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Proceedings of the AFCRL Scientific Balloon Symposium

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Proceedings of the AFCRL Scientific Balloon Symposium

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Abstract

Sixteen of the twenty papers presented at the Symposium are herein published. They provide a reasonable balance between balloon-borne experiments and recent developments of balloon technology. Balloon technology presentations include plastic balloon capabilities, both in-being and projected, current shape studies for new designs, a survey of sensing elements for the balloon environment, and the development of a new heavy load balloon material. Two balloon astronomy programs and related stabilization systems are presented, as is the case for manned balloon astronomy. Other scientific applications of balloons include atmospheric optics and atmospheric sampling programs, jet stabilization of a balloon gondola, and the ROBIN and ROSE balloon systems. Other types of balloons discussed are tethered balloons, hot air balloons, and the neoprene vertical sounding balloon.

Contents

PROCEEDINGS OF THE AFCRL SCIENTIFIC BALLOON SYMPOSIUM

I Introduction

Robert M. Slavin
Chief, Aerospace Instrumentation Laboratory
Air Force Cambridge Research Labs

In a nation where, in the past five years, the technology of rockets, missiles, satellites, and if I may, astronauts, has captured the imagination of the scientist, engineer, and academician, the hearts of the entire population, and the lion's share of the tax dollar, the science of ballooning has made tremendous strides forward with no national recognition by the scientific community, the principal user of the balloon. The purpose of the Symposium is to re-introduce the scientific community to the capabilities of the plastic balloon, through a free exchange of ideas and information concerning balloon-borne scientific experiments and a review of recent developments in balloon materials, design, and instrumentation.

But first, a word on who we are and what we do. Our Balloon Group at AFCRL has existed as a unit for approximately thirteen years. Our overall responsibility has been the design of balloons, companion instrumentation and launch procedures to meet both the operational and scientific needs of the Air Force. In 1962, our mission was expanded with the acquisition of the balloon activity at Holloman AFB, New Mexico. The subsequent establishment of the Research and Development

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Test Branch at Holloman has brought us into more frequent contact with scientists formulating and preparing balloon experiments and with governmental agencies interested in the functional testing of rocket and satellite components. The Holloman launch site and its adjacent White Sands Range facilities, when combined with our Chico, California launch site, enables us to launch scientific balloon payloads year round with tracking, control, and recovery capability.

The subject matter of our Symposium can be broken down into four general areas. Balloon Technology, Scientific Uses of Balloons, Balloon Astronomy as a Specific Use, and Unique Types of Balloons. Each of the speakers has been selected because of his contribution to the advancement of science through research and development, using balloons. Of course, as we all know, the government, through its many agencies, supports most balloon research programs, either directly, or indirectly through grants and contracts. So it can be said that, as taxpayers, we all have had a part in the development of balloon technology and its increased application to scientific research.

I hope that this symposium will provide a reasonable balance between balloon borne scientific experiments and the more recent developments in balloon technology, and that each of you will find the time spent here to be rewarding.

II Balloon Capabilities and Futures

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Abstract

A resume of the present load/altitude capabilities of plastic balloons, including taped and tapeless polyethylene, Mylar-scrim, superpressure, and air-launched, is presented. Objectives of present research in balloon technology are described: namely, extensions of present altitude and load limits through material and design studies, increased reliability, longer duration and reduced costs of very heavy-load balloons.

1. INTRODUCTION

If you take a moment to peruse the program, you will find that this session is entitled, "Balloon Capabilities and Technology". The afternoon session tomorrow and the talk by Dr. Ross on Friday morning will be concerned with specific aspects of the same general topic. The discussions of balloon technology will deal entirely with the various types of plastic balloons, both free and tethered, and will include space inflatables.

Within the scheme of things, this is a technology of comparatively recent vintage--a product of cooperative university, contractor, and governmental efforts during the past fifteen years. Prior to World War II scientific ballooning as we know it today was confined to an exceedingly small number of projects which were severely limited by the rather expensive and heavy rubberized fabrics in use at the time. Some of you may recall the flights of the Explorers I and II, and the several flights of Dr. Picard and his wife. Each individual flight was a scientific undertaking of major proportions.

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After the War, the advent of commercially available plastic sheeting of comparatively high quality made the creation of inexpensive balloons for high-altitude experimentation a most attractive possibility. The early work by General Mills, New York University, and others was largely successful, and this success with rather light payloads created a burgeoning of demands for vehicles to carry heavier payloads to higher altitudes for longer durations. With heavier payload flight came problems which dramatized the need for more detailed materials data, for improvements in fabrication techniques and flight control instrumentation, and for a clearer understanding of the dynamics and thermodynamics of flight.

In 1951, a tri-service contract was initiated with the University of Minnesota to study the physics of ballooning. This study, together with independent work at Tufts University under Dr. Howell, work by the balloon manufacturers, and an active in-house program undertaken on a continuing basis by the Air Force, has provided the technological framework within which we operate today.

Surely there are still unsolved problems, but the rapidity with which the technology has advanced can be judged from the fact that in the late 40's payloads were limited to the few hundred-pound range, altitudes to 100, 000 feet, and durations less than one day; whereas today, payloads exceeding 5, 000 pounds, altitudes above 140, 000 feet, and flight durations to 30 days have been achieved. Balloon-borne experiments not possible ten years ago are now conducted on a virtually daily basis.

1.1 Foreign Balloon Technology

Before launching into the specifics of my talk, I have two items which may be of general interest. I find, in my contacts, that most people assume that ballooning is now a wholly American institution and that at the present time, virtually all of the world's scientific ballooning is being done in this country. Of course, this simply is not so. During the past two years, balloon-borne scientific experiments have been flown in France, India, and Australia, relating to problems in meteorology, atmospheric composition, atmospheric structure, and astronomy. You may remember an article and pictures in LIFE magazine several years ago, showing Professor Dolfus of the Paris Observatory using an enormous cluster of rubber balloons as the vehicle for a manned astronomy experiment. The Soviets have also been involved with balloon experimentation. One article released in February of this year discussed an experiment much like the extended parachute jump of Captain Joseph W. Kittinger Jr. Let me read just a short excerpt: *

"On 31 October 1962, at 7:40 a.m., the aerostat, "Volga", with Col. P. Dolgov and Maj. Ye Andreyev aboard, lifted off. Andreyev was scheduled to make a

*Romanyok, V., Kryl'ya voding, No 2, Feb 1963, 12-13.

delayed-release jump, while Dolgov, holder of the Order of Lenin for testing and perfecting the outfitting of the cosmonauts, was to test a parachute system he had developed and which, in earlier tests with a dummy, worked faultlessly. At an altitude of 13,000 m. the temperature was -65°C. By 10.09 am the Volga had attained the scheduled jump altitude of 25,458 m. The atmospheric pressure at this altitude was 18mm Hg. At 10.13 am Andreyev left the gondola dropping 24,500 m in 270 seconds. His rate of fall through the rarified atmosphere was 900 km/hr. Andreyev's parachute opened at an altitude of 958 m. With this jump, Andreyev demonstrates that although difficult, it is possible to control one's body in free fall from the stratosphere and not use a stabilizing parachute. Dolgov, who left the gondola 1 min 18 sec after Andreyev, jumped from an altitude of 25,608 m; his parachute opened immediately, as scheduled. However, upon touchdown, 38 minutes later, Dolgov was dead (cause of death not given)."

In another article, the Soviet interest is expressed in one of the many potentials of the tethered balloon. To quote from the translation:*

"A group of Soviet Engineers - I. Spitsyn and R. Gokhman, both of them aviators, with the cooperation of Lev Konstantinov, Candidate of Technical Sciences, Vladimir Ustinov and G. Vaynshteyn - conceived an idea of using the energy of winds blowing in the tropopause, the discontinuity surface separating the stratosphere from the troposphere. The tropopause varies in height from about 55,000 ft at the earth's equator to 25,000 ft above the poles.

Scientists found that in the tropopause, in a comparatively thin layer of air, about 1 to 1-1/2 miles thick, extremely strong winds are blowing permanently with an energy 1000 to 2000 times greater than near the ground. Wind velocity amounts there to 80 up to 100 ft/sec. These truly inexhaustible resources of wind energy attracted the attention of the authors of the project of a "Tropopause Wind-Electric Power Station". The technical solution of such a power station presents innumerable difficulties. In all of the many variants of the projected station, it has to be carried out by an aerostat. Considering the weight of about 30 tons of such a 1.5 to 2 mw station, the aerostat would have to be about 330 ft long. The problem of maintaining such a station above a certain point of the earth is hard to solve considering the length of the cable which, if made of steel, could not sustain its own weight. Only synthetic cables could be used, for example enanthic or polypropylene ropes whose rupturing capacity exceeds 40 to 50 miles.

Other problems to be considered and overcome are such as lightning protection of the cable and rope in the near-the-earth layers, protection against its being covered with ice, protection of the enormous envelope of the aerostat against various atmospheric and cosmic effects, and so on.

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*A. Blokhin, Izvestiya, No. 291, Dec 9, 1962, p. 6.

The station would have to be assembled in its entirety at the factory and be hauled by planes to the place of future operation. There it will be attached to a surface anchor and a step-down transformer substation with automatic equipment will have to be built at this spot.

According to preliminary estimates, with continuous mass production of such wind-power stations the cost of installed capacity of 1 kw would amount to about 5 to 6 times less than at existing small rural electric power stations. In the future, even this low cost could be considerably reduced, which would help in solving the problem of electrification of remote virgin-land state farms and Siberian-forest settlements and industries which are located far from electrical power transmission lines. In addition to their basic purpose, such high-altitude electric power stations could be used for radio and television relay stations and automatic meteorological stations.

The project of such tropopause power stations has been discussed by the Technical and Economic Council of Ministers of USSR for Automation and Machine Building under the chairmanship of Academician A. I. Berg, and was evaluated as presenting an indisputable interest. This project underwent, at the beginning of 1962, a serious discussion at an enlarged meeting of the Technical Council of the Ministries of Power Engineering and Electrification where, in addition to power engineers and electrical engineers, several specialists on aeronautics, aerodynamics, meteorology, and aerology participated. The Council expressed an opinion for continuation of work for the realization of such a station.

From the time of the meeting of the Council, almost a whole year elapsed. And the vice-chairman of the Technical Council of the Ministry, I. Ugorets, still has not found the time to legalize this decision and to push forward further investigation. 'We think that also to the readers of Izvestiya it will not be indifferent to know how many more months (and maybe years) Ugorets will need in order to determine at last his own attitude to this daring project'."

2. DISCUSSION

The purpose of this talk is to present a thumbnail sketch of the immediate capabilities of balloon flight, to consider briefly some of the contemporary balloon flight problems and to discuss the future of ballooning.

To most people, all balloons are the rubber, meteorological type. To be sure, such balloons are enormously useful for carrying lightweight, expendable instruments to probe the troposphere and lower stratosphere. In general, these balloons rise at rate of 1,000 to 1,500 ft/min, reach their design ceiling altitude, and then burst. A balloon of this type, having a limited capability for short duration constant level flight, has been developed both by the Australians and by companies within our country. However, since the rubber balloon is inherently unstable, altitude control is difficult. In my mind, one should consider the rubber balloon ideal for its chief mission as a radiosonde carrier, but inherently unsuitable for constant level flight.

2.1 Zero Pressure Balloon

To most of this audience, the word balloon probably brings to mind the zero-pressure, constant level type. Fig. 1 illustrates the typical time-altitude flight curve of such a balloon. After an early morning launch, this flight is characterized by an ascent rate which is nearly constant to the designed ceiling altitude; flight at the maximum altitude until noon or shortly thereafter; a protracted, slow descent during the afternoon; a rapid, post-sunset descent to a night-time flight level that is determined by pressure-controlled ballast; constant level flight during the night, then a rapid ascent following sunrise to a daytime level that is slightly higher than that of the previous day. Of course, the ballast control level can be altered to provide either nearly constant day-night performance, or widely differing day-night floating levels as needed. Gas valving and ballasting can also be controlled by radio command to make the balloon flight performance conform to special scientific or mission requirements.

Figure 1. Normal Flight Profile of a Zero Pressure Balloon

Such balloons are most frequently launched by the "platform" method wherein the size of the gas bubble is carefully controlled to limit the amount of loose balloon material that is presented to the wind during the launching period. The successive steps in this type of launching are shown in Figs. 2 through 6. As these pictures indicate, the lifting gas is fed to the balloon bubble through a small diameter tube connected to the gas trailers or gas source. The bubble size is permitted to increase slowly as inflation proceeds. When the inflation is complete, the bubble is approximately 1/20 to 1/650 of the full volume of the balloon, depending upon the design ceiling altitude. That part of the balloon below the launch platform, is still uninflated. The balloon base is connected to a deployed parachute which, in turn, is connected to the payload. Depending upon the size, weight, and configuration of the payload, different payload launching vehicles are utilized; however, all are mobile to permit the payload to reach a point directly below the balloon before final release. While the capability of this launching system is dependent on balloon type, total inflation, payload size, experience of the launching crew, and so on, a major limiting factor is the surface wind. A reasonable maximum allowable surface wind velocity is 8 knots, although launchings have been made at more than twice that value.

Until recently, nearly all such zero pressure balloons were made from polyethylene. Polyethylene has a moderate tensile strength, low cold brittleness temperature (-68°C), moderate extensibility (this is rate and temperature dependent) and excellent storage properties. In addition, the heat sealability of this film and the inherent low cost of the resin make this an eminently suitable film for the low cost balloons required by the majority of scientific experimenters.

As in earlier days, the advent of increased payloads forced reassessment of the balloon capabilities. Tests of polyethylene balloons in the 4,000 pound payload range simply were not sufficiently successful to risk using such balloons to carry men or even expensive scientific experiments. For these extended requirements stronger films were developed. In many of the heavy payload programs the material now being used is a Mylar film of 1/2 or 1/3 mil thickness bonded to a leno weave of Dacron fibers. This laminate provides an exceedingly useful balloon film approximately eight times as strong as polyethylene (on an equal weight basis), having extremely high tear strength. As might be expected, the scrim balloon is expensive, costing nearly five times as much as an equivalent polyethylene balloon.*

Figure 7 shows the altitude-payload capability of several balloons of different sizes, both polyethylene and scrim. It seems reasonable to expect that the re-

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*NOTE: It is appreciated that the heavy payload high-altitude performance of a scrim balloon may be unobtainable with a polyethylene balloon and, therefore, such a comparison may be unreasonable. However, the comparison is perfectly valid if one considers payloads within the range of polyethylene balloon capability.

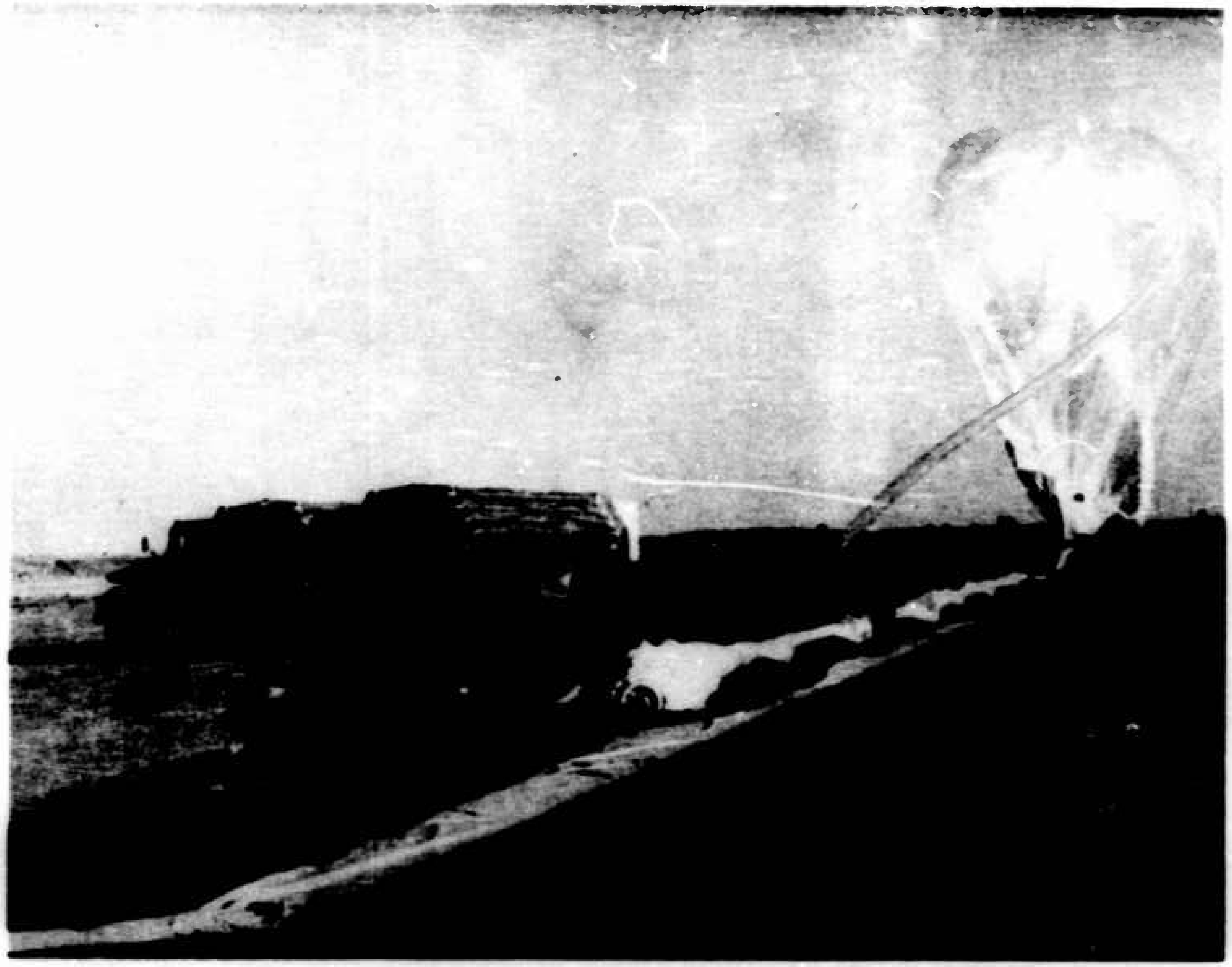

Figure 2. Inflation of a Zero Pressure Balloon in Launch Arm

Figure 3. Immediately After Release

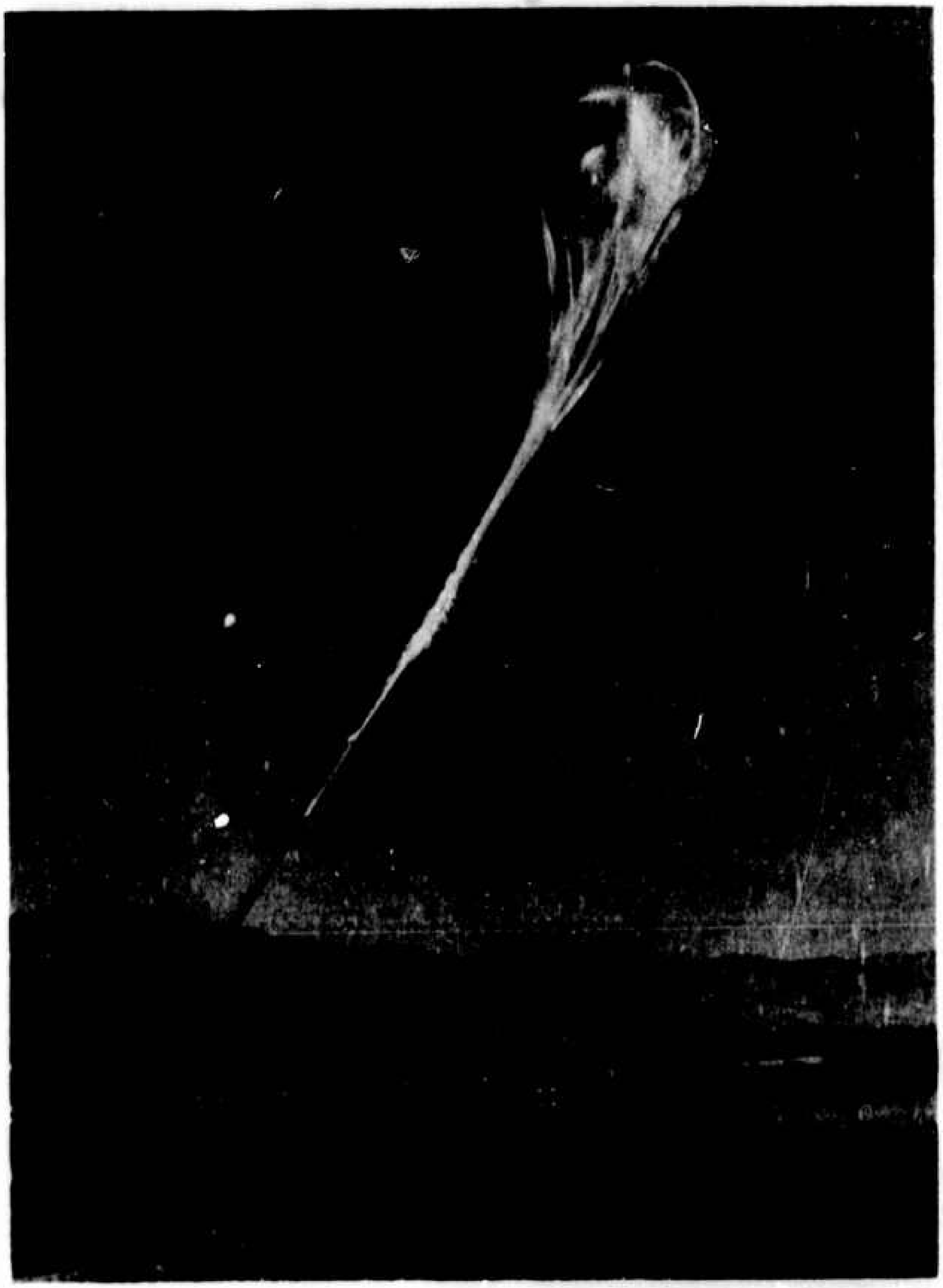

Figure 4. Launch Vehicle Driving Under Balloon

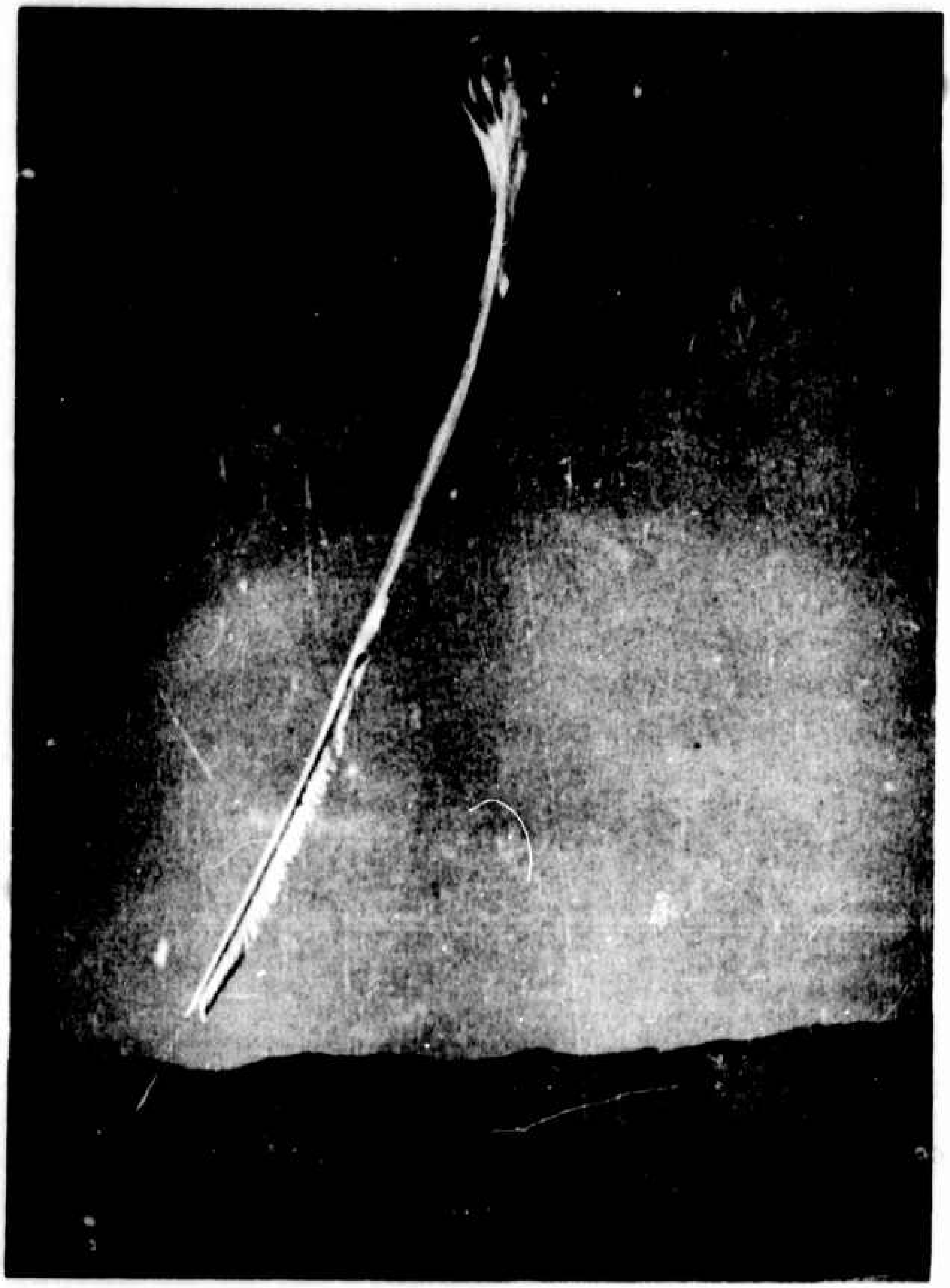

Figure 5. Launch Vehicle Almost in Position Under Balloon

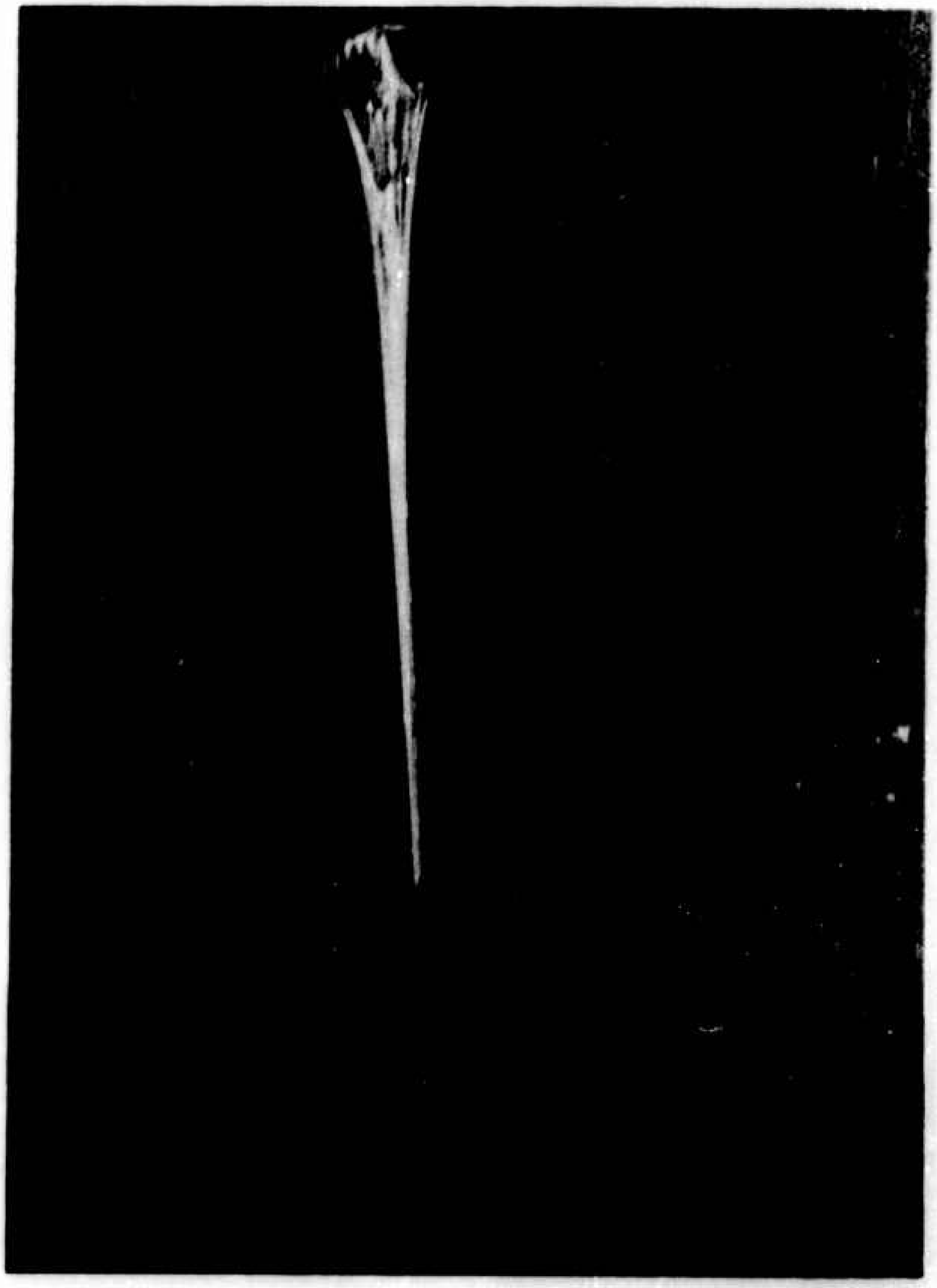

Figure 6. Release of Payload

liability of balloon flights would tend to decrease as one proceeds diagonally outward from the origin, to the heavier payloads and higher altitudes. However, the success of the scrim "3.2", (that is, 3.2×10^6 cu ft) and the 11.88 polyethylene balloon violates this rule of thumb.

Naturally, we at AFCRL are anxious to get the maximum "mileage" from the low cost polyethylene, or unsupported film balloon. Several programs now in progress -- materials evaluation and balloon shapes studies now underway at Litton Systems, Inc.; studies of balloon stress distribution at Raven Industries, and in-house investigations of the mechanisms of balloon failures -- are all directed, in part, toward this end. The Office of Naval Research task for development of polypropylene balloons is also aimed toward producing a more reliable, low cost balloon.

Two other approaches toward lowering the cost of balloons are worth mentioning. Unquestionably, the price of scrim balloons can be lowered through strict attention to each phase of manufacturing, and through a continuing search for less costly materials without necessarily compromising quality. A second possibility is the recovery and reuse of scrim balloons. Were it possible to recover and reuse a scrim-reinforced balloon, the arguments favoring search for a lower cost scrim material or a better balloon made from unsupported film would be considerably weakened. Such balloon recovery and reuse is considered to be entirely feasible and will be incorporated in the 1964 balloon development program.

Another realm of balloon technology is the creation of balloons to fly at heights above the 150,000 ft altitude range. In this case, the necessary approach is that of devising a lighter shell to encase the lifting gas. A number of balloon models have been made using films in the 1/4 to 1/7th mil thickness range, reinforced by steel, nylon and dacron fibers. To date, low-temperature environmental tests of these models (Figs. 8 and 9) have been promising but not conclusive. The unsupported plastic films, a possible alternative, appears to offer little promise for flight of appreciable payloads to altitudes above 150,000 ft.

In summary, Figure 10 illustrates the realms within which balloons of various types of construction may be expected to operate. The ultra-lightweight, supported film balloons fall in section A; the normal polyethylene types and un-reinforced balloons fall in regions B and C; and the scrim reinforced Mylar balloons satisfy the requirements shown in the C region.

2.2 Superpressure Balloon

The superpressure balloon is an entirely different sort of vehicle. The essence of its performance is that it changes neither volume nor weight during its entire flight, consequently, remains at a constant air density level both day and night. As might be expected, the temperature of the balloon changes diurnally, causing the

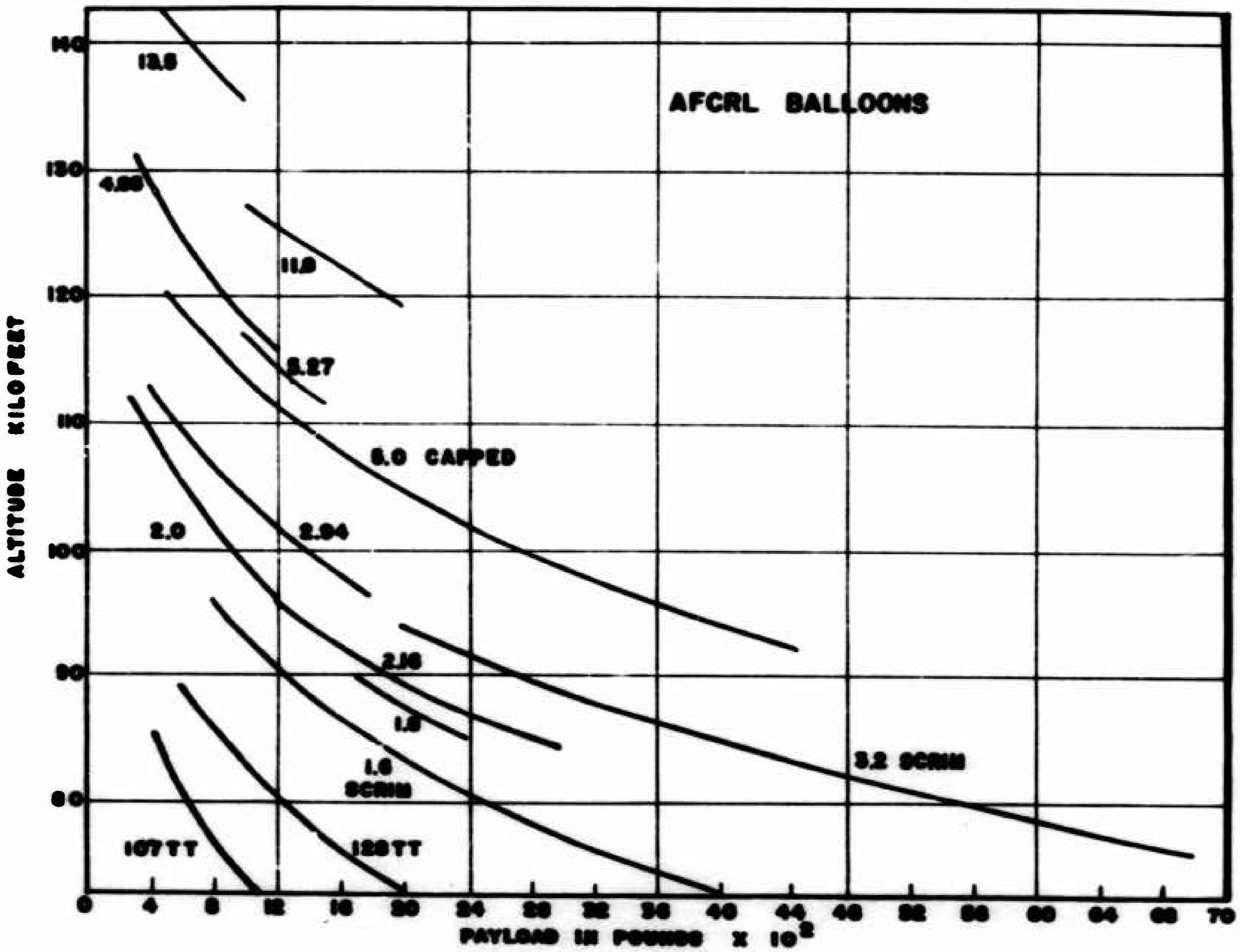

Figure 7. AFCRL Balloon Capabilities, Altitude vs Payload

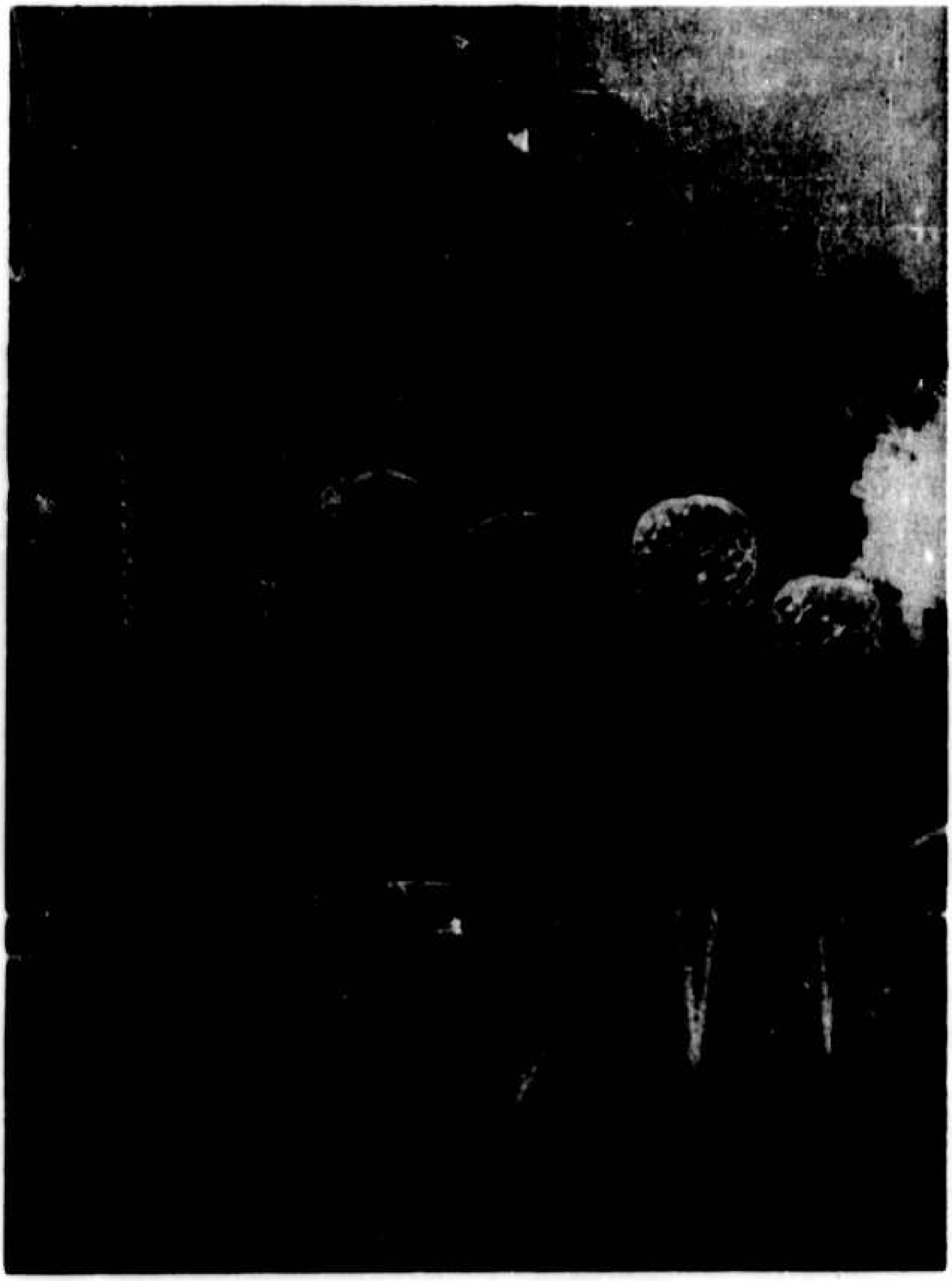

Figure 8. Ultra-thin Film Model Balloons

Figure 9. Inspection of Ultra-thin Film Balloon

lifting gas pressure to vary accordingly. However, as long as the lifting gas pressure does not fall below that of the surrounding air, the balloon stays full and the constant density, level flight performance is maintained. Figure 11 illustrates both the constant altitude profile and the diurnal variation in differential pressure.

Figures 12 and 13 show the trajectories of our flights P-27, P-29, and P-34. In each case, the time of flight termination was controlled by pre-set timer, or by radio command, as indicated. These flights represent the limit of the demonstrated capability of superpressure balloons, as of today. The existing technology and the available high-strength, gas-tight materials can unquestionably support the extension of the superpressure balloon flight capability to higher flying balloons carrying greater loads (1,000 plus pounds to 100,000 ft).

It is most desirable to launch balloons from fixed ground installations whenever possible. However, when it is required to launch in remote areas, or to locate the balloon in space at a specified time, mobile ground launching stations are used in conjunction with forecasts of the ascent trajectory. In placing a balloon within a very limited spatial region, for example, within the eye of a hurricane, mobile ground launching is not an adequate solution.

2.3 Air Launched Balloon Device

To answer the requirement for very accurate balloon placement, a system was conceived for the air launching of a balloon from a fully self-contained package shown in Figure 14. Simply described, the package, containing balloon, parachute, lifting gas source, and instrumentation payload is released from an airplane. Sub-

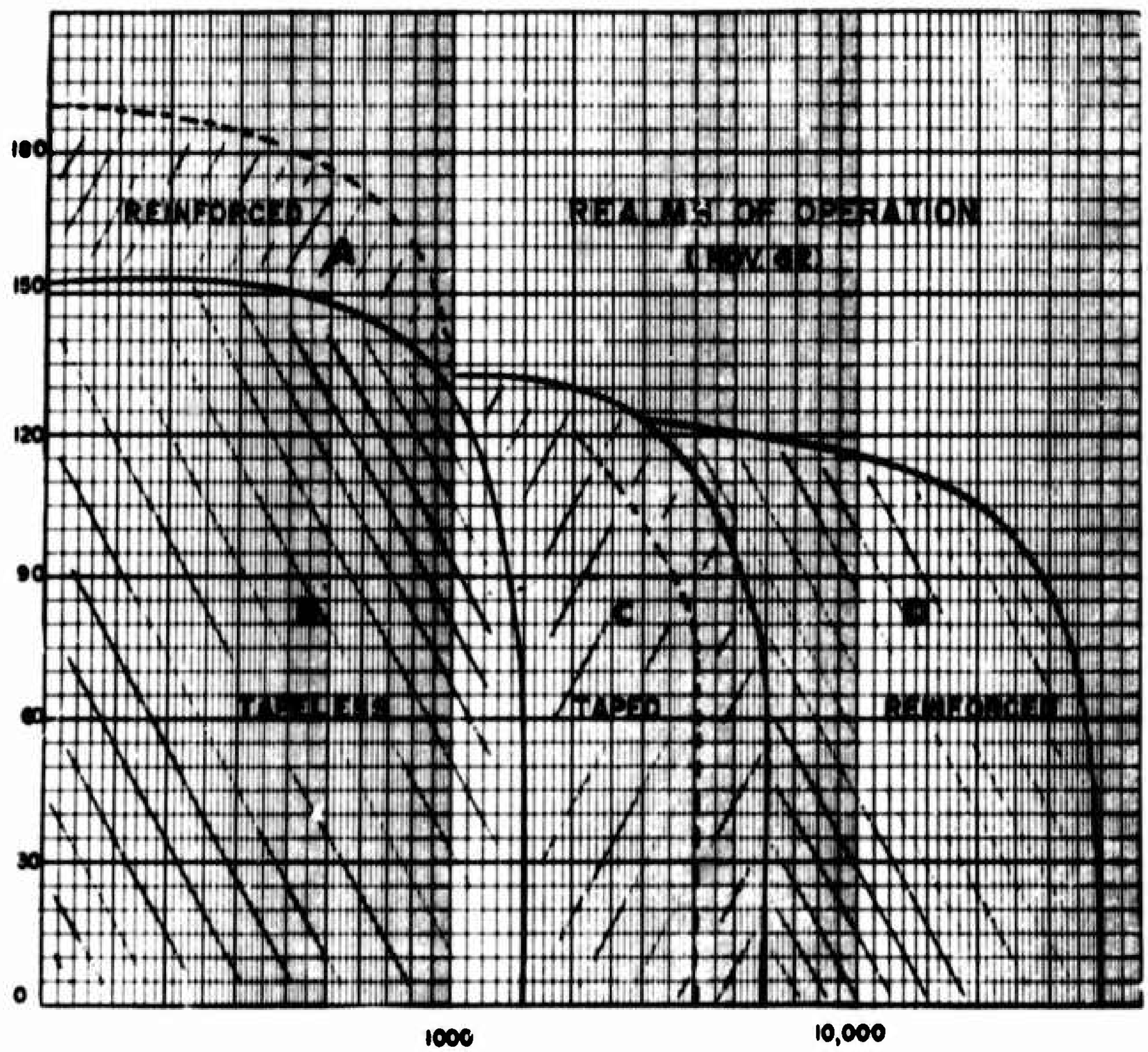

Figure 10. Realms of Operation of Balloons as of November 1962

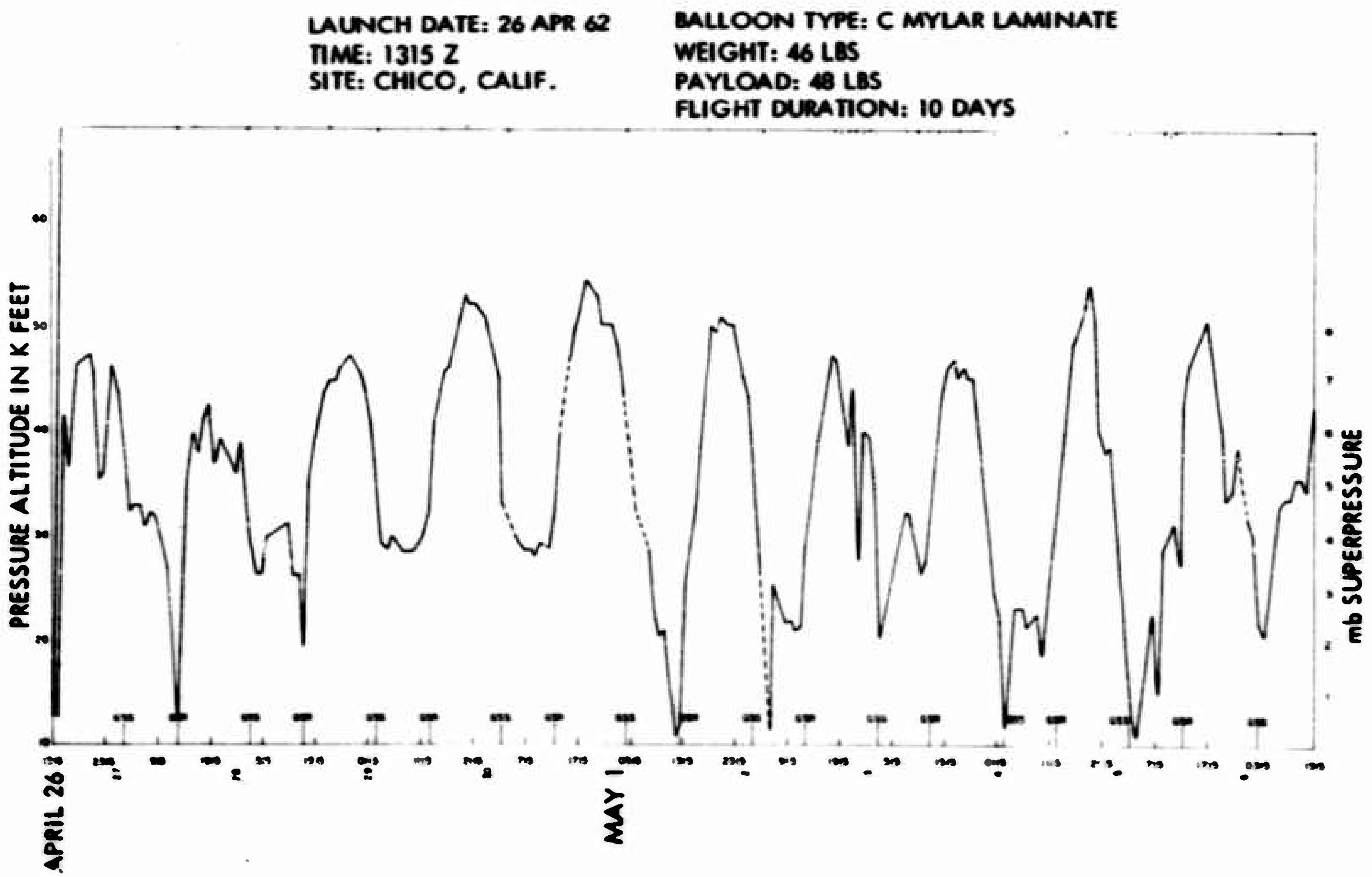

Figure 11. Superpressure Balloon Flight P-26, 26 April 1962

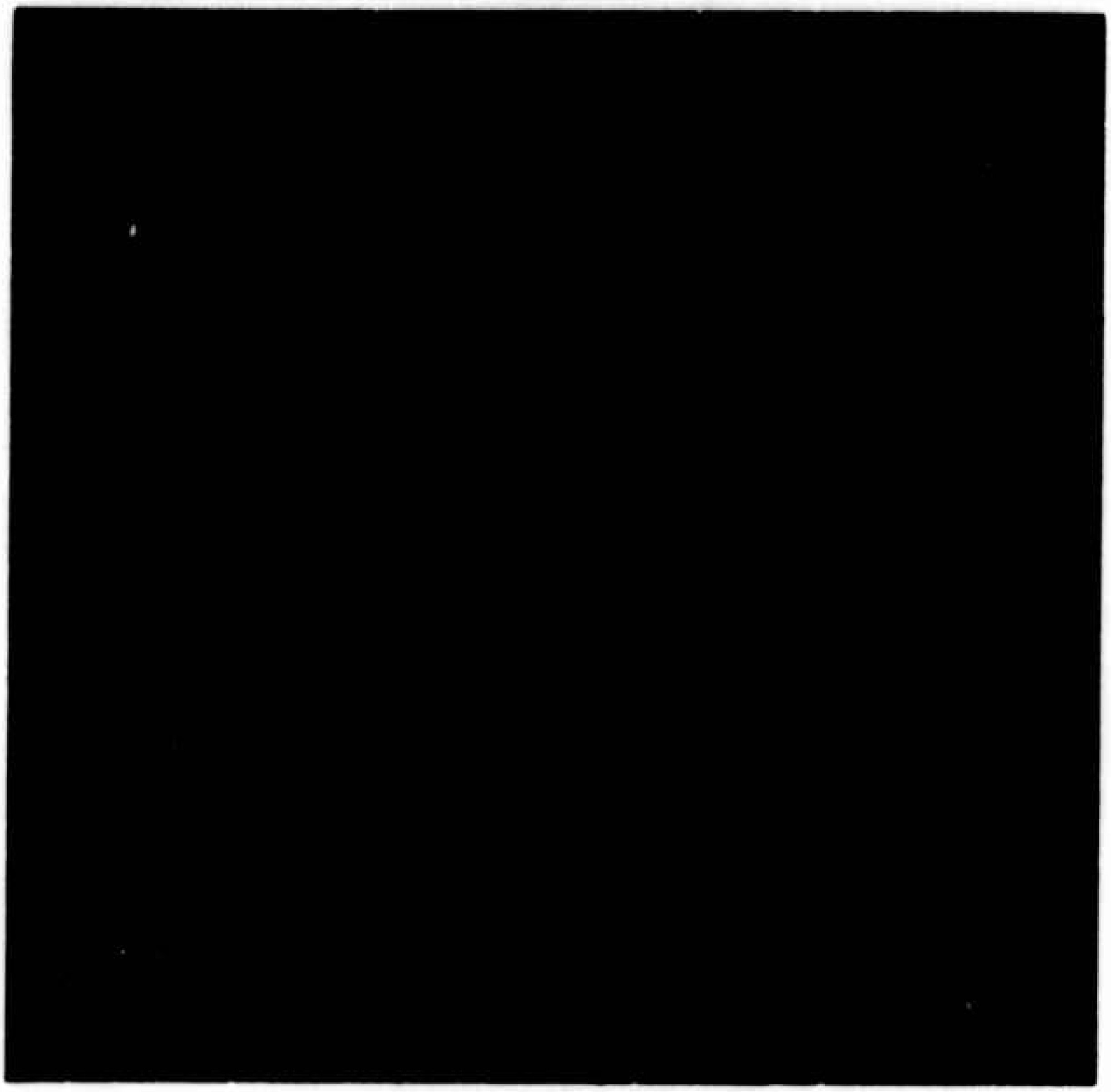

Figure 12. Trajectory of Superpressure Balloon Flights P-27 and P-29

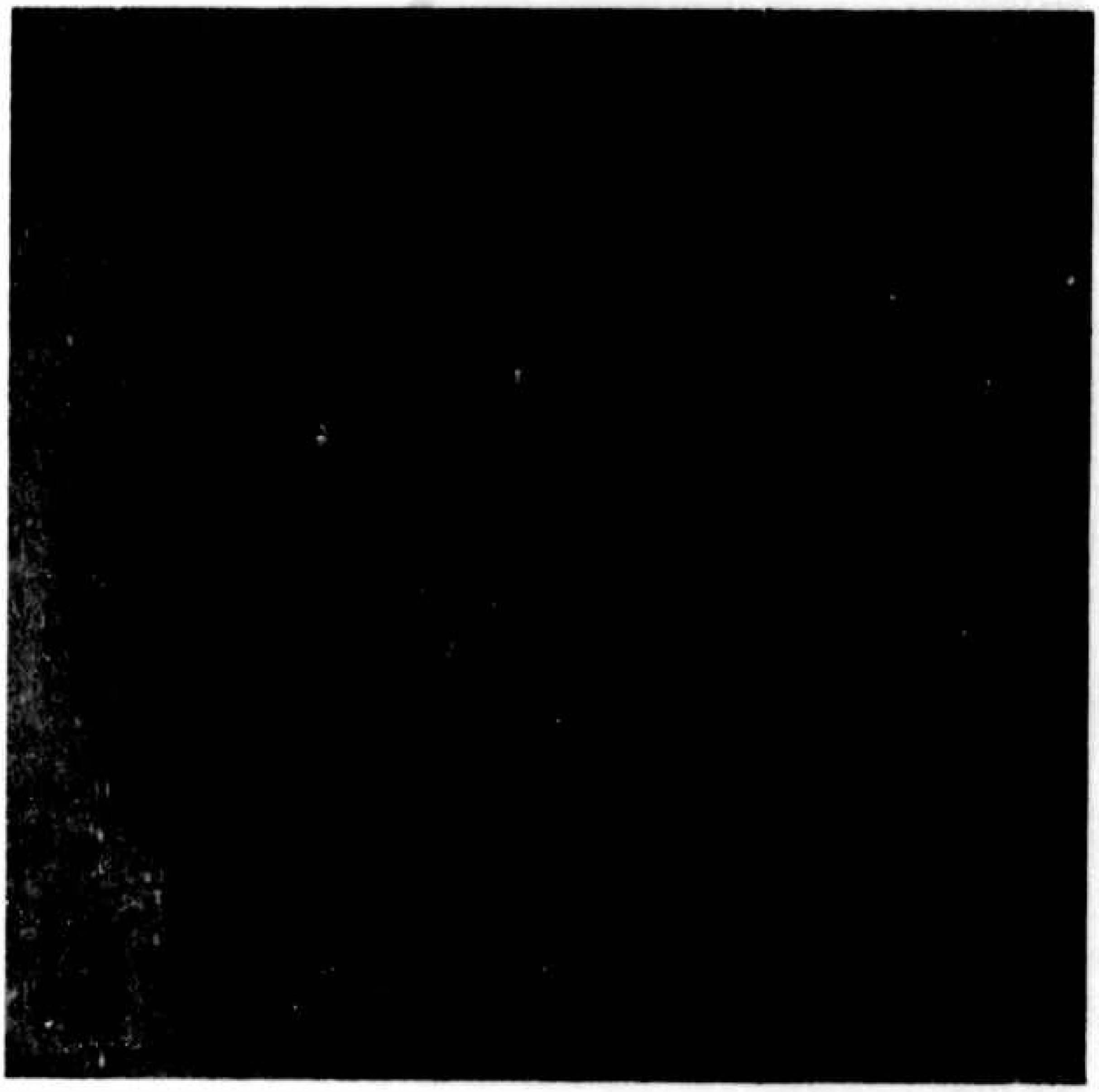

Figure 13. Trajectory of Superpressure Balloon Flight P-34

Figure 14. Air Launched Balloon Device

sequent to deployment of the main parachute the balloon unrolls from a protective bag at the parachute apex and a time programmed gas inflation begins. The lifting gas flows from the compressed gas cylinder through a high pressure hose to the parachute apex and into the balloon. After a period of 60 to 90 seconds, the inflation is completed and the balloon is released from the parachute and launching device. The balloon then ascends to its design ceiling altitude and performs as programmed; the launching device descends and may be recovered and reused. Although such a launching system is costly and surely will not fill all needs, it is not dependent upon surface winds, places no weight penalty on the balloon by virtue of the launching technique and can be extended to balloon and payload combinations well in excess of the 70 pounds launched to date. Release of these launching devices has been achieved at altitudes up to 45,000 feet at MACH 0.9, and beyond separation of the launching device from the aircraft, there appears to be no serious problem related to higher altitudes and greater speeds. Figure 15 is useful for determining "ball park" figures for balloon size and package size for a given payload-altitude requirement. However, the launching speed, device cost, launching altitude, and time at altitude are all exceedingly important considerations which in selected cases can considerably alter this graphical information.

3. SUMMARY

It is apparent that this talk amounted to a simple broad-brush treatment of the entire field of ballooning and left much unsaid. However, it was my intention to provide something of a framework for the specific balloon technology talks which follow. Surely these talks will both fill the voids in my integrated picture of the field of ballooning and provide an insight into the course of current developmental efforts. Since many areas have been discussed, let me emphasize a few important points.

1. Unsupported film balloons have carried payloads to 4500 pounds, but the reliability above 3000 pounds leaves much to be desired. A great deal of developmental effort is being directed toward obtaining more reliable low cost balloons, since a major segment of the scientific balloon experimenters simply cannot afford expensive balloons.

2. The flight of payloads in the 10,000 to 20,000 pound range is clearly feasible with supported film balloons. The current cost of such balloons is high. Major cost savings can be made through value engineering, redesign, careful materials selection, and recovery. Such procedures will, it appears, result in a substantial reduction in costs with little or no reduction in quality.

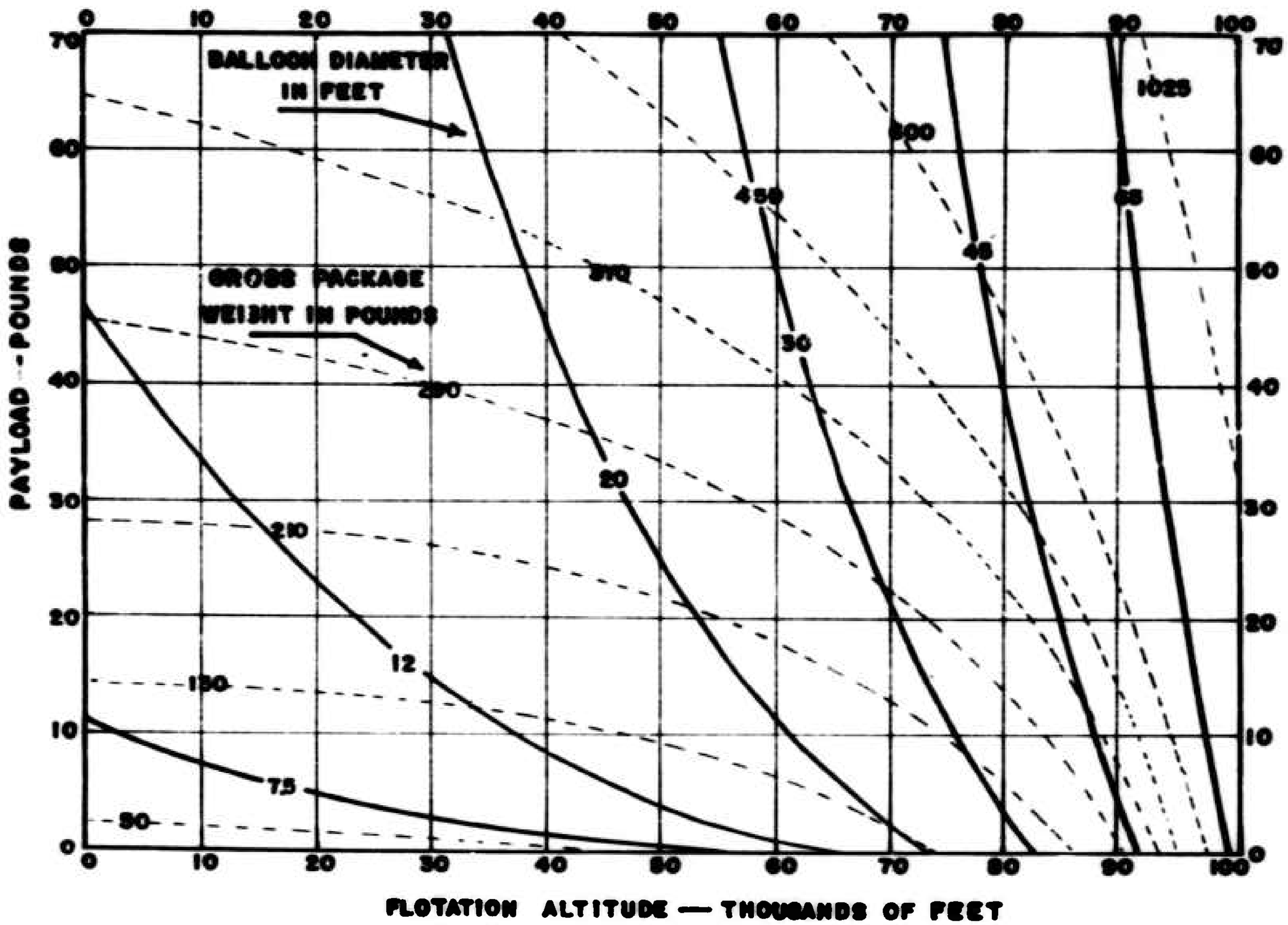

Figure 15. Payload vs Flotation Altitude for Various Diameters of Balloons and Gross Air Launched Package Weights

3. Flights in the greater than 160,000 foot altitude range with several hundred pound payloads will be possible with the advent of ultra-thin reinforced films.

4. Aerial launching of balloons for flight of 100 pound payloads to an altitude of 100,000 feet is perfectly feasible.

5. Superpressure balloons with flight durations well in excess of 3 months can be made with very little further development. The extension of the superpressure balloon to altitudes and payloads of 100,000 feet and 1000+ pounds appears to be a straightforward extension of the already existing technology.

And finally, it is evident that substantially improved flight capabilities will result from programmed developments. The ultimate usefulness of the balloon vehicle will, however, depend primarily upon the imagination and inventiveness of the user.

III Stresses and Configurations of Natural-Shaped Balloons

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Abstract

The equations derived in the early work by the University of Minnesota for the stresses in free balloons have been verified. The coordinates for natural-shaped balloons as determined by the University on an analog computer have been refined by digital computer techniques. In addition, a larger class of balloon shapes have been computed, including larger sigma values, both super- and sub-pressures, non-zero circumferential stresses, and other than "flat-top" balloons. The meridional stresses have also been investigated.

1. INTRODUCTION

This is a report on some of my investigations of the theoretical shapes and stresses of fully-inflated free balloons. The most recent published report on the shape of balloons appeared in 1953[1] and concerned work performed at the University of Minnesota. Since that time, new manufacturing techniques have been devised, new materials have become available, and new operational methods have been put into use. Thus a new look at balloon design was indicated. Furthermore, I was interested in comparing my results, using a digital computer, with those of the University, which utilized an analog computer.

2. DISCUSSION

With these items in mind, I began a search of the literature for earlier papers on the shape of inflated devices. The earliest references that I found were to graphical[2] and mechanical[3] solutions for the shape of a lighter-than-air craft, such as an airship; this work was done in 1914. These authors assumed that the weight

(Author's manuscript received for publication 31 December 1963)

of the material was negligible. In Reference 3 a closed solution to this same problem, in terms of elliptic integrals, was reported. In the determination of the shape of an airship it is possible to separate the meridional and longitudinal stresses. With some modification, these same works would be applicable to the shape of a balloon with zero circumferential stress. It was also found that there is a considerable body of literature on parachutes where studies had been made of the shape of inflated objects of that kind. For their purposes, these investigators assumed that the pressure inside the parachute remained constant.

The next significant contribution was the development of the "natural shape" by the University of Minnesota, and the publication of their famous sigma tables.[1] These authors assumed that the material was thin, perfectly flexible, and non-extensible and that the solution would be a balloon which is rotationally symmetric about a vertical axis. Furthermore, they assumed that the density of the gas within the balloon and that of the surrounding air was constant and they also specified that the circumferential stress should be zero. I have used the same assumptions, except that I have, in addition, considered the case of non-zero circumferential stress.

In the development of the equations, it is convenient to non-dimensionalize the equations. In so doing, the expression for sigma falls out. Sigma is nothing more nor less than the unit weight of the balloon material made non-dimensional. Sigma is a very important parameter for two reasons: If we make an assumption concerning the general shape of the balloon--for example, one having a flat top and we make an assumption concerning the circumferential stress (zero, for example)--then sigma uniquely determines the shape of the balloon. In addition, sigma is made up of three factors: the unit weight of the balloon material, the balloon payload, and the buoyancy of the gas at the float altitude. These three factors are those most apt to be known by the designer at the outset of his design. Thus, having made the general assumptions mentioned above, the designer can, with very little effort, determine the shape, volume, and size of his balloon. I do not mean to oversimplify this process but, in principle, this is what occurs.

In my calculations, I used a modification of the Runge-Kutta method for the solution of simultaneous differential equations. I do not have a closed solution. The solution is found by trial and error. Some of my results are indicated in the following figures.

Figure 1 shows several variations on a natural-shape balloon. I would like to see the term "natural-shape" reserved for balloons with zero circumferential stress. By zero super-pressure is meant that the pressure inside the balloon at the bottom apex is equal to the pressure of the outside atmosphere at that point. In Figure 1, the middle shape represents the standard flat-top balloon. Many different sizes with

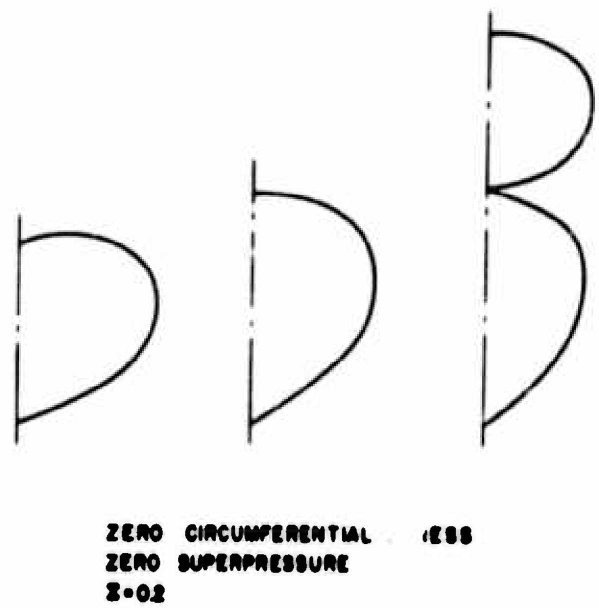


Figure 1. Variations on a Natural-Shape Balloon

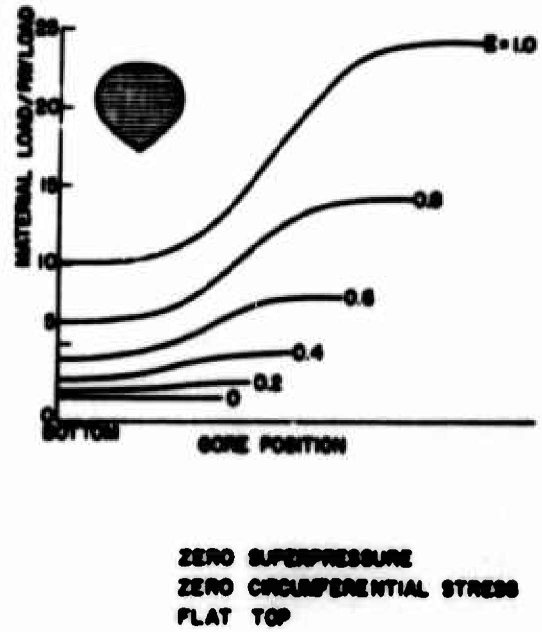


Figure 3. Total Meridional Load in Balloon Material

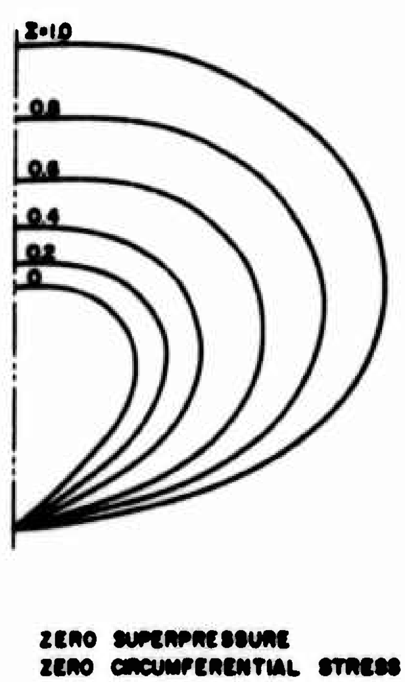


Figure 2. Balloon Shapes, Flat Top

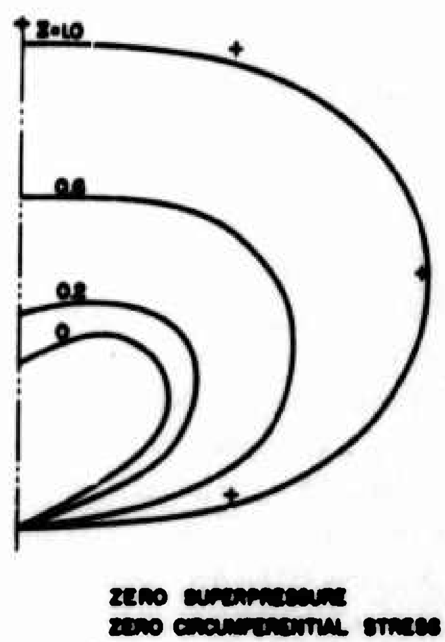


Figure 4. Balloon Shapes, One-Half Load at Top

many different weights and types of material have been flown. The shape on the left is a balloon with part of the payload mounted at the top. A variation on this design could involve a cord or cable connected from the top to the bottom of the balloon with all the payload mounted at the bottom. Another variation might involve several cords from the payload at the bottom to several points at the top. The shape at the right is a double-balloon shape. Although the total payload is carried at the bottom, part of the payload is supported by the upper balloon. An obvious variation of this design would be a change in the size of the upper balloon. There is no fundamental reason why there could be no more than two balloons. There could be three or even more. In any case, the top balloon will have a flat top.

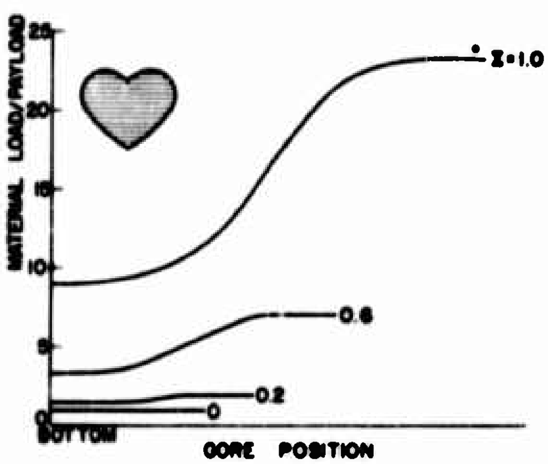
Figure 2 is the result of calculating the shape of the flat-top balloons when sigma ranges from zero to 1.0. This range will cover practically all balloon designs. The University of Minnesota calculated only shapes for sigma from zero to 0.4. It is of particular interest to note that all of these shapes will lift exactly the same payload. The smallest balloon (sigma equal to zero) has just enough volume to lift the payload. The larger volumes represented by the larger shapes are required to lift the payload plus the weight of their own balloon. The largest balloon has a volume approximately 22 times that of the smallest balloon.

Figure 3 shows the total load in the balloon material, that is, the vertical load tangent to the surface of the balloon. The same range of sigmas is used as given in Figure 2. For sigma equal to zero, the total film load is constant from the bottom to the top of the balloon. As sigma increases, the total film load increases until, for sigma equal to 1.0, the total film load at the top of the balloon is approximately 24 times the payload itself. For large sigma, the payload becomes a relatively small portion of the total weight of the system.

Figure 4 shows shapes of balloons that have some load at the top. For this particular design, half the load is mounted at the top. Again, each of these shapes will lift exactly the same payload. The crosses marked near the curve for sigma equal to 1.0, represent the shape of the balloon that has no load at the top.

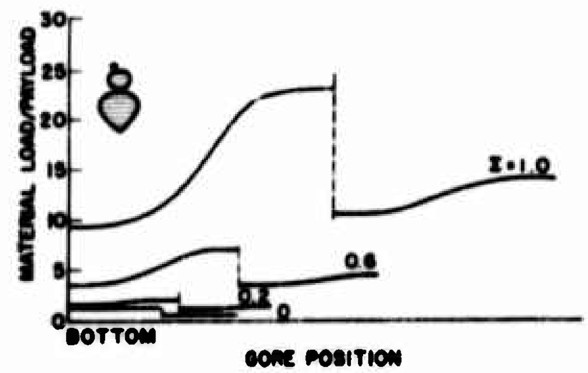
Figure 5 again shows the total load in the balloon material for balloons with half the load at the top. The shape of the curves is much the same as for the flat-top balloon. The dots indicate the position of the corresponding sigma-equal-to-1.0 curve for flat-top balloons. It is seen that the material load has been somewhat reduced when part of the load is at the top of the balloon. As a result, for the same payload one could use a slightly lighter material in this design of balloon.

Figure 6 shows three different shapes of double balloons. I have chosen to present balloons wherein half of the load is carried by the upper balloon. For comparison, the dotted curves are the corresponding shapes of the flat-top balloon for the same payload. I wish to call your attention to the upper balloons. In each case, the same sigma was used for both the upper and lower balloons. The two



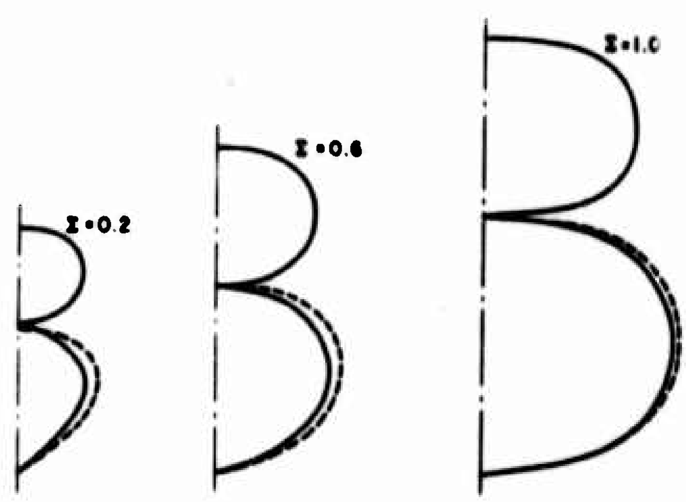
ZERO SUPERPRESSURE
ZERO CIRCUMFERENTIAL STRESS
ONE-HALF LOAD AT TOP

Figure 5. Total Meridional Load in Balloon Material, One-Half Load at Top



ZERO SUPERPRESSURE
ZERO CIRCUMFERENTIAL STRESS
DOUBLE BALLOON, ONE-HALF LOAD ON EACH

Figure 7. Total Meridional Load in Balloon Material, Double Balloon



ZERO SUPERPRESSURE
ZERO CIRCUMFERENTIAL STRESS
ONE-HALF OF LOAD SUPPORTED BY EACH BALLOON

Figure 6. Double-Balloon Shapes

would be much the same shape except that the upper balloon is subjected to a super-pressure. The super-pressure is represented by the height of helium in the lower balloon. Figure 7 presents the total material load in the double-balloon design. The striking difference in these curves is the reduction in film load in the upper balloon. These results are for the same sigma in both the lower and upper balloons, but with such a reduction in material one would use a considerably reduced sigma. I conclude that from purely load-carrying considerations, the fully inflated double-balloon system would be heavy compared to other designs.

Figure 8 summarizes some of the weight information for these natural-shape balloon designs. These data are for a sigma of 0. 2. The bottom curve compares the weight-to-payload ratio for balloons with zero load at the top--increasing to an abscissa value of 1/2 where one half the payload is at the top of the balloon, and decreasing to an abscissa value of -1/2 where one half the payload is supported by a second balloon. Again, it is seen that the double-balloon system is heavy. The upper curve compares the weight-to-payload ratio for balloons with various values of super-pressure. One method for obtaining super-pressure would be to hang a duct below the bottom of the balloon. If the duct length were equal to the height of the balloon, the abscissa value would be 1. It is seen that balloons with negative values of the abscissa, that is, sub-pressure, are heavy. The minimum weight for a balloon occurs when the duct length is approximately one half the height of the balloon.

The foregoing have all had the circumferential stress specified as zero. When considering non-zero circumferential stress, I have found that the variety of balloons becomes so great that it is not practical to attempt to give generalized balloon designs. For that reason I have investigated a balloon which is designed to lift 40 pounds to 70, 000 feet. One and one half mil Mylar material was used with a super-pressure of 5 millibars. This results in a sigma of 0. 24 (Figure 9). These two curves are for a balloon with zero circumferential stress and one with a circumferential stress of 5 pounds per inch. Both of these balloons are wider than the corresponding spherical balloon. Figure 10 presents the stresses in the balloon. In this case, I have chosen to present actual stresses rather than total film loads. As one might expect, introduction of a circumferential stress results in a reduction in the corresponding meridional stress. The two balloons have constant circumferential stresses of zero and 5 pounds per inch, respectively.

