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VOL. XVI • FINAL PROGRESS REPORT

RESEARCH AND DEVELOPMENT IN THE FIELD OF HIGH ALTITUDE PLASTIC BALLOONS

SPONSORED JOINTLY BY THE ARMY, NAVY AND AIR FORCE UNDER CONTRACT NONR-710(01) WITH THE OFFICE OF NAVAL RESEARCH

DECEMBER 15, 1951 TO AUGUST 31, 1956

16 231

PREPARED BY DEPARTMENT OF PHYSICS · UNIVERSITY OF MINNESOTA · MPLS., MINN.

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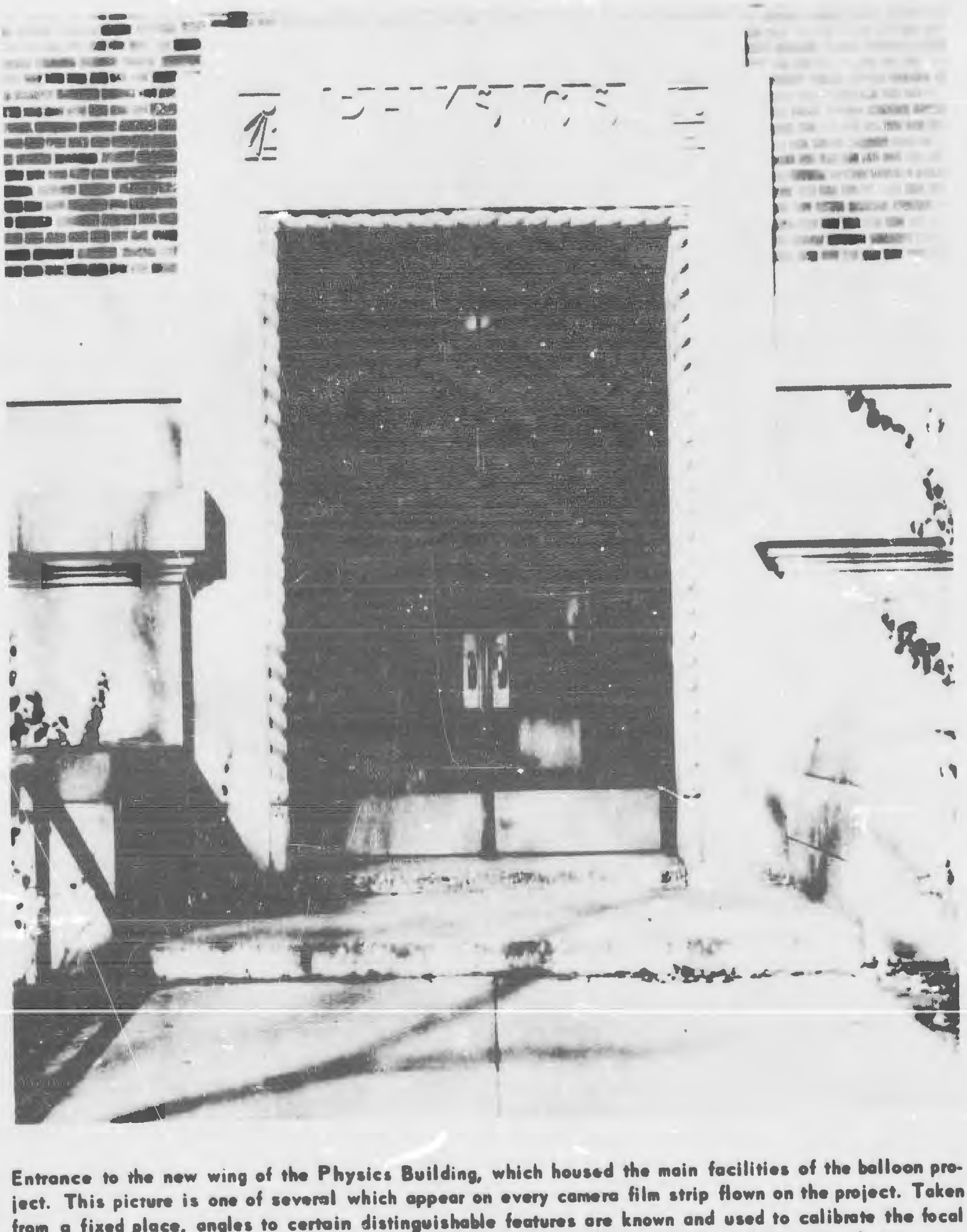

Entrance to the new wing of the Physics Building, which housed the main facilities of the balloon project. This picture is one of several which appear on every camera film strip flown on the project. Taken from a fixed place, angles to certain distinguishable features are known and used to calibrate the focal length for each camera in order that balloon altitudes may be accurately determined from 'down' pictures

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A recently designed computer, useful in obtaining balloon lifts and theoretical ceilings, is included in this report on the inside of the front cover. To obtain theoretical ceiling, set gross weight opposite lifting gas (zero superheat is assumed) and the indicator to the balloon volume. Standard pressure and temperature conditions are given along with the ceiling altitude.

SECTION I PROJECT SUMMARY

Inflation of a Mylar tetroon bubble prior to weigh-off. The gross inflation is precisely obtained in weigh-off when the gas just lifts the sum of the load weight, the weight representing the free lift, and the entire balloon, most of which is rolled into the ball at the lower right.

BALLOON PROJECT FINAL REPORT

ONR Project Nonr-710(01), the High Altitude Plastic Balloon Research Program, was established December 13, 1951 and sponsored jointly by the Army, the Air Force and the Navy. The following report constitutes a final report on this program. It is also Volume XVI of the series of reports published on this project. Since we became aware (on August 10, 1956) of the Air Force's desire to discontinue their support of the project as of the end of August 1956, some of the previous policies of detailed reporting of flights must be foregone in producing this final report. In all, throughout the project a total of 313 generally major or experimental flights have been carried out, in addition to 380 radiation temperature soundings. The flights through Flight 250 are reported in the usual detail. Flights subsequent to this are not reported in detail, but those flights particularly significant with respect to recent objectives of the program are discussed in those chapters of Volume XV* to which they pertain. With this introduction we will attempt to review briefly the results of the project which we consider to be the most fundamental.

The principal achievements of the project are summarized in pages II-15 to II-37 following. The references give the approximate date at which each was initiated. Many of these developments have been previously described in detail, and references are frequently given to the reports in which the original work is described.

At the time of the inception of the HAB program the physical properties of the flight of plastic balloons to high altitude were not understood in detail, and it later turned out that many of the important physical features of balloon flight were not even appreciated in principle. Part of the motivation for the organization of the project arose from the fact that while somtimes high altitude flights were quite spectacularly successful, very frequently plastic balloons failed for unknown reasons. Shortly before the beginning of the project, a series of cosmic ray flights in New Mexico were flown with very poor success, a large number of these flights failing at intermediate altitudes. It was the general objective of the project to study those fetaures of balloons which would lead to better understanding of the physical properties of balloon flights and to the improvement of the plastic balloon as a vehicle, as well as to determine such basic meterology as affected balloon flight.

Among these features of balloon flight which were unknowns and problems were (1) why balloons sometimes failed to reach their predicted theoretical ceiling; (2) why balloons appeared to have a rise rate "constant" at all altitudes; (3) why some balloons descended at sunset while others remained aloft at night without ballast;

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* In preparation

(4) specific causes of failure at intermediate altitudes near the tropopause; and (5) great difference in stability between the stratosphere and troposphere observed with large balloons (e.g., Explorer II). Much of the approach of the project toward obtaining knowledge with respect to the project objectives is indicated by the achievements in Section II of this report. Although it will not be possible to discuss the principal achievements of the project in detail, a brief outline will be given here of the most important of these results.

At the very beginning of the project it was realized that documentation of balloon flight would be an extremely important and necessary adjunct to the understanding of failures of balloons and to the determination of the flight characteristics of balloons. For this reason very complete records of every flight were obtained, including general movies of the launching, still pictures of the launching and complete documentation with respect to all equipment flown. One of the very fruitful tools throughout the work on balloons was the standard camera developed at the beginning of the project. Cameras of this type were used routinely to photograph the balloon (up pictures) in each flight, to photograph the ground (down pictures) and thus determine the trajectory, and even on occasion to photograph the interior of the balloon by means of cameras hung within the crown.

One of the most obvious problems to study immediately was the response of the balloon to buoyancy unbalance (free lift). In order to know the initial weigh-off with high accuracy, which would be required in order to correlate rise rates with initial free lift, it was necessary to develop launching techniques in which the balloon could be precisely weighed off and launched under a variety of circumstances. This led to the so-called Minnesota launching method in which the balloon is packaged in such a way that it is launched with a restricted bubble and inflates itself in the air. In order to package the balloons for flight in this way, it was necessary to hang the balloon up and re-fold it into the threefold arrangement. In carrying out the operations required to do this, it was frequently found that the adhesive tapes which carried the load in the early designs stuck across the polyethylene and produced damage. This original weakness of the pressure-sensitive tape balloon led us to carry out many of the early flights with double-wall balloons in which the outer layer of polyethylene could be torn by misplaced tape without causing damage to the gas barrier. It was realized, however, that a solution other than the double-wall balloon would have to be found.

Originally, calculations on the stresses in the balloons were nonexistent, as was a balloon design in which the stresses were readily calculable. A step had been made in this direction by General Mills, with the help of Ralph Upson, in the attempt to manufacture balloons with zero circumferential stress. The stress calculation was carried out to the best of our ability for the original cone-on-sphere balloon and for natural shape balloons. In addition to this, the shape of zero-circumferential-stress balloons was determined for a variety of pressure levels with the aid of the REAC analog computer. In order to test the theory of balloon stresses and to examine zero-circumferential-stress balloons, hangar inflations of large plastic balloons were carried out in the Weeksville Naval Air Station hangar. Since air and helium diffuse into each other very slowly at atmospheric pressure, it was necessary to carburate a mixture containing only a few percent helium into these balloons in order to cause them to lift themselves and a small additional load without introducing excessive lift when full. A standard 250,000 cubic foot balloon would lift eight tons on the ground if filled with pure helium, and would fail at a much smaller gross lift than this. The hangar inflation bore out the theory of stresses in a balloon very well. The cases in which failure took place occurred in the places and in the manner in which the stress calculations had indicated failure would occur.

In the early flights one of the phenomena frequently present and poorly understood was the fact that balloons would not level abruptly on reaching ceiling, but appeared to climb very slowly for long periods of time from the region below their ceiling altitude to an altitude considerably lower than the theoretical ceiling based on the calculated volume of the balloons. The up camera pictures, together with model tests, furnished the answer to this problem and indicated that a different type appendix would need to be invented. The contamination of the lifting gas in the balloon by the intaking of air through the appendix during ascent and the subsequent mixing of this air with the helium caused a perturbation to the flight, making it difficult to predict or to understand quantitatively. Although air and helium do not readily mix at sea level pressure, the mixing occurs at a rate which varies inversely with the pressure of the gas. It could be calculated and verified experimentally that at an altitude of 100,000 feet this mixing of air and helium occurred in a matter of hours, thereby permanently contaminating the lifting gas. An understanding of the hydrostatics of balloons, which was acquired at this time through the calculation of families of natural shaped balloons, led to the knowledge that air would be sucked into ascending balloons. Since any contamination of the helium in a balloon has a deleterious effect, a number of appendix designs were attempted to eliminate the possibility of air intake. The one which was finally successful was the so-called duct appendix, which not only eliminates the intaking of air in the balloon, but allows the realization of any of the family of natural shapes by making it possible to fix the so-called zero pressure level (at which the pressure inside the balloon is exactly equal to external atmospheric pressure) at any desired position with respect to the apex of the balloon. The duct appendix comes out of the top of the balloon at a point above the highest region that the zero pressure level can reach in flight and extends either to the apex or to some other point determined by whether it is desired to fly the balloon at zero pressure at the bottom, super pressure or subpressure.

