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STUDY OF THE FEASIBILITY OF USING PLASTIC BALLOONS TO CARRY AN ARRAY OF LOADS AT AN ALTITUDE OF 100,000 FEET.

FINAL REPORT

(CONTRACT Nonr-1589(02))

GENERAL MILLS, INC.
MECHANICAL DIVISION

Engineering Research and Development Department
MINNEAPOLIS, MINNESOTA

10059
[redacted]

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STUDY OF THE FEASIBILITY OF USING PLASTIC BALLOONS TO CARRY AN ARRAY OF LOADS AT AN ALTITUDE OF 100,000 FT.

by

Marvin A. Sandgren

FINAL REPORT
Project 85027
15 March 1955 to July 1955
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ABSTRACT

A study was made to determine the feasibility of using high altitude plastic balloons to carry arrays of 100 lb and 1500 lb payloads at an altitude of 100,000 ft and have the arrays pass over a point on the earth at a specified time. The payloads would have to be spaced 1000 ft apart and arrangments having loads on both vertical and horizontal axis were investigated. The study revealed that the only array feasible at this time would consist of five 100 lb payloads supported from a single large balloon. A tailored tapeless balloon similar to, but slightly larger than, balloons which have already been used would have to be engineered. At least one balloon should be flight tested before proceeding with the proposed operation.

Launching the balloon from an aircraft carrier at sea would provide the mobility required to fly the loads over a target point. Four flights should be planned. By obtaining rate of rise and trajectory data from the first flights and relocating the launching point accordingly, it should ultimately be possible to fly the loads within 3.2 miles of the target point. The balloon would be designed for an altitude of 100,000 ft on the basis of the NACA standard atmosphere. Actual altitude attained could vary from 4365 ft below to 4625 ft above 100,000 ft because of effects from atmospheric variations, balloon volume variations and operational factors. To shorten the length of load train to facilitate launching a vertical array of loads, it would be necessary to develop special reels to contain the load lines until after launching. The reels should be field tested prior to the operation. Suitable instrumentation has already been

developed for satisfying the flight termination, tracking, and recovery requirements of the operation.

A suitable balloon design is not yet available for carrying a 1500 lb payload and associated flight gear to 100,000 ft. Payloads in a horizontal array would have to be supported from separate balloons. The altitudes of the various balloons could be expected to vary approximately 425 ft above or below 100,000 ft. The balloons would have to be tied together to limit the horizontal spacing and small rocket motors would be needed to oppose the horizontal forces resulting from the weight of the tie lines. Suitable rockets could very likely be developed. However, in view of the altitude variation of the balloons and the extreme difficulties in launching a multiple-balloon system, particularly from a ship at sea, horizontal arrays are not considered feasible for 1000 ft spacings at this stage of development in the field of high altitude balloon operations.

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I. INTRODUCTION

In 1946 General Mills, Inc. undertook the development of high altitude plastic balloons in connection with Project "Helios" (Contract No. N6Onr-252, Office of Naval Research). Project "Helios" became Project "Skyhook", the pioneer project in the successful application of plastic balloons to a wide variety of high altitude research. During the past 9 years, General Mills, Inc. has remained keenly interested in the research, development, and operational activities associated with high altitude plastic balloons. Consequently, when the Office of Naval Research introduced a possible new application of high altitude plastic balloons, they found that General Mills, Inc. was interested in the problem. Under Contract Nonr 1589(02), General Mills, Inc. has conducted a study to determine the feasibility of using balloons to accomplish the objectives outlined below.

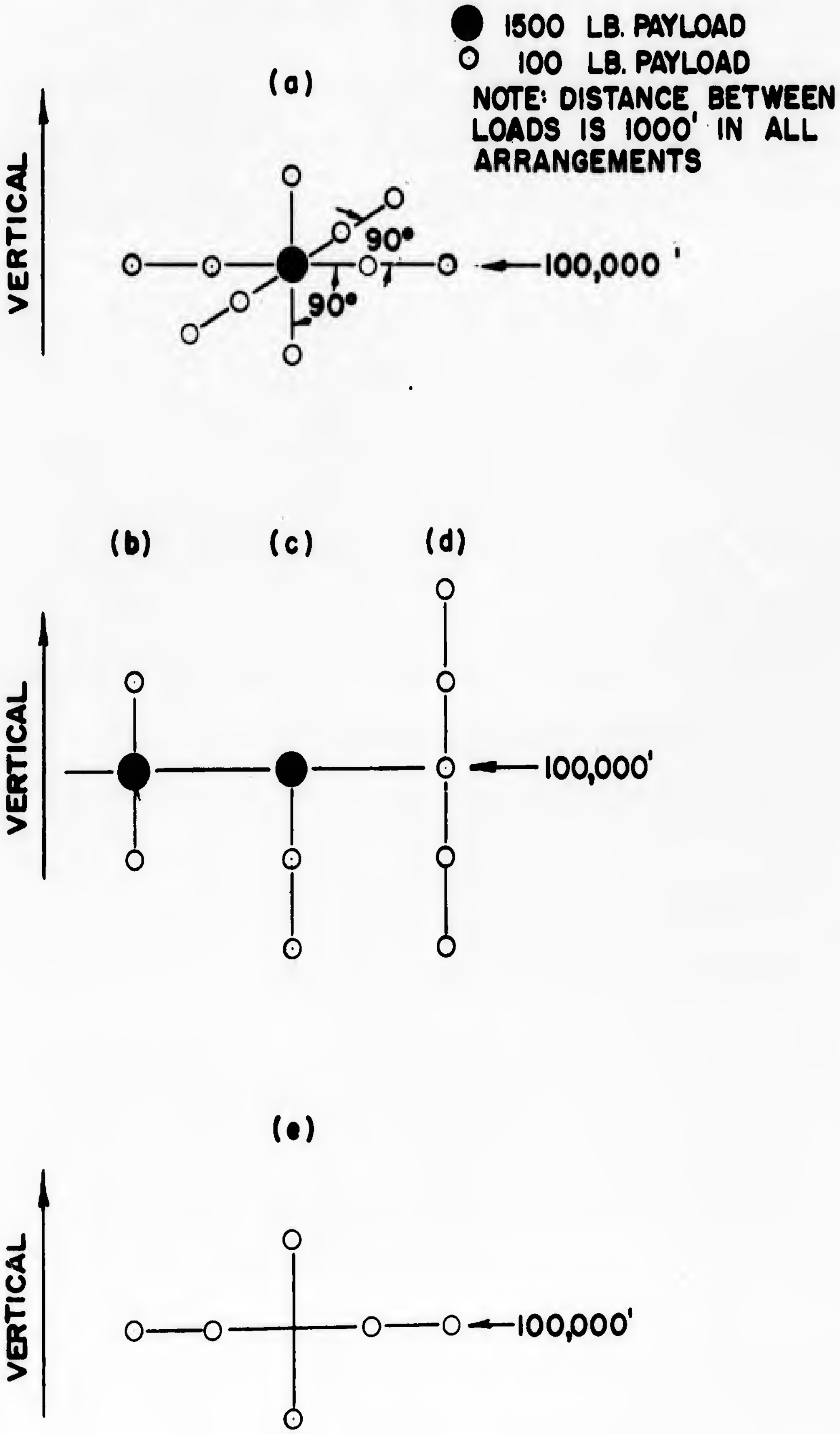
The object of the operation is to fly an array of loads at an altitude of 100,000 ft or greater, over or near a fixed point on the surface of the earth at a given time. Two sizes of payloads, 1500 lbs and 100 lbs, are being considered. Definite space relationships have been specified for these loads. Various acceptable configurations are presented in Figure 1. The preferred arrangement is shown in Figure 1 (a). The other arrangements are alternates (in order of preference) which could be used. In all cases the distance between loads should be 1000 ft. If 1000 ft spacing is not maintained, the separation must be known while the flight is in progress. The altitudes of the array must also be known while the flight is in progress.

The heavy payload must be command-controlled and will be made to fail safe. The speed of descent and impact of the heavy load must be slow enough so that the payload will not be damaged or caused to malfunction. In case the operation is aborted, it must be possible to predict an impact point and to direct vehicles to that area for recovery. The minor payloads must also be recovered with minimum delay.

The problems associated with this proposed operation have been divided into the following seven categories: load, altitude, separation, trajectory, duration, instrumentation, and operations. Problems in the "load" category are associated with getting the loads up to the desired altitude of 100,000 ft. The "altitude" and "separation" problems have to do with keeping the array at the proper altitude and maintaining the required distance between loads. Problems encountered in getting the array over the desired place at the desired time fall in the "trajectory" and "duration" categories. Data telemetering, data recording, flight control and radio command control are typical "instrumentation" problems. The "operations" problem include getting the balloons into the air, obtaining performance data, and recovering the loads after flight termination.

The results of the study are summarized in Section IX of this report. The various problems are presented and evaluated in Sections II-VIII. Some useful engineering data relating to the evaluation of the problems is presented in the Appendices.

FIGURE 1
PAYLOAD ARRANGEMENTS



II. LOADS

A. Net Loads to be Carried

In analyzing the balloon requirements to support the specified loads, there are two possible procedures. The first is to assume that a separate balloon will be used for each payload in the array. The other is to assume that one balloon will support several payloads wherever possible. For example, each of the five payloads in Figure 1 (d) could have its own balloon, or all five might be suspended from one balloon. In Figure 5 (e), separate balloons would have to be used for the four loads on the horizontal axis, but one balloon might support both loads on the vertical axis. Carrying a 1500 lb payload to an altitude of 100,000 ft is a sufficient challenge so that it would be unwise to assume that a balloon for this load will also carry two 100 lb loads. Thus, at least two balloons, and preferably three, would be required to carry the loads in the vertical axis in Figures 1 (a), (b) and (c).

It will be necessary to carry flight instrumentation along with the payload. It is estimated that flight gear will weight up to 100 lb when a single payload is carried on a balloon and approximately 200 lb for a load train supporting five 100 lb loads from one balloon as in Figure 1 (d).

Consequently, for purposes of this study, the balloon requirements for three load sizes were considered; these are 1600, 700 and 200 lb.

B. Past Balloon Performance

A 1600 lb payload has never been carried to an altitude of 100,000 ft on a balloon. Heavier loads have been carried on plastic balloons but to lower maximum altitudes. The heaviest load ever flown on a plastic balloon was carried on GMI Flight 797 on July 25, 1952. The load on the balloon was 2360 lb. The gross weight was 2931 lb. Gross weight is the total load supported by the lifting gas. It includes the balloon weight and all flight gear attached to the balloon. Unfortunately, the balloon failed when it reached an altitude of 67,000 ft. The reason given for failure was that the 200 ft per min rate of rise was too high for proper gas valving through the tight appendix valve used. A 1161 balloon was used.

On an earlier flight, GMI Flight 794[1] on July 1, 1952, a load of 1879 lb was successfully flown at an altitude of approximately 67,000 ft for an extended period of time. A 1161 balloon was used on this flight too. The 1161 balloon can carry only 650 lb (gross weight) at 100,000 ft. The balloon weight constitutes a large portion of this gross weight. The weight for a 1161-A is 304 lb; for a 1161-E, it is 620 lb.

Loads in excess of 1600 lb have also been carried on smaller balloons but to lower maximum altitudes. On GMI Flight 768, May 6, 1952, a load of 2057 lb was successfully carried to an altitude of 45,000 ft and flown for an extended period of time. The gross weight was 2321 lb. A GMI 734 EH balloon was used. On GMI Flight 767[2] on May 2, 1952, a load of 1820 lb was successfully flown at 45,000 ft on a GMI 734 EH balloon.

More recently, the Air Force has been making repeated flights of loads of 2000 lb at altitudes of 80,000 ft using 128 TT balloons. The 128 TT is a tailored, tapeless balloon, the design of which permits use of higher rates of rise. Ascent rates of 800 ft per min have been used successfully.

Record altitude for a plastic balloon was obtained on GMI Flight 1150, May 18, 1954. A 201 TT, 3.2×10^6 cu ft balloon was used. A load of 400 lb was carried to 115,800 ft. This flight demonstrated that it is feasible to carry a 400 lb load above the required altitude of 100,000 ft. The time-altitude curve for this flight (Dwg. No. A-21519-C) is presented in Appendix A.

C. Tailored Tapeless Balloons

The record-breaking 201 TT balloon was a tailored tapeless balloon which assumed a "natural" shape when fully inflated. The natural shape is illustrated in the photograph of an inflated balloon presented in Figure 2. This picture was made during a ground inflation test of a 128 TT balloon made of 2 mil polyethylene. In designating the balloon type, the 128 is the nominal diameter in feet and the "TT" means "tailored tapeless". Other types of balloons have other letter designations. A load of 4100 lb was successfully supported by the balloon in this test. In addition to the 201 TT and the 128 TT, General Mills, Inc. has manufactured and flown a number of other sizes of tailored tapeless balloons. These include the 150 TT, 134 TT, 131 TT, 126.5 TT, 121 TT and the 61 TT. New balloons are being designed to meet the changing requirements of the different projects at General Mills, Inc.

All of these tailored tapeless natural shape balloons are similar in that the same philosophy is followed in designing and flying them. It is also possible to design and build balloons of any nominal

Figure 2

G.M.I Balloon Shape During Final Stages Of Inflation
uct Shows Natural Folds As It Drapes Around Balloon
Cone Angle 73° (G.M.I Photograph No. 8514)

diameter to fit specific load-altitude requirements. There is, however, a theoretical limit to the load which can be carried on tapeless polyethylene balloons. The maximum allowable gross weight appears to be approximately 2000 lb. It is estimated that for a system with a gross weight of 2000 lb, designed for an altitude of 100,000 ft, the balloon would weigh approximately 1000 lb. This allows 1000 lb for the net load consisting of the payload and the flight gear. Obviously, a tapeless polyethylene balloon would be unable to carry the 1600 lb load to altitude. To accomplish this task it would be necessary to develop a new balloon using a stronger material or using high-strength tapes to reinforce the polyethylene. General Mills, Inc. is now in the initial phases of a project sponsored by the Office of Naval Research, under Contract No. Nonr 1589(06), to develop a balloon to carry 1600 lb to 100,000 ft. It is quite possible, however, that none of these balloons will have been flight tested before the spring of 1956.

D. Balloon Recommendations

In consideration of the time and expense associated with developing a new type balloon, it is recommended that the balloon loads be adjusted to accommodate the currently available balloon sizes or new sizes which can be designed similar to existing balloons. The tailored tapeless design has been analyzed to determine the maximum load which can be carried to 100,000 ft without overextending this design philosophy. It is felt that a balloon large enough to carry 700 lb could be built successfully. It would have the following estimated characteristics:

Estimated balloon weight	710 lb
Balloon film	2 mil polyethylene
Volume	1,535,000 cu ft
Gore length (incl. elongation)	222.3 ft
Number of gores	57
Gross weight	1410 lb
Balloon diameter	157.0 ft

It is strongly recommended that at least one of these balloons be flown experimentally to demonstrate its suitability before proceeding with fabrication of balloons for the intended operation.

For the 200 lb payload, a 134 TT balloon could be used. A number of 134 TT balloons have already been built and flown successfully. A 134 TT made of 1.5 mil polyethylene would carry 200 lb to an altitude of 104,000 ft. Typical characteristics of the 134 TT are as follows:

Balloon weight	410 lb
Balloon film	1.5 polyethylene
Volume	805,000 cu ft
Gore length (incl. elongation)	179 ft
Number of gores	46 tailored and 2 straight
Gross weight	610 lb
Balloon diameter	134.0 ft

Theoretical load-altitude curves for the 128 TT (Dwg. No. A-17440-A), 134 TT (Dwg. No. A-31489-A), 150 TT (Dwg. No. A-18767-A) and 201 TT (Dwg. No. A-15941-B) are presented in Appendix B.