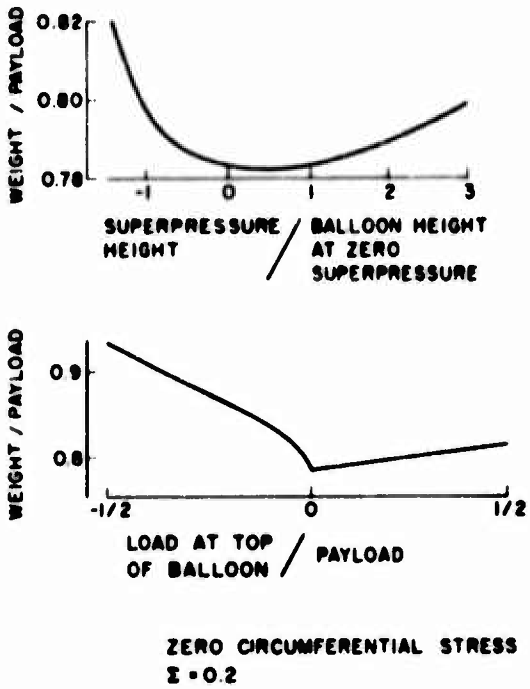


Figure 8. Weight of Balloons

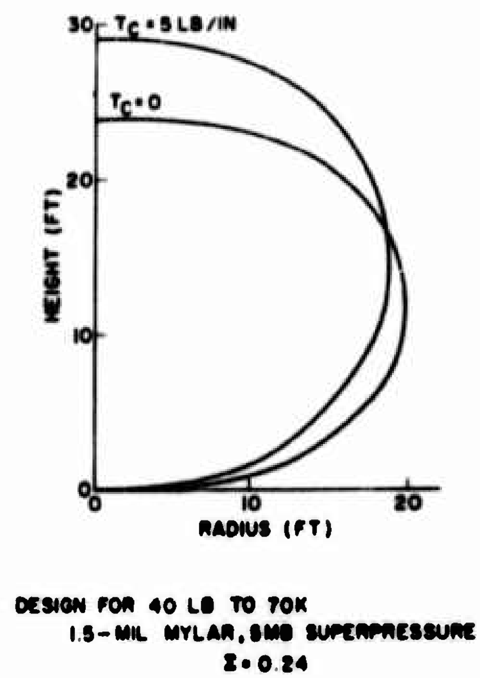


Figure 9. Effect of Circumferential Stress

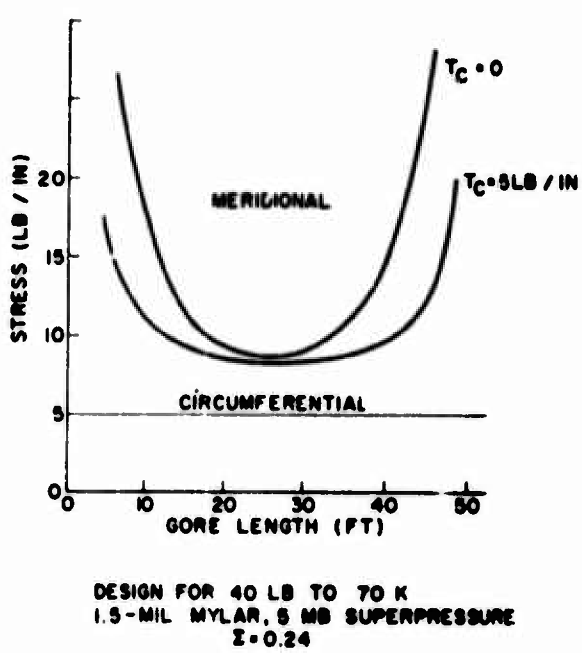


Figure 10. Comparison of Stresses

3. SUMMARY

In conclusion, the results of my investigation have been: The work of the University of Minnesota has been verified, although there was never any doubt as to the validity of their work. The sigma tables have been extended to cover most balloon designs. Various shapes have been studied and ways to reduce weight have been investigated; some methods of reducing their weight have been shown here. Certain knowledge of the stresses in the balloons has been determined. Finally, as a result of my work in calculating the shapes, I believe that special designs should be investigated carefully using computer analysis rather than by reliance on sigma tables alone.

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IV Expanded Use of Inflatables Through New Materials

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Abstract

This paper covers the latest advances made in laminate materials which have made possible heavy load carrying balloons, long duration flights without ballast, space communication satellites, and space inflatables. Scrim-reinforced plastic films have made possible balloons capable of carrying loads like the 14,500 pound gross of the Stratoscope II program and 7,000-pound gross of the Stargazer program, and at the same time permit shock-free static launches in 20 MPH winds. Bi-lam Mylar spheres have demonstrated 30-day flights at a constant altitude without ballast. The Echo II communication satellite is built of a 7-layer laminate material which is less than 1 mil thick, yet when this thin plastic is deployed in space, it becomes rigid enough to hold its shape against the forces of solar pressure, drag, and micrometeorites.

1. INTRODUCTION

The last three years have brought a number of significant advances in balloon technology, expanding the usefulness to heavier payloads, longer duration flights, and to space inflatables. The most significant accomplishments are 1) the 13,500 pound Stratoscope II balloon system, incorporating a cable restrained pilot balloon attached to a reefed main balloon and permitting shock free static launches in moderate winds; 2) the 34-foot diameter spherical balloons flown by Air Force Cambridge which carried a 50-pound payload at a constant altitude of 66,000 feet for a flight duration of 30 days; 3) the 100-foot diameter Echo 1 communication satellite placed into orbit approximately three years ago.

The high altitude research balloon has always relied to a large degree on the packaging industry. The polyethylene balloon came as a result of the carrot bag and the very thin films available today are a direct result of a competitive substitute for paper in the dry cleaning industry. Mylar and other high performance plastics are also an outgrowth of the demand in the United States for a better, stronger, and more attractive package for marketing products. The relatively limited amount of film consumed in balloon work and the high cost of development of a new plastic film capability has been a prime factor in limiting the industry to basic packaging materials.

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These basic films have served well for the early research flights of the 40's and 50's which were in most cases light payloads and relatively inexpensive equipment. Today, however, with the more complex requirements of our space age, such as expensive and complex telescopes and research equipment, requirements for better balloon control in air-space, and special payload handling conditions, the payloads are becoming heavier and the requirements for reliability are more important. These more complex requirements require a good deal of time and work to design and set up. Ideal flight conditions cannot always be obtained with respect to geographical location, time of day, season, or cost of field operations. The balloon system, therefore, must be capable of survival with a high degree of reliability.

The standard packaging films by themselves have not been able to satisfy these advanced requirements. However, through combining the properties of existing materials in such a way as to produce a hybrid material approaching the balloon designer requirements, some outstanding results have been achieved. We have designed a material to meet a vehicle requirement, we have not designed the vehicle around an existing material.

2. DISCUSSION

2.1 Heavy-Load Balloons

Under Contract with ONR, a study was established to develop a heavy load material with the following requirements:

1. High tensile and impact strength.
2. Low service temperature - 100 C.
3. Absolute tear stopping properties at low temperature and room temperature.
4. Weight equivalent to 2-mil poly or less.
5. Forgiveness, a high degree of latitude in handling and fabrication to reduce the probability of fabrication defects and flight damage. It is impractical to consider that a large plastic balloon can be given 100 percent inspection and, of course, it is impossible to pretest the balloon prior to flight. Therefore, it is important to design the reliability into the basic material and balloon design.

This study resulted in what we call the GT-10, GT-11, and GT-12 laminates consisting of 1/4-mil, 1/3-mil, and 1/2-mil Mylar respectively, laminated to a 12 by 4, two ply fill, 220 denier Dacron leno with GT-301 adhesive system (Figure 1). This all-polyester film has thermal properties similar to Mylar with added tensile and tear strength (Figure 2). The GT-10 weighs the same per unit area as 1.8-mil

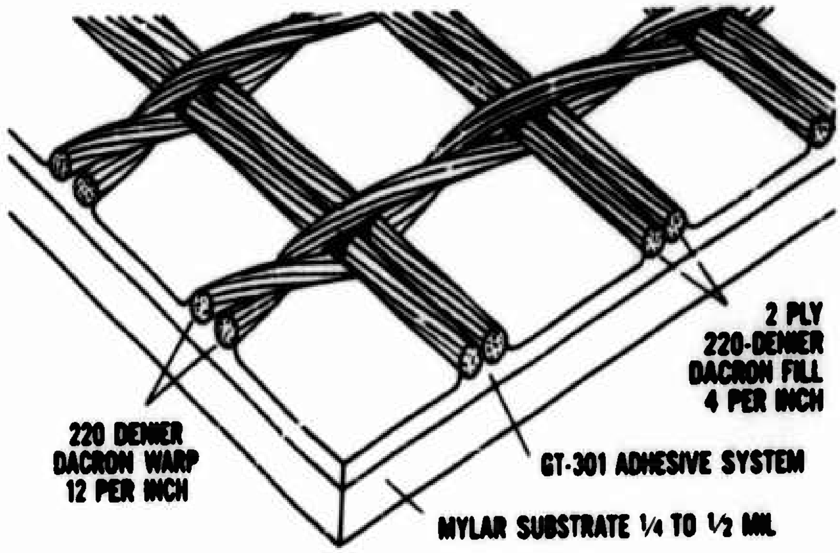

Figure 1. GT-10 Series Materials

	STRENGTH TO WEIGHT RATIO	TEAR RATIO
POLYETHYLENE	1	1
MYLAR	7	0.2
GT-10	17.2	40
GT-11	16.6	40
GT-12	15	40

Figure 2. Comparison of the Mechanical Properties of Five Balloon Films

polyethylene and has an ultimate tensile of 40 pounds per inch in the machine direction and 30 pounds per inch in the transverse direction. Seals can be made on this material which have the same strength as the film.

Other combinations of plastic films and woven materials were also investigated. However, this particular combination (Mylar-Dacron) resulted in the best balance of properties at a moderate cost. The substitute of less expensive materials, for example biaxially oriented polypropylene film, polypropylene fibers, rayon fibers, would reduce the cost of the material slightly; however, some loss in strength properties of the materials also resulted from the substitutions.

Although the GT-10 series material has been in existence only three years its records have been outstanding. Four of the five major telescope and camera flights are now being carried on GT balloons. Some 75 balloon flights have been made to date with no catastrophic failures in flight. These balloons have not been found to be sensitive to ascent rates, dynamic launches, high shears, or low temperature environments. Balloons built of these materials have carried payloads up to 11,000 pounds and gross system weights of 13,500 pounds. In the case of the Stratoscope II balloon system (Figure 3) the top balloon not only carries the gross system of 13,500 pounds but also experiences an additional stress due to the superpressuring of the top balloon during gas transfer. This more than doubles the loading in the balloon skin.

Most balloon users today recognize the merits of the GT-10 balloon and would use them except for one factor: Cost. A GT-10 balloon sells for three times that of the tape poly balloon of the same size. However, I would like to emphasize that balloon costs alone are not a valid comparison in establishing which balloon is the most economical in a given application. Reliability, cost of a second flight, instrumentation calibration and possible loss, helium, flight operations, and most important, loss of valuable time on the part of the scientists should also be taken into consideration. In the case of most research flights, the operational costs of a second flight alone are greater than the cost of one GT-10 balloon.

A major part of the cost of these balloons is in the basic material. Polyethylene costs approximately 90 cents per pound while the Mylar used in GT-10 costs $3.50 per pound and must then be processed by bonding to a woven fabric. The cost of these GT-10 balloons has over the past six months been reduced by a factor of 30 percent due to value engineering and a larger volume. The G. T. Schjeldahl Company is under contract with the Air Force Cambridge Research Laboratories for this value engineering and for the development of a lower cost material to extend the applications of these balloons to other programs. The present cost of the GT-10 series balloon along with the new non-woven material now being developed for Air Force Cambridge (GT-2929) are shown in the following table. (Figure 4) As volume increases through a broader use of these reinforced balloon materials, we expect the cost to be reduced even further.

Work is continuing on the recovery and reuse of these balloons. If provisions are made to reef or sleeve the balloon on descent, recovery with minimum damage is possible. Figure 5 shows a concept which is being evaluated for balloon recovery. The feasibility of recovery and reuse has already been demonstrated. Two balloons have been damaged in launch, repaired, and reflown. Two out of four 3.2 million cubic feet GT-12 balloons flown at Holloman have been recovered and returned to the factory for inspection and repair. These balloons had no reefing sleeves or provisions for quick release of the gas on impact. They were merely picked up by the recovery crew in the field and placed in a large box with no protective sleeve.

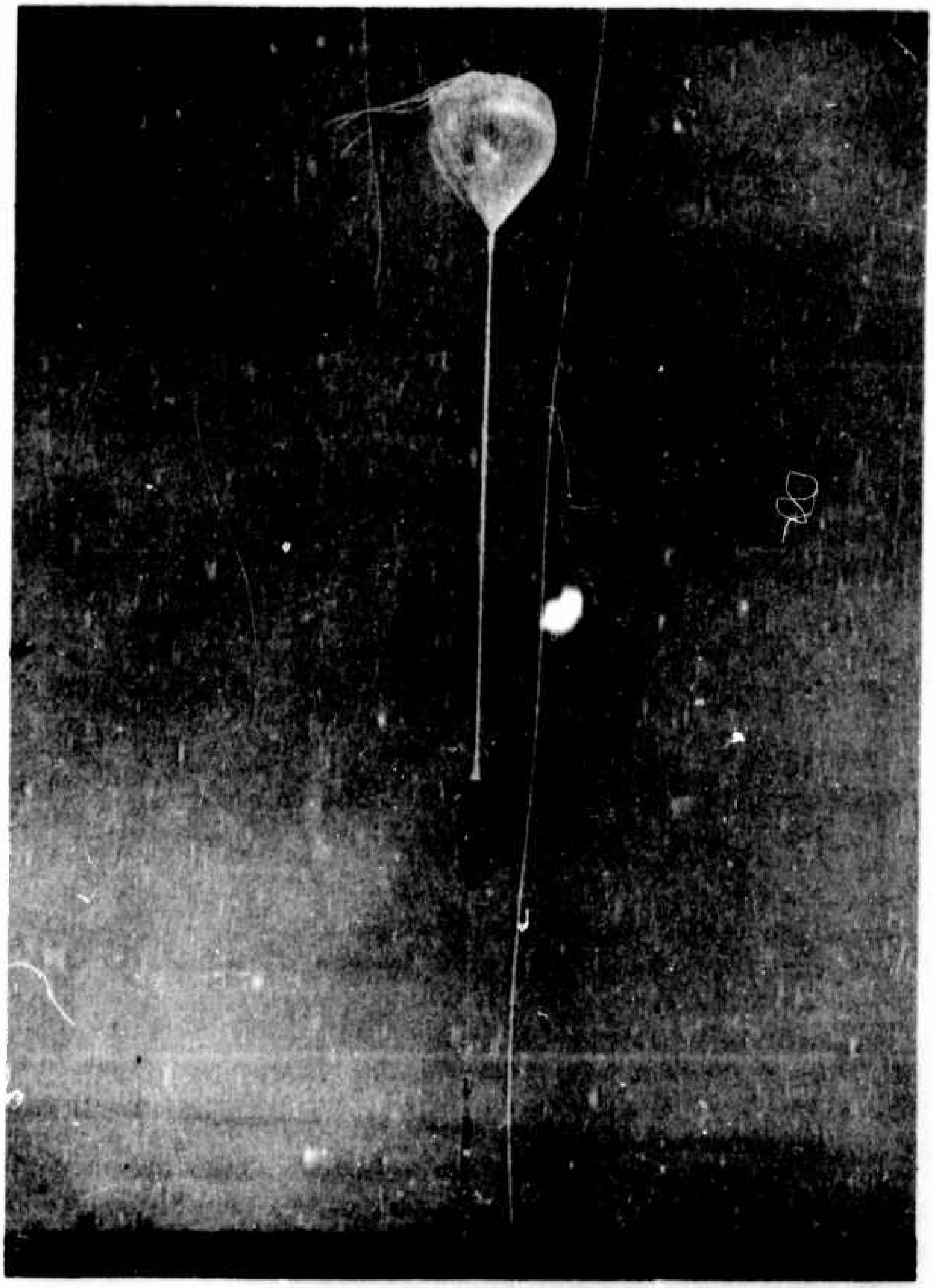

Figure 3. Stratoscope II Balloon System Ready for Launch

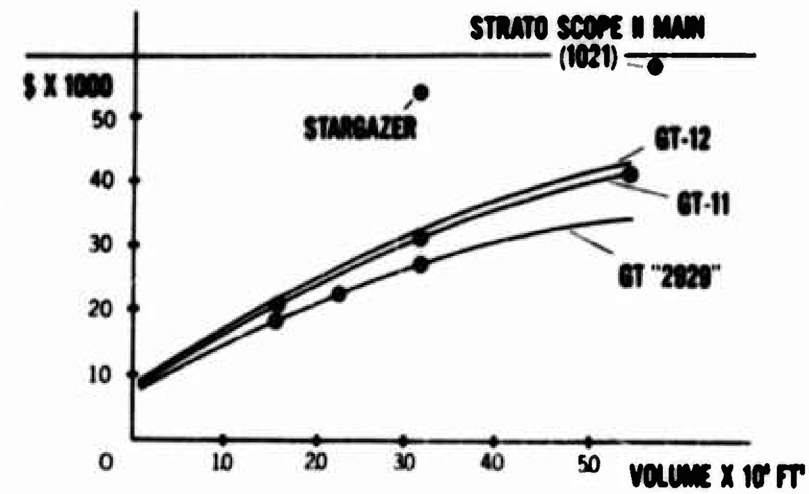

Figure 4. Balloon Costs for GT-Scrim Reinforced Balloons

3. SUPERPRESSURE SYSTEM

Materials development also played a very important part in the superpressure balloon program. Some success had been achieved with a plain Mylar sphere with flight durations of from two to ten days. In each case, however, the pressure in the sphere gradually reduced each day until the balloon descended. The permeability rate of Mylar balloons as determined from small model balloons indicate leakage and permeability rates which would permit flight durations of several months or longer. It appears therefore that the leakage problem is not due to the permeability of the Mylar, the seams, or the minimal handling given the small model balloons used in this evaluation. Rather the leakage is due to gross pin holes resulting from either a lack of quality control on the fabrication of larger balloons or developed from abrasion of the Mylar against itself.

In order to correct this problem the Schjeldahl Company developed a bi-laminate Mylar (Figure 6) which exhibited a high degree of abrasion resistance and appears to cancel inherent materials defects. This, coupled with a bi-tape seam gave a tight balloon system capable of flight durations of 30 days or longer. Air Force Cambridge Research Laboratories has flown a number of these bi-lam Mylar spheres with a high degree of success. One of these spheres, a 34-foot diameter made of a lamination of 3/4-mil by 3/4-mil Mylar carried a 50 pound payload to 66,000 feet for a flight duration of 30 days. No ballast was used on this flight. The flight was terminated after 30 days on command indicating that even longer flight durations may be possible.

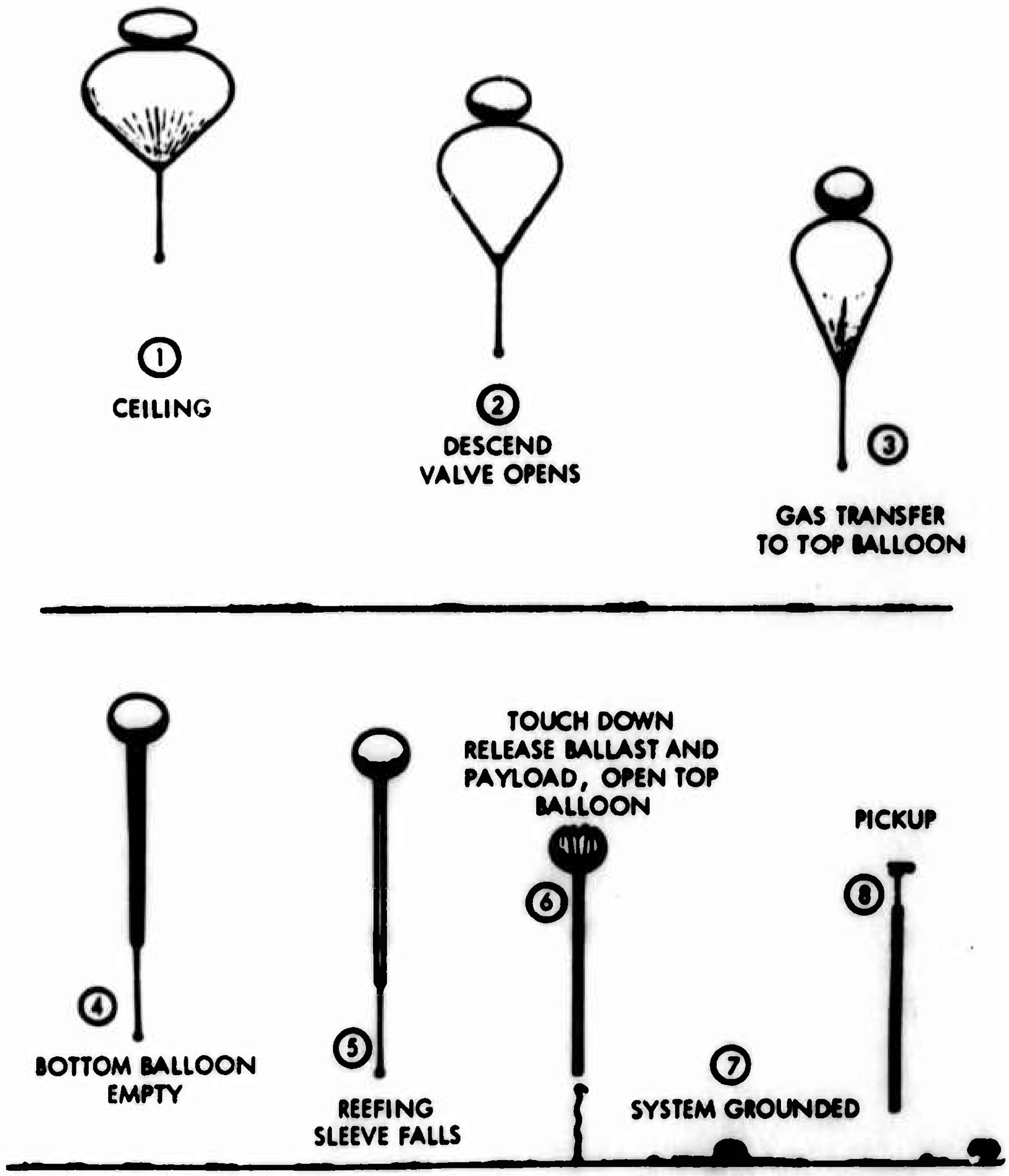

Figure 5. Schematic of a Two-Balloon Recovery System

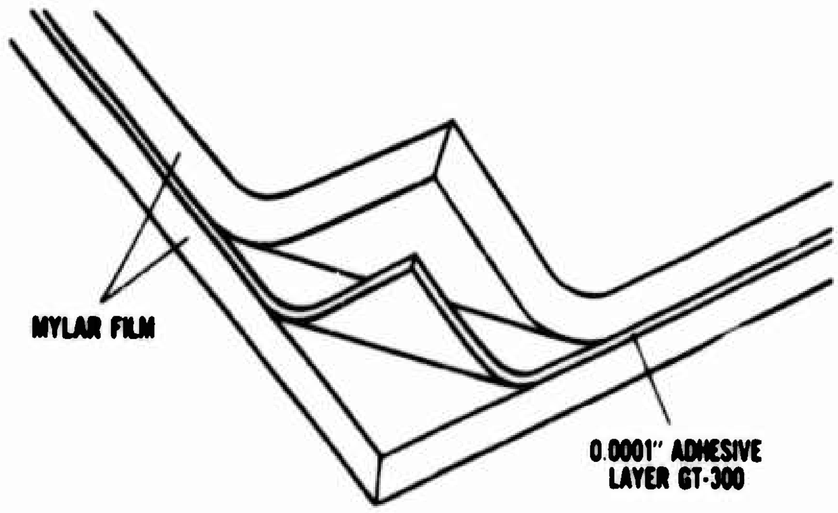

Figure 6. Bi-Lam Materials

With Mylar film available in various thicknesses from 0.15-mil, 0.25-mil, 0.35-mil, 0.50-mil, 0.75-mil, 1.0-mil, and so on, multi-layer laminations can be made to satisfy most balloon design requirements. Although at the present time the heaviest payload carried on a Mylar superpressure balloon has been approximately 80 pounds, heavier loads are within the capability of present designs.

4. COMMUNICATION SATELLITES

The Echo I communication satellite extended the use of the plastic balloon from the stratosphere into space orbit. Echo I was an inflatable sphere 100-foot in diameter made of 1/2-mil metalized Mylar. The aluminum thickness on this sphere was approximately 2,500 angstroms, or equivalent to approximately 4 pounds of aluminum on the entire surface of the 100-foot diameter sphere (Figure 7).

Before launching, 10 pounds of benzoic acid and 20 pounds of anthraquinone were inserted into the deflated sphere. The balloon was then folded accordion fashion and placed inside a 26.5-inch diameter magnesium container which carried this sphere into orbit. Two minutes after the payload was injected into orbit the magnesium container was separated by an explosive charge and the benzoic acid expanded to inflate the Echo I sphere into a spherical shape. The artraquinone provided a progressive subliming inflation material to keep the sphere inflated for approximately seven days, even though micrometeorite punctures of approximately 0.5 square inch per day were expected.

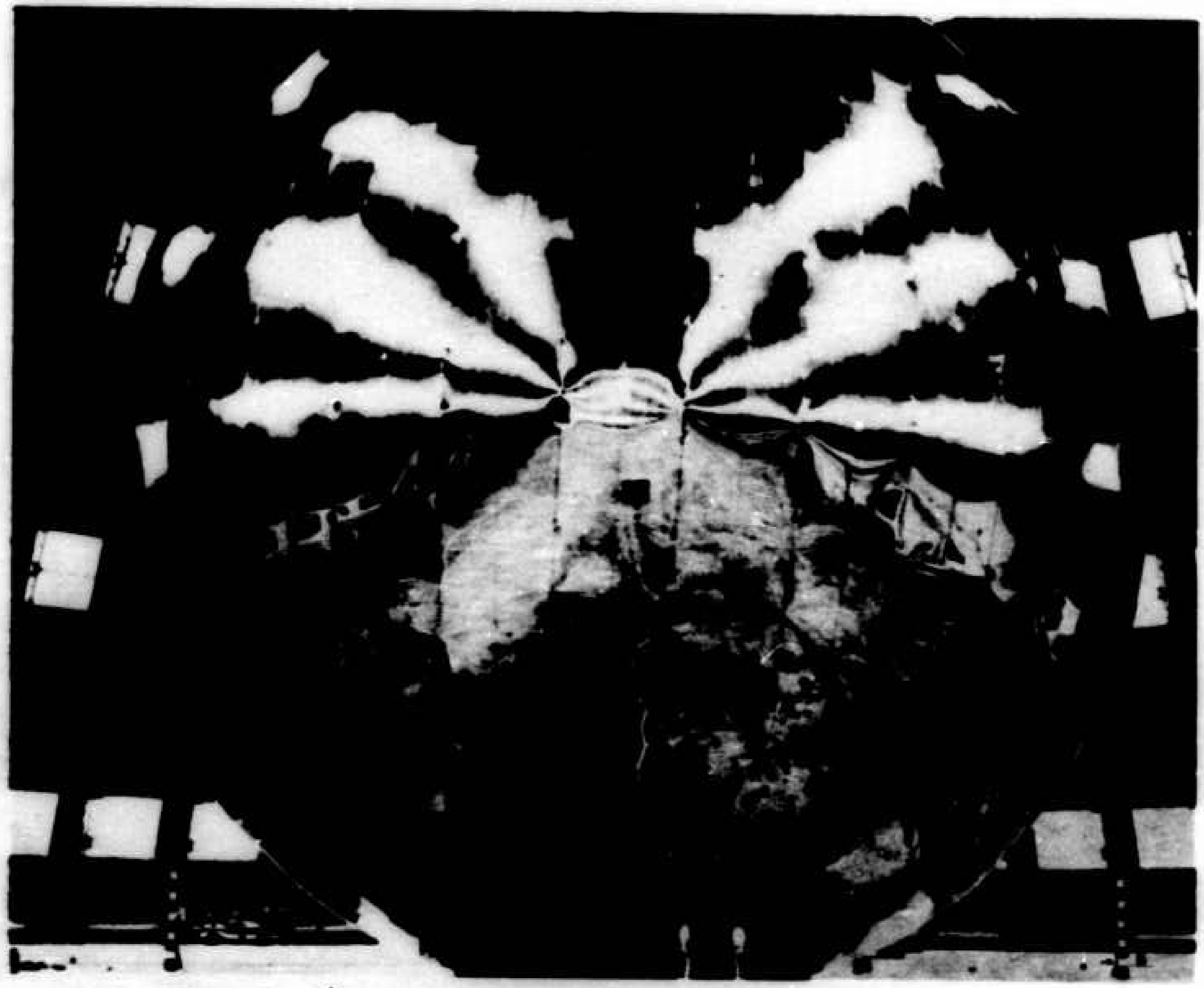

Figure 7. Static Inflation Test Echo I. Sphere, 100-ft diameter, of .0005-in. thick metalized Mylar and sealed with Schjel-Bond 301.

Echo I has performed well as a communication satellite research tool. It is believed that the skin of the Echo has become somewhat wrinkled due to the effect of the deforming forces of solar pressure, electrostatic drag, and micrometeorite punctures. However, the satellite is still being used for communication experiments after three years in orbit.

As a result of the success achieved with Echo I, a program was undertaken to develop the 135-foot diameter Echo II or A-12 sphere designed to have twice the cross-sectional area of the Echo I and to be rigid enough to withstand the deforming forces of space. Again the problem which faced the balloon designer was finding a material which 1) was exceedingly light weight, 2) could be packaged in a minimum space, and 3) then deployed and rigidized in space. The result of this study was a seven-layer material approximately 3/4-mil thick (Figure 8). This material is basically a lamination of 0.00018 inch thick aluminum foil on both sides of 0.00035 inch thick Mylar. In order to control the inflation material (acetamide) and keep the temperature of the sphere within that which the acquisition beacons would operate, it was necessary to thermal balance treat the inside and outside surface of this material. Alodine 401-45, an inorganic chemical treatment of the aluminum, was used to increase the emmissivity of the outside surface from 0.02 to 0.18. The inside surface of the sphere was coated with a carbon black to increase the heat transfer from one side to the other thereby helping to control the temperature gradients and reduce hot spots.

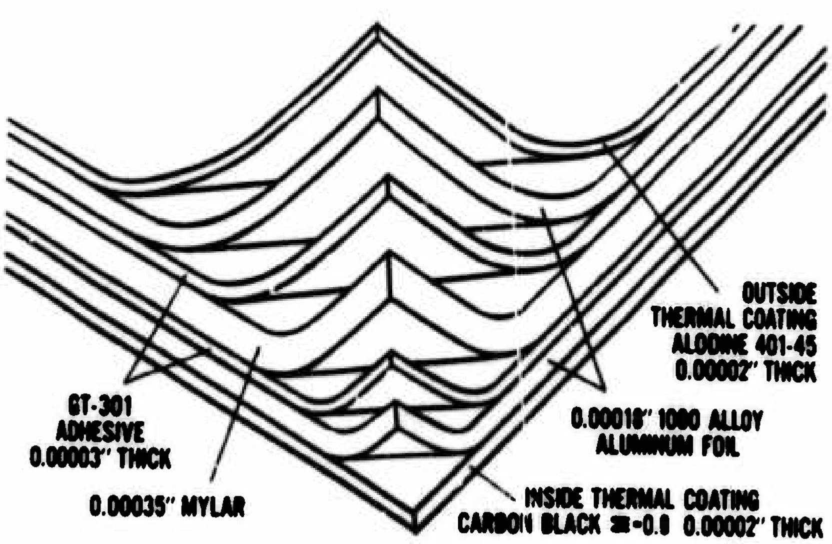

Figure 8. Echo II Lamination

In Echo I the Mylar exhibits a memory to the folds generated in packing the sphere into the canister. In the Echo II material these folds are removed when the sphere is deployed and the skin stressed to the yield point of the aluminum foil. The aluminum, being dead soft and having a higher modulus than the plastic, maintains and rigidizes the spherical surface. The stress-strain characteristics of this lamination are shown in Figure 9. As can be seen by this curve, the material must be stressed to approximately 4, 500 psi to reach the yield point of the composite laminate. However, through model tests it was determined that a stress of 2, 000 psi would remove the wrinkles in sufficient degree to satisfy the reflection requirements of the Echo experiments.

This seven-layer lamination was calculated to be approximately 50 times more rigid than the Echo I satellite, even taking into account that the measured rigidity falls to approximately one-third that computed for this material, based on the bulk modulus of the components. A number of testing techniques were used in evaluation of the rigidity of this material including taper or deflection tests, diaphragm tests, hemispherical deflection tests, and cylinder compression tests. Testing of a material of this type is not easy, since small wrinkles or imperfections in the surface being measured often exceeded the thickness of the material and therefore influenced the results. The cylinder test, however, appeared to give the most consistent results and was considered a standard for evaluation of materials (Figures 10 and 11) . The discrepancy in rigidity observed from these tests was believed to be from the aluminum foil. The ability to produce an aluminum sheet 54 inches wide to a thickness of 0. 00018 inch is a significant advancement. It is believed that small pin holes and imperfections in the rolled sheet accounted for this discrepancy in the modulus. It was impossible to run strain curves on the aluminum itself as the samples tended to tear well before reaching the yield point of the aluminum.

The Echo II satellite has completed all of its qualifying tests and is presently ready for shooting into orbit early next year. Figure 12 shows the Echo II satellite during static inflation tests at Weeksville, North Carolina.

Concurrent with the work on Echo II, the Schjeldahl Company has been engaged in advanced materials for space inflatables. One of these programs with NASA has resulted in the development of a lighter weight, rigidizable material for larger passive communication reflectors. Studies conducted by NASA have shown that, for an operation communication satellite network, a 425-foot diameter sphere will be required to give adequate band width for one television channel.

The feasibility portion of this materials study has been completed and prototype spheres are now under evaluation. This material, like Echo II, is a lamination of plastic and aluminum (Figure 13). The plastic in this case is biaxially oriented polypropylene with a tensile strength of 30, 000 psi in both directions and a density of 0. 92. Polypropylene was chosen because of its high strength-to-weight ratio

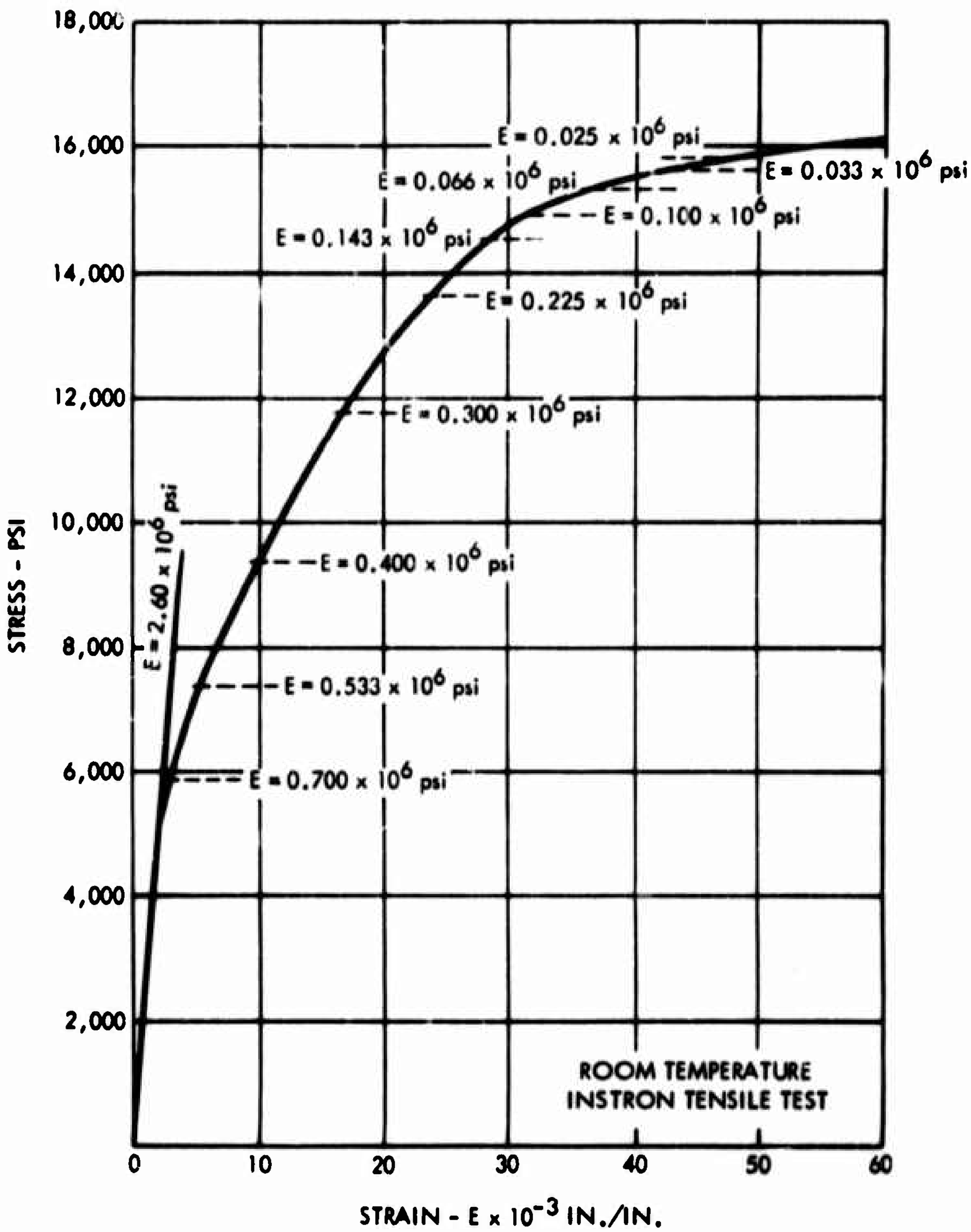

Figure 9. Stress-Strain Curve for X-15 Laminate

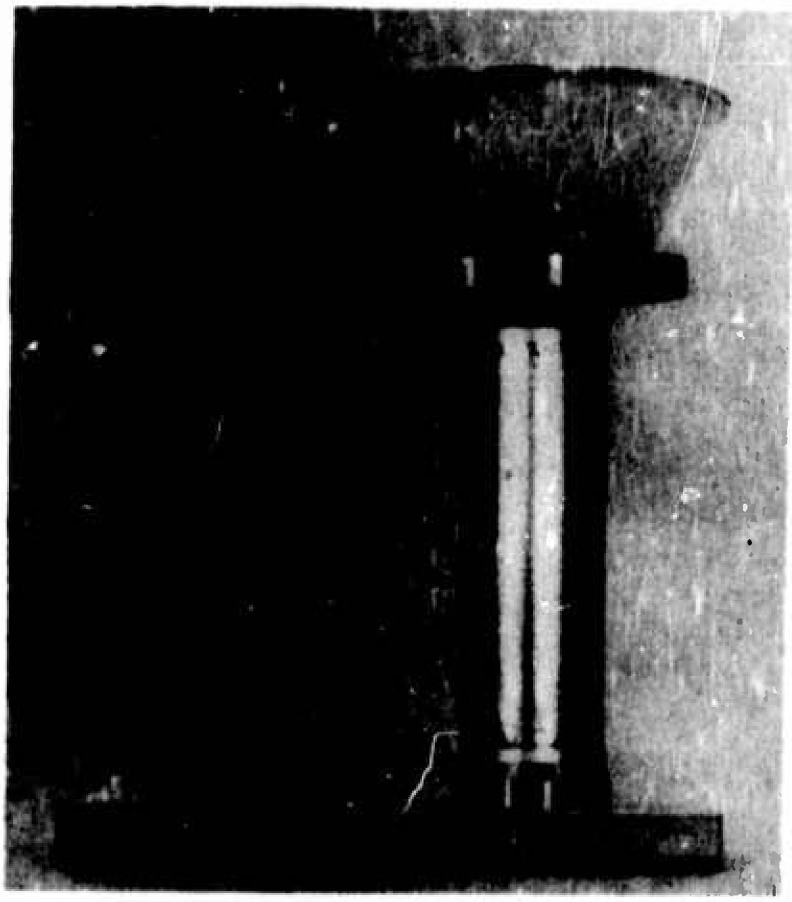

Figure 10. Cylinder Compression Test

Figure 11. Pictorial Results of Cylinder Compression Test

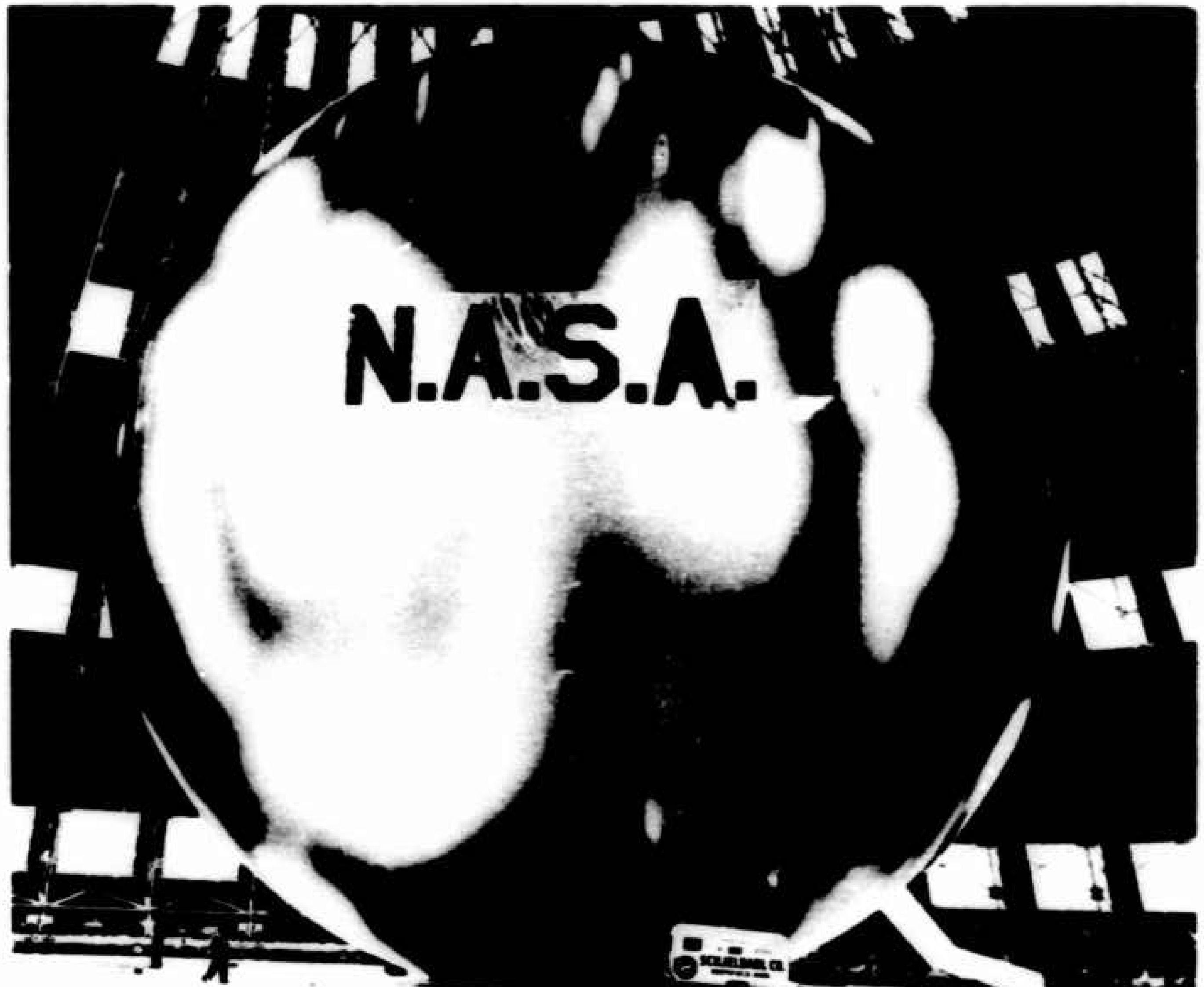

Figure 12. Static Inflation Test Echo II. Sphere, 135-ft diameter, of .00018-in. thick aluminum foil on both sides of .00035-in. thick Mylar bonded with Schjel-Bond 301.

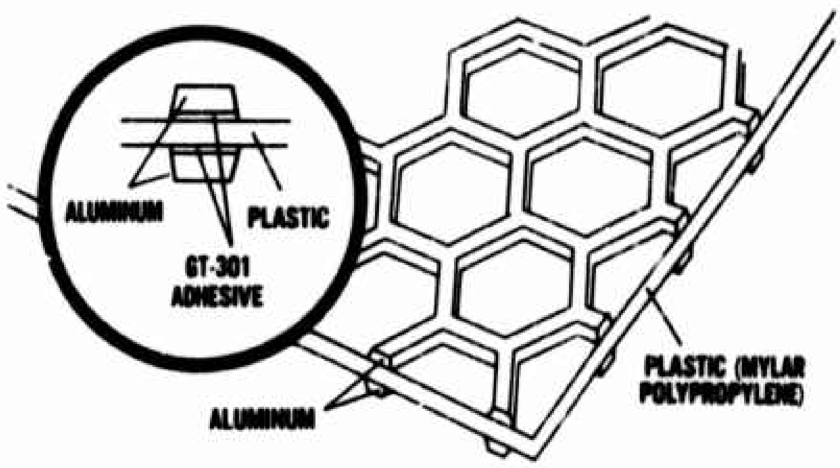

Figure 13. Advanced Material for Rigidized Communication Satellites

and its resistance to discoloration in a space environment. The aluminum in this case is milled out in a hex pattern to 1) reduce the satellite weight, and 2) allow 90 percent of the solar energy (1.3×10^{-9} psi) to pass through the satellite and therefore reduce the required rigidity.

Further study to reduce the weight of these communication satellites is presently under study. One technique employs a lenticular shape reflector which is oriented by means of gravitational gradients (Figure 14). This system has a potential of reducing the weight of a given reflector by as much as 40 percent. Also by using solar reflective and absorbing coatings and passing a current through the torus it would be possible to change the orientation of the reflector when it is not in use. This can be used as a station keeping function or it might be used to move the satellite into a higher orbit.

Each of these balloon applications has been made possible by 1) availability of a wide range of packaging materials in this country and 2) a decided effort by the balloon engineer to make use of the materials or combination of materials he has at hand. As I said earlier, first establish the design requirements, temperature, strength, tear, permeability, and so on, then choose the material which best meets these requirements. If one does not exist, do not be afraid to combine or modify these materials to give the desired results. This may be contrasted with the approach of designing the system around a material.

It is not possible here to go into all of the new materials developed or being developed for inflatables. I will therefore list only a few of the programs in existence or being considered for inflatables.

1. ROBIN - A one-meter diameter sphere containing an octahedral corner reflector which is ejected from a rocket nosecone at 250, 000 feet and used to determine meteorological parameters from 250, 000 feet down to 100, 000 feet.

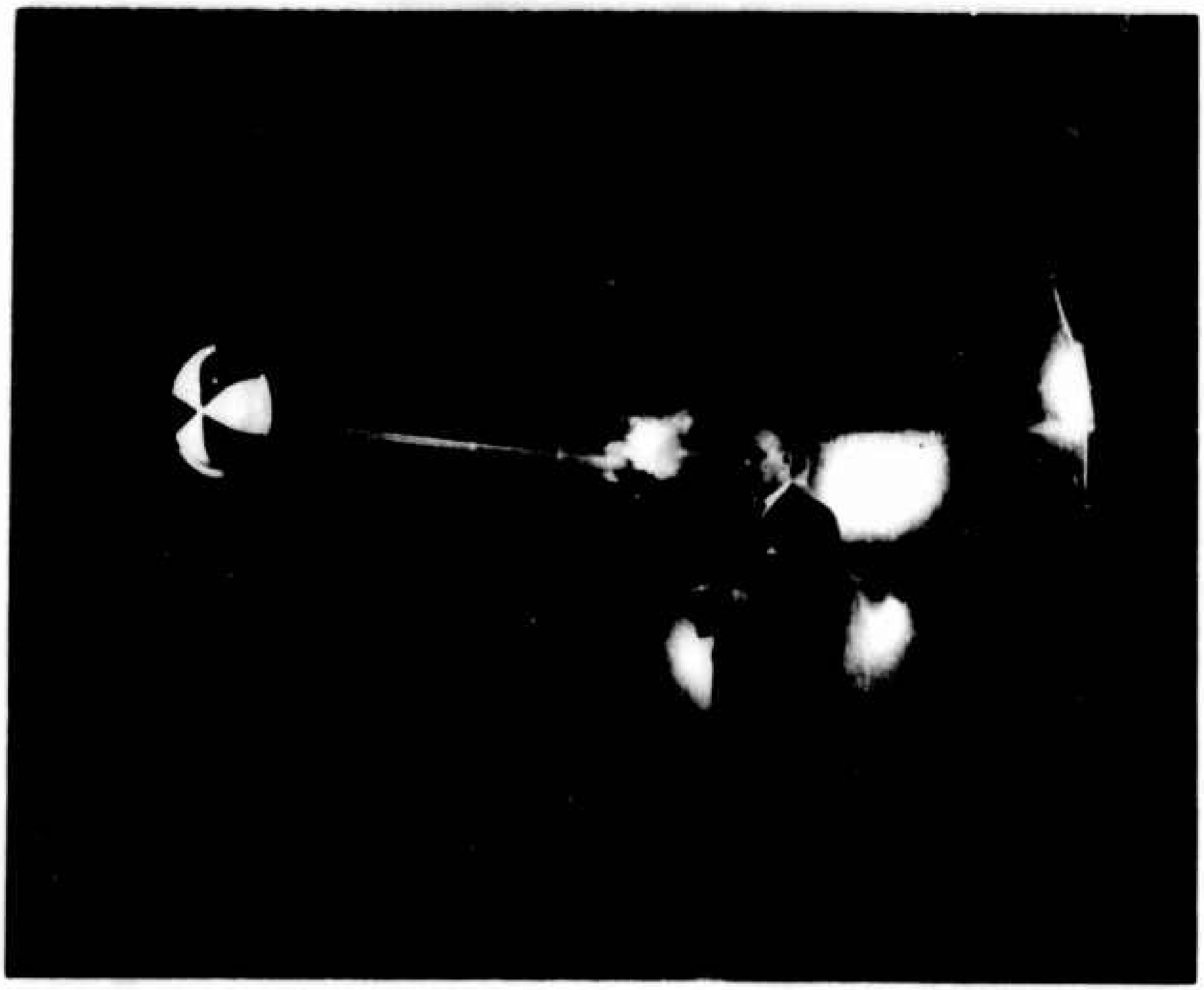

Figure 14. Lenticular Shaped Reflector

2. Targets or decoys which are carried aloft in a rocket nosecone and then ejected and inflated (Figures 15 and 16). The canisters, inflation mechanisms, deployment, and inflatables used in these programs have been thoroughly evaluated and in some cases are presently in production. These systems use either RF reflective materials with a plain plastic backing or systems which will rigidize when erected in space.

3. Antennas - Space inflatable antennas are another ideal application for inflatables. (Figure 17) The ability to pack these inflatables in a minimum space and their light weight requiring a minimum torque moment to orient, are important factors.

4. Solar Concentrators and Solar Cell Arrays - Some work on inflatable solar concentrators has been done although the main problem still is obtaining high efficiency. To date we have achieved approximately 50 percent efficiency from an inflatable and rigidizable concentrator. Inflatable mattresses can also be used to deploy and serve as a rigid mounting for solar cell panels.

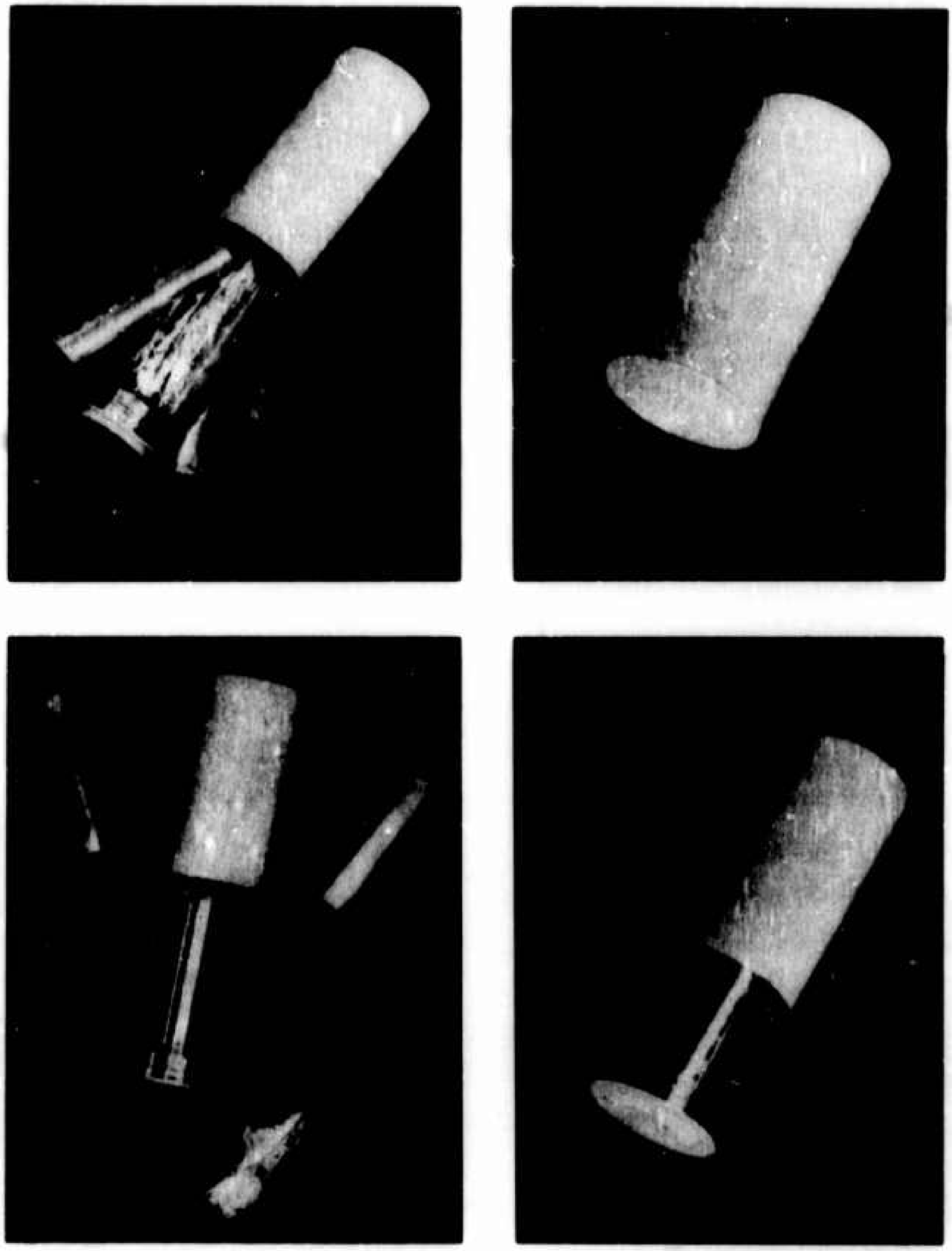

Figure 15. Space Inflatables

Figure 16. Space Inflatables

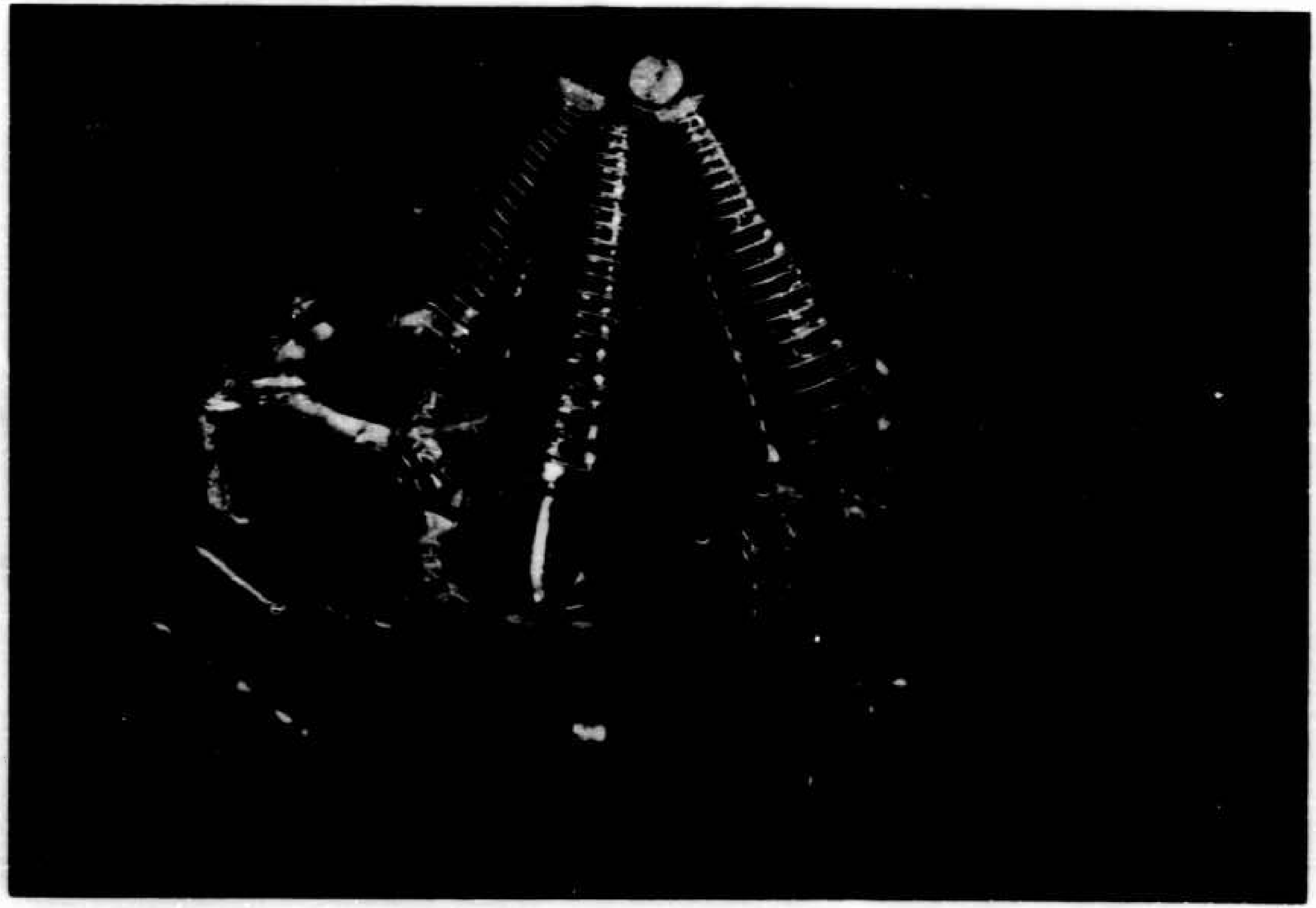

Figure 17. Space Inflatable Antenna

5. Solar Sails - These are another application for light weight inflatable devices. Large surface areas containing reflective and absorbing coatings can be used for station keeping, orientation, or as a true solar sail for propelling an object through space.

6. Re-Entry Devices - A considerable amount of work has been done on inflatable type re-entry devices. These include the Ballute which is a spherical shaped drag device and the Regallo Wing which is a steerable parachute type glider for re-entry of space vehicles. Many other types of re-entry devices are being considered which make use of the inflatable concept. One of the more interesting is a nosecone or umbrella shaped device which cradles a man re-entering from space. This device would work similar to a parachute. If a man had a malfunction of his space vehicle he could eject himself, inflate the cone shaped re-entry device and return safely to earth. Most of these devices require extremely high temperature resistant materials. The most successful have been metal fabrics impregnated with silicone compounds. H-film, a new product of DuPont which has a service temperature exceeding 800 F, is also being considered for some of these applications.

7. Manned-Space Station (Figures 18, 19, and 20) - This series of pictures demonstrates one concept for the use of inflatables in connection with an orbiting space station. Materials for such an application are not available today, however, a good deal of effort is now being placed on their development. The advantages of this concept are obvious. First, inflatables are lighter weight and capable of being packaged in a minimum space, and, secondly, they can be deployed in space without having astronauts exposed to the space environment in bolting, welding, or fastening sections of the space station together.

Inflatables are playing a bigger role today than ever. Through new materials, I am sure we will see an even greater expansion in this field in the years to come.

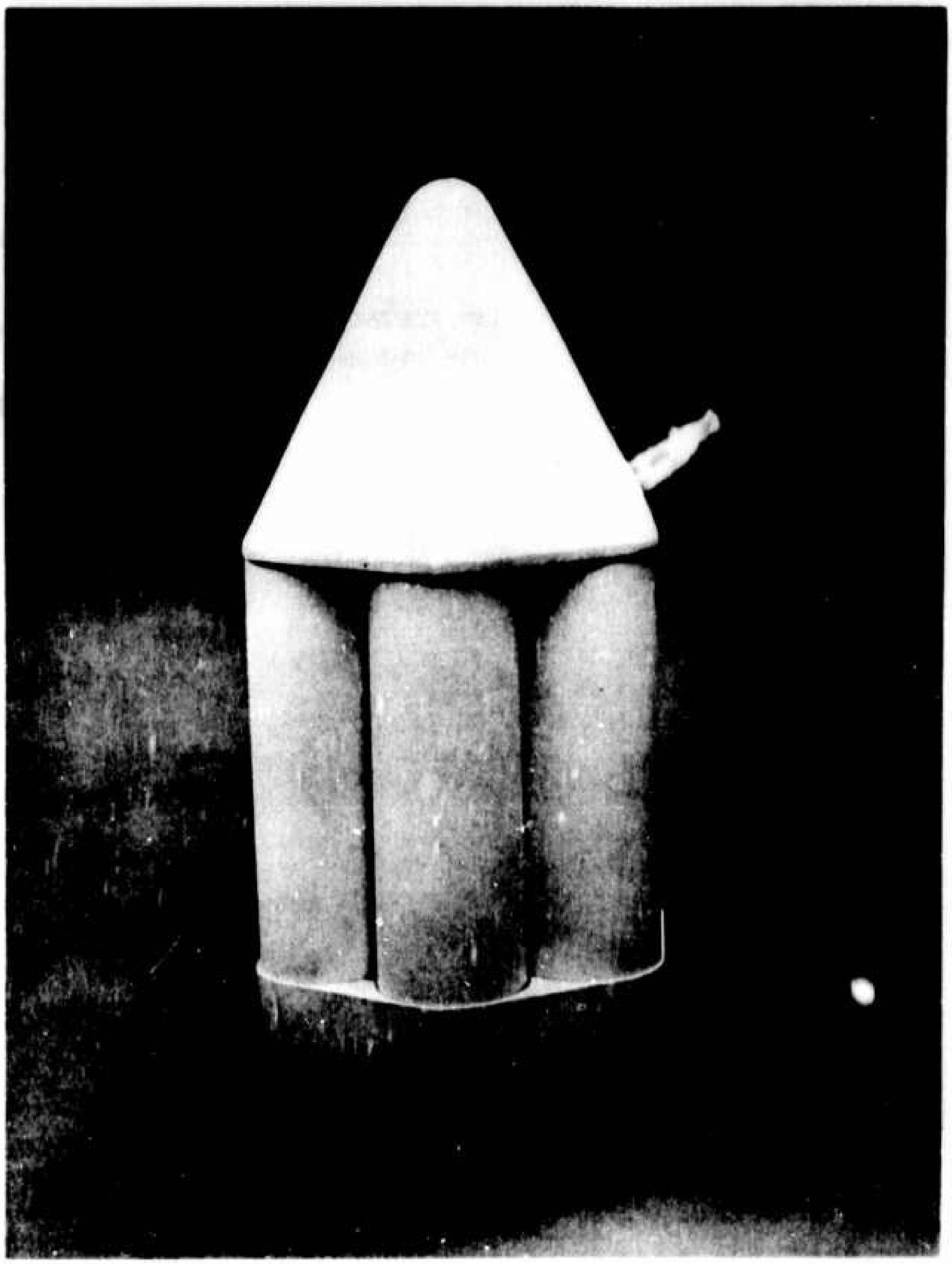

Figure 18. The Erectable Space Station in Folded Condition As It Would Be Mounted on the Nose of a Launching Booster

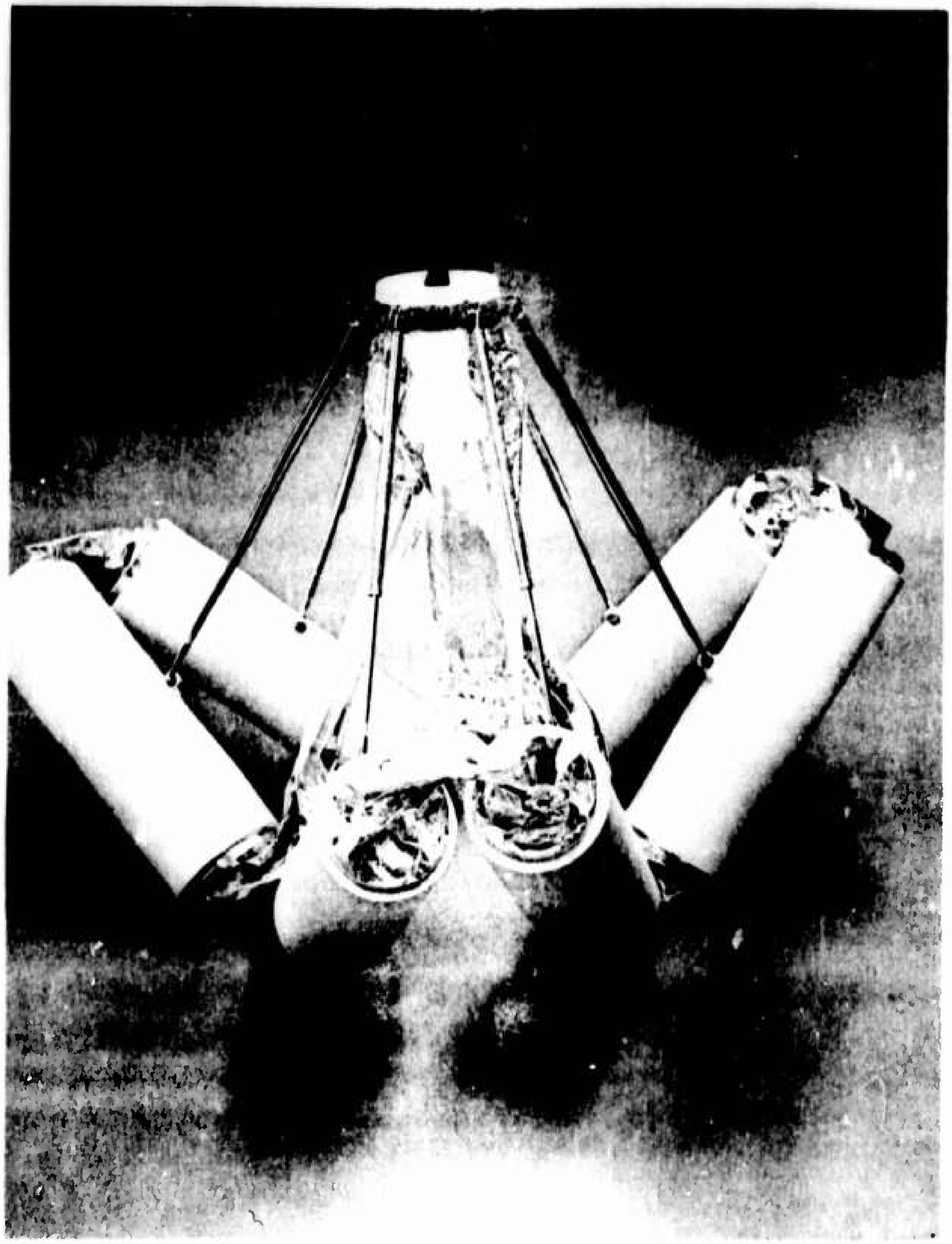

Figure 19. Space Station Is Shown About Half-Erected

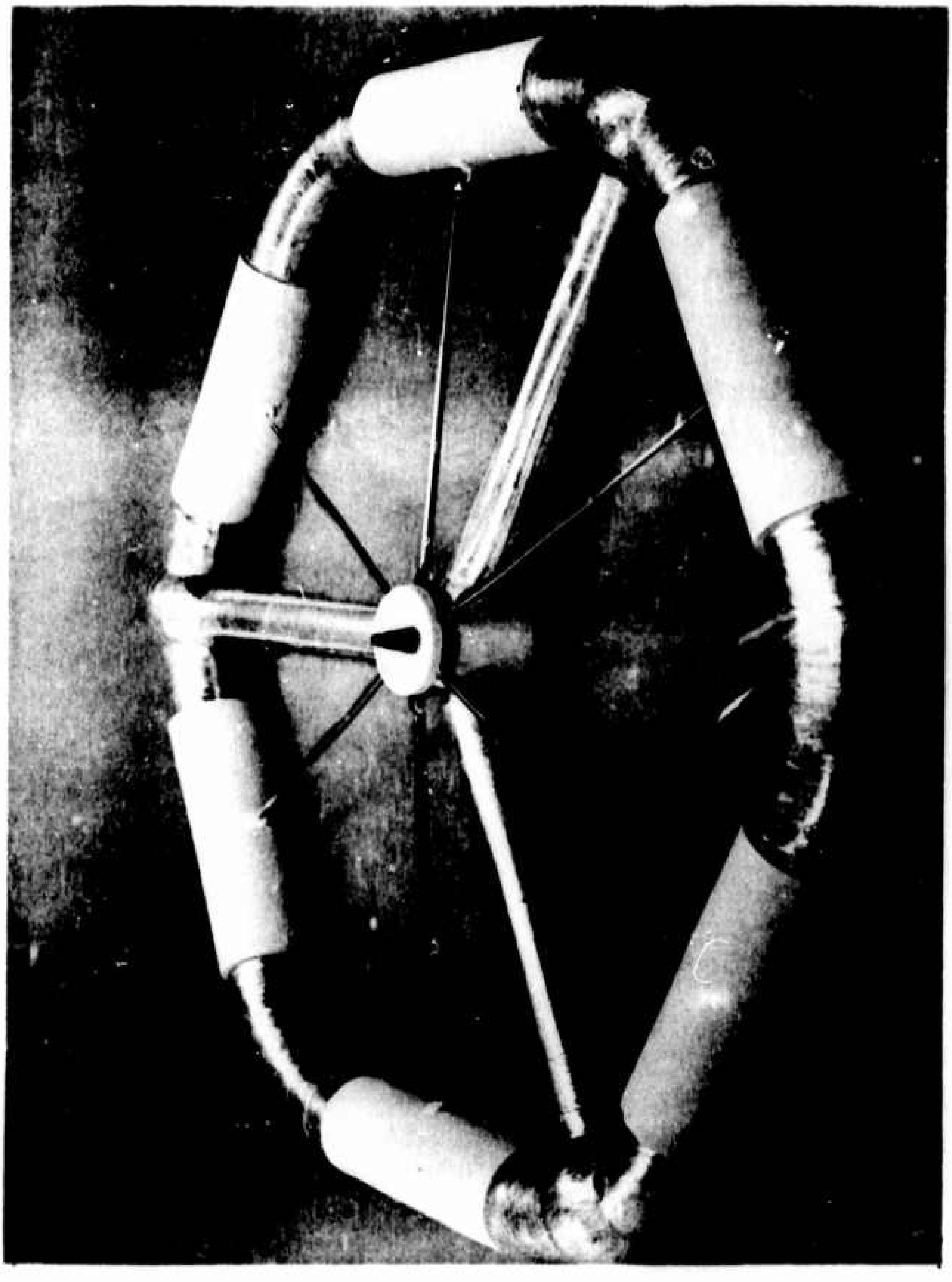

Figure 20. View of the Completely Erected Space Station

V Reaction Jet Azimuth Control System for Gondola Stabilization

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Abstract

An azimuth control system for orientation and stabilization of a 3000 pound balloon-borne gondola about the vertical axis is described in this paper. The control system employs nitrogen gas stored under high pressure as the thrusting propellant. A magnetometer and a rate gyro provide attitude and attitude rate information for the nonlinear on-off control system. Attitude control is held to a tolerance of ± 0.1 degree with a maximum deadband rate of 0.07 degree per second.

1. INTRODUCTION

Heavy-load balloons represent near-ideal vehicles for basic research and developmental testing above the principal part of the earth's atmosphere. Many possible applications require or would be greatly expedited by a simple control system for orienting and stabilizing the instrument gondola about the vertical axis. One experiment of this nature is the Aerospace Photographic Reconnaissance Experiments (APRE) being conducted by Honeywell Aeronautical Division as prime contractor to the Reconnaissance Laboratory, Aeronautical Systems Division, USAF, under Contract AF 33(657)-7171.

In this application, as in many other potential experiments, an azimuth orientation system was required to control the orientation of a large gondola to ± 0.1 degree of geographic reference with minimum rate disturbance during the stabilization mode.

A stabilization mechanization utilizing cold nitrogen gas as the propellant was selected because of its inherent simplicity and reliability and the minimum constraints placed on over-all vehicle design. In the past, azimuthal stabilization of large gondolas has been obtained by employing the inertia-wheel approach in which a large portion of the gondola load (for example, batteries) or added weights are mounted so as to present a large inertia against which force can be exerted by the payload to maintain the desired reference. The payload is pivoted below the inertia load with

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inertia load "rigidly" attached to the balloon suspension. The balloon itself contributes to the total inertia load and actually provides inherent rotational damping for dissipation of integrated inertial forces (for example, inertia-wheel velocity).

A reaction jet control system allows the complete gondola to be independent of the balloon system with the total gondola load suspended below a pivot bearing. In the application to be described the total gondola weight is approximately 3000 pounds with a vertical polar moment of inertia of 250 slug-ft^2.

2. SYSTEM DESCRIPTION

A photograph of the over-all gondola assembly being used in the APRE program is shown in Figure 1. The gondola consists basically of a pressurized and temperature-controlled gondola structure housing precision photographic and other electronic equipment for high-altitude photography of objects located or flown below the gondola and within the narrow camera field of view. The camera is equipped with a 48-inch F/4 lens and weighs approximately 400 pounds. The entire gondola is suspended by a bearing assembly which, except for frictional coupling, isolates the gondola from the balloon and parachute. A slip-ring array is an integral part of the pivot bearing assembly to allow signal and power transmission from the gondola to the upper part of the over-all flight train.

Program operations require that a specific camera (gondola) axis be oriented and stabilized to a known geographic reference. A block diagram of a cold-gas reaction jet control system developed for this purpose is shown in Figure 2. A magnetometer is used as the basic attitude reference. Rate information is obtained from a body-mounted spring-restrained rate gyro.

Attitude and/or rate information control, via logic circuitry, electromechanical valves to release propellant in the appropriate direction to maintain the desired attitude position and rate stability. The propellant in this case is dry nitrogen gas. The basic characteristic or stability of the system operation is determined by the switching line or the ratio of rate to attitude authority and the allowable system deadband. The mechanization results in a nonlinear on-off control system with control exerted only when rate and/or attitude exceed the design limits. In the APRE application, these limits were ± 0.1 degree attitude and 0.07 degree per second rate.

An analytical block diagram of the system is shown in Figure 3 where control torque is shown as T_C and disturbance torque as T_D. The disturbance torque input is the effect of frictional coupling of the gondola to the balloon suspension through the pivot bearing. Large balloons typically exhibit, in the float condition, a continuous rotation or large-amplitude oscillation with a period on the order of 4-5 revo-

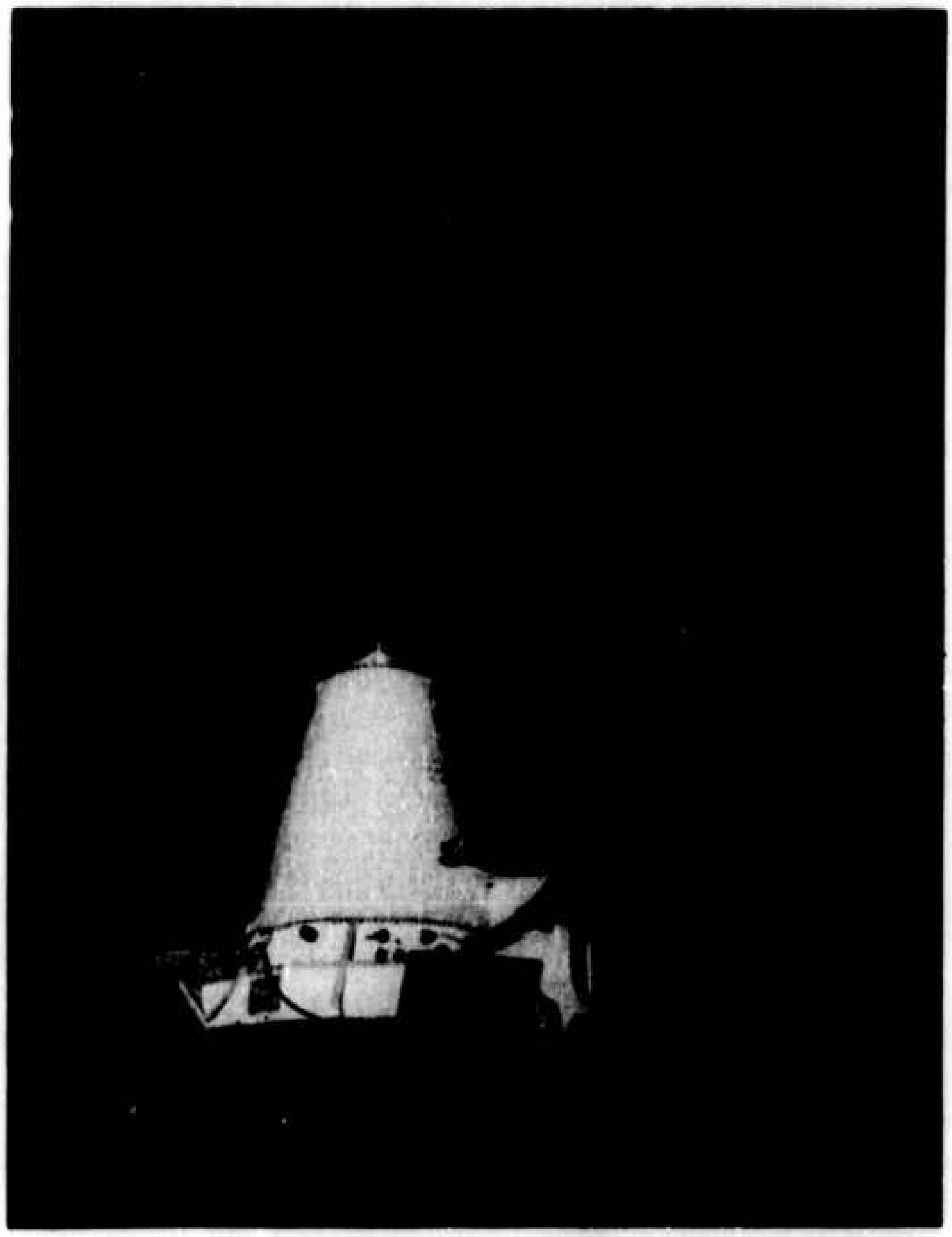


Figure 1. Over-all View of APRE Gondola

lutions per hour. This rotation is coupled to the gondola through the pivot bearing friction. The transmitted torque must be overcome by the reaction thrust to maintain the gondola in the desirea attitude position.

