19 23	19 29	19 36	19 44
	20	18 07	18 16	18 25	18 37	18 43	18 51	18 59	19 10	19 15	19 20	19 26	19 33	19 41
	21	18 06	18 15	18 25	18 36	18 42	18 49	18 58	19 08	19 13	19 18	19 24	19 31	19 38
	22	18 06	18 15	18 24	18 34	18 41	18 48	18 56	19 06	19 11	19 16	19 22	19 28	19 35
	23	18 06	18 14	18 23	18 33	18 39	18 46	18 54	19 04	19 08	19 14	19 19	19 25	19 32
	24	18 06	18 14	18 23	18 32	18 38	18 45	18 52	19 02	19 06	19 11	19 16	19 22	19 29
	25	18 05	18 13	18 22	18 31	18 37	18 43	18 51	19 00	19 04	19 09	19 14	19 20	19 26
	26	18 05	18 13	18 21	18 30	18 36	18 42	18 49	18 58	19 02	19 06	19 12	19 17	19 23
	27	18 05	18 12	18 20	18 29	18 34	18 40	18 47	18 56	19 00	19 04	19 09	19 14	19 20
	28	18 04	18 12	18 19	18 28	18 33	18 39	18 46	18 54	18 58	19 02	19 06	19 12	19 17
	29	18 04	18 11	18 18	18 27	18 32	18 37	18 44	18 52	18 55	18 59	19 04	19 09	19 14
	30	18 04	18 10	18 17	18 25	18 30	18 36	18 42	18 50	18 53	18 57	19 01	19 06	19 11
	31	18 04	18 10	18 16	18 24	18 29	18 34	18 40	18 48	18 51	18 55	18 59	19 03	19 08
Sept.	1	18 03	18 09	18 16	18 23	18 28	18 33	18 38	18 45	18 49	18 52	18 56	19 01	19 05
	2	18 03	18 09	18 15	18 22	18 26	18 31	18 36	18 43	18 46	18 50	18 54	18 58	19 02
	3	18 03	18 08	18 14	18 21	18 25	18 29	18 35	18 41	18 44	18 47	18 51	18 55	18 59
	4	18 02	18 08	18 13	18 20	18 24	18 28	18 33	18 39	18 42	18 45	18 48	18 52	18 56
	5	18 02	18 07	18 12	18 18	18 22	18 26	18 31	18 37	18 40	18 43	18 46	18 50	18 53
	6	18 02	18 06	18 11	18 17	18 21	18 24	18 29	18 35	18 37	18 40	18 43	18 47	18 50
	7	18 01	18 06	18 10	18 16	18 19	18 23	18 27	18 32	18 35	18 38	18 41	18 44	18 47
	8	18 01	18 05	18 10	18 15	18 18	18 21	18 25	18 30	18 33	18 35	18 38	18 41	18 44
	9	18 00	18 04	18 09	18 14	18 16	18 20	18 24	18 28	18 30	18 33	18 35	18 38	18 41

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Sept.	8	5 54	5 50	5 46	5 40	5 37	5 34	5 29	5 24	5 22	5 19	5 16	5 13	5 10
	9	5 54	5 50	5 46	5 41	5 38	5 34	5 30	5 26	5 24	5 21	5 18	5 15	5 12
	10	5 54	5 50	5 46	5 41	5 39	5 35	5 32	5 27	5 25	5 23	5 20	5 18	5 14
	11	5 54	5 50	5 46	5 42	5 39	5 36	5 33	5 29	5 27	5 25	5 22	5 20	5 17
	12	5 53	5 50	5 47	5 42	5 40	5 37	5 34	5 30	5 28	5 26	5 24	5 22	5 19
	13	5 53	5 50	5 47	5 43	5 41	5 38	5 35	5 32	5 30	5 28	5 26	5 24	5 22
	14	5 53	5 50	5 47	5 44	5 42	5 39	5 36	5 33	5 32	5 30	5 28	5 26	5 24
	15	5 52	5 50	5 47	5 44	5 42	5 40	5 38	5 35	5 33	5 32	5 30	5 28	5 26
	16	5 52	5 50	5 47	5 45	5 43	5 41	5 39	5 36	5 35	5 34	5 32	5 30	5 28
	17	5 51	5 50	5 48	5 45	5 44	5 42	5 40	5 38	5 37	5 35	5 34	5 32	5 31
	18	5 51	5 50	5 48	5 46	5 44	5 43	5 41	5 39	5 38	5 37	5 36	5 35	5 33
	19	5 51	5 49	5 48	5 46	5 45	5 44	5 42	5 41	5 40	5 39	5 38	5 37	5 36
	20	5 50	5 49	5 48	5 47	5 46	5 45	5 44	5 42	5 42	5 41	5 40	5 39	5 38
	21	5 50	5 49	5 48	5 47	5 47	5 46	5 45	5 44	5 43	5 42	5 42	5 41	5 40
	22	5 50	5 49	5 49	5 48	5 47	5 47	5 46	5 45	5 45	5 44	5 44	5 43	5 43
	23	5 49	5 49	5 49	5 48	5 48	5 48	5 47	5 47	5 46	5 46	5 46	5 45	5 45
	24	5 49	5 49	5 49	5 49	5 49	5 49	5 48	5 48	5 48	5 48	5 48	5 47	5 47
	25	5 48	5 49	5 49	5 50	5 50	5 50	5 50	5 50	5 50	5 50	5 50	5 50	5 50
	26	5 48	5 49	5 50	5 50	5 50	5 51	5 51	5 51	5 51	5 52	5 52	5 52	5 52
	27	5 48	5 49	5 50	5 51	5 51	5 52	5 52	5 53	5 53	5 53	5 54	5 54	5 54
	28	5 48	5 49	5 50	5 51	5 52	5 53	5 53	5 54	5 54	5 55	5 56	5 56	5 57
	29	5 47	5 49	5 50	5 52	5 53	5 54	5 55	5 56	5 56	5 57	5 58	5 58	5 59
	30	5 47	5 49	5 50	5 52	5 53	5 55	5 56	5 57	5 58	5 59	6 00	6 00	6 02
Oct.	1	5 47	5 49	5 51	5 53	5 54	5 56	5 57	5 59	6 00	6 01	6 02	6 02	6 04
	2	5 46	5 49	5 51	5 53	5 55	5 57	5 58	6 00	6 01	6 02	6 04	6 05	6 06

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Sept.	8	18 01	18 05	18 10	18 15	18 18	18 21	18 25	18 30	18 33	18 35	18 38	18 41	18 44
	9	18 00	18 04	18 09	18 14	18 16	18 20	18 24	18 28	18 30	18 33	18 35	18 38	18 41
	10	18 00	18 04	18 08	18 12	18 15	18 18	18 22	18 26	18 28	18 30	18 33	18 35	18 38
	11	18 00	18 03	18 07	18 11	18 14	18 16	18 20	18 24	18 26	18 28	18 30	18 33	18 35
	12	18 00	18 03	18 07	18 10	18 12	18 15	18 18	18 22	18 23	18 25	18 27	18 30	18 32
	13	17 59	18 02	18 05	18 09	18 11	18 13	18 16	18 20	18 21	18 23	18 25	18 27	18 29
	14	17 59	18 01	18 04	18 07	18 09	18 12	18 14	18 17	18 19	18 20	18 22	18 24	18 26
	15	17 58	18 01	18 03	18 06	18 08	18 10	18 12	18 15	18 16	18 18	18 19	18 21	18 23
	16	17 58	18 00	18 02	18 05	18 06	18 08	18 10	18 13	18 14	18 15	18 17	18 18	18 20
	17	17 58	18 00	18 01	18 04	18 05	18 07	18 08	18 11	18 12	18 13	18 14	18 16	18 17
	18	17 58	17 59	18 00	18 02	18 04	18 05	18 06	18 08	18 09	18 10	18 11	18 13	18 14
	19	17 57	17 58	18 00	18 01	18 02	18 03	18 05	18 06	18 07	18 08	18 09	18 10	18 11
	20	17 57	17 58	17 59	18 00	18 01	18 02	18 03	18 04	18 05	18 05	18 06	18 07	18 08
	21	17 56	17 57	17 58	17 59	17 59	18 00	18 01	18 02	18 02	18 03	18 03	18 04	18 05
	22	17 56	17 56	17 57	17 57	17 58	17 59	17 59	18 00	18 00	18 00	18 01	18 01	18 02
	23	17 56	17 56	17 56	17 56	17 56	17 57	17 57	17 57	17 58	17 58	17 58	17 58	17 59
	24	17 55	17 55	17 55	17 55	17 55	17 55	17 55	17 55	17 55	17 55	17 55	17 56	17 56
	25	17 55	17 54	17 54	17 54	17 53	17 53	17 53	17 53	17 53	17 53	17 53	17 53	17 53
	26	17 55	17 54	17 53	17 52	17 52	17 52	17 51	17 51	17 51	17 51	17 50	17 50	17 50
	27	17 54	17 53	17 52	17 51	17 50	17 50	17 49	17 48	17 48	17 48	17 47	17 47	17 47
	28	17 54	17 53	17 51	17 50	17 49	17 48	17 47	17 46	17 46	17 45	17 45	17 44	17 44
	29	17 54	17 52	17 50	17 49	17 48	17 47	17 46	17 44	17 44	17 43	17 42	17 41	17 40
	30	17 53	17 51	17 50	17 47	17 46	17 45	17 44	17 42	17 41	17 40	17 40	17 38	17 37
Oct.	1	17 53	17 51	17 49	17 46	17 45	17 44	17 42	17 40	17 39	17 38	17 37	17 36	17 34
	2	17 53	17 50	17 48	17 45	17 44	17 42	17 40	17 38	17 37	17 36	17 34	17 33	17 31

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Oct.	1	5 47	5 49	5 51	5 53	5 54	5 56	5 57	5 59	6 00	6 01	6 02	6 02	6 04
	2	5 46	5 49	5 51	5 53	5 55	5 57	5 58	6 00	6 01	6 02	6 04	6 05	6 06
	3	5 46	5 49	5 51	5 54	5 56	5 58	6 00	6 02	6 03	6 04	6 06	6 07	6 09
	4	5 46	5 48	5 52	5 55	5 56	5 59	6 01	6 04	6 05	6 06	6 08	6 09	6 11
	5	5 45	5 48	5 52	5 55	5 57	6 00	6 02	6 05	6 06	6 08	6 10	6 11	6 13
	6	5 45	5 48	5 52	5 56	5 58	6 01	6 03	6 07	6 08	6 10	6 12	6 14	6 16
	7	5 45	5 48	5 52	5 56	5 59	6 02	6 05	6 08	6 10	6 12	6 14	6 16	6 18
	8	5 44	5 48	5 52	5 57	6 00	6 03	6 06	6 10	6 12	6 14	6 16	6 18	6 20
	9	5 44	5 48	5 53	5 58	6 00	6 04	6 07	6 11	6 13	6 15	6 18	6 20	6 23
	10	5 44	5 48	5 53	5 58	6 01	6 05	6 08	6 13	6 15	6 17	6 20	6 22	6 25
	11	5 44	5 48	5 53	5 59	6 02	6 06	6 10	6 14	6 17	6 19	6 22	6 25	6 28
	12	5 43	5 48	5 54	6 00	6 03	6 07	6 11	6 16	6 18	6 21	6 24	6 27	6 30
	13	5 43	5 48	5 54	6 00	6 04	6 08	6 12	6 18	6 20	6 23	6 26	6 29	6 33
	14	5 43	5 48	5 54	6 01	6 04	6 09	6 14	6 19	6 22	6 25	6 28	6 31	6 35
	15	5 43	5 48	5 55	6 01	6 05	6 10	6 15	6 21	6 24	6 27	6 30	6 34	6 38
	16	5 42	5 48	5 55	6 02	6 06	6 11	6 16	6 22	6 26	6 28	6 32	6 36	6 40
	17	5 42	5 49	5 55	6 03	6 07	6 12	6 18	6 24	6 27	6 30	6 34	6 38	6 43
	18	5 42	5 49	5 56	6 04	6 08	6 13	6 19	6 26	6 29	6 32	6 36	6 40	6 45
	19	5 42	5 49	5 56	6 04	6 09	6 14	6 20	6 27	6 31	6 34	6 38	6 43	6 48
	20	5 42	5 49	5 56	6 05	6 10	6 15	6 21	6 29	6 32	6 36	6 40	6 45	6 50
	21	5 42	5 49	5 57	6 06	6 10	6 16	6 23	6 30	6 34	6 38	6 42	6 47	6 53
	22	5 41	5 49	5 57	6 06	6 11	6 17	6 24	6 32	6 36	6 40	6 44	6 50	6 55
	23	5 41	5 49	5 58	6 07	6 12	6 18	6 26	6 34	6 38	6 42	6 47	6 52	6 58
	24	5 41	5 49	5 58	6 08	6 13	6 19	6 27	6 35	6 39	6 44	6 49	6 54	7 00
	25	5 41	5 50	5 58	6 08	6 14	6 21	6 28	6 37	6 41	6 46	6 51	6 56	7 03

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Oct.	1	17 53	17 51	17 49	17 46	17 45	17 44	17 42	17 40	17 39	17 38	17 37	17 36	17 34
	2	17 53	17 50	17 48	17 45	17 44	17 42	17 40	17 38	17 37	17 36	17 34	17 33	17 31
	3	17 52	17 50	17 47	17 44	17 42	17 40	17 38	17 35	17 34	17 33	17 32	17 30	17 28
	4	17 52	17 49	17 46	17 43	17 41	17 39	17 36	17 33	17 32	17 31	17 29	17 27	17 26
	5	17 52	17 48	17 45	17 41	17 39	17 37	17 34	17 31	17 30	17 28	17 26	17 24	17 23
	6	17 52	17 48	17 44	17 40	17 38	17 35	17 32	17 29	17 28	17 26	17 24	17 22	17 20
	7	17 51	17 47	17 43	17 39	17 36	17 34	17 31	17 27	17 25	17 23	17 21	17 19	17 17
	8	17 51	17 47	17 43	17 38	17 35	17 32	17 29	17 25	17 23	17 21	17 19	17 16	17 14
	9	17 51	17 46	17 42	17 37	17 34	17 31	17 27	17 23	17 21	17 18	17 16	17 14	17 11
	10	17 50	17 46	17 41	17 36	17 33	17 29	17 25	17 20	17 18	17 16	17 14	17 11	17 08
	11	17 50	17 45	17 40	17 34	17 31	17 28	17 23	17 18	17 16	17 14	17 11	17 08	17 05
	12	17 50	17 45	17 39	17 33	17 30	17 26	17 22	17 16	17 14	17 11	17 08	17 05	17 02
	13	17 50	17 44	17 38	17 32	17 29	17 24	17 20	17 14	17 12	17 09	17 06	17 02	16 59
	14	17 49	17 44	17 38	17 31	17 27	17 23	17 18	17 12	17 10	17 07	17 03	17 00	16 56
	15	17 49	17 43	17 37	17 30	17 26	17 22	17 16	17 10	17 07	17 04	17 01	16 57	16 53
	16	17 49	17 43	17 36	17 29	17 25	17 20	17 15	17 08	17 05	17 02	16 58	16 54	16 50
	17	17 49	17 42	17 35	17 28	17 23	17 18	17 13	17 06	17 03	17 00	16 56	16 52	16 47
	18	17 49	17 42	17 35	17 27	17 22	17 17	17 11	17 04	17 01	16 57	16 53	16 49	16 44
	19	17 48	17 41	17 34	17 26	17 21	17 16	17 09	17 02	16 59	16 55	16 51	16 46	16 41
	20	17 48	17 41	17 33	17 25	17 20	17 14	17 08	17 00	16 57	16 53	16 48	16 44	16 38
	21	17 48	17 40	17 33	17 24	17 19	17 13	17 06	16 58	16 54	16 50	16 46	16 41	16 36
	22	17 48	17 40	17 32	17 23	17 17	17 11	17 04	16 56	16 52	16 48	16 44	16 38	16 33
	23	17 48	17 40	17 31	17 22	17 16	17 10	17 03	16 54	16 50	16 46	16 41	16 36	16 30
	24	17 48	17 39	17 31	17 21	17 15	17 09	17 01	16 52	16 48	16 43	16 38	16 33	16 27
	25	17 48	17 39	17 30	17 20	17 14	17 07	17 00	16 50	16 46	16 42	16 37	16 31	16 24

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SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Oct.	24	5 41	5 49	5 58	6 08	6 13	6 19	6 27	6 35	6 39	6 44	6 49	6 54	7 00
	25	5 41	5 50	5 58	6 08	6 14	6 21	6 28	6 37	6 41	6 46	6 51	6 56	7 03
	26	5 41	5 50	5 59	6 09	6 15	6 22	6 29	6 39	6 43	6 48	6 53	6 59	7 05
	27	5 41	5 50	5 59	6 10	6 16	6 23	6 31	6 40	6 45	6 50	6 55	7 01	7 08
	28	5 41	5 50	6 00	6 11	6 17	6 24	6 32	6 42	6 47	6 52	6 57	7 03	7 10
	29	5 40	5 50	6 00	6 11	6 18	6 25	6 34	6 44	6 48	6 54	6 59	7 06	7 13
	30	5 40	5 50	6 00	6 12	6 19	6 26	6 35	6 45	6 50	6 56	7 01	7 08	7 16
	31	5 40	5 50	6 01	6 13	6 20	6 27	6 36	6 47	6 52	6 58	7 04	7 11	7 18
Nov.	1	5 40	5 51	6 01	6 14	6 20	6 28	6 38	6 49	6 54	6 59	7 06	7 13	7 21
	2	5 40	5 51	6 02	6 14	6 21	6 30	6 39	6 50	6 56	7 01	7 08	7 15	7 23
	3	5 40	5 51	6 02	6 15	6 22	6 31	6 40	6 52	6 57	7 03	7 10	7 17	7 26
	4	5 40	5 51	6 03	6 16	6 23	6 32	6 42	6 54	6 59	7 05	7 12	7 20	7 28
	5	5 40	5 52	6 03	6 17	6 24	6 33	6 43	6 55	7 01	7 07	7 14	7 22	7 31
	6	5 40	5 52	6 04	6 17	6 25	6 34	6 44	6 57	7 03	7 09	7 16	7 24	7 33
	7	5 40	5 52	6 04	6 18	6 26	6 35	6 46	6 59	7 05	7 11	7 18	7 27	7 36
	8	5 40	5 52	6 05	6 19	6 27	6 36	6 47	7 00	7 06	7 13	7 20	7 29	7 39
	9	5 40	5 52	6 05	6 20	6 28	6 38	6 49	7 02	7 08	7 15	7 23	7 31	7 41
	10	5 41	5 53	6 06	6 21	6 29	6 39	6 50	7 04	7 10	7 17	7 25	7 34	7 44
	11	5 41	5 53	6 06	6 22	6 30	6 40	6 51	7 05	7 12	7 19	7 27	7 36	7 46
	12	5 41	5 54	6 07	6 22	6 31	6 41	6 53	7 07	7 14	7 21	7 29	7 38	7 49
	13	5 41	5 54	6 08	6 23	6 32	6 42	6 54	7 09	7 15	7 23	7 31	7 41	7 51
	14	5 41	5 54	6 08	6 24	6 33	6 43	6 56	7 10	7 17	7 25	7 33	7 43	7 54
	15	5 41	5 54	6 09	6 25	6 34	6 44	6 57	7 12	7 19	7 26	7 35	7 45	7 56
	16	5 41	5 55	6 09	6 26	6 35	6 46	6 58	7 14	7 21	7 28	7 37	7 47	7 59
	17	5 42	5 55	6 10	6 26	6 36	6 47	7 00	7 15	7 22	7 30	7 39	7 50	8 01

SUNSET AND TWILIGHT, 1945

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L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Oct.	24	17 48	17 39	17 31	17 21	17 15	17 09	17 01	16 52	16 48	16 44	16 39	16 33	16 27
	25	17 48	17 39	17 30	17 20	17 14	17 07	17 00	16 50	16 46	16 42	16 37	16 31	16 24
	26	17 47	17 39	17 29	17 19	17 13	17 06	16 58	16 49	16 44	16 40	16 34	16 28	16 22
	27	17 47	17 38	17 29	17 18	17 12	17 05	16 57	16 47	16 42	16 37	16 32	16 26	16 19
	28	17 47	17 38	17 28	17 17	17 11	17 03	16 55	16 45	16 40	16 35	16 30	16 23	16 16
	29	17 47	17 38	17 28	17 16	17 10	17 02	16 54	16 43	16 38	16 33	16 27	16 21	16 14
	30	17 47	17 37	17 27	17 15	17 09	17 01	16 52	16 41	16 37	16 31	16 25	16 18	16 11
	31	17 47	17 37	17 26	17 14	17 08	17 00	16 51	16 40	16 35	16 29	16 23	16 15	16 08
Nov.	1	17 47	17 37	17 26	17 14	17 07	16 58	16 49	16 38	16 33	16 27	16 21	16 14	16 06
	2	17 47	17 36	17 25	17 13	17 06	16 57	16 48	16 36	16 31	16 25	16 18	16 11	16 03
	3	17 47	17 36	17 25	17 12	17 05	16 56	16 46	16 34	16 29	16 23	16 16	16 09	16 00
	4	17 47	17 36	17 24	17 11	17 04	16 55	16 45	16 33	16 27	16 21	16 14	16 07	15 58
	5	17 47	17 36	17 24	17 10	17 03	16 54	16 44	16 31	16 26	16 19	16 12	16 04	15 55
	6	17 47	17 36	17 24	17 10	17 02	16 53	16 42	16 30	16 24	16 17	16 10	16 02	15 53
	7	17 47	17 36	17 23	17 09	17 01	16 52	16 41	16 28	16 22	16 16	16 08	16 00	15 50
	8	17 47	17 35	17 23	17 08	17 00	16 51	16 40	16 27	16 20	16 14	16 06	15 58	15 48
	9	17 47	17 35	17 22	17 08	16 59	16 50	16 39	16 25	16 19	16 12	16 04	15 55	15 46
	10	17 48	17 35	17 22	17 07	16 58	16 49	16 37	16 24	16 17	16 10	16 02	15 53	15 43
	11	17 48	17 35	17 22	17 06	16 58	16 48	16 36	16 22	16 16	16 08	16 00	15 51	15 41
	12	17 48	17 35	17 21	17 06	16 57	16 47	16 35	16 21	16 14	16 07	15 58	15 49	15 38
	13	17 48	17 35	17 21	17 05	16 56	16 46	16 34	16 19	16 13	16 05	15 57	15 47	15 36
	14	17 48	17 35	17 21	17 05	16 56	16 45	16 33	16 18	16 11	16 04	15 55	15 45	15 34
	15	17 48	17 35	17 20	17 04	16 56	16 44	16 32	16 17	16 10	16 02	15 53	15 43	15 32
	16	17 48	17 35	17 20	17 04	16 54	16 44	16 31	16 16	16 08	16 00	15 52	15 41	15 30
	17	17 48	17 35	17 20	17 03	16 54	16 43	16 30	16 14	16 07	15 59	15 50	15 39	15 27

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L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east
For further explanation see page 502. For southern latitudes see page 503

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Nov.	16	5 41	5 55	6 09	6 26	6 35	6 46	6 58	7 14	7 21	7 28	7 37	7 47	7 59
	17	5 42	5 55	6 10	6 26	6 36	6 47	7 00	7 15	7 22	7 30	7 39	7 50	8 01
	18	5 42	5 56	6 10	6 27	6 37	6 48	7 01	7 17	7 24	7 32	7 42	7 52	8 04
	19	5 42	5 56	6 11	6 28	6 38	6 49	7 02	7 18	7 26	7 34	7 44	7 54	8 06
	20	5 42	5 57	6 12	6 29	6 39	6 50	7 04	7 20	7 28	7 36	7 46	7 56	8 09
	21	5 42	5 57	6 12	6 30	6 40	6 51	7 05	7 22	7 29	7 38	7 48	7 58	8 11
	22	5 42	5 58	6 13	6 31	6 41	6 52	7 06	7 23	7 31	7 40	7 49	8 01	8 14
	23	5 43	5 58	6 14	6 31	6 42	6 54	7 08	7 24	7 33	7 41	7 51	8 03	8 16
	24	5 43	5 59	6 14	6 32	6 43	6 55	7 09	7 26	7 34	7 43	7 53	8 05	8 18
	25	5 43	5 59	6 15	6 33	6 44	6 56	7 10	7 28	7 36	7 45	7 55	8 07	8 21
	26	5 44	5 59	6 15	6 34	6 45	6 57	7 11	7 29	7 37	7 47	7 57	8 09	8 23
	27	5 44	6 00	6 16	6 35	6 46	6 58	7 13	7 30	7 39	7 48	7 59	8 11	8 25
	28	5 44	6 00	6 17	6 36	6 47	6 59	7 14	7 32	7 40	7 50	8 01	8 13	8 28
	29	5 44	6 01	6 17	6 36	6 48	7 00	7 15	7 33	7 42	7 52	8 02	8 15	8 30
	30	5 45	6 01	6 18	6 37	6 48	7 01	7 16	7 35	7 43	7 53	8 04	8 17	8 32
Dec.	1	5 45	6 02	6 19	6 38	6 49	7 02	7 17	7 36	7 45	7 55	8 06	8 19	8 34
	2	5 46	6 02	6 19	6 39	6 50	7 03	7 19	7 37	7 46	7 56	8 08	8 21	8 36
	3	5 46	6 02	6 20	6 40	6 51	7 05	7 20	7 39	7 48	7 58	8 09	8 22	8 38
	4	5 47	6 03	6 20	6 40	6 52	7 05	7 21	7 40	7 49	7 59	8 11	8 24	8 40
	5	5 47	6 04	6 21	6 41	6 53	7 06	7 22	7 41	7 50	8 01	8 12	8 26	8 42
	6	5 47	6 04	6 22	6 42	6 54	7 07	7 23	7 42	7 52	8 02	8 14	8 27	8 44
	7	5 48	6 04	6 22	6 43	6 54	7 08	7 24	7 44	7 53	8 03	8 15	8 29	8 45
	8	5 48	6 05	6 23	6 43	6 55	7 09	7 25	7 45	7 54	8 05	8 17	8 30	8 47
	9	5 49	6 06	6 24	6 44	6 56	7 10	7 26	7 46	7 55	8 06	8 18	8 32	8 49
	10	5 49	6 06	6 24	6 45	6 57	7 10	7 27	7 47	7 56	8 07	8 19	8 33	8 50

SUNSET AND TWILIGHT, 1945 493

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Nov.	16	17 48	17 35	17 20	17 04	16 54	16 44	16 31	16 16	16 08	16 00	15 52	15 41	15 30
	17	17 48	17 35	17 20	17 03	16 54	16 43	16 30	16 14	16 07	15 59	15 50	15 39	15 27
	18	17 49	17 35	17 20	17 03	16 53	16 42	16 29	16 13	16 06	15 57	15 48	15 38	15 25
	19	17 49	17 35	17 20	17 02	16 53	16 41	16 28	16 12	16 04	15 56	15 47	15 36	15 23
	20	17 49	17 35	17 20	17 02	16 52	16 41	16 27	16 11	16 03	15 55	15 45	15 34	15 21
	21	17 50	17 35	17 19	17 02	16 52	16 40	16 26	16 10	16 02	15 53	15 44	15 32	15 20
	22	17 50	17 35	17 19	17 02	16 51	16 39	16 26	16 09	16 01	15 52	15 42	15 31	15 18
	23	17 50	17 35	17 19	17 01	16 51	16 39	16 25	16 08	16 00	15 51	15 41	15 29	15 16
	24	17 50	17 35	17 19	17 01	16 50	16 38	16 24	16 07	15 59	15 50	15 39	15 28	15 14
	25	17 51	17 35	17 19	17 01	16 50	16 38	16 23	16 06	15 58	15 48	15 38	15 26	15 12
	26	17 51	17 36	17 19	17 01	16 50	16 37	16 23	16 05	15 57	15 47	15 37	15 25	15 11
	27	17 51	17 36	17 19	17 00	16 49	16 37	16 22	16 04	15 56	15 46	15 36	15 23	15 09
	28	17 52	17 36	17 19	17 00	16 49	16 37	16 22	16 04	15 55	15 45	15 35	15 22	15 08
	29	17 52	17 36	17 19	17 00	16 49	16 36	16 21	16 03	15 54	15 44	15 34	15 21	15 06
	30	17 52	17 36	17 19	17 00	16 49	16 36	16 21	16 02	15 53	15 44	15 33	15 20	15 05
Dec.	1	17 53	17 36	17 19	17 00	16 48	16 36	16 20	16 02	15 53	15 43	15 32	15 19	15 03
	2	17 53	17 37	17 20	17 00	16 48	16 35	16 20	16 01	15 52	15 42	15 31	15 18	15 02
	3	17 53	17 37	17 20	17 00	16 48	16 35	16 20	16 00	15 51	15 41	15 30	15 17	15 01
	4	17 54	17 37	17 20	17 00	16 48	16 35	16 19	16 00	15 51	15 41	15 29	15 16	15 00
	5	17 54	17 38	17 20	17 00	16 48	16 35	16 19	16 00	15 51	15 40	15 28	15 15	14 59
	6	17 55	17 38	17 20	17 00	16 48	16 35	16 19	15 59	15 50	15 40	15 28	15 14	14 58
	7	17 55	17 38	17 20	17 00	16 48	16 35	16 19	15 59	15 50	15 39	15 27	15 13	14 57
	8	17 56	17 39	17 21	17 00	16 48	16 35	16 18	15 58	15 49	15 39	15 27	15 13	14 56
	9	17 56	17 39	17 21	17 00	16 48	16 35	16 18	15 58	15 49	15 38	15 26	15 12	14 56
	10	17 56	17 39	17 21	17 01	16 49	16 35	16 18	15 58	15 49	15 38	15 26	15 12	14 55

494 SUNRISE AND TWILIGHT, 1945

L.M.T. OF SUNRISE (SUN'S UPPER LIMB) AND BEGINNING OF MORNING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Dec.	9	5 49	6 06	6 24	6 44	6 56	7 10	7 26	7 46	7 55	8 06	8 18	8 32	8 49
	10	5 49	6 06	6 24	6 45	6 57	7 10	7 27	7 47	7 56	8 07	8 19	8 33	8 50
	11	5 50	6 07	6 25	6 46	6 58	7 11	7 28	7 48	7 58	8 08	8 20	8 35	8 52
	12	5 50	6 07	6 25	6 46	6 58	7 12	7 29	7 49	7 59	8 09	8 22	8 36	8 53
	13	5 50	6 08	6 26	6 47	6 59	7 13	7 30	7 50	8 00	8 10	8 23	8 37	8 54
	14	5 51	6 08	6 26	6 48	7 00	7 14	7 30	7 51	8 00	8 11	8 24	8 38	8 56
	15	5 51	6 09	6 27	6 48	7 00	7 14	7 31	7 52	8 01	8 12	8 25	8 40	8 57
	16	5 52	6 09	6 28	6 49	7 01	7 15	7 32	7 52	8 02	8 13	8 26	8 41	8 58
	17	5 52	6 10	6 28	6 50	7 02	7 16	7 33	7 53	8 03	8 14	8 27	8 42	8 59
	18	5 53	6 10	6 29	6 50	7 02	7 16	7 33	7 54	8 04	8 15	8 28	8 42	9 00
	19	5 53	6 11	6 29	6 51	7 03	7 17	7 34	7 55	8 05	8 16	8 28	8 43	9 01
	20	5 54	6 11	6 30	6 51	7 03	7 18	7 34	7 55	8 05	8 16	8 29	8 44	9 01
	21	5 54	6 12	6 30	6 52	7 04	7 18	7 35	7 56	8 06	8 17	8 30	8 44	9 02
	22	5 55	6 12	6 31	6 52	7 04	7 19	7 36	7 56	8 06	8 18	8 30	8 45	9 03
	23	5 55	6 13	6 31	6 53	7 05	7 19	7 36	7 57	8 07	8 18	8 31	8 46	9 03
	24	5 56	6 13	6 32	6 53	7 05	7 20	7 36	7 57	8 07	8 18	8 31	8 46	9 03
	25	5 56	6 14	6 32	6 54	7 06	7 20	7 37	7 58	8 08	8 19	8 31	8 46	9 04
	26	5 57	6 14	6 33	6 54	7 06	7 20	7 37	7 58	8 08	8 19	8 32	8 46	9 04
	27	5 57	6 15	6 33	6 54	7 07	7 21	7 38	7 58	8 08	8 19	8 32	8 47	9 04
	28	5 58	6 15	6 34	6 55	7 07	7 21	7 38	7 58	8 08	8 19	8 32	8 47	9 04
	29	5 58	6 16	6 34	6 55	7 07	7 21	7 38	7 59	8 08	8 19	8 32	8 47	9 04
	30	5 59	6 16	6 34	6 55	7 07	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 04
	31	5 59	6 16	6 35	6 56	7 08	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 04
	32	6 00	6 17	6 35	6 56	7 08	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 03
	33	6 00	6 17	6 35	6 56	7 08	7 22	7 39	7 59	8 08	8 19	8 32	8 46	9 03

SUNSET AND TWILIGHT, 1945 495

L.M.T. OF SUNSET (SUN'S UPPER LIMB) AND END OF EVENING TWILIGHTS (CIVIL AND NAUTICAL) ON THE MERIDIAN OF GREENWICH

To obtain G.M.T. add the longitude if west, and subtract if east.
For further explanation see page 502. For southern latitudes see page 503.

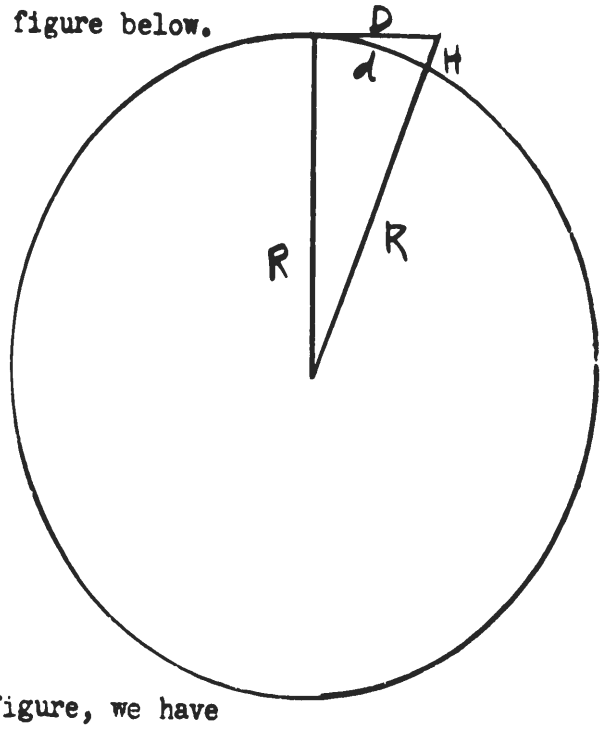
Date	Lat.	0°	+ 10°	+ 20°	+ 30°	+ 35°	+ 40°	+ 45°	+ 50°	+ 52°	+ 54°	+ 56°	+ 58°	+ 60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Dec.	9	17 56	17 39	17 21	17 00	16 48	16 35	16 18	15 58	15 49	15 38	15 26	15 12	14 56
	10	17 56	17 39	17 21	17 01	16 49	16 35	16 18	15 58	15 49	15 38	15 26	15 12	14 55
	11	17 57	17 40	17 22	17 01	16 49	16 35	16 18	15 58	15 48	15 38	15 26	15 11	14 54
	12	17 57	17 40	17 22	17 01	16 49	16 35	16 18	15 58	15 48	15 38	15 25	15 11	14 54
	13	17 58	17 41	17 22	17 01	16 49	16 35	16 19	15 58	15 48	15 38	15 25	15 11	14 54
	14	17 58	17 41	17 23	17 02	16 50	16 35	16 19	15 58	15 48	15 38	15 25	15 10	14 53
	15	17 59	17 41	17 23	17 02	16 50	16 36	16 19	15 58	15 48	15 38	15 25	15 10	14 53
	16	17 59	17 42	17 23	17 02	16 50	16 36	16 19	15 58	15 49	15 38	15 25	15 10	14 53
	17	18 00	17 42	17 24	17 03	16 50	16 36	16 20	15 59	15 49	15 38	15 25	15 10	14 53
	18	18 00	17 43	17 24	17 03	16 51	16 37	16 20	15 59	15 49	15 38	15 25	15 11	14 53
	19	18 01	17 43	17 25	17 04	16 51	16 37	16 20	15 59	15 49	15 38	15 26	15 11	14 53
	20	18 01	17 44	17 25	17 04	16 52	16 37	16 20	16 00	15 50	15 38	15 26	15 11	14 54
	21	18 02	17 44	17 26	17 04	16 52	16 38	16 21	16 00	15 50	15 39	15 26	15 12	14 54
	22	18 02	17 45	17 26	17 05	16 53	16 38	16 22	16 01	15 51	15 40	15 27	15 12	14 54
	23	18 03	17 45	17 27	17 05	16 53	16 39	16 22	16 01	15 51	15 40	15 27	15 13	14 55
	24	18 03	17 46	17 27	17 06	16 54	16 40	16 23	16 02	15 52	15 41	15 28	15 13	14 56
	25	18 04	17 46	17 28	17 06	16 54	16 40	16 23	16 03	15 52	15 42	15 29	15 14	14 56
	26	18 04	17 47	17 28	17 07	16 55	16 41	16 24	16 03	15 53	15 42	15 30	15 15	14 57
	27	18 05	17 47	17 29	17 08	16 55	16 41	16 24	16 04	15 54	15 43	15 30	15 16	14 58
	28	18 05	17 48	17 30	17 08	16 56	16 42	16 25	16 05	15 55	15 44	15 31	15 17	14 59
	29	18 06	17 48	17 30	17 09	16 57	16 43	16 26	16 06	15 56	15 45	15 32	15 18	15 00
	30	18 06	17 49	17 31	17 10	16 57	16 43	16 27	16 06	15 57	15 46	15 33	15 19	15 02
	31	18 07	17 50	17 31	17 10	16 58	16 44	16 28	16 07	15 58	15 47	15 34	15 20	15 03
	32	18 07	17 50	17 32	17 11	16 59	16 45	16 29	16 08	15 59	15 48	15 36	15 21	15 04
	33	18 08	17 51	17 32	17 12	17 00	16 46	16 30	16 09	16 00	15 49	15 37	15 22	15 06

Restricted Security Information

THE BALLOON SUNSET NOMOGRAPH

The purpose of this nomograph is to determine the time increment which must be added to ground sunset in order to obtain balloon sunset or which must be subtracted from ground sunrise in order to obtain balloon sunrise. The time increment is a function of several variables such as the height of the balloon, the latitude of the balloon, and the declination of the sun (i.e. the day of the year).

The time increment is proportional to the square root of the height of the balloon providing that second order effects are neglected. This can be shown with the aid of the figure below.



From the geometry of the figure, we have

$$D^2 + R^2 = (R + H)^2$$

$$D^2 + R^2 = R^2 + 2RH + H^2$$

or

$$D = 2RH$$

if the second order effect is neglected. The distance d is approximately equal to D, the difference being that between the angle intercepted by the distance D (in radians) and the tangent of that angle. The error

involved is small, being less than 1% when the balloon is 150,000 feet high. The error due to neglecting the second order effect will be less than 0.3% when the balloon is 150,000 feet high. It can be shown that $d_{miles} = 1.22\sqrt{H_{feet}}$. This does not take refraction into consideration. After refraction is included[1], the equation becomes $d_{miles} = 1.32\sqrt{H_{feet}}$. This constant assumes conditions of refraction such as occur near sea level, and this constant was used in the construction of the nomograph because at the time of the balloon sunset the sunlight does go through the atmosphere near sea level. Considerations since the construction of the nomograph indicate that for a balloon at 100,000 feet. the constant should be reduced by about 3-4%. Thus, in this case the nomograph will give a time increment which will be 1-2 minutes too large if the time increment is of the order of 50 minutes.

The time increment is also proportional to the secant of the latitude because the tangential velocity caused by the earth's rotation is proportional to the cosine of the latitude.

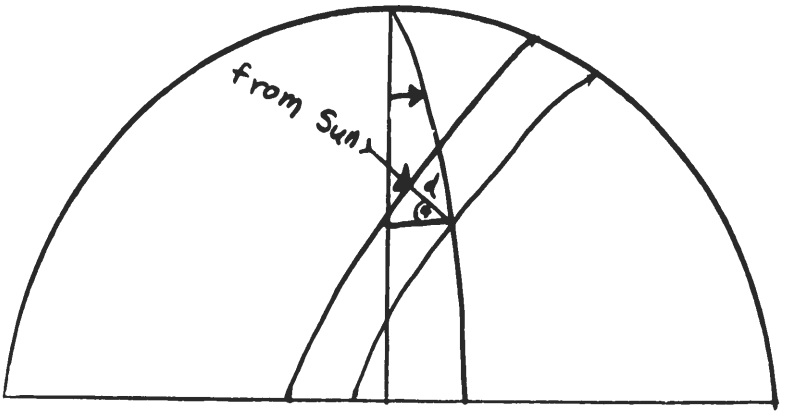
The above variables would give the correct value for the time increment if the sun set exactly in the west and rose directly in the east. Since this occurs on only two days of the year, this effect must also be taken into consideration. Referring to the figure below, one can see that as a first approximation, the time increment will be proportional to the sec Ψ where

$$\sin \Psi = \frac{\sin |\delta|}{\cos \phi}$$

δ = declination of the sun

ϕ = latitude of the balloon

[1] Chauvenet, SPHERICAL AND PRACTICAL ASTRONOMY, Vol. I.



Comparison with tables in the AMERICAN AIR ALMANAC and calculations showed that the time increment increased a little faster than the sec Ψ. This was allowed for on the nomograph by lengthening the scale factor on scale D by a small amount greater than that dictated by the scale factors of the other scales and the relative spacings of the other scales.

It is evident that the symmetry exhibited on scale A where only the absolute value of the declination of the sun is taken in account does not exist in general. However, as long as one does not go above 50 degrees north latitude, the symmetry is good. The value of the declination of the sun on scale A may be read approximately from the nomograph. It may be obtained more accurately from:

1. THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC
2. THE BRITISH NAUTICAL ALMANAC
3. THE K AND E SOLAR EPHEMERIS

The latitude and longitude of the balloon may be best obtained from the SECTIONAL AERONAUTICAL CHARTS, which can be read to an accuracy of one minute. The latitude of the balloon must be known to the nearest 1/4 of a degree in order to obtain the local civil time (LCT) of sunset (or sunrise) to the nearest minute. These LCT of sunset (and sunrise) of the sun's upper limb and on the ground beneath the balloon can be obtained from the first two

sources at the top of this page. THE BRITISH NAUTICAL ALMANAC contains data for each day so that only interpolation for latitude is required.

To convert LCT to standard time it is necessary to add 4 minutes for each degree of longitude west of the standard meridian (i.e. 75, 90, 105, and 120 degrees) and subtract 4 minutes for each degree of longitude east of the standard meridian. Therefore in order to obtain the standard time of ground sunset (or sunrise), it is necessary to know the longitude of the balloon to the nearest 1/4 degree interval.

The greatest errors in the time increment occur when the altitude of the balloon is large (i.e. over100,000 feet), when the latitude is near 50 degree north, and when the declination of the sun is large in absolute value. Consideration and practice with the nomograph since its construction, coupled with the small errors cited previously indicate that for large values of the time increment, the following corrections would be helpful:

30-40 minutes	subtract 1 minute
40-50 minutes	subtract 2 minutes
50-60 minutes	subtract 3 minutes

Since in most practical cases, the time increment is about 30 minutes, the above may in most cases be ignored.

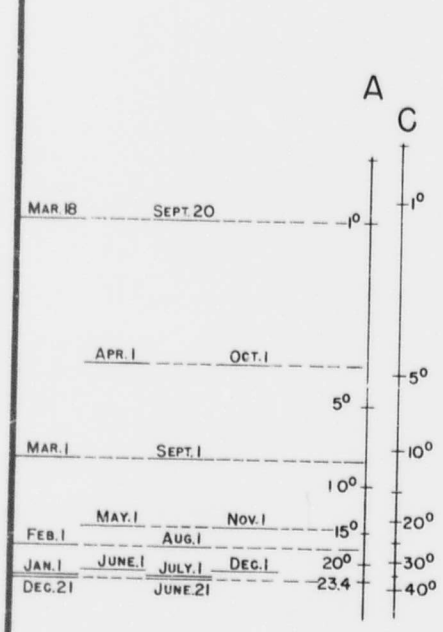
Observations of the balloon at balloon sunset with a 10-inch refracting telescope indicate that the observed times of balloon sunset occur from 2-4 minutes earlier than the calculated balloon sunset. This is partially due to the errors cited above. It must be remembered that the calculated balloon sunset assumes a smooth earth with no clouds. It is not difficult to see that clouds from 200-400 miles west of the balloon could cause the balloon sunset to occur earlier than predicted. Furthermore, it must be noted that

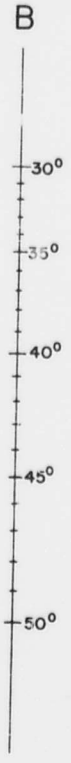
the balloon sunset is calculated for the time when the sun's upper limb disappears. Thus, while the geometry of the situation is very definite, the fading of the light of the balloon is not as definite. Thus, it is not surprising that observations have an uncertainty of a minute or more.

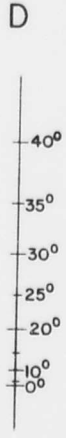
Therefore, it seems that one should expect the calculated time of balloon sunset to be accurate within 2 minutes at least with the probability that any error is such as to make the calculated value occur later than the observed value.

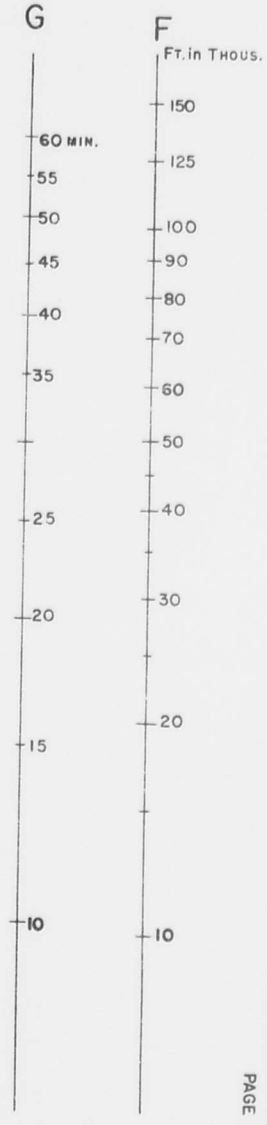
BALLOON SUNSET

E









DIRECTIONS

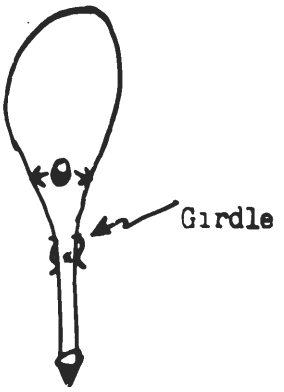
1- FIND THE DECLINATION OF THE SUN ON SCALE 'A'.
2- CONNECT SCALE 'A' TO THE APPROXIMATE LATITUDE OF THE BALLOON ON SCALE 'B'.
3- READ SCALE 'C' AND TRANSFER THE READING TO SCALE 'D'.
4- CONNECT SCALE 'B' AND 'D' TO INTERSECT REFERENCE LINE 'E'.
5- CONNECT THIS POINT ON 'E' WITH THE ALTITUDE OF THE BALLOON (in ft.) ON SCALE 'F'
6- READ SCALE 'G' THIS IS THE TIME (in minutes) WHICH MUST BE ADDED TO THE TIME OF SUNSET IN ORDER TO OBTAIN THE APPROXIMATE TIME OF BALLOON SUNSET.
ON SCALE 'C': 90± 'C' EQUALS THE APPROXIMATE AZIMUTH OF THE SUN AT SUNSET.

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RESTRICTED SECURITY INFORMATION

THE GIRDLE AS AN AUTOMATIC APPENDIX

The girdle which acts as a clamp during the inflation of the balloon top in the Minnesota launching method is released from the inner tire at an altitude of about 12,000 feet. At this altitude the tire falls into the load ropes at the bottom of the balloon. At the instant of tire release the balloon looks like the sketch below:



At first glance it might seem that the girdle should immediately slip down to the bottom of the balloon. On setting the problem up, however, one finds that the girdle may or may not slip, depending on the weight of the girdle relative to the tension in the tapes. The angle θ (for a given ratio of girdle weight to tape tension) at which the girdle slips depends on the coefficient of friction between the girdle and balloon. The physics of the problem is illustrated in the two photographs. In the first photograph the ring is stable, and in the second the angle θ is just large enough to cause the ring to slide down. Analysis of the problem leads to the following equation

$$\mu = \frac{\left(\frac{1 + \frac{W}{L}}{\cos\theta} - 1 \right)}{\frac{1}{2}\log\left(\frac{1+\sin\theta}{1-\sin\theta}\right) + \frac{1}{2}\,\frac{W}{L}\left(\theta^2 + \frac{\theta^4}{4}\right) + \ldots} .$$



The angle between the strings is small enough so that the ring is stable requires force to move it up or down.

An approximate solution is

$$\mu = \frac{\left(\frac{1 + \frac{W}{L}}{\cos\theta} - 1\right)}{\frac{1}{2}\log\left(\frac{1 + \sin\theta}{1 - \sin\theta}\right)}$$

where

μ = coefficient of friction

W = weight of girdle

L = tension in load tapes

θ = cone angle at which slipping takes place.

The solution to the equation is shown in the graph for various values of $\frac{W}{L}$. For polyethylene on polyethylene the coefficient of friction is about 2, and the angle at which slipping takes place is about 170°. This is demonstrated by the up pictures from Flight 5 (appendix 6) in which the balloon became nearly spherical above the girdle before slipping took place.

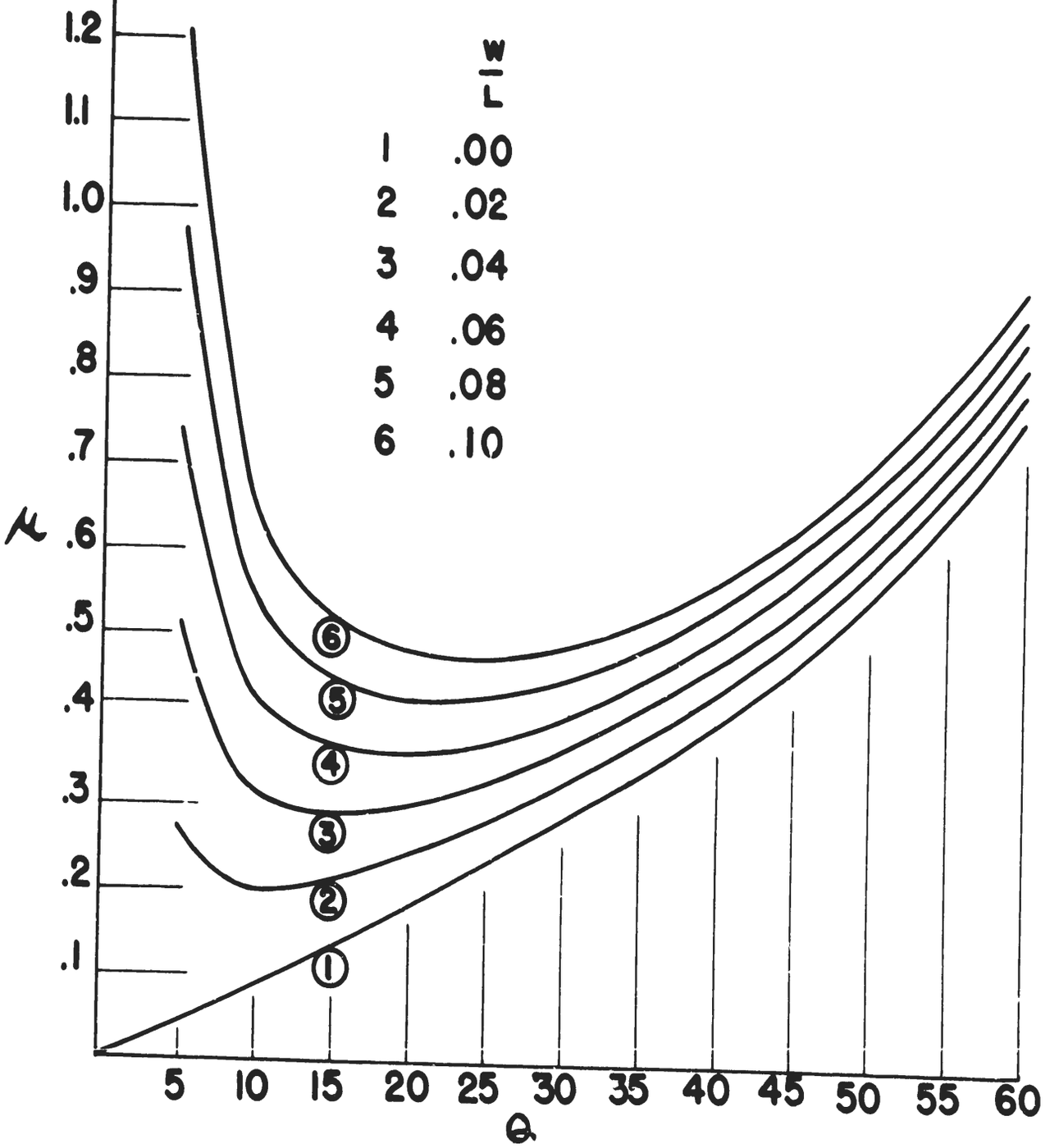
In later flights we used a nylon-tape-wrapped girdle for which the coefficient of friction was about 0.25. The range of loads flown put us between curves 2 and 3 on the graph. With heavy loads (curve 2) it was sometimes observed that the girdle came down in steps as expected. The girdle should come down in steps because as soon as θ becomes large enough to cause the girdle to slip against static friction, the girdle will start down and will descend until θ has decreased enough to just hold against sliding friction. (The coefficient of sliding friction is less than the coefficient of static friction.) With light loads (curve 3) the girdle was observed to come down in one step.

To take an illustration, assume that the girdle weighs 2% of the tension in the tapes and that it has a coefficient of static friction of 0.3 and a coefficient of sliding friction of 0.25. It will commence to slip

whenever θ becomes as large as 26° and will stop when θ has decreased to 19°. (See values for curve 2 on the graph.)

It is believed that the automatic functioning of the appendix will keep a desirable aerodynamic shape during the ascent and thereby minimize balloon failures in the jet stream.

COEFFICIENT OF FRICTION AS A FUNCTION OF ANGLE FOR VARIOUS RATIOS OF RING WEIGHT TO TAPE TENSION.



SECTION V

INSTRUMENTATION

The standard gondola flown on each flight is built up on a magnesium rack 2' x 2' x 2' with legs extending below and with brackets above for connection to the balloon load ring. This rack is insulated by a 4" Styrofoam box and protected by a heavy canvas case with zipper closures. There are handles provided on this case for carrying the gondola and windows cut for the cameras. For gondola details see BA 411 D; BA 411 D1; BA 411 D2; BA 411 D3. Standard instruments flown are these:

A. A barograph and thermograph of the smoked disc type, driven by a clock-work mecha sm;

B. A cut-down timer consisting of two clock-work mechanisms connected in parallel to their own battery to explode two 4-grain squibs (see drawing BA 438 B; CR 406A in Appendix 11);

C. A low-altitude cut-down device which advances step-wise as the balloon ascends and fires a squib from its own battery on descent of the balloon. This is so adjusted that it fires at 30,000 feet or below but not above that altitude. (see drawing BA 410 D, Appendix 11);

D. An up camera electrically driven to take pictures at 1-minute intervals and so mounted as to take pictures of the balloon. It has a capacity of film to last for 10 hours. This camera has a lens with an angle which allows the balloon to be photographed from the center to the outside edge and contains a filter to sharpen the contrast of the pictures. (see drawings CR 88-1, CR 88-2, CR 88-3, BA 417D, B 418 B2, B418 B3, B 418 B1, in Appendix 11);

E. A down camera electrically driven to take pictures of the

ground at 1-minute intervals with the capacity for ten hours. This camera has a slightly longer focal length than the up camera and contains no filter (see drawings listed under D and B418D, Appendix 11);

F. A modified Olland cycle to feed altitude information to the radio transmitter. This cycler consists of a motor-driven cylinder with two helices of different pitch wound upon it. A bellows-actuated arm sweeps the length of this cylinder as pressure decreases, sending electric pulses of varying time intervals to the transmitter. (see drawings BA 421D, Appendix 11);

G. An antenna dropper, pressure actuated to release the transmitter antenna at a pre-set altitude after launching. The antenna is rolled in a ball, and the weight of the antenna is supported by a nylon fishline in order to prevent the antenna from breaking. A lead weight at the end of the fishline insures the antenna hanging straight. (see drawing BA 427C, BA 435D, Appendix 11);

H. A flashing warning light operated from its own battery and actuated by a pressure switch or timing device to start the flasher at 30,000 feet on descent only.

Several types of clock-work mechanisms have been tried for the barograph-thermograph driving mechanisms, and at present a cheap alarm clock mechanism, with a take-off from the 24-hour alarm setting hand, is being used. This mechanism is de-greased before flight and lubricated with kerosene in place of oil, which might solidify and stop the

mechanism. An ordinary lubrication with kerosene lasts for approximately 3 days if the mechanism is not sealed to prevent evaporation. The timer mechanisms currently being used are the same alarm clocks as those used for the barograph-driving mechanisms. These clocks have a 24-hour alarm setting, and the clock is so altered that the unwinding of the alarm key trips a micro-switch to close the blowdown circuit. These clocks are also lubricated with kerosene but will last, when they are sealed in their cases, for at least 10 days on one lubrication. No difficulty has been encountered from kerosene lubrication in any flight thus far. Several other timing mechanisms were used before the present device was standardized, and none of them was considered to be very reliable. A small Minneapolis-Honeywell thermostat timer proved to be quite unreliable even before de-greasing and re-lubrication. Other alarm clock mechanisms have also been used, but the present type of Montgomery Ward clock so far is the most reliable. We are not yet completely satisfied with these timers, however, and other jeweled mechanism clocks are being tested for possible future use.

The cut-down device has proved quite reliable if adjusted properly. Each device must be calibrated before each flight, and within the error of custom-made shop manufacture the mechanisms are more or less standard. There have been 3 failures in 30 of these mechanisms to date, and there is a possibility of alteration in the future.

The cameras used are also made in our shop with commercially bought diaphragm, shutter and lenses. These cameras have been powered by 3 different motors to date. The motor which has proved to be most reliable is the small Brailsford motor driven by a 6-volt battery. Amglo motors were very unreliable and would often stall during a flight, or even run in re-

verse in case of a slight film jamming. Hayden motors proved to quite reliable but have been in short supply. Some difficulty has been encountered in getting even steps between individual frames on the film, but this has been traced to the tension of the spring driving the take-up roll and pressure of the film pressure plate. A more positive cam mechanism to trip the shutter is now in use.

The cyclers which are used have undergone several changes. It was discovered that radio sonde altitude records were not sufficiently accurate at high altitudes and, in addition, allowed equivocation as to ascent or descent. This was replaced by a single-helix rotor which also did not make clear whether the balloon was ascending or descending. The double helix was then designed and, with proper calibration, has proved to give accurate records within the error of the bellows itself. These rotors were at first commercially made by the Maico Company of Minneapolis, but it was discovered that extreme care in finishing of the surface of a rotor is necessary, and the Physics Department shop now makes these rotors. A Brailsford motor is used to drive the rotor, and there is a reference pip which gives a recorded measure of the constancy of its speed.

Seven modifications of the antenna dropper were necessary before a design was achieved which was completely reliable. At first a model airplane pneumatic timer was used to delay the dropping of a rolled-up antenna until a pre-set time interval had elapsed after launching. This device and other early models of pressure-operated bellows mechanisms were found to release the antenna ball prematurely. The present mechanism, which consists of a positive latch type of holder and a bellows which releases the latch, has been completely reliable both in holding the antenna during a rough truck ride from the laboratory to the launching site and also in releasing the

antenna at the proper altitude after launching.

Several airplane warning beacons have been tried, using motor-driven interval timers and bellow-operated starting switches. No failures were experienced with these flashers, but present models being flown are commercial electric truck flares which are considerably smaller and lighter than the types devised in this laboratory.

Special instrumentation has included ballasting devices of several types. Canvas bags filled with measured loads of fine iron shot were released by squibs activated by pressure switches or electrically driven sequence timers. A ballast dropper of a more advanced design consisting of a tank of 250-pound capacity which had a motor driven screw to dump the ballast from the tank has been used. This was radio-controlled from the ground and also had a telemetering device to sen information concerning the amount of ballast in the tank. This telemetering device had a motor-driven cam which sent a regularly timed electric impulse to the radio transmitter and a cam mounted on a pulley which rotated in reference to the motor-driven cam as ballast was dropped from the spring-hung tank. This system has proved adequate for telemetering purposes, but simplicity of construction has forced us to re-design this telemeter. The ballast hopper has seen limited use and will be described in more detail in a later report. A magnetic ballast-dropping valve has also been designed and tested satisfactorily. The valve is almost identical to that designed at Tufts College for Moby Dick. It consists of a permanent magnet across an air gap in a dumping tube in which the iron shot is held normally. A bucking electromagnet, actuated by radio command from the ground, releases the iron shot to fall through the dumping tube.

There are two devices pertaining to the cut-down system which will

soon be made standard. One is a time-delay relay which puts a warble modulation on the transmitter for 1½ minutes before cut-down by the timers. This "warblator" provides a signal to trackers, warning them of the cut-down of the balloon. The other device, still being improved, is a means of cutting down the balloon when the voltage of the main batteries falls below a certain value. Originally, this device compared the main battery voltage with that of a reference battery, but because of circuit difficulties it was found that a low-drain holding relay is simpler and more reliable.

The main power source used for our flights are Willard 6-volt batteries, and a Mallory vibrapack is used to provide B+ voltages for the radio gear. These cells have proved quite reliable, but a battery is not flown for more than one flight, to eliminate the possibility of failure due to sulfation or cracked battery cases. Whenever dry cell batteries are flown, they also are flown for one flight only. The used flight batteries are charged and used in the laboratory.

The main problem so far has been reliability of equipment. Clock-work mechanisms, particularly, have been troublesome. Amglo motors, which were used extensively early in the project, have proved to be so unreliable that all the motors used now are Brailsford. The low current drain and small size of the Brailsford are added features.

Tracking operations consist of operating the theodolite at the launching site, but in some cases a portable theodolite is sent out. Men have been trained in the use, setting up, and locating procedures for theodolites. During a flight readings are taken at 5-minute intervals on WWV time and sent into the tracking center for plotting. Notes on appearance of the balloon and function of various pieces of equipment in flight are also taken.

SECTION VI

TELEMETERING AND ELECTRONICS

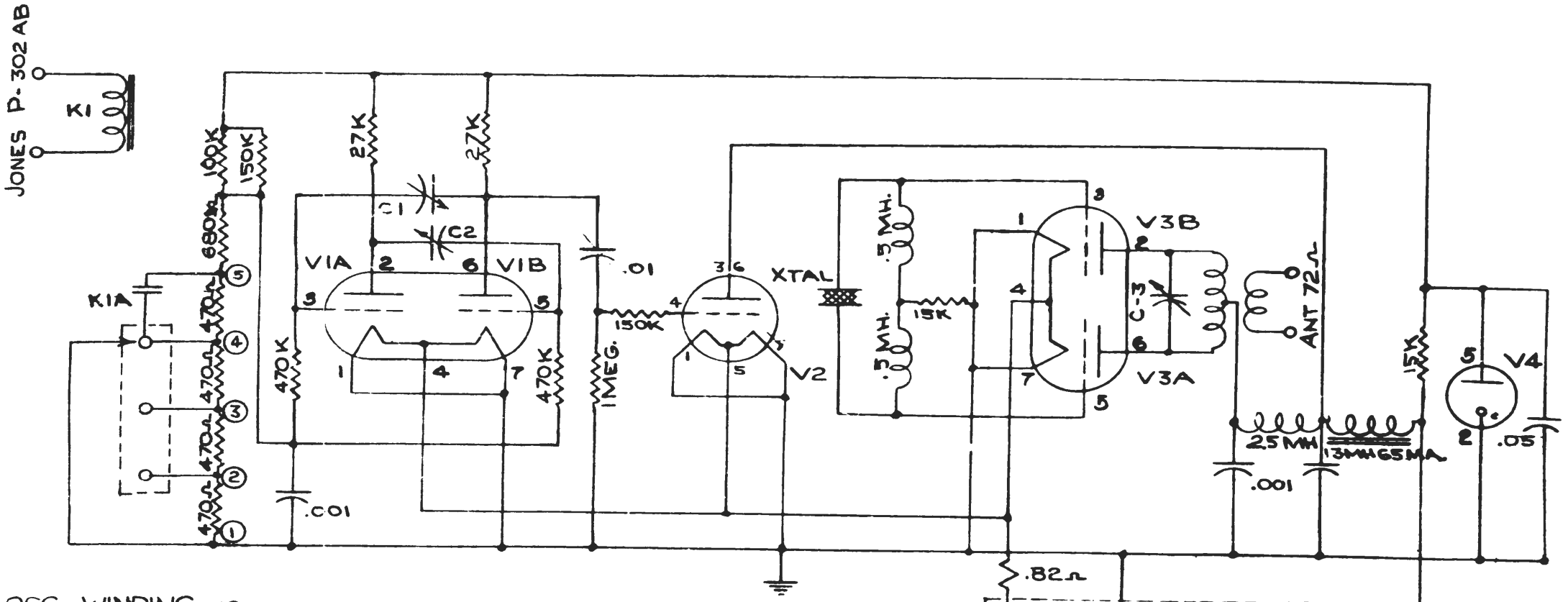
I. FLIGHT EQUIPMENT

A. Transmitting Equipment

It was decided to use the low-frequency balloon-borne transmitters for the initial stages of operations (the short-range operations) because the beacons could be simple and consume a low amount of power. The transmissions on these frequencies were in the range of the automatic direction finder equipment installed in the University Beechcraft and in the Navy tracking truck, and therefore these vehicles could be used for tracking purposes with this beacon. The frequencies used until the present time have been 1746 KC, 1724 KC and 1638 KC. It was found that after sunset there was an interfering signal on 1724 KC from a police station at Little Rock, Arkansas, which caused operations to be almost impossible. However, on the other two frequencies operations were found to be good both day and night.

1. 1-watt Beacon.

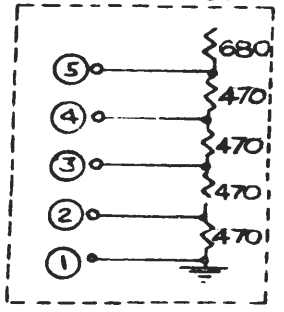
The low-frequency beacon is described in detail in drawing # 1T11-1B2. The beacon transmitter consists of 1 tube, which is V3 in the diagram. It is a type 3A5 tube and works as a push-pull crystal-controlled oscillator. The transmitter is Heising modulated. The modulator tube is a type 3A4, which is designated V2 in the diagram. The sub-carrier frequency is generated by a 3A5 type tube which is connected as a multivibrator. The frequency changes are made by changing the voltage applied to both grids of the tube which is designated V1 in the diagram. It was found necessary to regulate the voltage supply to the low frequency audio oscillator. Therefore, a type 5651 voltage regulator tube was added to the transmitter. This regulates the supply voltage for tube V1 at



OSC. WINDING = 120 TURNS NO. 30 ENAMELED ON 1" DIA. - C.T.

ANT. WINDING - 5 TURNS NO. 22 ENAMELED EVENLY SPACED OVER OSC. WIND.

JONES PLUG CODING No. P-306AB



FOR UNITS WITH EXT. PRESSURE INDICATOR

C1 - C2	160 - 500 MMF
C-3	5 - 50 MMF
V1 V3	3A5
V2	3A4
V4	5651

DEPT. OF PHYSICS U. OF MINN.

BALLOON PROJECT SECT.

DWG. NO.	SHOP DWG. NO.	DRAWN BY	CHECKED BY	DATE
ITLI-142	E-ITLI-127	L.E.P		28 May 52
LOW FREQ. XTMR 1W. XTAL CONTROL 2KC SUB CARRIER ITLI WITH V.R. & MOD.			MOD. 1	
			MOD. 2	
			MOD. 3	

Restricted Security Information

[illegible] volts. The voltage at the grid of V1 which regulates the output frequency of this audio oscillator is determined by a resistive load which is shown to the far left of the diagram. From [illegible] information, one of these resistive values 1, 2, 3, 4 or 5 is shown to ground, and the audio frequency which is found at the [illegible] terminal. The modulation percentage obtained is approximately [illegible].

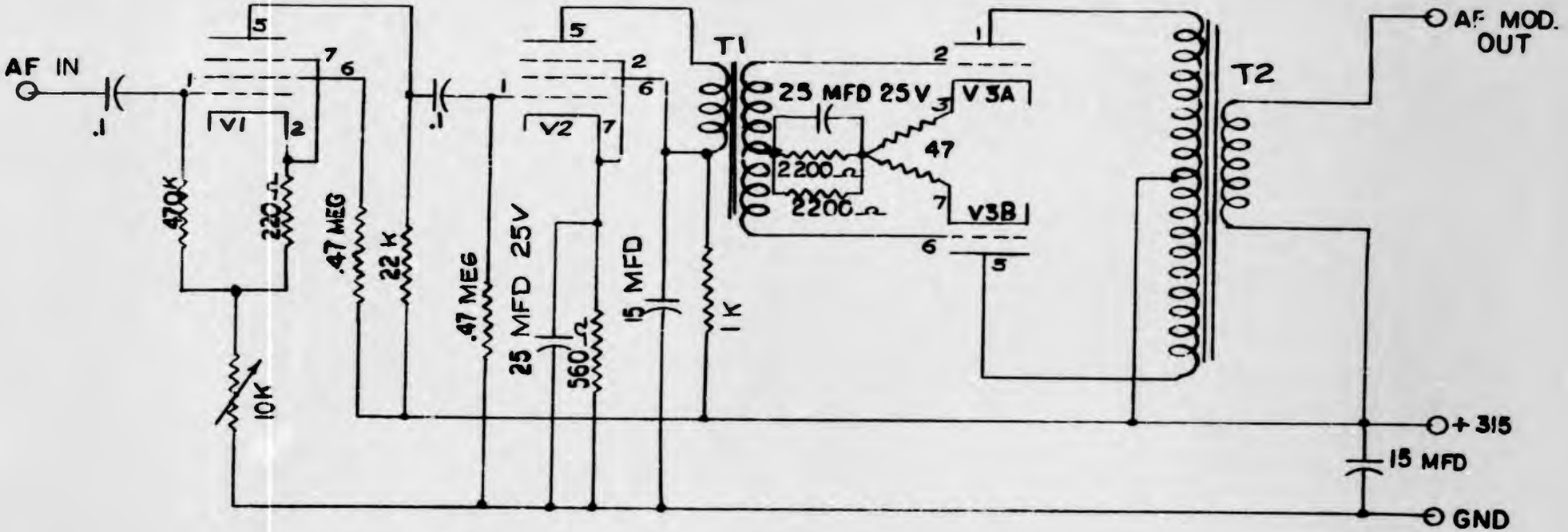
With the type of transmitter shown here the modulation output is always a square wave, and therefore it contains a large number of harmonics. In experimental design it was found that following the audio modulating signal was necessary to reduce this square wave to approximately a sine wave, and this was accomplished by inserting a resistance in the circuit across the modulation choke, which is designated by 13 resistor, 65 milliamps, on the diagram.

7. Antenna.

The antenna used with this transmitter is of the zeppelin type. It consists of a quarter wave of twin lead plus a half wave of single conductor. The twin lead is 11.5 meters long, and the half wave length used is 86 meters. The antenna wire is wrapped in a ball with the twin lead on the outside and is dropped after the transmitter has been carried into the air.

8. 5-watt beacon.

In one experiment a 5-watt beacon was used. This transmitter consisted of a crystal-controlled oscillator and a conventional final amplifier. The drawing number is 2TL-124 for this transmitter. The type of modulation was class B. The modulator for this transmitter unit is shown in drawing number 2TL-123. The modulator consists of 4 tubes, 2 voltage amplifiers and a class B power amplifier.



T1 - STANCOR # A3812 PRI. 10K PLATE TO PLATE C.T., SEC. 4K

T2 - TRIAD MIX PRI. 10K C.T., SEC. 5K

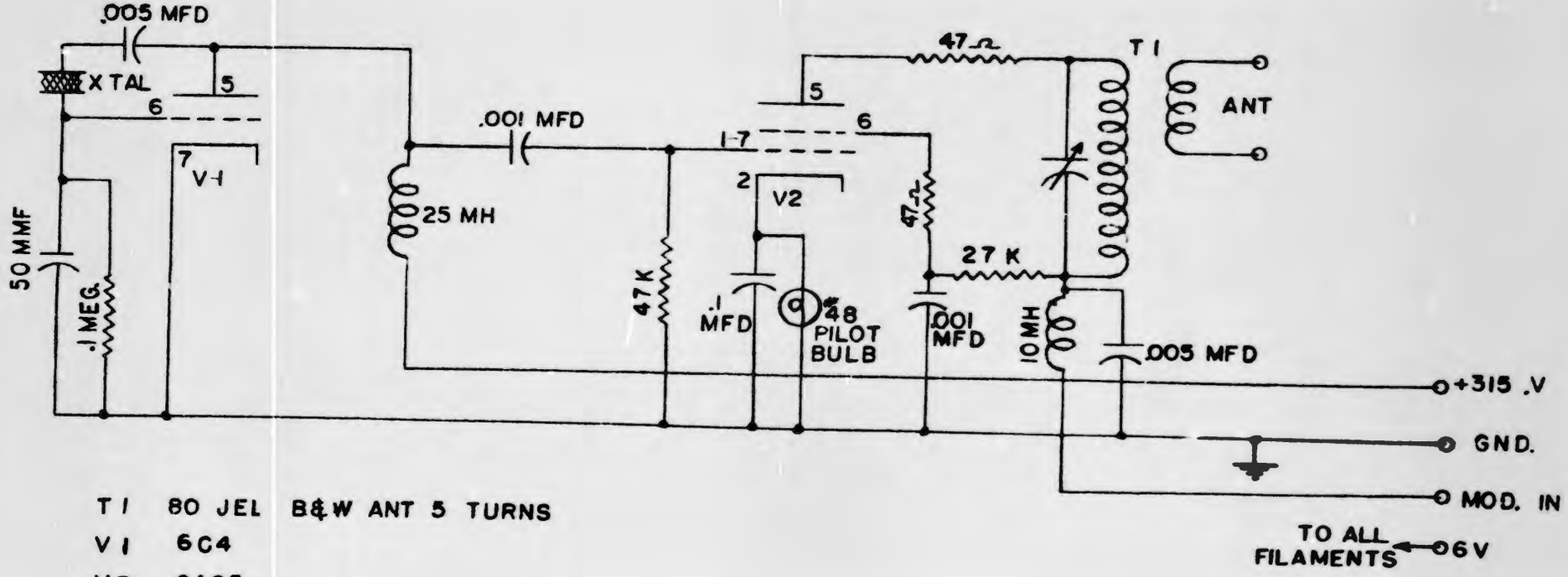
V1 6BH6

V2 6AK6

V3 12AU7

DEPT. OF PHYSICS U. OF MINN. BALLOON PROJECT SECT.				
DWG NO.	SHOP DWG. NO.	DRAWN BY	CHECKED BY	DATE
2TL-123	E-2TL-92	LEP	[illegible]	13MAR 52
AUDIO FREQ. MOD. FOR 5 WATT XTMR.			MOD. 1	
			MOD. 2	
			MOD. 3	

Restricted Security Information



T1 80 JEL B&W ANT 5 TURNS
V1 6C4
V2 6AQ5

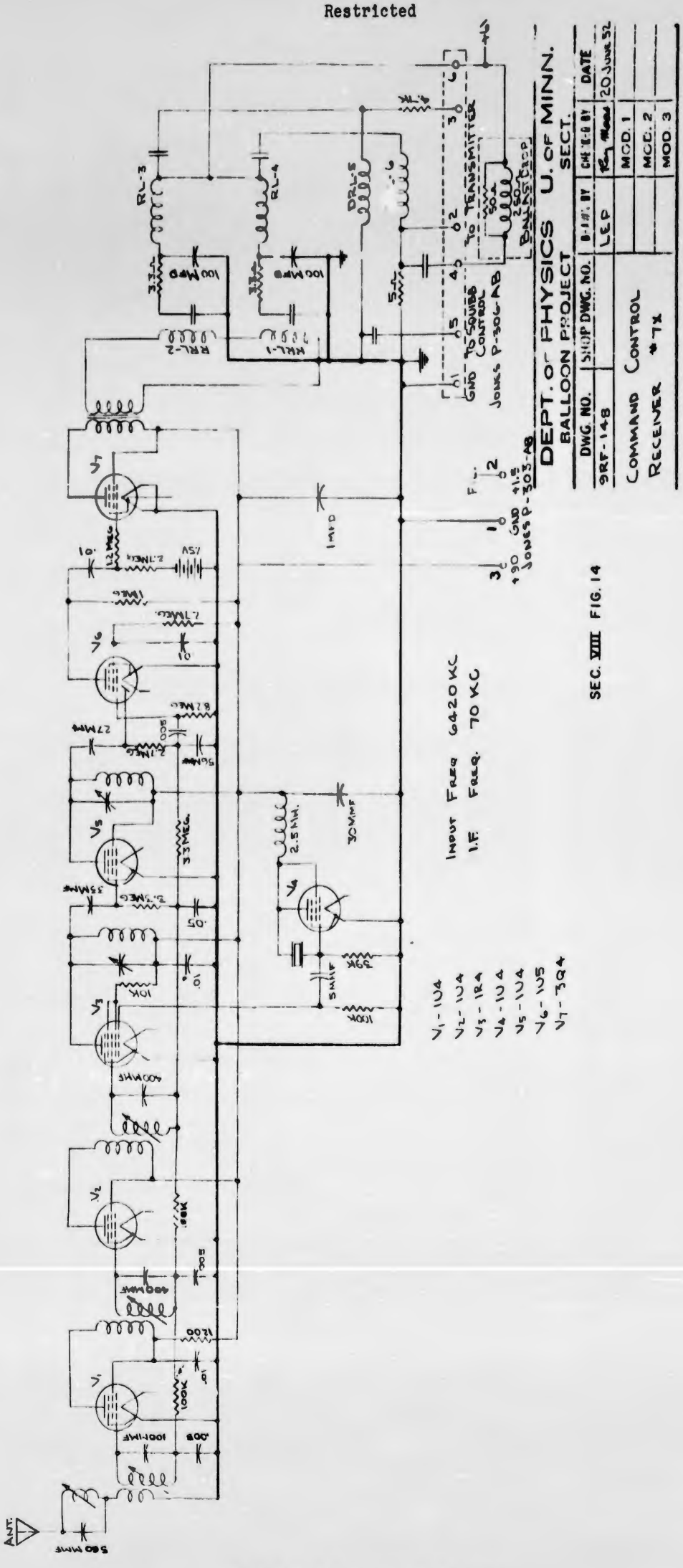
DEPT. OF PHYSICS U. OF MINN. BALLOON PROJECT SECT.				
DWG. NO.	SHOP DWG. NO.	DRAWN BY	CHECKED BY	DATE
2TL-124	E-2TL-93	LEP	Q.L.Pt.	13MAR52
5 WATT LOW FREQ CRYSTAL CONTROLLED TRANSMITTER			MOD. 1	
			MOD. 2	
			MOD. 3	

Restricted Security Information

Any source of audio signals can be fed into the modulator unit. For example, the output of a command receiver or the normal sub-carrier oscillator can be fed into this modulator. The antenna used with this transmitter is the same as that described for the 1-watt beacon. This type of transmitter shows linear modulation, whereas the 1-watt beacon shown in drawing 1TL-142 is not linear and can be used only for sub-carrier transmission. This non-linearity present in the 1-watt transmitter is not detrimental for the present use, as with only a single sub-carrier present, there can be no mixing or cross talk such as would be present with more than one frequency occurring at one time.

4. Power Supply.

The power supply for the beacon transmitter consists of a 6-volt Willard battery number ER40-6. This battery is in a plastic case, and its capacity is 40 ampere hours. The high voltage (180 volts D.C.) necessary for operation of the beacon transmitter is generated by a Mallory type 551 vibrapack. The vibrapack has internal filtering, and a condenser of the order of 8-10 mfd is added as additional filtering. This is normally sufficient. A source of 2 volts is taken from 1 cell of the 6-volt battery, and this is reduced to 1.5 volts by a series resistor to supply the filaments of the tubes in the transmitter. It was found that the 6-volt supply, which is also used for other equipment such as motors, needs to be filtered, and this was done by using condensers of the order of 1 mfd at 200 volts paper and also 25 mfd at 25 volts at motor terminals. The total current drain from the 6-volt storage battery to operate the 1-watt beacon transmitter is approximately 2 1/2 amperes. It has been



SEC. VIII FIG. 14

found that 1 storage cell of 40 amoere hour capacity will operate the transmitter equipment for approximately 15 hours.

B. Command Receivers

The command receiver used is of the super heterodyne type, AM, crystal-controlled. It is shown in drawing 9RF-148. It operates on a fixed frequency of 6420 Kc. The oscillator frequency is 6490 Kc, which results in an IF frequency of 70 Kc. The sensitivity of this receiver is approximately 1 microvolt for 20 milliwatt output, and it is AVC controlled. This makes its power output constant from 2.5 microvolts to over 1,000 microvolts input. There are two RF stages for image rejection, and one IF stage at 70 Kc. for narrow band width. The band width is approximately 1 Kc. The total power consumption of the receiver is about 1½ watts. It draws 12 milliamps of B supply at 90 volts and about 370 milliamps of A supply at 1½ volts. The receiver, when commanded, operates a resonant relay of the Stevens Arnold type. These relays have fundamental frequencies from 153 cycles to 442 cycles and a band-width ± 2%. The relays will operate on 18 milliwatts, and they have about 300 ohms impedance. These resonant relays have to operate an auxiliary relay in order to be useful, and in turn this auxiliary relay operates a time delay relay to prevent spurious noise from accidentally triggering the command operation.

The RF and antenna coils are modified commercial coils. The first IF coil is manufactured from a 10 millihenrie high-Q choke as a tuned-plate untuned grid type of IF transformer. The second detector IF transformer is of the conventional tuned-plate tuned diode with AVC takeoff. AVC action is used on both RF amplifier converters and RF amplifiers. There are 7 tubes incorporated in this receiver. The first two are RF amplifiers. There is a converter tube, one IF amplifier and two audio amplifier stages. This leaves one tube for the high-frequency crystal-controlled oscillator. A

crystal-controlled oscillator is used for stability of operation because with the narrow band width of 1 Kc., a drift over ½ Kc. at any one time cannot be tolerated. There is also a tuned trap in the antenna circuit of this receiver to reject any signal from the beacon transmitter that might get in, and this trap prevents any interaction between the beacon transmitter and the receiver. The 2 RF amplifiers are 1U4S, the converter is a 1R5, the IF amplifier is a 1U4, the audio amplifier is a 1U5 and the power amplifier (audio amplifier also) is a 3Q4. The 3Q4 also operates with a fixed bias battery of 7½ volts.

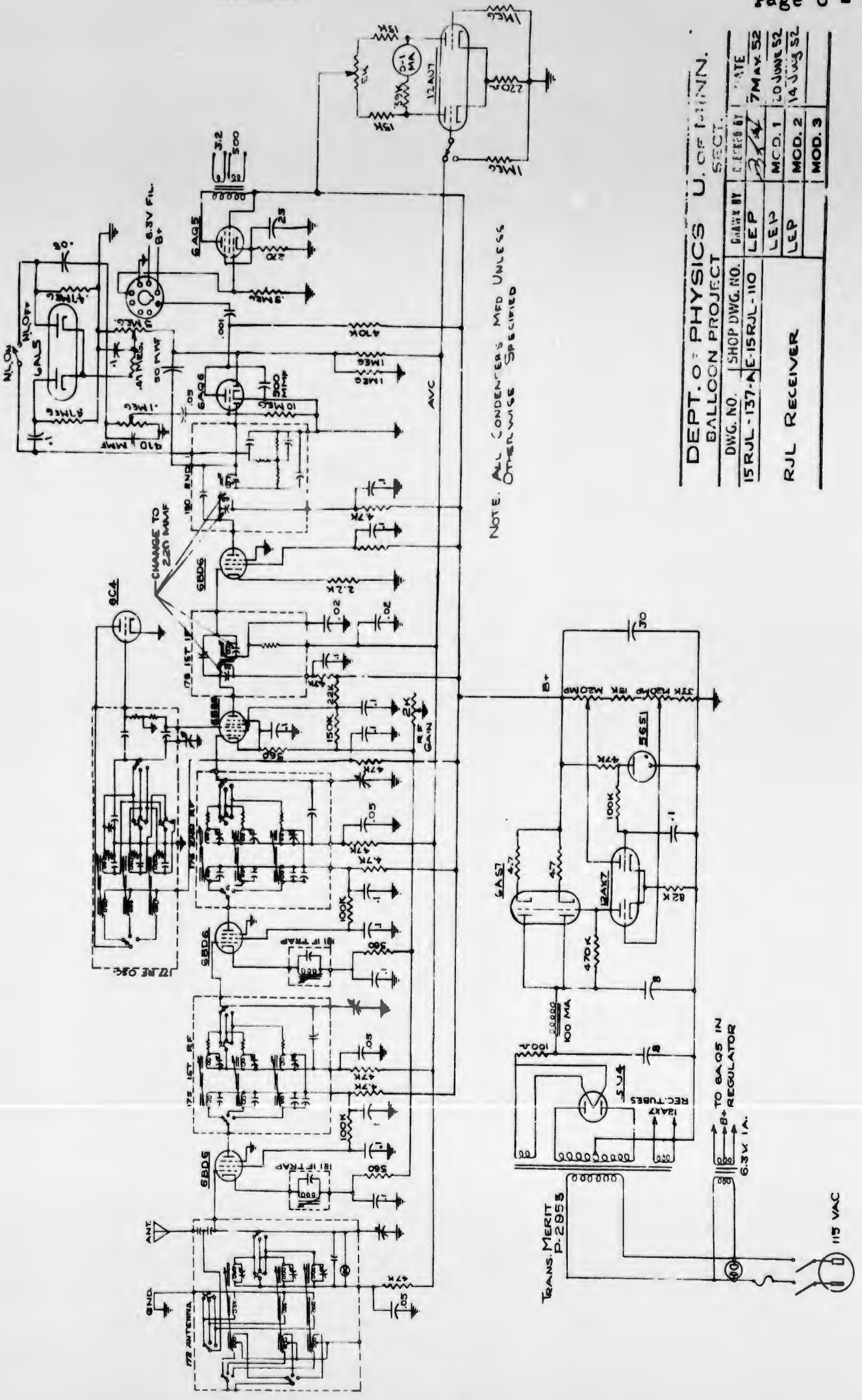
The antenna used on these receivers is taped to one of the balloon load tapes. The antenna is 11 meters long, which is one quarter wave length for 6420 Kc., and the receiver is current fed.

II. GROUND EQUIPMENT

A. Sub-carrier Receiving and Data Recording Equipment.

1. Low-Frequency Receivers.

The equipment used at the tracking center for receiving the low-frequency sub-carrier transmissions is shown in detail in drawing 15RWL-137-8. Pictures are included in Appendix 2. These receivers were constructed using RF transformers, IF transformers and IF traps from surplus BC433G receiver equipment. The loop transformer which is found in the above equipment was not used. The IF frequency is 152 Kc., and therefore the equipment is essentially narrow band. Use of sub-carrier frequencies above approximately 5,000 cycles would not be feasible with this equipment. The power supply used is of the highly regulated type, in which positive feedback is incorporated in the regulator amplifier to increase the feedback gain and eliminate ripple. This regulator also reduces the effect of line changes on


DEPT. OF PHYSICS U. OF MINN.
BALLOON PROJECT
SECT.
DWG. NO. | SHOP DWG. NO. | DRAWN BY | DATE
15RJL-137-A | E-15RJL-110 | LEP | 7 MAY 52
MOD. 1 | LEP | 10 JUNE 52
MOD. 2 | LEP | 14 JULY 52
MOD. 3
RJL RECEIVER
NOTE. ALL CONDENSERS MFD UNLESS OTHERWISE SPECIFIED
CHANGE TO 220 MMF
6AQ5
6AG6
6BD6
6C4
6SQ7
6SN7
12AU7
12AT7
12AX7
6AL5
6.3V FIL.
B+
AVC
ANT.
GND.
TRANS. MERIT P-2955
115 VAC
TO 6AQ5 IN REGULATOR
6.3V 1A.
REC. TUBES

tuning and increases the stability of the receiver. There is provision made for insertion of a filter between the first audio-frequency amplifier and the final output power amplifier, which is a 6AQ5 type tube in the diagram. The octal socket, which is used for the insertion of a filter, is shown. This is wired so that National type SOJ-3 Select-O-Ject units may be used with these receivers to filter out noise which is outside the sub-carrier frequency band. It is found that during most normal operations the use of this unit is unnecessary. However, during severe thunder storms and poor reception conditions, it is found that the Select-O-Ject does improve reception to a great extent.

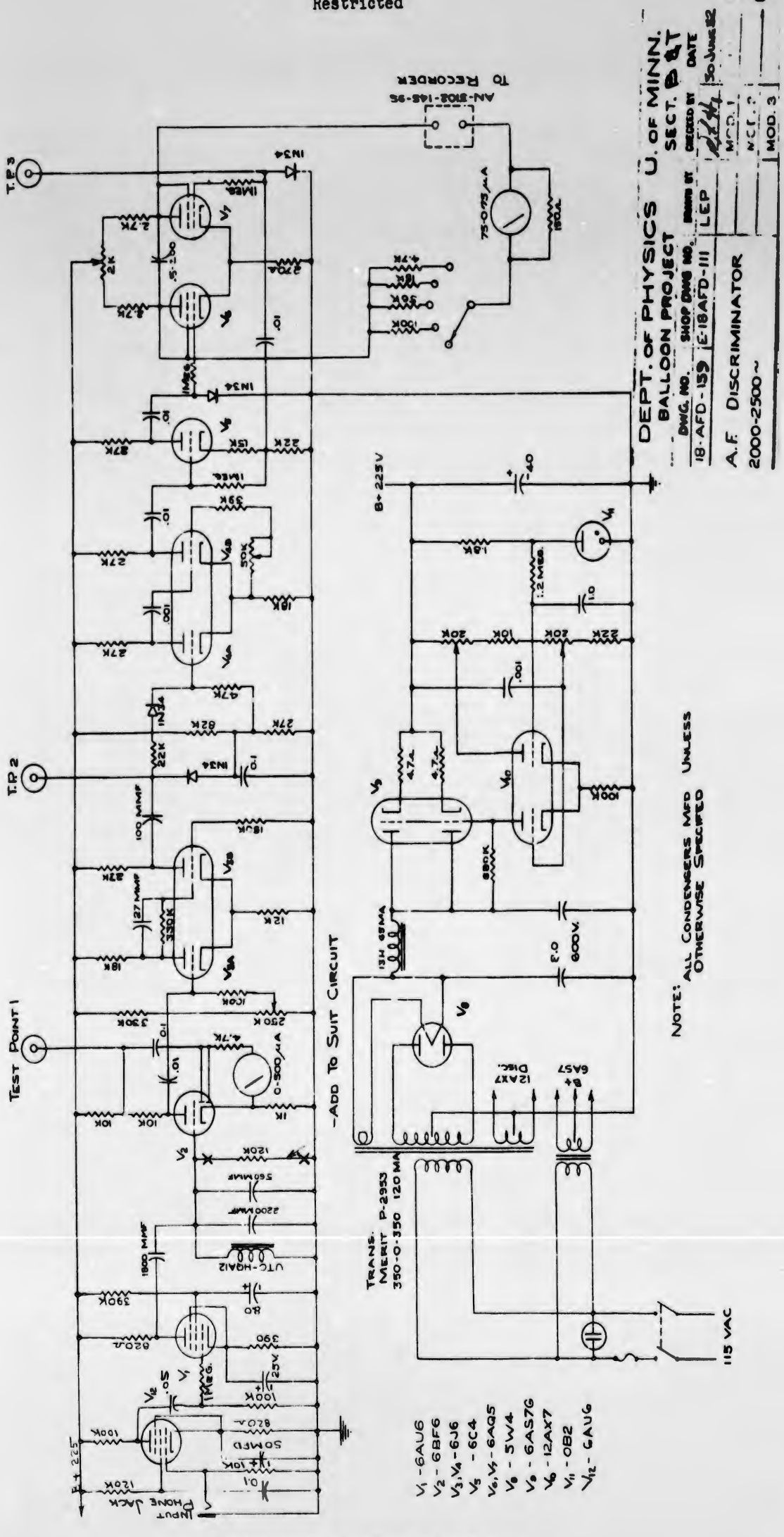
There are two outputs from the receiver. One is a low-impedance output at 3.2 ohms which is used to drive a loud speaker directly, and the other output at 500 ohms is used to feed the audio-frequency signal to an audio-frequency discriminator which will be described later.

2. A.F. Discriminators.

The audio-frequency discriminator used to demodulate the sub-carrier information is shown in detail in drawing 18-AFD-138 and is shown pictorially in Appendix 2. The design for this equipment is based on a system described by Sloughter and Ellis*. In some of the early operations a single sub-carrier discriminator from the type AN/AKT-5 equipment was used. However, it was found that if for some reason or other the sub-carrier frequency shifted more than 150-200 cycles away from the normal center frequency of 2250 cycles, the sub-carrier was out of range of the discriminator, and demodulation could not be accomplished. The discriminator used at present can be tuned so as to have a center

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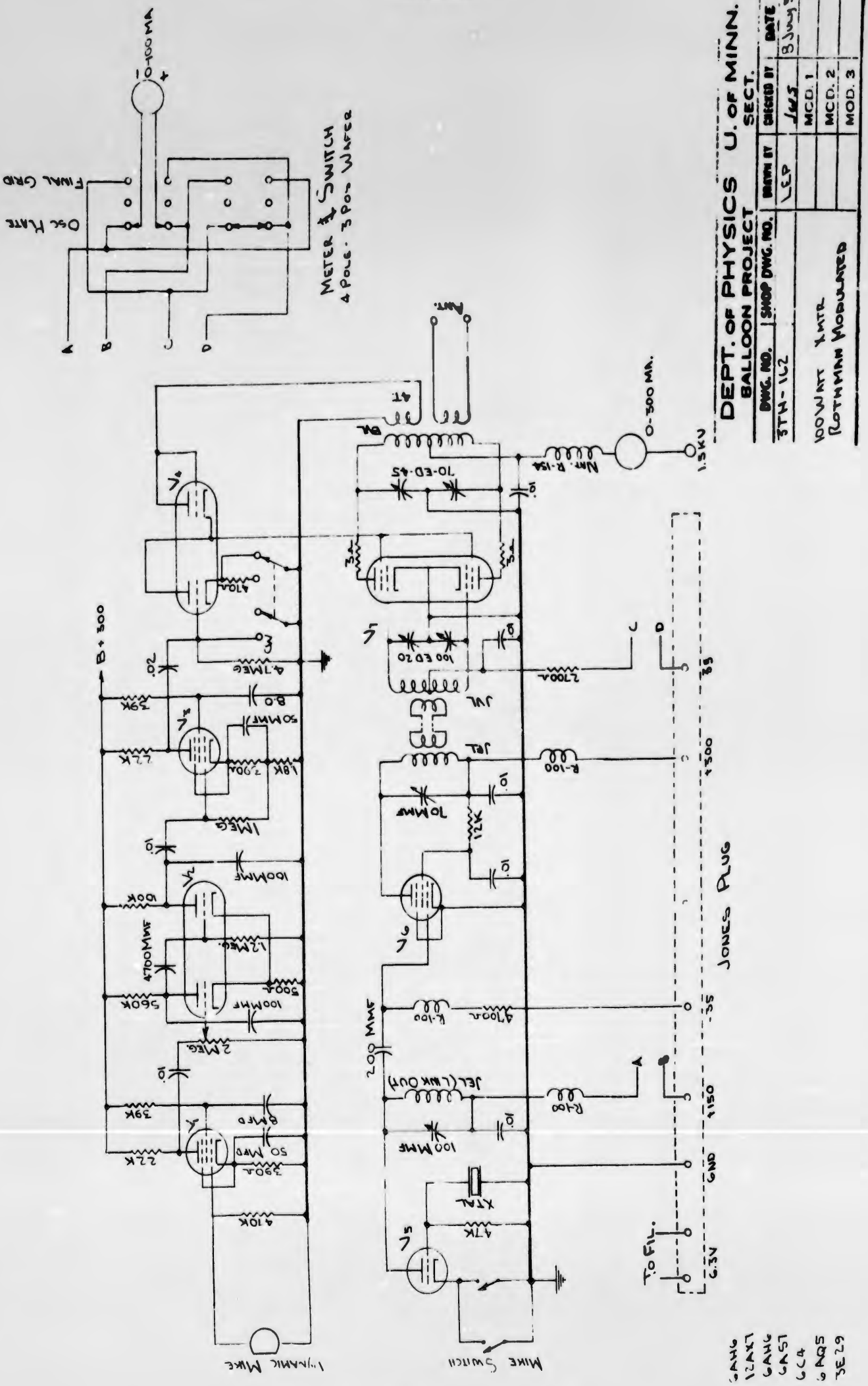
*Linear Discriminator for F-M Telemetering, Gordon S. Sloughter and Richard T. Ellis, ELECTRONICS, June, 1951, p. 113.


DEPT. OF PHYSICS U. OF MINN.
BALLOON PROJECT
SECT. B&T
DWG. NO. 18-AFD-159
SHOP DWG NO. E-18AFD-111
DRAWN BY LEP
CHECKED BY
DATE 30 June 52
MOD. 1
MOD. 2
MOD. 3
A.F. DISCRIMINATOR
2000-2500~
TO RECORDER
AN-3102-14S-9S
T.P.3
T.P.2
TEST POINT 1
-ADD TO SUIT CIRCUIT
B+ 225V
TRANS. MERIT P-2933 350-0-350 120 MA
115 VAC
INPUT PHONE JACK
NOTE: ALL CONDENSERS MFD UNLESS OTHERWISE SPECIFIED
V1 - 6AU6
V2 - 6BF6
V3, V4 - 6J6
V5 - 6C4
V6, V7 - 6AQ5
V8 - 5W4
V9 - 6AS7G
V10 - 12AX7
V11 - 0B2
V12 - 6AU6

frequency from 2000 to 2500 cycles. It was found that this discriminator has a linear output over a wider frequency range than the equipment first used. Its linear range is from about 2000 cycles to 2500 cycles when the center frequency is adjusted to 2250 Kc.

The power supply used is of the positive feedback regulator type, and furnishes 225 volts DC to the discriminator.

The input circuit designated by V12 on the diagram was added as an amplifier to increase the gain ahead of the discriminator and to allow the operators to reduce the audio signal level at the receiver and eliminate noise in the operation center. The second tube, which is designated as V1, Type 6AU6 is a limiter amplifier. It is adjusted to limit the output to a definite level, and it feeds into a high-Q audio filter which is shown by a choke number UTC-HQA12 and the associated condensers. The signal then feeds into V2, which is an audio amplifier and also a detector tube. The two diode plates incorporated in this tube are used to rectify the audio-frequency voltage and apply this to a meter which shows the signal level after filtering. This is necessary to show the operator that the sub-carrier frequency is in the right range as frequencies outside this range will not indicate above a certain low level on the meter. The stage designated by V3 is connected as a Schmitt-type trigger circuit. This stage is used to generate one short positive pulse per cycle from the audio-frequency of the sub-carrier. These single pulses are fed through the diode shaping circuit which comes out to test point 2 and into tube V4A. Tube V4A is connected as a univibrator. Each positive pulse of sufficient amplitude into V4A causes the tube to generate a single square pulse of a definite length. This pulse length is determined by the adjustment of the 50,000 ohm resistor shown connected at one end to the cathodes of V4 and at the other end to a 39,000 ohm resistor which is connected to the grid of



7 - 6AH6
12AT7
7 - 6AH6
7 - 6AS7
7 - 6C4
7 - 6Q5
7 - 3E29

enables the pen to move from one end of the chart to the other in aproxi-mately 1 second. The other is the extremely accurate paper movement which allows the operator to record the time accurately on the paper at long intervals such as a half hour. It has been found on runs of 6 to 8 hours that the paper error due to the change in paper speed was often less than 1 second and never over 2 or 3 seconds.

B. Communications Equipment

1. 100 Watt Transmitter.

At present a crystal-controlled transmitter with approximately 100 watts output power is used at the tracking center. The transmitter is shown in detail in drawing no. 3TH-162.

The Rothman modulation system is used. This modulator is novel due to the fact that it uses radio frequency output of the final amplifier in the transmitter to supply voltage for the screen-grid modulator. This system has several advantages. The component parts in the modulator are small, and the power used to supply the modulator is also small as compared to the 50% of average power output which must be supplied to a class B modulator when that is used. Radio frequency power from the final amplifier is picked up by the 4-turn coil shown in the diagram and is fed back to the plate in the second section of the type 6AS7 vacuum tube in the modulator. The plate of the first section of this tube and the cathode of the second section are connected to the screens of the 3E29 final output tube. The audio-frequency modulation is fed into the grid of the first half of the 6AS7. The principle of operation is that the audio frequency on the first grid of the 6AS7 changes the

impedence of this section of the tube to ground and therefore provides more or less loading on the 4-turn feedback coil which is connected to the final amplifier. Therefore, the screen is supplied with a sine wave of voltage which is similar or closely approximates the audio frequency which is fed into the amplifier of the modulator section.

This system appears to be linear, and the frequency range is much greater than needed. In fact, the low frequency limit is only controlled by the characteristics of the voltage amplifier preceding the modulator tube (type 6AS7) and could, of course, be direct coupled. The upper frequency limit appears to be around 40 KC.

The Rothman modulator transmitter is mounted in a relay rack, and the transmitter with its associated power supplies is shown in Appendix 2. The relay rack is placed close to a window on which lead-through insulators are placed to carry the power out to feed the antennas. Two types of antennas are used. One is a vertical whip, and the other is a flat-top half-wave antenna which is fed by a quarter wave matching line.

Prior to installation of the Rothman modulated transmitter, a type ATD transmitter, which has approximately 40 watts output power, was used for communications on 6420 KC.

2. Receiving Equipment.

The receiver used for communications is an PRO-50T1. The antenna used with this receiver consists of 6 wires, approximately one wave length at 6420 KC, which run from the top of a 40-foot tower to a terminating resistor of about 500 ohms on the ground. Two adjacent antennas are used at once to form a V-type antenna. A switching system has been arranged using a Ledex stepping switch so that

any pair of antennas may be used. An indicator using a similar stepping switch is installed at the operating position so that the operator knows which V antenna he is using. It is found that this type of antenna has considerable gain and that it reduces interfering signals from other directions.

3. Direction Finding Equipment.

A type DAQ automatic direction finder has been installed in the tracking center. Its antenna is located on a 40-foot windmill tower which was erected adjacent to the tracking center building. The equipment at present is operating. However, the calibration has not been completed.

4. Panoramic Receiver.

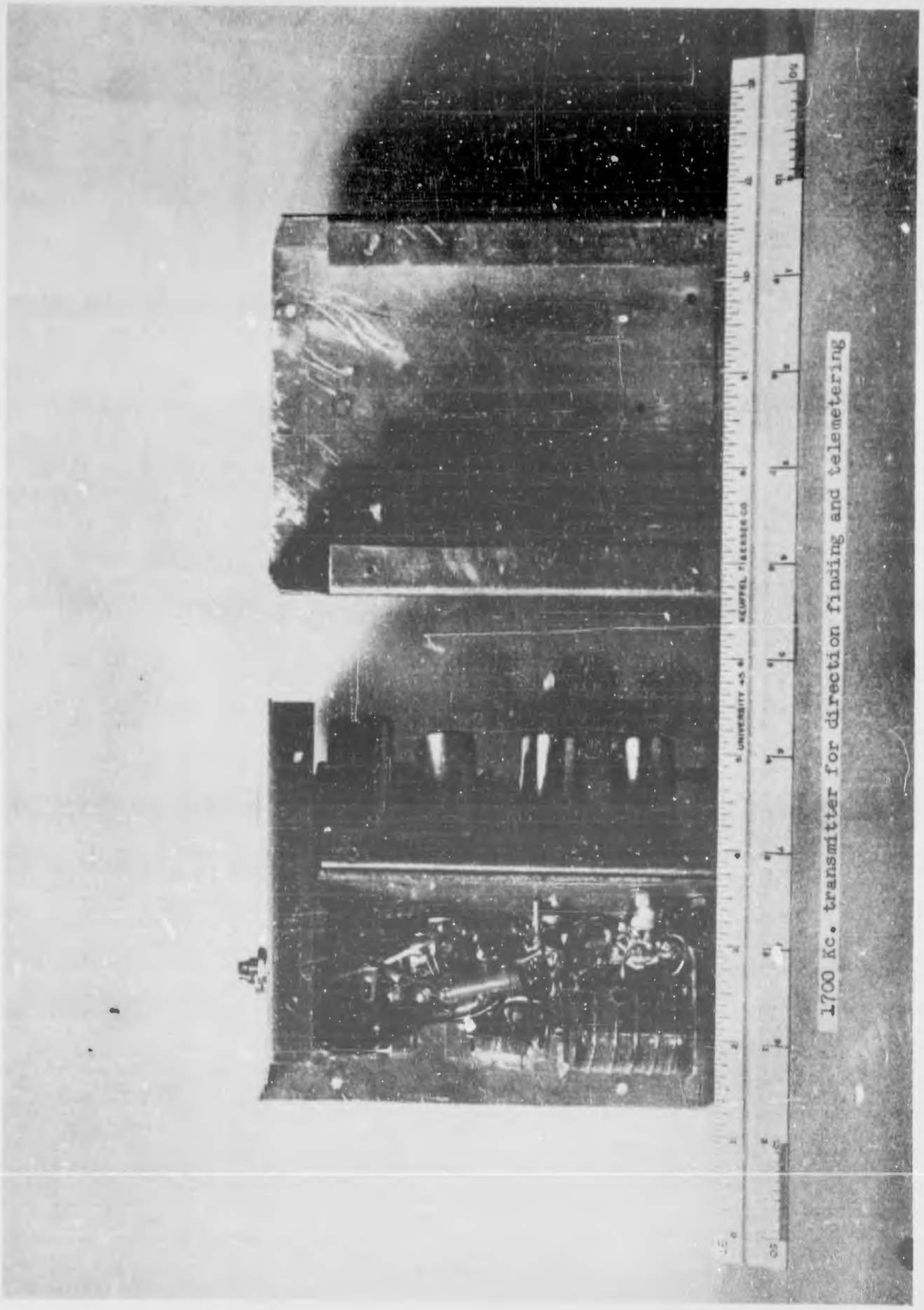
There is also installed in the tracking center a panoramic receiver which has a frequency range of 4 megacycles to 28 megacycles. This is type RCD equipment. It is found to be useful for certain applications such as picking out one signal from other interfering signals, although it is found that this equipment is not as satisfactory for ordinary communication work as the HRO.

APPENDIX II

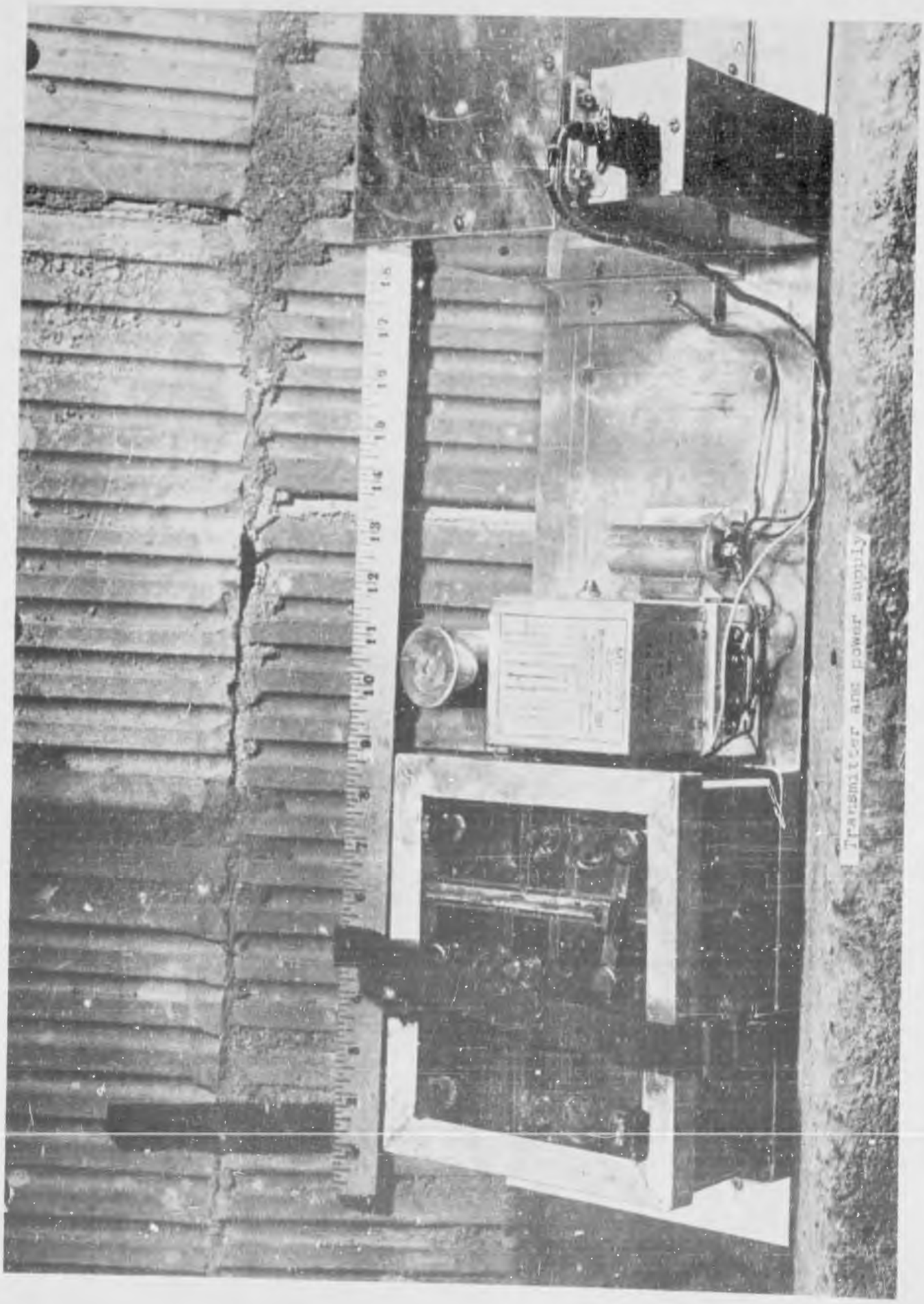
INSTRUMENTATION AND TELEMETERING

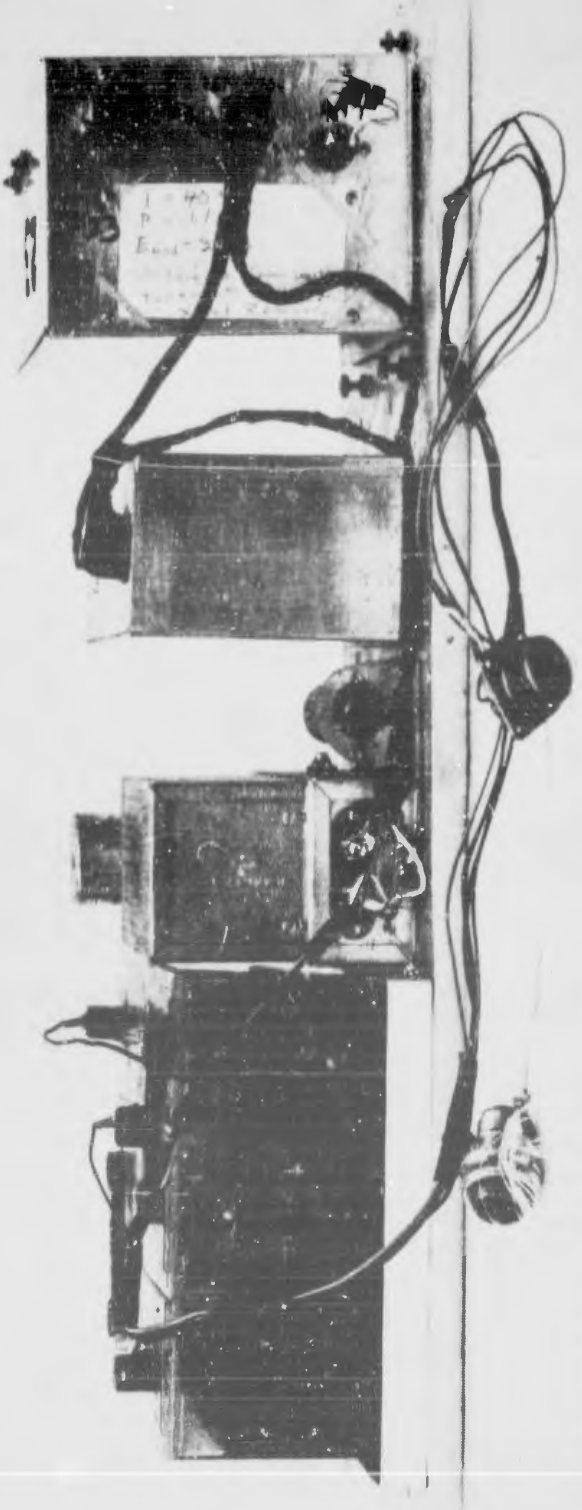
This appendix contains photographs of the various standard equipment used in flights. Included are photographs of the antenna dropper, low frequency transmitter, clock timer, blowdown box, flasher beacon, Olland cycle modulator, multiple stack recorder, command receiver, crown camera, up and down cameras, ballast gondola, telemetering discriminators and receivers, and recorders. Also included are block diagrams and photographs of most of the gondolas flown in the present series of twenty flights.