III. ALTITUDE

A. General Discussion Concerning the Altitude of Balloons

There are two aspects to the problem under study which require that the balloon position in space be investigated. The first is the 100,000 ft altitude requirement, and the second is the requirement for 1000 ft spacing of the balloons in the array. The 100,000 ft altitude desired is a true altitude. Because of manufacturing variations, atmospheric variations and operational errors, the true altitude will not be exactly 100,000 ft. It is important to know how much the altitude can be expected to vary from 100,000 ft.

A 1000 ft spacing has been specified for all loads in the various arrays, as shown in Figure 1. Where these loads are to be uniformly spaced on a horizontal line a separate balloon would be required for each load. Consequently, the altitude attained by each balloon will determine the vertical positioning of the load attached to that balloon. Since both horizontal and vertical positioning will affect the spacing between loads, it is necessary to analyze altitude performance in connection with determining the feasibility of the 1000 ft spacing. Before proceeding with an analysis of past balloon flight records and the factors affecting altitude performance, it may be well to review briefly the pertinent terminology and phenomena associated with high altitude balloon flights.

A balloon is able to support a load by virtue of the buoyant force resulting from the displacement of air by a lower density gas such as hydrogen or helium. If the floating altitude and the load are specified, it is possible to calculate the volume of lifting gas required by assuming an ideal atmosphere and applying the ideal gas laws. In balloon operations, the NACA standard atmosphere[3] is used. In these calculations the gross weight, or total weight supported by the lifting gas, is used. The gross weight and volume are related by the following equation when the balloon is in equilibrium:

$$W = V(\rho_a - \rho_g) \qquad \text{(III-1)}$$

where W = gross weight

V = balloon volume = volume of lifting gas = volume of air displaced

ρ_a = density of air

ρ_g = density of lifting gas

The altitude associated with such calculations is referred to as the theoretical ceiling. As is to be expected, this theoretical ceiling is seldom, if ever, attained exactly. The actual altitude varies from the theoretical because of the following factors:

1. Variation in balloon volume from the ideal volume because of:
    - a. Manufacturing tolerances
    - b Stretch of plastic film because of balloon loading
2. Errors in weight determination
3. Leakage of lifting gas out of balloon
4. Leakage of air into balloon during ascent to dilute the lifting gas.
5. Gas impurities
6. Variations from the standard atmosphere
7. Superheating of the lifting gas

The extent to which these factors affect the altitude will be elaborated upon after presenting some actual flight performance data.

B. Flight Performance Data

A number of past balloon flights have been analyzed to obtain altitude data which would provide a measure of the accuracy with which an altitude of 100,000 ft can be attained. All of the flights studied had balloons made with a side duct appendix. Data on balloons with the bottom appendix were not used since these balloons are most susceptible to altitude variation due to air entering the balloon through the appendix during ascent. In order to provide quantitative data on flights of large balloons it has been necessary to include data for flights to altitudes less than 100,000 ft.

Table C-1 in Appendix C contains the data for a series of flights made with 134-TT balloons. The altitude performance data for the seven flights is summarized in Table I below. The attained altitude data was derived from records obtained with pressure-sensing instruments which were calibrated to provide altitude information. The theoretical altitude data is based on balloon volume and gross load as given in Dwg. A-31489-A, Appendix B. The difference in altitude was obtained by subtracting the theoretical ceiling altitude from the actual attained altitude. It was found that the measured altitude ranged from 1400 ft above to 2700 ft below the theoretical ceiling. The absolute magnitude of the difference ranged from 650 ft to 2700 ft. Four flights were below and three were above theoretical ceiling.

Table C-2 contains the data for a series of 27 flights made with 79N balloons. While these flights are all to lower altitudes than the

TABLE I

ALTITUDE PERFORMANCE DATA
FOR 134 TT BALLOONS

Balloon No.	Theoretical Ceiling Altitude, Ft	Maximum Altitude Attained, Ft	Difference in Altitudes, Ft
1	95,650	96,300	650
2	96,550	98,000	1,450
4	96,800	98,000	1,200
5	96,250	94,750	- 1,500
6	96,400	95,000	- 1,400
8	97,400	94,700	- 2,700
12	93,800	92,800	- 1,000

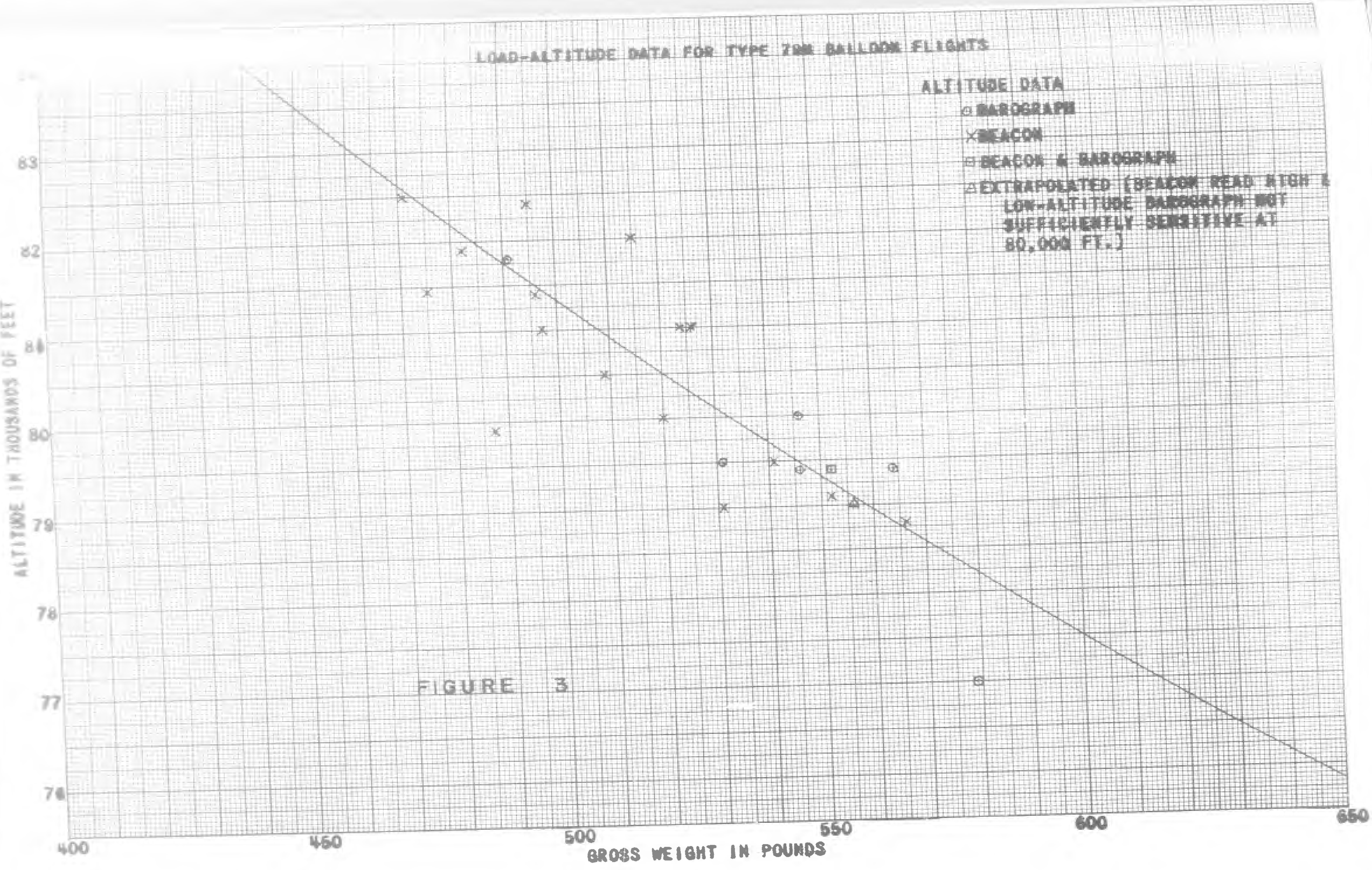

LOAD-ALTITUDE DATA FOR TYPE 70M BALLOON FLIGHTS
ALTITUDE DATA
⊙ BAROGRAPH
× BEACON
⊞ BEACON & BAROGRAPH
△ EXTRAPOLATED (BEACON READ HIGH & LOW-ALTITUDE BAROGRAPH NOT SUFFICIENTLY SENSITIVE AT 80,000 FT.)
ALTITUDE IN THOUSANDS OF FEET
83
82
81
80
79
78
77
76
400
450
500
550
600
650
GROSS WEIGHT IN POUNDS

FIGURE 3

desired 100,000 ft, the data is presented because of the number of flights made with the same type of ducted balloon. Three of these flights failed, leaving 24 flights which provided useful data. Since the 79N is considered to be a constant volume balloon, the attained altitude for these flights has been compared with the theoretical ceiling by means of Figure 3. The continuous curve in this diagram is a plot of the theoretical altitude versus gross weight. Each separately plotted point represents the attained altitude plotted against the gross weight for the particular flight. Thus, the vertical distance from the separately plotted point to the continuous curve gives the difference between attained altitude and theoretical ceiling. The measured altitude ranged from 2000 ft below to 1300 above theoretical ceiling. The absolute magnitude of the difference ranged from 100 ft to 2000 ft. Fifteen flights were below and nine flights were above theoretical.

C. The Effects of Factors Contributing to Altitude Variations

In the previous section the magnitude of the altitude variation from theoretical ceiling was shown. Now it becomes desirable to determine what, if anything, can be done to decrease the magnitude of variation. This requires an analysis of the factors contributing to the altitude variation. Some contributing factors have already been listed. These factors will be discussed in the following paragraphs:

1. Variation in Balloon Volume

Equation III-1 relating gross weight to balloon volume and gas densities can be placed in a different form which will permit a calculation of the change in altitude associated with a given change in volume for a fixed gross weight. From the ideal gas law:

$$\rho = \frac{pM}{R\,T} \qquad \text{(III-2)}$$

where ρ = density

p = absolute pressure

M = molecular weight

R = universal gas constant

T = absolute temperature

Thus Equation III-1 becomes:

$$W = V \left[\frac{p_a\,M_a}{RT_a} - \frac{p_g\,M_g}{R\,T_g} \right] \qquad \text{(III-3)}$$

For purposes of this analysis, p_g can be considered as the average pressure of the lifting gas within the balloon. This pressure is essentially equal to the pressure of the surrounding air, p_a. Therefore:

$$W = \frac{V\,p_a\,M_a}{R\,T_a} \left[1 - \frac{M_g}{M_a} \quad \frac{T_a}{T_g} \right] \qquad \text{(III-4)}$$

or:

$$W = V\rho_a \left[1 - \frac{M_g}{M_a} \quad \frac{T_a}{T_g} \right] \qquad \text{(III-5)}$$

The amount of "superheating" of the lifting gas will determine the ratio T_a/T_g. For the height interval over which Equation IV-5 is to be applied in this analysis, the superheating will be essentially constant and the ratio, T_a/T_g, can be assumed to remain constant. Therefore, for a fixed gross weight the density will be inversely proportional to the volume. Consequently, if the actual volume, V', differs from the design volume, V, the balloon will not go to the theoretical altitude but to an altitude where the air density

$$\rho_a' = \rho_a \times \frac{V}{V'}$$

where ρ_a is the air density at the theoretical altitude.

The shift in altitude required to produce this compensation in density will depend upon the temperature gradient existing at flight altitude when the balloon is flown. The magnitude of the shift can be estimated by assuming that the temperature remains constant with altitude over the relatively small height interval involved.

For a natural shape balloon, the volume varies as the gore length cubed. An error of 0.5 per cent in gore length results in a 1.5 per cent error in volume. For the 134TT balloon with a gore length of 179 ft, an error of 0.5 per cent is 0.9 ft. This 0.9 ft includes the manufacturing tolerance plus the error in calculating the stretch because of loading. The latter is further complicated by the effects of temperature on the film. Thus, a 0.5 per cent error is considered to be a conservative estimate. At 100,000 ft, this 1.5 per cent error in volume will result in a 1.5 per cent change in density or a shift in altitude of approximately 325 ft.

2. Error in Weight Determination

The error in determining the gross weight of the system will depend upon the accuracy of the scale used and the care exercised in weighing the load and the balloon. With a good scale, a careful technician should be capable of determining the weight to within ± 0.5 per cent. Referring to Equation III-5, and again assuming that T_a/T_g remains constant, if the volume remains fixed, the gross weight will be directly proportional to density. Therefore:

$$\rho_a' = \rho_a \times \frac{W'}{W}$$

where ρ_a = density at theoretical altitude

W' = true weight

W = weight arrived at by determination of gross weight with scales ($W = W' + \text{Error}$)

At an altitude of 100,000 ft, a 0.5 per cent change in density would be associated with a shift in altitude of approximately 100 ft.

3. Leakage of Lifting Gas

All balloons lose lifting gas because of porosity and diffusion leakage through the plastic film. The University of Minnesota[4] reports that most properly handled balloons exhibit leakages of the order of 2 per cent per day or less when inflated with helium. For balloon flights which are to remain aloft for extended periods of time, this loss is compensated for by dropping ballast automatically. For short duration flights, such as contemplated in the operation being studied, it is not necessary to use ballast. Immediately upon reaching altitude the balloon will have to valve out the excess lifting gas needed to drive the balloon to altitude. The gas remaining in the balloon will continue to expand slowly because of solar heat transferred through the plastic film. The "superheating" continues until equilibrium is attained. During this superheating period an additional amount of gas will be valved. Thus, leakage at a rate of 2 per cent per day will be insignificant as compared to this normal valving and will not affect the altitude for flights of one or two hours' duration at altitude. However, gross leakage because of rips or holes in the film must be avoided by proper handling if successful flights are to be obtained.

4. Leakage of Air Into the Balloon

Experience has shown that open appendix balloons tend to take on air through the appendix during ascent. Mixing air with the lifting gas results in an increased apparent molecular weight. The effect of increasing the molecular weight of the lifting gas can be seen by examining Equation III-5 which is rewritten below:

$$W = V \rho_a \left[1 - \frac{M_g}{M_a} \frac{T_a}{T_g} \right] \qquad \text{(III-5)}$$

W, V, and M_a remain constant for a given balloon. Changing M_g a small amount will not cause $\frac{T_a}{T_g}$ to change significantly. Consequently, if M_g is increased, ρ_a will have to increase accordingly to satisfy the equation. Therefore, if the molecular weight increases because of air mixing with the lifting gas, the balloon will level off at a lower altitude where the air density is higher.

A great deal of effort has been devoted to the problem of keeping air out of the balloon. In the fall of 1952, the University of Minnesota[5] applied the principles of the duct appendix to balloon design and this has proved highly successful in excluding air. The duct appendix is attached to the balloon near the top and extends down the outside of the balloon. For a balloon with a duct appendix, leakage of air into the balloon is considered to be an insignificant factor affecting balloon altitude. For this reason, only balloons with the duct appendix were considered in the analysis of flight performance data. The duct appendix should be specified for the balloons to be used in the contemplated operation.

