2. Manual of Photogrammetry, American Society of Photogrammetry, 1952.
3. Church, Professor Earl F., Bulletins Nos. 15 and 19 on Aerial Photogrammetry; Syracuse University, Syracuse, New York, 1945, 1949.
4. Shewell, H. A., "The Use of the Cambridge Stereo Comparator for Air Triangulation"; *The Photogrammetric Record,* London, Vol. II, September, 1953.
5. Herget, Paul, "Interim Report on Ground Position Computation from Shoran-Controlled Photography"; *WADC Technical Paper* 179, Wright Air Development Center, January, 1954.
6. Schmid, Helmut H., "An Analytical Treatment of the Problem of Triangulation by Stereo Photogrammetry"; *Ballistics Research Laboratory Report* 961, October, 1955.
7. Anderson, Ralph O., "Photogrammetric Control Extension"; Edwards Brothers Inc., Ann Arbor, Michigan, 1947.
8. Merritt, E. L., "Control Extension with Ground Control at the Flight Ends, and Control Extension Based on Shoran Established Nadir Points"; Photogrammetry Inc., Silver Spring, Maryland, 1954. Air Force Contract No. 33(616)-2140.
9. McNair, A. J., Shu, C. S., Moeller, C. M., and Rutledge, J. R., "Reports on Analytical Aerial Triangulation" for U. S. Army Engineer Research and Development Laboratories; Cornell University, 1955, 1956.

*Strato-Lab Balloon Photography**

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Abstract: *An account is presented in narrative form of the first-known attempt to obtain and utilize mapping-photography taken from an altitude considerably in excess of the operational ceiling of present-day reconnaissance aircraft. A free-flight unmanned plastic balloon was used to carry a mapping camera aloft in a pressurized gondola to an altitude of approximately 89,000 feet. The results of limited photogrammetric instrument tests which were conducted using this photography are given along with general observations on photographic quality and the amount of detail obtainable.*

As the operational ceiling of modern aircraft is steadily increased, it becomes increasingly important that investigations be conducted on the feasibility of utilizing very high-altitude photography in the preparation of charts and topographic maps. In the field of commercial mapping the problems which may be encountered in mapping from high altitudes are understandably of little or no concern, certainly at the present time. In this field the flight altitude can readily be adjusted as dictated by the precision of the methods and equipment employed to meet the particular map-accuracy requirements. This is not the case, however, with the military. The situation may arise in which mapping-photography, must, of necessity, be taken from extremely high altitudes. Then, too, with the advent of more precise plotting equipment it is conceivable that in the not-too-distant future, mapping from extremely high altitudes could become economically feasible even from a commercial standpoint, especially for small-scale mapping. Up to the present time no high-altitude mapping-photography has been available to test the feasibility of employing present mapping methods and equipment in the preparation of maps. As a result, estimates of the capabilities of present mapping equipment at altitudes of 50,000 feet, and above, have been obtained for the most part through extrapolation from data obtained at lower altitudes. Obviously, this leaves much to be desired.

Data derived from theoretical studies on the effects of atmospheric haze and refraction upon high-altitude photographs are invaluable, but this does not alleviate

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the need for actual test photography.

As conditions at high altitudes have unfolded unique problems in the realm of aero-medicine which were not encountered at low altitudes, likewise, there may be hidden obstacles awaiting the aerial photographer and the photogrammetrist. It is entirely possible that the conventional mapping cameras or some of the auxiliary equipment will, for some unforeseen reason. not function properly at extremely high altitudes, thereby necessitating the development of new equipment. On the other hand, it may be found that conventional mapping cameras will suffice. In this case successful mapping from stratospheric regions would hinge upon the development of high-altitude reconnaissance aircraft and more accurate photogrammetric plotting equipment and methods.

In anticipation of a need for means of maximum exploitation of extremely high-altitude photography in the future, advantage was taken of a rare opportunity to obtain a limited amount of experimental mapping-photography from altitudes considerably in excess of the operational ceiling of present day reconnaissance aircraft. Because the number of photographs obtained, which were suitable for photogrammetric evaluation, was extremely limited, the results of the investigation are by no means conclusive. The data acquired, however limited, and the manner in which the photography was obtained, should be of considerable interest to photogrammetrists since this is the first known attempt to obtain and utilize mapping-photography taken from such high altitudes.