Antenna crimper mechanism, left, and mounting case, right. The tape around the wound-up antenna is removed before launching.

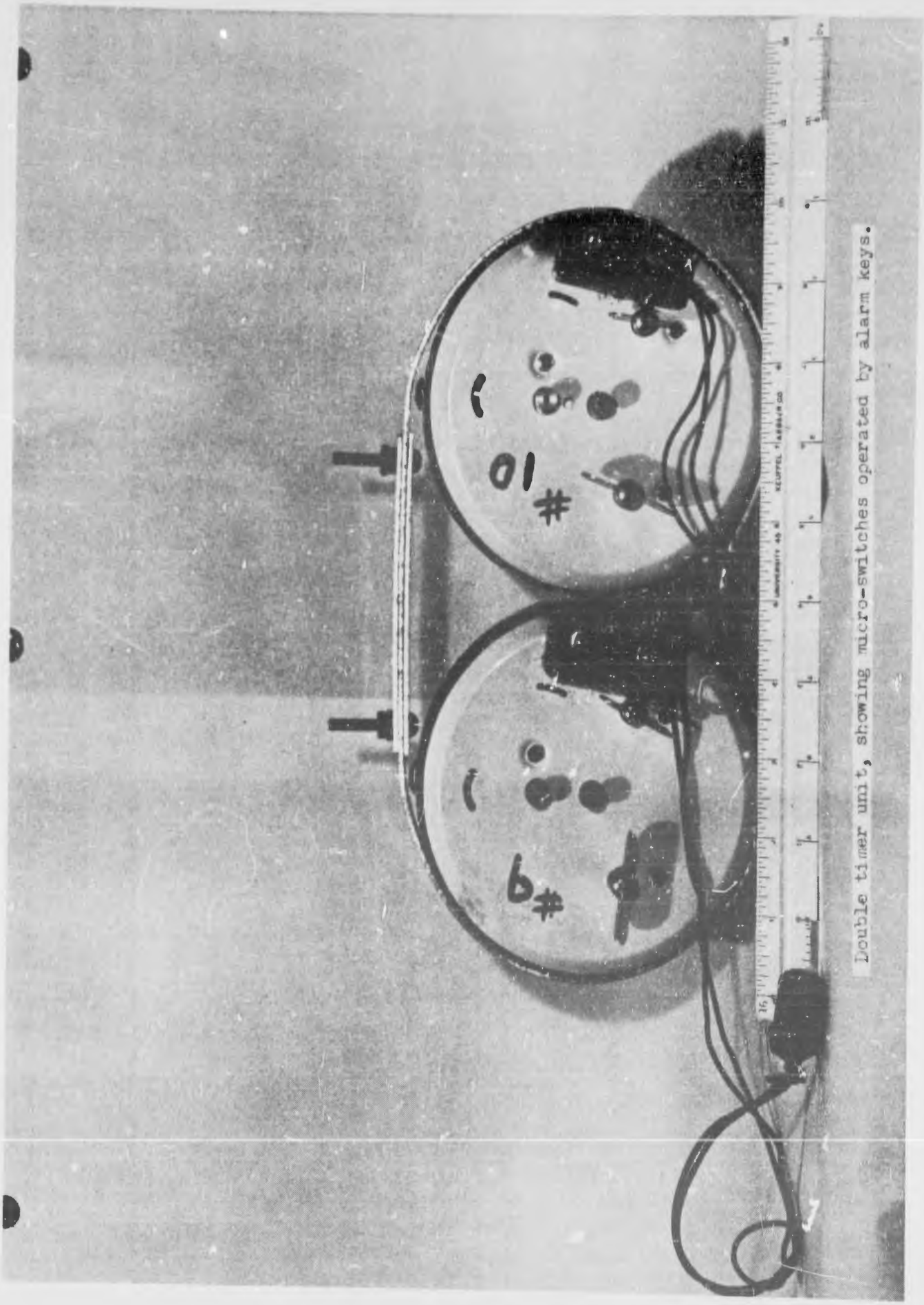


1700 Kc. transmitter for direction finding and telemetering


Transmitter and power supply



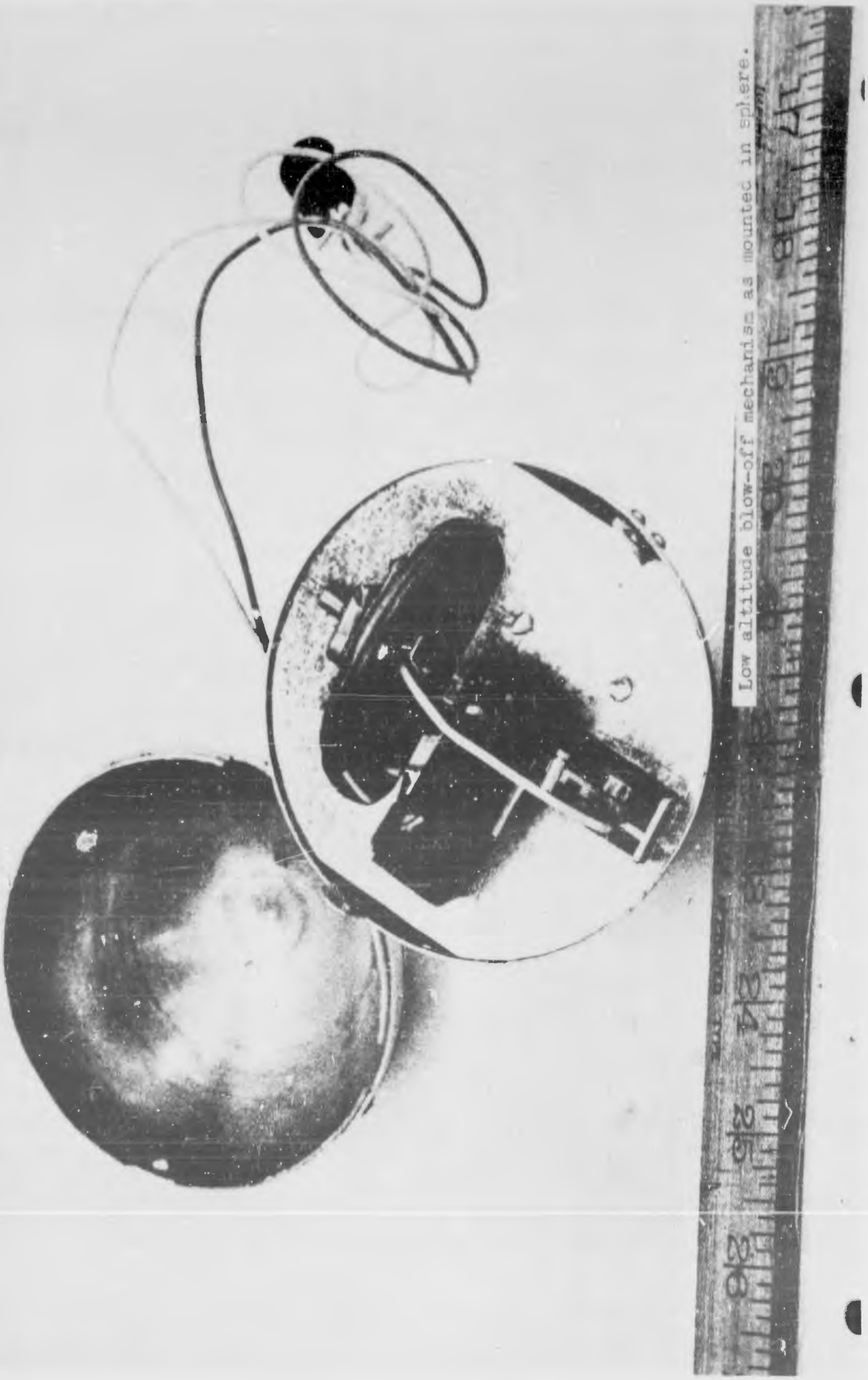
Transmitter, right, power supply, left, showing Ollard cycle mounted at right center.



Double timer unit, showing micro-switches operated by alarm keys.

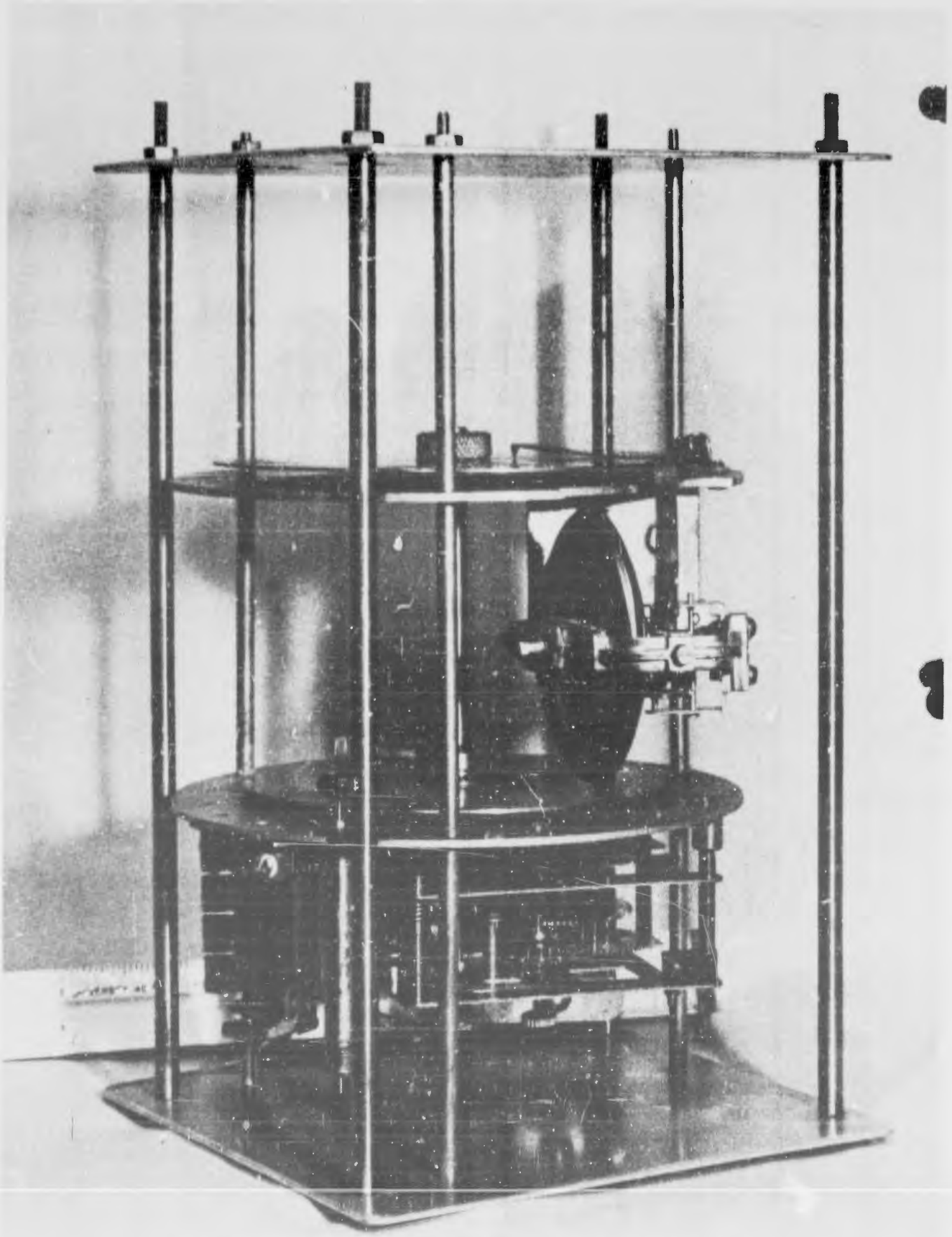
Blow-down box used on later flights showing low altitude blow-down, lower left, thermal delay relay, top left, and squib batteries in case at right.

Two types of flasher beacons, both equipped with low altitude cut-in switches.

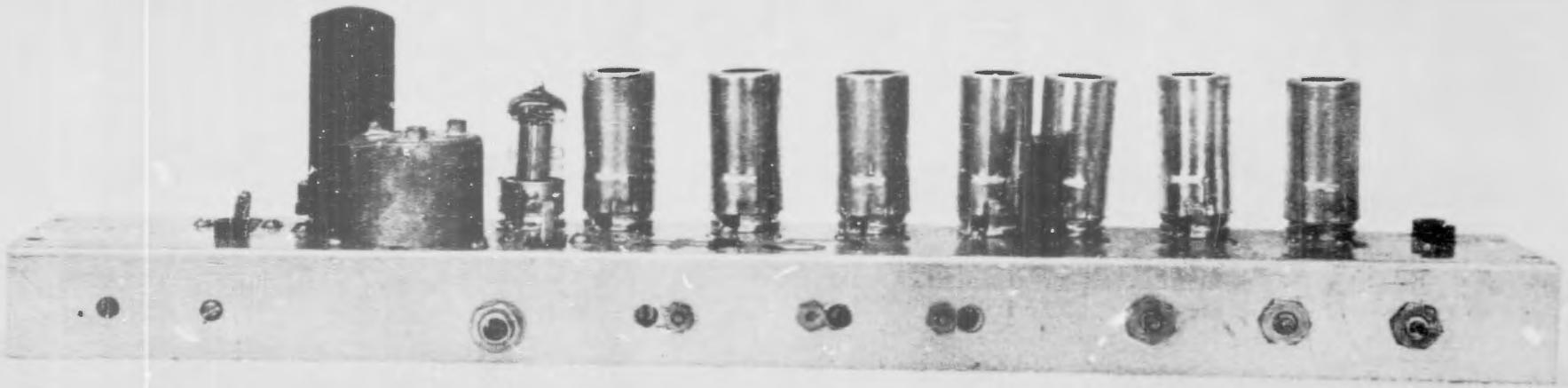


Low altitude blow-off mechanism as mounted in sphere.

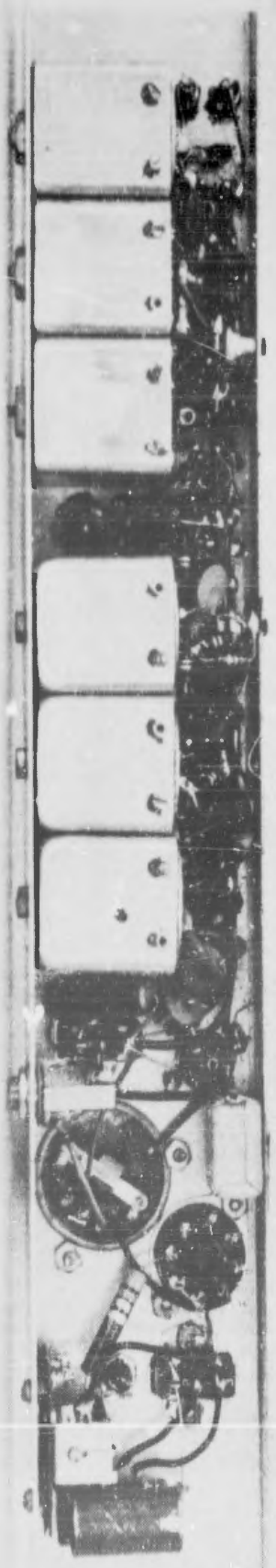
Fig. 1. The Ireland rotor drives the helix at 1,200 r.p.m. The angle arm is operated by the solenoid drive at right.



Baro-thermograph. The bi-metallic element at lower left records on the lower disc. The barograph records on the upper.

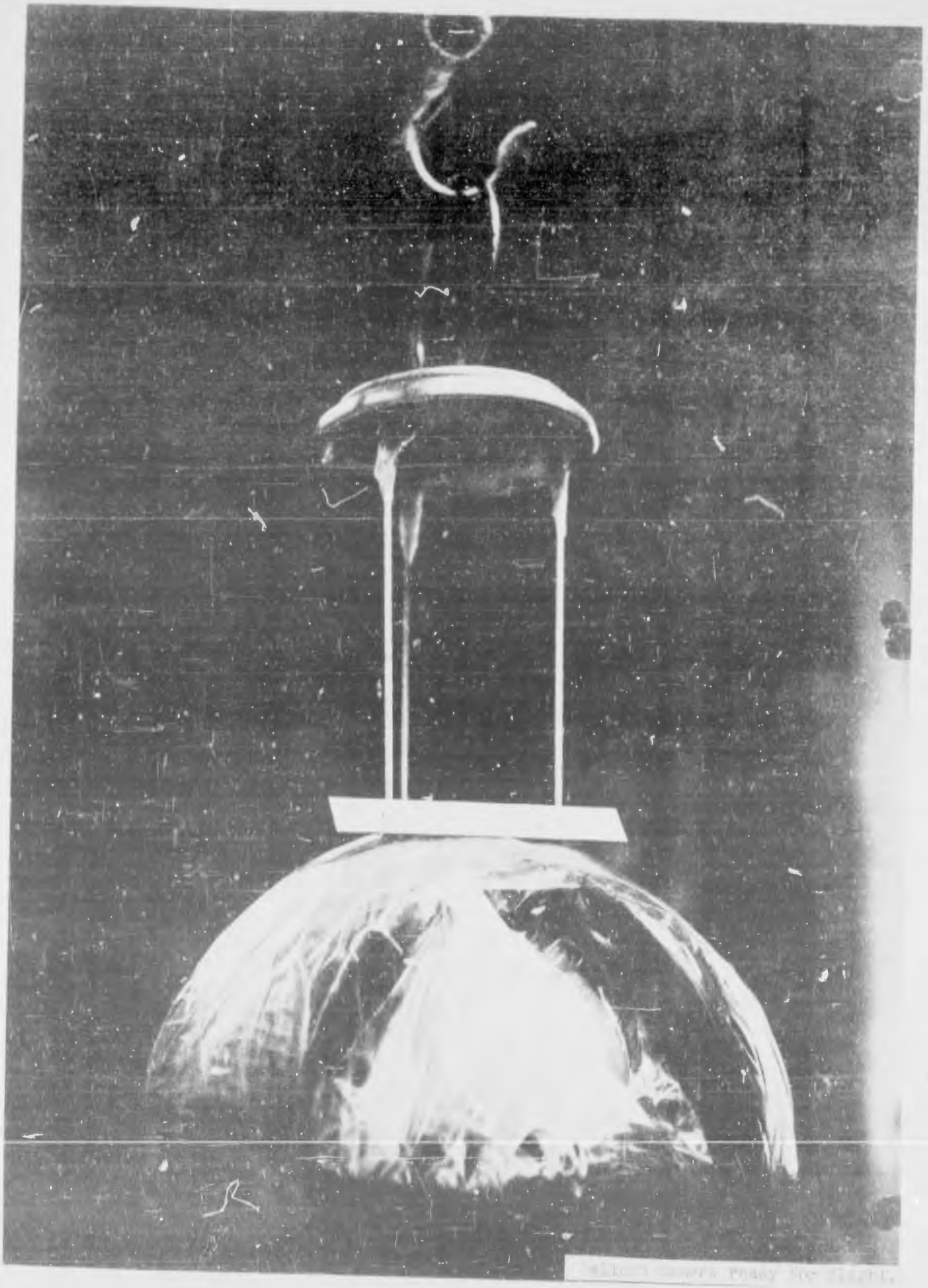


Superheterodyne command receiver showing resonant relay at left end and crystal for local oscillator at right center.

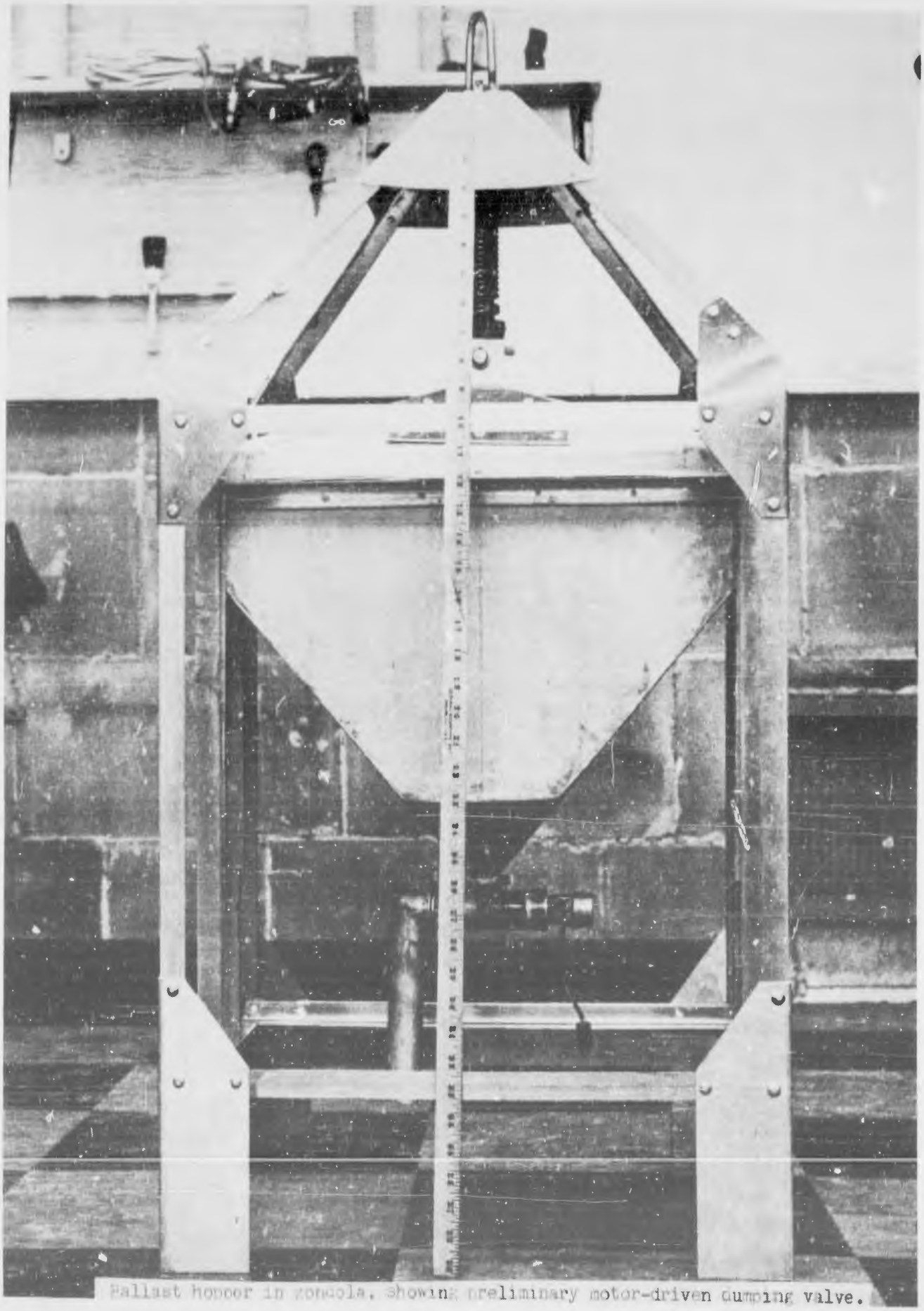


Under-chassis view of command receiver.

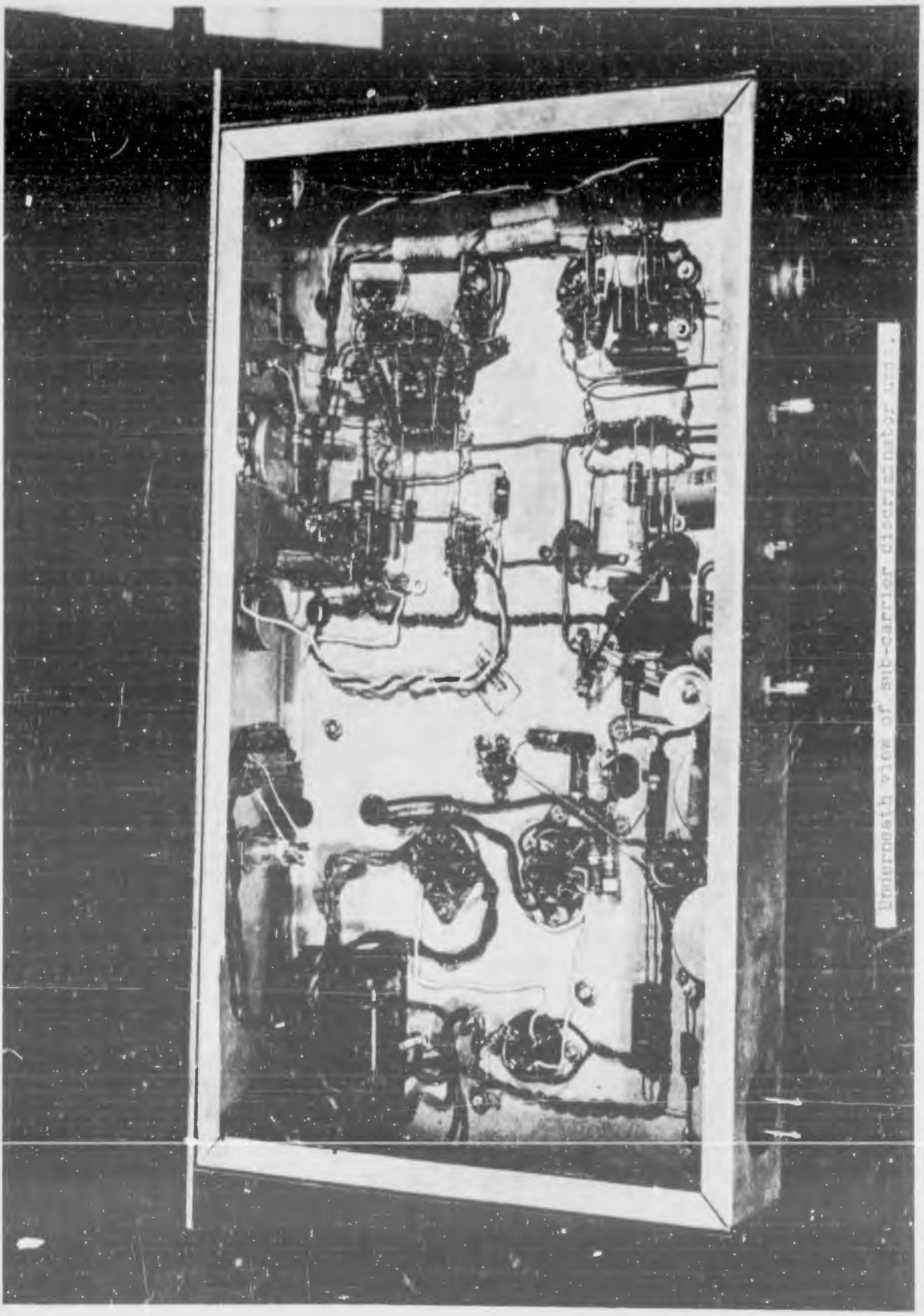
Automatic camera for photographing balloon interior, shown connected to balloon top-ring unit.



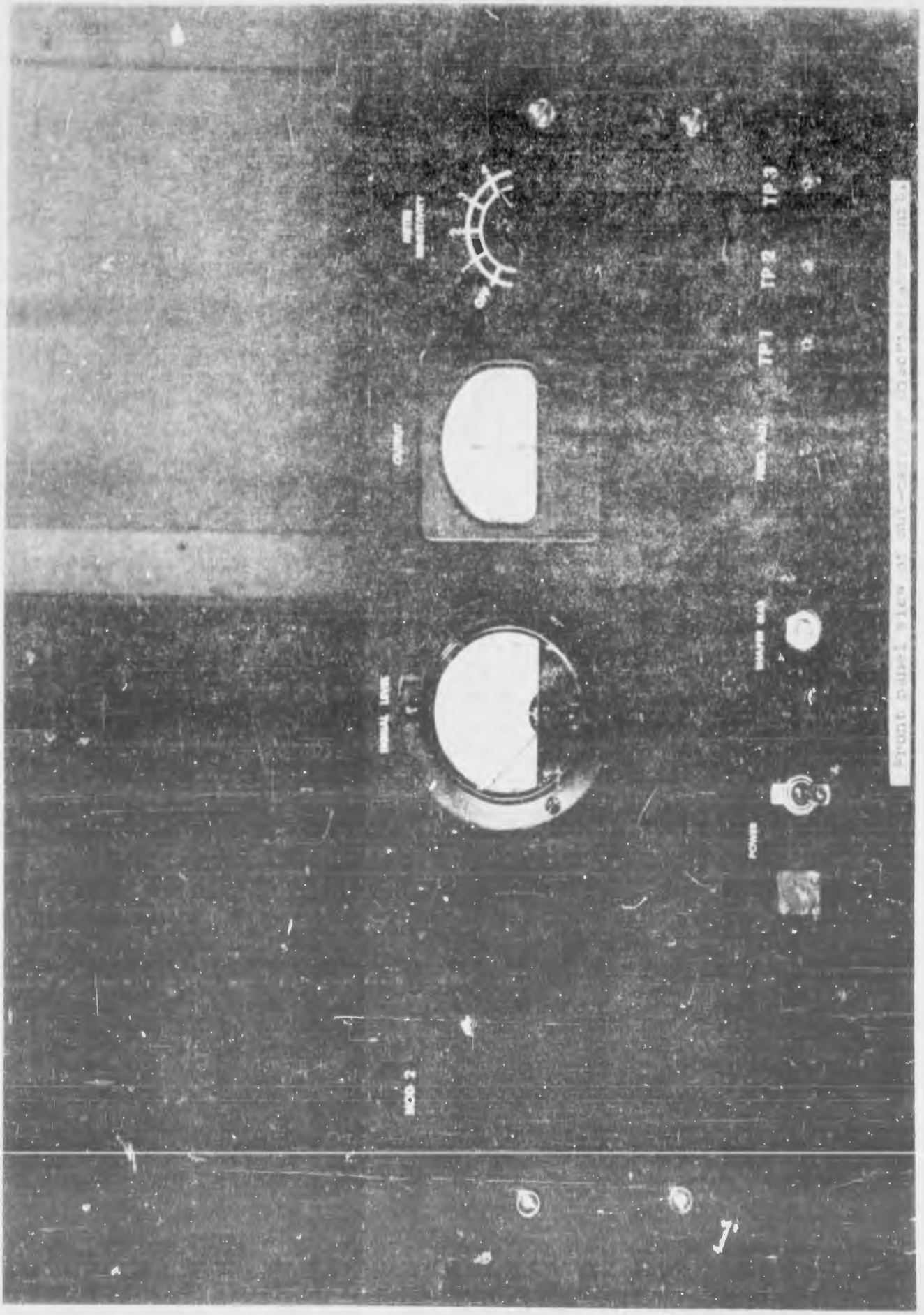
Automatic camera for photographing the ground(left), and for photographing balloon from below(right).

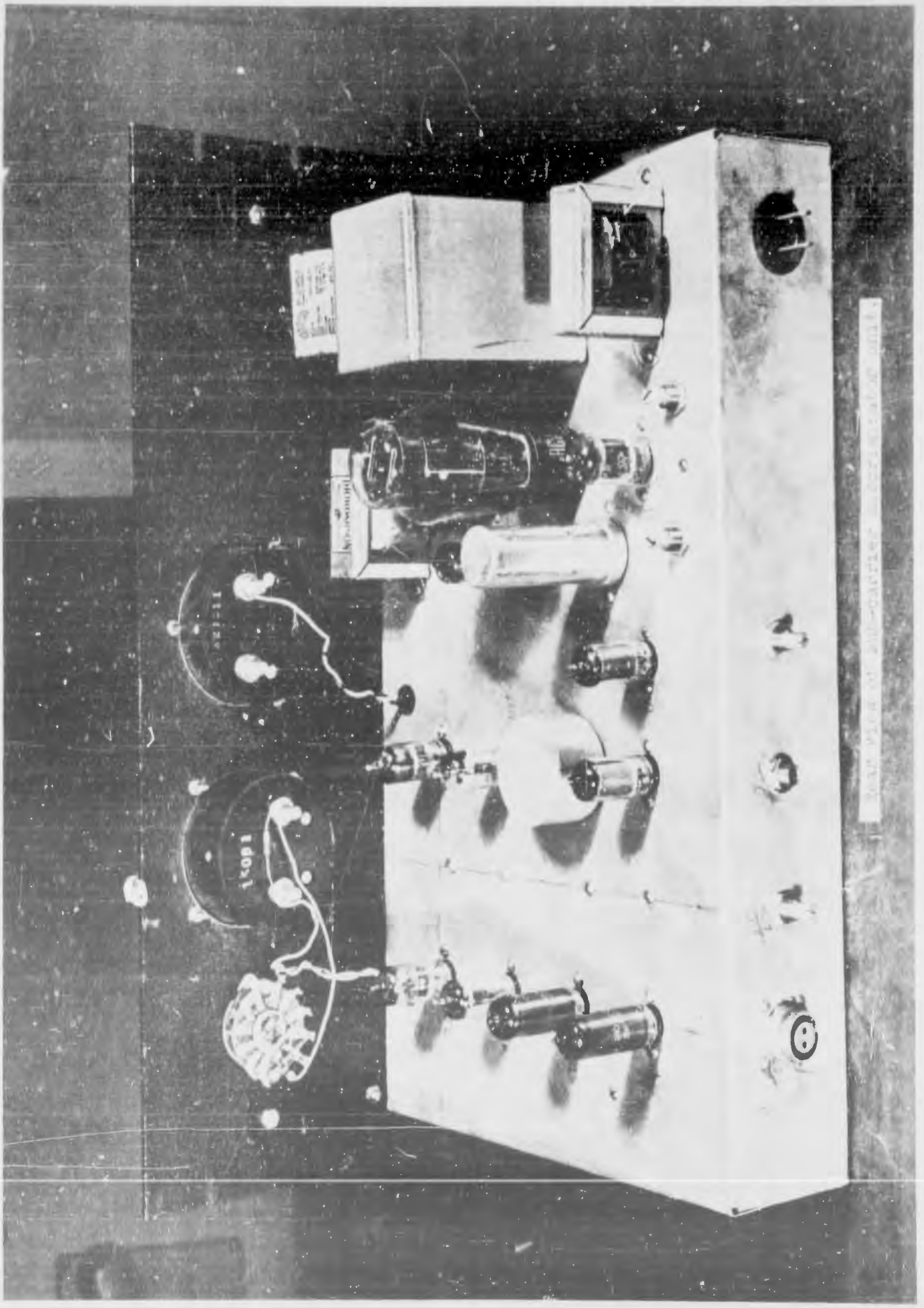


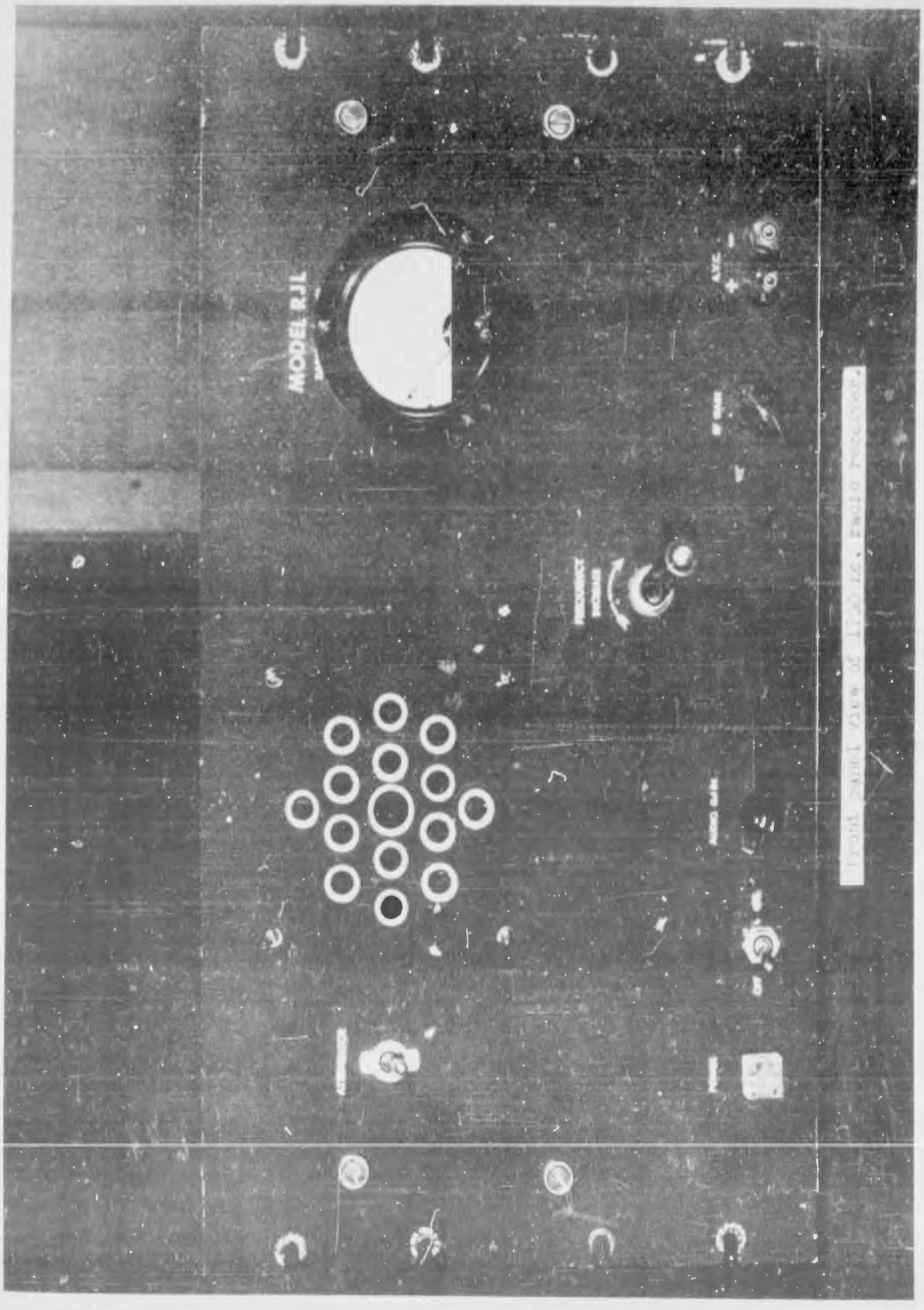
Ballast hopper in gondola, showing preliminary motor-driven dumping valve.

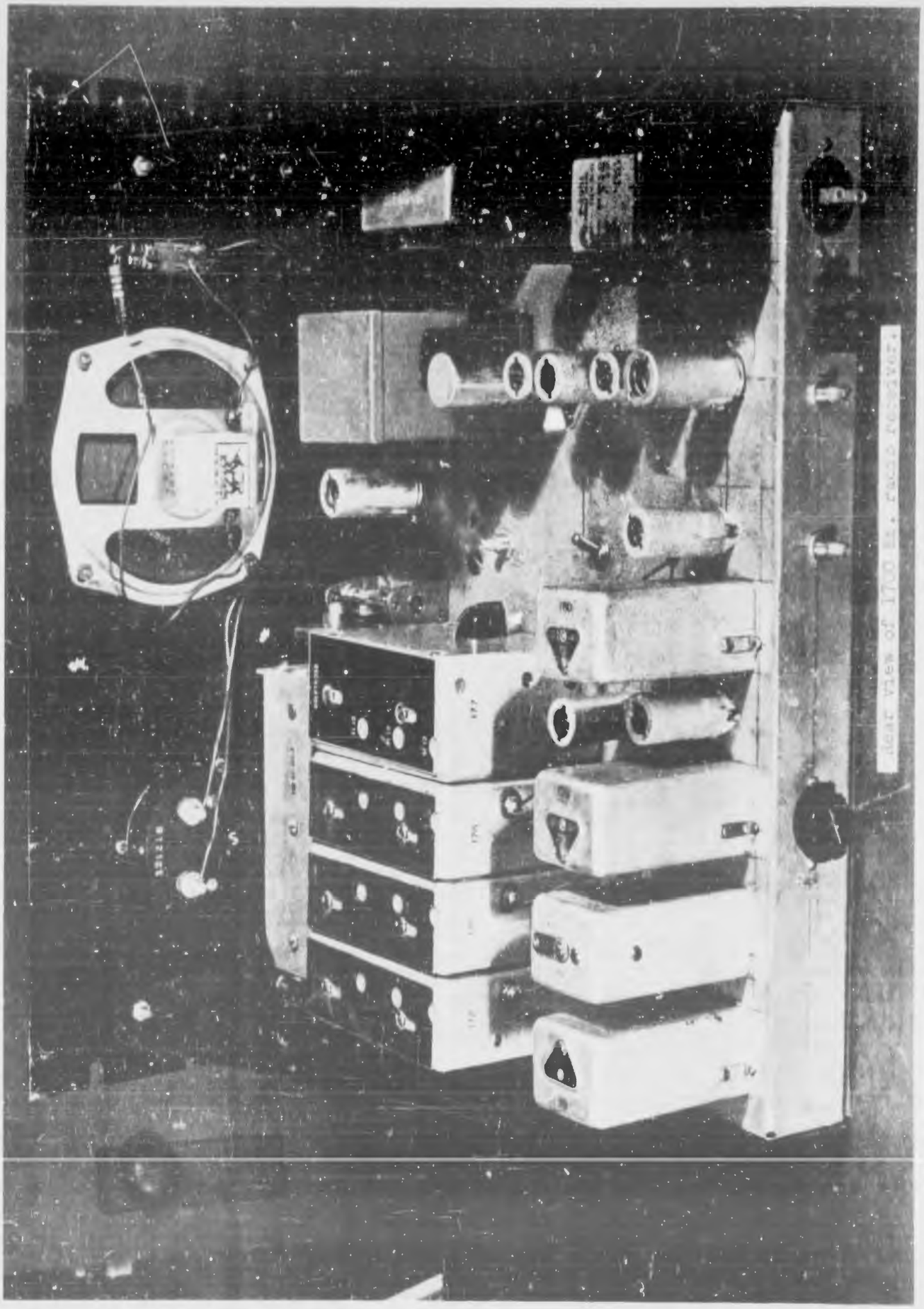


Underneath view of six-carrier discriminator unit.

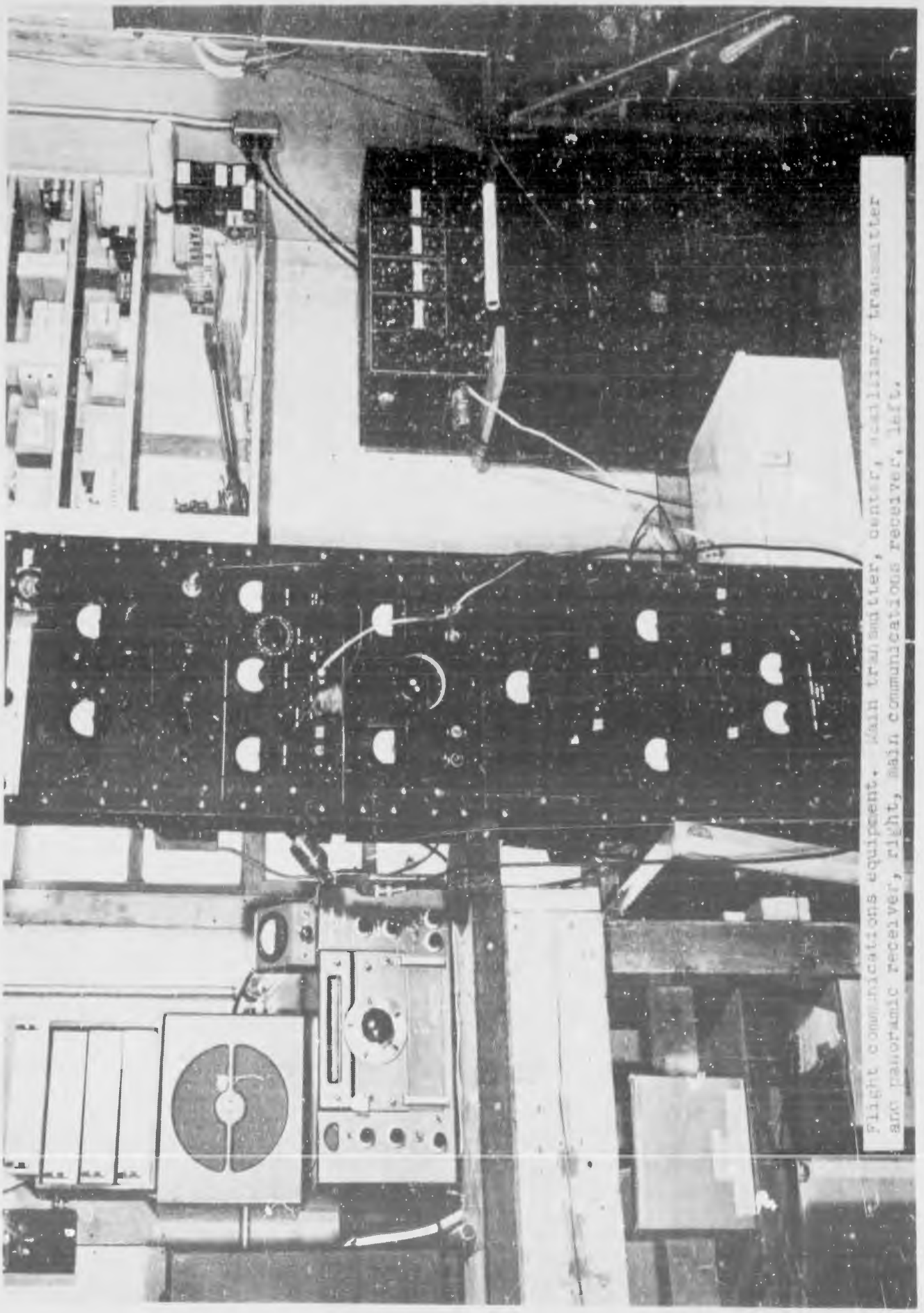

TP1
TP2
TP3
POWER



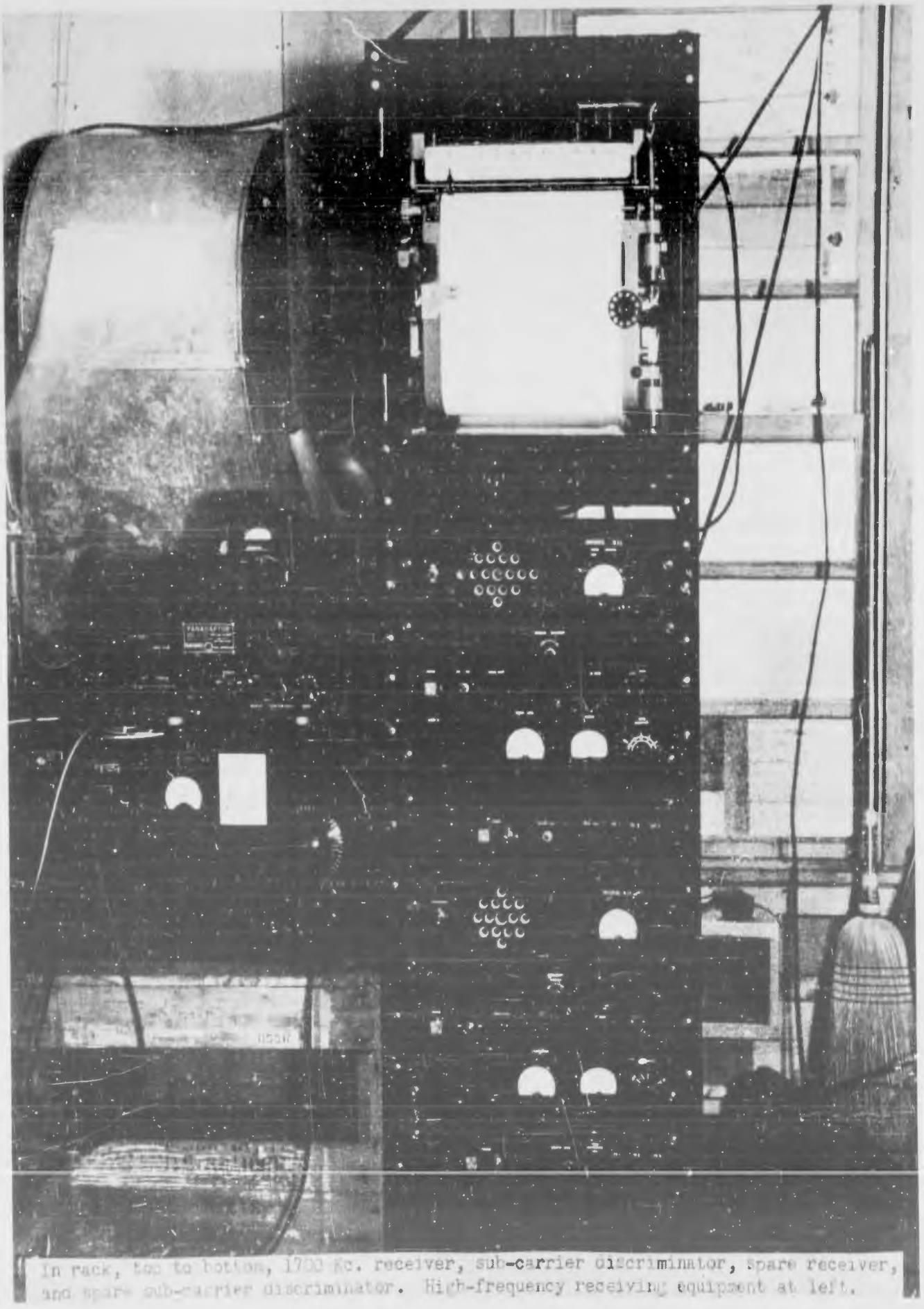

MODEL RJL



Rear view of ITO-1, radio room.



Flight communications equipment. Main transmitter, center, auxiliary transmitter and panoramic receiver, right, main communications receiver, left.



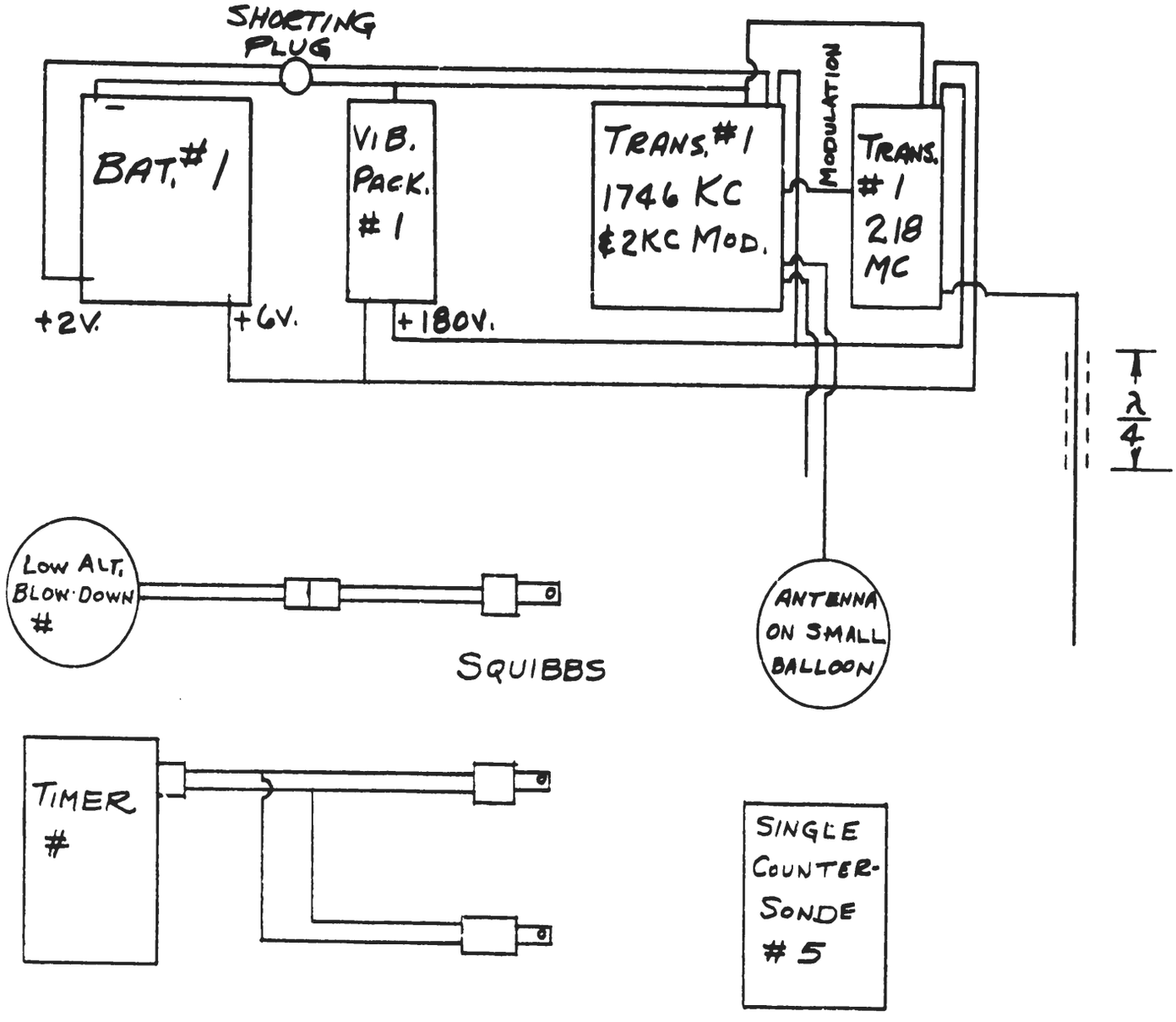
In rack, top to bottom, 1700 Kc. receiver, sub-carrier discriminator, spare receiver, and spare sub-carrier discriminator. High-frequency receiving equipment at left.



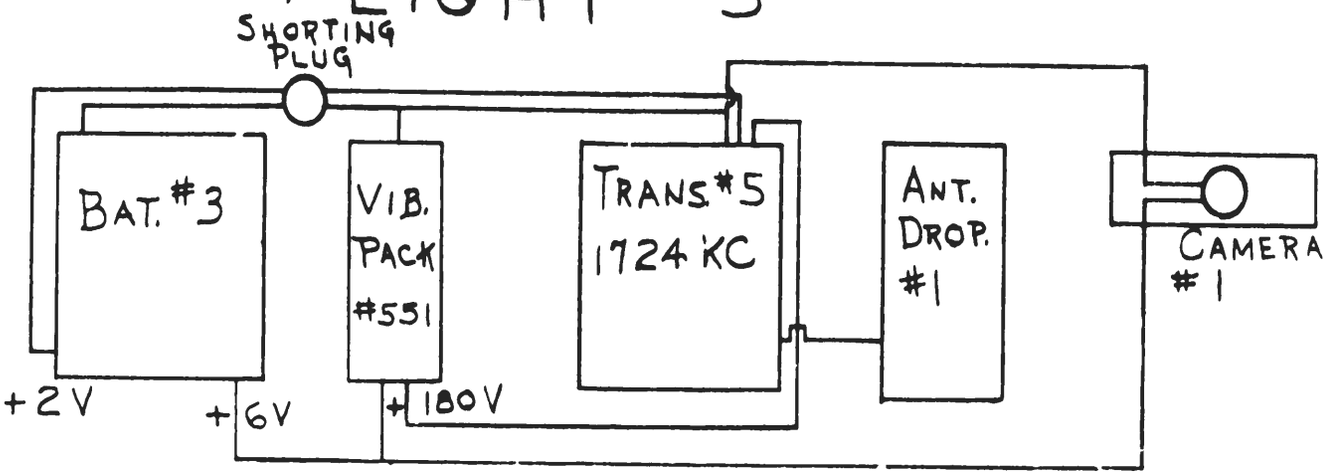
Balloon inflation and instrumentation for Flight #3.

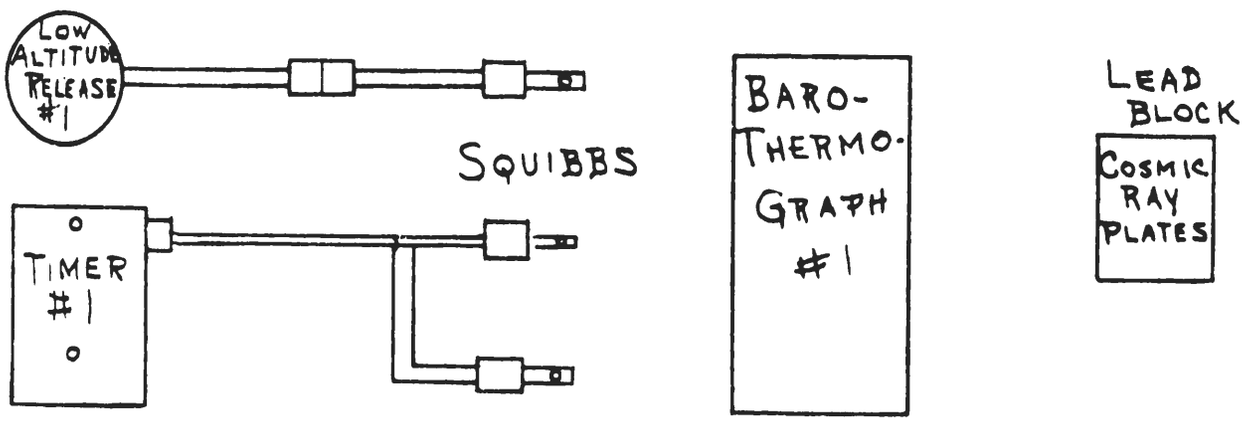
Instrumentation as returned from Flight #3.

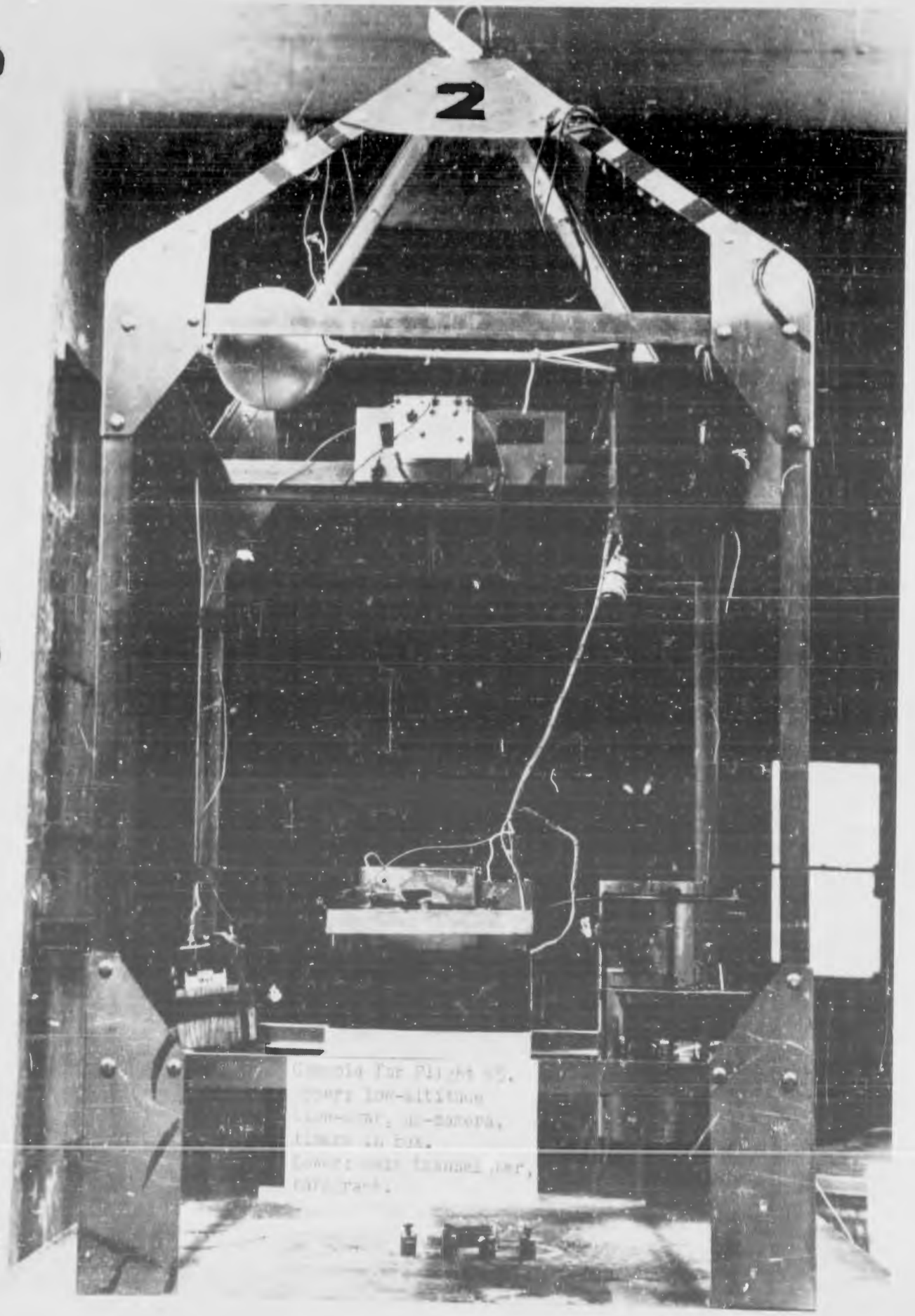
FLIGHT #4


SHORTING PLUG
BAT. #1
VIB. PACK. #1
TRANS. #1 1746 KC ±2KC MOD.
MODULATION
TRANS. #1 218 MC
+2V.
+6V.
+180V.
λ/4
LOW ALT. BLOW-DOWN #
SQUIBBS
ANTENNA ON SMALL BALLOON
TIMER #
SINGLE COUNTER-SONDE #5

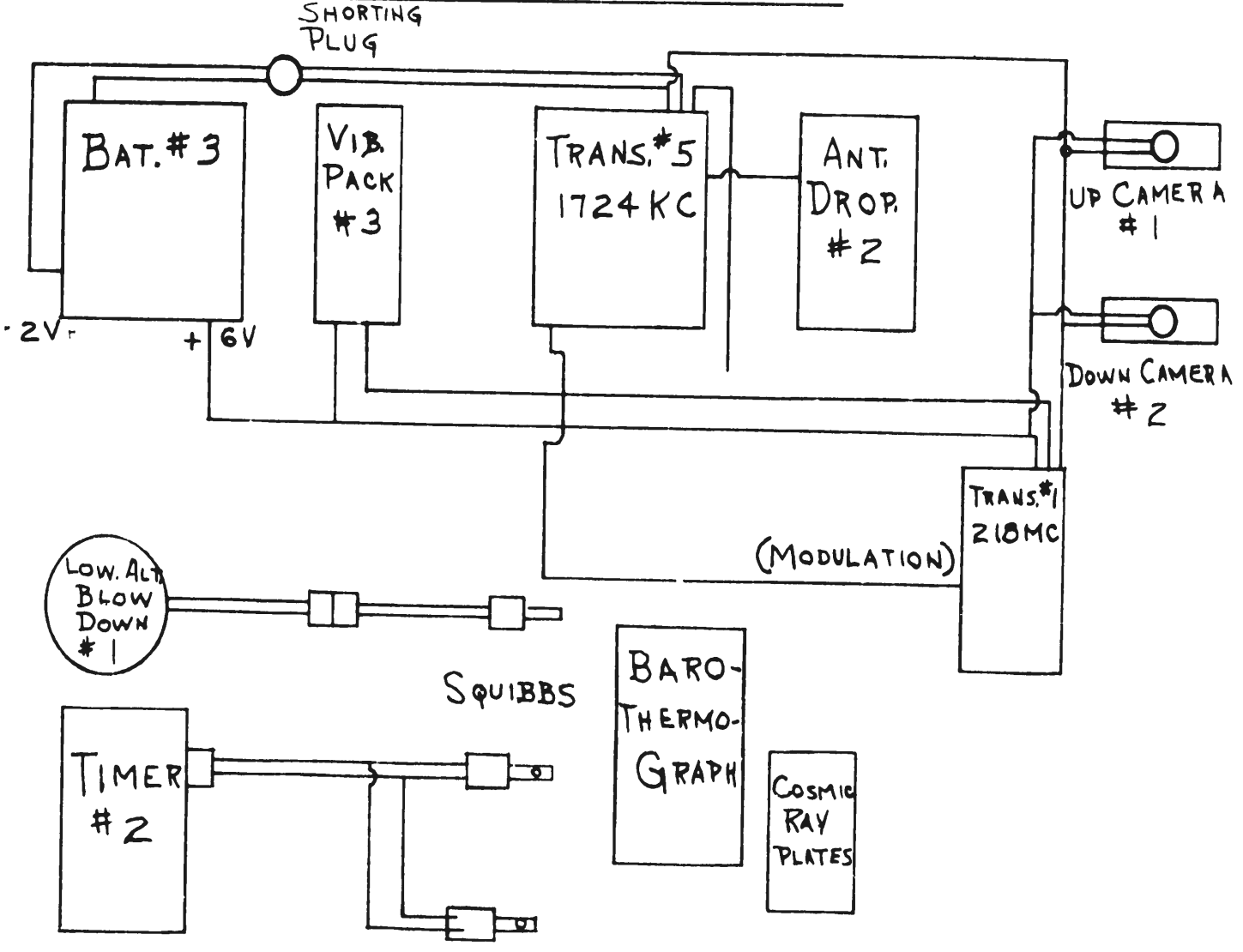
FLIGHT # 5

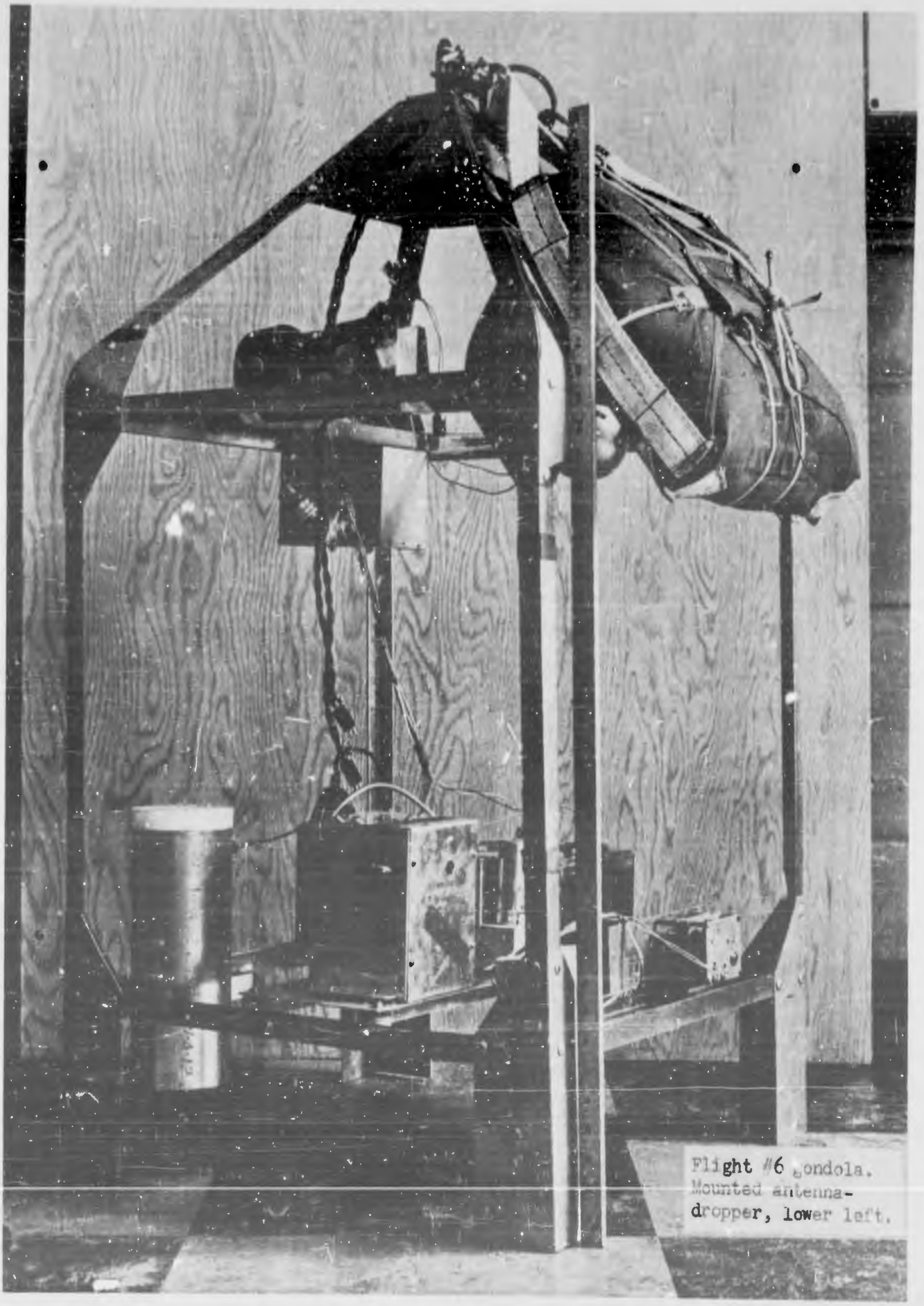

SHORTING PLUG
BAT. #3
VIB. PACK #551
TRANS. #5 1724 KC
ANT. DROP. #1
CAMERA #1
+2V
+6V
+180V


LOW ALTITUDE RELEASE #1
SQUIBBS
TIMER #1
BARO-THERMO-GRAPH #1
LEAD BLOCK
COSMIC RAY PLATES


2

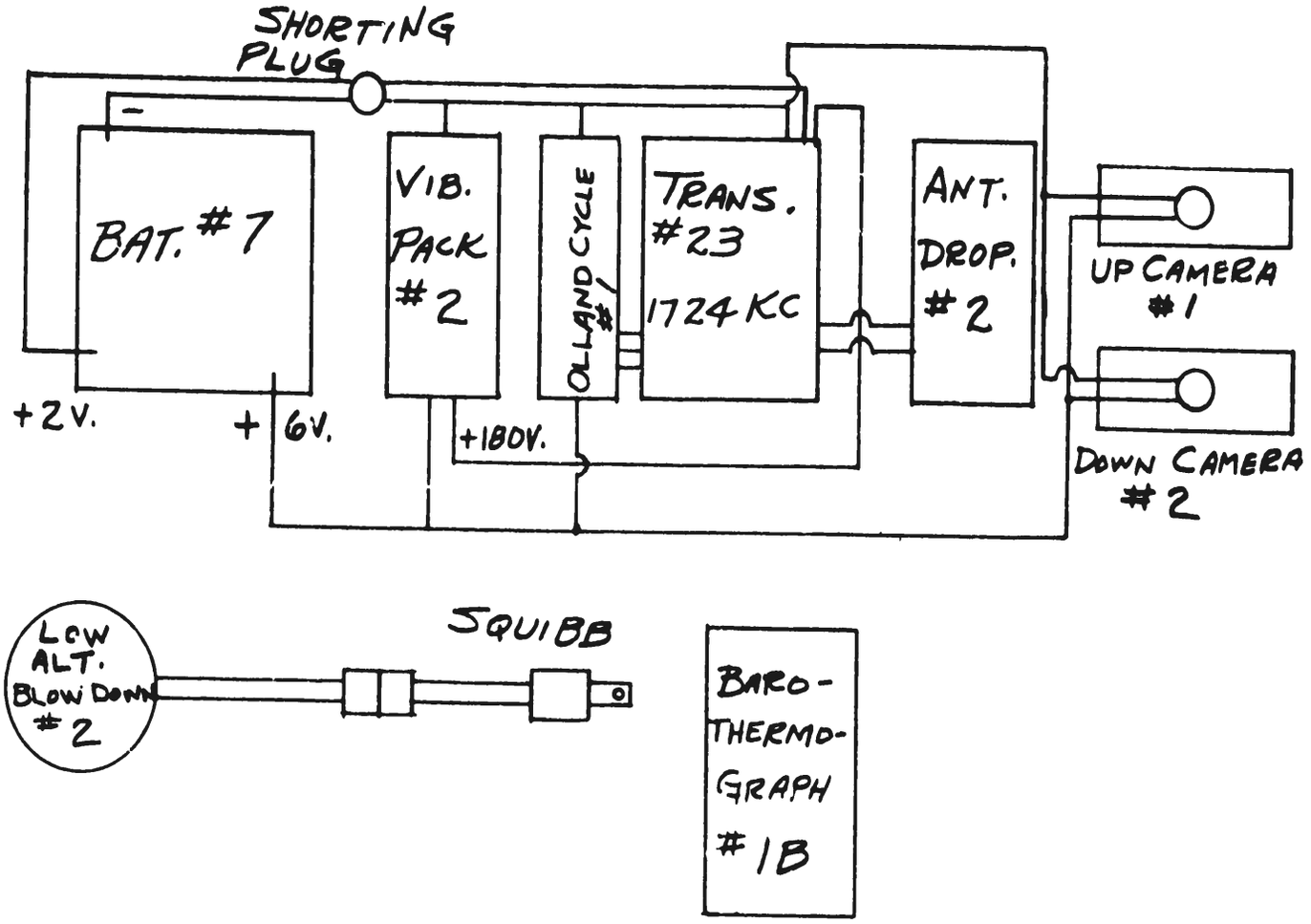
FLIGHT #6


SHORTING PLUG
BAT. #3
VIB. PACK #3
TRANS. #5 1724 KC
ANT. DROP. #2
UP CAMERA #1
DOWN CAMERA #2
-2V
+6V
TRANS. #1 218 MC
(MODULATION)
LOW. ALT. BLOW DOWN #1
SQUIBBS
BARO-THERMO-GRAPH
COSMIC RAY PLATES
TIMER #2

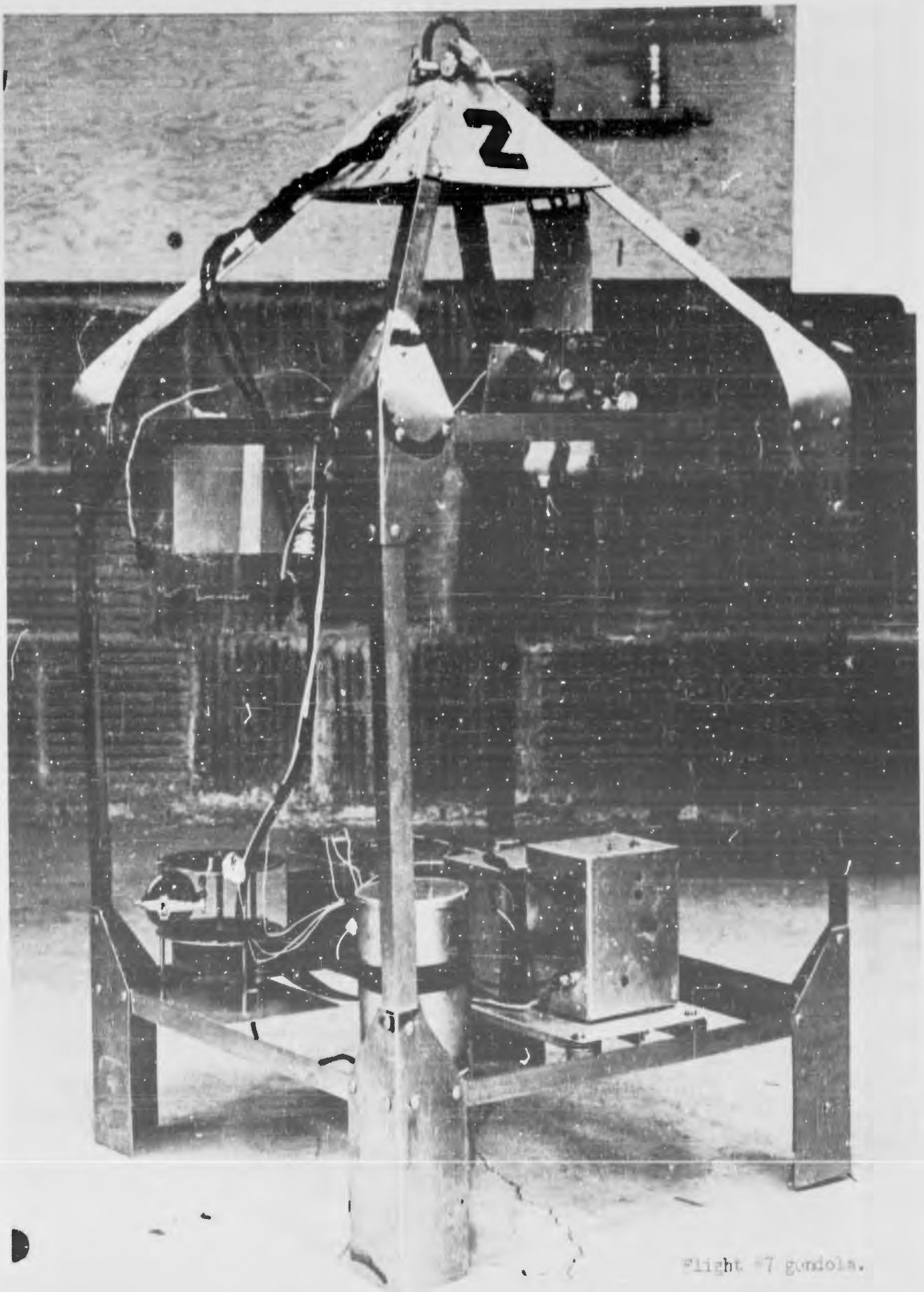


Flight #6 gondola. Mounted antenna-dropper, lower left.

FLIGHT #7

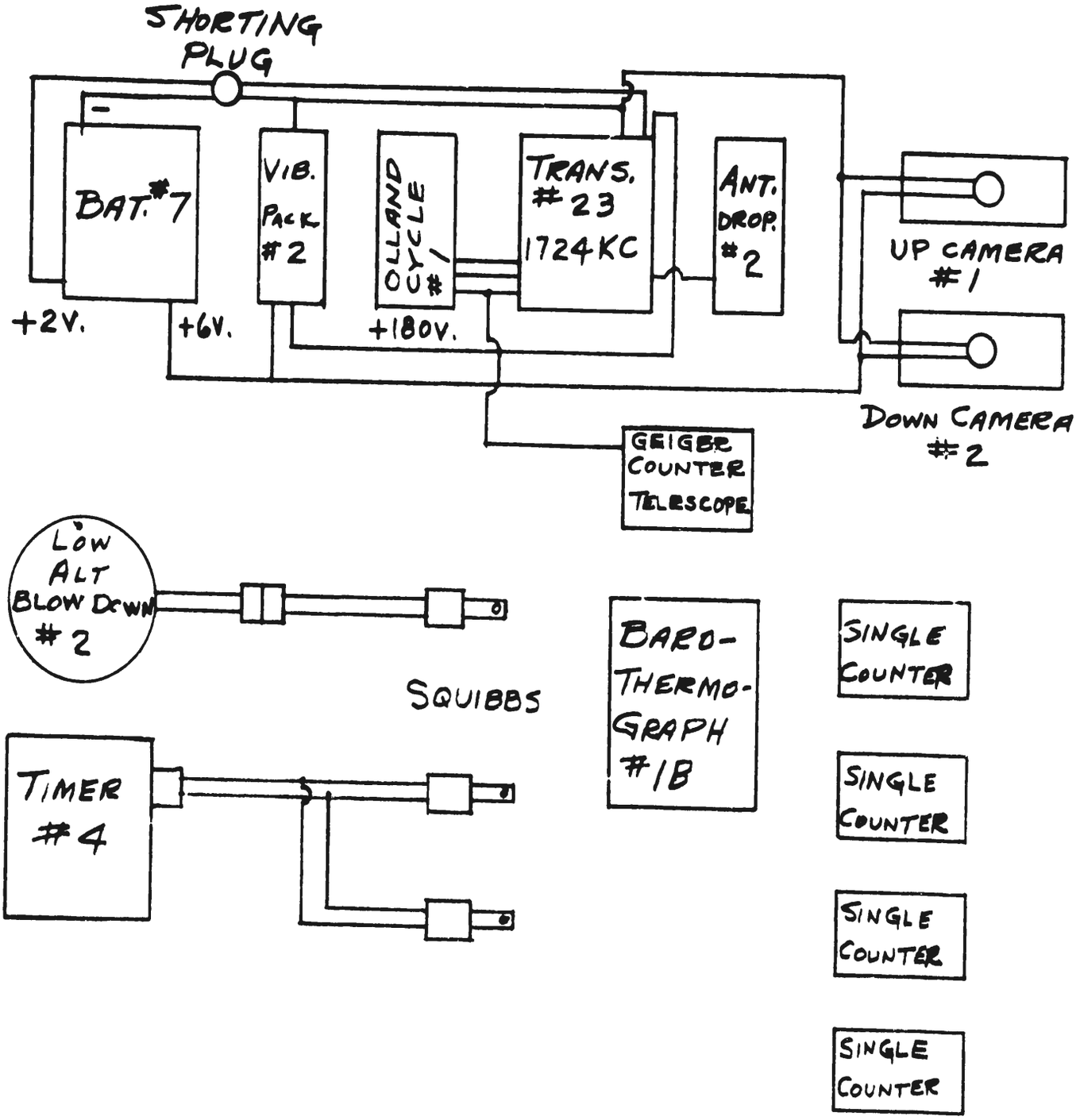


BARO-THERMO-GRAPH #1B

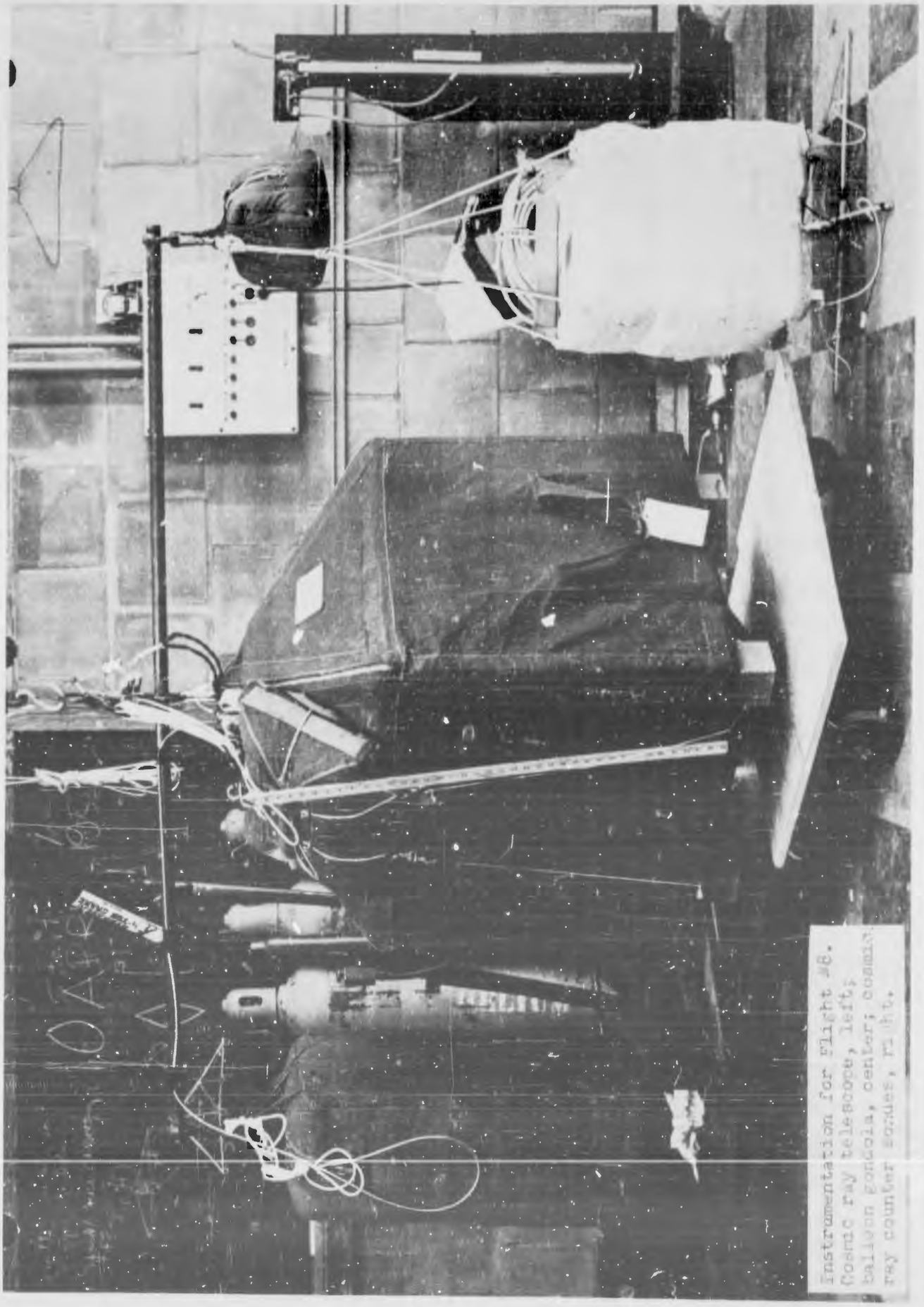


Flight #7 gondola.

FLIGHT #8

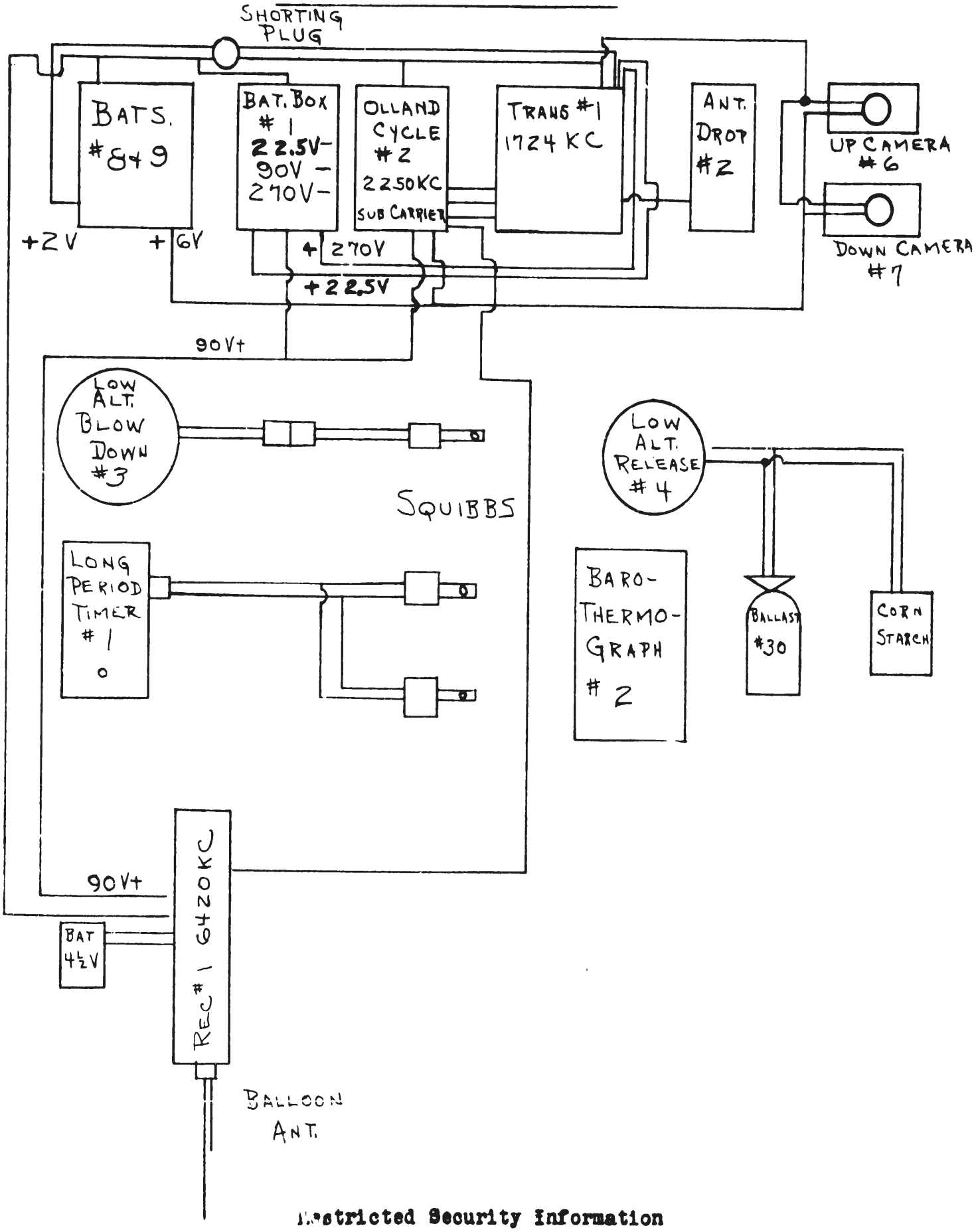


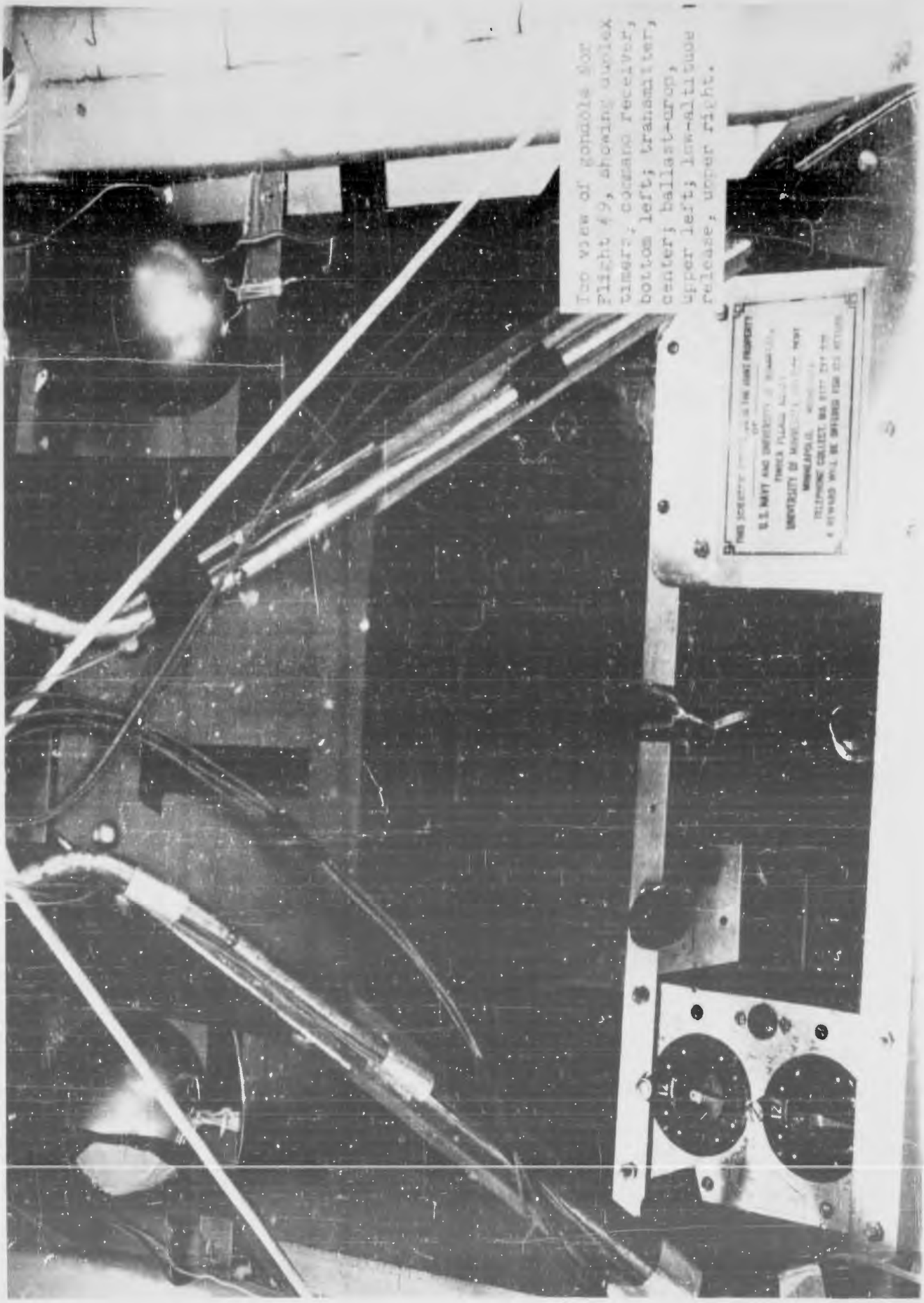
Restricted Security Information



Instrumentation for Flight #6.
Cosmic ray telescope, left;
balloon gondola, center; cosmic
ray counter boxes, right.

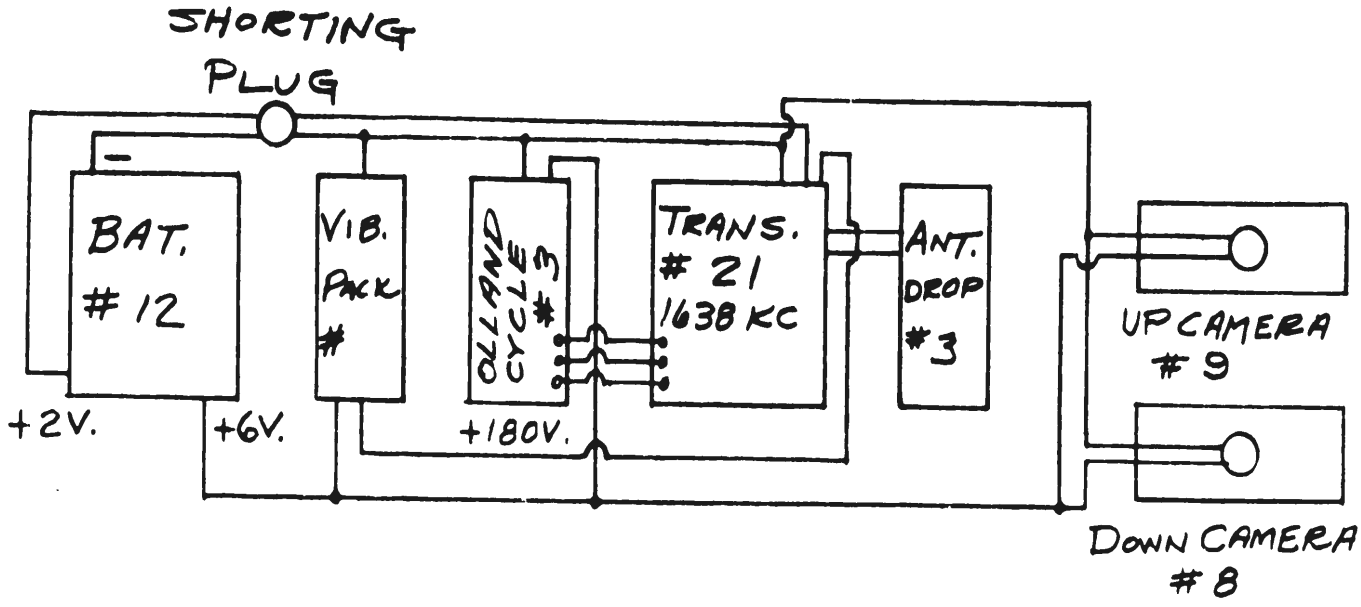
FLIGHT #9

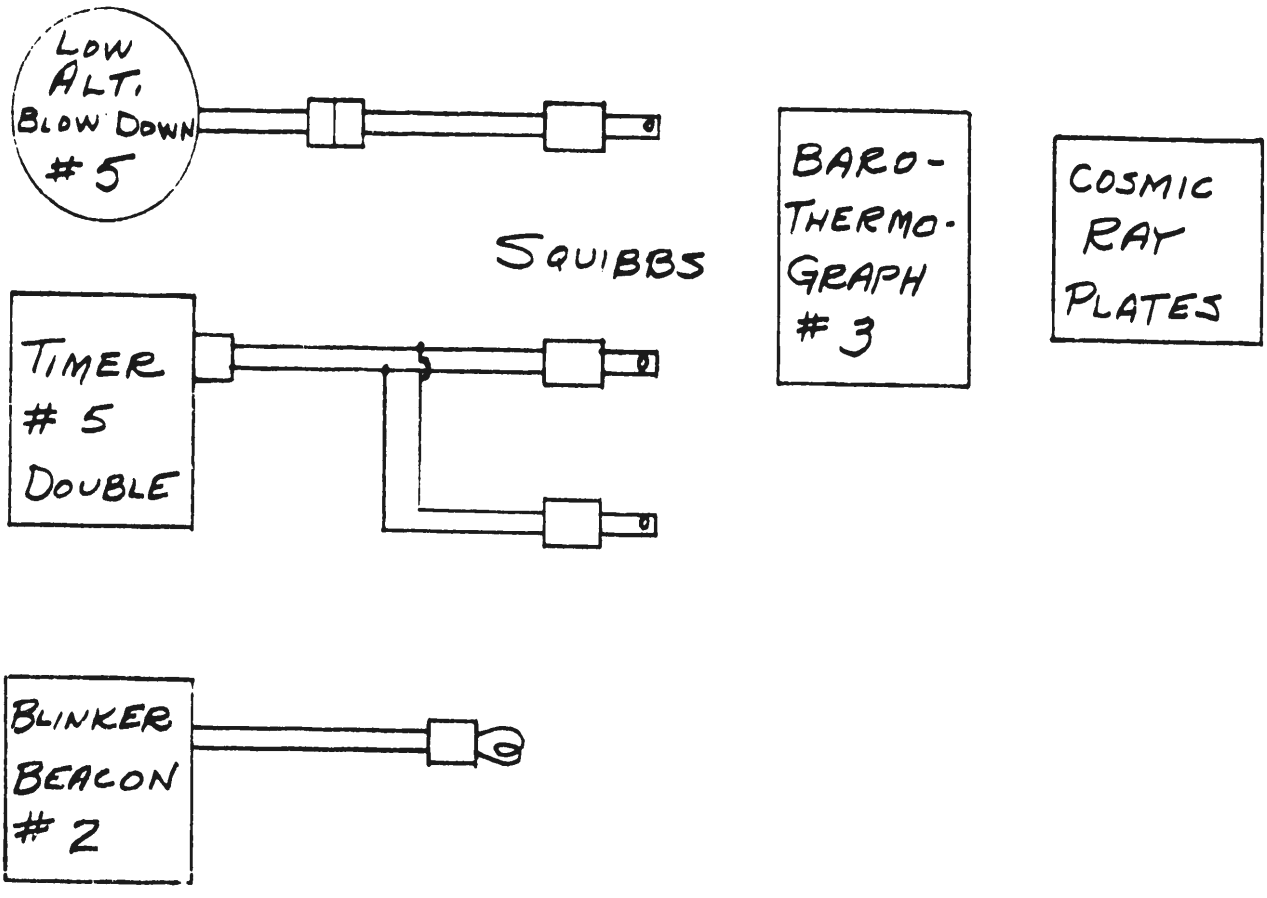

SHORTING PLUG
BATS. #8 & 9
+2V
+6V
BAT. BOX #1
22.5V-
90V -
270V-
OLLAND CYCLE #2
2250KC
SUB CARRIER
TRANS #1
1724 KC
ANT. DROP #2
UP CAMERA #6
DOWN CAMERA #7
+270V
+22.5V
90V+
LOW ALT. BLOW DOWN #3
SQUIBBS
LOW ALT. RELEASE #4
LONG PERIOD TIMER #1
BARO-THERMO-GRAPH #2
BALLAST #30
CORN STARCH
90V+
BAT 4½V
REC #1 6420 KC
BALLOON ANT.

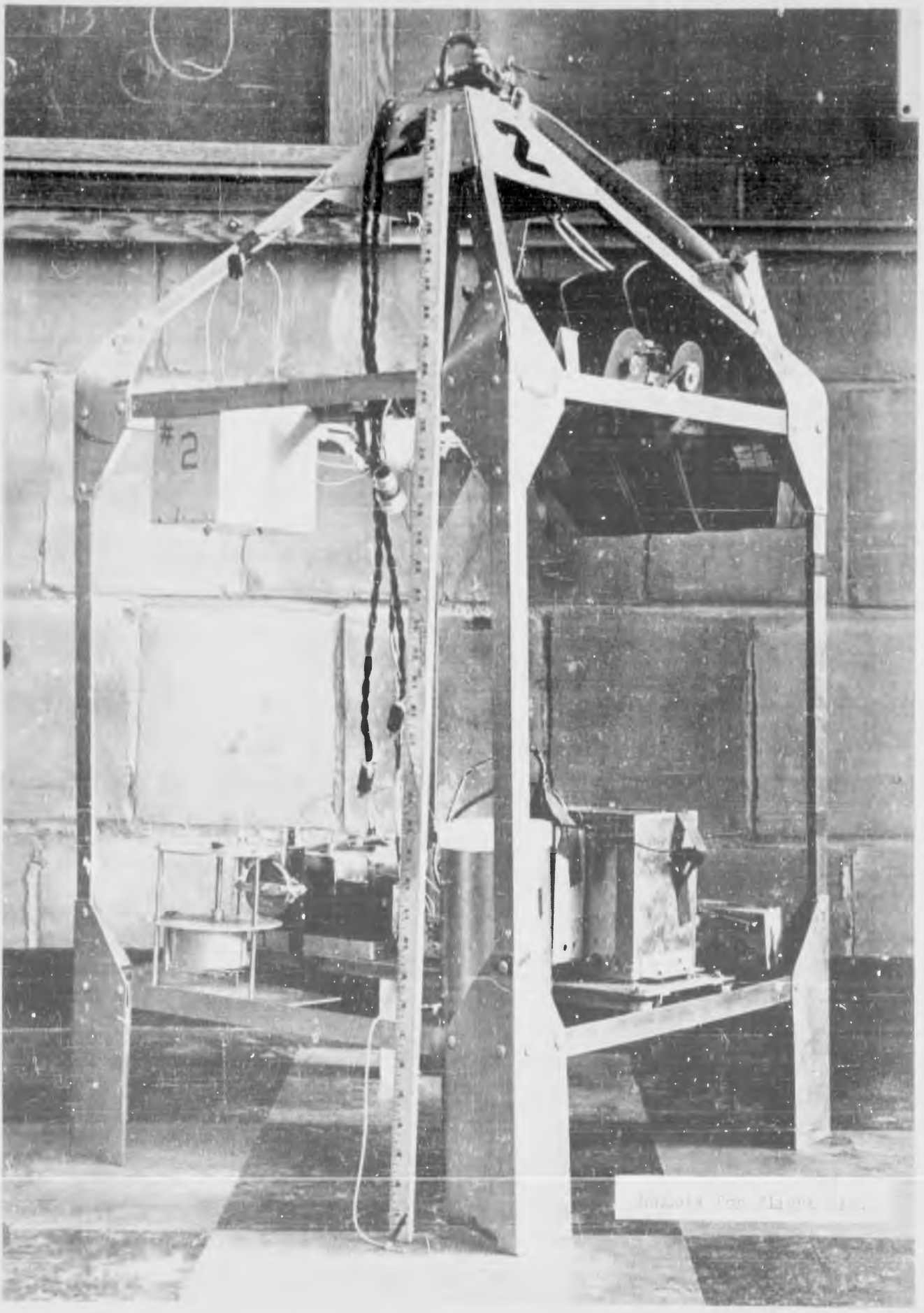


Top view of console box Flight #9, showing duplex timers, command receiver, bottom left; transmitter, center; ballast-drop, upper left; low-altitude release, upper right.

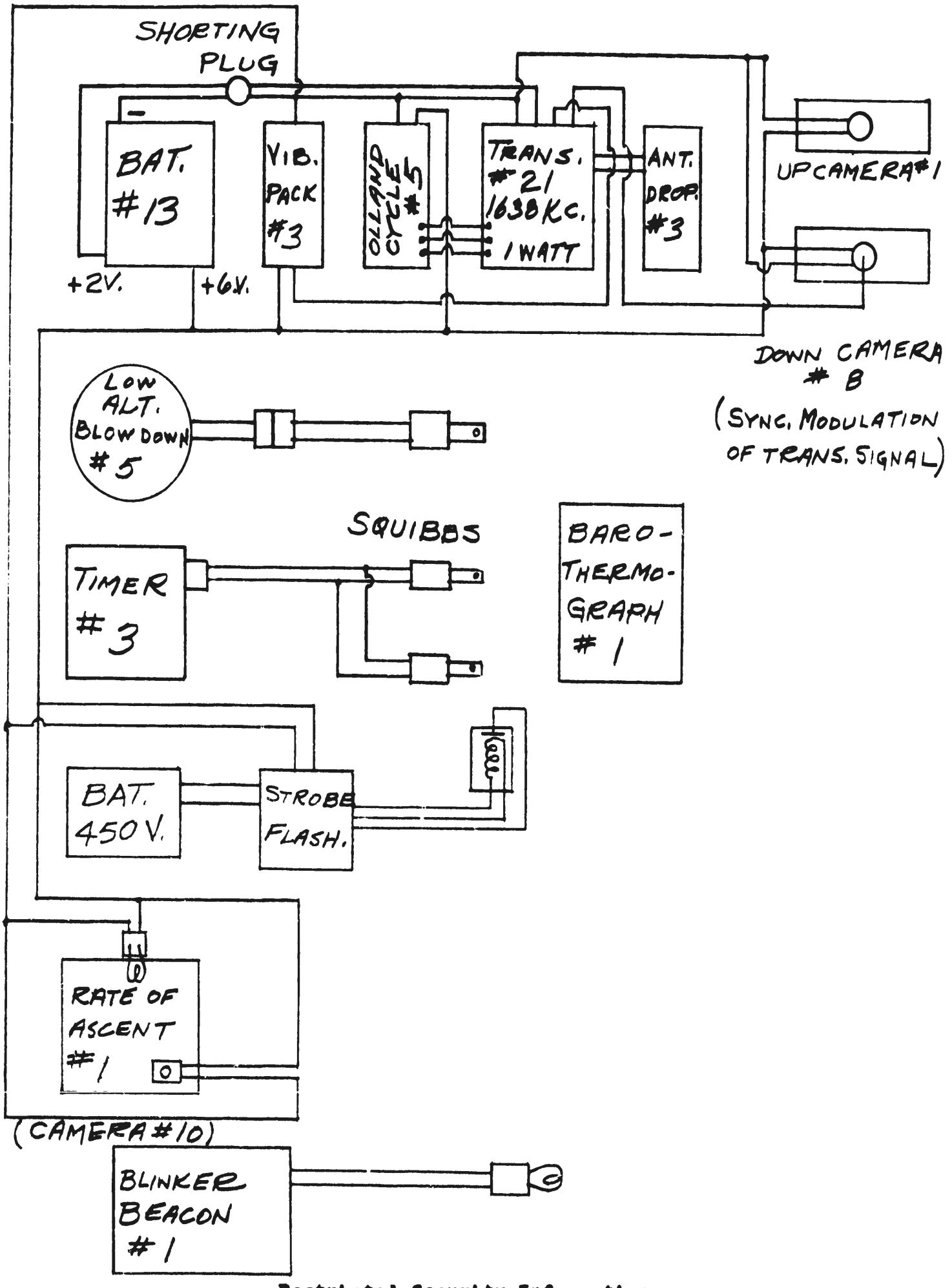
FLIGHT #10


SHORTING PLUG
BAT. #12
VIB. PACK #
OLLAND CYCLE #3
TRANS. #21 1638 KC
ANT. DROP #3
UP CAMERA #9
DOWN CAMERA #8
+2V.
+6V.
+180V.