5. Gas Impurities

Impurities in the lifting gas will change the density of the gas and, as a consequence, will affect the altitude to which a given gross weight can be lifted by a specified volume of gas. The effects of gas impurities can be analyzed in the same manner as were the effects of air leakage into the balloon in the previous paragraphs. Impurities which increase the molecular weight will lower the maximum altitude, and hydrogen, which lowers the molecular weight, will increase the maximum altitude. Helium is generally used in ship-board operations and would almost certainly be used in the operation under study. Grade A helium is used with essentially 100 per cent[6] purity so there is no need to consider the effects of gas impurities on balloon altitude.

6. Variations from the Standard Atmosphere

In balloon operations the load-altitude calculations are based on the NACA standard atmosphere. Altitude is usually determined by means of a pressure-sensing device and then the pressure readings are converted to altitude using the NACA atmosphere data. This procedure introduces two factors relative to the balloon altitude which should be acknowledged.

The first of these factors is the vertical shift in any given pressure level from the standard height as given in the NACA tables. The height of a particular pressure level is determined by the temperature characteristics of the air between that pressure level and the ground. Since balloon altitude as recorded or telemetered is based on pressure, this variation in actual height is not apparent in balloon performance data. Dr. Homer T. Mantis, meteorologist at the University of Minnesota, advises that this shift in the pressure level may be as great as 2,000 ft at high altitudes.

The second factor is the altitude variation resulting because the actual temperature at flight altitude does not correspond with the NACA standard used in calculating balloon performance. Since the balloon altitude depends upon air density, this temperature variation will cause a shift in altitude which will be sensed by the altitude instrument. The altitude shift resulting from a given temperature difference (from NACA standard) can be approximated.

Designating the standard (NACA) density at 100,000 ft as ρ_s and the actual density as ρ_o, one can write

$$\frac{\rho_o}{\rho_s} = \frac{T_s}{T_o}$$

assuming that both the standard and the actual conditions are written for the same pressure level. Since the balloon system was designed for a density ρ_s, it will not go to the standard pressure level, but will seek a level where the pressure and temperature are such that the density $\rho = \rho_s$. Using the ideal gas law and the differential equation for hydrostatic equilibrium in the atmosphere, it is possible to obtain an expression relating density and vertical displacement.

By logarithmic differentiation, Equation III-2 becomes:

$$\frac{d\rho}{\rho} = \frac{dp}{p} - \frac{dT}{T}$$

The differential equation for hydrostatic equilibrium can be written as:

$$\frac{dp}{p} = - \frac{M}{RT} dz \qquad \text{(III-6)}$$

The temperature can be expressed as:

$$T = T_0 - az \qquad \text{(III-7)}$$

where $$a = -\frac{dT}{dz} = \text{lapse rate} \qquad \text{(III-8)}$$

Also: $$dz = -\frac{1}{a}\ d\,(T_0 - az) \qquad \text{(III-9)}$$

Therefore,

$$\frac{d\rho}{\rho} = \frac{M}{aR} \times \frac{d\,(T_0 - az)}{T_0\ \ az} - \frac{d\,(T_0 - az)}{T_0 - az}$$

or $$\frac{d\rho}{\rho} = \left(\frac{M}{aR} - 1\right) \frac{d\,(T_0 - az)}{T_0 - az} \qquad \text{(III-10)}$$

Integrating between the limits of o and z gives

$$\frac{\rho}{\rho_0} = \left(\frac{T_0 - az}{T_0}\right)^{\frac{M}{aR} - 1} \qquad \text{(III-11)}$$

where the subscript "o" refers to conditions at a given height and ρ is the density at a distance z from this height.

Radiosonde temperature data were obtained during GMI Flights 1071 through 1083 made in the Galapagos Islands from September 6 to 12, 1953 for the Office of Naval Research (Contract No. Nonr 875(00), Annex X). The average of the temperature at 22 millibars on five days in this period was found to be -53°C. For the temperature soundings made in connection with GMI Flight 1074, the gradient was 0.82°C per 1000 ft from 36 up to 22 millibars. On Flight 1083, the gradient was 0.96 per 1000 ft from 38 up to 21 millibars. These values agree well with the gradient of 0.92°C per 1000 ft (3°C per kilometer) adopted by the International Civil Aviation Organization for the region above 82,000 ft (25 kilometers). Using the gradient of 0.92 and the average temperature of -53°C and extrapolating from 22 millibars to 11 millibars (99,852 ft) results in a temperature of -34°C (-29°F).

The standard temperature at 100,000 ft as currently used in balloon engineering is -67°F. General Mills, Inc. is now planning to adopt the International Civil Aviation Organization standard which uses a temperature gradient of $+3^{\circ}C$ per kilometer from 25 km and up. Using this value and the -29°F obtained above it is possible to obtain the magnitude of z.

$$\frac{\rho}{\rho_o} = \frac{\rho_s}{\rho_o} = \frac{460-29}{460-67} \cong 1.096$$

where $a = -0.001646^{\circ}F$ per ft (based on the ICAO gradient of $+3^{\circ}C$ per kilometer)

$M = 29$

$R = 1544 \ \frac{lb_f}{lb_m} \ \frac{ft}{{}^{o}R}$

Substituting in Equation III-11 gives $z = -1,944$ ft.

Thus, because the actual temperature at the 11 millibar level is -29°F rather than -67°F (the NACA standard used in engineering calcullations) the balloon will go to an altitude 1,944 ft below this level in order to find the proper density. If the actual temperature is less than the standard, the balloon will rise above the expected level.

7. Superheating of the Lifting Gas

It has long been known that the temperature of the lifting gas in a floating balloon may exceed the temperature of the surrounding air because of solar heating. The radiation is absorbed by the balloon fabric or film and transferred to the lifting gas by convection. This so-called "superheating" is usually not considered when making load-altitude calculations. However, the superheating causes the density of the lifting gas to be less than the theoretical value.

As a result the balloon will tend toward an altitude greater than theoretical because of superheating.

Equation III-5 can be used to estimate the upward altitude shift to be expected because of superheating. Combining the volume, V, with the gross weight, W, this equation may be written for two situations with and without superheating. Thus:

$$\frac{W'}{V} = \rho_a \left[1 - \frac{M_g}{M_a} \frac{T_a}{T_g} \right] = \rho_a' \left[1 - \frac{M_g}{M_a} \frac{T_a'}{T_g'} \right] \qquad \text{(III-12)}$$

where the primed values refer to the case with superheating. Without superheating $T_g = T_a$. Also, for purposes of this analysis the air temperature can be considered constant over the relatively small shift in altitude involved. Therefore, $T_a' = T_a$. The gas temperature can be expressed as $T_g' = T_a' + \theta = T_a + \theta$ where θ is the "superheat". Consequently, Equation III-12 yields:

$$\frac{\rho_a'}{\rho_a} = \frac{1 - \frac{M_g}{M_a}}{1 - \frac{M_g}{M_a} \frac{T_a}{T_a + \theta}} \qquad \text{(III-13)}$$

The magnitude of this superheat has been investigated using direct and indirect approaches. The gas temperature has been measured directly. On GMI Flight 462, June 4, 1951, air and gas temperatures were measured at an altitude of 80,000 ft using shielded thermistors and found to be -58°F and -25°F, respectively. This results in θ = 33°F. This value is in good agreement with earlier data obtained by the New York University College of Engineering[7] during the period August 1949 to March 1950. For these flights at an altitude of approximately 40,000 ft, the measured free air and gas temperatures show that θ ranged from 10 to 20°C (18 to 36°F).

The University of Minnesota[8] has investigated Θ by analyzing the balloon performance when the superheat is removed at sunset. By determining the sunset rate of descent and by ballast dropping experiments they have obtained values for the percent loss of lift at sunset of air displaced. For a 73-ft diameter balloon made of 2 mil polyethylene with one set of load tapes they report a 6 per cent loss of lift. Using Equation III-5 it is possible to show that Θ would have been approximately 25°F to produce this 6 per cent loss at sunset.

Using the value of $\Theta = 33°F$ obtained on GMI Flight 462, where the air temperature was -58°F and the lifting gas was helium, Equation III-13 can be solved to obtain the change in air density required to compensate for the superheating of the lifting gas. Thus:

$$\rho_a' = \left[\frac{1 - \frac{4}{29}}{1 - \frac{4}{29}\ \frac{402}{402+33}}\right] \rho_a$$

$$\rho_a' = 0.988\ \rho_a$$

The increase in height necessary to produce this change in density is approximately 260 ft.

8. Summation of Altitude Variations

Now that the individual factors have been analyzed, it becomes possible to combine them to determine the total possible variation from theoretical altitude. The various factors are summed up below.

Variation in volume	± 325 ft
Errors in weight determination	± 100 ft
Leakage of lifting gas	None

Leakage of air into balloon	None
Gas Impurities	None
Variations from the NACA standard atmosphere (2000' + 1940)	±3940 ft
Superheating of the lifting gas	+260 ft
Total	+4625 ft -4365 ft

Thus the actual altitude can be as much as 4625 ft above or 4365 ft below the theoretical ceiling if no special altitude controls are applied.

Fortunately, if the relative altitude of balloons in an array is the only concern, and the true altitude is not critically important, only the first two factors need be considered. This is true because all balloons launched at approximately the same time on any one day will be subjected to the same atmospheric conditions. Therefore, the altitude variation is reduced to ± 425 ft in connection with discussing the feasibility of the 1,000 ft spacing. Consequently, if two adjacent balloons are assumed to have a horizontal spacing of 1,000 ft and the variation in vertical position is ± 425 ft for each balloon, it is possible for the slant distance between balloons to range from 1000 to 1300 ft.

D. Altitude Control

Having presented data on actual and theoretical altitude performance, the possible use of special control instrumentation to improve performance will now be discussed. Such altitude control is achieved by carrying expendable ballast on the balloon and dropping ballast or valving gas to cause the balloon to ascend or descend. Both automatic and remote control instrumentation have been used to implement ballasting or valving.

The simplest automatic system is one in which a baro-switch in series with a battery and valve system such as an electro-magnetic valve would control the flow of steel-shot ballast whenever the balloon descends below a pre-set pressure level. No control of maximum altitude is provided except by automatic gas valving through the balloon appendix at the ceiling established by the gross weight - volume relationship of the balloon system. As ballast is expended this ceiling increases. However, in a properly operating system the balloon will tend toward the control level because of loss of gas through leakage and diffusion.

For flights which are not required to continue through a sunset, good level flight has been shown by the University of Minnesota[9] on 73-ft balloons by employing dry ice as ballast to compensate for leakage and diffusion losses. In a series of flights from Pyote AFB, Texas, the dry ice consumption was about 0.5 lb per hour at an altitude of approximately 85,000 ft.

More elaborate altitude control systems employing both gas valving and ballasting have been used. In 1952 General Mills, Inc., conducted a program for the Navy Bureau of Aeronautics (Contract Order No. N6ONR-25209) in which an experimental control system was built for selecting and maintaining any of several possible altitudes. Altitude selection and flight termination was accomplished through radio control. Successful flight demonstration of the system was not achieved. However, on May 11, 1955, on GMI Flight No. 1356, a radio-controlled system was flown and the altitude repeatedly changed by alternate gas valving and ballasting. In this flight the gas valve and ballast valve were operated directly with a radio-control. The control of the flight was based on radio commands to the balloon based on altitude data telemetered from the balloon to the control point in a tracking aircraft.

Data is not available on the accuracy with which the altitude can be controlled by the above methods. Since these methods depend upon a baro-switch or a bellows-actuated altitude telemetering device for altitude sensing, this device is necessarily the limiting factor. Experience in calibrating such devices at General Mills, Inc. indicates that an error of at least ± 0.5 millibars at the range of 10.68 millibars (100,000 ft) can be expected with carefully calibrated instruments. At an altitude of 100,000 ft 0.5 millibars is equivalent to approximately 950 ft. The analysis made earlier in this report had demonstrated that balloons, manufactured in accordance with present specifications and launched at the same time under conditions where the gross weight has been carefully measured, can be expected to attain the same altitude within ± 425 ft. Consequently, the use of altitude controls in an operation planned for the 100,000 ft height would be expected to impair rather than improve performance. An exception would be the use of dry ice ballast to compensate for normal gas loss due to diffusion and leakage through the balloon wall.

IV. SEPARATION

A. The Need for Connecting Links Between Balloons

This section of the report is devoted to a discussion of the problems associated with dispersing a number of balloons to form an array with the desired relative positioning and spacing where the arrangement is not restricted to a single vertical line. Unfortunately, it is not possible to arrange the balloons and their loads on the surface in the desired pattern, then release them simultaneously and have them arrive at an altitude of 100,000 ft in this same pattern. Variations in rates of rise will cause the balloons to change their relative horizontal positioning as they gain altitude. An example will be presented here to illustrate this dispersion during ascent. It is assumed that the integrated wind from surface level to 100,000 ft is 5 miles per hour while the wind at 100,000 ft is 80 miles per hour. The nominal rate of rise of the balloons is 800 ft per min and the variation is estimated to be at least ± 5 per cent. A balloon rising at 800 ft per min would reach 100,000 ft in 125 min and would travel 10.41 miles in reaching altitude. A second balloon rising at 760 ft per min would reach ceiling altitude in 131.5 min and would travel 10.95 miles. During the 6.5 min interval the first balloon, now traveling at 80 miles per hour, would move an additional 0.87 miles for a total distance of 11.28 miles. Thus, the separation of the two balloons at 100,000 ft would be 0.33 miles if they were launched from the same spot on the surface at the same time. Therefore, to insure the desired 1000 ft horizontal spacing, it would be necessary to employ some means of tying the balloons together.

The simplest tie would consist of a length of line joining two balloons. Unfortunately, the weight of the line is sufficient to force the two balloons together unless some opposing force is introduced to keep them separated. A rigid connector would eliminate the need for this separating force, but a continuous beam 1000 ft long supported only at the ends is not feasible. Such a beam would weigh several hundred thousand pounds. A beam supported at several points by additional balloons could conceivably be developed but would be a very difficult system to fly. A "weightless" connecting device could be made from a length of tubing inflated with hydrogen or helium. If this tubing were made from 0.001 inch polyethylene, it would have to be 20 ft in diameter to support its own weight at 100,000 ft if inflated with helium. However, a 1000 ft length of 20 ft tubing would be very unstable axially. It is highly probable that it would never inflate to a straight section but would have several kinks and bends. Furthermore, a system joined by lengths of this tubing would be very difficult to fly. Therefore, the most promising possibility for a connection between balloons is to tie them together with a length of light-weight line and keep them separated by employing a horizontal force to oppose the horizontal tension from the weight of the line.