With the introduction of the duct and the elimination of the complication of air intaking, the characteristics of the balloon flight were immediately altered. For example, sunset descent rates, instead of being 50 feet per minute as is frequently observed in open appendix balloons, were very much higher – as much as 300 feet per minute, and showed the qualitative behavior that one would expect to occur, such as the increase in rate of descent or decrease in rate of rise in passing through the tropopause, which had not been observed on open appendix balloons.

The introduction of the duct also brought into focus a number of other physical effects of great importance to balloon flights but previously not present or not observed. Among these should be cited (1) thermal oscillations, oscillations of the balloon about its equilibrium position at ceiling of amplitude of the order of 200 feet and with a period of 5 minutes to 7 minutes, which could be understood theoretically on the basis of the compressional heating and expansional cooling of the gas as it approached an equilibrium altitude; (2) thermal bounces. The term "thermal bounces" is used to apply to cases in which the balloon may instantaneously be moving very rapidly although it will ultimately reach equilibrium without valving gas. The most striking example of the thermal bounce can be obtained by allowing a ducted balloon to descend at sunset and then, after an appreciable loss of altitude has occurred, ballasting by exactly the amount required to level the balloon off. After the ballast has been dropped, the balloon will rise at a very appreciable rate, for a distance as great as a mile, and abruptly level off with oscillations but at an altitude far below its theoretical ceiling. The physical phenomena that takes place is that the balloon descending after sunset descends at such a rate that the gas inside maintains almost precisely that superheat above the outside air which it had during the daytime. The superheat during the descent is produced by adiabatic compression of the gas and, if ballast is dropped, the balloon must reach equilibrium by cooling this gas, which it does by rising abruptly, expanding the gas to the nighttime equilibrium temperature at rest. In any system involving ballasting of balloons, the existence of thermodynamic bounces is of great importance since it makes the control problem easier, always bouncing the balloon off the ballasting contact before adequate ballast has been dropped in a properly designed system. The existence of thermodynamic effects, in other words, introduces into a simple control system an under compensation of the kind which is frequently put into servo systems artificially in order to make them stable.

The introduction of the duct system also allowed complete control of the balloon. Ballast could be dropped and the balloon would return to the theoretical ceiling of the system. In the case of the open appendix balloon, one is at the mercy of the intake in air which contaminates the balloon gas by a varying amount depending on the distance and time spent below the ceiling at which the balloon was full. In short, the duct made the balloon a navigable device in the vertical direction, responding to valving and ballasting in a simple way.

In the attempt to understand the relative magnitudes of the aerodynamic drag and the thermal change in temperature of the gas called thermodynamic drag, it was desired to fly balloons up and down through the atmosphere and to determine their response to certain gain or loss of lift at various altitudes. The first methods attempted to study this problem involved radio control of valves, tow balloons, and ballasting devices. Although a final system developed for this purpose was relatively successful, it was found to be difficult to interpret the results in a satisfactory way. The solution of the problem was found to be a technique called the step flight technique in which a controlled balloon, called the lead balloon, (read as the mineral lead – suggests the stability of the system) is used as a platform with respect to which one could measure the absolute value of the lift of a balloon, called the tow balloon, attached to it. The lead balloon time-altitude curve was programmed with a ballast programmer, and the tension existing between the tow balloon and the lead balloon was recorded and telemetered in a long series of flights which lead to the formulation of a satisfactory picture of the aerodynamics and thermodynamic drags.

In the course of this study, a number of interesting and only partially expected results were obtained. To cite only one example of this, one step flight was made in which the tow balloon was inflated with methane gas rather than helium. In the case of the helium inflation, it had always been observed, as anticipated, that as soon as the balloon began to rise, expanding the gas, the gas would cool and thereby cancel out by its change in temperature a large portion of the initial buoyancy of the system. This change in buovancy or thermal drag increased as the velocity increased, approximately as the first power of the velocity. The dependence of this thermal drag on the lapse rate of the atmosphere and the lapse rate of the helium gas was understood, and it was clear that if the lapse rate of the atmosphere and the lapse rate of the inflation gas were the same, the thermal drag effect would not exist. In the methane inflation the atmospheric conditions were such that the atmospheric lapse rate actually exceeded the lapse rate of the lifting gas of the balloon, which meant that as the system rose the atmosphere cooled more in the troposphere than the balloon gas did as the altitude was increased. The result of this was that instead of having thermal drag one had thermal lift, and the faster the system rose the more thermal lift it acquired. This produced a potentially unstable situation only stabilized by the aerodynamic drag. This instability could occur frequently with low gamma gases in the troposphere. It points up, for example, a definite control problem with troposphere balloons inflated with gases, such as hydrogen or methane or ammonia.

A striking result of the step flights, and one which turned out to be of great significance, was the magnitude of the buoyancy difference that the static balloon system had at different positions in the atmosphere. Once it was appreciated that this effect existed, it was rather easy to understand and evaluate the mechanism on the basis of the partial clamping of the polyethylene or Mylar balloon to the atmospheric infrared radiation, and the resulting change in balloon gas temperature at rest from that of the surrounding air.

The step flights, together with calculations based on the Elsasser summertime atmospheric radiation, led to the general conclusion that the balloon ran cold with respect to the air in the troposphere, warm in the low stratosphere, and cold again at very high altitude where the air temperature rises. The step flight measurements, however, could only be conveniently carried out at altitudes of the order of 50,000 feet, and for this reason another method to study this atmospheric temperature field was sought. The successful solution to this problem was the invention of the Mylar or polyethylene shielded black ball radiation detector. It was found experimentally that the equilibrium temperature of a black spherical surface surrounded by a Mylar shield very closely approached that of the balloon system. Because these lightweight detectors could be flown on Rawin flights, the series of radiation measurements were carried out with them through a period of a year with flights almost every night. It became clear from the study of these black ball soundings that the temperature of a black object in radiation equilibrium decreased steadily in the atmosphere, reaching an equlibrium value somewhere above the tropopause. Since it is well known that the air at very high altitudes begins to warm again with increasing altitude due to the absorption of ultra violet light by the ozone, it was clear that a great stability effect should occur at altitudes near and above 100,000 feet. This mesosphere stability was predicted to be as great as 20 or 30% of the gross lift of the system at altitudes of the order of 130,000 feet. One of the most recent results of the project was a demonstration by Mylar balloon flights to 130,000 feet and subsequently to 145,000 feet, that this mesosphere stability does indeed exist, that it is necessary above 100,000 feet to ballast the balloon in order to take it to its full ceiling, either day or night, and that the magnitude of the effect could be as high as 25%. Since the measured sunset effect on Mylar balloons was less than 6%, it is clear that descent in the temperature field can much more than compensate for the magnitude of the sunset on the balloon. This was also directly demonstrated by flights which leveled at a night-time altitude and climbed to a daylight altitude, or flew at an altitude during the day and descended to a stable altitude at night. This result is of some importance since it means that aside from leakage, balloon flight should be possible durationwise until the material from which the balloon is made becomes degraded and thereby leaky. Following this series of flights, a quarter mil Mylar balloon was flown to an altitude in excess of any previously obtained with plastic balloons, namely 145,000 feet.

In pursuing the problem of balloon shape, it became clear that a simple type of natural shape balloon could be manufactured by constructing a cylinder, clamping it at the ends, and allowing it to take on a shape in which the natural shape required a circumferential size at the equator less than the circumference of the original cylinder. In the balloon of this design, in principle, the tension of the material is all meridianal, that is from top to bottom, and is everywhere the same. The balloon may be considered essentially as a rope which picks up the load, and the stress calculations are quite straightforward and simple. With a high-strength material such as Mylar available, a cylinder balloon appears to be a very desirable configuration for heavy load applications. The theory of the cylinder balloon was checked with moderate inflations, and it is believed that loads as great as 20,000 pounds could be readily carried by Mylar cylinders.

Frequently, the introduction of a complete cylinder adds enough weight to cause an appreciable altitude loss without gain in reliability with a light load, and for this reason the so-called semicylinder was introduced in which a portion of the balloon is natural shape with cylindrical ends of such dimension that enough material exists to carry the load required. Balloons of this design have been used with reasonable success. It should be noted that the philosophy of balloon design expressed throughout the progress of the project involves the elimination of pressure-sensitive tapes because of their unreliability.

A recent design of the balloon manufacturers in which the pressure-sensitive tape is replaced by heat-sealed tapes was tested by the project and also appears to be a reasonable solution to the sticky tape problem.

The ultimate design developed on the HAB project for very high-altitude balloons was arrived at only during the last few months of the project but made possible the high altitude flights previously referred to. The design is called the Tetroon and is produced by taking a cylinder of the appropriate dimensions and sealing the two ends of the cylinder at right angles to one another. The load is attached by tying a rope to one of the four corners of the balloon. The tetroons flown on the project were flown without appendices since the altitude reached in most cases was high enough so that ballast was required to take the balloon to ceiling, and it was unnecessary to valve gas. This simple design only involves straight seals in the balloon material, an asset with Mylar, and has only about a 20% volume deficit or 3,000 ft. altitude deficit from a spherical balloon of the same weight when operated as a zero-pressure-at-the-apex configuration. It was also found that the tetroon was quite satisfactory from a super-pressure standpoint, and model tests and hangar inflations of forty-foot balloons showed that the equivalent super-pressure of the order of 25% of the ambient pressure at ceiling altitude could be realized with a forty-foot tetroon. It can be seen, therefore, that in addition to the mesosphere stability, super-pressure stability can be obtained with tetroons and super-pressure can be used as a cushion in bringing the balloon to ceiling. The tetroon appears to be a better super-pressure vehicle than the super-pressure cylinders flown in rather large numbers earlier in the project for constant-level meteorological trajectories.

Because of the very pronounced effects of air intake in balloons, an appreciable effort was expended by the project to determine ways in which air could be utilized to produce stability without introducing contamination to the lifting gas. This effort led to two successful designs of stable balloon systems utilizing air. These were called respectively the gaboon and the shroud. The gaboon has a large open-bottom bag which hangs below the primary balloon system and which can in-take and warm air provided it is in a position in the atmosphere in which the equilibrium temperature is warmer than that of the surrounding air. The gaboon also allows warming of intaken air through adiabatic compression of the air during descent. The shroud is basically the same except that it hangs over the balloon and is somewhat simpler to use operationally. It was shown that both the gaboon and the shroud were successful means of utilizing air without contaminating the helium and that they provide at certain times of the year, balloon systems which can stabilize out sunset or leakage loss of lift without requirement of ballast expenditure.

It should be stated that throughout the project, in order to obtain the type and quality of information desired, a great deal of instrumentation development was required. Examples of this development are the high-altitude, precise Olland cycle, the potentiometers used to telemeter tension between the lead and tow balloon or between the balloon and gaboon systems, and the radio control equipment used to ballast and valve balloon devices.

In short, it is believed that the HAB program has lead to the following: (1) basic understanding of the design factors, structurally, for plastic balloons; (2) a number of new balloon design configurations, i.e., the cylinder, semi-cylinder, natural-shaped family, tetroon; (3) a basic understanding of the statics of balloons in the temperature field in which the balloon flies, leading to the possibility of mesosphere stability; (4) by the introduction of the duct a balloon system which becomes navigable in the vertical direction without the perturbing effect of intake in air, (5) three ways for producing extremely long duration flight, i.e., the temperature field, the gaboon and the shroud; (6) the constant level super-pressure plastic balloons; (7) an understanding of the dynamics of the balloon system, including the thermal and aero drag, and the quantitative contributions of thermal and aero drag to moving balloons; (8) balloon systems capable of going to a region in the atmosphere previously unexplored in detail, between 100,000 and 150,000 feet by the successful application of quarter mil Mylar to the construction of tetroons.