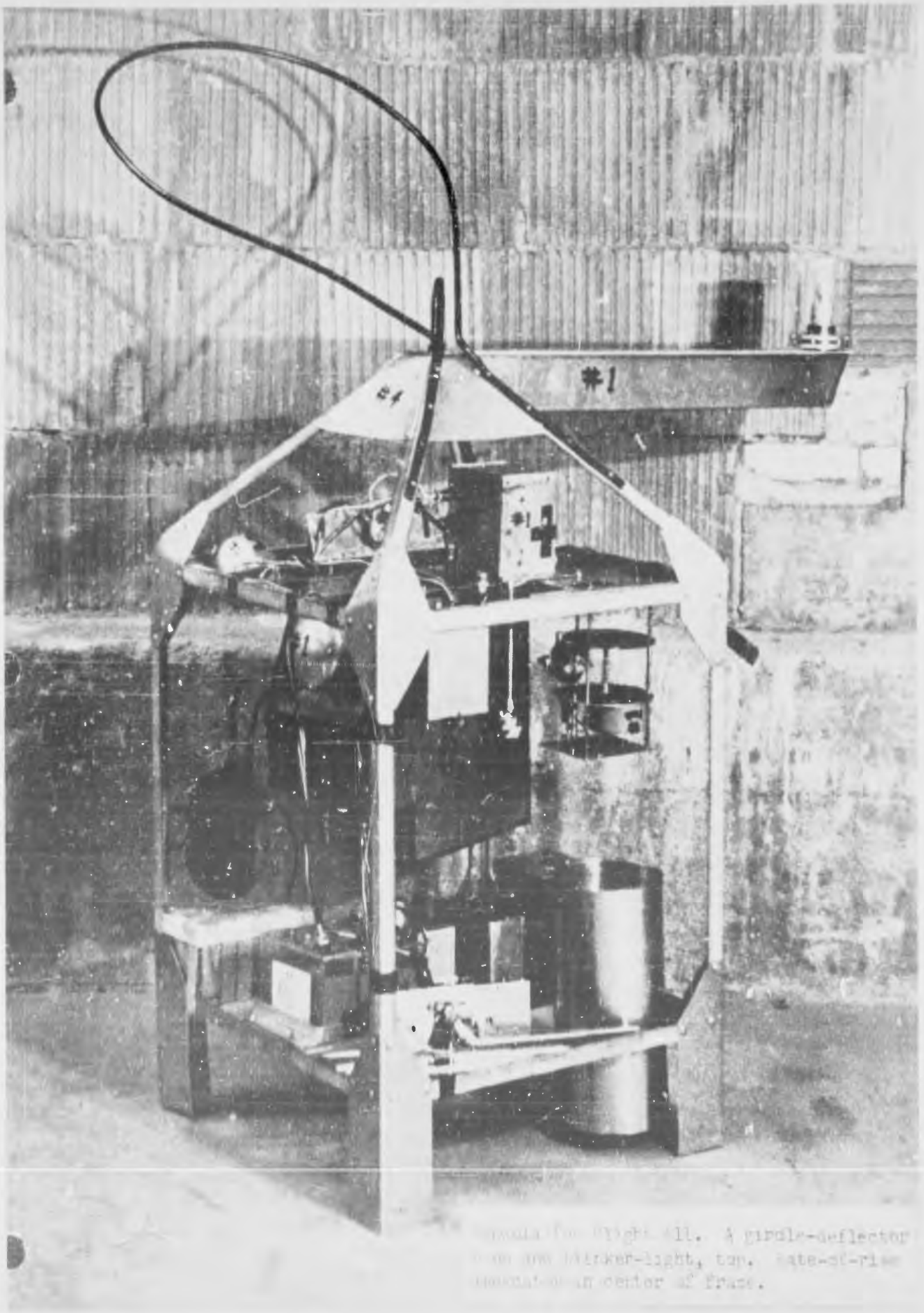

LOW ALT. BLOW DOWN #5
SQUIBBS
TIMER #5 DOUBLE
BARO-THERMO-GRAPH #3
COSMIC RAY PLATES
BLINKER BEACON #2


#2

FLIGHT # 11

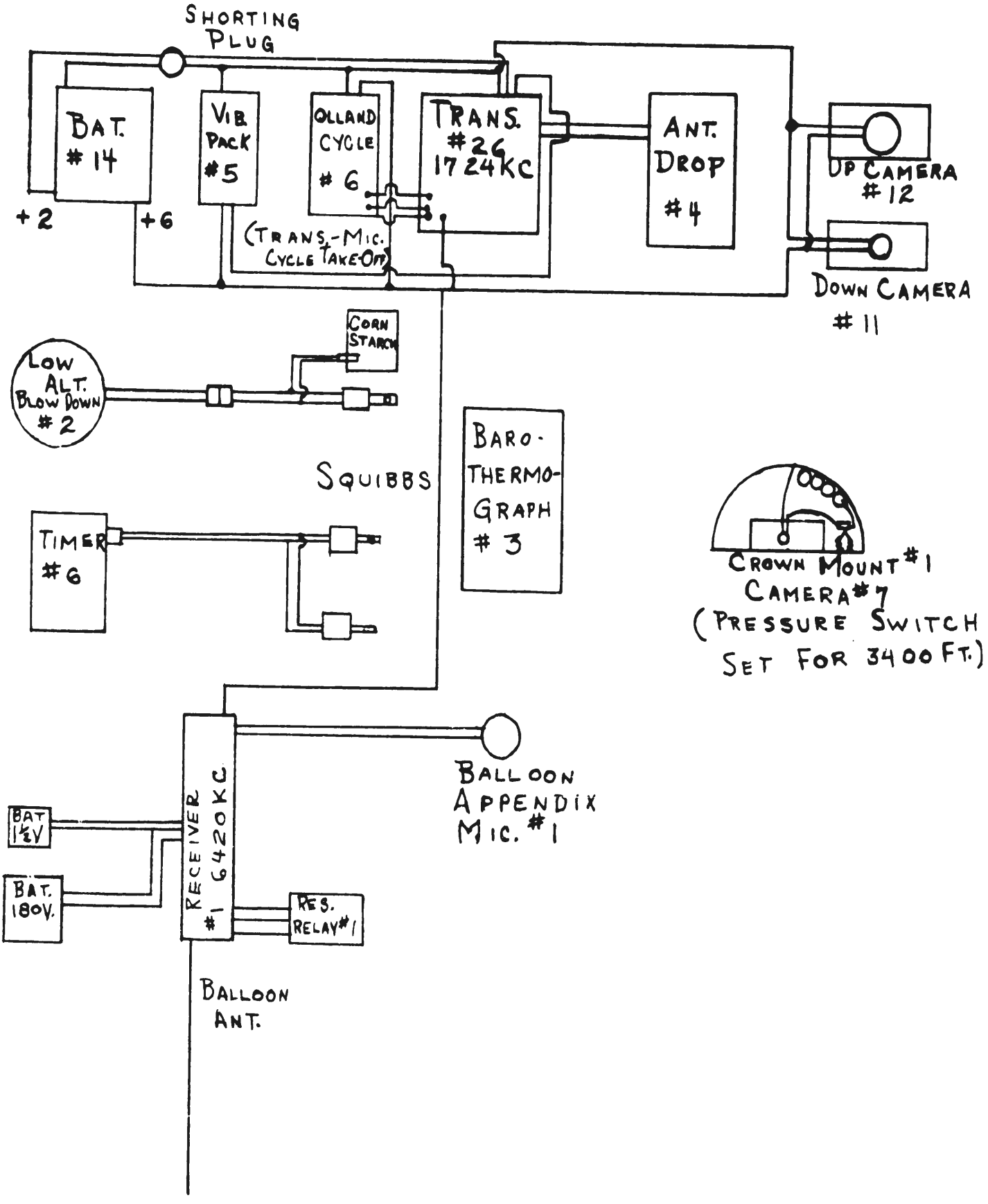


Restricted Security Information



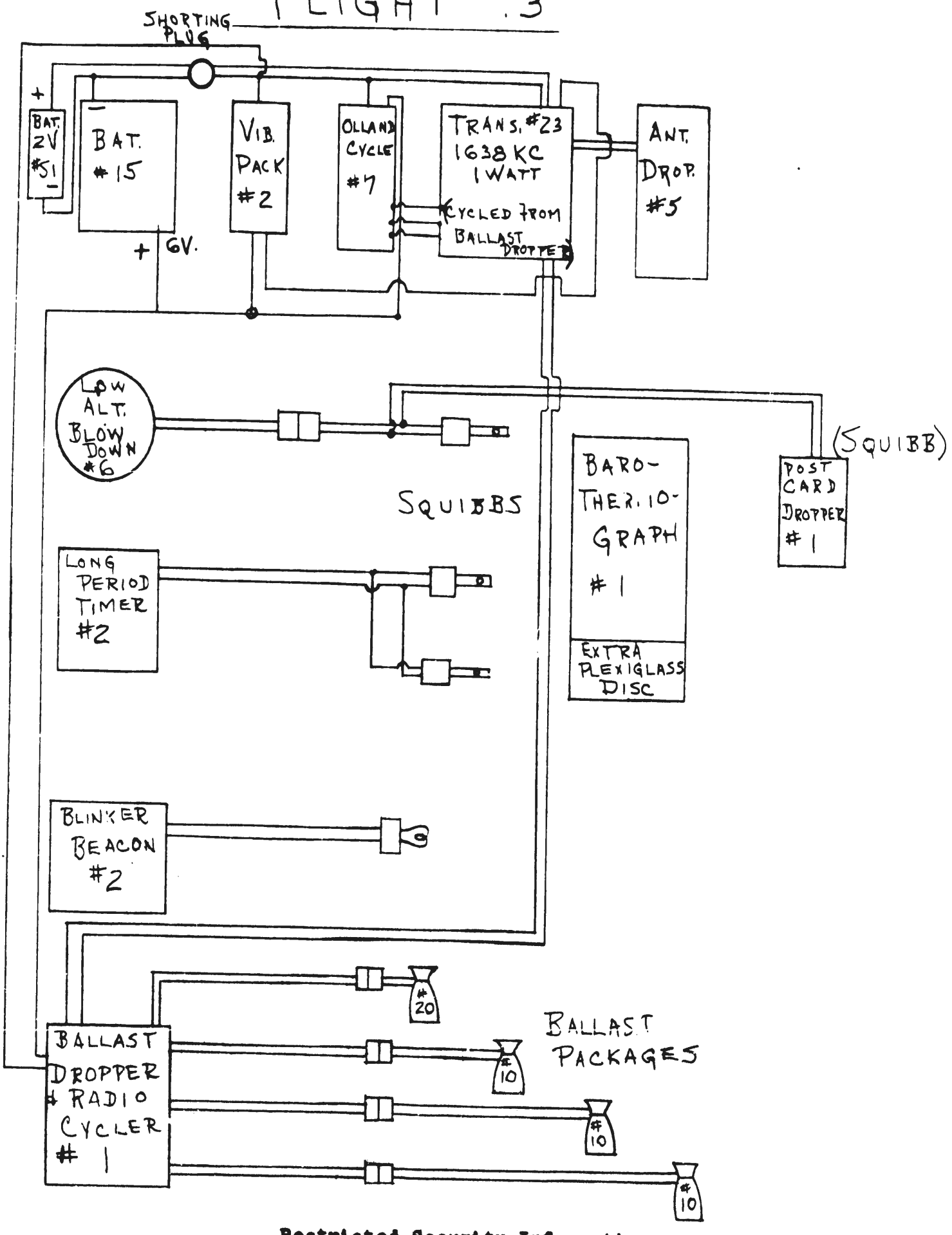
Restricted Security Information

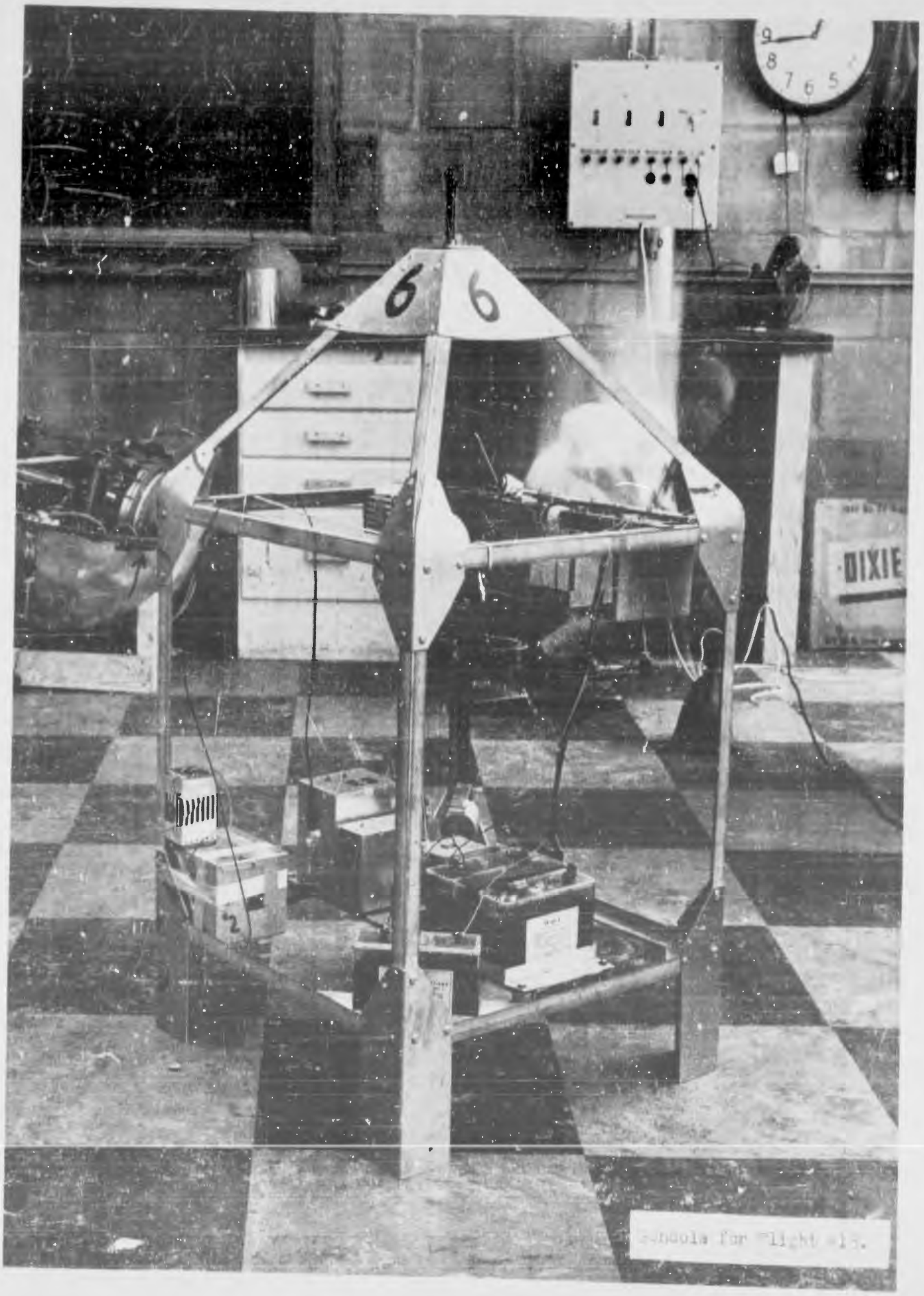
FLIGHT #12



Restricted Security Information

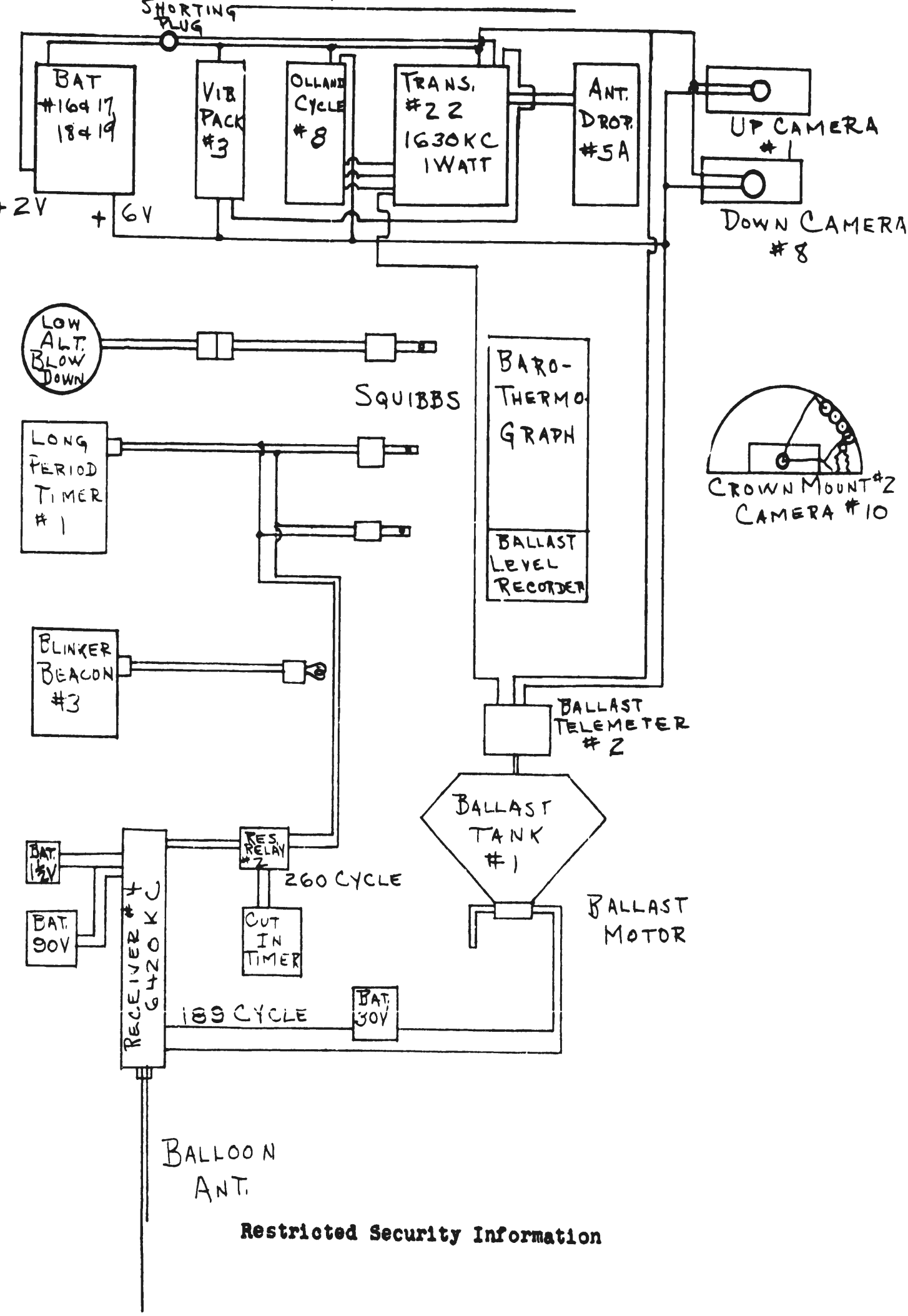
FLIGHT #13


SHORTING PLUG
+
BAT. 2V #51
−
BAT. #15
+ 6V.
VIB. PACK #2
OLLAND CYCLE #7
TRANS. #23 1638 KC 1 WATT
CYCLED FROM BALLAST DROPPER
ANT. DROP. #5
LOW ALT. BLOW DOWN #6
SQUIBBS
(SQUIBB)
POST CARD DROPPER #1
BARO-THER. IO-GRAPH #1
EXTRA PLEXIGLASS DISC
LONG PERIOD TIMER #2
BLINKER BEACON #2
#20
#10
#10
#10
BALLAST PACKAGES
BALLAST DROPPER & RADIO CYCLER #1

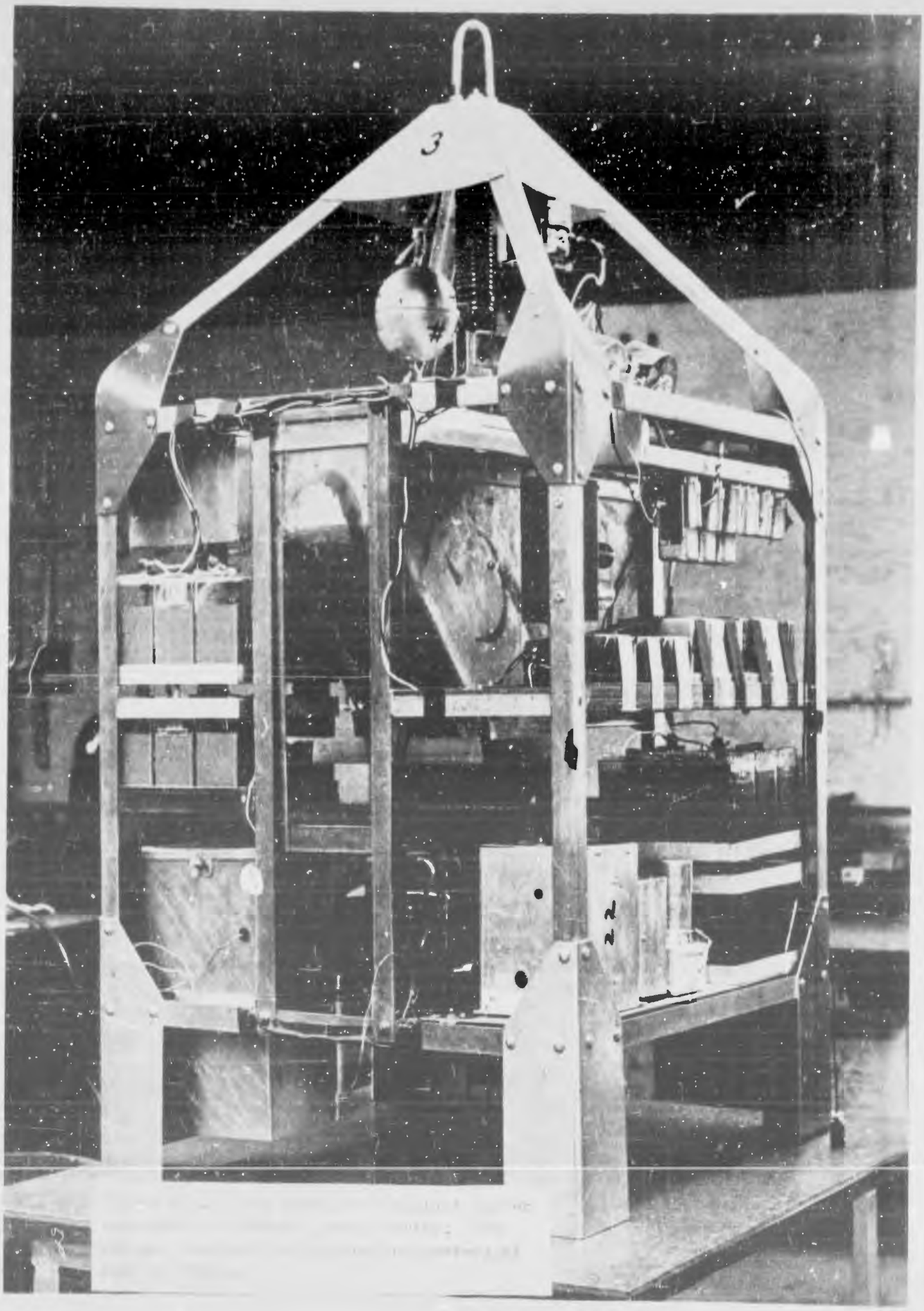


Schools for Flight Crews.

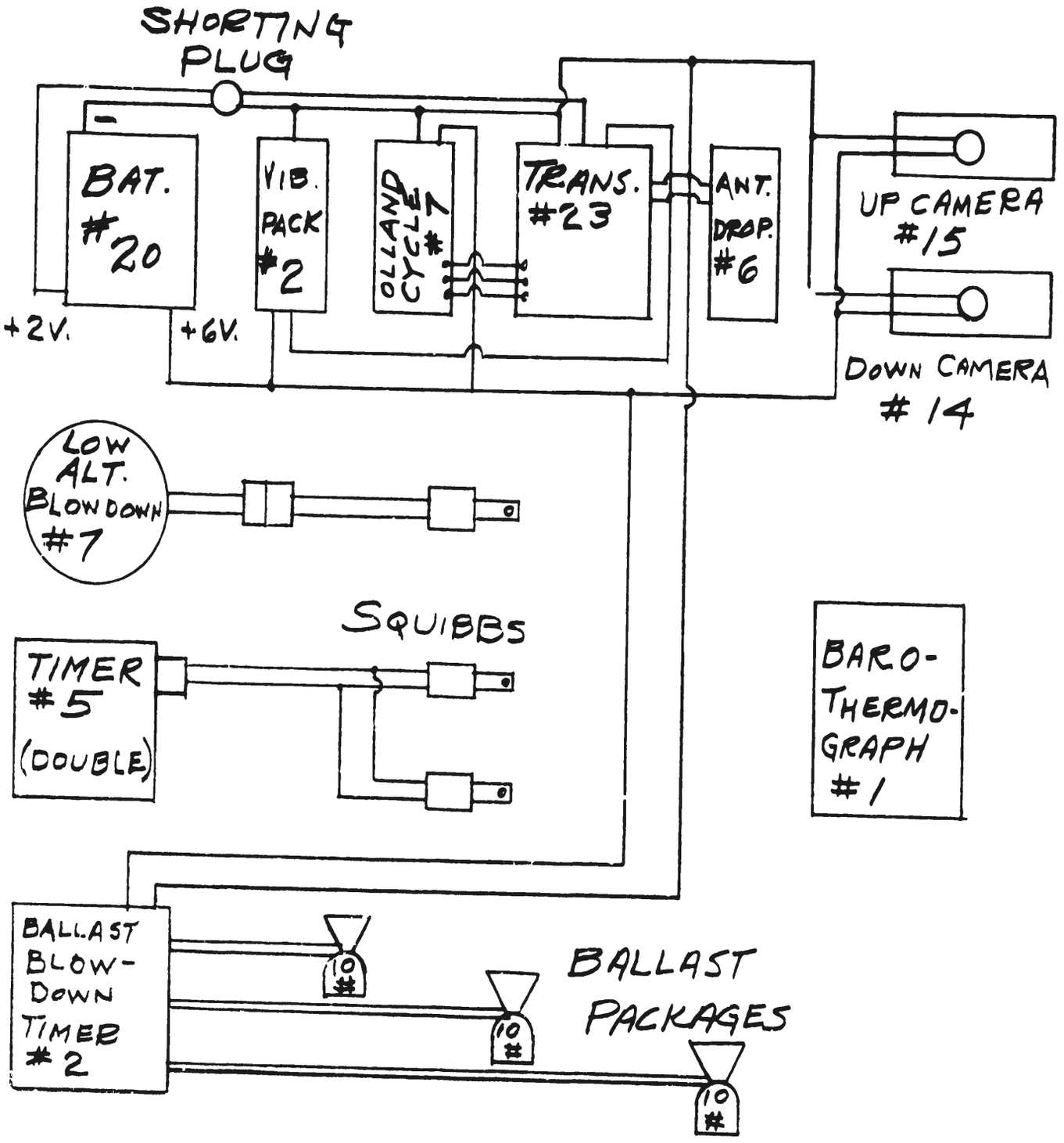
FLIGHT #14



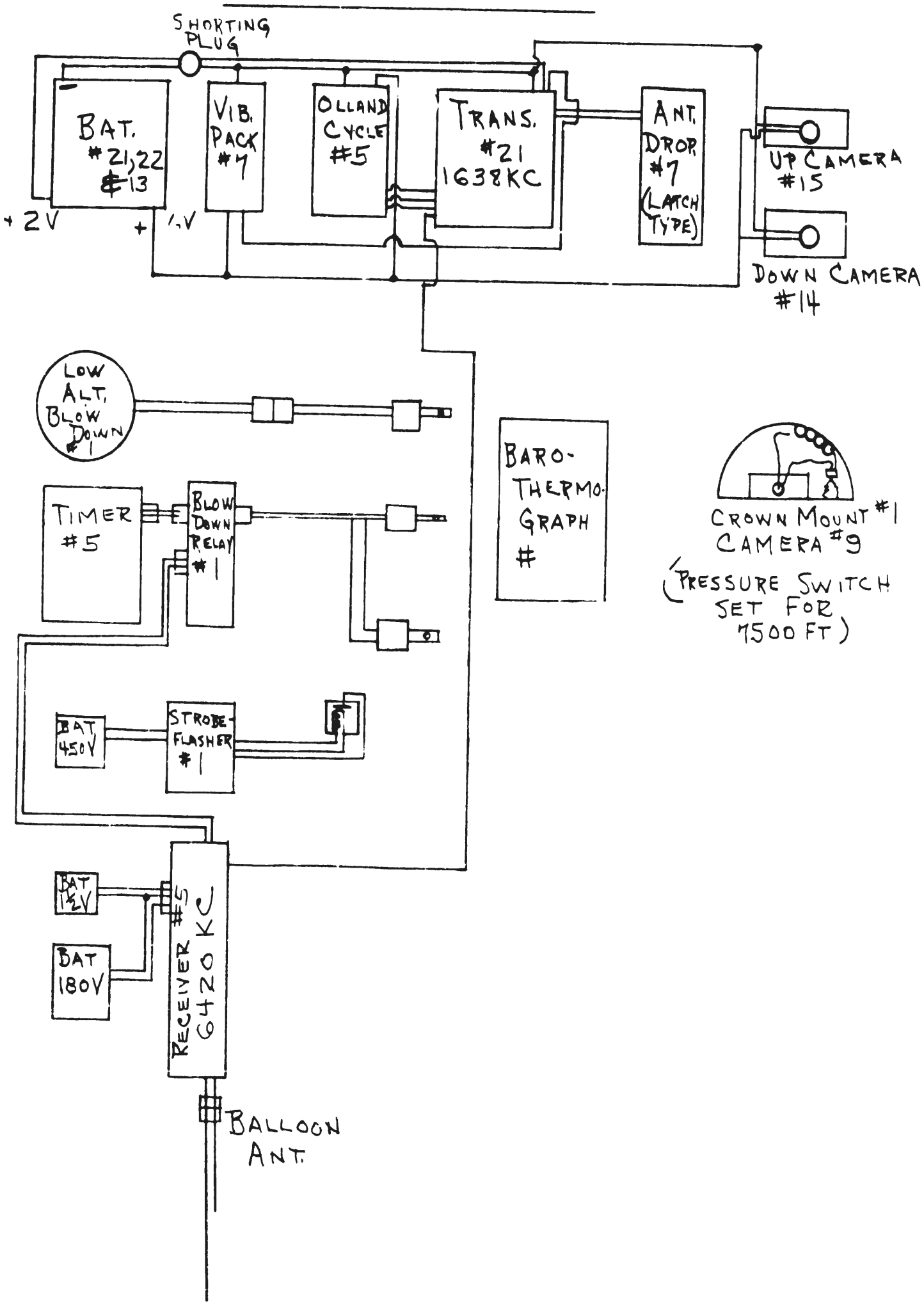
Restricted Security Information

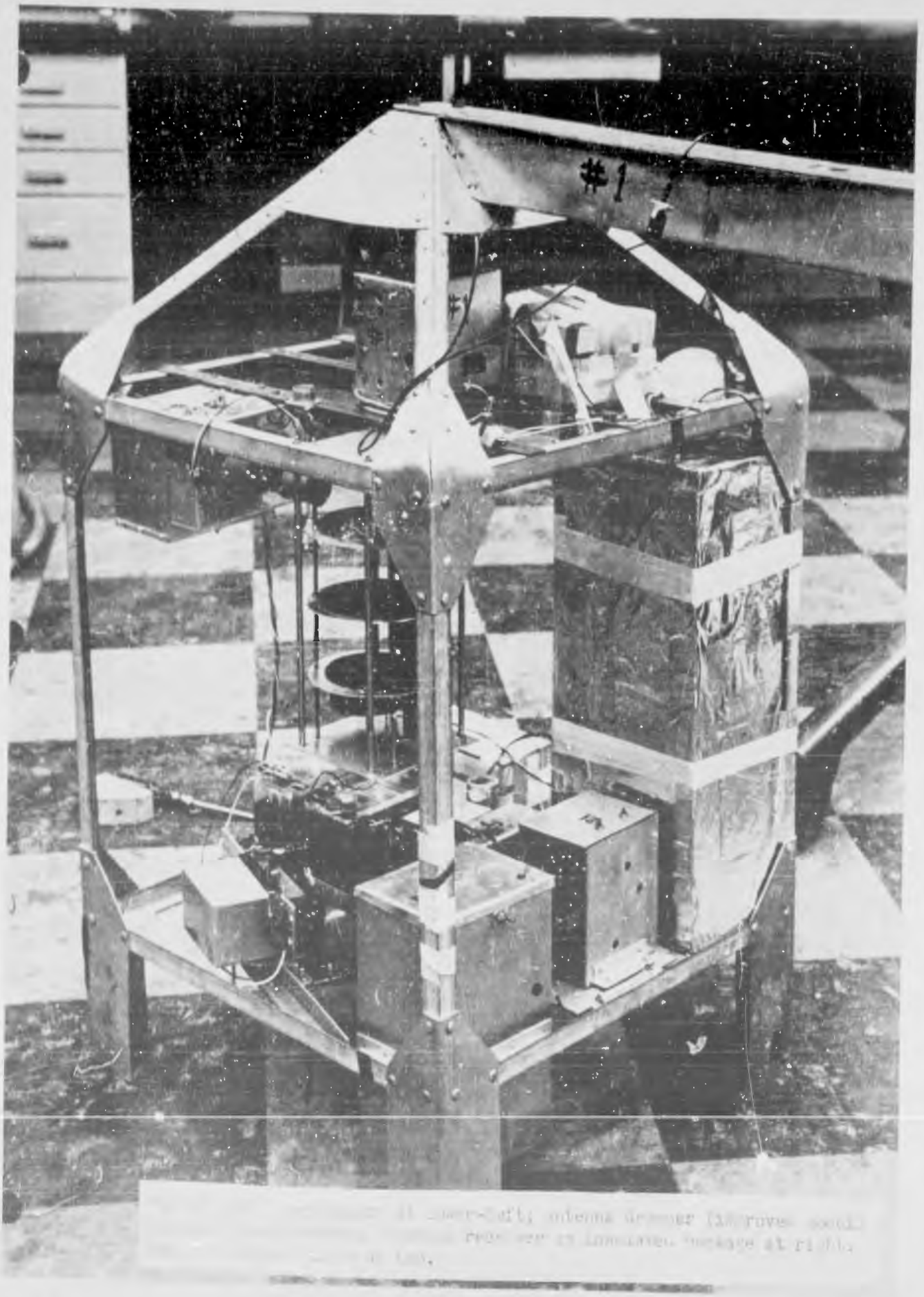


FLIGHT #15


SHORTING PLUG
BAT. #20
VIB. PACK #2
OLLAND CYCLE 7 #
TRANS. #23
ANT. DROP. #6
UP CAMERA #15
DOWN CAMERA #14
+2V.
+6V.
LOW ALT. BLOW DOWN #7
SQUIBBS
TIMER #5 (DOUBLE)
BARO-THERMO-GRAPH #1
BALLAST BLOW-DOWN TIMER #2
10 #
10 #
10 #
BALLAST PACKAGES
BAT. 450V.
STROBE FLASHER #1

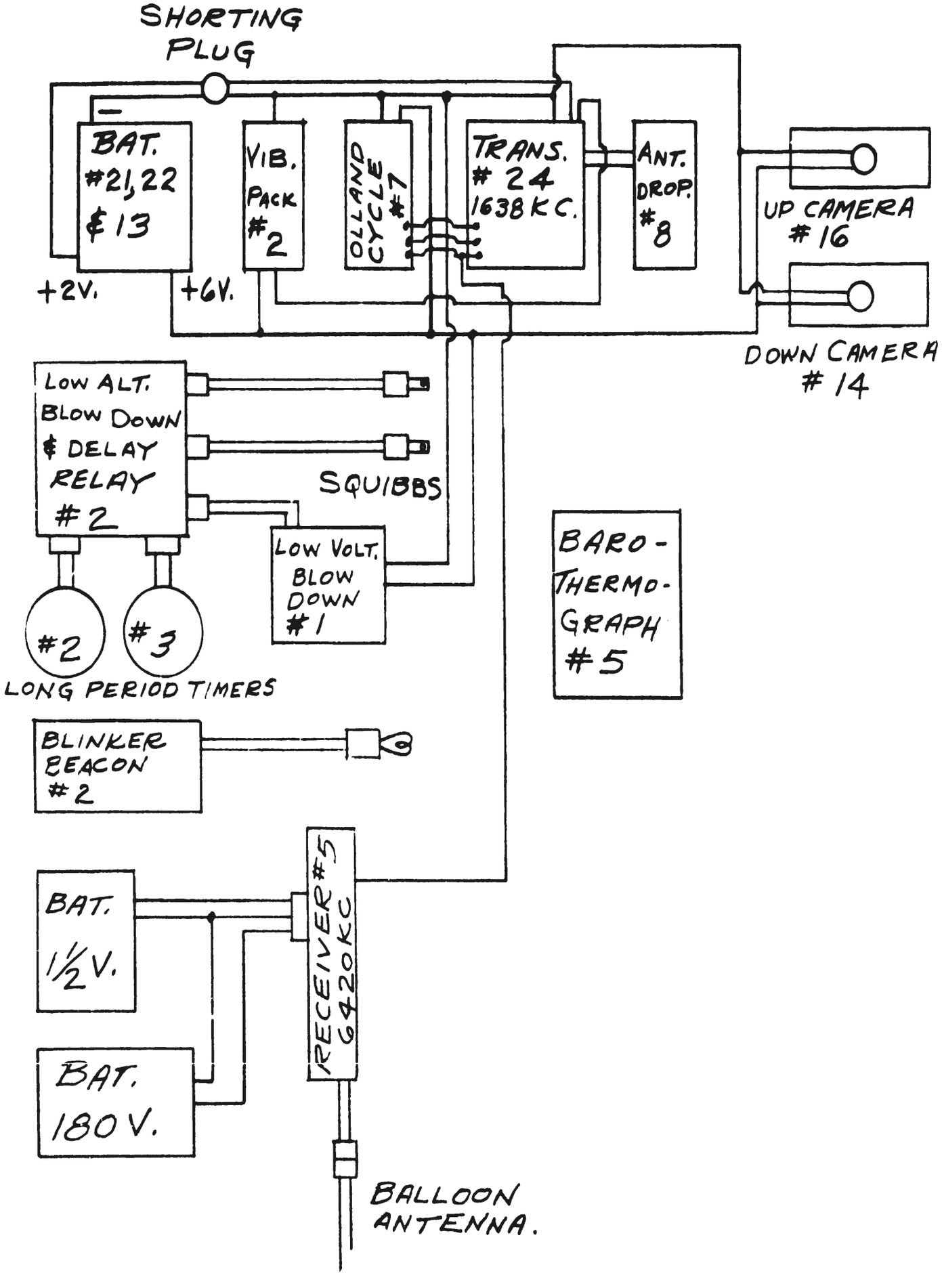
FLIGHT #16

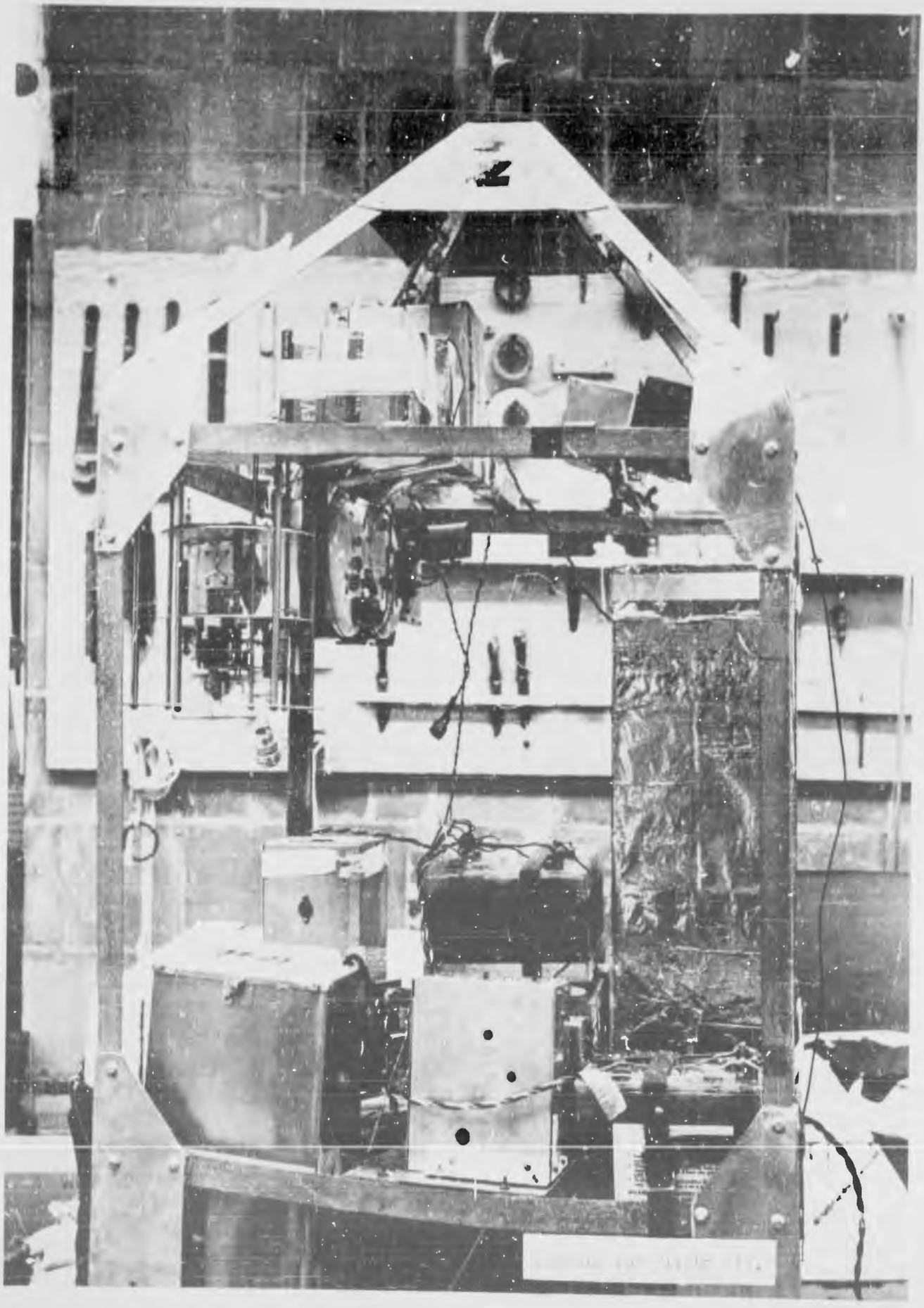

SHORTING PLUG
BAT. #21,22 & 13
VIB. PACK #7
OLLAND CYCLE #5
TRANS. #21 1638KC
ANT. DROP #7 (LATCH TYPE)
UP CAMERA #15
DOWN CAMERA #14
+2V
+1.V
LOW ALT. BLOW DOWN #1
TIMER #5
BLOW DOWN RELAY #1
BARO-THERMO-GRAPH #
CROWN MOUNT #1
CAMERA #9
(PRESSURE SWITCH SET FOR 7500 FT)
BAT 450V
STROBE-FLASHER #1
BAT 12V
BAT 180V
RECEIVER #5 6420 KC
BALLOON ANT.

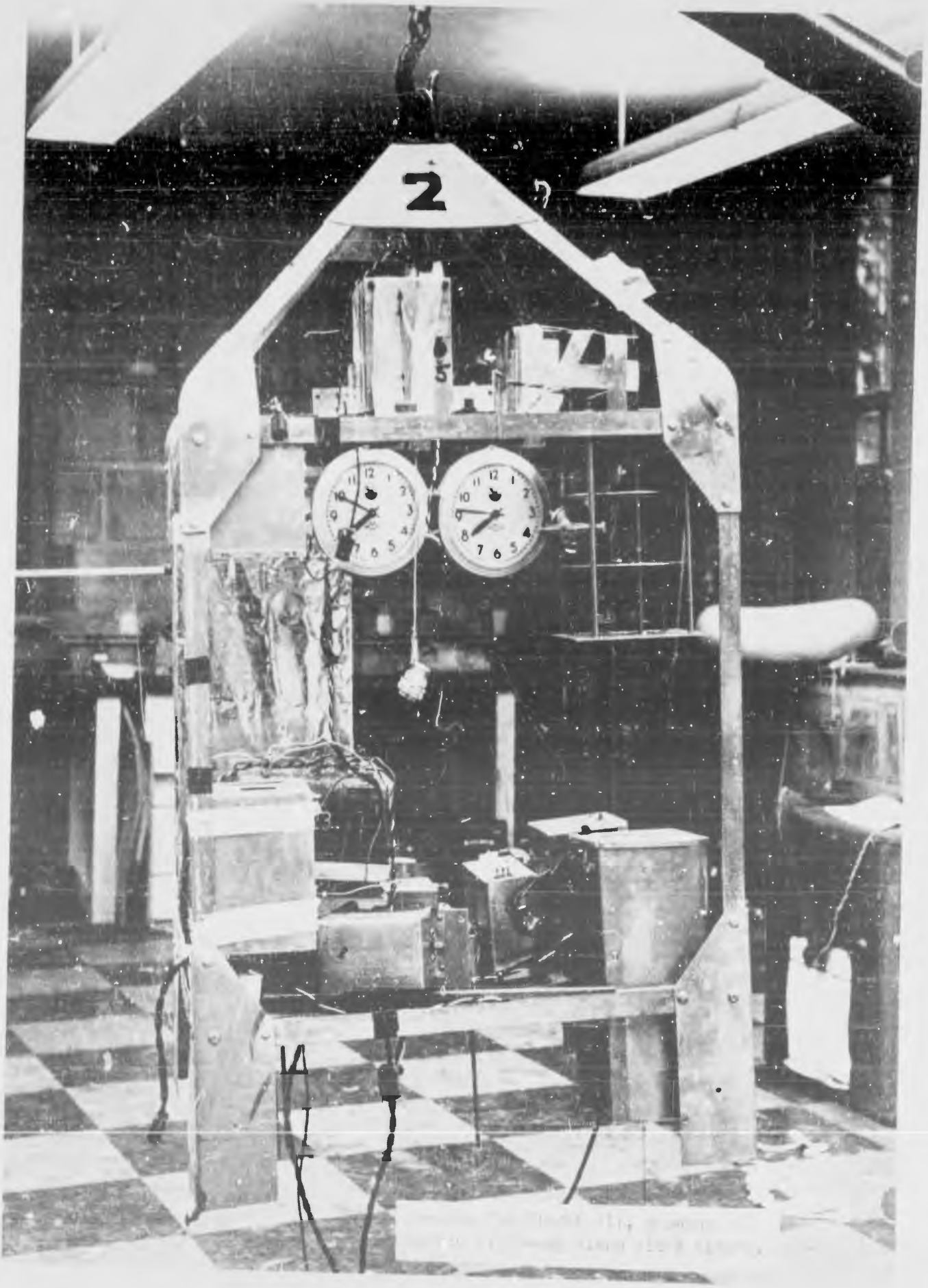


Restricted Security Information

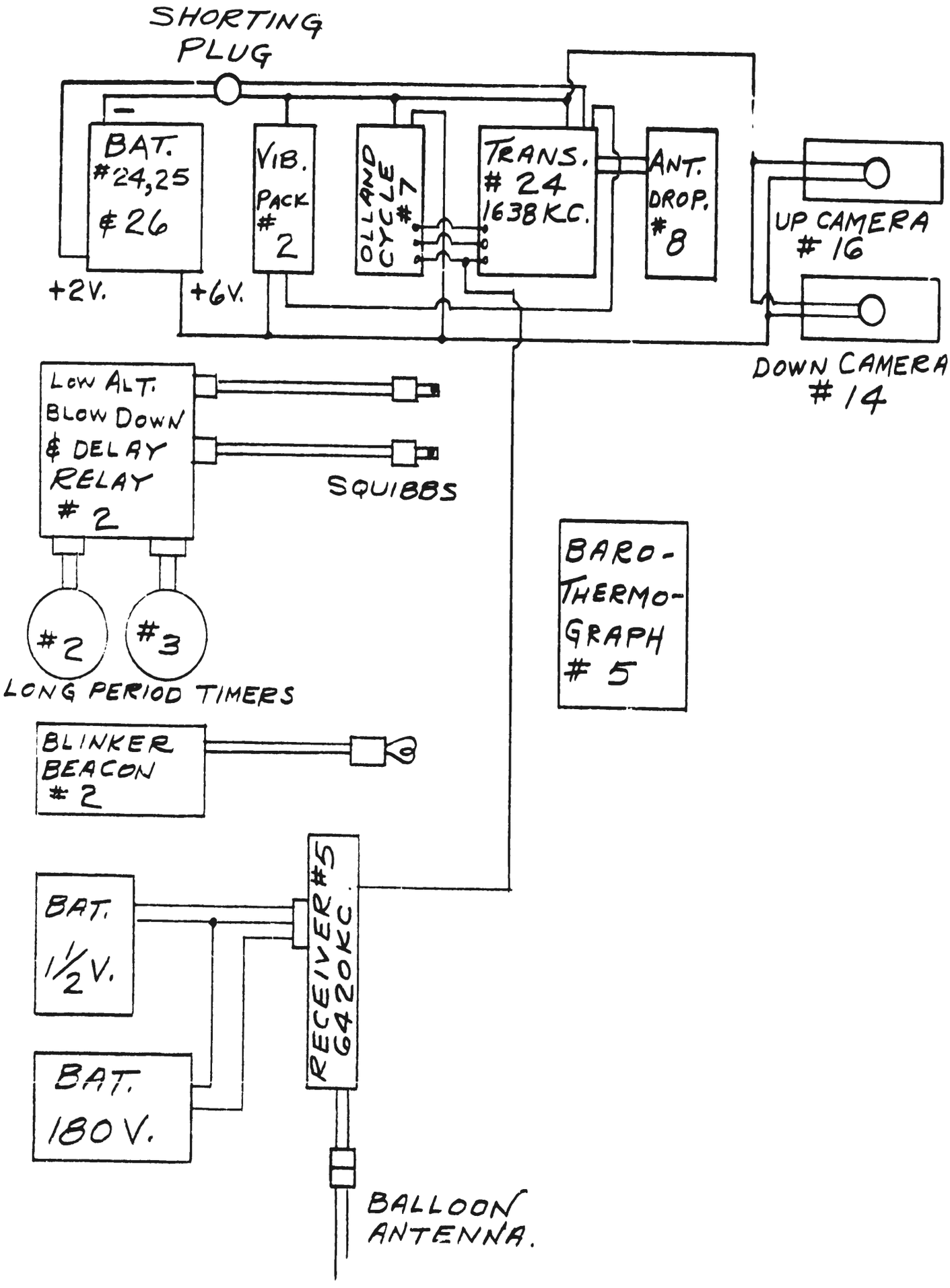
FLIGHT #17

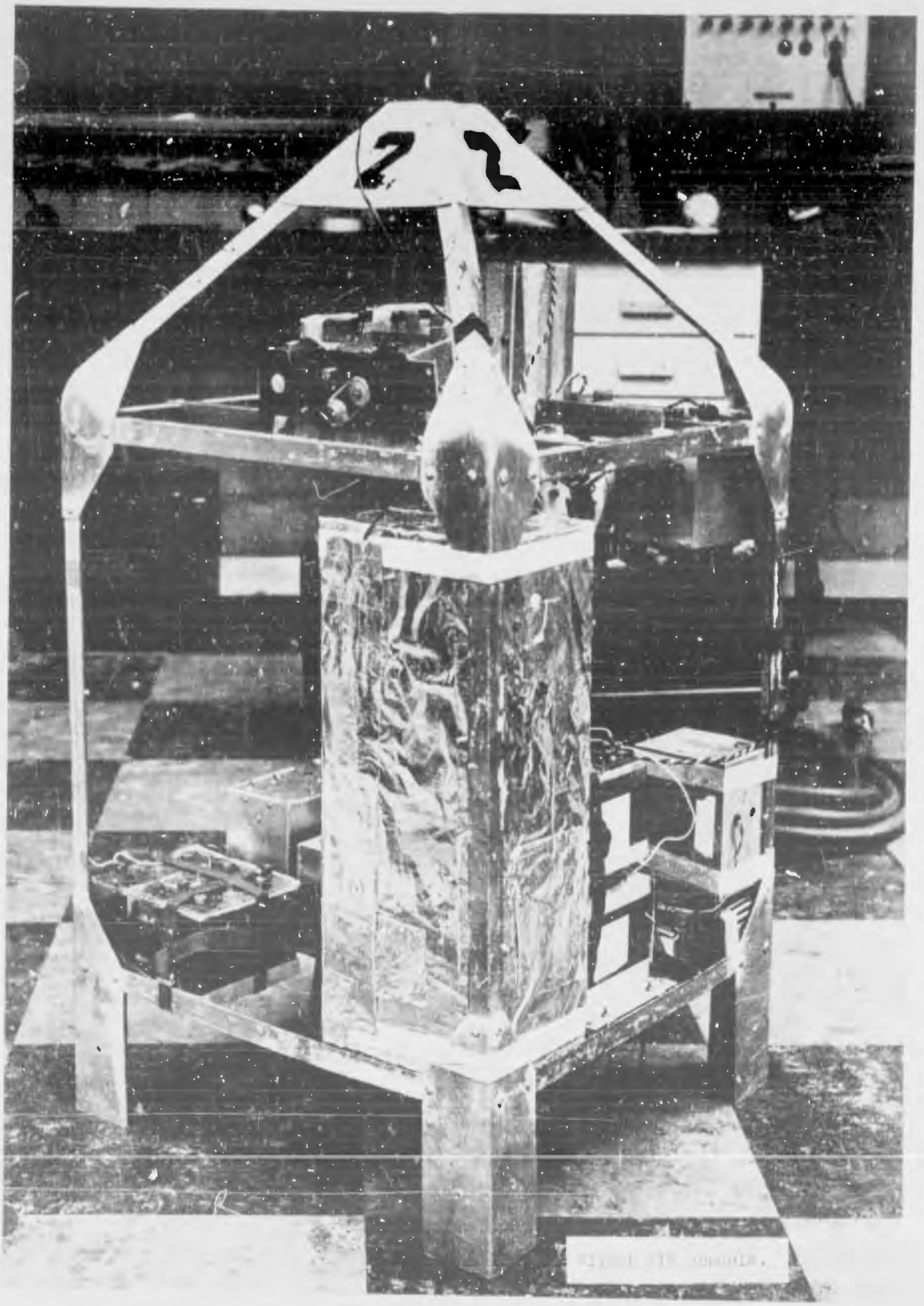

SHORTING PLUG
BAT. #21, 22 & 13
VIB. PACK #2
OLLAND CYCLE #7
TRANS. #24 1638 KC.
ANT. DROP. #8
UP CAMERA #16
DOWN CAMERA #14
+2V.
+6V.
LOW ALT. BLOW DOWN & DELAY RELAY #2
SQUIBBS
LOW VOLT. BLOW DOWN #1
#2
#3
LONG PERIOD TIMERS
BARO-THERMO-GRAPH #5
BLINKER BEACON #2
BAT. 1½ V.
BAT. 180 V.
RECEIVER #5 64.20 KC
BALLOON ANTENNA.



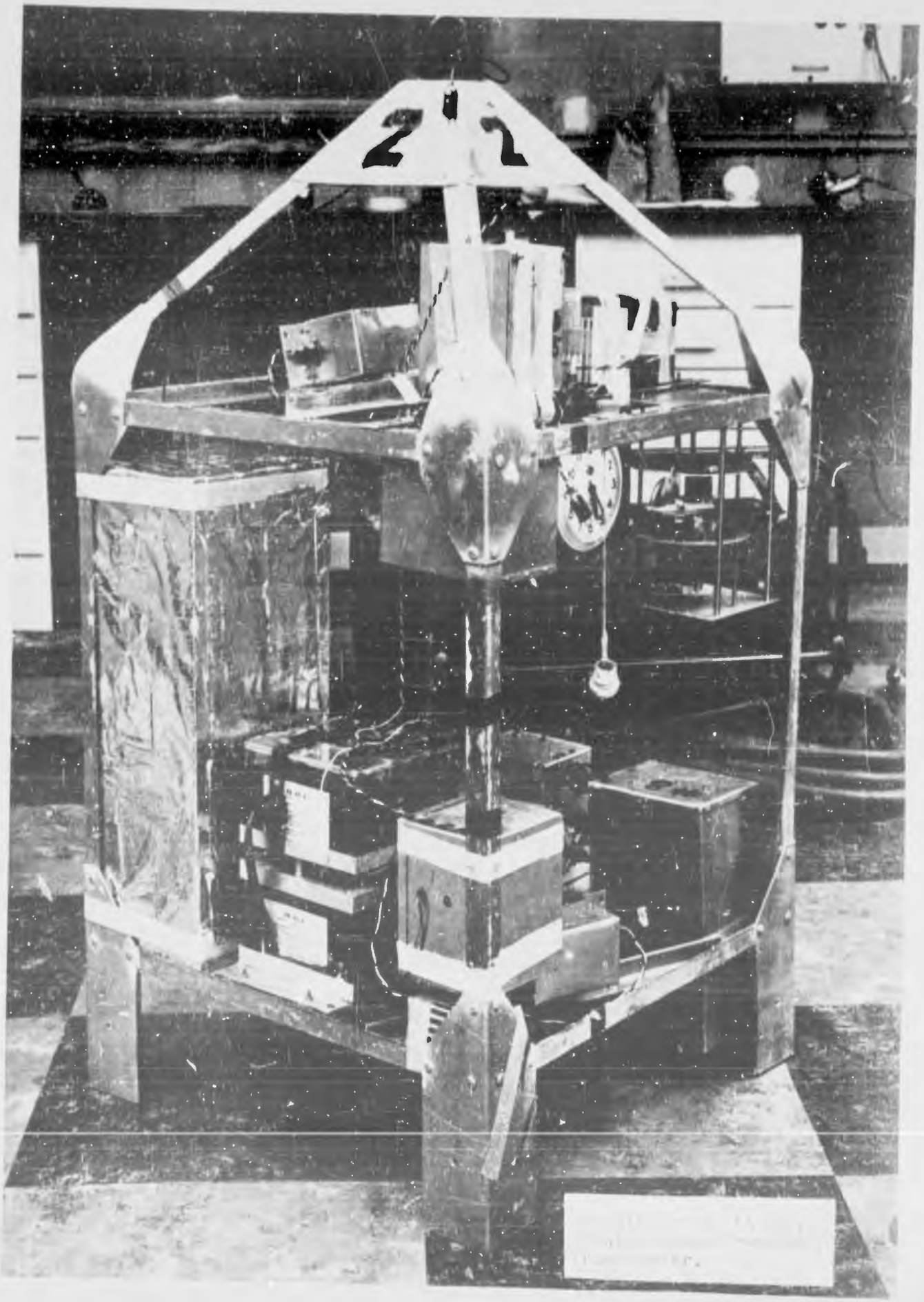

2

FLIGHT #18

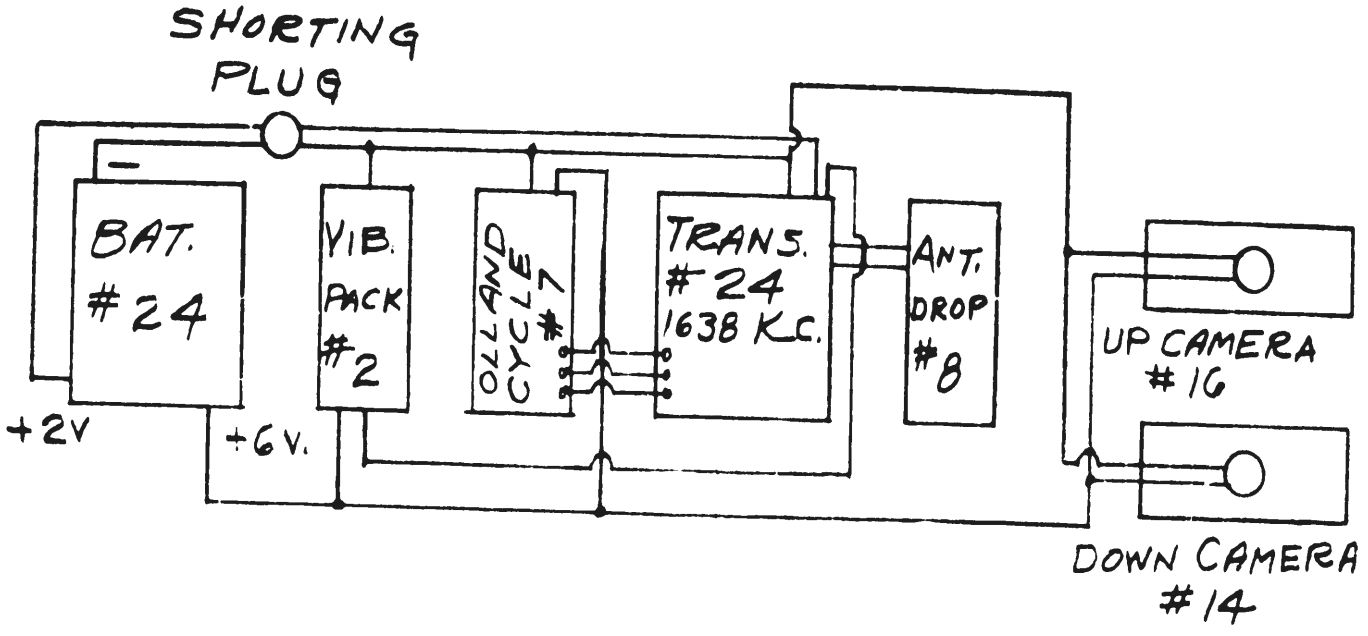

SHORTING PLUG
BAT. #24,25 & 26
VIB. PACK # 2
OLLAND CYCLE #7
TRANS. # 24 1638 KC.
ANT. DROP. #8
UP CAMERA # 16
DOWN CAMERA # 14
+2V.
+6V.
LOW ALT. BLOW DOWN & DELAY RELAY # 2
SQUIBBS
#2
#3
LONG PERIOD TIMERS
BARO-THERMO-GRAPH # 5
BLINKER BEACON # 2
BAT. 1½V.
BAT. 180 V.
RECEIVER #5 6420 KC
BALLOON ANTENNA.

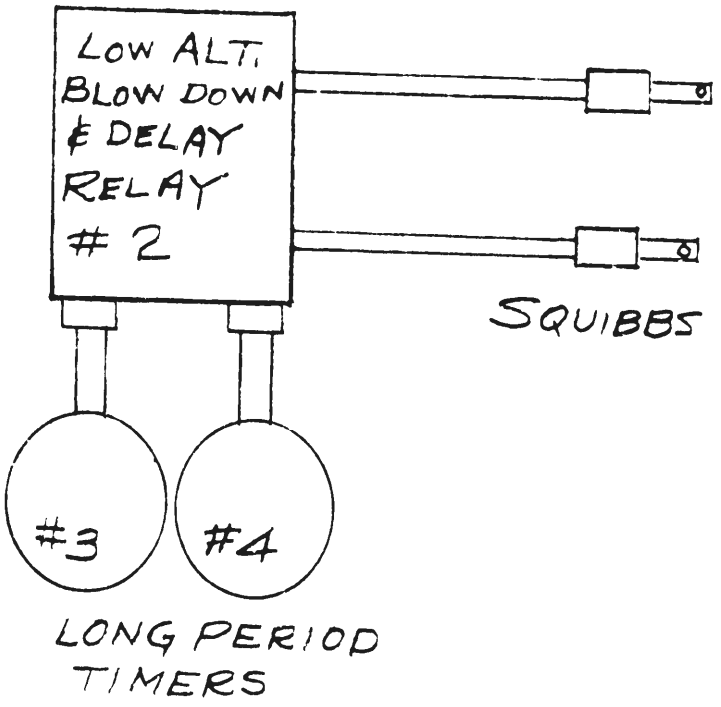


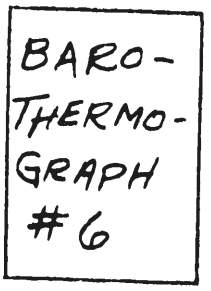
Restricted Security Information

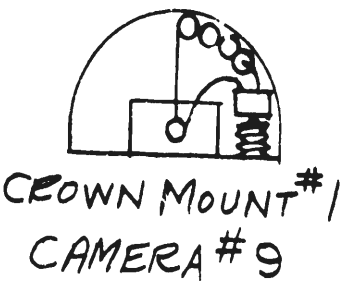


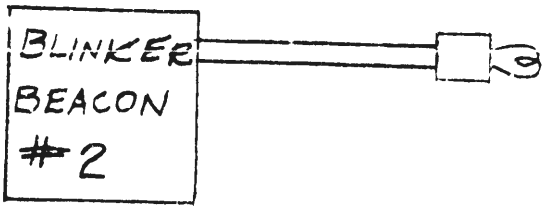
FLIGHT #19

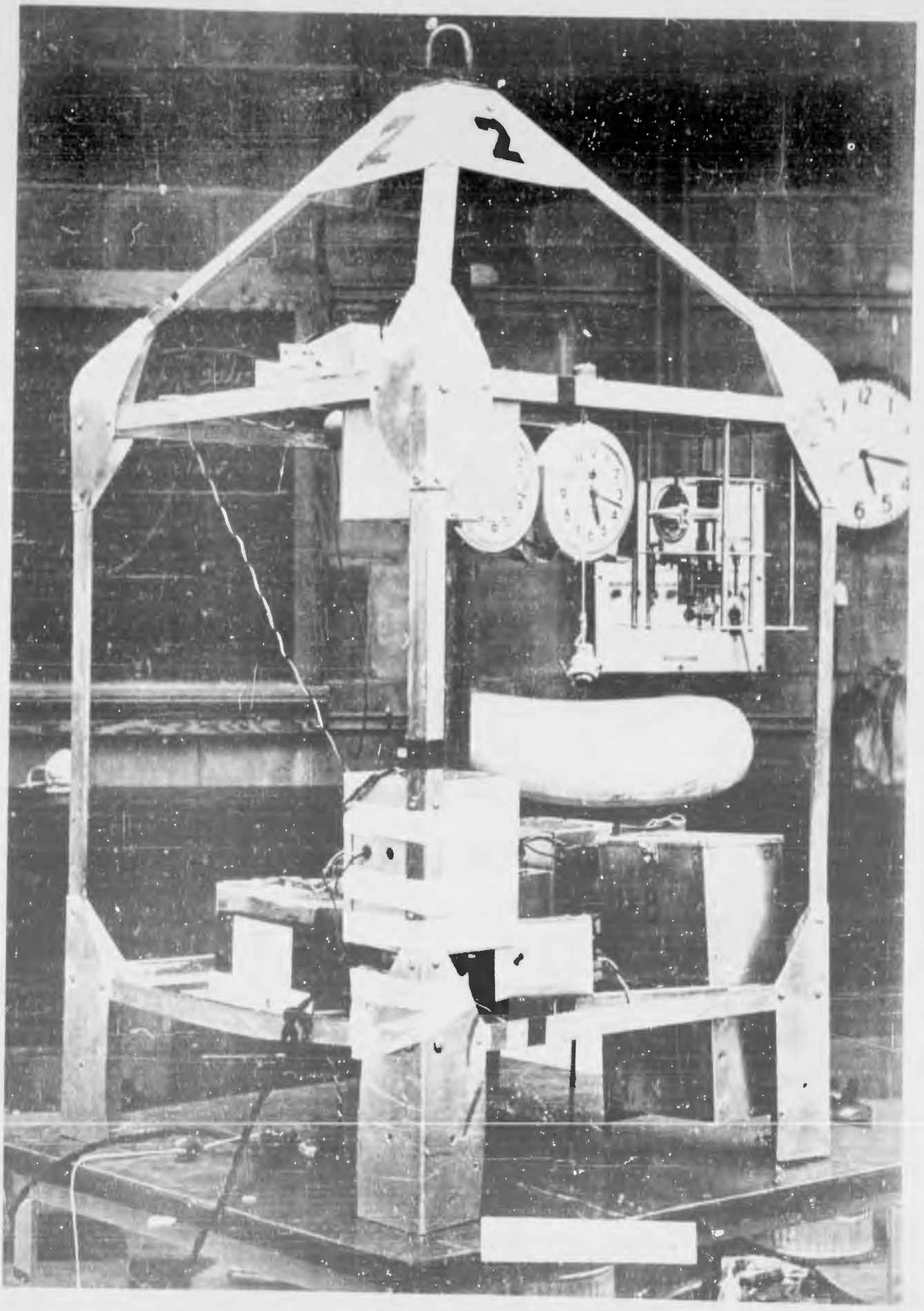

SHORTING PLUG
BAT. #24
VIB. PACK #2
OLLAND CYCLE #7
TRANS. #24 1638 K.C.
ANT. DROP #8
UP CAMERA #16
DOWN CAMERA #14
+2V
+6V.


LOW ALT. BLOW DOWN & DELAY RELAY #2
SQUIBBS
#3
#4
LONG PERIOD TIMERS

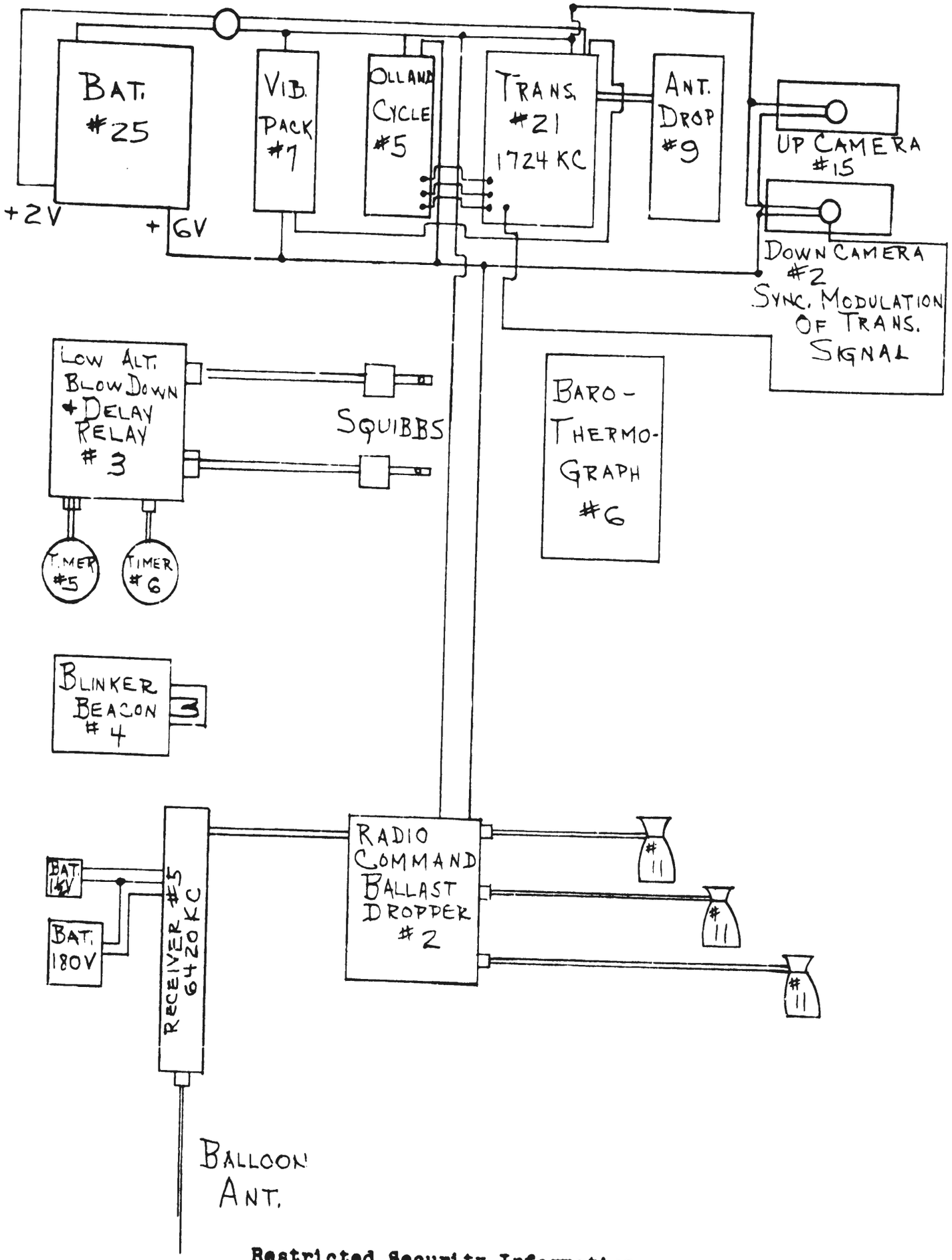

BARO-THERMO-GRAPH #6


CROWN MOUNT #1
CAMERA #9

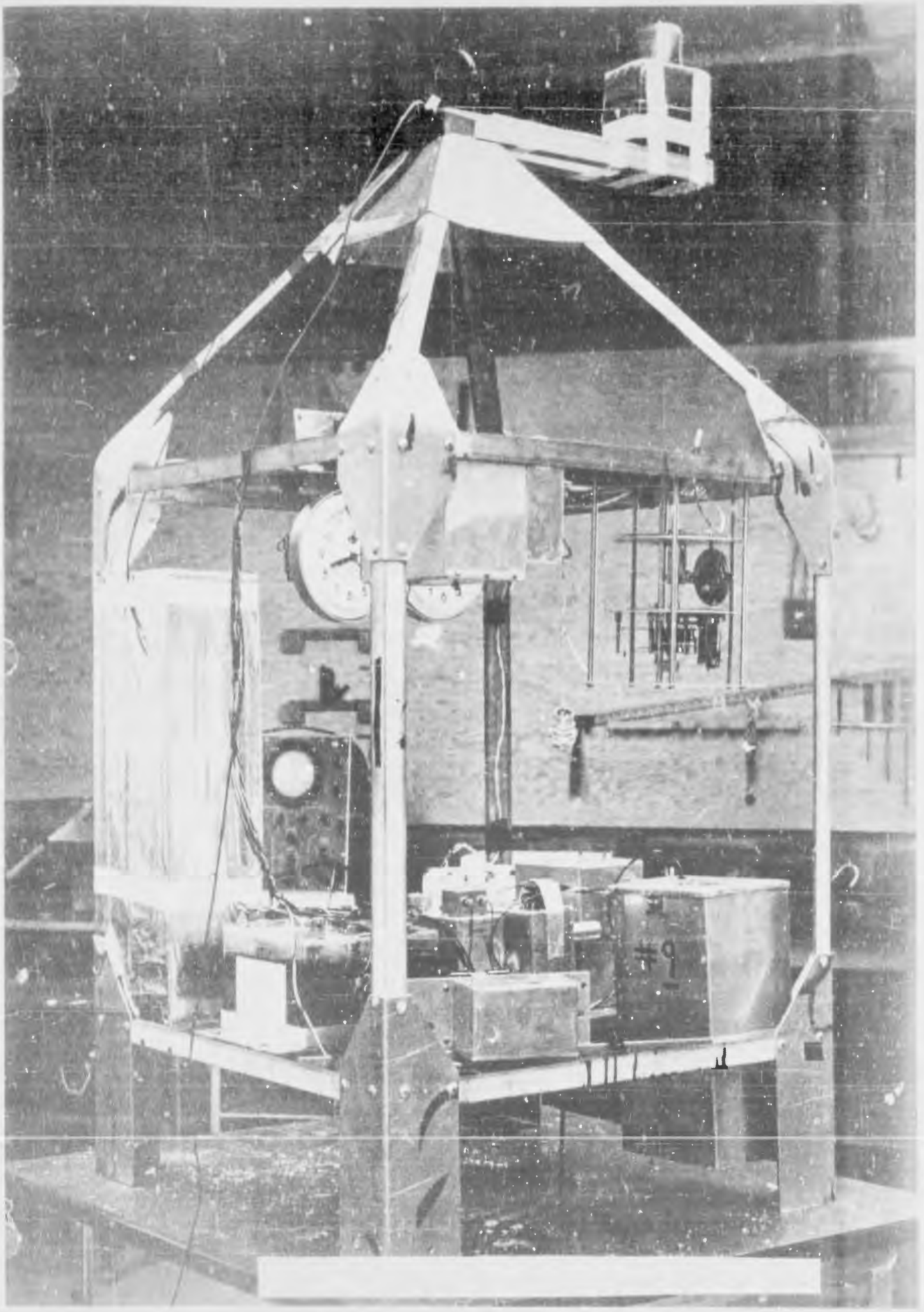

BLINKER BEACON #2



FLIGHT # 20



Restricted Security Information

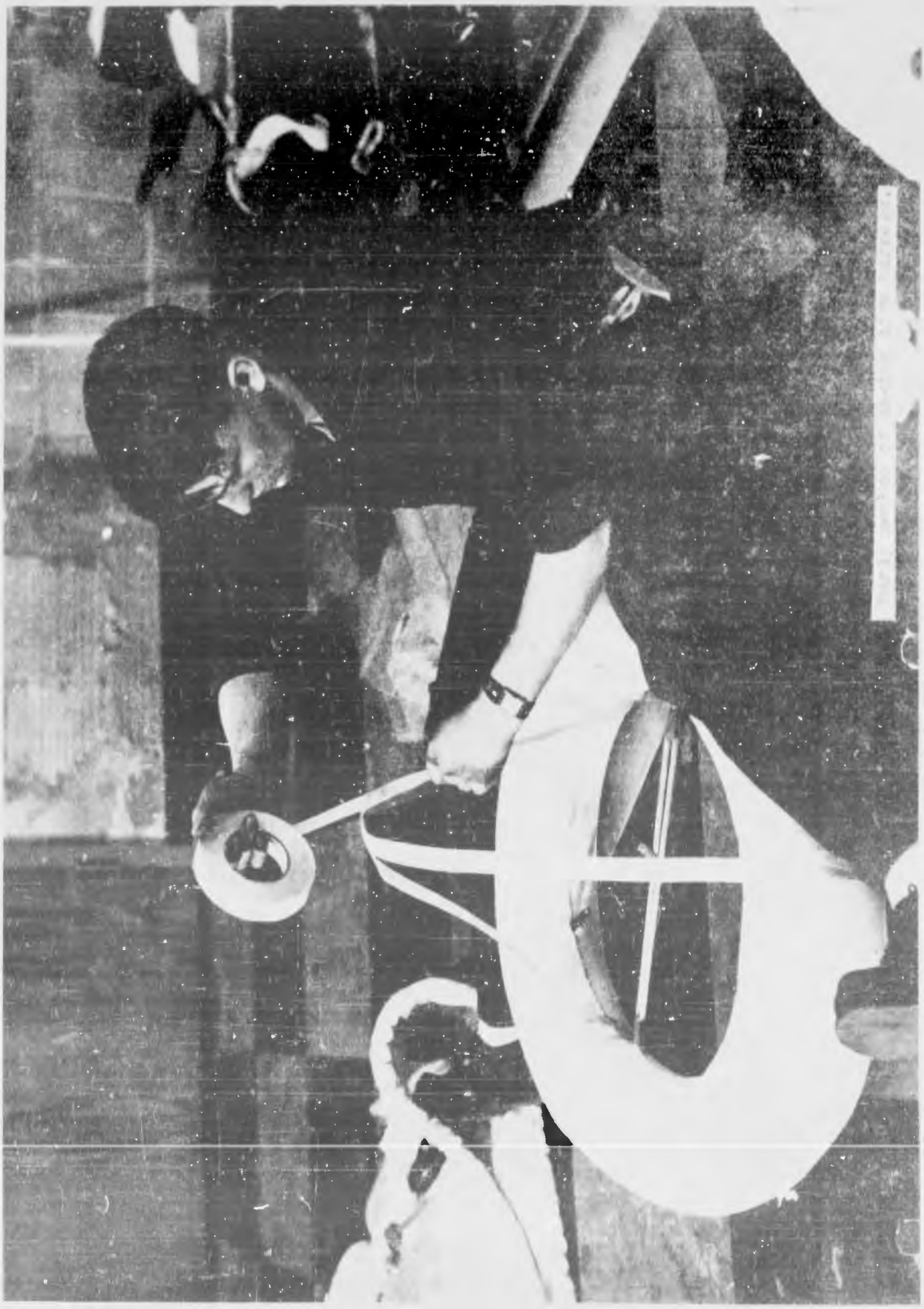

#9

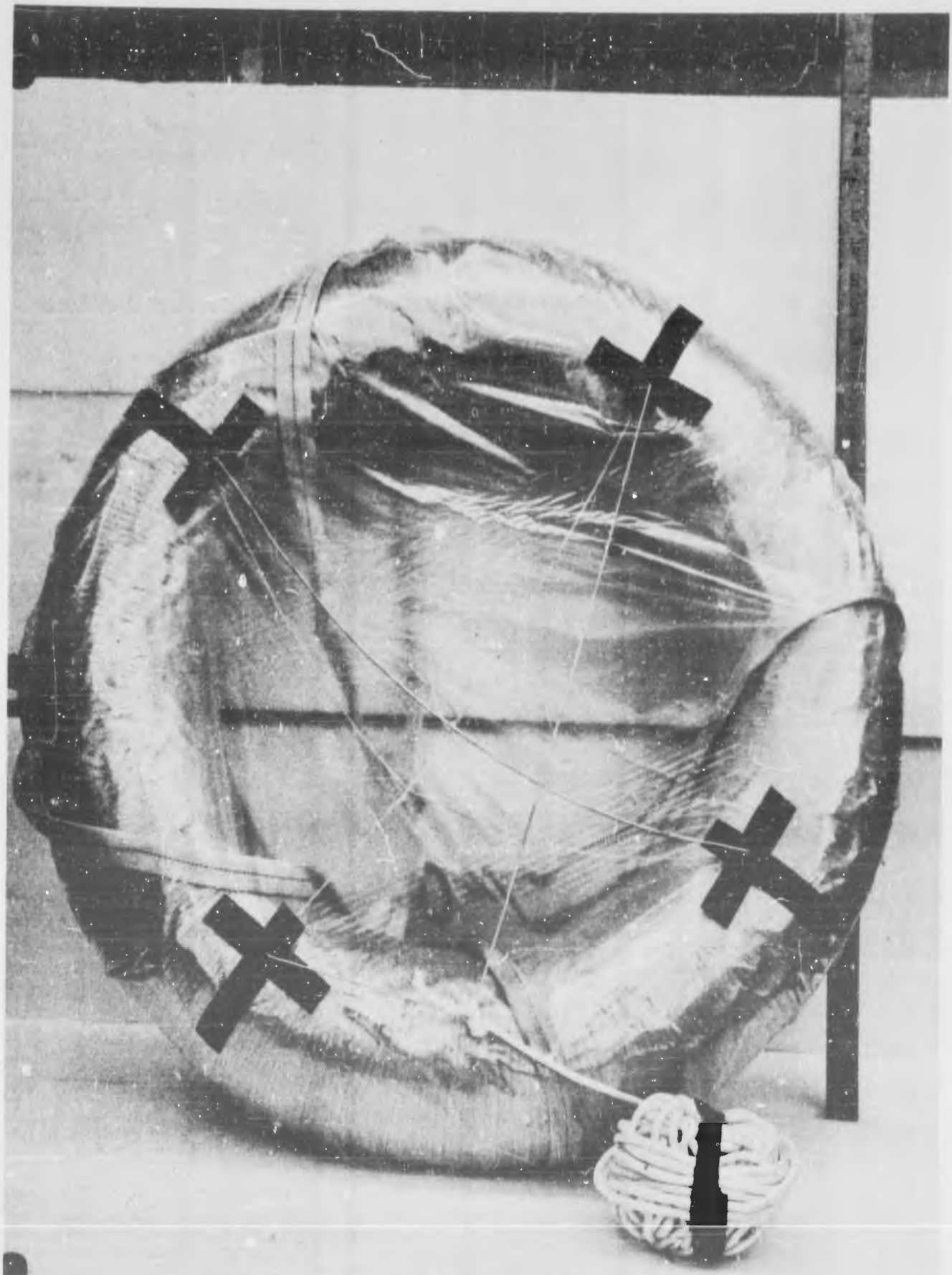
APPENDIX III

BALLOON HARDWARE

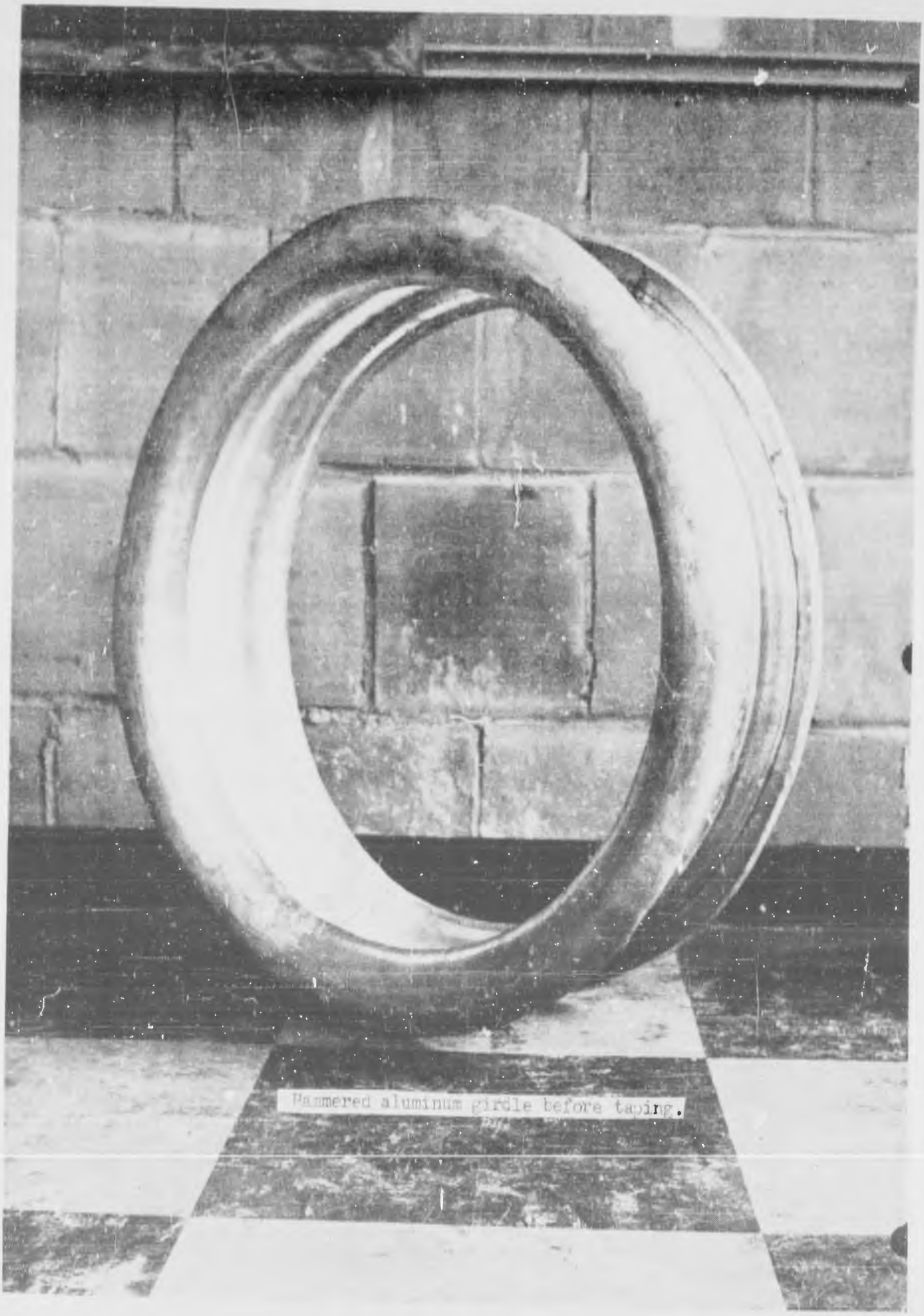
These pictures show the hardware required for launching balloons by the Minnesota method. This hardware consists of a balloon top ring, tire and diaphragm, an aluminum girdle, an aneroid tube deflator, an inflation thimble, canvas corset and a torque wrench.

Balloon top ring shown disassembled at right. Note O-ring seals on aluminum riser.

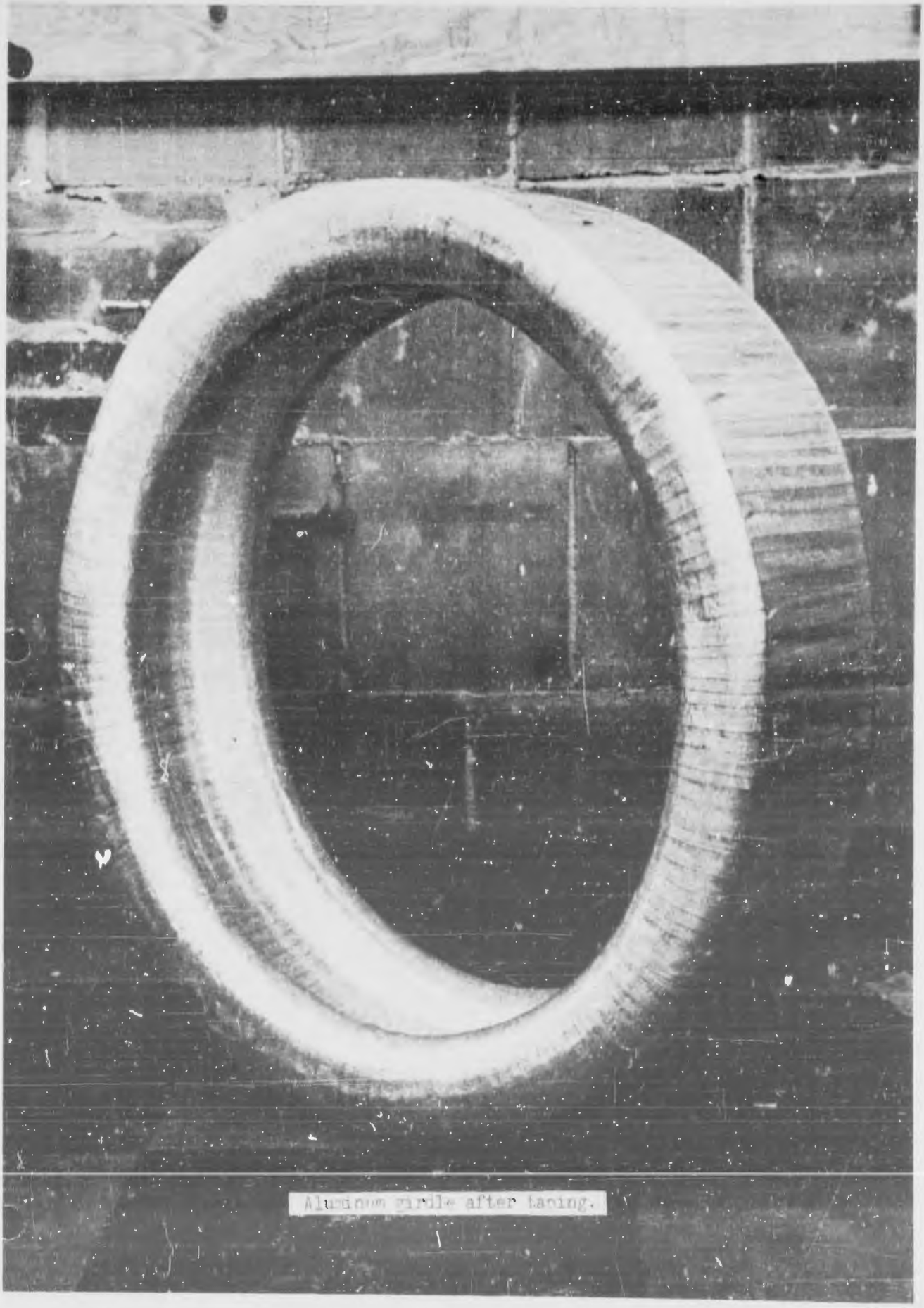




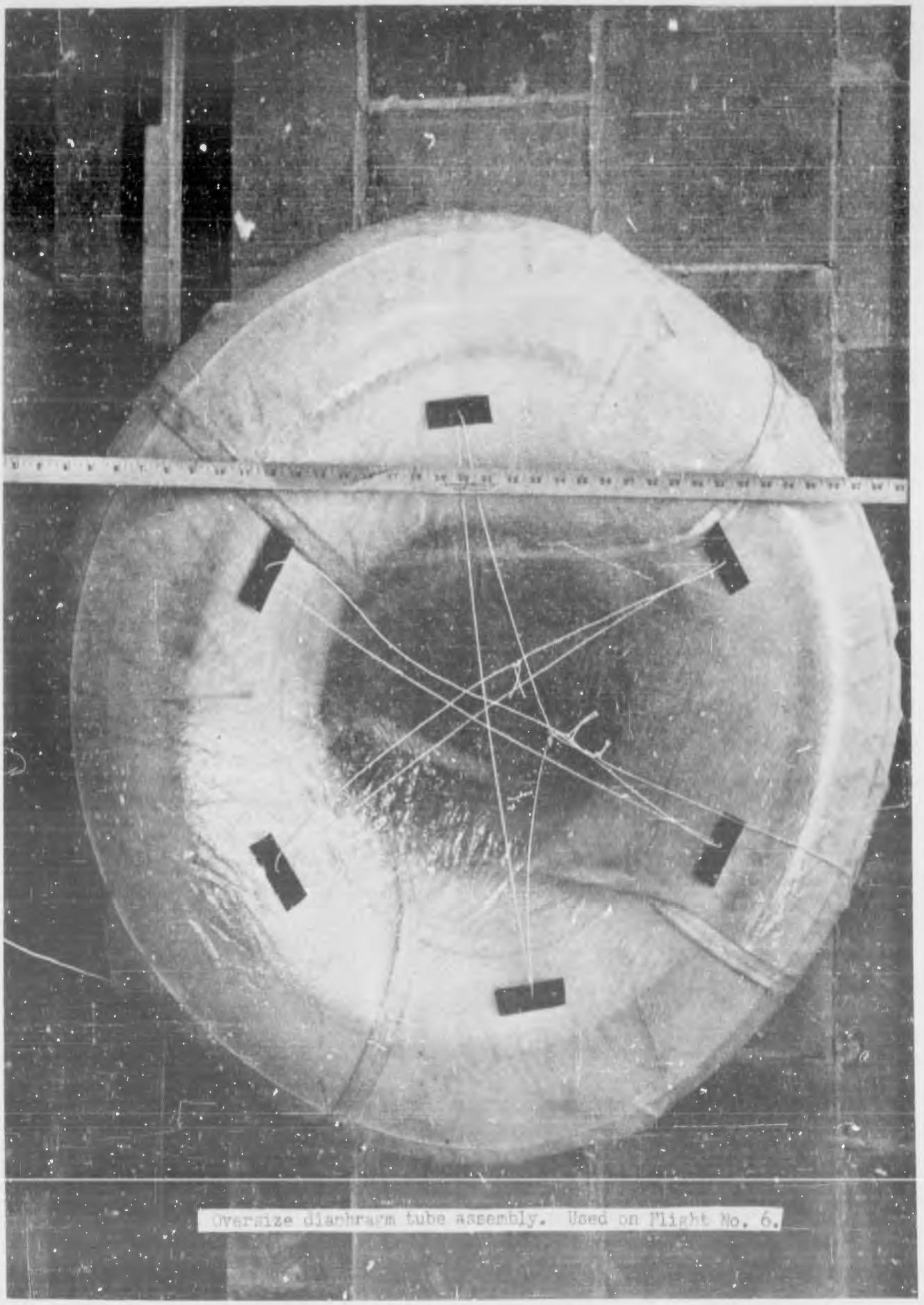
Diaphragm tube completely rigged, ready for insertion in balloon. Note diaphragm ripcord.



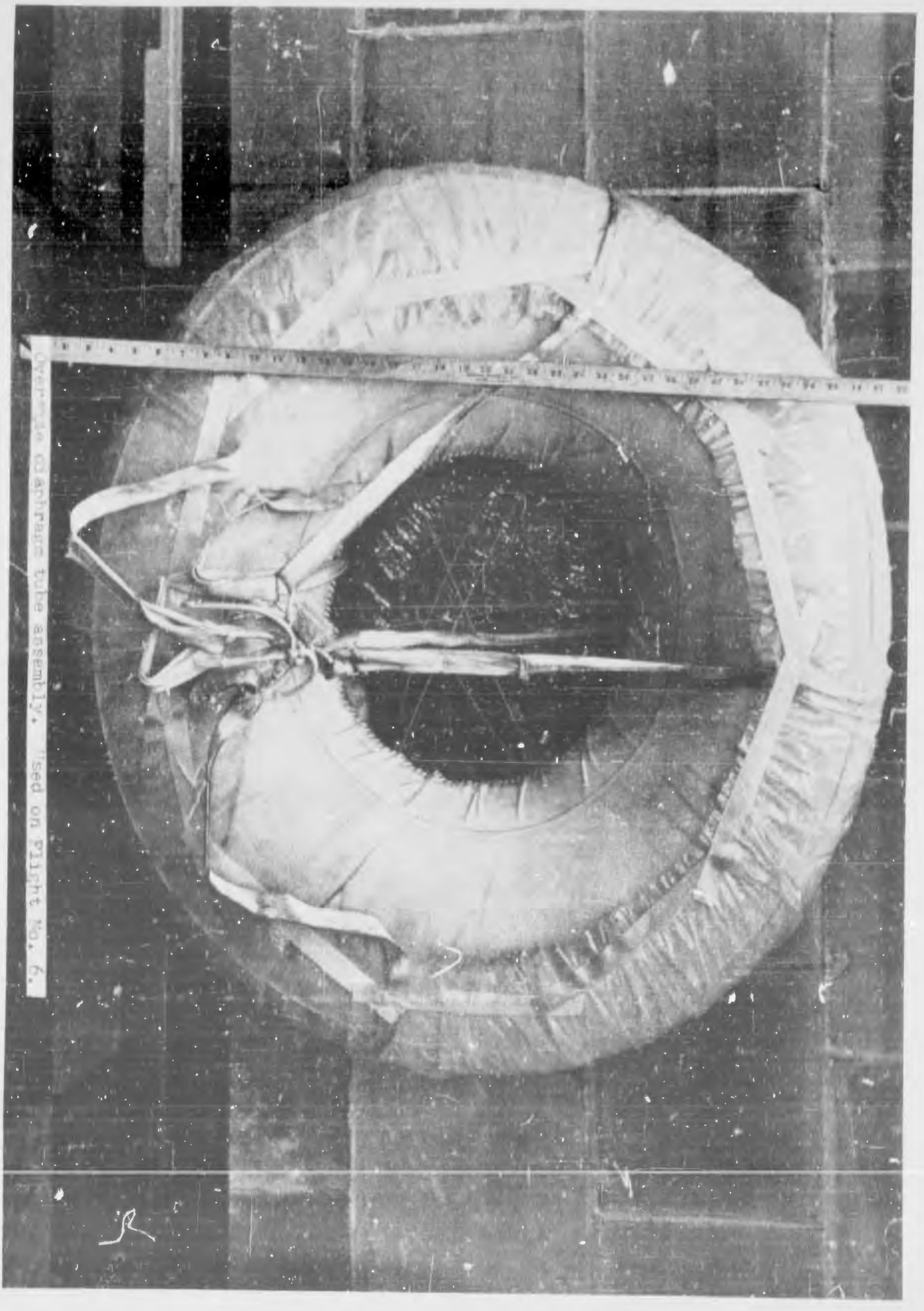
Hammered aluminum girdle before taping.



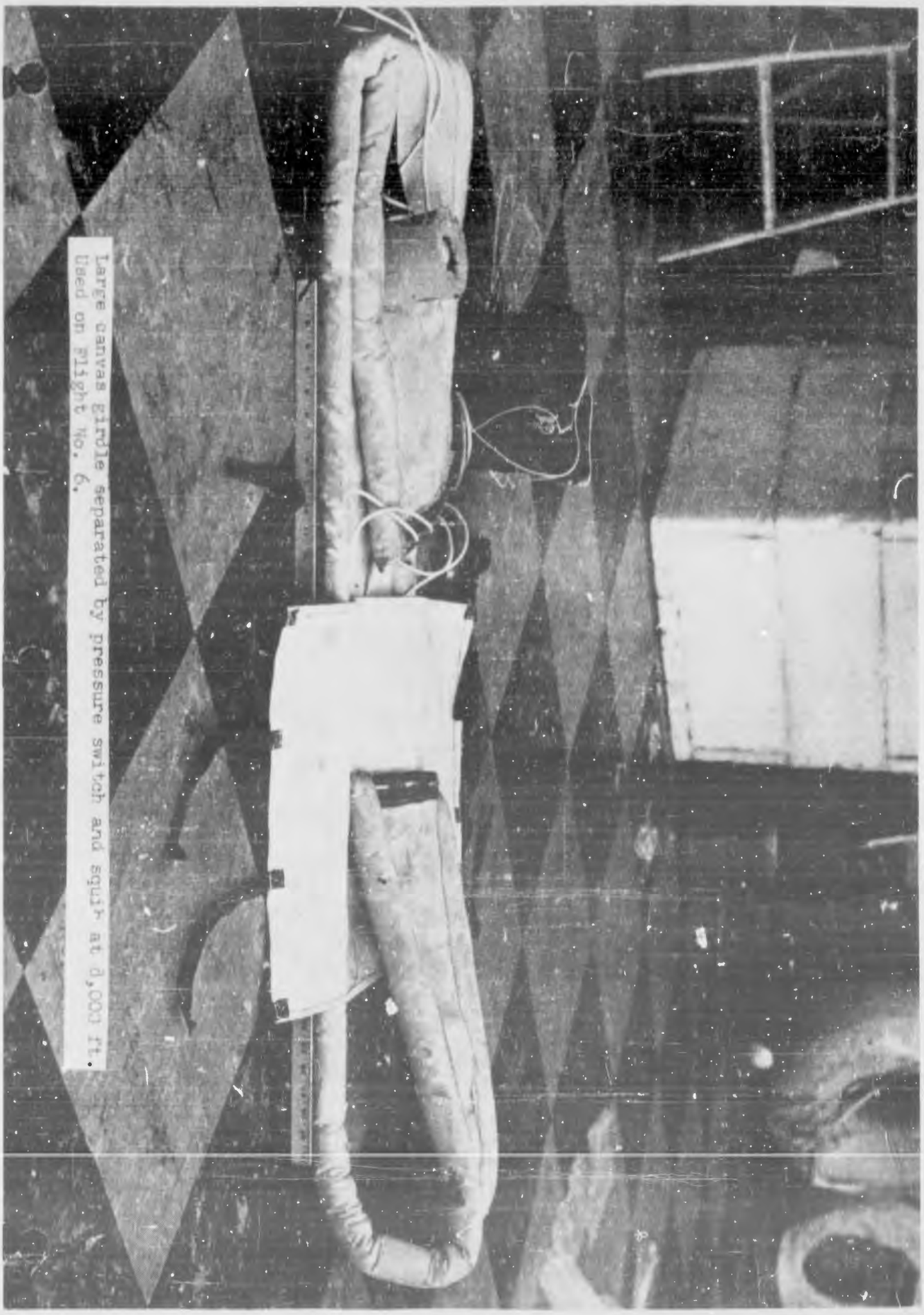
Aluminum girdle after lacing.



Oversize diaphragm tube assembly. Used on Flight No. 6.



Diaphragm tube assembly. Used on Flight No. 6.



Large canvas girdle separated by pressure switch and squir at 9,000 ft. Used on Flight No. 6.

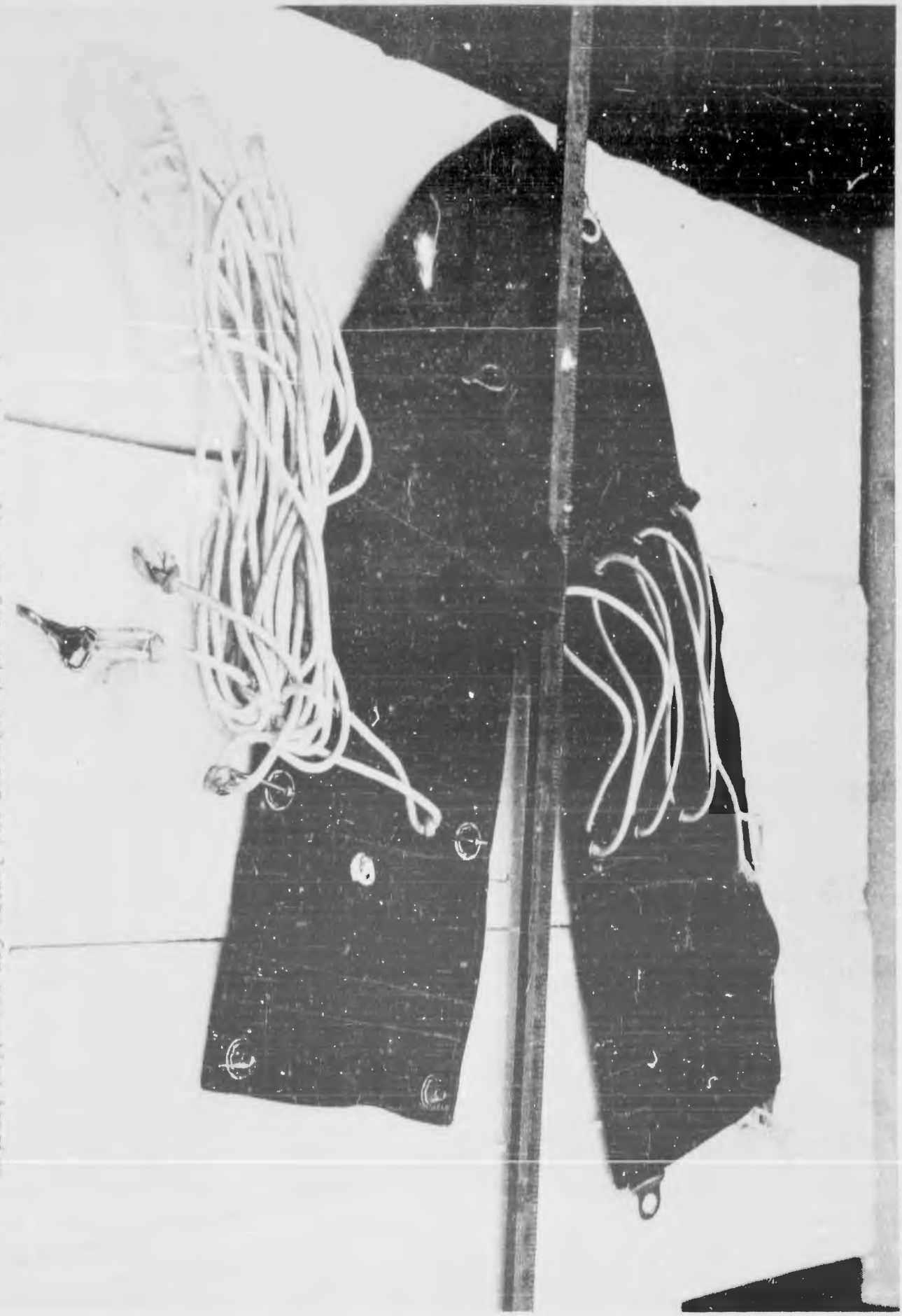
Aneroid tube deflator. The aneroid bellows is on opposite sides of round plate at center.



Inflation thimble.



Inflation thumb.



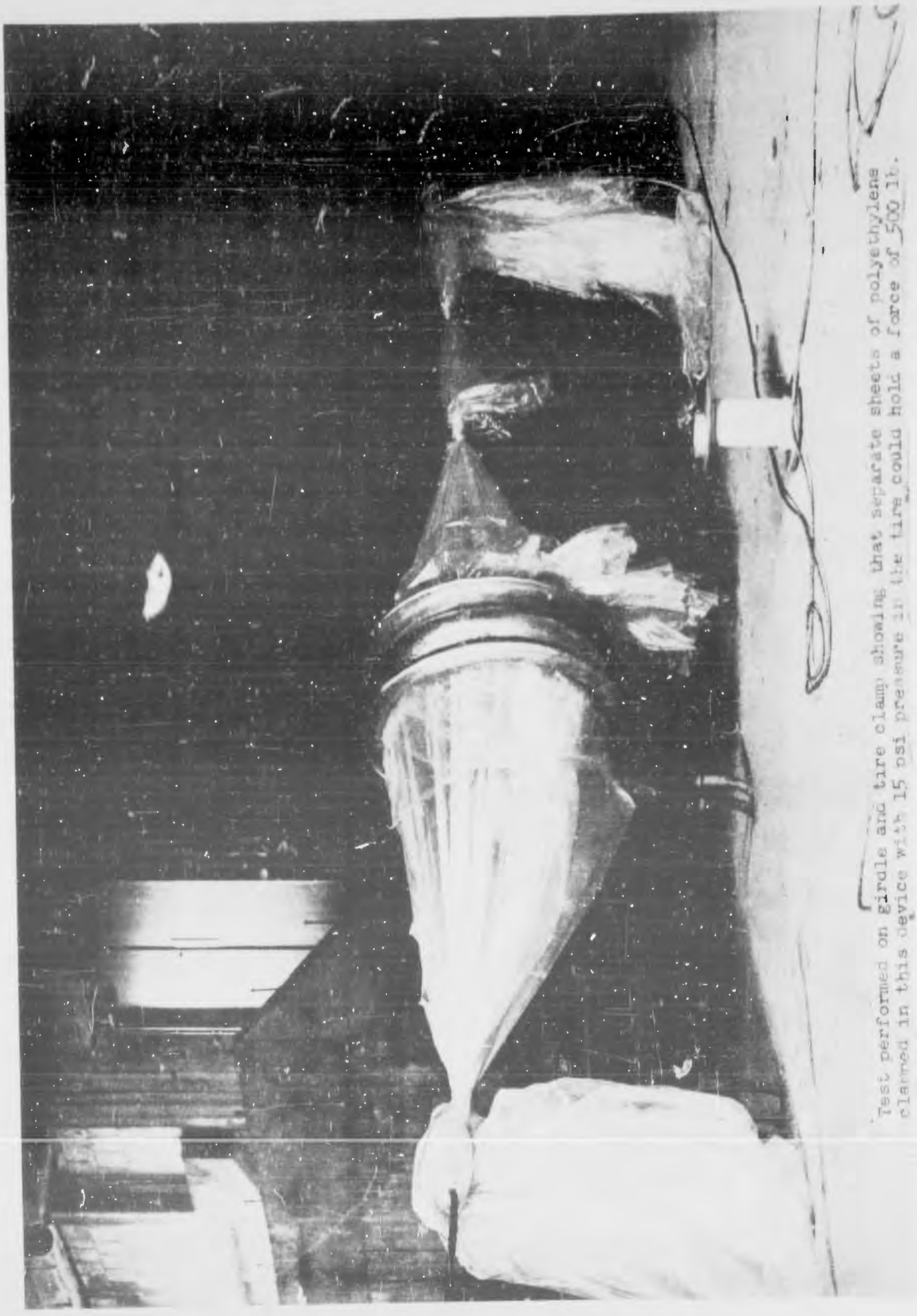
Restricted Security Information



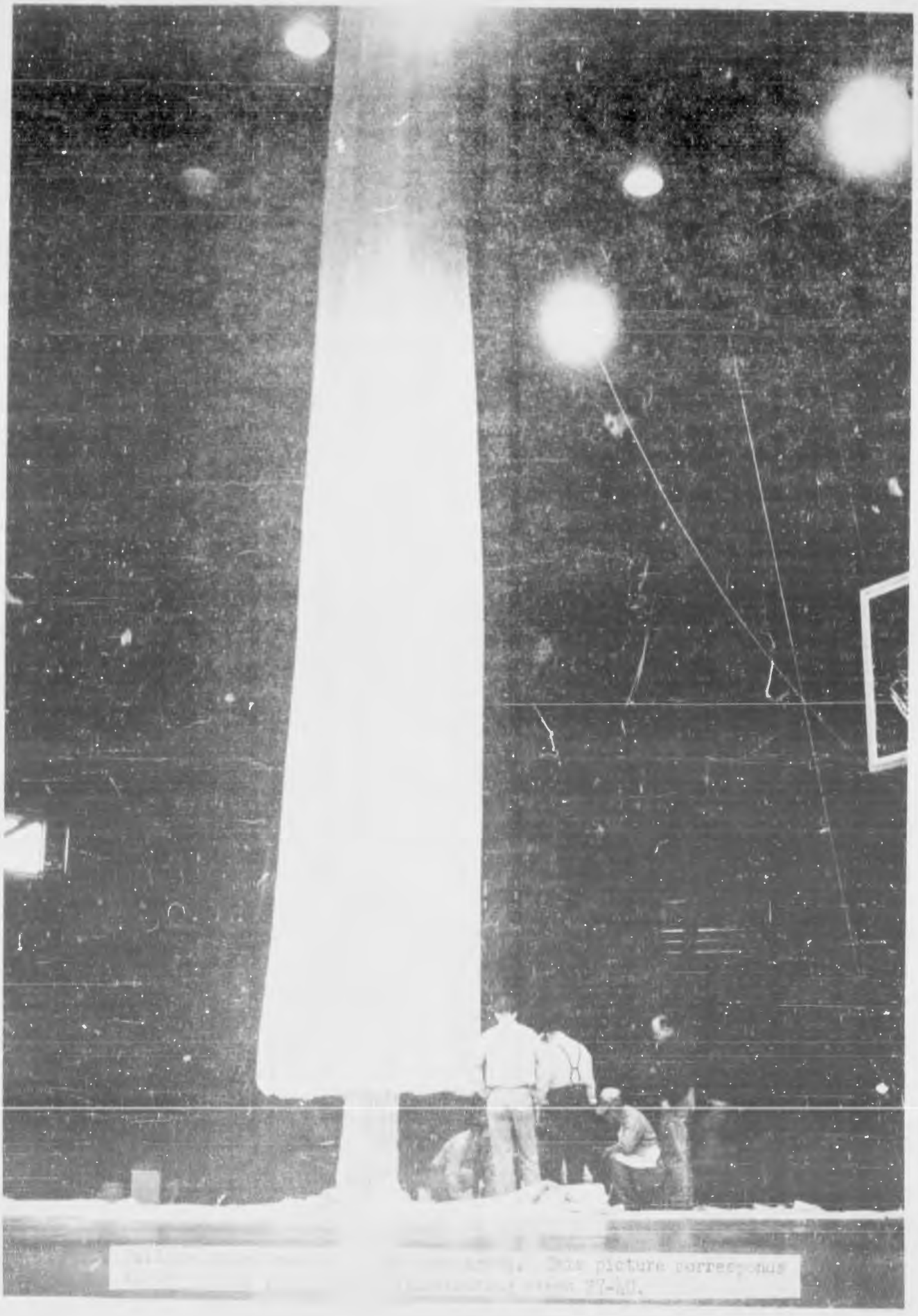
Torque-wrench for measuring lift of balloon.