B. Force Required to Keep Balloons Separated

The magnitude of the force required was determined by applying the equations for a catenary having the supports on the same level. The equations used are presented in Appendix D along with a sample calculation. The results of these calculations are presented in Figure 4 in the form of a series of curves. The horizontal tension

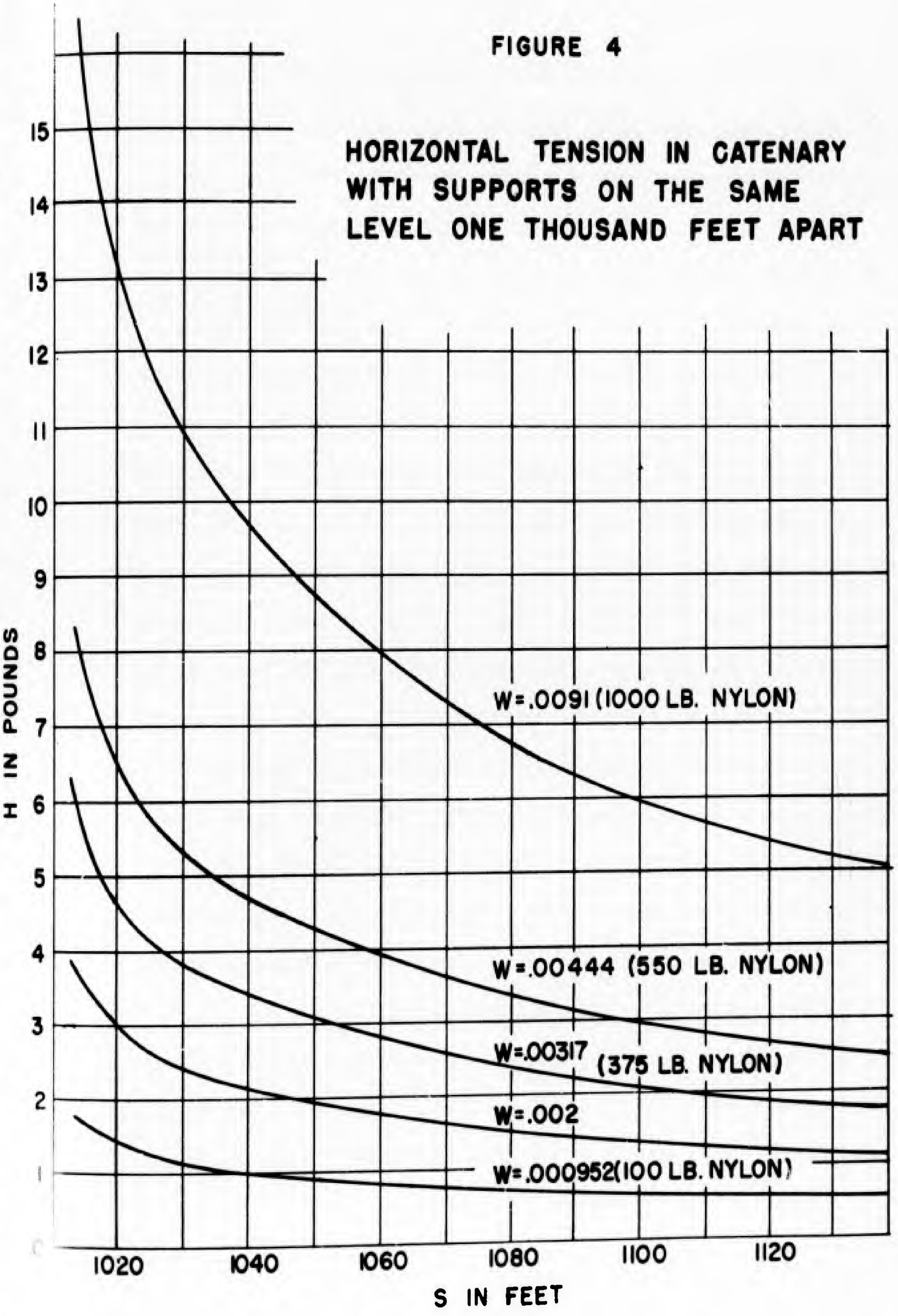


FIGURE 4

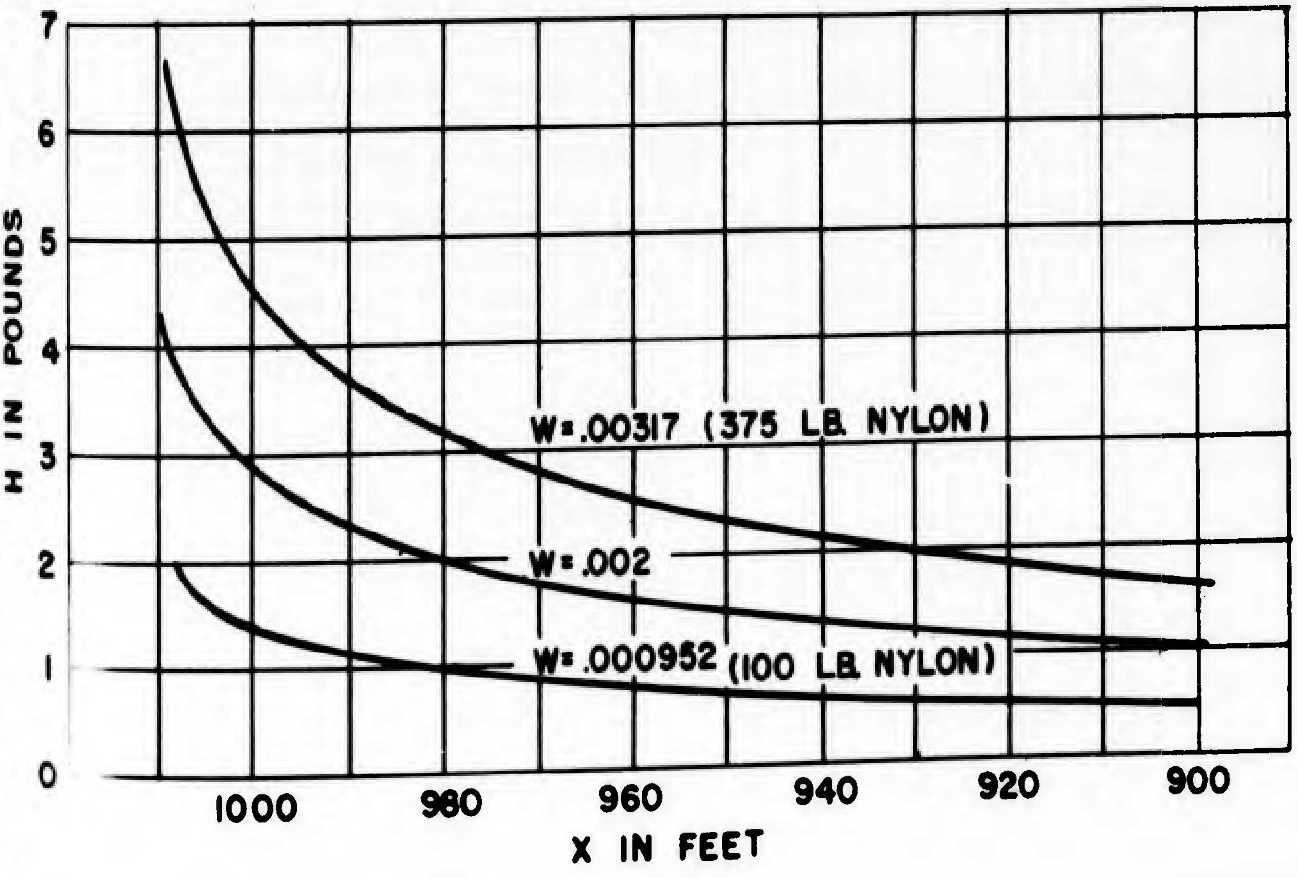
HORIZONTAL TENSION IN CATENARY WITH SUPPORTS ON THE SAME LEVEL ONE THOUSAND FEET APART in pounds has been plotted against the length of the catenary in feet. Length here is stretched length. In making up the tie lines the stretch of materials such as nylon line would have to be considered. A family of curves was obtained by varying the weight per foot of catenary. The distance between supports was held at 1000 ft.

Since the horizontal component of the tension in a catenary is equal for all points in the catenary, it is also the horizontal force acting on each of the supports. This is the force which must somehow be provided if the balloons are to maintain the desired 1000 ft spacing. The curve for the 100 lb test nylon shows that the horizontal force can be less than one pound if the length of the catenary is greater than 1040 ft. As the catenary length is increased, the slope of the curve decreases. This means that, for a catenary which hangs far below the supports, a small change in horizontal tension is associated with a rather large change in the distance between supports. Therefore, if the distance between supports (balloons) is to be controlled closely, the length of catenary should be about 20 ft greater than the desired 1000 ft spacing so that the distance between supports is not too sensitive to changes in the horizontal force.

Figure 5 was prepared to show the relation of the horizontal force to the distance between supports. The length of catenary is 1020 ft for all cases. The three catenary weights used are the same as for the three lower curves in Figure 4. If the 375 lb test nylon were used, the force would have to be 4.5 lb or more; for the 100 lb test, 1.4 lb or more.

FIGURE 5

HORIZONTAL TENSION IN CATENARY
WITH SUPPORTS ON THE SAME LEVEL
CATENARY LENGTH = 1020 FEET



C. Methods for Forcing Balloons Apart

Because of the low air density at 100,000 ft, only a few methods are available for developing a horizontal force. Three methods which could conceivably be used are discussed in the following paragraphs.

1. Rocket Motor

A low-thrust rocket motor could be supported from balloons at the ends of the array in such a way that the thrust could be used to force the balloons apart. A schematic arrangement is pictured in Figure 6. Here the payloads form part of the array depicted in Figure 1 (a). The rockets are supported from their own balloons so that there will be no danger of interference with the payload. A steering device would be required to keep the rocket directed properly. By using identical rockets the net horizontal force would be zero and the array would not be forced off the desired trajectory. (It is recognized that the thrusts will not be exactly the same, and a small net horizontal force will result.)

The weight of each rocket motor can be estimated by using the following thrust equation given by Sutton.[10]

$$F = \frac{w\, v_2}{g} + (p_2 - p_3)\, A_2 \qquad \text{(IV-1)}$$

where F = thrust, lb

w = flow through nozzle, lb per sec

v_2 = flow velocity at nozzle exit, ft per sec

p_2 = pressure at nozzle exit, lb per sq ft abs

p_3 = ambient external pressure, lb per sq ft abs

A_2 = area of nozzle exit, sq ft

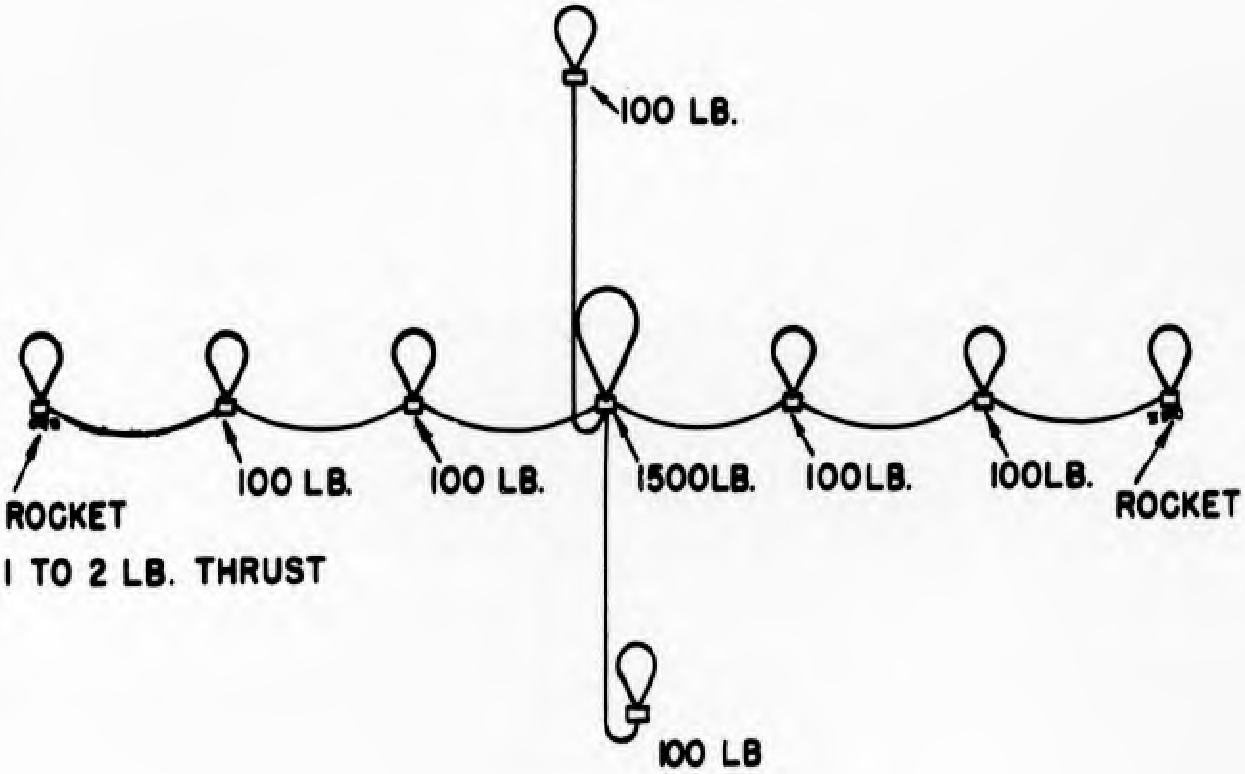


FIGURE 6

USE OF ROCKET MOTORS TO MAINTAIN HORIZONTAL SPACING

Sutton[10a] shows that optimum thrust is obtained when the expansion ratio is one, i.e., $p_3/p_2 = 1$. Assuming optimum conditions, the pressure thrust term can be dropped and only the momentum thrust term remains giving:

$$F = \frac{w\,v_2}{g} \qquad \text{(IV-2)}$$

In order to obtain the relatively long operating time and the thrust control needed for the balloon operation, it would very likely be necessary to use a liquid propellant with a low operating temperature. Concentrated (85-90 per cent) hydrogen peroxide is such a propellant. According to Sutton[10], concentrated hydrogen peroxide could produce an exhaust velocity of approximately 4,000 ft per sec. Referring to the bottom curve in Figure 5, if 100 lb test nylon were used for a 1020 ft tie line, the thrust would need to be 1.5 lb. It is conceivable that a system could be developed in which the total operating time for the rocket would not exceed two hours. With this information and Equation IV-2, it is possible to calculate the weight of fuel required and estimate the total filled weight of the rocket motor.

Rearranging Equation IV-2 and inserting the values for thrust and velocity:

$$w = \frac{F\,g}{v_2} = \frac{1.5 \times 32.2}{4000} = 0.0121 \text{ lb per sec}$$

or 7200 x .0121 = 87.2 lb for 2 hours. Assuming the dry weight of the rocket to be about 30 per cent of the fuel weight or 26 lb, the total weight would be 115 to 125 lb.

In searching for information on a suitable rocket, the only data obtained for a low thrust rocket was in connection with applications to helicopter rotors. Bergaust[11] describes a rocket boost system developed by Reaction Motors, Inc., and installed on a Sikorsky HRS-2 helicopter. The three rockets, one in each rotor tip, provide six minutes of operation at full power during which time 300 lb of 90 per cent concentrated hydrogen peroxide are consumed. Each rocket weighs about one pound and is capable of providing a thrust of 40 lb. With minor modification, the unit is adaptable to a thrust range of 15 to 85 lb. The dry weight of the complete system is 67 lb.

This rocket appears to be very similar to the unit described in a Reaction Motors, Inc. report[12] received from the Office of Naval Research for study. The letter transmitting the report contains pertinent information and is included as Appendix E. This rocket can provide a thrust of approximately 30 lb. It weighs about one lb and has a fuel consumption of about 25 lb per hour per lb of thrust.

The helicopter rocket is not suitable for application to the balloon problem without modification. However, with additional development work it should be possible to obtain a rocket for balloon propulsion which would operate satisfactorily at high altitudes. It should be noted that 90 per cent H_2O_2 has a freezing point of 12.6°F and, therefore, a special housing would be required to prevent freezing. Additional problems associated with control of the rocket and steering the balloons would also require further work.