In conclusion, it is the firm conviction of the project members that the progress made toward understanding plastic balloons has been achieved by applying the same scientific methods to this problem that characterize physics department basic research in other fields, such as cosmic rays or nuclear physics. The special contributions to the art from the University of Minnesota Balloon Project came because of the atmosphere of free inquiry characteristic of University research, and make this program unique among balloon programs.

SECTION II PROJECT ACHIEVEMENTS

The step flight gondola, containing some 700 lbs. of fine steel shot ballast, is programmed to control the altitude of the two-balloon system. Performance data, consisting of balloon, air and radiation temperatures, ambient pressure, and lift of the balloon under study, called the tow-balloon (left), are taken through a series of climbs and level flights, recorded internally and telemetered to the ground receiving and recording stations. Thirty of these flights were made to study night, day, and seasonal effects, and the performance of different lifting gases.

SECTION II INDEX

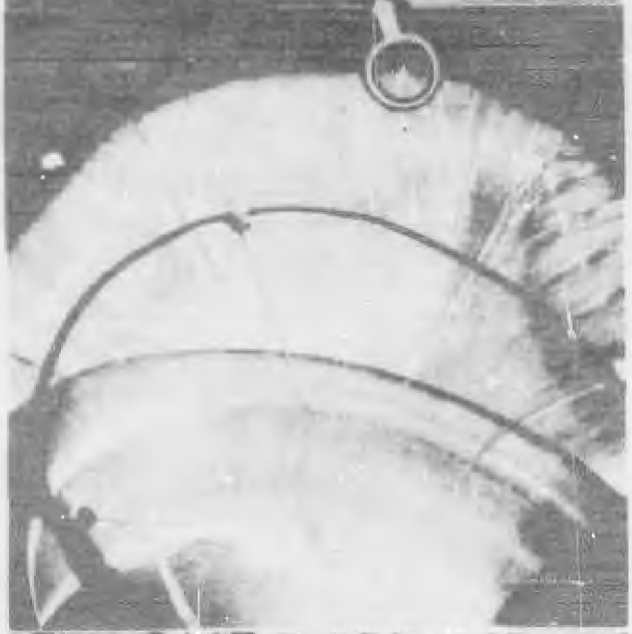
INDEX - continued

PROJECT ACHIEVEMENTS

1 DEMONSTRATION OF INCOMPATABILITY OF PRESSURE SENSITIVE TAPES IN PLASTIC BALLOONS.

Pointed out one of the principal causes of balloon failure for early designs.

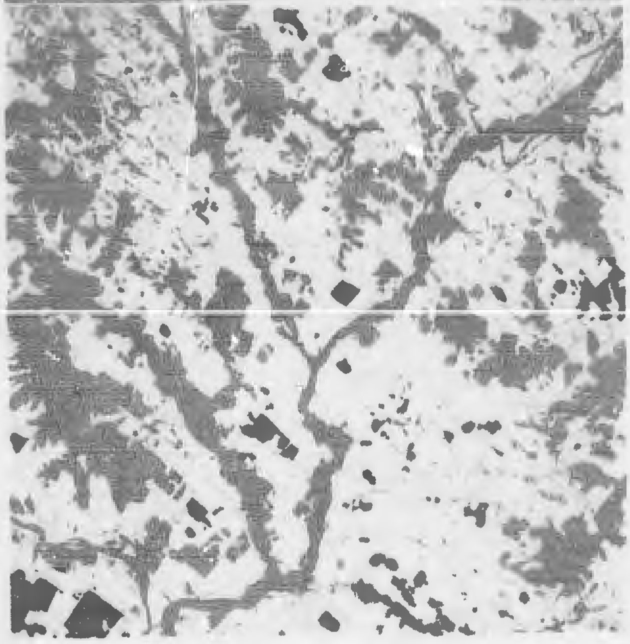
Early 1952
Vol. IX – p 41
Vol. V – p 115



2 INTRODUCED ROUTINE UP AND DOWN CAMERA TECHNIQUES.

Photographs of the balloon in flight for analysis of performance, Down Camera photographs for precise trajectory information.

March 15, 1952
Vol. VII – p 14



3 DEVELOPED THE "MINNESOTA LAUNCHING METHOD."

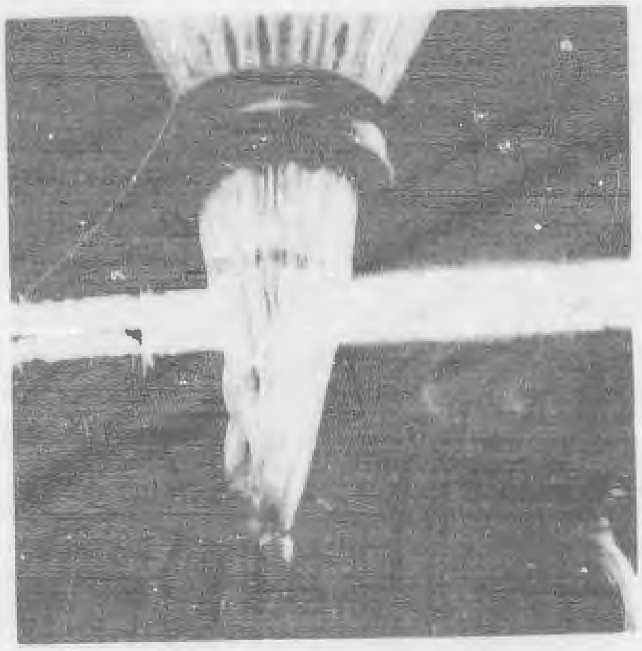
Allows the balloon to be inflated with a minimum of exposed material and makes possible precise weigh off.

Early 1952
Vol. 1 – Sect. II
Vol. VIII

4 SUGGESTED THE POSSIBILITY OF THE "GIRDLE" AS AN AUTOMATIC APPENDIX.

Automatically restrains the excess material in flight.

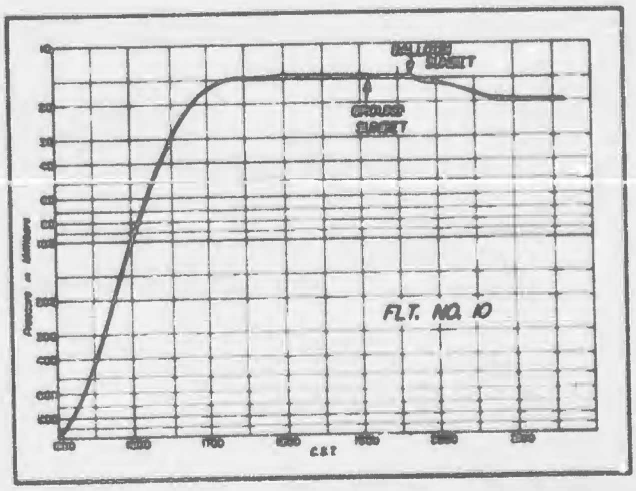
March 1952
Vol. VII – p 16
Vol. I – p 80



5 DEMONSTRATION OF STABILITY AGAINST SUNSET EFFECT AT HIGH ALTITUDE.

High altitude stability later became an important phase of ballooning.

April 1952
Vol. VII – p 28
Also observed prior to this by General Mills in project "Gopher."



6 NATURAL SHAPE BALLOONS

Made quantitative the Upson concept of zero circumferential stress balloons.

Throughout 1952
Vol. I – Sect. III

7 THERMODYNAMIC DRAG

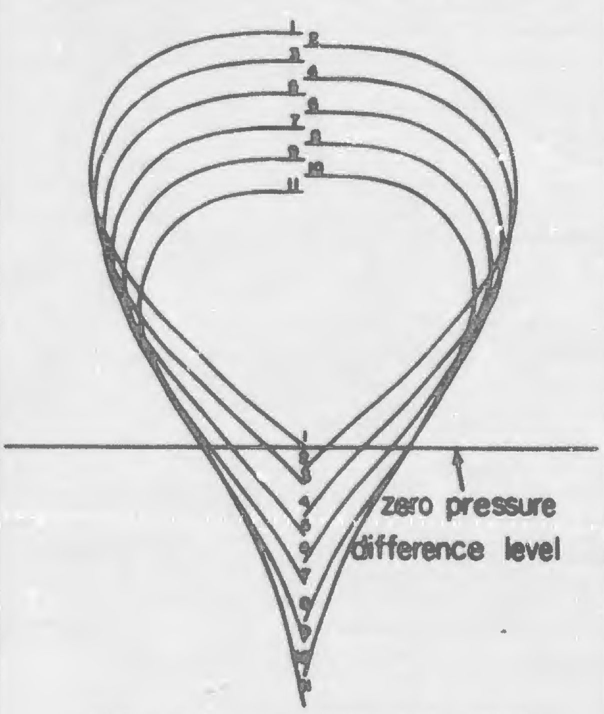
Introduced and expanded the concept of Thermal Drag.

1952 to Present
Vol. I – Sect. IV
Vol. V – Sect. VI-E

8 AERODYNAMIC DRAG

Developed the theory of aero-drag and produced means for quantitative calculations.

1952 to 1955
Vol. I – Sect. IV
Vol. V – Sect. VI-E



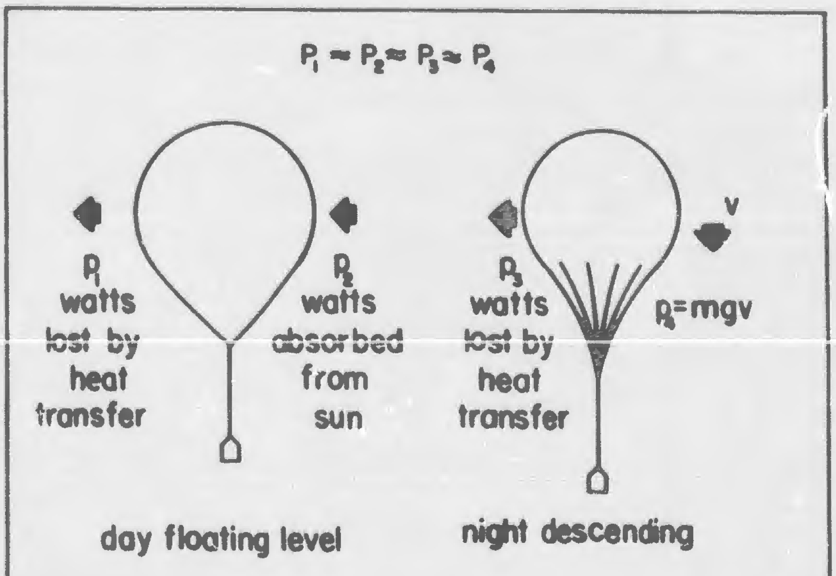
Natural Shape of Expanding Balloon

$$\boxed{P = C_1 (L+4)^{\frac{3}{4}} \frac{G^{\frac{1}{4}}}{T^{\frac{1}{2}}} v^{\frac{3}{4}} + C_2 \frac{P^{\frac{1}{3}}}{T^{\frac{1}{3}}} G^{-\frac{1}{3}} v^2}$$

9 THE ENERGY CONCEPT

Demonstrated that many features of balloon behavior could be predicted from the conservation of energy. e.g. Critchfield's Theorem.