Inner tire and diaphragm illustrating method for ripping the diaphragm off.



Test performed on girdle and tire clamp showing that separate sheets of polyethylene clamped in this device with 15 psi pressure in the tire could hold a force of 500 lb.



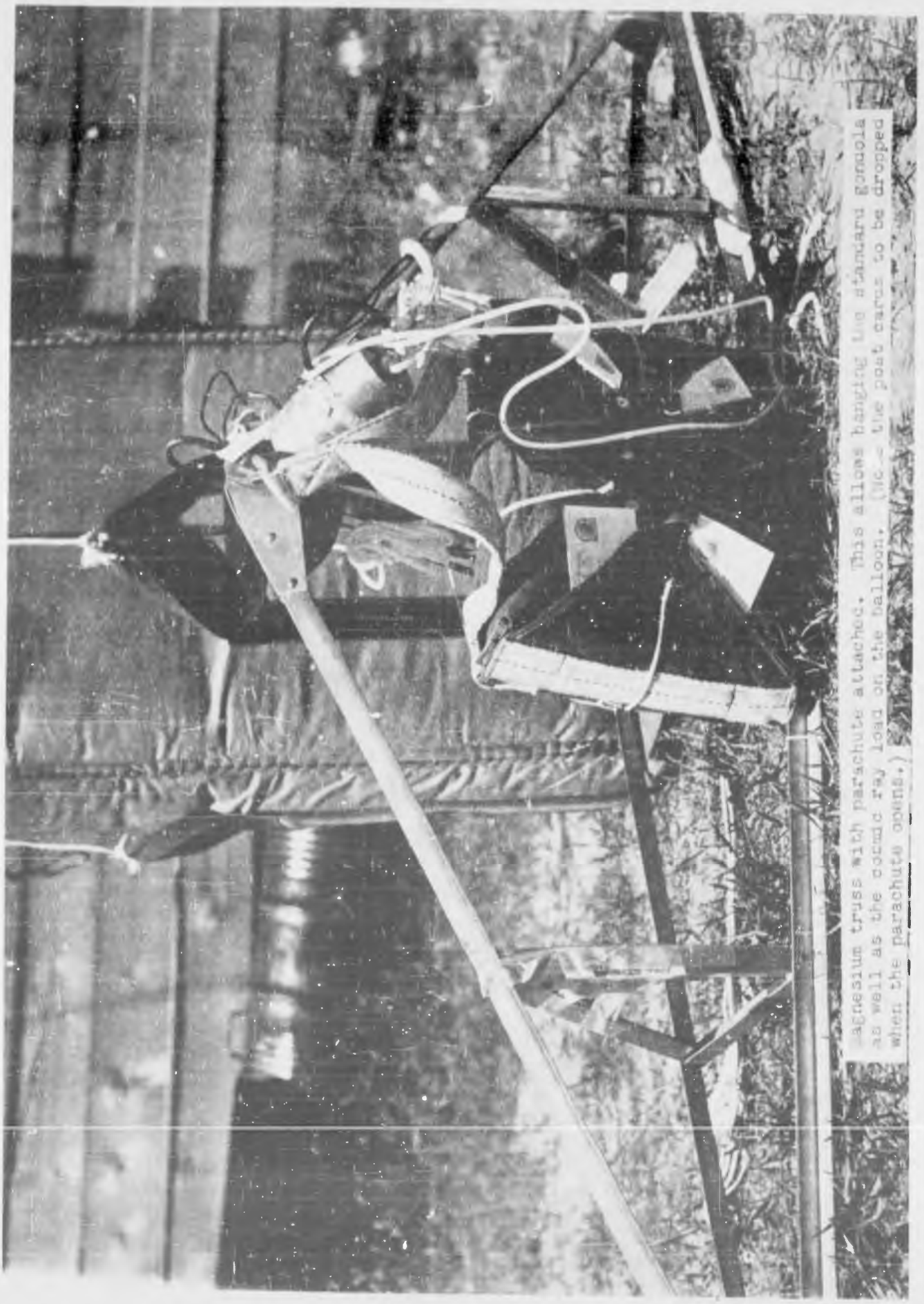
APPENDIX IV

LAUNCHING METHOD

Photographs included in this appendix show the various phases of a Minnesota launching. Photographs were obtained from two flights, Flights 9 and 16, one of which carried cosmic ray gear.



Installing ground stake for tie down



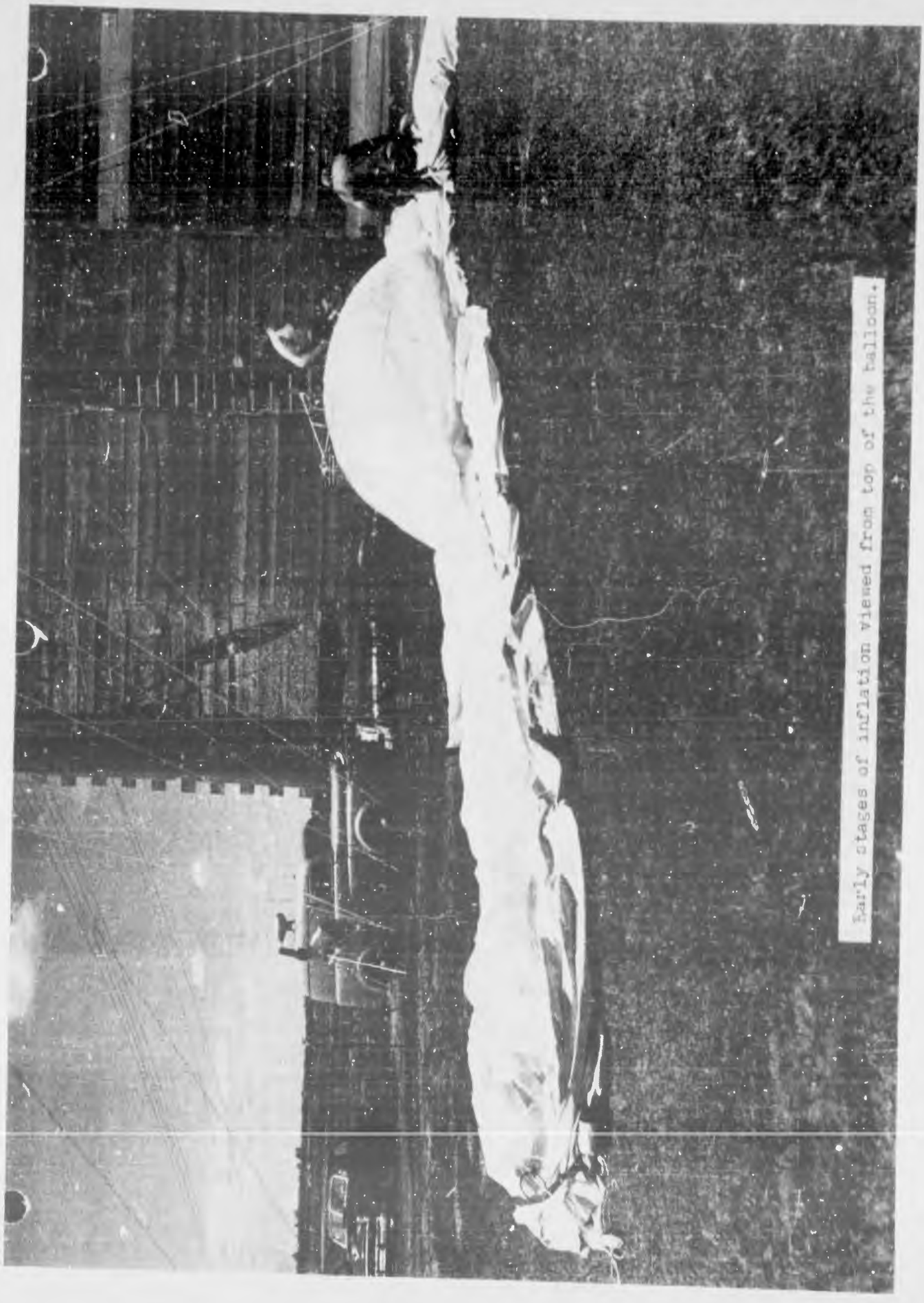
agnesium truss with parachute attached. This allows hanging the standard gondola as well as the cosmic ray load on the balloon. (NOTE - the post cards to be dropped when the parachute opens.)



Corset at the bottom of the balloon showing quick releases.



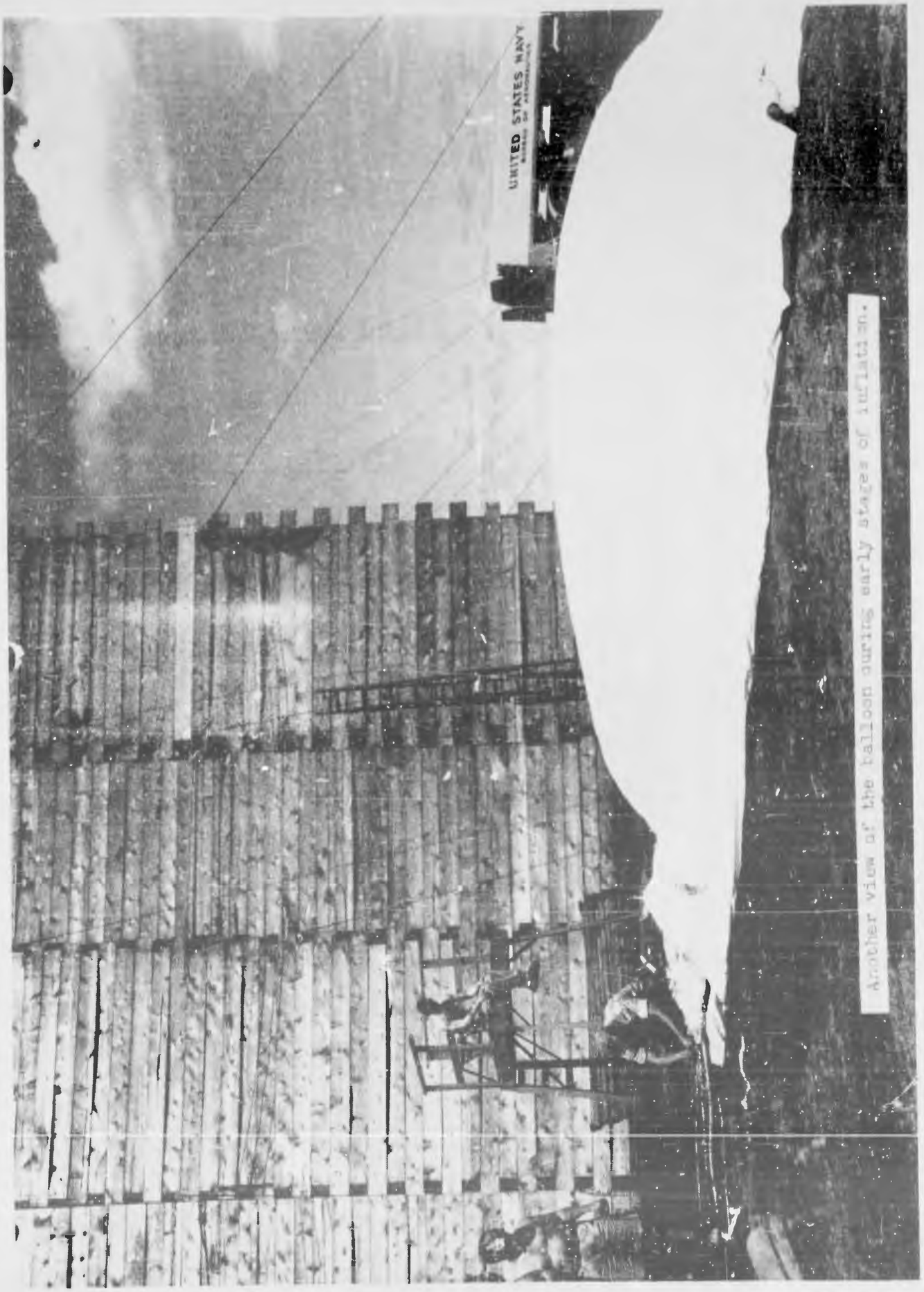
Beginning of inflation observed from the bottom of the balloon



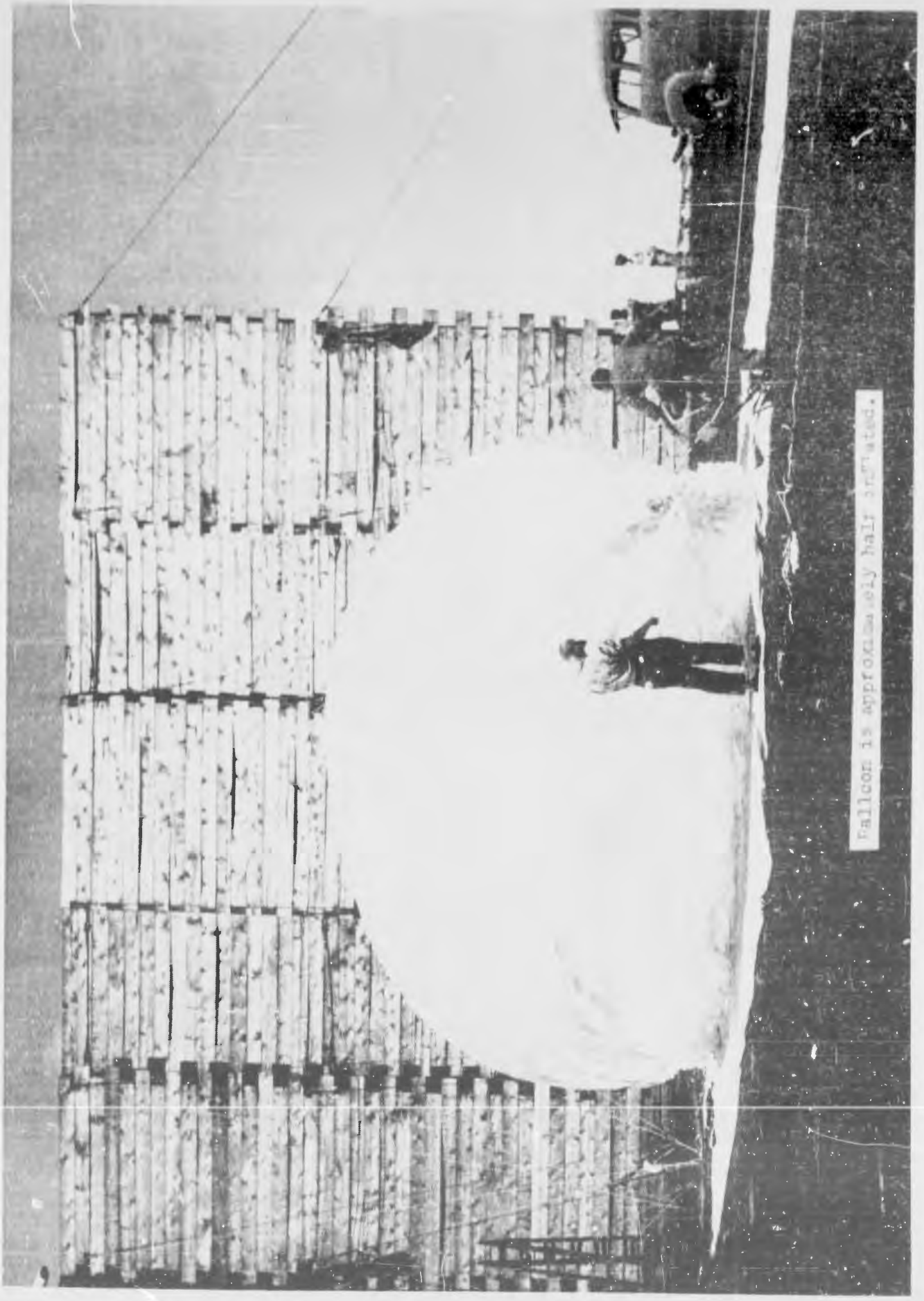
Early stages of inflation viewed from top of the balloon.



Close-up of leading ring and groove six feet from the end of the cable.

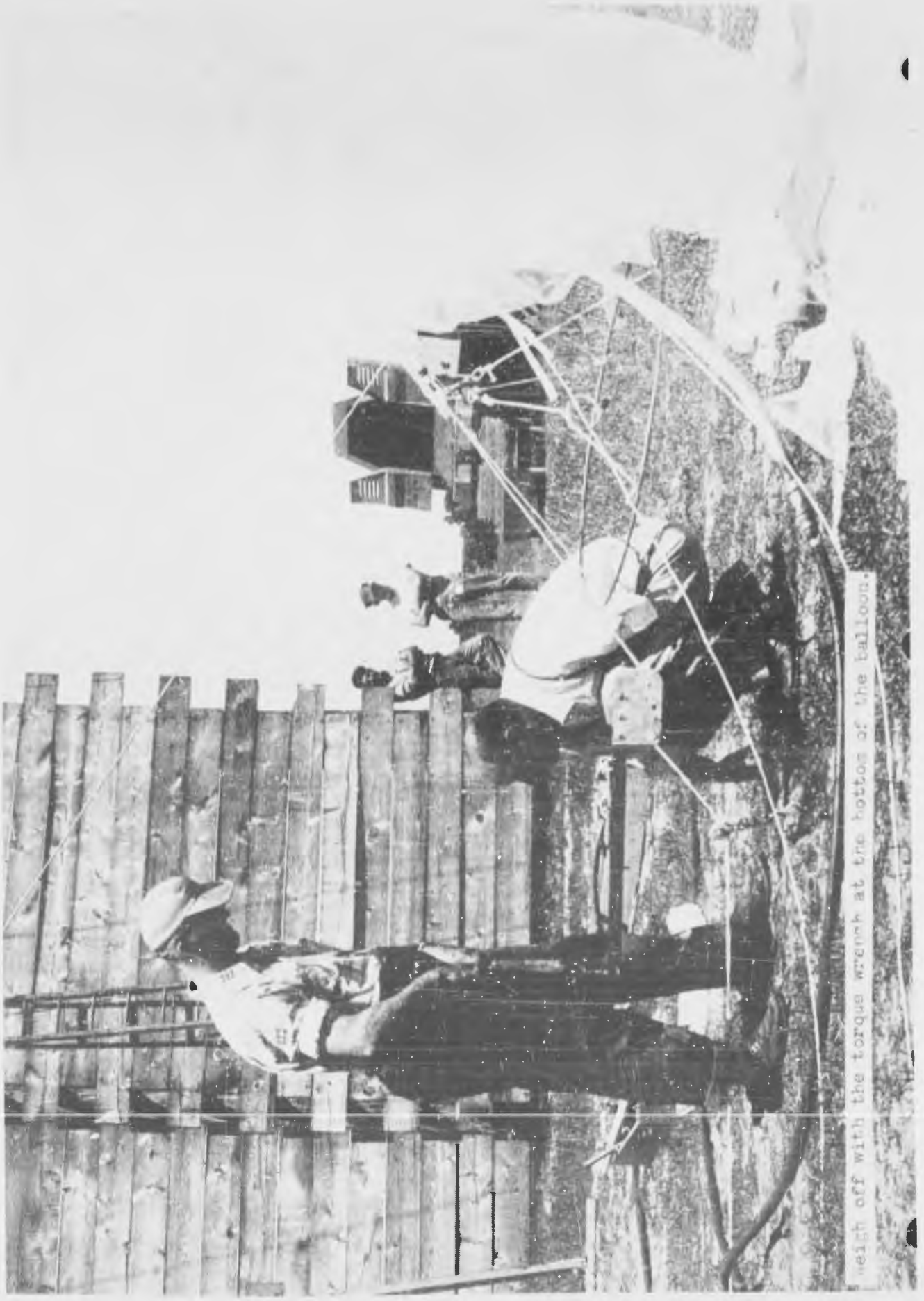


Another view of the balloon during early stages of inflation.

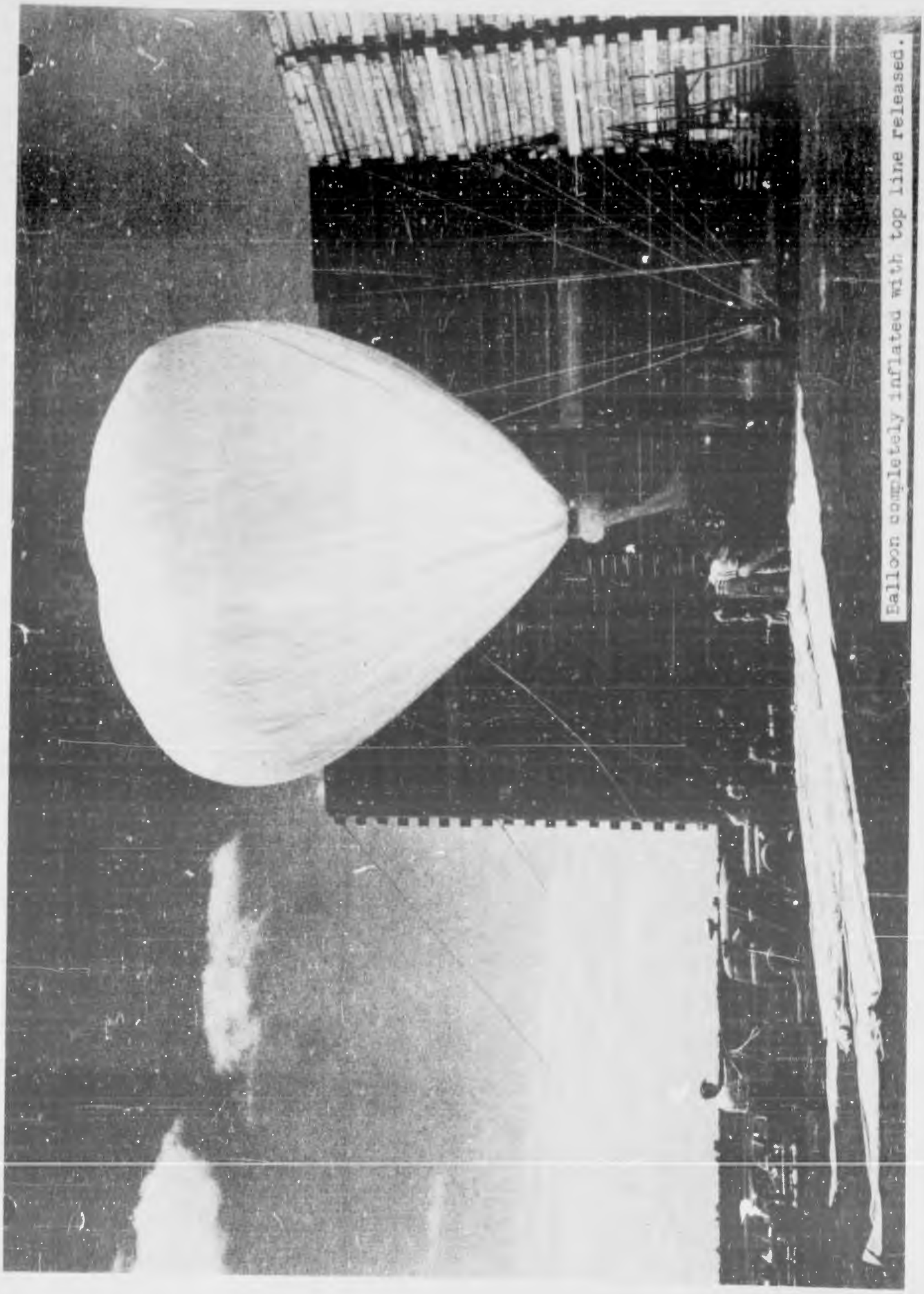

Falcon is approximately half serrated.



Weigh off with the torque wrench at the crown of the balloon.



Weighing off with the torque wrench at the bottom of the balloon.



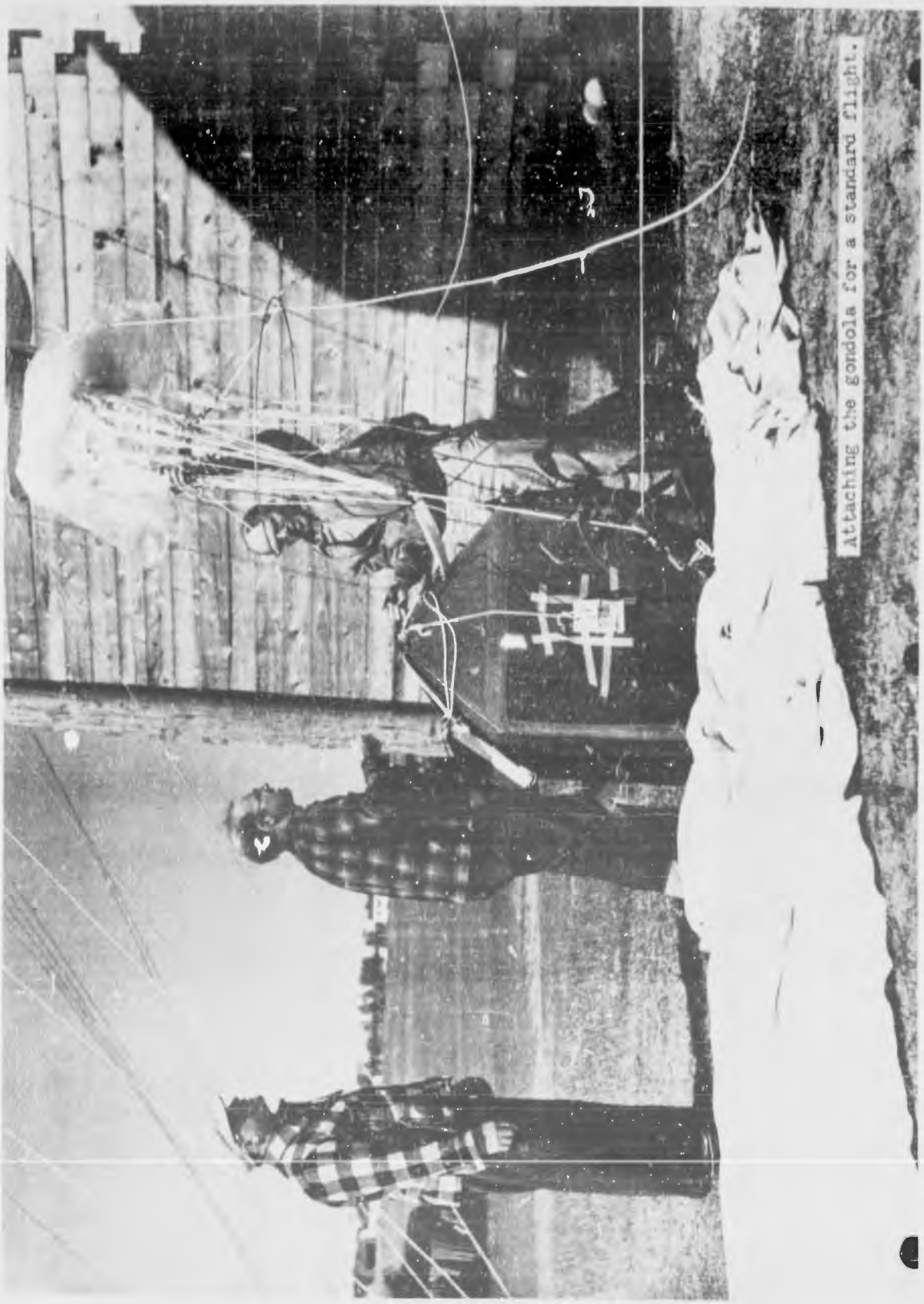
Balloon completely inflated with top line released.



Another view of the completely inflated bubble.

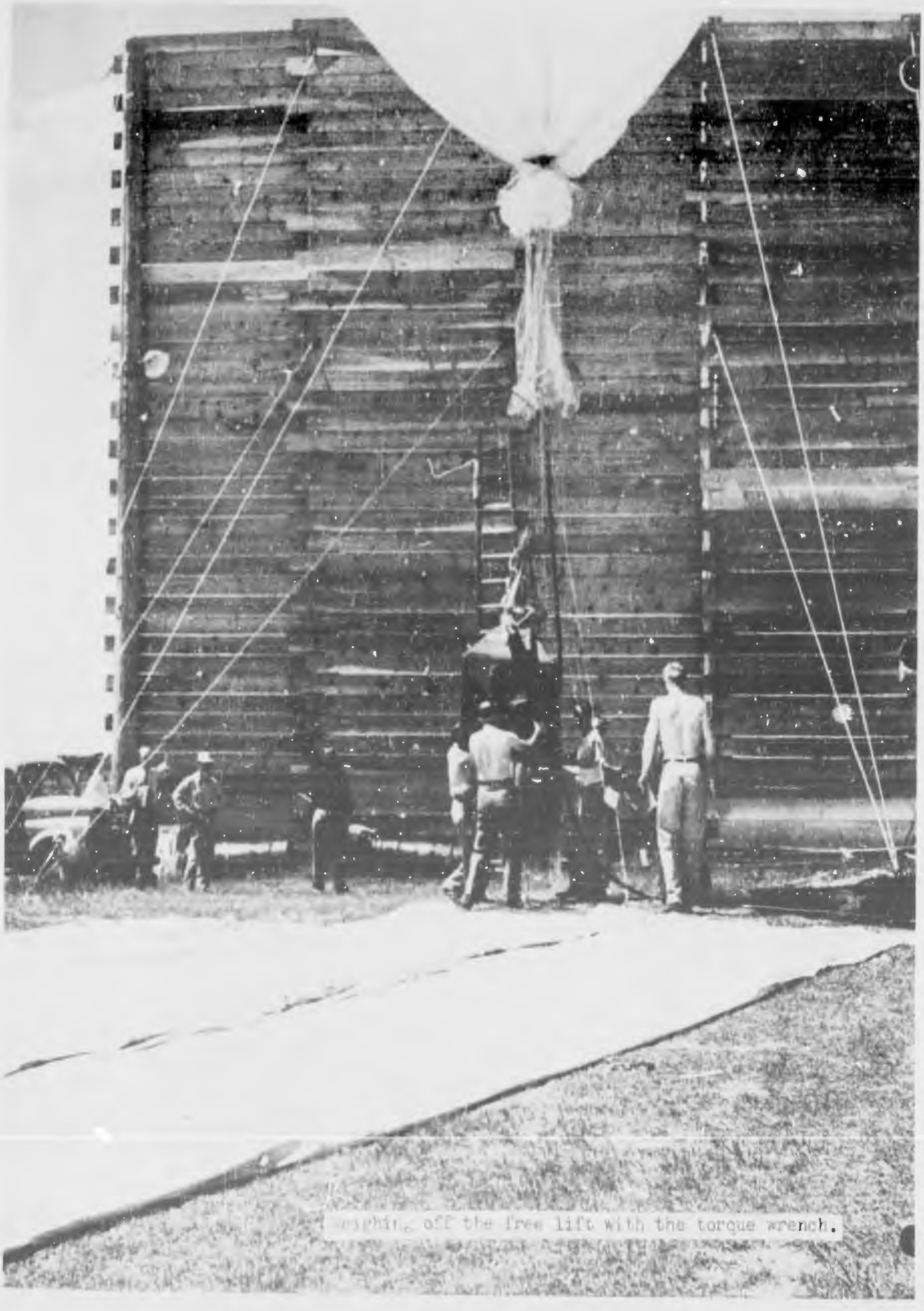


going through the check list on the standard gondola.



Attaching the gondola for a standard flight.

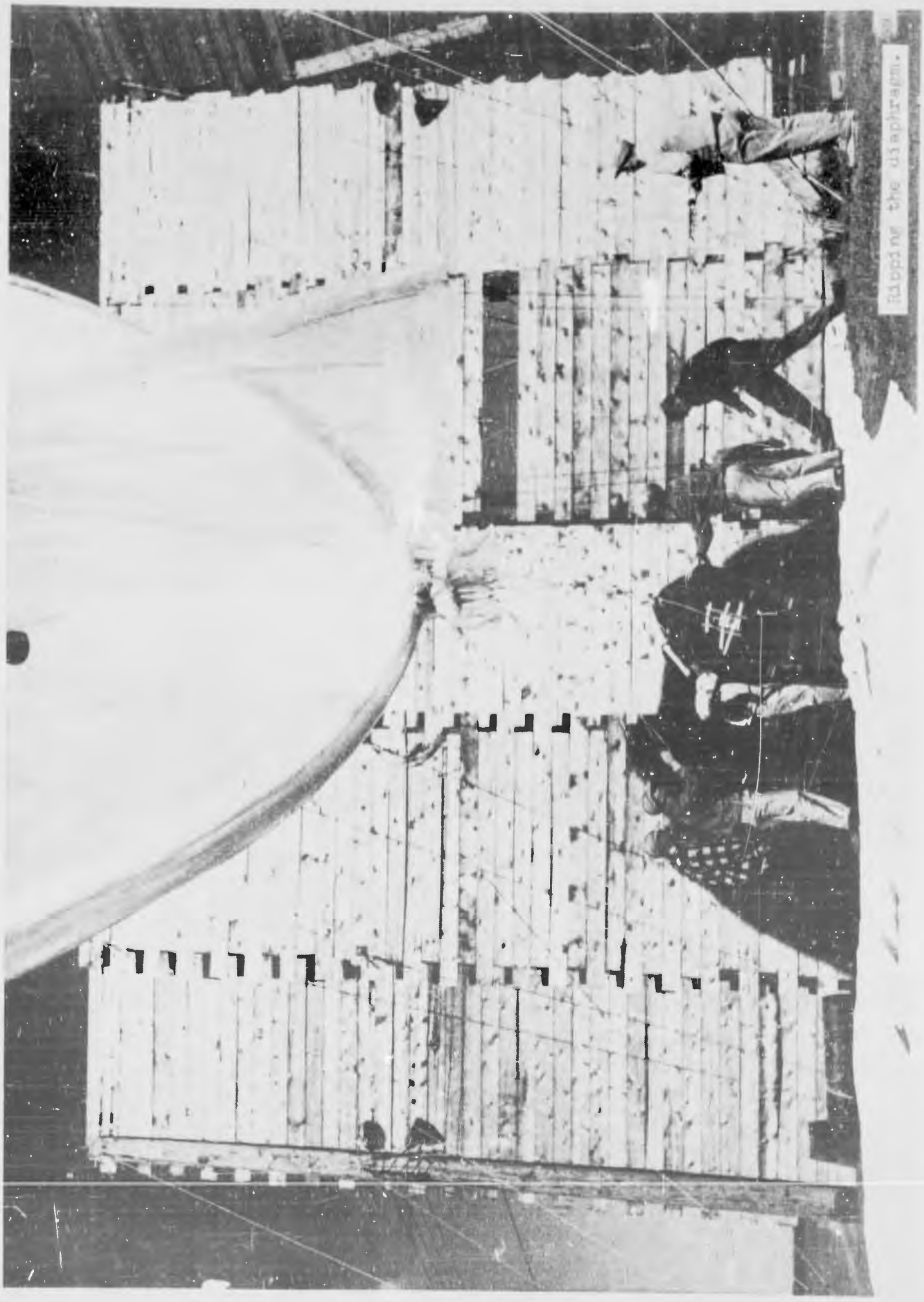
Attaching the gondola to the rip tape of the balloon (the ring above the gondola catches the aluminum girdle).

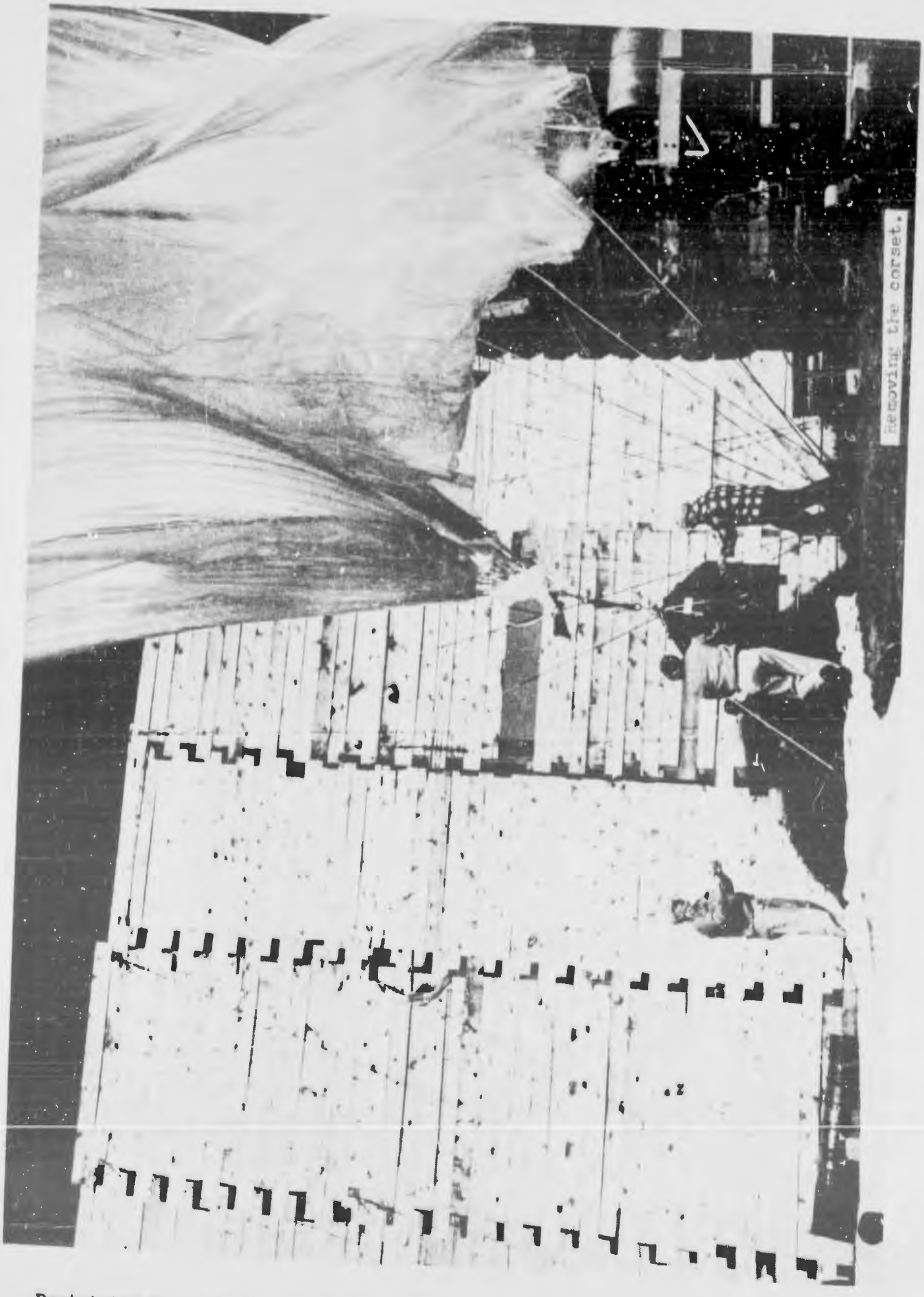


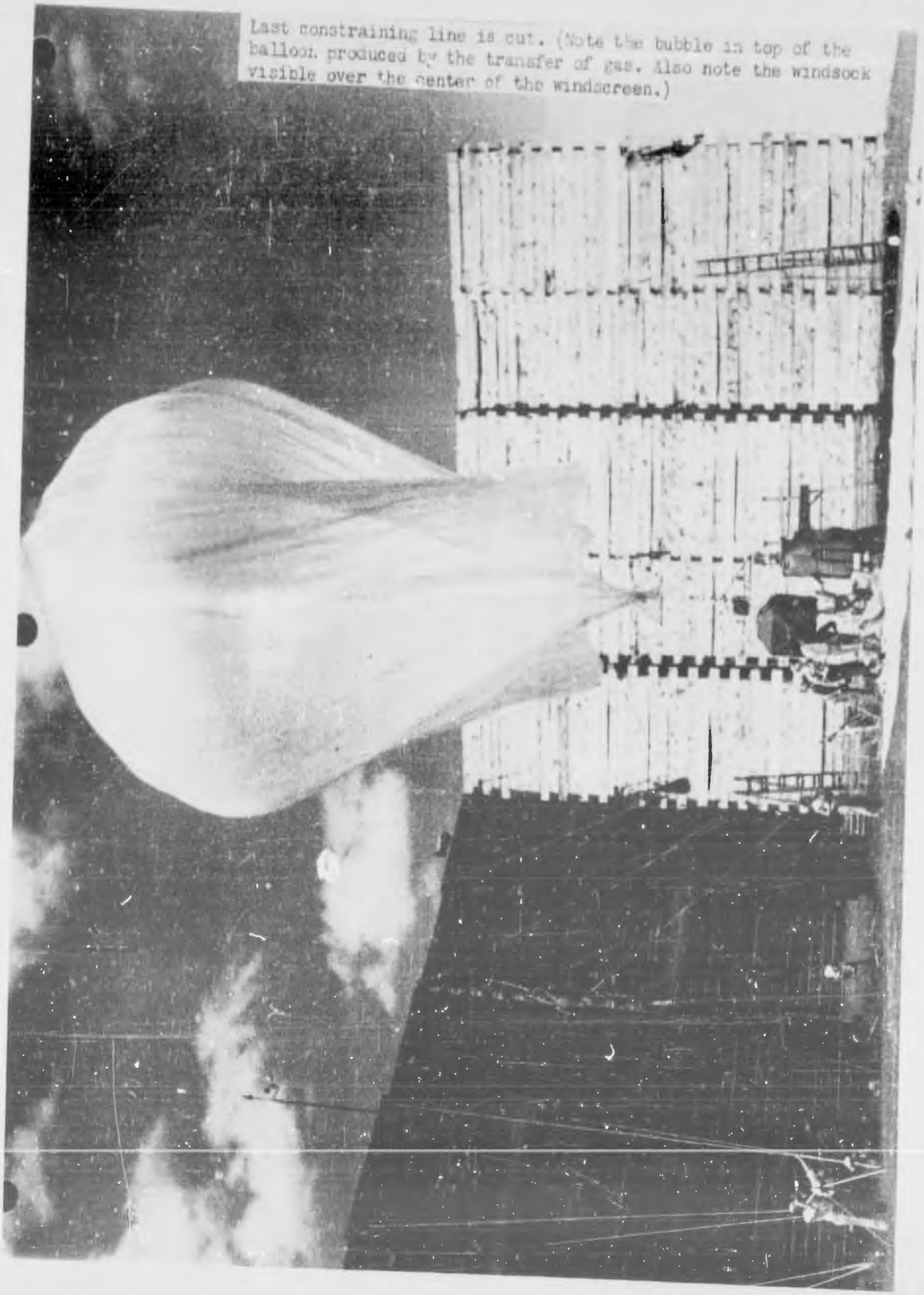
[illegible] off the free lift with the torque wrench.



Measuring the free lift on a flight carrying cosmic ray gear.


Ripping the diaphragm.

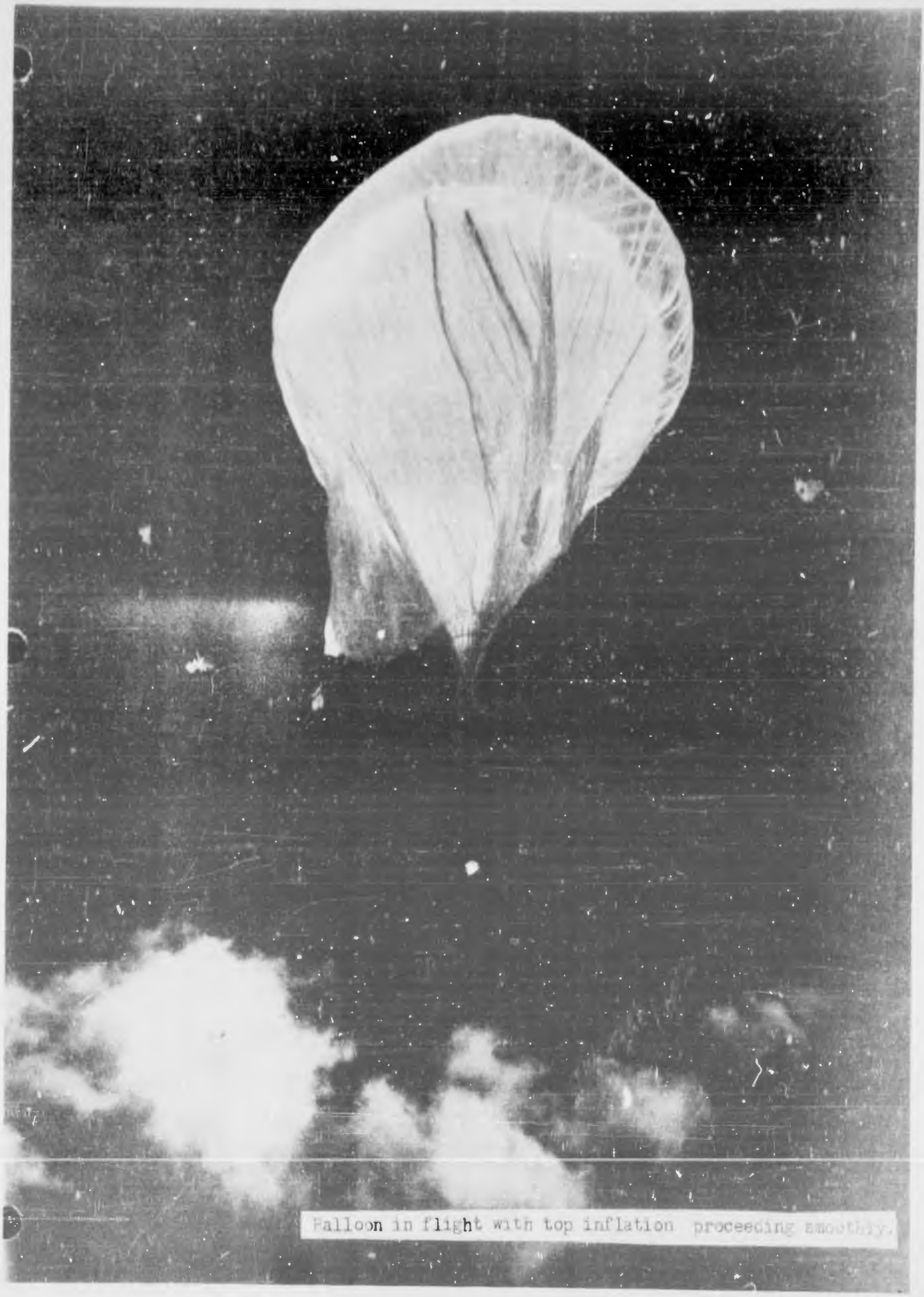

removing the corset.



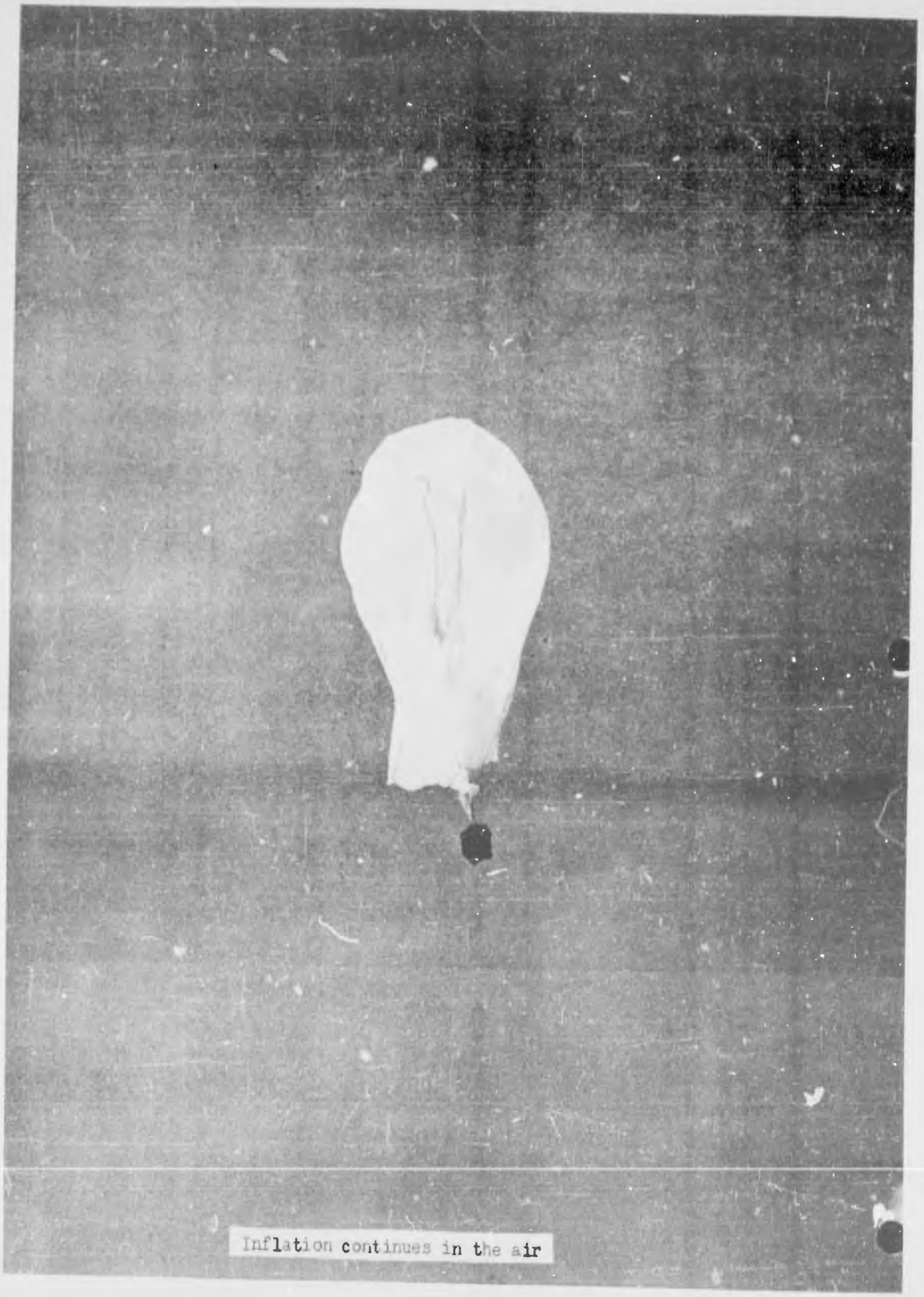
Last constraining line is cut. (Note the bubble in top of the balloon produced by the transfer of gas. Also note the windsock visible over the center of the windscreen.)



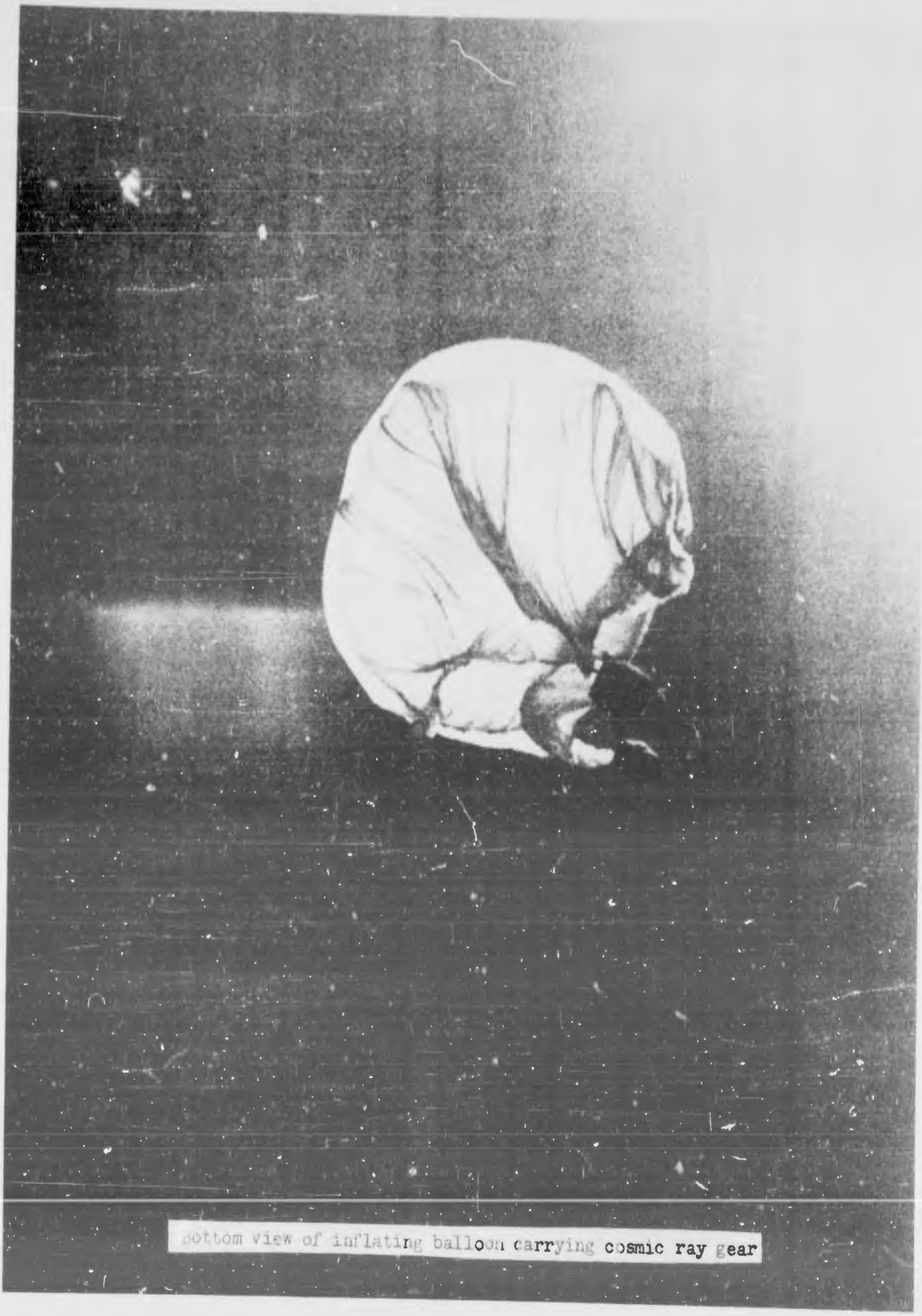
...ad shortly after take off.



Balloon in flight with top inflation proceeding smoothly.



Inflation continues in the air



Bottom view of inflating balloon carrying cosmic ray gear

APPENDIX V

ASTRO PHOTOGRAPHS OF LAUNCHING

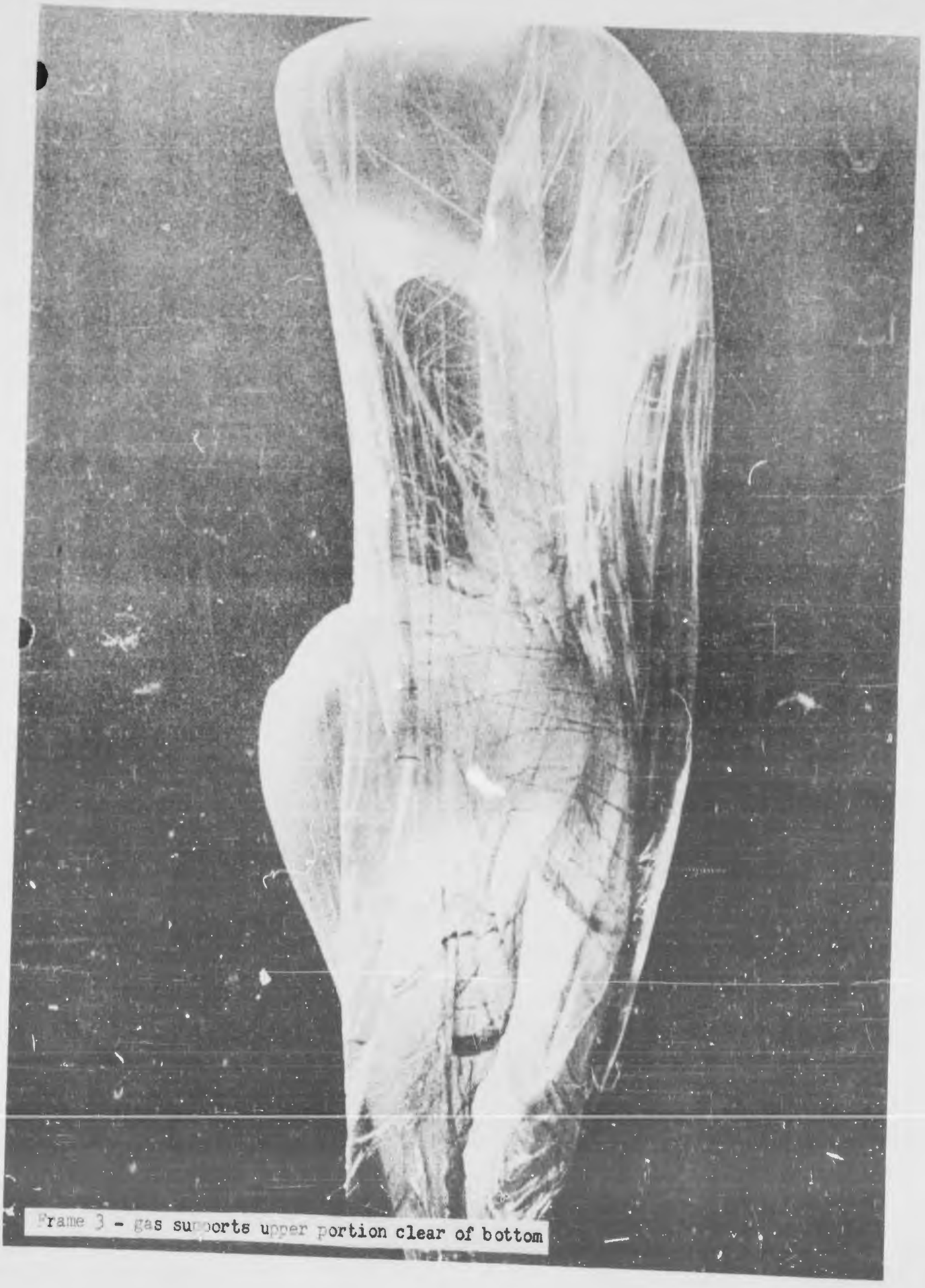
The following series of photographs was made with an astro-lens Leica camera during the initial stages of a flight just after launching. They show the process of transferring gas from the lower portion of the balloon to the upper through the torn out diaphragm. The entire process requires about two minutes and, as can be seen at the end of this stage, the balloon is completely extended with the bottom third constrained by the girdle. This girdle is released at a predetermined altitude, usually about 20,000 feet, and the balloon then has the appearance shown in Frame 21. If the correct slipping conditions are obtained, the girdle remains in place and is forced slowly downward by the expanding balloon above it.



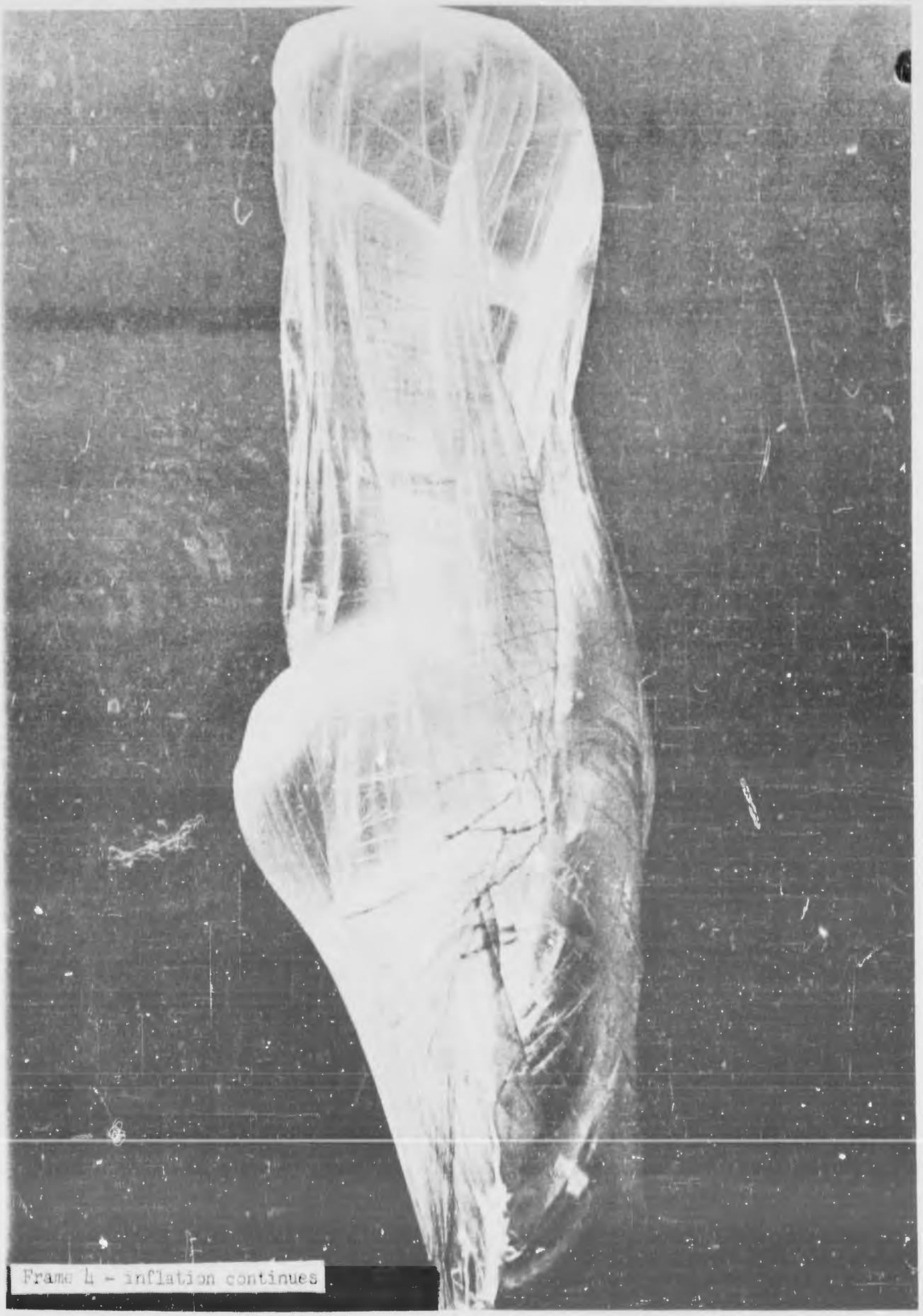
Frame 1 - balloon launching



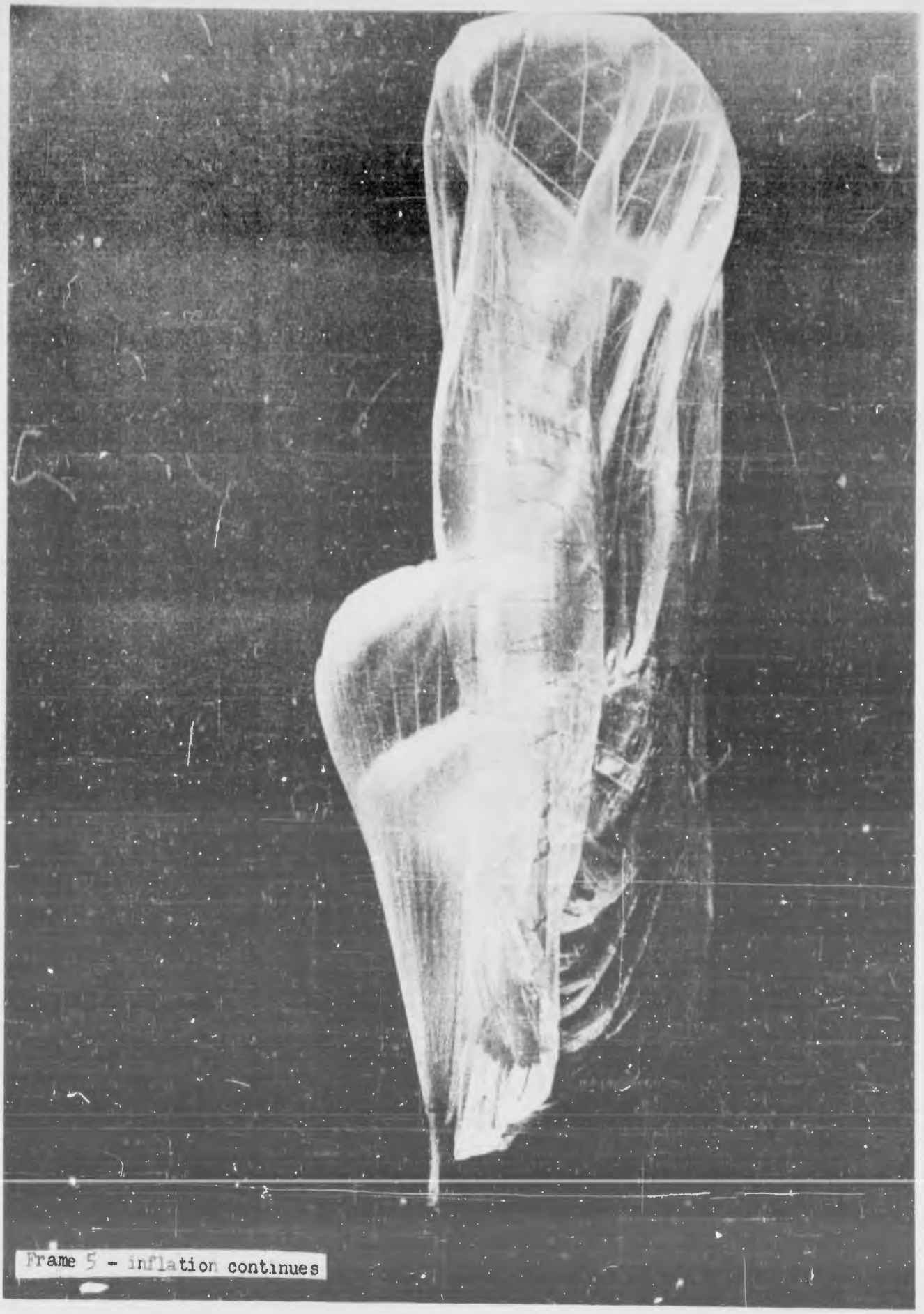
Frame 2 - beginning of gas transferral



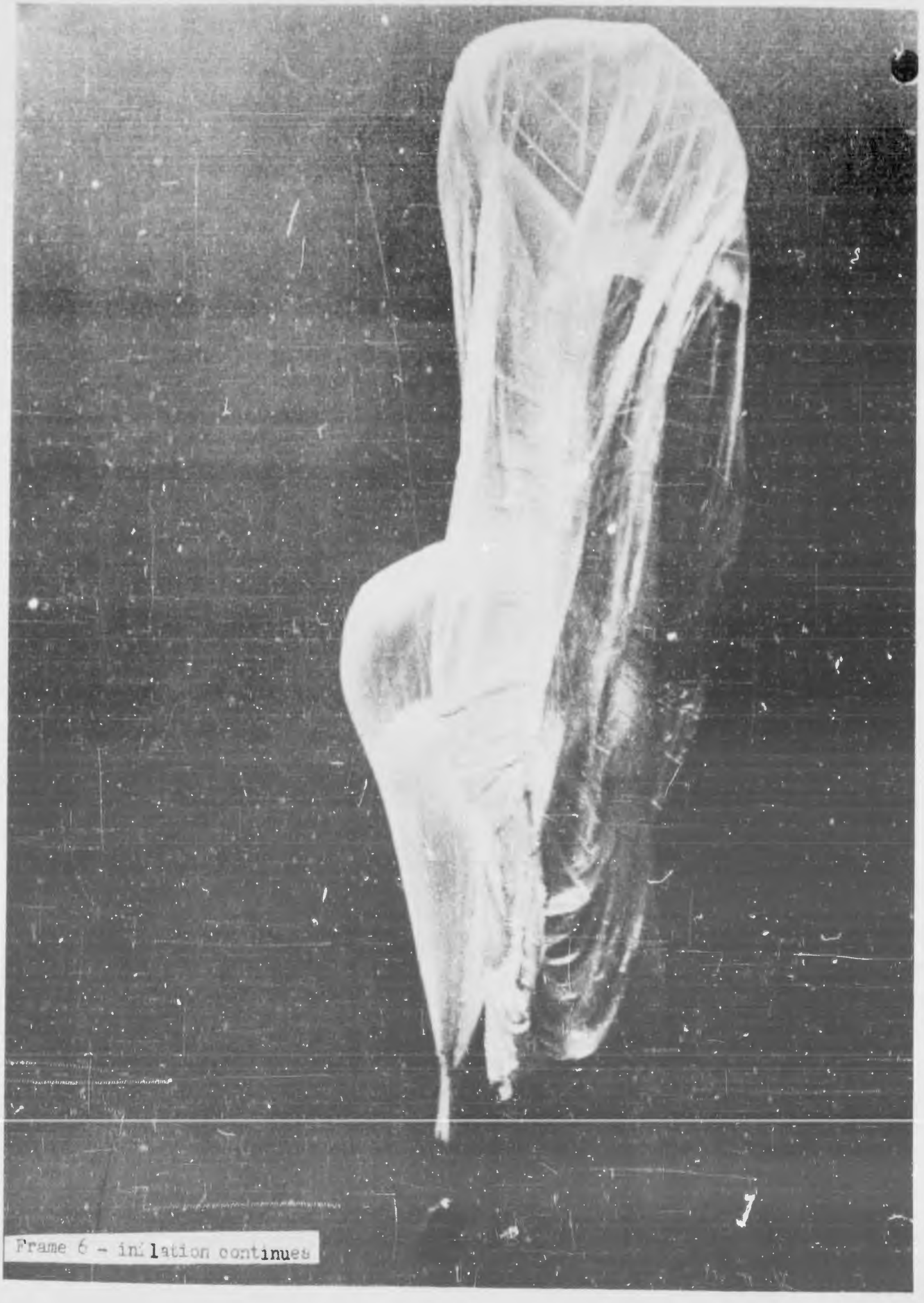
Frame 3 - gas supports upper portion clear of bottom



Frame 4 - inflation continues



Frame 5 - inflation continues



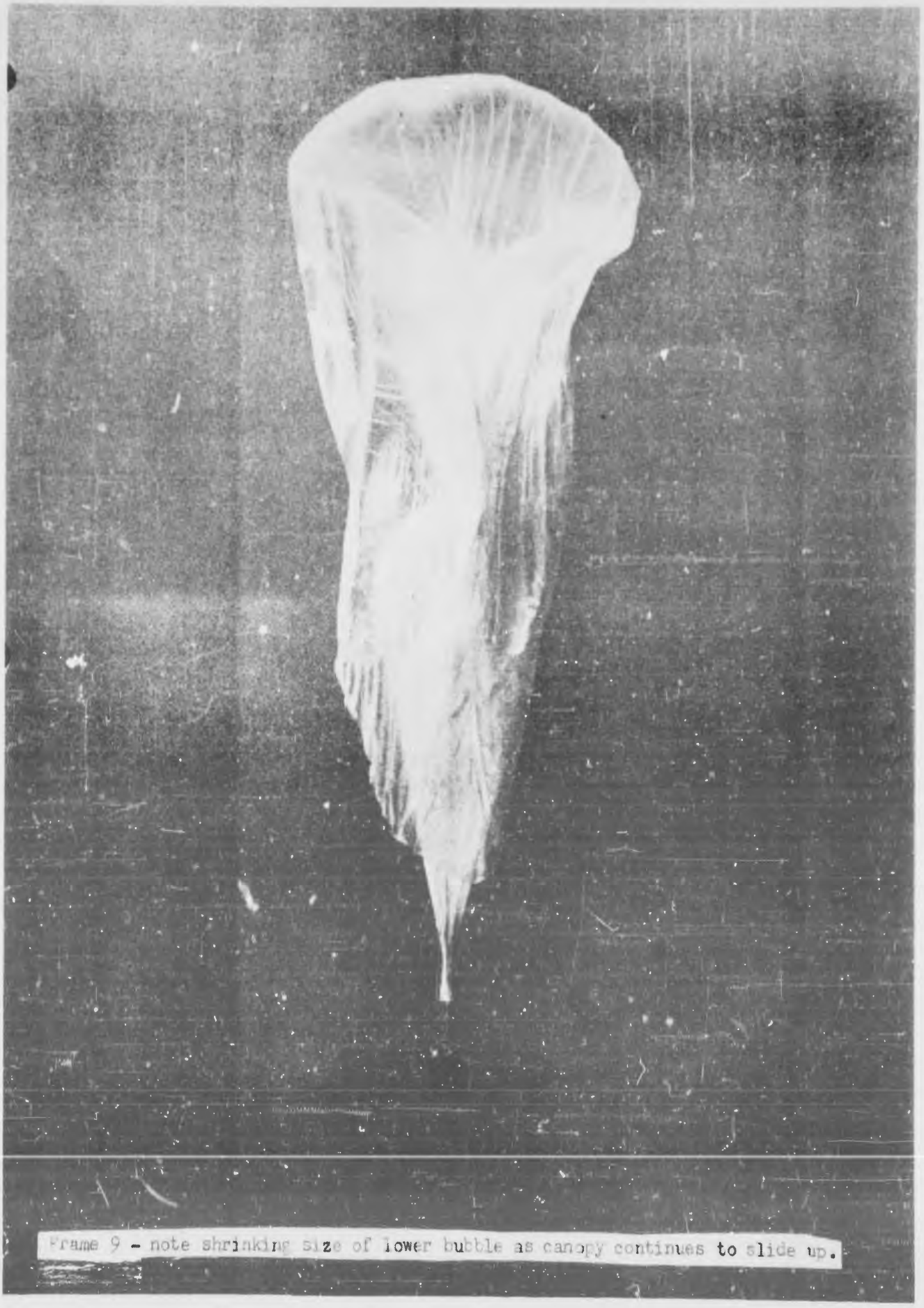
Frame 6 - inflation continues



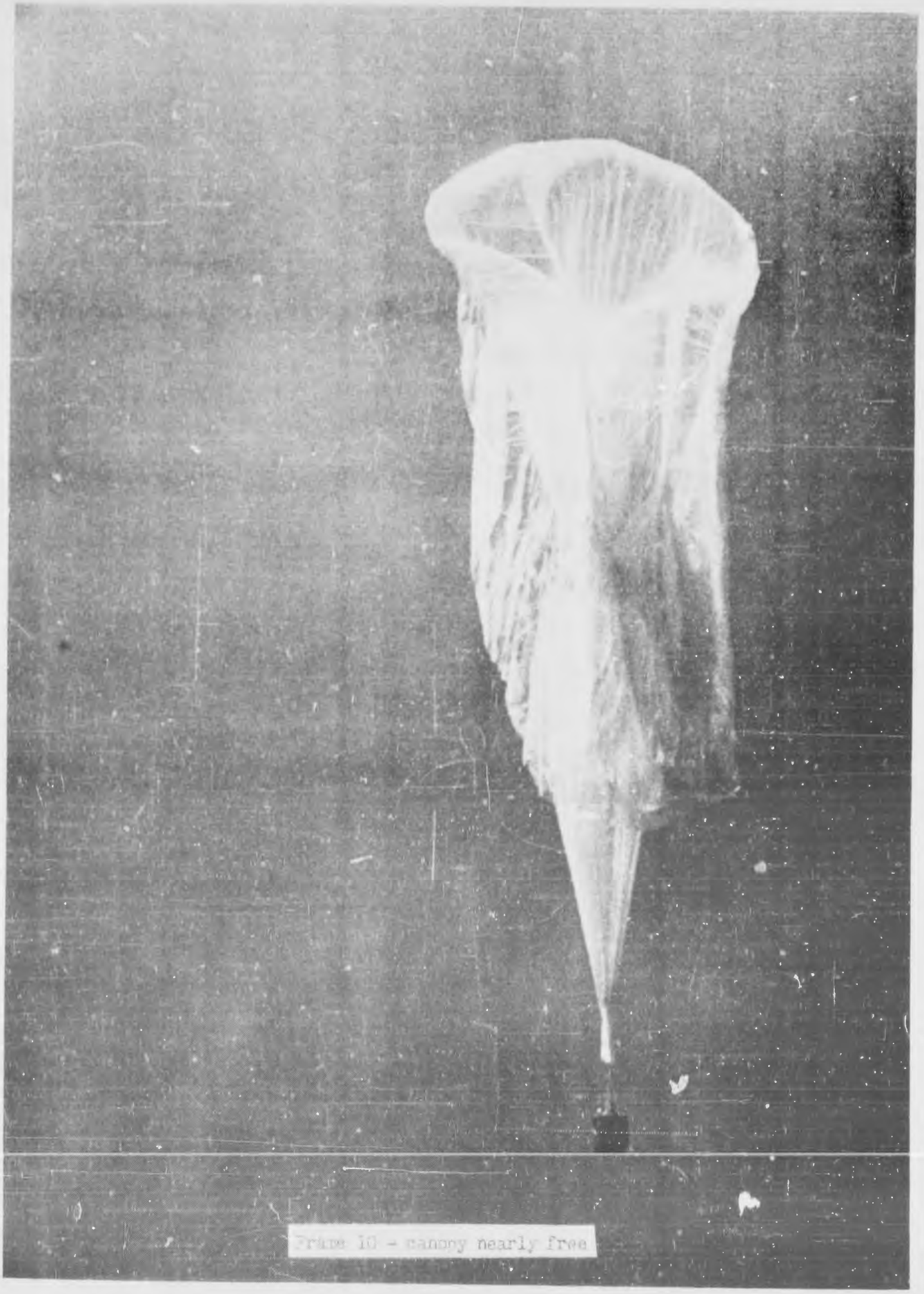
Frame 7 - note relatively little motion of top section with respect to bottom.

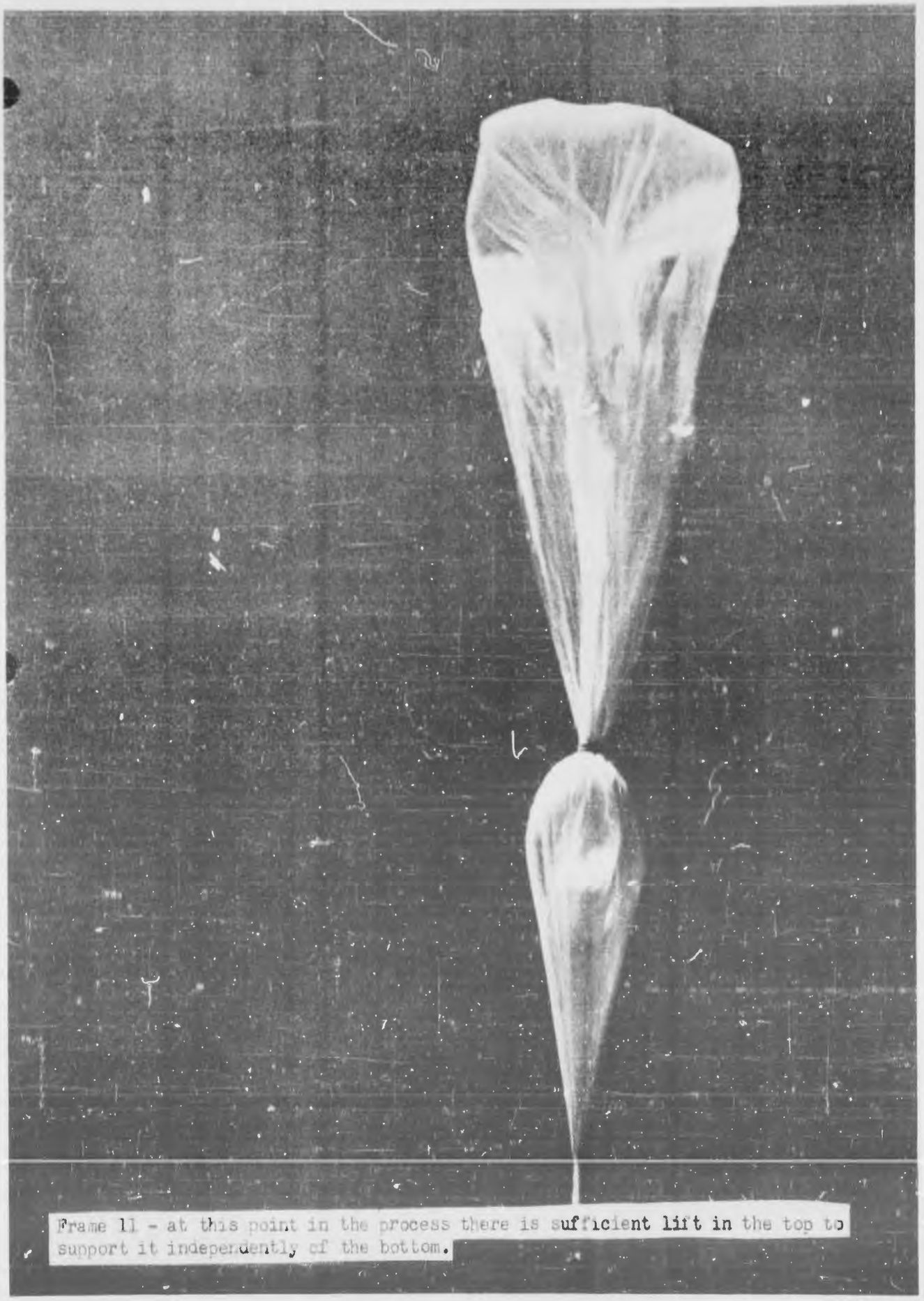


Frame 8 - lower folds of canopy begin to slide up

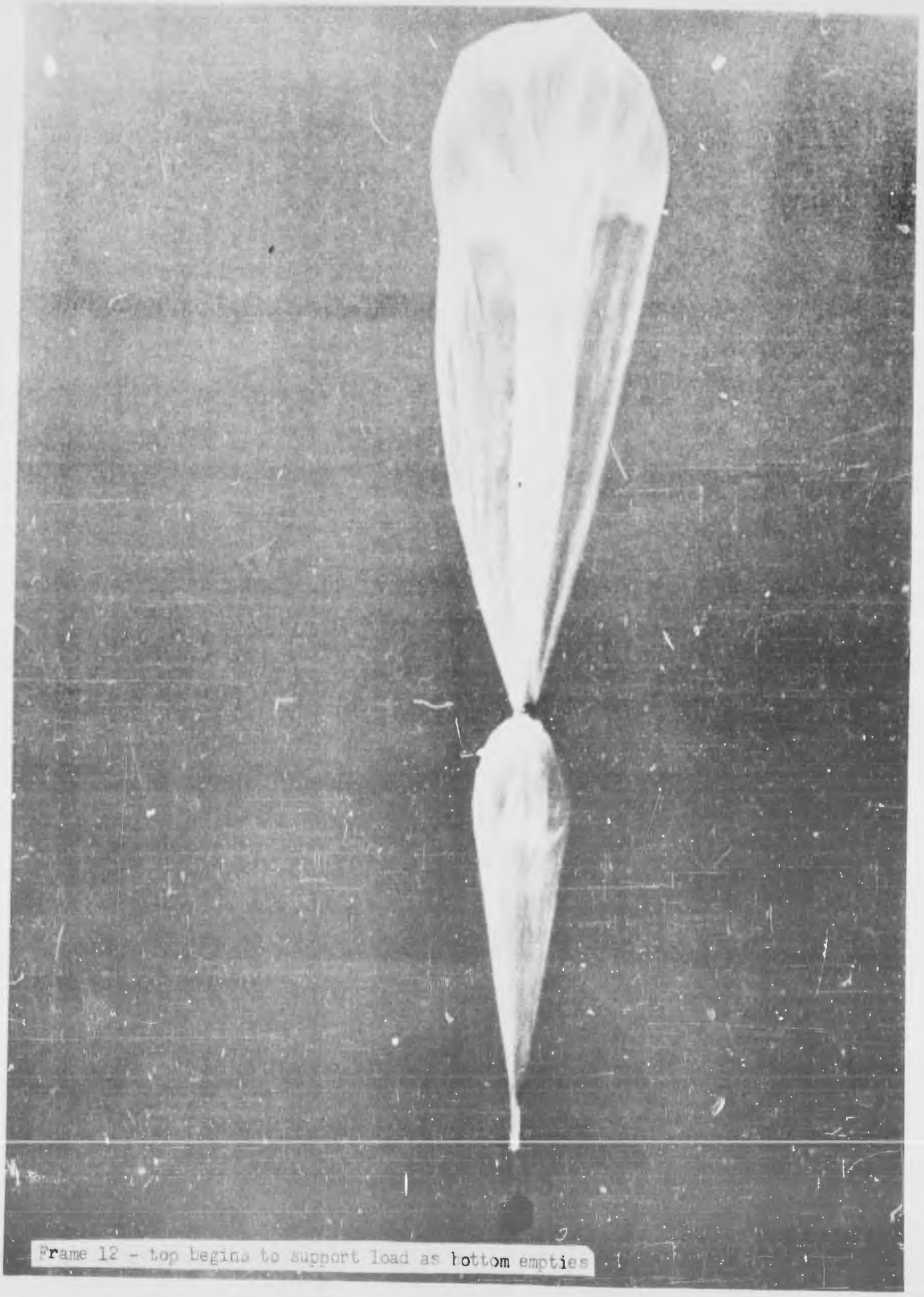


Frame 9 - note shrinking size of lower bubble as canopy continues to slide up.

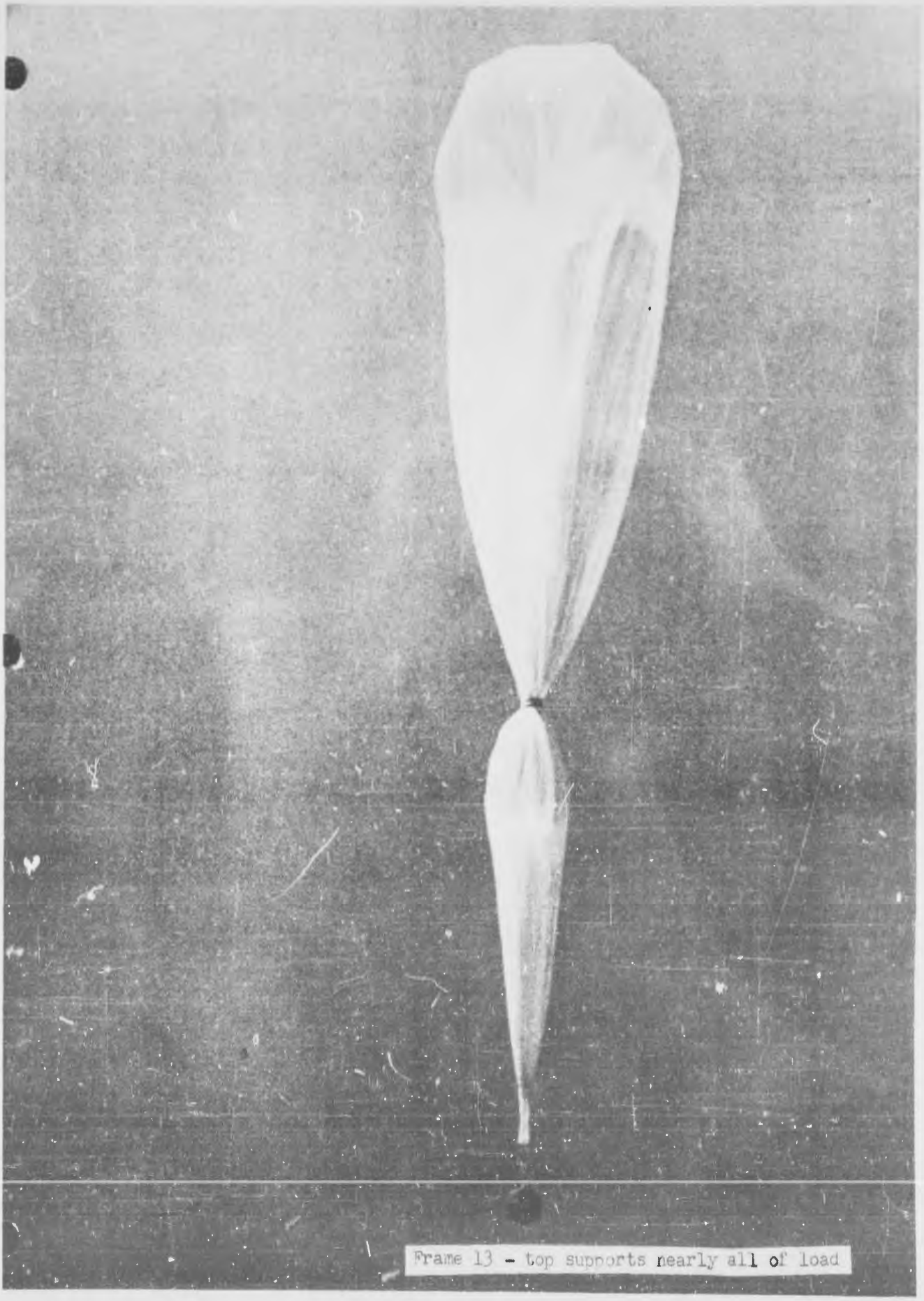

Frame 10 - canopy nearly free



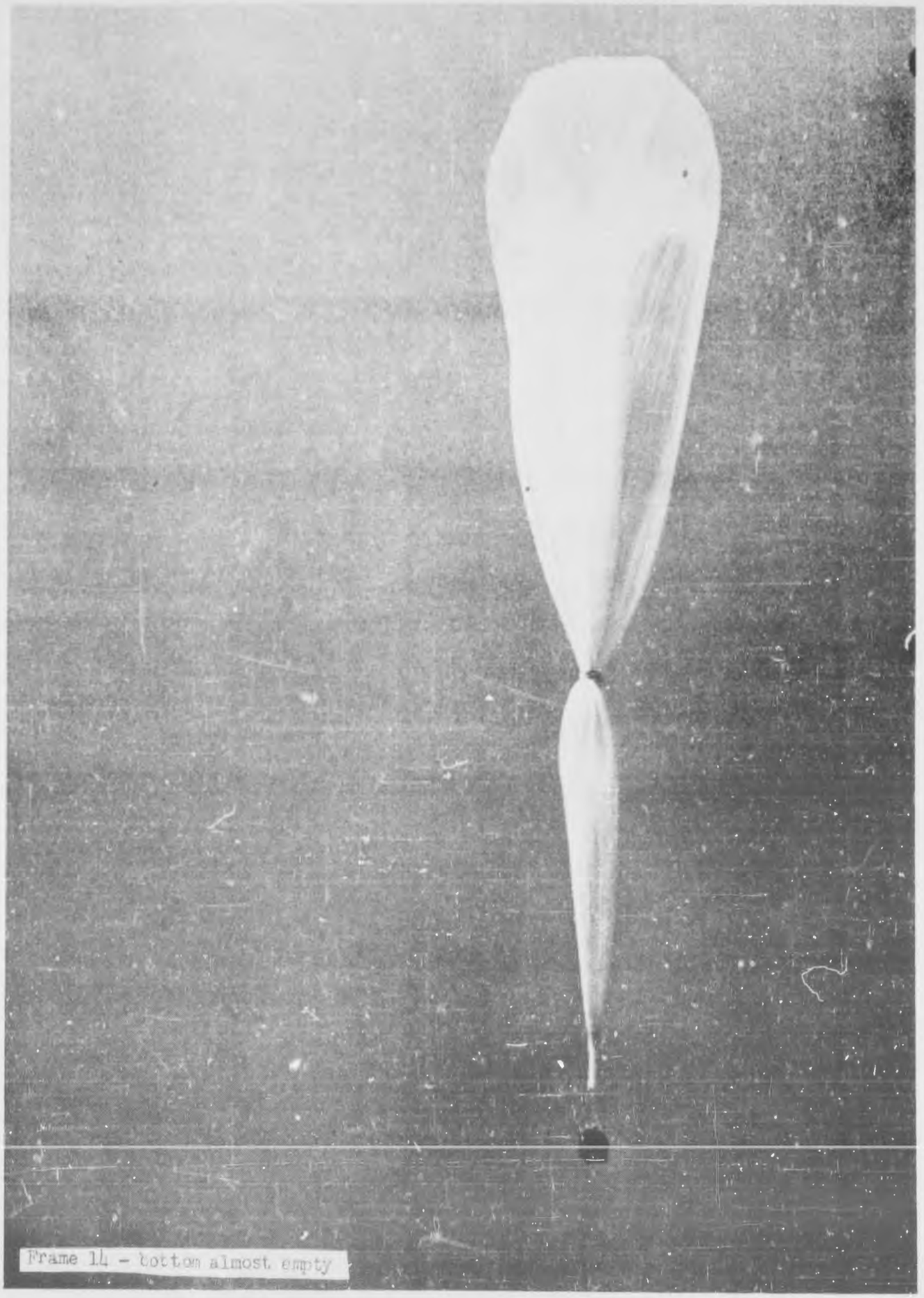
Frame 11 - at this point in the process there is sufficient lift in the top to support it independently of the bottom.



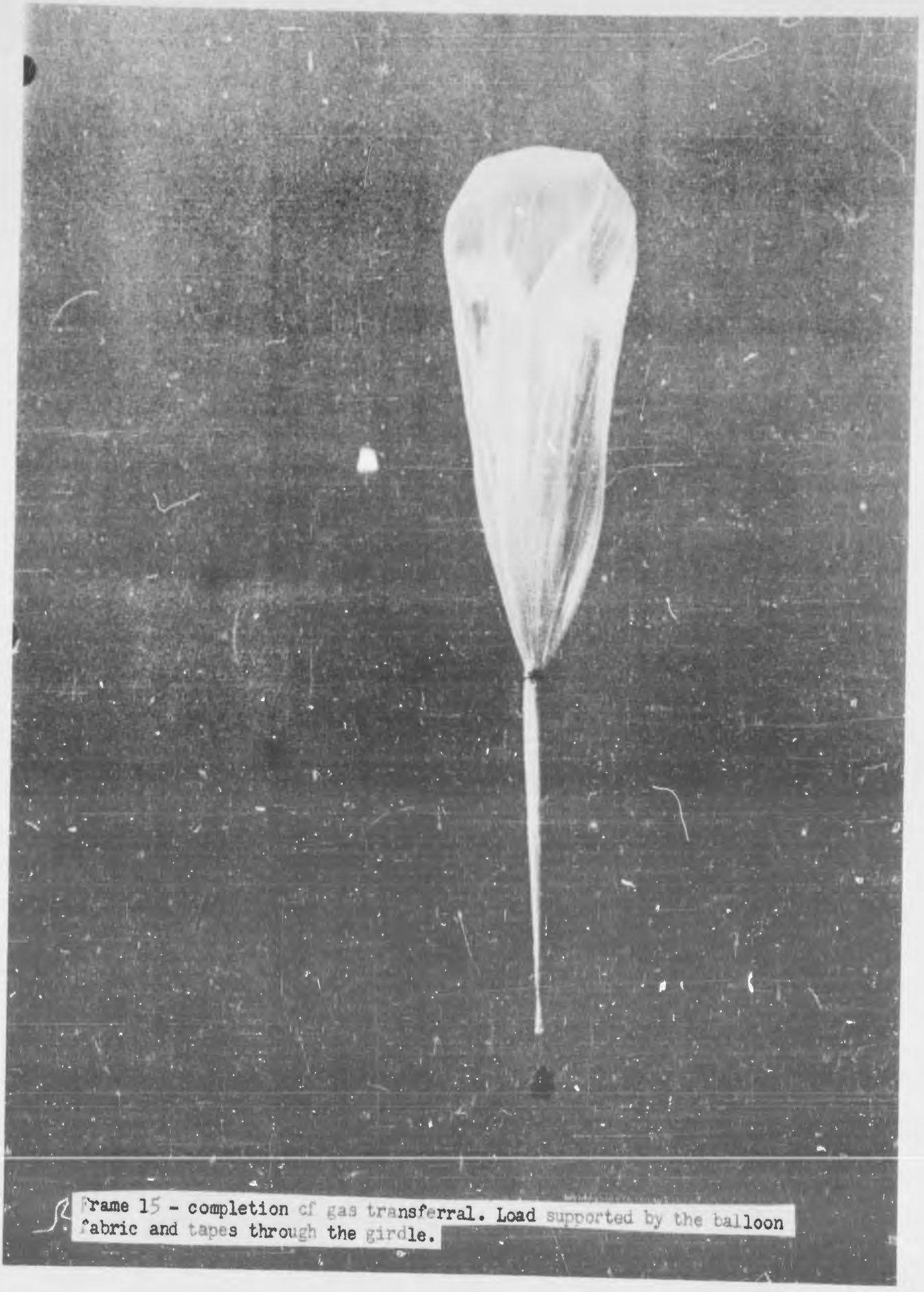
Frame 12 - top begins to support load as bottom empties



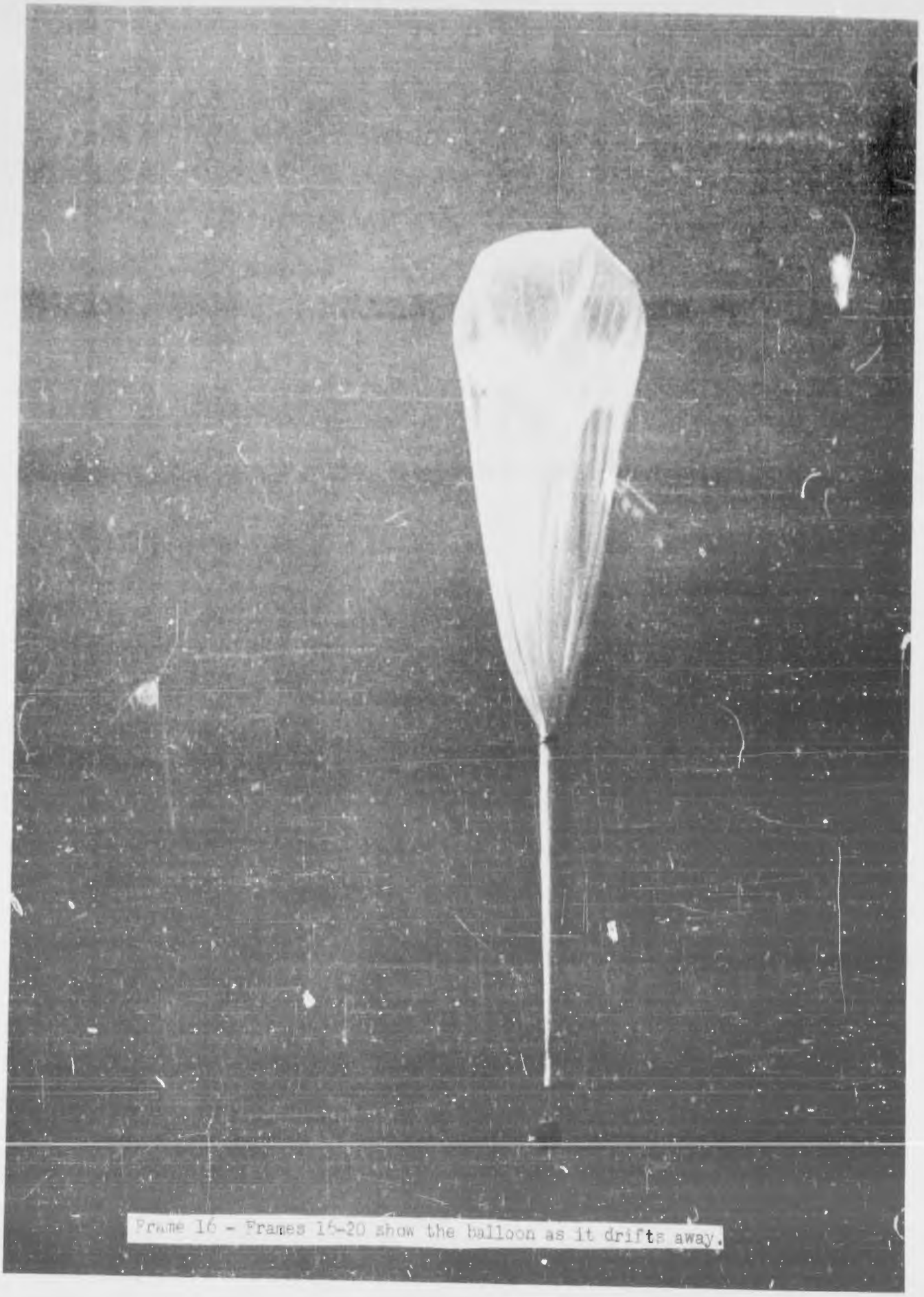
Frame 13 - top supports nearly all of load



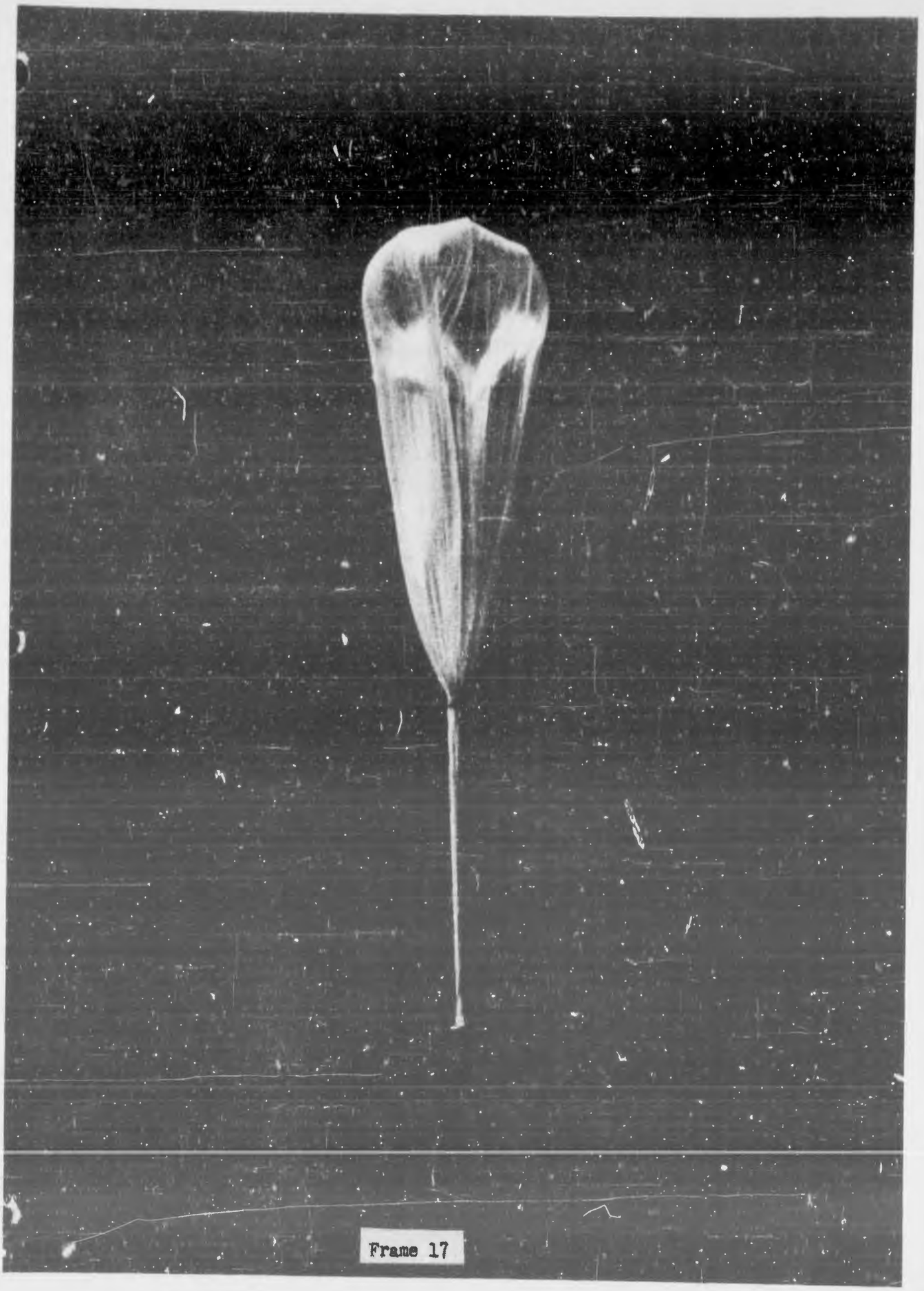
Frame 14 - bottom almost empty



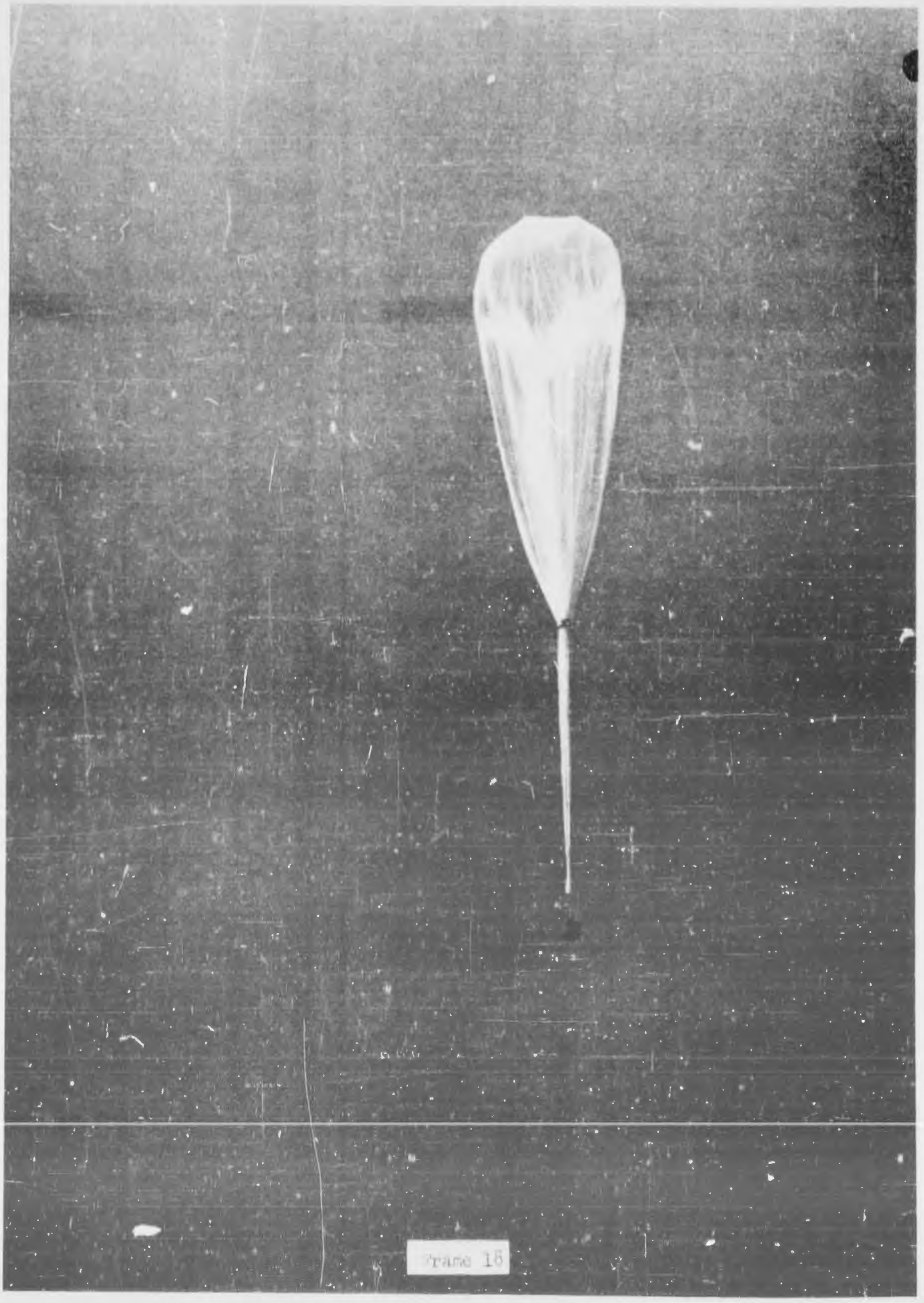
Frame 15 - completion of gas transferral. Load supported by the balloon fabric and tapes through the girdle.