2. Balloon "Sea Anchor"

A second method which could conceivably be used to keep the balloons apart is illustrated schematically in Figure 7. In this system, the lower balloon is floating in an air mass moving at a velocity less than that of the air at 100,000 ft where the payloads are floating. As a result, the lower balloon lags behind and causes the payload balloons to spread out in the direction of motion of the system. The forces causing separation result from the aerodynamic drag on the balloons because of motion relative to the surrounding air. The equation defining various relationships for the system are developed in Appendix F. Using these equations and the data presented in Figure 5, the required difference in wind velocity at the two levels can be estimated.

Because of the low air density at 100,000 ft the aerodynamic drag force is very small for balloons moving at low velocity relative to the wind. Since the magnitude of the vertical wind gradient is not expected to be large, it is necessary to use the catenary which will give the smallest horizontal force requirement. Referring to Figure 5, it is evident that a force of 0.75 lb is possible using 100 lb test nylon.

Therefore, assume that the horizontal tension in the right hand catenary is 0.75 lb. Then from Equation E-6 and F-6:

$$H_5 = R_2 = 0.75$$

This value can be used in Equation F-9 to determine the relative velocity, $V_2 - V_3$, at the upper level (assumed to be 100,000 ft). First it will be necessary to decide upon the balloon size from which to calculate the profile area, A_2. If it is assumed that the 100 lb payload and an additional 100 lb of flight gear are carried by each

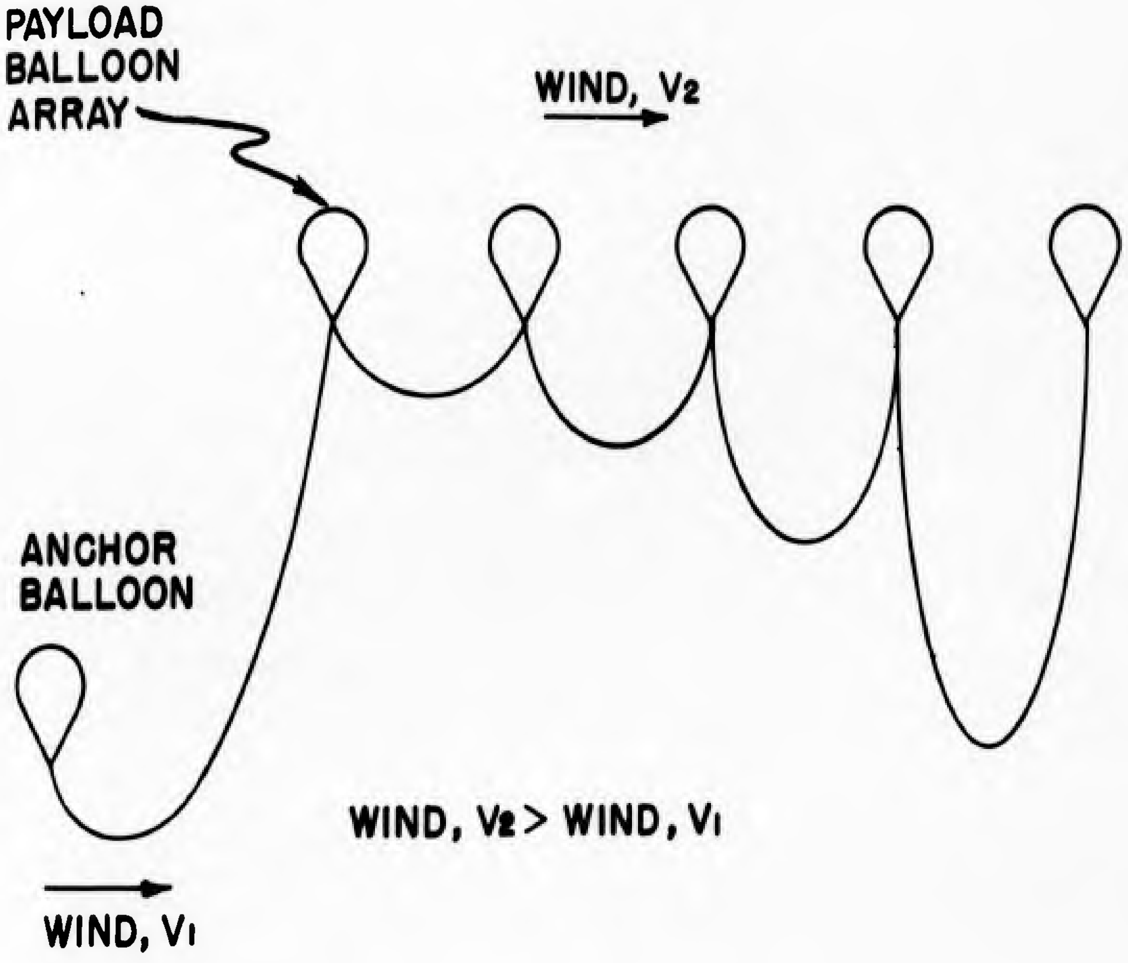


FIGURE 7

BALLOON "SEA ANCHOR" USED TO KEEP BALLOONS SEPARATED balloon, the balloon will be of a size such that the profile area is approximately 6,940 sq ft. The air density at 100,000 ft using the NACA data is:

$$\rho_2 = \frac{pM}{RT} = \frac{22.31 \times 29}{1554 \times 393} = 0.001067 \text{ lb per cu ft}$$

Substituting these values in Equation F-9 gives:

$$0.75 = 1/2 \times \frac{.001067}{32.2} \times 6940 \times 0.7 \, (V_2 - V_3)^2$$

$$V_2 - V_3 = \sqrt{9.33} = 3.05 \text{ miles per hour} \quad \text{(IV-3)}$$

Assuming the anchor balloon, (a), to be 2000 ft below the others results in an air density, $\rho_1 = 0.001119$ lb per cu ft. From Equation F-1, $R_1 = 5\ R_2 = 3.75$ lb. If the same size balloon is used throughout, $A_1 = A_2 = 6940$ sq ft. Therefore:

$$3.75 = 1/2 \times \frac{.001119}{32.2} \times 6940 \times 0.7 \, (V_3 - V_1)^2$$

$$V_3 - V_1 = \sqrt{44.4} = 6.66 \quad \text{(IV-4)}$$

Adding Equations IV-3 and IV-4 gives the required difference in wind velocity at the two levels, i.e.,

$$V_2 - V_1 = 9.71 \text{ miles per hour}$$

By using the largest balloon now available as the anchor, it would be possible to obtain an area, for A_1 of approximately 10,000 sq ft. This area gives a relative velocity at the lower level

$$V_3 - V_1 = 5.55 \text{ miles per hour}$$

and a difference in velocity at the two levels equal to

$$V_2 - V_1 = 8.6 \text{ miles per hour}$$

Although the winds at 100,000 ft vary with the season and the latitude, Brasefield[13] obtained data on rocket flights at White Sands Proving Ground during 1950 and 1951. The following values were calculated from curves given in Brasefield's paper.

East - West Component

For period of April thru September:

Velocity at 30 km - 20 mph

Gradient at 30 km - 1.02 mph per 1000 ft

For period of October thru March:

Velocity at 30 km - 60 mph

Gradient at 30 km - 2.29 mph per 1000 ft

North - South Component

Negligible velocity both periods

In evaluating the "sea anchor" technique the following factors should be considered:

(1) Based on the averages presented above, it appears that the required gradient is large enough to necessitate placing the anchor balloon prohibitively far below the others.

(2) Variations in the magnitude of the vertical wind gradient will change the spacing between balloons.

(3) Because of variations in winds it would be necessary to measure balloon spacing by some method.

3. Electrostatic Repulsion Force

Bodies carrying like electrostatic charges tend to repel one another. The repulsion force is dependent upon the charges on the various bodies, the distance between them, and the capacitivity of the medium surrounding the charges. It is conceivable that the repulsion force could be used to keep the balloons in an array apart if they were joined by lightweight nylon lines. To determine the feasibility of the use of electrostatic charges, a system of two identical balloons was investigated and the charge required on each balloon was calculated. By assuming a rate of loss of charge, it was possible to estimate the power and weight requirements for such a system.

Calculations for determining the required charge are presented in Appendix G. It has been assumed that identical spherical balloons 110 ft in diameter are used and that the balloon fabric will conduct electrostatic charges. The repulsion force required is assumed to be 1.5 lb, the same as for the rocket motor analysis. This force is necessary for a spacing of 1000 ft between balloons when a 100 lb test nylon line 1020 ft long is used. It was found that, to produce a force of 1.5 lb, each balloon must be charged to a potential of 4,560,000 volts or a charge of 0.0085 coulombs.

The equipment required to produce this potential would very likely be quite massive. For example, a Van de Graff[14] electrostatic generator built for the Oak Ridge National Laboratory in 1951 weighs 19 tons. This is a 5,000,000 volt generator producing an analyzed beam of 4 microamperes. A 4.5 million - volt generator would be a large piece of equipment. Since it would be necessary to carry the generator along with the balloon to keep it charged properly, a Van de Graff generator could not be used. Other types of equipment now used to produce these high voltages are also prohibitively massive.

Another requirement for an electrostatic charge to be built up on a balloon is that the balloon be conductive. Large balloons have never been made from conductive material. However, polyethylene and Mylar films coated with a very thin layer of aluminum are available and the balloon engineers at General Mills believe that a suitable conductive balloon could be developed using these new materials. The suppliers would have to improve their manufacturing processes so that wider sheets or tubing could be made available. Sealing techniques suitable for the metal-coated plastic would have to be developed.

In summary, it appears that the use of the electrostatic force of repulsion between two charged balloons is not feasible at this time.

V. TRAJECTORY

A. General Discussion

Balloon trajectory is of importance primarily because the path which the balloon or array of balloons will follow must be known if the balloon loads are to be carried over a fixed point on the earth. Trajectory is of additional importance in relation to the recovery of the loads after being released from the balloon. So, for recovery purposes the path followed by the descending load must be studied in addition to the balloon trajectory up to the point of release. Release should occur very shortly after the loads pass over the target.

In past balloon delivery trajectory studies conducted by General Mills, Inc., the load delivery event has been initiated by a timer mechanism and variations in distance along the path of motion as well as variations normal to this path had to be considered. For the application discussed in this report, the time of arrival over the target point can vary because the initiation of the desired event or events can be controlled by observers at the time the balloon array arrives over the desired point. Consequently, the variation normal to the path of motion is the only parameter we are concerned with. Further, there is no requirement for the distance from the launching site to the target point. This means that since the flight duration should be as short as possible to minimize errors in trajectory forecasting, the trajectory will consist essentially of the path followed by the balloon array as it ascends to 100,000 ft.

It is assumed that the operation will take place in the Pacific Ocean in the Tropics. In September, 1953, General Mills, Inc. personnel participated in a series of high altitude balloon flights launched near the Galapagos Islands, in connection with Contract No. Nonr 875(00), Annex X. In this region they found that the surface winds were generally from the east. However, the integrated wind vector from the ground up to about 80,000 ft was generally from the west. The magnitude was observed to be under five knots. Above 80,000 ft easterly flow increasing with altitude was encountered with resulting high velocity movement toward the west. On the basis of these observations it is estimated that the balloon array will be approximately 50 miles to the west of the launching site at the time ceiling altitude is attained. Because the winds at the lower levels are very light, and because the winds at the higher levels are almost due west, the north-south component of the integrated wind will probably be less than 5 miles per hour.

B. Variation in Trajectory Forecasting

To provide the best forecast of the balloon position relative to launching site after rising to 100,000 ft, it will be necessary to obtain the integrated wind from ground to altitude using sounding balloons. Then, by determining the time of ascent for the large balloons, based on the predicted rate of rise, the position at the completion of ascent can be calculated. If sounding balloons are flown repeatedly prior to the operation, it should be possible to base the forecast on data approximately one hour old. (This is the approximate time required for a sounding flight.)

Variations from the calculated position will occur from three sources:

(1) Actual rate of rise different from predicted rate of rise

(2) Errors in measurement of integrated wind with sounding balloons

(3) Variation in integrated wind over one-hour period between sounding balloon flight and operational flight.

These sources of error are discussed in the following paragraphs. A value for the magnitude of the total variation in position is estimated.

1. Rate of Rise

The ascent velocity of a balloon is dependent upon several factors, some of which are difficult to evaluate. The aspect of balloon physics related to vertical motion has been studied and formulas and charts have been developed in connection with investigating the rate of rise[15]. However, in spite of the good work which has been done, it is not yet possible to calculate accurately the rate of rise of a balloon system (balloon and load train) not yet flown.

The rate of rise can be varied by changing the free lift (excess gas) used to force the balloon upward. Some personnel at General Mills, Inc. prefer to base the amount of free lift on experience with previous flights rather than to use a formula of questionable or limited accuracy. To obtain the best results, the adjustment of free lift should be based on a previous flight with an identical balloon system launched under similar meteorological conditions. Obviously, this is not possible when flying an untried system. In this situation, it is necessary to use the data most applicable to the new balloon and the judgement of the operating personnel becomes an important element.

Performance data for past balloon flights was studied in an effort to provide answers to two questions: (1) If initital free lift is based on presently available flight data, what variation in rate of rise can be expected?; (2) If identical flights are launched simultaneously, what is the variation?

The first question is important in connection with the accuracy with which the trajectory of the first flight of an untried system can be predicted. The second question is related to the improvement in accuracy to be obtained by using the trajectory of the first flight as a guide in relocating the launching site for the second flight.

Past flights most nearly approaching the contemplated operation were those employing 134 TT balloons at altitudes between 90,000 and 100,000 ft. Some data from these flights was presented and discussed in the altitude analysis section of this report (see Appendix C, Table 1). Data pertinent to the rate of rise is presented below in Table II. Even though the free lift was essentially the same for all seven flights, the rate of rise varied considerably. The average rate for the seven flights was 601 feet per minute. The spread between the minimum and maximum was 232 feet per minute which is 38.6 per cent of the average. Such a wide spread introduces the possibility of a large error in a forecast based on the predicted rate of rise. This large error in predicting the rate of rise may occur on the first flight, but on subsequent identical flights made on the same day or the following day, the error should be reduced if the rate is predicted on the basis of the first flight.

TABLE II

Data on Rate of Rise of 134 TT Balloons

GMI Flight No.	Gross Weight, lb	Free Lift lb	Rate of Rise*, ft/min	Maximum Altitude, ft	Time and Date of Launching
1230	872	76.5	484	96,300	0642; 5 Oct. 54
1255	838	75.0	568	98,000	0715; 12 Nov. 54
1262	852	76.6	716	94,750	0642; 22 Nov. 54
1273	833	75.0	635	98,000	0859; 19 Dec. 54
1279	846	76.0	543	95,000	0818; 29 Dec. 54
1306	953	76.0	705	92,800	0723; 9 Mar. 55
1317	794	71.5	558	94,700	0921; 15 Feb. 55

* As determined from the time required to reach maximum altitude.

In 1951, General Mills, Inc. conducted an operation on which identical balloons were launched simultaneously . Whereas the balloons used were only 25 feet in diameter and the maximum altitude was only approximately 30,000 feet, it is believed that the variation in rate of rise for these flights is indicative of the minimum which can be achieved in variation in rate of rise. The data for these flights is presented in Table III. It should be noted that the balloon type, balloon load, free lift and altitude were essentially the same for all flights.

For Flights 557 and 558, which were launched together, the average rate of rise was 820 feet per minute. One rate was 40 feet per minute greater than the other. This difference is 4.9 per cent of the average.

For Flights 560, 561, and 562, the average rate was 858 feet per minute. The spread was 25 feet per minute or 4.1 per cent of the average.

For Flights 566, 567, and 568, the average rate was 838 feet per minute. The spread was 50 feet per minute or 6 per cent of the average.