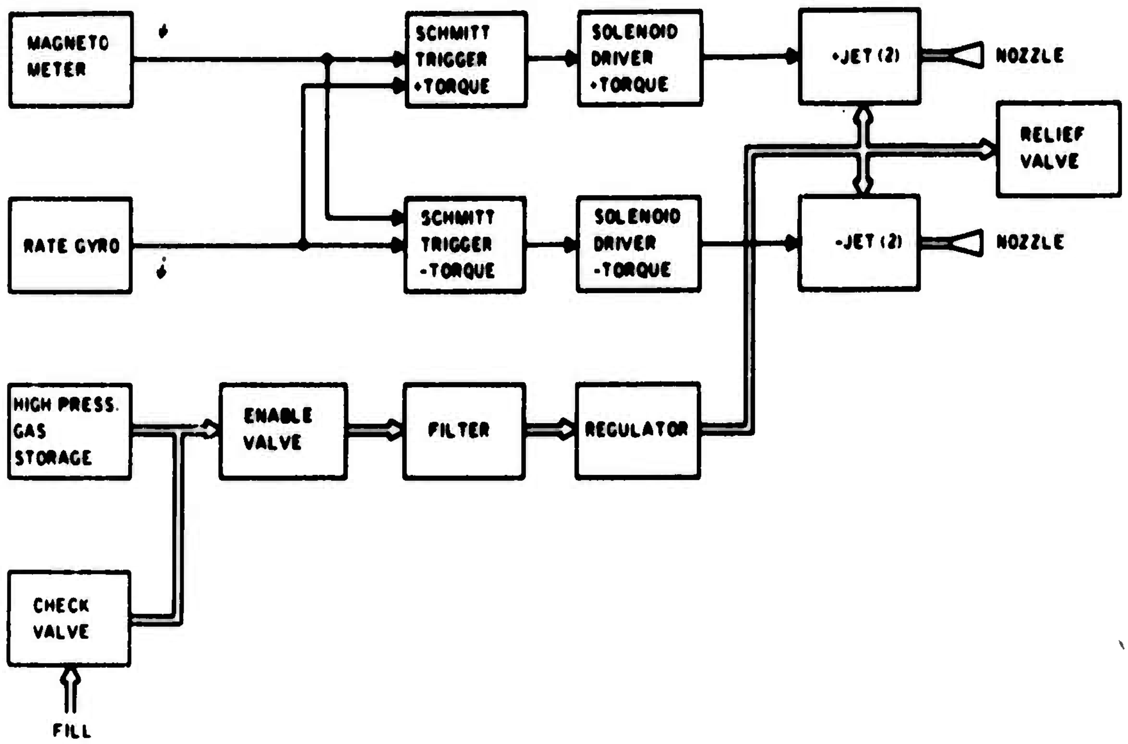
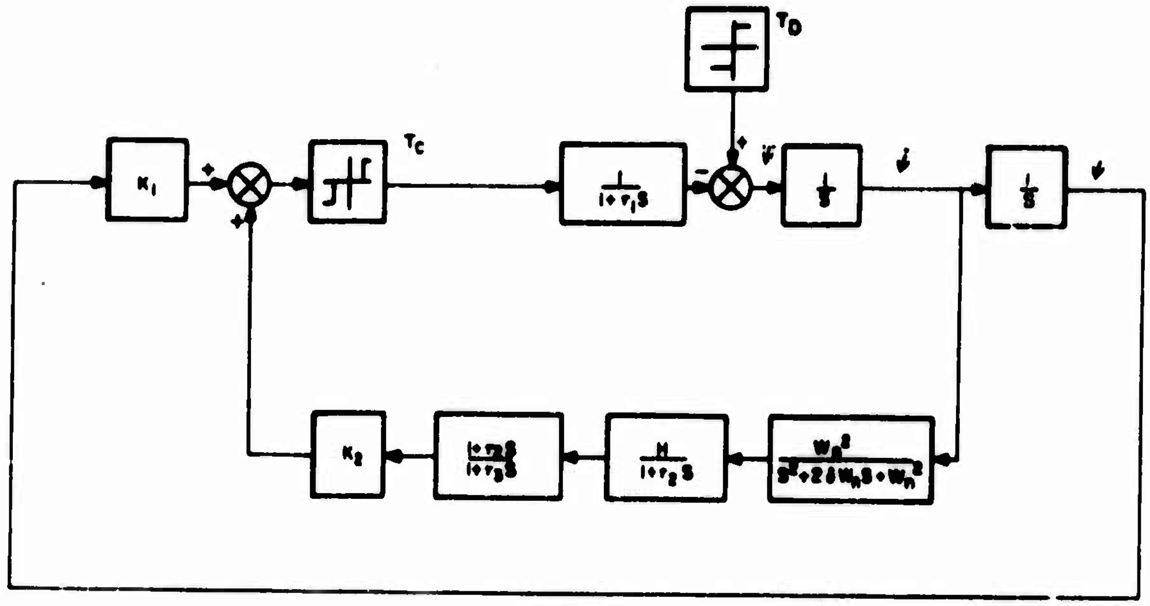


Figure 2. Functional Block Diagram of Azimuth Control System

Figure 4 illustrates a generalized phase-plane plot on which are shown instantaneous values of ψ and $\dot{\psi}$ resulting from control and disturbance torques during attitude hold. The abscissa of the plot is attitude error and the ordinate attitude rate. The two parallel lines are the switching lines, that is, the region beyond which control authority is exerted by rate and/or attitude error. The relative control authority between attitude error and attitude rate is determined by the slope of the switching line. The region between the switching lines is the region of no control and represents the system "deadband". The selection of the slope of the switching line and the deadband are calibrated values determined as the result of extensive system simulation work.

Over-all system operation in the presence of a disturbing torque is described in the following paragraphs (refer to Figure 4).

Commencing at point A, assume balloon rotation is such as to produce a positive disturbance torque ($+T_D$). $+T_D$ acts to increase both ψ and $\dot{\psi}$ along ABC. At point B control torque is commanded ($-T_C$). Because of the pull-in time of the solenoid valve and the thrust buildup time, $-T_C$ does not become effective until point C. ($-T_C$ $+T_D$) then acts to decrease ψ and $\dot{\psi}$ along CDA as $|T_C| > |T_D|$. At point D, zero control torque is commanded but because of the dropout time of the solenoid valve and thrust decay time, T_C does not actually go to zero until point A



T_D = DISTURBANCE TORQUE

T_C = CONTROL TORQUE

ζ = GYRO DAMPING RATIO

J = GONDOLA INERTIA

H = RATE GYRO HYSTERESIS

W_n = RATE GYRO NATURAL FREQUENCY

K_1 = MAGNETOMETER GAIN

K_2 = RATE GYRO GAIN

τ_1 = REACTION JET PULL IN/DROP OUT TIME

τ_2, τ_3 = TIME CONSTANT

Figure 3. Analytical Block Diagram

is reached. The disturbance torque carries the system to point B and the cycle repeats. If the balloon rotation is continuous, the gondola will oscillate slowly as illustrated about one edge of the deadband. If the balloon rotation should reverse, the sign of T_D reverses requiring control torque of opposite sign. The system will then operate about the opposite side of the deadband.

A linear recording of attitude error (magnetometer output) taken during a flight operation is shown in Figure 5. The trace illustrates the gondola attitude during the acquisition process and after attitude hold has been achieved. Although the response is typical of the response of systems similar to Figure 3, the specific time constants and the decrement during acquisition are, of course, characteristic of the specific gondola described. The maximum attitude error is ± 0.1 degree with a maximum rate of ± 0.07 degree per second.

Control system fuel consumption is a direct function of the disturbance torque (in this case bearing friction) and rate deadband. The limit cycle frequency (that is,

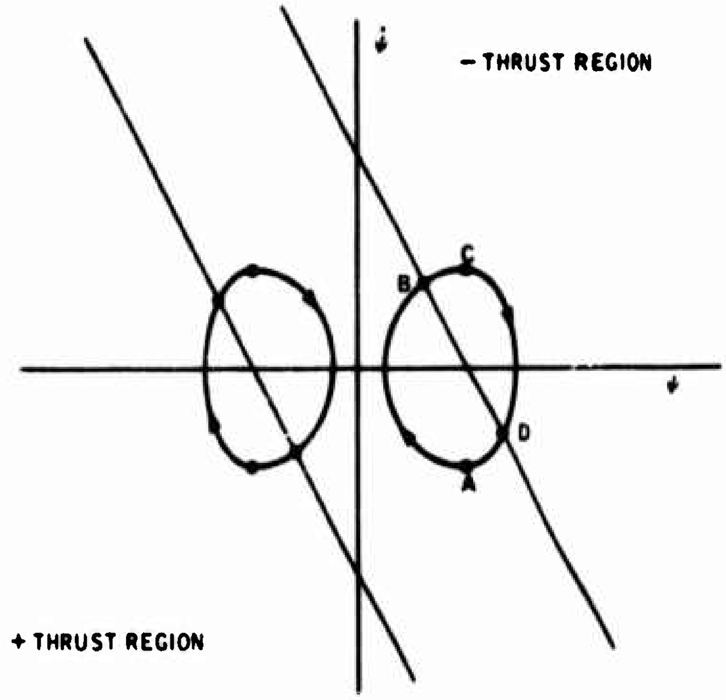


Figure 4. Phase Plane Plot of Azimuth Control System During Attitude Hold Mode

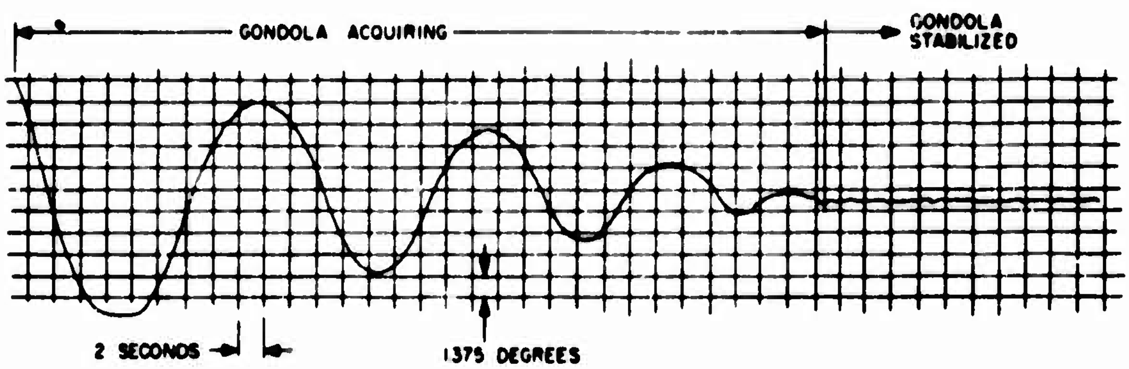


Figure 5. Azimuth Control System Magnetometer Output (Degrees from Null)

frequency of deadband oscillation) is:

$$f_{lc} = \frac{1}{\frac{\Delta\dot{\psi}}{T_D\ J} + \frac{\Delta\dot{\psi}}{T_C - T_D\ J}}$$

where

$\Delta\dot{\psi}$ = rate change to produce control thrust

T_D = disturbance torque

T_C = control torque

J = gondola inertia

Reaction jet duty cycle time is simply:

$$D = \frac{T_D}{T_C}$$

Thus given a total impulse, I, total operating time is calculated as

$$t = \frac{I}{T_D \times D} = \frac{I}{T_D \times T_D / T_C} = \frac{I\ T_C}{T_D^2}$$

The principal unknown effect here, of course, is the time existence of T_D. The above expression for t is actually an accumulated operating time. If the balloon is in continuous rotation, ti is total time. However, if the balloon is actually oscillating slowly or not rotating or oscillating at all, the available control time is appreciably extended. The most logical and conservative assumption is to assume that T_D exists for the length of the mission (or the controlled portion of the mission) and to calculate the gas storage requirements on that basis.

The subject program required a total control time of six hours. The following parameters resulted in the most nearly optimum system for the application:

Nitrogen Storage	3600 cubic inches at 4500 psig
Total Impulse	1800 lb-sec
Disturbance Torque	0.5 lb-ft
Control Torque	3 lb-ft

A photograph illustrating the installation and mounting of the reaction control jets is shown in Figure 6. Two jet and nozzle assemblies, one for each direction of thrust, are mounted on the end of a tubular moment arm. A detail view of the reaction jet valve and nozzle assembly is shown in Figure 7. An identical moment arm supporting an identical jet and nozzle assembly is located on the opposite side of the gondola so that a torque couple is produced for each direction of rotation. Although a single thrust arm could be employed, the application of a coupling greatly alleviates thrust alignment tolerances with respect to gondola center of gravity. Low-pressure gas is supplied to the jets at 170 psig via low strength tubing from a mechanical pressure regulat located within the gondola shell. The gas is stored, in this application, at 4500 psig in four stainless steel spherical tanks each connected to a stainless steel manifold which terminates after filtering in the regulating device. Photographs illustrating the installation of the storage tanks and associated plumbing during early phases of system fabrication are shown in Figures 8 and 9.

3. GROUND HANDLING

The gas storage tanks of the azimuth control system must be charged prior to each flight operation and topped off prior to launch to replenish gas used during preflight testing. The high-pressure gas transportation cart shown in Figure 10 is used for transport of gas to the launch site or other areas as required. At Holloman Air Force Base, New Mexico, the gas transportation cart is filled with clean, dry nitrogen to about 5500 psig at the Sled Test Facility. Gas transfer to the gondola tanks is by simple pressure equalization. The transportation cart tanks have a total internal volume of nine cubic feet. With a gondola tankage internal volume of about two cubic feet the equalized pressure during transfer is about 4700 psig.

The transportation cart tanks are forged of high strength steel and have a burst p. essure of 20,000 psig. Tank manifolding is stainless steel tubing. A view showing location of the 'ransportation cart on the vehicle used to transport the gondola to remote launch sites is shown in Figure 11.

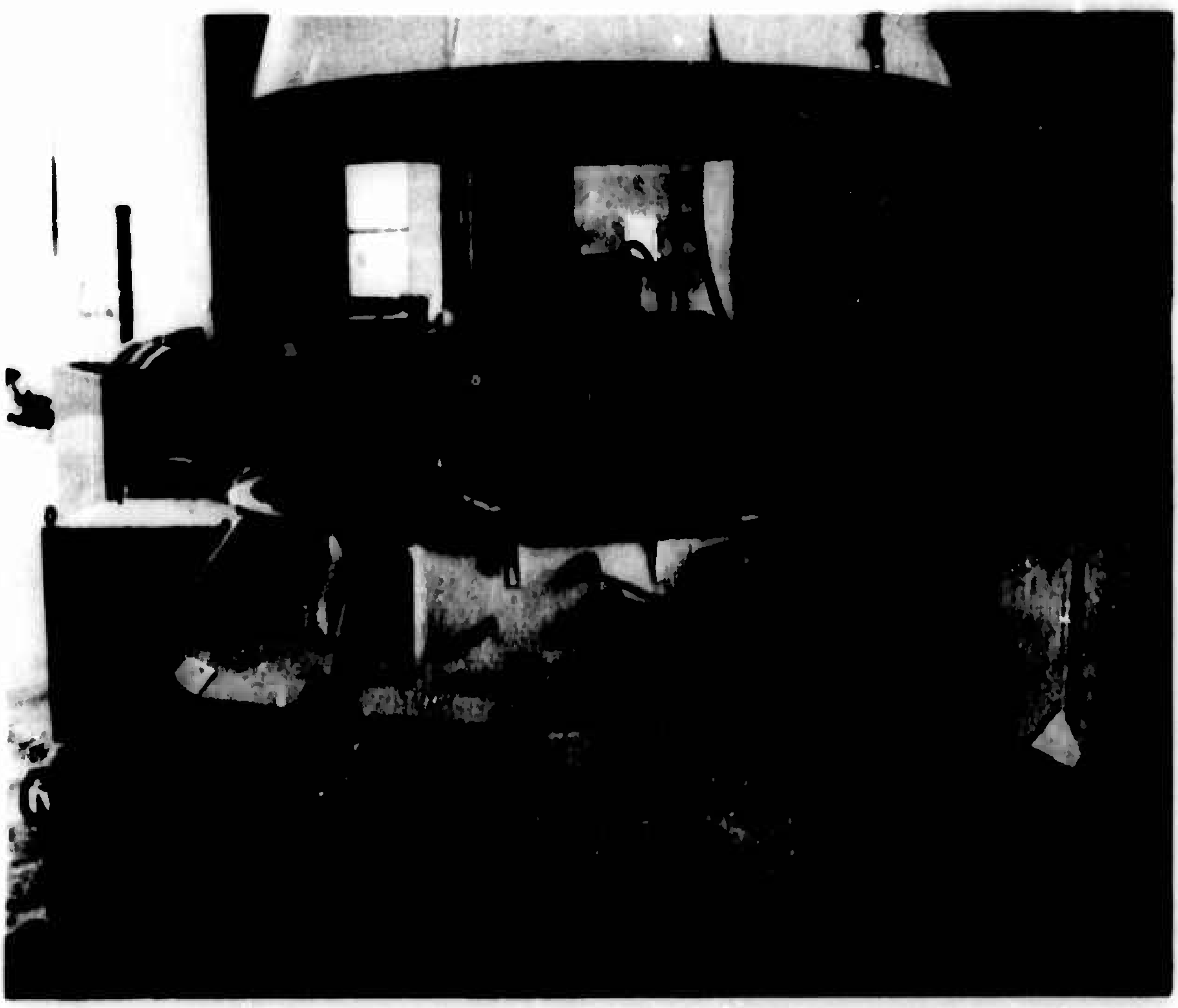


Figure 6. View of Gondola Showing Reaction Jet Installation

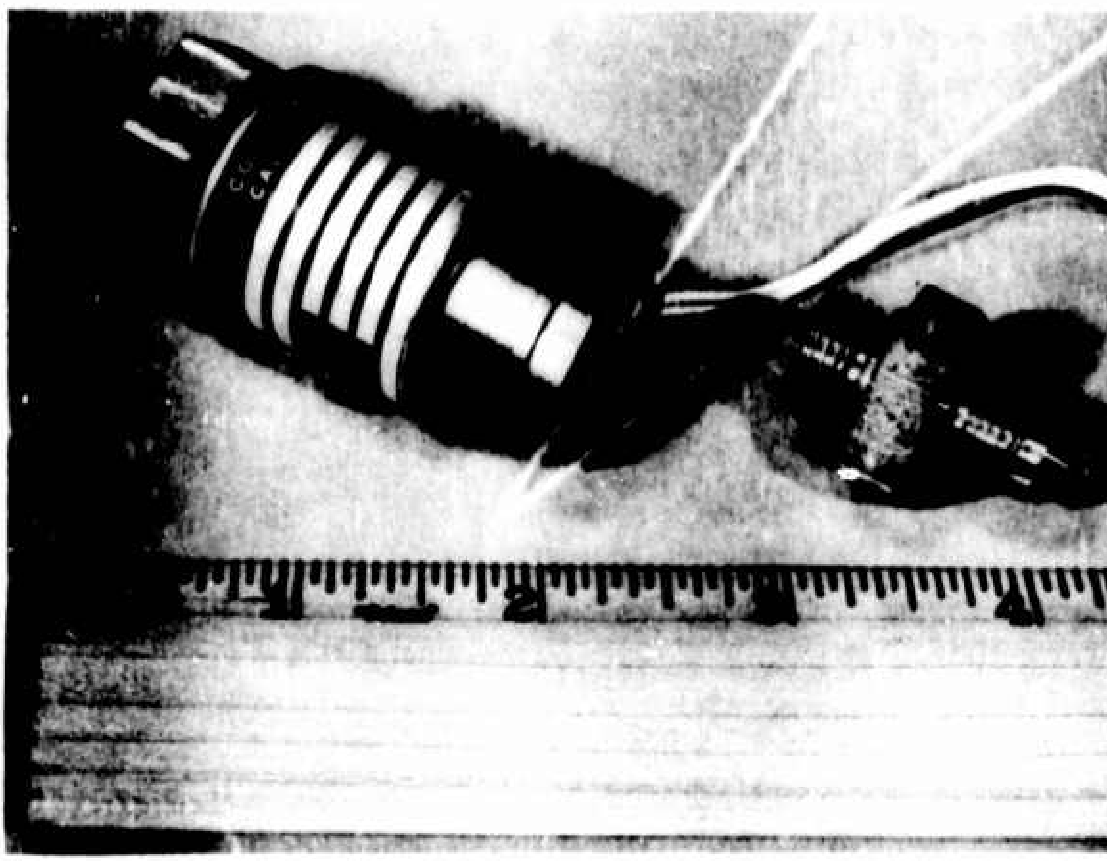


Figure 7. Detail View of Reaction Jet Valve and Nozzle Assembly

Figure 8. Photograph Showing Installation of Azimuth Control System Plumbing. Only one arm of control system jet couple is shown.

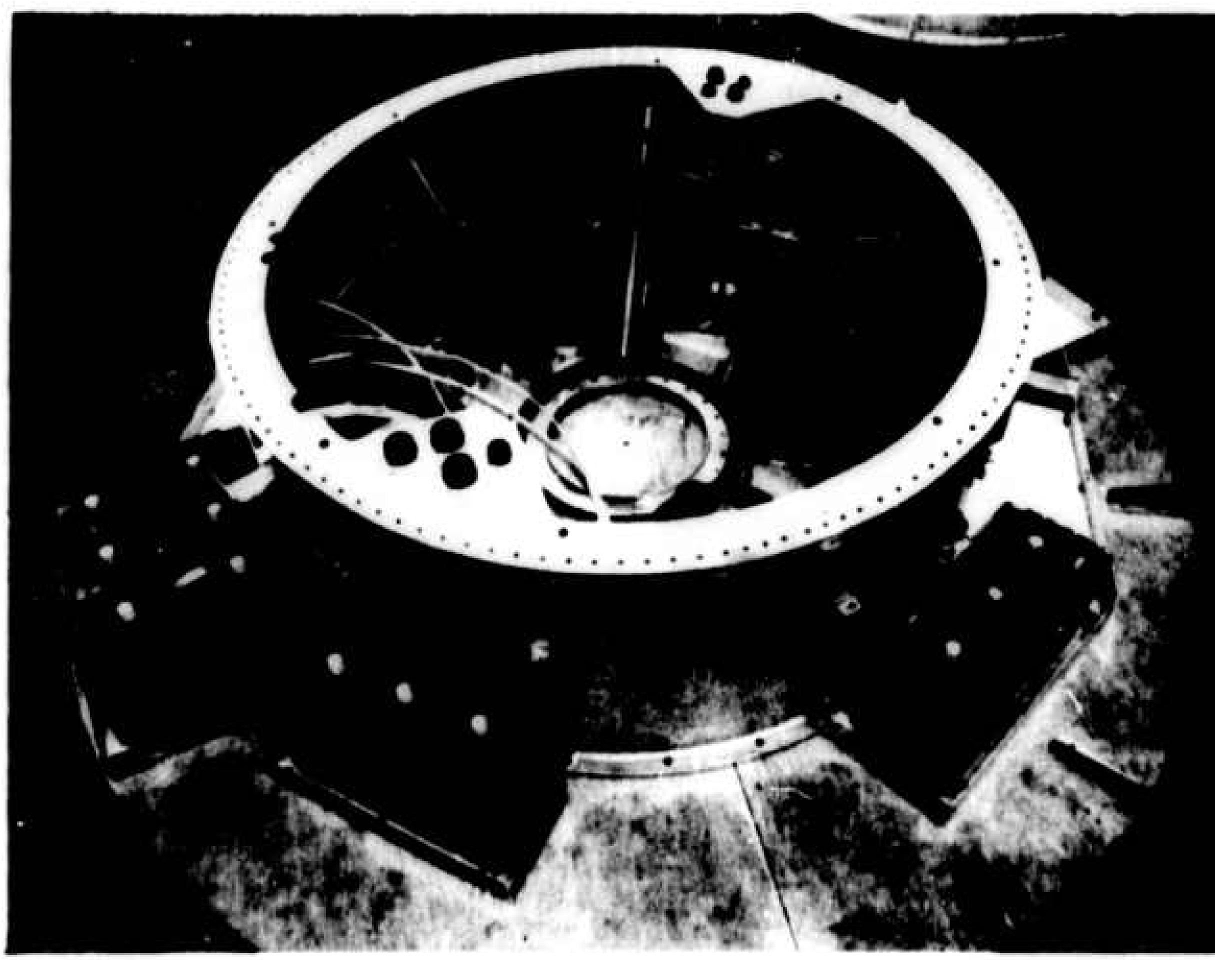


Figure 9. Photograph Showing Gas Storage Manifolding

Figure 10. Photograph of Gas Transportation Cart

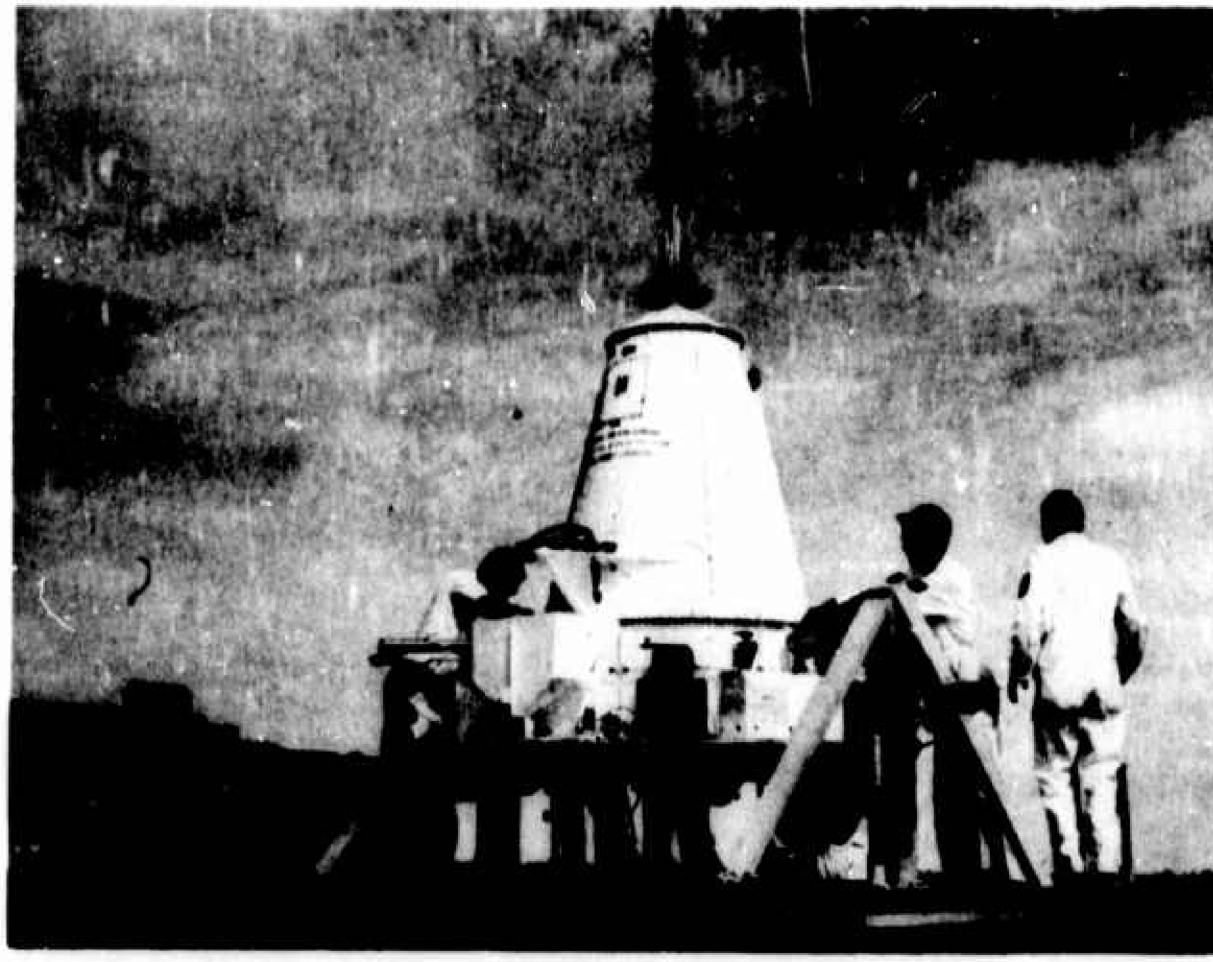


Figure 11. Photograph Showing Installation of Gas Storage Cart in Transportation Vehicle

4. SUMMARY

The reaction jet approach to azimuthal control and stabilization of balloon-borne payloads has potential for a broad range of applications requiring moderate control accuracy. Although this approach cannot optimally achieve the precise control possible with fine inertial devices, it provides a refreshing simplicity over the cumbersome and large inertia wheels commonly associated with balloon azimuth stabilization systems. These inertia wheels, frequently loaded with batteries and other paraphanelia, present very difficult structural and power transfer problems which are never totally solved.

The structural simplicity possible using reaction jet control is evidenced by the relatively clear structure shown in Figure 1.

Although a magnetometer has been discussed as the system attitude reference, other basic sensors such as sun sensors for sidereal time orientation or radio-frequency devices for specific ground-based orientation are certainly applicable as the situation demands.

VI Status of Meteorological Sounding Balloons

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Abstract

The current status of the various types of balloons used in meteorological sounding operations is discussed. Balloons include the expansible neoprene kind used for standard radiosonde flights, as well as the rocket-ejected ROBIN falling sphere and the ROSE rising rigid sphere. Recent advances in the design and performance of these balloons are described along with problem areas for future consideration.

1. INTRODUCTION

In assessing the status of meteorological sounding balloons this paper will be concerned with balloons quite a bit different in nature than most of those that will be under discussion at this Symposium. Meteorological balloons include, of course, the expansible neoprene type normally used by Air Force, Weather Bureau and other agencies in routine sounding operations, and in addition some special purpose plastic types also used for meteorological observations. In the latter category are the rocket-ejected ROBIN falling sphere and the ROSE rising rigid sphere.

1.1 Radiosonde

Almost everyone is familiar with the standard balloon-borne radiosonde technique of sounding the atmosphere. The radiosonde carried aloft by a balloon from which it is separated by about 100 ft. of cord telemeters to a ground receiving station information on various thermodynamic parameters of the atmosphere. Its space position as determined by the ground tracking equipment permits calculation of wind data. Although improvements are continually being made in both the ground and airborne equipments the major problem as far as consistency of performance and adequacy of the data-gathering is the balloon carrier. Thus a comprehensive balloon

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research and development program is being carried on to improve balloon performance. Practically all of this type of balloon work in the United States is funded by Air Force Cambridge Research Laboratories and the Army's Meteorological Division at Ft. Monmouth, N. J.

The seemingly simple weather balloon is in fact a rather complex fabrication. In addition to the basic neoprene latex, a balloon film contains such materials as plasticizers, accelerators, anti-ozonants, anti-oxidants and reinforcing agents, to name some of them. The film must have elongation, modulus and tensile strength characteristics to achieve the desired height and rate of rise requirements and to permit inflation and launching handling and wind buffeting without damage. Since there is usually a long time lapse between the fabrication of a balloon and its actual flight, the film must have an adequate aging capability. It must perform in weather extremes of temperature, precipitation and winds. And with all this it must be low-cost.

A film study contract during the past few years with the Kaysam Corporation of America by the Army has endeavored to investigate many of the areas mentioned previously. Without doubt this program has been very productive. As an example one of its results has been the currently standard ML-537 balloon, a relatively small 800 gm balloon capable of reaching 100,000 ft. in height at a minimum rate of rise of 1000 ft./min. both at night and during the day. The ML-537 represents a 10-20,000 ft. height improvement over the separate day and night balloons it replaced. It also has a specified 80% reliability, as compared to the previously required 60%. The cost of this balloon in procurement is in the order of \$7-\$8.

Recent advances in the balloon study program indicate that an operational balloon capable of rising consistently to about 125,000 ft. is not too far off. This should be only a little larger and slightly more costly than the ML-537. We believe that considerable progress will continue to be made beyond that. Meteorological balloons have already been flown to 150,000 ft. on several occasions, although admittedly they have been of a fairly large size and consistent performance has not been possible.

As has been pointed out, progress in meteorological balloons is in general very satisfactory. However there are also some definite problem areas with which we are concerned. The foremost of these is the cold temperature effect on a balloon film. This problem exists in the tropics, where the extremely cold tropopause temperatures, as low as -90°C, often cause freezing of the film during nighttime flights. Solar heating of course, prevents this freezing occurrence in the daytime. Special purpose tropical balloons are now being used to penetrate the cold tropopause layer. However these balloons, because of the extra plasticizer required for freeze resistance, are fairly soft and easily damaged. Another cold temperature problem is found in wintertime arctic flights. Here the temperatures are not as extreme as the tropical minima, but the consistent cold throughout the duration of the flight tends to deteriorate balloon performance. One of the major goals in our current R&D program is to try to overcome these cold temperature effects.

1.2 Fast-Rise Balloon

Another balloon effort which continues to be somewhat of a problem is the development of a satisfactory 100,000 ft. fast-rise balloon. The requirement for a fast-rise balloon is two-fold: (1) It will cut down the time needed to make a flight (it takes about an hour and a half at the present time with the standard balloon), and (2) It will permit more accurate and complete data to be received from radiosondes launched when strong jet stream wind conditions exist, resulting in very low tracking angles. Low elevation angles could mean distorted transmitting signals because of ground reflections and also data deterioration because of the trigonometric nature of the data reduction technique used.

Several configurations have been investigated for a possible optimum fast-rising balloon. These included a thick walled spherical balloon and a two-piece streamlined or tear-drop type. The current design being investigated utilizes the principle of one balloon inside another, with an attached tail for streamlining purposes. The inner balloon is a 2000 gm size, with the outer one somewhat smaller and designed to break and drop off at 50,000 ft. The inner balloon then continues on essentially as a sphere. Preliminary results with this balloon look encouraging. Design criteria are day and night performance to at least 100,000 ft. with a minimum ascension rate of 1700 ft./min.

Before leaving the expansible balloon discussion it might be of interest to mention that at least three efforts have been made in recent years to design plastic balloons as radiosonde carriers. Unfortunately, none of these programs came even close to success with respect to height or rate of rise performance. In any case it does appear that cost-wise the use of a plastic operational balloon at this time is prohibitive. Perhaps in the not too distant future, materials and techniques will be available to produce a reliable and low cost plastic sounding balloon.

1.3 ROBIN System

With Air Force requirements now existing for obtaining meteorological information far above the capability of the balloon-radiosonde system, in particular for support of the missile program, AFCRL has become deeply involved in the development of meteorological rocket systems. One of the payloads developed which has proved to be highly successful is the ROBIN sphere. The ROBIN is carried aloft in a deflated form by the rocket (the ARCAS and LOKI-DART are the two types of meteorological rockets currently being used). Ejected at apogee - somewhat above

200,000 ft. - the sphere is inflated to a superpressure of 10 to 12 mbs by the vaporization of 35 cc of isopentane liquid contained in a capsule within. As it falls the one meter diameter, half-mil mylar ROBIN, weighing about 100 gms, is tracked by ground radar. Accurate space-time data permit the calculation of wind, density, temperature and pressure as a function of height through use of the basic equations of motion, gas laws and hydrostatic relationship. The sphere has a built-in metallized mylar corner reflector for radar tracking although a simpler metallized skin has also been successfully flown.

This rather radical technique for atmospheric sensing is currently being standardized for Air Force operational use. It is also being used to obtain high altitude meteorological data by the Navy and NASA. When tracked by an extremely high precision radar such as the C-band AN/FPS-16 wind accuracies of the order of a few knots and density accuracies of about 2 to 3% are obtainable. Temperature and pressure data, also computed from the ROBIN flight, are somewhat less accurate than the density. An error analysis of the ROBIN system shows that these accuracies are essentially dependent on three factors: the sphere drag coefficient, the measurement of fall velocity and acceleration, and the tolerance to which the sphere is fabricated. The first of these, that of drag, has been the subject of a very comprehensive program in the high-speed variable-density wind tunnel of the University of Minnesota where tests of small spheres ranging from 3/4 to 2 in. in diameter were performed over a wide range of Mach and Reynolds Numbers that the falling ROBIN experiences. In this region (M = 0.9 and below and R = 1000 to 40,000), a good part of the data represents spherical drag information never before obtained, a sizable contribution to aerodynamic state-of-the-art. Velocity and acceleration measurements are a function of the tracking accuracy. In the case of the FPS-16 its angular accuracy is about 0.1 mil and range about 3 yards. As for fabrication the required ROBIN dimensional tolerance and weight measurement is 1/2% - no problem has been experienced in attaining this.

The advantages of the passive ROBIN technique are its simplicity (no mechanical parts, no electronics) and its cost, currently about $100. On the debit side are its need for a high precision radar and a fairly good-sized computer. As for the latter problem, it appears that an IBM 1620 might be satisfactory. In any case the operational use of the ROBIN system is restricted mainly to the various missile ranges where the required facilities exist. For general weather service rocket applications AFCRL is developing a rocketsonde telemetering payload similar to the balloon-borne radiosonde - in fact, both systems will use the same basic ground equipment.

One of the more serious problems that has been encountered in the ROBIN development has been that of premature balloon deflation. This problem is gradually being overcome by redesign of the inflation capsule, improved fabricating and packing techniques and elimination of powder burn holes on the film from the rocket separation charge. A technique has been built into the computer program to analyze the fall rate curve to detect the occurrence of the deflation. Print-out of the thermodynamic data then automatically stops. Wind data, however, are still valid - although the accuracy in tracking a deflated sphere is only slightly less than a fully inflated one.

In addition to the deflation investigation current efforts are arrived at getting ROBIN data to higher altitudes. Using a vehicle such as sidewinder - ARCAS, we believe it is feasible to eject the ROBIN at 450,000 ft. and make useful measurements from about 330,000 ft. down. The program encompasses a study of the sphere configuration for optimum performance in that rarefied atmosphere as well as a continuation of the Minnesota drag work to cover the added height.

1.4 ROSE System

The other plastic balloon application, that of the ROSE rising rigid sphere, evolved from an Air Force requirement for more detailed information on the structure of the wind field in the region from the surface to at least 65,000 ft. for the design and test of missile and rocket systems. While generally good wind data can be obtained from the standard rawinsonde flights, these are actually winds averaged over a two minute time interval (approximately 2000 ft.). Much more detailed information was needed for certain uses in missile design and testing. Various wind shear probes under investigation, including a rocket-smoke trail technique, appeared to be too complex and costly for operational use.

The ROSE balloon is similar to the ROBIN in that it is a superpressured sphere and is tracked by a high precision radar to get accurate space-time data. It is solely a wind sensor, however, whose accuracy is a function of the radar accuracy and its response to extreme wind shears such as are encountered in gusts. Preliminary analyses of the ROSE performance indicate that it is capable of measuring wind data through a layer of 100 ft. to an accuracy of about 1 m/sec.

In its current configuration the ROSE balloon has a diameter of 2 meters and is fabricated of 1/2 mil metallized mylar. It has two exhaust valves and an inflation valve made of teflon, positioned such that the sphere is statically balanced. In operation it is inflated with helium or hydrogen to an overpressure of 8 mbs. Upon release from the ground it exhausts enough gas to maintain approximately this overpressure, as it rises at an average ascension rate of 1000 ft./min. to a maximum height of 75,000 ft. The weight of the balloon is 280 gms. It costs about $55 in relatively small procurement quantities.

ROSE is presently being used at the Atlantic Missile Range and other sites to support both Air Force and NASA missile programs. In addition, the Climatological Branch of the Aerospace Instrumentation Laboratory is conducting a program at Eglin AFB whereby a ROSE flight will be made daily for a year to determine day to day variability of the wind. In addition, on some days multiple flights will be made to investigate the diurnal variability.

The ROSE program has its problem area also. Recent flights in the Lakehurst, N. J. Hangar under calm conditions indicate a somewhat oscillatory pattern to the flight path in several tests. We are investigating this phenomenon at the present time to try to determine its cause and magnitude. While future events could conceivably force us to modify the ROSE system, we believe it will still continue to be a valuable tool for meteorological sounding.

VII Balloon-Borne Sampling Program in the Stratosphere

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Abstract

Programs involving unmanned balloon flights have been successfully conducted to determine the concentration and distribution of radioactive debris and viable microorganisms in the stratosphere. These programs have required development of high-efficiency filtration and impaction units, associated with high-volume, high-velocity air-moving equipment. By proper design of sampling equipment and suitable programming of the flight, it is possible to minimize contamination from non-stratospheric sources. Balloon flights provide a suitable and inexpensive method for conducting routine probes for sampline of large volumes of air within discrete strata of our stratosphere.

1. INTRODUCTION

During the last two decades, significant amounts of terrestrial debris have been added to the particulate material native to our stratosphere. The possibility of further high-altitude nuclear detonations, and the proposed re-entry burnup of nuclear-reactor-powered space vehicles, promise to increase concentrations of man-made contamination.

The study of local concentrations, settling rates, and circulation patterns in this envelope of particulate matter is of considerable significance to man because it affects his earth environment and his future travels, through and beyond, into space. Space travel requires a knowledge not only of the inanimate particulate make-up of our stratosphere, but of any living organisms in this layer -- because of the possibility of contaminating sterile vehicles destined to be landed on other planets.

Early recognition of the importance of monitoring the effect of man's activities upon the make-up of the particle sheath which envelopes the earth, led various government agencies to initiate programs aimed at sampling and identifying particulates from various strata above the earth. Balloons are well-suited to this task because they are relatively inexpensive, can be launched from diverse sites, and can carry relatively large sampling payloads to altitudes as high as 150,000 ft,

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keeping them there for hours or days with little expenditure in energy.

This paper describes several high-volume balloon-borne sampling systems that have been developed in our laboratories to obtain information on the particulate make-up of the stratosphere.

2. COLLECTION OF RADIOACTIVE PARTICULATES

The U. S. Atomic Energy Commission (AEC) for several years has sponsored a worldwide program geared for collecting samples from a variety of geographic locations at altitudes principally from 60,000 to 110,000 ft. These samples were for radioactive assay, primarily. This began as a crash program because of the pressing need for information concerning the nature, concentration, and distribution of radioactive debris injected into the stratosphere during tests of nuclear weapons.

In the early planning stages of this program, it became evident that large-volume filter samplers capable of efficiently collecting submicron particles and suitable for use with high-altitude balloons did not exist. The "Ashcan" filter sampler, so-called because of its classical shape (Figure 1), was developed to overcome this void.

In 1957, a critical re-examination of the Ashcan system was undertaken by our organization in a research program supported by the AEC. Early in this investigation, the Ashcan system was shown to have a number of deficiencies, the most important of which was a low and unpredictable collection efficiency.

To overcome these deficiencies, the Direct-Flow Particle Sampler, shown schematically in Figure 2, was developed in our laboratories. The Direct-Flow Sampler is a balloon-borne device designed to filter very large volumes of stratospheric air at altitudes between 50,000 and 100,000 ft. It utilizes a 0.5-hp Torrington blower to pull air at high velocities through 1 sq ft of filter paper. The physical size of the sampler is indicated in Figure 3.

The filter mat used in this sampler is a high-porosity paper, fabricated by the Institute of Paper Chemistry (IPC-1478). High-collection efficiency for submicron-sized particles is achieved by operating well into the impaction regime,that is, the high velocity of air moving through the filter (600 cfm at 80,000 ft) promotes collection of small particles on the filter fibers by the impaction mechanism.

A flowmeter mounted in the blower exhaust-duct counts the number of ambient cubic feet of air drawn through the system. The flowmeter is essentially a low-drag propeller anemometer.

In operational use this unit is lifted to a pre-determined sampling altitude where a timer-programmer actuates the blower. During the sampling period, the

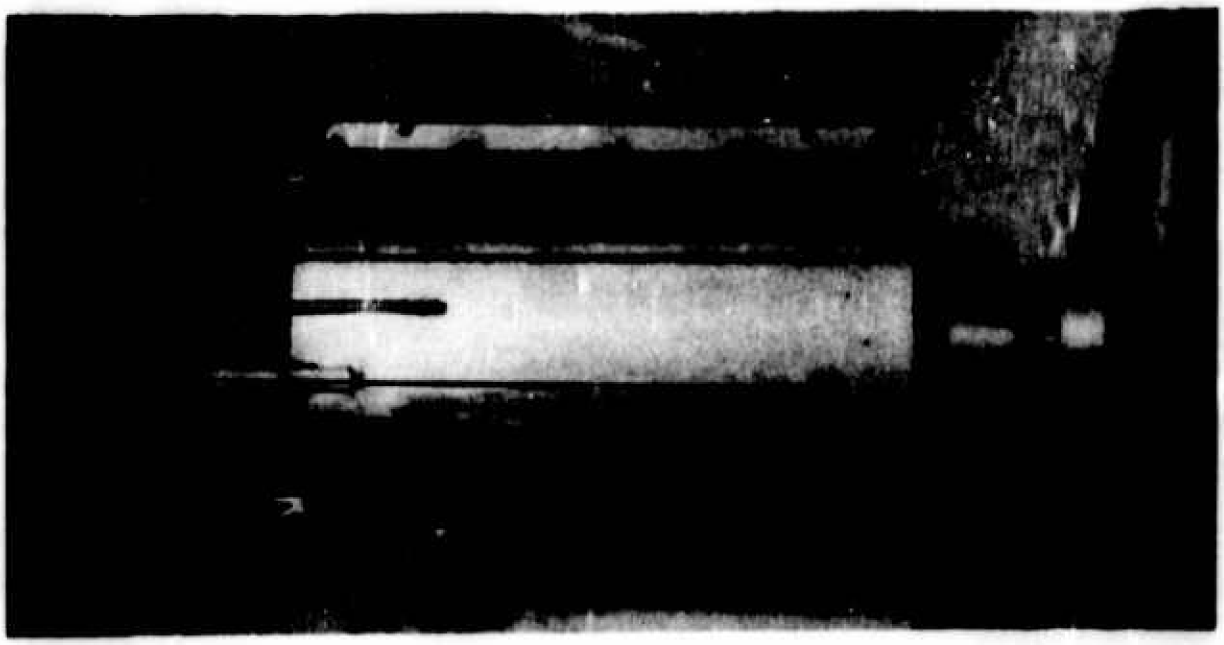

Figure 1. AEC "Ashcan" Particle Sampler

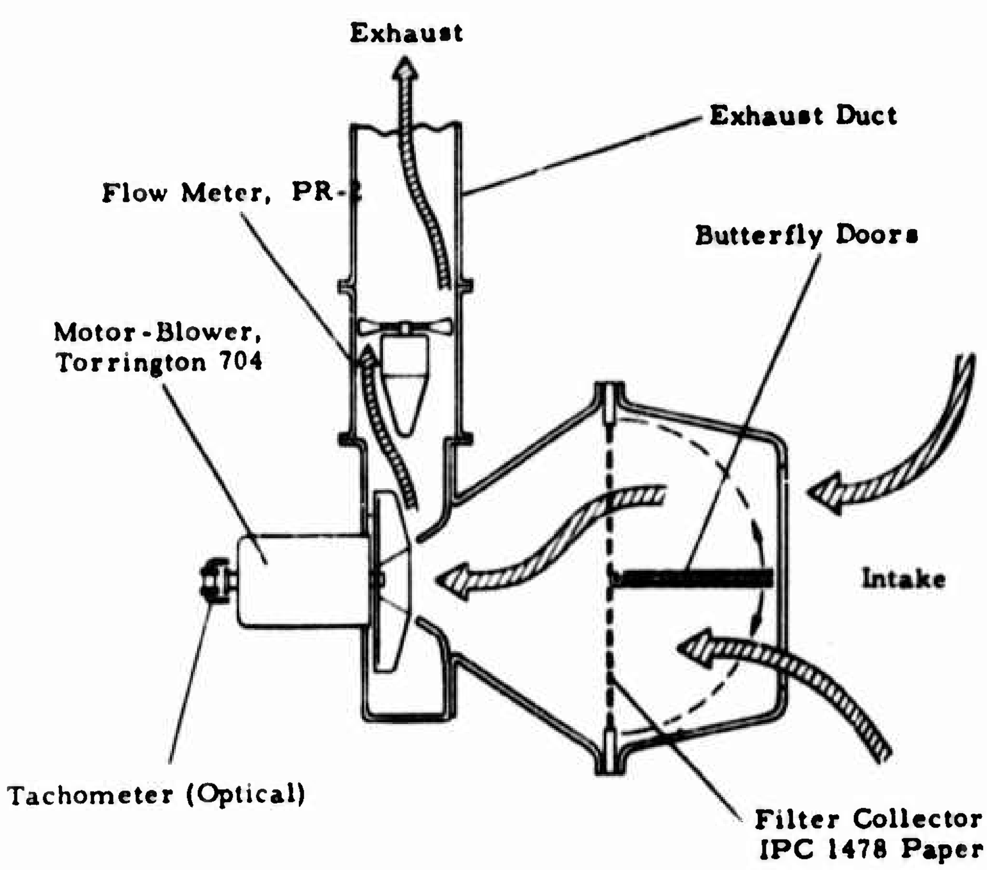

Figure 2. AEC Direct-Flow Particle Sampler Model DFS-2B (Balloon Borne)

Figure 3. Photograph of Model DFS-2B Direct-Flow Particle Sampler

balloon floats at a constant level. The length of the sampling period (set into the programmer) varies from 15 minutes to 4 hours, depending upon the operating altitude. Normally such a range is sufficient to allow the processing of a volume equivalent to 1000 standard ft^3.

Direct-Flow Samplers are presently being flown in research flights by our group at Minneapolis and, operationally, to monitor radioactive debris in the stratosphere by the U. S. Air Force at San Angelo, Texas, and by the Australian government at Mildura, Australia.

All of the operational sampling equipment with which we are familiar, including the Direct-Flow Sampler as just one example, employ blowers driven by dc electric motors to move air through the sampling system. At altitudes below 80,000 ft the performance of the motor-blower system has been reasonably good. At altitudes above 80,000 ft, however, the problems of motor burnup and decreasing blower efficiency begin to appear. Above 110,000 ft, these problems become so acute that the motor-blower combination is extremely ineffective.

Even at lower altitudes, motor-blower systems tend to contaminate the local ambient air with oil vapors, and carbon dust from the motor brushes. Also, the electric storage batteries, required to operate the motors, frequently boil off significant quantities of electrolyte during a sampling mission, thus adding to the contamination. Another disadvantage of this system is the relatively high weight of these storage batteries.

To overcome these difficulties, and to provide a balloon-borne sampling capability at altitudes above 100,000 ft, a new air-moving device has been developed in our laboratories under contract to the AEC. This device is an air-ejector pump. Earlier, ejectors have been used in such diverse applications as ventilating mine shafts and providing thrust augmentation for jet aircraft. The air-ejector pump has several very desirable characteristics: it is light-weight, mechanically simple, highly reliable, gives off no contaminating by-products, and has a high volume capability.

A preliminary theoretical evaluation of the operation of jet-ejector pumps at reduced pressures indicated that this device should substantially exceed the performance of motor-blower air-moving systems at altitudes from 80,000 to 150,000 ft.

On the basis of these evaluations, a program was initiated to develop an ejector-powered aerosol sampler, capable of operation at altitudes to 150,000 ft, sampling rates to 1000 ft^3 per minute, and total-sample capacity of 100,000 ft^3 ambient air. The first unit developed, an air-ejector-powered filter sampler, is shown schematically in Figure 4.

In principle, the operation of the air-ejector pump is exceedingly simple. The

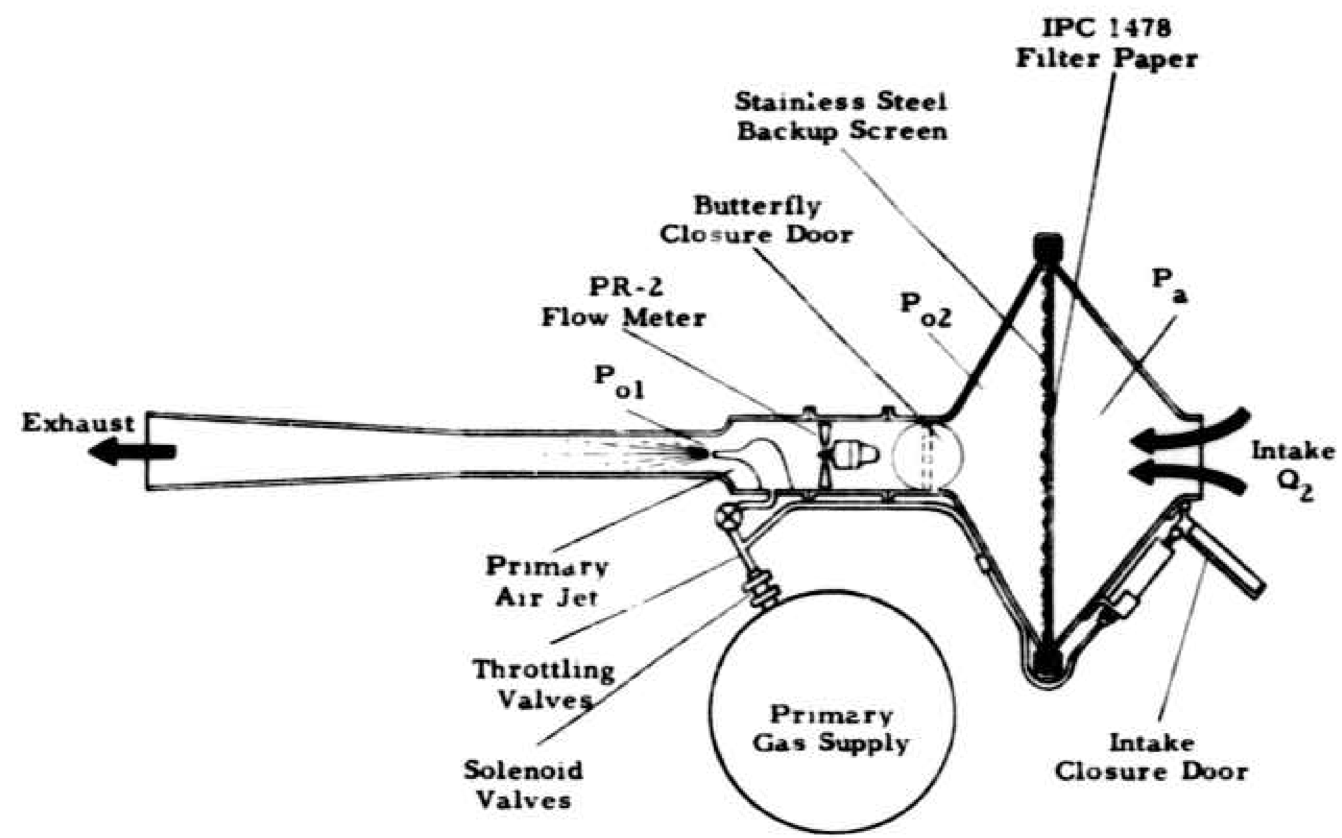

Figure 4. AEC Air-Ejector-Powered Filter Sampler (Balloon Borne)

only moving element in the pump is the air itself. The power supply consists of a titanium storage vessel in which compressed gas (in our case, nitrogen) is stored at a pressure of 3000 psi. Gas issuing from the storage vessel is called the primary, or driving gas. The primary gas passes through a regulator in which its pressure is adjusted to the desired primary pressure. This driving gas, upon discharging from the primary nozzle at high velocity, impinges upon the air molecules in the mixing tube and, through a process of turbulent exchange of momentum, induces a velocity in the secondary, or driven gas. The outflow of the combined primary and secondary gas through the mixing tube and diffuser produces a decrease in local static pressure at the secondary nozzle, thus causing air to be "pumped" into the system to satisfy the vacuum.

The primary-gas system is utilized to open and close the inlet door to the sampler by means of a pneumatic cylinder. The outlet is left open until completion of sampling, at which time a spring-loaded butterfly door is shut by severing a tie-back line with an explosive actuator (squib). The outlet of the filter housing is connected to a flowmeter.

In order to eliminate as many variables as possible in the evaluation of the ejector pump, it was decided to mate it to a collection medium identical to that used in the Direct-Flow Sampler (Figures 2 and 3). For this reason, IPC-1478 filter paper was used.

A family of curves was developed from the combined theoretical and experimental data for use in predicting the performance for the air ejector sampler operating at various altitudes. Figures 5 and 6 show the operating characteristics of the system at 110,000 ft and 130,000 ft respectively. It should be pointed out that these graphs are peculiar to the specific ejector-pump design presently used.

The curved lines in Figures 5 and 6 represent the performance of the sampler for the case of 2 ft^2, 4 ft^2, and 8 ft^2 of filter paper. These lines show how much ambient air will be drawn through the filter collector in the time required to expend 30 lb of compressed nitrogen. The vertical dashed lines correspond to primary-pressure ratios and enable the selection of a primary-pressure setting which will produce the desired rate of secondary air flow.

It is evident from these curves that an increase in sampling rate obtained by raising the primary-gas pressure incurs a penalty in the form of a lower mass ratio, that is, less air will be pumped by each pound of primary gas.

The use of these curves facilitates setting the system parameters prior to the flight so as to achieve any desired operating point within the capability of the pump.

The system is launched and samples are collected with the pump hanging vertically on a three-cable suspension harness as shown in Figure 7.

On descent, an explosive actuator severs one of the cables to allow the gondola

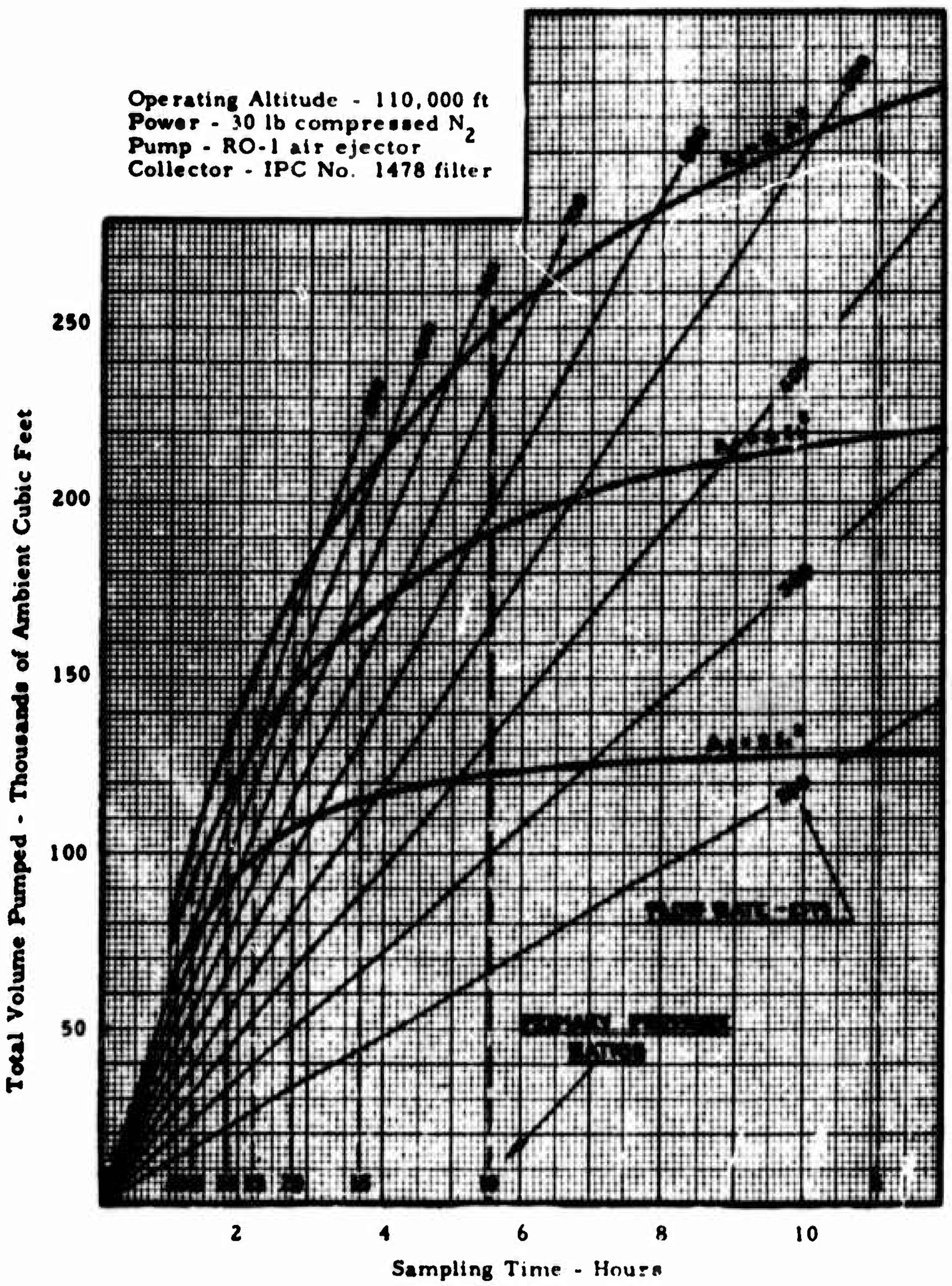

Figure 5. Sampler Characteristics, 110,000 feet

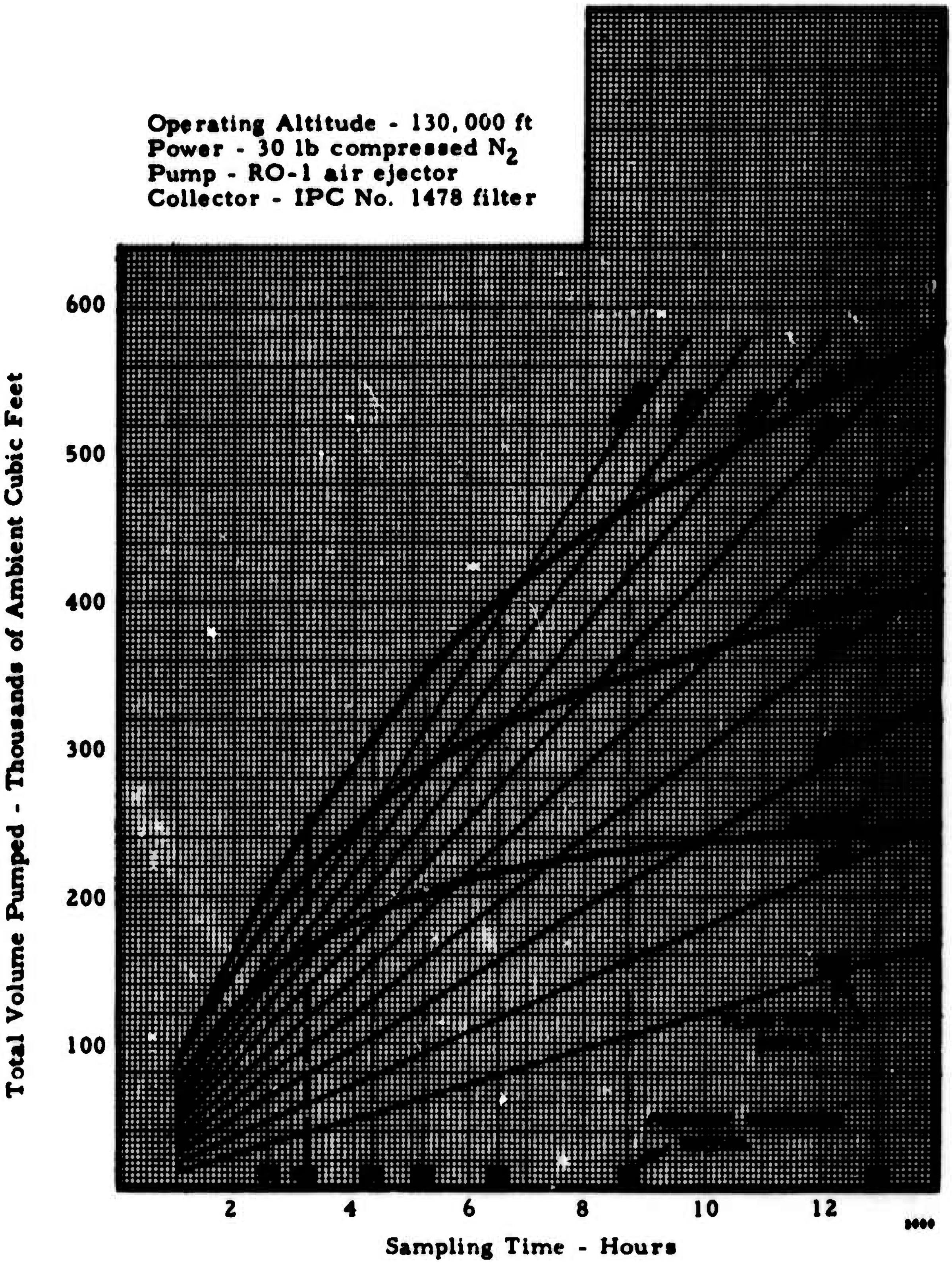

Figure 6. Sampler Characteristics, 130,000 feet

Figure 7. Photograph Showing the Pump Hanging Vertically on a Three Cable Suspension Harness

to rotate 90°. In this impact attitude the pressure vessel is positioned below the sampling apparatus. Additional protection is afforded in the form of a fiberglass hemisphere lined with 2 inches of polyurethane foam attached to the underside of the pressure vessel. In the event of severe impact-shock, the main frame of the gondola is designed to fail in a predictable manner to sever the mixing tube and diffuser while leaving the filter housing intact.

The development of the air-ejector pump has now made feasible the routine use of lightweight balloon-borne samplers in altitudes ranging from 100,000 to 150,000 ft. Such a sampling system need not be confined to the use of filter paper.

At these altitudes, jet impactors do not suffer from the deficiencies associated with lower altitudes -- namely, the need for small, high-velocity jets, involving relatively high-pressure drops that require the use of heavy pumping systems. At high altitudes, the particle-slip factor becomes extremely large, permitting low-velocity jets to be used for the efficient collection of submicron aerosols. Also, by using a multiple-jet concept which we are currently developing for the AEC (Figure 8), flow rates attainable through impactor collectors can be made to compare favorably with those attained with filter collectors.

The advantages of impactors are obvious when the interest centers on determining particle size, concentration, and morphology. Samples are collected on a flat surface and are concentrated in a small area readily available for microscopic analysis. Cascading of sharp-cutoff impactor-stages permits inflight classification of the aerosol cloud with respect to particle size.

The air-ejector pump described in this paper was designed to fulfill a very specific purpose. Perhaps the most significant finding of the study leading to the development of this apparatus was the excellent agreement between theoretical predictions and experimental results. The ability of the design equations to accurately define the optimized values of the design parameters suggests that ejector pumps to fulfill other specific requirements could be designed directly from these equations without need for intermediate steps such as model-building and testing.

In summary of this particular work, it may be said that the proved ability of the air-ejector pump to move large quantities of air at high flow rates with no moving parts and no injection of heat or particulate matter into the ambient surroundings, should make this device a suitable tool for many stratospheric-sampling programs involving balloon-borne instrumentation.

3. EXPLORATION OF THE STRATOSPHERE FOR VIABLE MICROORGANISMS

The sampling systems described above are designed primarily for the collection

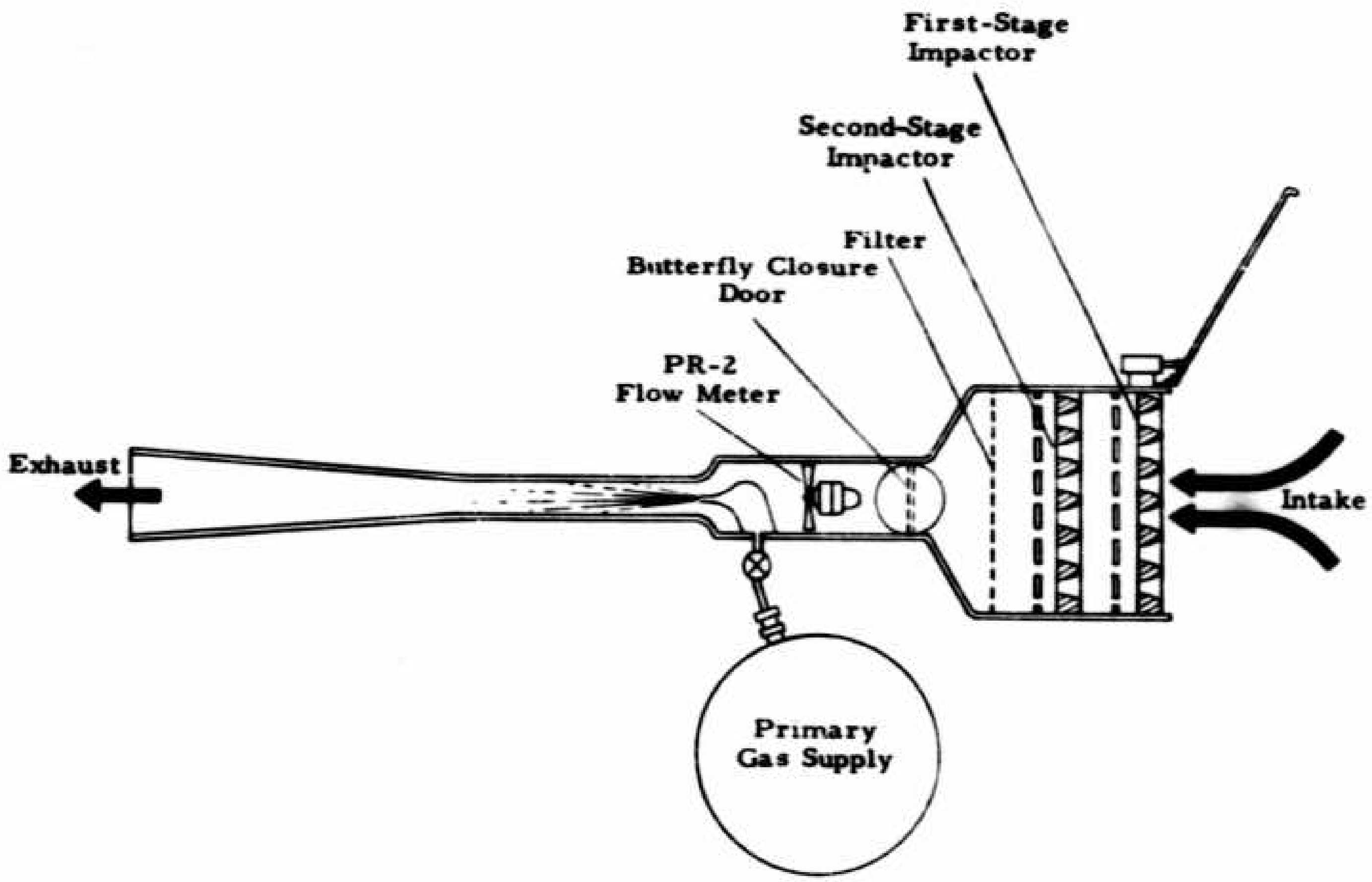

Figure 8. AEC Air-Ejector-Powered Impactor Sampler (Balloon Borne)

of submicron particles in the stratosphere. Under contract to the National Aeronautics and Space Administration (NASA) our organization also has developed an autoclavable, large-volume air sampler to collect, detect, and identify viable microorganisms in the stratosphere. Scientists are interested in this field for several reasons: because of information that could be gained about life in hostile environments; because such information is needed to determine the probability of contaminating sterile vehicles destined to be landed on other planets; because quantitative and qualitative biological data would help elucidate unknown facts about global air movements and long-range, long-time dispersal of terrestrial organisms; and, above all, because studies of the microbiology of our own stratosphere would help in the design of experiments to detect life on other planets.

To our knowledge, only one serious attempt had been made, prior to our work, to detect the viable flora in the stratosphere. This was performed 30 years ago by Rogers and Meier* who released a sterile-tube sampler from the balloon, Explorer No. II, at about 70,000 ft. Although these investigators found organisms in their sampler, the lack of adequate controls, the absence of quantitative air-flow measurements, and the nonreplication of the work has permitted reasonable doubt concerning the validity of their findings.

In 1962, our group undertook a comprehensive study of this subject for NASA. Our objectives were to design and fabricate several large-volume air samplers capable of withstanding autoclaving; to test this equipment for reliability and contamination control; and to fly these samplers by balloon and acquire samples of the viable microflora in the stratosphere for subsequent laboratory enumeration and identification.

The major problems faced in this study were the following:

1) Design of a sampler that would efficiently trap 1-micron particles under stratospheric conditions of temperature and pressure, without interfering with the viability of living cells it entrapped.

2) Acquisition of large and known volumes of stratospheric air.

3) Design and fabrication of a piece of equipment capable of being autoclaved at 120 C under 15 psi for 1 hr, that would then operate at -50 C and 0.01 atmosphere; such an instrument should be sufficiently large to sample 100,000 ft^3 of ambient air in a short time, and sufficiently refined to exclude 1 microgram of extraneous dust while impacting at 1000 ft/min on the ground upon recovery.

4) Development of an analytic technique which could assay the collected microorganisms and simultaneously exclude extraneous contamination.

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*Rogers, L. A. and Meier, F. C. The collection of microorganisms above 36,000 ft. In National Geographic Society -- U. S. Army Air Corps stratosphere flight of 1935 in the balloon, Explorer II. Washington, D. C. National Geographic Society, 1936. pp. 146-51

5) Programming of the stratospheric flight so that all known and most unknown sources of contamination would be minimized, and incorporation of controls that would discern the distinction between organisms trapped in the stratosphere and those entrained by error before launch, after impact, and during analysis.

Some of these problems are truly formidable. While we are not certain that they are all satisfactorily solved, we have made certain advances in this field. We have within the last year successfully flown four probes to altitudes between 65,000 and 90,000 ft as part of the program.

As shown in Figure 9 the sampling unit consists essentially of the modified direct-flow sampler. Each sampling unit is fitted with a circular filter of polyurethane foam approximately 1 ft^2 in area. Collection efficiency above 40,000 ft is greater that 90 percent for 1-micron particles at the programmed air flows (500 to 1000 fpm). Polyurethane was chosen, after evaluating a variety of potentially useful filters, on the basis of its efficiency, chemical, and biological inertness, low pressure-drop, ease of sterilization, and ease of recovery of biological particles for culturing and identification.

We recognized that filtration, as a collection method, might be inimical to the viability of vegetative cells. This was weighed against the need of acquiring large samples with relative ease in a limited time period. We hoped that any organism already present in the stratosphere would be sufficiently hardy to withstand our collection precedure.

Air was pulled through the filter by a Torrington blower powered with a Westinghouse dc aircraft motor. The air was exhausted through a high altitude flow meter to measure the volume sampled.

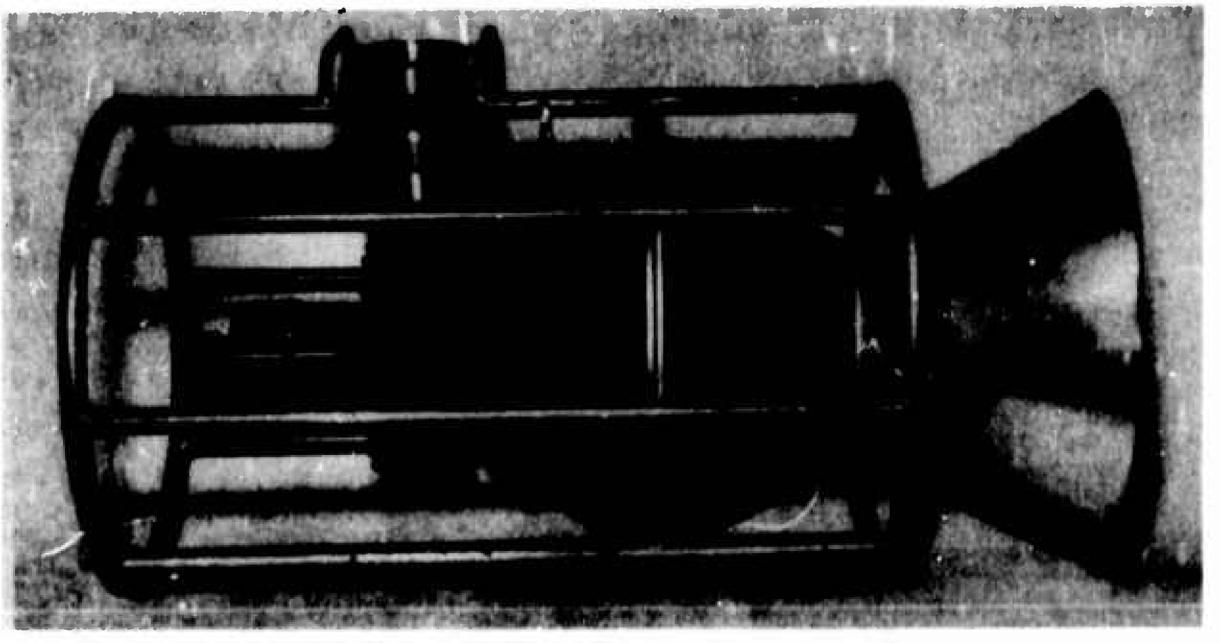
Each unit contained a spring-loaded, self-locking gate that remained cocked open during launch, ascent, and sampling. At the termination of a given sampling sequence, a squib was fired releasing the spring on these sealing gates. The gates, when shut and locked, protected and filter from extraneous contamination during descent and impact.

To protect the interior of the sampler from contamination during launch and ascent, the sampler units were fitted with dust covers and nylon shrouds after assembly. The units were then wrapped in surgical paper and sterilized in hospital autoclaves.

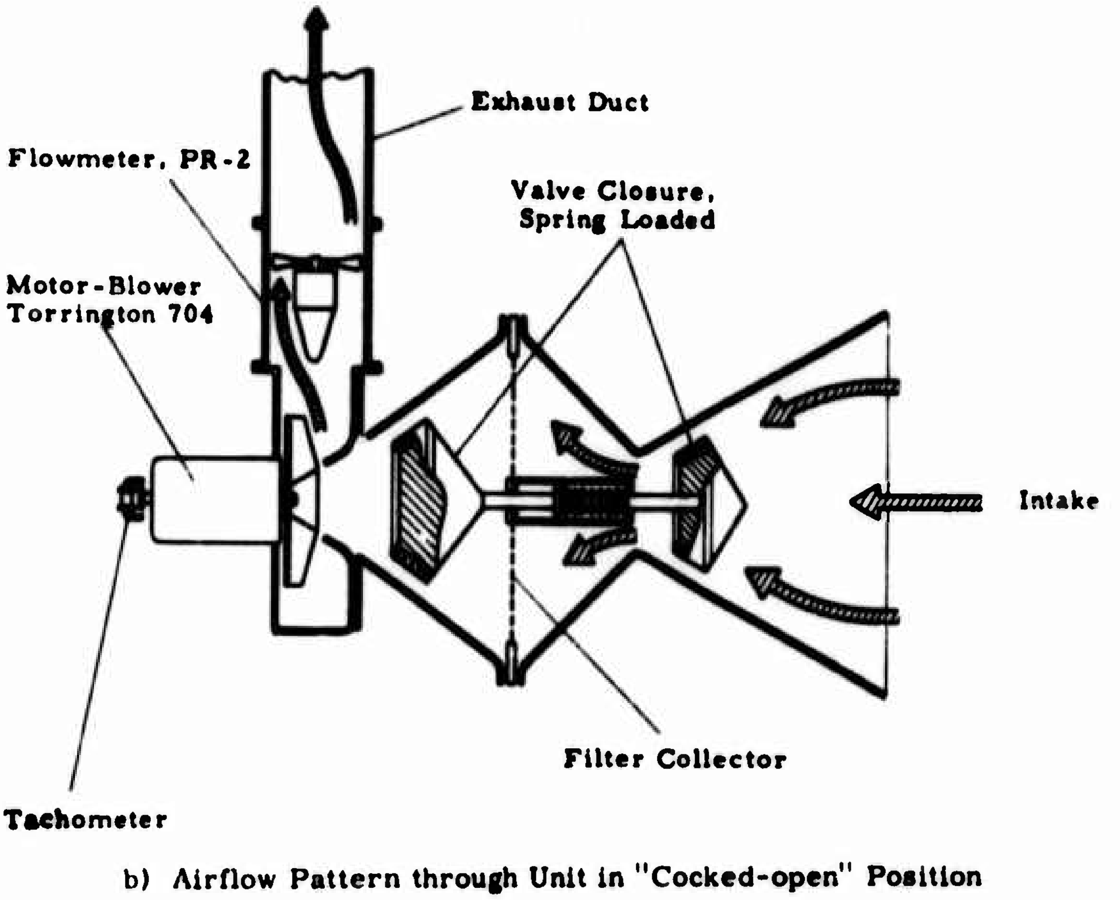
The sampling payload (Figure 10a) consisted of four of these sampling units mounted vertically on the four corners of a gondola in which were nested the power packs and the regulating and recording instruments. The air inlet was pointed downward for sampling during descent.