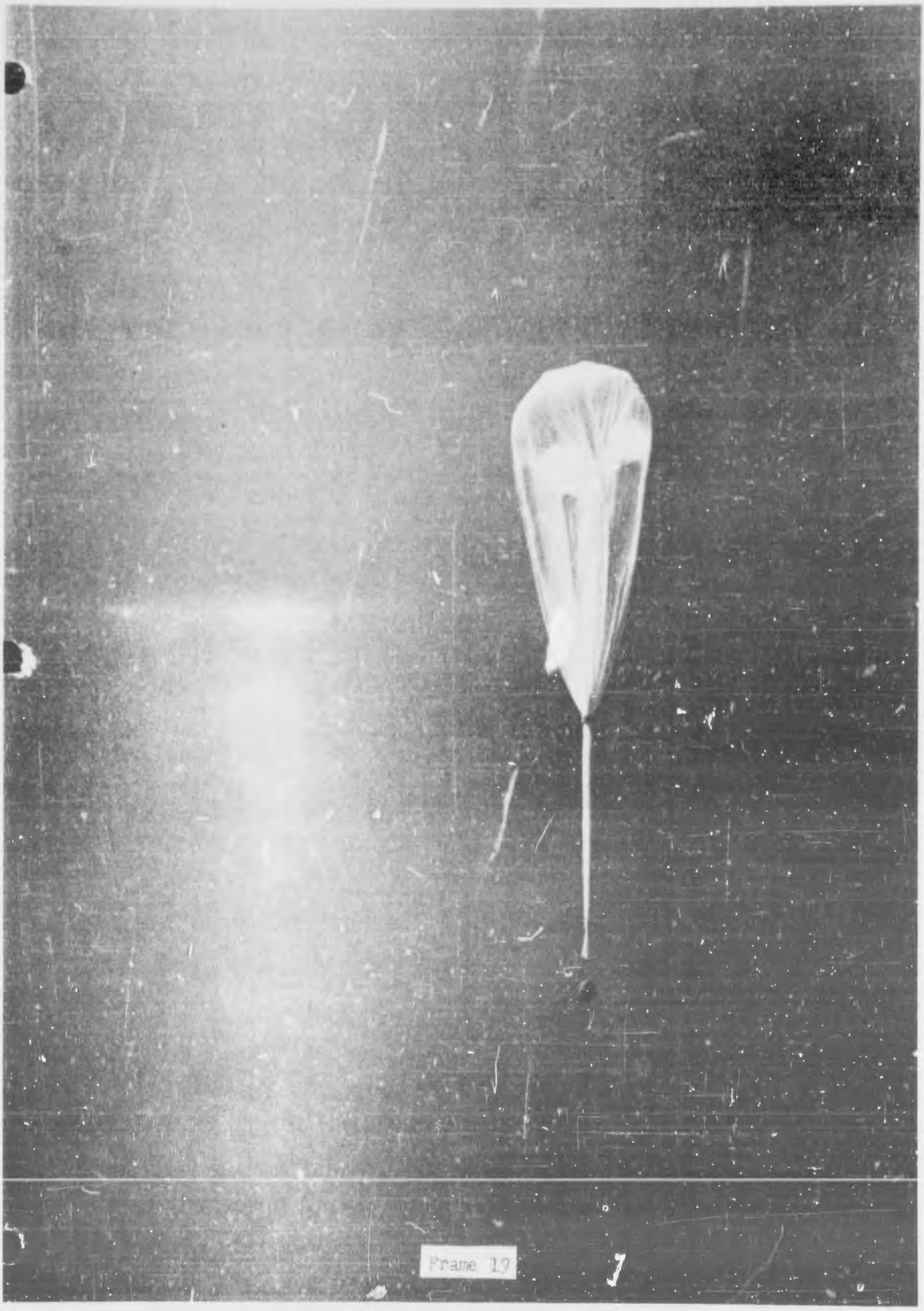


Frame 16 - Frames 16-20 show the balloon as it drifts away.

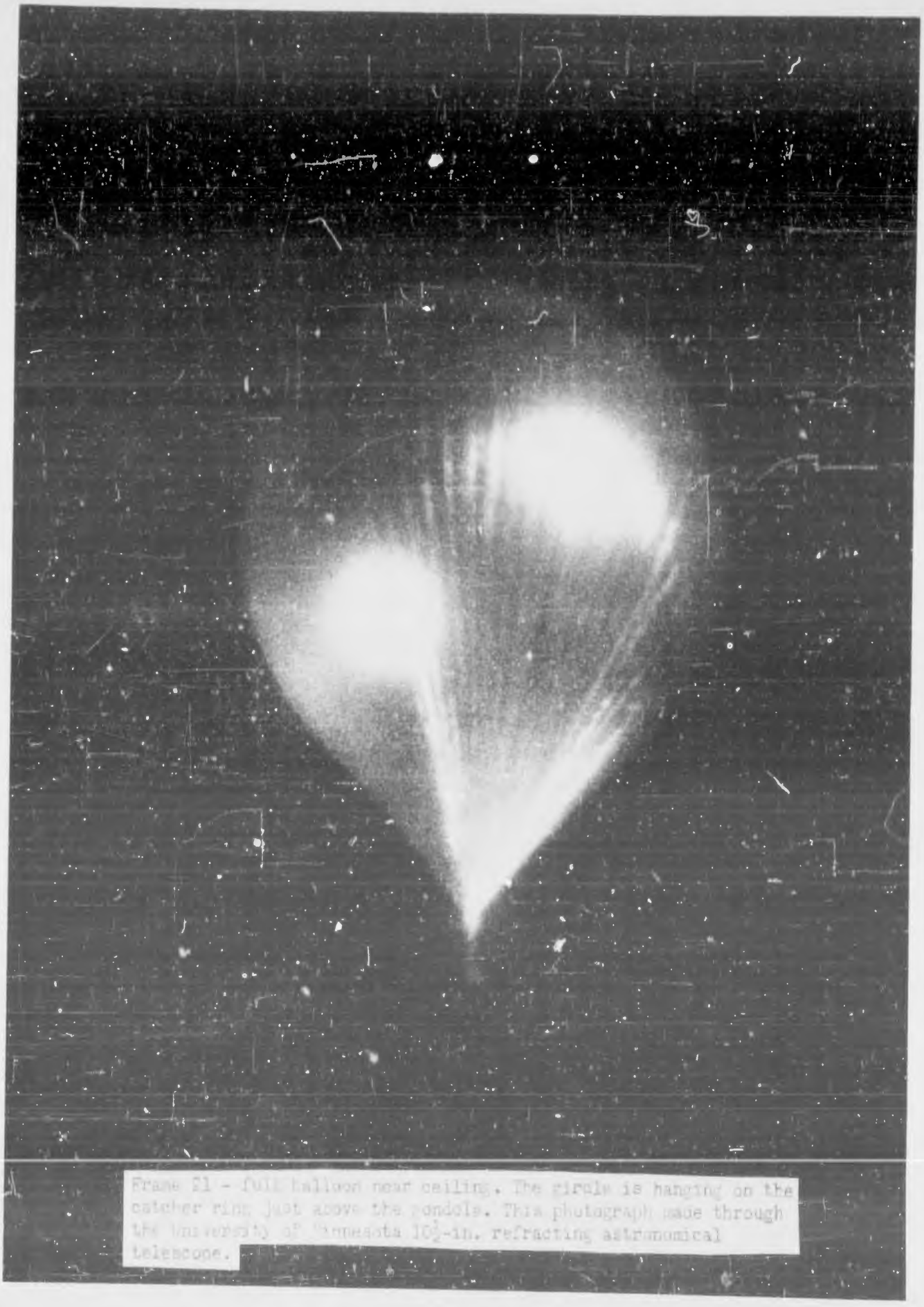


Frame 17


Frame 15


Frame 19





Frame 21 - full balloon near ceiling. The circle is hanging on the catcher ring just above the gondola. This photograph made through the University of Minnesota 10½-in. refracting astronomical telescope.

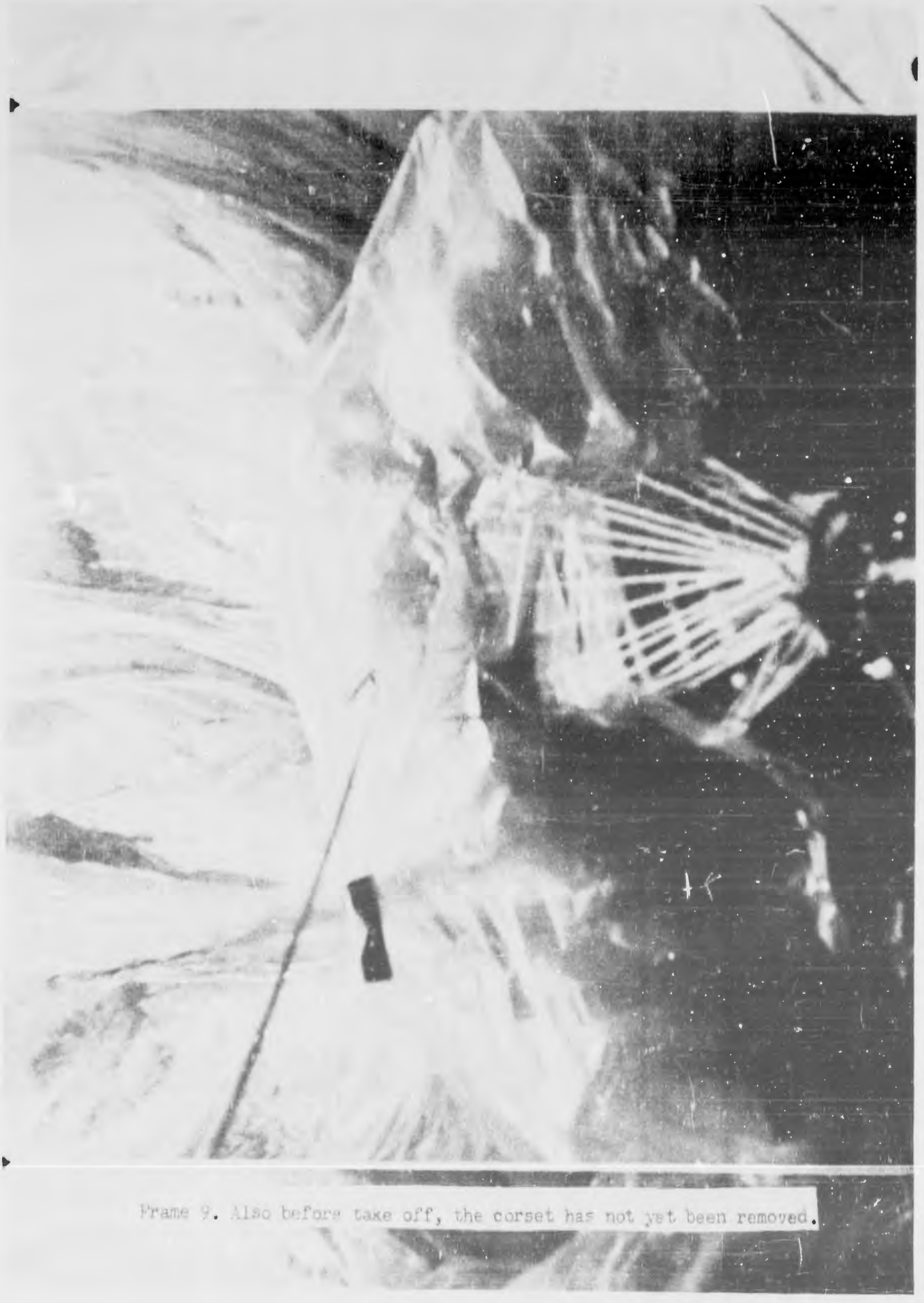
APPENDIX VI

UP PHOTOGRAPHS FROM FLIGHT 5

The following sequence of photographs was obtained with the up camera in the gondola on Flight 5. This was the first flight in which cameras were flown. Because of the high coefficient of friction for polyethylene rubbing on polyethylene the girdle in this flight did not slip until the balloon became almost spherical above it. By the time the timers terminated the flight, the girdle had slipped half way down the tail of the balloon. It can be noted in these pictures that the girdle, which acts as an automatic appendix, maintains a favorable aerodynamic shape throughout the flight.



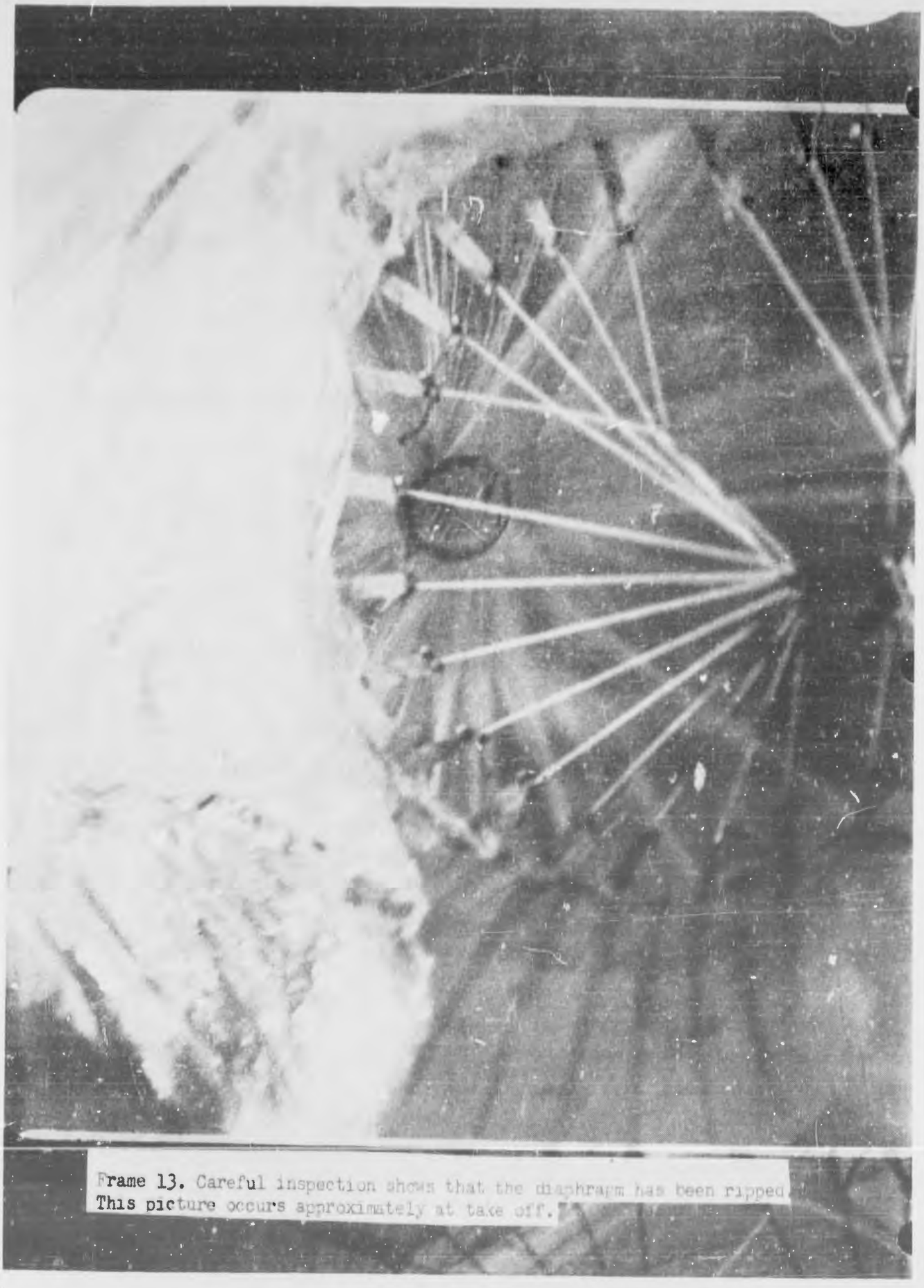
Frame 3. This shows the balloon before take off with the inflation hose in place.



Frame 9. Also before take off, the corset has not yet been removed.



Frame 12. The corset has been removed but the diaphragm still intact.

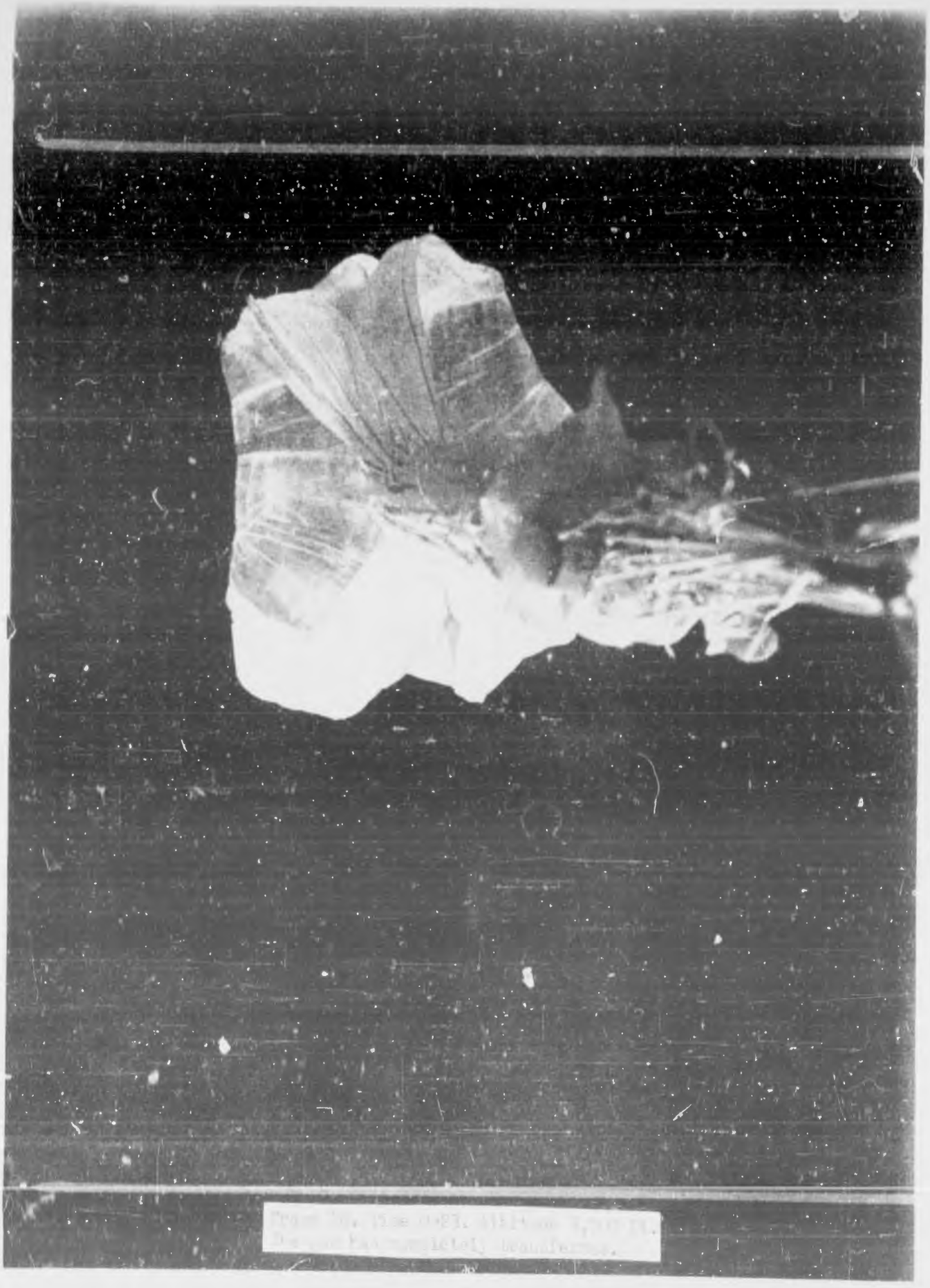


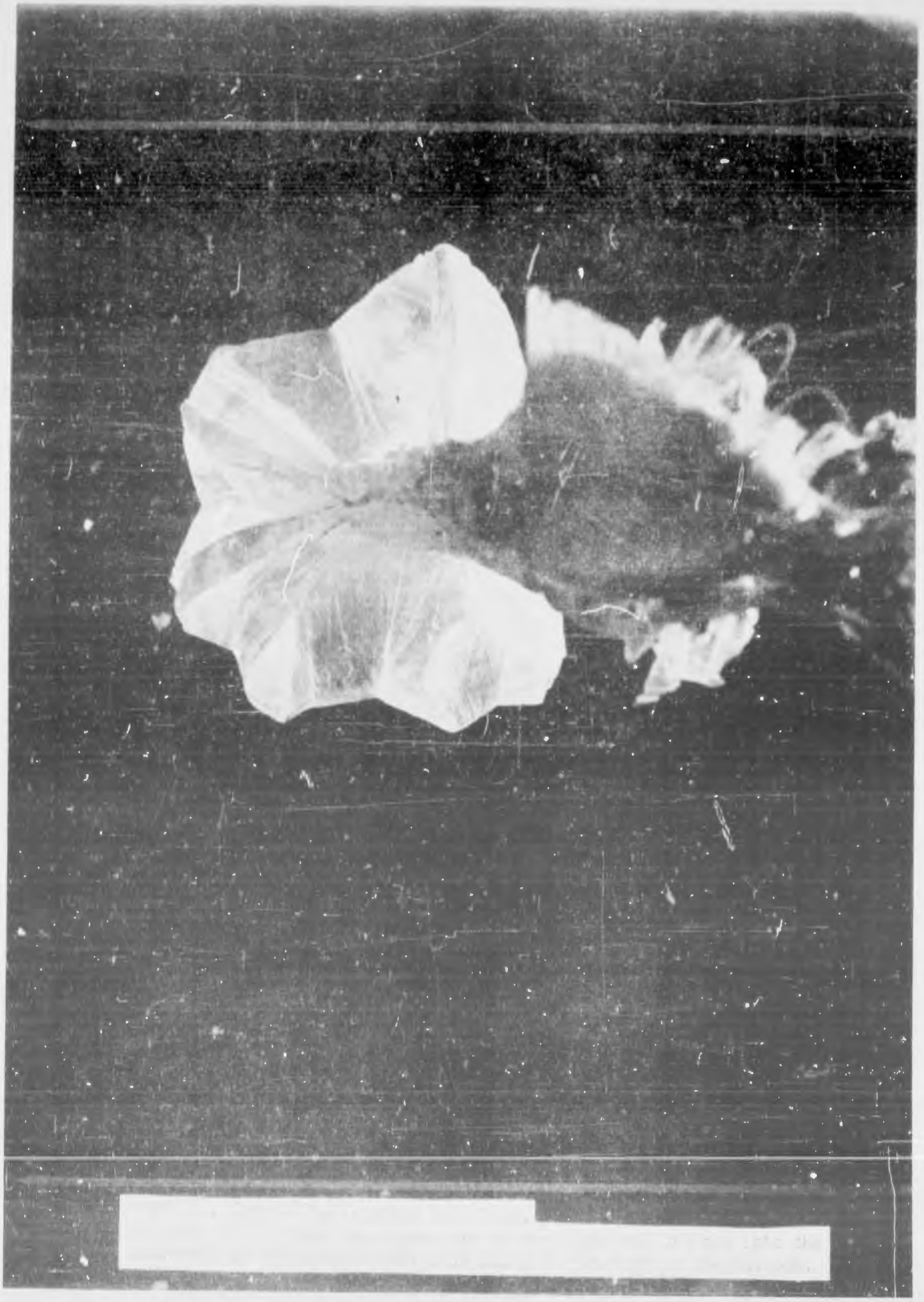
Frame 13. Careful inspection shows that the diaphragm has been ripped. This picture occurs approximately at take off.



Frame 11. Top is inflating and balloon is at an altitude of about 1,000 ft.

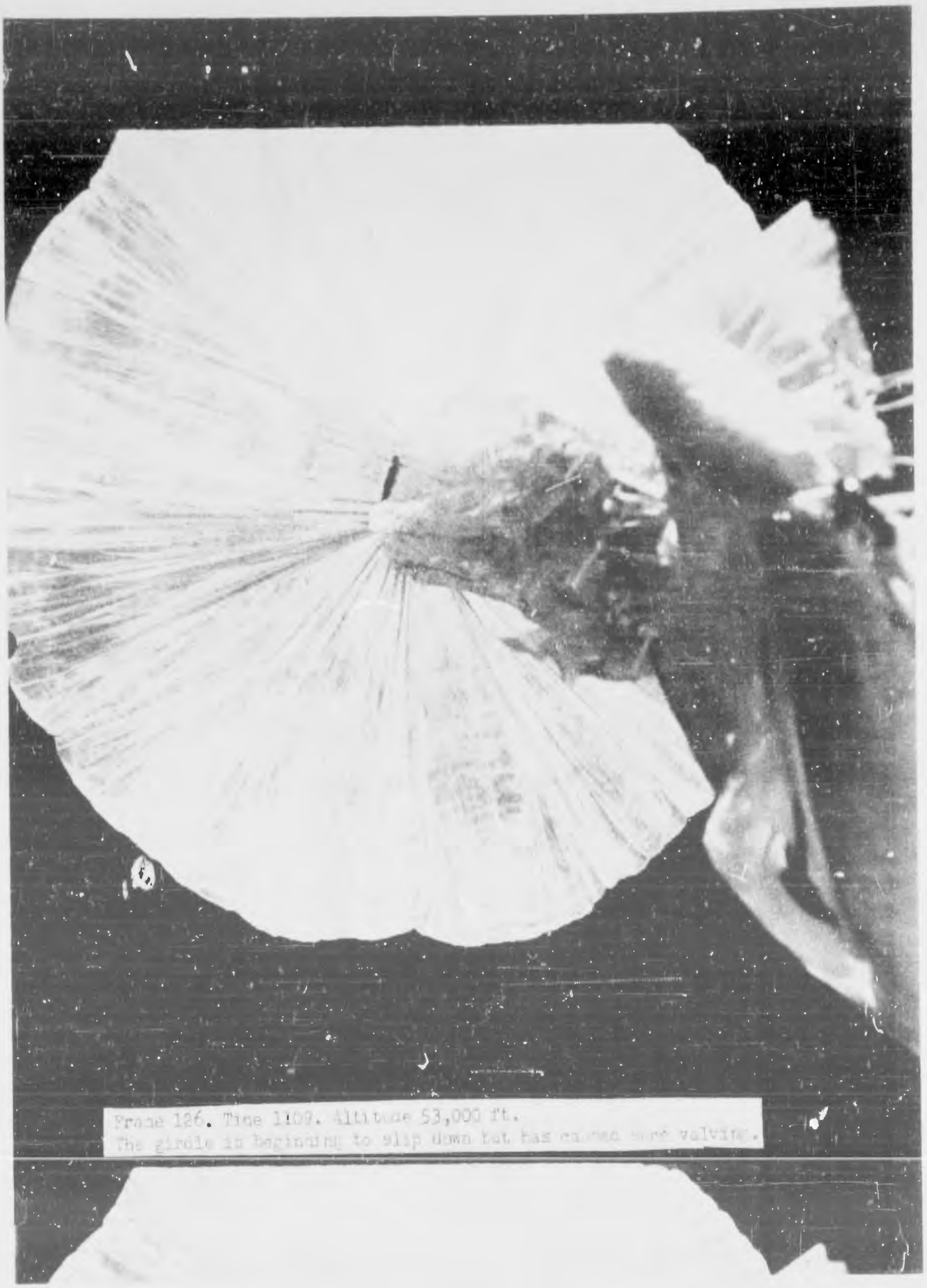




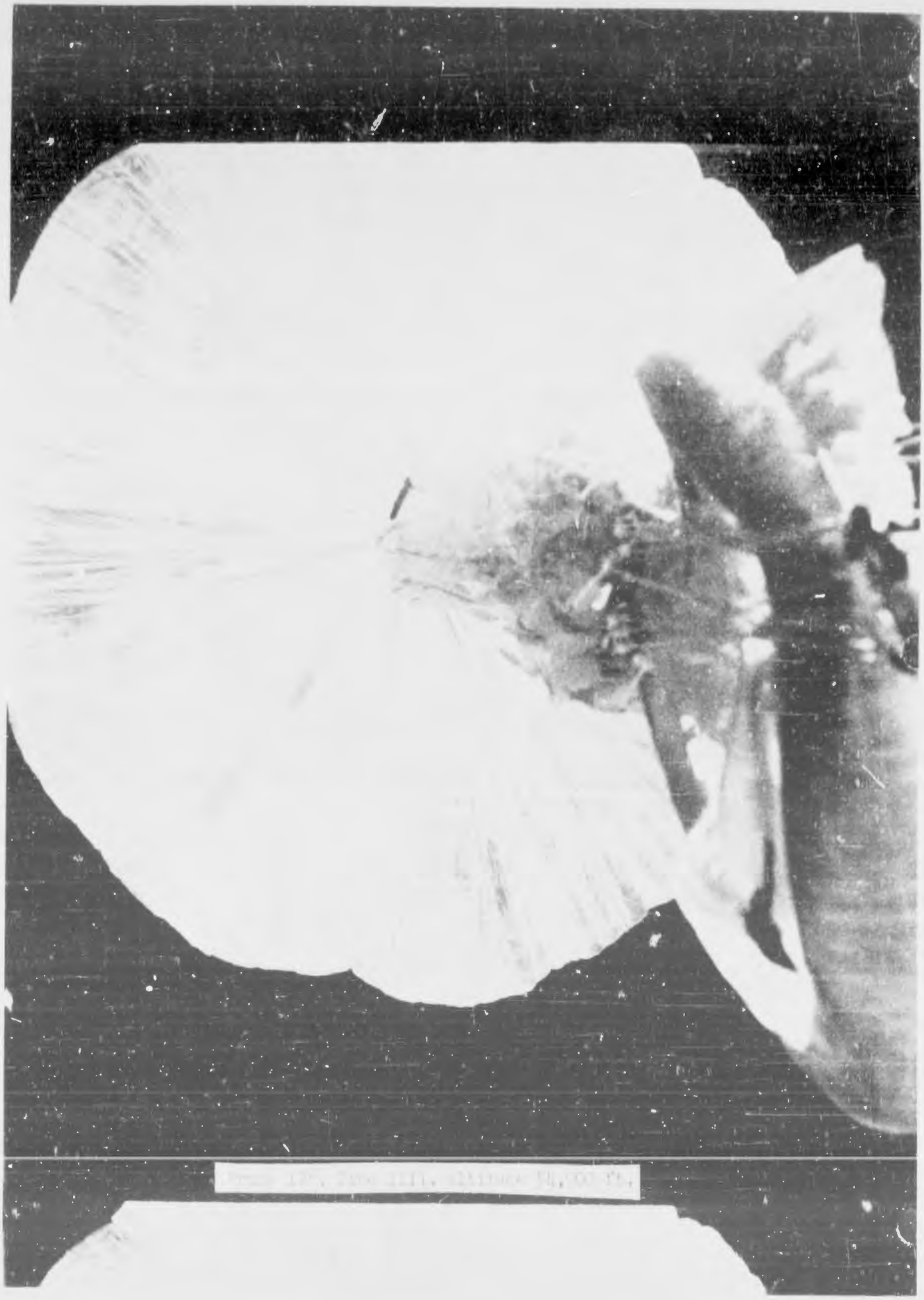


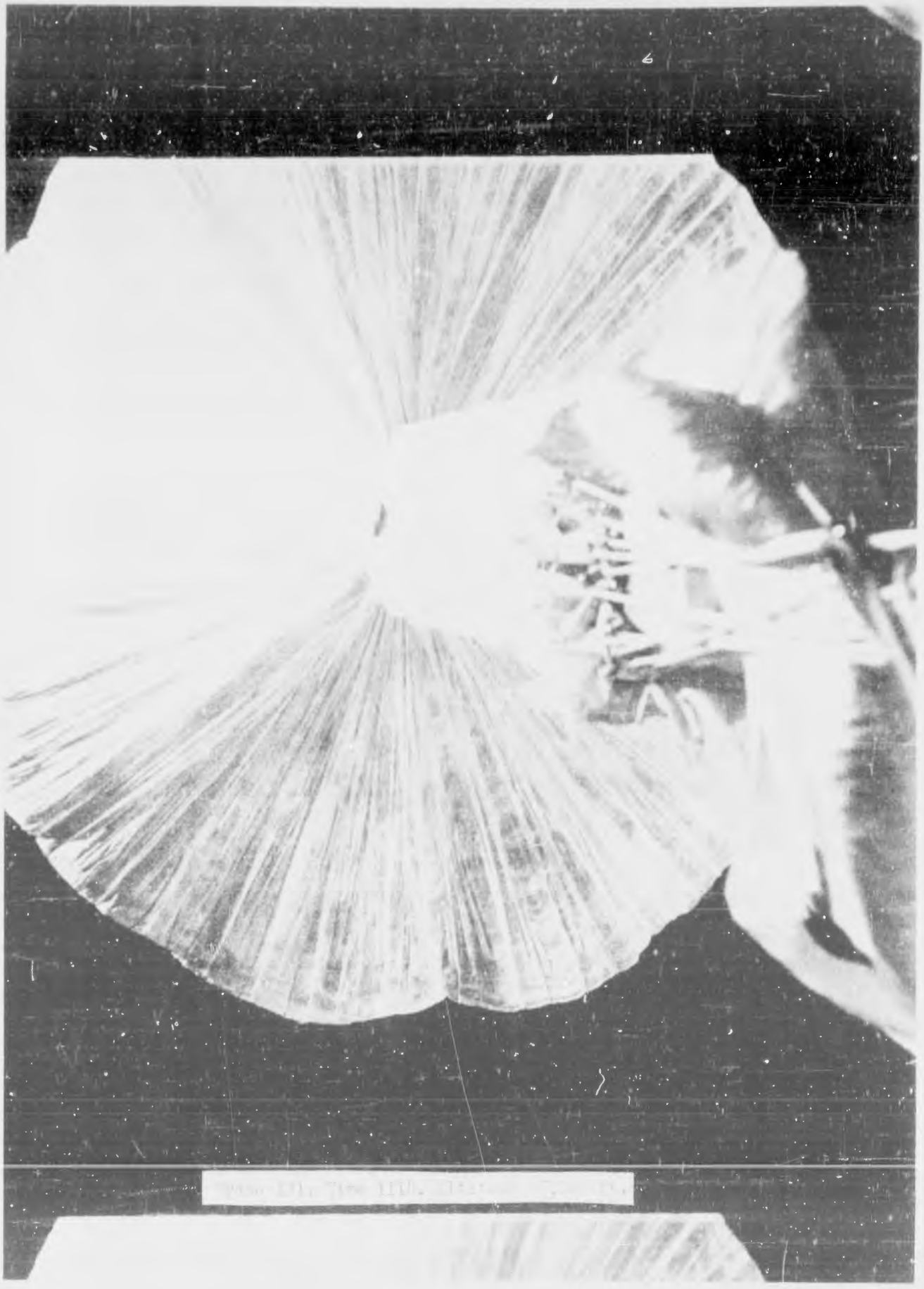


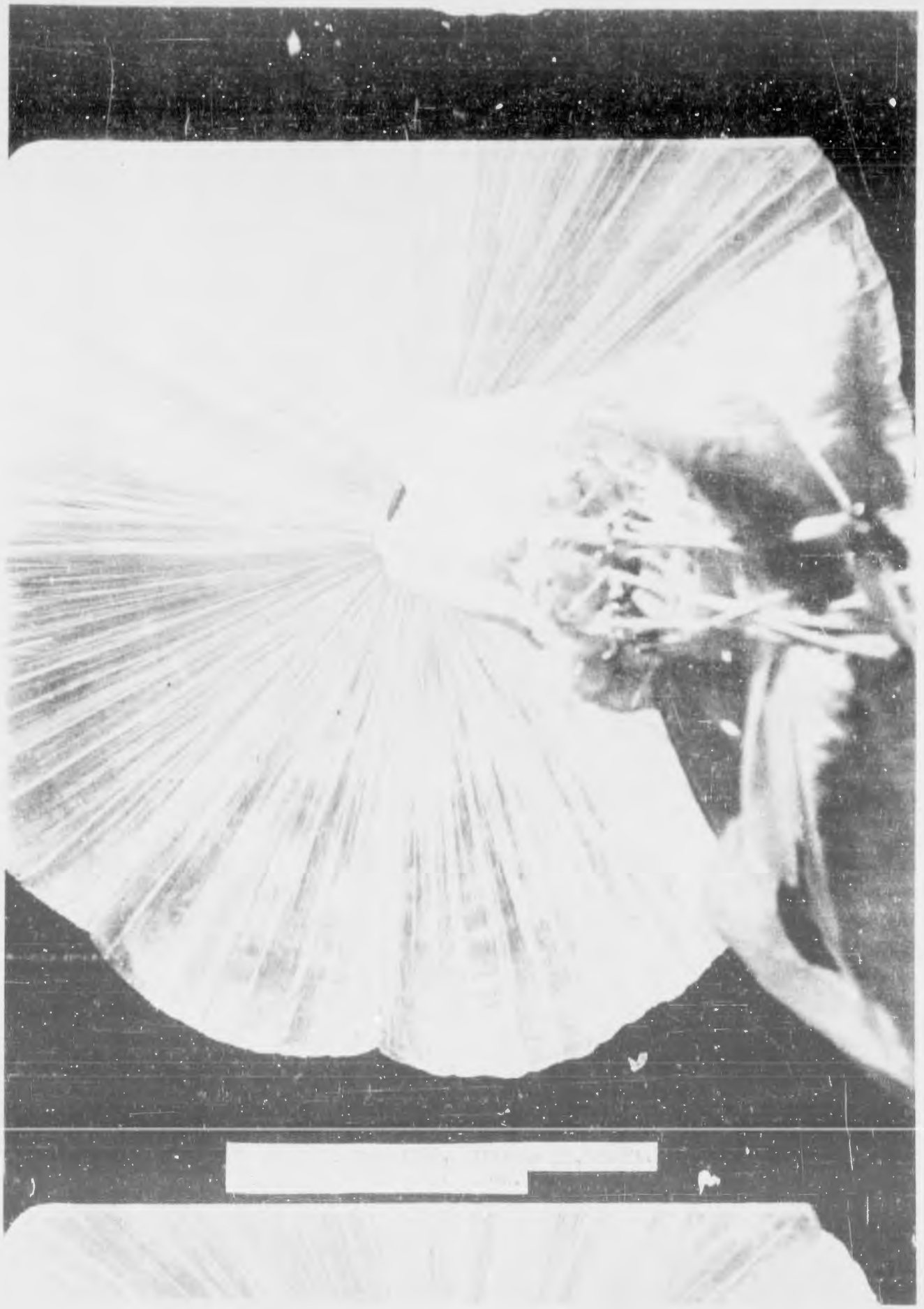


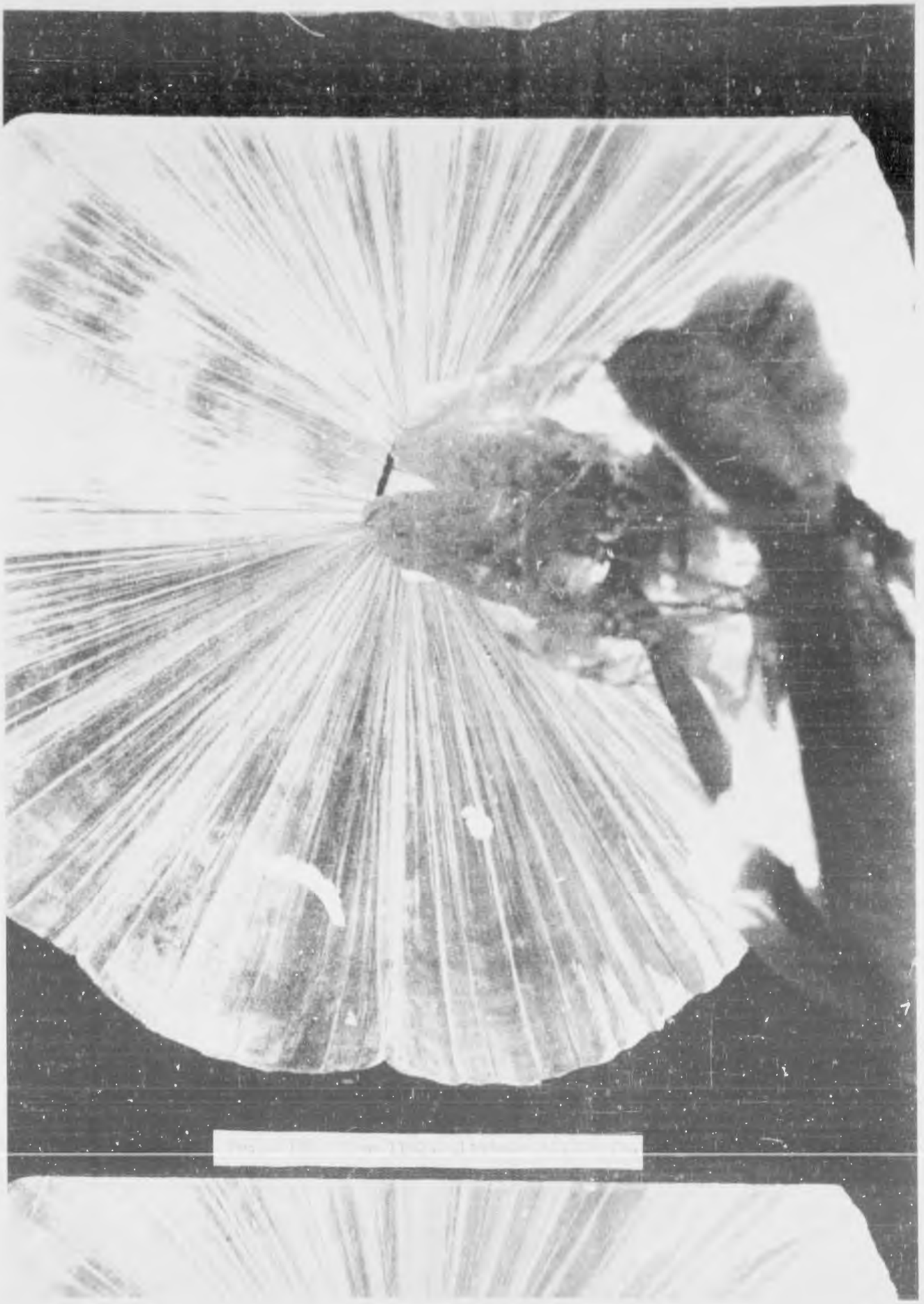


Frame 126. Time 1109. Altitude 53,000 ft.
The girdle is beginning to slip down but has caused more valving.





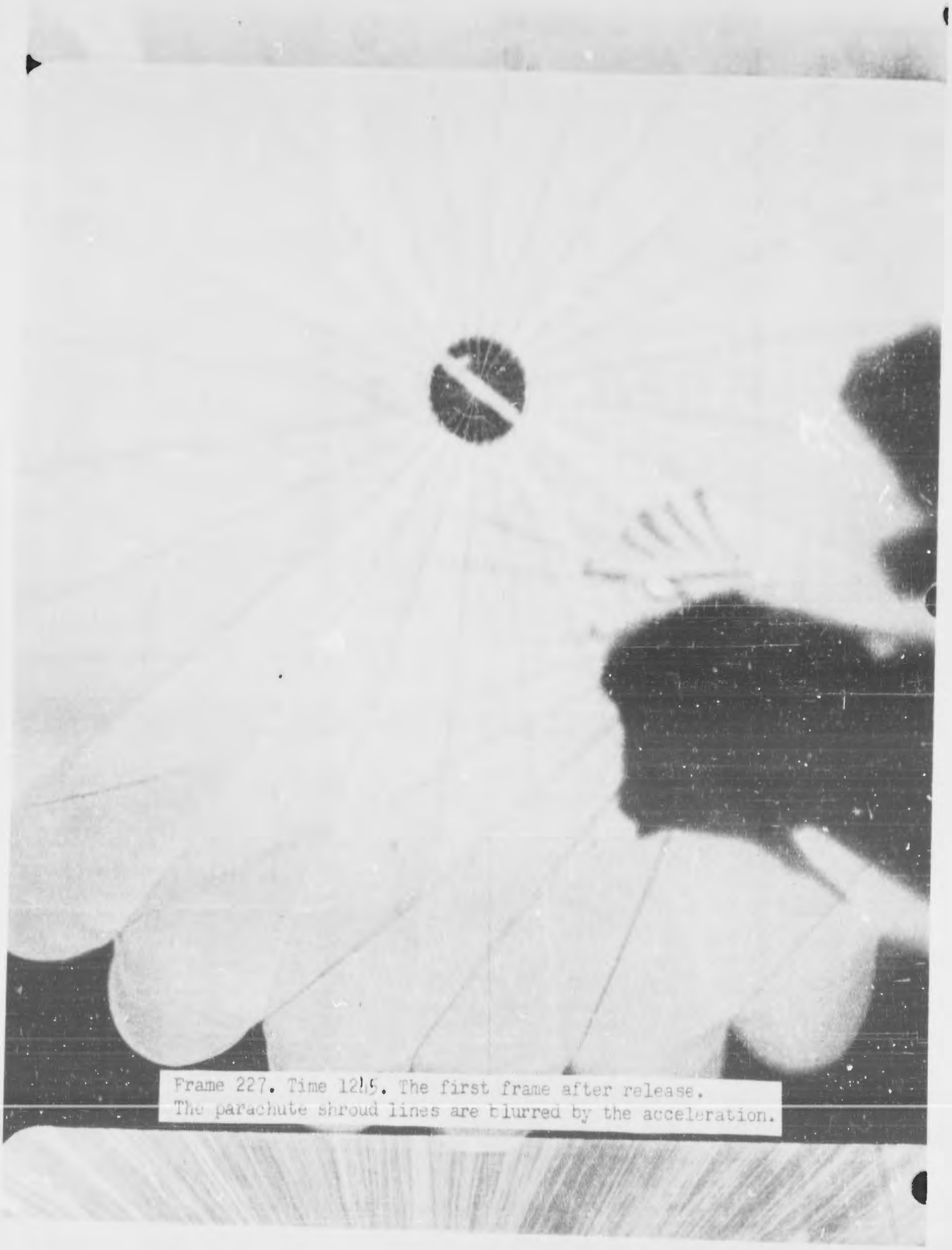








Frame 270. Time 12hh. Altitude [illegible] ft.
This is the last frame before tower release.



Frame 227. Time 12[illegible]. The first frame after release.
The parachute shroud lines are blurred by the acceleration.

APPENDIX VII

UP PHOTOGRAPHS FROM FLIGHT 6

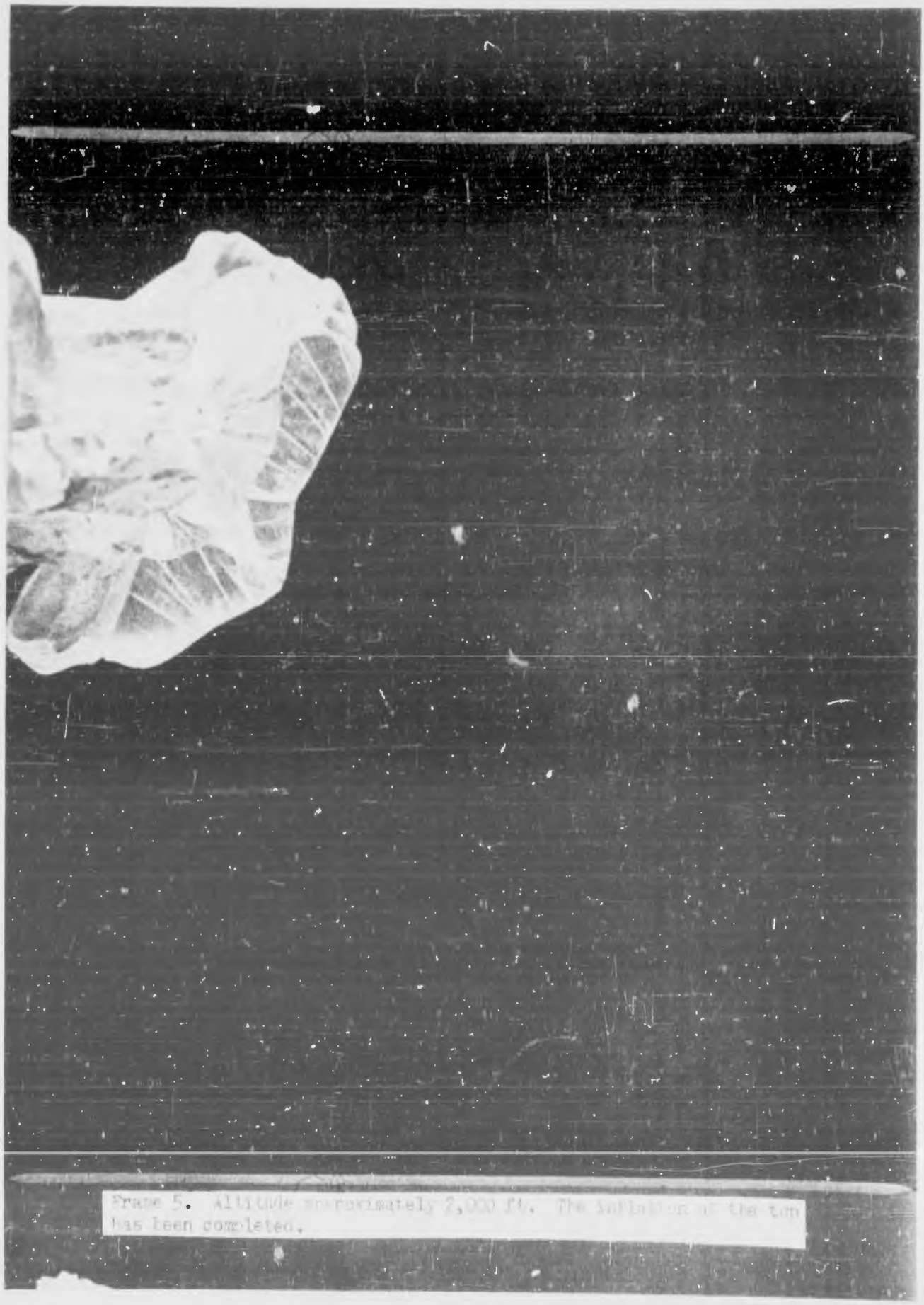
The following set of photographs was taken with the up camera in Flight 6. In this flight the canvas girdle was blown off at 8,500 feet. The sequence shows the turbulent motions of a balloon under normal conditions. Comparison of these pictures with pictures in Appendix 6 shows that a balloon equipped with a girdle that stays in place is less subject to turbulent damage. These pictures allow some observation of the top portion of the balloon.



Figure 2. View of balloon during inflation.



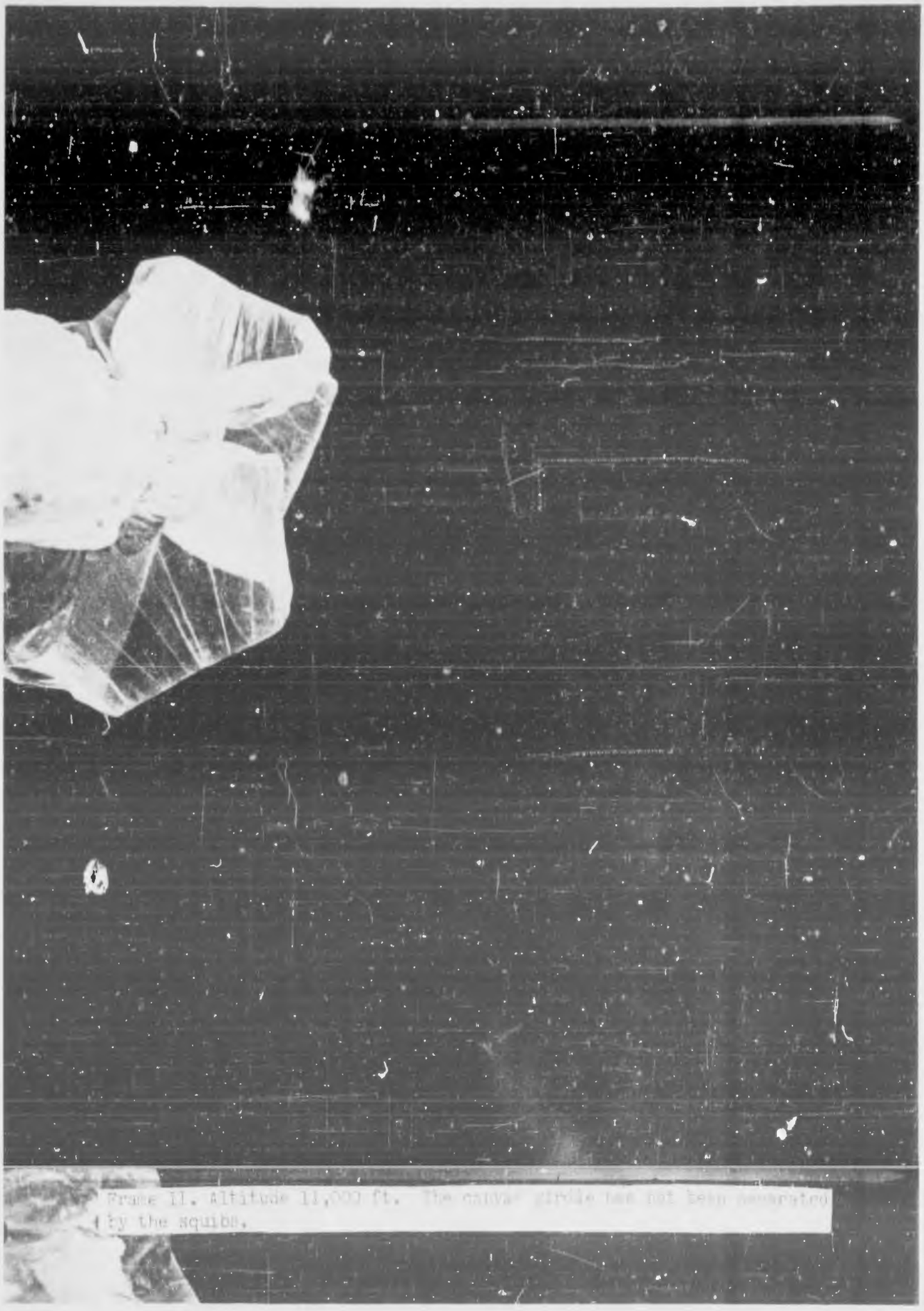
Frame 4. The balloon is at approximately 1,000 ft. and the inflation of the top is proceeding. There is still some air in the appendix bubble.



Frame 5. Altitude approximately 2,000 ft. The initiation of the turn has been completed.



Frame 10. Altitude 10,000 ft. Circle is still in place.



Frame 11. Altitude 11,000 ft. The canvas girdle has not been separated by the squibs.



Frame 12. Altitude 12,700 ft. The canvas shield has been separated and has fallen free.



Frame 14. Altitude 14,000 ft. Notice the violent motion of the plastic.



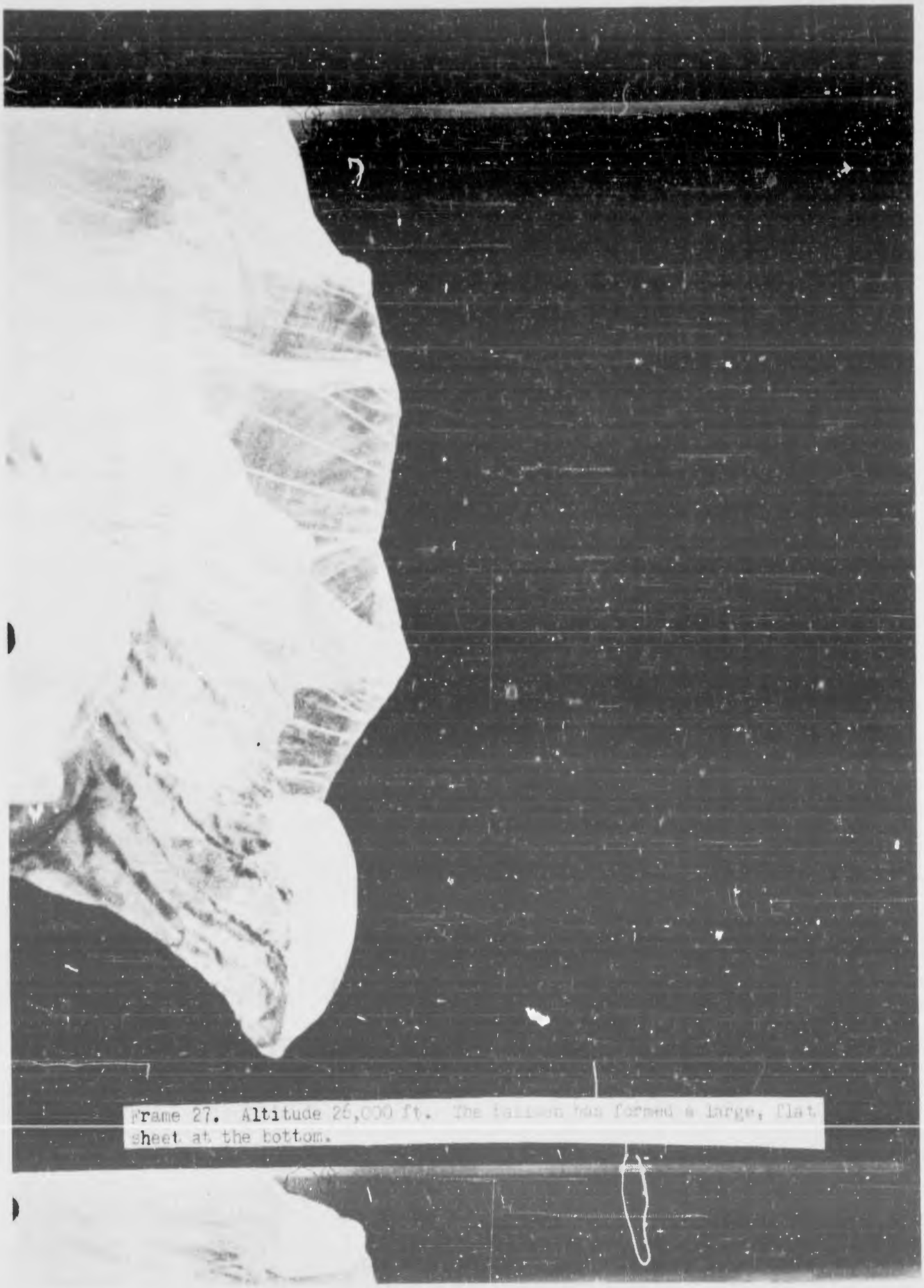
Frame 16. Altitude 18,000 ft. The loose bottom portion of the balloon is buffeted by the passing air.



Frame 24. Altitude 23,000 ft. More violent motion of the missile.



Frame 25. Altitude 25,000 ft.



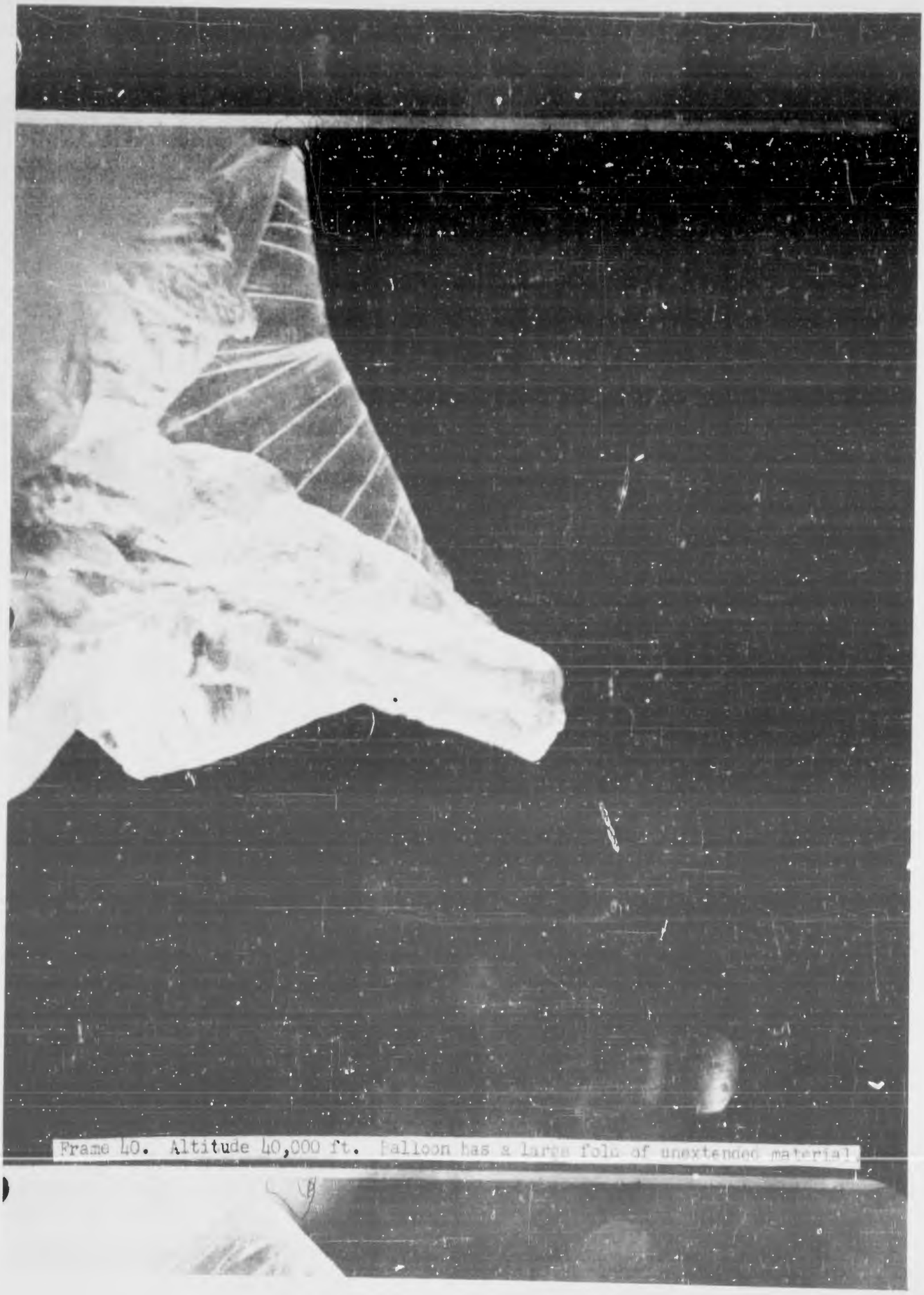
Frame 27. Altitude 25,000 ft. The balloon has formed a large, flat sheet at the bottom.



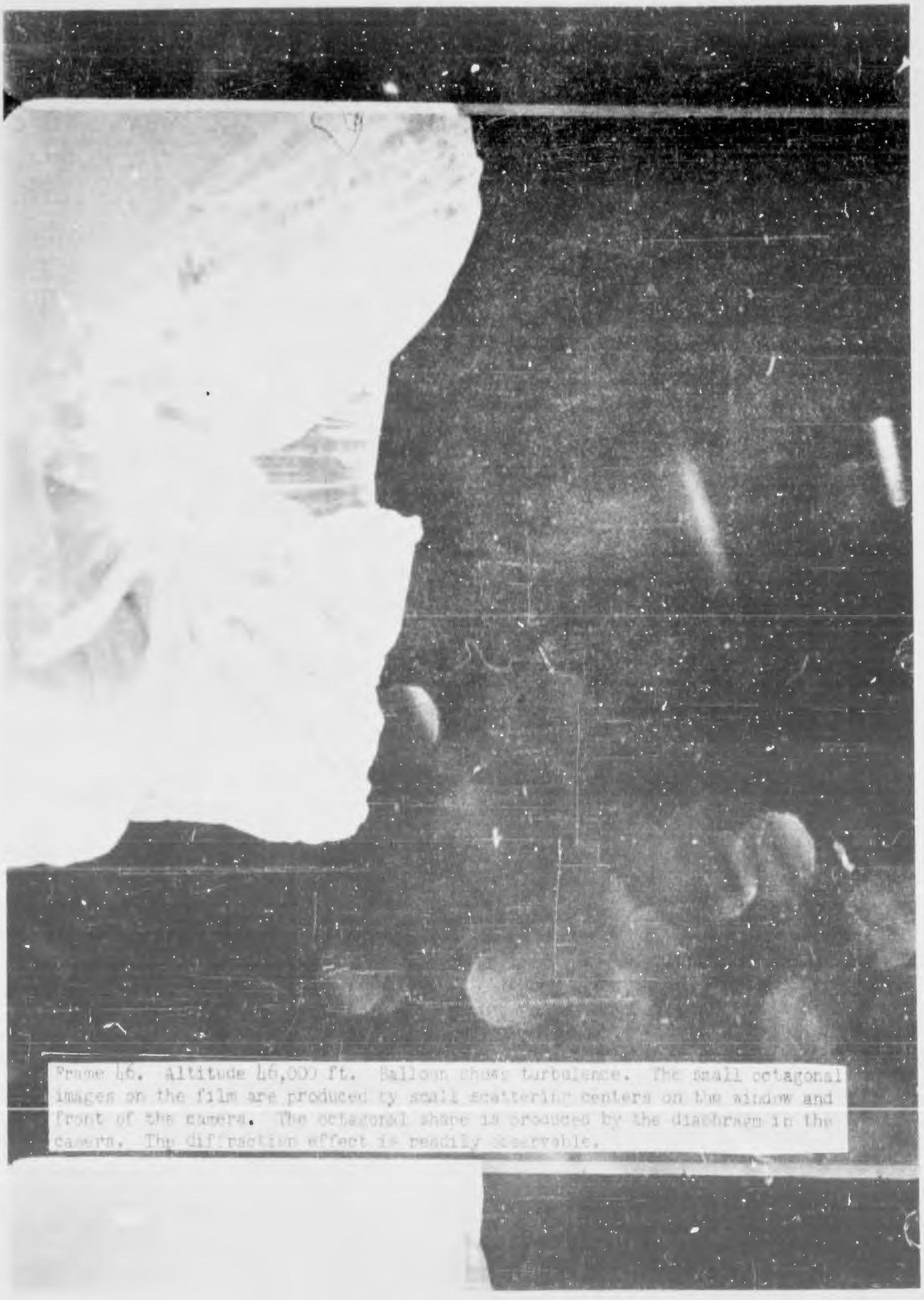
Frame 28. Altitude 27,000 ft. More turbulence.


Frame 30. Altitude 20,000 ft.


Frame 35. Altitude 34,000 ft.



Frame 40. Altitude 40,000 ft. Balloon has a large fold of unextended material.



Frame 46. Altitude 46,000 ft. Balloon shows turbulence. The small octagonal images on the film are produced by small scattering centers on the window and front of the camera. The octagonal shape is produced by the diaphragm in the camera. The diffraction effect is readily observable.



Frame 56. Altitude 57,000 ft. The balloon is beginning to take on a square shape with loose, unfilled regions at the corners of the square.



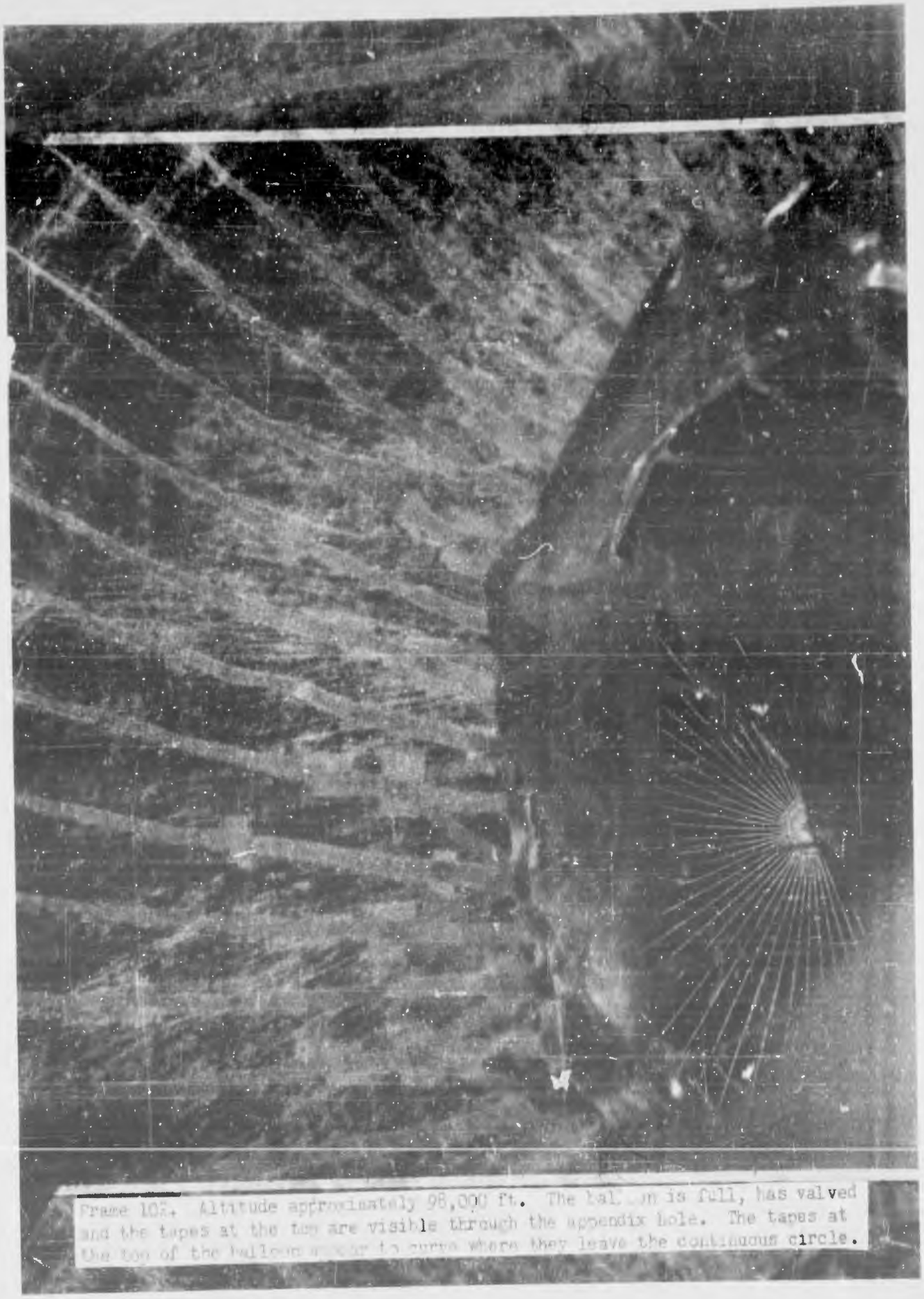
Frame 63. Altitude 65,500 ft. Balloon now appears quite square and the corner sections are beginning to unfold.



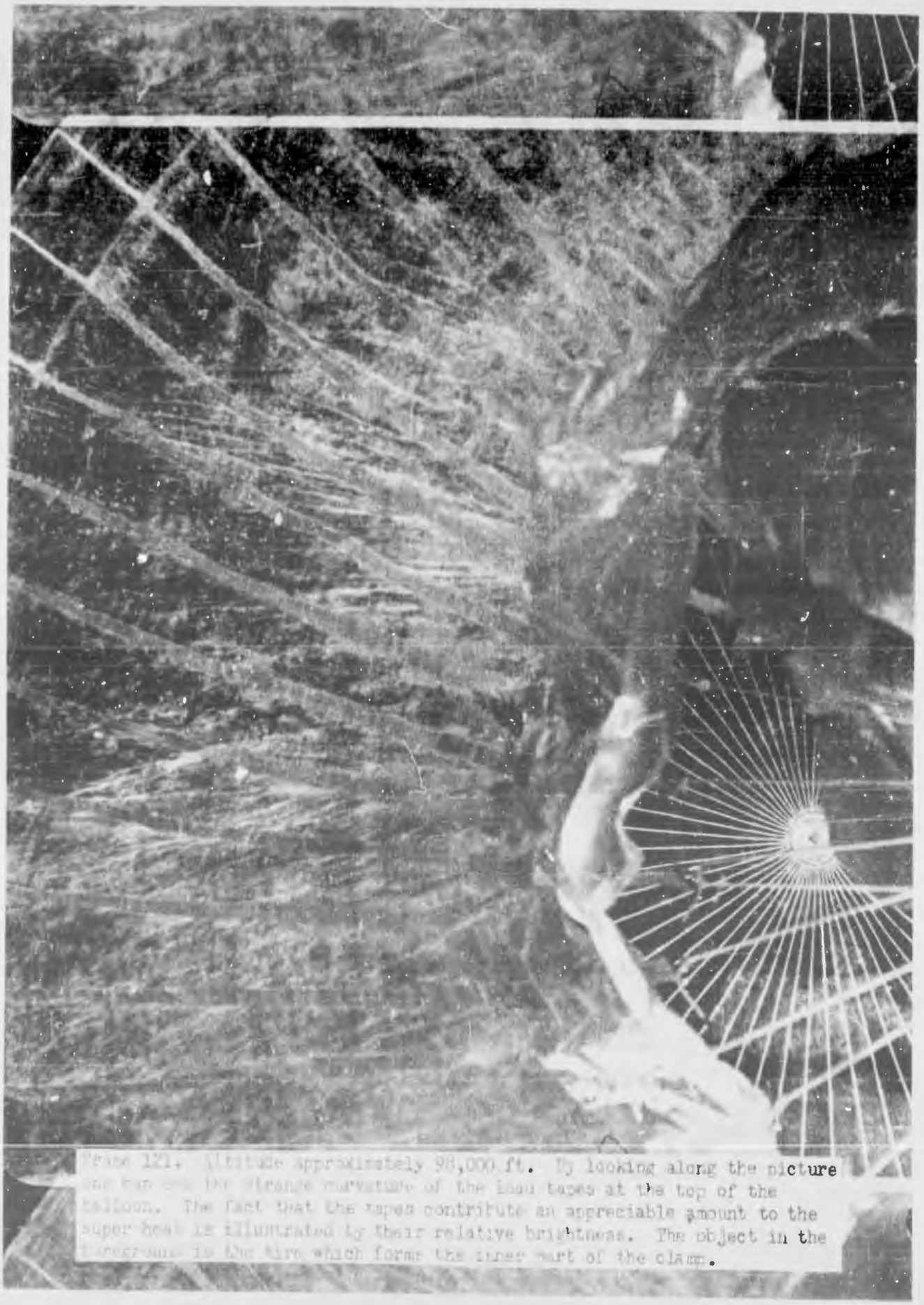
Frame 78. Altitude 75,000 ft.



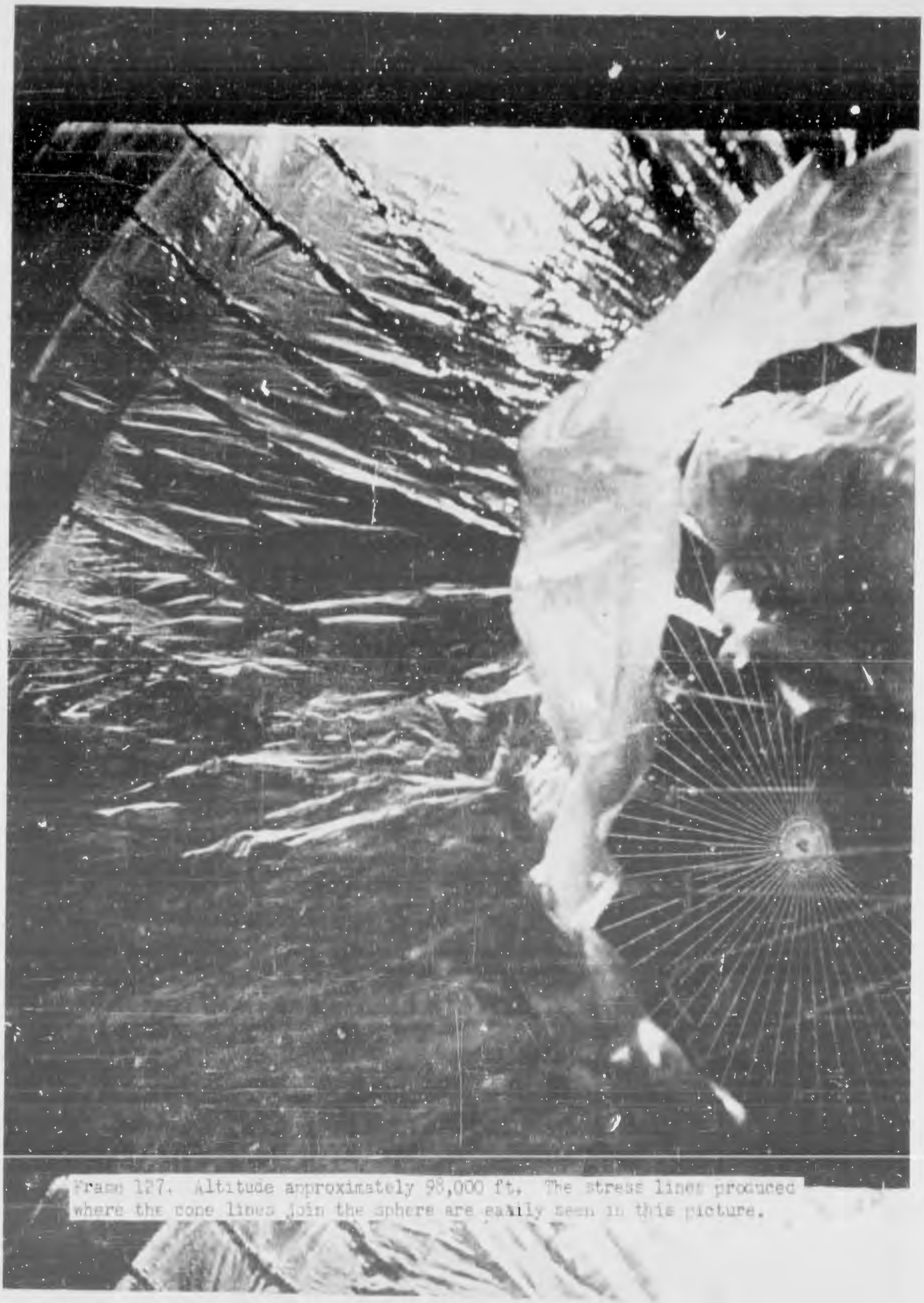
Frame 87. Altitude 82,000 ft. The balloon is probably octagonal. The regions of negative curvature are still evident.



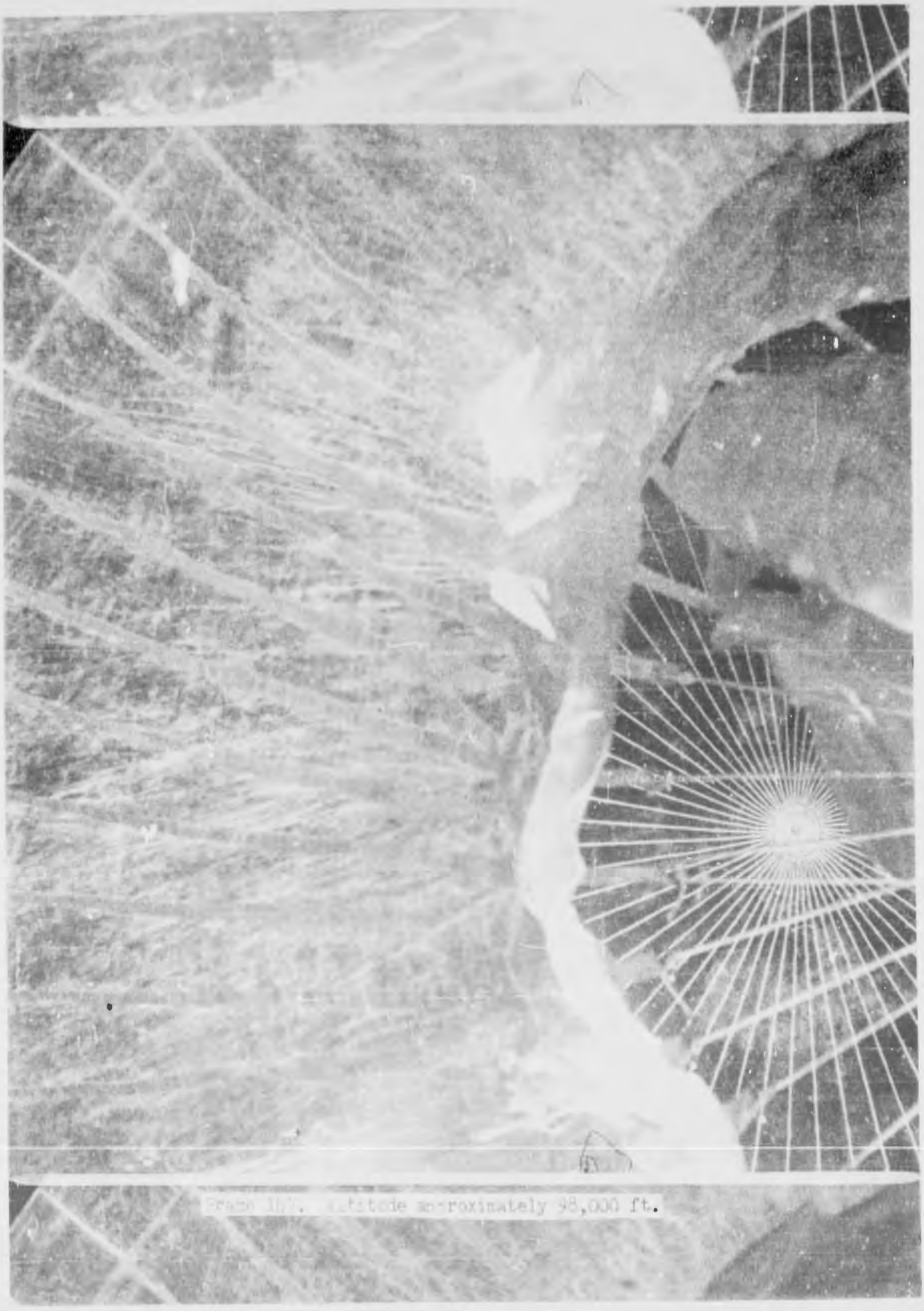
Frame 103. Altitude approximately 98,000 ft. The balloon is full, has valved and the tapes at the top are visible through the appendix hole. The tapes at the top of the balloon appear to curve where they leave the continuous circle.



Frame 121. Altitude approximately 98,000 ft. By looking along the picture one can see the strange curvature of the load tapes at the top of the balloon. The fact that the tapes contribute an appreciable amount to the super heat is illustrated by their relative brightness. The object in the foreground is the wire which forms the inner part of the clamp.



Frame 127. Altitude approximately 98,000 ft. The stress lines produced where the cone lines join the sphere are easily seen in this picture.



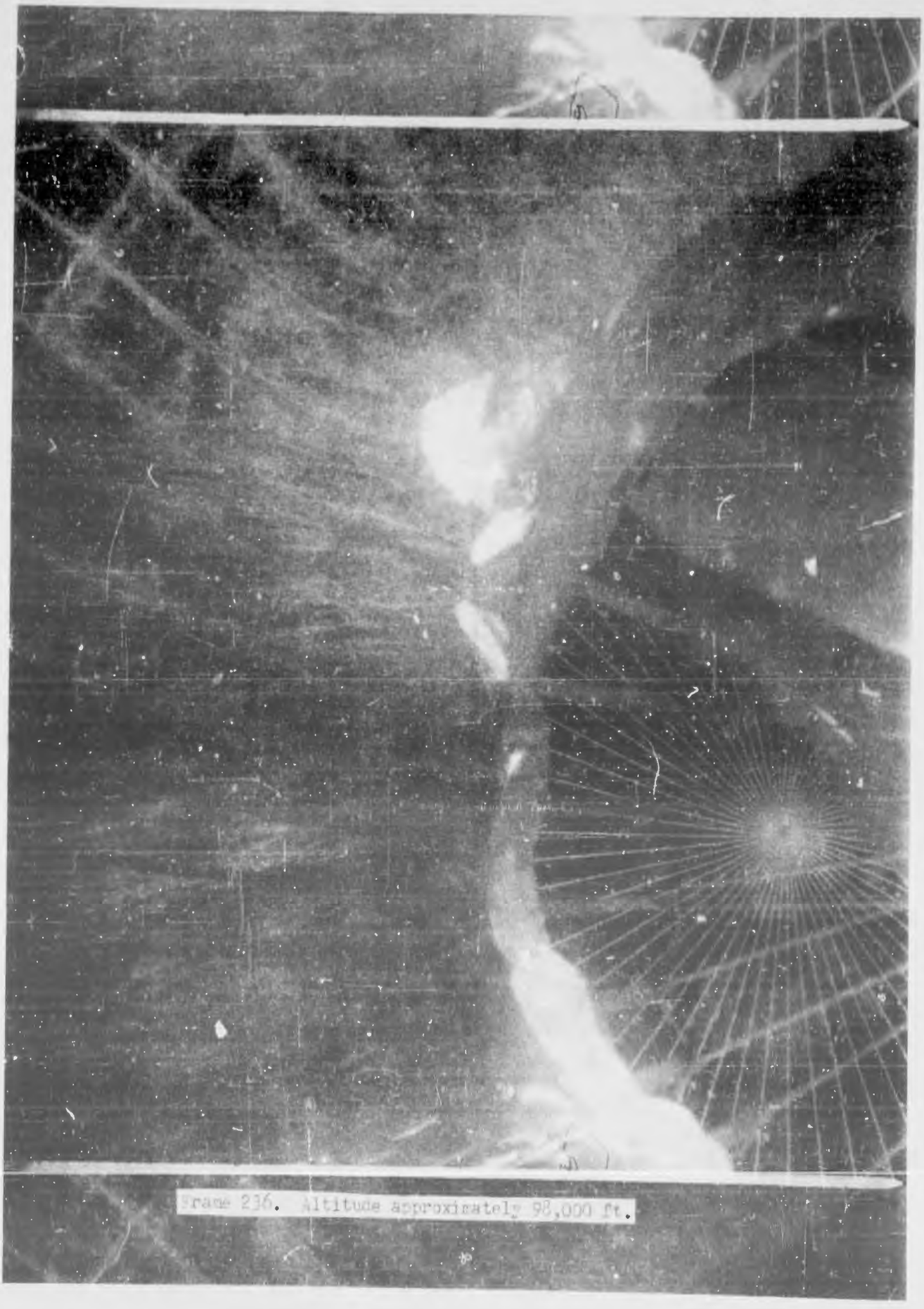
Frame 107, altitude approximately 98,000 ft.



Frame 187. Altitude approximately 98,000 ft. The absence of detail in this photograph is due to the fact that the solvent in the rubber cement used to attach the window was evaporated onto the window.



Frame 205. Altitude approximately 93,000 ft. Because of the darkness of the sky the highlights produced by the sun are extremely pronounced.



Frame 236. Altitude approximately 98,000 ft.



Frame 252. Altitude approximately 50,000 ft.



Frame 260. Altitude approximately 90,000 ft. The load has just been released by timers. The parachute can be seen pulling out and a small part of the full balloon is visible near the parachute.



Restricted Security Information

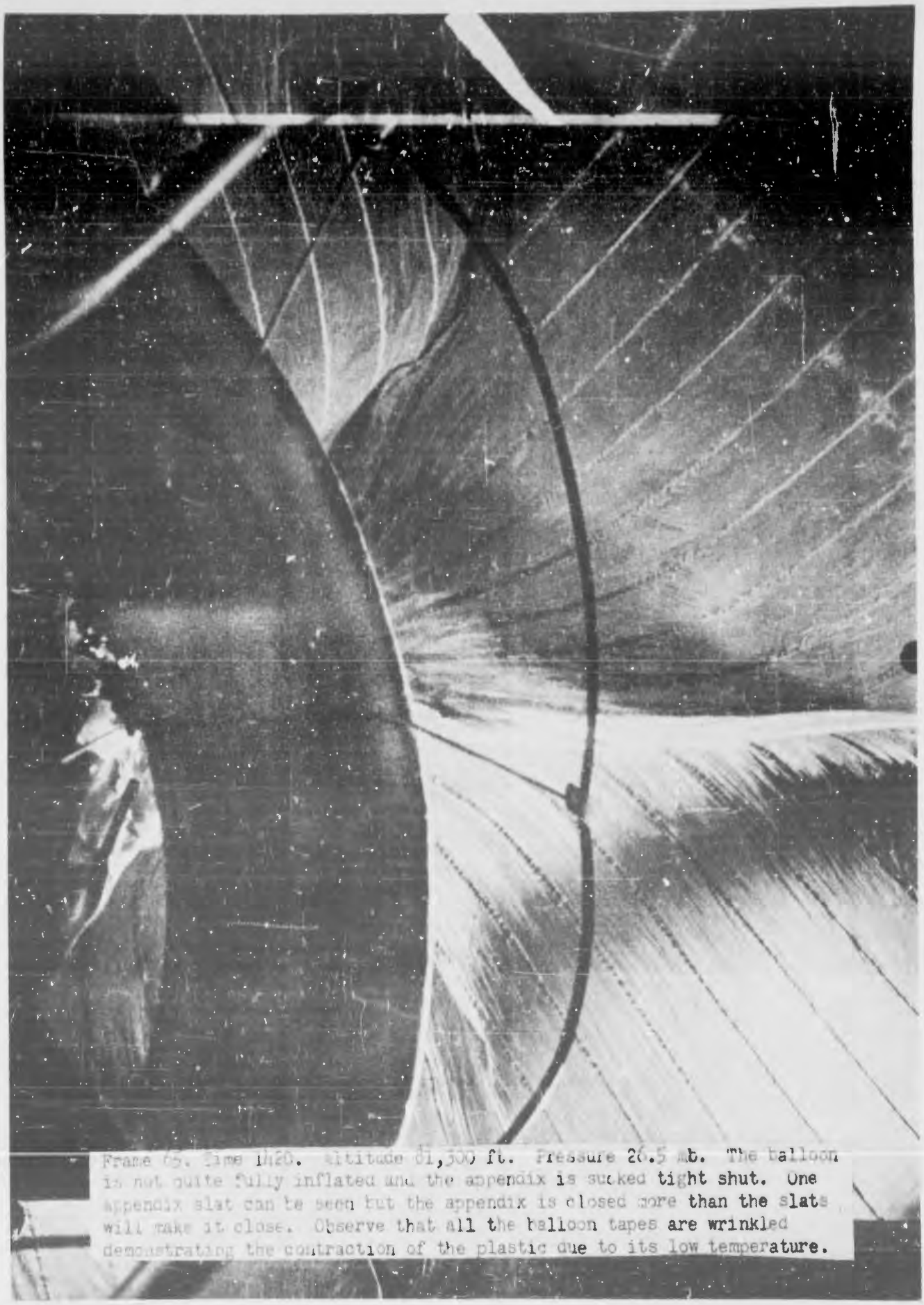


Frame 773. Another view of the parachute during descent.

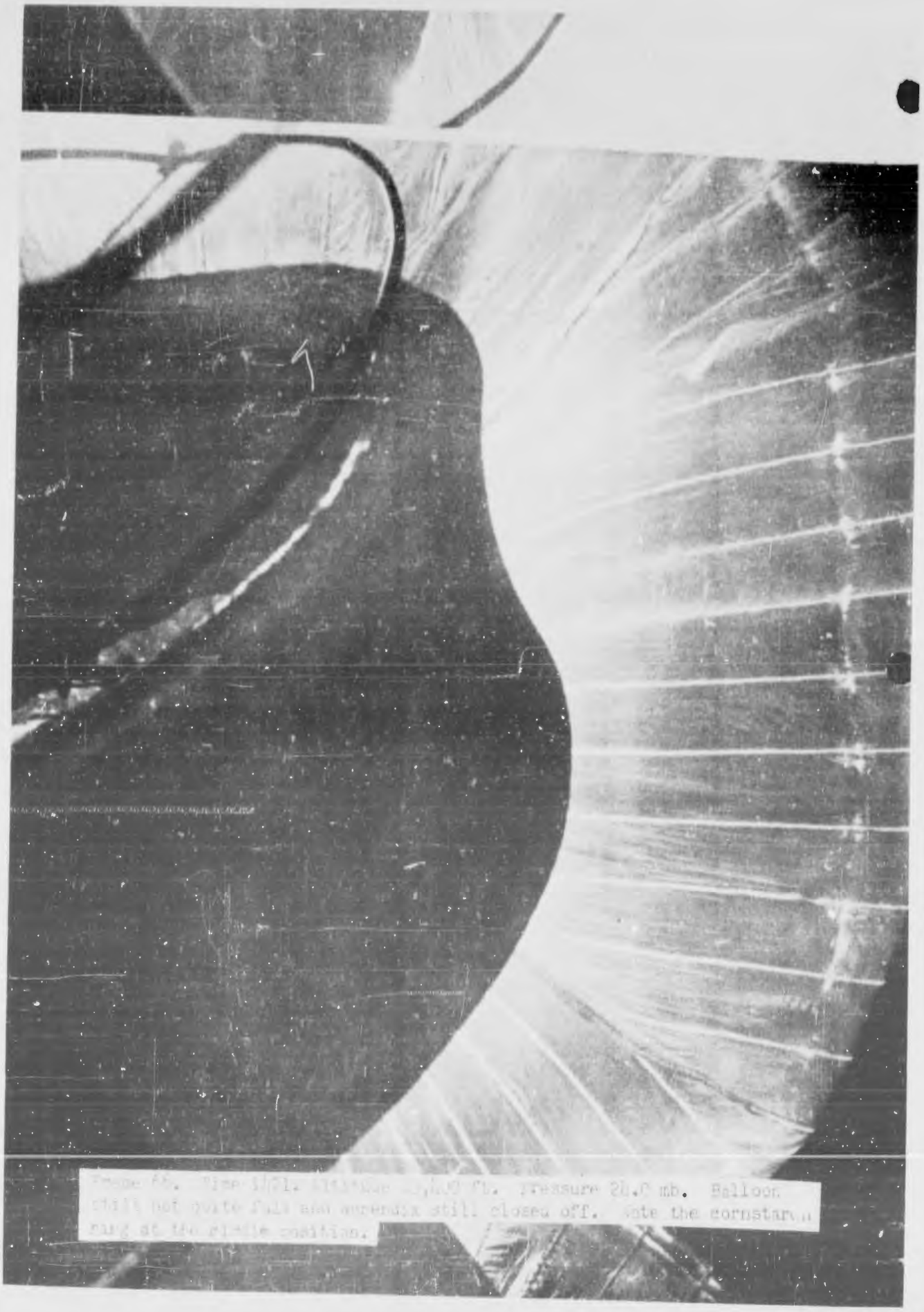
APPENDIX VIII

UP PHOTOGRAPHS FROM FLIGHT 19

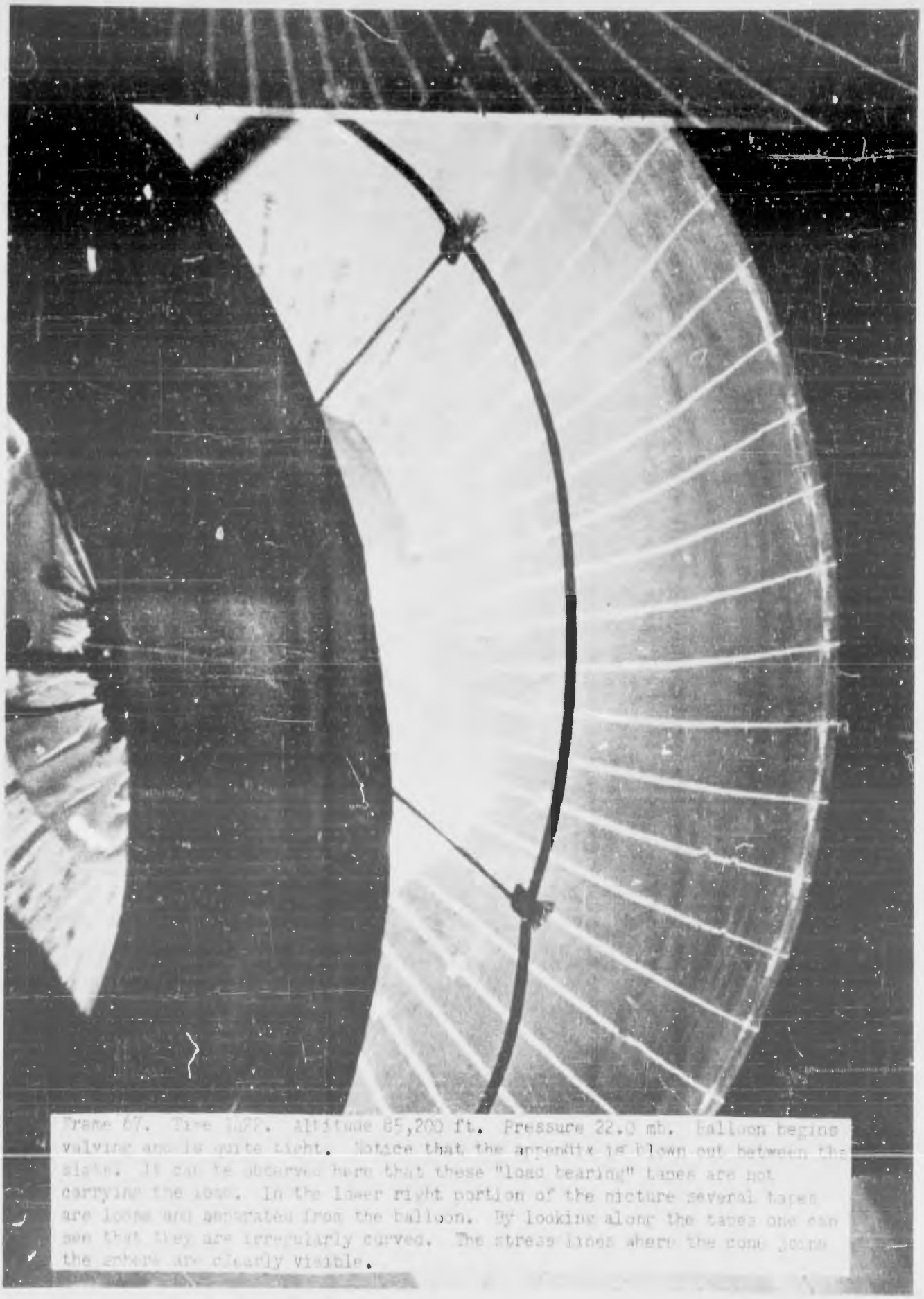
The following series of photographs was made with a camera in the gondola, arranged to photograph the balloon in flight. This series from Flight 19 illustrates the appearance of the balloon during valving.



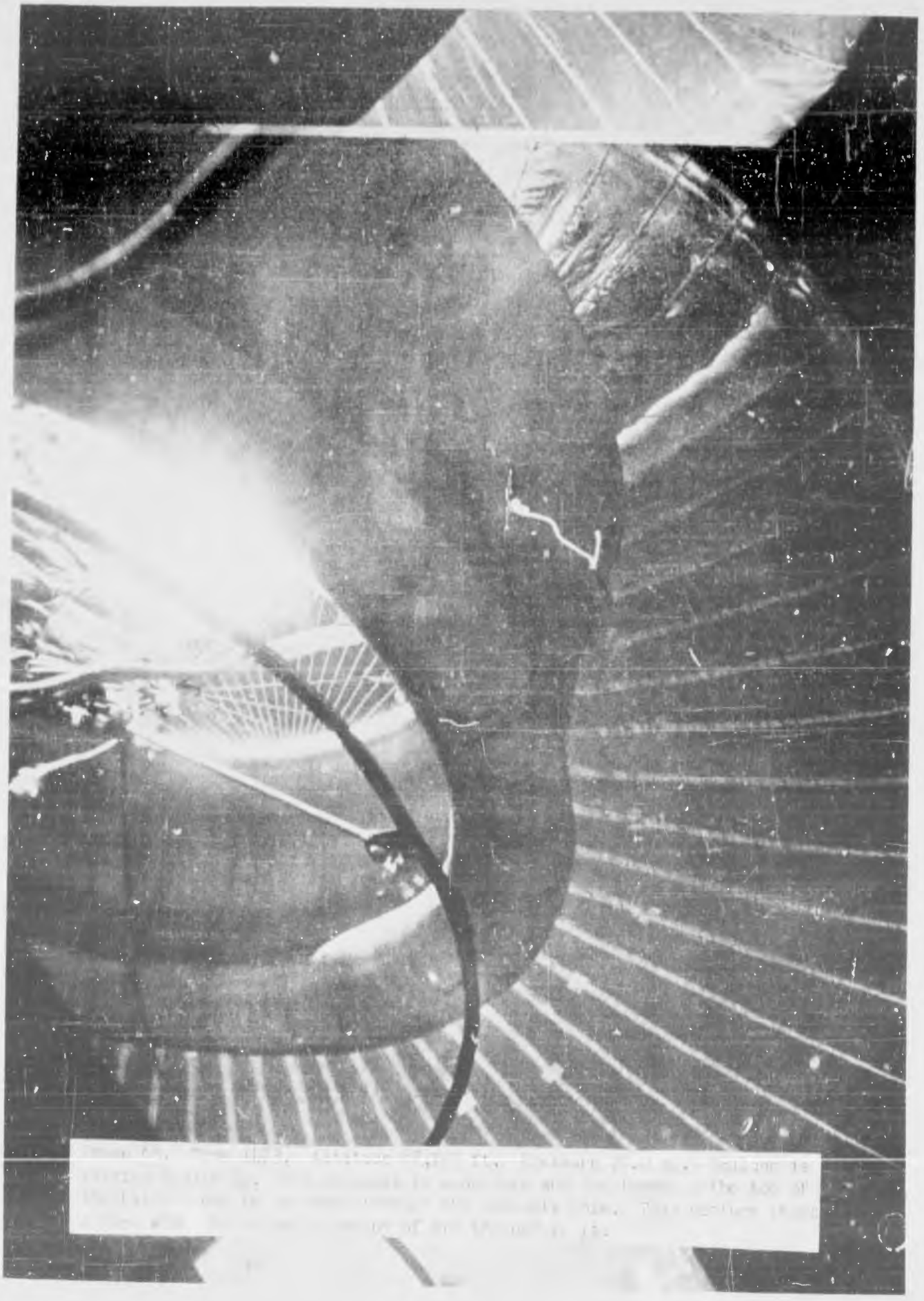
Frame 65. Time 1h20. Altitude 81,500 ft. Pressure 26.5 mb. The balloon is not quite fully inflated and the appendix is sucked tight shut. One appendix slat can be seen but the appendix is closed more than the slats will take it close. Observe that all the balloon tapes are wrinkled demonstrating the contraction of the plastic due to its low temperature.

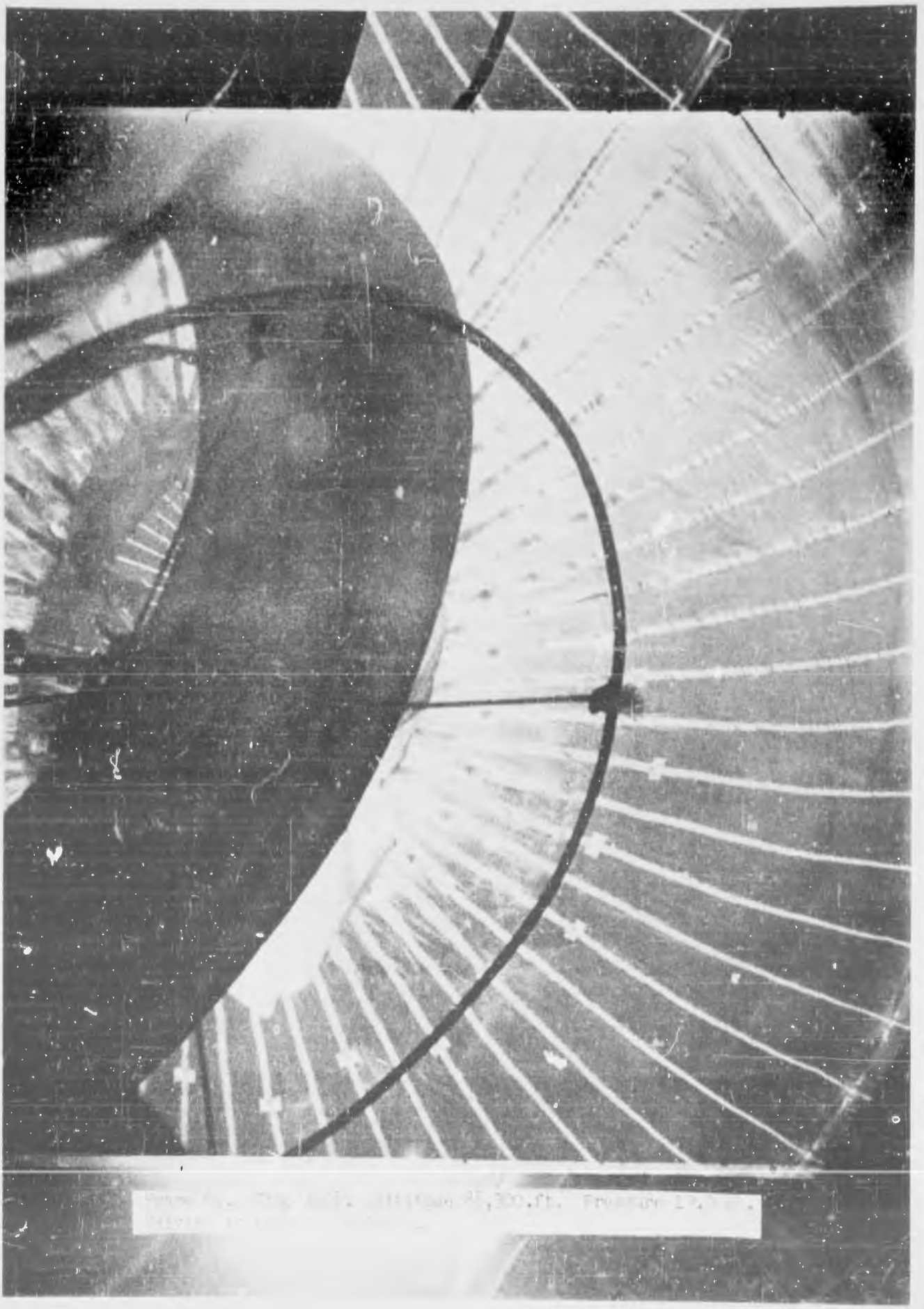


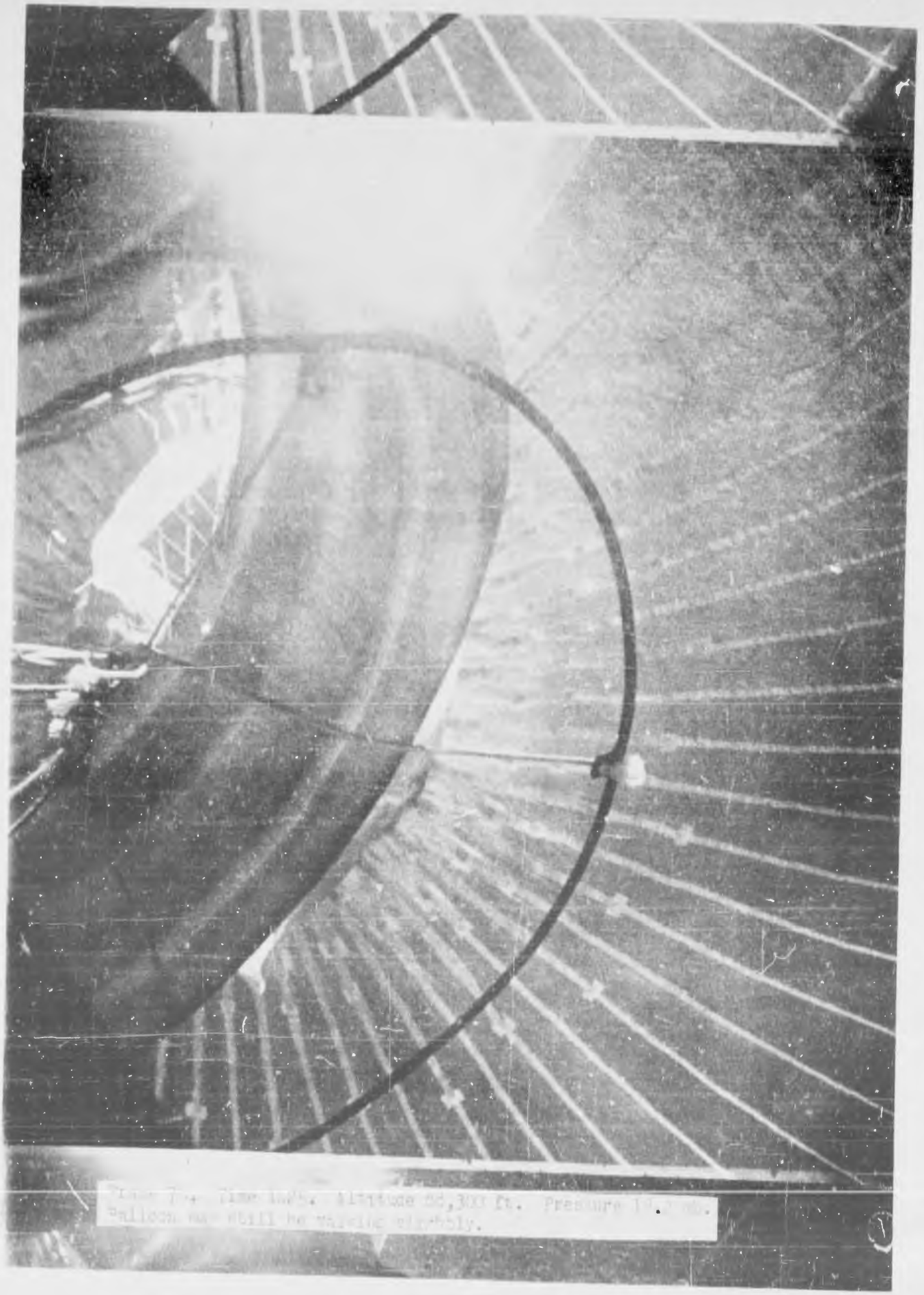
Restricted Security Information



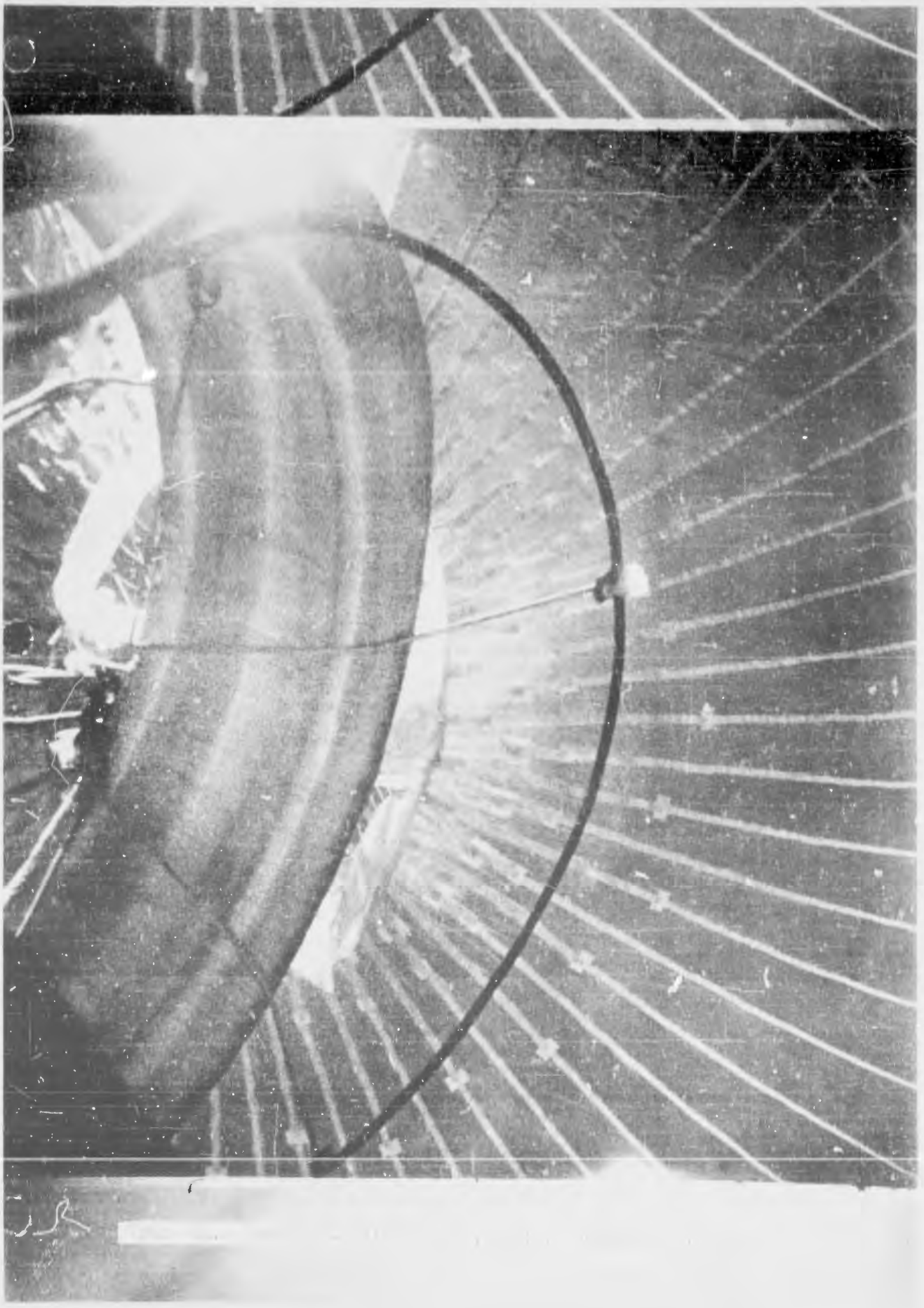
Frame 67. Time 1077. Altitude 85,200 ft. Pressure 22.0 mb. Balloon begins valving and is quite tight. Notice that the appendix is blown out between the sights. It can be observed here that these "load bearing" tapes are not carrying the load. In the lower right portion of the picture several tapes are loose and separated from the balloon. By looking along the tapes one can see that they are irregularly curved. The stress lines where the gore joins the others are clearly visible.