In February 1955 the Engineer Research and Development Laboratories was given the opportunity to obtain very high altitude mapping-photography by participating in the Navy STRATO-LAB program. This program, which was designed to facilitate research from a manned "space" laboratory attached to a plastic balloon, afforded a unique opportunity to obtain experimental mapping-photography from an altitude far above any previously attained with mapping cameras.

ERDL cooperated with the Office of Naval Research and its contractor, Winzen Research, Incorporated, Minneapolis, Minnesota, in the planning and execution of a photographic mission in which a standard 6-inch focal-length T-11 mapping camera was mounted in a 30-inch diameter pressurized gondola and carried aloft by a free-flight plastic balloon to an altitude of approximately 89,000 feet. This particular flight was one of the feasibility demonstration flights in the STRATO-LAB system development program. Although much of the photography was not usable because of the rotational position of the camera at time of exposure, fogging of the film, or excess cloud cover, a sufficient amount of clear stereo-coverage over a recently mapped area was obtained to permit photogrammetric instrument testing of several stereo-models.

The material comprising the balloon itself was polyethylene plastic film only 0.002 inch thick. The material, which is available in continuous sheets up to 9 feet in width, was cut and pieced together so that, when fully inflated with helium, the balloon would take the general shape of a sphere with a conical lower section. The balloon was $92\frac{1}{2}$ feet in diameter with a total volume of 427,500 cubic feet. A diagram showing the balloon, the pressurized capsule containing the camera, and a radio beacon used in tracking the apparatus is presented in Figure 1.

The camera was rigidly mounted in a 30-inch diameter spherical gondola which was in turn suspended below the balloon using an unpacked but collapsed parachute as a means of suspension. The top of the parachute was connected to the apex of the lower conical surface of the balloon through a mechanism which auto-

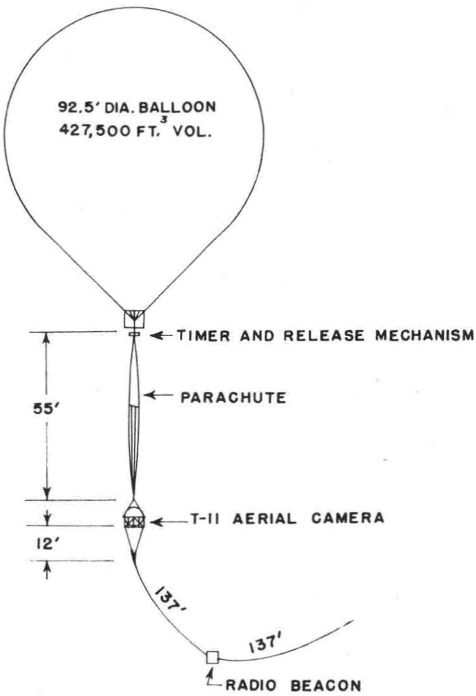

FIG. 1. The Strato-Lab vehicle which was used to obtain mapping photography from an altitude of approximately 89,000 ft.

matically released the balloon and permitted the gondola to parachute back to earth after a preset time lapse.

The gondola assembly is shown in Figure 2 being made ready for the flight. The gondola shell, which was fabricated of spun aluminum in two sections, was completely sealed following the installation of the camera. Storage batteries were supported above the top half of the sphere by means of a special battery rack. These batteries supplied electrical power for operation of the intervalometer, camera cycling, and for operation of the vacuum pump. The vacuum pump, which provided vacuum for flattening the film against the camera back, was turned on 6 seconds prior to each exposure, and shut off immediately following the exposure by a circuit of relays. This was done to conserve power and to effect a savings in weight by reducing the number of storage batteries to be carried aloft. The top half of the sphere also contained an electrical pass-through which was the sole connection to the outside of the sealed gondola. The bottom half of the sphere contained the camera window, the camera with its auxiliary equipment, and, on the outside, a shock absorbing structural framework for protection of the window and camera upon landing. Selective painting of the gondola helped to maintain the ambient temperature within reason, so that neither the film nor the camera operation would be adversely affected.