After the samplers were attached to the gondola, the complete payload was kept under ethylene oxide pressure until ready for launch (Figure 10b).

During launch (Figure 11) the sterile interior of each unit was maintained invio-

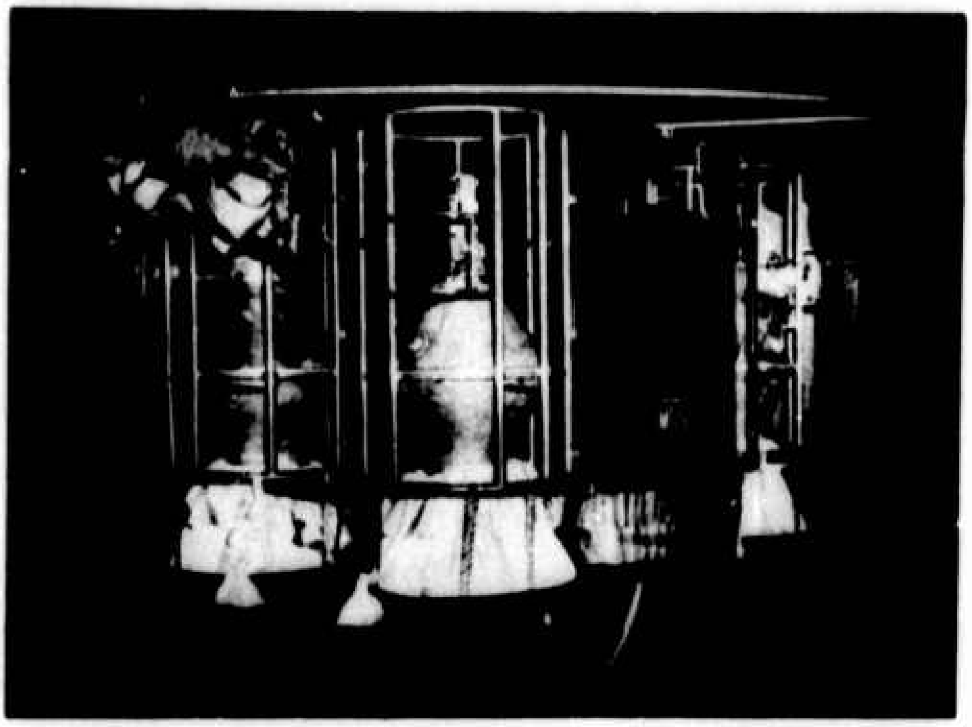


a) Unit Ready for Attachment to Gondola

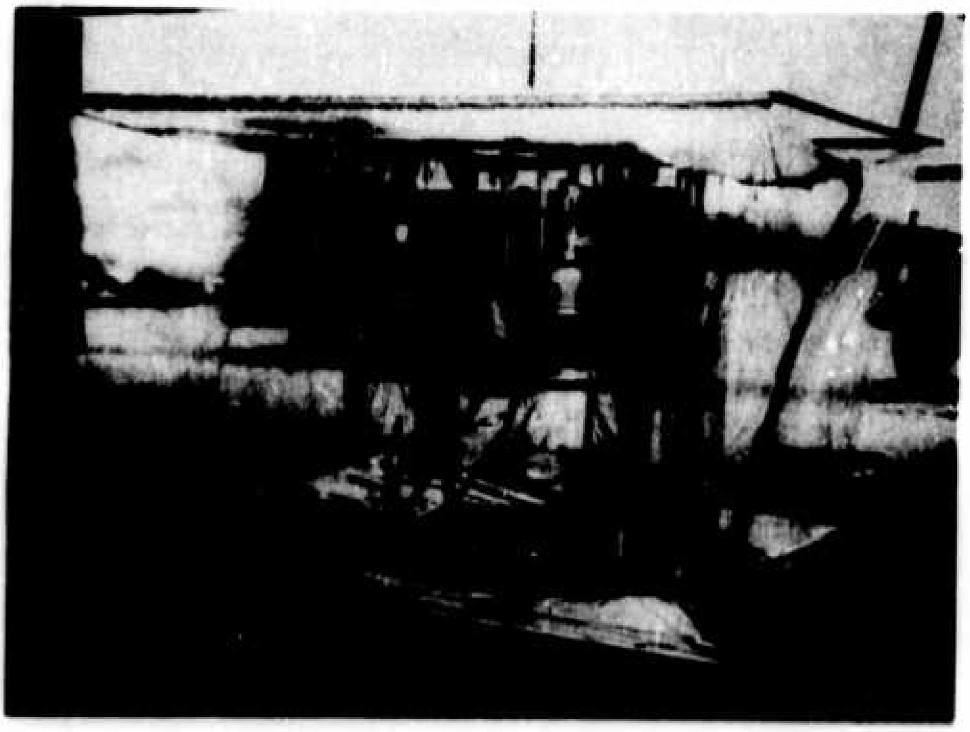


b) Airflow Pattern through Unit in "Cocked-open" Position

Figure 9. Individual Sampling Unit



a) After Attaching Samplers to Gondola



b) Storage in Ethylene Oxide Atmosphere

Figure 10. Final Payload

Figure 11. Launch of NASA Sampling Payload

a) Sealed Unit in White Room Preparatory to Filter Exposure

b) Aseptic Exposure of Filter Pad

c) Dissection of Filter Material from Frame

d) Bagging of Filter Segment

e) Extraction and Membrane Filtration

f) Plating Membrane Filters

Figure 12. Laboratory Sequence of Filter Analysis

late by the dust covers and shrouds which were jettisoned as the balloon approached sampling altitude. In order to avoid any contamination by fall-off from the balloon, the samplers were programmed to initiate their collection only after descent had started. By coordinating the descent rate, the sampling rate, and the dimensions of the air inlet, contamination was minimized by achieving isokinetic sampling of a virgin column of stratospheric air. Thus, small particles from the balloon would "fall away" from the inlet and large particles would "fall past" the inlet. Flight plans called for sequential sampling of several profiles during descent from 90,000 to 40,000 ft. One unit was programmed to take a sample of the initial thousand feet of descent to determine the amount of contamination from fallout. A second unit ascended and descended closed, and was designed to measure incidental contamination during storage, from leakage in the stratosphere, and from impact. These data were then excluded in evaluating samples for the stratosphere.

Upon recovery, the samplers were removed to a laboratory sterile room as shown in Figure 12 where surgical cleanliness was employed for opening the units, removing the filters, and extracting the contaminants.

We believe that four flights constitute a mere exploratory study, and that our data are insufficient for the derivation of reliable inferences. Furthermore, on several occasions, minor malfunctions of the sealing mechanisms permitted excessive contamination with dust-borne bacteria after impact. When such a malfunction occurs the signal from 100,000 ft^3 of stratospheric air can easily be masked by the normal bacterial content of several micrograms of dust. Statistics tell us that experiments dealing with very few organisms have to be repeated many times to establish reliability. Nonetheless, we are of the opinion that we have had some success, and we have gained a wealth of experience. We feel confident that we can establish a limit on viable microorganisms in the stratosphere as being somewhat less than one organism per 1000 ft^3 of ambient air. The predominant organism above 40,000 ft appears to be a small green mold, Cladosporium. Above all, we know that we are standing on the edge of some very useful and intriguing methodology in our use of balloon-borne instruments for biological quantitation in the stratosphere.

4. SUMMARY

This report concerns two of the programs in which we are engaged that involve balloon-borne sampling probes. For this particular work which, of necessity, requires sampling large volumes of air within discrete strata of our stratosphere, we have found the high-altitude balloon to be an indispensable carrier vehicle.

VIII The AFCRL High Altitude Atmospheric Optics Program

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Abstract

A review of the atmospheric optics program conducted at AFCRL for the past several years is presented. The experimental program has developed into three routines of measurements which utilize the high altitude balloon vehicle. These are sky brightness, near-sun brightness, and albedo measurements. The physical structure of each system is described and earlier results are presented. Adjunctive measurements of gondola rotation and pendular action are included. Future developments outlined in terms of vehicular requirements and experimental apparatus are presented.

1. INTRODUCTION

There would appear to be two practical and most probable reasons for the presence of this paper in the program. These are age and continuance. The work to be described was commenced in the year 1953, under the direction of Dr. Vincent J. Stakutis, and was termed Atmospheric Visibility Studies. The effort has been continuous since that time except for the period 1959-1961 when the group was involved in systems work, regretfully.

It is hoped that this paper will convey two impressions. The first is that there does exist a tangible product resulting from this work. The second is that our group has a rather deep attachment to the high altitude balloon as a test-bed vehicle. Indeed, it is only in this most recent period that we are preparing instruments for rocket and satellite probes.

2. DISCUSSION

Perhaps the age of the program will be excuse enough for a brief reminiscence. The work was established in response to an Air Force aeromedical query. What

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would be the levels of natural illumination available for cockpit lighting when an aircraft is at a cruising altitude greater than 50,000 feet ? This immediately defines the measurement program. The spectral region is confined to the visible (broadly 4000 to 7000 Angstroms). The measurements are to establish the daytime radiational contributions of the sunlight, skylight, earthlight and airlight to the cockpit environment. It is also easily recognized that the high altitude balloon meets well the extended period of data sampling which is implied by such a requirement.

A with many others who have worked in experimental programs, our earlier field endeavors were heartless. Our "learning how" process ran the gamut from cranky mechanics, through erratic electronics to bursting balloons. Gradually, a measurement program and results developed.

It seems somewhat remarkable that the earliest configuration of this program is still recognizable but has broadened into a more fundamental consideration of the process of transfer of optical radiation. Nevertheless, the basic considerations remain - the measurement of sunlight, skylight, groundlight and airlight, but at increasing altitudes and over a much wider spectral region.

The wide dynamic range of intensities to be found in any sequential measurement of direct solar radiation and sky dictate either some remarkable electronics and optical designs or the separate measurement of these two radiational levels. This latter course we have adopted.

Measurements of the sun and near-sun radiances are accomplished by the accurate pointing of the instruments with a biaxial solar pointing control, developed and fabricated by the Hi-Altitude Instrument Co. of Golden, Colorado. The pointing method is most conventional. Optical sensors (coarse and fine eyes) generate off-target error signals. These signals are part of a closed servo loop. Its purpose is to minimize the amplitude of the error signal. The result has been a system which has a pointing accuracy of ± 34 min. of arc, for 90% of the measurement period.

Fig. 1 illustrates the major structure of the pointer and the measurement units. Within the yoke is the near sun photometer and mounted above this is the direct sun photometer. External to this unit at the center of the light frame is the occulter disc. This is of such a size and at such distance from the near-sun entrance optics as to prevent the direct photospheric light from being incident on the objective lens. The diffracted radiation is eliminated within the optical barrel by proper apertures and baffling. Rotating scan apertures to the rear of collector optics perform the near sun radiance sampling at selected angles from the center of the solar disc. The semi-vertical can on the outboard side of the yoke contains the "eyes" of the pointer.

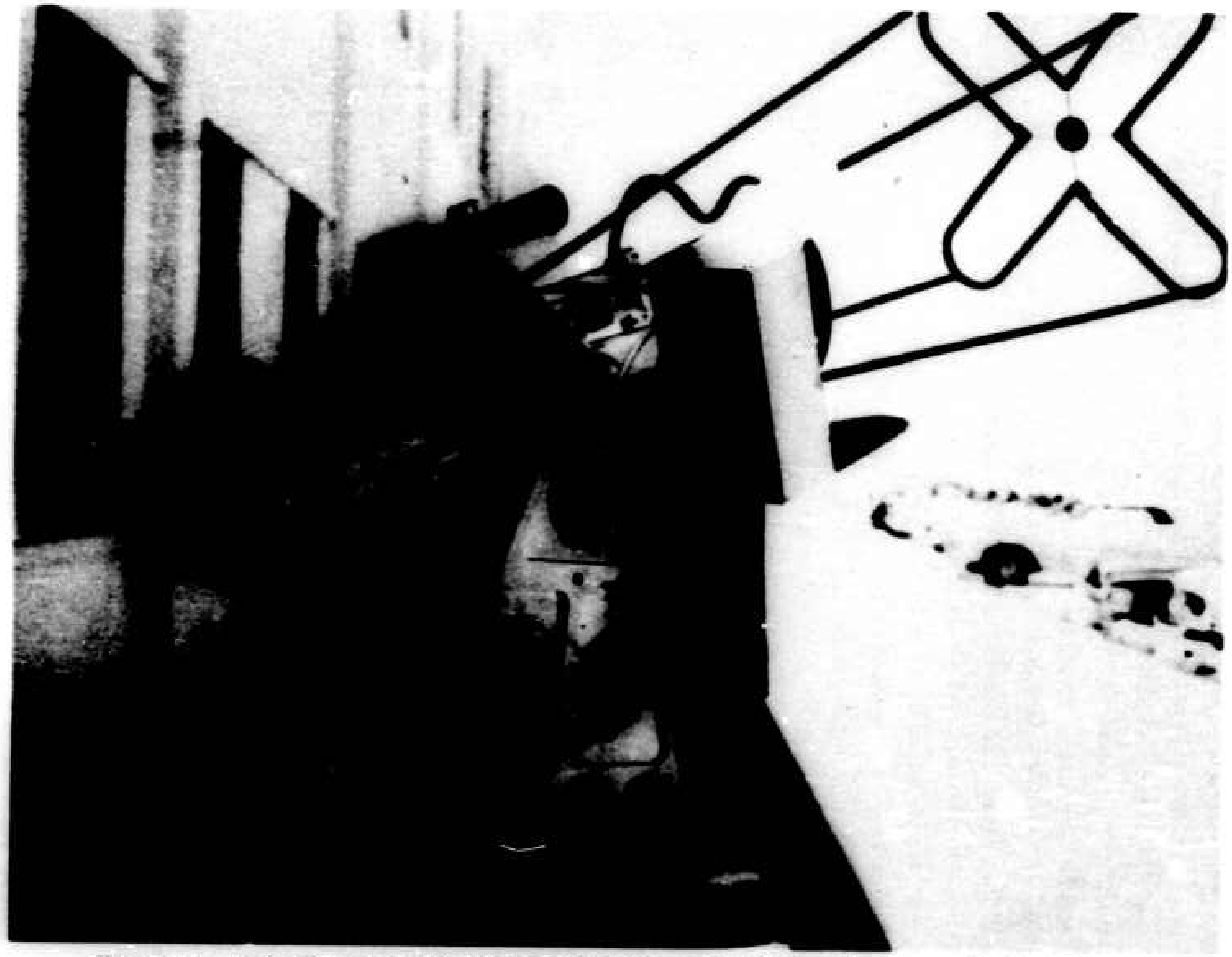

Figure 1. The Principal Structure of the Bi-axial Pointer System with the Direct Sun and Near Sun Photometers Mounted Within the Yoke. Also shown Mounted at the Extreme is the Occulter Disc.

Not visible in the illustration but located in the main frame of the gondola is a small airborne FM/FM seven channel tape machine being used as the primary data recorder.

Fig. 2 presents some of the data obtained from a high altitude balloon flight in the Spring, 1962 above New Mexico. It presents the measured near-sun brightness at angles of 2°, 2-3/4° 5°, and 7-1/4° from the center of the solar disc in four quadrants about this center. There is the obvious and marked decrease in the near sun brightness for all angles as the altitude increases. Further at two different altitudes there is a marked increase in the brightness values suggesting the interposition of "scattering clouds" into the optical path. The temporal and spatial nature of such stratospheric anomalies is further emphasized by the results of an earlier flight of that day in which no such increases were observed at corresponding points.

Fig. 3 presents the measurement of the direct solar radiation and the almost logarithmic change as a function of altitude. Actually, it is a very smooth curve since the excursions are within the recording inaccuracy. The most prominent feature is that the brightness value at float is about 95% of the extraterrestrial value of the direct solar flux.

For the sake of verbal convenience only, the second part of the measurement program is termed albedo. Since this term defines a ratio of upwelling to downwelling radiation in presence of real surfaces the designation is not correct. Rather, only the upwelling light is measured and the values are correlated with terrain photographs, altitude and meteorological status of the atmosphere.

Fig. 4 illustrates the first spectrograph which was used to record photographically the upwelling radiation spectrally, from 4000 to 7000 Angstroms. A Dallmyer lens and B&L plane diffraction grating form the principal elements of the littrow mount unit and produce a reciprocal dispersion factor of 80 A/mm at the film plane. The instrument is suspended within a conduit framework by means of springs and held in the nadir direction. A continual framing camera, originally developed by the University of Minnesota for balloon studies, provided the terrain identification record. The entire frame except the optical aperture was enclosed in polyethylene to effect the "greenhouse" condition and a stable temperature of +25°C during the flight period. A series of models, of varying volumes and material reflectivities, had been flown by pi-balls out of the local area, in order to establish the most effective greenhousing.

While the data developed from such flights is more comprehensive, Fig. 5 is presented to illustrate a particular formalism of some results. The overall display is a chromaticity diagram (of the right angle type). Its purpose is to illustrate real colors in compact mathematical form. Its validity is based upon the tristimulus color representation. Herein the spectroradiometric values of the radiation are

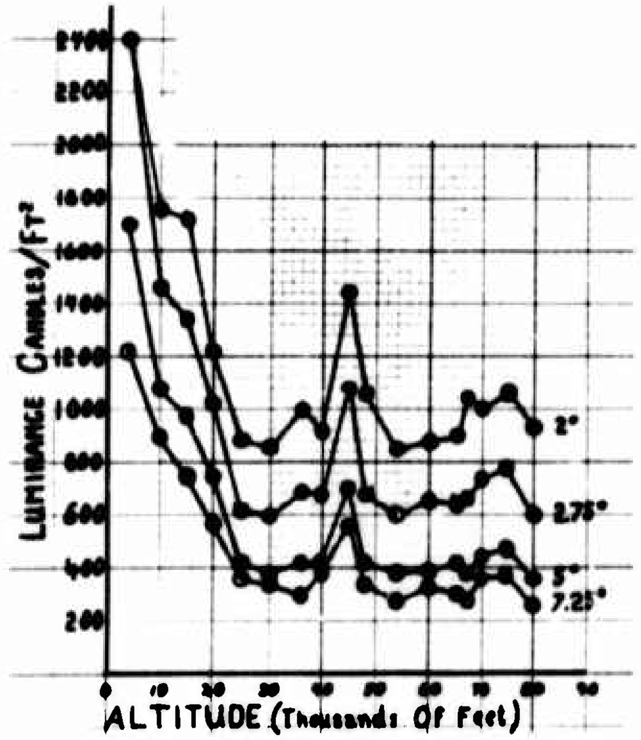

Figure 2. Near-sun Luminance as a Function of Altitude.

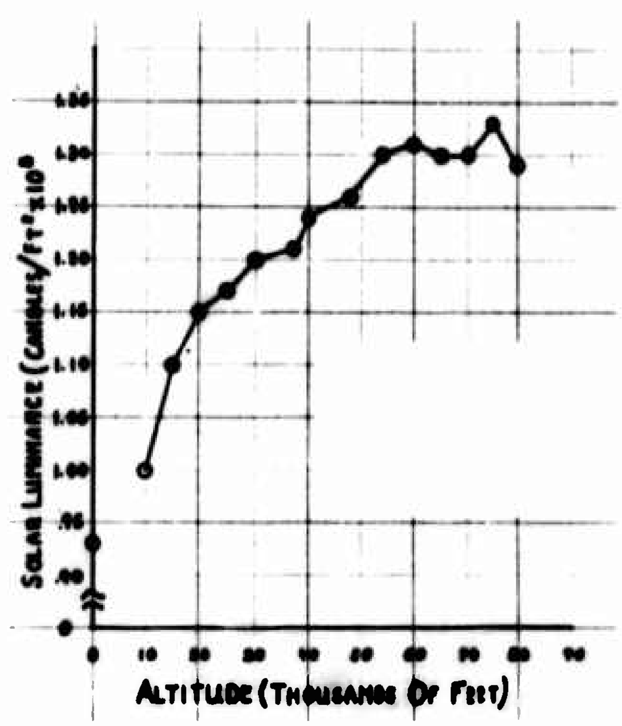

Figure 3. Direct Solar Luminance as a Function of Altitude.

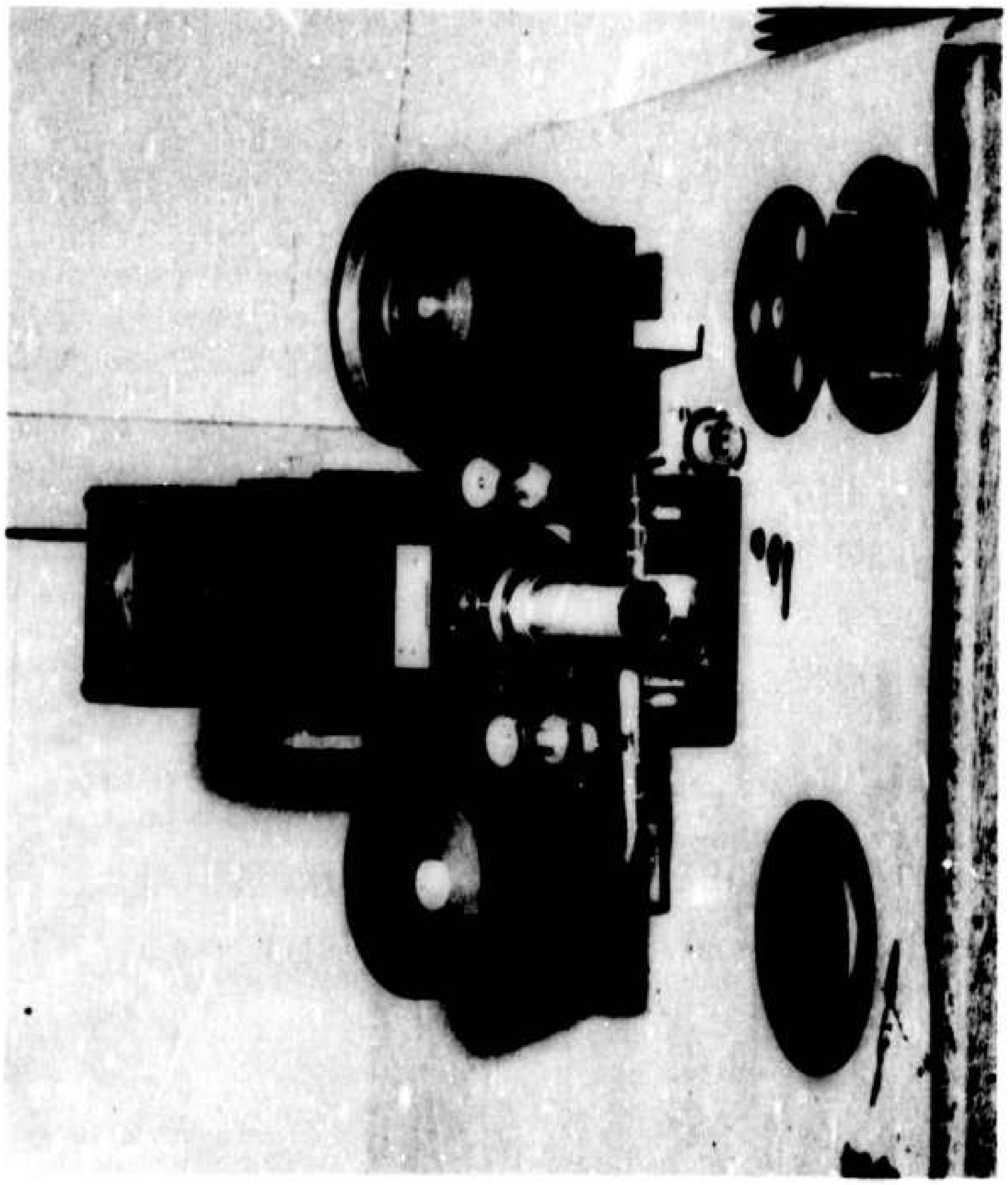

Figure 4. The Original Balloon Borne Spectrograph for Albedo Studies.

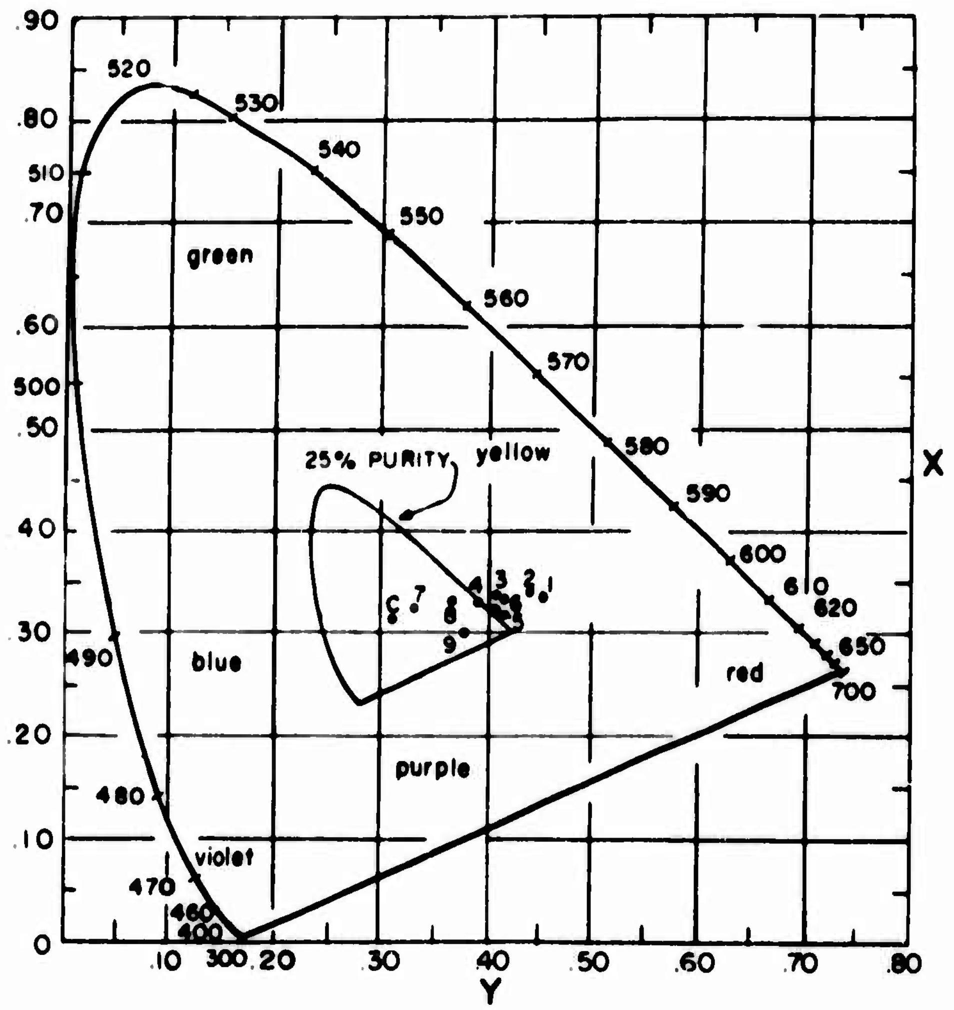

Figure 5. Chromaticity Diagram to Illustrate the Loci of Radar for Desert Terrain. Standard Illuminant is "C".

combined with standard photopic response values to produce the tristimulus values. These numbers when presented as coordinates of a point in the chromaticity diagram illustrate several of the more important color properties of the object. Since the color of an object is markedly dependent upon the nature of the incident radiation, it is necessary to compare the plotted value with a standard which most nearly approximates the given condition of natural illumination. In this flight, the position C, which describes the color of the average daytime sky, is the standard source. Any color which is found on the perimeter of the diagram has a spectral purity of 100%. A color coincident with point C has then a spectral purity of 0%. The dominant wavelength is that pure spectral color, which when mixed with the standard, will reproduce the given color. This is determined graphically by the intersection of the line drawn through point C and the given color with the chromatic perimeter. For this Fig. 5, each point represents a different altitude of measurement of desert area, except for points 6, 7 and 9. For example, point 1 is at 10,000 feet, point 2 is at 20,000 feet, and so on. All show approximately a dominant wavelength of 6000Å but the value wanders about 200Å during the period of changing altitude. The purity is quite low, 20-25%.

The failure to recover this instrumentation after a flight resulted in the design of a new set along entirely different lines. Fig. 6 presents an overall view of this balloon-borne system. Directed toward the nadir is a set of twenty-seven individual photometers and centered in the cluster is a Beattie-Coleman 35mm camera to record the terrain features. The collimating optics (3° total angle) are common for all units and most have the same type detector - a CdS cell. Each is different by reason of an interference filter, centered at every 200 Angstroms from 3900Å to 9100Å and each having a bandpass of 75Å.

The output of these detectors, calibrate levels, pressure, temperature and camera operations are commutated and recorded on the on-board seven channel FM/FM tape recorder. The recovered tape is played back through conventional equipment and displayed on a recording oscillograph. A Benson-Lerhner "Oscar" is used to measure the amplitudes and card-store for automatic plotting.

Fig. 7 illustrates a particular record for a measurement over cultivated area in the North Central region of the United States. The difference between the two graphs is due to atmospheric change. Both observations are at 86,000 feet. The broken curve is produced by a very thin cloud at the fringe of a cumular formation which was moving into the photometer field of view. The result is a decrease in apparent radiance of about 10% and a shift at the peak wavelength of 150 Angstroms.

The final part of the atmospheric optics program is the sky radiance task. These measurements are accomplished by studding one side of a rectangular parallelepiped shaped gondola with photometer units oriented at different vertical angles. Azimuthal scan is dependent upon gondola rotation. Each elemental photometer consists of a Fresnel lens and a photovoltaic cell, modified with a viscor filter. Mounted atop the balloon is a loosely-gimbaled radiance and irradiance measurement equipment as shown in Fig. 8. A 16 conductor cable running vertically down the perimeter of the balloon furnishes the signal leads into the main gondola. All signals activate microammeters and these are recorded by Keystone A-9 cameras. Photographic recording of a sun dial furnishes the azimuthal information. Fig. 9 illustrates these principal elements. But the principal feature which is not at all obvious in the foregoing is the very arduous task of data reduction.

Fig. 10 is intended to display in a quick fashion the results of some earlier measurements. For this display, one should imagine himself as a pilot flying at an altitude of 90,000 feet and located at the center of the display. The difference between these two displays is the condition of the atmosphere. The less turbid

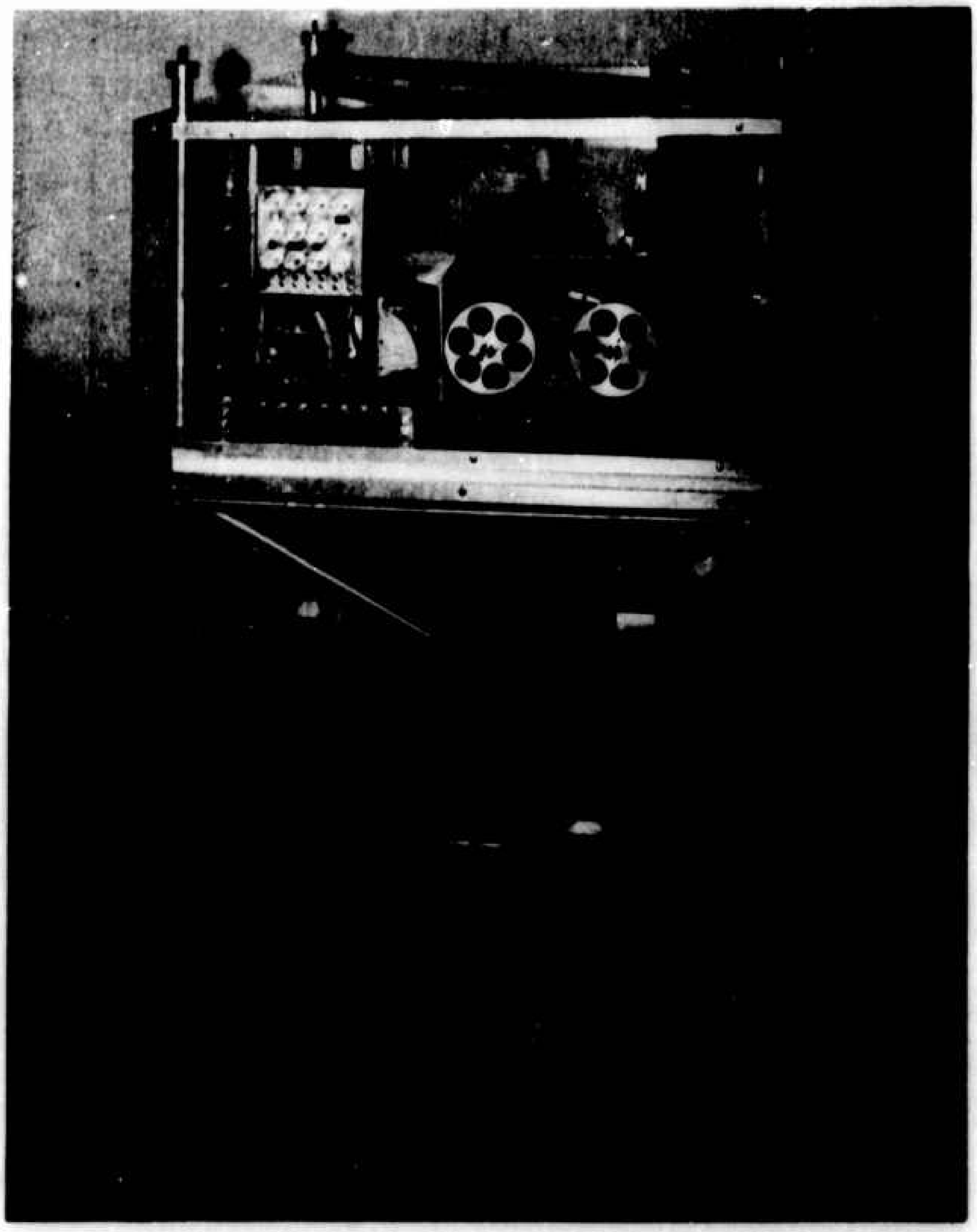

Figure 6. The Present System Designed for Albedo Measurements. Lower Center is the Array of Photometers, Nested about a Camera and Spring-linked to the Gondola Frame. The Tape Recorder is at the Upper Right Foreground.

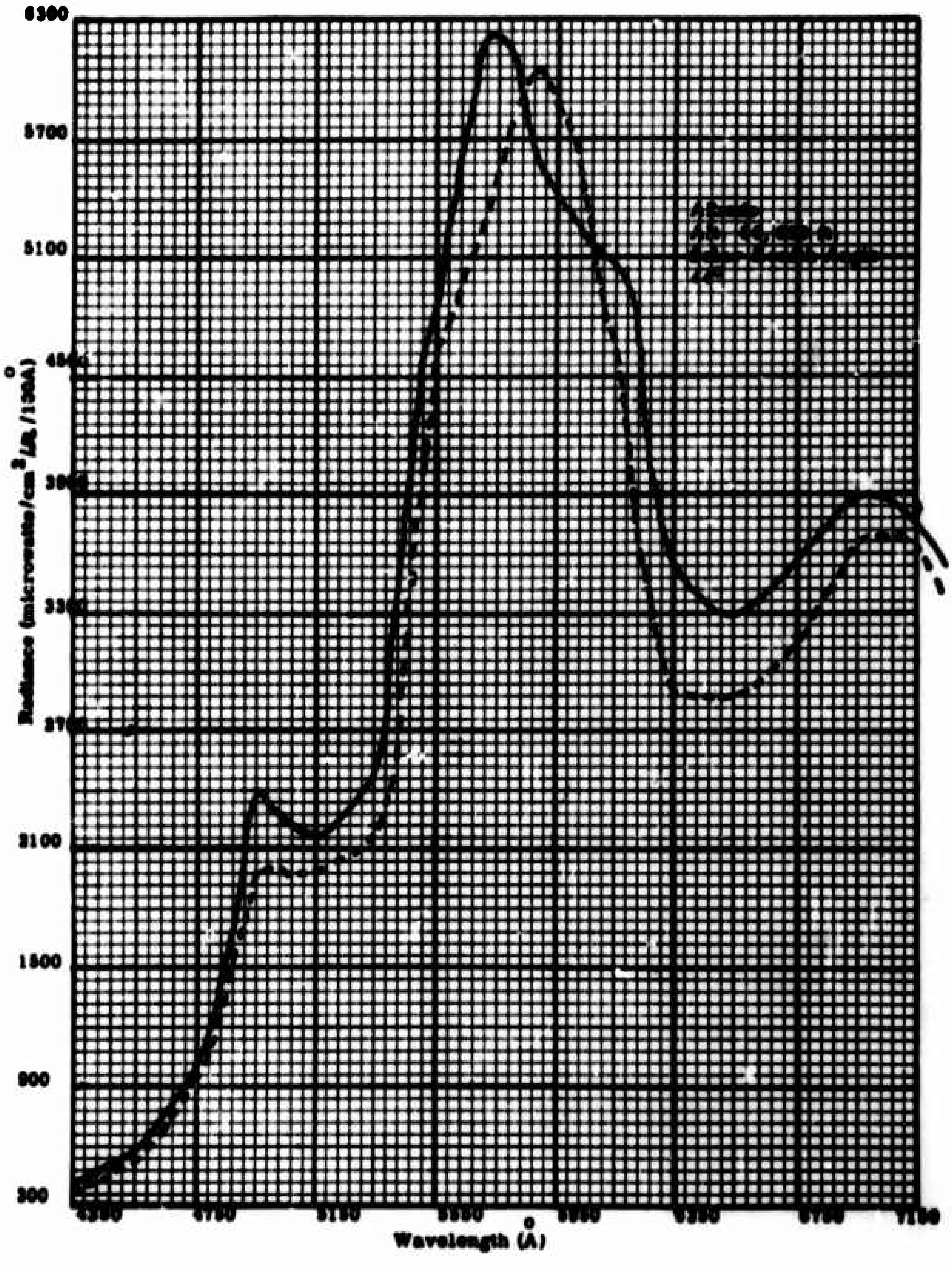

Figure 7. Apparent Spectral Radiance of Cultivated Area During Growing Season as Measured from 86,000 Feet.

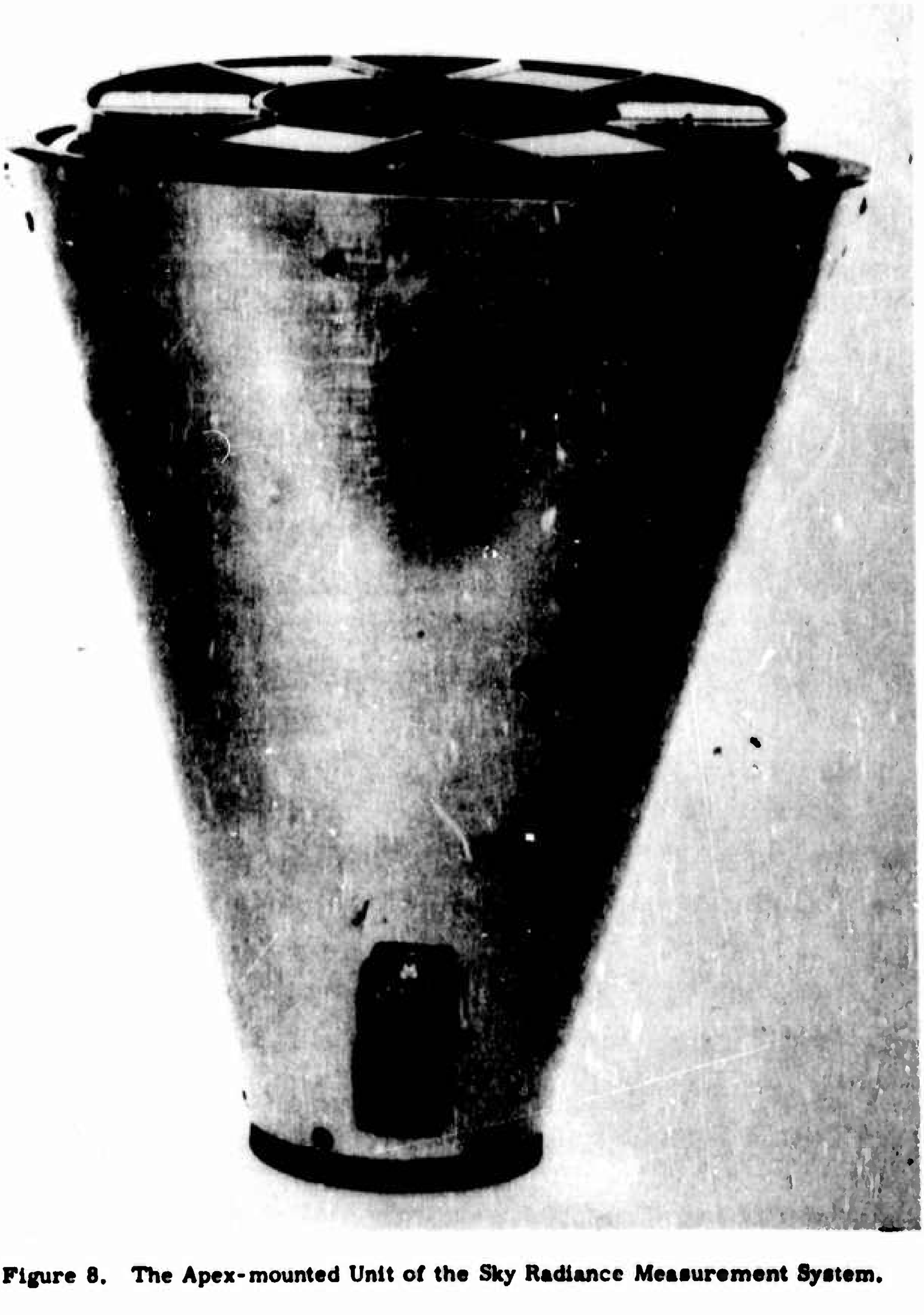

Figure 8. The Apex-mounted Unit of the Sky Radiance Measurement System.

Figure 9. The Sky Radiance Gondola. The Radiance Boxes are Mounted on the Top Tier. Recording of the Data is Performed at the Second Level. At the Lowest Level, partially hidden, are the Horizon Radiance Optics and Control Mechanisms.

COMPARISON OF 7/19
AND 9/13 SKY LUMINANCE

(IN CANDLES / $FOOT^2$)
VALUES AT 90K FT.

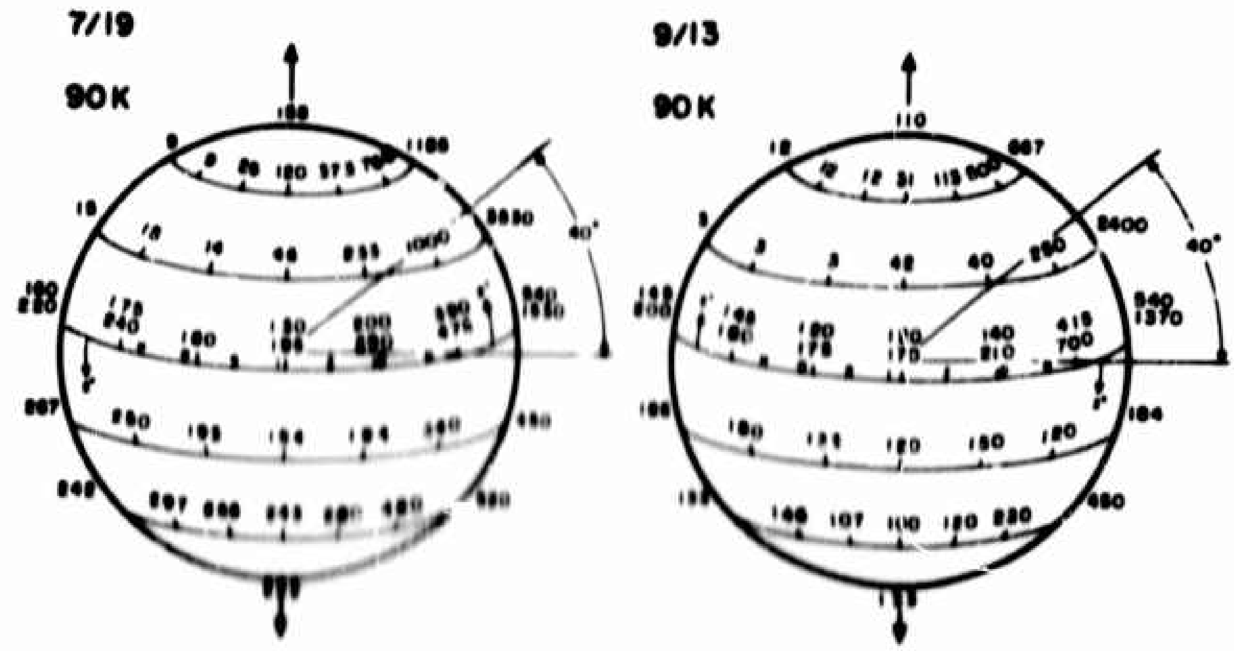

Figure 10. The Distribution of Sky Luminance for two Different Conditions of the Atmosphere.

atmosphere is indicated by the flight of 9/13. The most interesting feature deliberately is not shown, for later measurements show the sky dome brightnesses at 90,000 feet to be lower than these values by a factor of one-half.

It is always interesting to use numbers to derive other results and possible applications. For target detection at high altitudes, the problem becomes one of Signal-to-Noise Ratio. Fig. 11 is responsive to such a query. Specifically, given a background brightness of 10 candles/ft^2, at which wavelengths and fields of view will the signal of a second magnitude star exceed the background? With reference to Fig. 9, and the text the look angle is elevated to coincide with the solar elevation angle but is displaced 30° in azimuth from the sun. The conclusion as illustrated by Fig. 10 is based upon two premises. The star signal has a spectral distribution like the sun. The scattering is solely a Rayleigh-type and is of such magnitude that it results in a photopic observation of a 10 candle/ft^2 value at the stated location.

Usually, the rotation of the gondola is to our advantage since it will provide the azimuthal scan action with reference to the sun. A necessary measurement for any

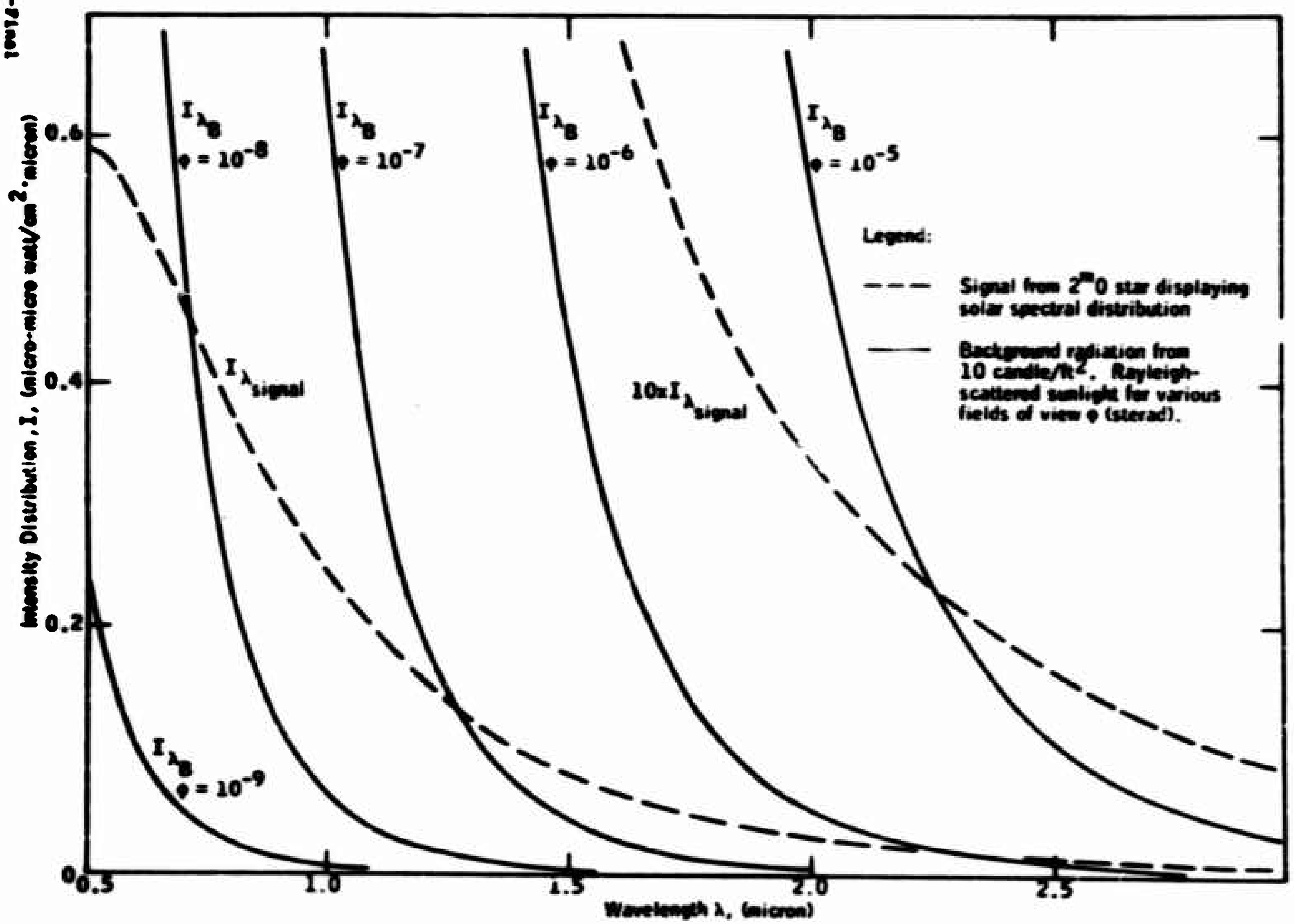

Figure 11. Field of View and Wavelength of Observation Necessary for Target Detection.

of our flights is the sensor look angle with reference to the sun. During the program a sundial in various forms has been used and the sun image or a sun-cast shadow has been recorded photographically to establish the azimuthal orientation of the gondola.

Data from nine flights have been compiled and analyzed. The rate of sampling has been as follows: for two flights, once every ten seconds; for four flights, once every five seconds, for three flights, continuously for twenty seconds every fifty seconds. In all flights, the suspension is a single load line with the length varying from 90 feet to 500 feet. The system, then, is loosely coupled and the discussion is concerned with motion-time of the gondola, and not of the balloon . The coordinate system is orthogonal and is established by the vertical load line. Rotation or oscillation is in the plane normal to this line. Pendular action refers to the motion out of this plane.

In every instance, from altitudes greater than 15, 000 feet to cutdown, in a normal flight profile, there is no pendular action in excess of a 1/2° displacement. The method of measurement is insensitive to a motion less than this value. It should be noted that in any of the gondolas there are no large internal moments because of peripheral actions in the gondola.

The motion in the plane is a combination. We speak of a rotation and of an oscillation. There is a general rotation of the gondola in a particular direction (cw or ccw) and superimposed on this are the oscillations.

The rotational speed has a wide range of magnitudes - from 6°/sec to 0. 1°/sec. This latitude of values appears to be associated with density-altitude and vertical rate through the medium. For example, at the lower altitudes and a rapid rise rate, the rotational rate is low. At the higher altitudes (with a rapid rate of rise) the rotational speed is high. Whereas, with a low rate of rise, the rate of rotation is correspondingly low.

The oscillatory rate appears to depend upon two conditions. These are the bag surface condition (its flaccidity) and the vectorial change in the horizontal wind profile with altitude. At the lower altitudes and with a change in the second factor, the oscillation rate is 6-12 degrees/sec. At float altitude, the rate never exceeds 1 degree/sec.

Our present program is configured to gain spectroradiometric measurements of all that has been discussed here and to also perform spectropolarimetric analysis of natural sky and earth radiation using instrumentation, similar optically to the unit described by Sekera and Rao. [1]

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1. Photoelectric Skylight Polarimeter by C. R. N. Rao & Z. Sekera AFCRL-63-809 (June 1963)

IX Orientation of Balloon-Borne Instruments*

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Abstract

Balloons have proven to be valuable platforms from which to make scientific measurements, including high resolution photography of the sun in particular. These and other astronomical observations require accurate orientation of the instrument relative to a celestial frame of reference. Appropriate sensors must be included in the orientation system to sense deviation of the instrument from the desired orientation, actuators must be provided to correct the orientation error, and a suitable gimbal system must be devised to minimize the restraint of the instrument by the balloon system.

Though the suspension system and balloon environment pose many design constraints, such as the order and configuration of the gimbals, the choices are usually compromises. Photoelectric sensors aided by inertial rate detectors used in conjunction with torque motors and three or more gimbals have proven to be a popular and effective combination.

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*To be included in a Contribution from the Observatory.

†Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

The orientation of a balloon-borne instrument entails the use of one, two, or three gimbals, depending on whether simple uniaxial control, biaxial pointing, or triaxial stabilization is required. Uniaxial control suffices if it is necessary only to have one side of the instrument oriented, say, toward the sun; biaxial, if the instrument, such as a telescope, must be pointed at a celestial target such as a star, and triaxial, if the target is an extended source, the image points of which must be held stationary in the focal plane of the instrument, as for high resolution photography of the moon. Uniaxial control is perhaps best exemplified by the solar azimuth-pointing platform (SAPP) shown in Figure 1. In this instance, the platform is the gimbal, the axle of which is a vertical shaft attached to the load lines of the balloon through a swivel and a universal joint and to the trapeze bar beneath, through a universal joint. This platform was built by the Ball Brothers Research Corporation for the Air Force Cambridge Research Laboratories [Dolder and Johnson, 1960] for use on long duration balloon flights to accommodate various solar instruments including a solar sextant. The upper and lower universal joints were used to decouple the platform from asymmetrical rigging of the load lines

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and asymmetrical loading of the trapeze bar, respectively. In this control system, the platform was torqued in azimuth against the trapeze bar used as a reaction wheel. Friction in the swivel and air drag on the trapeze bar prevented exceeding the maximum speed of the torque motor. A D.C. torque motor was used to drive the platform relative to the trapeze bar in a direction dictated by photoelectric solar sensors [Nidey and Stacey, 1956].

Inasmuch as the balloon may be rotating in azimuth some tens of degrees per minute, it is apparent that an azimuth gimbal such as the one used on the SAPP is a necessity in any balloon-borne orientation system. If the instrument is to be pointed at a target not on the horizon, a second gimbal is required. The second gimbal is usually an elevation gimbal as on Stratoscope I [Danielson, 1961] shown Figure 2. The orientation system for Stratoscope I was built at the University of Colorado by the author and associates for the Princeton University Observatory. The telescope was supported on a composite shaft by three bearings, as shown in Figure 3. Overconstraint of the shaft was obviated by a flexure member used as a zero-backlash universal joint. A pair of magnetic clutches were used to drive the telescope in elevation against the azimuth gimbal.

The advantages of the magnetic clutches included the absence of backlash, a twenty-fold power amplification, proportionality of torque with excitation, and independence of torque with speed of slippage. Nonetheless, with the advent of transistor amplifiers, the clutches have been supplanted by the more stable and efficient torque motor.

The azimuth gimbal in turn was driven by clutches against a reaction wheel which consisted of six batteries mounted on a rigid framework between the gimbal and the load lines. The lower separator of the multiline suspension system was coupled to the reaction wheel by a torque limiter and an aircraft universal joint. The limiter was used to avoid twisting the load lines during initial orientation in which the torque derived from the clutches could easily have exceeded the windup torque of the suspension system; and the U-joint to relax the tolerances on the distribution of the mass and the equality of the lengths of the load lines.

Though adequate control torque could have been derived directly from the suspension system, the reaction wheel was deemed necessary to maintain proper slippage of the clutches, as well as to place the torsional oscillation frequency of the reaction wheel with concomitant phase shift well below the critical bandpass of the control system. Similar considerations will in general favor the choice of a suspension system with a low torsional constant used in conjunction with a large reaction wheel. The low torsional constant in turn permits a relatively long period for the pendulum motion of the gondola beneath the balloon.

One difficulty associated with the component of the pendulum motion normal to the elevation axle is rotation of the image in the image plane of the telescope. At

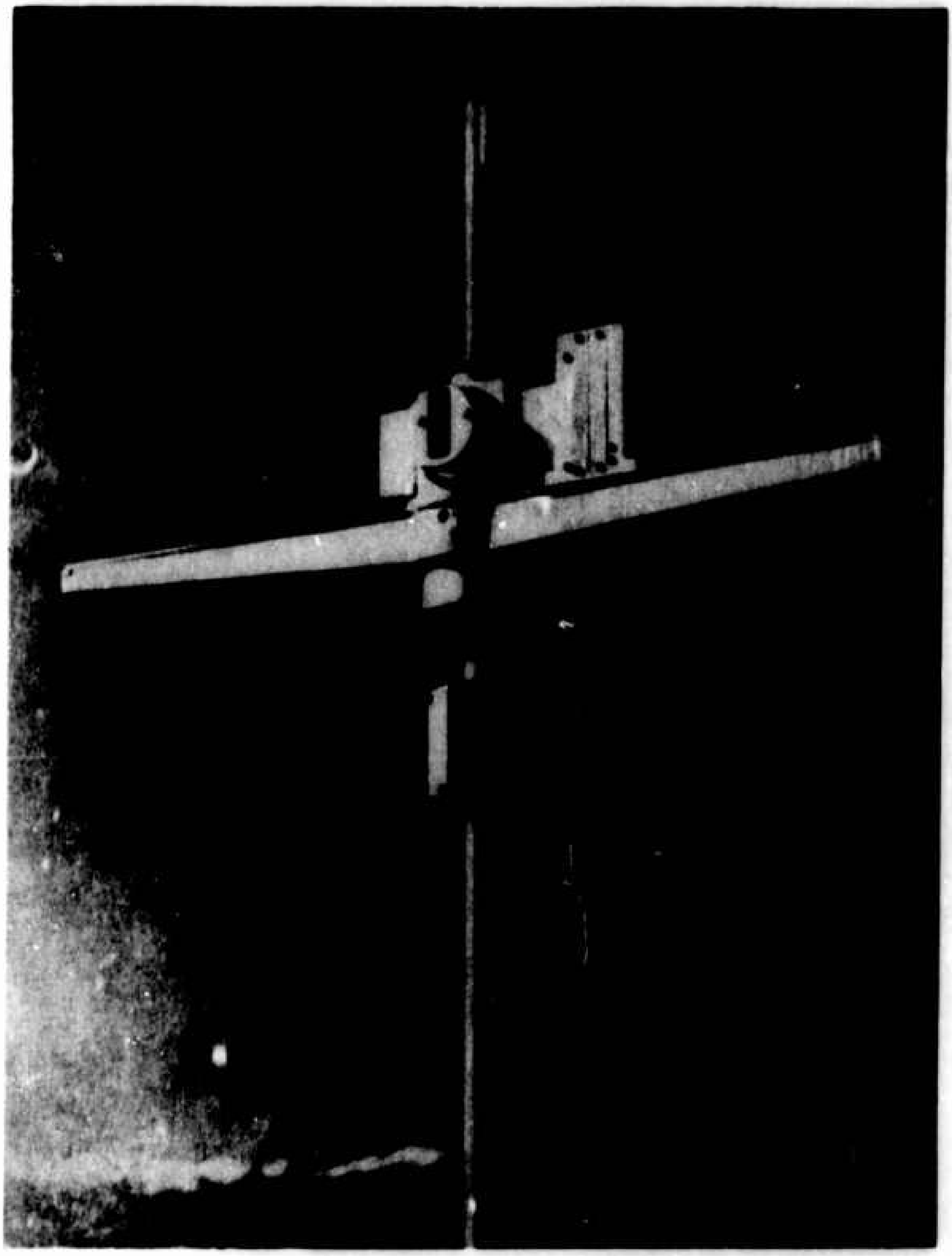

Figure 1. The Solar Azimuth-Pointing Platform
[Ball Brothers Research Corporation photograph]

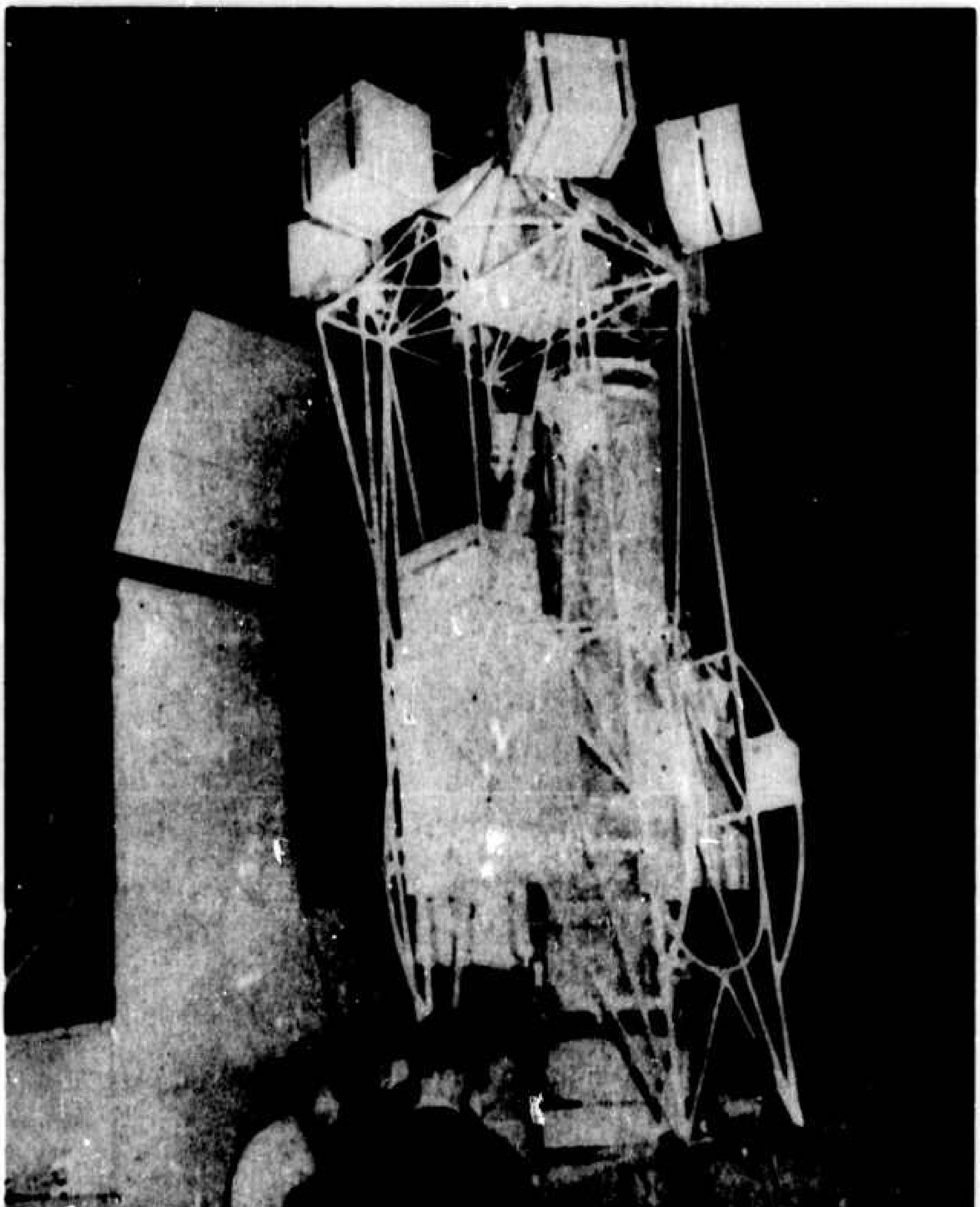

Figure 2. The Stratoscope I System
[General Mills photograph]

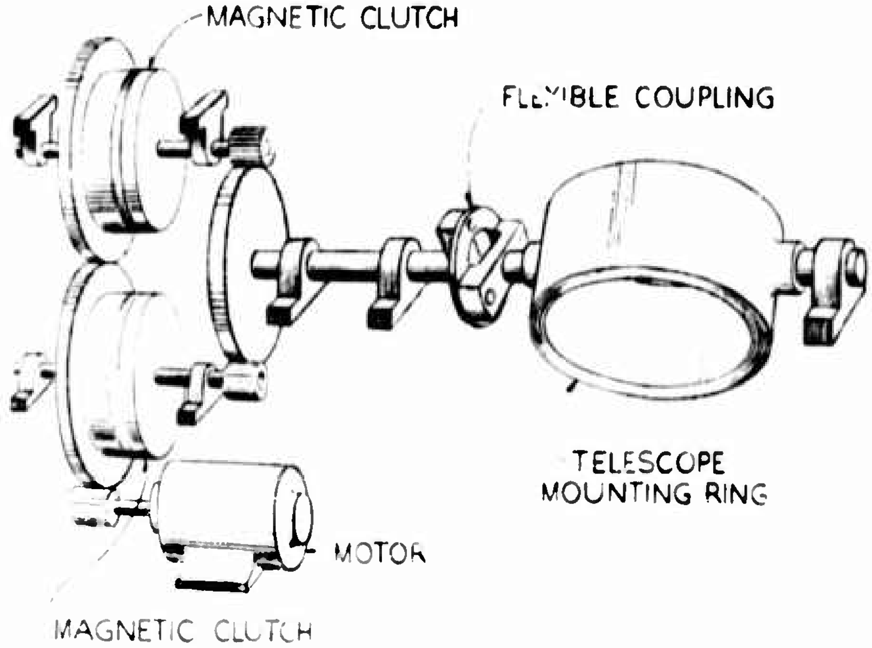

Figure 3. The Stratoscope I Elevation Shaft and Drive System

float altitude the half amplitude of the motion has been measured to be of the order of 0.1 degree or 2×10^{-3} radians. The angular subtense of the moon is 2×10^{3} sec of arc. Hence, if a photographic exposure of the moon were to require 10 seconds, a major fraction of the pendulum period, the maximum resolution at the limb of the moon would be 4 sec of arc, or some twelve-fold less than that obtainable on the ground.

A second difficulty is forced oscillation of the azimuth gimbal [Nidey, 1963]. The amplitude of the oscillation varies as the tangent of the altitude of the target: at 45° a 0.1° half angle pendulum motion would require an equal forced oscillation of the telescope. A third gimbal decouples the telescope from the pendulum motion; hence, obviates both the image rotation and the forcing. The third axle is usually normal to the elevation axis, making the telescope ring a cross-elevation gimbal. This gimbal arrangement is illustrated by the University of Arizona's Polariscope shown in Figure 3. One of the chief advantages of this gimbal system is that the cross-elevation axis is always normal to the axis of the telescope; and the elevation axis, nearly so. Thus, the control gain about these two axes can be adjusted to nearly the optimum value in spite of a large difference in the longitudinal and transverse moments of inertia of the instrument. Control signals for these two axes may readily be derived from a photoelectric guide telescope [Nidey, 1961] mounted collinearly with the instrument.

A single photoelectric guide telescope can produce only two independent control signals, however. Thus the control signal for the third gimbal must be derived from limit stops between the cross-elevation and elevation gimbals, a second offset guide telescope, an inertial element, the magnetic or gravitational field of the earth, or a combination of two or more of these sources. Pendulum motion of the gondola limits the accuracy obtainable from the gravitation field, whereas the magnetic field is variable with geographic position. Hence, an inertial element, such as the floated rate integrating gyroscope, torqued by signals from the limit stops or from the offset telescope, is a more effective source of the third control signal. Indeed, it may be advantageous to use an orthogonal pair of rate integrating gyros on the instrument ring to provide primary control of the elevation and cross-elevation gimbals. This is especially true if one wishes to select a number of different celestial targets by remote control. Of late, the floated gyroscopes have become available on the surplus market at a fraction of the original cost; thus, the chief remaining deterrent is the complexity of the power supplies and the control circuitry.

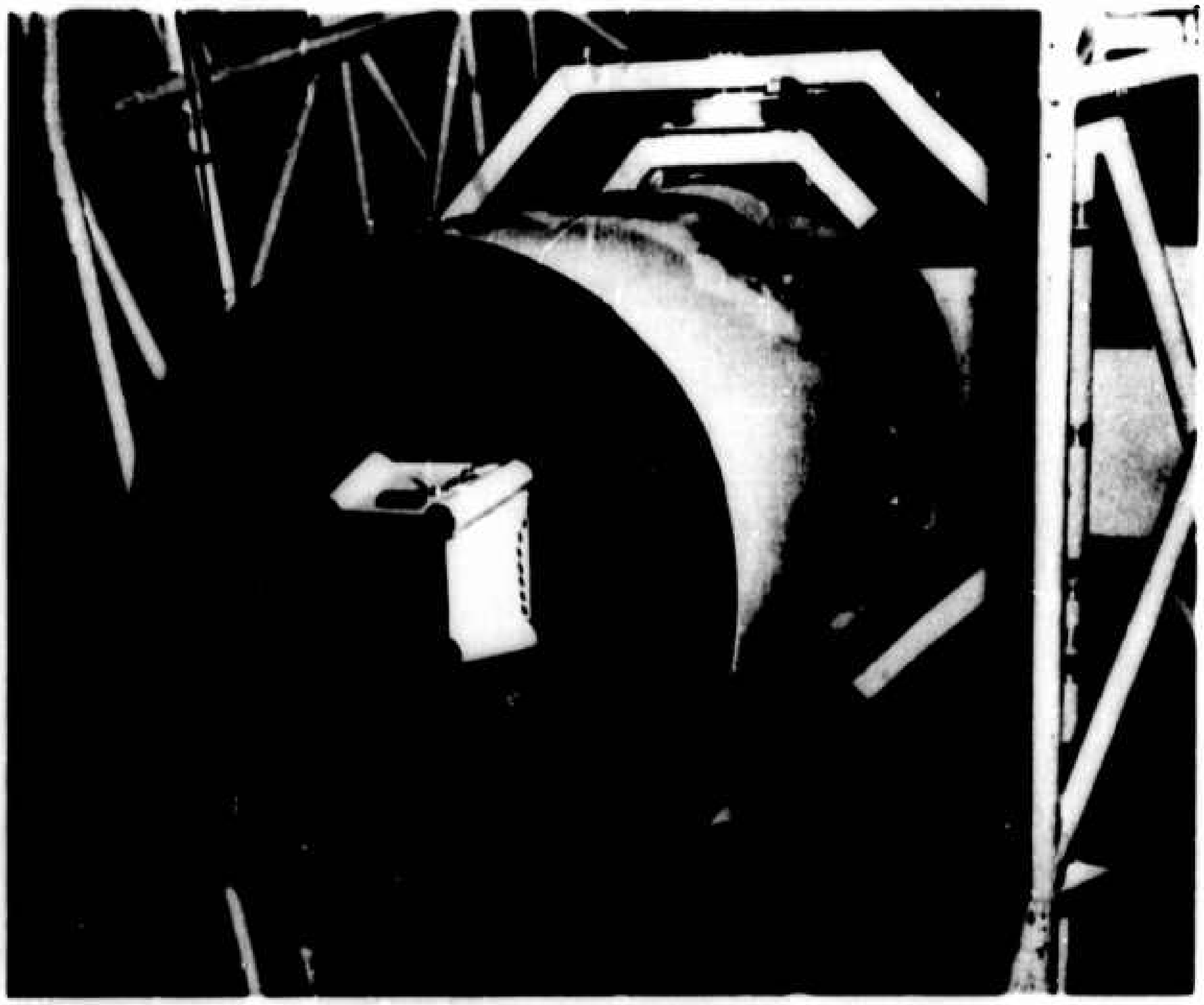

Figure 4. The Polariscope Gimbal System
[University of Arizona photograph]

With floated gyroscopes and torque motors, accuracy of control of a few seconds of arc is now being reported. The accuracy of control is limited by the sensor and by the perturbations. With a photoelectric guide telescope the former limit is set by the photon noise; that is, the random arrival of quanta at the photodetector. For a 4-inch objective telescope trained on a first magnitude star, the photon noise limit is of the order of 3 millisec of arc, assuming an integration time of 0.05 sec and average transmission and sensitivity. This limit is well beyond that currently required. The limit set by perturbations is not.

I have already mentioned the perturbation due to gimbal restraint, the forcing of the azimuth gimbal. Another perturbation is presented by the friction in the gimbal bearings. The bearing friction can be ameliorated by using floated bearings such as oil pad, pneumatic, or mercury bearings, by using flexure members, or by using dynamic bearings such as a triple race bearing, the intermediate race of which is continuously driven.

Inertial and viscous reaction in the motive element can be avoided by the proper choice of motors and by proper design of the power amplifier. Geared servomotors should be avoided, not only because of backlash, but also because of the reflected rotor inertia and back EMF. As the gondola oscillates, the rotors must be correspondingly accelerated and decelerated, necessitating inertial and viscous reactions which perturb the instrument. The viscous reaction can be minimized by designing the output stage of the power amplifier as a high impedance driver; the inertial reaction can be eliminated only by direct coupling the rotor to the gimbal. Hence, the torque motor is superior in this regard to the geared servomotor.

To avoid perturbations with translational motion of the balloon, the gimbals must all be carefully balanced. Furthermore, film transport mechanisms, and so on, must be carefully engineered to maintain balance throughout the flight and to provide counter-motion to negate inertial reactions when components are accelerated and decelerated.

Though I have used three specific systems to illustrate the principles of orientation of the balloon-borne instrument, it must be appreciated that the variations are legion. The choices of gimbals, motors and sensors can be made only by careful evaluation of the scientific objectives of the mission. It must be recognized that even the more ideal components do not combine all the desired characteristics; hence, compromises must be made.

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X Bal-Ast Daylight Tracking System

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Abstract

In the Bal-Ast program for infrared planetary spectroscopy off-set suntracking is used for coarse orientation of the spectrometer-telescope, so as to keep the planet in the field of the telescope for the duration of a 1-2 hour observation period. The planet's image is then transferred to the entrance slit of the spectrometer by means of an optical relay, controlled by a startracker. A final tracking accuracy of 5-10 arcseconds is achieved. This paper describes details of the suntracking system and its performance during a May 1963 flight.

1. INTRODUCTION

In 1959 the presence of water-vapor in the atmosphere of Venus was established in a flight made by Ross and Moore.[1] The amount of precipitable water over the effective reflective layer was estimated to be 6 ± 5 mg cm^{-2}. Repeated measurements were highly desirable on account of the large experimental error. For this purpose the Bal-Ast program was developed, which is based on observations in daytime. This has the advantage that Venus can be observed at culmination, thus minimizing residual absorption by the earth's stratosphere. At the same time a system for automatic acquisition and tracking was introduced, in which the sun is used advantageously as a unique tracking reference point. This eliminates the necessity of an observer, which simplifies flight procedures and permits a quieter control of the gondola.

The water-vapor content of the Venusian atmosphere is derived from the attenuation in an absorption band at 1.13 microns. The Bal-Ast equipment consists of a Schmidt telescope of 30 cm effective diameter and a Czerny-Turner grating spectrometer in which a multiple exit slit array is used to obtain high luminosity.[2] Offset sun tracking is used to keep Venus in the field of the telescope during a 1-2 hour observation period. Planet tracking is then achieved by locating the Venus image in the focal plane of the telescope and transferring it to the entrance slit of

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the spectrometer.[3]

This system was completed and flown for the first time in May 1963. Unfortunately, due to an electrical breakdown, no data were obtained. Down-camera motion pictures, taken during the flight, revealed, however, that the sun tracking system had worked satisfactorily. Another flight is now planned early in 1964. Recently estimates have been made of the water-vapor content of Venus, based on observations from the ground. These estimates are in agreement with the Moore-Ross data, but are considerably impeded by the water-vapor content of the earth's atmosphere.[4,5] Continued high altitude observations are, therefore, still imperative.

2. TRACKING SYSTEM

2.1 Off-set Sun Tracking

The position of the sun relative to Venus can be characterized by the Venus elongation β and by angle ρ between the line Sun-Venus and the vertical through Venus. (Figure 1) During the observation period β can be considered as constant. The angle ρ, however, increases with time due to the earth's rotation. This provides the basis of the Bal-Ast sun tracking system. The telescope is kept pointing at Venus by tracking the sun at an off-set angle equal to β, the plane of this angle being rotated so as to follow the change in ρ. The mechanism involved is called the β-ρ device. It consists of a small unit, mounted on the telescope. (Figure 2) The off-set angle is introduced by means of a reflecting prism, the angle ρ by its rotation. (Figure 3) The sunsensor is a rotating semi-circular silicon cell. After pre-amplification the output is resolved in elevation and azimuth servo-signals, which are fed into the telescope elevation drive and an azimuth torque motor respectively, the latter rotating the telescope platform and the gondola against a heavy reaction wheel.

The angle ρ is a periodical function of time, which is, however, practically linear in a 2-hour interval around Venus transit time. A constant speed rotation of the prism is therefore adequate to keep Venus in the field of the telescope. The angle ρ varies slightly with the geographical position of the balloon. In programming a flight, the prism-drive is set for the best approximation to a pre-flight prediction of the balloon trajectory. Deviations from linearity can thus be limited to a fraction of a degree.

2.2 Planet Tracking

The transfer of the Venus image to the spectrometer is made with the help of a startracker, mounted in a gimbal system so as to pivot around the center of curva-

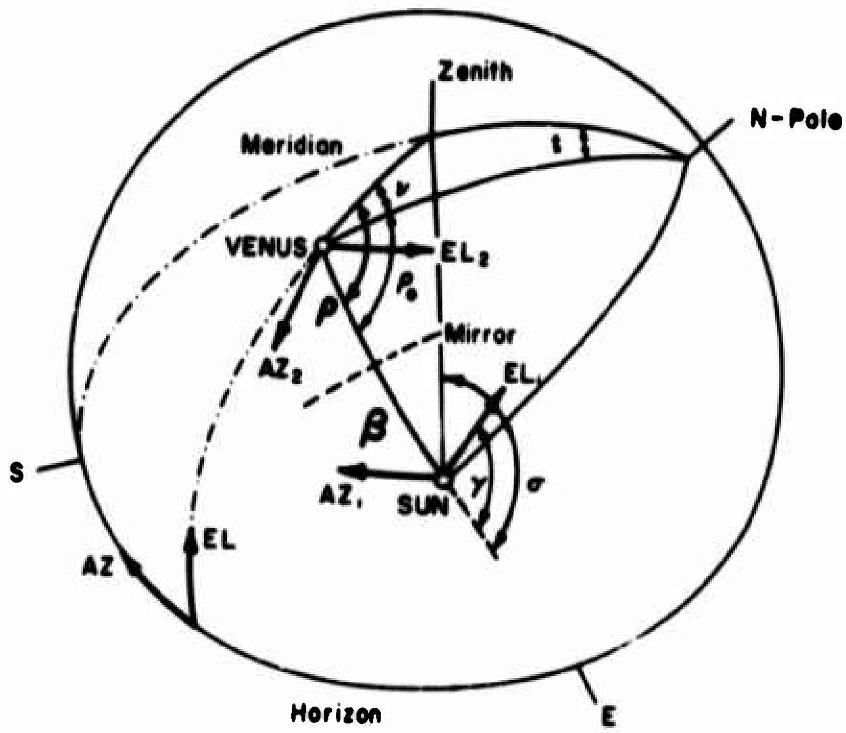

Figure 1. Geometry of Off-Set Suntracking System. Explanation in Text.

ture (monocentric point) of the telescope mirror. As is evident from Figure 2, the Venus image is transmitted to the monocentric point from any position in the focal plane, the instant the startracker is centered on Venus. The light is then reflected towards the condenser system of the spectrometer (not shown in Figure 2) by means of the monocentric mirror, which at all times bisects the angle between the startracker and the fixed direction of the outgoing beam. The monocentric Venus image can therefore be considered as an immobile light source for the spectrometer, as long as the startracker is operative.