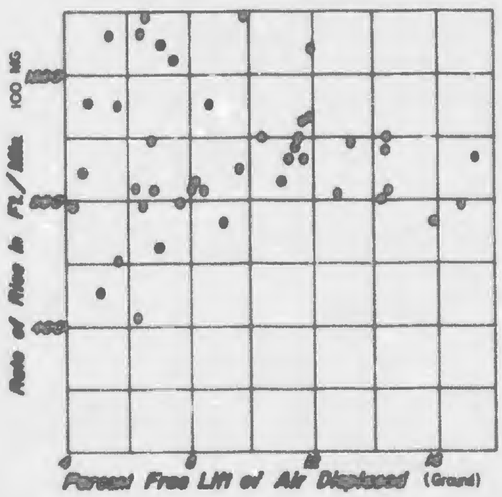
1952 to Present
Vol. I – Sect. VI pp 60-63

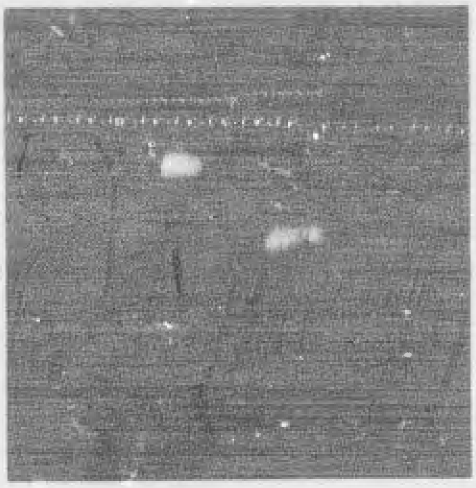


10 HIGH ALTITUDE RISE RATE UNDETERMINED BY GROUND FREE LIFT

Careful measurements showed that regardless of ground weigh-off, balloons attained a fixed rise rate in the stratosphere. This was later shown to be due to the temperature field influence.

Vol. V
Sect. VI A





11 DUCT APPENDIX

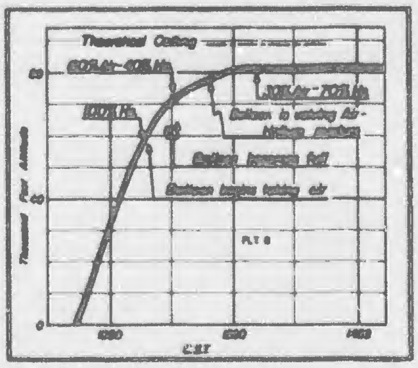
Invented this appendix which positively excludes air intake by the balloon.

September 26, 1952
Vol. VI – pp 69-75

12 EFFECT OF AIR INTAKE

Showed that air intaking produced a large and uncertain perturbation in balloon flight.

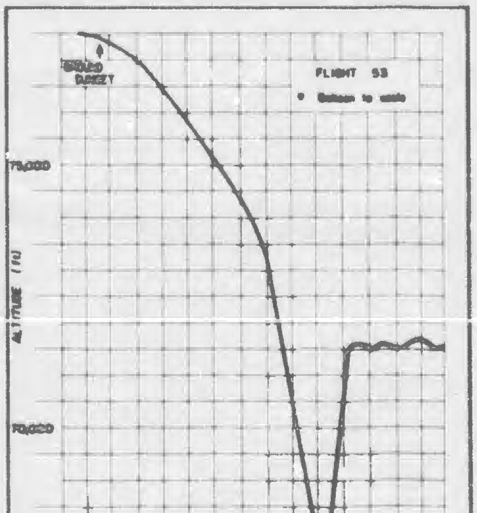
Late 1952
Vol. V – Sects. V & VI
Especially pp 169-176



13 THERMAL BOUNCES

The introduction of the duct produced the discovery of a new dynamic phenomena of great importance in control of balloons

January, 1953
Vol. VI – pp 197-202



14 RADIO COMMAND

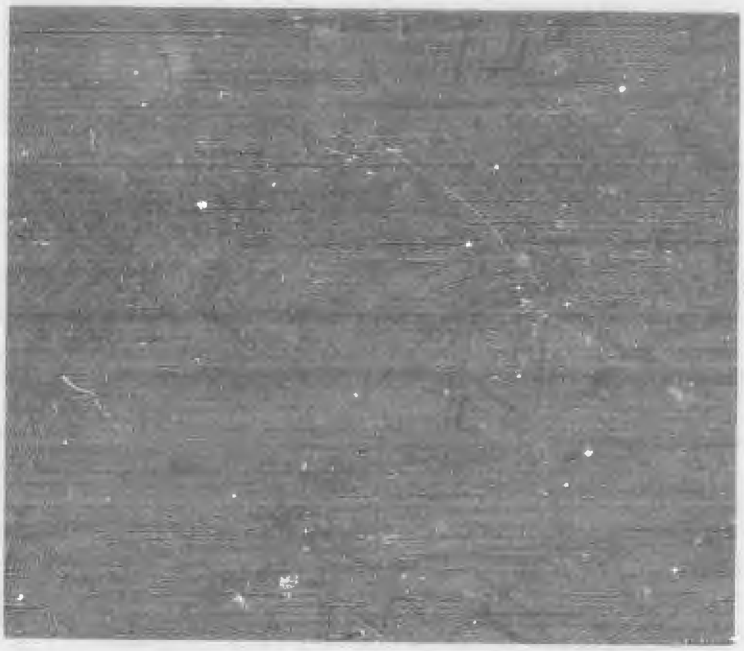
Used radio command to terminate derelict flight.

July 15, 1952
Vol. VI – pp 28-29

15 RADIO CONTROL OF VALVING AND BALLAST

Ballasting and valving were accomplished through a radio link.

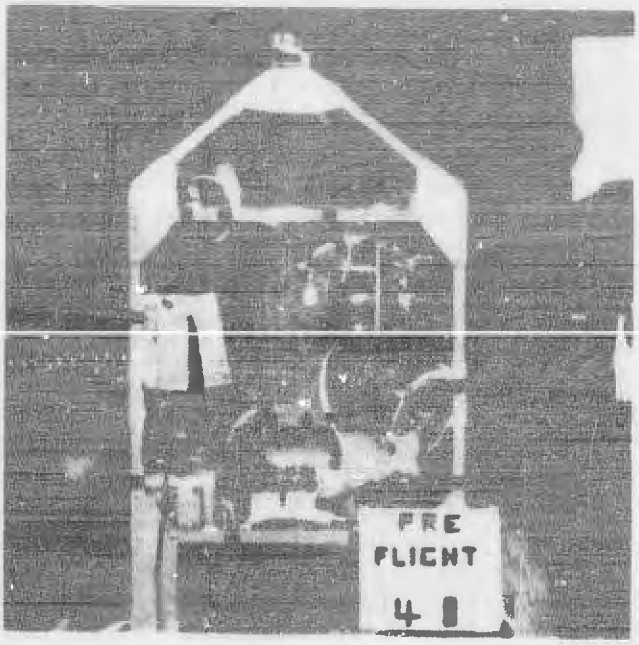
October, 1952
Flight 41



16 RADIO CONTROL OF TOW BALLOON AND BALLAST

Tow balloon was cut by radio and ballast dropped on command.

January, 1953
Flight 56

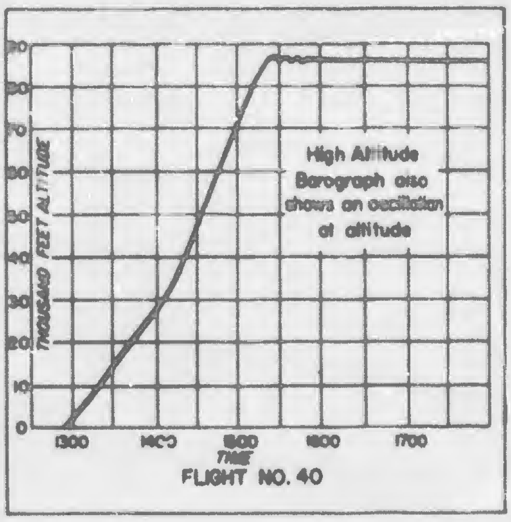


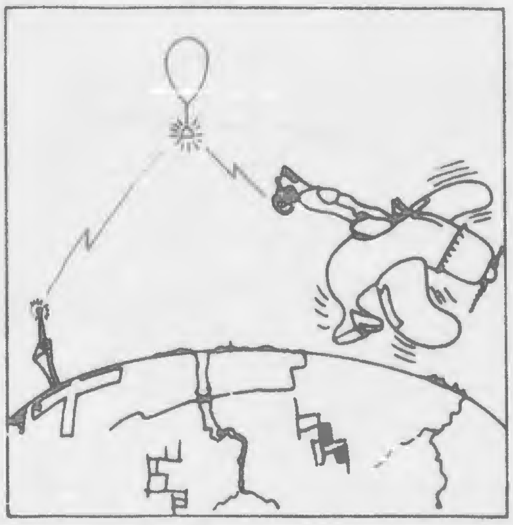
17 THERMAL OSCILLATIONS

The duct appendix also made manifest oscillations (thermal) at floating altitude.

Note: it appears that the precipitous ballasting required on the Explorer II flight was the result of a thermal oscillation.

October, 1952
Vol. VI – pp 197-202

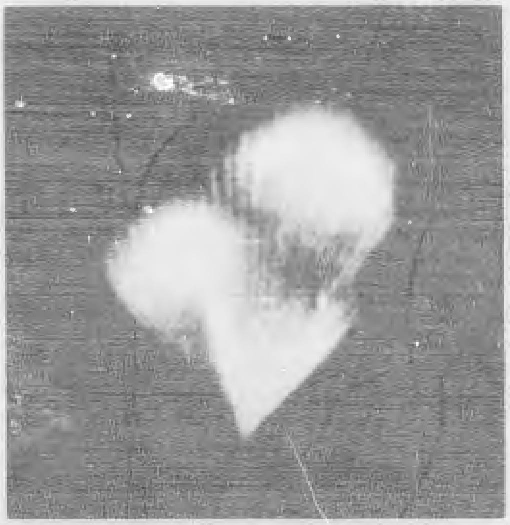




18 THE BALLOON AS A RADIO RELAY LINK

The balloon was successfully used as a radio relay link between the Beechcraft airplane and the tracking center when direct communication from the plane to the center could not be heard.

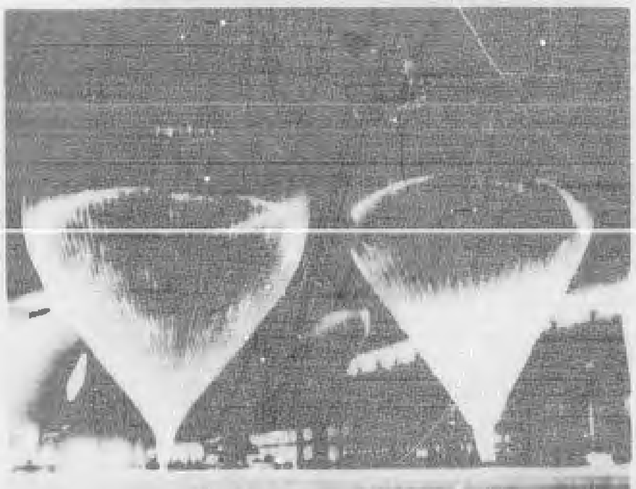
May 12, 1952
Vol. III – p 33



19 SUNSET EFFECTS

Evaluated the magnitude of the sunset effect on polyethylene ballons and mylar ballons.