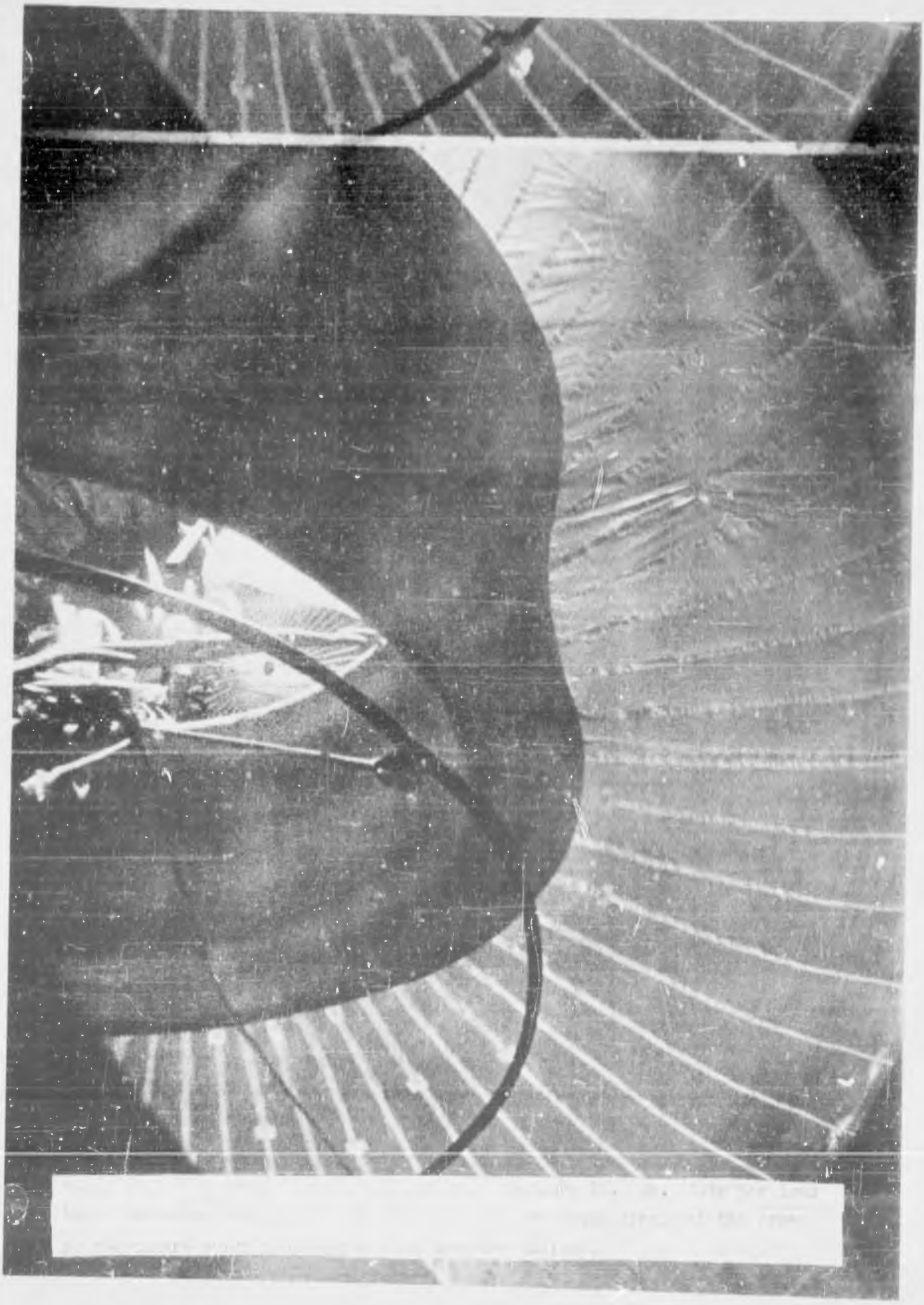




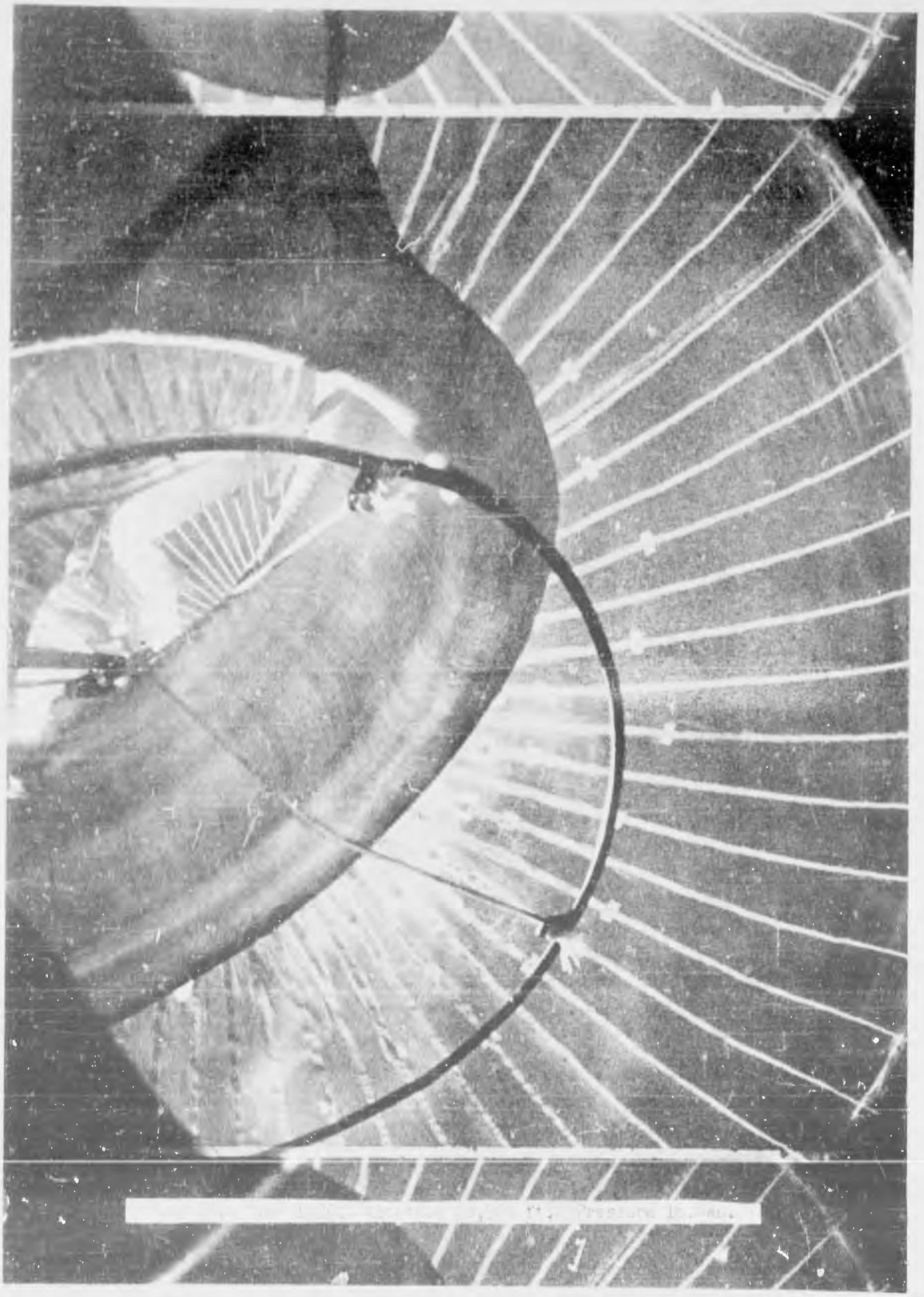
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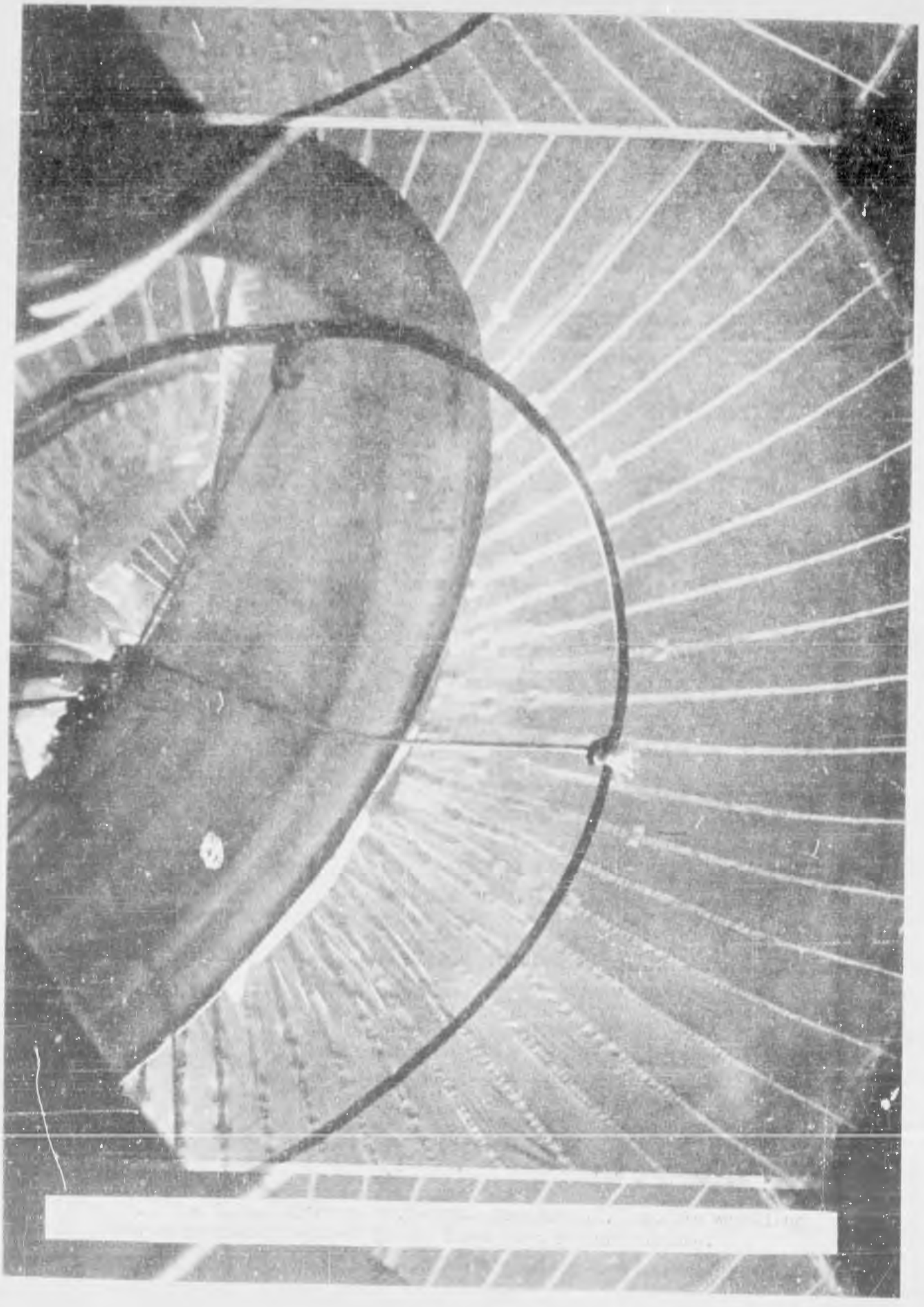


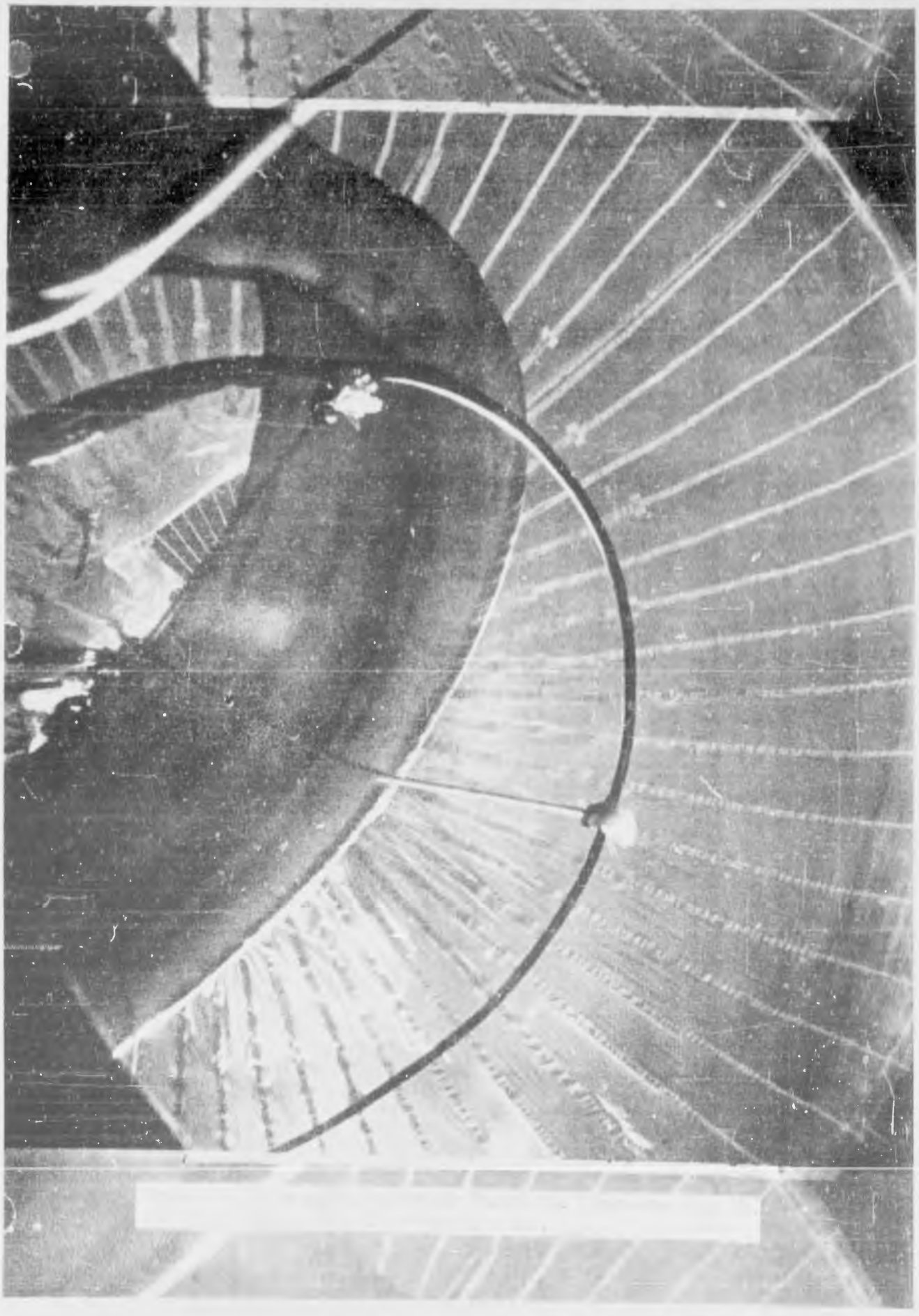


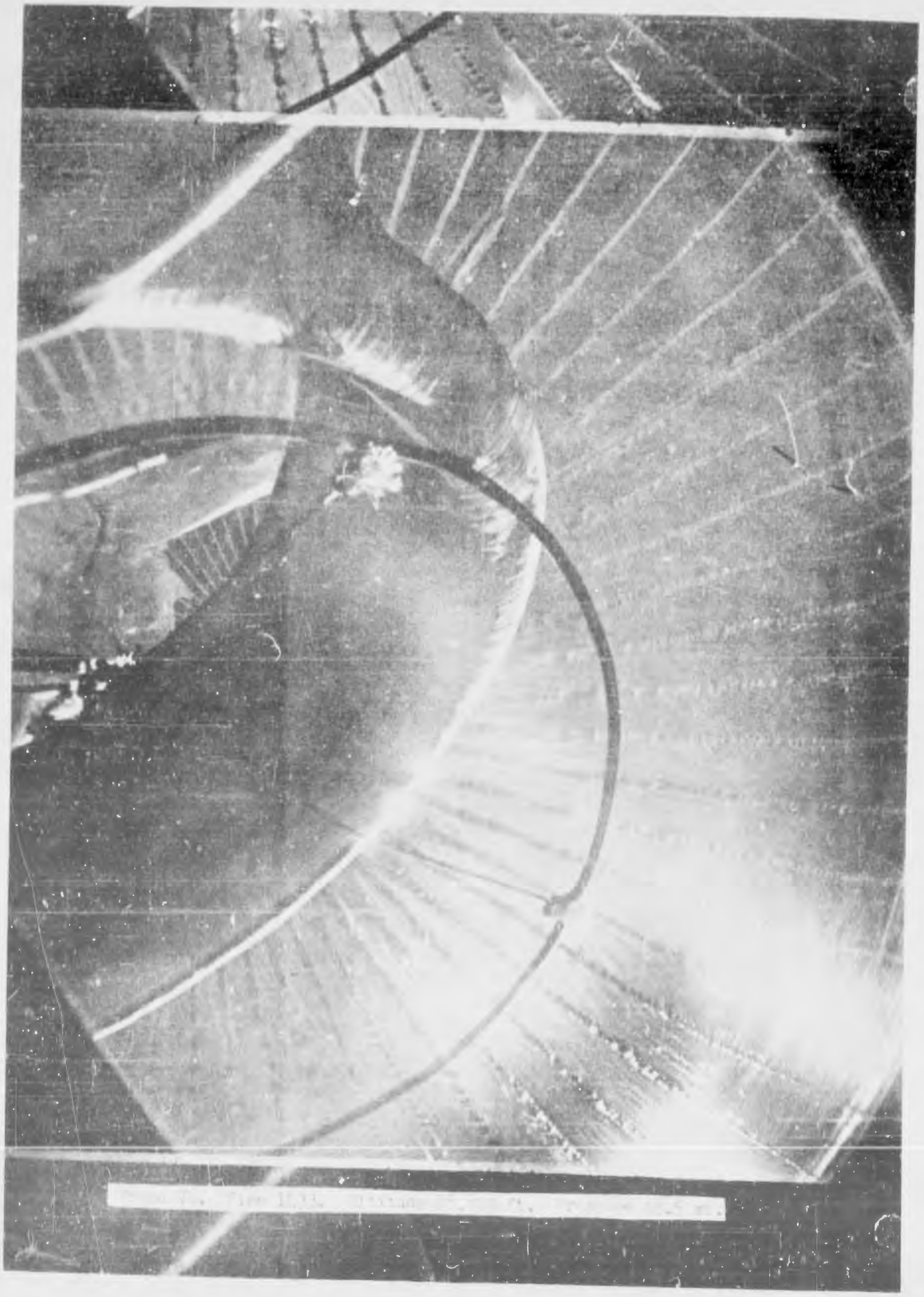


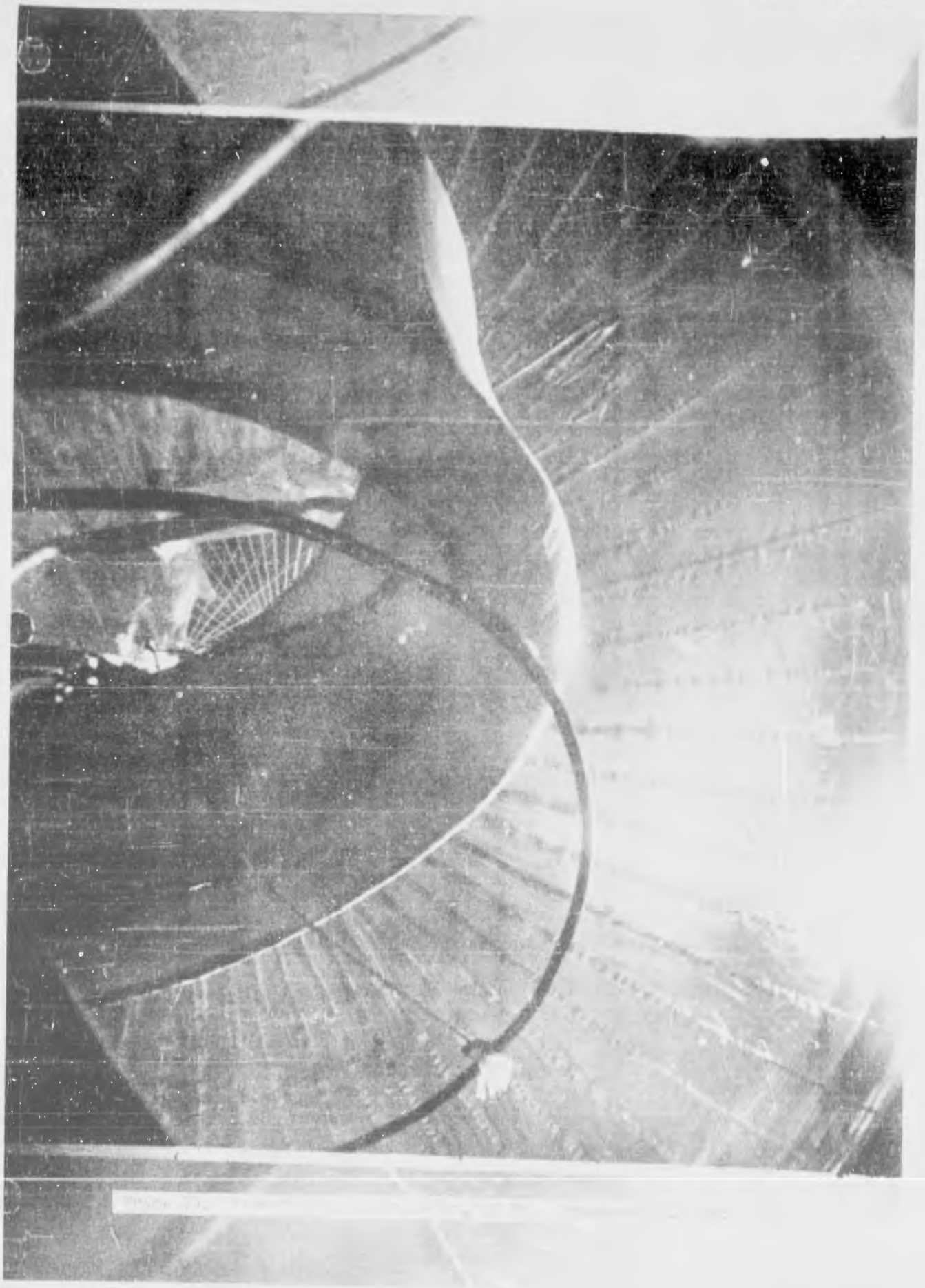




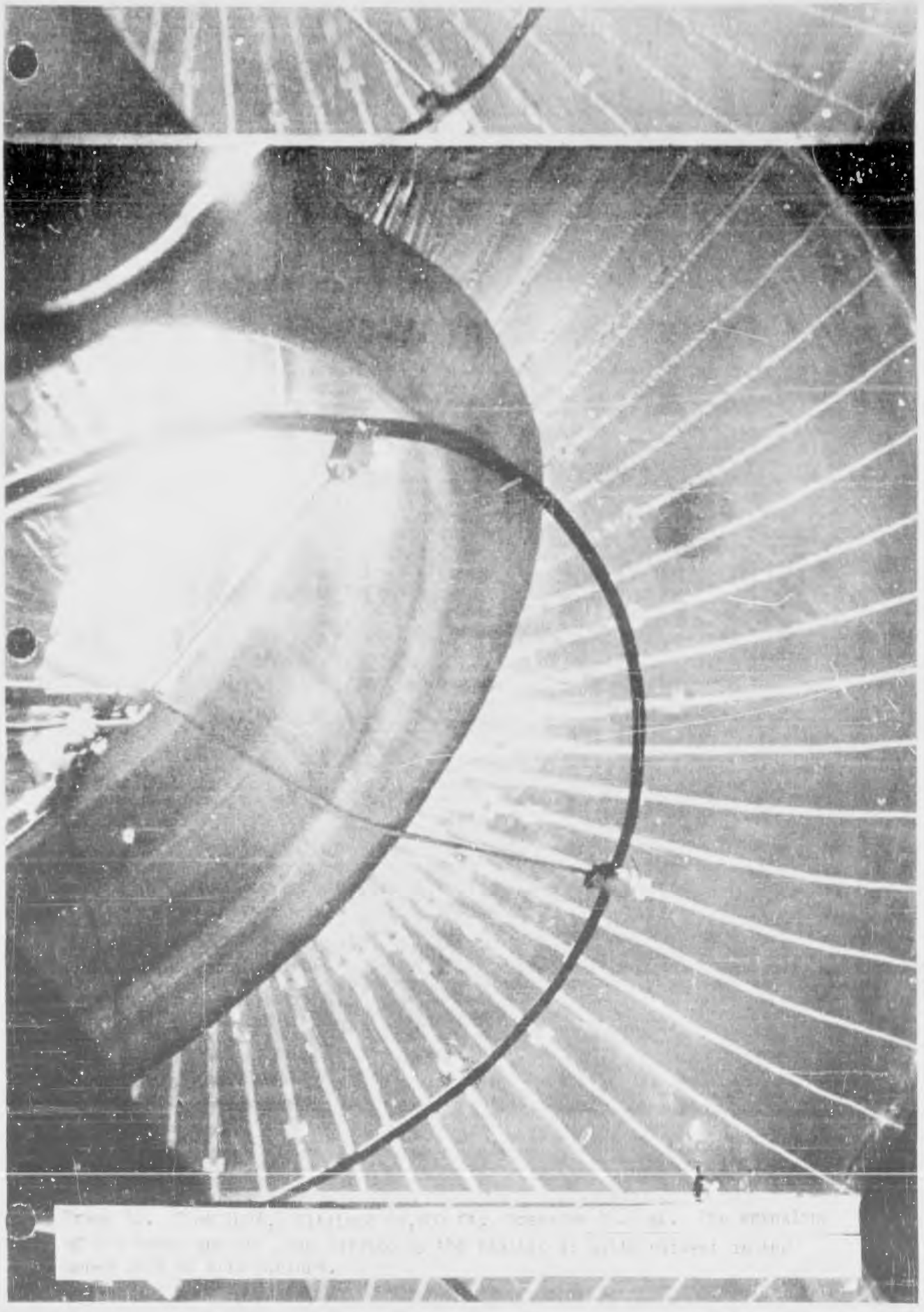


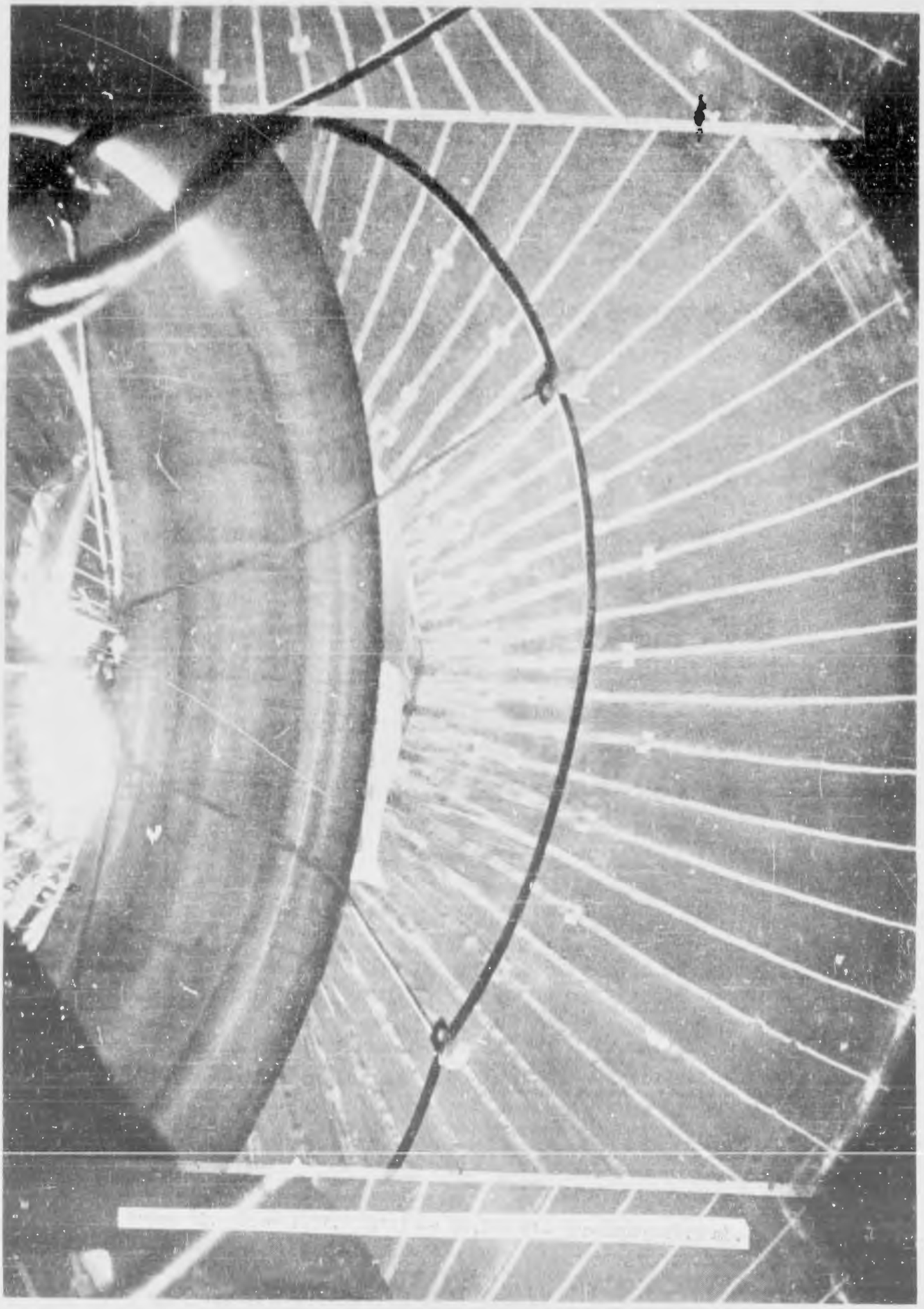


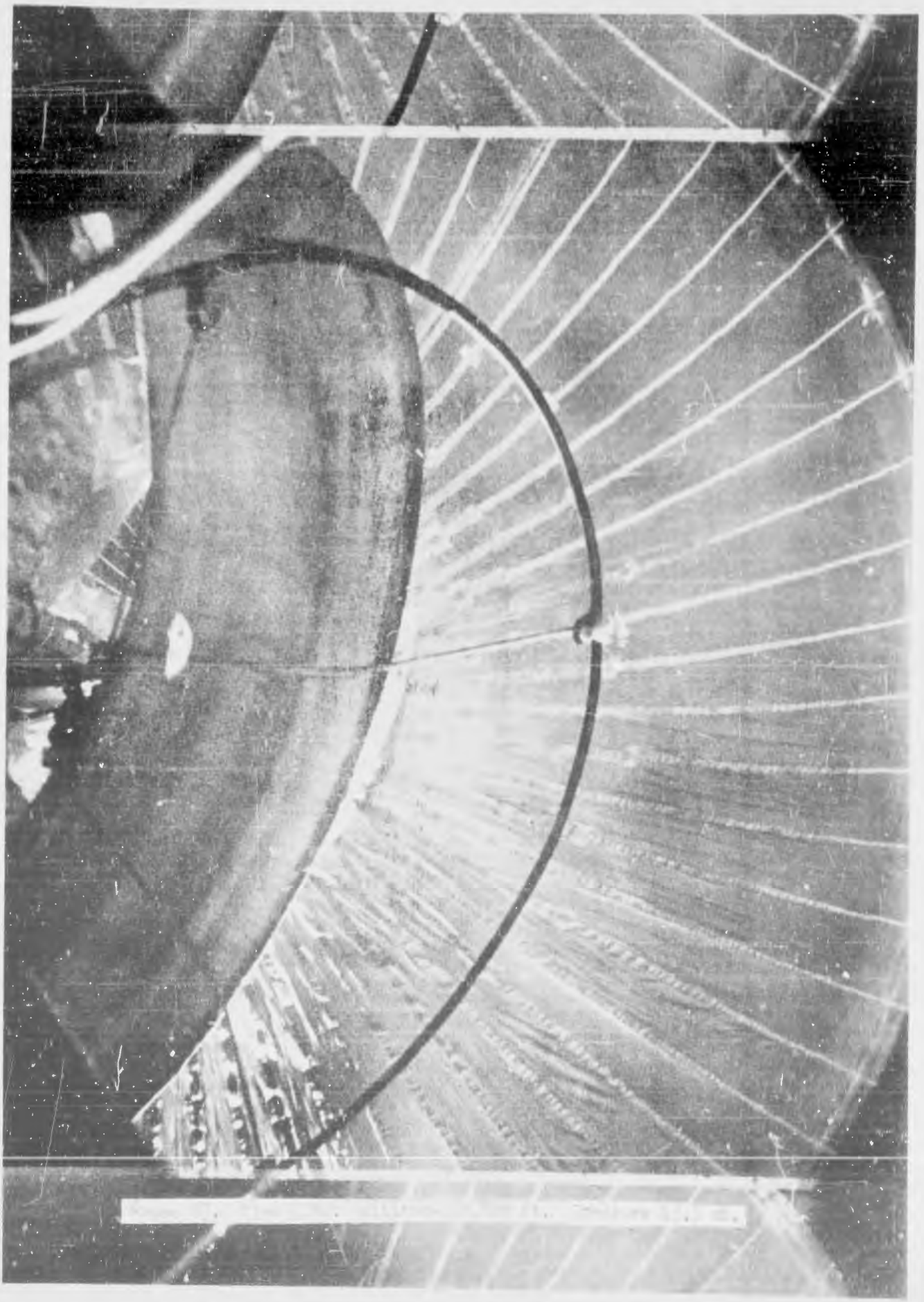




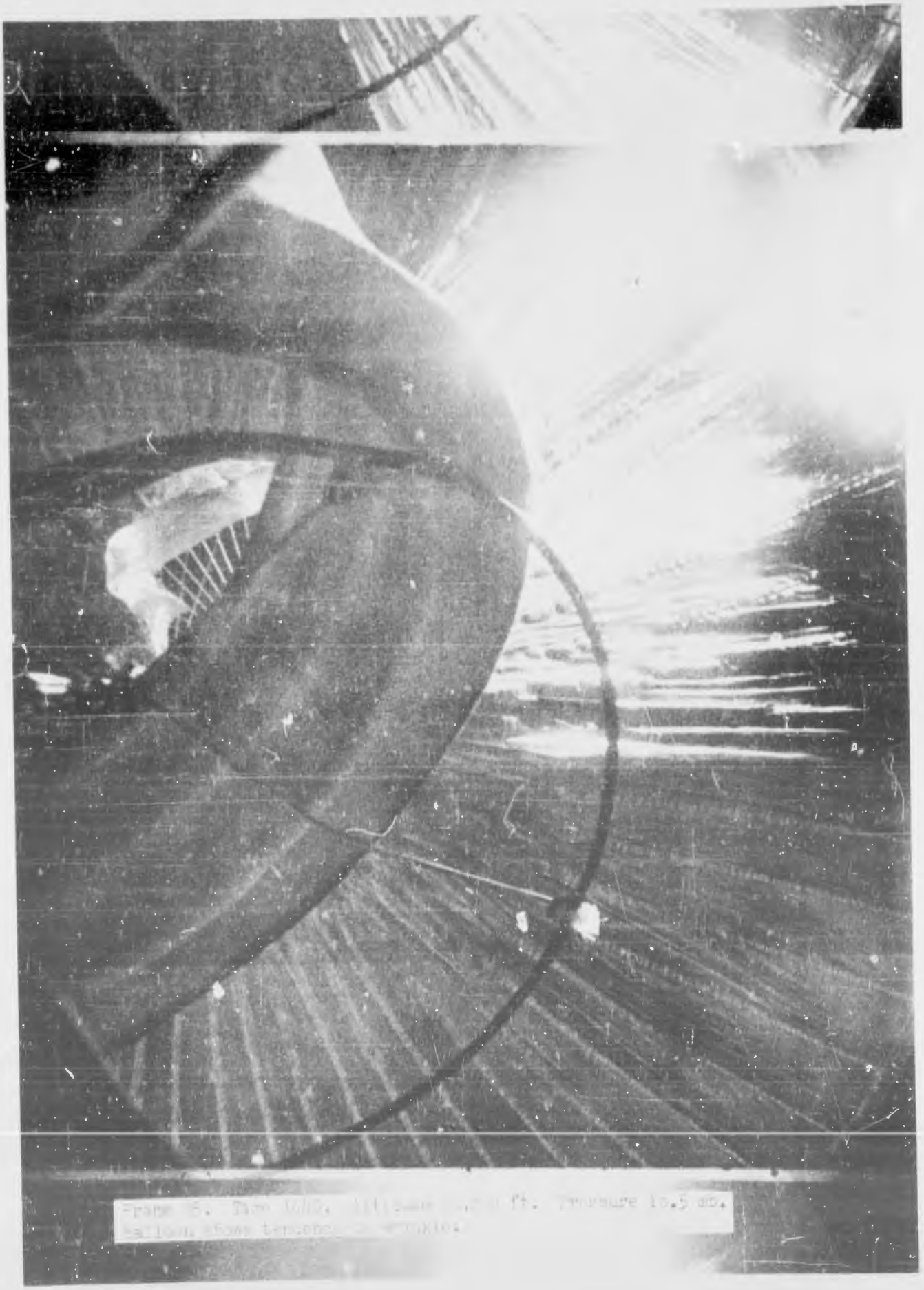




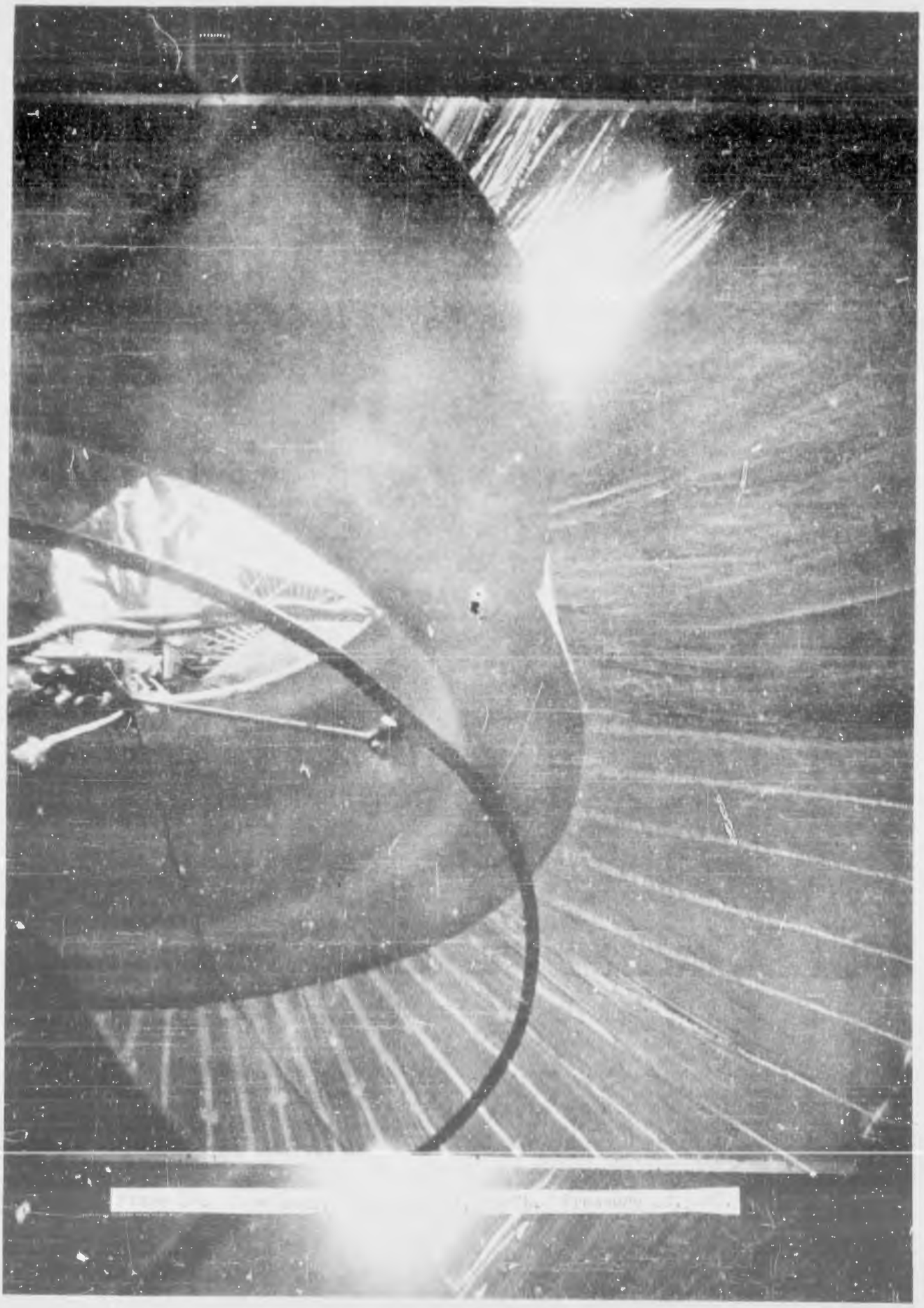


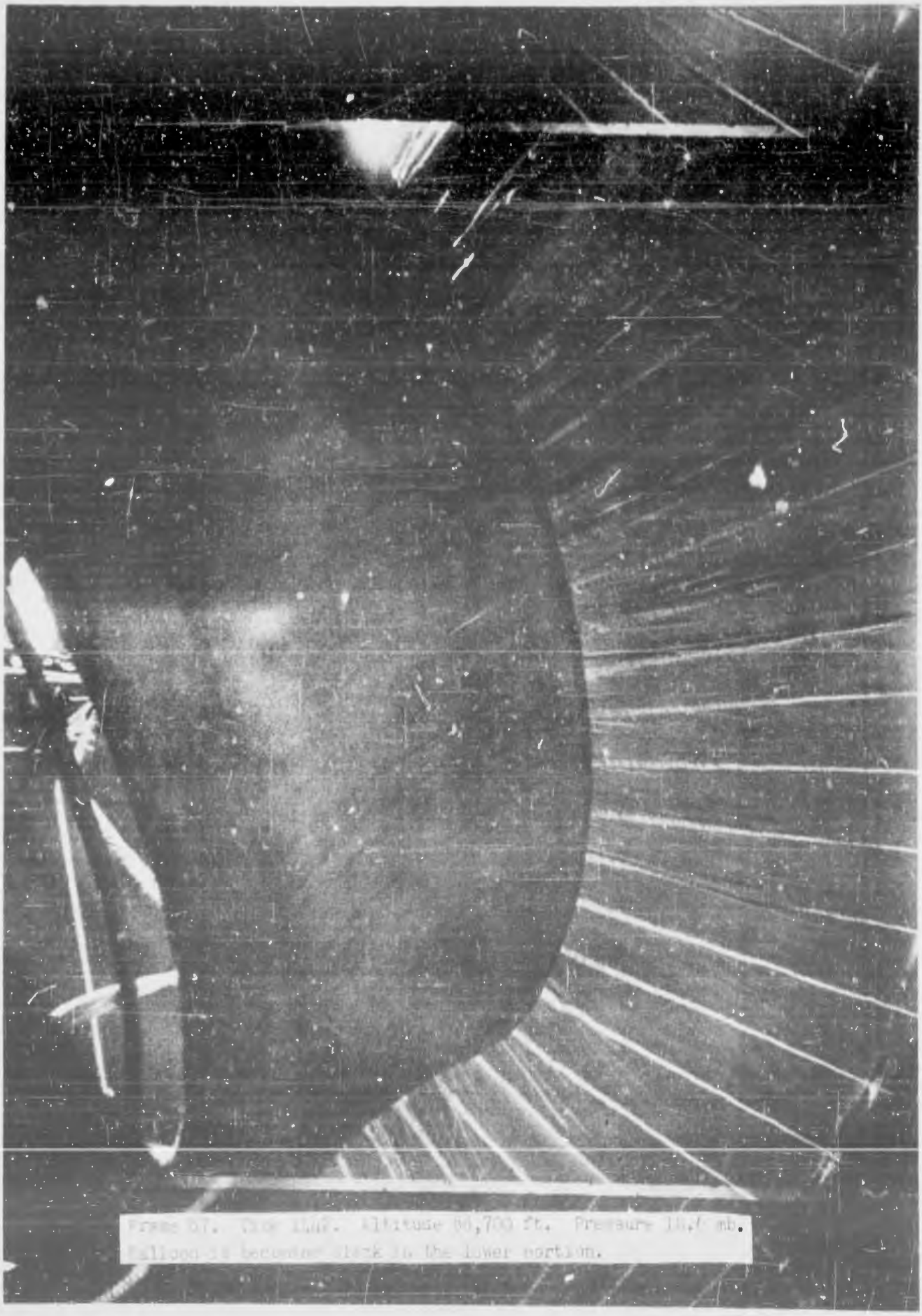




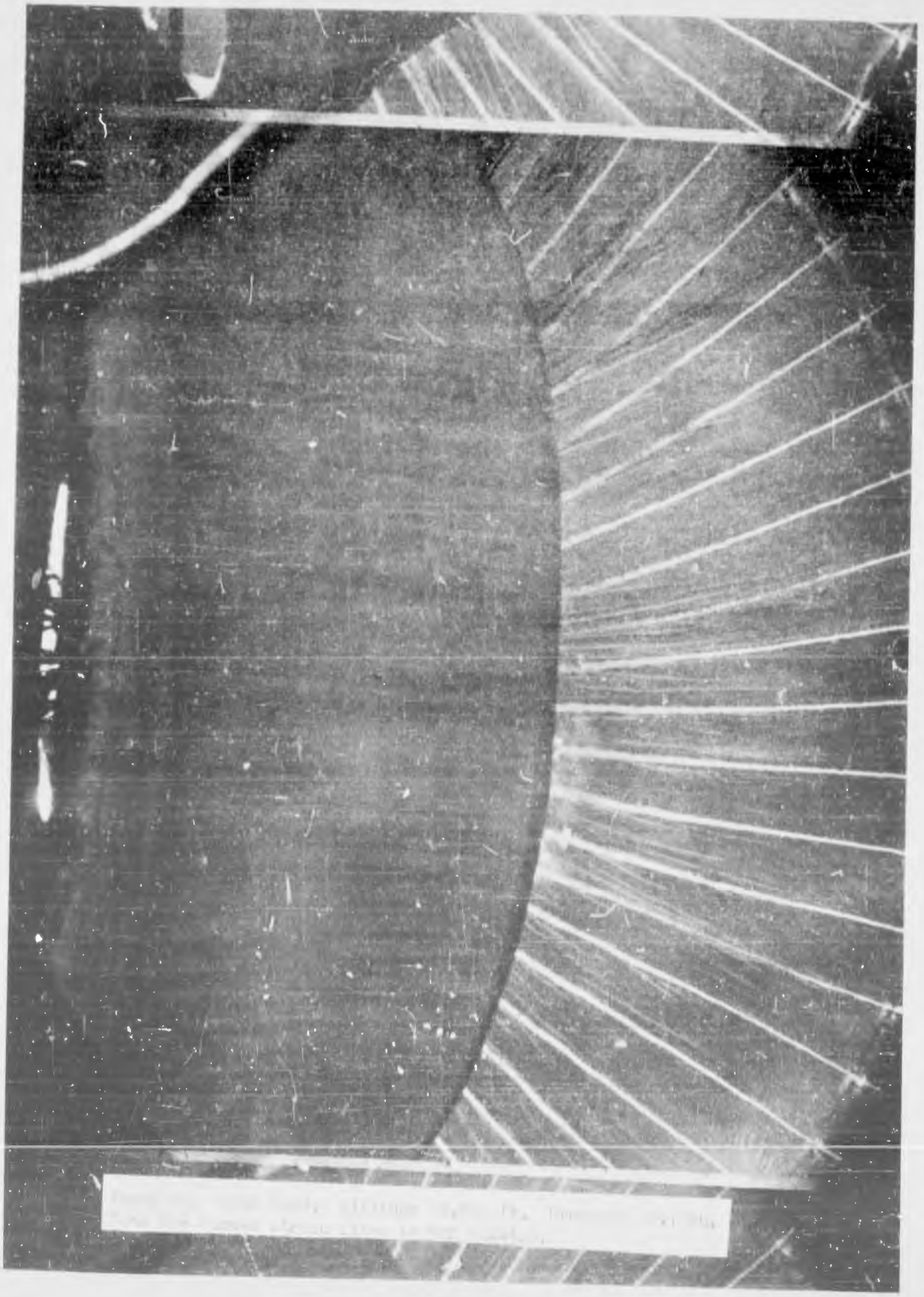


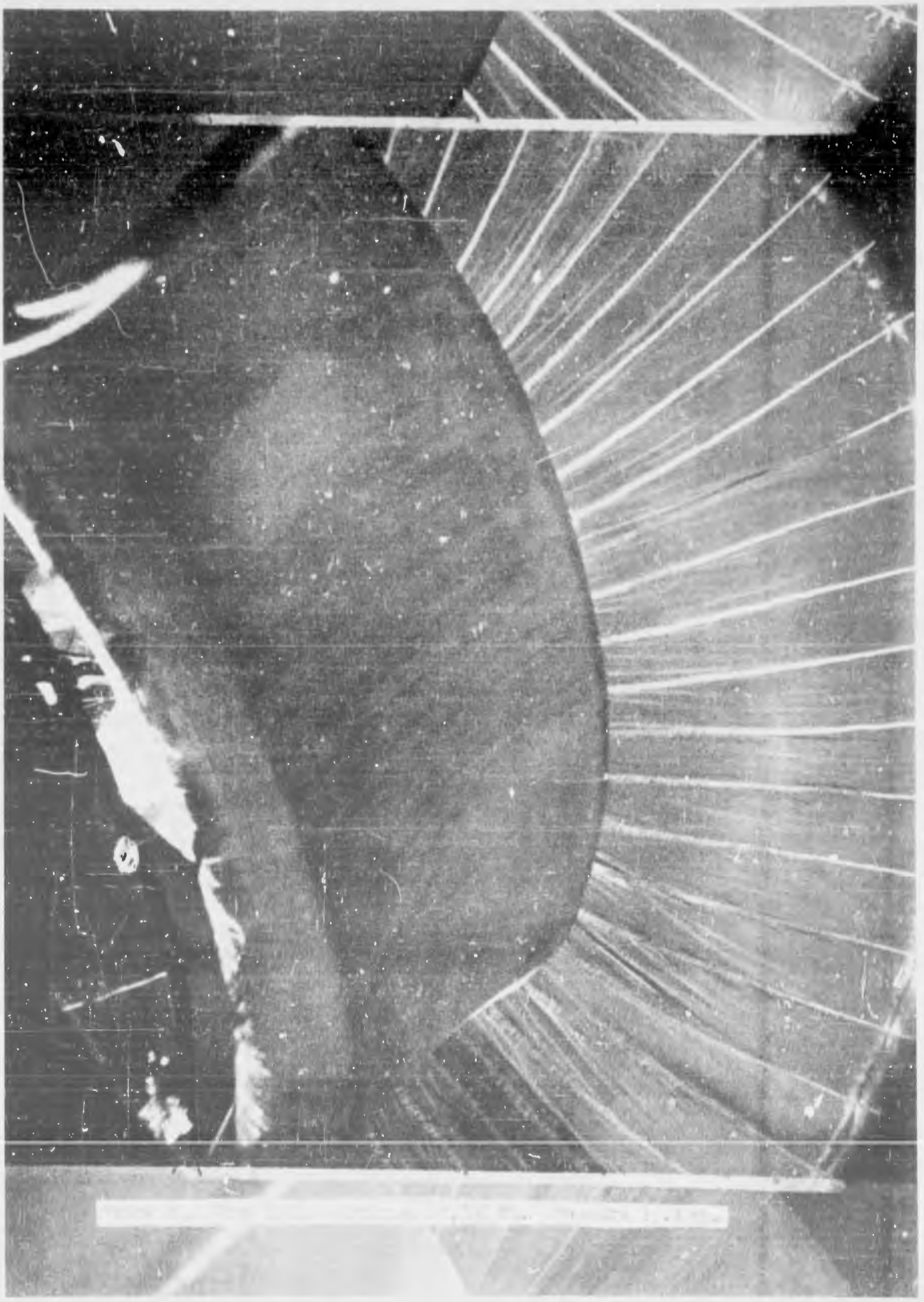
Frame 5. Time 0.05. Altitude [illegible] ft. Pressure 10.5 atm. Earlier shown tensor [illegible]

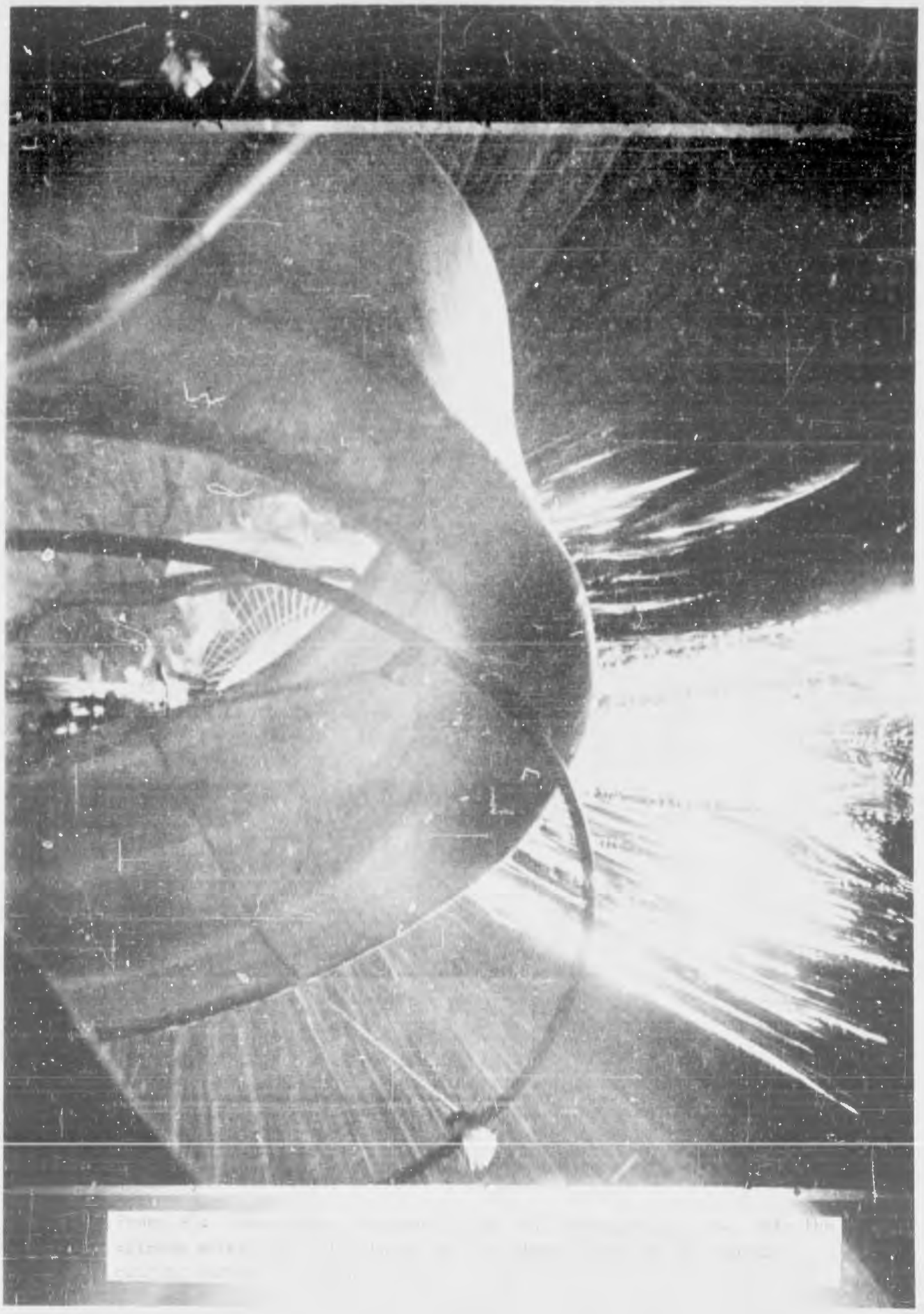


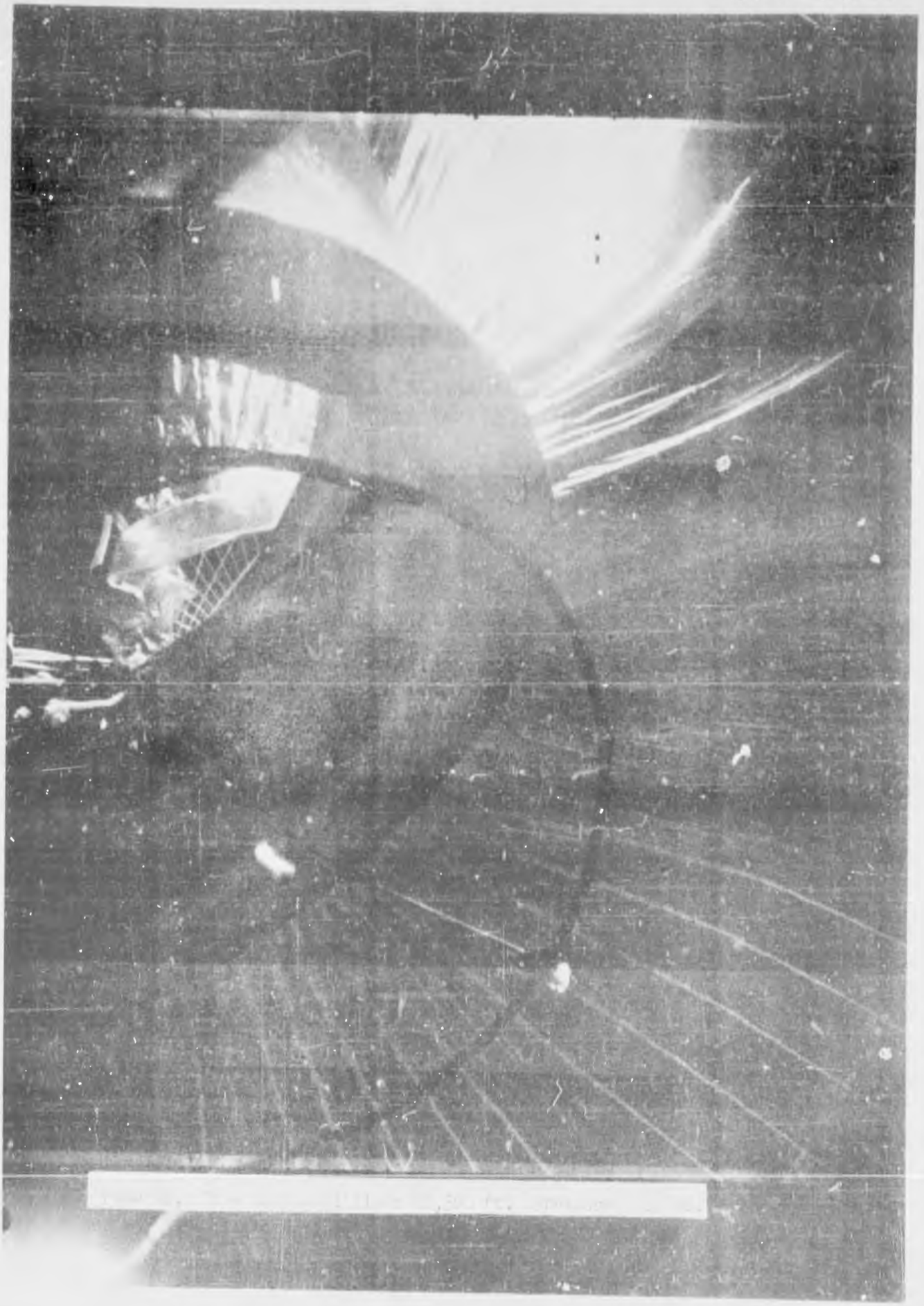


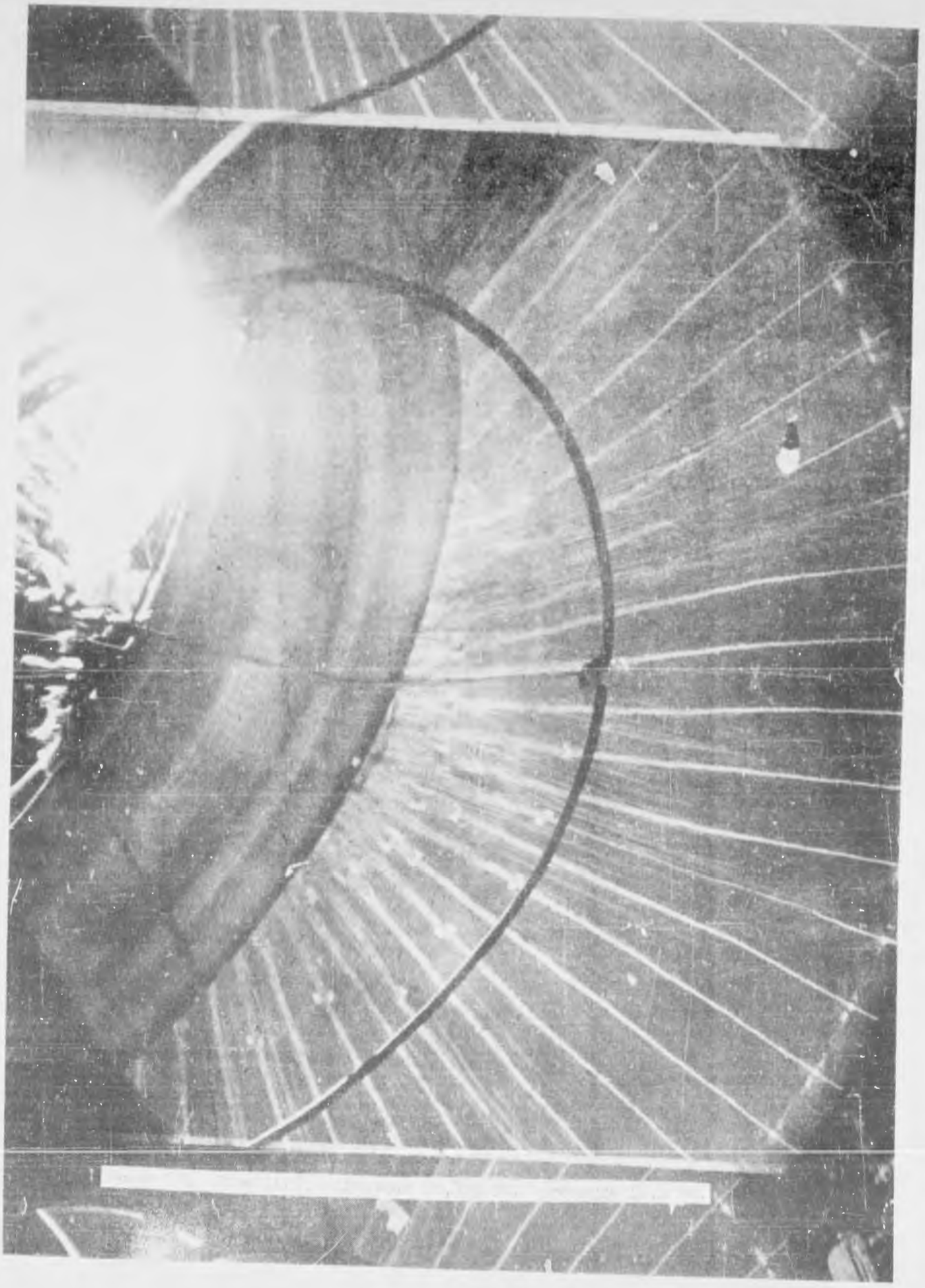
Frame 81. Time 1445. Altitude 98,700 ft. Pressure 10.7 mb.
Balloon is becoming black in the lower portion.

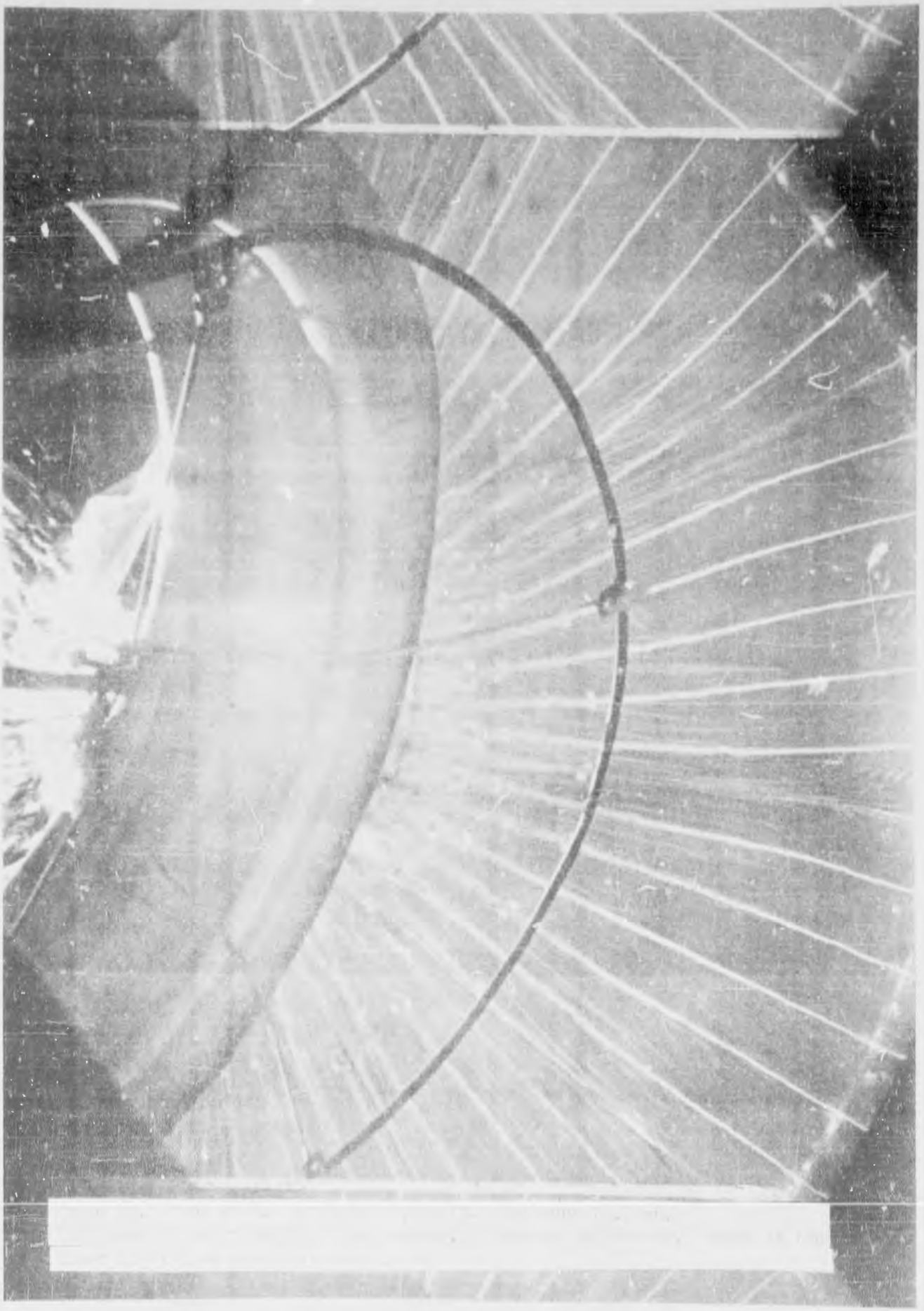


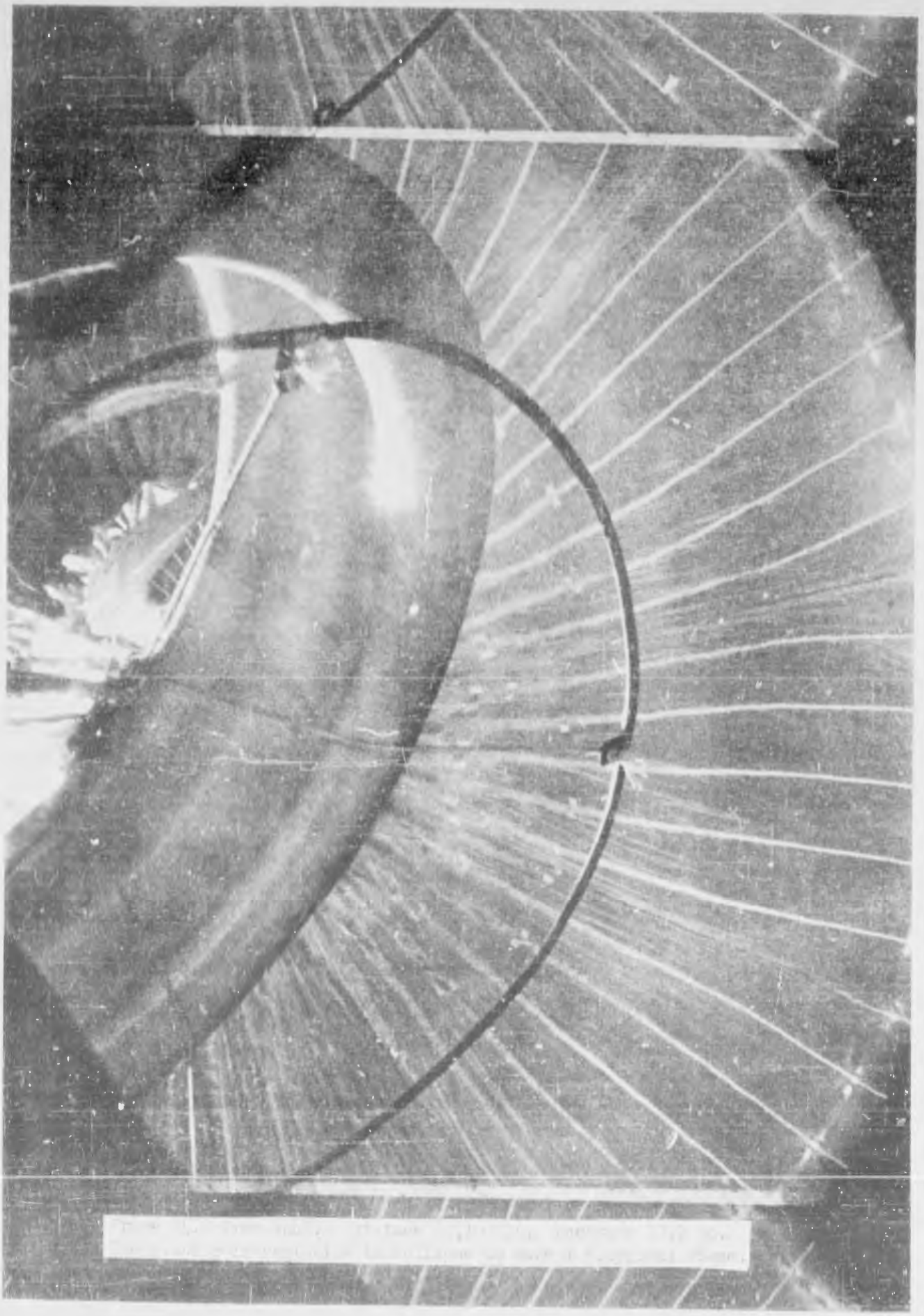


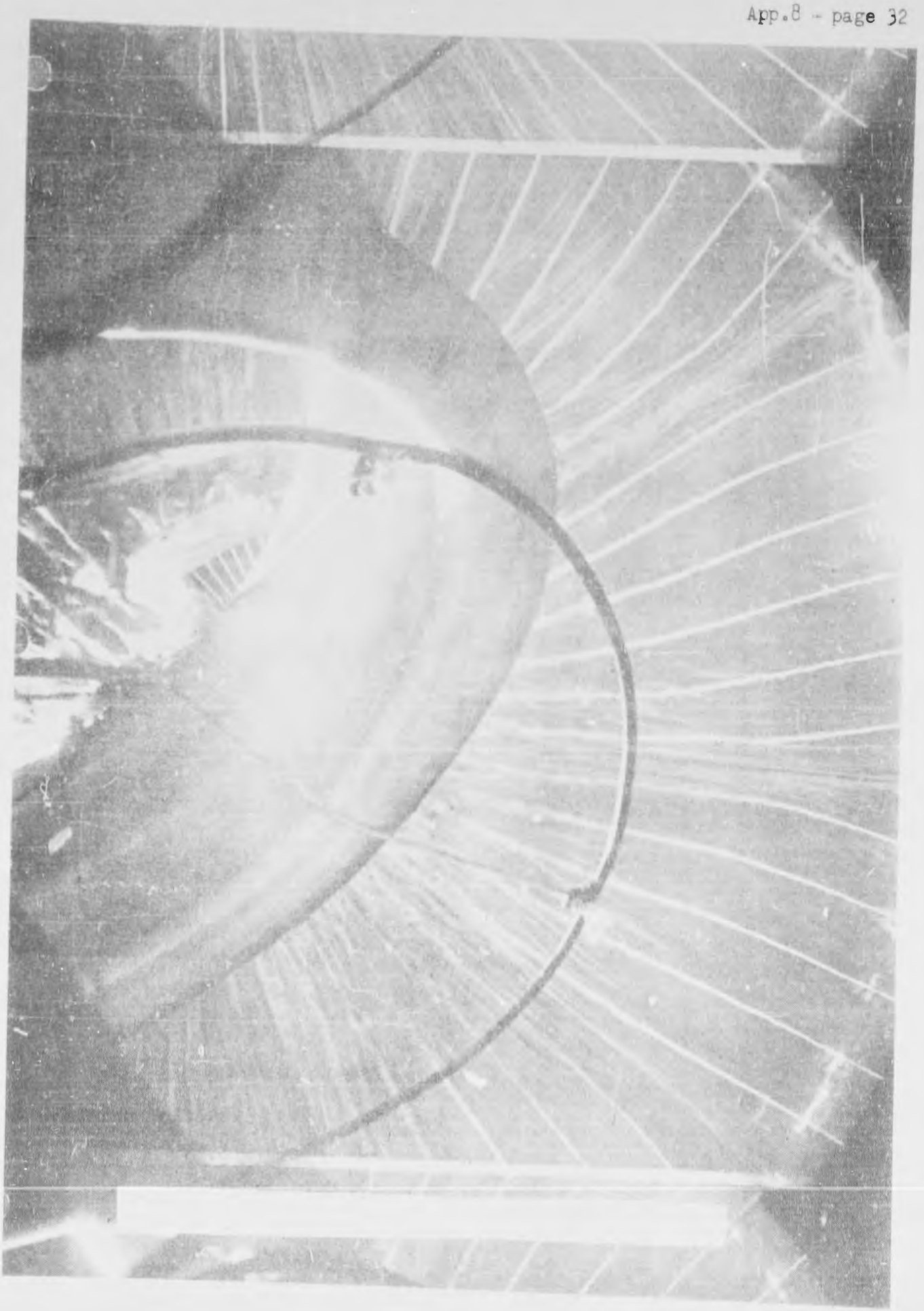


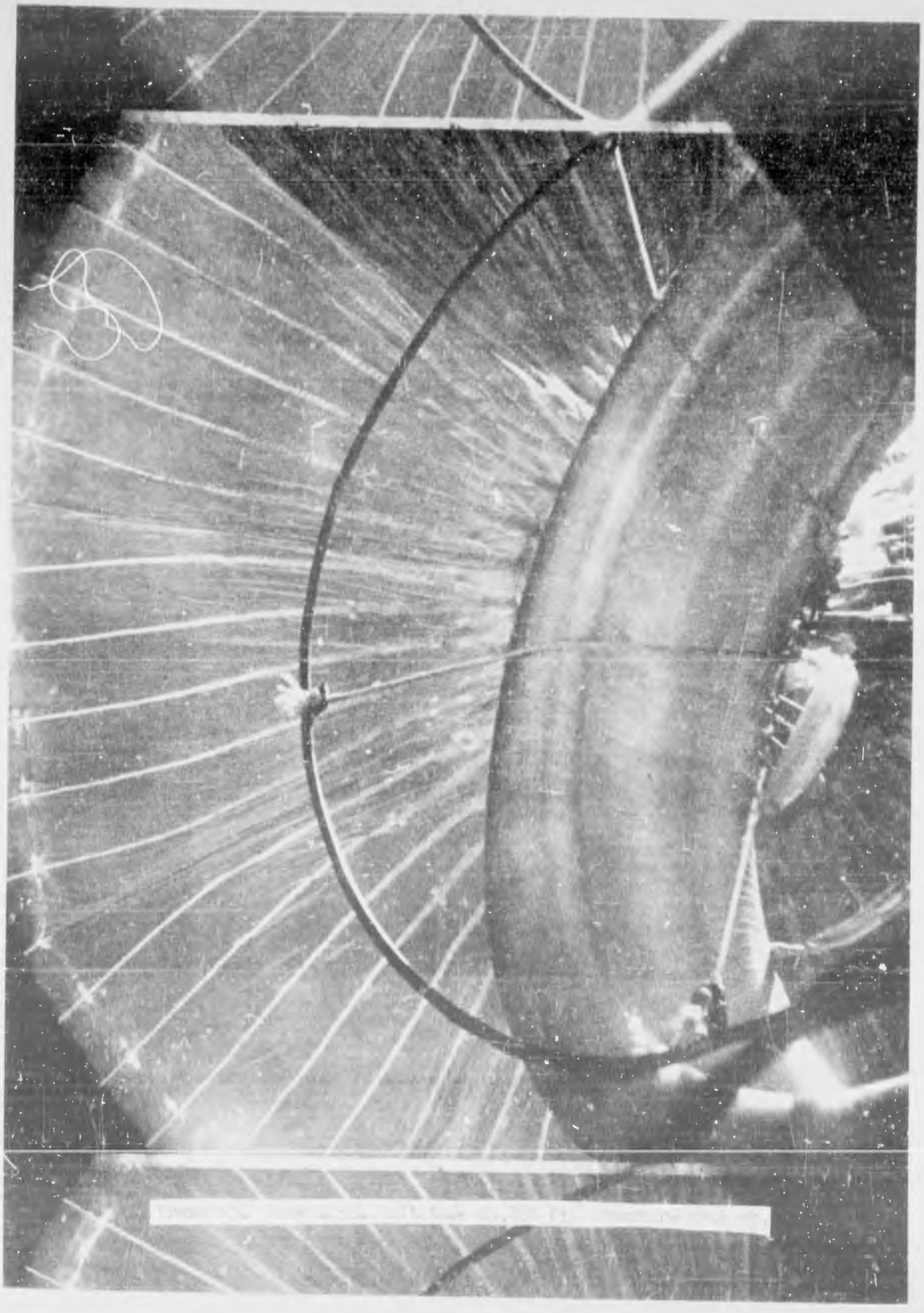


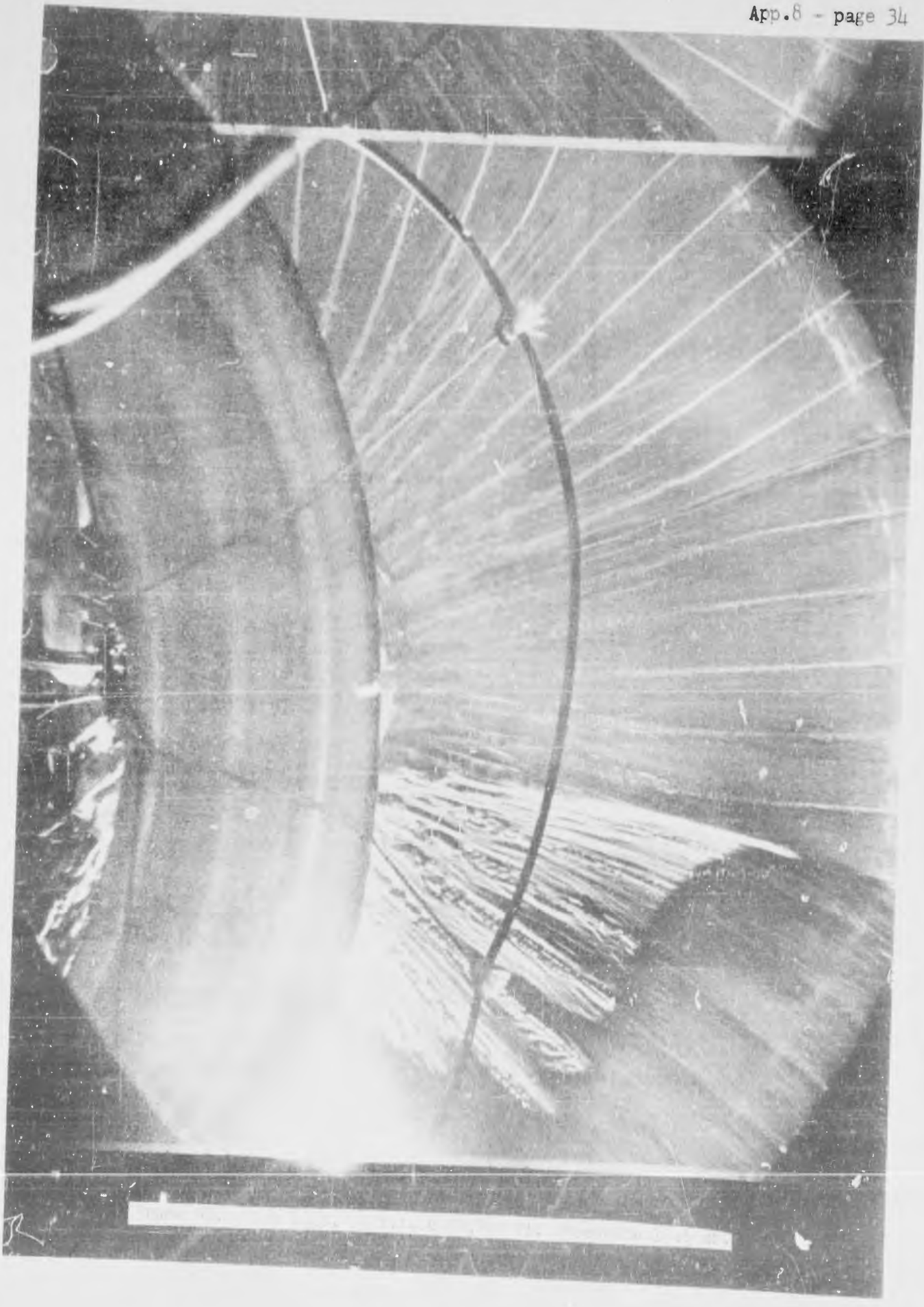


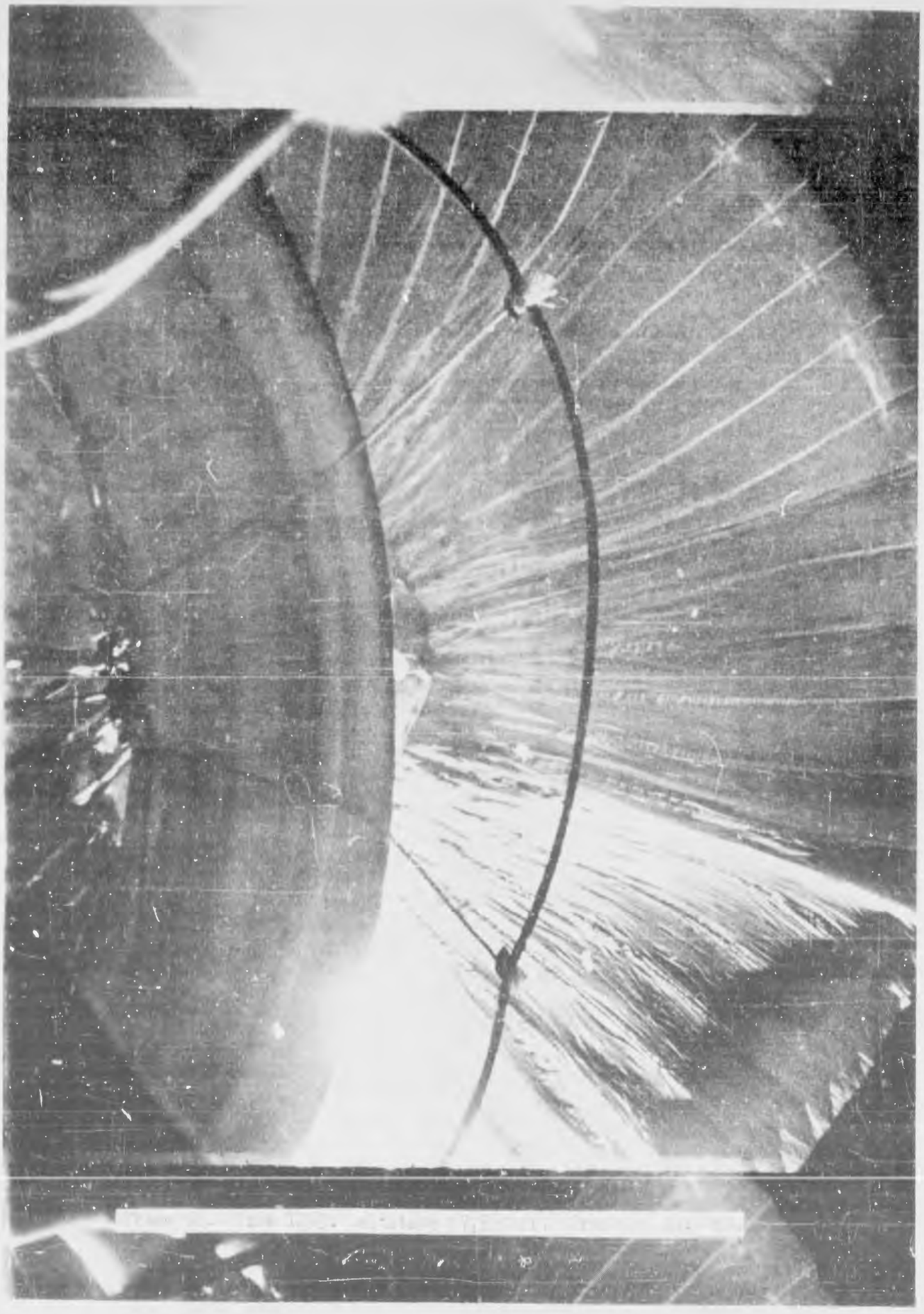


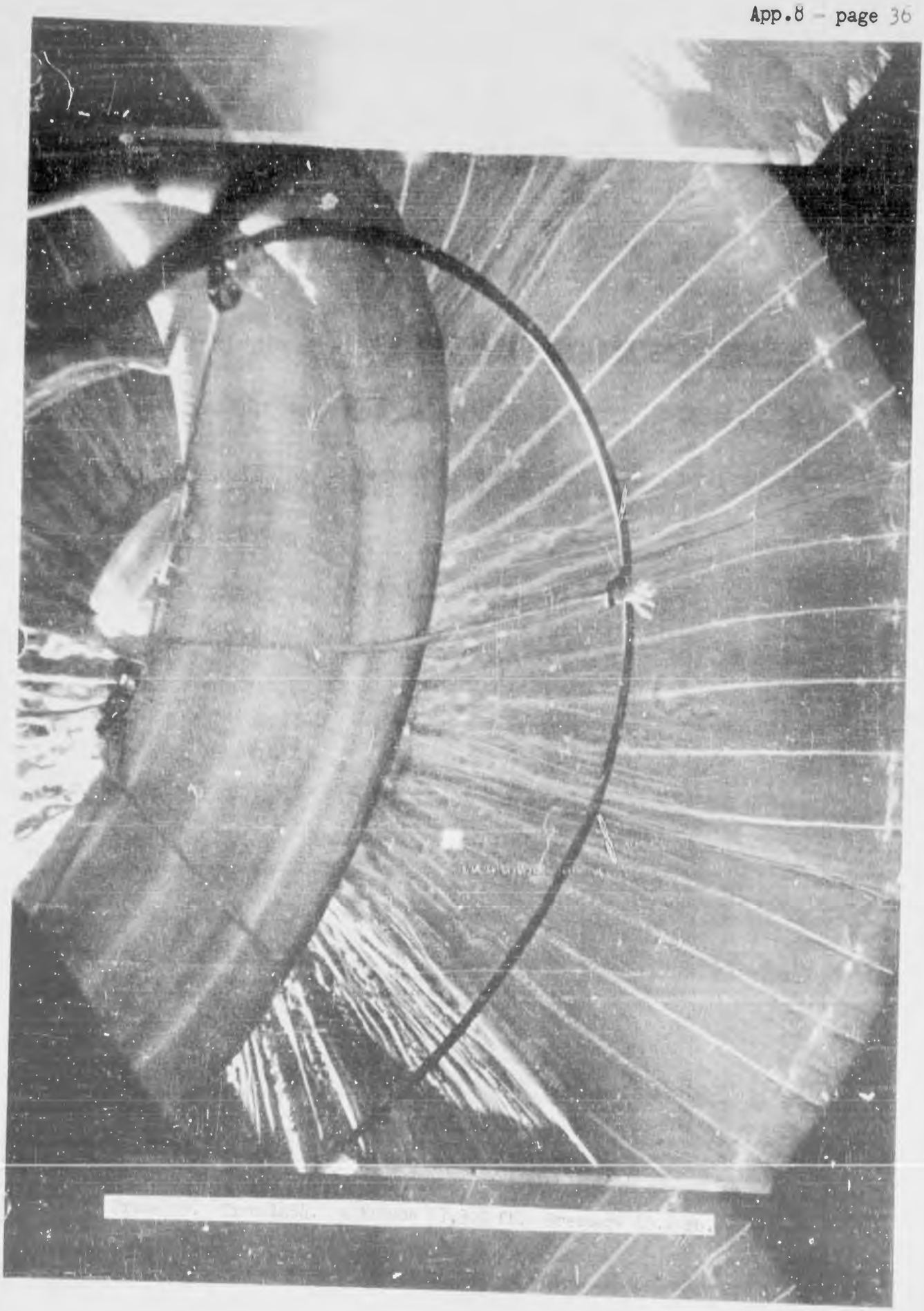


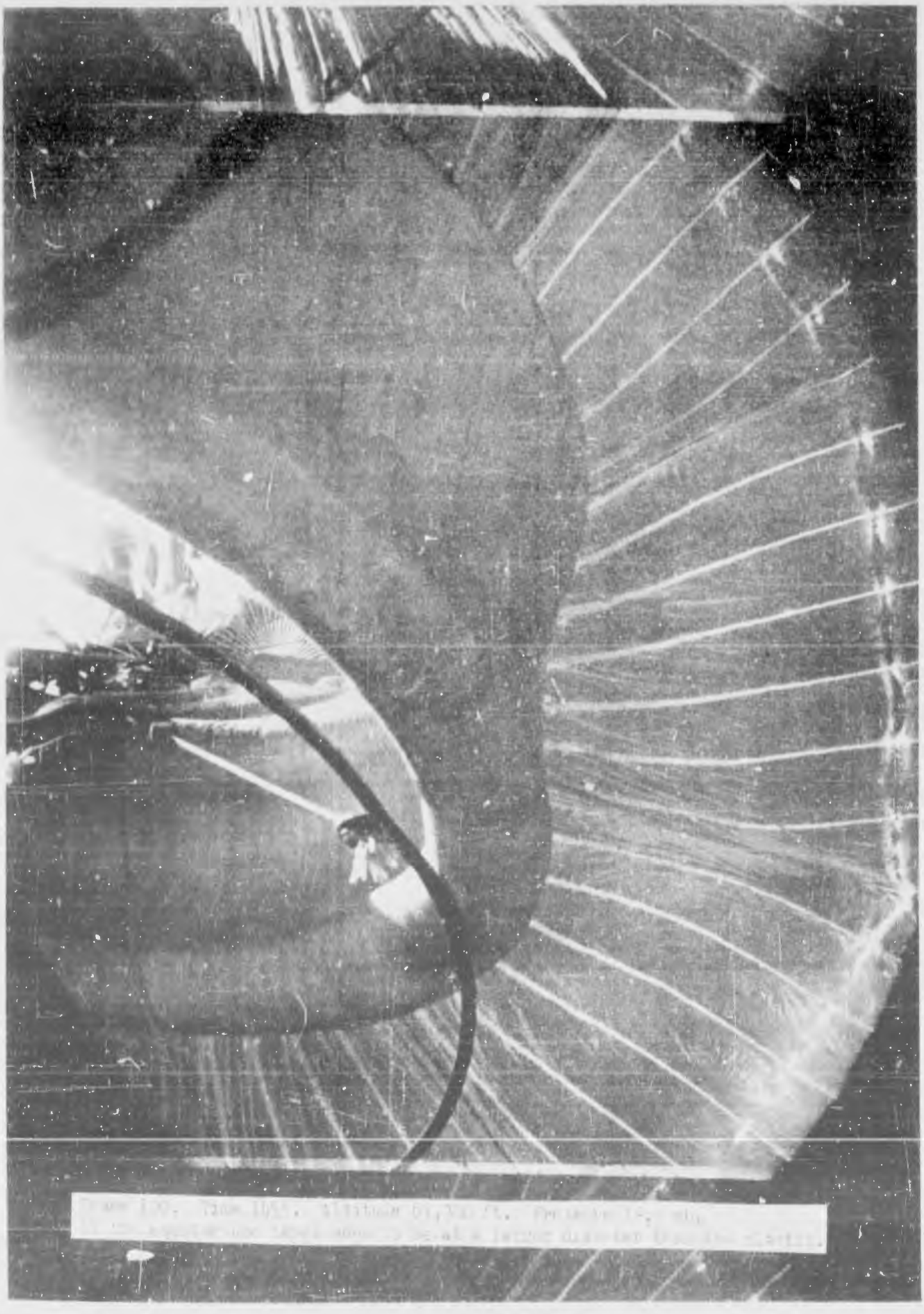


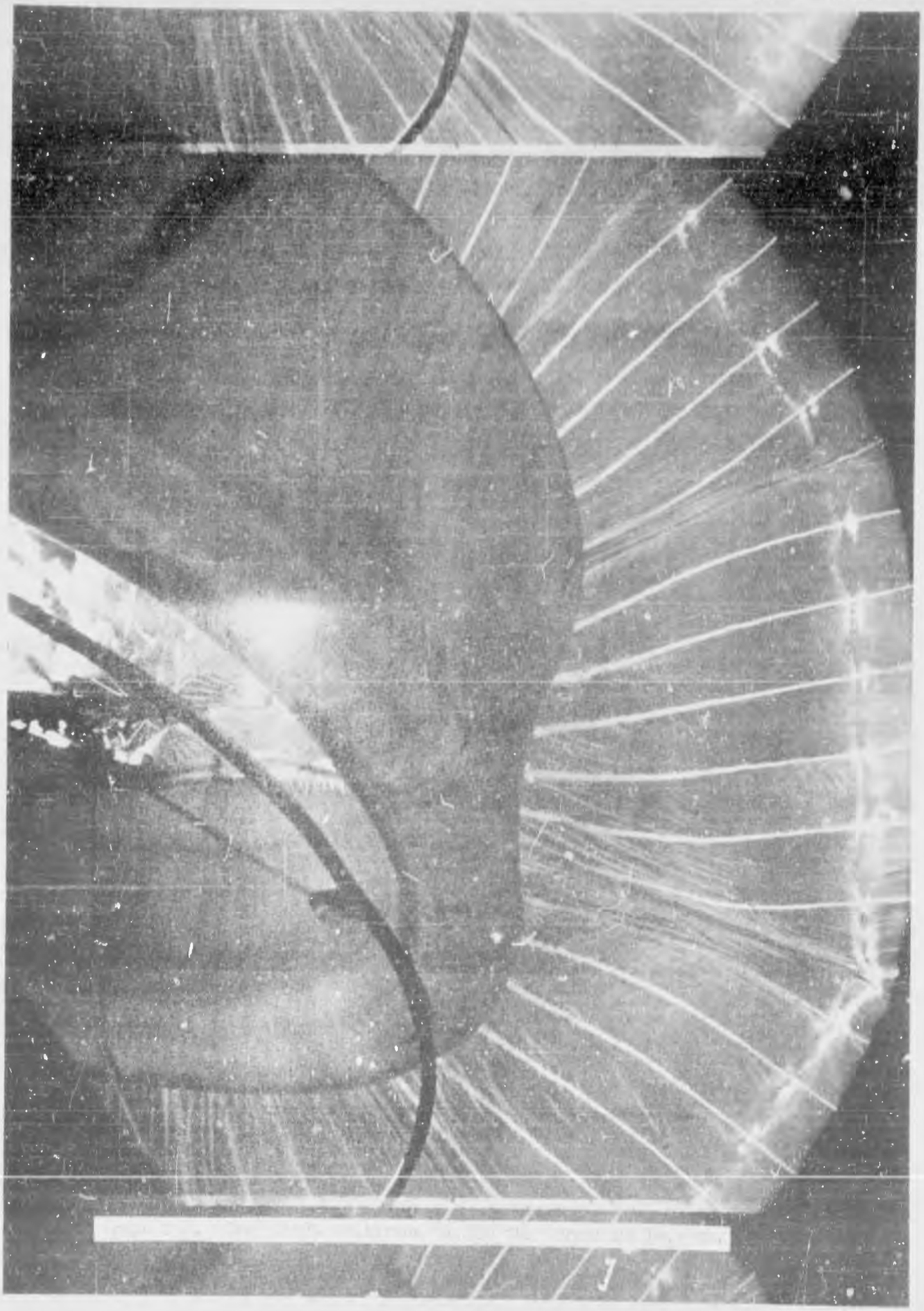


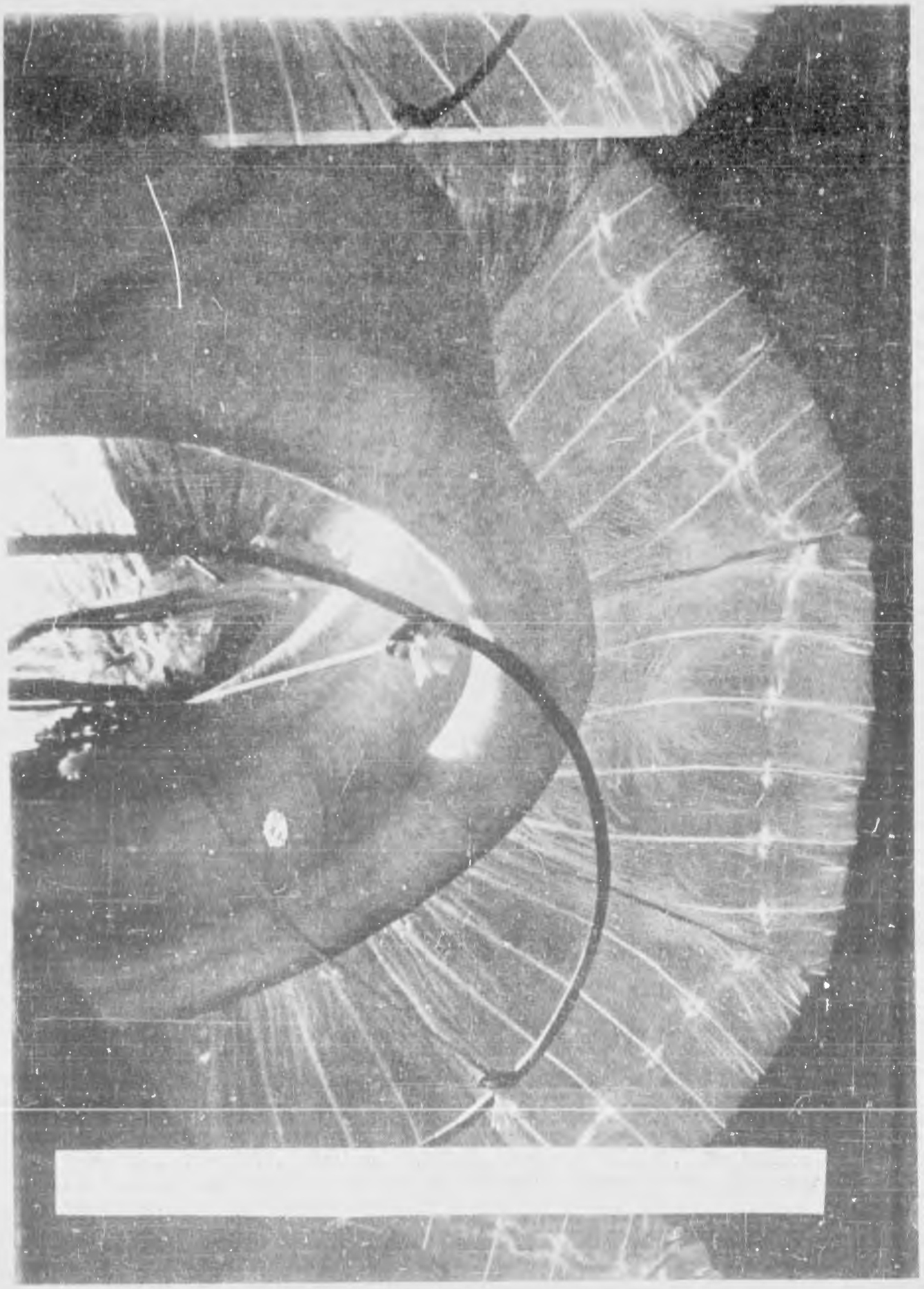












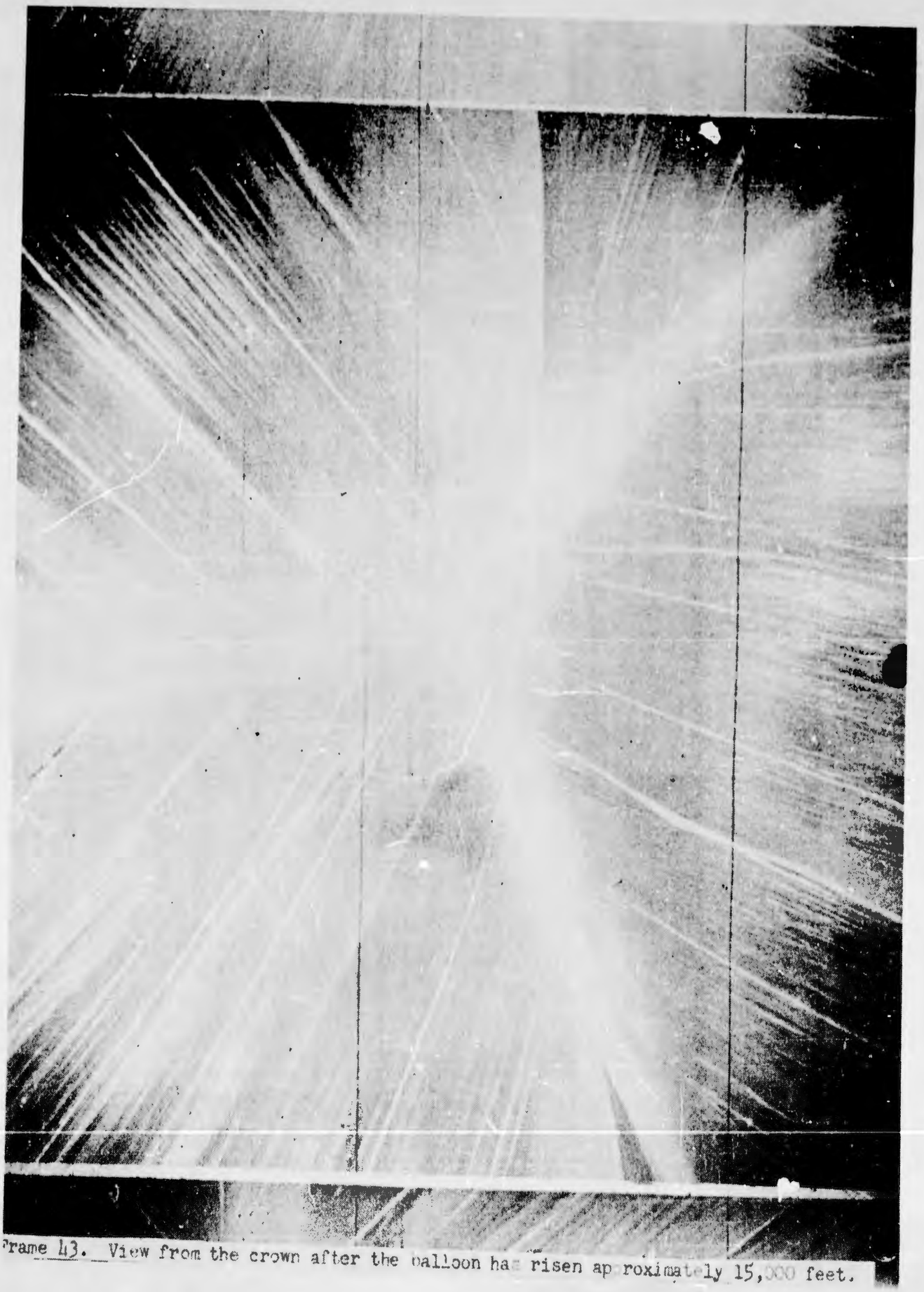
APPENDIX IX

CROWN PHOTOGRAPHS FROM FLIGHT 19

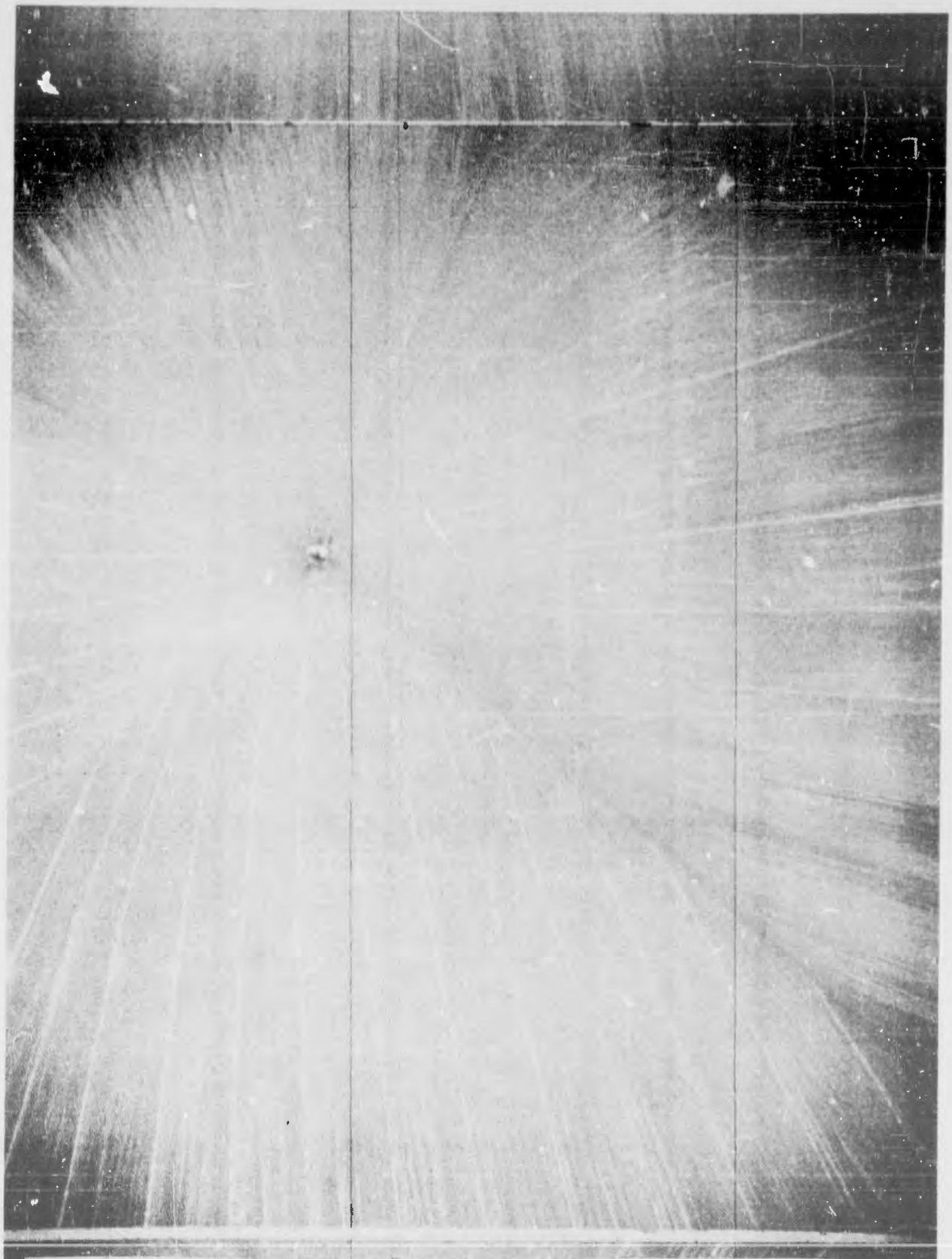
The following set of pictures was obtained with a camera suspended from the crown of the balloon in Flight 19. The complete set of pictures is available, but only a few are reproduced here to show the operation of the more or less conventional appendix during valving and to illustrate the appearance of the balloon as it slowly descends. Many of the pictures correspond to frames taken from the camera in the gondola in this same flight. For example, Frame No. 55 in this appendix corresponds to Frame No. 67 in Appendix 8.