The sensing system of the startracker consists of a 10 cm Cassegrain telescope with a vidicon tube as a sensor, covering a field of 1°. Venus is located by means of an image dissecting scan across the photocathode while the startracker is centered in the telescope. After acquisition the startracker is servo-adjusted to center Venus in its field where it is held with a precision of 5 to 10 arcseconds during the tracking mode. Considering that the diameter of Venus atdichotomyis approximately 30 arcseconds, this precision is satisfactory for the present observations.

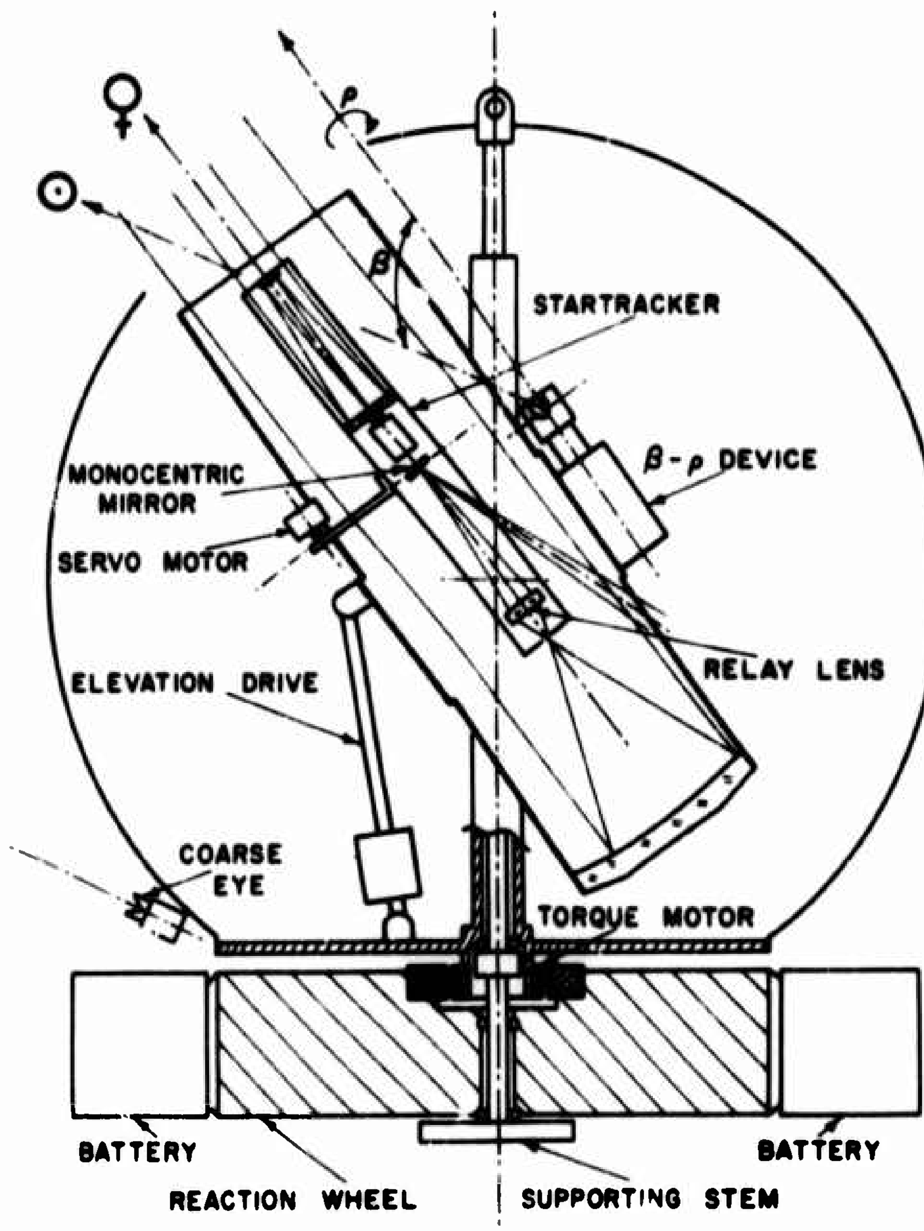

Figure 2. The Bal-Ast Balloon Borne Spectrometer - Telescope With Tracking Devices. (Spectrometer Not Shown).

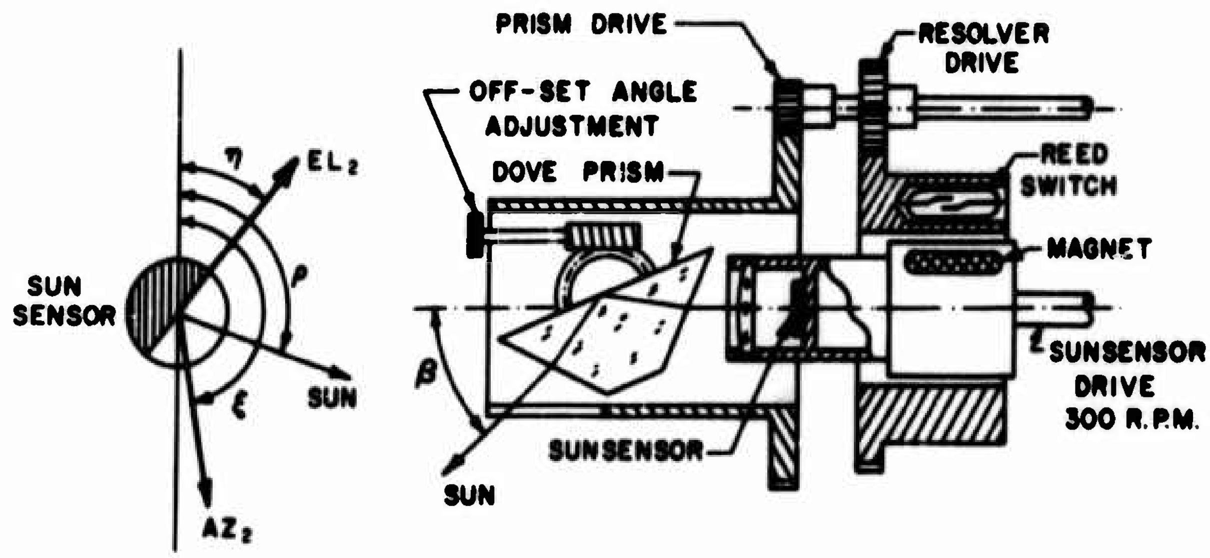

Figure 3. The β -ρ Device, Schematic.

2.3 Tracking Procedure

With the above system, acquisition and tracking is achieved in the following steps:

1) After arrival of the balloon at float altitude (25 - 30 km) a programmer switches on a set of 4 sunsensors (so called coarse eyes) mounted in pairs outside the gondola, which adjust the platform in azimuth, so that the telescope, preset in elevation, is pointing at Venus within a few degrees. At the same time, the sun is brought into the 20° field of the sun tracker.

2) Shortly after the sun has been acquired the sun tracker is switched on. If the balloon is close enough to the predicted position, (for example within 50 km) the β -ρ device will bring Venus into the 1° field of the centered startracker and Venus acquisition follows. Unexpected deviations from the predicted balloon trajectory may, however, occur. In such an event the startracker may not be able to locate Venus, in which case a scanning mode of the prism rotation is initiated. Since β is invariable, a scan in ρ of sufficient amplitude (for example 3°) will necessarily in time time bring Venus in the startracker field.

3) After Venus acquisition the β -ρ device and the startracker remain in operation for the duration of the observations. During this period the startracker can follow Venus out to 3° from the telescope axis, thus allowing deviations of the balloon trajectory up to several 100 kilometers in the later part of the flight.

3. SUN TRACKER PROGRAMMING

3.1 Prism Rotation Rate

The angle ρ is the sum of the parallactic angle ν and the angle ρ_o (North-pole, Venus, Sun), which can be considered as invariant during the observation period. (Figure 1)

$$\rho = \rho_o - \nu \tag{1}$$

The characteristic properties of ν can be derived from the following equations:

$$\sin \nu = \cos \phi \sin (\underline{t} - \Delta\lambda)/\cos Z \tag{2}$$

$$\sin Z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos (\underline{t} - \Delta\lambda) \tag{3}$$

δ = declination Venus

Z = Venus elevation

$\underline{t}$ = Venus hour angle relative to reference meridian

$\Delta\lambda$ = latitude difference balloon and reference meridian

ϕ = longitude balloon

First the dependence of ν on time will be considered (ϕ fixed, $\Delta\lambda$ = o). The ν-function has an inflection point at $\underline{t}$ = o (Venus transit time) and is therefore practically linear in the time interval of interest ($-15° < \underline{t} < 15°$). The rate of change at $\underline{t}$ = o is given by

$$\dot{\nu} = \cos \phi / \cos (\phi - \delta) \tag{4}$$

Deviations from linearity are of the third order in $\underline{t}$. These can be partly compensated by choosing a prism rotation rate that is slightly lower than indicated by Equation (4). An example is given in Figure 4. The prism rotation rate is set to give correct ρ - values at 9:21, 10:04 (Venus transit) and 10:47. The deviation $\Delta\rho$ is smaller than 15 min of arc within ± 50 min from Venus transit time. Due to this deviation the position of Venus in the telescope changes with time. The errors in elevation and cross-elevation are respectively given by

$$x = \frac{\delta \alpha_v}{\delta_\rho} \cos Z \, \Delta\rho = -\cos Z \tan (\alpha_v - \alpha_s) \cot{}an\, \rho \, \Delta\rho \tag{5}$$

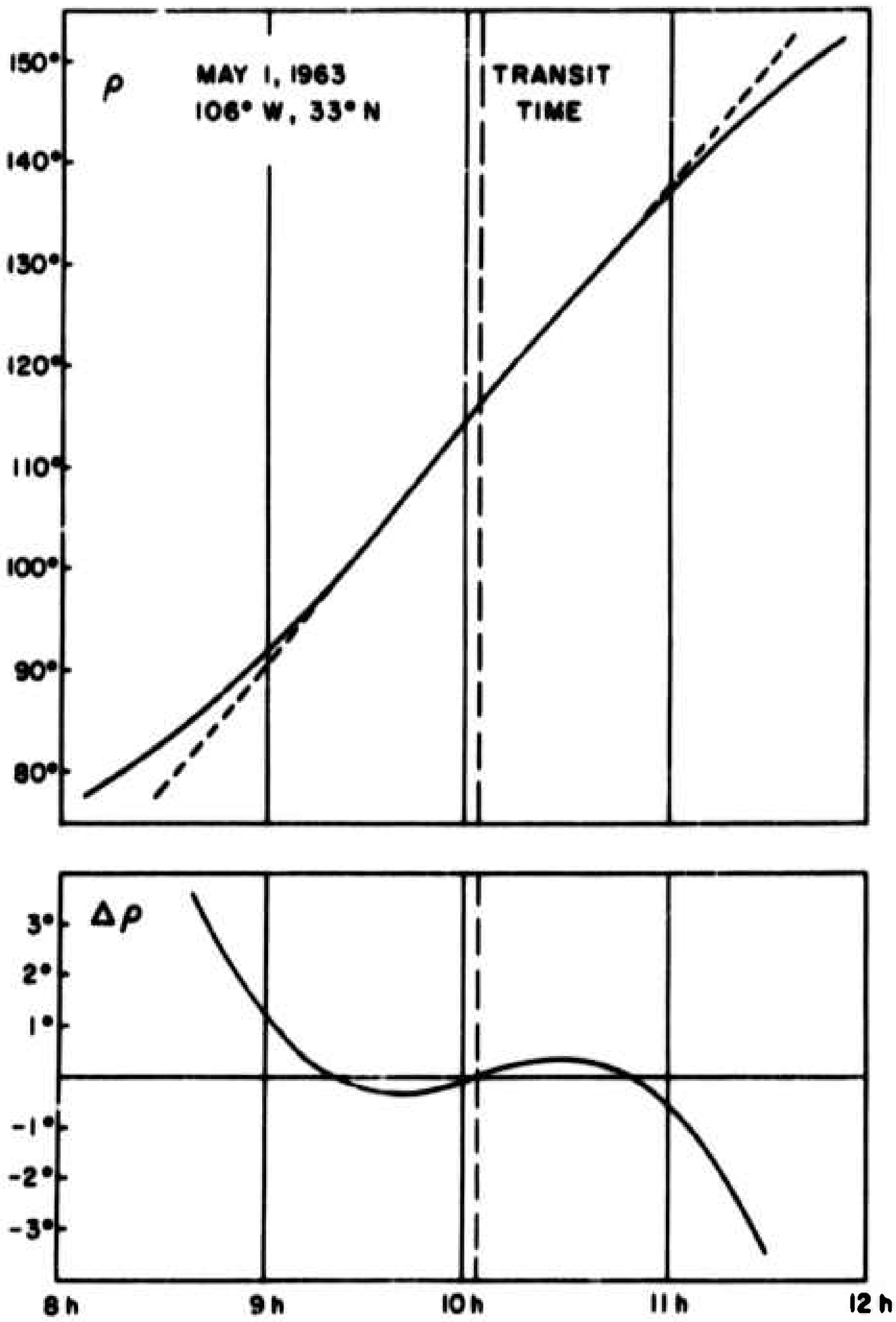

Figure 4. Example of the ρ-Function and the Deviation $\Delta\rho$ From a Linear Approximation.

$$y = \frac{\delta Z}{\delta \rho} \Delta\rho = -\cos Z \tan(\alpha_v - \alpha_s) \Delta\rho \qquad (6)$$

with

α_v = azimuth Venus

α_s = azimuth Sun

As a result, Venus describes a trajectory in the field of the telescope as is shown in Figure 5. Venus is off-center by 23 min of arc at the most. The Venus declination in this example is +2°. With greater declinations the ρ-rate and non-linearity increase, which may in certain instances lead to a reduction of the usable observation period.

3.2 Resolver

The function of the resolver in the β-ρ device is to derive azimuth and elevation servo-signals from the sun-sensor output. If the sun is off-center, a 50 cycle A.C. signal is generated, which has its maximum value in the direction of the sun image. After amplification, this signal is fed through magnetic reed switches into the azimuth and elevation servo circuits (Figure 3). The switches have to be placed in proper position in order to minimize cross-talk, which necessitates programming of the resolver. The image of the sun on the sun-sensor is formed through reflection by the Dove-prism, the reflecting plane being the bisecting plane of the off-set angle. (Figure 1) Upon displacement of the gondola in elevation, the sun moves in the direction EL_1, in a plane parallel to the vertical plane through Venus. The angle γ between EL_1 and the line Sun-Venus is given by

$$\tan\gamma = \tan\rho \cos\beta \qquad (7)$$

The sun image therefore moves in a direction EL_2 at an angle η with the vertical through Venus, given by

$$\eta = \gamma + \rho - 180° \qquad (8)$$

In order to prevent elevation signals entering into the azimuth servo circuit, the azimuth reed switch must be placed such that it is closed when the sensor dividing line lies in the direction EL_2, as is shown in Figure 3. For not too large values of β the angle γ is approximately equal to ρ. At greatest Venus elongation (β = 47°)

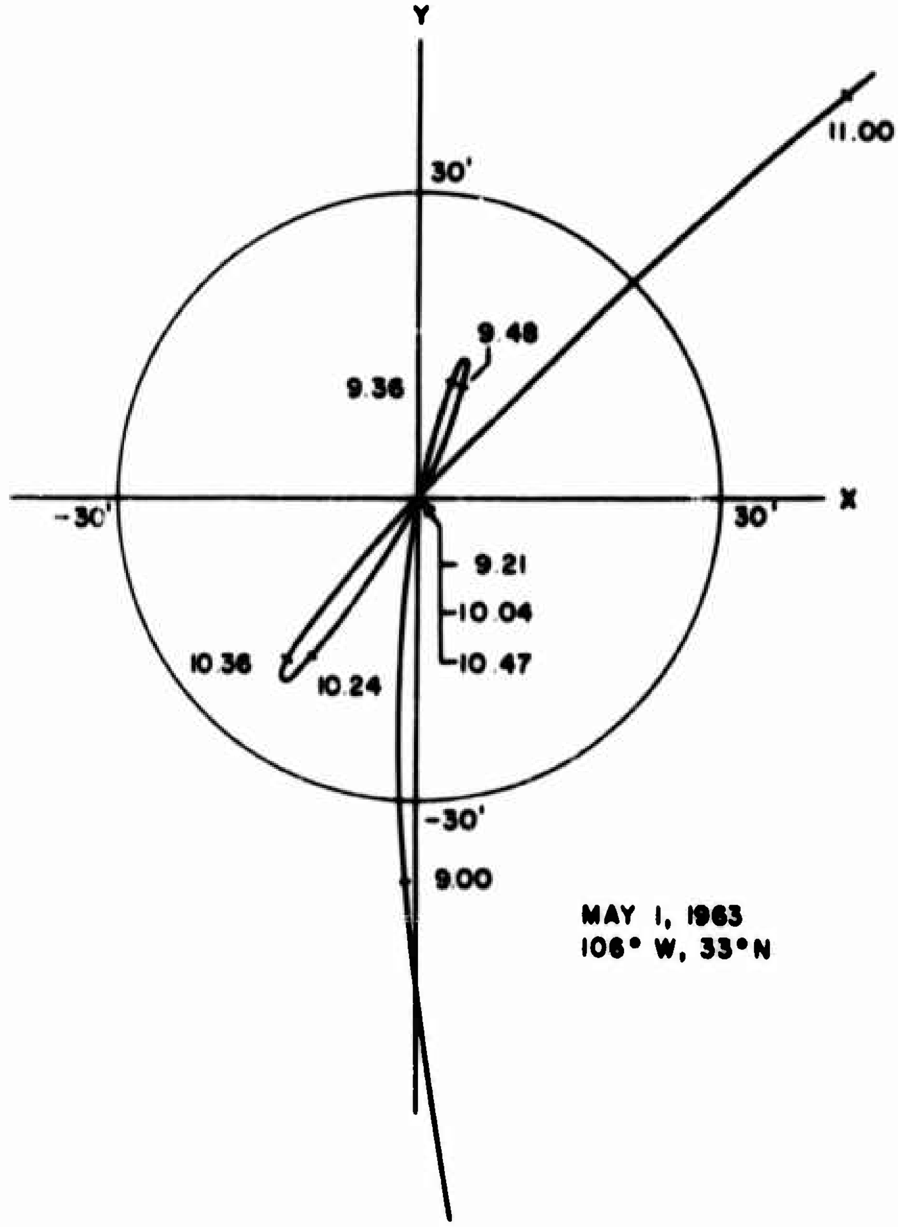

Figure 5. Calculated Trajectory of Venus in a Telescope, Guided by Off-Set Suntracking.

the maximum possible difference is approximately 10°. A 1:2 ratio between the rotation of the prism and the azimuth reed switch mounting ring is therefore satisfactory. Using an optimized average value for γ , the error in the azimuth switch position can be kept smaller than 5°.

Upon movement of the gondola in azimuth the sun image on the sunsensor is displaced in the direction AZ_2, at an angle ξ with the vertical, given by

$$\xi = \rho + \sigma - 90° \qquad (9)$$

where σ is the angle Zenith-Sun-Venus. In this case the situation is complicated because the angle σ changes non-linearly during the observation period. A compromise can be made by using the same 1:2 ratio and an optimum average value of σ for each particular occasion. Some crosstalk from azimuth into elevation will remain, but this was found to be tolerable, the elevation drive being rather sluggish.

3.3 Balloon Trajectory

In programming the β-ρ device the change in balloon position has to be taken into account. On the basis of a predicted balloon trajectory ρ is calculated for various times during the observation period and the prism rotation is set to give the closest approximation to these values.* The trajectory prediction can, however, never be completely exact. If the balloon misses the predicted position by distances $\Delta\phi$ and $\Delta\lambda$ in latitude and longitude respectively, and error $\Delta\rho$ results, given by

$$\Delta\rho \cos Z = \Delta\phi \sin \alpha_v + \Delta\lambda \cos \alpha_v \cos \phi \qquad (10)$$

The tolerances for $\Delta\phi$ and $\Delta\lambda$ depend on various factors. At acquisition time α_v is approximately 150°. The balloon position therefore has to lie in a NW - SE band. If it were required that Venus be brought in the startracker field, without making use of scanning in ρ, the band would only be approximately 50 km wide. This is a rather severe condition, which, however, was met during the May 1963 flight, due to the facts that acquisition time was only 3 hours after launch and weather conditions very stable. With the ρ - scan available, practically any possible deviation can be met. The permitted balloon position band widens up with approximately 100 km for every degree increase in ρ - scan amplitude.

After acquisition, the startracker can follow Venus out to 3° off axis, which means that the balloon position is not at all critical.

4. PERFORMANCE

Observation of the Venus trajectory in an auxiliary telescope provides a convenient way to test the sun tracker performance on the ground. In tests made prior to the May 1963 flight, trajectories very similar to the one in Figure 5 were observed. The positions of Venus, however, were sometimes off by 10 to 15 min of arc, as a result of cumulative errors in alignment, boresighting and leveling of the telescope platform. (Figure 6) The tracking stability was found to be 1 - 2 min of arc.

*Tables of the ρ -function as a function of t, ϕ and λ were computed for use in the field. However, values of the parallactic angle ν can be read directly from azimuth tables by interchanging the input parameters latitude and declination.

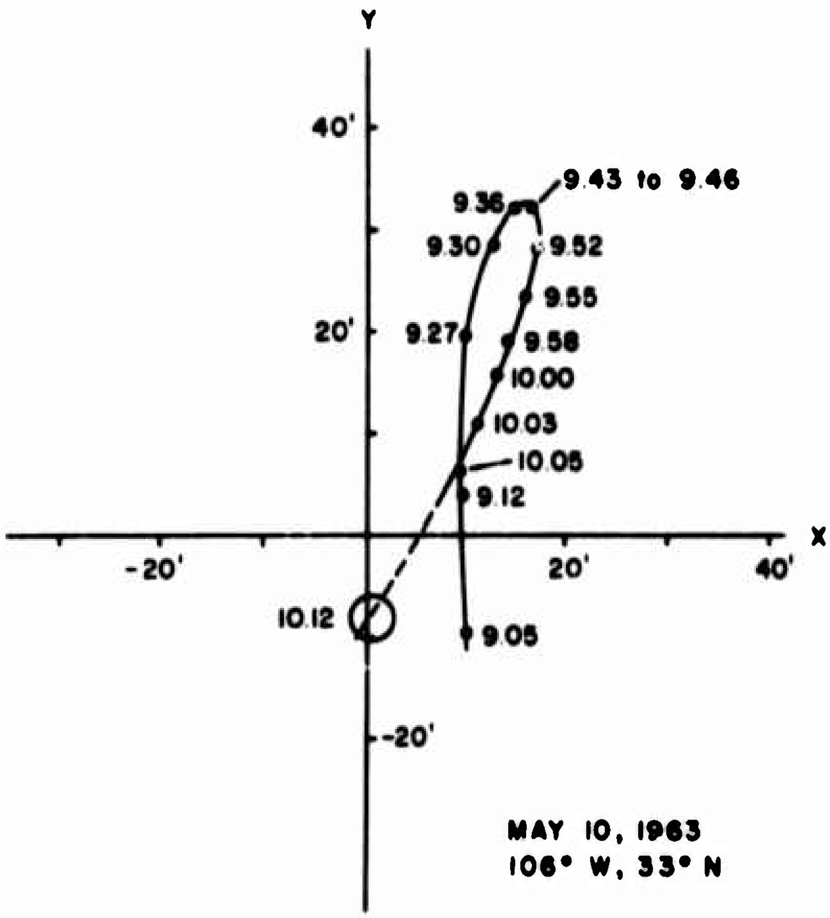

Figure 6. Observed Venus Trajectory in Auxiliary Telescope. β -ρ Device Programmed to Bring Venus to Center at 9:12 and 10:12.

The observed random errors in the position of Venus were mainly due to wind forces on the gondola. In flight, the tracking stability should therefore be better than 1 min of arc.

A record of the performance of the suntracking device in flight was obtained from down-camera motion pictures. The pictures, taken at a rate of 8 frames per minute, show the orientation of the gondola relative to the ground. At sun-acquisition the rotation of the gondola ceases and is reduced to oscillations of a few degrees amplitude. At the same time the reaction-wheel comes into action. After transition to the sun tracking mode the gondola becomes very stable and the reaction-wheel more vivid. Since the startracker did not come in operation, the ρ - scanning mode initiated soon after sun acquisition. In the beginning the modulation in azimuth is practically zero, but towards the end of the observation period it becomes very noticeable because of the rapid increase of the derivative in Equation (5). Quantitative analysis of limited accuracy was possible in a few instances where distinct ground features were available. The overall decrease of azimuth and the modulation by the ρ - scan, however, were found to lie within the expected limits.

The analysis of the pictures, combined with the results of pre-flight ground tests gives us reason to believe that off-set sun tracking has proven to be a valuable tool in the study of astronomical objects that lend themselves for daytime observation.

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XI The Case for Manned Balloon Astronomy

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Abstract

The merits of manned balloons are set forth in terms of the ultimate objectives of astronomy. For balloon astronomy to develop into a standard technique applicable to a host of astronomical problems (rather than to have one or two special balloon flights mounted for the execution of one or two specific narrow tasks) calls for an observatory carried routinely to altitude. An astronomer can then perform the same tasks he performs in an earth-based observatory dome: exercising on-line judgment, performing a series of observations at will, checking instrument calibrations, and providing final image stabilization. He does the latter not by attempting to move the entire telescope mass, but by rapid manual, eye-controlled motions. In this way it is possible for him to get sharp stellar images in an exposure of an hour or more. To provide this sort of stabilization for periods of an hour or so by unmanned means is formidable. An astronomer placed in a gondola built to astronomical specifications (not a left-over medical test box) in which the light from celestial objects is admitted directly into the cabin, can serve the cause of astronomy much more effectively over the long pull than would a long series of individual unmanned flights, each geared to one and only one experiment.

It is paradoxical that in the national space effort the emphasis --- billions of dollars worth of emphasis --- is being placed on the goal of man in space, as distinct from emphasis on having instruments in space, yet in balloon astronomy there is great difficulty in finding support for sending even one competent astronomer aloft (as the fate of Project Stargazer eloquently attests) even though the arguments for the former are trenchantly germane to the latter.

Indeed, the arguments for man in space can so logically and with such great force, be applied to man in local "balloon space" that one might defend the thesis that the cart is very much before the horse. That is, for experiments and observations in "near-space", which is just a stone's throw from the surface of the earth, man is the logical experimenter and observer. In astronautical space, it might be argued, in a territory that has many more unknowns than does balloon space, and where the hazards are more long-range and generally greater, instruments could well precede man in the natural course of evolution, as fishes and reptiles preceded man on earth.

Before these arguments are examined, it should be stressed that we are not dealing with an "either-or" situation. The case for manned balloon astronomy does not imply the case against instrumented balloon astronomy. It is a question of complementarity and of emphasis, not of mutual exclusiveness.

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First, then, we must see whether the arguments in favor of man in space have validity when applied to balloon astronomy. Let us, therefore, examine what the arguments for man in space are, and let us next examine what balloon astronomy is and then make a critical appraisal of the advantages and disadvantages of the presence of an astronomer in a balloon astronomy operation.

There are many arguments given for placing man into space in order to land on the moon and, eventually, to go on to the physical exploration of the planets. It would, of course, seem at the start that the majority of these arguments must be valid in their own context solely from the budgetary support for such a program. Isn't it unthinkable that billions of dollars would be committed by this country by responsible officers of the government advised by many equally responsible senior scientists, to a "moondoggle"? In the August, 1963, issue of ATLANTIC, Robert Jastrow and Homer Newell, both top scientific leaders in NASA, state some of the man-in-space arguments in their article "Why Land on the Moon?". They defend the expenditures for man in space ably. "Some scientists feel", they write, "that most facts of scientific interest about the moon and planets can be learned by remote control instruments alone, at less cost than manned operations. An editorial in SCIENCE estimates that robot instrument landings will see us through all the important phases of the lunar exploration program at 1% of the cost of the Manned Space Budget. Actually, an inspection of the NASA budget indicates that the Surveyor Project for unmanned lunar landings is more nearly 10% of the cost of the Apollo Project including the development costs in each program. On a per-flight basis in the long range continuing programs, the cost ratio is 16%. When allowance is made for the increased chance of success in the mission which results from plugging man into the control system, the comparison of costs is still more favorable to manned operations". I pause to remark that if this is true for the Man in Space effort, it is even more so in the case of Manned Balloons. If balloon astronomy is to become an accepted technique in astronomy, as is today the use of radio telescopes and coronagraphs, for instance, then man in the system will reduce costs - not increase them - in the long run. Jastrow and Newell go on to say, "But a comparison of costs is not the only issue. The question is, will a robot instrument do everything that a man can do?" "The answer", they say, "is that in early stages the simplest observations can be made by remote control. In later stages when more difficult experiments are attempted for answers to the important questions, the trained human observer brings to the supervision of these experiments the ability to deal with unforeseen difficulties and to respond to unanticipated opportunities. The automatic instruments in this advanced stage of the program must be designed with great complexity and a heavy price in reliability in cost and development to achieve even the crude imitation of sophistication and flexibility. The balance of cost and reliability then tips in favor of the human participant, expensive though it is to bring him to the scene."

Saying that these arguments would not apply to balloon astronomy simply reflects lack of knowledge of the true nature of balloon astronomy. If in balloon astronomy we were asking for simple experiments and simple observations, the case for instrumented balloons would be strong - as it is in the relatively simple type of balloon experiments in cosmic ray, sky brightness, and air sample studies. There are indeed a great many scientific observations of various types that can be made from balloons in which the presence of a man is just not needed. He is not needed for basically uncomplicated or elementary experiments, but the only thing that is "elementary" about balloon astronomy is the vehicle. And this is elementary only in the sense that we are still at the beginning stages of knowing how to use the balloon vehicle as an appropriate booster. Having been painfully involved as an intimately interested observer at some balloon launchings, I can attest to the fact that watching those procedures was a poignant reminder that we have much more to learn.

Balloon astronomy calls for sophisticated rather than simple experiments and observations. To defend this I think it is necessary for us to take a look at what the astronomer does as part of his regular duties at an earth-based observatory.

Perhaps I should interject here that I will take it for granted that in this audience no time need by spent extolling the virtues of meta-atmospheric observations, observations made from above all, or most all, of the earth's atmosphere. From a scientific viewpoint, the atmosphere is the astronomer's greatest enemy. There is no contesting that point. The only point under discussion here is, what are the objectives of balloon astronomy, as distinct from scientific ballooning in general, that can best be accomplished in the long run by placing the astronomer aloft with the balloon. For this, as I said, it is necessary to have an understanding of what the astronomer's problem on earth is. For unless we understand precisely what it is he does on earth it is meaningless to discuss whether he, or an instrument should do these things at 80,000 feet.

At the risk of being elementary, let me point out that an astronomer generally works in an observatory dome in an atmospheric environment which is at equilibrium with that outside the dome. The raw material the astronomer uses, namely the incoming radiation, is gathered by a suitable instrument, and presented to the astronomer for his use. Depending on his particular program, and he usually has several on the fire, and depending on the nature of the night, he examines either the direction, the quantity, or the spectral quality of the incoming radiation. Under direction we may list all the aspects of celestial mechanics, which depends only on the direction on which a celestial object is sighted, and all direct photography, too, because a photograph of a star field or of solar granulation or of distant galaxies depends only on making sure that the many directions from which this radiation has come are all set down in proper arrangement on a photographic plate or other recording medium.

If he chooses to examine the quantity of the incoming radiation he may still use the photographic plate, as in photographic photometry, but today, more and more he will use photoelectric photometry in its various forms. If he chooses to do this photometry at many different wavelengths he is doing spectrum analysis, especially when the wavelength intervals are of the order ϵ where ϵ approaches zero. In examining the direction, quantity, and quality of the incoming radiation, he can use one or more of the following instruments: a camera, a spectroscope, or spectrograph, a filar micrometer, one of several types of photometers, a bolometer, a thermocouple, an image orthicon, and from time to time, more specialized equipment such as an interferometer, a polarimeter, magnetometer, a photometric grating, and so on. I have been thinking largely of optical and infrared radiation but one must, of course, extend the spectrum to include the radio regions of the spectrum. With respect to the infrared, it furnishes one of the prime reasons for balloon astronomy, namely the fact that from balloon altitudes one has a virtually unimpeded access to the infrared.

Many of these instruments, attached directly at the focal plane of the telescope, are but the first part of a train of recording instruments such as oscillographs, magnetic tapes, recording galvanometers, and so on, all with their associated power supplies, and so on. Suppose now, if instead of the man being present in the observatory dome, every one of these functions had to be performed in the dome by telemetry command from an office several miles away. Suppose that when some minor adjustment went wrong the astronomer was not permitted to come to the observatory dome to put in a new fuse, to adjust a loose wire, to check out this and that, and one hundred or more small things, how much astronomy would get done? And, where would the money come from for all these complex command systems? I grant you that if he had one observation to perform, and only one, and if that were all this astronomer were interested in and could consider his career closed after he accomplished that one observation, then one could say, let him command the telescope from a distance.

Even so, he would have to supply, again by command, image stabilization. Now one might easily think that images for an earth-based astronomer are already stabilized and that image stabilization is something we need be concerned with only in balloon astronomy. But this is not the case. It is the astronomer himself who provides the final image stabilization. The fine photographs one sees of galaxies and star clusters have required time exposures of the order of hours rather than minutes. The resolution of some elliptical galaxies into their component stars required exposures of 4 hours! These pictures would never have been obtained simply by having a camera clamped to the end of the telescope, pressing a button and letting the telescope follow the field. Imperfections in the telescope drive must be smoothed out as well as the effects of differential refraction and, most important of all, long period atmospheric oscillations. An entire star field can make slow excursions of many seconds of arc; such image excursions must be compensated for. Such long term excursions occur presumably because of "swells" in the atmosphere as against the small eddies which produce scintillation and image motion.

How does the astronomer provide this stabilization? By guiding his recording device by eye and hands. In stellar photography it has been customary for decades for the plate holder to have a separate eyepiece which is set on a guide star under high magnification. The astronomer does his best to keep the guide star image on the cross wires. He does this by the use of a double screw plate-holder, moving the plate in two coordinates as quickly and smoothly as possible. To try to move the entire mass of the telescope to accomplish this final image stabilization would, of course, be absurd.

The time-honored hands, eyes, and brain method of final image stabilization has on occasion been replaced in earth-based observatories by photoelectric guiding devices. These can be a great convenience for the astronomer but they have not been widely adopted principally because the astronomer himself is a remarkably efficient on-line computer with judgment. Even so, photoelectric devices require frequent fine adjustments by the astronomer.

Now the type of image stabilization required on the surface of the earth is quite different from that required in a balloon. Atmospheric effects are virtually gone, but the telescope and gondola motions must be compensated for. First-order stabilization of the gondola can be accomplished by cold gas jets, to about one minute of arc. This, incidentally, disposes of arguments about "biological noise". Even if the astronomer should make large scale motions in moving about in the gondola, jet stabilization will easily compensate therefor. Superposed on this, if necessary, the astronomical instruments can have first-order gyro-stabilization which, in effect, would be much akin in function to the drive of the earth-based telescope. The final image stabilization, however, can superbly be accomplished by the presence of the astronomer, using the same methods he uses in his earth-based observatory. To repeat, the highly sophisticated stabilization which is required in unmanned balloon astronomy, stabilization to the order of a tenth of a second of arc for many purposes, and which is extremely costly and probably difficult to maintain for several hours, can be reliably supplied by the observer himself. He can, being a sentient servo system, provide this critical image stabilization by the "simple" use of his eyes, hands, and brains.

He can do a host of other things with his eyes, hands, and brains, too. He can make adjustments. If one envisions a properly designed astronomical gondola, one in which only the light gathering apparatus in exterior to the gondola but the gathered light is introduced into the capsule, he can then in the course of several hours' observation perform a host of experiments on the incoming radiation. He can use a photometer, a spectrograph, a photographic plate; he can make sure the focus is correct; he can make sure the light is going into a small diaphragm; he can make sure he is on the right star, and if he looses the star he can re-acquire it in short order. Presumably, when he makes these complex adjustments, he will not suffer from a noisy resistor or a cracked insulator or a damaged transistor in his brain pan.

I think you will see now why I feel that the reasons given by Jastrow and Newell and other apologists for a man in space apply even better to balloon astronomy. We can paraphrase their "outer-space" reasons in another way: man, the scientist, can exercise on-line judgment. He can meet new situations as they arise. He can interpret first hand. He can make instrumental adjustments. He can improvise. He can evaluate the unexpected. He is a built-in computer.

Can instruments do this rather than man? Clearly, instruments cannot improvise, evaluate, exercise judgment, and so on. It can be argued that the judgment can be exercised on the ground by men watching dials, meters, and other gear "attached by telemetry" to the balloon possibly several hundreds of miles away. But one minor part out of thousands failing to function can throw out that entire intricate communications link. The command networks are notoriously tricky, critical, and expensive. The proponents of man in space continue: instruments are a "go - no go" proposition whereas man can always salvage something out of an experiment even if malfunctions occur in certain portions. Man can communicate his findings to a panel of experts on earth, by simple voice transmission, and allow them to exercise judgment for him should the pressures of the moment and his immediate environment tend to cloud his judgment. He is still on hand to carry out, in situ, the results of his and his colleagues' judgments.

You will remember that all this is said by man-in-space proponents despite the tremendous life supporting gear to keep a man alive in outer space. Many arguments are marshaled for man's value in this volume of space, which is much farther out than balloon space, and for establishing that his value outweighs the problems and costs of the life support system necessary to put him there.

However, when we come to "inner local space", or balloon astronomy space, often the opposite arguments are given, often by the same people, who do not realize how complex the problems of balloon astronomy are and who still perhaps think of balloons as modern versions of an ancient Chinese toy. Balloon astronomy may be a new field, but the problems this new technique seeks to solve are still the same old complex, tricky problems that the astronomer must face on earth. Very paradoxically, some of those who defend man in space when it comes to the great beyond indicate that in balloon space it is too costly to consider life support systems and that instruments can do better than man in focusing the optical equipment, adjusting gains and meter settings, and so on. I think it is profitless to pursue this extreme paradox further. The fact remains that the basic arguments for man in outer space do apply most directly to the presence of man in balloon astronomy. It cannot be gainsaid that the presence of man in the framework of the experiment permits the making of many critical instrumental adjustments by hand rather than by telemetry and makes possible his seeing for himself, first-hand, how the observation goes.

I might note, in passing, that Project Gemini is now asking for suggestions for astronomical experiments and observations to be carried out by the two astronauts when they are circling the globe. This is commendable, for it recognizes the importance of man as a scientific observer, even though the objectives of Project Gemini are different from those of basic astronomy. The difference between Project Gemini and Manned Balloon Astronomy is simply that Project Gemini does not exist primarily for the benefit of astronomy and further, it is ephemeral. But it underlines the need -- for the benefit of astronomy in the long run -- of providing a capsule built with the astronomer's needs in mind (not just any old capsule or gondola left over from some other experiment) and capable of supporting life safely and routinely for a period of days, and to have said capsule carried aloft by fully air worthy balloons.

I am led to consider at this juncture a frequent misunderstanding in the matter of balloon astronomy. It is sometimes stated that there is no point to pushing for balloon astronomy, and manned balloon astronomy in particular, because balloons are interim vehicles, and that their usefulness will vanish when orbiting astronomical observatories are in more general use. I think this attitude again reflects a lack of understanding of the problems of the astronomer and of the potential of balloons.

Why in the world send up a satellite if a balloon can do the job as well, and in many cases better and almost certainly much more cheaply? Better, because if a transistor goes bad in the satellite, you've had it unless you want to bring the satellite back to earth and relaunch it. In the manned balloon, the observer merely gets out a small soldering iron and replaces the transistor, or better, replaces a troublesome module. You will remember that in this context we are bringing the light into the gondola so that the great majority of the astronomical instruments and auxiliaries are at cabin pressure.

Or, if it is a more major breakdown, he returns to earth, repairs the damage and starts up again, like the clerk in heaven in Mark Twain's story "Captain Stormfield's Visit to Heaven". In this story, you will remember, the clerk of heaven in attempting to help Captain Stormfield find his way about, tries to find the earth on their huge map of the universe. He used a balloon to ascend and explore the various parts of the map. It seems he got hungry, came down, packed a lunch, and went up again. This would have been more difficult had he been using a satellite.

It would also be more difficult to perform several interchangeable observations at will. An astronomer in a balloon gondola can, however, obtain the infrared spectrum of a flare star, switch to the photometer and obtain the scintillation-free light curve, and swing the camera in place and take a photograph of the field. He can visually examine planetary and lunar markings and make an on the spot decision as to which to observe, and how to observe them. And in all these cases he is able to make last minute critical adjustments of various kinds, adjustments which can easily make the difference between success and failure.

The visual examination of planetary and lunar details alone could well justify manned balloon astronomy, even in the absence of the battery of other reasons already given. The overwhelming difficulty in observing planetary details, say, the decades-old controversy-producing matter of the canals of Mars, for instance, is not the faintness of the object nor the resolving power of our telescopes but the many disturbing effects of the atmosphere which can be lumped under the omnibus term of "astronomical seeing". Even on nights of "good seeing" fine markings on the moon and the planets can be glimpsed only at momentary instants of comparative atmospheric quiet. If Mars were viewed from above the atmosphere, even though the image were not well stabilized and roamed through the field, the observer's eye could easily accommodate to such motions and could continuously discern a wealth of details only tantalizingly suggested by momentary glimpses from the surface of the earth. The chance to visually observe the moon and planets for hour after hour, uninterrupted by the "deafening noise" of the earth's atmosphere, would be an opportunity devoutly desired by many, many astronomers. This vision brings to mind the remark of the late Henry Norris Russell, "When good astronomers die they do not go to Heaven, they go to the moon." The undistorted vision provided by an airless moon can be virtually duplicated by a man in a balloon just fifteen to twenty miles above the surface of the earth.

In short, I emphatically believe that the astronomer and his instruments should be carried to the top of the atmosphere in a routine basis. By routine I do not mean every Monday, Wednesday, and Friday, but I do mean that such observations should be carried out without fanfare and troublesome publicity. The day may well come when an astronomer will prepare for a series of observations at the top of the atmosphere with no more concern that he now gives to his preparations for observations at a mountain-top observatory.

Now perhaps I have not clearly separated the desiderata of making astronomical observations from the top of the atmosphere from the present technical capabilities of launching a balloon with, say, a two-ton load, to 80, 000 feet for a period of many hours.

The scientific mission must be examined entirely on its own merits and the technical capability of providing the logistics for that mission must also be examined separately. There are observations of the outside universe that can be made only from above the atmosphere. The importance of making such observations must be assessed quite separately from the capability of carrying them out. If they are truly important, then the means of making them should be examined. If we don't have the capability we should admit it and do something about developing it, before we attempt to marry the scientific mission to the technical logistics capability. Otherwise we run into the amateur theatrical type of fiasco we had with Stargazer in which a scientific mission was shot down because of our lack of understanding of static electricity and explosive squibs, among other things. Clearly there could not have been a Project Mercury without an adequate booster. Likewise, Stargazer was impossible without an adequate booster.

I should like to assume, in presenting the thesis for Manned Balloon Astronomy, that this nation certainly has the capability of learning how to launch large balloons with ease, with safety, and with confidence. There certainly is no reason at the present stage of the technical development of this country, to have balloon launching a "crossed fingers" operation, or having to resort to the use of good luck charms. I am simply going to assume that if this nation is capable of developing boosters to the moon and beyond it is capable of a booster to 80, 000 feet.

In summing up, I believe we have the following: What is balloon astronomy? As a technique, balloon astronomy, as distinguished from other types of scientific ballooning, consists of making those observations in astronomy which cannot be made from the surface of the earth, or which can be made better and with greater significance from altitude.

The observations in balloon astronomy are not elementary. In attempting to make better observations than can be made on earth, it is obvious that one must utilize the reservoir of sophistication in observational techniques found in the major observatories on the surface of the earth. Obtaining good spectrograms of stars, distortion-free photographs of star clusters and distant galaxies, the light curves of eclipsing variables, or photographs of fine planetary and lunar surface details, are not elementary operations. Therefore, Jastrow and Newell's statement in the recent ATLANTIC MONTHLY holds particularly: "In the early stages the simplest observations can be made by remote control. In the later stages, when more difficult experiments are attempted, a trained human observer brings to the supervision of these experiments the ability to deal with unforeseen difficulty and to respond to unanticipated opportunities." And I would like to add to that -- the ability to make those delicate, on the spot adjustments to equipment, that can be made only by the watchful human eye, the trained hand and the alert brain, those adjustments which so frequently spell the difference between a failure and an eminently successful experiment.

XII High Altitude Survey Balloons

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Abstract

Sea-Space Systems has developed a small balloon which can achieve altitudes up to 150,000 ft, carrying survey instrument payloads. This balloon utilizes the Corporation's new balloon fabric -- MERFAB. Because of its very light weight and high strength, MERFAB allows the construction of balloons with extreme altitude performance and cold temperature accommodation. Operational objectives of this survey balloon include launching ease along with reasonable cost and good reliability. The new concept in launching is directed towards one man operation in elevated winds. Recent flight experiences with the balloon and unique launching technique have indicated very satisfactory results.

1. INTRODUCTION

The development of MERFAB, a new light balloon fabric, is involved primarily with the desire to go to altitudes of 150,000 feet and above. This desire stems from the fact that conventional balloon practice appears to have an asymptote ceiling at 150,000 feet. This is a barrier which SSS would hope to raise. In order to do this, it is necessary to achieve a considerably lighter fabric than is generally available, the latter being associated with Mylar, polypropylene, polyethylene and some of the more recent scrim types. Three years ago, it was the conclusion that, in order to go towards lighter fabrics, a thinner film was required; and, that going to thinner films it would be found they were necessarily rather weak and would not handle the loads that would be experienced in a flight from launch thru the tropopause to altitudes of 150,000 feet. As a consequence the films would have to be reinforced to some degree. Thus, it was necessary to create a very thin film which would take the gas pressure and then by the use of reinforcing mesh, the strength requirements could be met.

The films used for MERFAB in SSS' current efforts are directed primarily towards the utilization of a 1/4 mil thickness made from a polyethylene derivative. Strength members are nylon bonded to the polyethylene in a number of different grid patterns depending upon the particular strength requirements of the

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system. The test units in Figure 1 embody several different approaches to grid patterns. Some initial problems were encountered with delamination at altitude environmental temperatures of minus 90 degrees F; handling temperatures in the regime of minus 110 degrees F are now easily satisfied. A second aspect, that of fabricating an operational balloon of this very light material, involves the problem of quality control. It was found that the conventional techniques for quality control do not apply because the material is relatively fragile; thus, the handling processes require special attention and seaming techniques are unique. These factors have received developmental effort over the past two years with a resulting low weight high strength fabric and a compatible processing technique.

It is interesting to note that, originally when SSS first started making the very light fabrics, it was done by hand on a loom with weavers passing the shuttle back and forth; this, of course, was a very laborious process. About the time a crew of Navajo Indian rug weavers was engaged, Mr. Tom Kelly said we were violating the child labor laws, and it would have to be done a different way. Consequently, during the summer of 1963, SSS completed the development of a prototype fabrication machine to effect the weaving automatically. The machine not only weaves, but it also laminates and cures in one continuous process.

Now, turning to the potential of this fabric, the drive to date has been directed primarily toward very high altitude flights. If lower flight altitudes are desired -- say 100,000 feet or less -- and the job can be done with a polyethylene or neoprene type balloon, MERFAB does not appear to have application; however, if altitudes in excess of 100,000 feet are required and in particular altitudes of 150,000 feet, then MERFAB is strongly indicated. For future reference in the case of superpressure balloons and/or load carriers, it appears that the material has excellent potential.

As a first step in using MERFAB for an operational application it was felt that a modest case should be attempted involving a sounding balloon which would carry a small payload to an altitude of 150,000 feet. This useage means generating the capability of built-in gas containment with a large expansion ratio. By way of visualization, if one starts with a cubic foot of lifting gas at sea level, it will expand to well over 350 cubic feet by the time it gets to the altitudes of interest; MERFAB can represent this type of volumetric change capacity.

Now for this first step, what are the specifics that would be desirable? Certainly, there are a number of scientists and military personnel who would be interested in carrying scientific payloads to 150,000 feet. As a consequence, it was determined that a reasonably small scientific payload to that altitude would be commensurate with a radiosonde. Thus a design point of 150,000 feet with a 3.5 pound payload was chosen. Certainly, weather considerations were paramount including the accommodation of temperatures in the equitorial regions to minus 90 degrees F; the latter

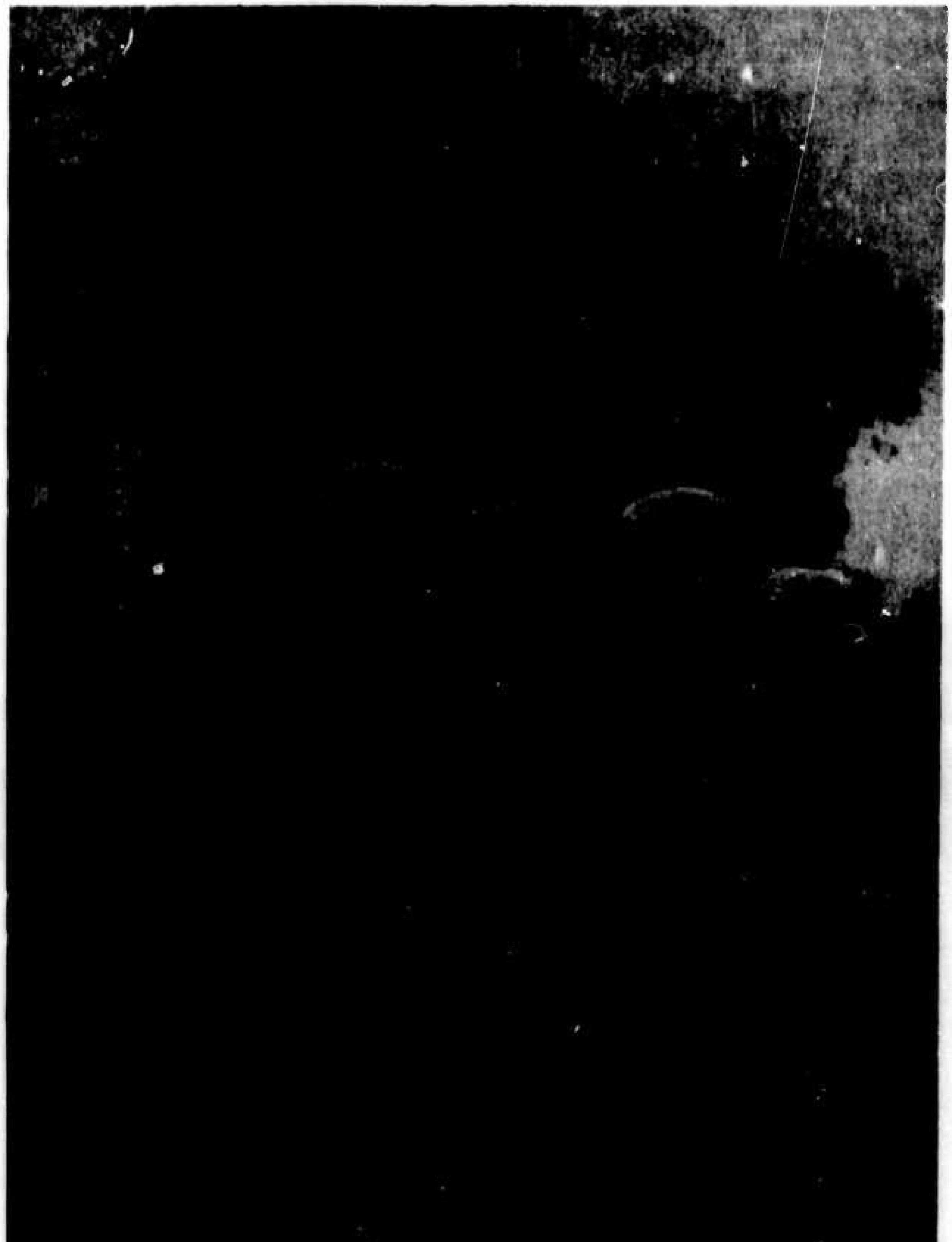

Figure 1. Inflation of Balloon Samples Prior to the Environmental Test Sequence

create major problems for neoprene type balloons. In order to stand strong wind shears in transit of the tropopause the design should have a large degree of structural capacity. Lastly, there was a strong desire to create a balloon that had launching ease for the untrained user.

In reference to previous balloon history, it is a well established fact that balloon launching is quite a problem. Thus, one of the major objectives was to provide a balloon that a scientist could take in the back of his truck or station wagon, quickly set it up and launch by pulling a lever. His efforts, then would not be expended on the support train for the balloon or launching equipment but rather he could concern himself primarily with the scientific experiment. Thus, the design must generate a launching technique that can accommodate a reasonable amount of wind, has a flexible mobile launching capability, and can be launched by one man if necessary.

The design point of 150,000 feet and a 3.5 pound payload is shown on the performance graph, Figure 2. The curve gives the general operational effectiveness of the MER-H-3 design. If the balloon performance capability is examined, it is seen that a 12 pound payload can be lofted to 140,000 feet.

MER-H-3 Balloon specifications are presented in Figure 3. The size of the sea level bubble is 10 feet in diameter with the top 9.5 feet above the ground. Considering that there is probably quite a long line associated with the payload in order to remove it from the air stream perturbations caused by the balloon, a launch train of approximately 200 feet results. It should be noted that this is a fairly lengthy train for a one man launch. The balloon at 150,000 feet will have a 79 foot diameter. At launch it requires 534 cubic feet of lifting gas.

In operational launches, it has been demonstrated that one man can prepare and fill the balloon in approximately 30 minutes; launching is effected by a lever release. The latter, in addition to creating one man feasibility, is extremely effective in situations where the launch has to be coordinated with another operation with release on the zero countdown. For some cases a reasonable amount of acceleration control has been included to limit the high "g" dynamic launch loads.

In terms of the balloon launching hardware, Figure 4 represents a complete system including a radiosonde payload and associated parachute. The balloon is packed in a box, which sits in a foldable launcher. The gas requirement can be effected with three standard bottles. Figure 5 shows the launcher set up for operation and the balloon protective covering folded out. Attention must be given to the protection of the balloon material because it cannot be handled in the conventional manner. It is relatively fragile and if pulled with the fingers, stress concentrations can result with the possibility of gas leakage. Thus, the protective system is designed to prevent the user from actually grasping the balloon itself with his hand.

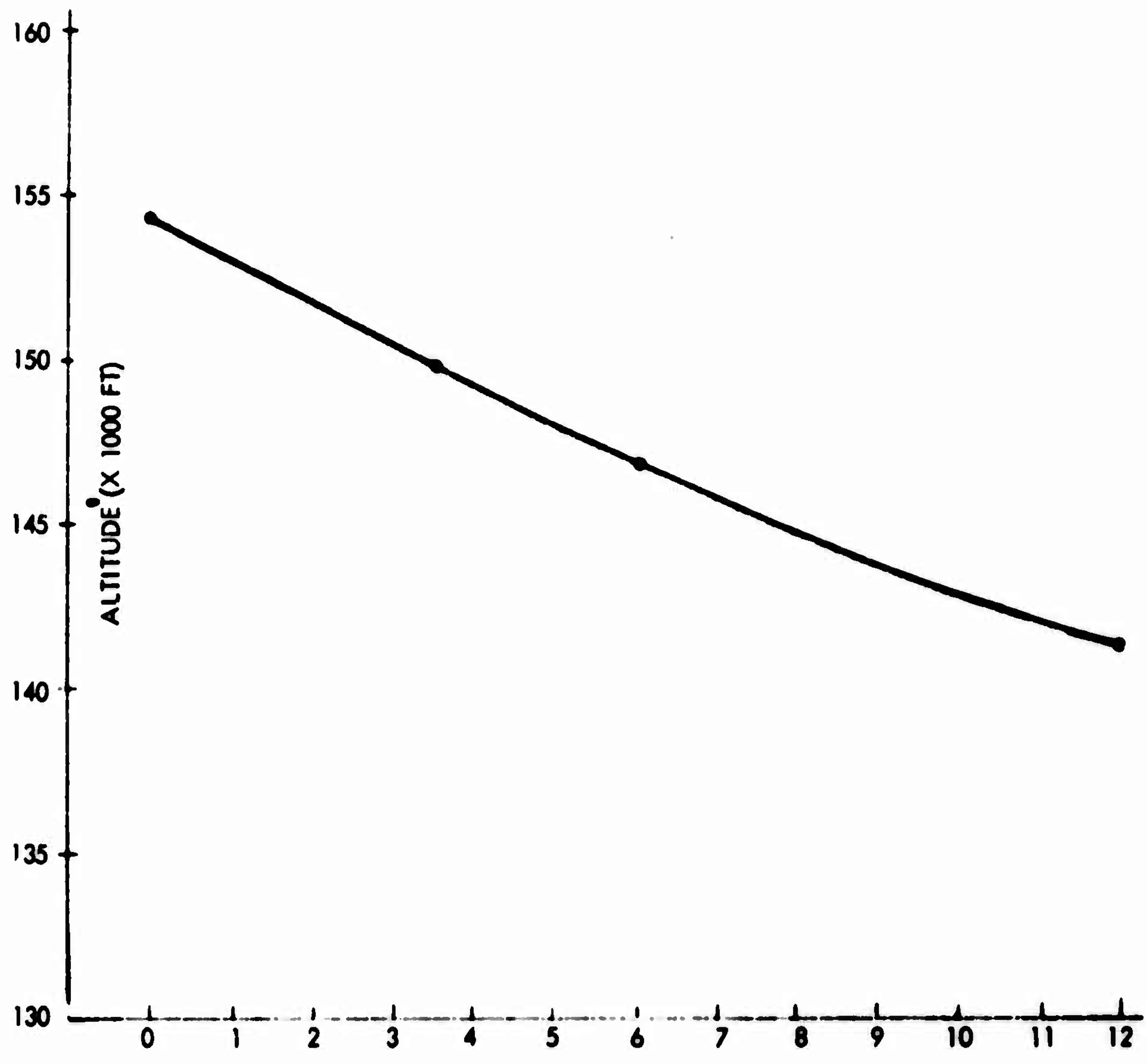

Figure 2. Payload vs Altitude for MER-H-3 Design

The balloon is contained in its transportation box with the balloon never emerging from the box until the actual launch. The section that is inflated for the initial bubble fill is protected by an outside sheath covering which comes off after launch.

In Figure 6 the bubble is fully inflated, ready for launch. It should be noticed that the launcher has two arms to the front, and one arm to the rear. This configuration allows orientation of the twin arms into the wind in such a way as to resist the wind forces. There is a tab arrangement to hold the bubble secure and shield the balloon from wind gusts. The taut bubble installation can sit in a reasonable amount of wind, then, with a man to the rear holding the payload in one hand, the

PERFORMANCE:	3.5 LBS TO		150000 FT
SIZE:	S.L. BUBBLE	-	10 FT DIA. 9-1/2 FT GND. TO TOP
	S.L. TRAIN	-	200 FT w - P.L.
	150 K ALT	-	79 FT DIA.
FILL REQ.	H_E GAS @ S.L.	-	534 FT^3 STP
LAUNCH	ONE MAN PREP.	-	30 MIN.
		-	LEVER RELEASE
		-	"G" CONTROL

Figure 3. MER-H-3 Balloon Characteristics

Figure 4. Complete MER-H-3 System, Including Radiosonde Payload and Associated Parachute

Figure 5. Launcher Set Up for Operation with the Balloon Protective Covering Folded Out

Figure 6. Bubble Fully Inflated, Ready for Launch

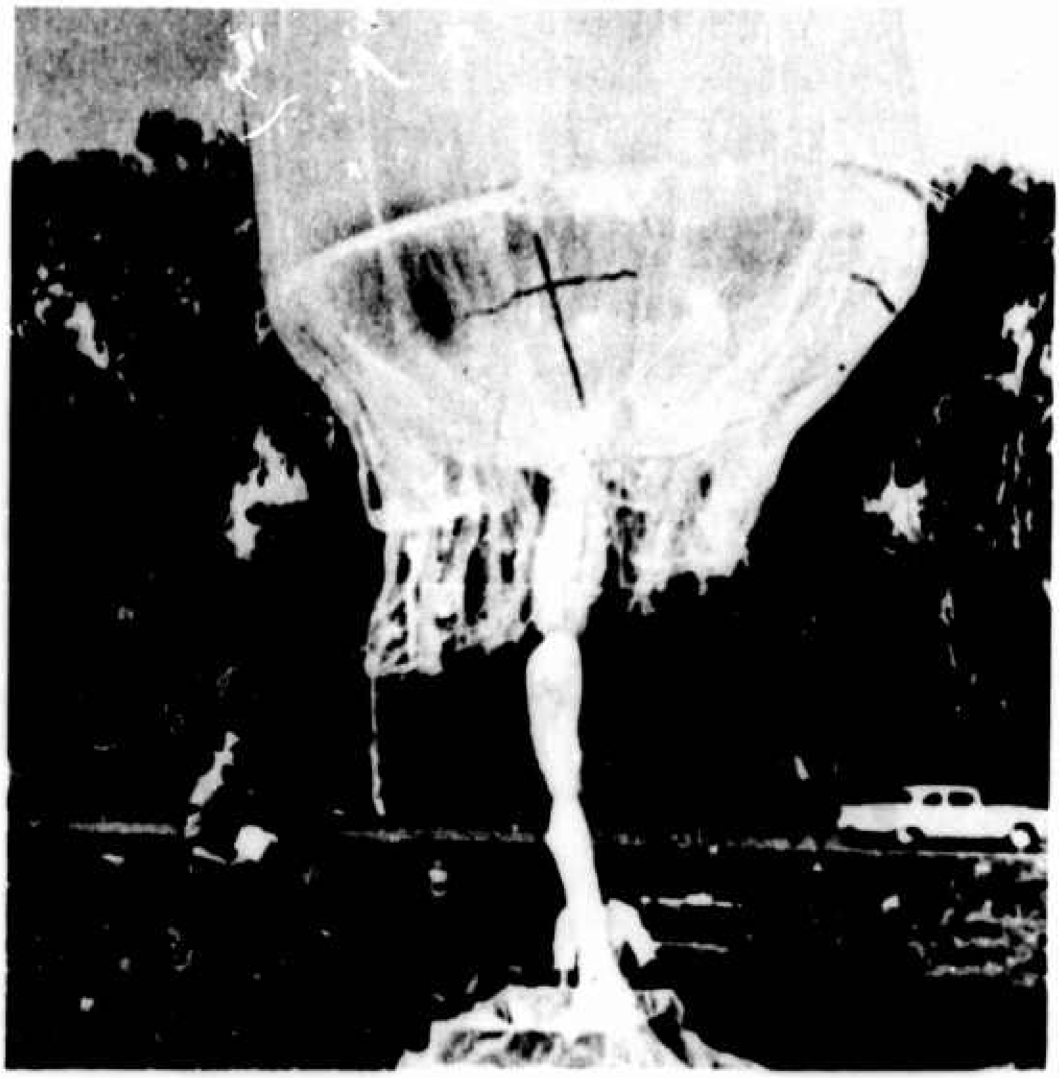

Figure 7. MER-H-3 an Instant after Release

balloon can be launched by pulling the release lever with the other. Launchings to date have been highly successful. The maximum condition experienced in the lee of an inflation building has been in a wind of 20 knots with gusts to 28; this represents a high capacity to accommodate wind.

It is felt that the launch capability described above can go to even larger bubbles associated with 2 million cubic feet balloons while still maintaining the system portability. Several launches are scheduled with 1.5 million cubic feet balloons carrying 25 pound payloads using this same launch equipment.

Figure 7 shows the MER-H-3 balloon just an instant after release. It is seen that the protective sheath has now cleared the launcher; it will be released after the balloon has ascended further. Additional protection of the fabric during ascent trajectory is achieved by a system of reefing which is removed progressively as the

Figure 8. MER-H-3 Ascending

balloon goes to altitude. The next two figures successively picture the bubble and launch train as the balloon clears the ground; the long length of the train is clearly visible.

Flight progress to date can be summarized for a unit whose performance altitude was 146,000 feet in the following AEC press release:

"Near record altitudes for unmanned balloons were reached in test flights at Tonopah (Nev.) Test Range when one reached an altitude of 145,000 feet (about 27 miles) on October 4.

"The previous National Aeronautics and Space Administration record of 148,000 feet was set by a U.S. Navy Skyhook balloon on September 4, 1959.

"Designed to carry radiosonde weather observing equipment, the balloons were tracked by radar to give wind observations and altitudes with about 50-foot accuracy.

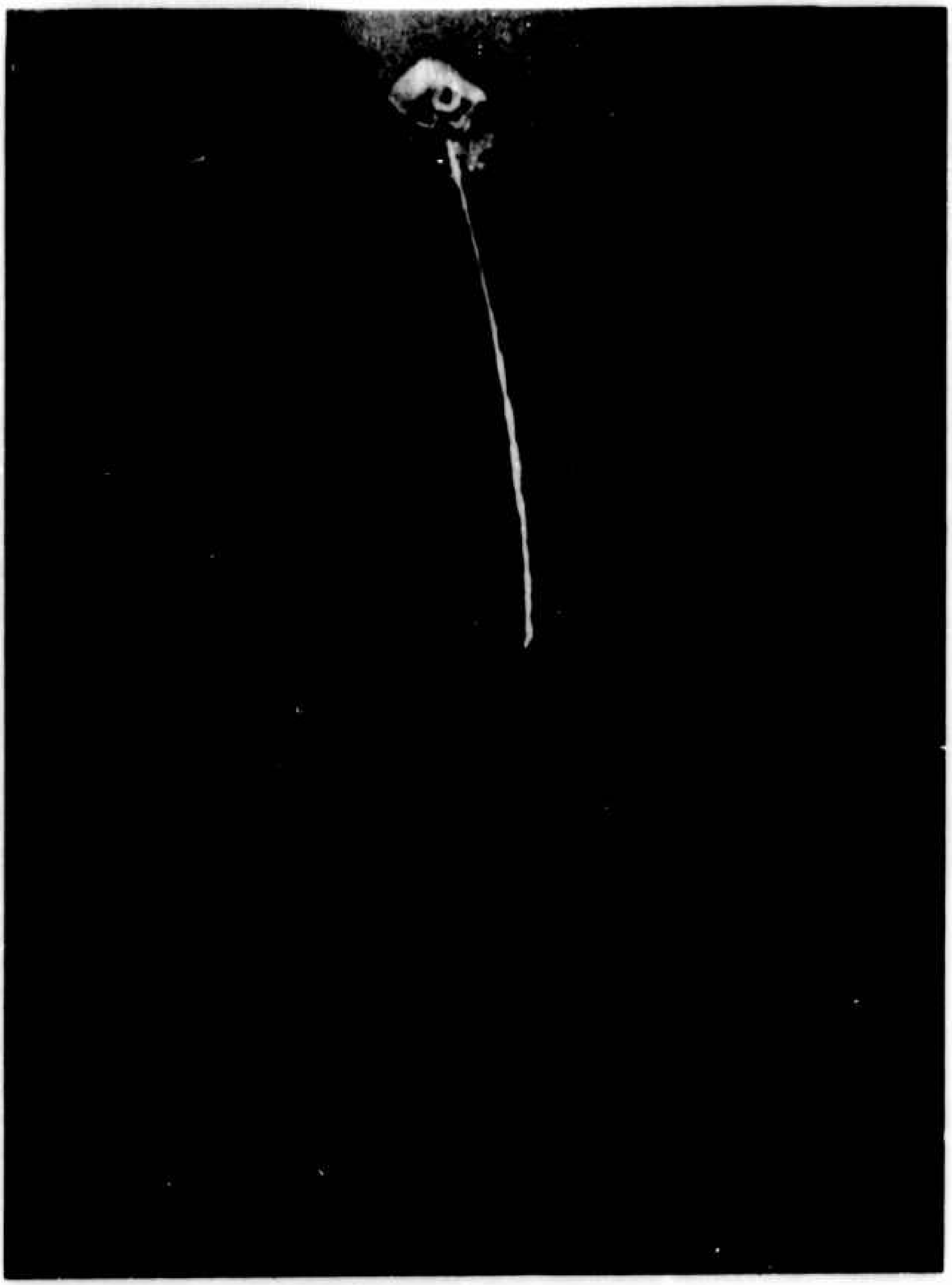

Figure 9. Launch Train Deployed

"Weather data at these altitudes are used in studies of world-wide stratospheric fallout.

"The balloons were designed and manufactured by Sea-Space Systems, Inc., of Torrance, California. A thin polyethylene plastic film is used to make them retain flexibility at temperatures as low as -112 degrees F, which is often encountered in the stratosphere."

In summary, the following accomplishments appear pertinent:

(a) three years of developmental work have achieved a light, relatively strong fabric having potential for high altitude balloon flight,

(b) a launching technique exhibiting very desirable operational characteristics has been realized,

(c) the MER-H-3 balloon vehicle for carrying a 3.5 pound scientific payload to 150,000 feet is considered to be off-the-shelf; larger payloads to 12 pounds can be carried to 140,000 feet, and

(d) there is strong growth potential holding promise for larger payloads to altitudes on the order of 150,000 feet.

XIII Capabilities of Captive Balloon Systems

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Abstract

Captive balloon systems fall into three categories: (1) spherical or natural shaped balloons, (2) aerodynamically shaped or blimp shaped balloons, and (3) captive balloons employing flex-wing, Regallo-wing, and kiting principles. This paper is concerned with the capabilities of the first two categories only.

Natural shaped captive balloons have been inflated to a gross lift of 11,000 pounds and have been flown to altitudes of 1500 feet above the terrain. The C_D of these balloons is approximately .45 when pressurized. Development of "sail effects" on slack balloons imposes a severe limitation on their usage in winds above 20 knots.

Aerodynamically shaped balloons carrying payloads of 6,000 pounds have been flown to altitudes of 5,000 feet above the terrain and have remained stable in winds in excess of 50 knots. Altitudes as high as 15,000 feet have been achieved with aerodynamically shaped captive balloons.

1. NATURAL SHAPED CAPTIVE BALLOONS

The first large "Natural Shaped" (inverted tear drop) captive balloons, of modern vintage, were built in 1956 for use as aerial supports for nuclear weapons and measurement devices. The largest of these balloons had a gross lift of 11,000 pounds at 6,000 feet above Mean Sea Level and were elevated to about 1500 feet above the terrain.

These balloons were built utilizing a nylon cloth shroud and a polyethylene liner. The nylon weighed 3.4 oz./sq. yd. and had a warp and fill strength in excess of 300 lbs./in. Liners were made from 2 mil thick polyethylene. End fittings were coupled together after the liner was placed in the shroud.

Tests in various wind conditions indicate that the drag coefficient of large natural shaped captive balloons is about 0.45. Also since these balloons are not pressurized, high wind loading conditions cause severe "sails" or cupping to occur which can produce cable loads in excess of 25,000 pounds. Shroud-liner natural shaped balloons have safely withstood such forces.

The greatest deterrent to the use of natural shaped shroud-liner balloons is the high drag coefficient which causes a large horizontal displacement in winds over 20 knots.

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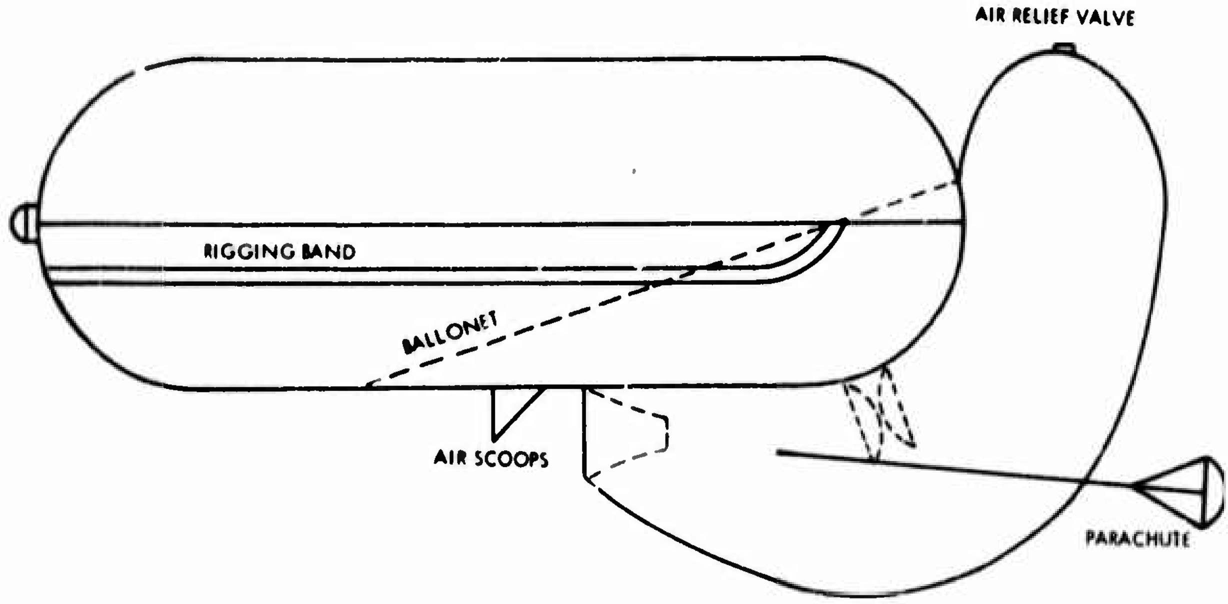

Figure 1. German Drachen Balloon

2. HISTORY OF STREAMLINE SHAPED CAPTIVE BALLOONS

Development of streamline shaped captive balloons probably began about 1893 when Perceval and Sigsfeld designed the German Drachen balloon. At the beginnin of World War I the French designed and manufactured the Caquot balloon, named for its designer Major Caquot. This design was copied by Great Britain, the Unite States, Russia and Germany. Many balloons of this basic design were flown. Size ranged from about 20,000 cubic feet to about 35,000 cubic feet.

The Drachen balloon had a cylindrically shaped envelope with hemispherically shaped ends. A large rudder and small parachutes as shown in Figure 1 provided directional stability. It was pressurized by ram air only.

The Caquot balloon was more streamlined. There were many variations of envelope shape and tail fin design. A sketch of a typical Caquot type balloon is shown in Figure 2. They were also pressurized with ram air.

During World War I captive balloon development was also pursued in Italy. These balloons were similar in design to the Caquot type except that their fineness ratio was much smaller.

Development of the well known barrage balloons began about 1926 in England. Other than the construction and flying of these balloons, no further work of significance was accomplished until about 1956. At this time under sponsorship of the U. S. Air Force, work was started on the development of captive balloons using stronger and lighter synthetic films and fibers in their construction.

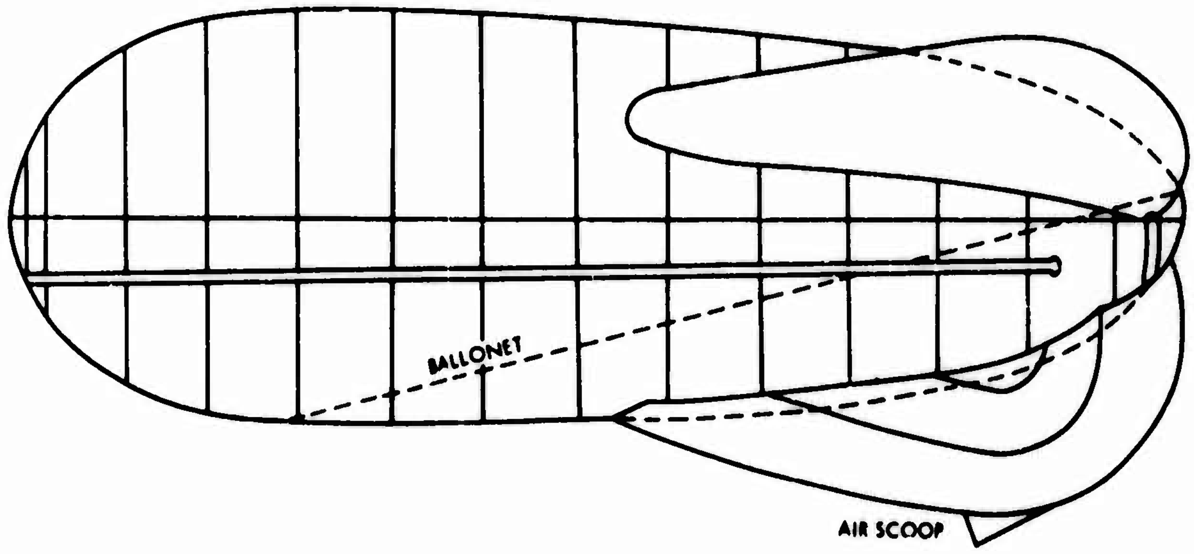

Figure 2. Caquot Balloon

The first experimental model was constructed of a laminate of polyester and polyethylene. This balloon weighed about 17 pounds and had a volume of 775 cubic feet. This was probably the first captive balloon that employed an electrically powered fan to maintain differential pressure.

In 1957, also under U. S. Air Force sponsorship, a balloon was constructed using a nylon cloth envelope and polyethylene liner. This balloon weighed about 400 pounds and had a volume of about 16,500 cubic feet. It was also equipped with a pressurizing fan. Many shroud-liner balloons of this type were flown during the following two year period.

In 1958 work was started on the design and construction of a captive balloon using an old concept, for example, a resin coated fabric, but incorporating nylon, a lighter and stronger fabric, and E. I. duPont Hypalon, a better weathering and abrasion resistant coating. It had a volume of about 380,000 cubic feet and weighed about 8,000 pounds. A Navy Class "C" shape of 3 to 1 fineness ratio was used with three air inflated airfoil shaped tail fins. Differential pressure was maintained with motor driven fans. During the past five years approximately thirty balloons of this general type have been constructed and flown. There have been many variations in material, size, fineness ratio and shape.

3. FACTORS WHICH DETERMINE DESIGN OF CAPTIVE BALLOONS

The design of captive balloons for specific applications is largely dependent on (1) maximum and minimum wind velocity which will be encountered, (2) launch and flight altitude, (3) payload weight, (4) flight duration, (5) useful life of balloon, (6) stability and (7) temperature extremes.