The average rate of rise for all eight flights was 841 feet per minute. The spread was 70 feet per minute or 8.3 per cent of this average.

Because the loads and altitudes for these simultaneous launchings were less than for the contemplated operation and because the 251-B balloon has an appendix valve as compared to the side duct currently used, one may not be justified in saying that the data is directly applicable to the contemplated operation. However, it is doubtful that the performance obtained in these flights could be exceeded when using larger balloons at higher

TABLE III

Rate of Rise for Balloons Launched Simultaneously
Launched by General Mills, Inc. at Hill A.F.B., Ogden, Utah, in August 1951

GMI Flight No.	Load on Balloon*, lb	Free Lift, lb	$\frac{\text{Free Lift}}{\text{Gross Wt.}} \times 100$	Time** & Date of Launching	Maximum Altitude, ft	Rate of Rise ft/min
557	160	24	13	1750; 8 Aug	28,800	800
558	164	24	13	" "	30,000	840
560	163	24	13	1800; 17 Aug	31,500	835
561	155	24	13	" "	30,000	868
562	163	24	13	" "	30,000	870
566	161	26	14	1857; 26 Aug.	29,700	860
567	161	26	14	" "	29,850	810
568	164	26	14	" "	29,300	845

* Balloon type 251B; weight approx. 19 lb

** Mountain Standard Time

altitudes even though the side duct appendix is used on the larger balloons. Consequently it appears that the difference in rate of rise of two identical balloons launched simultaneously or within a short time of one another will be from 5 to 10 per cent of rise rate.

2. Wind Measurement

Unfortunately, a representative value is not available for the error in determining the integrated wind. The integrated wind is obtained from measurements of wind velocities above the point of observation. As the sounding balloons rises it also moves away from the point of release. Consequently, errors in measuring the angles of elevationa and azimuth and in measuring the altitude (or the slant range) all contribute to the error in determining the wind vectors at various heights. A direct measure of the total error could be derived by obtaining wind data and down-photographs on the same balloon flight. A down-camera is used to photograph the ground below the balloon at regular intervals to provide accurate fixes. According to Dr. H. T. Mantis, such a flight is planned by the University of Minnesota group. However, as pointed out by Rapp[16], the error in measuring the wind increases with the height. Consequently, for any data to be directly applicable, it should be obtained for altitude and wind conditions similar to those existing at the time and place where the operation in question is to be conducted.

A very rough estimate of the error was obtained by studying the results of Rapp who investigated the instrument error in measuring winds using both the Rawin set AN/GMD-1 and the CPS-10 radar wind computer. Data obtained indicated that the magnitude of the error was the same for both types of equipment. For the Rawin set AN/GMD-1 Rapp[16] reported an error variance of 2.96 meters^2 per second^2 (Rapp defines "probable error" as 2/3 square root of the error of variance, giving a probable error of 1.15 meters per second) in the south-north component at a height of 8.5 kilometers. The error variance in the east-west component at this height was 1.52 meters^2 per second^2 (probable error 0.82 meters per second). At this height the balloons were about 35 kilometers away and moving in a velocity of approximately 20 meters per second in a direction of about 35 degrees from north. Results indicated that the error increases at an increasing rate as the altitude increases; i.e., the error variance at 8 km is more than twice the error variance at 4 km. In view of this, one would expect the error variance at 30.5 km (100,000 ft) to be more than 3.5 times the error variance at 8.5 km.

The probable error for the integrated wind would be in the nature of an average of the values at the several layers from ground up to the maximum altitude. Consequently, this average value would be less than the error at maximum altitude. It would be dependent upon the actual trajectory of the sounding balloon. To extrapolate Rapp's data for higher altitudes and then apply it to a hypothetical trajectory is admittedly unjustified. Also, detailed calculations are not warranted. However, a few manipulations of the data do provide a very rough estimate of the probable error in the north-south component of the integrated wind.

The probable error presented by Rapp amounts to approximately 7 per cent of the velocity at 8.5 kilometers. The probable error is proportional to the square root of the error variance. Since the error variance at 30.5 km is estimated to be at least 3.5 times that at 8.5 km, the probable error at 30.5 km would be about 13 per cent of the velocity. Assuming the error in the integrated wind to be 70 per cent of that for the wind at a height of 30.5 km, the probable error would be 9.1 per cent. For purposes of this discussion a value of 10 per cent will be used.

There is another factor which should be considered in discussing the intrumental error in measuring winds. The data discussed above was obtained with land-based equipment where it was possible to operate from a fixed platform. If wind measurements are to be made from shipboard where the instrument platform is not fixed, it is logical to expect that instrumental errors would be somewhat greater. Data is not available to demonstrate this point. Since the probable error of plus or minus 10 per cent is such a rough estimate, there is nothing to be gained by refining this value to account for additional errors from shipboard operation.

3. Integrated Wind

Dr. Homer T. Mantis, Meteorologist at the University of Minnesota, Institute of Technology, was consulted for information regarding the large scale variation in the integrated wind. Dr. Mantis is well acquainted with balloon operations and is serving as meteorologist for the University of Minnesota High Altitude Balloon Program and has served as a consultant to General Mills, Inc. It is his opinion that a large scale variation of 1/2 knot can be expected in the integrated wind for a one-hour period. It is possible to have extreme days in which the variation in a one hour period will exceed this value. However, by closely observing meteorological conditions, it will be possible to avoid operation on extreme days.

By combining the three factors, i.e., variation in rate of rise, error in measuring the integrated wind, and the large-scale variation in integrated wind, the total variation in trajectory is obtained. For a trajectory which is essentially due west, the spread normal to the path can be obtained by using the north-south component of the wind when determining the effects of rate of rise and errors in measuring wind velocity. The one-half knot variation in integrated wind applies to all components. Thus, the variation either side of the predicted point resulting from each of the three factors is obtained as follows:

(a) From variation in rate of rise:

$$\text{distance} = \frac{\text{N-S component x ht x variation in rate of rise}}{\text{rate of rise (1+ variation in rate of rise)}}$$

(b) From error in measuring the integrated wind:

$$\text{distance} = \frac{\text{error in N-S component x ht}}{\text{rate of rise}}$$

(c) From large scale variation in integrated wind:

$$\text{distance} = \text{large scale variation x } \frac{\text{height}}{\text{rate of rise}}$$

The height for the contemplated operation is 100,000 ft. A rate of rise of 800 feet per minute can be assumed. In the previous paragraphs approximate values for other factors were presented as follows: (1) for variation in rate of rise, 10 per cent; (2) for error in the integrated wind, 10 per cent; and (3) for the large scale variation in the integrated wind, 0.5 knot or 0.58 miles per hour. The north-south component of the integrated wind will be assumed to be 5 miles per hour.

Using these values in Expressions (a), (b) and (c) above results in the following distances:

from variation in rate of rise.	± 0.95 miles
from error in measuring wind	± 1.04 miles
from large scale variation in wind . . .	± 1.21 miles
Total. . . .	± 3.20 miles

This variation normal to the westerly path of the balloon presupposes that a pilot flight of an identical balloon and load has been made to provide a good estimated rate of rise. For this pilot flight, the variation in rate of rise would be larger, approximately 40 per cent as compared to the 10 per cent used, and the resulting distance variation would be correspondingly larger. The total distance either side of the target for the pilot flight could amount to plus or minus 6.34 miles.

C. Balloon Guidance

At present there is no method for altering the direction of motion of a high altitude balloon other than by changing altitude to enter a different wind stream. However, it is quite possible that a method could be developed for propelling a high altitude balloon so as to improve the accuracy with which it would pass over a desired point. Steering could be accomplished by propelling the balloon in a direction approximately normal to the wind flow.

A suitable system would be one employing two oppositely-directed rocket motors aligned by means of a device such as a gyro control, a sun-seeker, or a magnetic heading instrument. Hydrogen peroxide rockets similar to the one discussed in Section IV,C,1 of this report would very likely be suitable for propelling the balloon.

A system which appears feasible would be to turn the rockets on and off by radio control. The balloon trajectory would be plotted continuously and corrected as necessary by use of the rockets. A pilot flight would provide a trajectory to serve as a guide.

The error in positioning a balloon by this method would depend upon the error in tracking or spotting the position of the balloon and the skill of the personnel controlling the rockets. The error in tracking the balloon would depend upon the type of equipment used and the skill of the operator. The magnitude of error to be expected can be obtained from the performance of the Rawin Set AN/GMD-1A which is used with Radiosonde AN/AMT-4 to track weather balloons. It has also been used to track high altitude plastic balloons. This set provides elevation and azimuth data and slant range when provided with the ranging attachment. The error in slant range is ± 17 yards and the error in azimuth and elevation (above about 10°) is approximately ± 0.1 degrees when used by experienced personnel. This equipment is designed for mounting on a fixed platform and would not be suitable for shipboard operation. However, the error values would be of the same order of magnitude for shipboard equipment of the same general design with a suitable automatic leveling system. Assuming the balloon to be approximately 50 miles slant range from the tracking point, the 0.1 degree error in azimuth is equivalent to 460 ft. The personnel controlling the rockets would not be able to position the balloon this close to the target except by chance. One would expect the total positioning error to be at least 10 times this or approximately plus or minus one mile. This performance would be obtainable only after personnel became trained in the art of directing balloon flights.

VI. DURATION

Flight duration is the total time which elapses between the moment the flight is launched and the time at which the released flight gear returns to the earth after flight termination. Flight termination is the time at which the load is released from the balloon. Thus the total duration is obtained by adding the time of rise to altitude, the time of floating at ceiling altitude, and the time of load descent on the recovery chute.

A. Time of Ascent

The time required to attain altitude will depend upon the rate of rise of the balloon. Rates in excess of 1000 ft per min are not considered safe. Rates much less than 200 ft per min are also avoided in connection with excluding air and prevention of trapping the balloon in an inversion. If the rate of rise is 800 ft per min, the time of ascent to 100,000 ft will be approximately 2 hours.

B. Time of Floating

There is no requirement for time at altitude. In fact, the shorter the time the better the accuracy of forecasting the trajectory. Consequently, the floating time should be kept to a minimum. Approximately 0.5 hours should be allowed for the balloon to stop oscillating after reaching altitude. This time would also be sufficient for the balloons to arrange themselves in the desired pattern.

C. Time of Descent

The time of descent of the load on a recovery parachute will depend upon the size of parachute used for any given load. Parachute performance curves for 28 ft, 32 ft and for 64 ft parachutes are presented in Appendix G. Impact velocities and descent times for 200 lb, 650 lb and 1600 lb loads using the above parachutes obtained from these charts are given in the following table. It can be seen that the time required for descent will be approximately 0.5 hours.

TABLE IV

Descent Time and Impact Velocity for Loads on Parachutes

Load, Lb	Parachute	Time, Min	Sea Level Impact Velocity, Ft per Sec
200	28-ft Flat	35	22
700	32-ft Flat	21	36
700	Two 32-ft Flat	30	25
1600	64-ft Flat	30	24

D. Total Flight Duration

The total flight duration will be

Time of ascent	2.0 hours
Time of floating	0.5 hours
Time of descent	0.5 hours
TOTAL	3.0 hours

VII. INSTRUMENTATION AND OPERATIONS

A. General

The discussions in this section are based on the premise that a ship-based operation is to be conducted. It is believed that for the type of operation contemplated there are two primary considerations which dictate a ship-based launching. These are:

1. The launching point must be capable of moving into the proper position to provide a trajectory over the target point.
2. The surface winds relative to the balloon must be very low (less than 3 knots) during inflation and launching because of the complex system being flown.

The latter condition can be obtained in ship-based launchings by heading the launching vessel with the wind. In a land-based launching it would be necessary to wait for days which offer both the necessary low surface winds and the proper upper air trajectory. Mobility on land is limited because of the launching site requirements.

General Mills, Inc. has participated in previous ship-based operations. Balloons have been launched from an icebreaker, a sea plane tender and an aircraft carrier. The aircraft carrier was found best suited for balloon launching because of the large clear deck and the visual observation of the inflation by the bridge. The icebreaker was used because of the ice conditions in the region of operation. When using a ship with a limited area of clear deck it was found necessary to lay the balloon out in the form of a spiral with the top of the balloon in the center. Other special techniques, such as top inflation of the balloon out of a special packing crate, may also be possible. However, even though the balloon is inflated satisfactorily a long load train may foul on structures above deck if insufficient clear area is available for the launching.

B. Tracking and Recovery

A suitable aircraft should be available for tracking the balloon and for spotting the loads for recovery. The aircraft should have radio direction-finding equipment for tracking the balloon by fixes on the 2 megacycle beacon. Standard air-to-ship communication equipment will be necessary for contact with the launching ship and the recovery vessel.

To insure expeditious load recovery, a small vessel such as a destroyer, destroyer mine sweeper or destroyer escort should be stationed downwind at the estimated load impact point. It is advisable to deploy a motor launch or other small vessel for the actual pickup of the recovered load since experience has shown that larger ships are not suitable for this purpose.

C. Flight Termination

It is possible to terminate a balloon flight in either of two ways: (1) By cutting the balloon free and allowing the load to descend by parachute, or (2) By valving gas to cause the balloon to descend with the load. Since the balloon cannot be reused even though recovered, the first procedure is the usual practice for a flight of the type being discussed here. A very reliable device has been developed and used for a number of years for freeing the load from the balloon. This device employs an electrically actuated squib to drive a shearing member through the load line. The electrical impulse required to fire the squib can be initiated by a timer or radio command signal. Often radio control, backed up by a dual mechanical timer, is used to obtain a system with very high reliability. Pressure switches are also used to initiate flight termination if the flight first ascends and then descends below a given altitude.

Flight termination instrumentation suitable for this application are fabricated and used by GMI on their routine research flight operations. One of the radio control receivers built by GMI is shown in Figure 8. The various connectors are used for the loop antenna, battery supply, and output to the squib. The device is flown on the balloon in a protective insulated container to assure proper operation under conditions of low temperature and rough handling. A horizontal loop antenna is used for decreasing the load line length for launching ease. However, the radio control is limited in that it is not possible to operate the receiver with a transmitter located directly beneath the receiving antenna since this is a void area for this or any other type of antenna ordinarily used on a balloon system.

The receiver shown operates on a crystal controlled frequency of 6425 kc. It is triggered by an amplitude modulated carrier signal using a 322 cps audio note for 10 seconds followed by a 442 cps audio note within 3 seconds. The radio frequency to which the receiver is tuned can be changed by replacing the crystal with one whose frequency differs from the intended frequency by 455 kc and retuning the input stages. Receivers can be designed for other frequencies as well; experience has shown, however, the 6 mc frequency to be the most reliable and useful.

RADIO CONTROL RECEIVER

Figure 8

CODE SONDE Altitude Beacon

Figure 9

Flight termination can be effected by the use of a standard audio generator to modulate the transmitter at the audio frequencies necessary for triggering. A Johnson Viking 2 has been found to be a good transmitter for radio control. The audio section of the transmitter should be modified to accommodate a number of resonant relays. Thus, by matching the relays in the transmitter with those in the receiver, there will be additional assurance that the exact frequencies are used. The characteristics of the resonant relays are such that it is best to approach the resonant frequency from the low side.

A variety of mechanical timers are used for flight termination depending upon the length of flight planned. Some of these are commercial time delay switches. Others are specially built devices using commercial clock movements or chart drives to actuate switches. Special precautions are necessary in cleaning and lubricating these timers to insure reliable operation at the low temperatures encountered at high altitudes. They are ordinarily flown in insulated protective containers.