The glass used for the camera window was a plane parallel glass blank 1 inch thick and 10 inches in diameter. The mounting flange with sealing gaskets utilized a $\frac{1}{2}$ inch portion of the outer circumference, leaving a 9-inch diameter opening. The glass blank, which was purchased from Optron Laboratories, Dayton, Ohio, was not originally ground for this specific purpose, but it possessed all the required optical characteristics. It exceeded the specifications for "Group M" camera windows, the most accurate used by the Air Force, which calls for parallelism of 4 seconds of arc and flatness to $2\frac{1}{2}$ fringes of mercury light. This particular window was parallel to 4 seconds of arc and flat to $\frac{1}{4}$ fringe of mercury light.

A view of the bottom half of the gondola, showing the camera with magazine removed, is shown in Figure 3. The camera was rigidly mounted with adjustments for proper positioning relative to the window. This simple type of rigid mount was decided upon after serious consideration had been given to various means of camera stabilization. Of primary concern was the uncontrolled rotation about the vertical axis of the balloon and camera between exposures. Such a random rotation could result in "crabbing" to such an extent that the photography would be practically useless for photogrammetric work. Because of the complexity and added weight of a satisfactory stabilizing system the idea was given up in favor of short exposure intervals, thereby obtaining a large number of photographs from which stereopairs could be selected with the desired overlap and base-height ratio. This latter method proved to be very successful.

The balloon was launched at 5:23 A.M. CST on 1 June 1956 from a point near Minneapolis, Minnesota. The actual launching is shown in Figure 4. Although the envelope was only partially inflated at the time of launching, it became fully expanded at ceiling as a result of the decrease in atmospheric pressure.

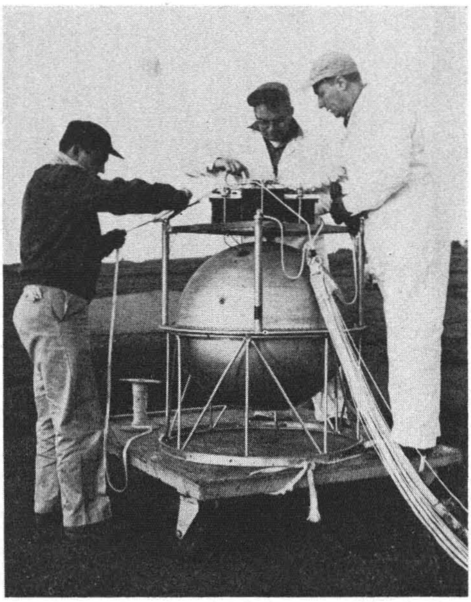

FIG. 2. The sealed spherical capsule, containing a T-11 6-inch Metrogon camera, is being made ready for the flight. A rack containing storage batteries straddles the top half of the sphere, and a shock-absorbing structural framework was built around the bottom half.

Figure 5 shows the balloon immediately following its release as it began its ascent at an average rate of 675 feet per minute. It drifted southward approximately seventy-five miles to the vicinity of Albert Lea, Minnesota, before reaching an altitude of 70,000 feet. At this point camera operation was begun automatically by a delayed action starter. The intervalometer began cycling the camera at regular two-minute intervals. The ascent to approximately 89,000 feet was quickly made and the balloon then leveled off and remained at or near this ceiling for 7 hours and 25 minutes.

After following roughly a west-southwest course for a distance of approximately 125 miles the balloon was released, the gondola and camera descended by parachute, and were recovered. Recovery of the camera was made immediately upon impact about two miles north of Marcus, Iowa, at 3:40 P.M. on the afternoon of the day of launching. Some damage was suffered by the gondola on impact due to landing in a tree but the camera was undamaged.

The majority of the exposures were made in the vicinity of 88,000 feet on Kodak Aerographic, Type Ia, Class L film, at a setting of f/11 at 1/150 of a second. Because a red filter matching the optical characteristics of the camera was not available, a minus blue filter was used. The film was processed in D-76 developer for about 30 minutes. The first thirty exposures of the roll contained scattered cloud cover, and the end of the roll was fogged, apparently during unloading of the film. The remainder of the film, containing approximately 150 exposures, was acceptable, but of slightly less density than desired.