Usually wind velocity is the most influential factor. The problem is twofold, that of balloon design and that of restraining the balloon with a suitable cable. Captive balloons have flown in winds up to 60 knots at 5,000 feet above Mean Sea Level.

In order to operate in high wind velocities a heavy and high strength tether cable must be used. No problem exists here in lifting the cable since the buoyant lift is augmented by aerodynamic lift. However, the balloon must also be capable of flying in a zero wind or minimum wind condition and lift the same heavy cable. Since buoyant force is proportional to displaced volume V, and aerodynamic forces are proportional to surface area of $V^{2/3}$, it is evident that balloon volume can be increased until both wind conditions are satisfied. The resultant size may however be prohibitive due to the extremely large and heavy handling equipment that would be required. Tail fin size and shape can also be varied such that a highly negative pitching moment coefficient is obtained. Figure 3 shows aerodynamic characteristics of a Viron captive balloon of 3.5 to 1 fineness ratio. In low wind velocities the pitch angle is set at about 10 degrees and as the wind velocity increases the pitch angle will decrease to about 5 degrees thereby reducing aerodynamic lift.

Aerodynamic drag must also be considered. One of the problems is that of determining the fineness ratio of a streamlined body of least resistance for a given volume V. The volume of a given shape is proportional to LD^2 or $D^2 f$ where: L = balloon length, D = balloon diameter and $f = L/D$ denotes fineness ratio. The frontal area A is proportional to D^2 or $(V/f)^{2/3}$. For a given wind velocity, air density and balloon volume, the drag $D = Cp\ 1/2\rho v^2 A$ is therefore proportional to $Cp/f^{2/3}$ where Cp = parasite drag coefficient. Curve I in Figure 4 indicates how Cp varies with fineness ratio and Curve II indicates the variation of $Cp/f^{2/3}$ with fineness ratio. Since envelope material strength and therefore weight are largely determined by maximum balloon diameter the more efficient design is one with a fineness ratio of about 5 or 6. Experiment has shown that these curves describe many bodies of various streamline form.

This admittedly has been a simplification of the problem for several reasons. One is that a zero pitch angle and therefore zero induced drag has been assumed. Bending moments in the envelope due to gust loads have also been neglected. Aerodynamic forces on the stabilizer fins have likewise been neglected. The foregoing analysis is nevertheless useful in obtaining a qualitative understanding of captive balloon design. Wind tunnel model tests and instrumented flight model tests are usually relied upon for design data.

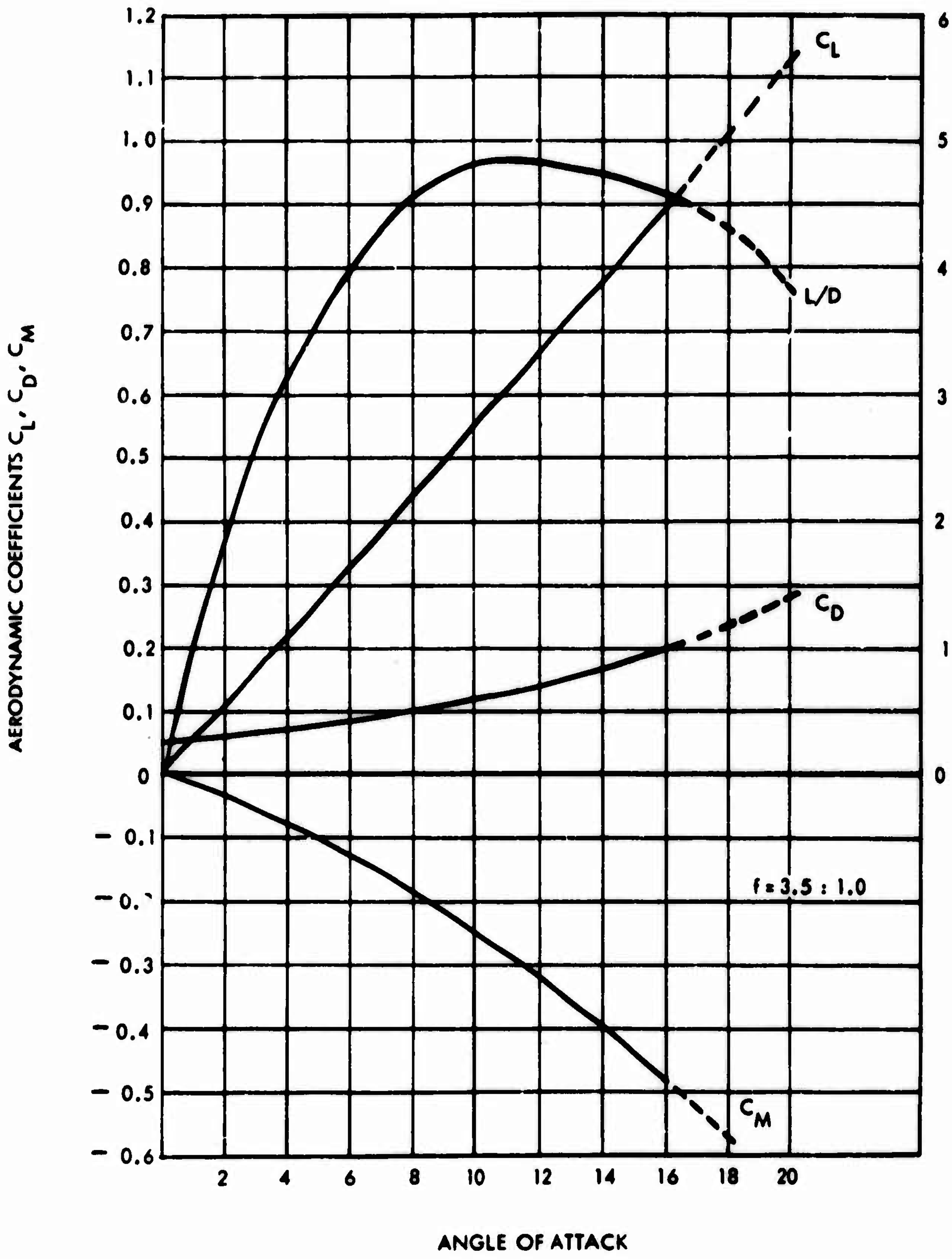

Figure 3. Aerodynamic Characteristics of Viron Captive Balloon

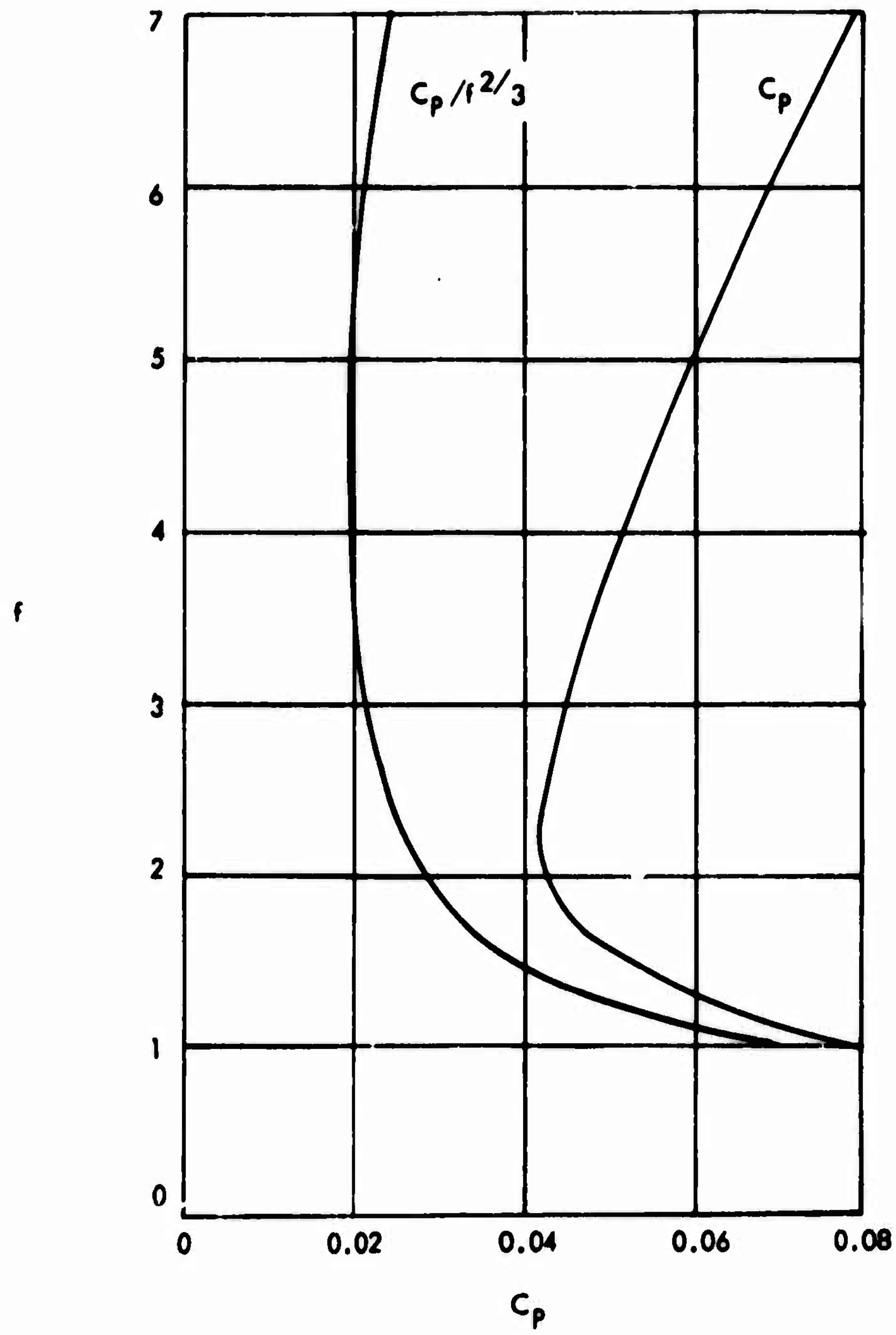

Figure 4. Drag Versus Fineness Ratio for Many Streamline Forms

Altitude capability for a given volume is determined by the total cable weight and payload weight that must be elevated, and the air density at flight altitude. Cable length and strength are therefore determining factors which in turn are determined by maximum wind velocity that will be encountered. Streamlined captive balloons have flown at altitudes up to 15,000 feet above Mean Sea Level in winds of about 25 knots. It is reasonable to assume that an altitude of about 25,000 feet could be attained with a balloon construction based on current design features.

Payload weight that can be carried by a captive balloon of a given volume is determined by air density at flight altitude, cable length and wind velocity. Figure 5 and Figure 6 are typical load-altitude curves based on current design practices.

Flight duration depends on permeability of the envelope material and capacity of the power supply that is used to run fans that pressurize the fins and envelope. Continuous one week flights have been conducted.

Useful balloon life is determined by degree of material abrasion that the balloon is subjected to in ground handling operations and weatherability of the material, especially its resistance to Ultraviolet degradation. With materials now in use at least one year of useful life can be expected.

Stability of captive balloons was first studied by Bairstow in 1915. He showed that the motion of a captive balloon could be calculated by the use of sixth degree equations, however his method has never been successfully applied since certain necessary derivatives have not been determined. Later several attempts for a solution were made whereby higher order terms of the differential equations were neglected. However, it has been found that stability of captive balloons is not amenable to calculation.

Instrumented flight tests have provided the most useful stability information although more work of this type needs to be done. Flight tests have shown that the motion of captive balloons is generally damped aperiodic, that is, when the balloon is disturbed, usually by a wind gust, it will converge to its equilibrium flight condition. This is true for both lateral and longitudinal motion. It has been found, however, that as the tether cable length is shortened, the motion becomes oscillatory, and with further shortening of the cable it becomes undamped and oscillatory. This condition is noticed at altitudes up to about 400 feet. At altitudes above 3,000 feet it is not uncommon for a balloon to remain within a circular flight area of 25 feet radius for an hour or longer when the winds are steady. Its motion at these altitudes is determined by wind conditions.

Temperature extremes that the balloon is expected to encounter affect balloon design in two ways. First, a suitable material must be used that will not become brittle in cold temperatures. Materials now being used have been flexed and

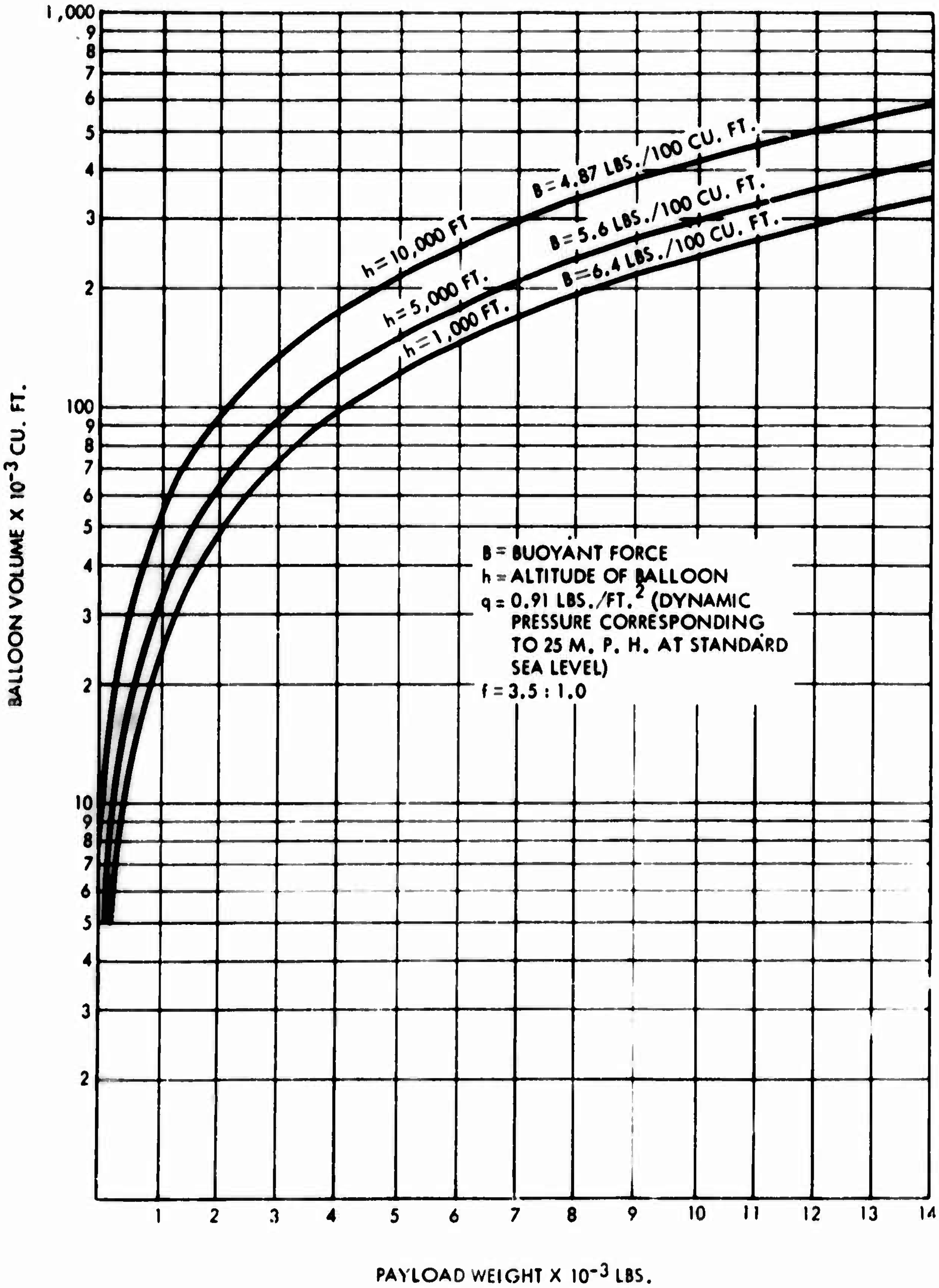

Figure 5. Payload Capability of Viron Captive Balloon for q = 0.91 lbs/sq ft.

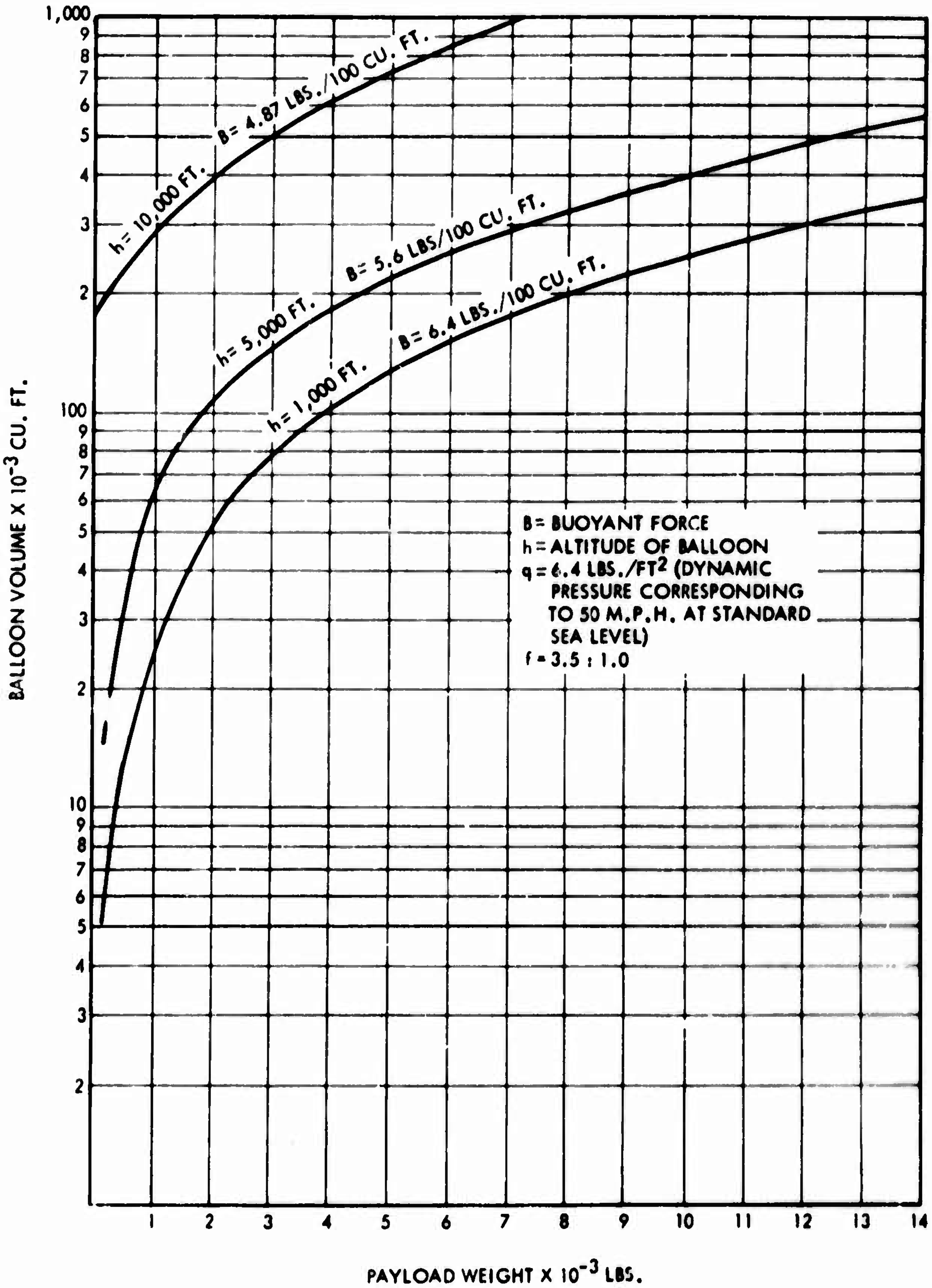

Figure 6. Payload Capability of Viron Captive Balloons for q = 6.4 lbs/sq ft.

loaded at temperatures as low as -150°F with no visual detriment. Second, the balloon and ballonet volume must be large enough so that at extremely cold temperatures when the ballonet is completely inflated the remaining volume of lifting gas is sufficient to support the load. Then too, as the temperature increases the balloon must be large enough to contain all the lifting gas as a result of expansion. If it is not large enough, gas will be expelled.

4. BASIC CAPTIVE BALLOON DESIGNS

Three basically different types of captive balloon designs are currently being pursued. The difference is essentially the method that is used to maintain a constant differential pressure. These methods are (1) a ballonet, (2) mechnical tension members and (3) highly elastic envelope material. The ballonet type is the most widely used. As gas in the envelope contracts or expands, air is forced into or out of the ballonet so that a constant pressure is maintained. An electrically powered blower actuated intermittently by a pressure switch forces air into the ballonet. When the pressure in the envelope and ballonet increases to a certain predetermined value, usually about 1.0 inch H_2O, the blower shuts off and a check valve closes. A valve expels air from the ballonet if the pressure becomes too high due to gas expansion.

Mechanical tension members are also used to compensate for volume changes. Steel springs, rubber cords and motor cable assemblies have been used internally such that the envelope cross section is formed into three or more lobes. In like manner, tension members have been attached tangentially to the outer surface of the envelope. Balloon circumference is thereby varied as gas expansion and contraction takes place.

The third method incorporates a highly elastic envelope skin. Volume changes are accomplished by stretching the envelope. Very little work has been done with this type construction. One of the reasons for this is the absence of a suitable lightweight, strong and impermeable material.

5. CURRENT DESIGN AND CONSTRUCTION OF BALLONET TYPE CAPTIVE BALLOONS

Most ballonet type captive balloons now being designed are constructed of longitudinal gores running the full length of the balloon, as shown in the photographs, Figure 7 and Figure 8. These gores are joined by sewing and use of adhesives or by adhesives alone.

Figure 7. 3-50-OC Viron Geocap Balloon

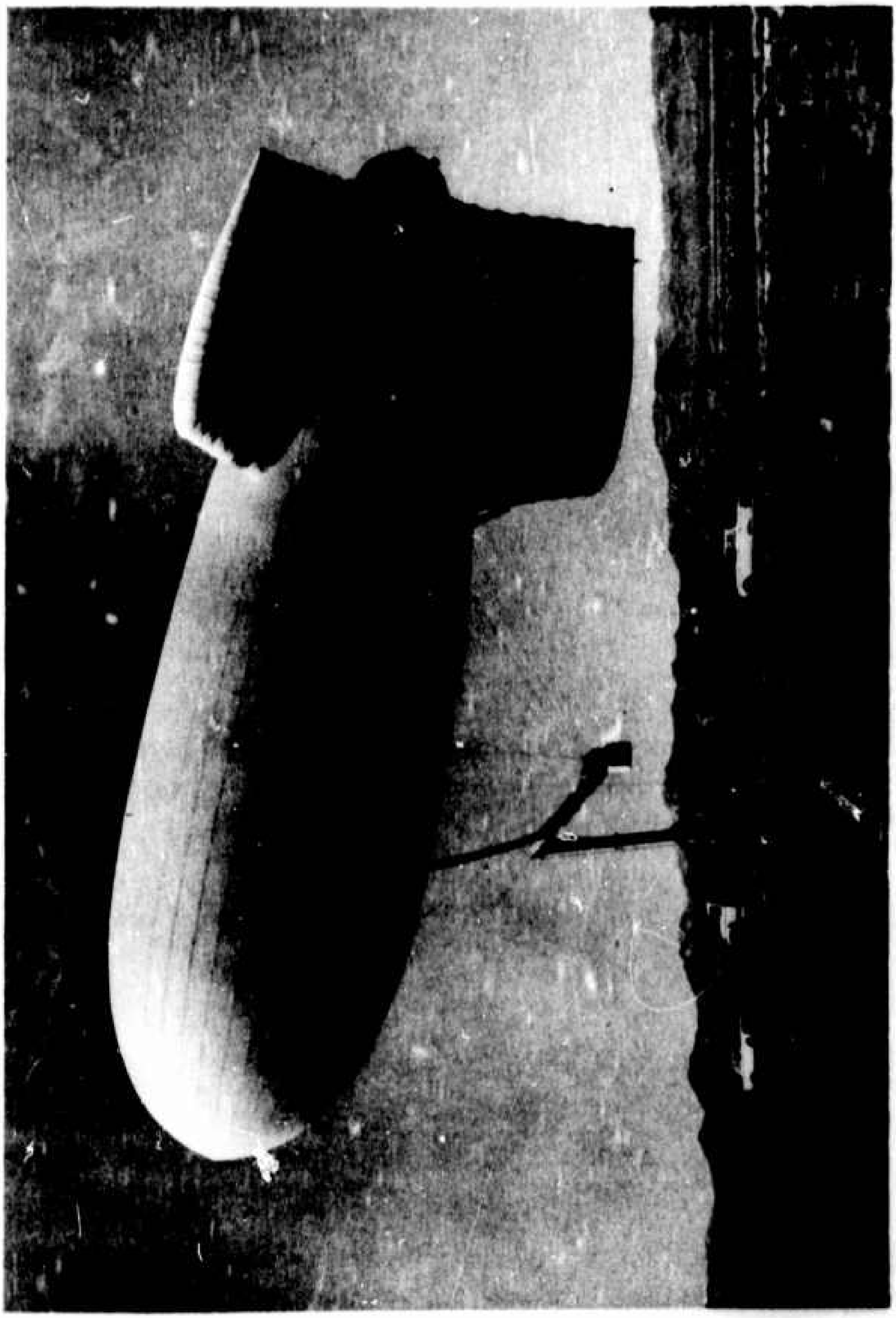

Figure 8. 3-161.8 Viron Geocap Balloon

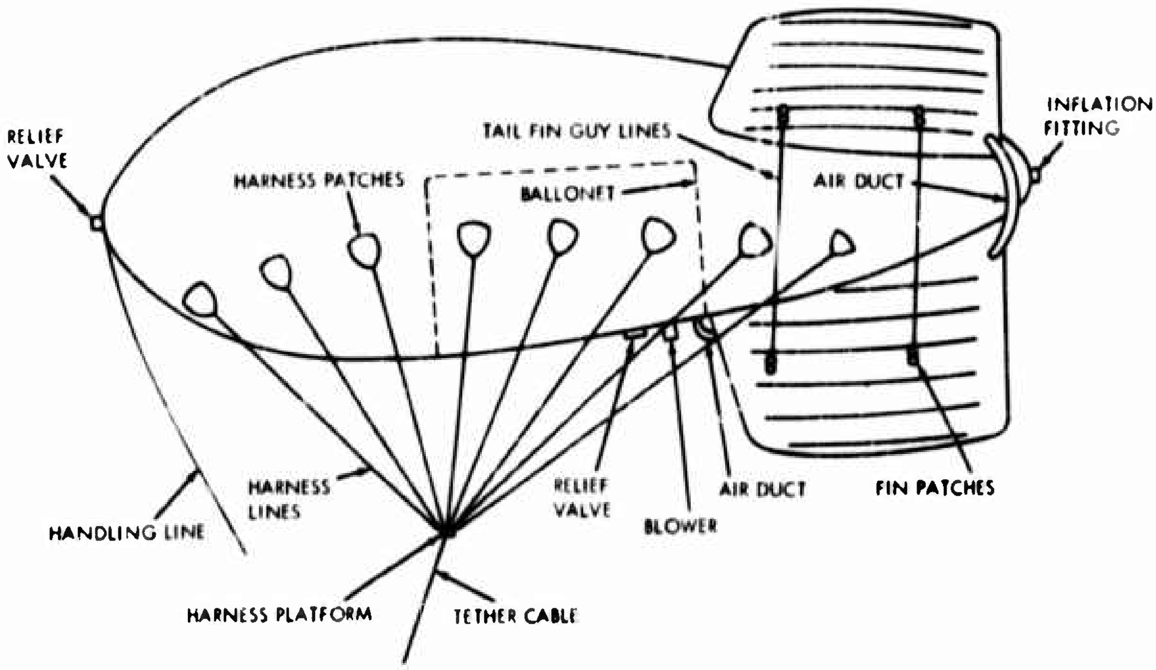

Figure 9. Sketch of Typical Viron Geocap

Inflatable fins are sewn to the surface of the envelope. The fins are shaped by sewing in nylon cloth ribs that are cut to an air-foil shape.

For some applications, fins are inflated with helium through a duct that connects them to the envelope. About 10 percent or 15 percent more lift is obtained in this way. However, due to the additional surface area, permeation is also increased. For most applications, the fins are air filled and connected to the ballonet compartment by a duct. A sketch of a typical ballonet type balloon now in use is shown in Figure 9.

In the past few years many new materials have been developed that are ideal for balloon use. These materials fall into two categories. These categories are (1) coated fabrics and (2) plastic films and combinations of coated fabric and plastic films.

Coated fabrics have been used extensively in captive balloons. Both cotton, dacron and nylon base fabrics have been used. Because of its higher strength to weight ratio, almost all large captive balloons are now being constructed of nylon. Coatings that have been used include neoprene, rubber, urethane and E. I. duPont Hypalon. Various pigments have been added to these coatings in order to shield the base cloth from ultraviolet radiation. Aluminum has been used extensively for this purpose. Tests have shown that for coated fabrics at least a 7 ounce total weight of two ply construction is required for good permeability. A permeability of less than 1/2 liter per square meter per 24 hours is being used as a design specification at Viron.

For smaller balloons, plastic films and combinations of films and coated fabrics are more suitable. Polyesters, polyethylene and urethanes are some of the films that have been used. They have been used as single sheets and bonded together in laminate form. Nylon and dacron threads and cloth have also been laminated between films and on the outer surfaces. Experience has shown that a total weight of at least 1-1/2 ounces per square yard is required for suitable permeability. However, a material this light does not have the required strength or tear resistance for use in captive balloons. At this time the lightest weight material suitable for captive balloon use weighs about 4 ounces per square yard. Figure 10 shows approximate envelope material weight versus balloon volume.

6. SUPPORT EQUIPMENT

Primary support equipment consists of tether cables and winches. Most balloons are flown on steel cables although synthetic fiber ropes are used on some small balloons. Steel is more widely used because of its better abrasion resistance. Figure 11 shows the strength versus weight of cables made from different materials.

A cable made up of glass roving impregnated with a resin has been investigated as one method of increasing the strength to weight ratio. Thus far brittleness of the glass fibers has been the hindering factor.

Standard winches with a few modifications have been adequate for all captive balloon flights thus far.

7. TYPICAL CAPTIVE BALLOON OPERATIONS

Captive balloons are inflated under a nylon web net for almost all operations. When inflation is completed, the harness lines are adjusted to proper tensions and the main tether cable attached to the harness rigging. For balloons larger than about 75,000 cubic feet the net is parted in the middle by firing pyrotechnic loaded cable cutters. For smaller balloons, it is pulled off by hand. Cable is then payed out at about 100 feet per minute until the balloon reaches operating altitude.

Captive balloons have been flown in extreme cold climates and in the tropics. They have been launched from both land and flight decks at sea.

Many operations require that the balloon be held in a precise position with respect to a ground reference point. This is accomplished by tethering the balloon with three cables where the cables approximate a tripod configuration. By selectively operating one or more tethering winches the balloon can be held in position. Television cameras and monitors have been used to view its position.

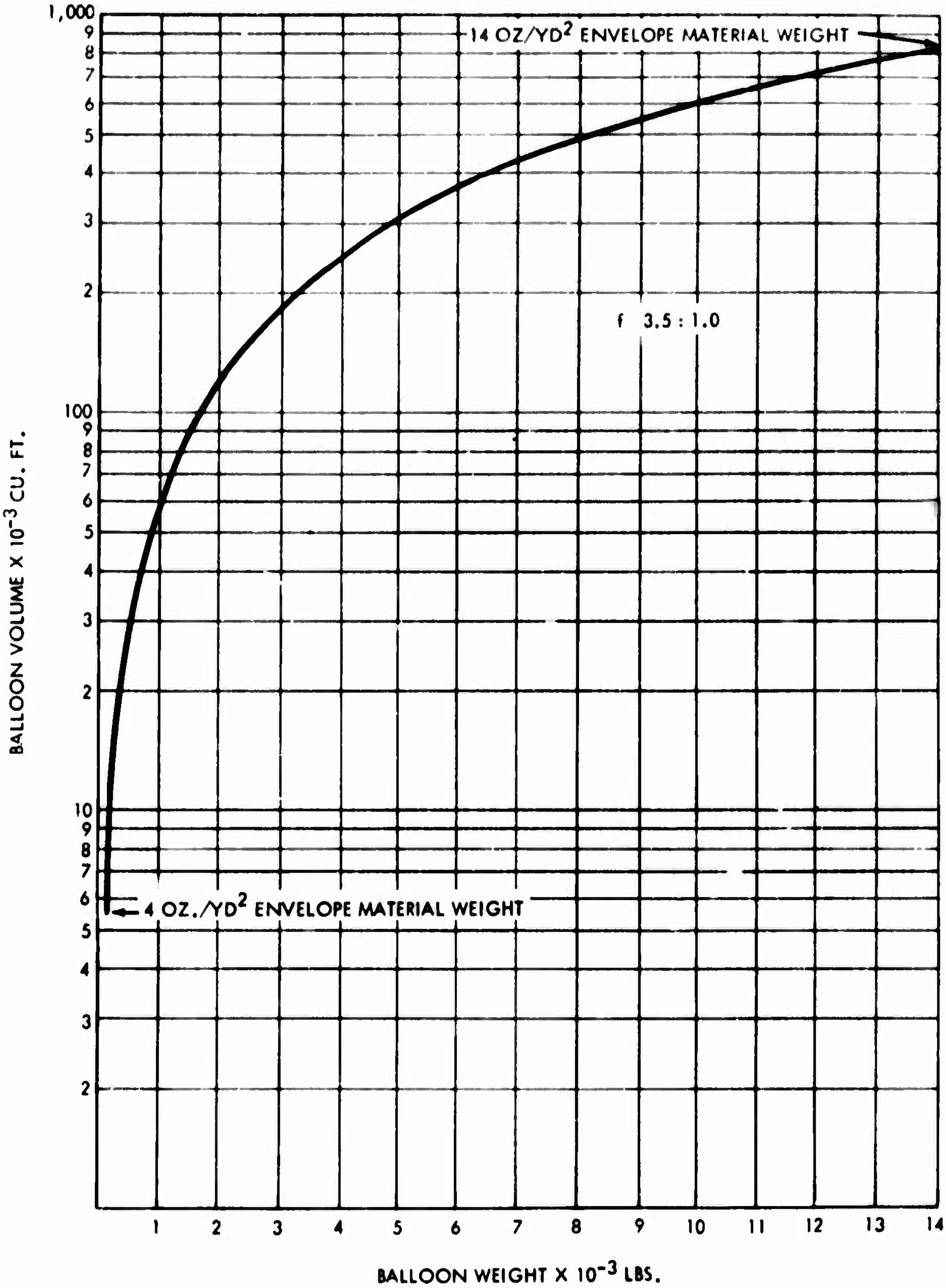

Figure 10. Balloon Weight Versus Volume for Viron Captive Balloons

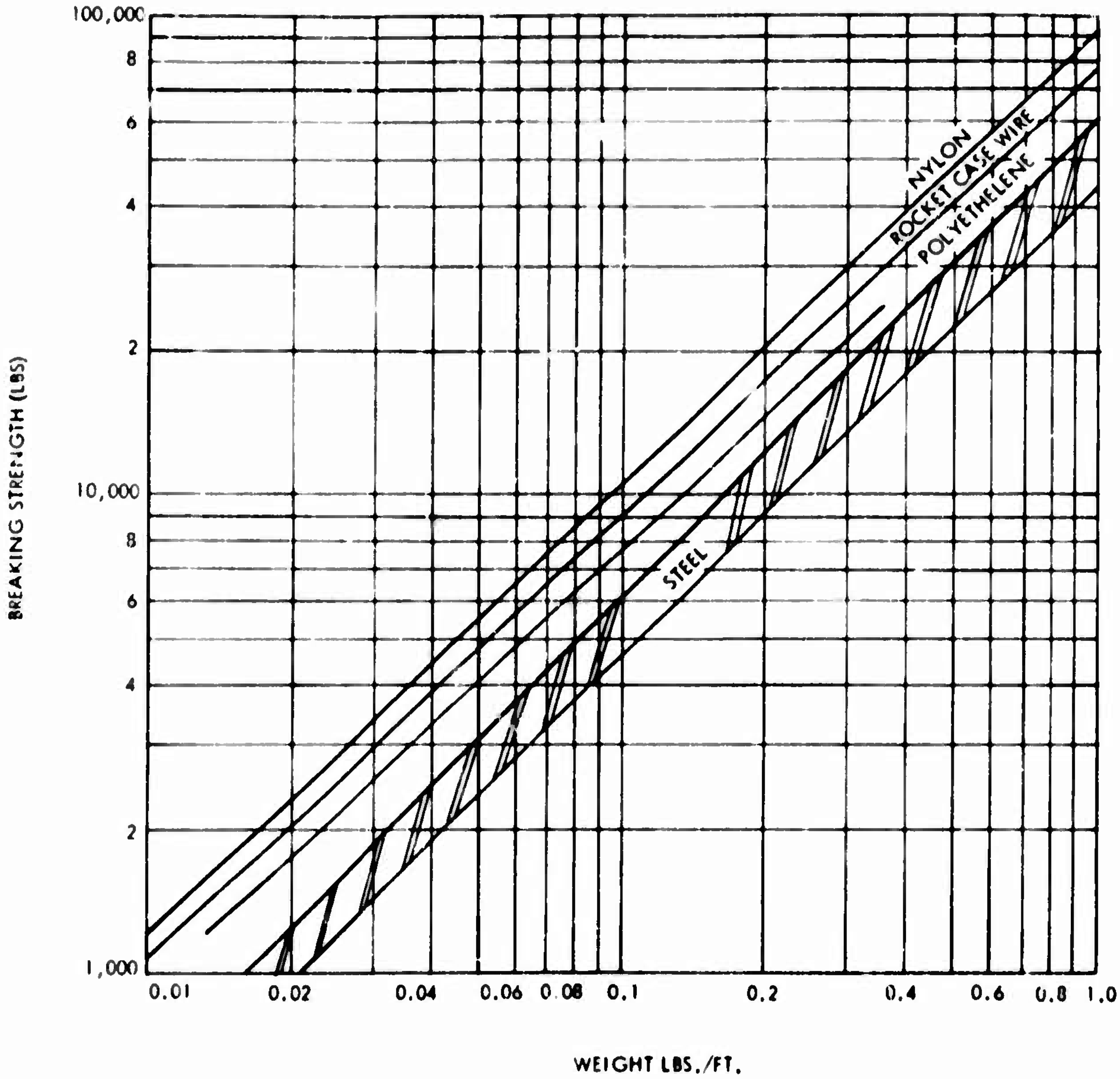

Figure 11. Strength Versus Weight for Various Cable Materials

A balloon flying at 1500 feet above terrain has been positioned to within ± 3 feet. The problem here was to design suitable equipment in which the deviation from the reference point could be monitored.

8. CAPTIVE BALLOONS FLOWN IN TANDEM

Captive balloons identical to those shown in Figure 8 have been flown in tandem, that is, three balloons were flown one on top of the other with a short length of cable separating them. The tether cable passed through the envelope surface. This method of tethering provides a more versatile system and is advantageous when high altitude tethering is required.

For operations where the payload weight is varied, this method of tethering is useful. For light loads a single balloon is used and for heavier loads one or more additional balloons are attached to the stacking cable. Then too, ground handling equipment can be standardized since only one balloon size is required regardless of payload weight.

High altitudes can be attained by tethering balloons in tandem. In this type of system, the balloons are separated by several thousand feet, the intermediate balloons used primarily to lift the tether cable. Although a high altitude flight has not been attempted with tandem balloons, it seems likely that an altitude of 40,000 feet to 50,000 feet could be attained with the present design.

9. COST

The cost of captive balloons varies considerably depending on design specifications.

Generally for balloons up to 500,000 cubic feet the cost is less than $100,000.00.

XIV The Applications of Hot-air Balloons to Scientific Programs

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Abstract

The recent development of balloon systems which derive lift from hot air is based on the use of modern envelope materials and in-flight fuel systems. The present capabilities of such systems are reviewed, and several applications are described.

1. INTRODUCTION

In 1783 men first left the earth in a flying machine -- a hot air balloon. This history making aerostat was built by the Montgolfier brothers of France. Following only three months of balloon experiments two men were lifted by a bag filled with smoke and hot air. The builders, not understanding the buoyancy principles involved, initially believed that it was the smoke which provided the lift.

When reports of these flights reached Professor J. A. E. Charles of Paris, who understood the principles of buoyancy, he mistakenly assumed that they had used hydrogen as a lifting gas. Thereupon, he set out to design a balloon to use hydrogen as a lifting medium and within a few weeks he built and flew the first lighter-than-air gas balloon.

Thus, for the past 180 years balloons have generally been classed as Montgolfier -- using hot air -- or Charlier -- using lighter-than-air gases. Certain basic differences characterize the two types.

Montgolfier balloons are initially inflated with hot air to yield the desired lift for flight. As heat is continually lost through the balloon envelope, heat must be continually added to the entrapped air to prolong the flight or to control the action of

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the balloon. Otherwise the lift diminishes, and the balloon settles back to earth. Charlier balloons are initially inflated with some lighter-than-air gas such as hydrogen, helium, or coal gas to yield the desired lift for flight. This lift causes the balloon to ascend to a position of equilibrium where the buoyant force and the system weight balance. As long as the balloon retains the gas its lift will remain relatively constant over long periods of time.

Both Montgolfier and Charlier balloons have been put to many uses. These applications include sport flying, atmospheric exploration, scientific experimentation, and the carrying of men and equipment aloft for military purposes. The aforementioned basic differences have determined which type has been used for specific applications. The economy of initial inflation of the Montgolfier type, along with its tolerance of small holes in the balloon envelope, has made it popular for exhibition and sport flying. In these applications, the envelope is deflated at the end of one flight and reused for the next. However, the duration of a Montgolfier balloon flight is limited by the ability to replace the heat lost through the envelope in flight, and the altitude is limited by the amount by which the entrapped air can be heated. Therefore the Charlier type has been used more extensively for scientific and military balloon programs calling for prolonged flight and/or altitudes in excess of 10,000 feet. For these applications, the balloon envelope must be completely gas tight.

In most modern high altitude flights the payload is returned to earth by parachute and the Charlier balloon and its lifting gas are expended.

The long-standing disregard of the hot air balloon as a scientific tool has been changed by the modernization of the Montgolfier.

Work done with these systems in recent years has led to the development of a versatile and valuable family of vehicles. Manned hot air balloon systems with on-board fuel supplies have been in extensive use since 1960, and unmanned versions have been used in several important programs.

This paper will present some of the foundations on which these modern Montgolfier systems are based, and review some of their operational characteristics and limitations. Specific examples will illustrate the uses of these systems.

2. TECHNICAL DISCUSSION

2.1 Balloon Buoyancy

All balloon systems derive their lift from the classical buoyancy concept. That is, a balloon has buoyancy equal to the weight of ambient air which it displaces. Thus the amount of lift depends on the volume of the balloon and the relative densities of the inflating medium and the ambient air.

$$L = V(\rho_a - \rho_b) \tag{1}$$

with

L = lift (lb)
V = volume (ft^3)
ρ_a = weight density of ambient air (lb/ft^3)
ρ_b = weight density of inflation medium (lb/ft^3)

Unfortunately, envelope volume, ambient air density, and inflation medium density can all vary. However, there is a maximum volume to which a balloon envelope may be inflated which, neglecting minor changes due to variations in shape with variations in load, may be considered as constant. Moreover, for most applications a hot air balloon is operated fully inflated. Thus, the envelope volume of a hot air balloon can usually be considered as a constant.

Ambient air density varies with ambient temperature and pressure. Both temperature and pressure vary with altitude which results in the ambient air density decreasing approximately exponentially with an increasing altitude. In general, the values associated with an ARDC model atmosphere are used for hot air balloon design.

Likewise the heated air which is used as a lifting medium in the hot air balloon varies in density with temperature and pressure. As these balloons are usually operated with an open throat at the bottom, the pressure within the envelope, neglecting head and ram effects, is equal to the ambient pressure. Thus, by considering fully inflated balloons, the buoyancy of a hot air balloon is controlled by the amount the enclosed gas is heated above the ambient temperature.

$$L = V\rho_a \left(1 - \frac{T_a}{T_b}\right) \tag{2}$$

with

T_a = absolute temperature of the ambient air
T_b = average absolute temperature within the balloon

(Equation 2 assumes that the balloon is filled with air. In actual usage the inflation gas is a mixture of air and combustion products. Thus, the results of Equation 2 are in error to the extent that the molecular weight of the inflation mixture varies from the molecular weight of air. The difference is small and may be neglected.)

Table 1 gives some comparisons of specific lift (lb/ft^3) for hot air at various temperatures (above ambient), and for other lifting gases at several altitudes in an ARDC model atmosphere.

TABLE 1. Specific lift of gases at various altitudes in an ARDC model atmosphere

Gases	Level	5000	10,000	15,000	20,000	25,000 ft
Hot air (200°F)	.0164	.0159	.0151	.0142	.0131	.0120
Hot air (250°F)	.0206	.0194	.0180	.0166	.0151	.0135
Hot air (300°F)	.0243	.0225	.0206	.0187	.0167	.0149
Coal gas (U. S.)	.0483	.0416	.0357	.0304	.0257	.0216
Ammonia	.0317	.0273	.0234	.0199	.0169	.0142
Helium	.0660	.0568	.0487	.0415	.0351	.0295
Hydrogen	.0712	.0614	.0526	.0448	.0379	.0319

In Equation 2, T_b is defined as the average absolute temperature within the balloon. In the case where fuel is carried on board and heat is generated in flight, there will be temperature gradients from the heat source to the outside of the balloon. These gradients will also vary along the height of the balloon. Figure 1 shows the results of measurements taken inside a static balloon in still air. It is interesting to note that the average internal temperature is about the same as the maximum skin temperature which was measured at the crown of the balloon. Figure 2 presents the specific lift of a hot air balloon at sea level as a function of balloon internal temperature when assuming ARDC model atmosphere ambient pressure and temperature. Figure 3 presents the specific lift of a hot air balloon at sea level as a function of ambient temperature when assuming a constant balloon internal temperature and ARDC model atmosphere ambient pressure. Figure 4 presents the specific lift of a hot air balloon as a function of altitude when assuming an ARDC model atmosphere, and a constant temperature differential ($T_b - T_a = k$).

It is evident that a decrease in balloon internal temperature or an increase in ambient temperature causes a decrease in specific lift. Likewise, an increase in altitude decreases the specific lift. Both of these results follow from Equation 1.

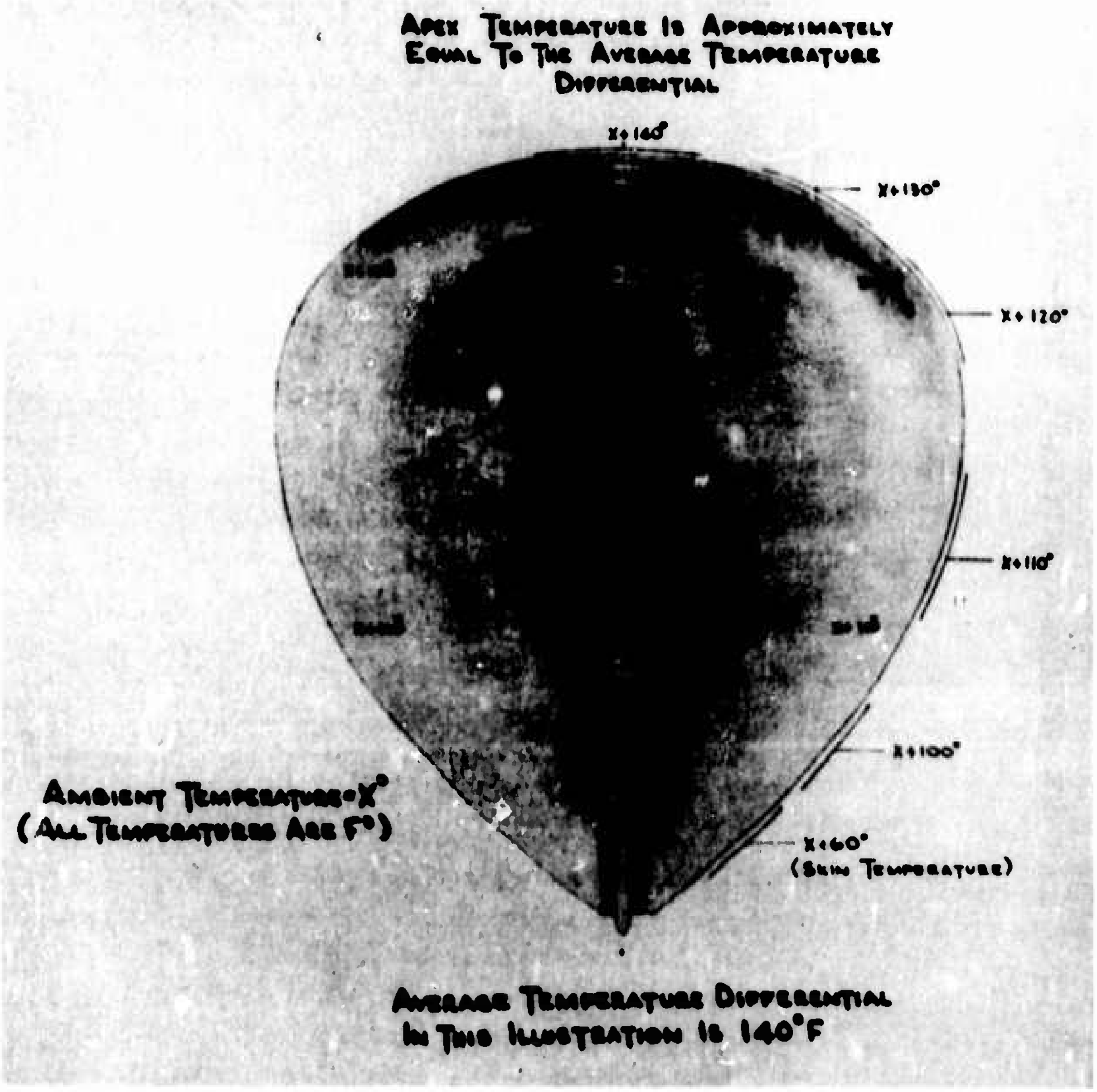

Figure 1. Internal and Skin Temperature Profile as Determined by Model Hot Air Balloon Experiments

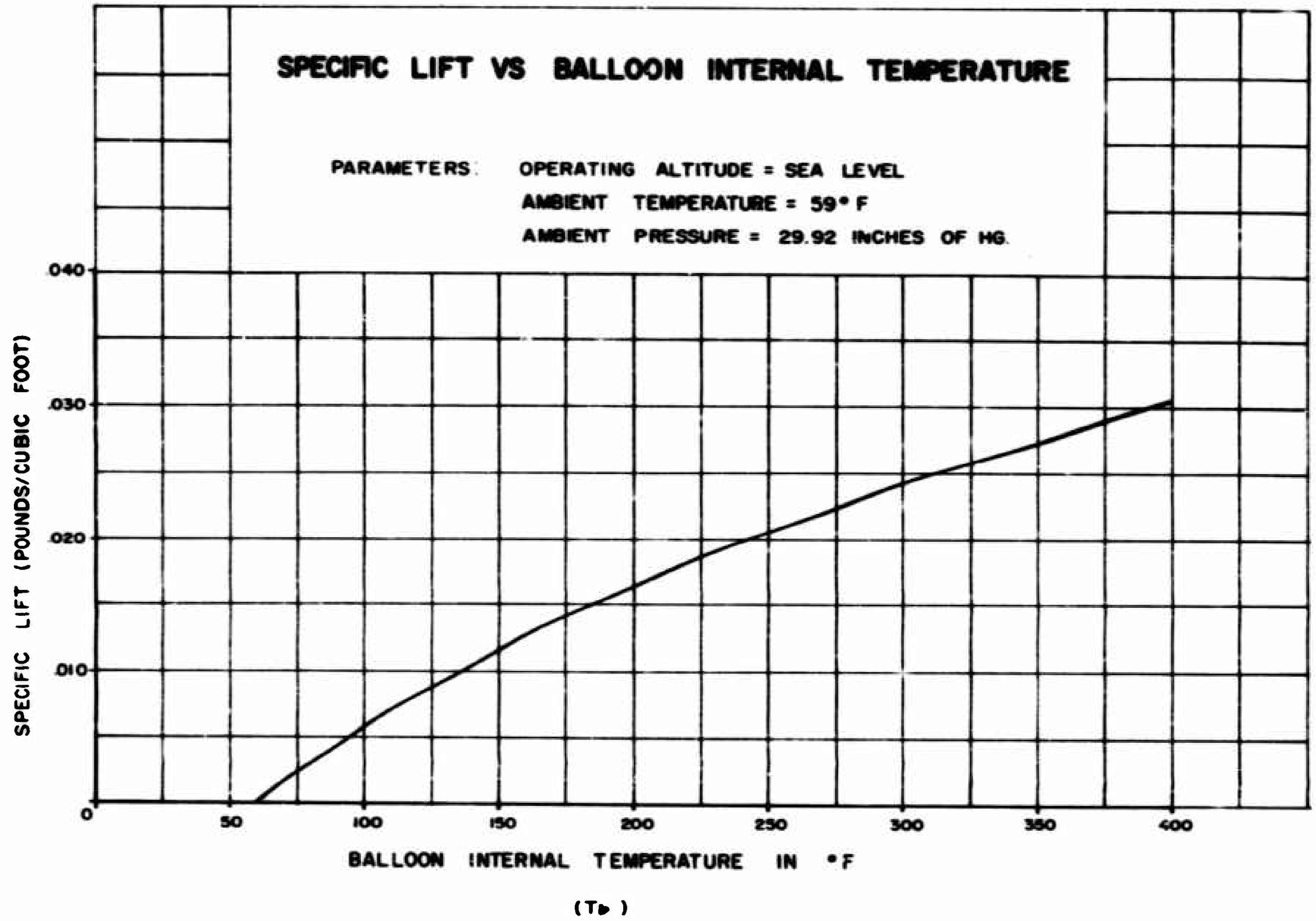

Figure 2. Specific Lift Vs Balloon Internal Temperature

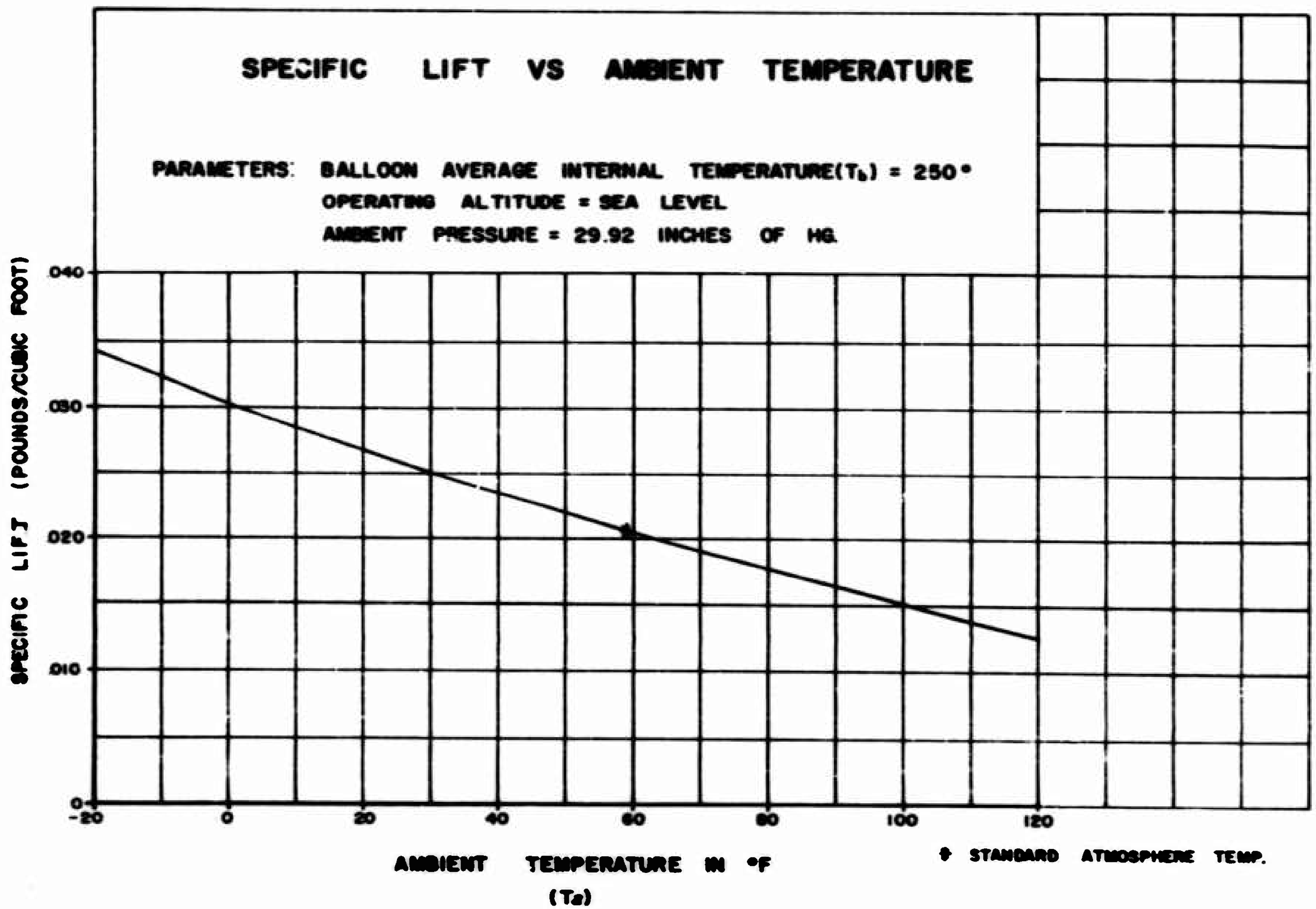

Figure 3. Specific Lift Vs Ambient Temperature

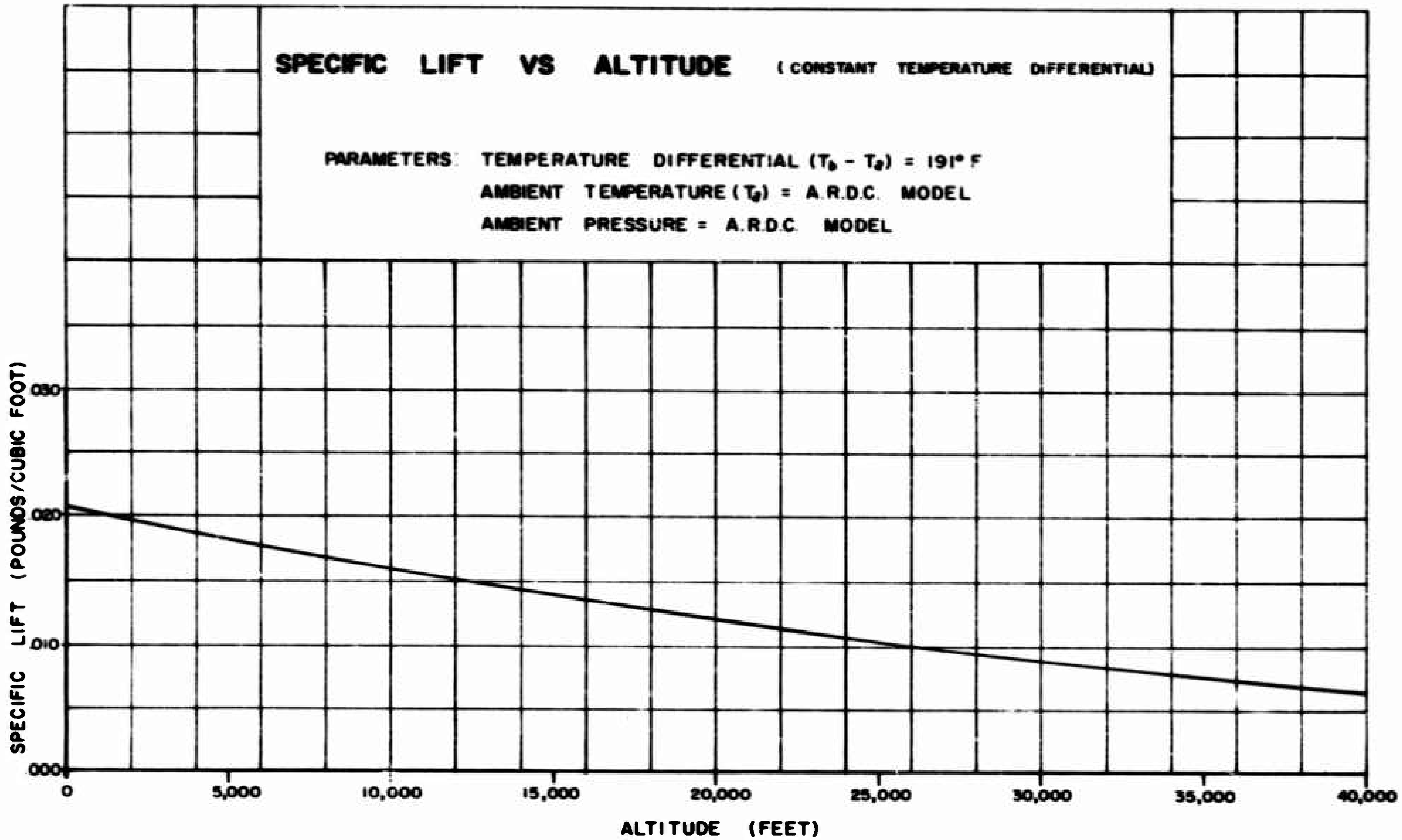

Figure 4. Specific Lift Vs Altitude (constant temperature differential)

Lift is a function of density differential. Perhaps a more significant illustration is provided in Figure 5 which presents the specific lift of a hot air balloon as a function of altitude when assuming an ARDC model atmosphere and a constant balloon internal temperature. This figure takes into account the combined effects of pressure and temperature changes in the atmosphere. Thus the increasing temperature differential as altitude increases is reflected in a greater specific lift at a given altitude than is evident in Figure 4. Likewise, Figure 6, which presents gross lift at several discrete altitudes as a function of balloon diameter, is based on a constant balloon internal temperature and an ARDC model atmosphere. Thus the gross lift of a given balloon in an ARDC model atmosphere can be conveniently calculated. For example, at 10,000 feet, a 50 foot balloon has a gross lift of 1,100 pounds, a 100 foot balloon 9,000 pounds, and a 300 foot balloon 250,000 pounds. Against this lift must be set the weight of the balloon system including envelope, rigging, and in-flight heating system to determine the payload which may be carried.

2.2 Balloon System Weight

2.2.1 ENVELOPE

Hot air balloon envelopes may be constructed from a variety of materials. A partial list of materials which have been utilized successfully includes:

a. Acrylic-coated nylon
b. Laminated mylar and nylon cloth
c. Laminated mylar and dacron scrim

All of these materials possess to varying degrees the following desirable characteristics:

a. High strength-to-weight ratio
b. High temperature resistance
c. Low or moderate porosity
d. Ease of fabrication
e. Resistance to damage and deterioration in use

All of the aforementioned materials can be used at temperatures up to 300°F. Other materials now under study may be usable at higher temperatures on future programs. At the present time, 300°F is taken as the upper limit.

Assuming typical values for some of the variables involved it is possible to arrive at some useful values for envelope weight as a function of balloon diameter. A 50 foot balloon has a weight of 45 pounds, a 100 foot balloon 500 pounds, and a 300 foot balloon about 18,000 pounds. These weights as taken from Figure 7 are based on the following assumptions:

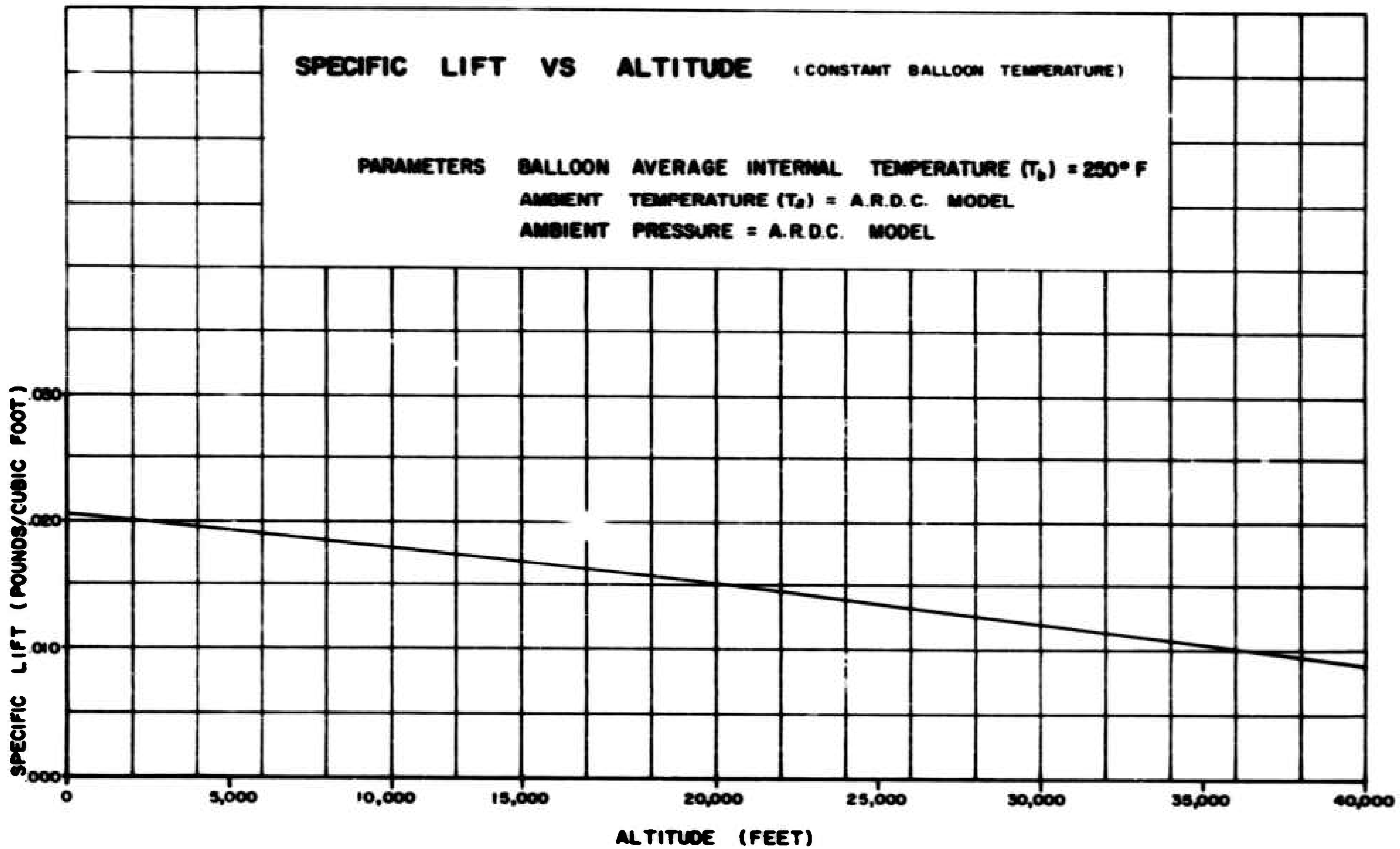

Figure 5. Specific Lift Vs Altitude (constant balloon temperature)

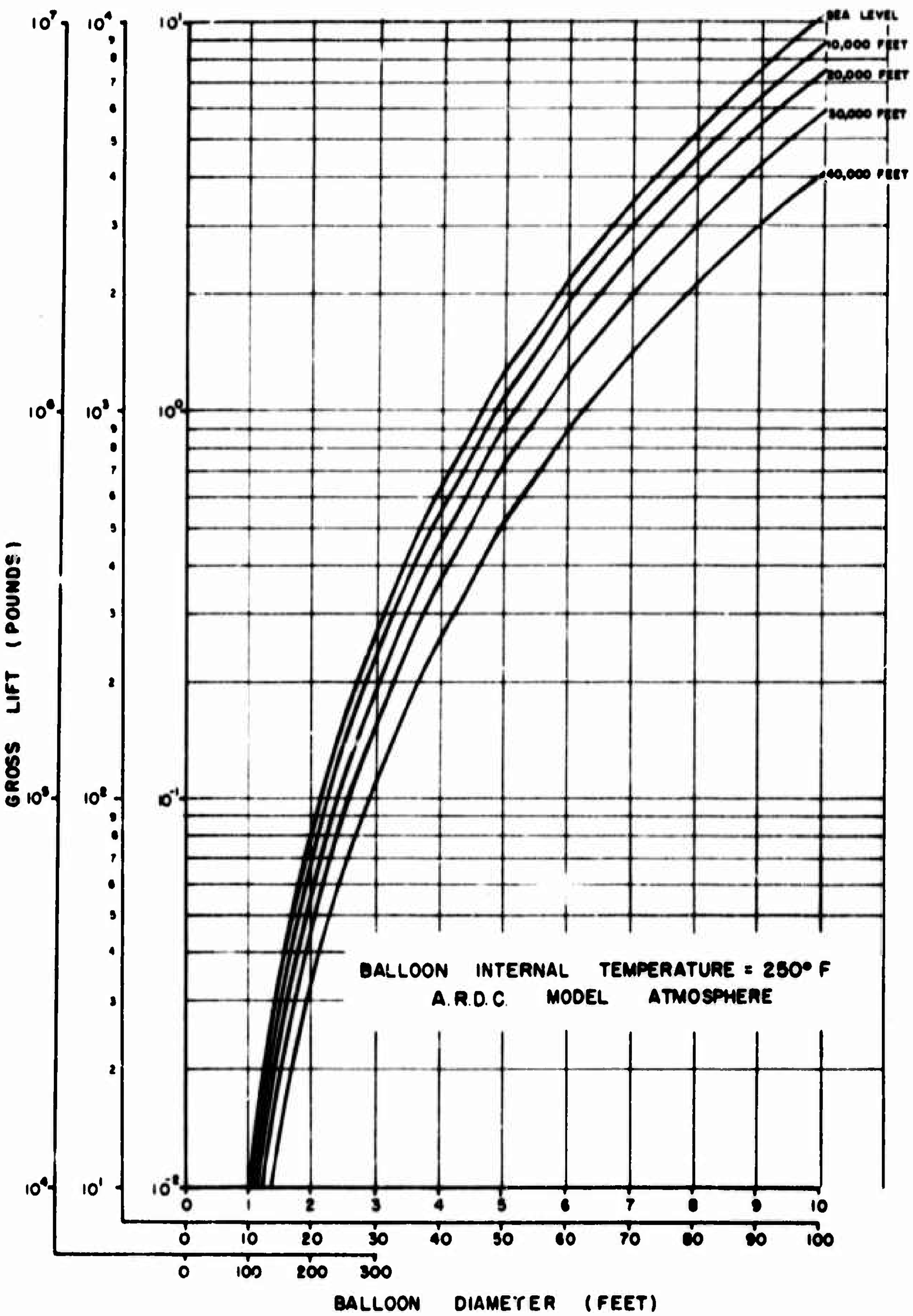

Figure 6. Gross Lift Vs Balloon Diameter

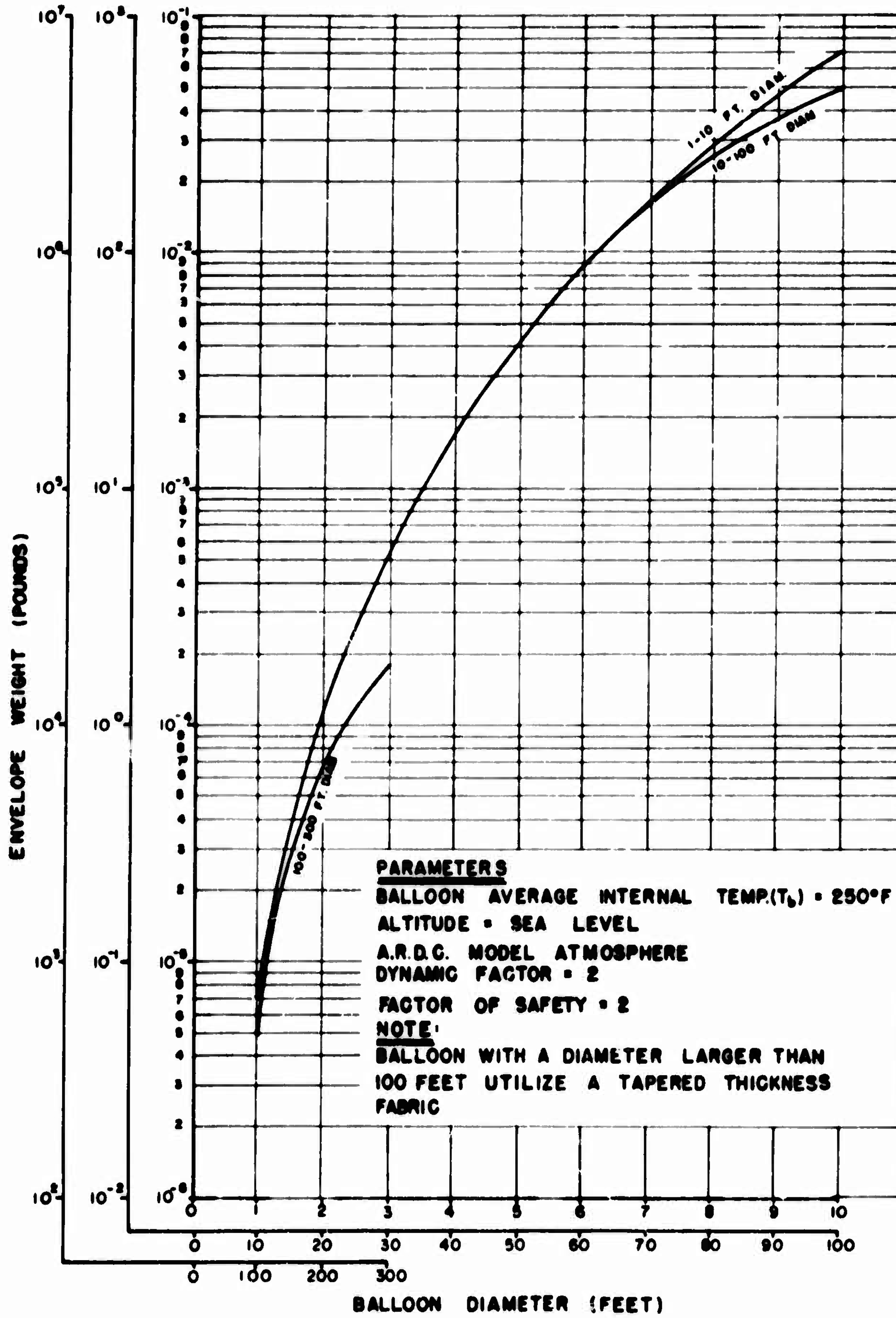

Figure 7. Envelope Weight Vs Diameter (ideal fabric)

a. Dynamic load factor = 2 (ground launched)

b. Factor of safety = 2 (manned system)

c. Balloon average internal temperature = 250°F

d. Operational altitude = from sea level up to 40,000 feet

e. An ARDC model atmosphere

Figure 7 assumes an ideal fabric (stepped above 100 feet) which is of such a thickness and weight as to have the required allowable strength at the throat of the envelope. This fabric will be extrapolated from an existing acrylic-coated nylon fabric which weighs .010 lb/ft^2, has a strength of 40 lb/lin inch, and a thickness of 3 mil. The 50 foot balloons that are now in use on the manned flight programs are constructed from this fabric and have a weight of approximately 100 pounds.

By specifically designing each balloon individually, reduction below the values of Figure 7 may be realized in the higher weights. For example, a 300 ft. envelope will weigh approximately 12,000 lbs when constructed of a combination of 2.3 and 2.7 ounce base fabric (heavier fabric in throat section).

2.2.2 RIGGING

The function of rigging is to support a useful load beneath the balloon envelope. For most of the applications of current interest, this load will include a heating system and fuel supply so arranged as to provide heat for extended flight duration. Generally, the heating system is supported at the base of the balloon with a number of load lines joining a stress distributing catenary curtain which is built into the balloon and a ring or bar to which the burner is mounted (Figure 8). Fuel tanks may be carried beside or below the burner, in any convenient location, as determined by the payload configuration. The payload itself, is generally suspended from the same load lines as the heater.

2.2.3 INFLIGHT HEATING SYSTEM

The most important single feature of the modern Montgolfier balloon systems is the ability to carry an inflight heating system. This inflight heating system not only extends the flight duration capability but permits accurate altitude control of the balloon system during flight. By regulating the heat input into the balloon the gross lift may be controlled to yield ascent, level flight, or descent as desired.

In theory, almost any fuel can be used to supply inflight heat. In practice, liquid fuels have the desirable quality of continually adjustable volumetric control. With suitable burners, any liquid fuel which is compatible with the operational envi-

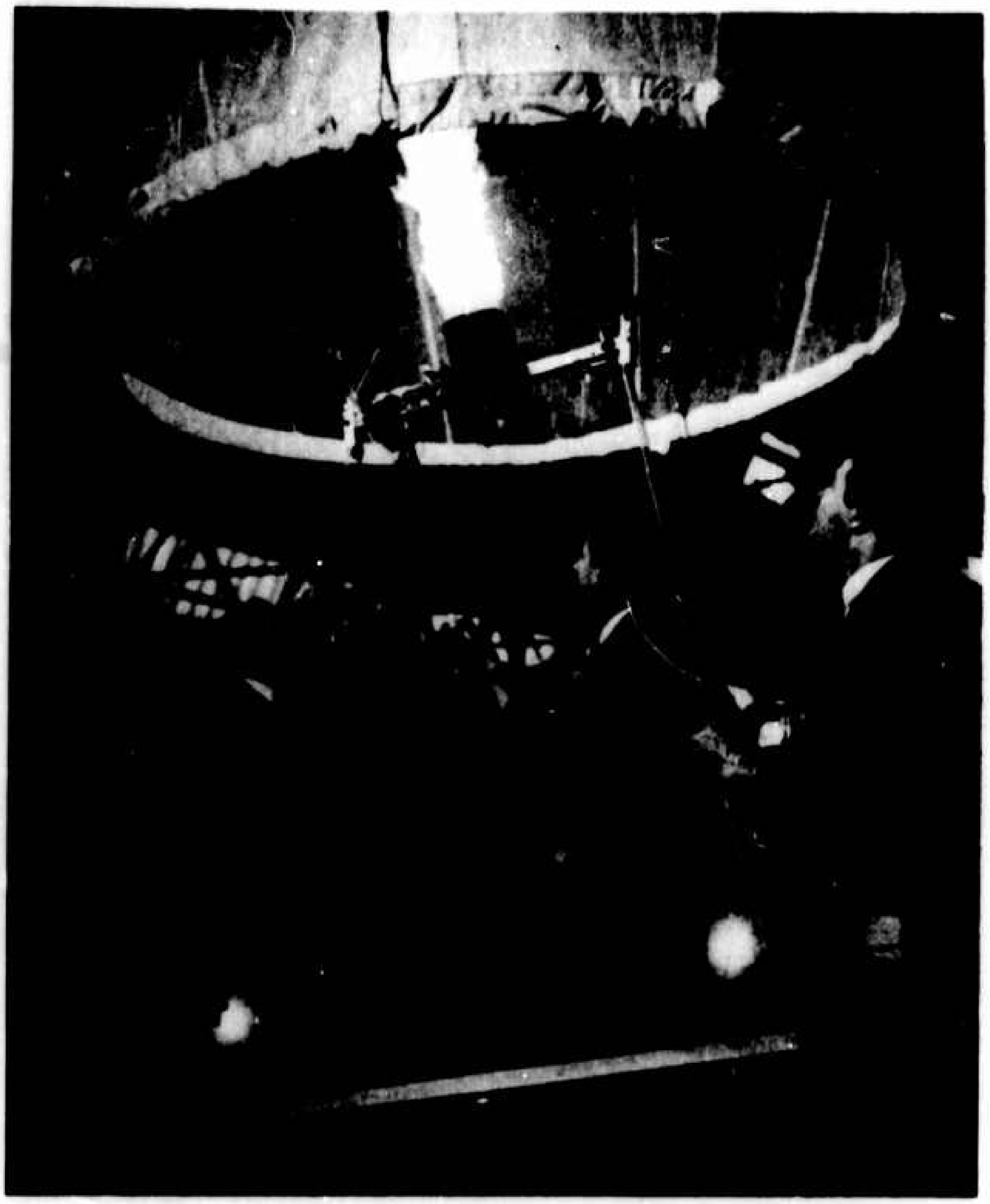

Figure 8. Typical Burner Mounting on Hot Air Balloon

ronment of the balloon could be used. Experience, however, has indicated that liquid propane, which passes cleanly through pre-heating coils is one of the more suitable fuels.