1952 to Present



20 HANGAR INFLATION OF LARGE BALLOONS

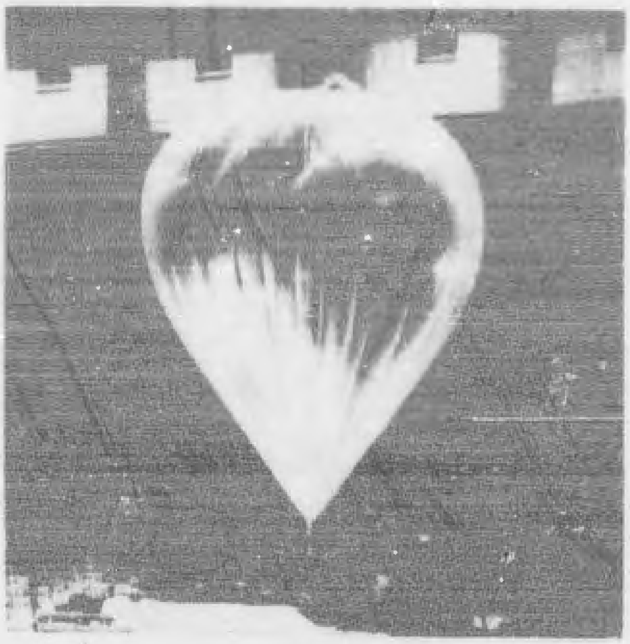
Developed techniques (gas needling) to hangar inflate and study the configuration and stresses in large balloons.

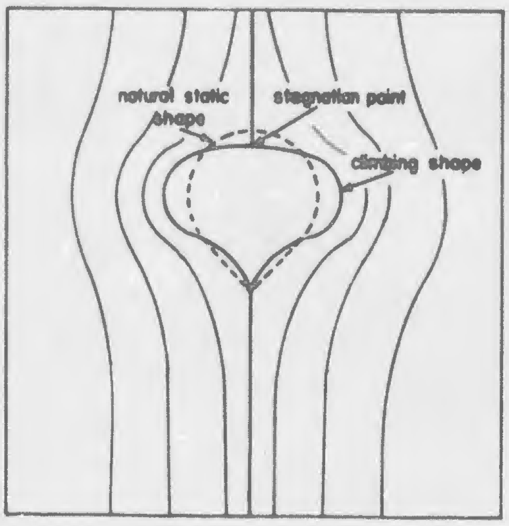
1952
Vol. V – Sect. IV

21 CYLINDER BALLOONS

Developed the theory quantitatively and showed by experiment that cylinder balloons had great potential for heavy load applications with readily calculable stresses.

1952, 1953
Vol. V – Sect. III-C

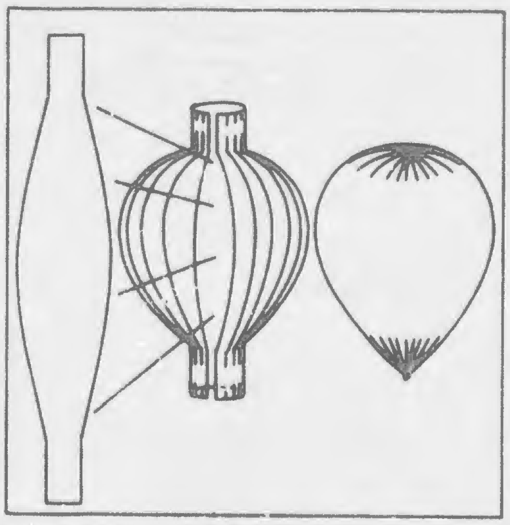




22 THE EFFECT OF AERODYNAMIC FORCES ON SHAPE

The concept of "dimpling" velocity and its effect on balloon shape.

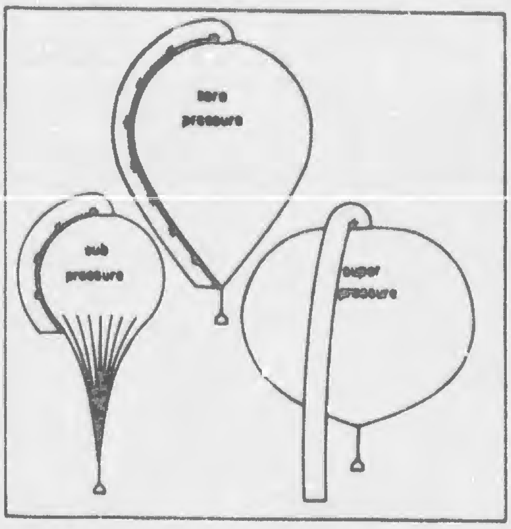
1952
Vol. V – pp 182-184



23 SEMI-CYLINDER BALLOON

Addition of cylindrical ends to a natural shape balloon allowed weight economy over the cylinder balloon when maximum loads are not carried.

1952
Patent application



24 THE HYDROSTATICS OF BALLOONS

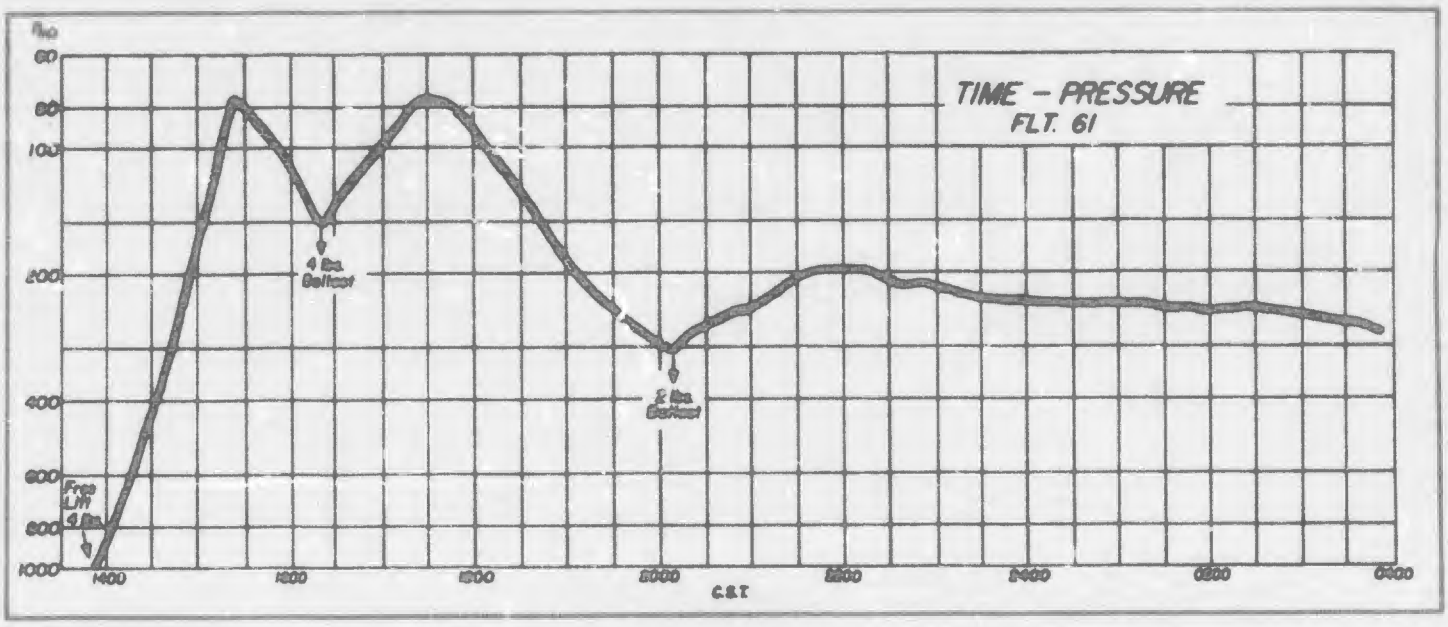
The introduction of the duct allowed a whole variety of natural shape balloons with the shape determined by the pressure level.

1952, 1953
Vol. V – Sect. III

25 MODIFIED OLLAND CYCLE FOR PRECISION PRESSURE MEASUREMENT

The ambiguities of the original Olland cycle were removed by design changes.

1952 to Present
Vol. V – pp 272-281



26 EFFECT OF DUCT SIZE ON VALVING - OVERVALVING

The possibility of overvalving with ducts too small for the balloon was demonstrated

1953
Vol. IX – Sect. II
Flts. 60, 61, 62, 69, 76

27 EFFECT OF DUCT SIZE ON VALVING - SUPERPRESSURE

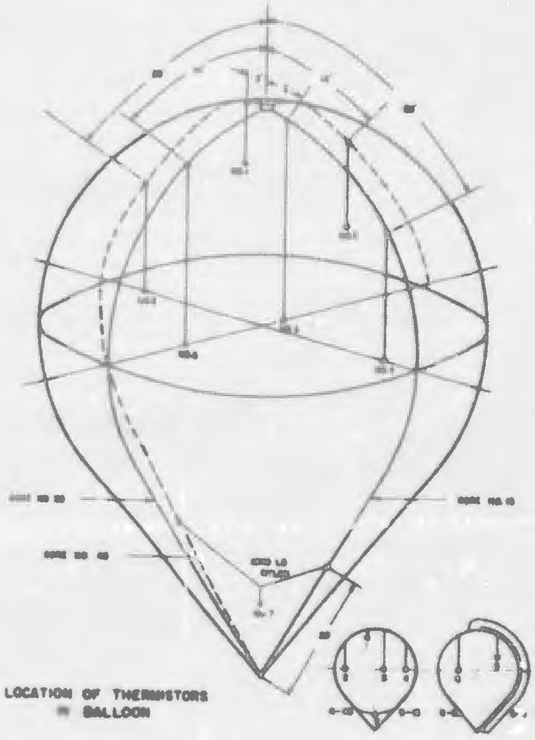
The necessary size of duct to eliminate superpressure was determined by theory and experiment.

1954, 1955
Flts. 137, 185, 188

28 DIRECT MEASUREMENT OF BALLOON TEMPERATURES

Allowed the determination of super heat of balloons in motion and at rest-- verified the feed-back theorem.

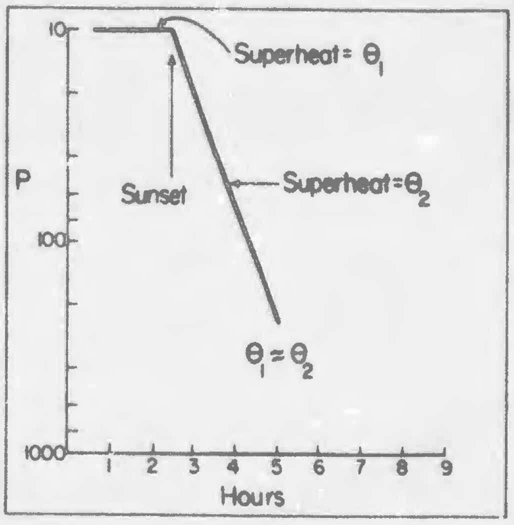
1953 to Present
Many flights --
See flight summary sheet



29 FEED BACK THEOREM

A useful application of the energy principle when aero drag is small -- the balloon never changes its superheat (even at sunset or sunrise) unless it ballasts or valves.

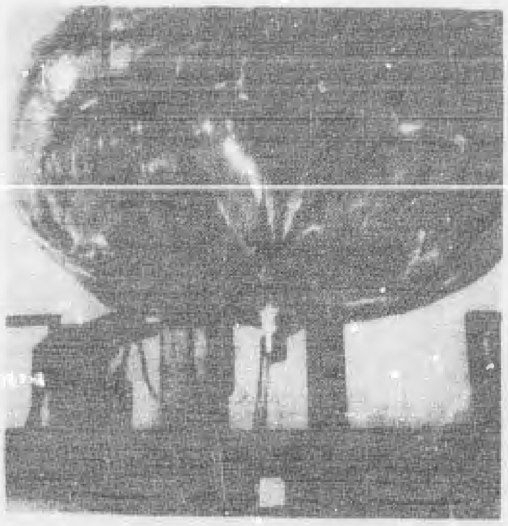
1953
Unreported



30 SUPER PRESSURE BALLOONS

Developed basic theory of super pressure balloons and verified this by flight and model tests with mylar cylinder ballons.