The indications were that the rate of drift was quite constant after the balloon had leveled off near the 88,000 foot level. The two-minute exposure intervals provided an average forward gain of slightly less than one-half mile between exposures, indicating a ground speed of approximately 15 miles per hour. The photography showed a continuous rotation of the balloon and camera but did not reveal any appreciable deviation of the camera axis from the vertical. The normal base-height ratio for vertical photography could be achieved in most cases through the selection of approximately every twentieth exposure. The number of satisfactory stereo-pairs that could be selected, however, was greatly reduced by the random rotation of the balloon, and the resulting variations in camera orientation relative to the flight line.

The wind currents were such that the balloon was carried over only one small area containing sufficient ground-control for photogrammetric instrument evaluation of the geometrical characteristics of the photography. Due to random camera orientations, only three stereo models at all suitable for the purpose could be found. The best model of the three was selected for a terrain model flatness test using a Wild A-7 Autograph. This model contained approximately 20 per cent cloud cover and had the rather low base-height ratio of .51. The scale of the photography was approximately 1:175,000 and, using 2.5 times enlargement in the instrument, the stereo model scale was established at 1:70,000.

The model was oriented to horizontal and vertical control selected from the Albert Lea quadrangle, USGS, 1:62,500 scale. Four photo identifiable horizontal points and 66 spot elevations were selected.

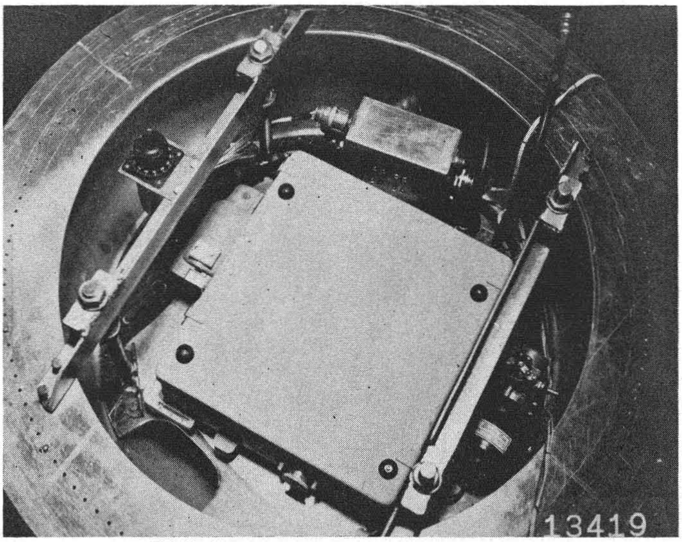

FIG. 3. A top view of the camera, with magazine removed, showing the top of the camera and some of its auxiliary equipment.

After scaling and leveling, the instrument elevation of all vertical check points were read and corrected for earth's curvature. After a conversion of the corrected instrument elevations to feet and a comparison with the map elevations, it was noticed that a very slight tilt correction to the level solution was desirable. This condition was believed to have been brought on by the combined effects of earth curvature and the assymmetric location of the level points. A mathematical tilt correction and re-index was performed. The root mean square error was found to be 12.89 feet or about 1/6,800 of the exposure altitude.

It is believed that compilations could be successfully accomplished, although none were attempted because of the lack of ground relief in the test area. The large amount of earth curvature encountered at such high altitudes, could conceivably have some effect on compilation accuracy since the corrections are very critical, especially at the model extremities. Because the earth's curvature is not automatically compensated in standard plotting equipment, compilations could become more tedious and time consuming, and perhaps decrease in accuracy as the exposure altitude is increased. Corrections for spot elevations read during flatness tests are not difficult to make, but the rapid fall-off at the model extremities would require frequent index corrections during contouring, making automatic compensation almost a necessity.

The tilt of both exposures used in the model flatness test was found to be less than 1 degree, indicating that the gondola, as supported by the balloon, was quite stable. The plotting instrument was also used to determine the exposure altitude of both photographs. One exposure was found to have been made at 87,000 feet above sea level and the other at 88,400 feet. This confirmed the balloon track data which indicated that the balloon had reached its maximum altitude of about 88,800 feet, in the vicinity of these two exposures.