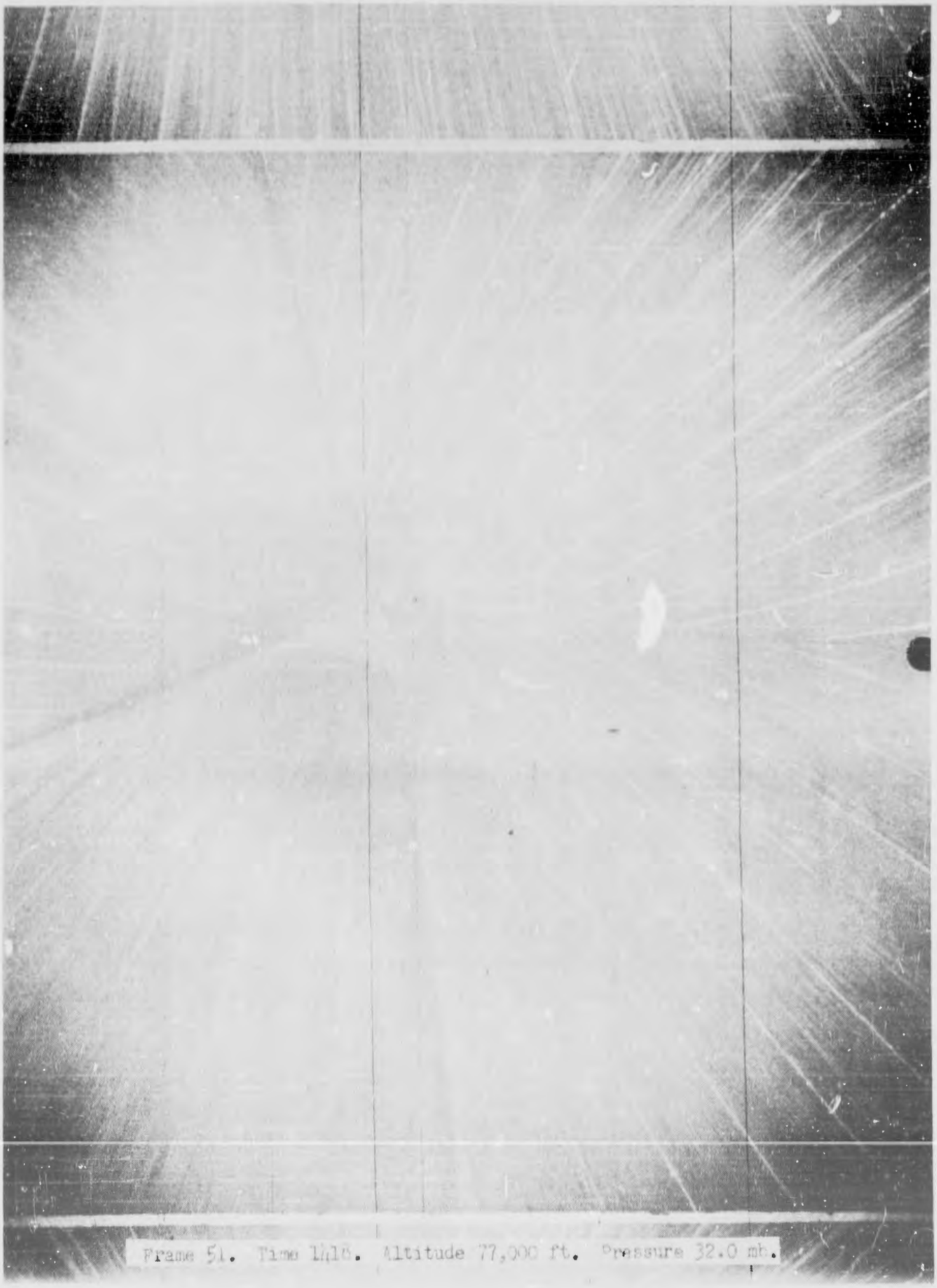
Frame 3. Altitude shortly after take off. This photograph taken from the crown of the balloon shows the regions of negative curvature which exist in an ascending balloon. It can be seen that the bottom of the balloon is very effectively sealed off



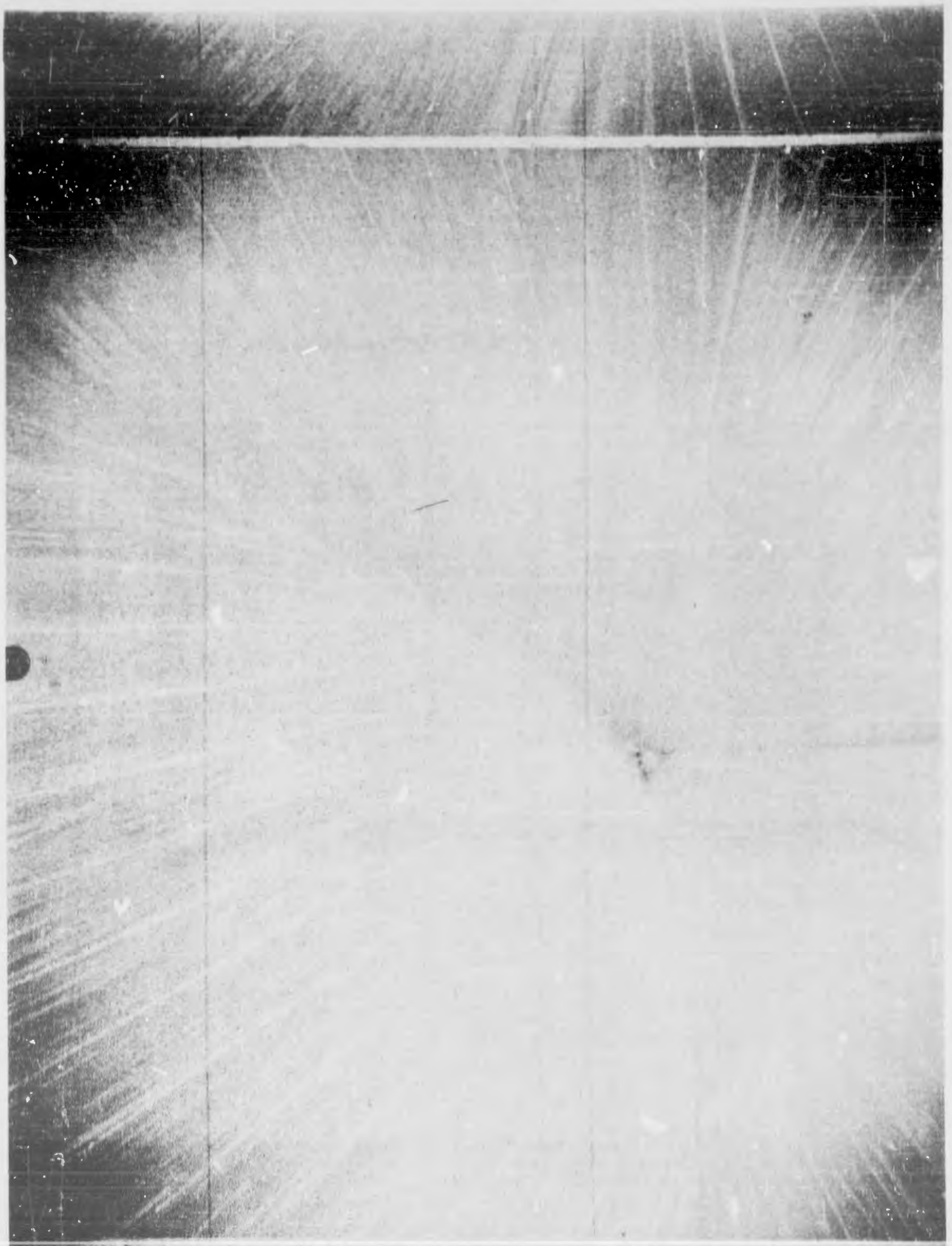
Frame 43. View from the crown after the balloon has risen approximately 15,000 feet.



Frame 50. Time 1417. Altitude 76,000 ft. Pressure 34.0 mb. The regions of negative curvature still exist and the balloon has not started to valve. Observe the strain lines in the polyethylene parallel to the tapes.



Frame 51. Time 1h18. Altitude 77,000 ft. Pressure 32.0 mb.



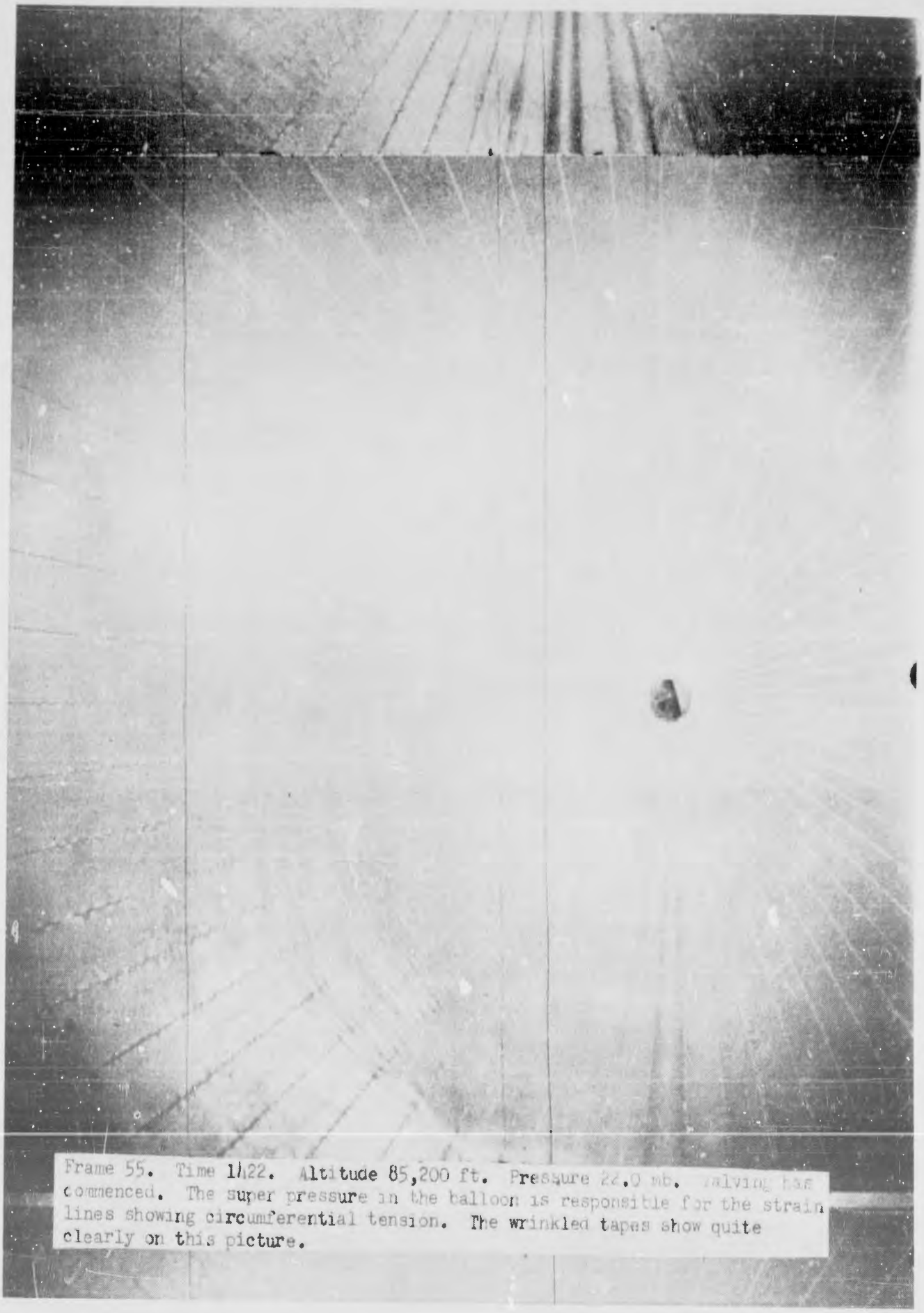
Frame 52. Time 1119. Altitude 79,300 ft. Pressure 29.0 mb. Definite sheets of polyethylene are still visible where negative curvature exists. The appendix is sucked tight against the load ropes.



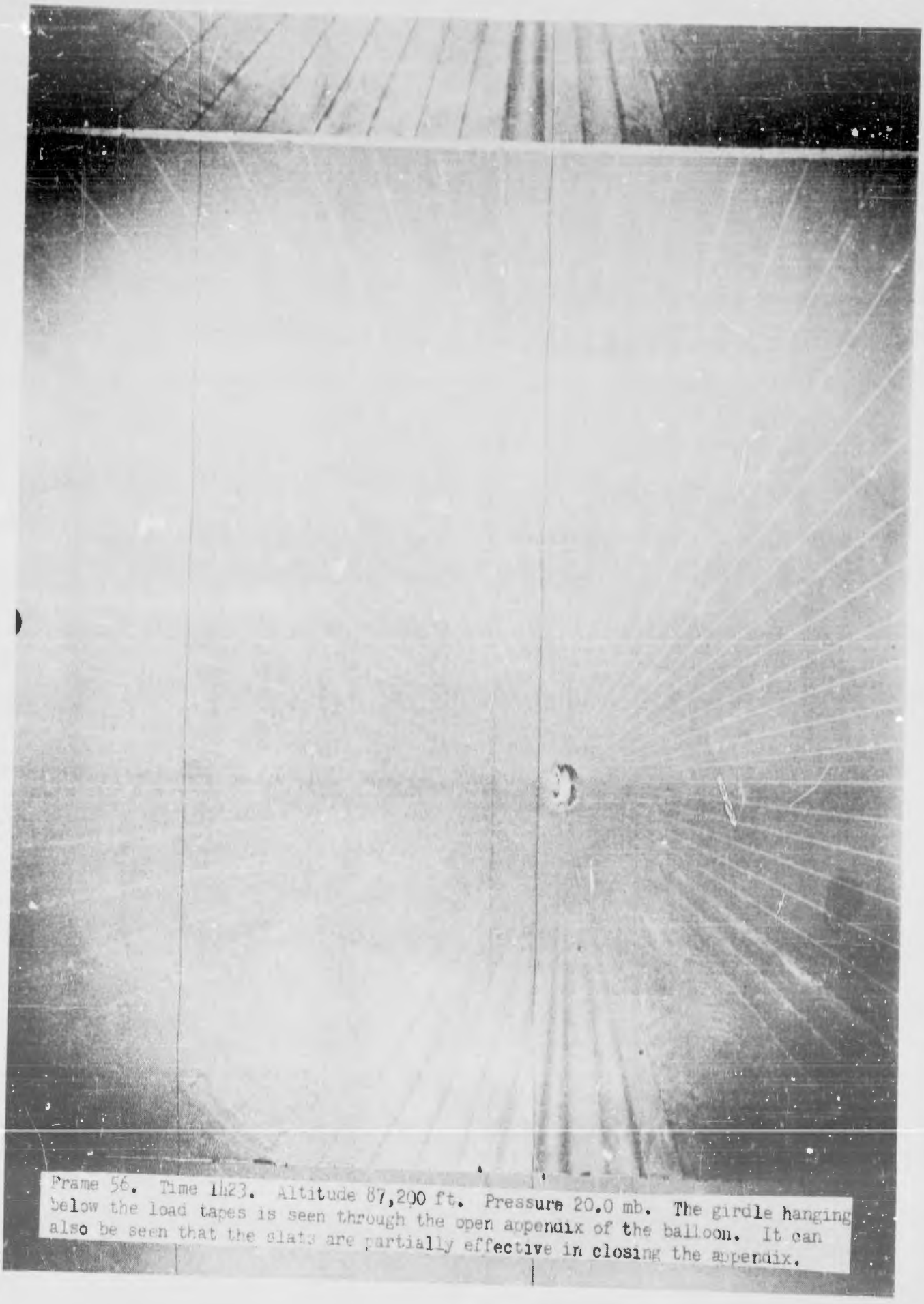
Frame 53. Time 1:20. Altitude 61,300 ft. Pressure 26.5 mb. The negative curvature regions begin to disappear and the appendix is tightly closed.



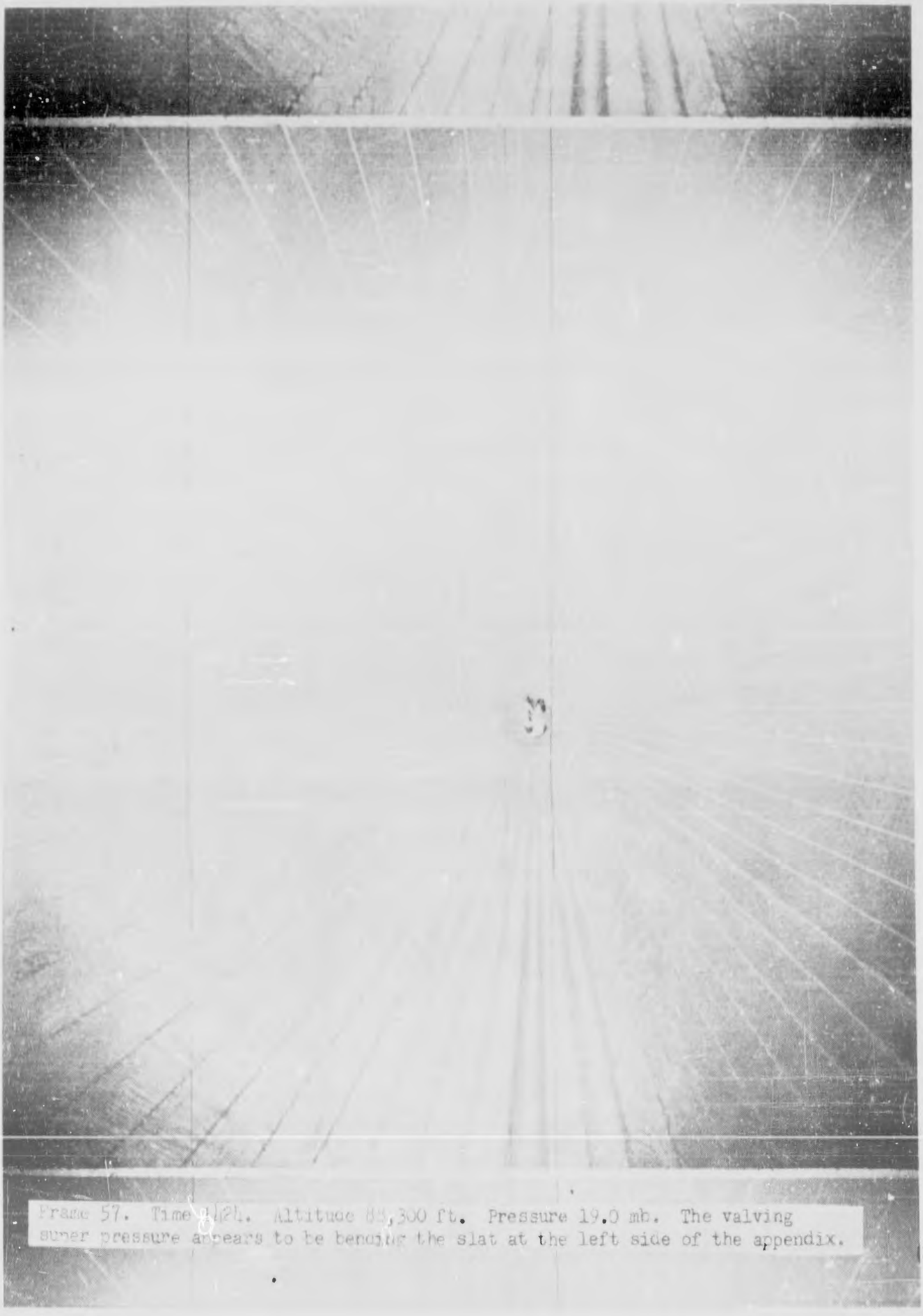
Frame 54. Time 1h21. Altitude 53,400 ft. Pressure 24.0 mb. The negative curvature regions have disappeared and the conical portion of the balloon is almost filled. A region of stress concentration is visible in the lower left.



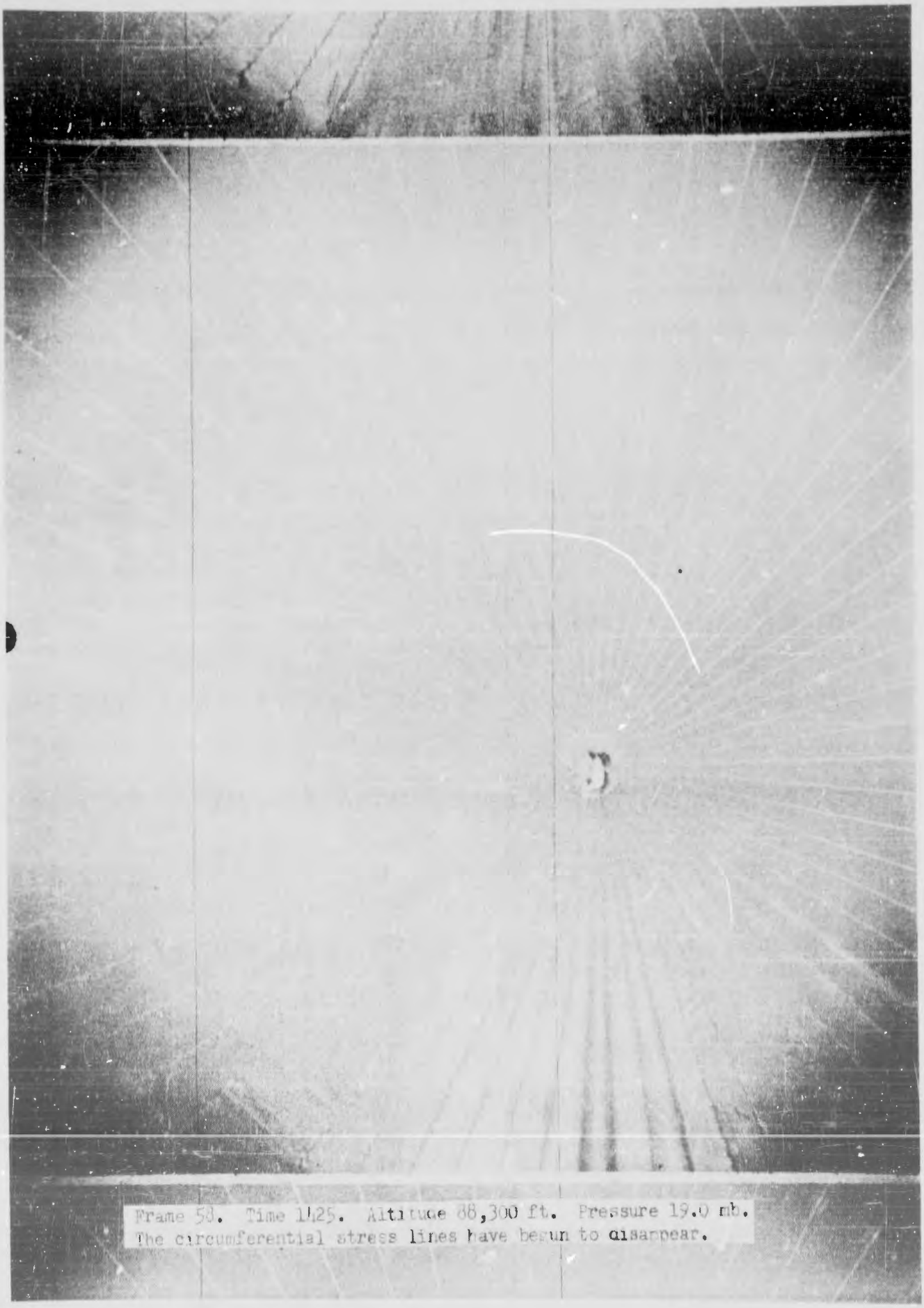
Frame 55. Time 1h22. Altitude 85,200 ft. Pressure 22.0 mb. Valving has commenced. The super pressure in the balloon is responsible for the strain lines showing circumferential tension. The wrinkled tapes show quite clearly on this picture.



Frame 56. Time 1423. Altitude 87,200 ft. Pressure 20.0 mb. The girdle hanging below the load tapes is seen through the open appendix of the balloon. It can also be seen that the slats are partially effective in closing the appendix.



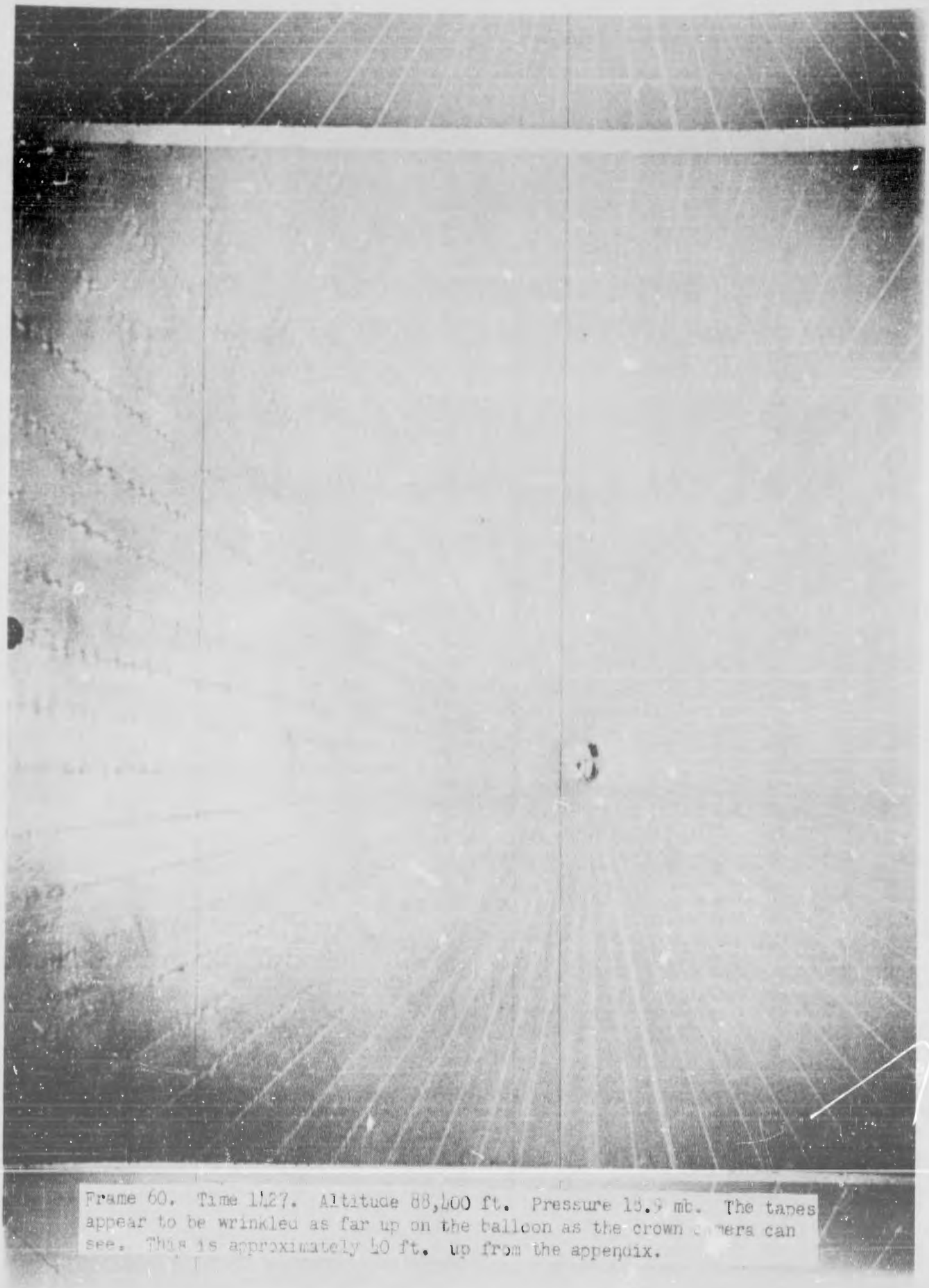
Frame 57. Time 0424. Altitude 85,300 ft. Pressure 19.0 mb. The valving super pressure appears to be bending the slat at the left side of the appendix.



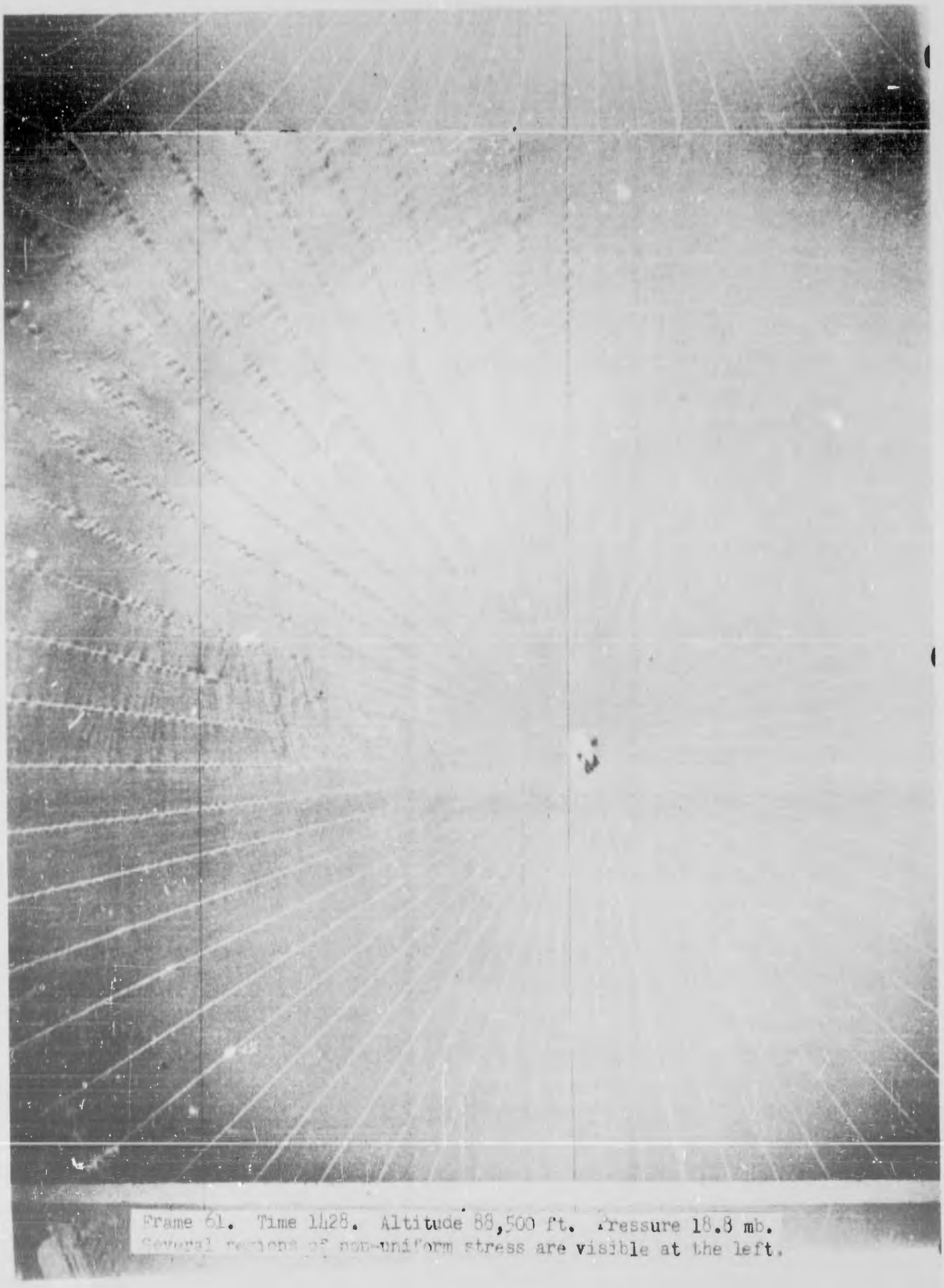
Frame 58. Time 1425. Altitude 88,300 ft. Pressure 19.0 mb.
The circumferential stress lines have begun to disappear.



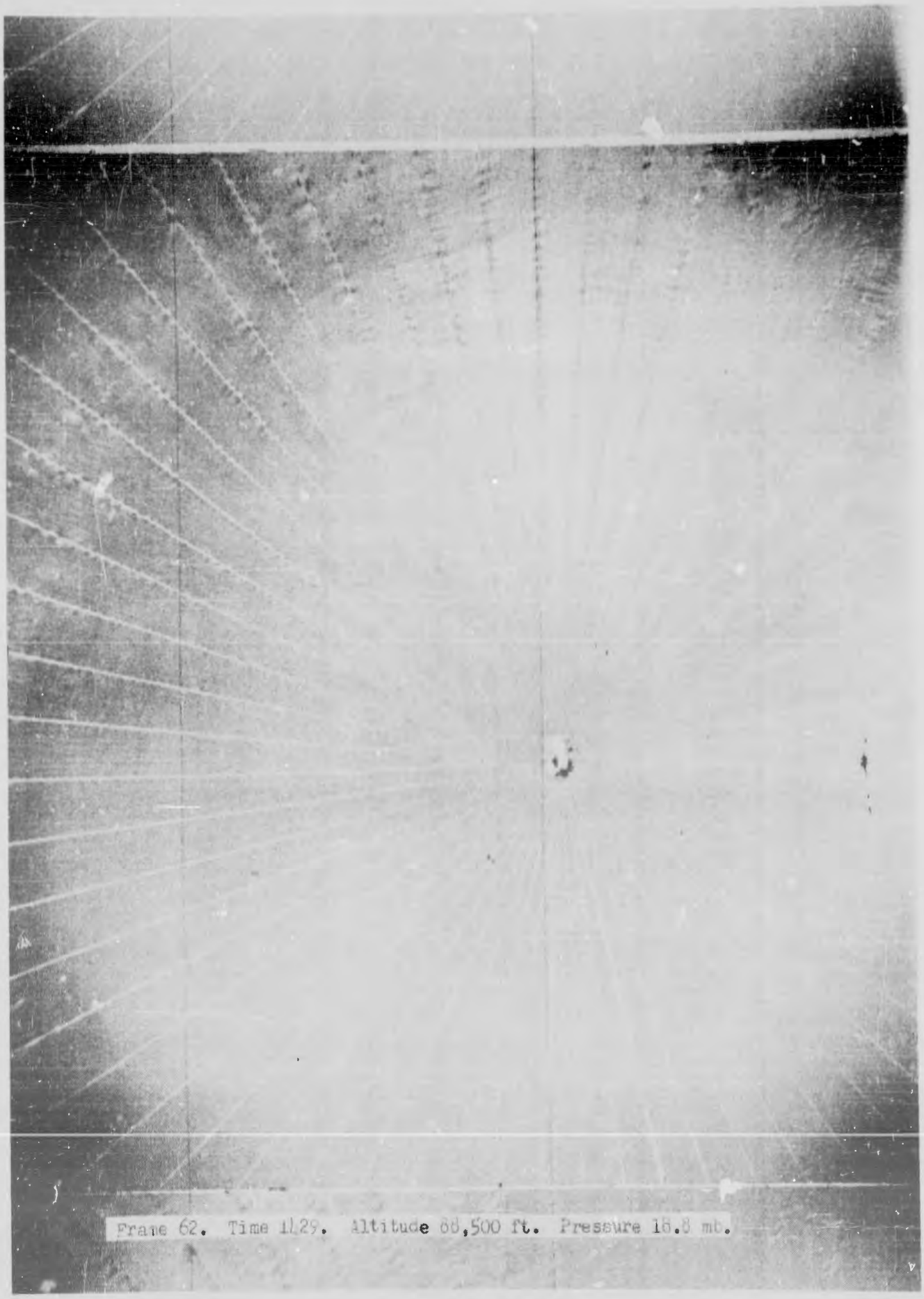
Frame 59. Time 1426. Altitude 88,300 ft. Pressure 19.0 mb.



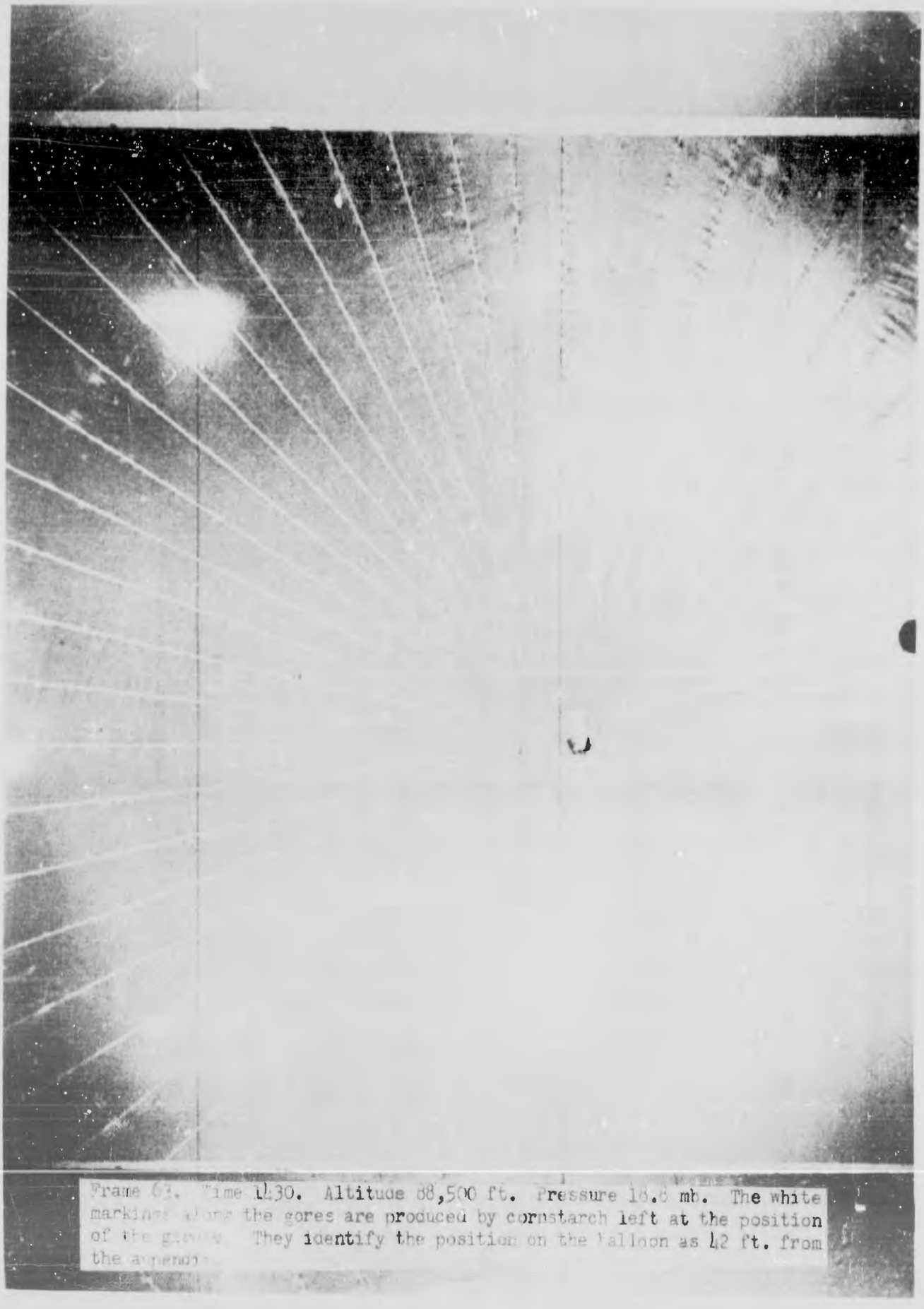
Frame 60. Time 1427. Altitude 88,600 ft. Pressure 15.9 mb. The tapes appear to be wrinkled as far up on the balloon as the crown cameras can see. This is approximately 40 ft. up from the appendix.



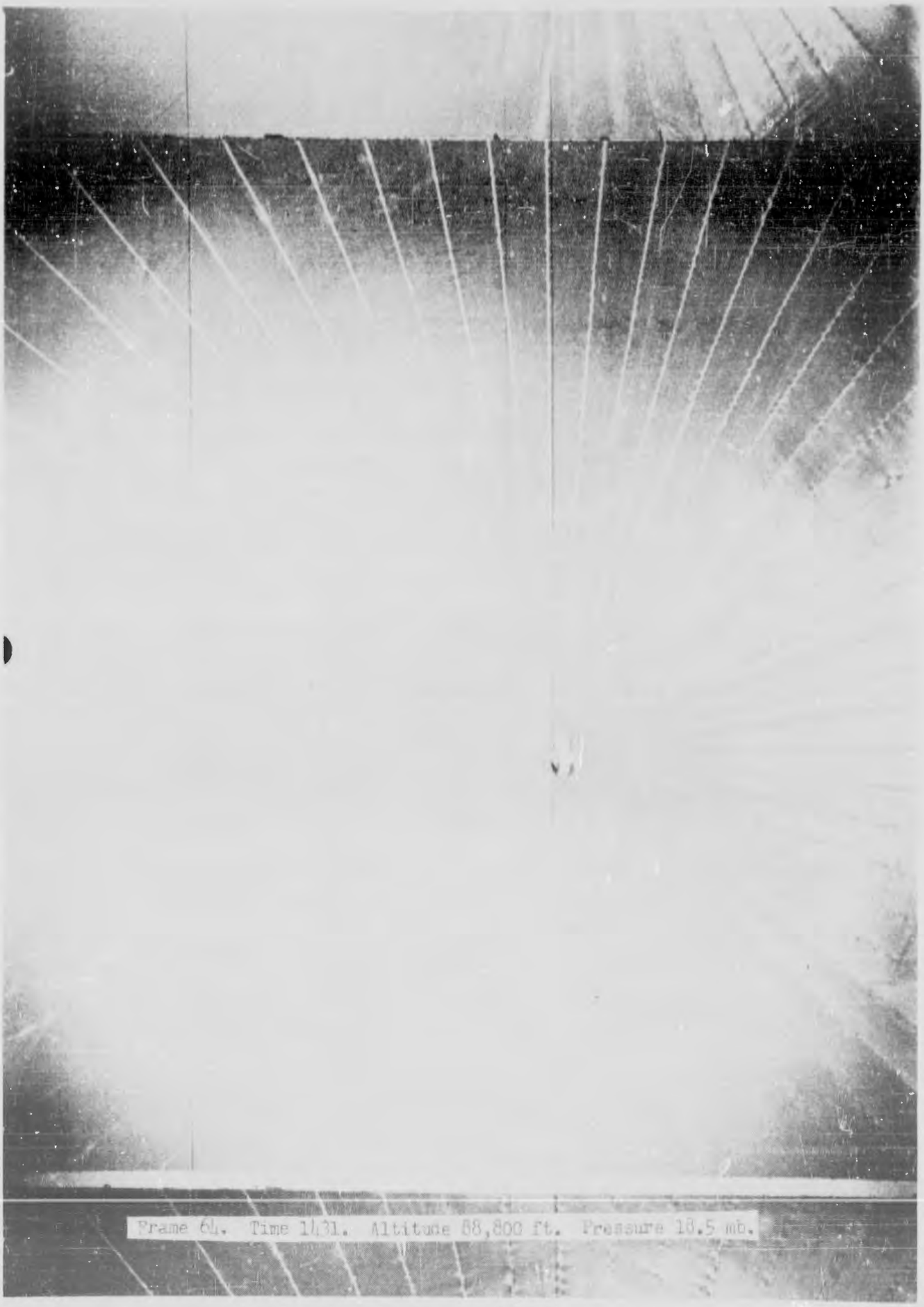
Frame 61. Time 1428. Altitude 88,500 ft. Pressure 18.8 mb.
General regions of non-uniform stress are visible at the left.



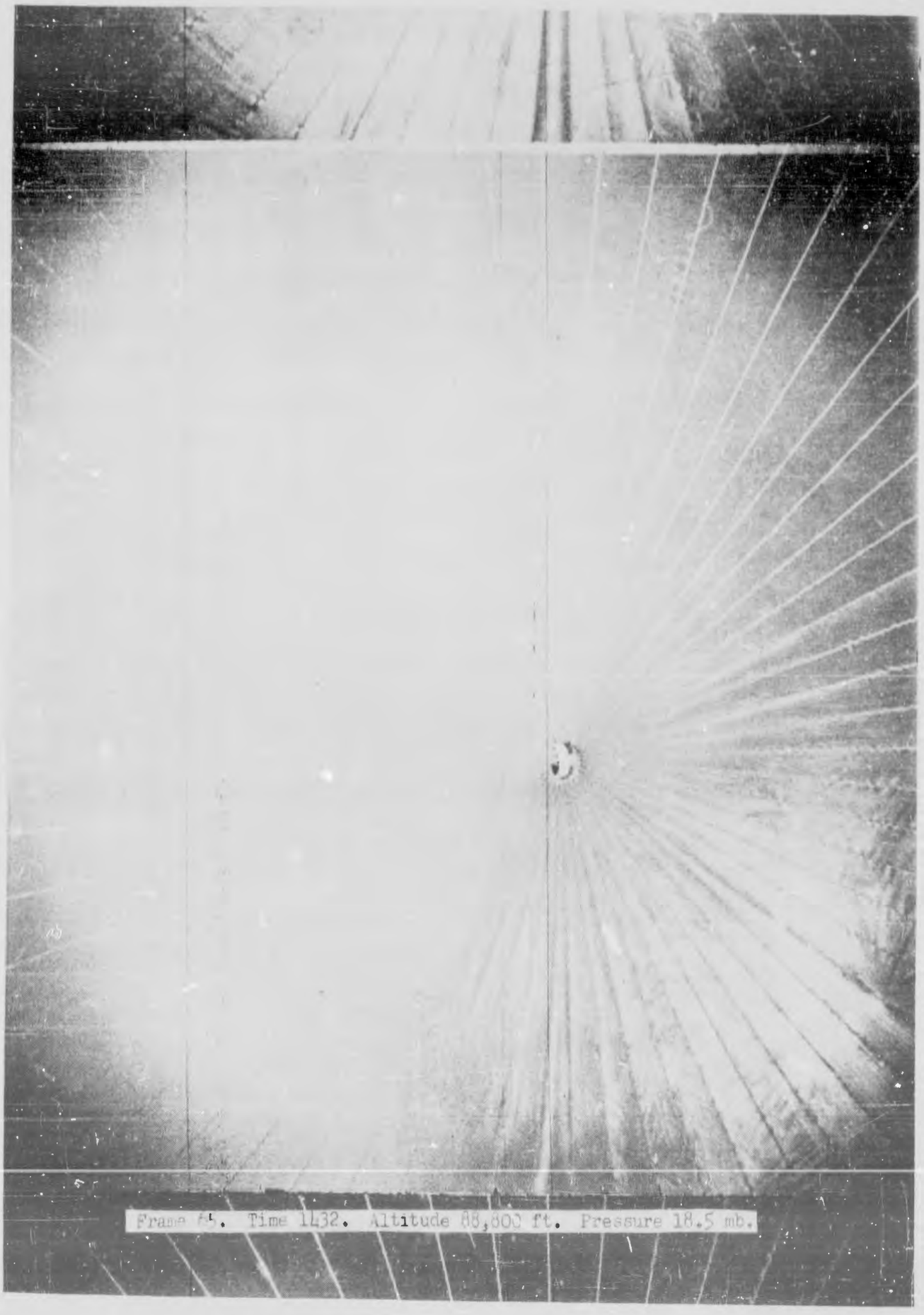
Frame 62. Time 1129. Altitude 88,500 ft. Pressure 16.8 mb.



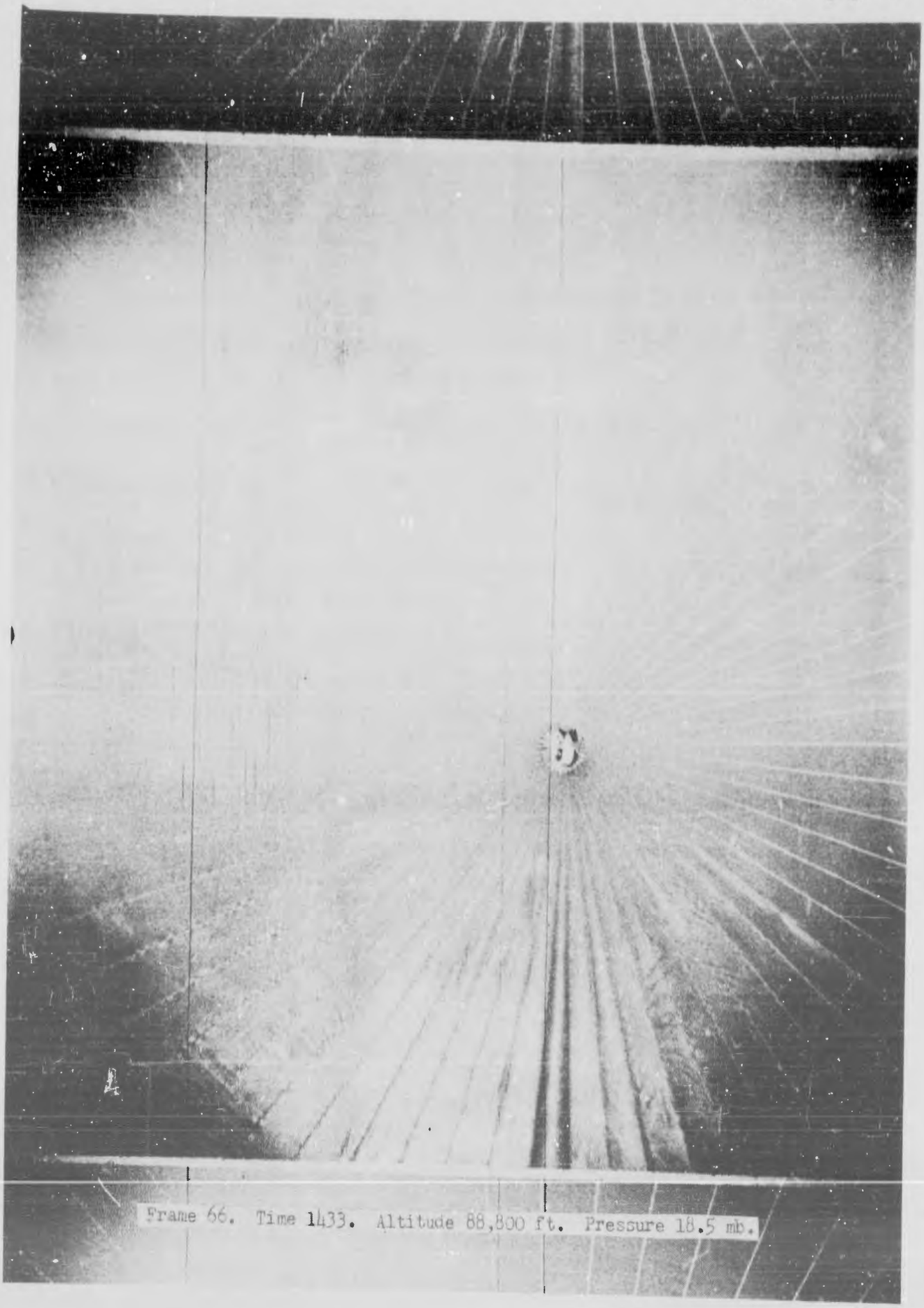
Frame 63. Time 1430. Altitude 88,500 ft. Pressure 16.6 mb. The white markings along the gores are produced by cornstarch left at the position of the gores. They identify the position on the balloon as 42 ft. from the apex.



Frame 64. Time 1431. Altitude 88,800 ft. Pressure 18.5 mb.



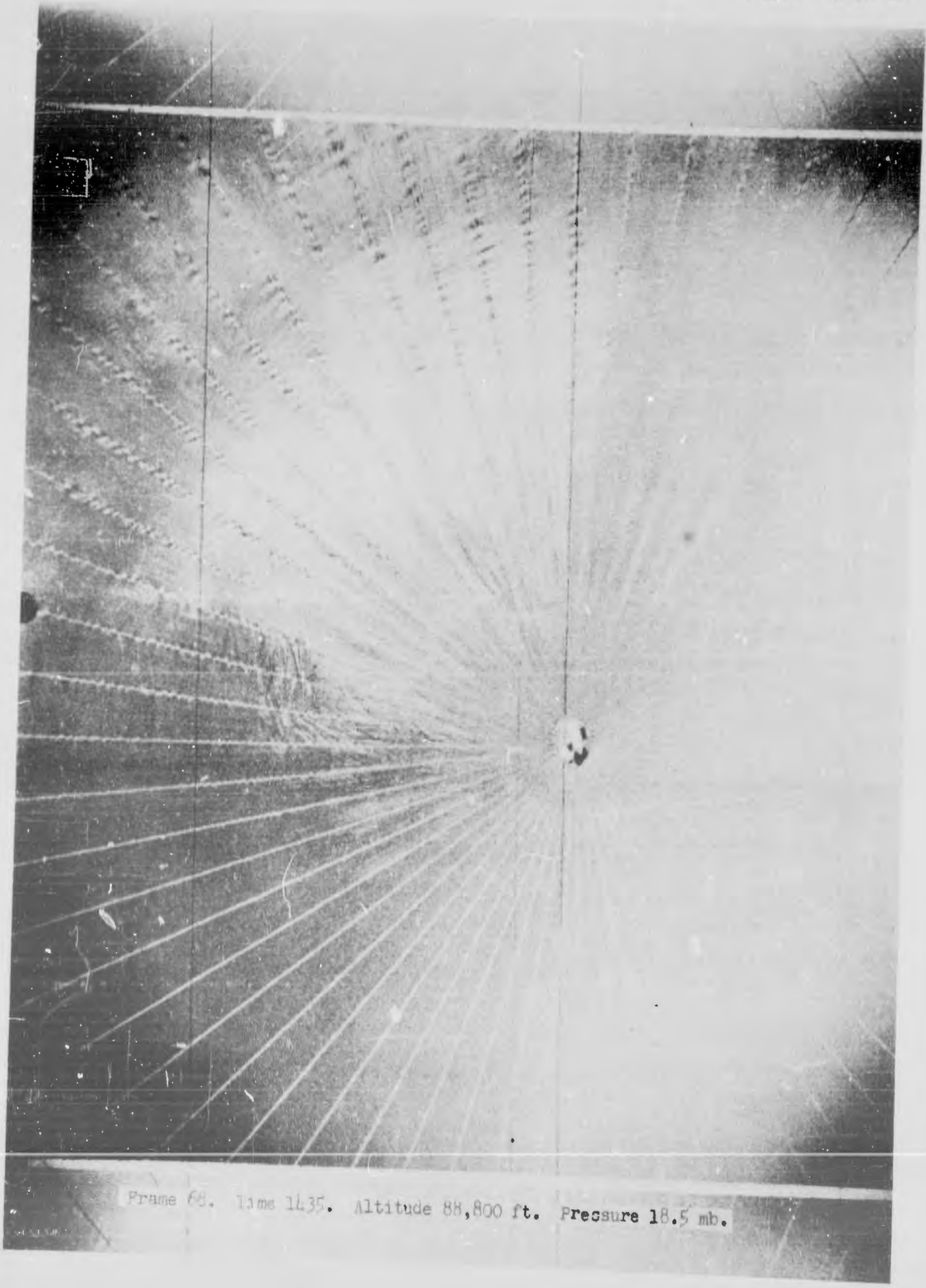
Frame 61. Time 1432. Altitude 88,800 ft. Pressure 18.5 mb.



Frame 66. Time 1433. Altitude 88,800 ft. Pressure 18.5 mb.



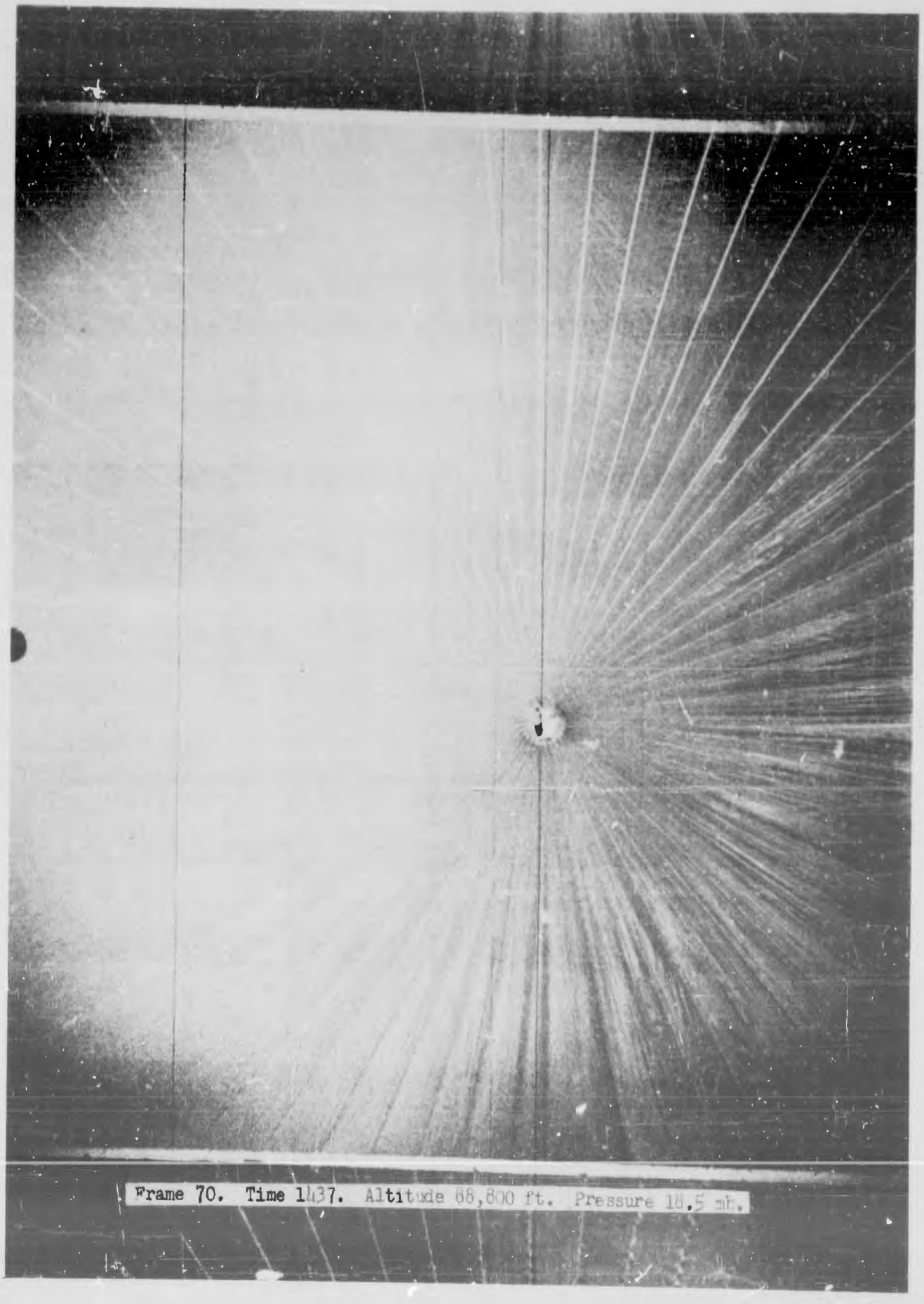
Frame 67. Time 1434. Altitude 86,800 ft. Pressure 18.5 mb.



Frame 68. Time 1435. Altitude 88,800 ft. Pressure 18.5 mb.



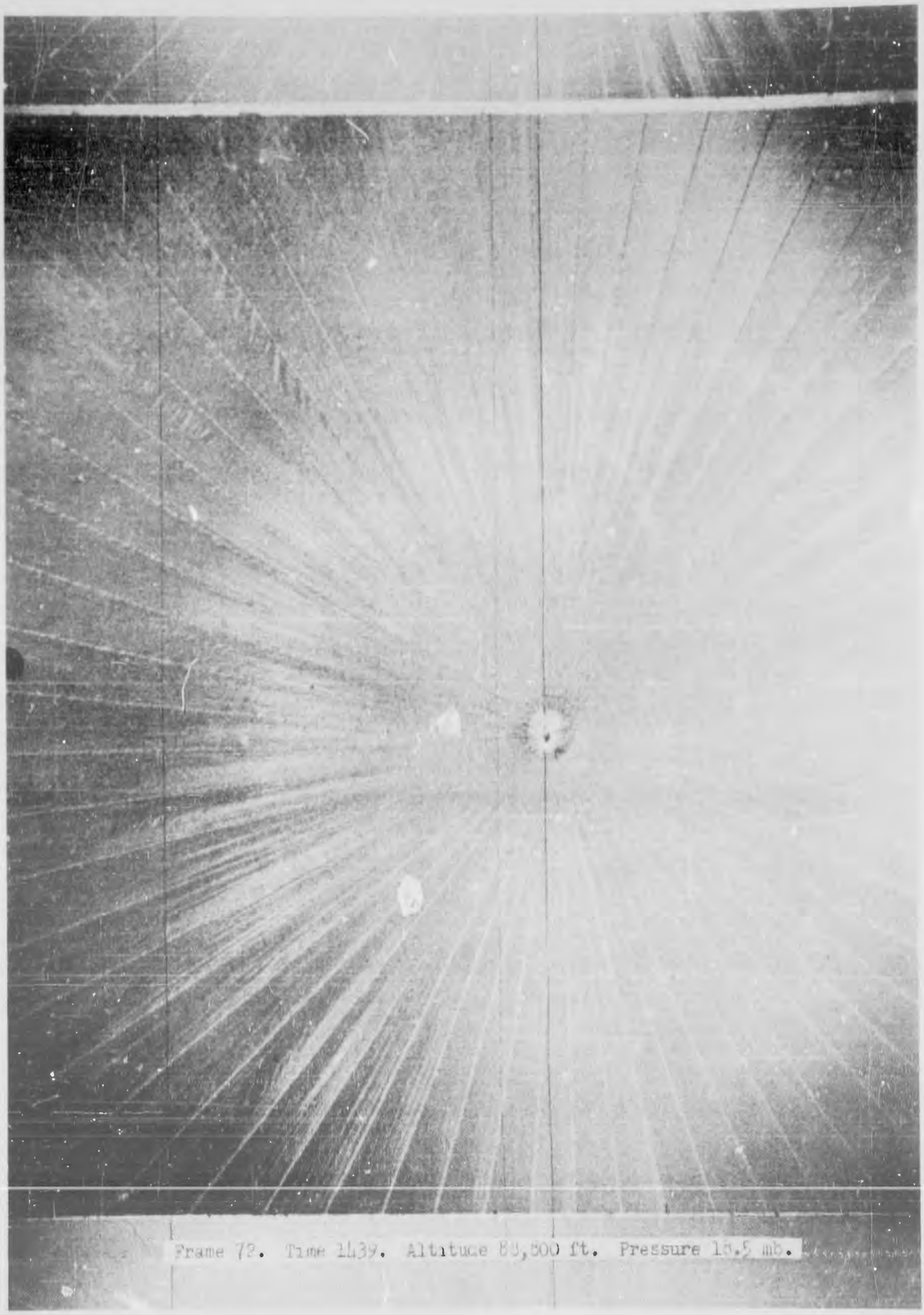
Frame 69. Time 1436. Altitude 88,800 ft. Pressure 15.5 mb.



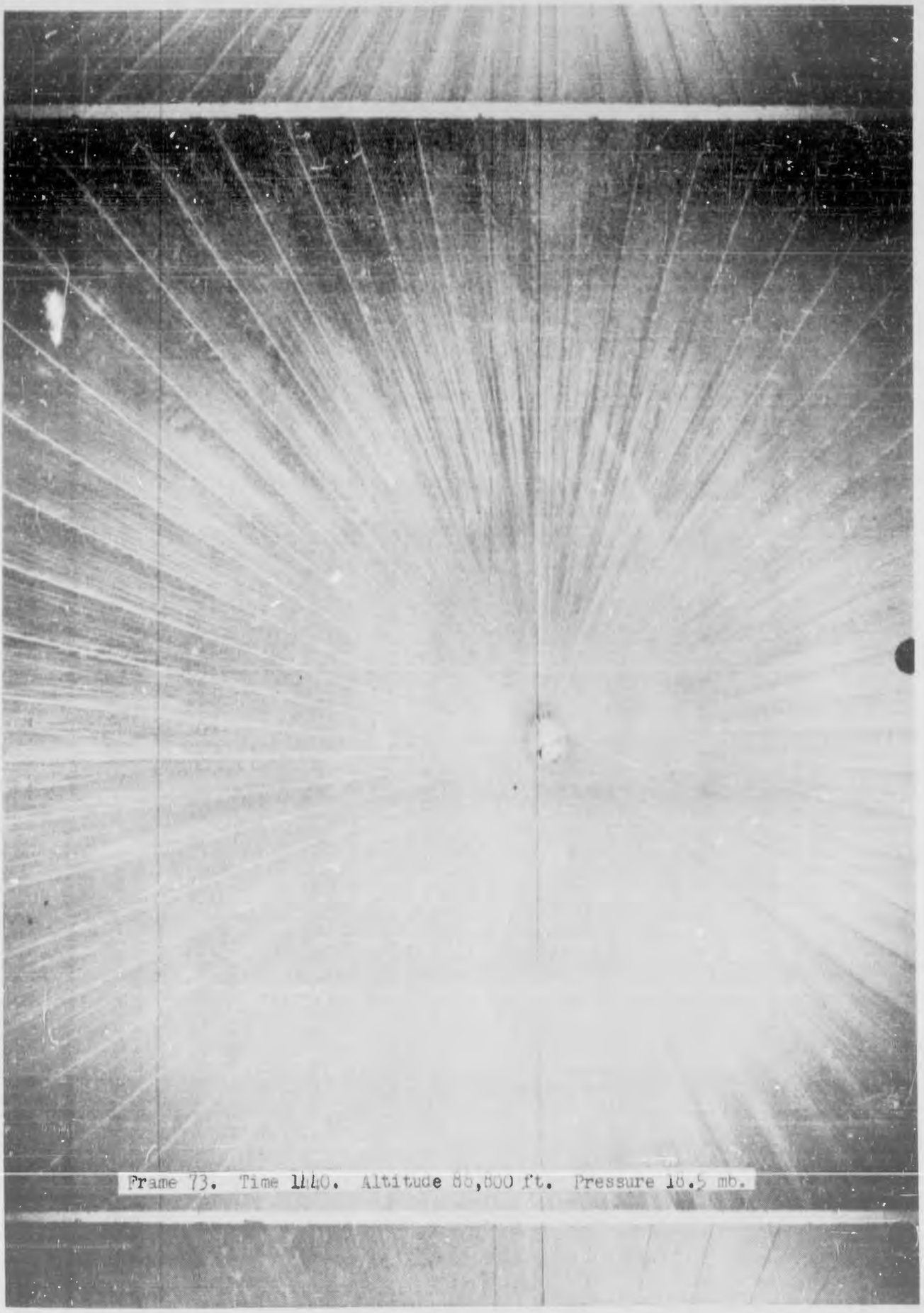
Frame 70. Time 1437. Altitude 88,800 ft. Pressure 18.5 mb.



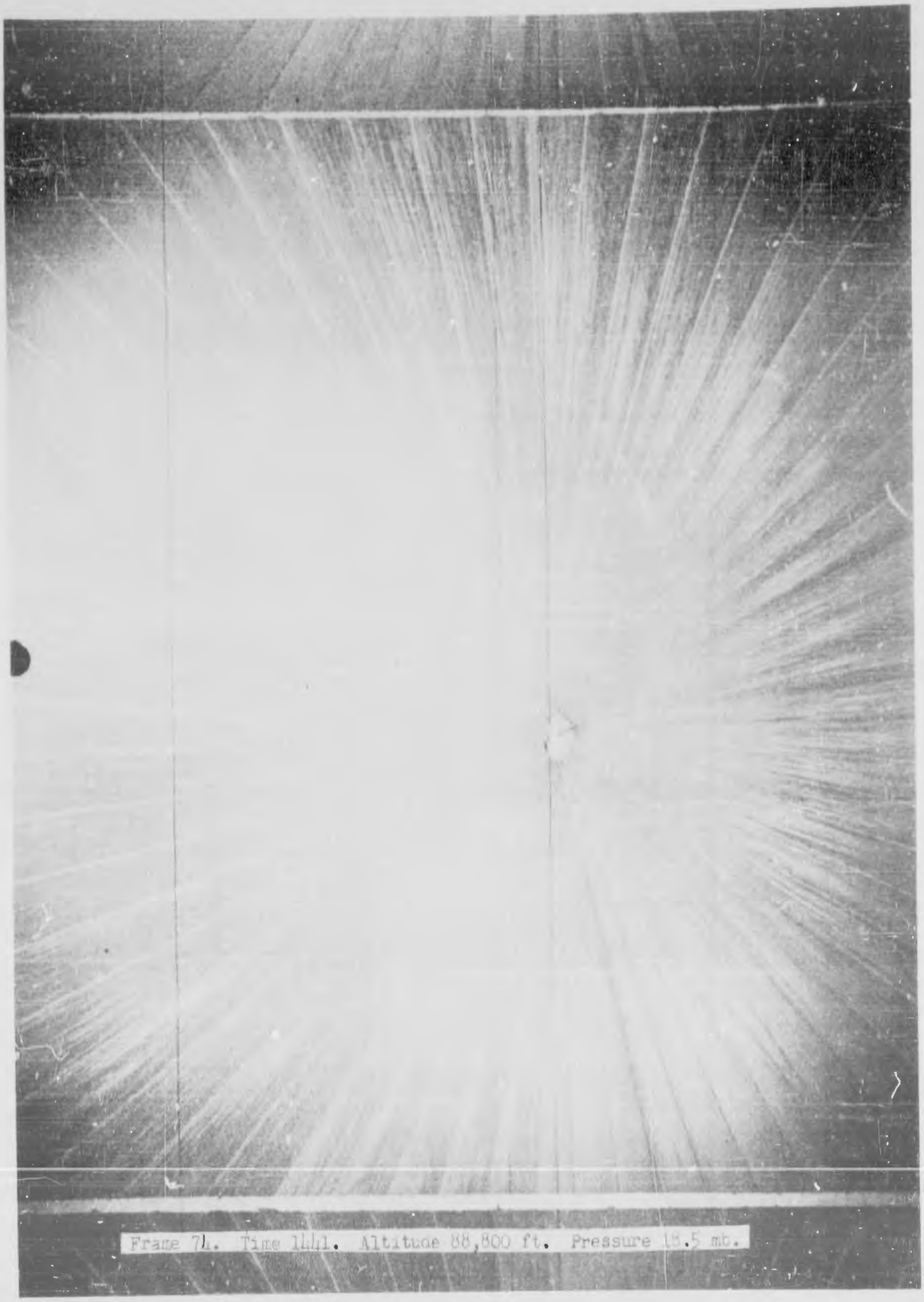
Frame 71. Time 1A:30. Altitude 50,800 ft. Pressure 10.5 mb. The appendix has definitely closed and the gores appear to be slack at the bottom.



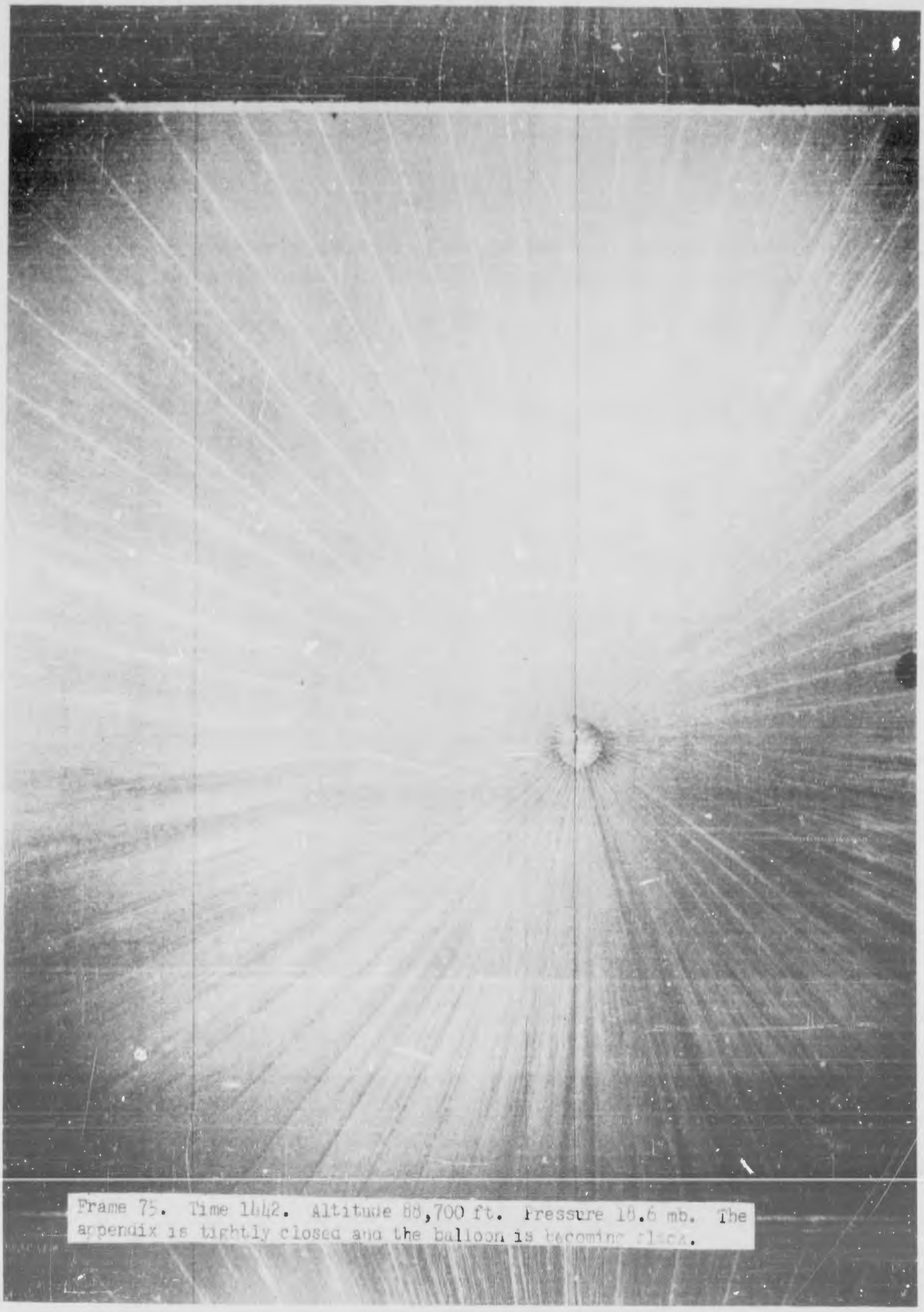
Frame 72. Time 1439. Altitude 80,800 ft. Pressure 16.5 mb.



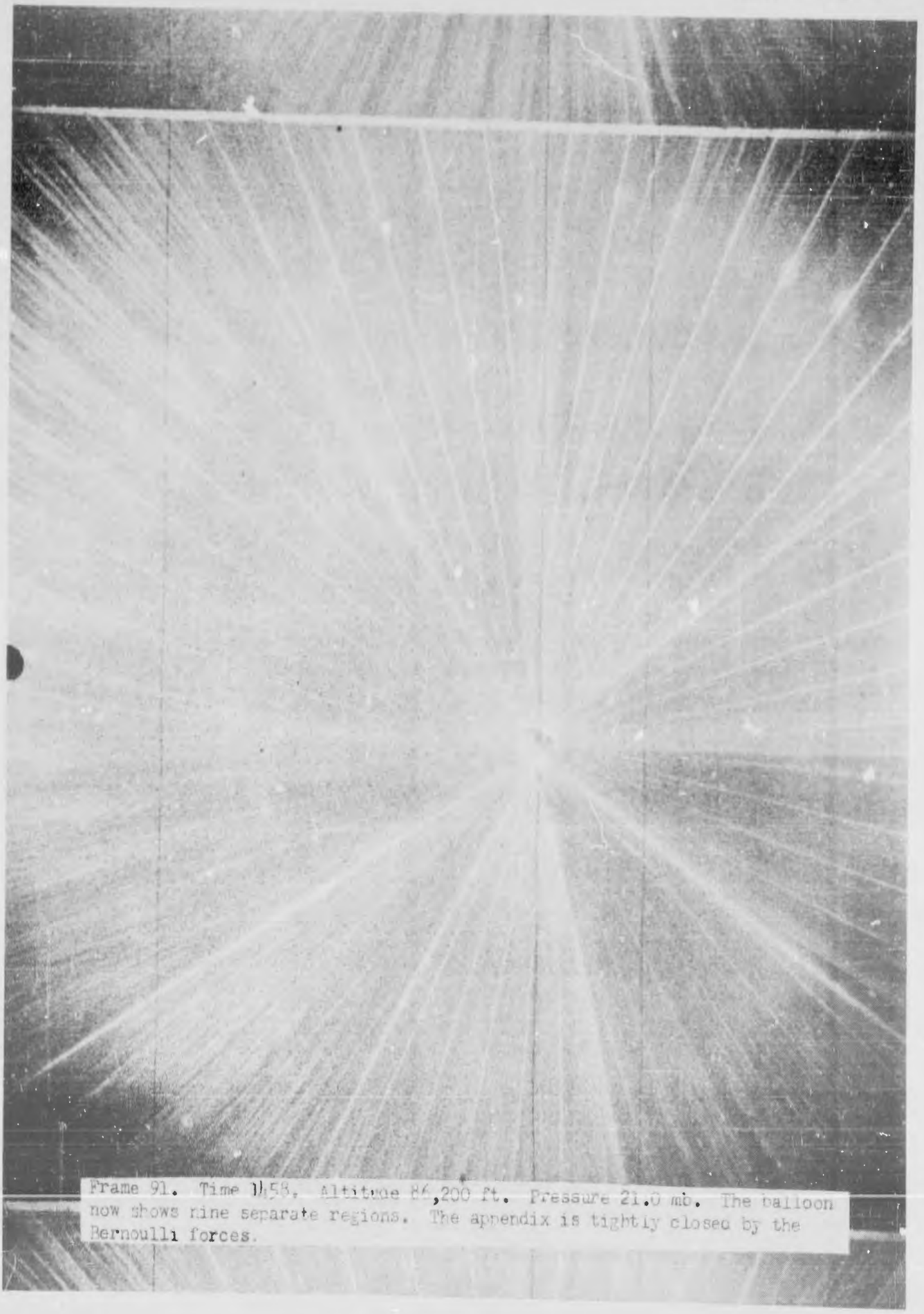
Frame 73. Time 1440. Altitude 80,800 ft. Pressure 16.5 mb.



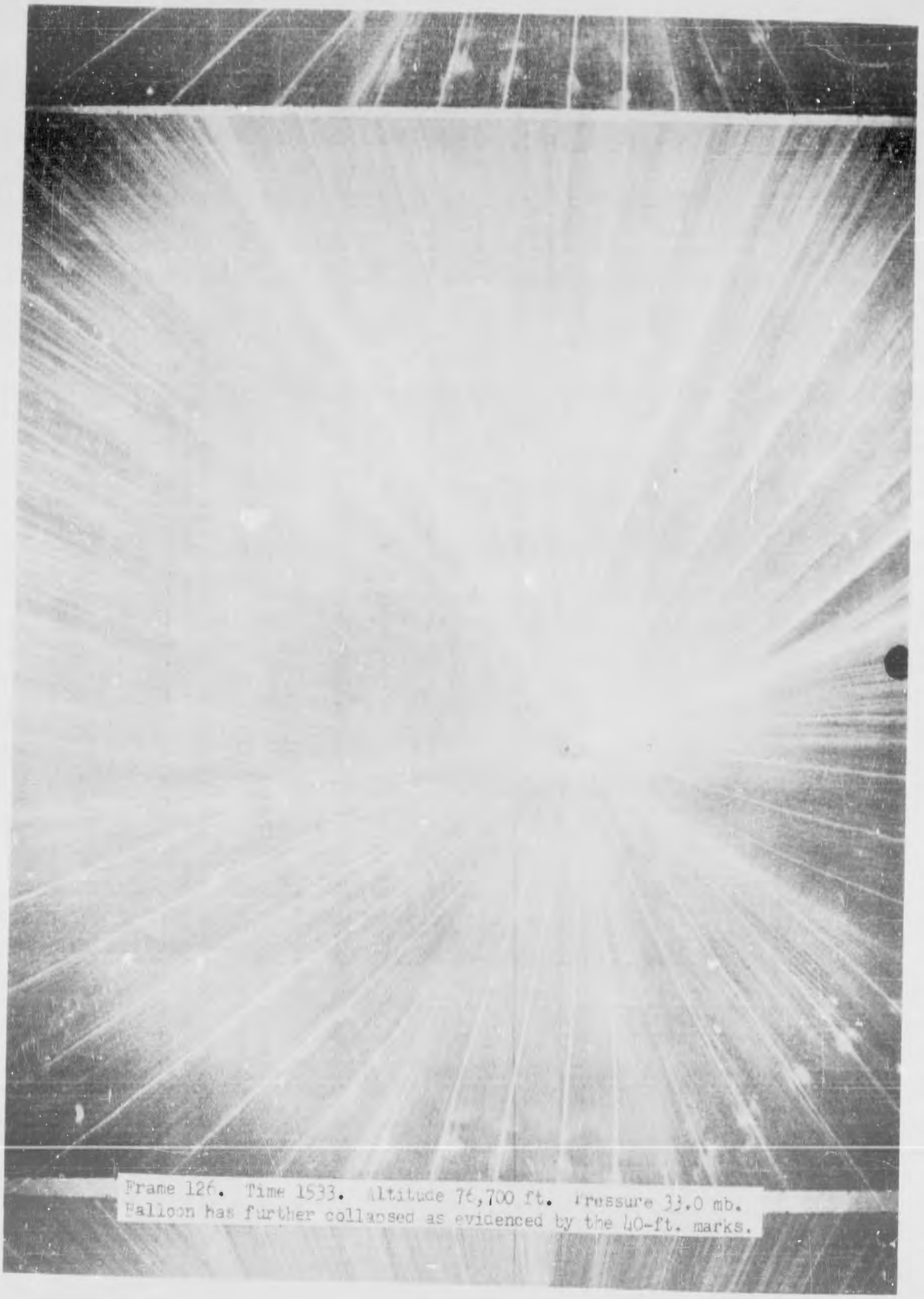
Frame 74. Time 1141. Altitude 88,800 ft. Pressure 15.5 mb.



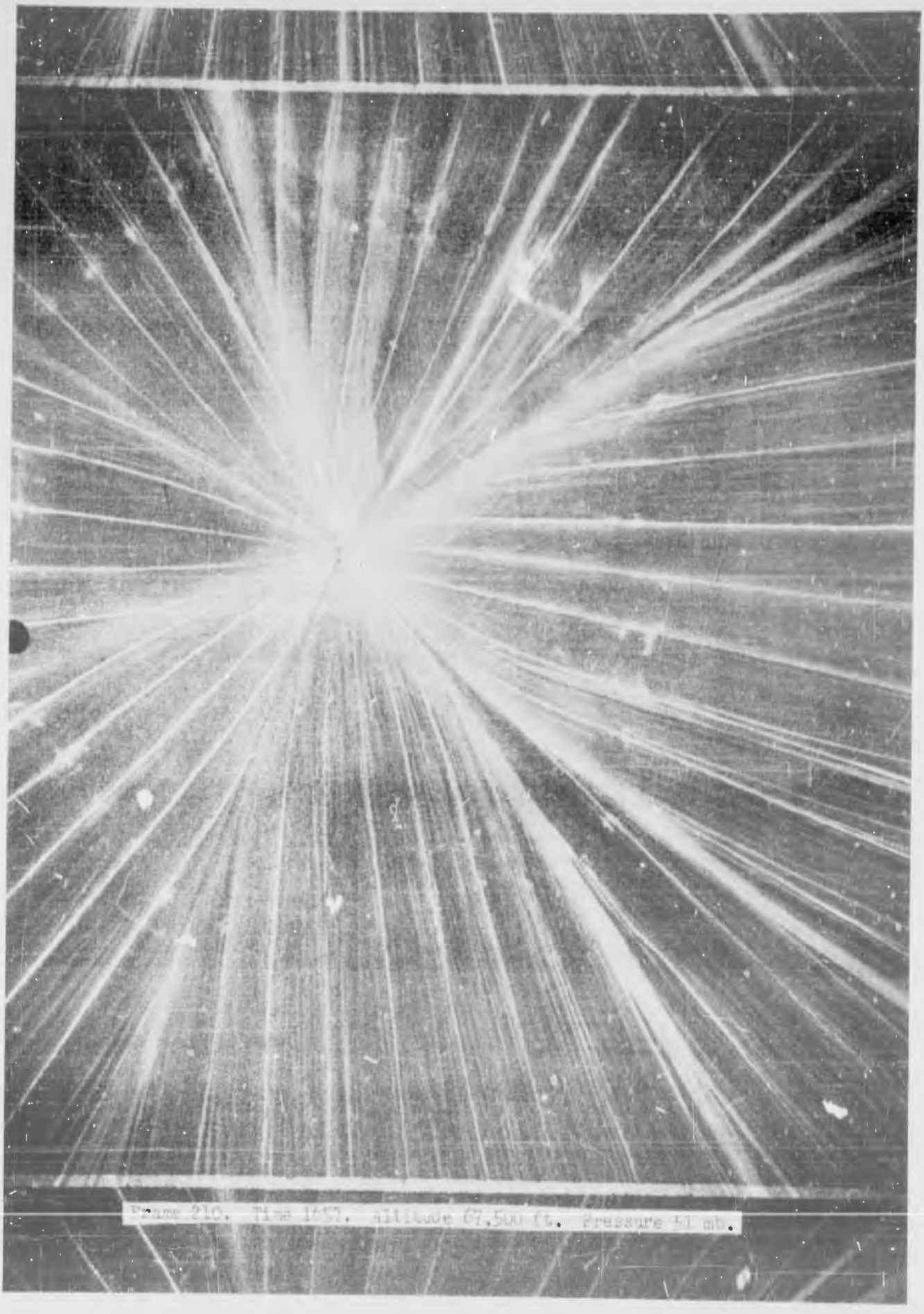
Frame 75. Time 1642. Altitude 88,700 ft. Pressure 18.6 mb. The appendix is tightly closed and the balloon is becoming slack.



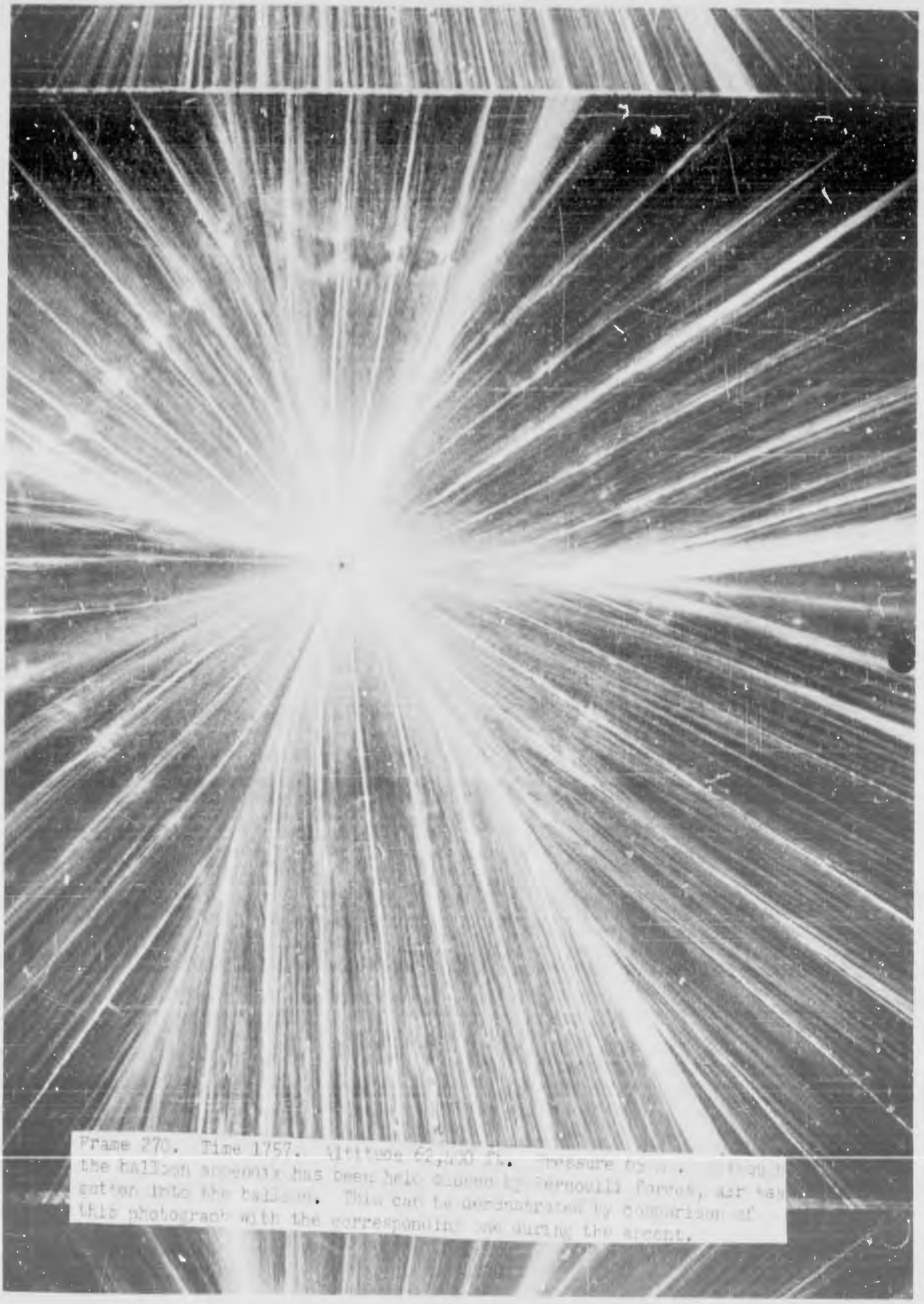
Frame 91. Time 1158. Altitude 86,200 ft. Pressure 21.0 mb. The balloon now shows nine separate regions. The appendix is tightly closed by the Bernoulli forces.



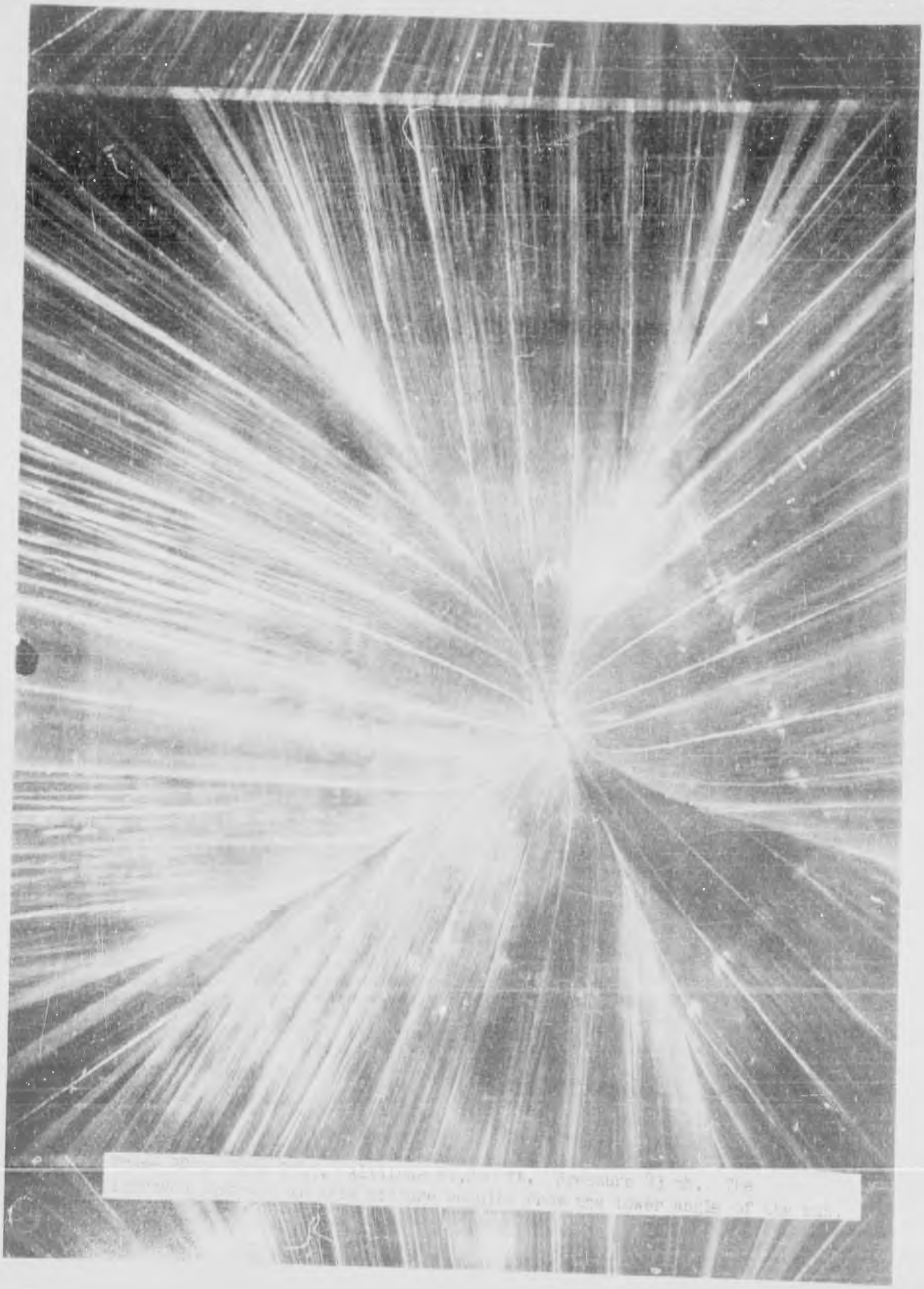
Frame 126. Time 1533. Altitude 76,700 ft. Pressure 33.0 mb.
Balloon has further collapsed as evidenced by the 40-ft. marks.

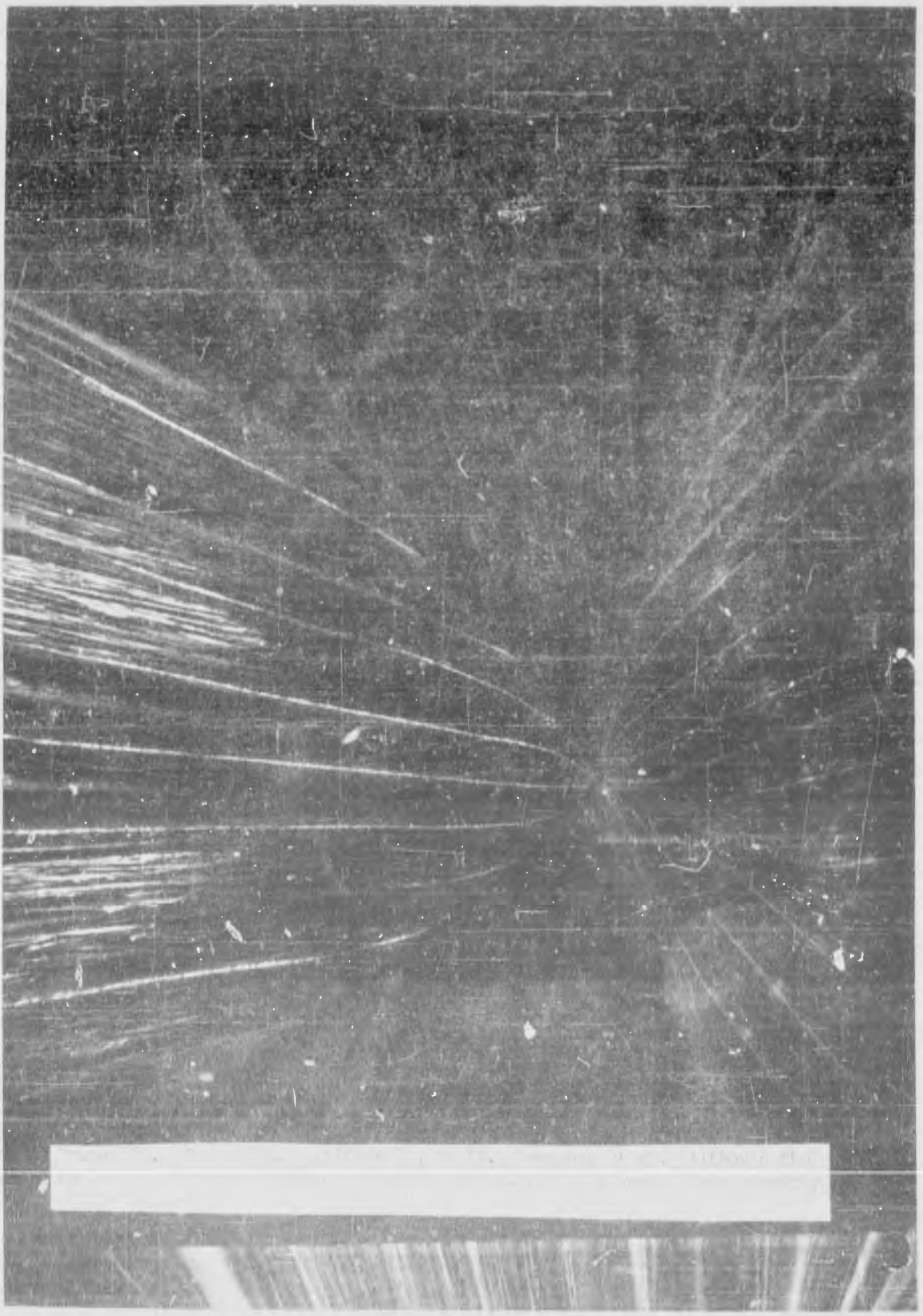


Frame 210. Time 1457. Altitude 67,500 ft. Pressure 51 mb.



Frame 270. Time 1757. Altitude 22,000 ft. Pressure [illegible]. [illegible] the balloon assembly has been held clear by Bernoulli forces, air has entered into the balloon. This can be demonstrated by comparison of this photograph with the correspondin[illegible] ascent.

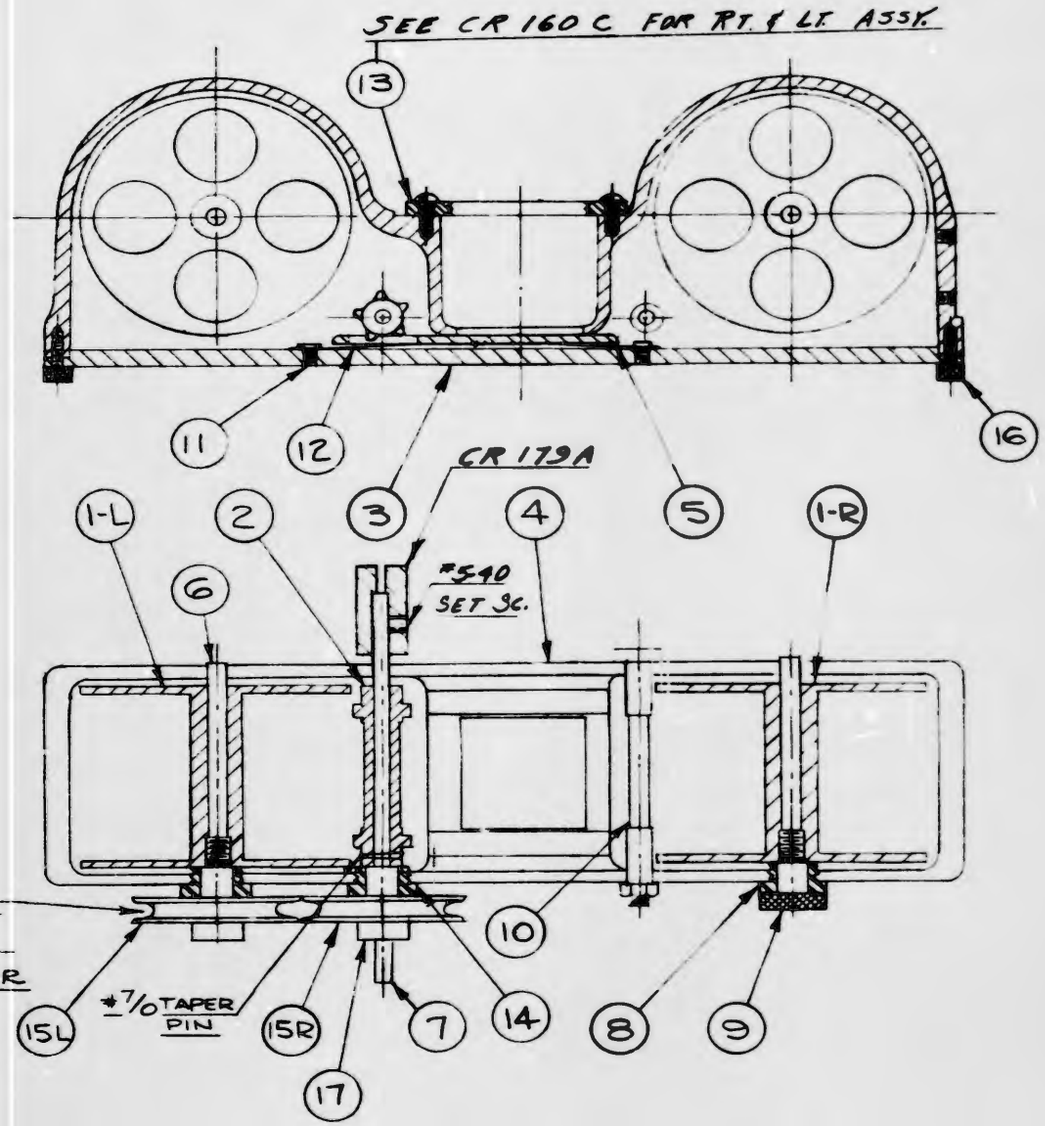




APPENDIX XI

TABLE OF CONTENTS - SHOP DRAWINGS

BA 414 D	Balloon Rigging Clamp
BA 416 D	Model 3 - Balloon Weight Torque Wrench
BA 412 D	Diaphragm Support
BA 431 C	Aneroid Tube Deflator
BA 434 C (Sheet #2 of 2)	Transmitter Case
BA 434 C (Sheet #1 of 2)	Transmitter Case
BA 433 D	Antenna Dropper
BA 427 C	Antenna Dropper
BA 411 D	Assembly - Unified Ballast System
BA 411 D-1	Details - Unified Ballast System
BA 411 D-2	Gondola Details - Unified Ballast System
BA 411 D-3	Ballast Hopper - Unified Ballast System
BA 421 D	Olland Cycle Assembly
CR 88 (Sheet #1 of 3)	Camera Assembly
CR 88 (Sheet #2 of 3)	Camera Detail
CR 88 (Sheet #3 of 3)	Camera Assembly
BA 418 D	Down Camera Adjustable Mount
BA 418 B-1	Up Camera Mount
BA 418 B-3	Camera Motor Cover (Brailsford)
BA 418 B-2	Camera Motor Cover (Amglo)
BA 417 D	Camera - Lens and Shutter Mechanism and Mount
BA 410 D	Low Altitude Balloon Release
CR 406 A	Squib Cutter
BA 438 B	Squib Cannon - 3000-lb. Rope

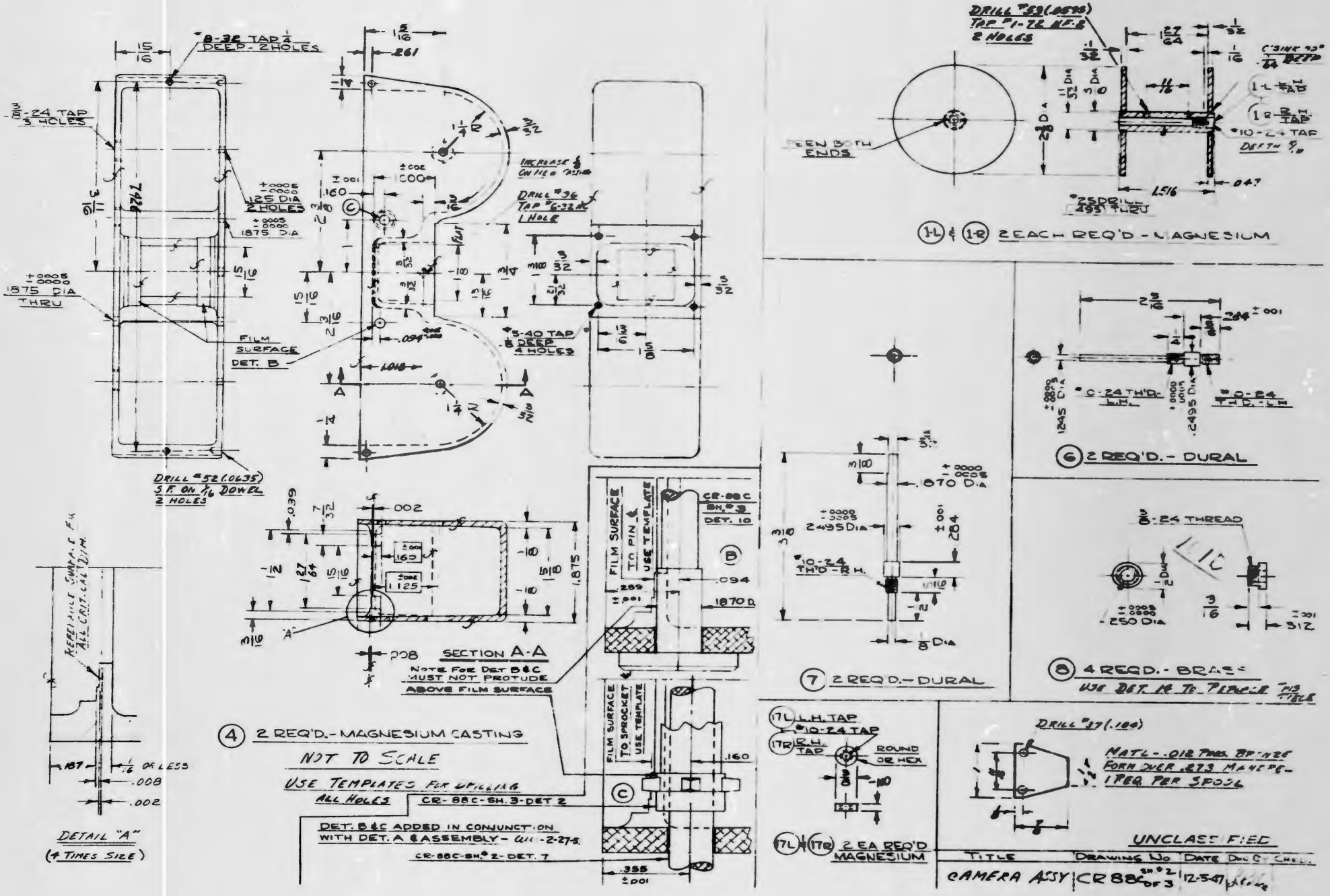


NOTE —
.012 DIA. PIANO WIRE
FOR SPRING BELT
WIND ON 3/32 DIA. ARBOR
WIND TIGHT 3 LG.
FREE LENGHT 4
APPROX.

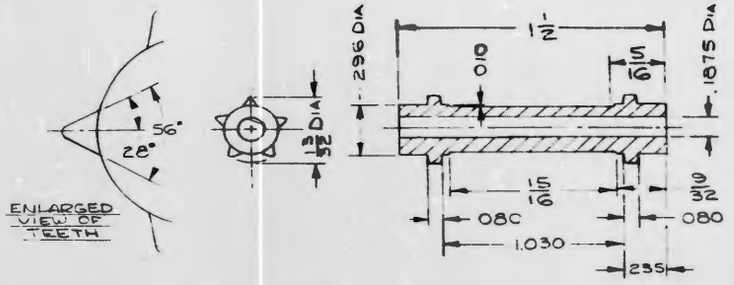
UNCLASSIFIED

TITLE	DRAWING NO.	DATE	DWN. BY	CHKD.
CAMERA ASSY	CR 88 54 1 Doc 3	12-5-47		

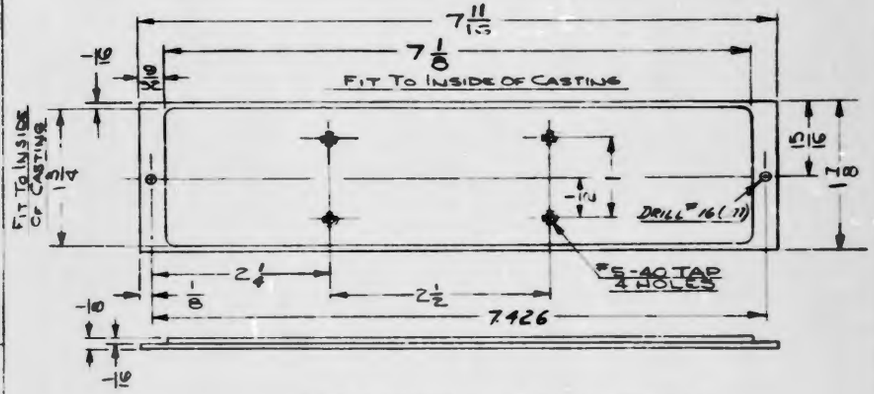
Restricted Security Information



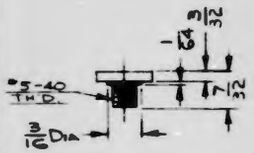
Restricted Security Information



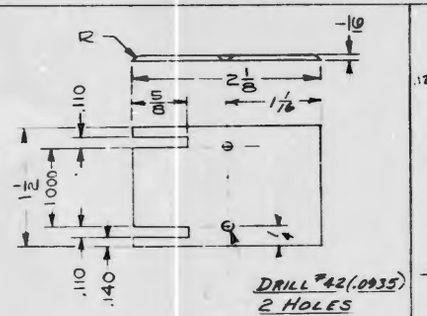
(2) 2 REQ'D. - MAGNESIUM
SCALE-DOUBLE SIZE



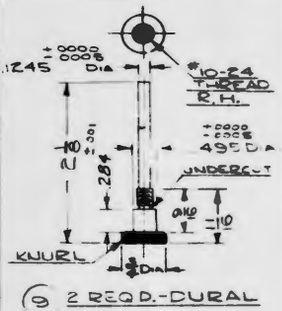
(3) 2 REQ'D. - MAGNESIUM



(11) 4 REQ'D.