1955
Vol. VI -- Sect. VI-E
Vol. VI -- Sect. III



31 INVESTIGATION OF NH_3 AS A LIFTING GAS

Several flights were made with pure ammonia and with helium-ammonia mixtures.

1951, 1952
Flts. 21, 24, 26, 27, 28, 42, 86

32 INVESTIGATION OF CH_4 AS A LIFTING GAS

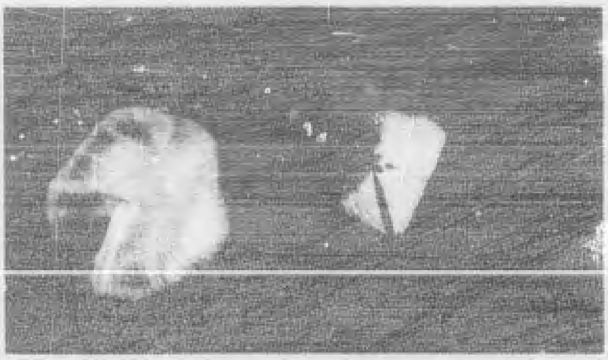
The existence of "thermal lift" with a low γ gas was demonstrated on a step flight. This can cause unstability in free flight.

April 1955
Flight 218

33 AUTOMATIC BALLAST WITH DRY ICE

The limitations and usefulness of dry ice as automatic ballast were investigated.

1952, 1953
Flights 33, 34, 107



A balloon photographs its dry ice ballast and another balloon below launched at the same time.

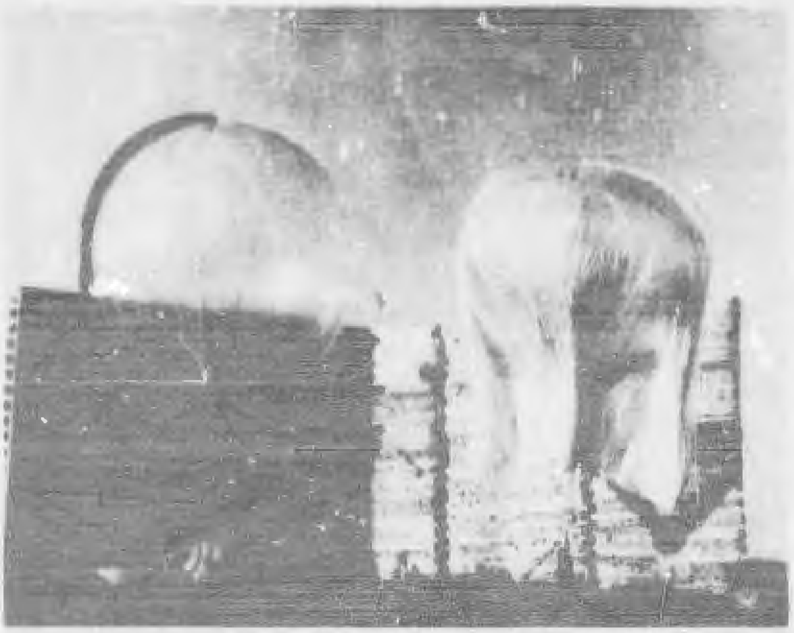
Texas, 1953
Flights 107 and 108

34

THE "LEAD BALLOON" TECHNIQUE

Programmed control of a flight profile by ballasting a full balloon.

April, 1953
Flight 68

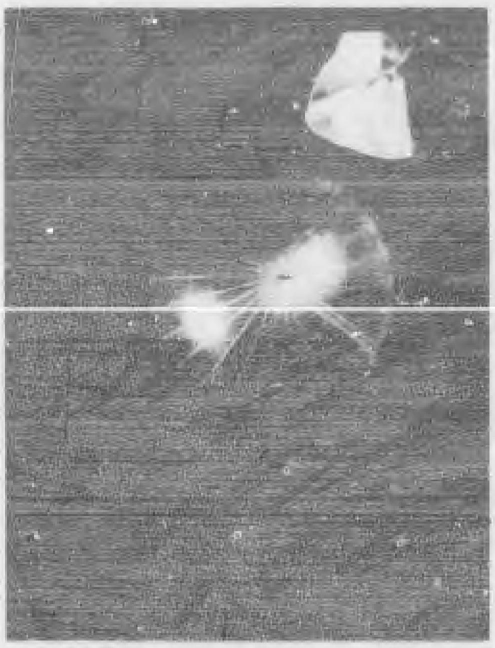


35

THE "STEP FLIGHT" TECHNIQUE

The development of a method of testing balloons in flight by measuring their lift relative to a "lead balloon."

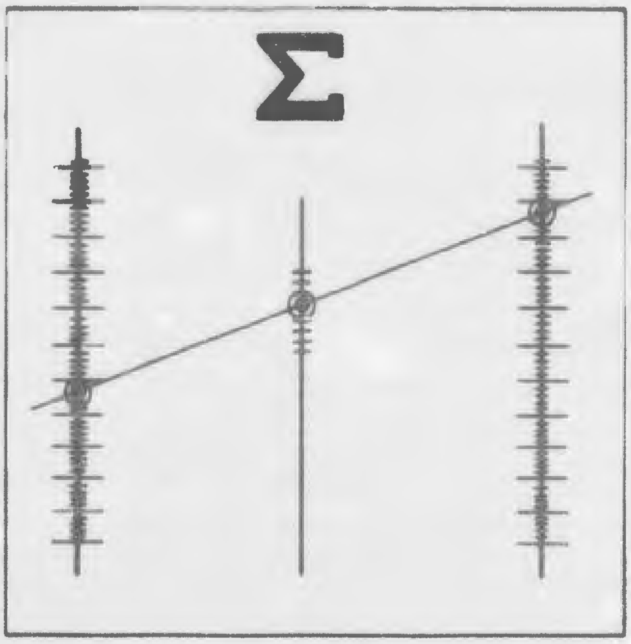
1953, 1954, 1955
Vol. VI – Sect. VI and
Flight Summary Sheets



36 "NATURAL BALLOON" SHAPES WITH FABRIC WEIGHT

REAC computer calculations were made of the family of natural shapes including the perturbation of fabric weight.

1953
Vol. IX – Sect. II

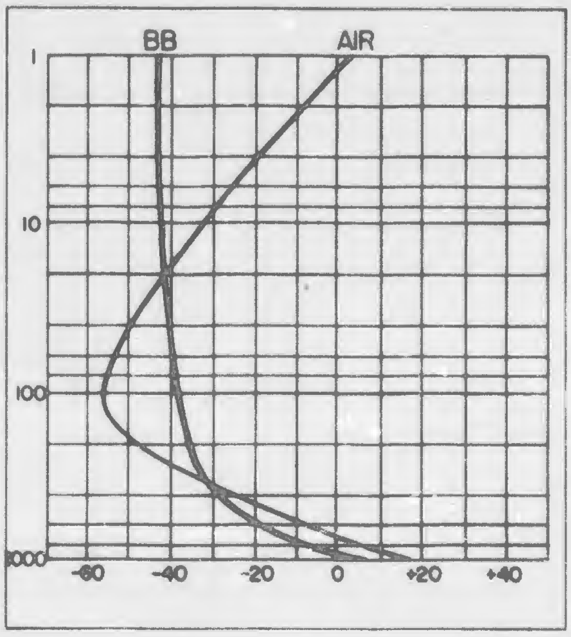


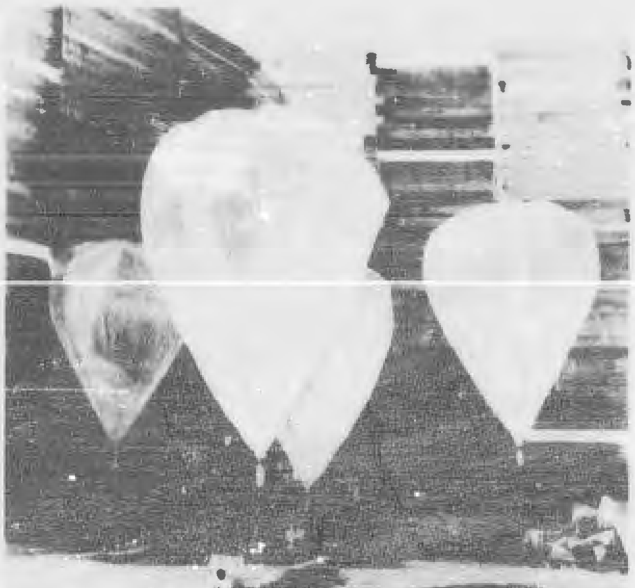
37 TEMPERATURE FIELD

Because of infra-red radiation the balloon acquires a static buoyancy which is a function of altitude and the meteorology. It has been shown on project flights that this is a factor of major importance in balloon behavior.

First demonstrated in Flight 80, July 3, 1953. Studied in detail up to termination of the project.

All step flights following Flight 80, see discussion in this report. Reported at Steering Committee meetings.





38 CONSTANT LEVEL METEOROLOGY WITH SUPER PRESSURE BALLOONS

A series of constant level trajectories were obtained at 30,000 feet with superpressure cylinder balloons.

1953 - 1956
Flights 85, 99 and others

39 MYLAR BALLOONS

Demonstrated the feasibility of mylar as a balloon material for heavier loads and higher altitudes.

1953 to 1956
Flight Summary sheets

40 BLACK BALL RADIATION DETECTION

First showed the qualitative similarity of the radiation temperature and the balloon temperature and suggested meteorological applications.

1952 to Present
Vol. IX Sect. IV

41 MYLAR AND POLYETHYLENE SHIELDED BLACK BALLS

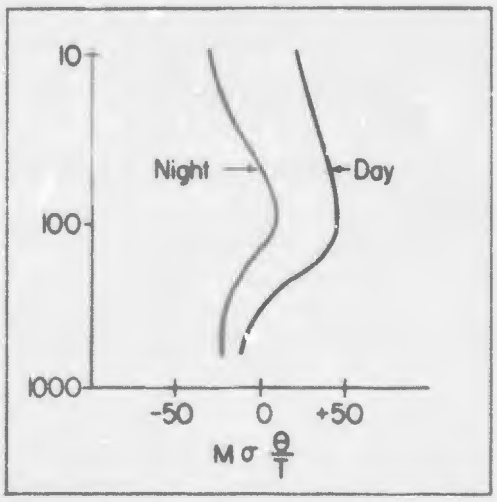
The increased sensitivity of the black balls shielded from forced convection allowed measurement of the temperature field with greater accuracy.

1954 to Present
Review of Scientific
Instruments July '56

42 DAILY RADIATION MEASUREMENTS UP TO 80,000 FEET FOR ONE YEAR

A survey of the temperature field became available for predicting the static behavior of balloons in all seasons at latitude 45°.

1954 to Present
RA Flts. 1 to 380



43 THE CONCEPT OF "BUOYANCY POTENTIAL"

A theoretical approach allowing the prediction of behavior of "Gaboons", shrouds, and bare balloons in the temperature field.

1955, 1956
Vol. XIII

44 THE "GABOON" PRINCIPLE

An auxiliary bag, "Gaboon" hung below the balloon was used to intake and warm air to stabilize the balloon against sunset effects.