D. Altitude Telemetering and Recording

The progress of a balloon flight is followed by means of a beacon which telemeters altitude information. The information may be received at a single control center or by a network. Receivers may be on land, sea or in the air. Present practice at General Mills, Inc. is to use code sonde altitude beacons. A typical unit is shown in Figure 9. This unit is flown on the balloon and transmits a group of Morse code characters which vary with pressure.

Most beacons are made to transmit on a 2-megacycle frequency. (Frequencies authorized for Navy balloon projects are listed in the following section of this report.) Deflection of the bellows moves the contact arm across the cylindrical contact drum which is rotated by a small battery-powered motor. A printed circuit on the drum generates the code modulation. Each unit is calibrated in the laboratory and is provided with a calibration curve. The technician monitoring the flight uses this curve to plot altitude as a function of time as the flight progresses. This instrument provides data on pressure altitude based on the NACA standard atmosphere.

It is customary to fly an inexpensive recording barograph on every flight to provide an independent record of the flight altitude. One such unit fabricated at General Mills, Inc. is shown in Figure 10. Deflection of the bellows moves the pointer toward the rim of the smoked disc which is rotated by a clock movement. These units are also calibrated in the laboratory and the record traced in the smoked disc is carefully analyzed after the recovered instrument is returned to the laboratory. The calibration and the altitude trace can be seen on the unit shown.

E. Frequency Authorized for Navy Balloon Projects

Following is a list of the frequencies which have been authorized for use on Navy balloon projects up to June 30, 1956.

The nature of the transmission authorized for each frequency is also indicated.

1638 kc - 2A2
1676 " - 2A2
1724 " - 2A2
2025 " - 2A2
3123 " - 2A2 and 6A3
3191 " - 0.1A1
6155 " - 0.1A1 and 2A2

6700.5 kc - 2A2 & 6A3
6933 " - 2A2
6835 " - 2A2
10710 " - 0.1A1
40.54 mc - 2A2
133.38 " - Ao and 6A3

RECORDING BAROGRAPH

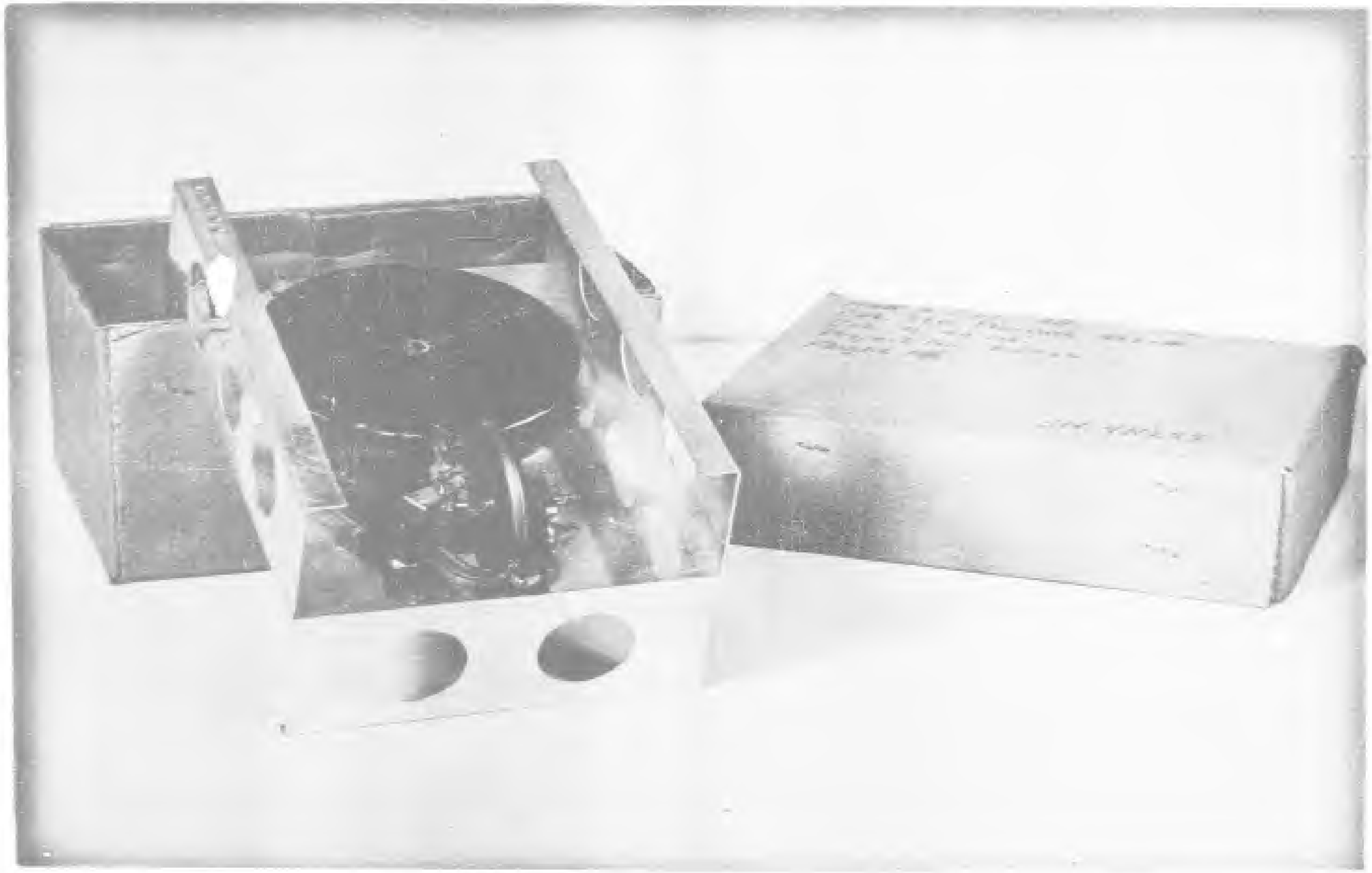


Figure 10

F. Balloon Load Train

The analysis presented in earlier sections of this report has shown that at the present time it is not possible to fly loads as large as 1500 lb to 100,00 ft. This eliminates the load arrays depicted in Figure 1 (a), (b), and (c). The arrangement shown in Figure 1 (e) would not be possible until a suitable means is developed for keeping balloons properly separated from one another. Even then, the distance between payloads would vary considerably because of the limitations in controlling balloon altitude at the 100,00 ft height. Further, launching such a multiple-balloon system at sea would be virtually impossible. This leaves the array in Figure 1 (d) as the only possible arrangement. This array could be supported by one large balloon. Launching such a system would undoubtedly require careful planning and preliminary rehearsing. Some elements of the system would have to be fabricated and tested prior to the actual operation.

A typical load train for flying five loads in a vertical line is illustrated in Figure 11. Because of the extreme extended length of this load train it would be advisable to employ reels to hold the 1000 ft lengths of cable until the system becomes airborne. By using reels the length could be held to approximately 600 ft for launching. The reels would be released by a pressure-actuated mechanism or a time-delay device after the system reached a suitable altitude.

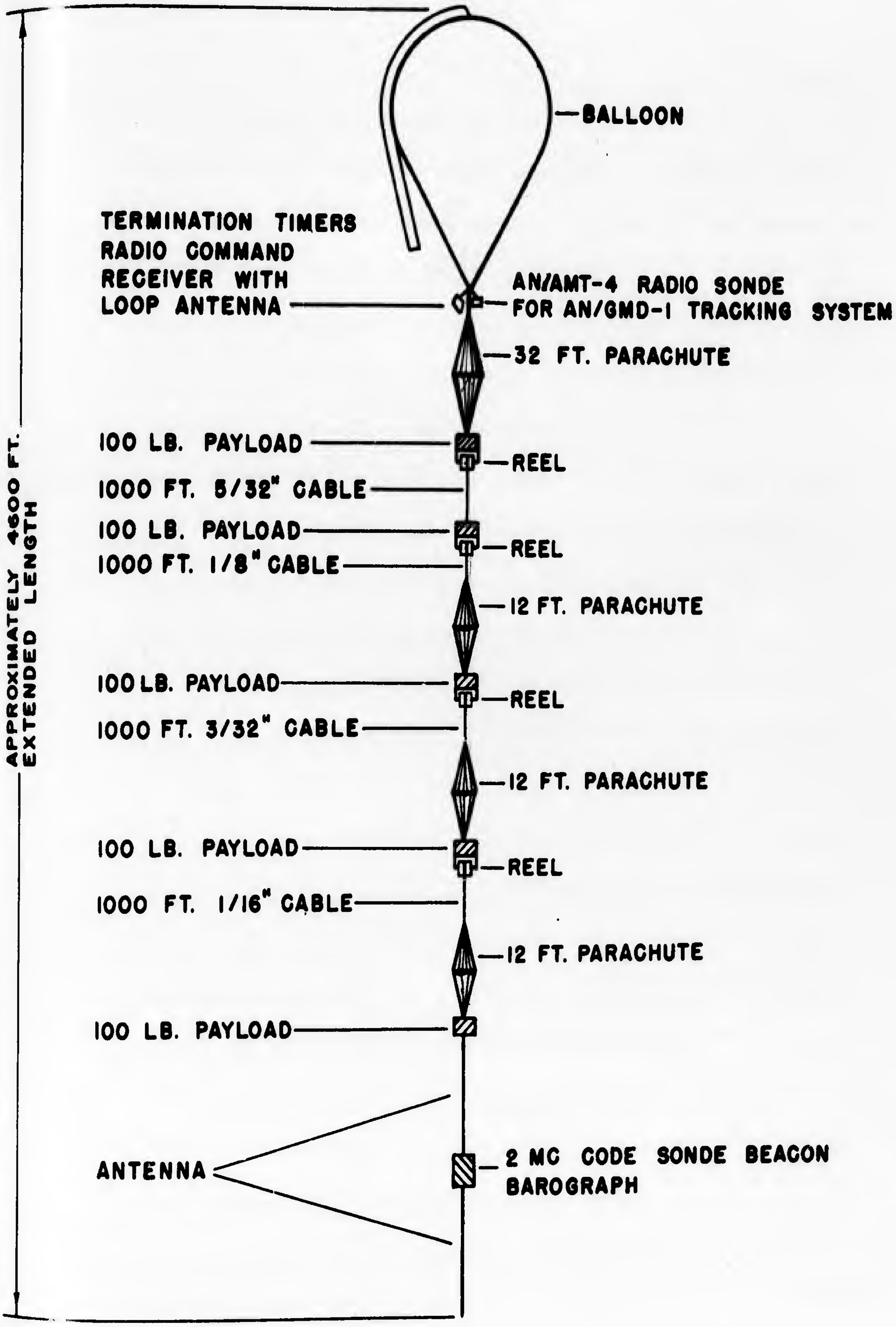


FIGURE 11

TYPICAL VERTICAL LOAD TRAIN FOR FIVE 100-LB PAYLOADS

The reels would not be capable of reeling in the cables once the load train became extended. It would be necessary to provide reels with brakes to limit the rate of paying out the cable. The cable diameter would be decreased progressively from the top to the bottom to minimize the cable weight. Nylon line might be substituted for some of the smaller cable to reduce the weight a few pounds. However, experience has shown that reels of this type employing cable work much better than those employing nylon line. Nylon tends to foul on the reel and lock. Strength and weight data for small diameter corrosion-resistant steel cable and for nylon cord is presented in Appendix I.

The termination timers and the radio command control receiver with its loop antenna should be placed directly below the balloon at the top of the load train. These items will be used in connection with separating the balloon from the load and for this reason should be mounted at or near the point of separation. The radio sonde for tracking should also be mounted at this point to keep the antenna away from the steel cable. The antenna on the 2 megacycle code sonde beacon for telemetering altitude is 270 ft long and the beacon should be placed at the end of the load train away from the steel cable. The barograph should be placed with this beacon so that barograph and beacon data can be compared.

Four parachutes are placed in the load train for recovery purposes. During descent the major portion of the load would be supported by the 32 ft chute at the top of the load train. The three 12 ft chutes would support some of the load but their main function would be to prevent whipping or oscillation of the long load train during descent. Experience has shown that severe oscillations can build up because of lack of damping in the low density atmosphere. The small chutes should provide the needed damping. To enable the chutes to open, the 12 ft chutes should be mounted in the load train so that the load is not transmitted through the chute. Performance data for parachutes is presented in Appendix H.

Some consideration was given to the possibility of using a suitable parachute for each load and severing each cable just above the chute at flight termination. However, with five loads to track down and recover rather than one, the recovery task would be more difficult. Also, the chances of losing a load would be increased.

An approximate weight analysis of the load train is given in Table V.

G. Lifting Gas

Both helium and hydrogen are used as lifting gases in balloon operations. Helium is customarily used in Navy balloon operations--particularily ship-based operations because of the fire and explosion hazard associated with the use of hydrogen.

The Bureau of Mines plants supply all of the helium used in balloon operations. However, all helium is obtained through the Navy Bureau of Aeronautics, Helium Branch. Since there are a variety of sizes of gas cylinders used in supplying helium, it may be advisable to request the assistance of the Helium Branch in scheduling the helium supply. When the ship to be used in the operation is known, the space available for helium stowage can be determined. On the basis of this information the

TABLE V

Approximate Weights for Load Train Shown in Figure 11

Payloads, 5 @ 100 lb each	500.0
Radio Command Receiver	10.0
Termination Timers (Dual)	6.0
Barograph	1.0
Code Sonde Beacon	15.0
AN/AMT-4 Radio Sonde	2.0
Parachutes	
12 ft flat 3 @ 2.15 lb each	6.5
32 ft flat	23.0
1000 ft 1/16" cable @ 0.75 lb/100 ft	7.5
1000 ft 3/32" cable @ 1.60 lb/100 ft	16.0
1000 ft 1/8 " cable @ 2.9 lb/100 ft	29.0
1000 ft 5/32" cable @ 4.5 lb/100 ft	45.0
Reels 2 @ 10 lb each	20.0
2 @ 15 lb each	30.0
Approximate Total Weight	711.0

helium supply people can ship the required amount of helium in suitable cylinders available at the time of the operation. The 22 ft higher pressure cylinders would very likely be best suited for the operation if adequate stowage space is available.

It is assumed that one successful flight over the target is the requirement. To succeed it may be necessary to launch one or two pilot flights. A fourth flight should be planned as a spare. It is customary to have available at least 10 per cent excess gas as a safety factor. The gross weight plus free lift on each flight would be approximately 1500 lb. Allowing for four flights and 10 per cent excess, 6600 lb of lift would be required. To provide this lift, 102,000 cu ft (70°F and 14.7 psia) of helium are needed.

VIII. ESTIMATED COSTS

A. General Discussion

Assuming that the proposed operation would be carried out at sea, the major portion of the expense for conducting such an operation would be associated with government-furnished services and equipment. These would include items such as launching and recovery vessels, the tracking aircraft, helium lifting gas, and upper air weather service. Also, government responsibilities associated with the payloads would be an important cost factor. No attempt has been made to estimate costs of such items.

However, there are certain materials and services customarily furnished by a contractor. Since estimates of costs of contractor-furnished items may be of value in evaluating the proposed operation, appropriate figures are presented below. It has been assumed that four flights would be made using the arrangements of Figure 11. The cost figures presented do not constitute a bid on the part of General Mills, Inc. and are intended for information purposed only.

In making these estimates it was assumed that the actual operation would be preceded by a developmental phase in which engineering prototypes of some of the unproved items such as the large balloon, and the cable reels will have been fabricated and field tested. Techniques for launching the long flight train would also be field tested during this phase. Costs for this developmental test phase would be in addition to those presented below, and would amount to about 75 per cent of the total for the actual operation.