A line of heat generators which use liquid propane has been developed. Some operate at tank pressure, others at reduced pressure supplied through pressure regulators. Most are equipped with parallel metering and on-off valves. The metering valve is used to achieve approximately level flight and the on-off valve is used to gain altitude rapidly and to check a descent by burning a relatively large quantity of fuel in a short time.

Tankage for liquid propane falls into two broad categories. I.C.C. approved tankage, for use in transporting propane and for contact with the general public, weighs approximately 75% of the contained fuel weight. Specialized flight tankage not to be handled by the general public can weigh as low as 45% of the contained fuel weight.

Some useful information concerning available propane inflight heating systems:

TABLE 2. In-flight heater data

Propane energy	21,560 Btu per lb
Burner weight	10 lb per million Btu/hr capacity
I.C.C. tank weight	75% contained fuel weight
Special tank weight	45% contained fuel weight
Energy output	800 hp per burner (typical)

The primary function of an inflight heating system for a ground-launched hot air system is to replace the heat lost through the envelope skin during flight. While in a condition of equilibrium, the balloon will move with the surrounding air and its heat losses will approximate those of a static balloon in still air. When ascending, the relative movement of the balloon through the air will increase the heat losses as a function of the ascent rate. Likewise, a descending balloon will have an increased heat loss due to the relative movement through the air and the ventilating effect of the ingested ram air. The heat loss rate of a static balloon in still air is a function of the following factors:

a. Envelope material
b. Envelope surface area
c. Balloon average internal temperature
d. Ambient air temperature

The burner capacity should match the heat loss rate with a suitable excess to allow for ascent or checking a descent.

The amount of fuel to be carried is a function of the heat loss rate and the desired duration of flight. Likewise, the tankage weight is a function of the amount of fuel to be carried.

Figure 9 is provided for use in estimating burner requirement and fuel and tankage requirements as functions of envelope diameter. This figure is based on several simplifying assumptions as follows:

a. Envelope material is metalized
b. Balloon average internal temperature is 250°F
c. Balloon is at a sea level throughout the flight
d. Flight is in an ARDC model atmosphere
e. Fuel requirement is based on level flight only

In addition to such liquid fuel in-flight heat systems, specialized pyrotechnic in-flight heating systems have been utilized. It is expected that, for some specialized applications, pyrotechnic heaters will be more appropriate than liquid fuel systems and will, therefore, be used.

A secondary function of the in-flight heating system is to assist in the initial warmup of the air within the balloon envelope. In the case of ground launched systems the initial warmup may be accomplished by an auxiliary burner-blower system in conjunction with the in-flight heater. In the case of mid-air deployment systems, the initial warmup may be accomplished by a one-shot liquid propane heater unit which is jettisoned after use. In certain specialized cases a pyrotechnic heater may be used for initial warmup. In any case, mid-air deployment systems and associated initial warmup heaters require specialized engineering.

2.2.4 INTEGRATED SYSTEM WEIGHT

The direct reading of an approximate payload in an ARDC model atmosphere as a function of balloon diameter is shown in Figure 10. The plot is based on the following simplifying assumptions:

a. Balloon average internal temperature is 250°F
b. Envelope material is based on an available fabric
c. Envelope material thickness is constant from throat to crown
d. Rigging weight is 10% of the envelope weight
e. Burner capacity allows a 50% increase in output over that which is required for level flight at sea level
f. Fuel required is sufficient for level flight only at sea level for the selected flight duration

Based on these assumptions, the payload capacity of a 50, 100 and 300 foot

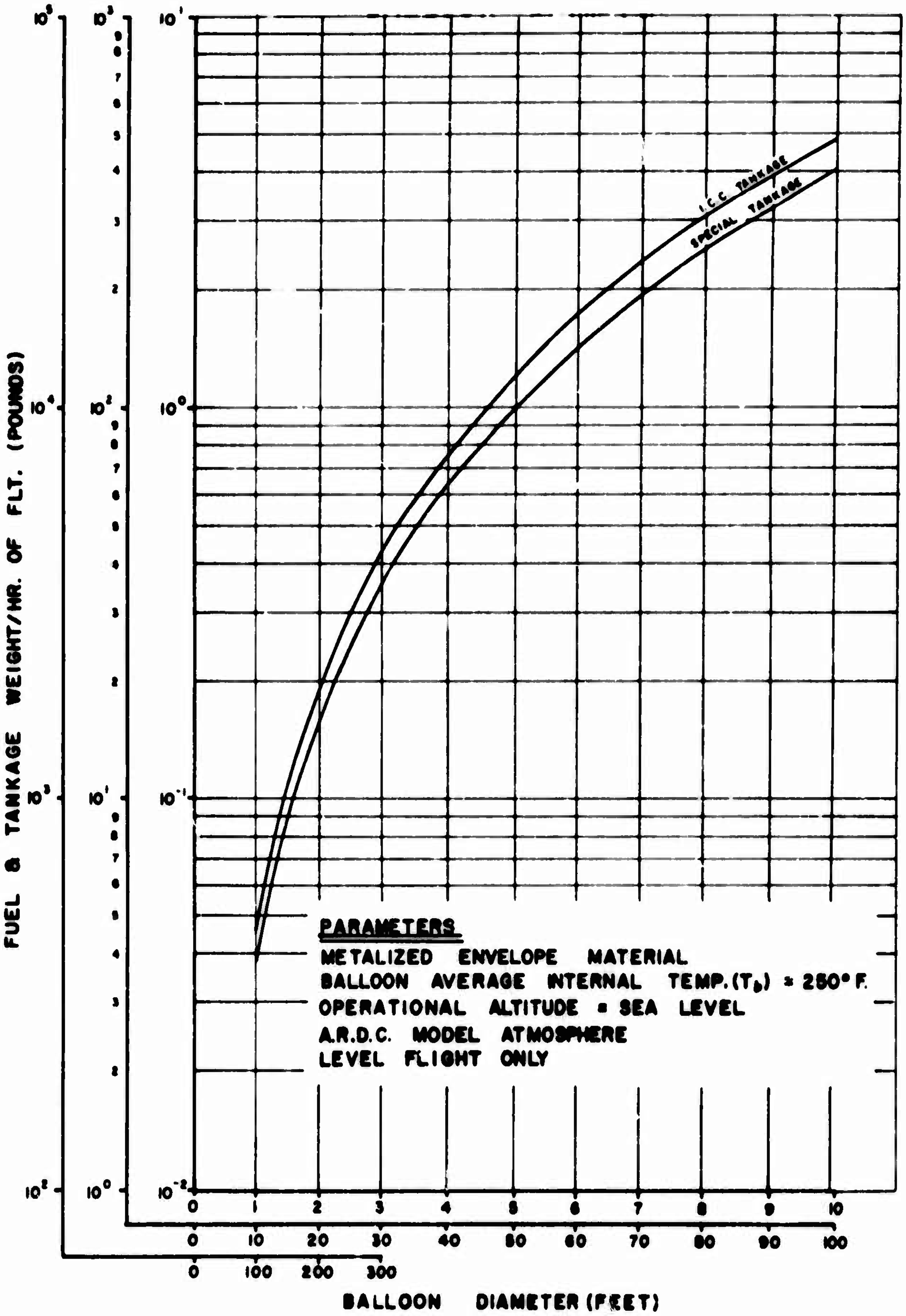

Figure 9. Fuel and Tankage Weight Per Hour of Flight Vs Balloon Diameter

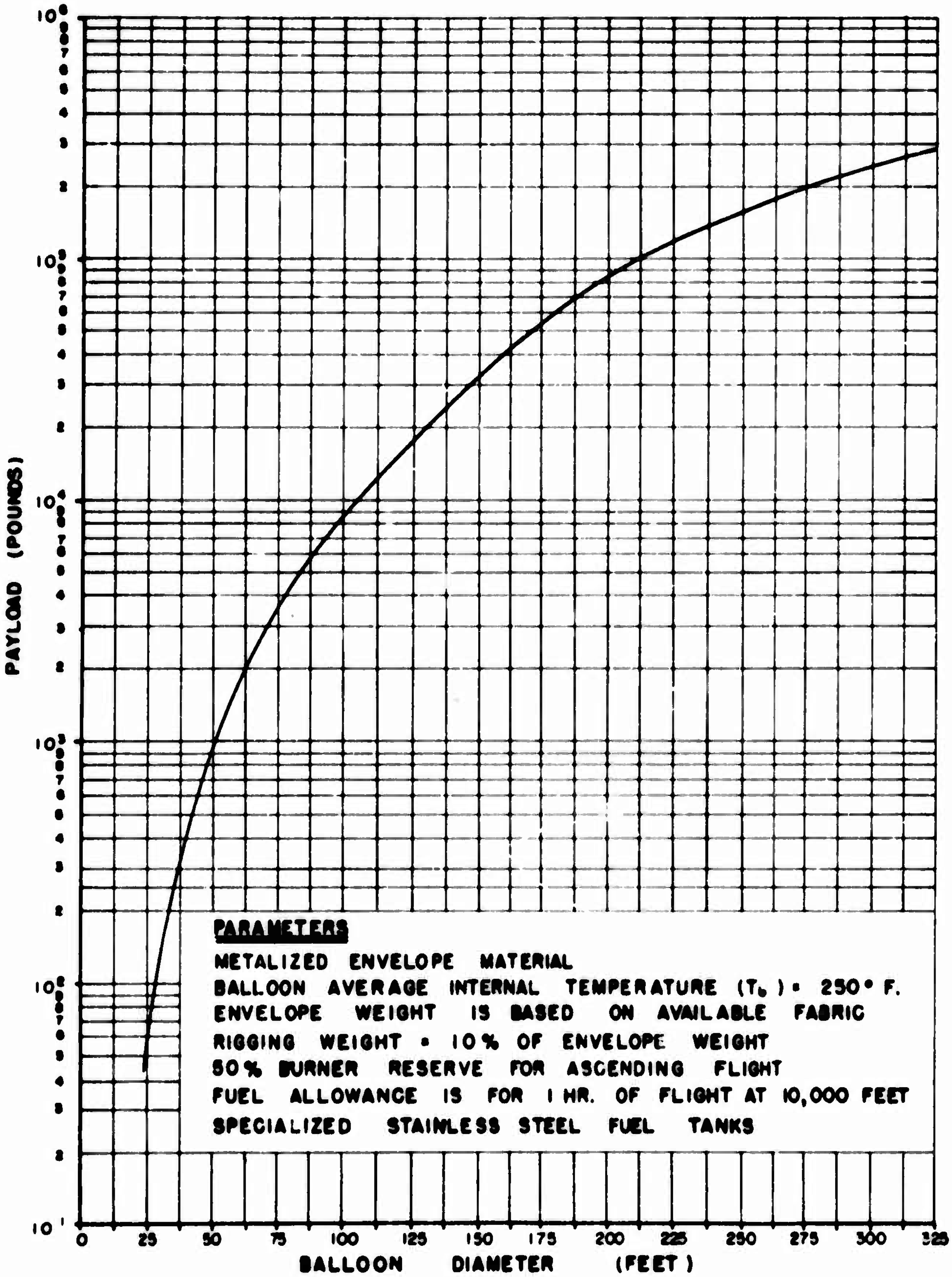

Figure 10. Payload Vs Diameter at 10,000 feet

balloon is approximately 1,000, 8,100 and 228,000 pounds when floating at 10,000 feet.

2.3 Hot Air Balloon Operation

2.3.1 LOGISTICS AND ECONOMY

The remarkable compactness of a hot air balloon system is of special interest in programs where logistic problems are important. Figure 11 presents the packed volume of the balloon envelope as a function of diameter based on an ideal fabric and packing factor of 2. A 50 foot balloon can be packed in a volume of 2.2 cubic feet while a 100 and 300 foot balloon would occupy 25 and 900 cubic feet respectively. Figure 12 presents burner and fuel tankage volumes as functions of balloon diameters for various flight durations. From these figures it is obvious that a hot air balloon system possesses very satisfactory logistic advantages when system weight is compared to payload capacity. These features are even more impressive when it is remembered that for every pound of lift obtainable from a compressed light gas, that is helium, hydrogen, and so forth, steel cylinders weighing up to 10 lbs are required to contain that gas. Thus the logistics of transporting lighter-than-air lifting gas to a remote launch site or in an airborne vehicle becomes quite formidable.

Hot air balloons hold economic advantages also, in that lighter-than-air lifting gases are not readily reclaimable from an inflated envelope at the termination of a flight. Thus the lighter-than-air balloon must be stored inflated between flights to conserve gas, or be reinflated with gas at approximately $1.00 per pound of lift for each flight. This economy reflects in logistics also in that the hot air balloon may be readily deflated and packed for transportation and/or storage at the end of a flight.

2.3.2 ENVELOPE INFLATION

It is customary to use an auxiliary blower unit initially to inflate the balloon for ground launch operations. As inflation proceeds, the inflation air is heated by auxiliary heaters and/or the inflight heater. Since commercial blowers are available in a wide range of capacities, it is possible to match blower capacity to balloon size to keep balloon inflation time relatively short. The average inflation time for a 50 foot balloon is approximately 10 minutes.

Balloon systems which are deployed in mid-air can be inflated by ingesting ram air through the open throat of the envelope as the system descends. The inflation air may be partially heated as it is ingested, or inflation may be completed with

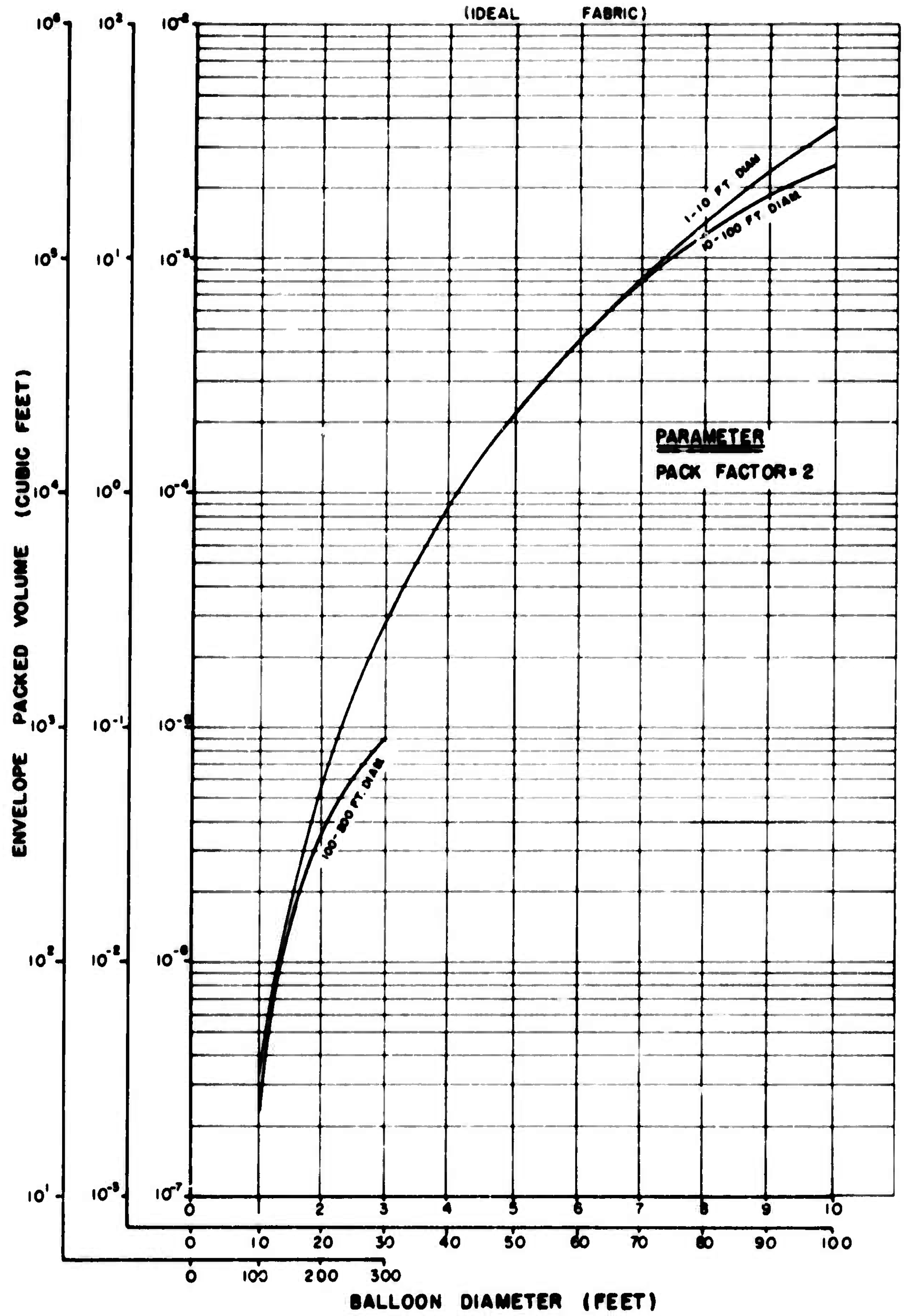

Figure 11. Envelope Packed Volume Vs Diameter

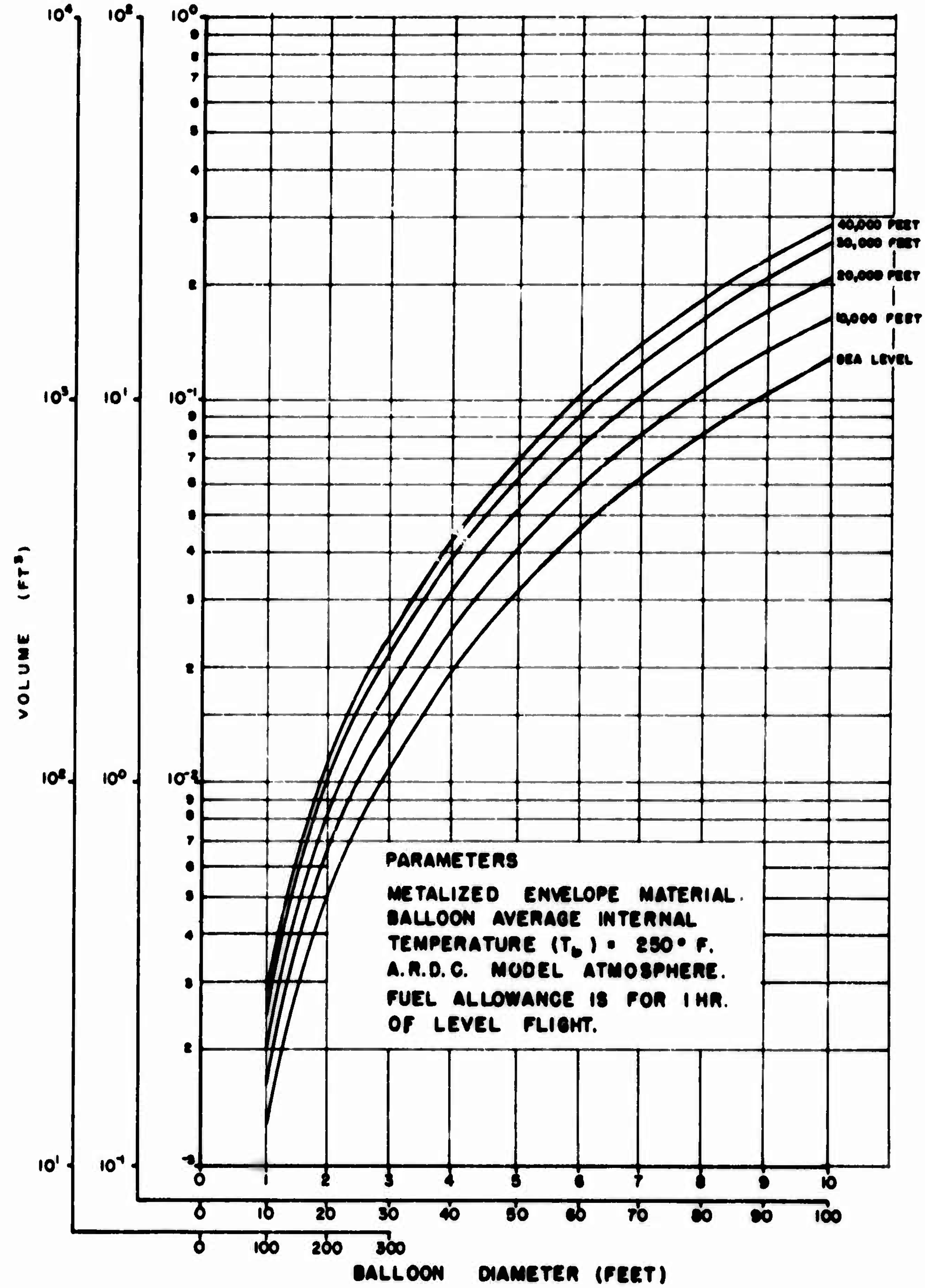

Figure 12. Burner, Fuel, and Tankage Volume Vs Balloon Diameter

air at ambient temperature. In either event, the fully inflated envelope will be rapidly heated to operational temperature. This rapid heating can be accomplished by an in-flight heater with a large capacity and/or an auxiliary one-shot heater which can be jettisoned after warmup is completed. Figure 13 is a time/altitude plot of a Raven Industries, Inc. drop test in which the envelope was filled by ram air at ambient temperature. The inflated envelope was then heated by a propane burner to bring about float and ascent. No attempt was made to control the heat output to bring about level flight, therefore, the system ascended until the fuel supply was exhausted.

Another means of heating the ingested ram air is by the use of pyrotechnic heat and/or gas generators. For some specialized applications the use of pyrotechnics is advisable.

2.3.3 IN-FLIGHT CONTROL

Balloon system control is limited to controlling the ascent or descent rates. Since the hot air balloon acts as a reefed parachute, the terminal velocity is low, even if in-flight heating is discontinued. This is illustrated in Figure 13 where the descent rate, after burnout, was approximately 15 ft/sec. In the 2-man personnel balloon, it has been found necessary to open vents in the balloon in order to descend at a rate in excess of 1,000 feet per minute.

Unlike actual parachutes, the hot air balloon can become buoyant at any given level within its operating range. Once the heat input is matched to heat losses, the system resembles a retro-rocket with a prolonged zero velocity capability. Altitude adjustments stepwise, and in either direction, may be repeated at will for as many times as desired, within the limit of fuel carried on board.

The maximum rate of rise which can be achieved by hot air balloons has not been clearly established but it is believed to lie between 1000 and 1500 fpm. It is not known what effect the heat output of the balloon will have on drag. The boundary control possibilities of hot air balloons remain to be studied.

2.3.4 LANDING

The ability of a hot air balloon to remain airborne at low altitudes for extended periods makes for ease in selecting a landing area. Once a landing site has been selected, the fuel is turned off and the balloon descends. For maneuvering in areas with limited space, a side vent may be opened to accelerate descent. Prior to touchdown all fuel valves may be turned off, to preclude any fires.

After the balloon load has reached the ground, the balloon may be rapidly deflated by a method in use on the reusable manned versions. A large aperture is opened

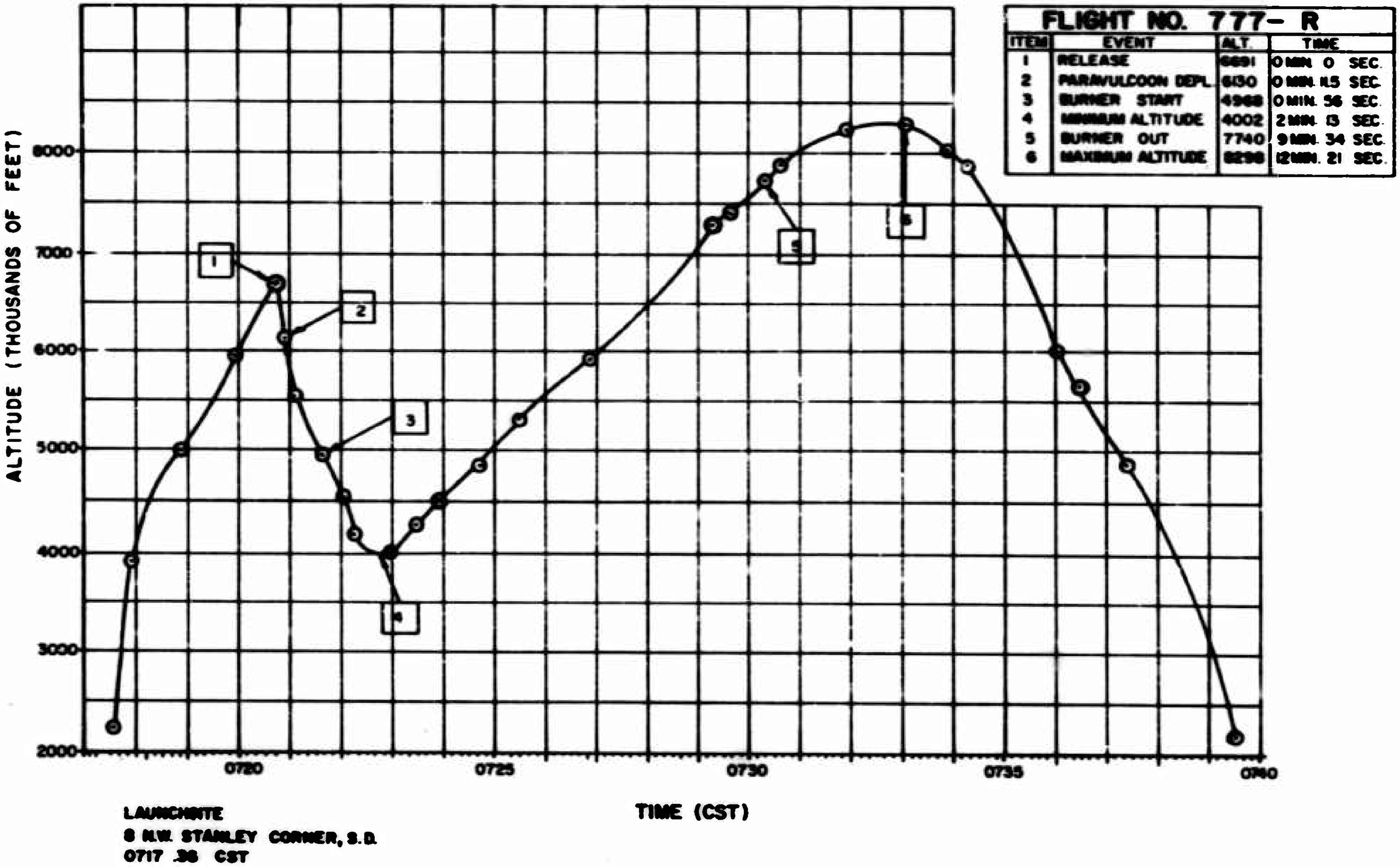

Figure 13. Recovery Test of September 26, 1961

in the crown, and complete deflation takes place in a few seconds. This aperture is readily closed, and the balloon is easily prepared for re-use.

3. APPLICATION

3.1 General

The present day hot air balloon has a wide range of applications which include:

a. Manned hot air balloons
b. Flare support systems
c. Mid-air recovery systems
d. Heavy-load transport systems
e. Captive hot air balloons

These application fall into two broad categories.

The first category includes those flights wherein the balloon is initially inflated on the ground by auxiliary equipment. The manned flights and the unwieldy load transportation flights fall into this category. The hot air balloon system has distinct advantages for applications of this category in the fields of logistics of ground launch equipment, cost of lifting gas, and reusability of the balloon envelope.

The second category includes those flights wherein the balloon in initially inflated in the air by airborne auxiliary equipment. Small, unmanned systems for supporting a light payload for 5 to 45 minutes, as well as systems for recovery of devices returning from outer space fall into this category. The hot air balloon system has distinct advantages for applications of this category in the logistics of airborne envelope inflation equipment and the maneuverability of the balloon system.

3.2 Specific

3.2.1 MANNED HOT AIR BALLOONS

The modern Montgolfiers which have been most used to date are piloted, reusable, manned balloons called VULCOONS. These are used for pilot training, scientific investigation, and sports purposes. Figure 14 illustrates such a Raven Industries balloon. This particular balloon is 50 feet in diameter and has a volume of 61,000 cubic feet. The material is 1.1 ounce nylon impregnated with an acrylic resin. It has a gross capacity of approximately 1130 pounds and a flight duration up to 6 hours with two persons aboard.

In April 1963, P. E. Yost and D. L. Piccard made the first successful crossing of the English Channel by hot air balloon. On other flights, durations of six hours and altitudes of 13,000 feet MSL have been achieved.

The amount of fuel required for a four hour flight is approximately 230 pounds

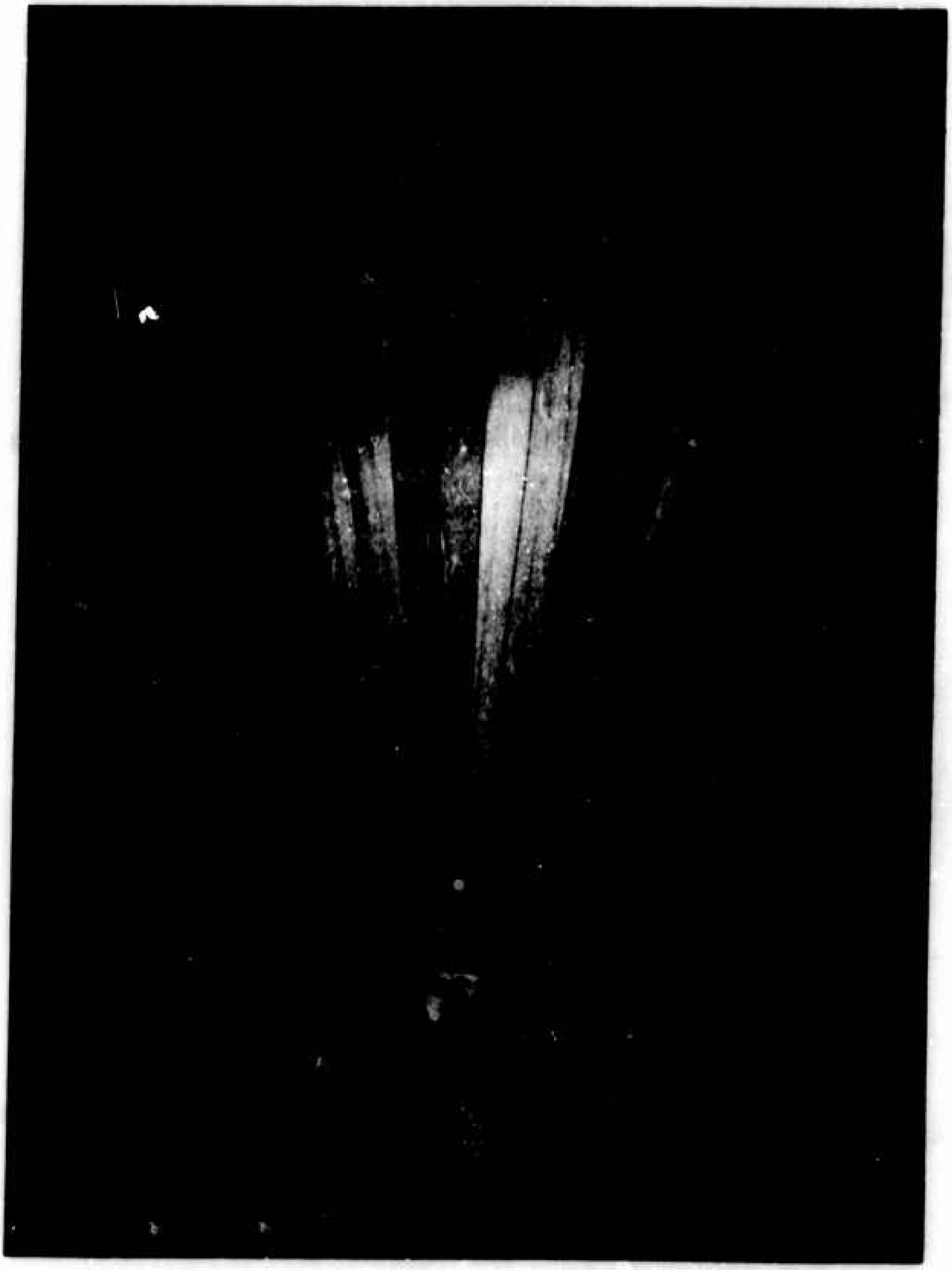

Figure 14. Fifty Foot Diameter, 61,000 Cubic Foot Hot Air Balloon

of propane at a cost of about $10.00. Standard accessory ground inflation equipment consists of a propane-engine-powered blower-burner unit which weighs less than 200 lbs. An advanced design ground inflation system which utilizes a 2 cycle engine, propeller and the flight burner has been made operational recently. This unit weighs 6 lbs and can inflate a 50 foot diameter balloon in less than 10 minutes. Thus, the entire balloon system and ground launch equipment can be transported to a suitable launch site with a pickup truck, small trailer or automobile.

By way of contrast, a helium filled balloon with a 600 pound payload would require $700.00 worth of gas for each filling. Furthermore, 7000 pounds of tankage would be required for the storage and transportation of this quantity of gas.

3.2.2 FLARE SUPPORT SYSTEM

The hot air balloon provides an excellent solution to the problem of providing uniform illumination for 5 - 45 minutes from an air launched flare. Whereas a parachute-suspended flare continues to descend as it burns, a flare supported by a hot air balloon can remain at a constant pre-selected altitude throughout its burning life.

The hot air balloon system accomplishes this result by utilizing the thermal output of the burning flare to initially heat the inflation air and to replace the heat lost during the flight. A Raven Industries test program using road flares and a polyethylene envelope (Figure 15) first proved the feasibility of this concept. These tests were followed by more elaborate tests on a classified program. Future developments may include longer burning flare systems capable of maintaining a constant altitude throughout an extended life. In recent tests a flare with an output in excess of five million candle power was brought to a zero descent velocity after being jettisoned from an aircraft. This was accomplished by replacing the conventional parachute suspension system with an open throat hot air balloon.

3.2.3 MID-AIR RECOVERY SYSTEMS

The hot air balloon can be adapted for mid-air deployment at velocities estimated to be as high as 600 feet per second. The envelope will fill with ram air, heated as inflation progresses, to decelerate the system and then hover at a preselected altitude. The system can then be remotely or internally controlled to ascend, hover, or descend as desired, to facilitate recovery of the returning payload. Such systems have been named PARAVULCOON -- they combine certain elements of a parachute with the VULCOON as shown in Figure 16. As an illustration, consider a 1000 pound capsule to be recovered. A hot air balloon system with an estimated weight of 175 pounds would have the capability of holding the 1000 pound capsule at 5000 ft. MSL for 30 minutes. A lighter-than-air balloon using helium as a lifting gas would require an estimated 175 pounds of helium. This quantity of

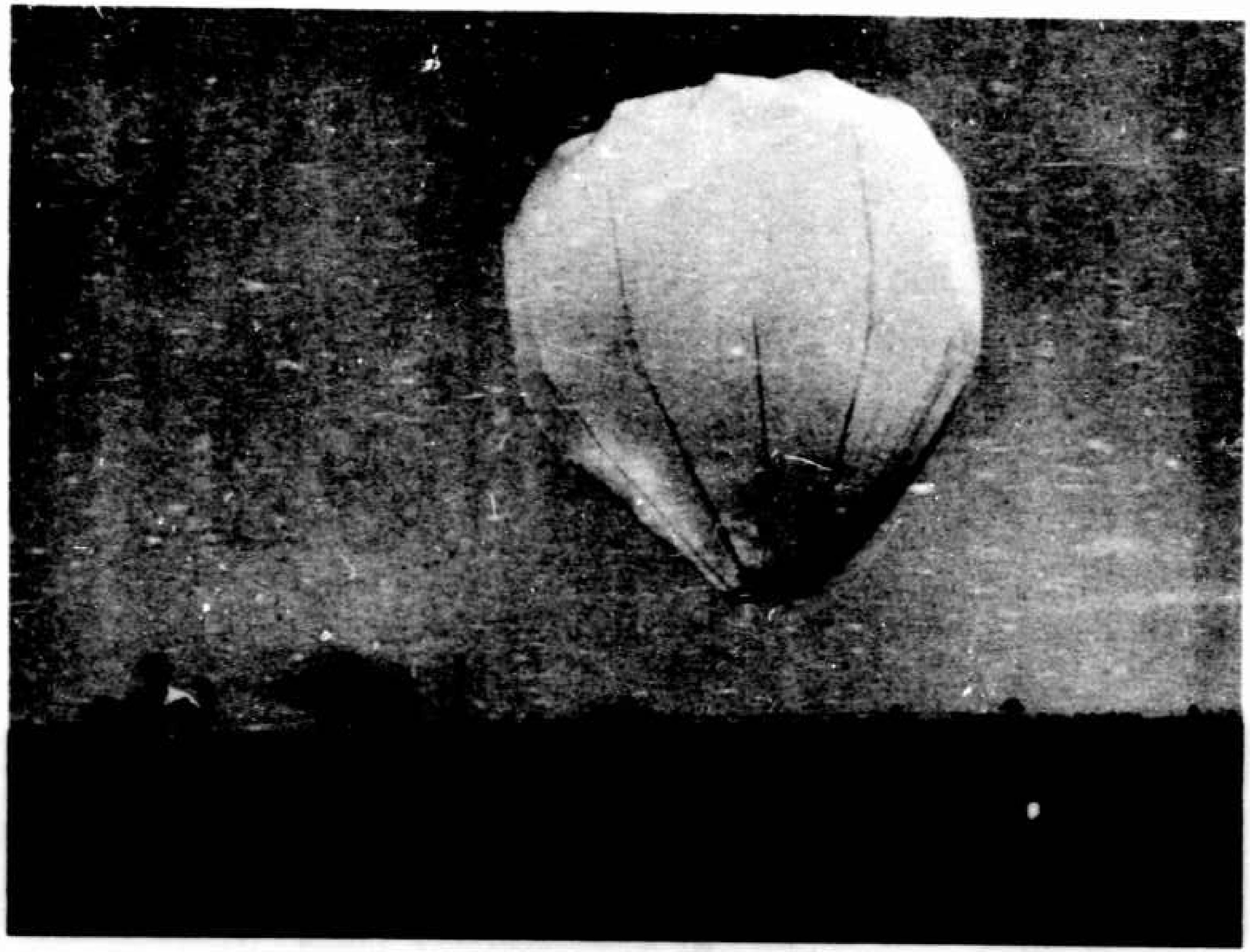

Figure 15. Test Vehicle for Flare Support Feasibility Study

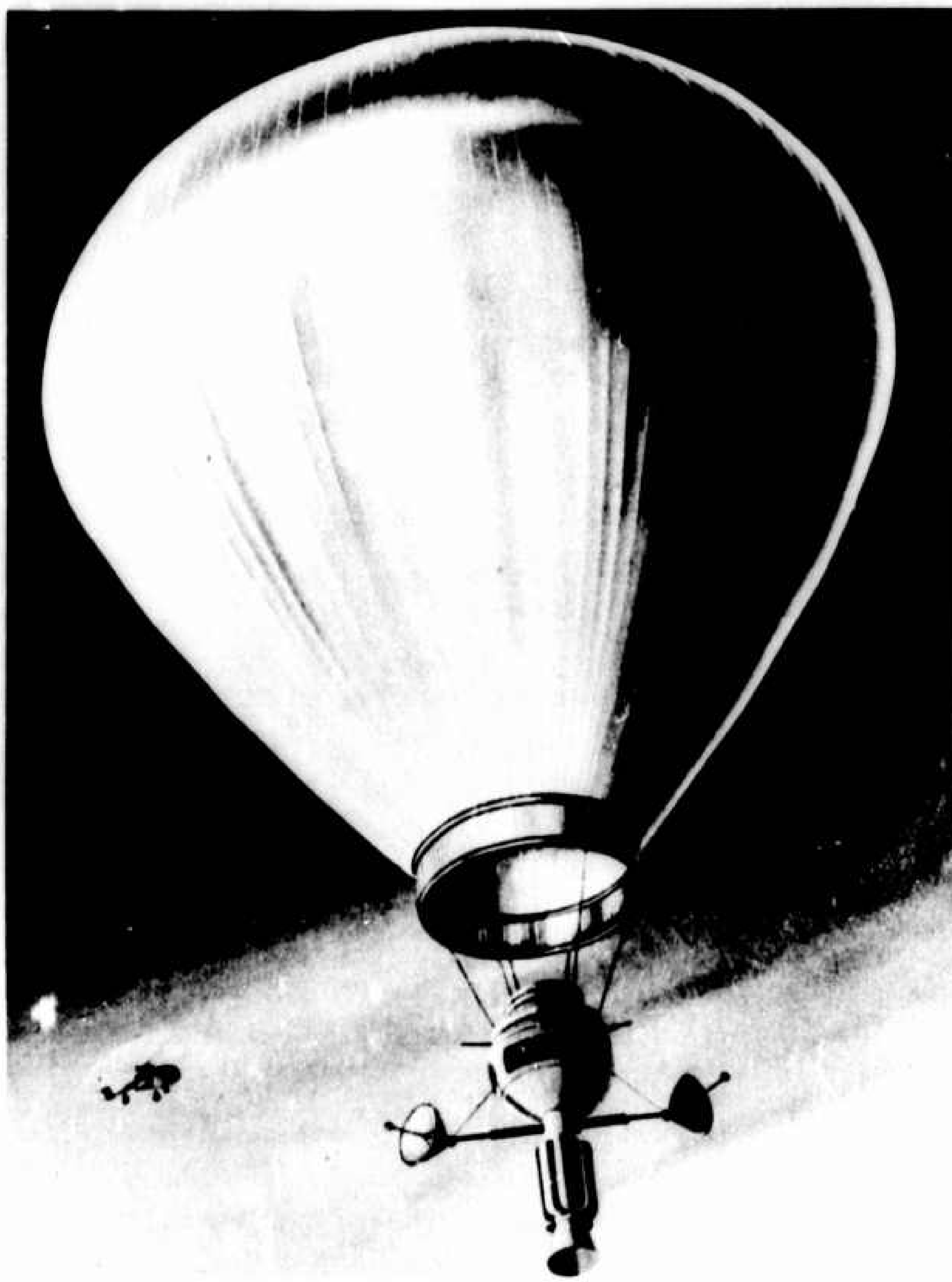

Figure 16. Paravulcoon Mid-air Recovery System

helium, if contained in high strength stainless steel tanks, would require approximately 1330 pounds of tankage which would have to be carried aboard until the balloon was inflated. Thus, the hot air balloon system would have a distinct system weight advantage for recovering the given payload. Furthermore, the lighter-than-air balloon, which requires excess gas and ballast for maneuvering, is much less maneuverable than the hot air balloon system.

A fixed part of the system weight of a PARAVULCOON system is the balloon, its rigging and container. For the most part the amount of fuel carried on board is determined by the desired duration of float. However, when descent is to be checked, a fixed initial heat must be provided. This can be considered separately from the sustaining heat needed. Figure 17 shows the initial heat requirements, as a function of envelope diameter. Figure 9 shows the amount of fuel and tankage required per hour of sustained flight as a function of diameter. This curve is applicable to all sorts of hot air configurations. The gross load for a PARAVULCOON may contain a higher fixed weight-to-payload ratio than systems designed for smaller dynamic loadings, but fuel consumption as a function of diameter is not affected.

3.2.4 HEAVY LOAD TRANSPORT SYSTEM

Another example of an application of the hot air balloon is the powered hot air airship. The vehicle, as shown in Figures 18 and 19 would be propelled by one or more standard turboprop engines.

From a viewpoint of efficient use of fuel, VULCRAFT is superior to conventional aircraft. A conventional aircraft utilizes shaft horsepower of the engine to provide both lift and motive power. The exhaust heat is wasted. VULCRAFT, as envisioned, will utilize the exhaust heat as a buoyant force.

The proposed aerostat would have a classical airship shape with a fineness ratio of approximately 3:1. A typical hot air airship descriptive summary is shown in Table 3. This particular theoretical model has a gross lift of 40,800 lbs and net cargo capacity of 31,300 lbs.

TABLE 3. Typical hot air airship descriptive summary

Volume	1,500,000 cu ft
Engine	1 Allison T-63
Shaft Horsepower	212 HP
Gross Lift (60°F ambient)	40,800 lbs
Aerostat Weight	3,000 lbs
Gondola and Power Plant Weight	1,850 lbs
Dimensions	180 ft long, 60 ft max dia
Gross Useful Load	35,950 lbs

TABLE 3. Continued

Crew (2 men)	500 lbs
Fuel and Oil (full capacity)	4,150 lbs
Net Cargo Capacity	31,300 lbs
Range (zero wind)	975 miles

3.2.5 CAPTIVE HOT AIR BALLOONS

The foregoing discussions of operations with hot air balloons have been directed to free balloons, either manned or unmanned. A special case is the tethered or captive balloon.

The unique features of ready, low-cost inflation at remote sites recommend this balloon for a number of uses. In some cases fuel systems are carried on board, while, for long periods of operation, a fuel line may be connected to a ground supply, to extend flight duration indefinitely.

These balloons need to be aerodynamically shaped to minimize drag, and slightly pressurized to maintain shape. They may be unmanned or carry a non-pilot who wishes to use an aerial observation post. A test bed model is now being constructed. This particular model is 80 ft long and is scheduled to be flown in a captive state in late 1963.

4. SUMMARY OF PRESENT CAPABILITIES

Some of the programs and applications presented for consideration in this paper have not yet been physically demonstrated, and the full value of this remarkable concept has not yet been assayed. The calculations presented here and in other technical studies suggest successful extrapolation to heavy load systems, re-entry retrieval of Saturn C-5 first stage boosters (130 tons) and many unique, specialized applications of the modern Montgolfier balloons. At this time, the following "state of the art" has been demonstrated.

1. Hundreds of hours of manned flight time have been successfully completed in single and multi-place balloons.
2. Loads of 2000 lbs have been carried with complete corroboration of design calculations.
3. Flare support systems have flown successfully.
4. Mid-air recovery has been successfully demonstrated with small payloads.
5. Raven Industries, Inc. and Minneapolis-Honeywell Co. are presently conducting a funded research program for NASA on the PARAVULCOON recovery system.
6. A hot air captive test bed is being fabricated at the present time.

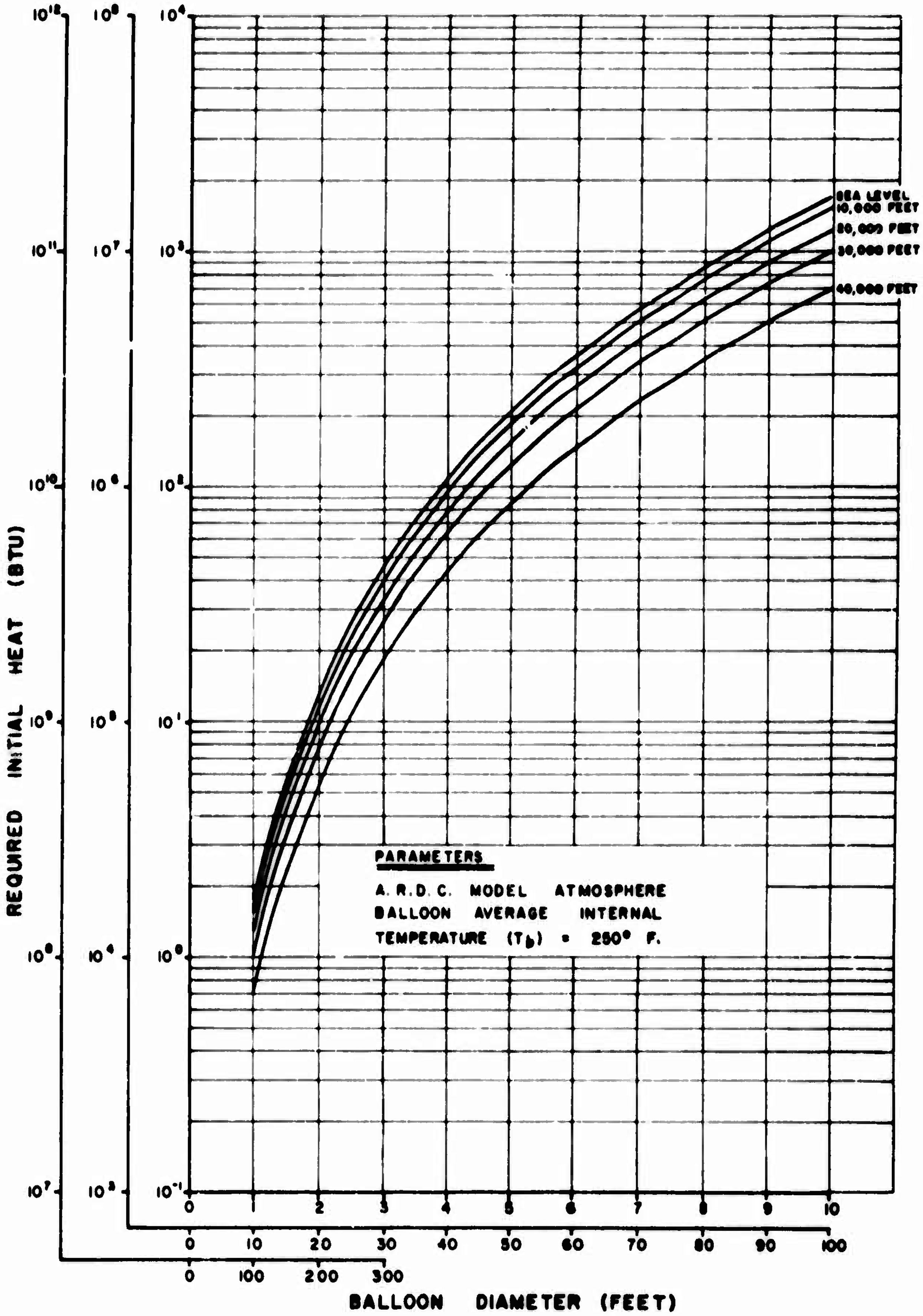

Figure 17. Required Initial Heat Vs Balloon Diameter

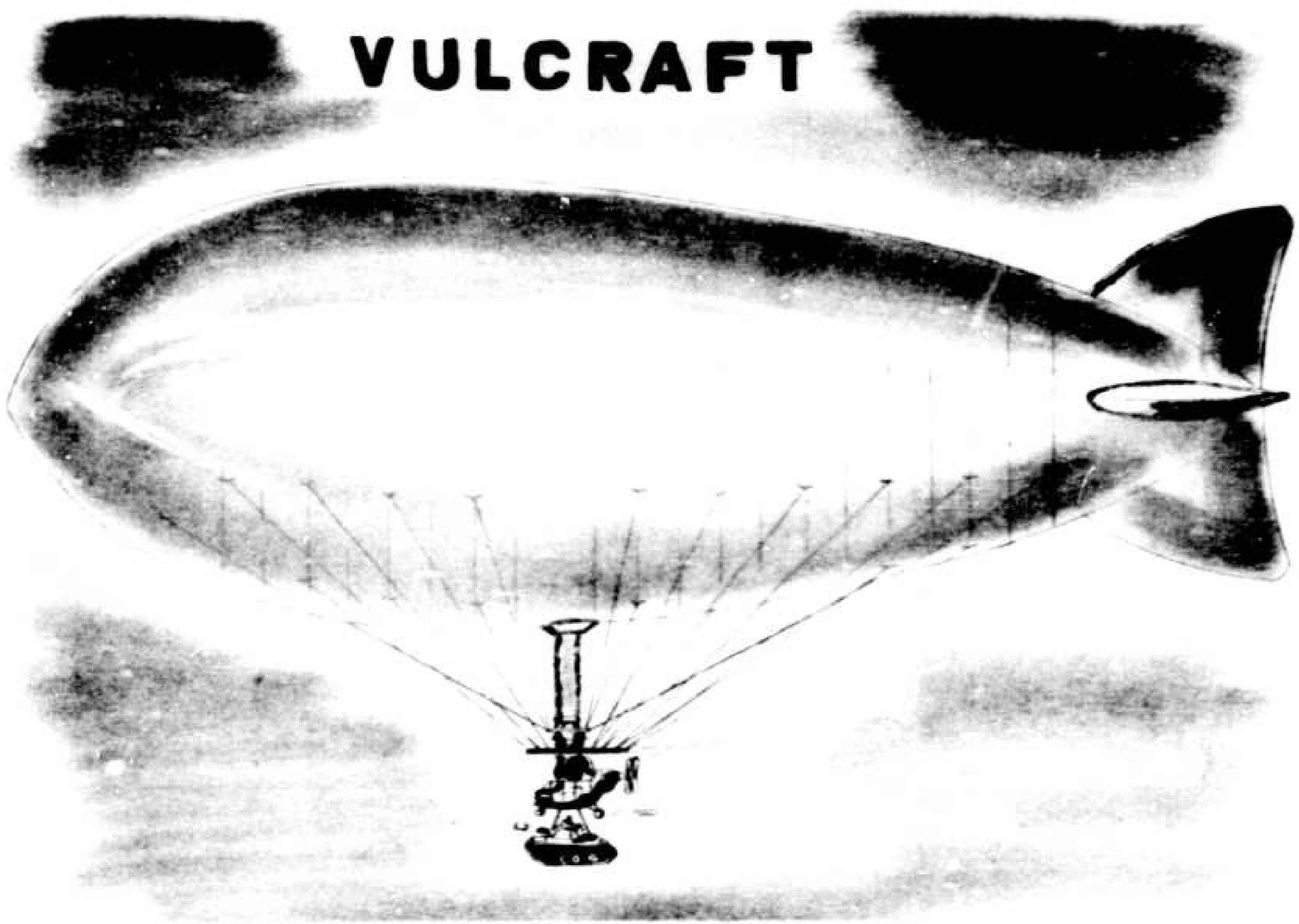

Figure 18. Vulcraft, a Powered Hot-Air Airship

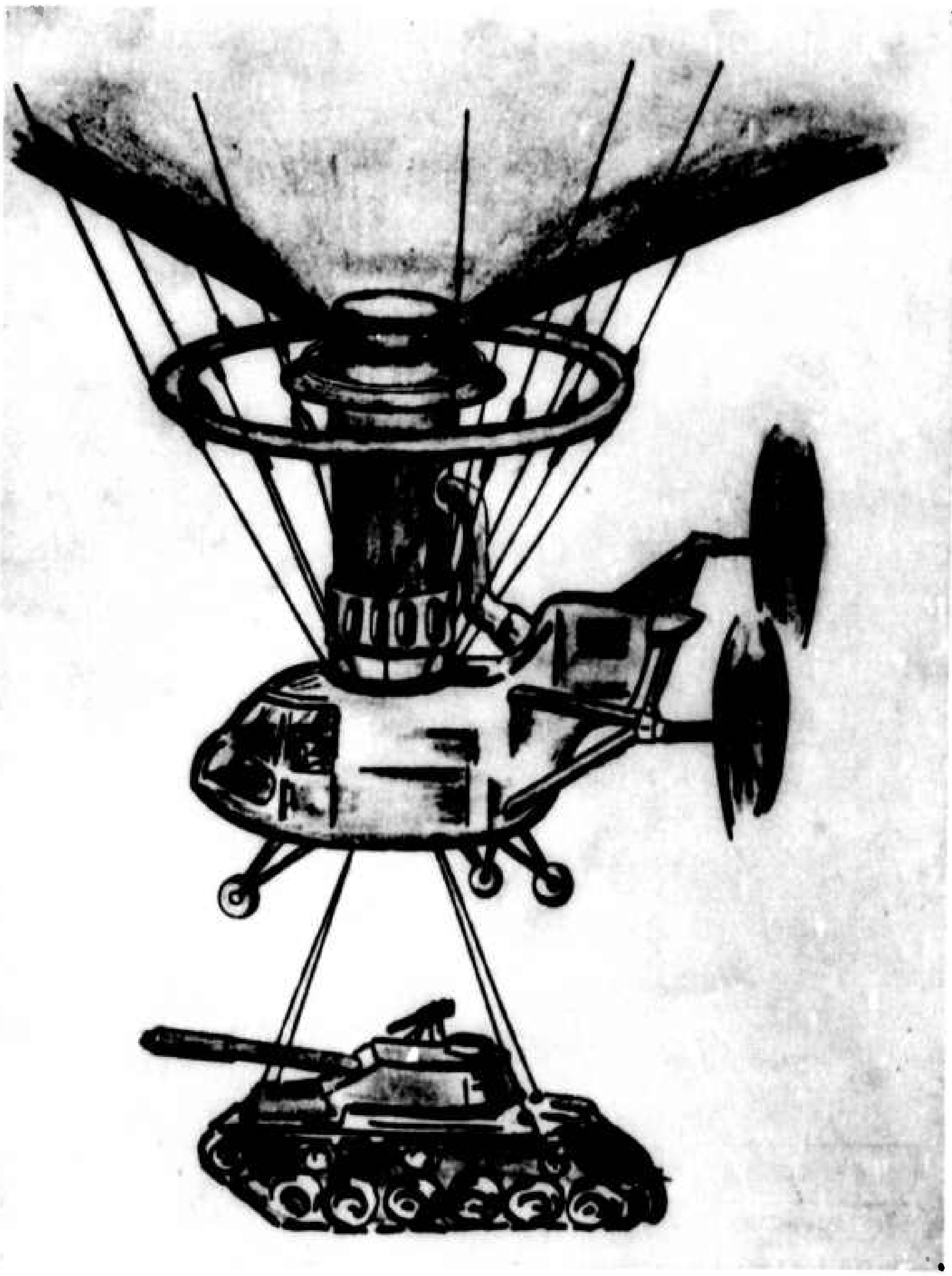

Figure 19. Vulcraft, a Powered Hot-Air Airship

XV Developments in Sounding Balloons

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Abstract

The requirements for relatively small and inexpensive balloons for use in routine upper air soundings are stimulating research programs directed toward (1) improving conventional neoprene balloons for vertical soundings and (2) developing new plastic balloons for horizontal soundings. Expansible neoprene balloons of various sizes are the "workhorses" of the vertical sounding network, and the numbers used increase each year. To meet the need for high altitude performance, research is continuously underway to provide new formulations and design modifications, such as the "streamlined" balloon. In addition, the prospect of augmenting conventional vertical soundings with horizontal sounding techniques in the next few years is producing a new line of research aimed at developing a practical one-seam "superpressure" plastic balloon which would float at constant level in conjunction with a Satellite Data Collection System.

1. DEVELOPMENTS IN SOUNDING BALLOONS

Many thousands of neoprene expansible balloons are used each year for routine vertical soundings of the atmosphere. Information obtained from these flights is used in the preflight preparations for the large plastic balloons that are being discussed here this week. Research is continually underway to provide new spherical balloon formulations, and new balloon designs, for higher altitudes, faster ascent rates, and more reliable performance. Periodically the results of this work are brought before groups such as this so that you know what tools are at your disposal.

Because you may be new to neoprene ballooning, I will tell you briefly how these balloons are made at Dewey and Almy. Practically all expansible balloons used in the United States today are made from duPont's synthetic rubber latex, called "Neoprene". This latex has to be compounded with other ingredients in our plant to give it the properties necessary for good flight performance. The balloons are made by a dip process utilizing a fluted mold. This mold is first dipped into a chemical coagulant. The coagulant-coated mold is then dipped into the balloon

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(Author's manuscript received for publication 31 December 1963)

compound and is allowed to dwell in this latex to build up a rubber film to a predetermined weight. The deposited rubber, called the "gel", must then be removed from the mold. After washing, the gel is inflated with air to increase the diameter four to five-fold, and to reduce the wall thickness from .02-.03 inches to .003-.005 inches. After the gel inflation the balloon is dried at the larger diameter. After drying, the balloon is deflated and vulcanized. The vulcanization step "crosslinks" the rubber molecules in much the same fashion that the threads are woven together in our shirts. This vulcanization gives the balloon the additional strength and elongation properties which make it a useful vehicle for meteorological soundings. The balloons are then individually inflated with air and are inspected for flaws prior to packaging and shipment to the customer.

Sounding balloons are supplied as either daytime or nighttime general purpose models. The daytime balloon cannot be flown at night, for it will freeze out (become brittle) and burst prematurely near the tropopause. The nighttime general purpose balloon can be flown either in the daytime or nighttime. The nighttime general purpose balloon has had more plasticizer added to it to prevent the balloon from bursting prematurely as it encounters the cold tropopause temperatures. At night the temperature of the gas within the balloon can be 5-10°C colder than the ambient air, whereas in the daytime the temperature within the balloon may be 20-30°C warmer than the atmosphere surrounding it. With this internal heating the film does not freeze out.

"Darex" sounding balloons are available in seven basic sizes, all in both daytime and nighttime versions. In the left hand column of the table is shown the approximate finished weights of the various balloons. The dayflight balloons are lighter than the nighttime versions, due to difference in plasticizer content. In the middle column is given the burst diameter for these balloons; and in the right hand column, the altitude capability. This data has been obtained from a multitude of actual flights on which 1100 to 1300 gram radiosondes were used. The balloons range in weight from 300 to 7000 grams, have burst diameters from 12 to 57 feet, and cost from $3 up to $100. Although most of our balloon production is in fulfillment of Government contracts, balloons are available to individuals as well. To obtain the desired altitude and rate of rise with the prescribed payload, the flight needs to be properly designed. With information on payload, desired altitude, and desired rate of rise, balloon recommendations can be made with greater confidence.

TABLE 1. Darex sounding balloons

Balloon Size (gm)	Burst Diameter (feet)	Burst Altitude (feet)
300	12	56,000
600	21	89,000
700	23	95,000
900	28	105,000
2000	36	114,000
2400*	40*	120,000*
6000/7000*	57*	129,000*
1100-1300 gram load. Helium. 1000 feet per minute ascent rate or greater.		
*Limited flight data.		

The most widely used balloons at the present time are the 600, 700, and 900 gram balloons which perform to 85,000 and 100,000 feet at an 80% performance level, at least in the temperate zones. This performance varies from one season to the next and from one location to the next. Inconsistent and unreliable performance is obtained on balloons used in the Tropics and in the Polar regions. In the Tropics an extremely cold tropopause is encountered, and in the Polar regions a double inversion - one right off the surface, and the other at the tropopause. Even the general purpose nighttime balloon does not perform satisfactorily and reliably in these Tropical and Polar regions at night. Special purpose balloons for these two regions are under development at the present time. The solution is not a simple matter. When antifreeze is increased in the balloon formula to protect it through the cold temperatures, strength and elongation characteristics decrease. The properties must be balanced off to provide a balloon which can be handled in the present shelters, can be released without being torn apart in winds up to 25 knots, and still make it through this cold region. In recent tests in the Tropics we have had fair success in obtaining a balloon which meets the handling and performance requirements. Additional experimental balloons were sent to the Antarctic in 1962 for tests; the results have not yet been reported.

The spherical balloons referred to so far have ascent rates in the order of 1000-1200 feet per minute. For certain applications, faster ascent rates are desired. A two piece balloon has been developed by Dewey and Almy under Army sponsorship. It performs in the daytime to 75,000 feet at 1700 feet per minute with a total lift of 6000 grams, the balloon itself weighing approximately 2300 grams. This is the balloon that the Army refers to as an ML 541, and we call it the "streamlined" or "skirted" balloon. A conventional spherical sounding balloon with the same lift would perform to the same altitude, but at a rate of rise not exceeding 1300 feet per minute. A second balloon, the ML 566, has been developed, also under Army/Air Force sponsorship, for daytime performance to 100, 000 feet at 1700 feet per minute. This balloon weighs approximately 3000 grams and is flown with a total lift of 8500 grams. Nighttime versions of these streamline balloons have not been successful, and additional develonment work is in progress.

In the late 1950's we started development work on a radar reflective neoprene balloon under Navy sponsorship. Dipoles (aluminum foil chaff) are adhered to the inner wall of the balloon in a random fashion. These balloons have been used at some of the missile tracking stations for obtaining accurate wind data rapidly, using available radar equipment. The 100 gram balloons have been used extensively, and the larger size sounding balloons have been used in limited tests. These balloons are available in sizes from the 30 gram pilot balloon up through the 2000 gram sounding balloon. A word of caution here, in that these Rabals are not satisfactory with just any radar set, and I cannot say which sets don't work with these balloons. Thus far it has been mainly trial and error at certain stations to determine if the Rabal balloons will work with the available radar set. If a radar set is available that can be used adequately with these balloons, it eliminates the need for the crews to man the theodolites which are used to visually track the pilot balloons to obtain this wind data.

In the realm of constant level ballooning, there is a constant level neoprene balloon that can be used for loads up to 10 pounds for performance to 110, 000 feet. These spherical constant level balloons contain a flapper valve which is tape operated. The operation is controlled by the diameter of the balloon. Constant level balloons have been flown in the daytime and also at night. They cannot fly through a sunset, for they are zero pressure balloons and do not carry ballast. In operation the balloon valves off the free lift at floating altitude, leaving only sufficient gas in the balloon to hold the balloon and payload at altitude. As the gas temperature within the balloon drops at night, there is no longer sufficient lift in the balloon to maintain it and its payload at the constant altitude. To obtain the longest flight, the balloon should be released after dark. The balloon can fly through a sunrise, more gas being valved off as it heats and expands. Flight durations as long as 12 hours have been obtained with this balloon. These balloons are quite small at release (5-7 feet), have ascent rates of approximately 1100 feet per minute, and are available in the seven sounding balloon sizes. Once again, to design a flight, the payload, floating altitude, rate of rise, and time of day of the flight need to be known.

Higher and more reliable balloon performance is much in demand these days, and a great deal is being done in research to improve the balloon films. Other phases of the balloon operation need attention to obtain the maximum altitudes from these balloons. The film is tender; it is only .003" to .005" thick, it is easily damaged, and it has low tear resistance. Improved performance can be obtained by careful handling. Because some of you may now be involved with these balloons or may become involved with them in the future, I have the following comments on balloon handling.

The storage of the balloon is important. Most balloons today do not need to be conditioned prior to flight so long as they are less than a year old and have been stored at temperatures warmer than 35°F. If the balloons have been stored at a temperature lower than 35°F, they should be brought back to 65-100°F for a minimum of 48 hours, and preferably a week, prior to flight. If storage at the 65-100°F temperature is not possible, it is then best to revert to the high humidity oven conditioning of balloons at 160-180°F. Balloons that are more than a year old should be conditioned for a minimum of 12 hours in a hot, humid chamber. If the chamber is not available, the boiling water technique - even with its hazards - is probably better than nothing at all. More information on aging and conditioning is being generated each year. Many improvements have been made in balloon compounds, reducing the need for conditioning. Periodically I am asked about diesel oil treatment of balloon films, and in most cases I would not recommend this treatment.

Care needs to be exercised even in opening the box containing the balloon. A blunt object should be used to slit the top tape. The balloons fit snugly in the boxes, and if a sharp object is used it is very easy to cut into the balloon film. The balloon in its bag should then be simply dumped out of the box onto the balloon inflation table. At the present time most of the sounding balloons are being packaged in heat-sealed plastic bags, although some still are being packaged in paper bags. With the paper bag it is best to tear the bag open from the mouth to the bottom and let the balloon roll out of the bag onto the inflation table, handling the balloon as little as possible. If it is necessary to handle the balloon, cotton or rubber gloves should be used. With the plastic bag, there is a "Tear Here" slit which makes opening this bag easier. Again, with this package, let the balloon roll out onto the table, holding onto the corners of the plastic bag to tip the balloon out so as not to snag the balloon.

A balloon inflation table is extremely useful to prevent damage to the balloon during preparation for flight. The Air Force Cambridge Research Test Facility at Bedford, Massachusetts, designed and built an aluminum frame mounted on casters to which has been lashed a canvas top. It is easy to tilt this balloon table on its side to facilitate cleaning the surface on which the balloon will be put. There are many other table constructions which might be recommended. Several stations use a plywood sheet on top of which has been put a canvas or plastic sheet to protect the balloon from splinters. The practice of laying the balloon out on the concrete floor should never be permitted. The change that this balloon film undergoes in flight is quite spectacular: when released, the balloon is .003-.005 inch thick, and by the time it gets to 100,000 feet the film is .0002 inch thick. At this thinness, a slight surface flaw can shorten the flight appreciably. The balloon inflation table is a means of minimizing the possibility of damage to the film.

While discussing balloon inflation equipment, the Canadian Department of Transport has a very neat, compact, easy-to-use balloon weigh-off nozzle which can be used to give accurate weigh-offs. It eliminates the need to counterbalance the weight of the hose, as is necessary in the U.S. Army and Weather Bureau nozzles. Drawings of this nozzle are available.

Much remains to be done in the way of neoprene balloon research to obtain reliable, consistent performance to 150,000 feet with a balloon which can be purchased at sufficiently low price so it can be used operationally. This work is in progress, and we hope in the next few years to be able to answer this need for higher altitudes. In our research facility a cold temperature burst chamber is used for evaluating small scale balloons made from new compounds. Also, an ozone chamber is used to study the ozone resistance of the new films. In addition to this film study work on neoprene balloons, we also hope to have answers to the fast rising balloon problem, so that, instead of taking 100 minutes to fly to 100,000 feet with a spherical balloon, this same altitude can be reached with a new type of balloon in 50 minutes without prohibitive costs or handling problems.

This discussion has been confined to vertical sounding neoprene balloons. Another method for studying our atmosphere is the Horizontal Sounding System, which has been referred to previously as the Global Horizontal Sounding Technique (or GHOST), and which has also been unofficially referred to as the STROBE concept. In the Horizontal Sounding System, constant level superpressure plastic balloons would circle the globe and transmit their meteorological data to either ground receiving stations or to orbiting satellites. Feasibility studies on this concept are underway at the present time under NASA sponsorship. At Dewey and Almy we are researching one phase of this system, the development of a one-seam superpressure constant level plastic balloon which is capable of long flight durations at predetermined altitudes. Our progress was described at the American Meteorological Society in a paper delivered in January 1962. We are still working on the project, and are making progress toward having a balloon ready for more extensive tests in 1964. Balloons up to 15 feet in diameter and capable of carrying a two pound load to 70,000 feet are being developed. Much work remains to be done on equipment for the GHOST System - on the plastic balloons themselves, the electronic equipment needed with the balloons, the satellites, and the read-out stations.

2. SUMMARY

Continual progress, then, is being made toward the improvement of neoprene balloons to keep pace with improvements in conventional sounding methods and in the development of entirely new balloons, both neoprene and plastic, for use in advanced techniques which will extend our knowledge of the atmosphere.

XVI Sensing Elements for the Balloon Environment

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Abstract

Sensing devices selected to measure the parameters of the balloon environment must not only give the desired accuracy but must also have an output compatible with the transmitting or recording instrumentation. The essential characteristic data of some sensing devices for three important parameters, temperature, pressure and rate of climb, are compiled in the following tables.

1. TEMPERATURE

In measuring the temperature of the ambient air, in order to hold the radiation error below the desirable accuracy level it is necessary to minimize the radiative heat exchange between the probe and the atmospheric radiation field. Table 1, column 6 shows the maximum radiation errors for four thermistors and two tungsten wire sensors when they are suspended in air at 2 mb pressure and -50°C in the daytime. The correlation between sensor size and the radiation error is obvious. But the power limit for the sensing devices also decreases with size (columns 4 and 5), and sensors with the highest accuracy can tolerate only very small measuring currents. The choice of proper sensor type must be governed by the value of the measuring current from the recording instrument. The rod thermistor can carry a large sensing current but because of its large radiation error it should only be used at a pressure level higher than 50 mb and with sufficient ventilation. The wire sensors have the smallest radiation error, but their small transfer coefficient, 0.4%, (column 3), requires the measuring equipment to have a much higher sensitivity then is needed when thermistors are being used.

The heat exchange between the balloon skin and the ambient air produces a layer of air around the balloon with a temperature quite different from the ambient air, Figure 1. In the nighttime this air layer is colder and drains downward, causing

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TABLE 1. Temperature

	OUTPUT	TRANSFER FUNCTION	POWER LIMIT SELF-HEATING $\leq .2°C$	PULSE POWER LIMIT	RADIATION ERROR	ACCURACY OF MEASURING EQUIPMENT
THERMISTOR BEAD 0.42" Dia. Alu coated	Resistance 1KΩ-10MΩ	Transfer Coeff. 4%/°C $R = R_o \cdot e^{B}\left(\frac{1}{T}-\frac{1}{T}\right)$	$1.5 \cdot 10^{-5}$ Watt	$3 \cdot 10^{-6}$ Watt sec	2.2°C	1 part in 250
THERMISTOR BEAD 0.14" Dia. Alu coated	Resistance 1KΩ-10MΩ	Transfer Coeff. 4%/°C $R = R_o \cdot e^{B}\left(\frac{1}{T}-\frac{1}{T}\right)$	$5 \cdot 10^{-6}$ Watt	$2.4 \cdot 10^{-5}$ Watt sec	1.0°C	1 part in 250
THERMISTOR BEAD 0.07" Dia. Alu coated	Resistance 1KΩ-10MΩ	Transfer Coeff. 4%/°C $R = R_o \cdot e^{B}\left(\frac{1}{T}-\frac{1}{T}\right)$	$2.5 \cdot 10^{-6}$ Watt	$7 \cdot 10^{-4}$ Watt sec	0.5°C	1 part in 250
THERMISTOR ROD 0.10" Dia. Alu coated	Resistance 1KΩ-10MΩ	Transfer Coeff. 4%/°C $R = R_o \cdot e^{B}\left(\frac{1}{T}-\frac{1}{T}\right)$	$5 \cdot 10^{-5}$ $\frac{\text{Watt}}{\text{inch}}$	$8 \cdot 10^{-4}$ $\frac{\text{Watt sec}}{\text{inch}}$	3.3°C	1 part in 250
TUNGSTEN WIRE $3 \cdot 10^{-4}$" Dia. Alu coated	Resistance 28 Ω/inch	Transfer Coeff. 0.4%/°C Linear	$3 \cdot 10^{-5}$ $\frac{\text{Watt}}{\text{inch}}$	$7 \cdot 10^{-11}$ $\frac{\text{Watt sec}}{\text{inch}}$	0.3°C	1 part in 2000
TUNGSTEN WIRE $1 \cdot 10^{-4}$" Dia. polished	Resistance 260 Ω/inch	Transfer Coeff. 0.4%/°C Linear	$2 \cdot 10^{-5}$ $\frac{\text{Watt}}{\text{inch}}$	$2.6 \cdot 10^{-12}$ $\frac{\text{Watt sec}}{\text{inch}}$	0.2°C	1 part in 2000

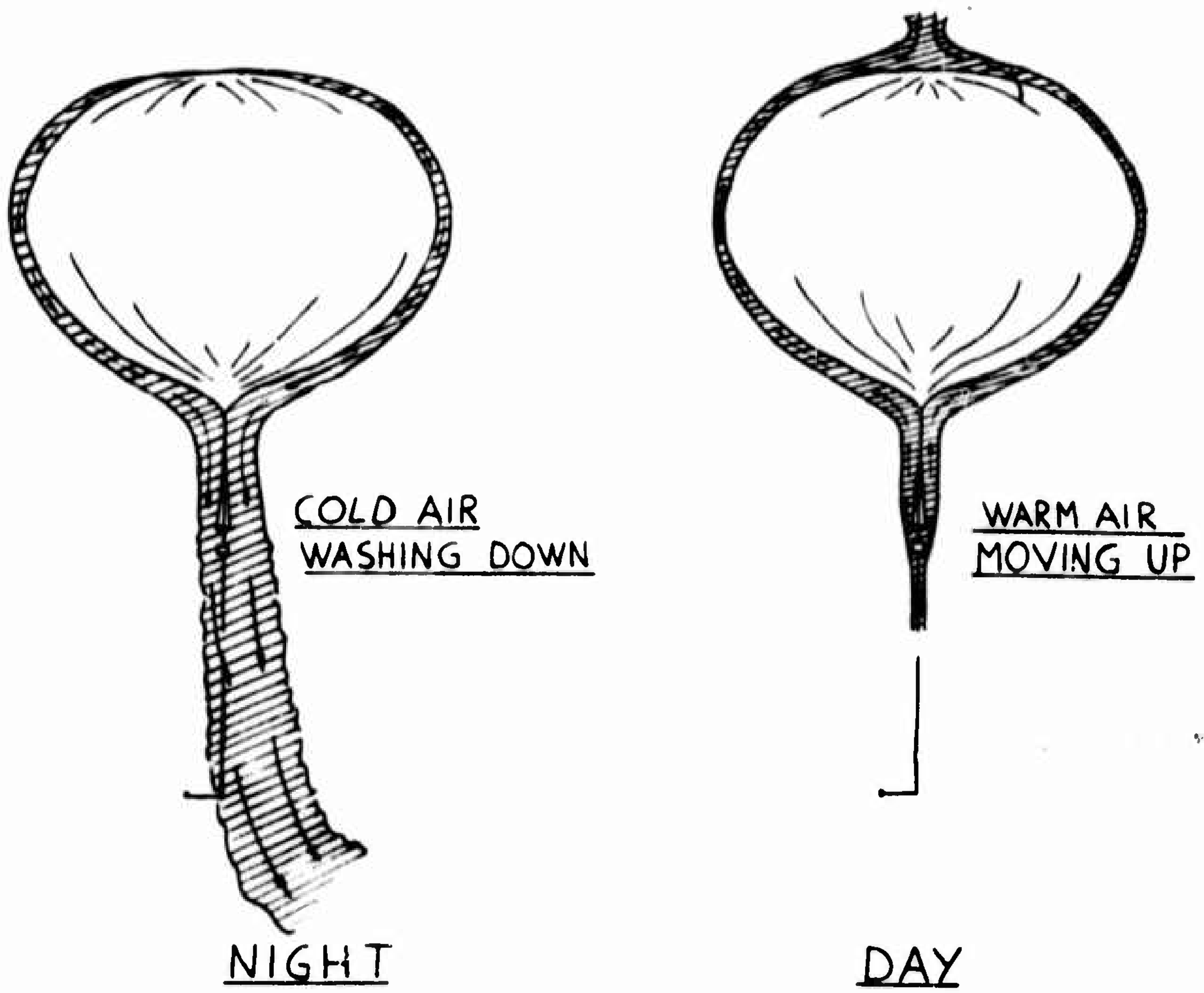

Figure 1. Balloon at Floating Altitude

the temperature around the gondola to drop considerably. In the wake of a slowly rising balloon, the daytime temperature of the air layer may rise 10° to 20°C or more above the ambient temperature. Several hundred feet below the gondola the temperature is usually undisturbed. Bulky holding brackets for the sensing devices can also exchange significant quantities of heat with the surrounding air and so introduce appreciable errors in temperature measurements.