September, 1954
to Present
Flight Summaries, also
Vol. XIII

45 THE SHROUD

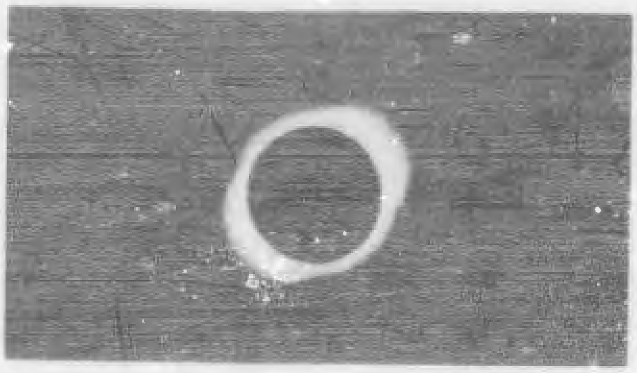
An extra canopy hung over the balloon uses intaken air to produce stability in the same way the "Gaboon" does.

Jan., 1955 to Present
Flt. 205 was the first test.
See flight Summary sheets.

46 ECLIPSE FLIGHT

A successful flight carried out during a total eclipse verified the prediction concerning balloon behavior.

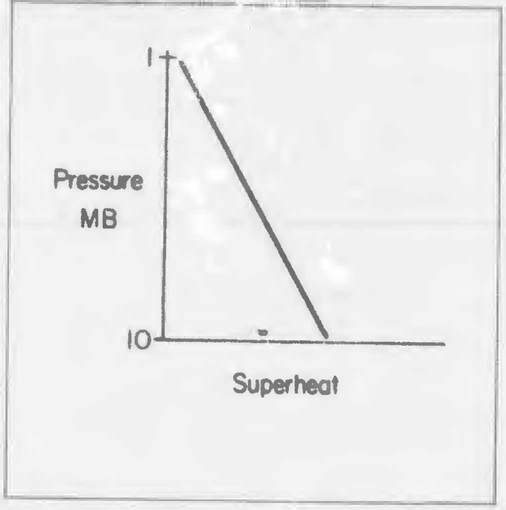
June, 1954
Flight 155



47 "POWDER PUFF" FLIGHT

A flight was made to observe with Up Camera pictures the extent of convection near the balloon by exploding powder charges.

April, 1955
Flight 217



48 MESOSPHERE STABILITY

The great stability introduced by the warming of the air above 100,000 feet was used to compensate for sunset.

1956
Flts. 277, 288, 290

49 THE "WEIGH-OFF" PLATFORM

A roller type weigh-off was first introduced. Modifications of this are now in use by most groups flying high altitude balloons.

July, 1954
Reported at Steering Committee meetings.

50 DIFFUSION STUDIES ON MYLAR

Contract with Karl Kammermeier led to demonstration of very low leakage of Helium through Mylar.

1953, 1954

Testing of "Mylar" to measure resistance to puncture by dirt particles.

51 BALLOON HARDWARE

Developed double ring and fittings for superpressure cylinder balloons and heavy load applications.

1953
Vol. IX - Sect. III

52 STUDY OF BALLOON LORAN SYSTEM

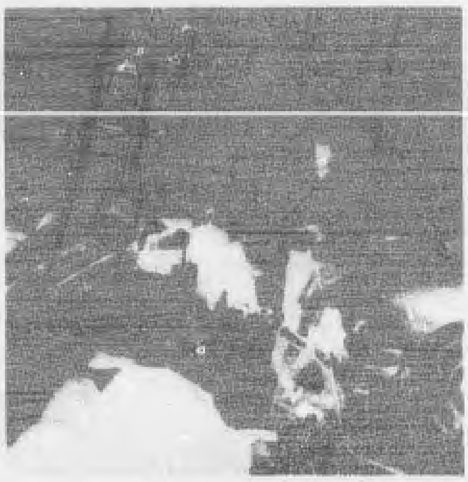
A theoretical study together with one flight indicated the difficulty of applying Loran to balloon navigation.

July 1953

53 BLACK BALLOON

A black polyethylene balloon was flown through sunrise to determine the maximum sunrise effect. The polyethylene melted after sunrise.

July, 1954
Flight 159



54 THE "RADIATION WIND TUNNEL"

Built a wind tunnel for testing radiation detectors. The ventilation and the temperature difference between radiation and air can be controlled.

1956 – Reported at Steering Committee Meeting

55 SIMPLE LAUNCHING ROLLER

Man-handled roller devised for launching moderate loads.

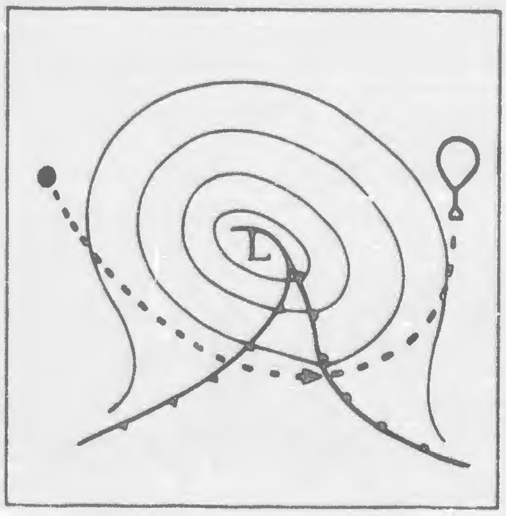
1955, 1956

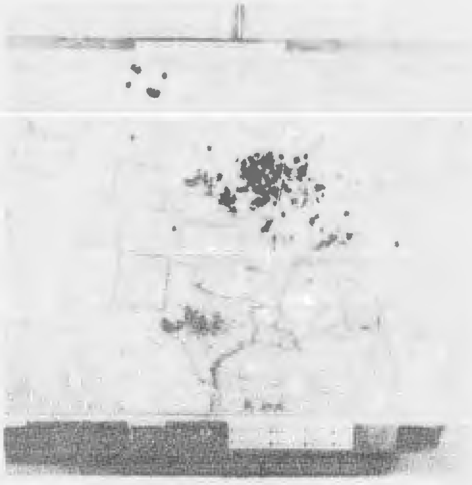
Vol. XV

56 SCALE OF MOTIONS STUDY

Analysis of the magnitude of velocity fluctuations with different periods with particular reference to the effect on representativeness of wind measurements.

1953, 1956
Vol. VIII – Sect. IX





57 HIGH ALTITUDE WIND SURVEY

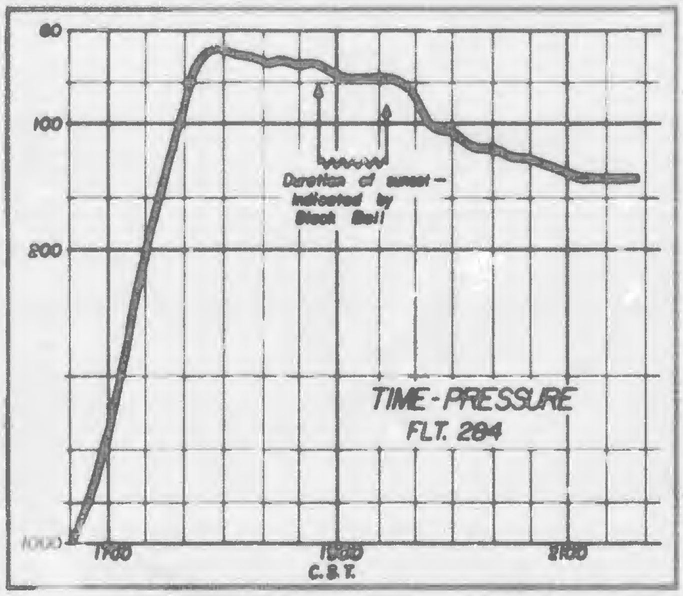
The mean zonal wind computed from the trajectories was found to be consistent with the mean pressure and temperature fields.

1952, 1956
Vol. XV

58 COMPLETE INSPECTION

The introduction of inspection techniques revealed many potential sources of failure.

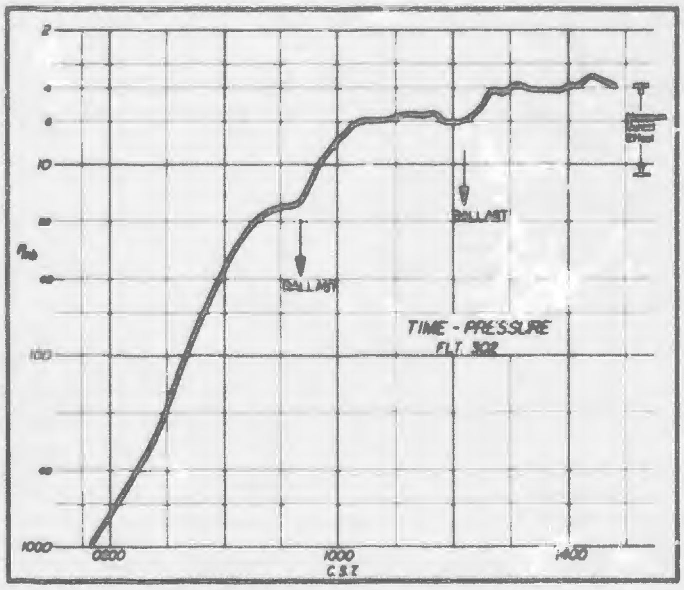
1952, 1956
Steering Committee Meeting
March, 1956



59 SUSTAINED FLIGHT ACCOMPLISHED BY A BARE BALLOON IN THE TEMPERATURE FIELD

A four day flight without ballast aboard showed the possibility of flight duration limited only by material survival.

1956
Flight 290



60 ELIMINATION OF THE APPENDIX

The mesosphere stability allows a tight balloon to be taken to ceiling. In Flight 302, 25% excess lift was required to reach ceiling.

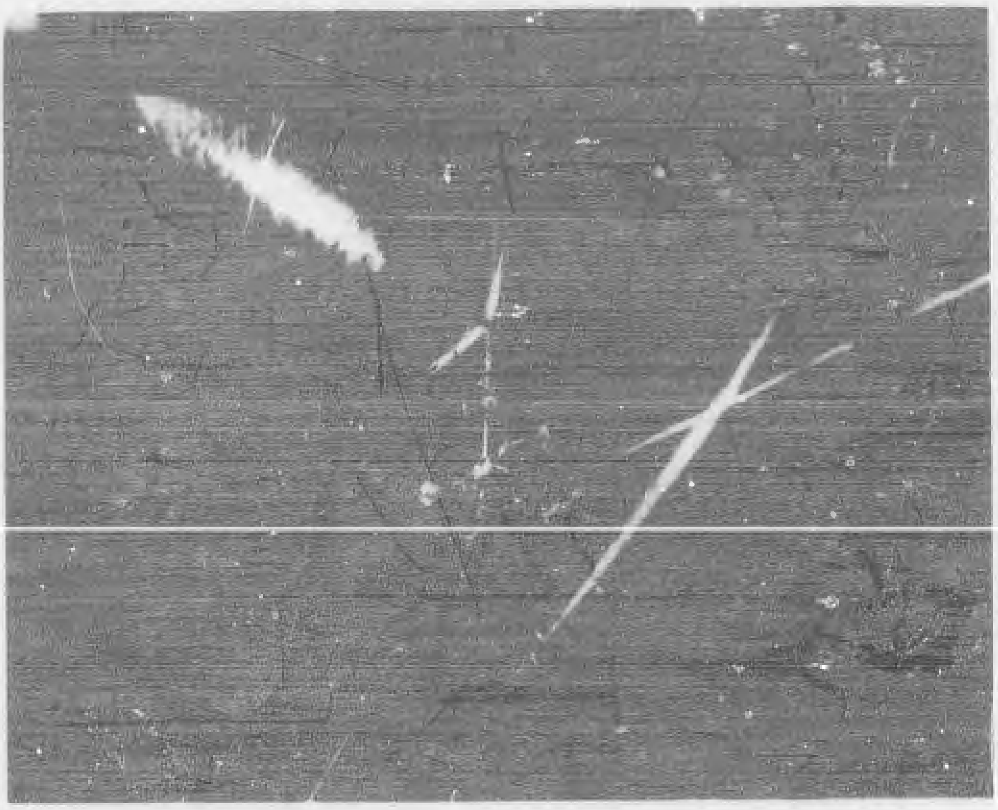
1956
Flight 302 and others

Photo Courtesy of Minneapolis Sunday Tribune

61 THE TETROON

A balloon design capable of very efficient use of material which can be made with straight seams with ¼ mil Mylar. This design makes possible an altitude of more than 140,000 feet with a 100 pound balloon.