(5) 2 REQ'D. - MAGNESIUM



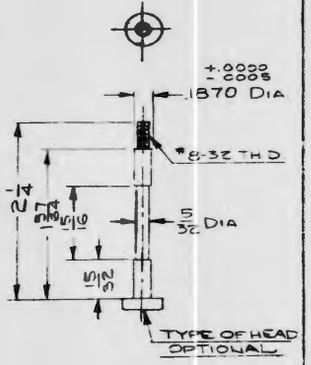
(9) 2 REQ'D. - DURAL



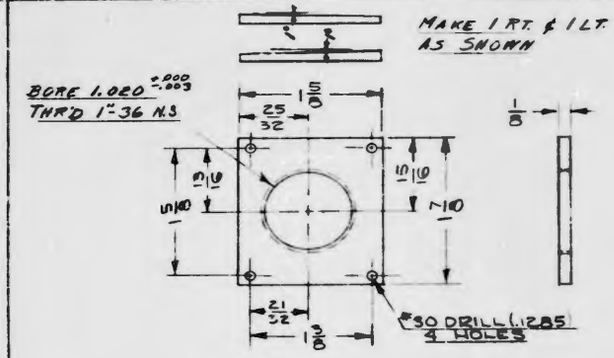
(12) 4 REQ'D. - .010 PHOSPHOR-BRONZE SPRING TEMP.



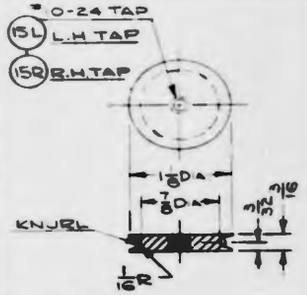
(14) 6 REQ'D. - BRASS



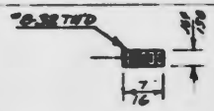
(10) 2 REQ'D. - DURAL



(13) 2 REQ'D. - MAGNESIUM



(15L) (15R) 2 EA REQ'D - MAGNESIUM



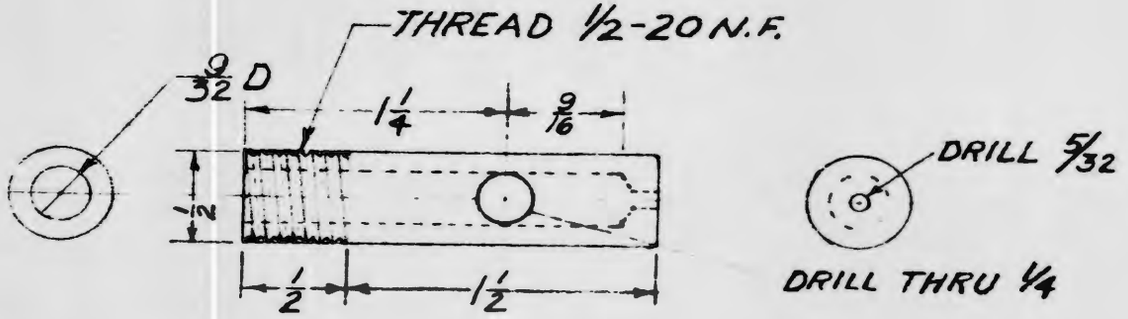
(16) 4 REQ'D.

UNCLASSIFIED

TITLE	DRAWING NO.	DATE	DWN BY	CHKD
CAMERA DETAIL	CR 88 50°3 OCT 2	12-5-67	J Rich	

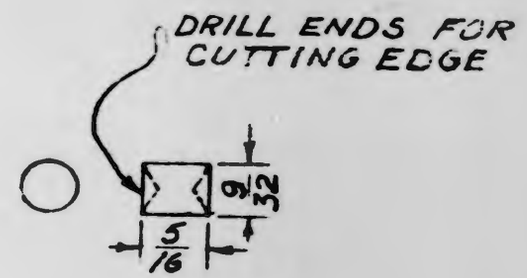
Restricted Security Information

A



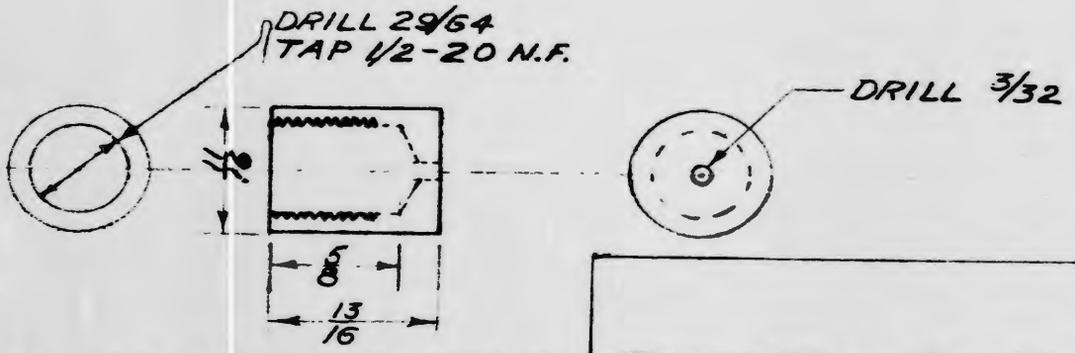
DURAL 24 ST 20 REQ'D.

C



DRILL ROD 20 REQ'D.

B



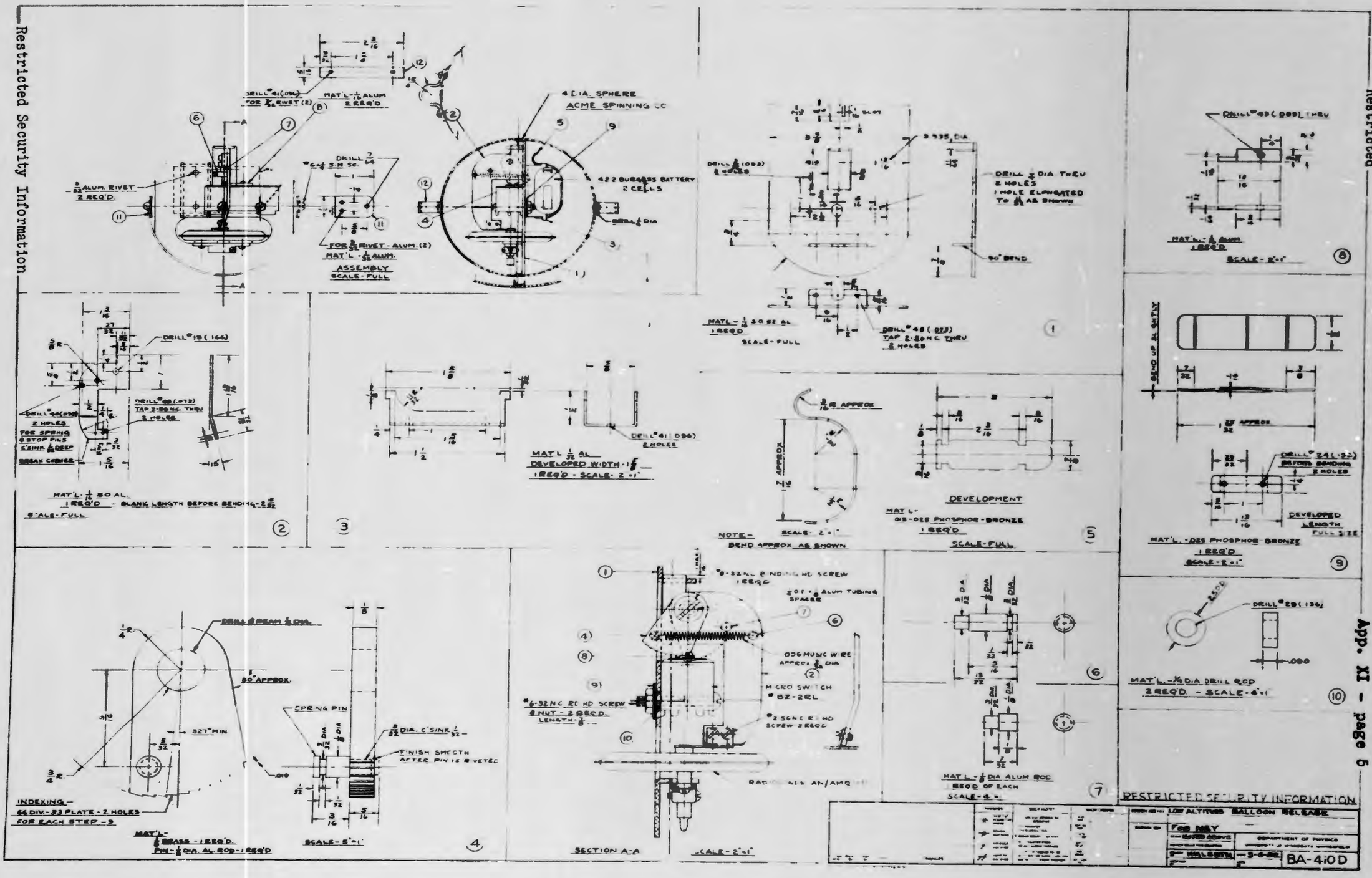
DURAL 24 ST 20 REQ'D.

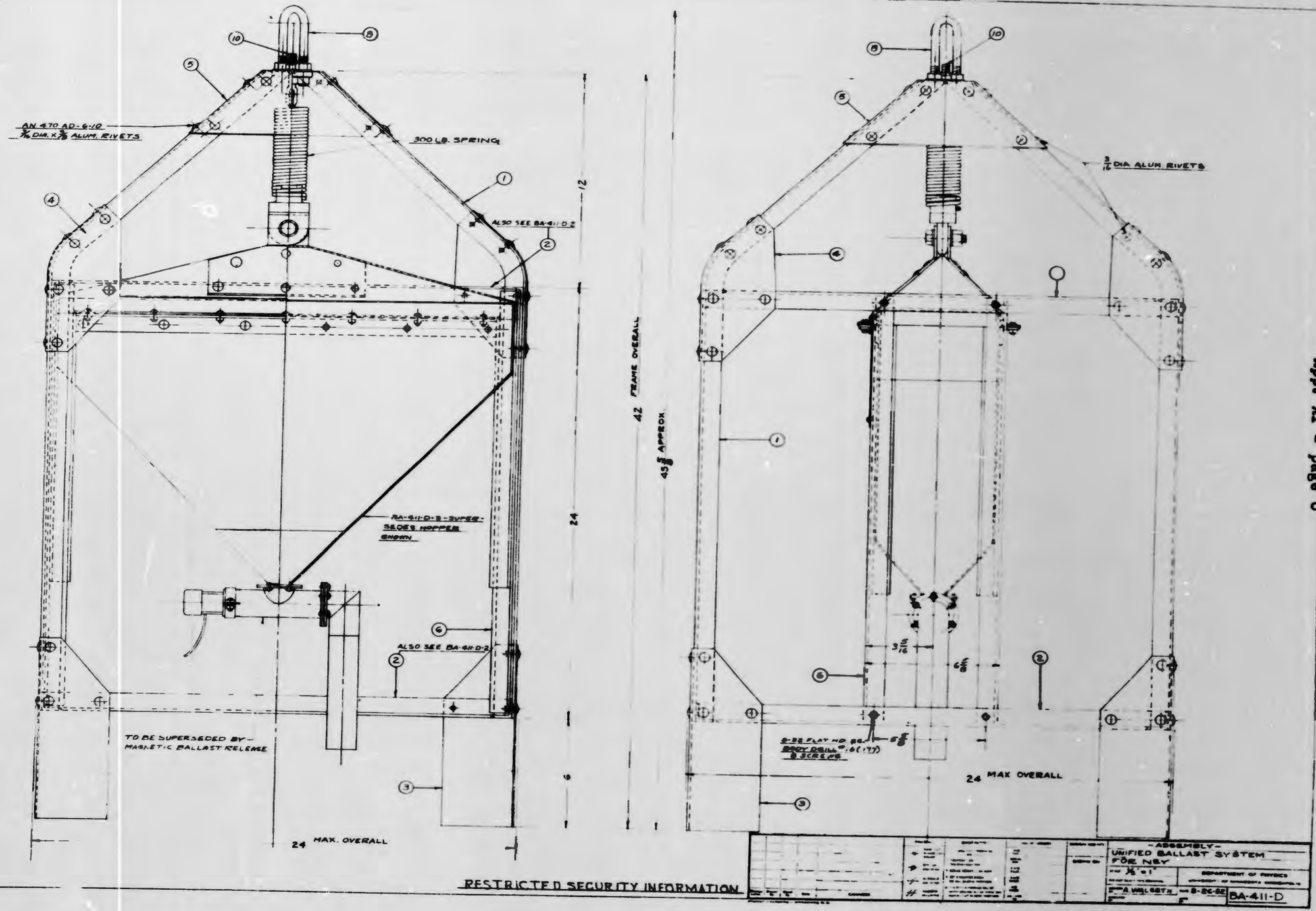
RESTRICTED SECURITY INFORMATION

UNIVERSITY of MINNESOTA - DEPARTMENT of PHYSICS					
Dwg. No.	N	Scale	Date	Drawn by	Checked by
CR40 6A		FULL	11-29-51	C. INGWELL	

For: NEY

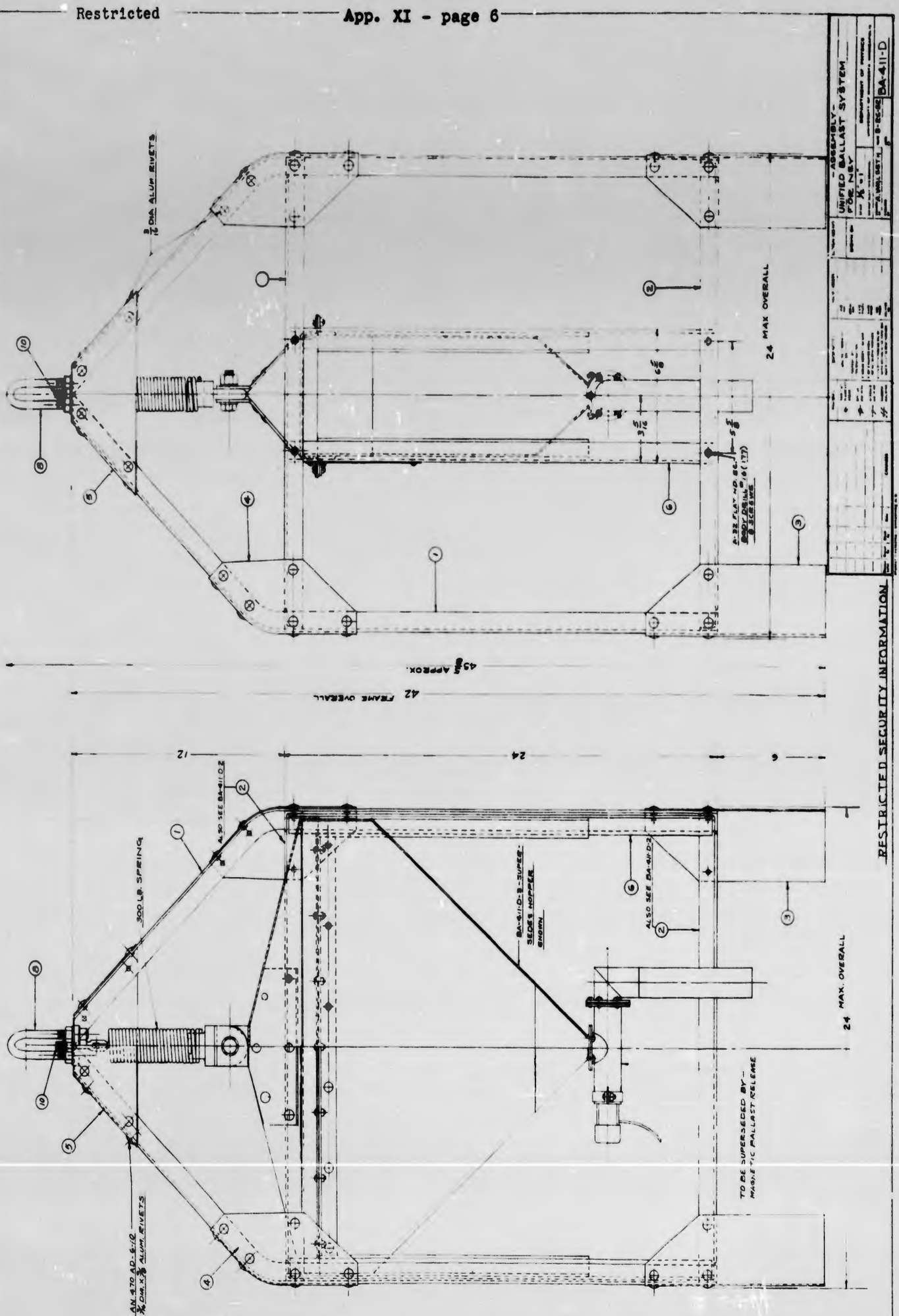
SQUIBB CUTTER

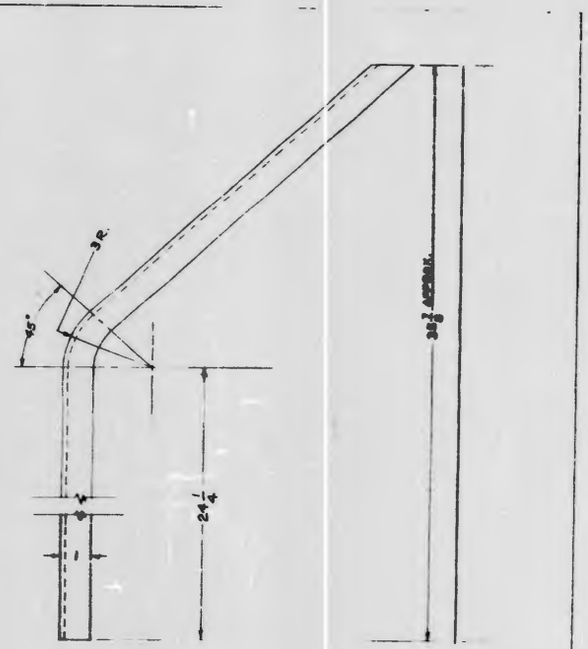

ASSEMBLY
SCALE - FULL
4 DIA SPHERE
ACME SPINNING CO
422 BURGESS BATTERY
2 CELLS
MAT'L - 1/16 ALUM
2 REQ'D
3/32 ALUM. RIVET
2 REQ'D
DRILL #41 (.096)
FOR 3/32 RIVET (2)
DRILL 7/64
#6-32 N.C. SC.
FOR 3/32 RIVET - ALUM. (2)
MAT'L - 1/32 ALUM.
DRILL 1/4 DIA
MAT'L - 1/16 SQ AL
1 REQ'D
SCALE - FULL
DRILL #48 (.076)
TAP 2-56 N.C. THRU
2 HOLES
DRILL 1/2 DIA THRU
2 HOLES
1 HOLE ELONGATED
TO 5/8 AS SHOWN
90° BEND
DRILL #19 (.166)
DRILL #40 (.098)
2 HOLES
FOR SPRING
& STOP PINS
C'SINK 1/64 DEEP
BREAK CORNER
DRILL #28 (.013)
TAP 2-56 N.C. THRU
2 HOLES
MAT'L - 1/16 SQ AL
1 REQ'D - BLANK LENGTH BEFORE BENDING - 2 5/32
SCALE - FULL
2
3
MAT'L 1/32 AL
DEVELOPED WIDTH - 1 5/8
1 REQ'D - SCALE - 2 : 1
DRILL #41 (.096)
2 HOLES
NOTE -
BEND APPROX AS SHOWN
SCALE - 2 : 1
DEVELOPMENT
MAT'L -
.015 - .025 PHOSPHOR - BRONZE
1 REQ'D
SCALE - FULL
5
DRILL #49 (.073) THRU
MAT'L - 1/16 ALUM
1 REQ'D
SCALE - 4 : 1
6
DRILL #24 (.152)
BEFORE BENDING
2 HOLES
DEVELOPED
LENGTH
FULL SIZE
MAT'L - .025 PHOSPHOR BRONZE
1 REQ'D
SCALE - 2 : 1
9
DRILL #29 (.136)
MAT'L - 1/4 DIA DRILL ROD
2 REQ'D. - SCALE - 4 : 1
10
DRILL & REAM 1/4 DIA.
80° APPROX.
.327" MIN
CPRING PIN
3/32 DIA. C'SINK 1/32
FINISH SMOOTH
AFTER PIN IS RIVETED
INDEXING -
66 DIV. - 33 PLATE - 2 HOLES
FOR EACH STEP - 9
MAT'L -
1/8 BRASS - 1 REQ'D.
PIN - 1/8 DIA. AL. ROD - 1 REQ'D
SCALE - 5 : 1
4
#8-32 NC BINDING HD SCREW
1 REQ'D
2.07" 1/8 ALUM TUBING
SPACER
.006 MUSIC WIRE
APPROX 1/4 DIA
MICRO SWITCH
#BZ-2RL
#2 SGNC R HD
SCREW 2 REQ'D
#6-32 N.C. RD HD SCREW
& NUT - 2 REQ'D.
LENGTH - 3/8
SECTION A-A
SCALE - 2 : 1
MAT'L - 1/8 DIA ALUM ROD
REQ'D OF EACH
SCALE - 6 : 1
7
RESTRICTED SECURITY INFORMATION
LOW ALTITUDE BALLOON RELEASE
FOR MAY
BA-410D



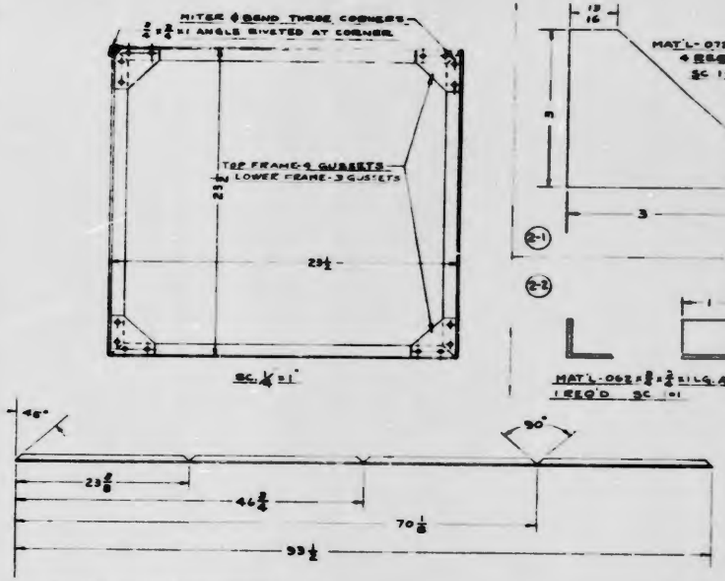
Restricted Security Information

RESTRICTED SECURITY INFORMATION

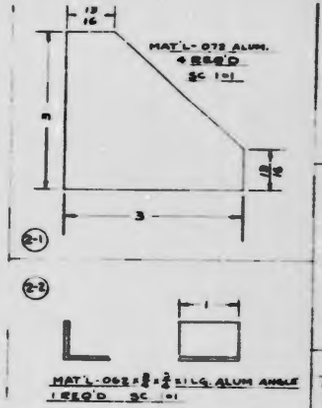

UNIFIED BALLAST SYSTEM
- ASSEMBLY -
FOR NEY
BA-411-D
RESTRICTED SECURITY INFORMATION
24 MAX OVERALL
42 FRAME OVERALL
43⅝ APPROX.
300 LB. SPRING
ALSO SEE BA-411-D-2
BA-411-D-3 SUPER-SEDES HOPPER SHOWN
TO BE SUPERSEDED BY MAGNETIC BALLAST RELEASE
AN 470 AD-6-12 OR ⅜ DIA. ALUM. RIVETS
⅜ DIA ALUM RIVETS



① MAT'L - 1"x1"x41" LG. MAG. ANGLE
4 REQ'D. - SCALE: 1/2"=1'



② MAT'L - 1"x1"x93½" MAG. ANGLE
2 REQ'D. SC. ½"=1'

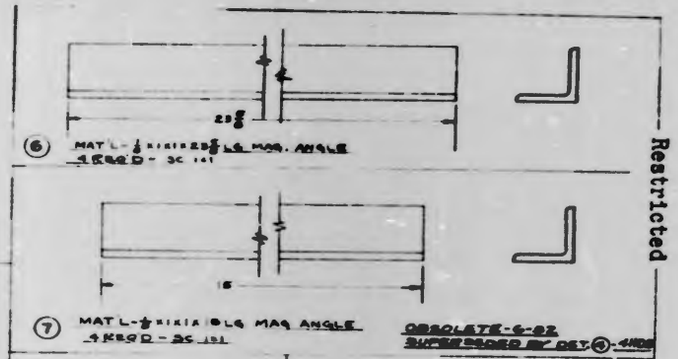


MAT'L - 072 ALUM.
4 REQ'D
SC 1:1

2-1

2-2

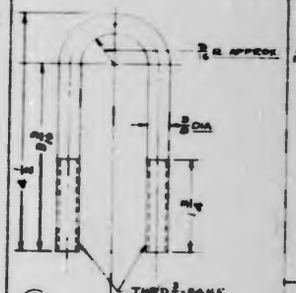
MAT'L - .062 x 1⅛ x 1⅛ LG. ALUM ANGLE
1 REQ'D SC 1:1



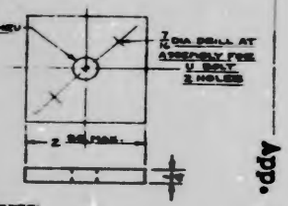
⑥ MAT'L - ¼"x1"x23⅜" LG. MAG. ANGLE
4 REQ'D - SC 1:1

⑦ MAT'L - ¼"x1"x15" LG MAG ANGLE
4 REQ'D - SC 1:1

OBSOLETE-6-62
SUPERSEDED BY DET ⑨-4 HOLES



⑧ MAT'L - ¾" DIA x 3⅝" LG. C.R. ST
1 REQ'D. - SC. 1:1



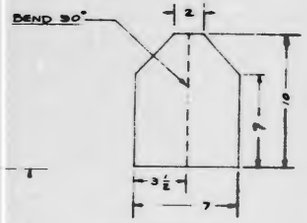
MAT'L - ¼" STEEL
1 REQ'D. SC 1:1.

⑨

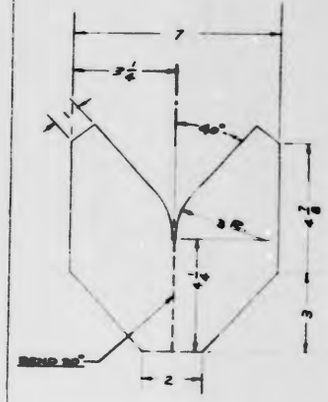


SC. ½"=1'

③

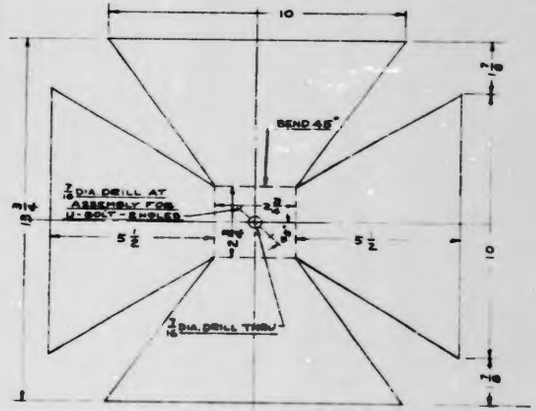


MAT'L - .072 ALUM.
4 REQ'D SC. ½"=1'

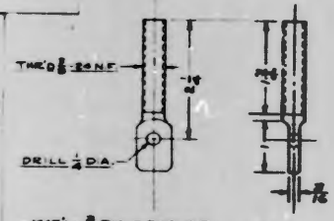


MAT'L - .072 ALUM.
4 REQ'D SC. ½"=1

④



⑤ MAT'L - .072 x 13⅝" x 13¾" ALUM
1 REQ'D. - SC. ½"=1



MAT'L - ⅜" DIA x 3" LG. C.R.
1 REQ'D. - SC. 1:1

⑩

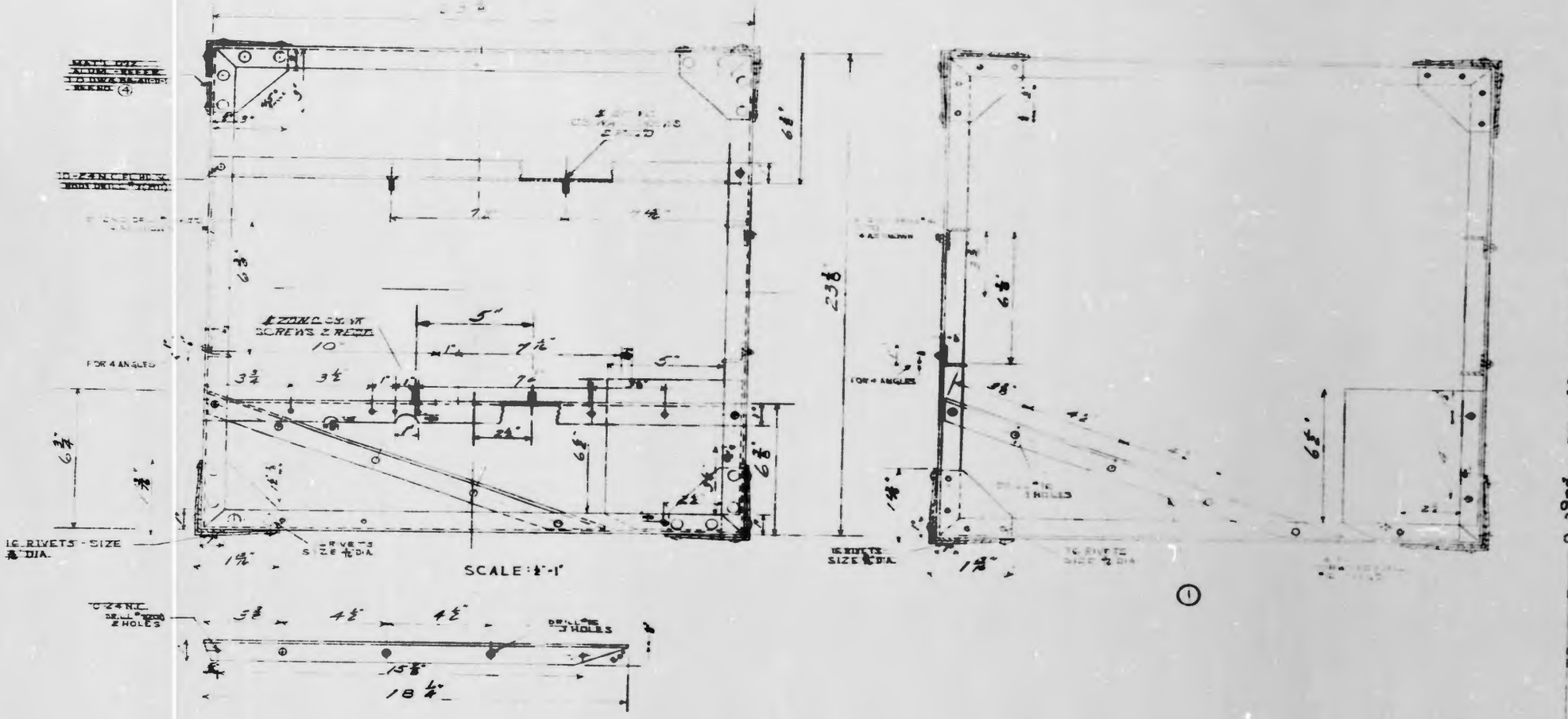
RESTRICTED SECURITY INFORMATION

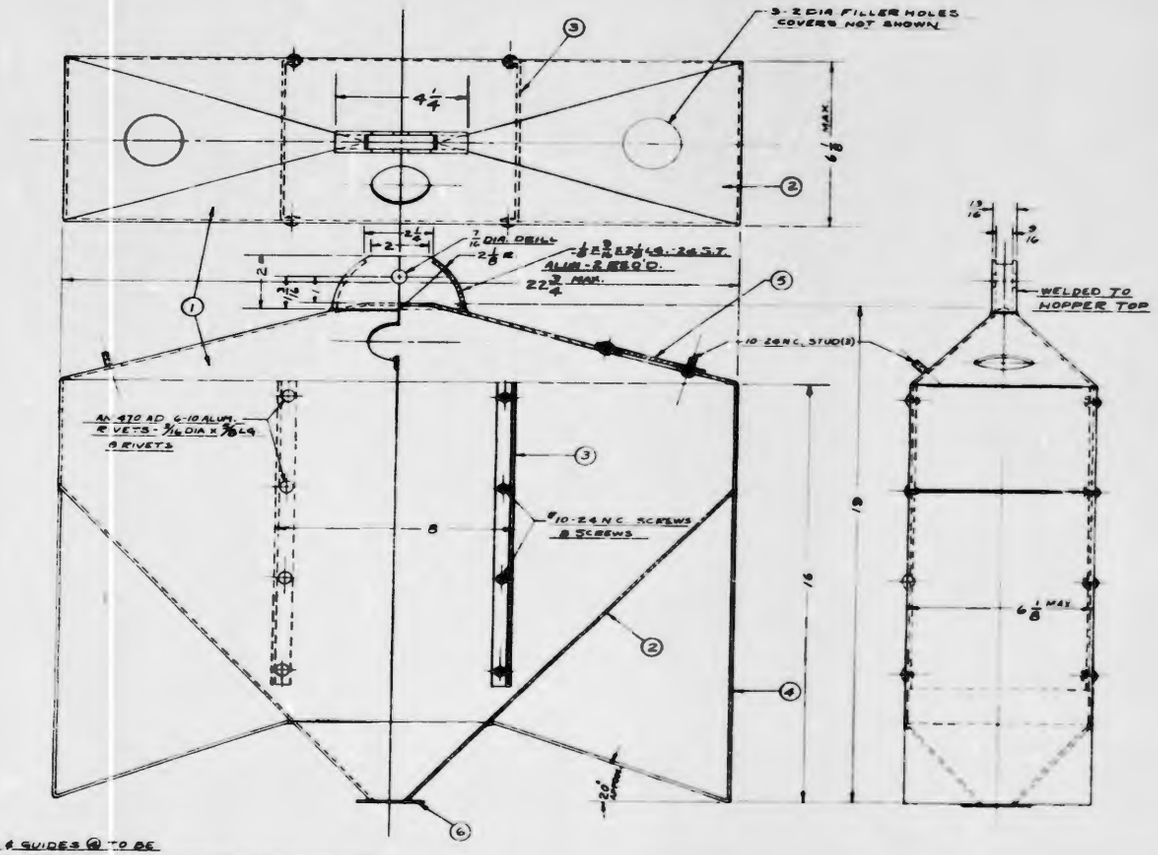
- DETAILS -
UNIFIED BALLAST SYSTEM
FOR NEY

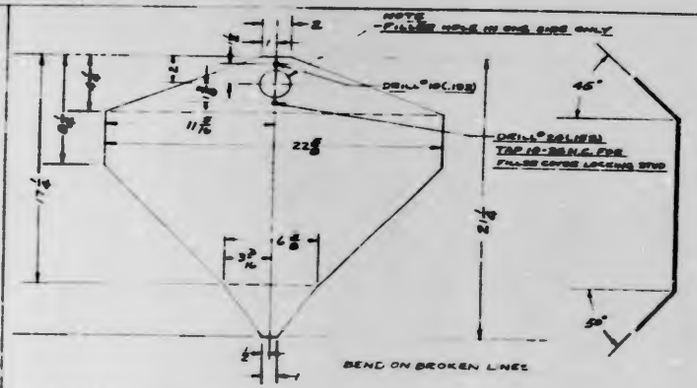
DEPARTMENT OF PHYSICS

DRAWN WALSETH 3-14-62

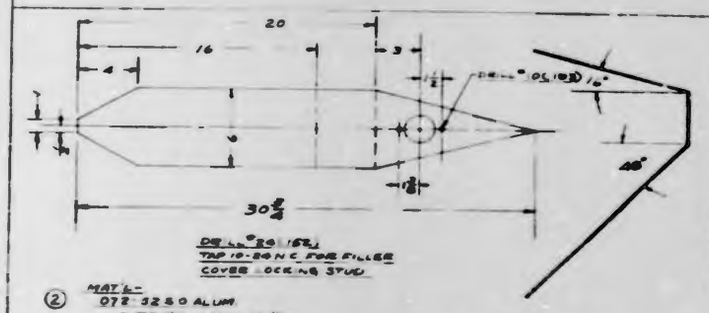
BA-411-D-1


SCALE: ½"-1"
FOR 4 ANGLES
16 RIVETS - SIZE & DIA.
DRILL 3 HOLES
23⅛
68"
5"
7½"
10"
18 ¼"
15⅝"





① MAT'L - .072 - 52 S.O ALUM. 2 REQ'D - SCALE - 1/2 = 1

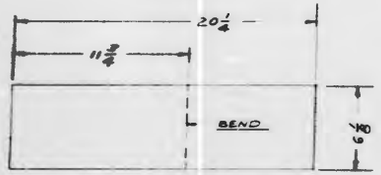


② MAT'L - .072 - 52 S.O ALUM. 2 REQ'D - SCALE 1/2 = 1

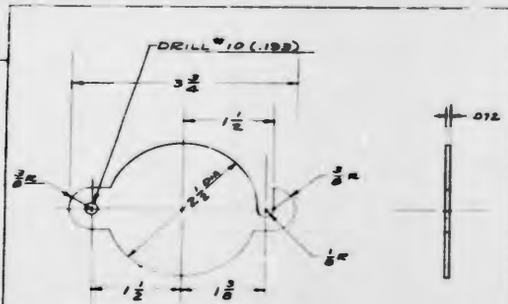


③ MAT'L - .072 - 52 S.O ALUM. 2 REQ'D - SCALE 1/2 = 1

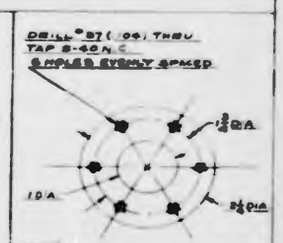
RESTRICTED SECURITY INFORMATION



④ MAT'L - .072 ALUM. (52 S.O.) 2 REQ'D - SCALE - 1/4 = 1

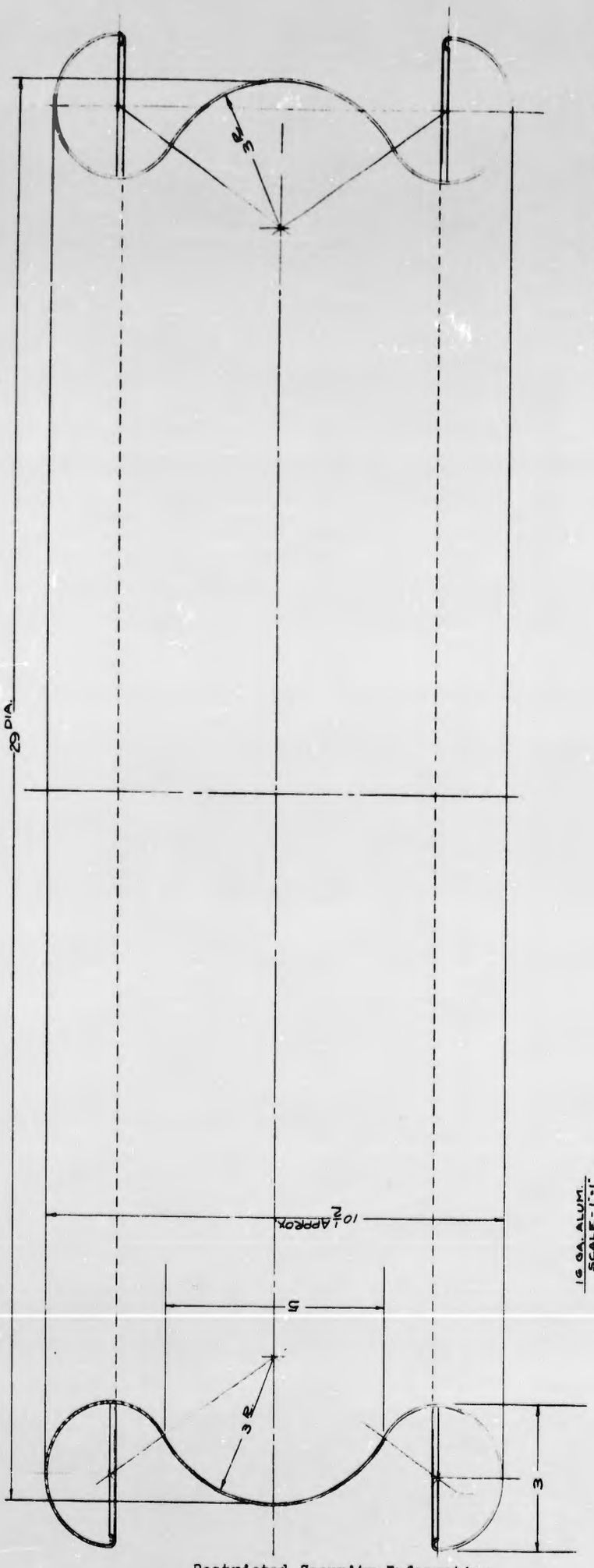


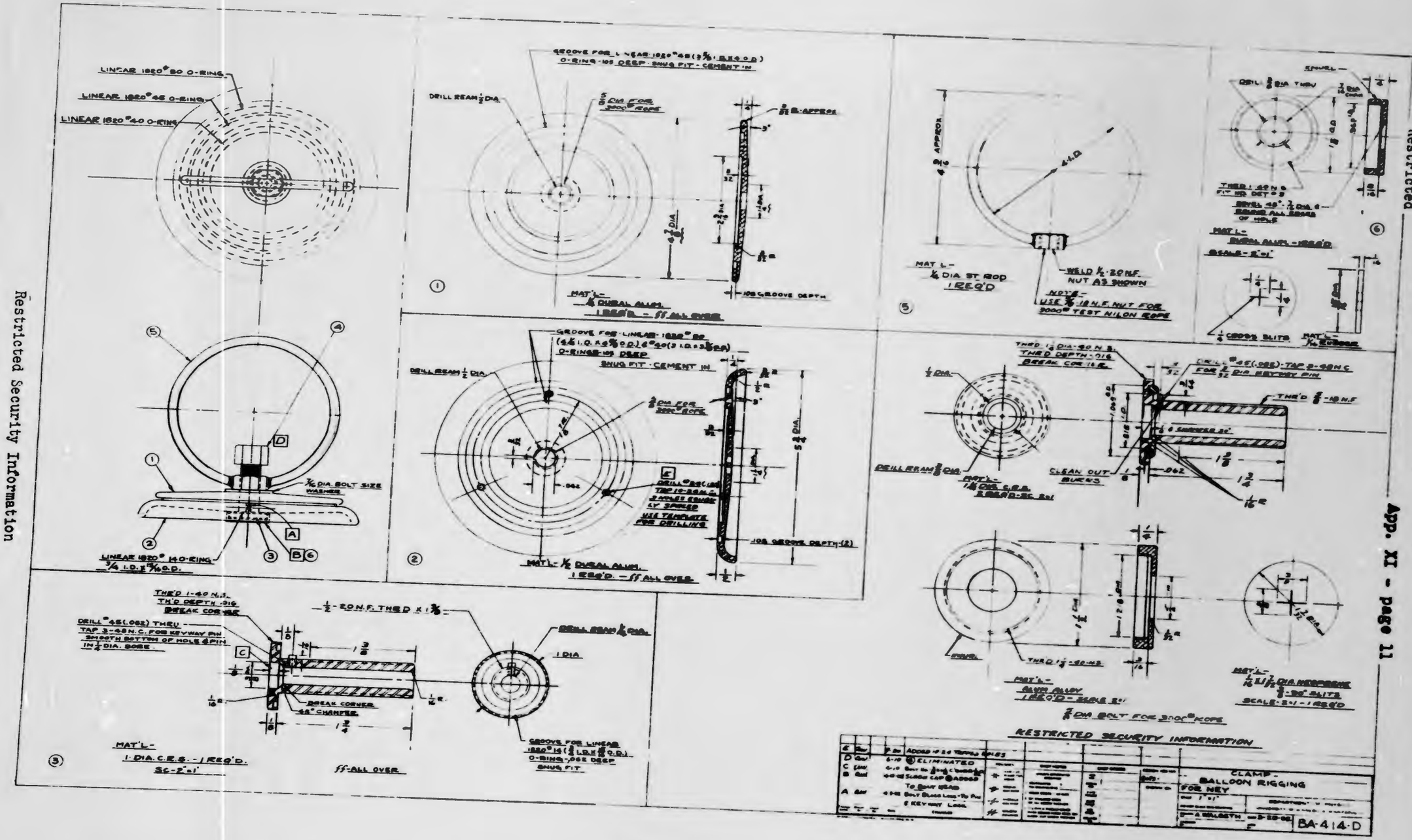
⑤ MAT'L - .072 52 S.O ALUM. 1 REQ'D - SCALE 1:1

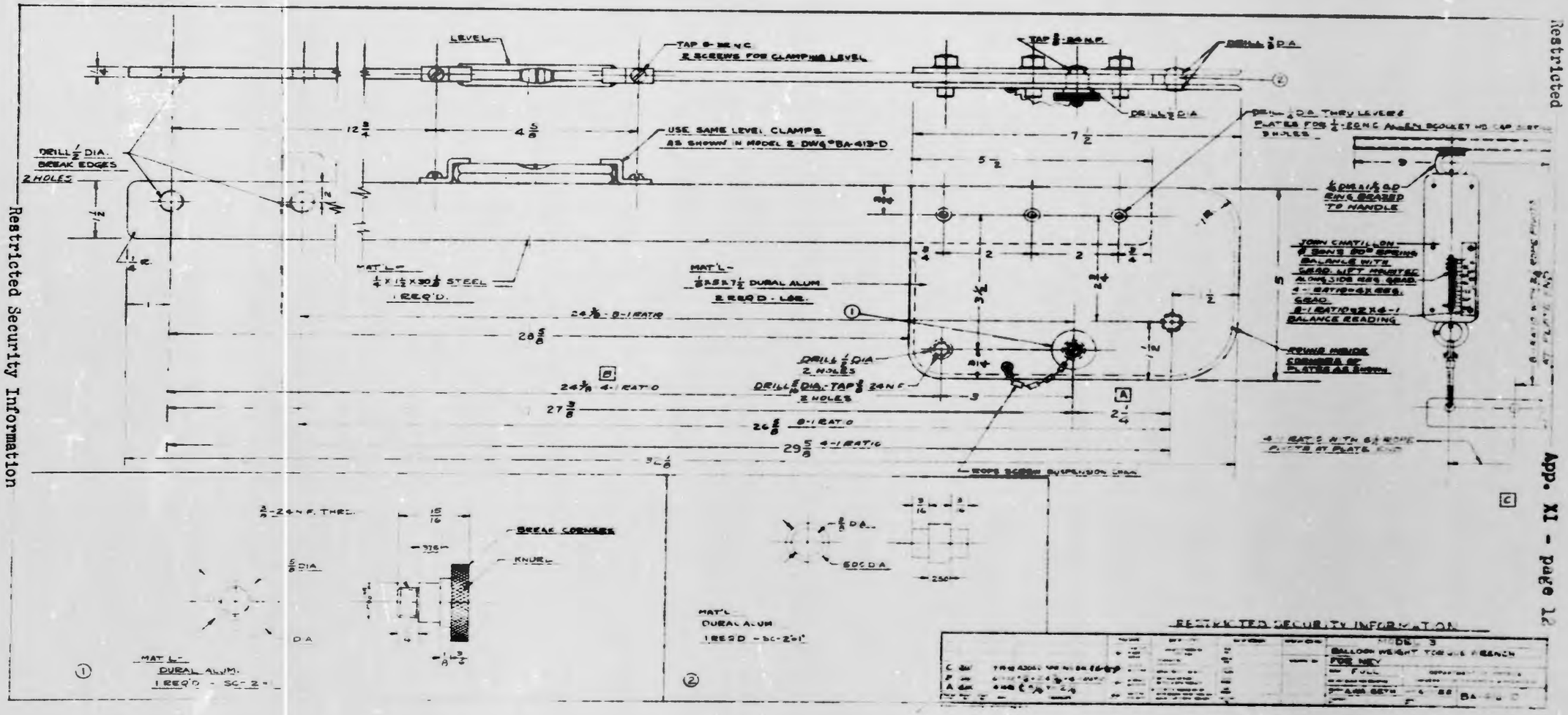


⑥ MAT'L - .125 ALUM. 1 REQ'D SCALE 1:1

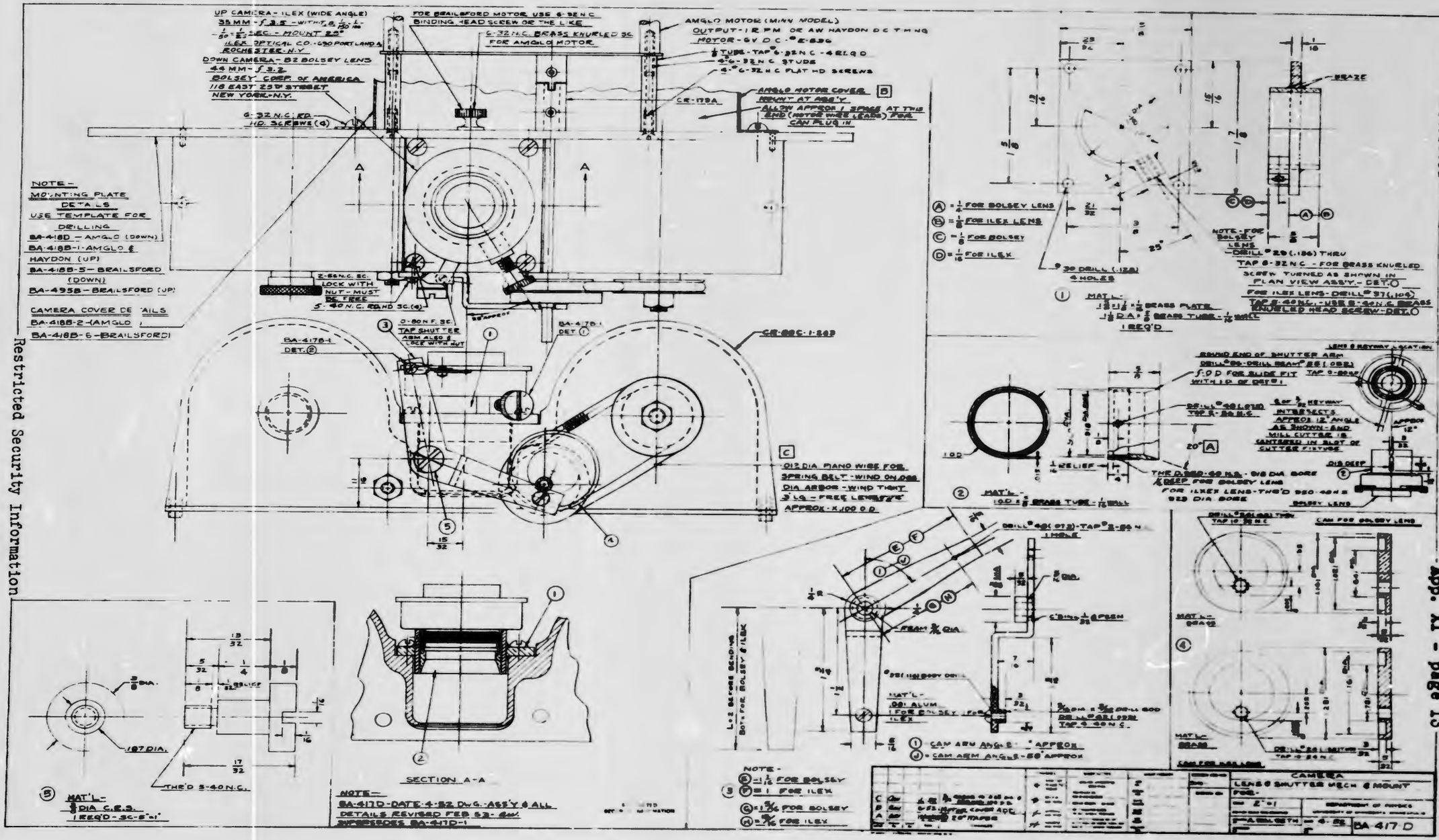
				BALLAST HOPPER UNIFIED BALLAST SYSTEM FOR NEV
				NOTES ABOVE
				SCALE AS SHOWN
				CA 4 D 3

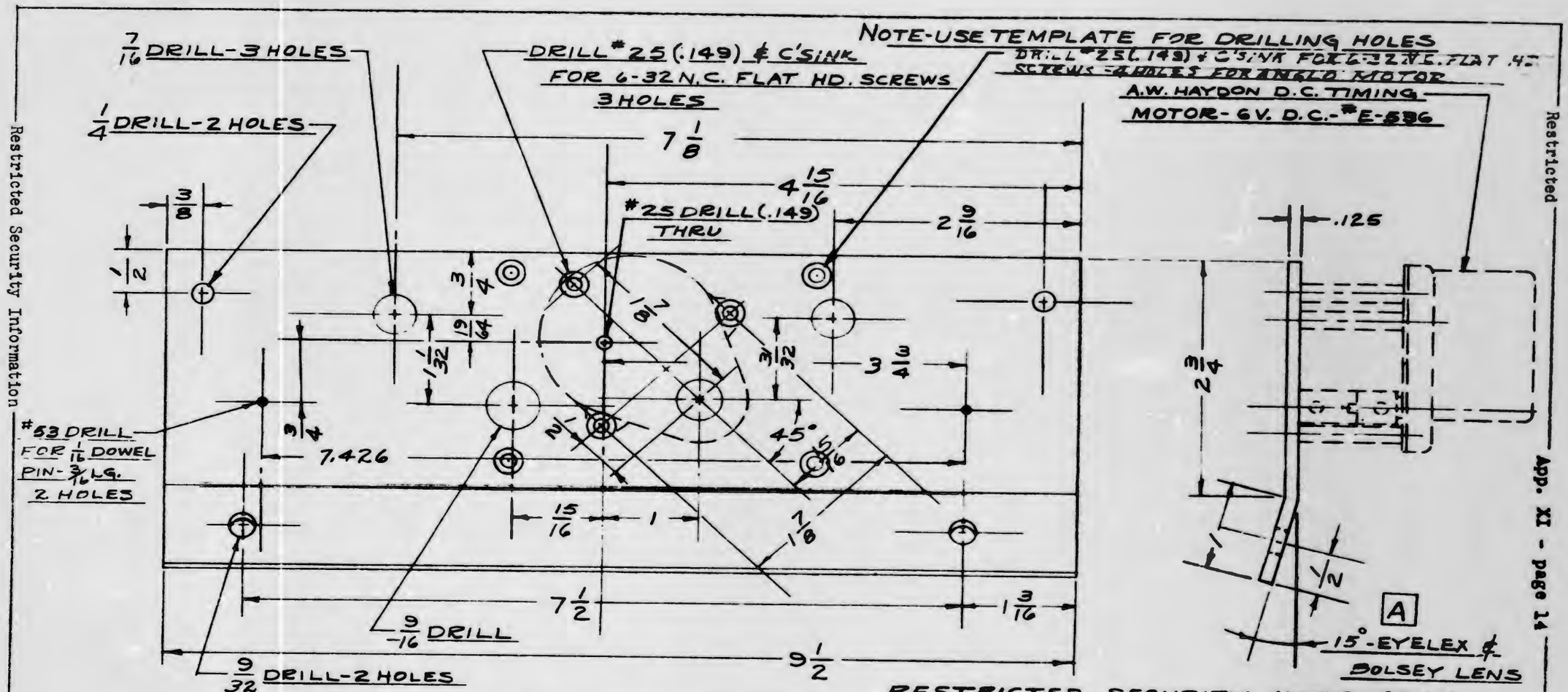

RESTRICTED SECURITY INFORMATION
UNIVERSITY of MINNESOTA DEPARTMENT of PHYSICS
Proj. No. 18
Scale 1"=1"
Date
Drawn by
Checked by
Dwg. No. SK-112-G
Drawn WALSETH
for NEY DIAPHRAGM SUPPORT
29 DIA.
10½ APPROX.
5
3 R
3
16 GA. ALUM.
SCALE - 1" = 1"


LINEAR 1820°80 O-RING
LINEAR 1820°46 O-RING
LINEAR 1820°40 O-RING
LINEAR 1820° 140 O-RING
3/4 I.D. x 15/16 O.D.
3/8 DIA. BOLT SIZE WASHER
GROOVE FOR LINEAR 1820°48 (3 5/8" I.D. x 3 3/4" O.D.) O-RING-.105 DEEP-SNUG FIT-CEMENT IN
DRILL REAM 1/2 DIA.
5/8 DIA FOR 3000# ROPE
MAT'L- 6 DURAL ALLOY. 1 REQ'D. - ff ALL OVER.
.105 GROOVE DEPTH
GROOVE FOR LINEAR 1820°48 (4 1/8" I.D. x 4 3/8" O.D.) & °40 (3 I.D. x 3 1/8" O.D.)
O-RING-.105 DEEP
SNUG FIT-CEMENT IN
DRILL REAM 1/2 DIA.
5/8 DIA FOR 3000# ROPE
DRILL #48 (.076) TAP 10-32 N.F. 3 EQUALLY SPACED
USE TEMPLATE FOR DRILLING
5 1/4 DIA.
.105 GROOVE DEPTH (2)
MAT'L- 1/2 DURAL ALUM. 1 REQ'D - ff ALL OVER.
4 1/2 APPROX.
4.40 D
MAT'L- 1/4 DIA ST. ROD 1 REQ'D
WELD 1/4-20 N.F. NUT AS SHOWN
NOTE- USE 5/8 18 N.F. NUT FOR 3000# TEST NILON ROPE
SWIVEL
DRILL 3/8 DIA THRU
THRD 1-40 N.S. FIT 3RD DET'D
COUNTERSINK 90° - 3/4 DIA. & REAM ALL EDGES OF HOLE
MAT'L- DURAL ALUM. - 1 REQ'D
SCALE- 2"=1'
4 CROSS SLITS
MAT'L- 1/16 RUBBER
THRD 1/2 DIA-20 N.F. THRD DEPTH-.016 BREAK COR. I.&E.
DRILL #45 (.082) TAP 5-40 N.C. FOR 5/32 DIA KEYWAY PIN
1/4 DIA.
THRD 5/8-18 N.F.
6 SHOULDER SC.
DRILL REAM 5/8 DIA.
CLEAN OUT BURRS
MAT'L- 1/8 CRS. C.R.S. 2 REQ'D-SC. 2=1
THRD 1 1/2-20 N.S.
MAT'L- ALUM ALLOY 1 REQ'D - SCALE 2=1
5/8 DIA BOLT FOR 3000# ROPE
MAT'L- 1/16 LI. 1/2 DIA NEOPRENE 3 - 3/4" SLITS
SCALE: 2=1 - 1 REQ'D
THRD 1-40 N.S. THRD DEPTH-.016 BREAK COR. I.&E.
DRILL #45 (.082) THRU
TAP 3-40 N.C. FOR KEYWAY PIN SMOOTH BOTTOM OF HOLE & PIN IN 1/4 DIA. BORE.
1/2-20 N.F. THRD x 1 3/8
DRILL REAM 1/2 DIA.
1 DIA
BREAK CORNER 45° CHAMFER
GROOVE FOR LINEAR 1820°18 (1 1/8 I.D. x 1 1/4 O.D.) O-RING-.062 DEEP SNUG FIT
MAT'L- 1 DIA. C.R.S. - 1 REQ'D. SC-2=1
ff-ALL OVER.
RESTRICTED SECURITY INFORMATION
D ADDED #10-32 THRD'D BOSS
C 6-19 ELIMINATED
B ADDED
A 4-40 SLOTTED CAP ADDED
To Body Head
4-40 Bolt Binds Lugs To Pin
1 Keyway Lock
CLAMP - BALLOON RIGGING FOR NEY
BA-414-D


LEVEL
TAP 8-32 N.C. 2 SCREWS FOR CLAMPING LEVEL
USE SAME LEVEL CLAMPS AS SHOWN IN MODEL 2 DWG "BA-413-D"
DRILL 1/2 DIA. BREAK EDGES 2 HOLES
MAT'L - 1/4 X 1 1/2 X 30 3/8 STEEL 1 REQ'D.
MAT'L - 3/8 X 3 1/2 DURAL ALUM 2 REQ'D - LOC.
24 3/8 - 8-1 RATIO
28 5/8
24 3/8 4-1 RATIO
27 3/8
26 5/8 8-1 RATIO
29 5/8 4-1 RATIO
DRILL 1/8 DIA 2 HOLES
DRILL 5/16 DIA - TAP 3/8 24 N F 2 HOLES
TAP 8-32 N.C.
DRILL 1/2 DIA
DRILL 1/4 DIA THRU LEVERS
PLATES FOR 1/4-20 N.C. ALLEN SOCKET HD. CAP SCREWS 2 HOLES
DRILL 1 1/4 O.D. RING BRAZED TO HANDLE
JOHN CHATILLON & SON'S COIL SPRING BALANCE WITH DEAD-LIFT MAGNETIC ALONG SIDE 8 1/2 GRAD. 4-1 RATIO 42 X 6-1 GRAD. 8-1 RATIO 42 X 6-1 BALANCE READING
POINTS INSIDE CORNERS OF PLATES AS SHOWN
3/8-24 N.F. THRD.
BREAK CORNERS
KNURL
5/8 DIA
DIA
MAT'L - DURAL ALUM. 1 REQ'D - SC-2"
1/8 DIA
MAT'L DURAL ALUM 1 REQ'D - SC-2"
RESTRICTED SECURITY INFORMATION
DR. 3
BALLOON WEIGHT TORQUE BRANCH FOR NAVY

Restricted


UP CAMERA - ILEX (WIDE ANGLE)
35 MM - f 3.5 - WITH 1, 1/2, 1/5, 1/25, 1/50, 1/100 SEC. - MOUNT 2.0"
ILEX OPTICAL CO. - 630 PORTLAND
ROCHESTER, N.Y.
DOWN CAMERA - B2 BOLSEY LENS
44 MM - f 3.2
BOLSEY CORP. OF AMERICA
118 EAST 25TH STREET
NEW YORK, N.Y.
FOR BRAILSFORD MOTOR USE 6-32 N.C. BINDING HEAD SCREW OR THE LIKE
6-32 N.C. BRASS KNURLED SC. FOR AMGLO MOTOR
AMGLO MOTOR (MINN MODEL)
OUTPUT - 1 R.P.M. OR AS HAYDON D.C. T.M.N.G.
MOTOR - 6V D.C. - "E-836
1/4" TUBE - TAP 6-32 N.C. - 4 REQ'D
4-6-32 N.C. STUDS
4-6-32 N.C. FLAT HD. SCREWS
AMGLO MOTOR COVER MOUNT AT ASS'Y.
ALLOW APPROX 1 SPARE AT THIS END (MOTOR WIRE LEADS) FOR CAN PLUG IN
CE-119A
6-32 N.C. RD. HD. SCREWS (4)
2-56 N.C. SC. LOCK WITH NUT - MUST BE FREE
5-40 N.C. RD HD SC. (4)
NOTE -
MOUNTING PLATE DETAILS
USE TEMPLATE FOR DRILLING
BA-418D - AMGLO (DOWN)
BA-418B-1 - AMGLO & HAYDON (UP)
BA-418B-5 - BRAILSFORD (DOWN)
BA-495B - BRAILSFORD (UP)
CAMERA COVER DETAILS
BA-418B-2 - (AMGLO)
BA-418B-6 - (BRAILSFORD)
0-80 N.F. SC. TAP SHUTTER ASM ALSO & USE WITH NUT
BA-417D-1 DET. 1
BA-417B-1 DET. 2
CE-88C-1-883
.012 DIA PIANO WIRE FOR SPRING BELT - WIND ON 088 DIA ARBOR - WIND TIGHT 3" LG. - FREE LENGTH APPROX - X.100 O.D.
A = 1/4 FOR BOLSEY LENS
B = 1/8 FOR ILEX LENS
C = 1/8 FOR BOLSEY
D = 1/16 FOR ILEX
30 DRILL (.128) 4 HOLES
BRAZE
NOTE - FOR BOLSEY LENS - DRILL "29 (.136) THRU
TAP 6-32 N.C. - FOR BRASS KNURLED SCREW TURNED AS SHOWN IN PLAN VIEW ASSY. - DET. 0
FOR ILEX LENS - DRILL "37 (.104)
TAP 4-40 N.C. - USE 6-40 N.C. BRASS KNURLED HEAD SCREW - DET. 0
MAT'L - 1/32 x 1/2 BRASS PLATE - 1/8 D.A. x 5/8 BRASS TUBE - 1/16 WALL
1 REQ'D
REMOVE END OF SHUTTER ARM
DRILL "29 - DRILL REAM" .188 (.1882)
5.0 D FOR SLIDE FIT WITH I.D. OF DET. 1
TAP 0-80 N.F.
DRILL "48 (.076) TAP 2-56 N.C.
5.0 x 3/32 KEYWAY INTERSECTS APPROX 12° ANGLE AS SHOWN - AND MILL CUTTER IS CANTERED IN SLOT OF CUTTER FIXTURE
APPROX 12°
20° A
.100
1/2 RELIEF
THD. 0.250-40 N.S. - .218 DIA BORE 1/4 DEEP FOR BOLSEY LENS
FOR ILEX LENS - THD. 0.250-40 N.S. .229 DIA BORE
DIA DEEP
BOLSEY LENS
LENS & KEYWAY LOCATION
MAT'L - .100 x 5/8 BRASS TUBE - 1/16 WALL
DRILL "48 (.076) - TAP 2-56 N.C. - 1 HOLE
CAM FOR BOLSEY LENS
MAT'L - BRASS
DRILL "28 (.1405) TAP 10-32 N.F.
CAM FOR ILEX LENS
MAT'L - BRASS
DRILL "28 (.1405) TAP 10-32 N.F.
1/4 R
FROM 3/16 DIA
.001 HIGH BODY DIA
MAT'L - .001 ALUM FOR BOLSEY & ILEX
3/16 DIA = 3/16 DRILL GOD DRILL "28 (.1405) TAP 6-40 N.C.
LAY BEFORE BENDING BOTH FOR BOLSEY & ILEX
① CAM ARM ANGLE - " APPROX
② = CAM ARM ANGLE - 88° APPROX
NOTE -
③ E = 1/16 FOR BOLSEY
F = 1 FOR ILEX
G = 1 3/16 FOR BOLSEY
H = 5/16 FOR ILEX
.187 DIA.
THD 5-40 N.C.
MAT'L - 3/8 DIA C.R.S. 1 REQ'D - SC-5-01
SECTION A-A
NOTE -
BA-417D - DATE 4-52 DWG. ASS'Y & ALL DETAILS REVISED FEB 53 - GMW
SUPERSEDES BA-417D-1
CAMERA
LENS & SHUTTER MECH & MOUNT
FOR:
DEPARTMENT OF PHYSICS
BA 417 D



RESTRICTED SECURITY INFORMATION

MAT'L-
.125 X 3 3/4 X 9 1/2 ALUM.
1 REQ'D

Change Letter	Drawn By	Check By	Date	CHANGES
A	AW		4/9/52	MOUNT-L-CHANGED FROM 25° TO 15°

FINISHES: SAW CUT, FLAME CUT, SHEAR; ROUGH MACHINE; AVERAGE MACHINE; SMOOTH MACHINE

SHOP NOTES: UNLESS OTHERWISE SPECIFIED
1. TOLERANCES ± ON DIMENSIONS
2. BREAK EDGES 1/64 MAX.
3. 30° CHAMFER ENDS OF ALL SCREW THREADS
4. 1½ PITCH THREAD RELIEF WITH ROUND NOSE TOOL ON MACH. CUT SCREW THREADS

SHOP ORDERS: NO. ISSUED; SERIAL NOS.; DATE ISSUED; DATE USED; NO. USED; DELIVERED TO

DESIGN JOB NO.

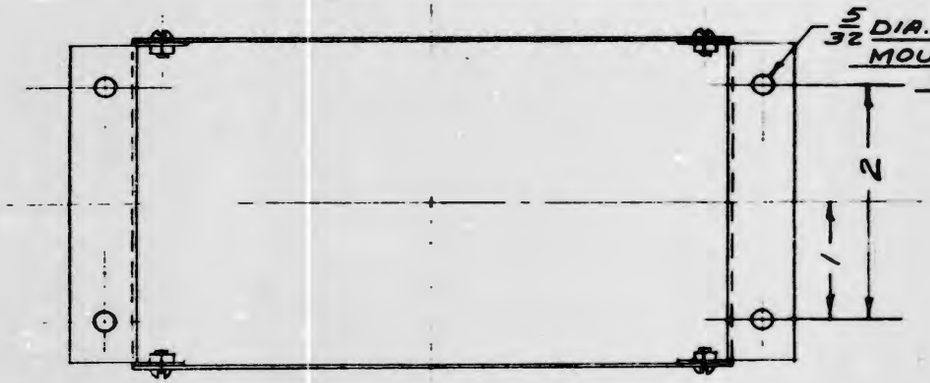
SHOWN ON

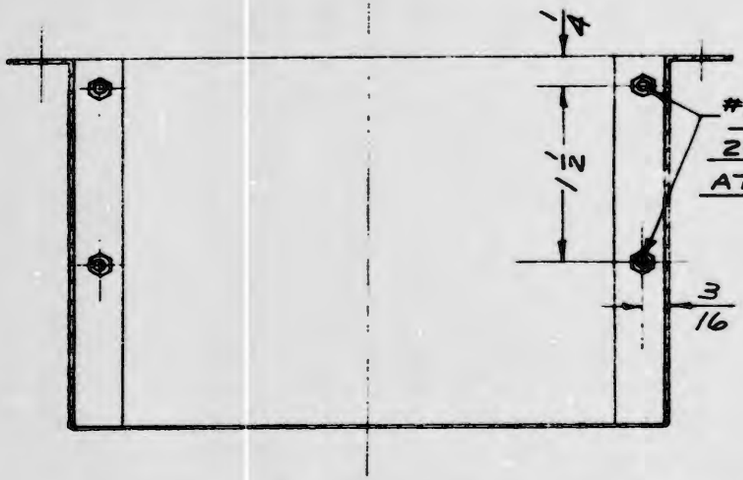
UP CAMERA MOUNT
ANGLO & HAYDON MOTORS
FOR-

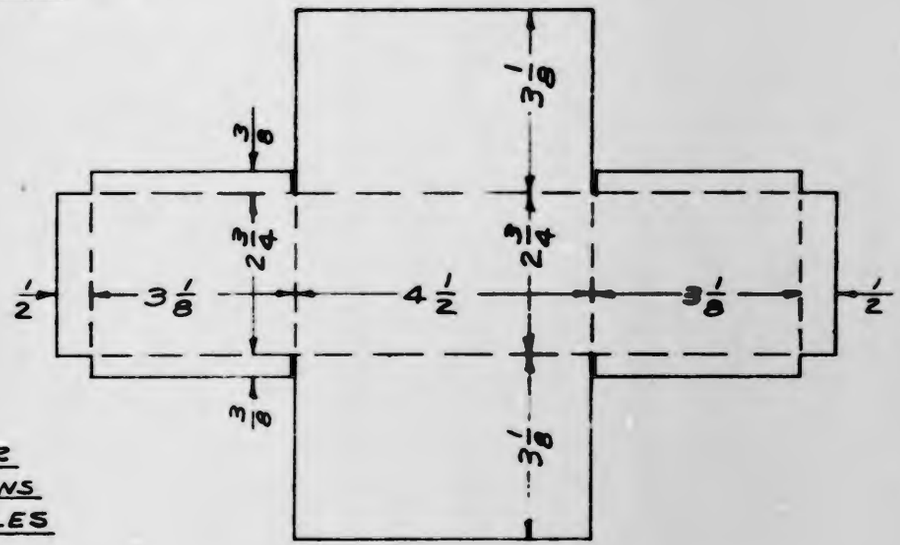
SCALE 1" = 1"
DO NOT SCALE THIS DRAWING
DRAWN BY A. WALSETH DATE 5-6-52
CHECKED BY APPD. BY

DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA MINNEAPOLIS

BA-418B-1





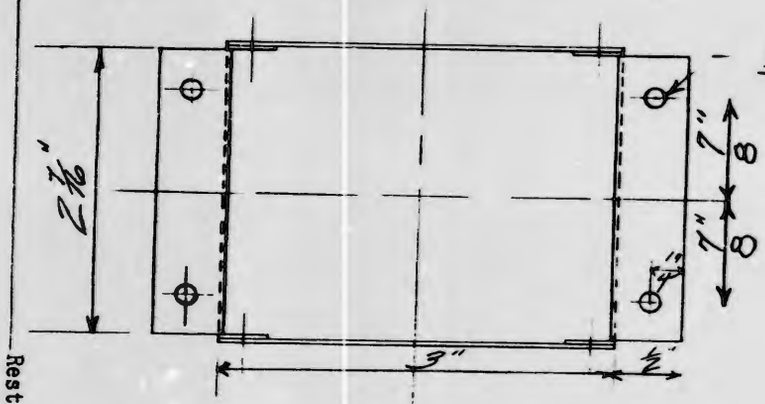


AMGLO MOTOR COVER DEVELOPMENT
MAT'L - .020 ALUM. - 1 REQ'D PER UNIT
SCALE - 1/2" - 1"

RESTRICTED SECURITY INFORMATION

CHANGES	FINISHES	SHOP NOTES	SHOP ORDERS	DESIGN JOB NO	CAMERA MOTOR COVER (AMGLO)
	SAW CUT, FLAME CUT, SHEAR	UNLESS OTHERWISE SPECIFIED	JOB NO.		
	ROUGH MACHINE	1 TOLERANCES ± IN DIMENSIONS	SERIAL NO.	SHOWN ON	FOR -
	AVERAGE MACHINE	2 BREAK EDGES 1/64 MAX.	DATE ISSUED		SCALE 1 = 1 — DEPARTMENT OF PHYSICS
	SMOOTH MACHINE	3 30° CHAMFER ENDS OF ALL SCREW THREADS	DATE REQD		DO NOT SCALE THIS DRAWING — UNIVERSITY OF MINNESOTA MINNEAPOLIS
		4 1½ PITCH THREAD RELIEF WITH ROUND NOSE TOOL ON MACH CUT SCREW THREADS	NO. REQD		DRAWN BY A. WALSETH — DATE 6-10-52 — BA-418-B-2
			DELIVER TO		CHECKED BY — APPR. BY

STANDARD PRINTING CO., WHITEWATER, WIS.

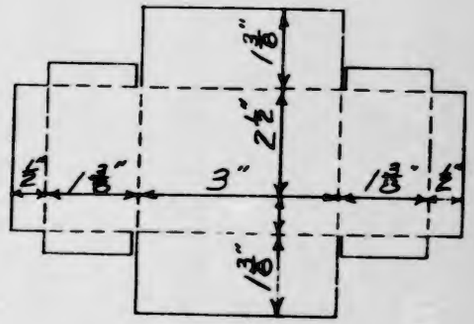


5/32 DIA. DRILL FOR #6-32 N.C. MOUNTING SCREWS 4 HOLES



#43 DRILL FOR 2-56 N.C. SCREWS

SCALE: 1"=1"
MAT'L .020 ALUM.



BRAILSFORD MOTOR COVER DEV'MENT
MAT'L .020 ALUM. - SCALE: ½"=1"

RESTRICTED SECURITY INFORMATION

Change Letter	Drawn By	Check By	Date	CHANGES

FINISHES: Saw Cut, Flame Cut, Shear — Rough Machine — Average Machine — Smooth Machine

SHOP NOTES: Unless otherwise specified
1 Tolerances ± .005 on dimensions
2 Break edges .1 max
3 30° chamfer ends of all screw threads
4 1½ pitch thread relief with round nose tool on mach cut screw thread.

SHOP ORDERS: Job No. — Serial No. — Date Issued — Date Rec'd — No. Rec'd — Delivered

DESIGN JOB No. — SHOWN ON

CAMERA MOTOR COVER (BRAILSFORD)

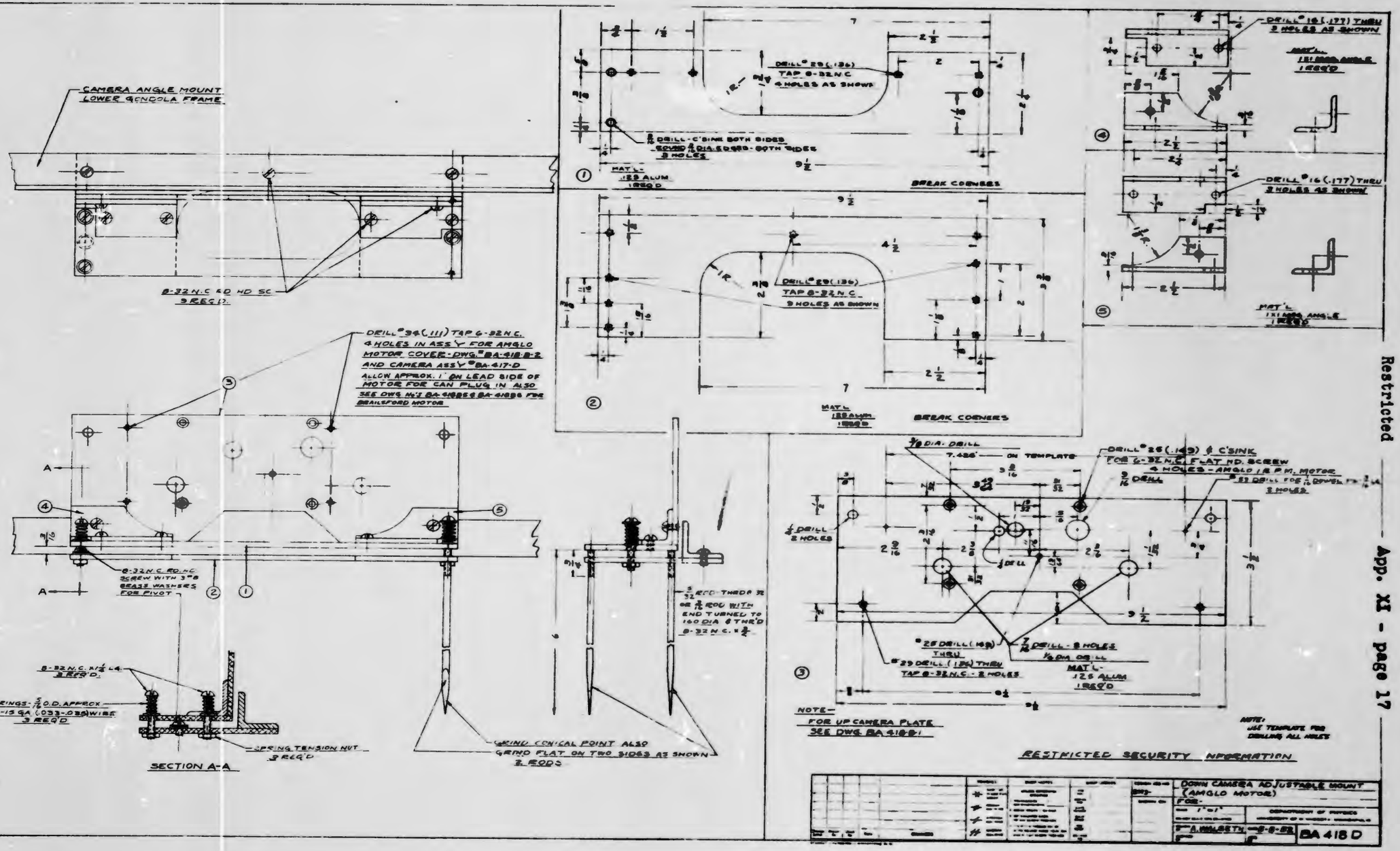
SCALE AS NOTED — DO NOT SCALE THIS DRAWING

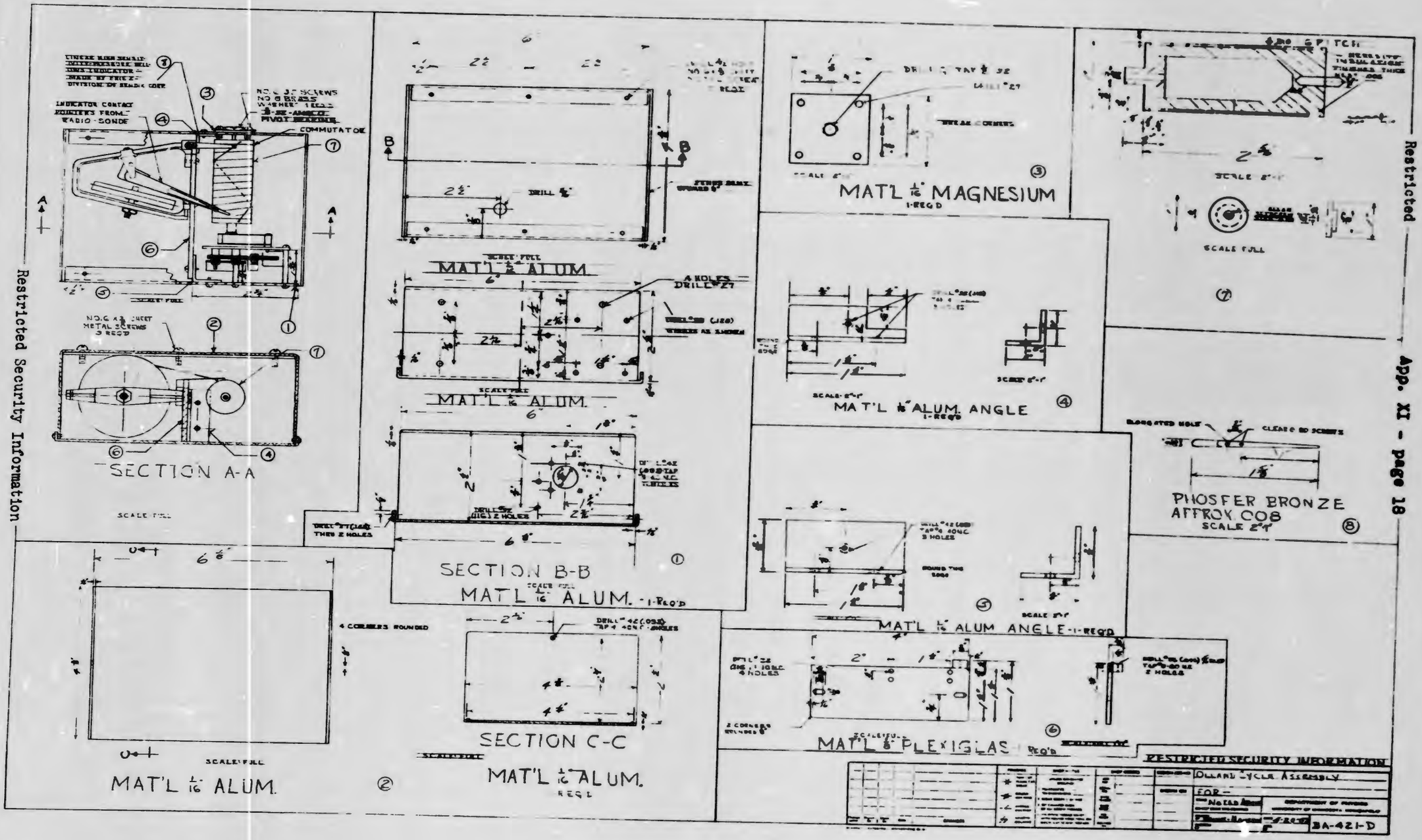
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA MINNEAPOLIS

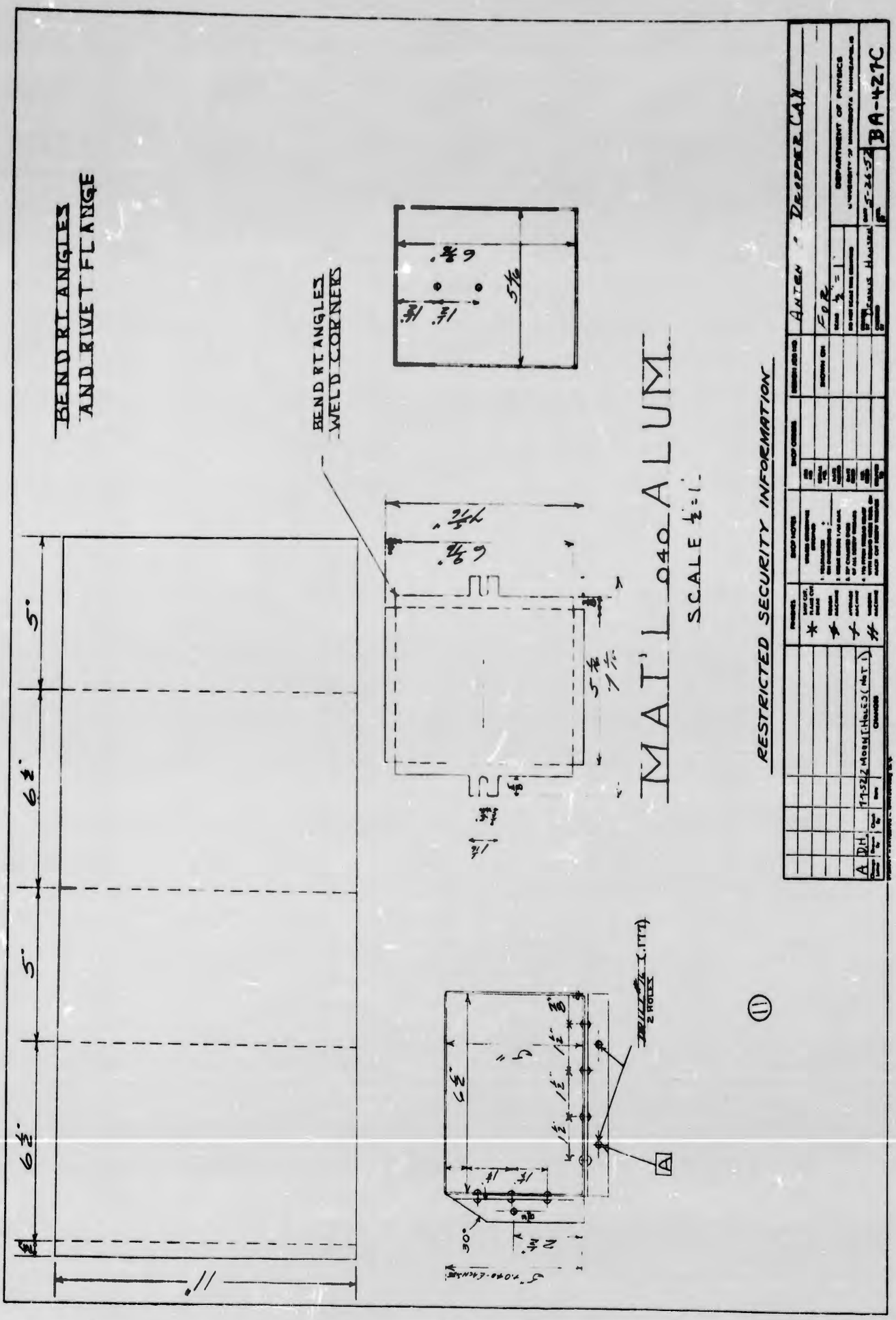
DRAWN BY DENNIS Ha. 56-8 — DATE 7-21-52 — CHECKED BY — APPD BY

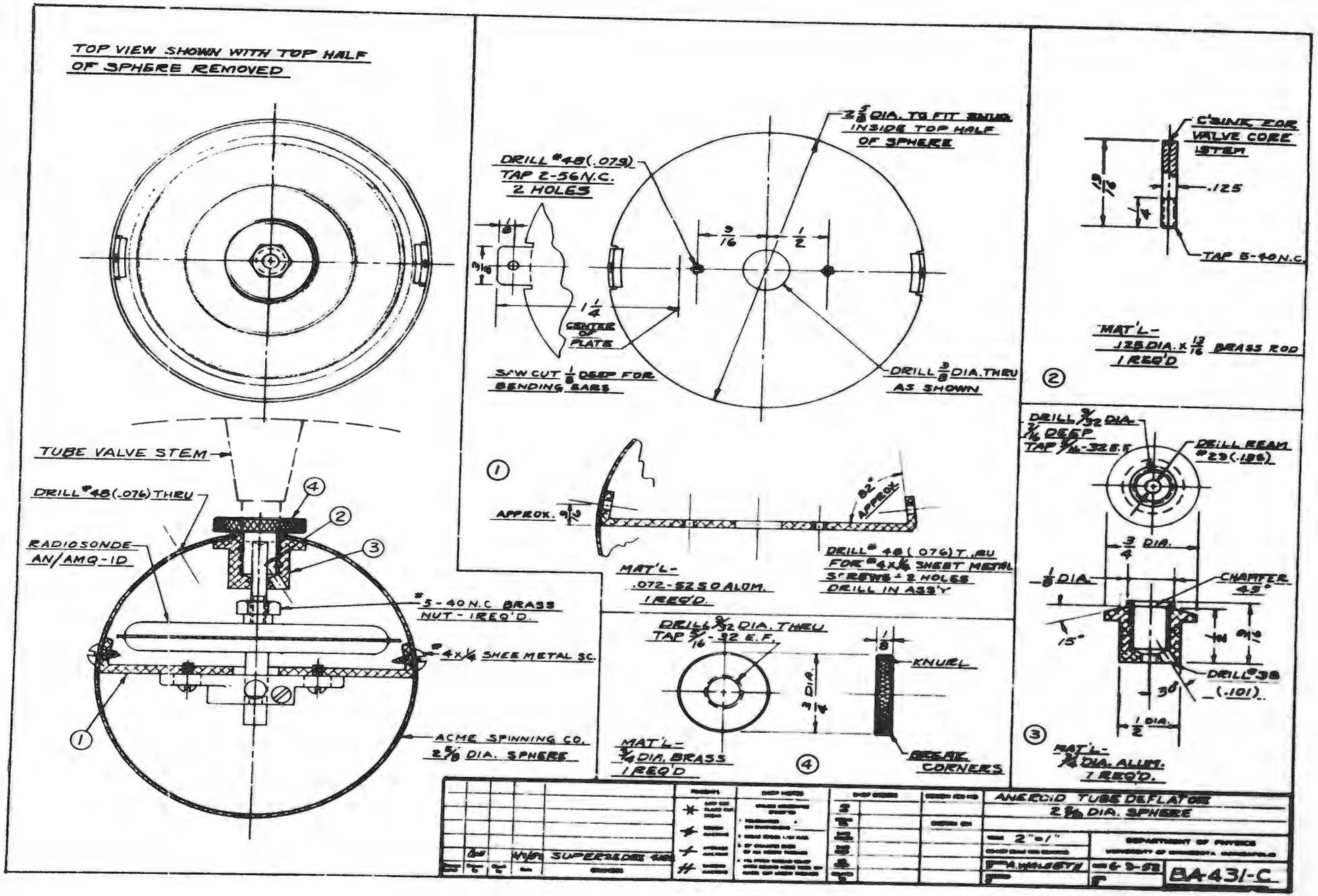
BA-418-B-3

STANPAT — PATENTED — WHITESTONE, N. Y.

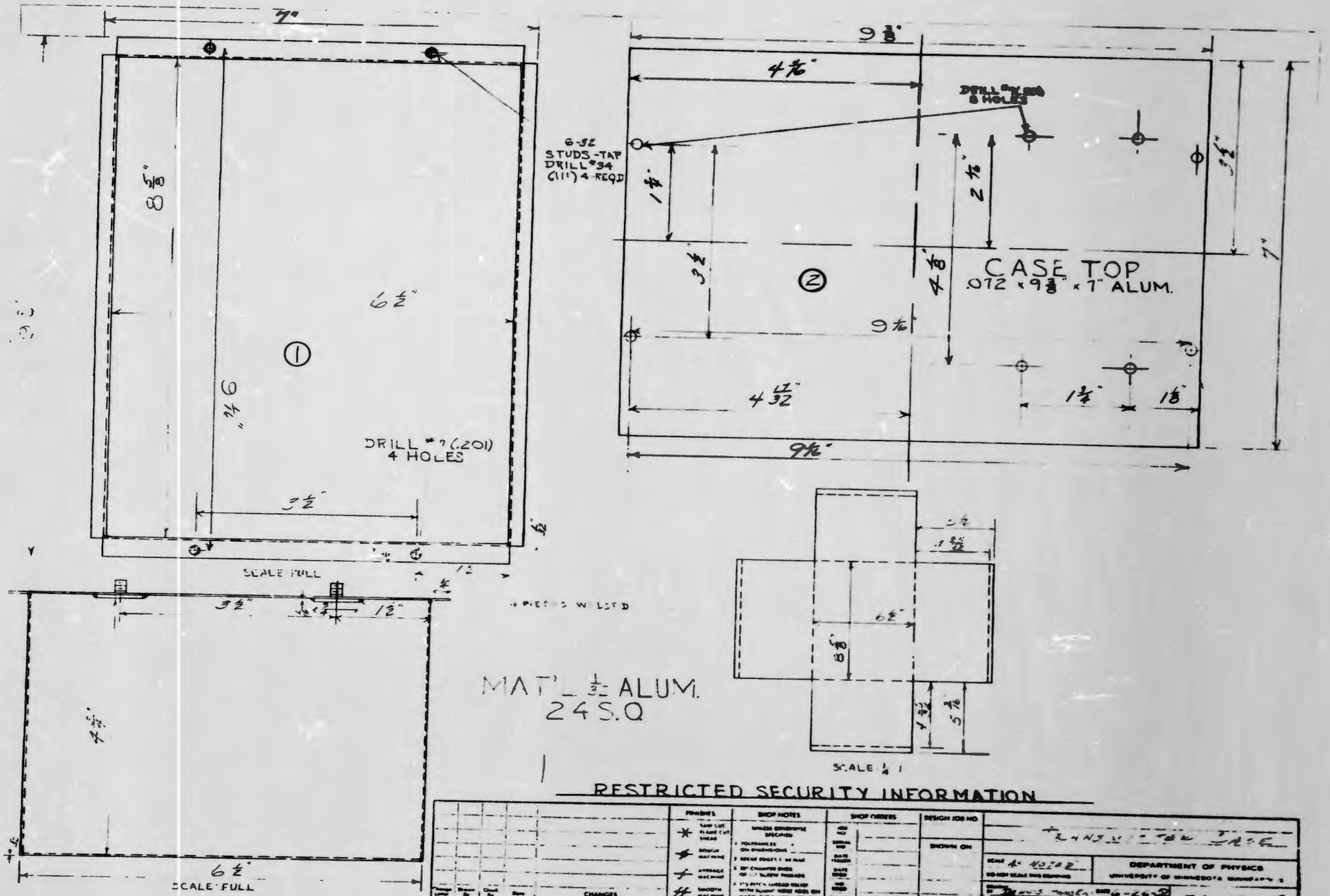

CAMERA ANGLE MOUNT
LOWER GONDOLA FRAME
8-32 N.C 2D HD SC
3 REQ'D
DRILL #29 (.136)
TAP 8-32 N.C
4 HOLES AS SHOWN
DRILL-C'SINK BOTH SIDES
BREAK CORNERS
MAT'L-
12S ALUM
1 REQ'D
DRILL #16 (.177) THRU
2 HOLES AS SHOWN
DRILL #39 (.111) TAP 6-32 N.C.
4 HOLES IN ASS'Y FOR AMGLO
MOTOR COVER-DWG. #BA-418-B-2
AND CAMERA ASS'Y #BA-417-D
ALLOW APPROX. 1" ON LEAD SIDE OF
MOTOR FOR CAN PLUG IN ALSO
SEE DWG. NO'S BA-418B5 & BA-418B6 FOR
BRAILSFORD MOTOR
8-32 N.C RD HD
SCREW WITH 3 #8
BRASS WASHERS
FOR PIVOT
8-32 N.C. X 1/2 LG.
3 REQ'D.
SPRINGS: 7/16 O.D. APPROX
14-15 GA (.033-.035) WIRE
3 REQ'D
SPRING TENSION NUT
3 REQ'D
SECTION A-A
GRIND CONICAL POINT AL30
GRIND FLAT ON TWO SIDES AS SHOWN
2 RODS
7/8 DIA. DRILL
7.484" ON TEMPLATE
DRILL #26 (.147) & C'SINK
FOR 6-32 N.C. FLAT HD. SCREW
4 HOLES - AMGLO 1.8 P.M. MOTOR
#31 DRILL FOR 1/16 DOWEL PIN
2 HOLES
1/4 DRILL
2 HOLES
#28 DRILL (.149)
THRU
#29 DRILL (.136) THEN
TAP 8-32 N.C - 2 HOLES
7/16 DRILL - 2 HOLES
1/8 DIA DOWEL
MAT'L-
12S ALUM
1 REQ'D
NOTE-
FOR UP CAMERA PLATE
SEE DWG. BA 418-B1
NOTE:
USE TEMPLATE FOR
DRILLING ALL HOLES
RESTRICTED SECURITY INFORMATION
DOWN CAMERA ADJUSTABLE MOUNT
(AMGLO MOTOR)
BA 418 D

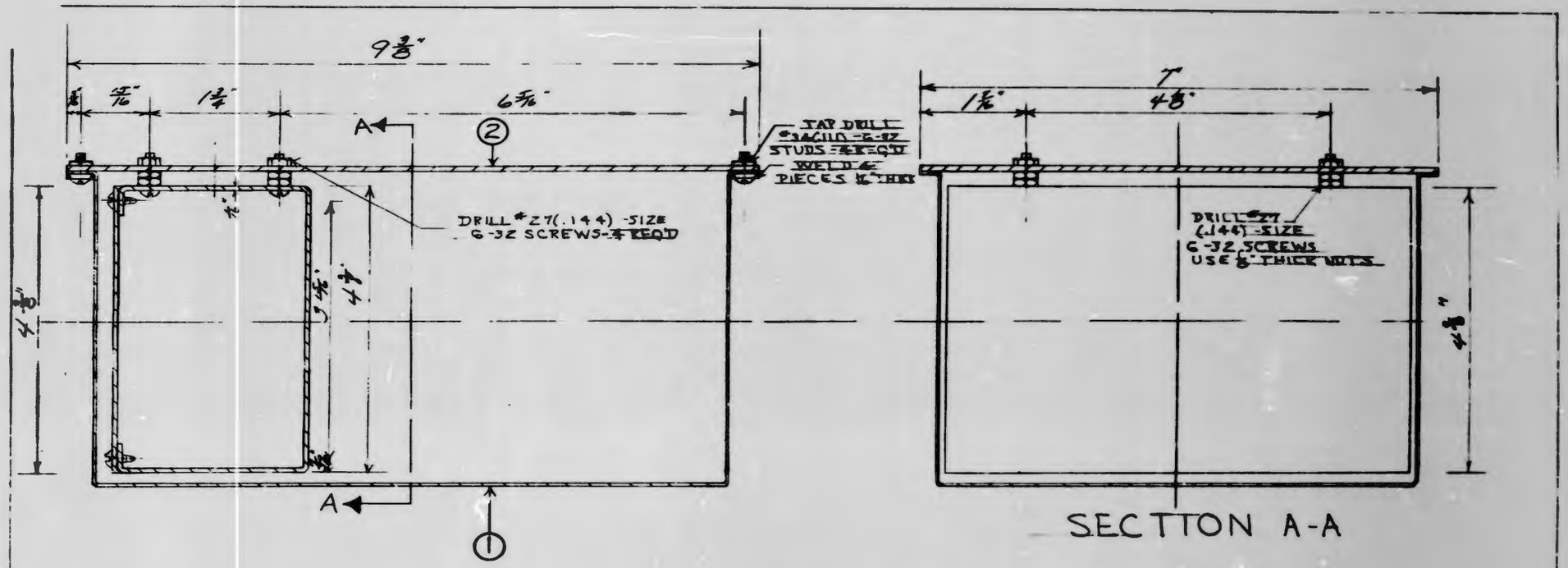

SECTION A-A
SCALE FULL
MAT'L 1/16 ALUM.
SECTION B-B
MAT'L 1/16 ALUM. - 1 REQ'D
MAT'L 1/16 ALUM.
SECTION C-C
MAT'L 1/16 ALUM.
REQ'D
MAT'L 1/16 MAGNESIUM
1 REQ'D
MAT'L 1/16 ALUM. ANGLE
MAT'L 1/16 ALUM ANGLE - 1 REQ'D
PHOSFER BRONZE
APPROX COB
SCALE 2"=1"
MAT'L 1/8 PLEXIGLAS
RESTRICTED SECURITY INFORMATION
OILANT CYCLE ASSEMBLY
BA-421-D


BEND RT ANGLES AND RIVET FLANGE
BEND RT ANGLES WELD CORNERS
MAT'L .040 ALUM
SCALE 1:1
RESTRICTED SECURITY INFORMATION
ANTEN - DEGREE CAN
BA-42IC
DEPARTMENT OF PHYSICS
5
6½
5
6½
11
30°
2 HOLES



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7"
8 5/8"
6 1/2"
9 1/4"
DRILL #7 (.201)
4 HOLES
3 1/2"
SCALE FULL
3 1/2"
1 1/2"
4 7/8"
6 1/2"
SCALE FULL
6-32
STUDS-TAP
DRILL #34
(.111) 4 REQD
9 3/8"
4 7/8"
DRILL #36 (.106)
8 HOLES
1 3/4"
2 1/4"
3 1/2"
3 1/2"
4 7/8"
CASE TOP
.072 x 9 3/8" x 7" ALUM.
9 1/4"
4 47/32"
1 3/4"
1"
9 1/2"
MAT'L 1/32 ALUM.
2 S.Q
SCALE 1/4 1
RESTRICTED SECURITY INFORMATION
DESIGN JOB NO
SHOWN ON
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA
BA-437-C
SHT 1 OF 2

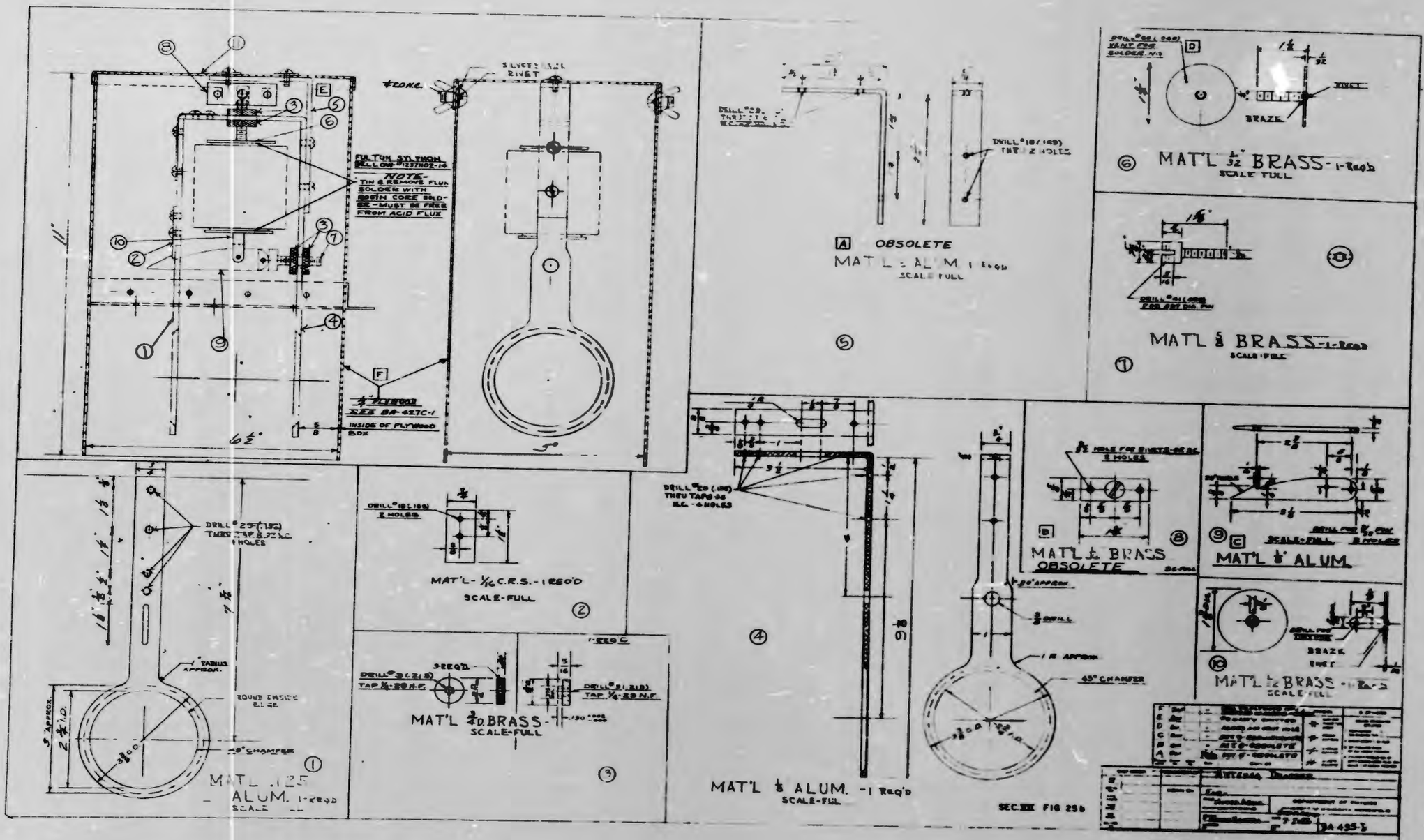


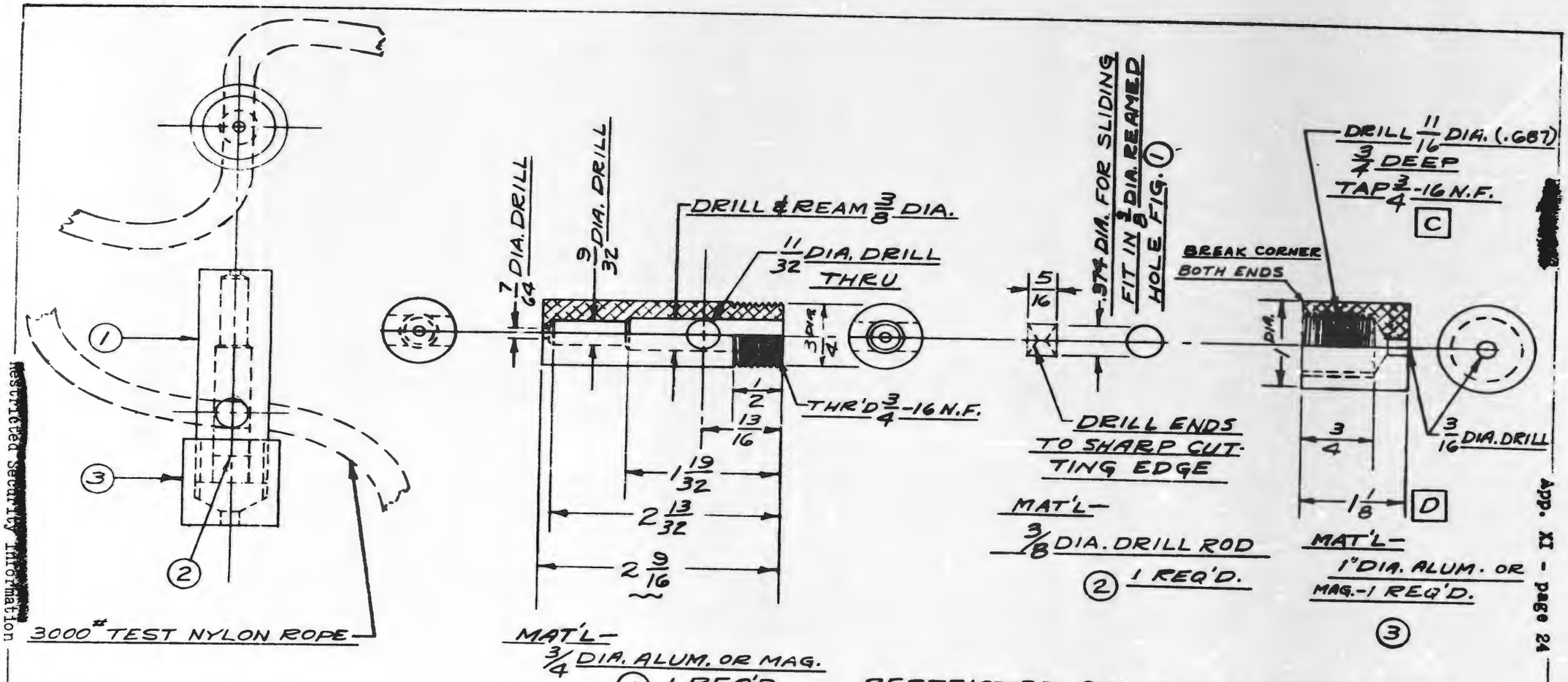
RESTRICTED SECURITY INFORMATION

								TRANSMITTER CASE	
							SHOWN ON	SCALE AS NOTED	DEPARTMENT OF PHYSICS UNIVERSITY OF MINNESOTA MINNEAPOLIS
								DRAWN DENNIS HANSEN	DATE 9-10-52
Change Letter	Drawn By	Check'd By	Date	CHANGES	FINISHES	SHOP NOTES	SHOP ORDERS	DESIGN JOB NO	B A-494 C SHT 2 OF 2

Declassified

App. XI - page 22


NOTE-
TIN & REMOVE FLUX
SOLDER WITH
ROSIN CORE SOLD-
ER -MUST BE FREE
FROM ACID FLUX
INSIDE OF FLYWOOD
BOX
A OBSOLETE
SCALE FULL
BRAZE
SCALE FULL
SCALE-FULL
SCALE-FULL
SCALE-FULL
SCALE-FULL
SCALE-FULL
OBSOLETE
SCALE-FULL
SCALE-FULL
SCALE-FULL
SEC. XIII FIG 25b
DA 425-1



MAT'L— 3/4 DIA. ALUM. OR MAG.
(1) 1 REQ'D.

MAT'L— 3/8 DIA. DRILL ROD
(2) 1 REQ'D.

MAT'L— 1" DIA. ALUM. OR MAG.-1 REQ'D.
(3)

RESTRICTED SECURITY INFORMATION

D	JW.		7/29/52	WAS 1-TO 1 1/8 LONG
C	JW.		10/28/52	CONE [B] CHANGED TO 11/16 DRILL-3/8 DEEP
B	D.H.		8/25/52	DRILL CONE IN CAP 3/4 DEEP
A	JW.		7/24/52	3/32 CAP END WALL TO 7/32
Change Letter	Drawn By	Check By	Date	CHANGES

FINISHES: * SAW CUT, FLAME CUT, SHEAR; ** ROUGH MACHINE; *** AVERAGE MACHINE; **** SMOOTH MACHINE

SHOP NOTES: UNLESS OTHERWISE SPECIFIED
1. TOLERANCES ON DIMENSIONS ±
2. BREAK EDGES 1/64 MAX.
3. 30° CHAMFER ENDS OF ALL SCREW THREADS
4. 1½ PITCH THREAD RELIEF WITH ROUND NOSE TOOL ON MACH. CUT SCREW THREADS

SHOP ORDERS: JOB NO.; SERIAL NO.; DATE ISSUED; DATE DUE; NO. REQD.; DELIVER TO

DESIGN JOB NO.

SHOWN ON

- SQUIBB CANNON -
3000# ROPE
FOR —

SCALE 1=1
DO NOT SCALE THIS DRAWING
DRAWN BY A. WALSETH DATE 7-14-52
CHECKED BY APPD. BY

DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNEAPOLIS

BA-438B

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AD 7599

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