2. PRESSURE

The pressure altitude measurement is often needed with an accuracy of 1 part in 2000 or better. This usually requires a pulse code transmission with an information content of more than 2000 bits. In Table 2 the characteristics of a number of pressure sensors are listed. The most frequently used pressure sensing device is

TABLE 2. Pressure

	OUTPUT	TRANSFER FUNCTION	HYSTERESIS	RESOLUTION	ACCURACY OF MEASURING EQUIPMENT	REMARKS
ANEROID	DISPLACEMENT 0 to 6 mm	LINEAR OR SLIGHTLY UNLINEAR	2 to 10 mb 0.25 to 2% FS	INFINITE		
ANEROID with OVERTRAVEL STOP	DISPLACEMENT 0 to 6 mm	LINEAR OR SLIGHTLY UNLINEAR	0.7 to 1.5 mb 0.4 to 1.5% FS	INFINITE		
ANEROID POTENTIO-METER	RESISTANCE	LINEAR OR SLIGHTLY UNLINEAR	0.3 to 2% FS	1 PART IN 300 TO 500	1 PART IN 500	
ANEROID WIRE STRAINGAGE	DC or AC VOLTAGE 1-3 mv/v	LINEAR OR SLIGHTLY UNLINEAR	0.3 to 2% FS	INFINITE	1 PART IN 500	
ANEROID with SOLID STATE STRAINGAGE	DC or AC VOLTAGE 20-30 mv/v	LINEAR OR SLIGHTLY UNLINEAR	0.3 to 2% FS	INFINITE	1 PART IN 500	
ANEROID with VARIABLE INDUCTANCE	AC VOLTAGE 5 mv/v	LINEAR OR SLIGHTLY UNLINEAR	0.3 to 2 % FS	INFINITE	1 PART IN 500	
BAROCODER	SEQUENTIAL PULSE CODE	STEP FUNCTION	2 STEPS 1% FS	1 PART IN 212		
PRESTRESSED DIAPHRAGM	RESISTANCE OR SHAFT-POSITION	LINEAR	0.5 mb .05% FS	1 PART IN 5000 TO INFINITY	1 PART IN 5000	$1500

TABLE 2., Continued

	OUTPUT	TRANSFER FUNCTION	HYSTERESIS	RESOLUTION	ACCURACY OF MEASURING EQUIPMENT	REMARKS
BALANCED FORCE TRANSDUCER	CAPACITY	LINEAR	.07 mb	INFINITY	1 PART IN 5000	$2500 TO 3000
QUARTZ BOURDON TUBE TRANSDUCER	SHAFT-POSITION	LINEAR	NONE	INFINITY	1 PART IN 20,000	$3000
ALPHATRON NRC 717,718	PULSE FREQUENCY 2 PPS TO 1800 PPS	NONLINEAR	NONE	1 PART IN 1500		AEC LICENSE REQUIRED
HYPSOMETER RADIOSONDE TYPE	RESISTANCE 16 K OHM TO 400 K OHM	LOG R NEARLY LINEAR WITH ALTITUDE	NONE	1% OF THE READING	1 PART IN 5000	55mb TO 1.5mb RISING BALLOON ONLY
HYPSOMETER TYPE 225	RESISTANCE 1 K OHM TO 200 K OHM	LOG R NEARLY LINEAR WITH ALTITUDE	NONE	0.5% OF THE READING	1 PART IN 5000	1000mb TO 2mb MINIMUM DURATION 7 DAYS

the corrugated diaphragm, or aneroid, either the full range aneroid, Table 2, row 1, or the low pressure type with an inside stop that permits expansion to start only when the pressure is lower than some preset value, usually 60 to 100 mb.

Constant mechanical strain produces creep in the wall material of these instruments and the creep causes a drift in the zero point, the so-called hysteresis shown in column 4. These hysteresis data together with the corresponding resolution values given in column 5 show that aneroids cannot be used for the pressure altitude accuracy mentioned above.

Aneroids are used in combinations with all kinds of displacement transducers, some of which are listed in Table 2, rows 3, 4, 5 and 6. The potentiometer type has the additional disadvantages that the wiper friction causes an additional hysteresis error, and the resolution is limited by the number of wire windings.

The baracoder is a pressure transducer with a self-contained measuring device. Its output is a pulse code. The resolution is limited, but types are available with two outputs for two different ranges.

Although work to improve the aneroids is still going on, it can be expected that as high altitude altimeters they will gradually be replaced by more sophisticated sensors such as those listed in Table 2, rows 8 through 13. The prestressed diaphragm is especially attractive because of its inherently stable zero point and transfer coefficient. The strain perpendicular to the diaphragm is so small compared to the radial strain that the resulting hysteresis is negligible. At present the prestressed diaphragm type transducers are quite expensive but it is possible that sometime more economical models will appear on the market. The pressure balance type altimeter is anotner alternative to overcome the hysteresis problem, but it, too, is quite expensive. A nearly ideal transducer is the quartz Bourdon tube. With no hysteresis, no change in sensitivity and an accuracy in the order of 0.02 mb over the entire range, this device offers more advantages than any other sensing element but its price is also quite high.

The problem in using each of these three last-named transducers is that their resolution is higher than that of the usual measuring instrumentation, and they require a servo-mechanism to convert the output into a shaft rotation. In this way the output can be digitized into a sufficient number of bits to contain the full information content of the measurement.

In the alphatron we have a completely different type of pressure transducer. This unit is attractive for the altitude range above 130 kilofeet, and for high rates of pressure change, for example, for dropsondes. It requires a second information channel for the measurement of the inside temperature. The alphatron cannot be used when the payload will not be recovered because of the regulations concerning the radioactive material.

Next on the list is the radiosonde hypsometer. Its range is limited but the accuracy is good. It can only be used when the rate of climb is above a certain positive value. No input power is required.

For constant level balloons we have developed the hypsometer models 224 and 225. They have a good accuracy and can be flown for a week or longer if the package temperature is at least 30°C below the boiling temperature of the liquid used in the hypsometer. These instruments will be described in section 4.

3. RATE OF PRESSURE CHANGE TRANSDUCER

Table 3 gives four different types of rate of climb transducers. The time constants of most of these transducers are proportional to the reciprocal of the pressure and are impractically long for high altitude measurements. The upper limit of the useful altitude range is therefore about 60,000 to 70,000 feet. The stretched diaphragm and aneroid force balance type transducers are quite expensive.

4. HYPSOMETER, TYPE 225

Figure 2 shows a cross section of the hypsometer type 225. The liquid, normal butylbenzene, is kept boiling in a vacuum flask by a heater coil. The coil is wound around a glass fiber wick. At the top of this wick are mounted two thermistors that sense the temperature of the vapor. The vapor can escape through a nipple at the top of the housing, but most of it condenses on the way up and returns as liquid to the reservoir. Figure 3 shows the relationship between boiling temperature and vapor pressure of two liquids that have been used for hypsometers. For the higher altitude range one has to use the liquid with the higher boiling temperatures. The resistance of the bead thermistor varies with the boiling temperature which, in turn, is a measure of the pressure. Then the standard atmosphere gives a relationship between pressure and altitude. These three functions are related in such a way that the logarithm of the output resistance is nearly proportional to the altitude, Figure 4. The accuracy of the hypsometer itself is shown in Curve A of Figure 5. Curves B and C give the high and low pressure accuracy of the combination of hypsometer with measuring equipment that has a resolution and accuracy of 200 ohms. It can be seen that there is considerably lower error and better resolution at the higher altitude portion of curves B and C than at the lower ranges.
It is possible to spread the resolution somewhat more uniformly over the upper range of altitudes by choosing a higher value resistance bead and connecting a fixed resistor in parallel with it, Curve D.

TABLE 3. Rate of climb transducer

	RANGE	OUTPUT	TRANSFER FUNCTION	ACCURACY	TIME CONSTANT			
					SEA LEVEL	30 K FT	60 K FT	90 K FT
THERMISTOR TYPE	30 K FT	VOLTAGE	LINEAR	30 - 50%	10 SEC	30 SEC		
ANEROID TYPE	70 K FT	SYNCHRO MOTOR SHAFT POSITION	LINEAR	5 - 10%	5 SEC	15 SEC	60 SEC	
STRETCHED DIAPHRAGM TYPE	100 K FT	VOLTAGE	LINEAR	5 - 15%	.1 SEC	.33 SEC	1.4 SEC	6 SEC
ANEROID FORCE BALANCE TYPE	60 K FT	SERVO SYSTEM SHAFT POSITION	LINEAR	10%	.1 SEC	.33 SEC	1.4 SEC	

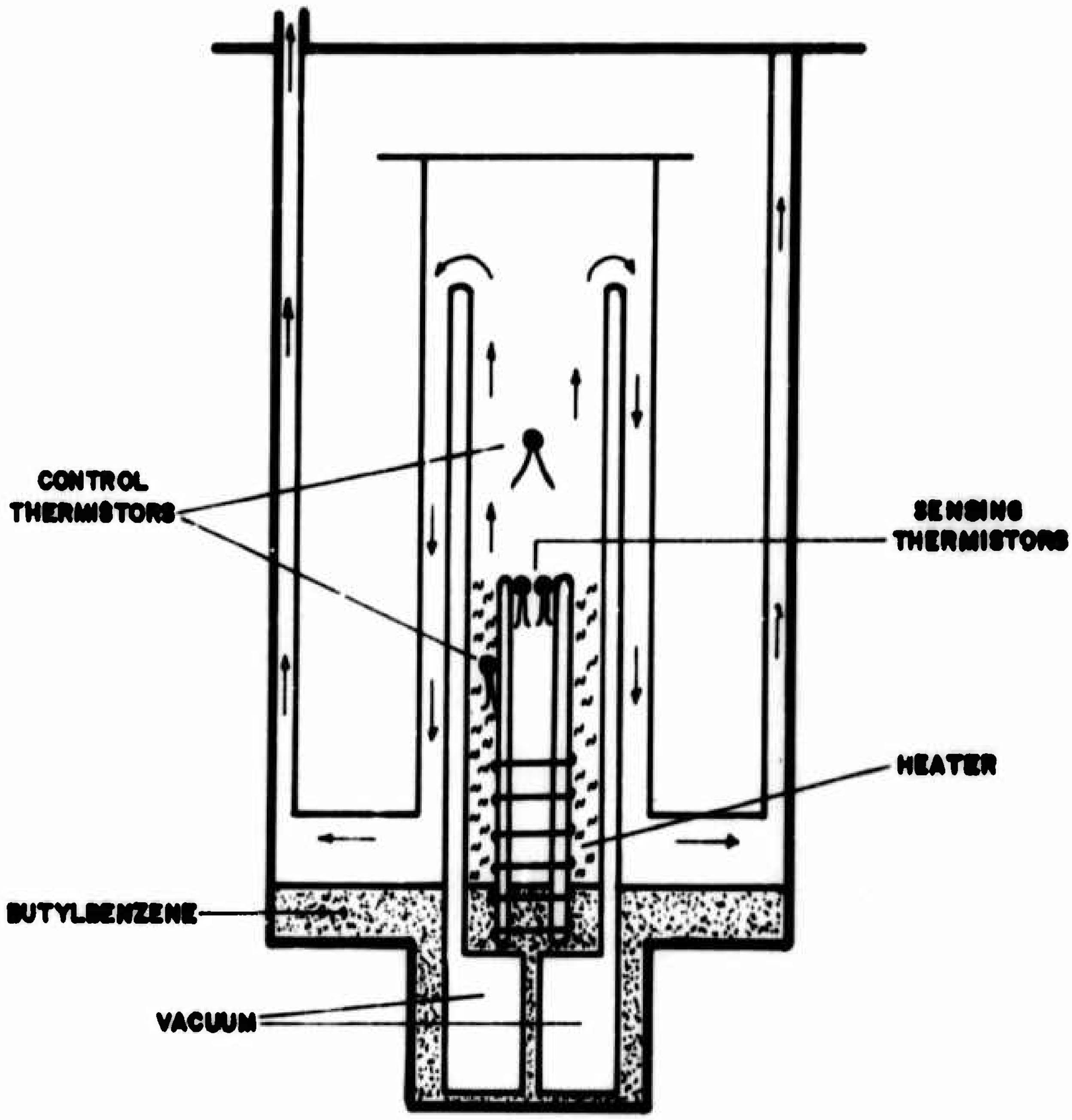

Figure 2. Hypsometer - Type 225

The theoretical upper altitude limit for the use of the hypsometer is surely much higher than the balloon will ever reach! In practice, however, there must always be enough cooling available to guarantee condensation of the vapor in order to keep the supply of liquid replenished during the desired period of operation. In wintertime the ambient temperature may be low enough for this purpose, but in summertime, at 50 km altitudes the ambient temperature may rise to 20°C or higher. However, this problem can be solved using thermoelectric cooling devices or other techniques.

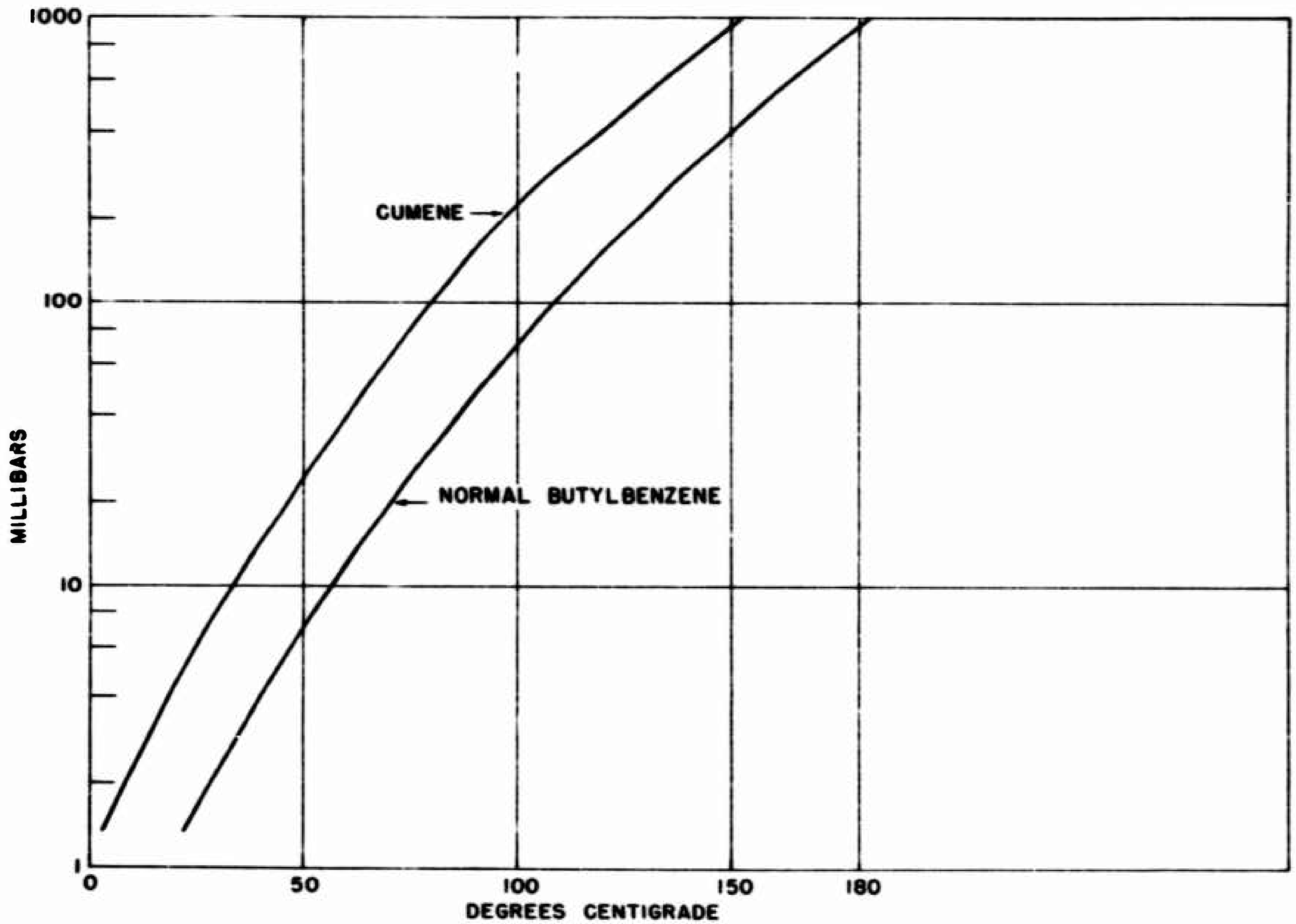

Figure 3. Boiling Temperature of Cumene and Normal Butylbenzene

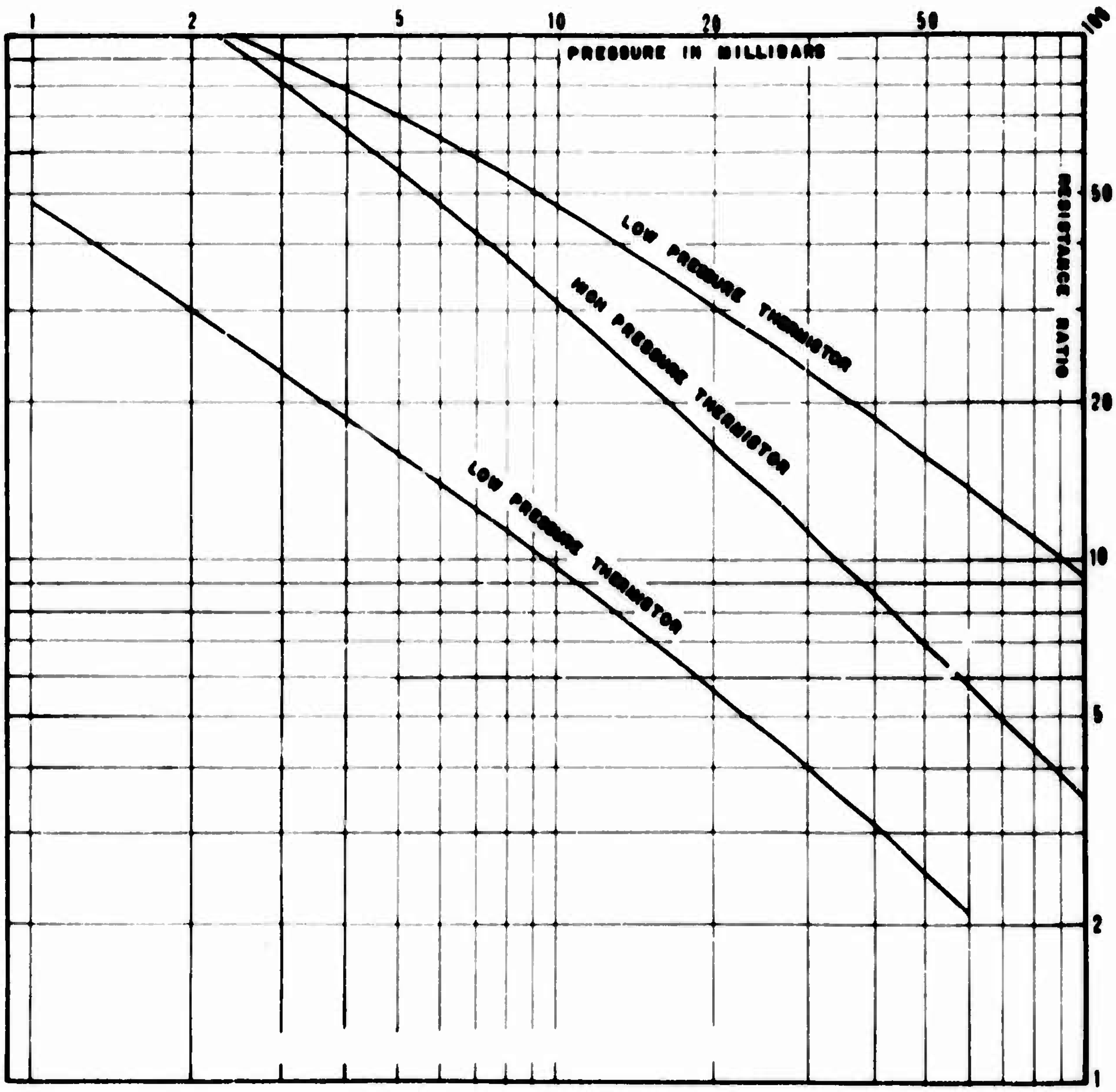

Figure 4. Calibration of Hypsometer Model 225

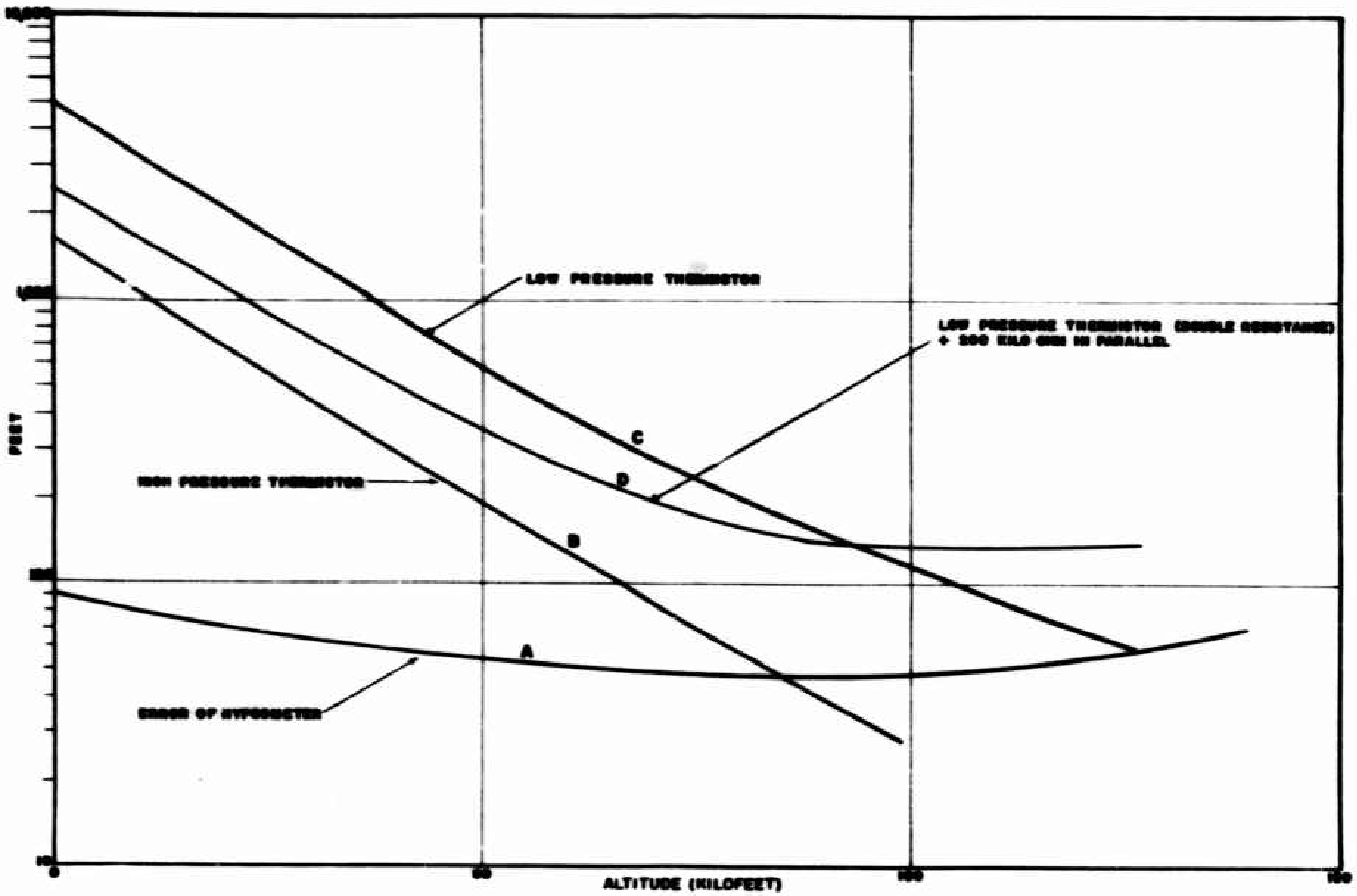

Figure 5. Error of Hypsometer Type 225

XVII Scientific Aspects of Stargazer

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Abstract

The manned Stargazer balloon flight (13 December 1962) and its experimental payload are described. The experiments were developed on the basis of establishing the feasibility of astronomical research from manned balloon-borne vehicles. The developments in testing of the instruments to carry out the experiments are discussed. The experience in handling the scientific equipment during the above flight is described.

1. INTRODUCTION

The purpose of the Stargazer program was to test the feasibility of doing astronomical research from a manned balloon borne vehicle In accordance with this, the telescope control system was designed to allow the observer to point it at a star and keep the star in the field of an optical link to a degree sufficient to allow a star tracker to lock on the star. The experiments were designed to test the probable reduction of atmospheric interference with astronomical observations. Scintillation, variation in the intensity of light from a star due to atmospheric turbulence at great distances from the telescope; seeing, distortion and motion of the star image due to atmospheric turbulence in the vicinity of the telescope; and the infrared absorption of star light by water vapor were the phenomena chosen to be studied.

The Stargazer program was initiated at the Smithsonian Astrophysical Observatory by the Air Force Office of Scientific Research. Later, the program was under the sponsorship of the Air Force Cambridge Research Laboratories and the scientific portion was conducted at Dearborn Observatory, Northwestern University. In association with Dearborn Observatory, the Experimental Astronomy Laboratory of the Massachusetts Institute of Technology was responsible for the

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telescope mounting and stabilization system. The Naval Ordnance Test Station furnished a scientific assistant and technical assistance in the design and construction of instruments to Dearborn Observatory. Wright-Patterson Air Force Base was responsible for the gondola and its fittings and the high altitude indoctrination of the observer. The R&D test branch of AFCRL was responsible for the launching at Holloman AFB, New Mexico.

1.1 Telescope

The telescope was a Cassegrain reflector. The primary mirror was 12 inches in diameter and the effective focal length was approximately 120 inches. The Cassegrain secondary mirror support system was designed and built by Ferson Optical Company. By a combination of Invar and aluminum components the focal point was held to within ± 0.001 inch over a temperature range of -60°C to +70°C.

A complete description of the telescope mounting and stabilization system is not a purpose of this paper. However, some discussion of its tracking limits is appropriate. The basic platform was gyro-stabilized to several minutes of arc with a two-gimbal system (elevation and train). Additional tracking to one minute of arc or better was accomplished by a star tracker.

A mirror was mounted under the main telescope. Its rotation in elevation was synchronized with motion of the main telescope so that light from the direction in which the telescope was pointed was directed through a porthole in the top of the gondola to the observer via an "optical link". This optical link consisted of an objective, relay lenses, and a wide-angle eyepiece. The field at the eyepiece was approximately 10°.

Figure 1 shows the telescope mounted on the gondola.

1.2 Design of Experiments

Scintillation, seeing, and interference by absorption of light by water vapor were to be studied by a photoelectric photometer, motion picture camera and infrared photometer, respectively. The above instruments were housed in a compartment mounted on the back of the telescope (see Fig. 1). They were mounted on a plate which was rotated to position the particular instrument in the focal plane of the telescope. Figure 2 shows the configuration of the experiments. Figure 3 is a block diagram of the experiments and associated circuitry.

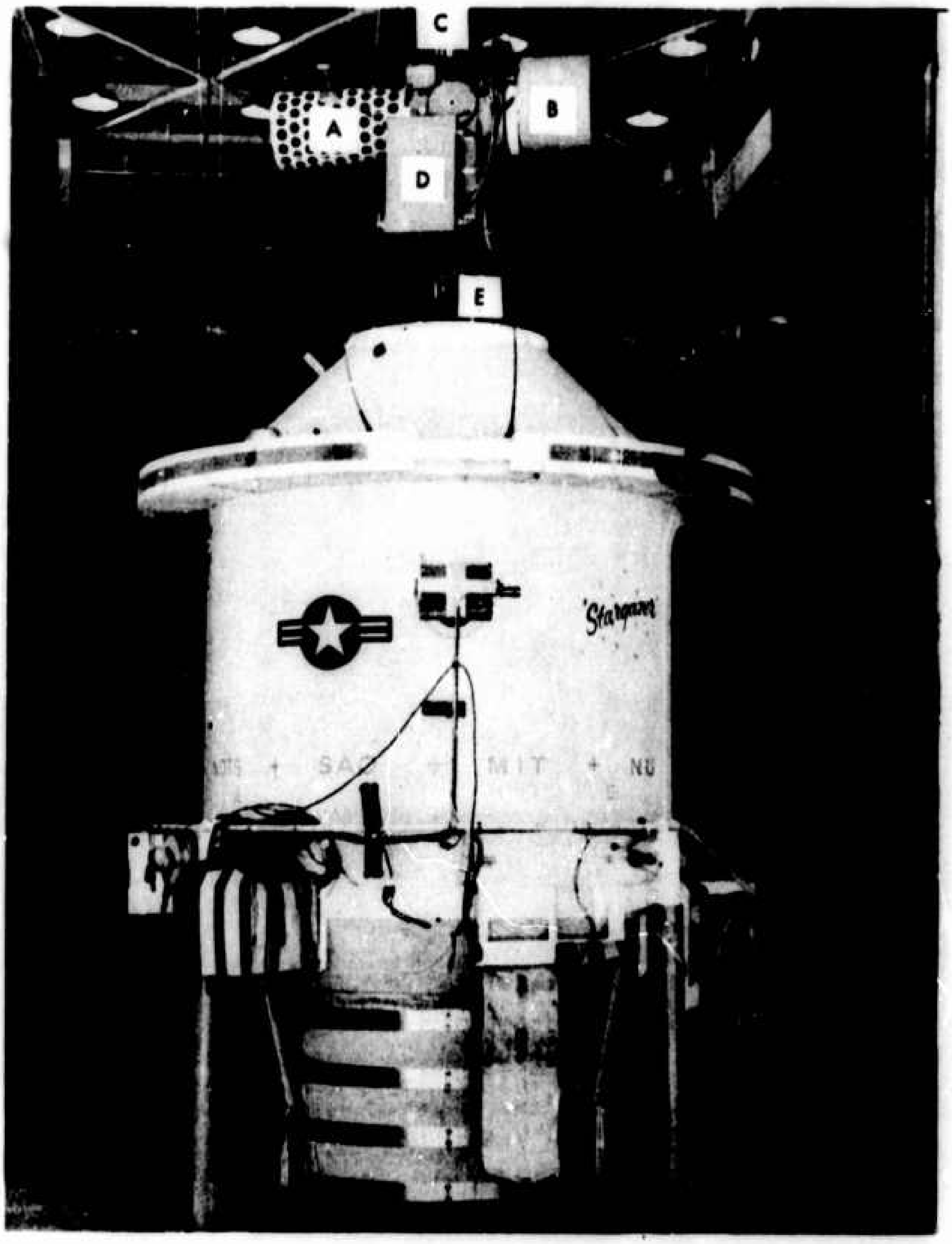

Figure 1. Telescope Mounted on Gondola. Forward Portion of Telescope, A. Experiment Compartment, B. Star Tracker, C. Stabilization Electronics Package, D. Base of Mounting, E.

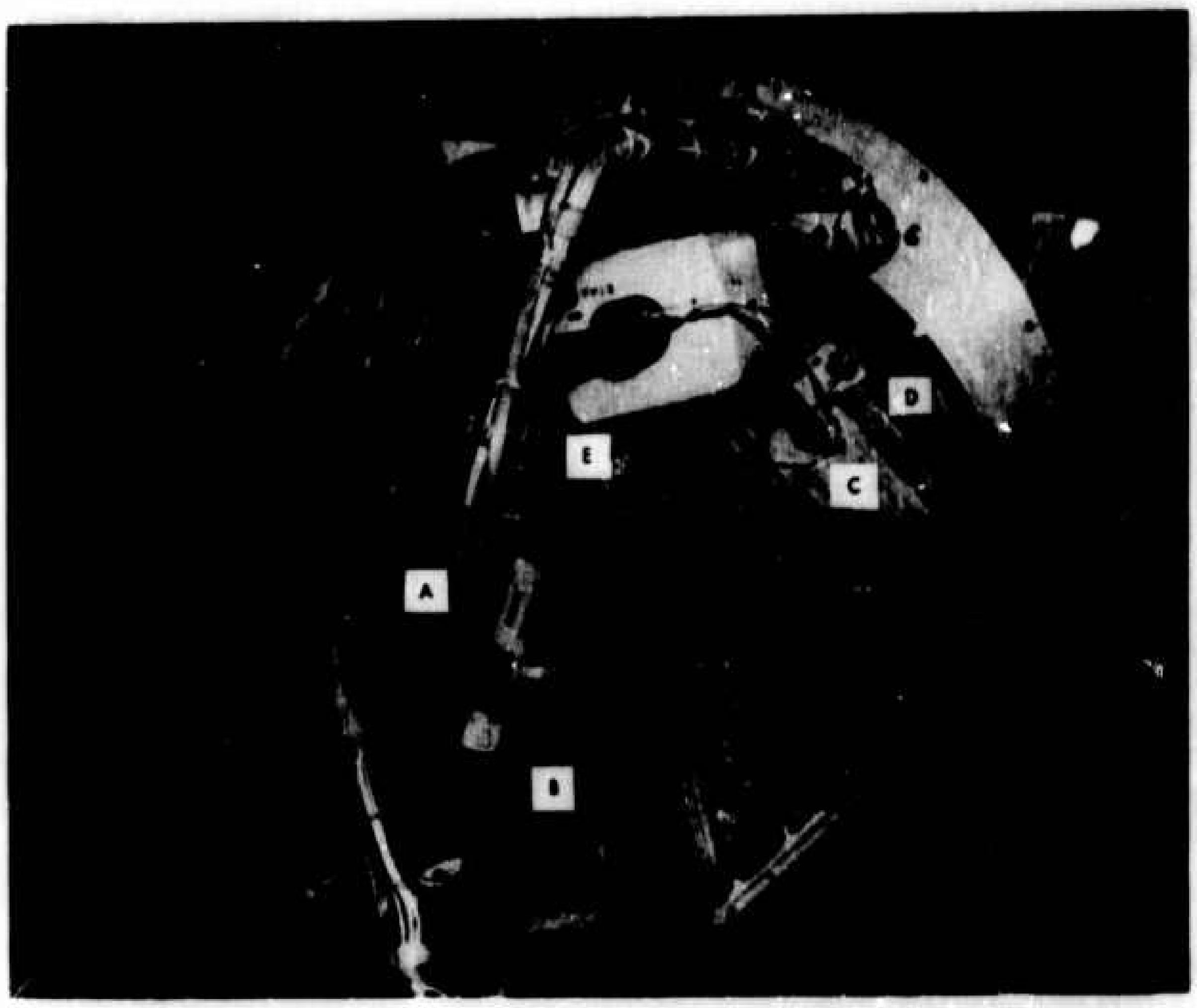

Figure 2. Interior of the Experiment Compartment. Scintillation Photometer, A. Camera, B. Infrared Photometer, C. Rotating Plate, D. Motor Drive, E.

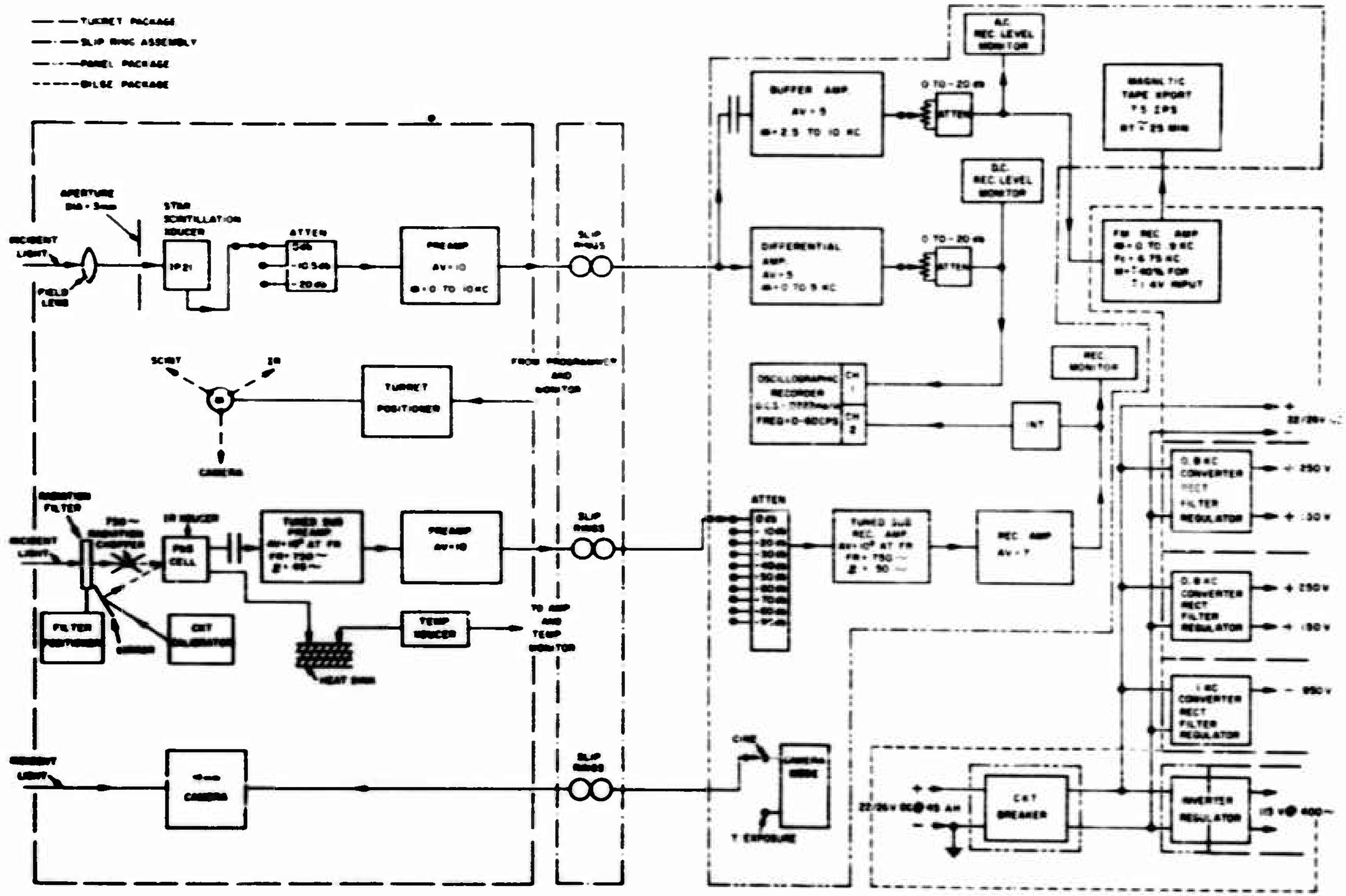

Figure 3. Block Diagram of Photometers and Camera With the Associated Circuitry.

The scintillation photometer was similar to those conventionally used for astronomical photometry. The signal from the detector (an RCA IP-28) was pre-amplified and split into AC and DC components. These were further amplified and recorded on an Ampex missile tape recorder and a Century Oscillograph, respectively. The recorded frequency range of the AC channel was 2.5 cps to 1000 cps. Both channels were calibrated with a DC and rms voltage, respectively, to allow a direct comparison of the scintillation signal with the intensity of the light from a star. In addition frequency response and linearity checks were performed. A test of the detector and electronic noise was performed with a tungsten lamp. The light from the lamp impinging on photomultiplier was varied and the output DC signal monitored. At the same time, the AC signal was recorded. Upon analysis, it was found that the noise was negligible in comparison with stellar scintillation.

For discussion of scintillation and additional references see: "The Present and Future of the Telescope of Moderate Size" published by the University of Pennsylvania Press (1958) and edited by Frank Bradshaw Wood which has two articles on the subject: "Photoelectric Studies of the Scintillation of Starlight" by W. M. Protheroe and "Our Knowledge of the Upper Atmosphere from Studies of the Scintillation of Visible Starlight" by G. Keller. A report (AFCRC-TN-57-237) by Roger Hosfeld and J. Allen Hynek entitled, "Field Test of Directional Scintillation" discusses correlations of scintillation with winds between altitudes of 15,000 and 45,000 feet.

A secondary experiment was devised for the photoelectric photometer. This experiment was designed to establish the feasibility of obtaining nighttime ozone concentrations and distribution with altitude by monitoring the near ultraviolet radiation from stars. The RCA IP-28 photomultiplier mentioned above was used because of its sensitivity to ultraviolet light. Filters with peak transmission at 3300 A and 3600 A were installed in a filter wheel in the photometer to compare a region of ozone absorption (Hartley and Huggins ozone bands) with clear wavelength, respectively. The filter wheel could be sequenced by the observer in such a way that a no filter, open position could be used for observations of scintillation, two broad-band and two narrow-band filters for the ultraviolet observations, and an opaque position for dark current readings.

A KD-7 Bell & Howell 16-mm motion picture camera was used for the seeing experiment. An out-of-focus star image was photographed at 12 fps. These photographs were examined for the presence and size of structural detail and the changes therein.

The infrared photometer consists of a filter wheel, a 750 cps chopper and a 1.8 mm × 1.8 mm PbS cell immersed in strontium titanate. The filter wheel has six positions: no filter, 1-3 μ pass filter, 1.5-1.8 μ pass filter, 2.1-2.5 μ pass filter, 2.5-3.0 μ pass filter (filter plus PbS cutoff) and an opaque position for dark current readings. The second and fourth filters are set for region of water vapor and absorptions. The signal was pre-amplified by a 50 cps tuned amplifier and further amplified and filtered with a 50 cps filter. It is then recorded by the Century Oscillograph. A small tungsten lamp was mounted in the photometer and diffuse light from it could be used to monitor changes in sensitivity of the PbS cell. As in the case of the photoelectric photometer, appropriate calibrations of response and tests of linearity were performed. Figure 4 shows the observer's panels.

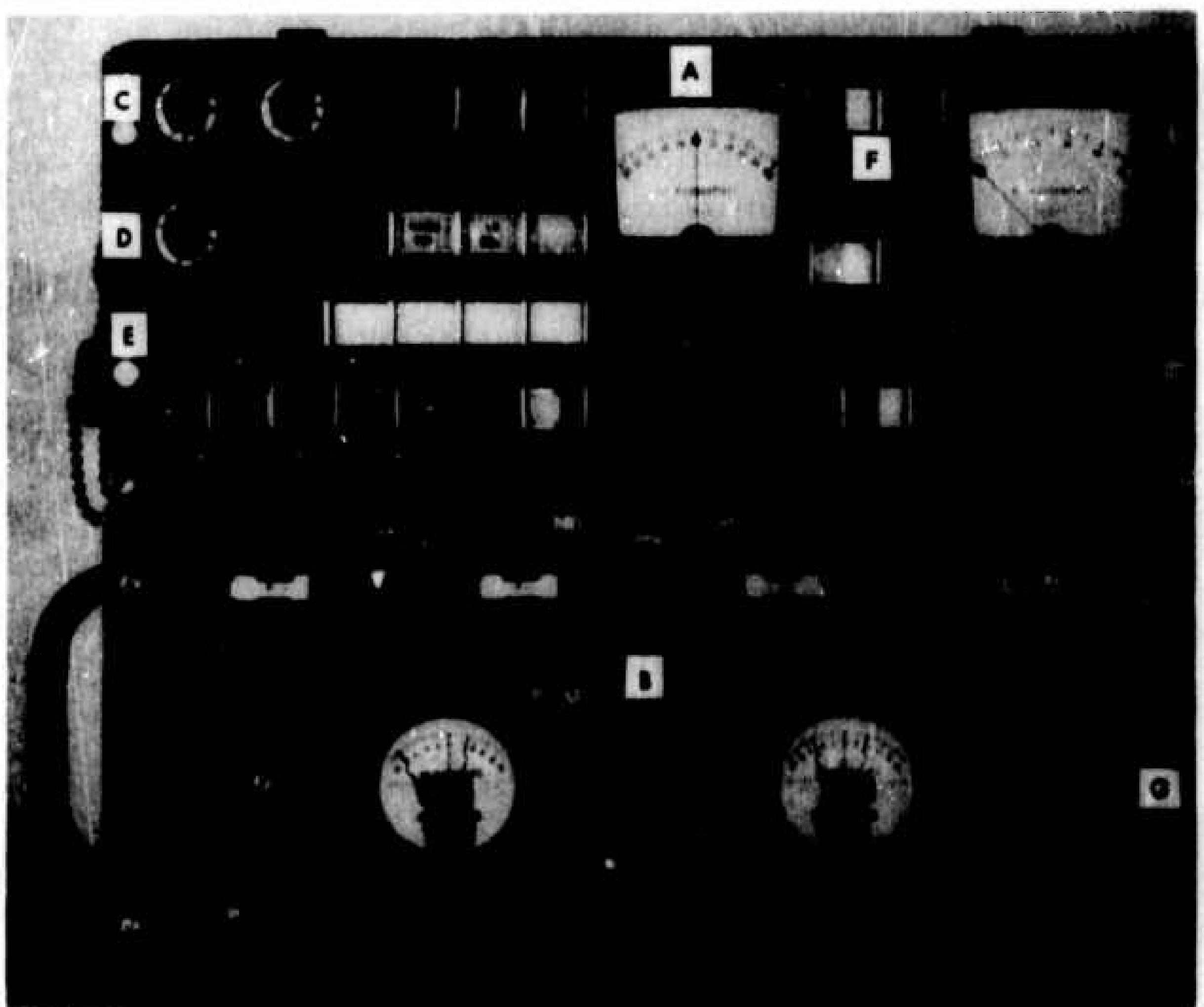

Figure 4. Observer's Panels. Panel to Operate Experiments, A. Panel to Operate Telescope, B. Scintillation Photometer Controls, C. Infrared Photometer Controls, D. Camera Controls, E. Recorder Controls, F. Elevation Angle Dial, G.

Some reference on infrared stellar photometry are: from a publication cited before, "An Infrared Technique for Stellar Photometry" by D. J. Lovell and G. R. Muzallia; and "Stellar Irradiance Measurements," final report of ITT Federal Laboratories of January 1963. The latter report includes an excellent bibliography of recent and earlier work in the field. A paper directly applicable to infrared stellar photometry from high altitude vehicles is "High Altitude Atmospheric Transmission Measurement" by F. Stauffer and J. Strong which appeared in Applied Optics, Vol. 1, p. 129, March 1962.

1.3 Environmental Testing

All components have been individually tested under conditions simulating the temperatures and pressures during a balloon flight. The environmental test procedures included testing experiments in the final configuration prior to mounting on the telescope, mounted on the telescope and in conjunction with the stabilization system, and, finally with the experiments, telescope, and stabilization system mounted on the gondola. The latter test was conducted in a chamber at Wright-Patterson Air Force Base with the pilot and observer aboard. The observer was able to perform certain operations as a test with the telescope and experiments. All components outside the gondola were tested for their operation at - 40°C or below and pressures equivalent to 80, 000 ft. or above. Components installed in the gondola were tested at temperatures of - 20°C or below and pressures equivalent to 30, 000 ft.

Because of power, weight and space requirements, it was not possible to control the temperature of the PbS cell in the infrared photometer. The above also ruled out incorporating a radiation standard such as a black body source. This made it necessary to calibrate the sensitivity of the cell with temperature. This was accomplished by installing the infrared photometer in a cold chamber and piping light from a standard tungsten lamp to the photometer. A sensitivity versus temperature curve is shown in Fig. 5.

1.4 Ground-based Observations of Stars

In order to establish the workability of the instruments in observing stars and to furnish comparison data with that to be obtained from a flight, a continuing observing program from the ground was conducted. In addition, an observing program just prior to a flight attempt was devised which included stars to be observed during the flight. The program included observations taken with the telescope mounted on an equatorial mount, on the stabilized mount, and finally on the gondola in order to be able to detect any interaction between components of the

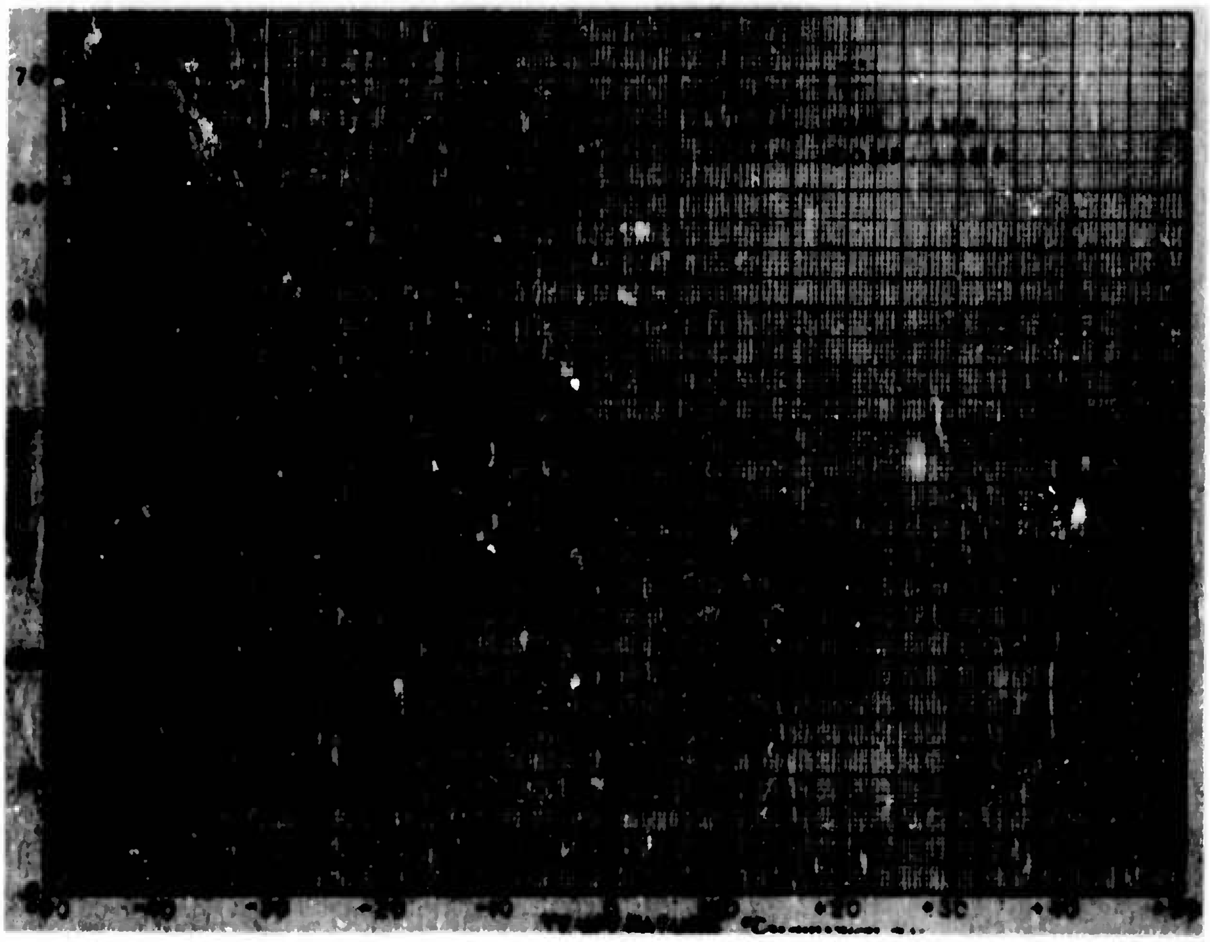

Figure 5. Temperature Sensitivity Curve of the Infrared Photometer. Ordinate is in Arbitrary Units.

integrated systems. Figure 6 shows the telescope as used for ground observations.

After being mounted on the gondola, a swing test was held to simulate possible motions of the gondola. Data was taken on stars to furnish a direct comparison of ground data with flight data and, again, to test for possible detrimental interactions between the various systems. Also, the observer obtained practice in handling the telescope and performing the experiments with the gondola in motion. Usually, the flight personnel were aboard and suited up as they would be for an actual flight.

Figure 7 shows an example of a scintillation run and Figure 8 shows a set of out-of-focus "seeing" images as taken from the ground.

Instruments were developed to observe seeing and scintillation from the ground while similar observations were being obtained at altitude during a flight.

Figure 6. The Telescope as Mounted to Obtain Observations of Stars From the Ground.

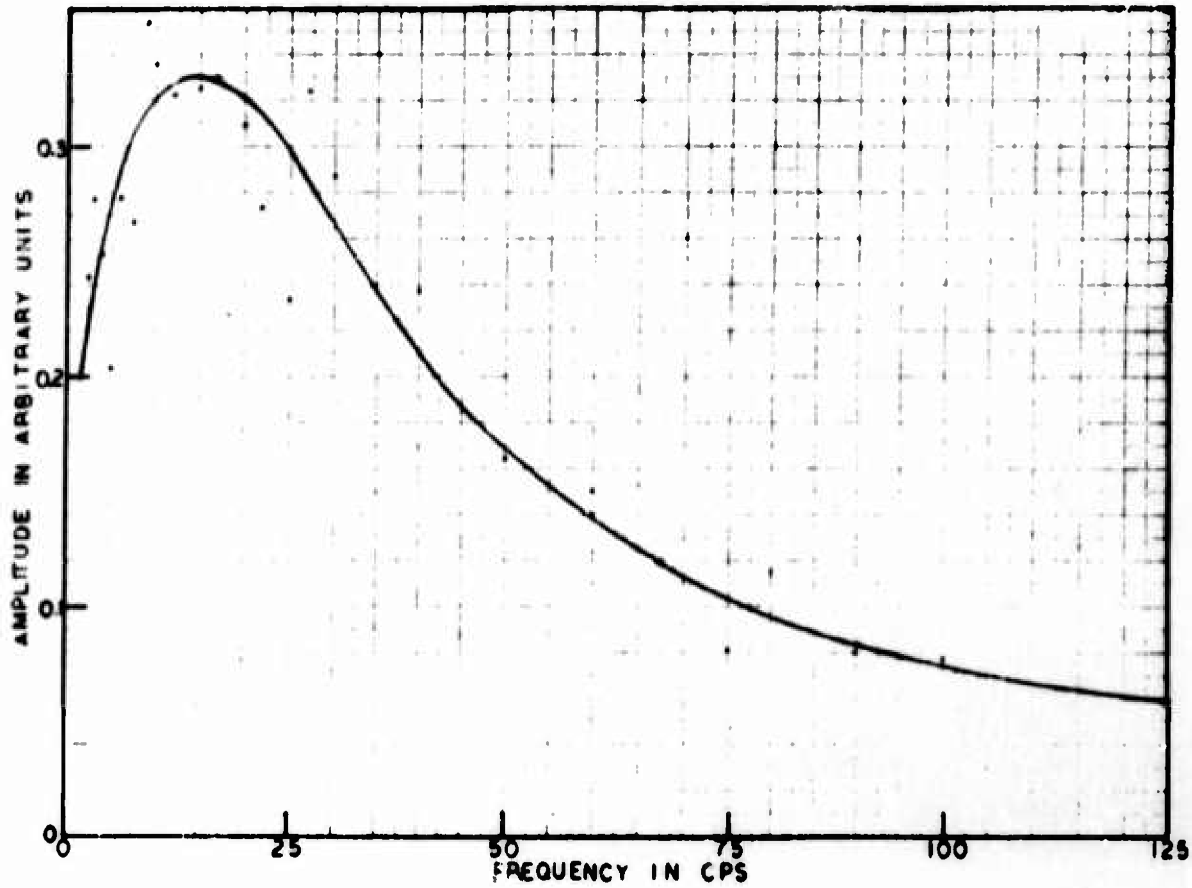

Figure 7. A Representative Scintillation Versus Frequency Curve. The Date Was Obtained by Observing Rigel on Oct. 26, 1961.

Figure 8. Out-of-Focus Images of Rigel Dec. 8, 1962, 9:12 P. M. Elevation Angle Approximately 32°.

1.5 Flight on 13 December 1962

On the above date a Stargazer manned flight was flown. The purpose of this paper is not to report on the mechanics of the flight, however, the flight was smooth with a minimum of gondola motion. Maximum rotational rates (during ascent and descent) were three degrees per second. During most of the flight period the rate was less than one degree per second. The above was determined by monitoring a standard aircraft compass. Estimates of pendulous motion were obtained from an undamped pendulum which indicated rates of approximately one degree per second.

During the nighttime observing period, the gyro-stabilized portion of the stabilization system worked well as evidenced by the ease with which the observer acquired stars on the observing program. Unfortunately, the star tracker which used a photomultiplier as a detector did not work due to high-voltage discharge. It was later determined that the potting at the base of the photomultiplier had been damaged during transport to the launch site. A similar difficulty appeared in the scintillation photometer. As a consequence of the above only seeing data was obtained. Figure 9 shows a set of photographs obtained on Rigel.

Figure 9. Out-of-Focus Images Obtained During Flight on Dec. 13, 1962, 1005 P. M., MST, Elevation Angle WAS Approximately 42°. Altitude Was Approximately 72, 500 ft.

A qualitative comparison of the photographs obtained on the flight with those from the ground indicate that seeing is markedly reduced. At this stage in the analysis of the seeing observations obtained in this manner, it is difficult to extract any numerical data from the photographs. It is possible that the residual seeing effects are a result of the rather larger effective structure of the balloon gondola system. Turbulence could arise through the wind resistance presented by the balloon or through convection around the total structure.

The method developed for acquiring stars which were on the program proved very satisfactory. Graphs of elevation angle and azimuth against the meridian angle of the star were made. An auxiliary graph of meridian angle against time was also made for the contemplated dates of a flight. As the meridian angle versus time plots is linear, many stars could be incorporated on one graph without confusion. The altitude and azimuth plots, of course, are good for very long periods of time. From the graphs, the altitude and azimuth were determined for the star to be observed. The telescope was set according to the elevation and train dials (see Fig. 4). As it turned out on the flight, only a rough estimate of the azimuth direction in which the telescope was pointed was needed. It was only necessary to set the telescope at the proper elevation angle and train the telescope in the direction toward the star until it appeared in the optical link. Several stars and the planet Jupiter were acquired in this manner. The stars were Capella, Aldebaran, Rigel, Betelgeuse, and Sirius.

While the 10° field of optical link was fine for acquiring stars, it proved inadequate for guiding the telescope to obtain data with the photometer. In preparation for the second flight attempts in March and April 1963, the optics of the optical link were improved. In addition, a short focal length eyepiece could be expeditiously substituted for the wide angle one in order to reduce the field to 3°. A swing test established that the improved optics and narrower field would give the observer the capability of guiding the telescope to obtain data should the star tracker, again, malfunction.

During the daylight period of the flight, a band-like structure was noted above an apparent broad haze layer above the horizon. This structure appeared in the general direction of the sun. Figure 10 shows a photograph of this phenomenon.

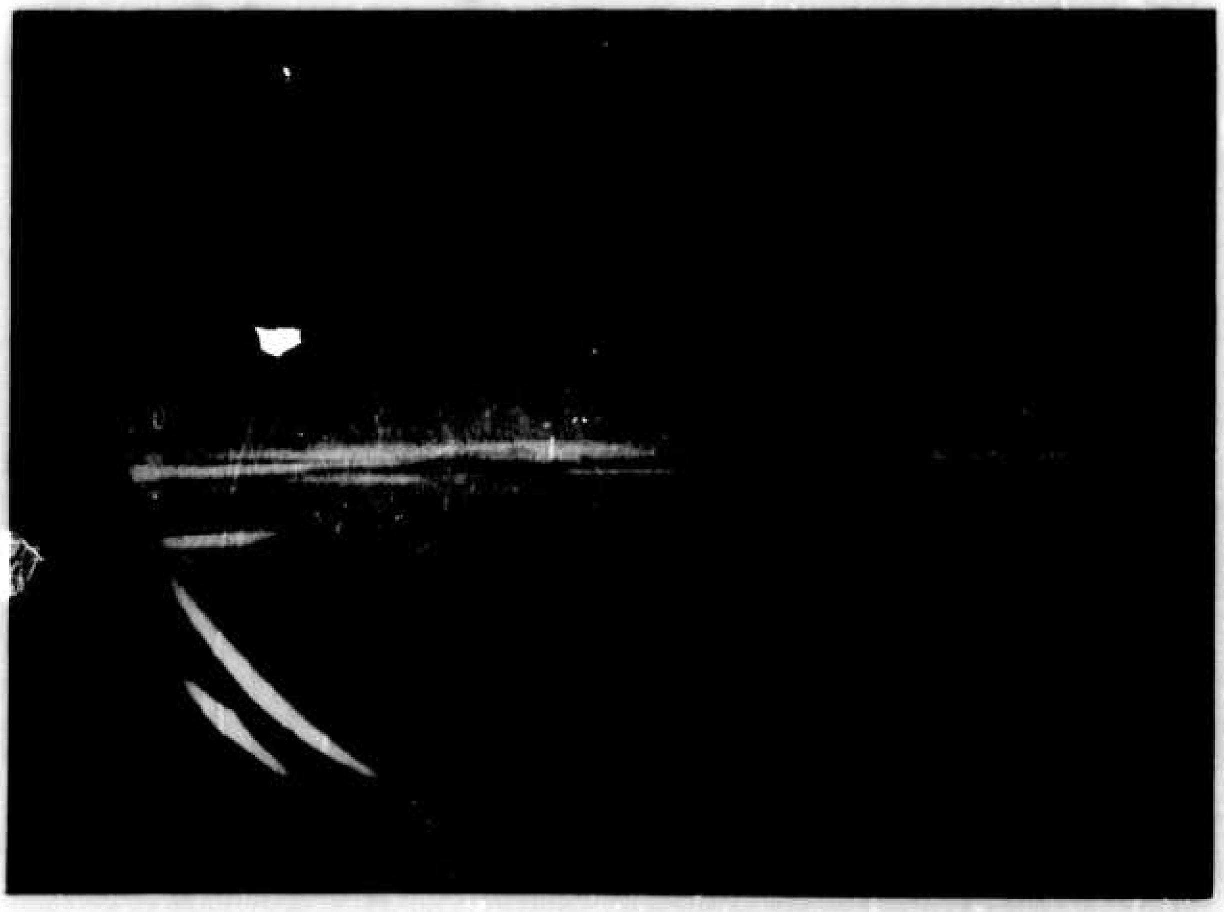

Figure 10. Photograph of the Horizon at an Altitude of 82,000 ft. During Flight of Dec. 13, 1962, 2:52 P.M., MST, Azimuth Was Approximately 210°. Band Structure, A. Haze Layer, B. Approximate Horizon, C. Spots at Top of Porthole Are Due to Reflections of the Sun.

The photographs were measured to obtain appropriate elevation angles of the bands above the estimated horizon. Rawindsonde data taken from Holloman AFB during

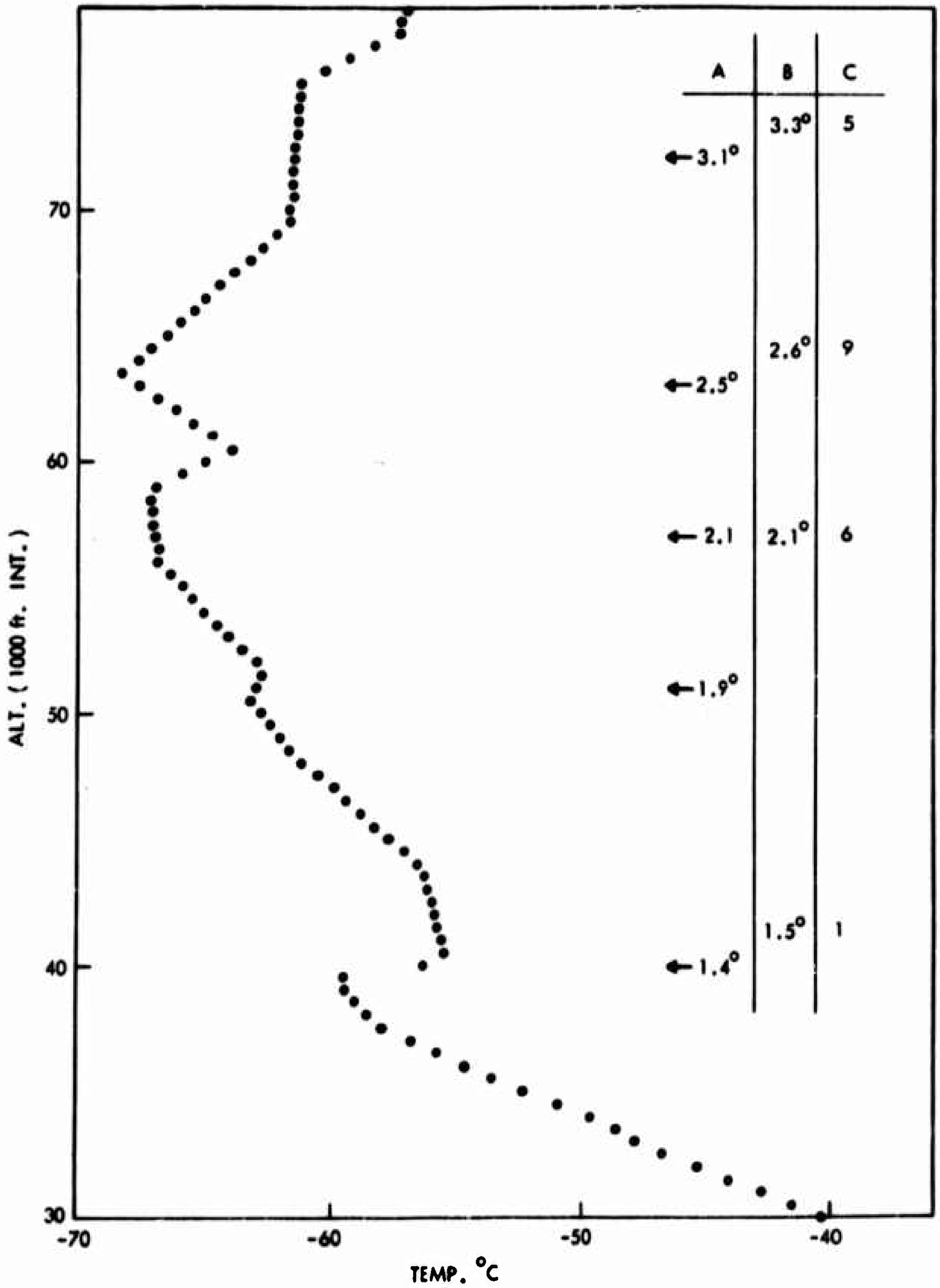

Figure 11. Rawindsonde Temperature Data at Holloman AFB, Dec. 13, 1962, 12:30 P.M., MST. Computed Elevation Angles of Temperature Features, as Indicated by Arrows Column A. Measured Elevation Angles of Bands From Photographs Taken During Dec. 13, 1962, Flight., Column B. Number of Plates on Which Band was Measured, Column C.

the flight was examined for the temperature distribution with altitude. Assuming a stable and uniform atmosphere over a wide region, elevation angles above the horizon were computed for layers corresponding to temperature minimum and portions of the temperature altitude curves where the temperature was constant over a large change in altitude. In support of the above assumption, an extensive, high pressure area was situated over the southwest during the period of the flight. Figure 11 shows the possible correlation between the observed bands and temperature features in the atmosphere. This data represents only a preliminary investigation of the observed phenomena and it is not possible, at this time, to say anything about the possible origin of the bands.

1.6 Conclusion

It might be said that the Stargazer program marks a beginning of the application of the concept of an observatory and its functions to high-altitude vehicles. The concept of an observatory usually includes the use of a telescope or telescopes as multipurpose instruments applied to a number of research programs. The variety of experiments attempted on the Stargazer flight associated with the capability of observing many astronomical objects is an approximation to the observatory concept. It is felt that the experience obtained on the flight demonstrates that it is entirely possible to construct a balloon borne observatory.

Acknowledgments

It was the author's pleasure to have worked with such an outstanding group of men assigned to the Stargazer program. Indeed, the important contribution made to the program by so many people might well be the subject of another report. Among those who should be especially acknowledged for their contributions are Dr. J. Allen Hynek, Director, Dearborn Observatory, Northwestern University, who was the principle investigator on the scientific part of the program; Major Thomas B. Spalding who acted as test director for AFCRL, and Major J.W. Kittinger, WPAFB, who was in charge of the gondola and its preparation for a flight as well as being responsible for the actual flight and piloted the balloon so successfully. Mr. Philip Morin and Mr. Robert E. Onley from Northwestern University did an outstanding work in fabricating the instrumentation for the Stargazer experiments.

XVIII Abstracts of Other Papers Presented at the Symposium, but not Published

BALLOON INSTRUMENTATION

Charles S. Tilton
Aerospace Instrumentation Laboratory
Air Force Cambridge Research Laboratories, Bedford, Mass.

The command, control and telemetry instrumentation required to support a typical balloon flight is discussed. Units for flight safety, control, command and telemetry and methods for data reception and tracking are illustrated. The flexibility of flight units to form composite equipments for support of a wide variety of scientific or equipment flight test requirements is shown.

A POINTING CONTROL FOR A BALLOON-BORNE TELESCOPE

Alvin H. Howell
College of Engineering, Tufts University, Medford, Mass.

A fully automatic system has been developed which can be programmed to acquire a number of planets or stars in sequence, and to track them with fractional-minute precision while being carried along at altitudes above 100,000 feet and at speeds of several tens of knots. The entire gondola is oriented in azimuth using the torsionally weak parachute as an implied azimuth bearing so that when the system is once aligned with its target, only minimal corrective forces are required to hold it there. Control of both the azimuth and elevation angles is achieved by pairs of spinning wheels that are precessed to apply torques for pointing.

STRATOSCOPE II

Martin Schwarzschild
Princeton University Observatory, Princeton, N. J.

The main characteristics of Stratoscope II, a 36-inch balloon-borne telescope will be discussed and its first flight in March 1963 will be described.

A STABLE SKY-HOOK - THE GOODYEAR VEE-BALLOON

Robert S. Ross
Goodyear Aerospace Corporation, Akron, Ohio

With the development of new lighter and more gastight balloon materials, it was natural to re-evaluate the tethered balloon system for current and future applications. Greater stability and increased lift under high wind conditions were two major aerodynamic improvements needed. Through a wind tunnel development program, free flight model tests, and full scale balloon flights, the Vee-Balloon was developed to correct these deficiencies in previous tethered balloon systems. Besides being an aerodynamically stable configuration, it also exhibits high lift-drag ratios at small angles of attack and, therefore, can carry a large diameter cable to greater heights than previously possible. Because of its shape, the Vee-Balloon is readily adaptable to a tandem system configuration which is often required for the achievement of high altitude flight with a tethered system.

The Vee-Balloon is already being applied to a number of missions where stability, flight endurance, and high altitude are prime prerequisites, and new uses for this versatile sky-hook arise daily.

FILM REPORT ON PROJECT BANSHEE - PHASE I

Jack R. Kelso
Defense Atomic Support Agency, Washington, D.C.

Project BANSHEE (Balloon and Nike Scaled High Explosive Experiment) is a joint Army, Navy, Air Force high altitude blast effects research program sponsored by the Defense Atomic Support Agency. This documentary film report (in color) covers primarily the development, coordination, and fielding of a series of complex scientific experiments in the upper atmosphere. Particular attention is devoted to unusual operational techniques utilized to conduct balloon flights in support of project activities during 1961 and 1962.

AIR FORCE SURVEYS IN GEOPHYSICS

No.100 A Phenomenological Theory of the Scaling of Fireball Minimum Radiant Intensity with Yield and Altitude *(U), H. K. Sen, Apr 1958. (SECRET Report)*

No.101 Evaluation of Satellite Observing Network for Project "Space Track", *G. R. Miczaika and H. O. Curtis, Jun 1958.*

No.102 An Operational System to Measure, Compute, and Present Approach Visibility Information, *T. O. Haig and W. C. Morton, III, Jun 1958.*

No.103 Hazards of Lightning Discharge to Aircraft, *G. A. Faucher and H. O. Curtis, Aug 1958.*

No.104 Contrail Prediction and Prevention *(U), C. S. Downie, C. E. Anderson, S. J. Birstein and B. A. Silverman, Aug 1958. (SECRET Report)*

No.105 Methods of Artificial Fog Dispersal and Their Evaluation, *C. E. Junge, Sep 1958.*

No.106 Thermal Techniques for Dissipating Fog From Aircraft Runways, *C. S. Downie and R. B. Smith, Sep 1958.*

No.107 Accuracy of RDF Position Fixes in Tracking Constant-Level Balloons, *K. C. Giles and R. E. Peterson, edited by W. K. Widger, Jr., Oct 1958.*

No.108 The Effect of Wind Errors on SAGE-Guided Intercepts *(U), E. M. Darling, Jr. and C. D. Kern, Oct 1958 (CONFIDENTIAL Report)*

No.109 Behavior of Atmospheric Density Profiles, *N. Sissenwine, W. S. Ripley and A. E. Cole, Dec 1958.*

No.110 Magnetic Determination of Space Vehicle Attitude *(U), J. F. McClay and P. F. Fougere, Mar 1959. (SECRET Report)*

No.111 Final Report on Exhaust Trail Physics: Project 7630, Task 76308 *(U), M. H. McKenna, and H. O. Curtis, Jul 1959. (SECRET Report)*

No.112 Accuracy of Mean Monthly Geostrophic Wind Vectors as a Function of Station Network Density, *H. A. Salmela, Jun 1959.*

No.113 An Estimate of the Strength of the Acoustic Signal Generated by an ICBM Nose Cone Reentry *(U), N. A. Haskell, Aug 1959. (CONFIDENTIAL Report)*

No.114 The Role of Radiation in Shock Propagation with Applications to Altitude and Yield Scaling of Nuclear Fireballs *(U), H. K. Sen and A. W. Guess, Sep 1959. (SECRET/RESTRICTED DATA Report)*

No.115 ARDC Model Atmosphere, 1959, *R. A. Minzner, K. S. W. Champion and H. L. Pond, Aug 1959.*

No.116 Refinements in Utilization of Contour Charts for Climatically Specified Wind Profiles, *A. E. Cole, Oct 1959.*

No.117 Design Wind Profiles From Japanese Relay Sounding Data, *N. Sissenwine, M. T. Mulkern, and H. A. Salmela, Dec 1959.*

No.118 Military Applications of Supercooled Cloud and Fog Dissipation, *C. S. Downie, and B. A. Silverman, Dec 1959.*

No.119 Factor Analysis and Stepwise Regression Applied to the 24-Hour Prediction of 500-mb Winds, Temperatures, and Heights Over a Silent Area *(U), E. J. Aubert, I. A. Lund, A. Thomasell, Jr., and J. J. Pazniokas, Feb 1960. (CONFIDENTIAL Report)*

No.120 An Estimate of Precipitable Water Along High-Altitude Ray Paths, *Murray Gutnick, Mar 1960.*

No.121 Analyzing and Forecasting Meteorological Conditions in the Upper Troposphere and Lower Stratosphere, *R. M. Endlich and G. S. McLean, Apr 1960.*

No.122 Analysis and Prediction of the 500-mb Surface in a Silent Area, *(U), E. A. Aubert, May 1960. (CONFIDENTIAL Report).*

No.123 A Diffusion-Deposition Model for In-Flight Release of Fission Fragments, *M. L. Barad, D. A. Haugen, and J. J. Fuquay, Jun 1960.*

No.124 Research and Development in the Field of Geodetic Science, *C. E. Ewing, Aug 1960.*

No.125 Extreme Value Statistics -- A Method of Application, *I. I. Gringorten, Jun 1960.*

No.126 Notes on the Meteorology of the Tropical Pacific and Southeast Asia, *W. D. Mount, Jun 1960.*

No.127 Investigations of Ice-Free Sites for Aircraft Landings in East Greenland, 1959, *J.H. Hartshorn, G. E. Stoertz, A. N. Kover, and S. N. Davis, Sep 1961.*

No.128 Guide for Computation of Horizontal Geodetic Surveys, *H. R. Kahler and N. A. Roy, Dec 1960.*

No.129 An Investigation of a Perennially Frozen Lake, *D. F. Barnes, Dec 1960.*

No.130 Analytic Specification of Magnetic Fields, *P. F. Fougere, Dec 1960. (CONFIDENTIAL Report)*

No.131 An Investigation of Symbol Coding for Weather Data Transmission, *P. I. Hershberg, Dec 1960.*

No.132 Evaluation of an Arctic Ice-Free Land Site and Results of C-130 Aircraft Test Landings — Polaris Promontory, No. Greenland, 1958-1959, *S. Needleman, D. Klick, C. E. Molineux, Mar 1961.*

No.133 Effectiveness of the SAGE System in Relation to Wind Forecast Capability *(U), E. M. Darling, Jr., and Capt. C. D. Kern, May 1961. (CONFIDENTIAL Report)*

No. 134 Area-Dosage Relationships and Time of Tracer Arrival in the Green Glow Program, *W. P. Elliott, R. J. Engelmann, P. W. Nickola, May 1961.*

No. 135 Evaluation of Arctic Ice-Free Land Sites - Kronprins Christian Land and Peary Land, North Greenland, 1960, *W. E. Davies and D. B. Krinsley, May 1961.*

No. 136 Missile Borne Radiometer Measurements of the Thermal Emission Characteristics of ICBM Plumes *(U), R. E. Hunter and L. P. Marcotte, Jul 1961. (SECRET Report)*

No. 137 Infrared Studies of ICBM Plumes Using Missile - Borne Spectrometers *(U), R. E. Hunter and L. P. Marcotte, Sep 1961. (SECRET Report).*

No. 138 Arctic Terrain Investigations Centrum Lake, N E Greenland, 1960, *S. M. Needleman Jul 1962.*

No. 139 Space and Planetary Environments, *S. I. Valley, Editor, Jan 1962*

No. 140 Proceedings of National Symposium on Winds for Aerospace Vehicle Design, *N. Sissenwine and H. G. Kasten, Co-Chairmen, Mar 1962.*

No. 141 Atlas of Monthly Mean Stratosphere Charts, 1955-1959, Vol. I, January to June, *H. S. Muench, May 1962.*

No. 142 Infrared Atmospheric Transmissions: Some Papers on the Solar Spectrum from 3 to 15 Microns, *J. N. Howard and J. S. Garing, Dec 1961.*

No. 143 AFCRL Ballistic Missile Infrared Measurements, IRMP 59/60, *T. P. Condron, J. J. Lovett and R. L. Morgan, June 1962.*

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