Several of the cloud-free models were studied with a hand stereoscope to determine the general features that may be identified on photography of this scale. Adequate topographic maps to confirm identification were not available to permit the gathering of numerical data on photo identification, However, the following observations were made:

a. All major roads and railroads appear to have been resolved and were identifiable.

b. Many farm roads were identifiable.

c. In built-up areas, normal dwellings and business establishments could not be individually identified. Identification in these built-up areas was limited to deter-

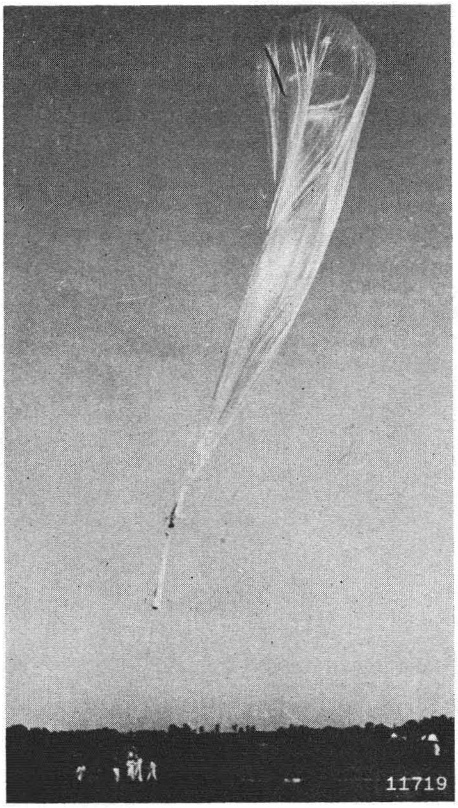

FIG. 4. The actual launching.

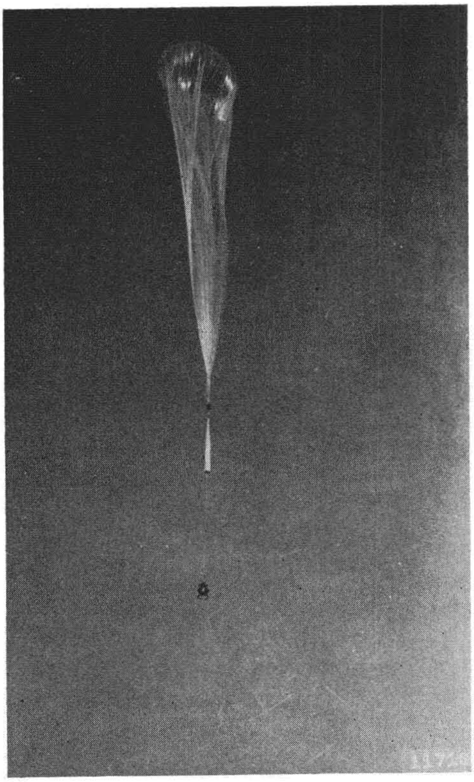

FIG. 5. The gondola, parachute and balloon immediately following its release.

mining approximate density of the buildings. Minor streets were not generally discernible.

d. Groups of farm buildings could be identified. The individual buildings could not be seen, but the typical farm dwelling area of several buildings and trees could be identified as a unit.

e. Vegetation, in general, could be identified only by tone and texture. Relief of vegetation was not visible.

f. The identification of ground detail appeared to be limited solely by the small scale of the photography. No evidence was present to indicate that other high altitude conditions reduced the ability to record ground detail.

If serious consideration is ever given to mapping from stratospheric regions, either because of a military necessity or because the development of more precise plotting instruments and techniques make it economically feasible for small-scale mapping, certainly, additional experimental photography must be obtained. Photography must be obtained which would permit tests to determine the effectiveness of aerotriangulation as well as compilations. If the camera is carried aloft by a balloon, provisions must be made for obtaining the proper overlap between successive photographs to insure adequate stereo-coverage. The utilization of a free-flight unmanned balloon as the camera vehicle, with the camera rigidly attached, leaves many elements of success of the photographic mission to chance.

The photography obtained on this first attempt, although not up to usual photographic standards, may be considered as a successful completion of the photographic mission for it has permitted the first testing of photography at this altitude in photogrammetric instruments.