1954 - Small Tetroon Model
1956 - Large Balloons
Flights 289 through 310



"Up camera" picture of tetroon under superpressure.

Flight 307

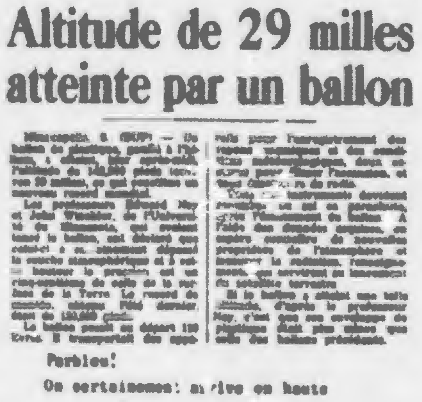
226,407

copies

LA PRESSE

Le plus grand quotidien français d'Amérique

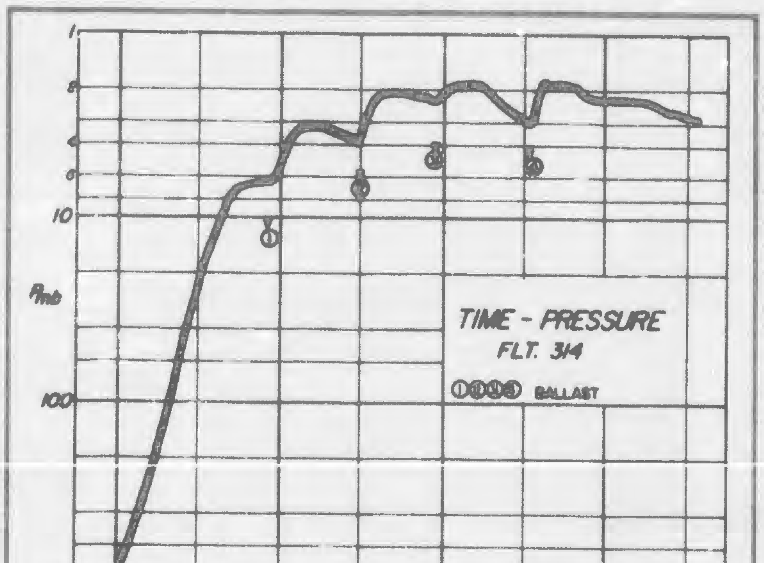
72e ANNEE — No 2?3 [illegible] — [illegible] 8 [illegible] 1956 PRIX : CINQ CENTS

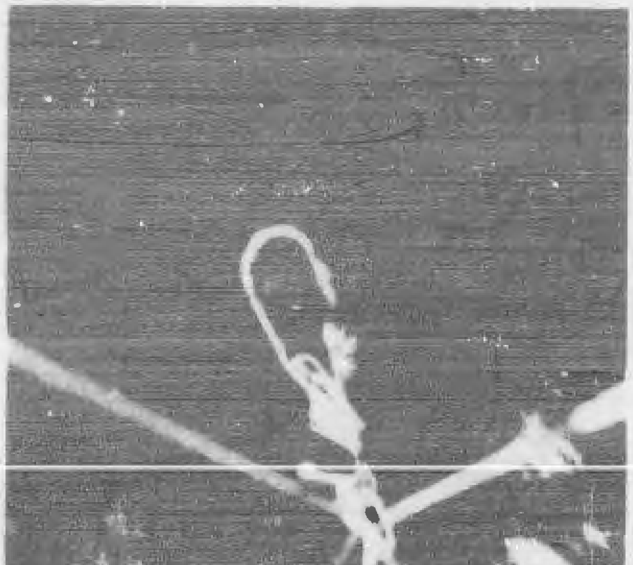


Altitude de 29 milles atteinte par un ballon

Parbleu!

On certainement arrive en haute





62 THE BALLOON ALTITUDE RECORD. FLIGHT 314

In a post-project flight September 7, 1956, a 160' Tetroon reached a well-documented pressure altitude of 1.79 ± .05 millibars and a height of 145,000 ± 1000 feet m.s.l.. The illustrations show the last minute patching of a hole, the launching, the Time-altitude curve, and a down picture of Minneapolis taken from 140,000 feet. The demonstration of a mesosphere vehicle opens the door to this scientifically unexplored layer of the atmosphere.

SECTION III PROJECT ORGANIZATION

An operation in which experiments are conceived, prepared, conducted, and the resulting data reduced and evaluated, is dependent upon people to make it go. The following pages present some of those responsible for this work.

PROJECT ADMINISTRATION

Through representatives in a steering committee, the three services in the Department of Defense participated in the guidance of the High Altitude Balloon program. This committee, together with other interested service personnel, met several times yearly with the project staff to be informed of its findings, to review its progress, and to discuss areas of further investigation. The balloon manufacturers were invited to attend these project presentations made in steering committee meetings held in Minneapolis.

Steering Committee Members

Army	
Dr. Michael Ference	1951-1953
Dr. Edward Fister	1953-1955
Dr. D. M. Swingle	1955-1956
Navy	
Commander M. H. Buaas	1951-1953
Commander M. D. Ross	1954-1956
Air Force	
Major Vic Genez	1951-1952
Major T. O. Haig	1952-1953
Mr. C. S. Tilton	1953-1956

Malcolm D. Ross **John W. Sparkman** **Robert C. Cochran**

OFFICE OF NAVAL RESEARCH LOCAL FIELD REPRESENTATIVES

1951 – 1952 1953 – 1955 1955 – 1956

Richard H. Brown

AIR FORCE CAMBRIDGE
RESEARCH CENTER
LIAISON OFFICER
1952 – 1956

Marshall W. Kieth

OFFICE OF NAVAL
RESEARCH RESIDENT
REPRESENTATIVE
1951 – 1956

PROJECT STAFF


Leland S. Bohl


Charles Critchfield


Robert L. Howard


William F. Huch


Raymond A. Maas


Homer T. Mantis


Edward P. Ney


Rudolph B. Thorness


John R. Winckler

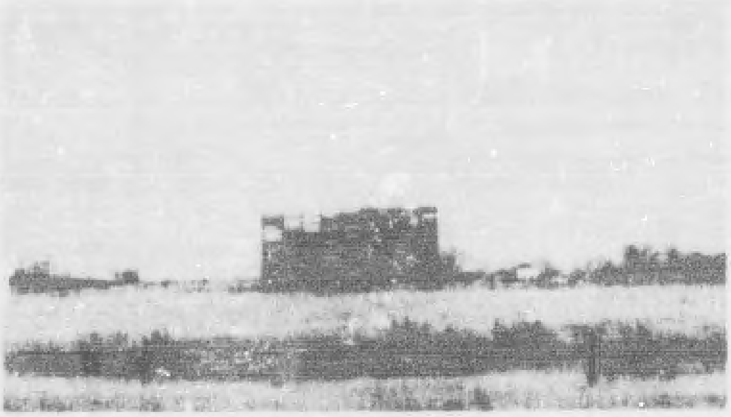

SPOOL TECHNIQUE

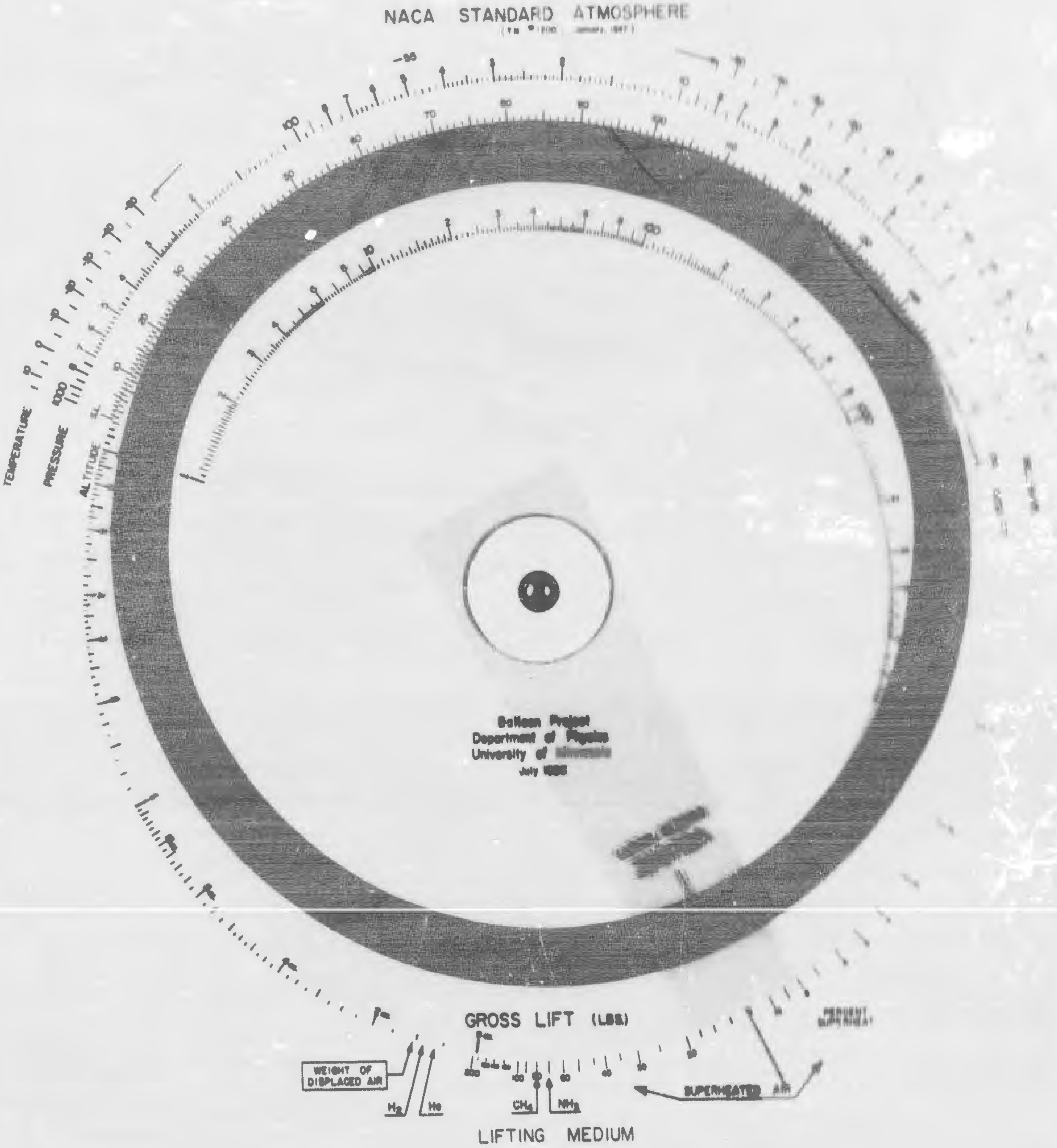

UP WIND LAUNCH


MINES A QUARTER MILLION
WHATS YOURS?


GOING UP

IN REFLECTION





BUOYANT FORCES IN THE STANDARD ATMOSPHERE

UNCLASSIFIED

UNCLASSIFIED