B. Equipment Costs

1. Balloon

157 TT, 2.0 mil polyethylene	$3,000	
Four 157 TT's		$12,000

2. Flight Instruments

Radio control receiver	$ 400	
Altitude beacon	300	
Recording barograph	75	
Termination timer	35	
	$ 810 per set	
Four sets instruments		$ 3,240

3. Rigging and Parachutes

32 ft parachute	$ 50	
12 ft parachutes (3)	30	
Cable	1330	
Reels (4)	2000	
Squib cannons, squibs, nylon line, insulated bags, etc.	50	
	$3,460 per flight	
For four flights		$13,840

4. Miscellaneous

Receiver for altitude telemetering	$1,000	
Transmitter and audio generator for radio control	1,000	
Inflation and launching equipment	2,000	
	$4,000	
TOTAL B		$ 4,000
		$33,080

C. Engineering and Operations Services Costs

Labor and burden	$ 9,640	
Subsistence and travel	4,780	
Packaging and shipping	2,000	
	$16,420	$16,420
TOTAL B AND C		$47,500

IX. CONCLUSIONS AND RECOMMENDATIONS

The objective of this study has been to determine the feasibility of flying an array of payloads over a target point by means of high altitude plastic balloons. For purposes of analysis, the general problem was divided into six parts: loads, altitude, separation, trajectory, duration, and operations and instrumentation. In summarizing the study results, the findings relative to each of these sub-divisions will be discussed as they apply to the desired objectives.

Whereas five arrays (as depicted in Figure 1) were originally presented as being usable in the contemplated operation, an analysis of the balloon requirements has shown that the arrays, including the 1500 lb load, are not feasible at this time because a suitable balloon is not available for carrying this load to the specified 100,000 ft minimum altitude. The load array of 100 lb payloads shown schematically in Figure 1 (e) would require five balloons. A proved balloon, the 134 TT, is available for supporting the 100 lb payload plus an additional 100 lb of auxiliary flight gear at 104,000 ft. A balloon suitable for supporting both loads on the vertical axis could be designed and fabricated using the proved tailored tapeless design and fabrication techniques. However, techniques would have to be developed for keeping the balloons in the desired positions. The balloons would have to be tied together to limit horizontal separation and such a complicated system would be fraught with launching problems and vulnerable to malfunction.

The most feasible load array is that in Figure 1 (d). It is estimated that, in addition to the five 100 lb payloads, it would be necessary to carry approximately 200 lb of associated flight instrumentation and rigging. There is good reason to believe that a suitable tailored tapeless balloon could be designed to carry this 700 lb load to 100,000 ft. Analysis shows that a 157 ft diameter balloon made of 2 mil polyethylene would be required. Tailored tapeless balloons, 150 ft and 201 ft in diameter, have already been built and flown successfully. However, these balloons were designed for smaller loads so it would be advisable to flight test a trial 157 TT balloon early in the program.

A typical load train comprised of the five 100 lb payloads is shown in Figure 11. This long train would be difficult to launch and would require careful preparation and planning. If the number of payloads could be reduced, or the spacing between loads could be shortened, the chances of success would be increased. For this reason, the array shown in Figure 1 (c), with two 100 lb loads suspended below the 1500 lb load, would be easier to fly if a suitable balloon were available. General Mills, Inc. is currently investigating a balloon design suitable for carrying a 1500 lb payload to 100,000 ft in connection with Contract No. Nonr 1589(06). If the results of this investigation are favorable, the vertical load array with one 1500 lb and two 100 lb payloads might be feasible.

The sponsor has indicated that it is necessary to fly the loads at an altitude of 100,000 ft or greater. Balloon engineering design and operations are based on the NACA standard atmosphere, and, consequently, the 100,000 ft altitude has been interpreted as a pressure altitude and not a geometric height. Analysis of altitude performance possibilities indicates that the actual geometric altitude attained by a balloon designed for 100,000 ft may vary from + 4,625 ft to - 4,365 ft. Most of this variation results from variance of actual meteorological conditions with the NACA standard. If several balloons are launched in the same atmosphere, the relative variation in altitude is reduced to ± 425 ft of the 100,000 ft pressure level. Currently available altitude control instrumentation is not capable of improving this performance.

As mentioned in a previous paragraph, it would be necessary to tie balloons together in order to maintain relative positioning in a horizontal configuration. Unfortunately, the weight of the tie-line is capable of forcing the balloons together if no opposing force is incorporated in the system. Hydrogen peroxide rockets, electrostatic repulsion, and a balloon "sea anchor" technique were investigated as possible means for keeping balloons apart. The rocket appears to be the only feasible method, and a suitable rocket is not presently available. It is believed, however, that, with additional development work, an exisiting rocket designed for helicopter rotors could be modified for this application. Low ambient temperature would very likely be an important factor to consider. Methods for directing and controlling the rocket would also have to be developed.

Accurate trajectory forecasting is necessary if the loads are to be carried over a specified target point. By limiting the flight duration to the approximately 2 hours required to attain altitude, the error in forecasting could be minimized. Factors affecting the error in forecasting are variations in rate of rise, error in determining wind velocities, and variations in the integrated wind. It is estimated that the first array of loads flown may pass as much as 6.34 miles either side of the target. By using the first flight as a means of obtaining rate of rise and wind vector data, it should be possible to reduce the error to ± 3.20 miles.

By limiting flight duration to the time required to attain an altitude of 100,000 ft, the errors in trajectory forecasting would be minimized. Assuming a rate of rise of 800 ft per minute, the ascent time would be 2 hours. The time required for the loads to descend by parachute would be approximately 0.5 hours. Thus, the total time in the air for a flight cannot be less than 2.5 hours. An additional 0.5 hours should be allowed for the balloon to level off at a maximum altitude, giving a total of 3 hours required per flight. Time for balloon layout and inflation and for recovery is not provided for in these figures.

The sponsor has indicated that the operation would very likely be conducted at sea. Launching from a ship will provide the mobility of launching site required in connection with flying the loads over the target point. Also, relative surface wind at launching can be controlled by heading the ship with the wind. A ship such as an aircraft aarrier with a large clear deck area visible from the bridge is considered necessary for launching the long complicated load train. To shorten the load train for launching it would be necessary to hold the 1000 ft lengths of cable on special reels which would pay out the line after the balloon was launched. A suitable radio control receiver is available for flight termination. It would be wise to incorporate a secondary timer-actuated flight termination device. The safety switch for flight termination in the event of balloon malfunction required on all flights in the United States is not considered necessary for an operation at sea. Altitude beacons for tracking the flight are also available. Because of the extreme length of load train, small parachutes should be placed in the lower sections of the load train to prevent violent whipping or bouncing of the lower loads during descent. These chutes would assist the main chute in slowing the rate of descent. It is estimated that one 32 ft chute and three 12 ft chutes will limit the velocity of a 700 lb load to 30 ft per sec at impact.

Because it would not be possible to conduct the proposed operation without resorting to equipment and techniques not proved in previous flight applications, it would be advisable to conduct some preliminary development work before attempting the actual operation.

Two objectives should be accomplished in this developmental phase. The 157 TT balloon should be designed and at least one (and preferably more) balloons should be fabricated and flown before ordering balloons for the actual operation. A 157 TT 2 mil polyethylene balloon is sufficiently different from balloons which have been flown to warrant a verifying flight test. Cable reels suitable for containing and paying out 1000 ft of cable should be designed and tested. Properly functioning reels would be important elements in the proposed flight train. Preliminary tests would provide an opportunity to correct the troubles which inevitably appear in new designs. Launching tests of the reels might well be incorporated with flight tests of the 157 TT balloon. These launchings would provide experience for the actual operation.

There is a third objective which should be considered for possible inclusion in the developmental phase. This is a small rocket motor system for propelling a balloon at 100,000 ft. This device might be considered desirable for improving the accuracy of flying the payloads over the target point. Also, if a horizontal balloon array is considered essential, the rocket motor would be required to keep the balloons separated.

It is estimated that the cost of the contractor-furnished material and services for the actual operation would be $49,500 and the cost of the development phase would be an additional $37,000.

BIBLIOGRAPHY

1. General Mills, Inc. Report no. 1153. Project Gopher flight data, vol. 3, by R. I. Hakomaki, October 31, 1952. (Contract AF33(600)-6298) (Secret).

2. General Mills, Inc. Report no. 1153. Project Gopher flight data, vol. 2, by R. I. Hakomaki, October 31, 1952. (Contract AF33(600)-6298) (Secret).

3. Warfield, C. N. Tentative tables for the properties of the upper atmosphere. NACA Technical note no. 1200 (1947)

4. Minnesota, University, Department of Physics. Progress report on research and development in the field of high altitude plastic balloons, vol. 1, for the period December 31, 1951 - June 15, 1952, pp. 4-54. (Contract Nonr-710(01), NR 320,159).

5. Minnesota, University, Department of Physics. Progress report on research and development in the field of high altitude plastic balloons, vol. 5, for the period June 15, 1952 - December 22, 1952, pp. III-E-43 thru 75. (Contract Nonr-710(01), NR 211,002)

6. General Mills, Inc. Report no. 1092. Topical report: Helium, by W. L. De Tuncq, 1952, p. 25.

7. N. Y. University, College of Engineering, Research Division. Technical report 121.05. High altitude balloon trajectory study, by William D. Murray and J. R. Smith, June 15, 1950.

8. Minnesota, University, Department of Physics. Progress report on research and development in the field of high altitude plastic balloons, vol. 6, for the period June 15, 1952 - December 22, 1952, VI-135. (Contact Nonr-710(01).

9. Minnesota, University, Department of Physics. Progress report on research and development in the field of high altitude plastic balloons, vol. 8, for the period January 20, 1953 - February 4, 1953, pp. X-100 thru 107. (Contract Nonr-710(01), NR 211,002).

10. Sutton, G. P. Rocket propulsion elements. N.Y., Wiley, 1949, p. 101; 10a) p. 57.

11. Bergaust, Erik. Rocket power for helicopters. Aero Digest 70, 4:32-38 (1955).

12. Reaction Motors, Inc. Report no. RMI-420-Fl. Final engineering report on the 16 pound thrust rocket engine for Rotor-Craft Corp., Glendale, Calif. (Confidential).

13. Brasefield, C. J. Winds at altitudes up to 80 kilometers. J Geophys Res 59: 233-37 (1954).

14. Van de Graaff generator. Mech Eng 73: 739 (1951).

15. Minnesota, University, Department of Physics. Progress report on research and development in the field of high altitude plastic balloons, vol. 1, for period December 13, 1951 - June 15, 1952; vol. 5, for the period June 15, 1952 - December 22, 1952; vol. 8, for the period January 20, 1953 - February 4, 1953. (Contract Nonr-710(01)).

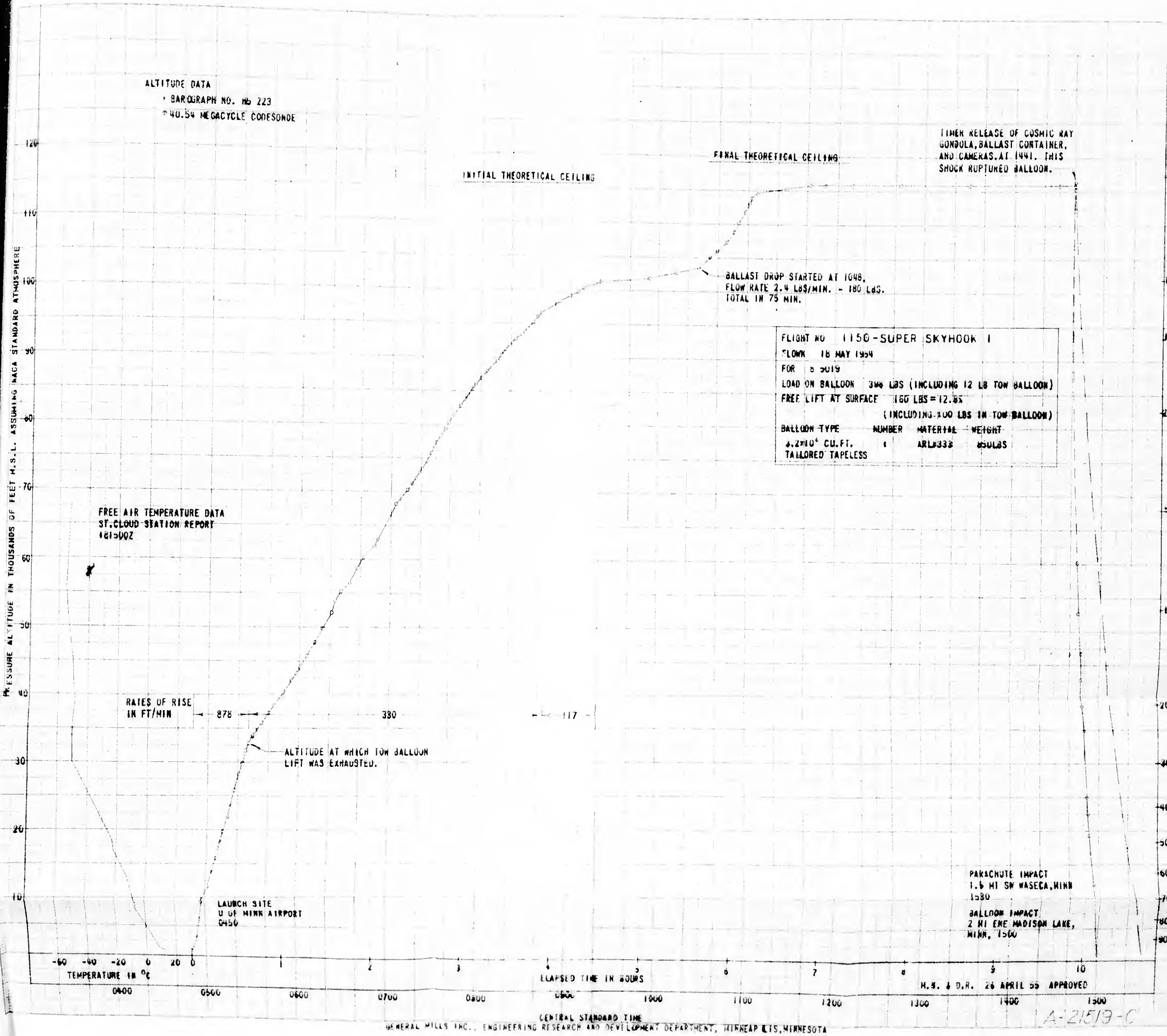
16. Rapp, R. R. The effect of variability and instrumental error on measurements in the free atmosphere. N. Y. University. College of Engineering. Meteorological Papers, vol. 2, no. 1, p. 29; p. 28, Fig. 4-5, Curve A; and p. 30, Fig. 6, Curve A (1952).

ACKNOWLEDGEMENTS

In gathering information during the study and in preparing this report the author obtained assistance from several members on the staff of the Engineering Research and Development Activity of the Mechanical Division of General Mills, Inc. In particular, Mr. J.R. Smith, Head of Balloon-Meteorology Section provided helpful guidance in the study; Mr. C.P. Merrell and his Data Analysis group assisted in analyzing balloon performance data; Miss Agnes Brown, Librarian, assisted in obtaining references consulted during the study.

The author wishes to express his appreciation to those who assisted him and to acknowledge their contributions.

APPENDIX A



FLIGHT NO 1150-SUPER SKYHOOK I
FLOWN 18 MAY 1954
FOR 8 5019
LOAD ON BALLOON 398 LBS (INCLUDING 12 LB TOW BALLOON)
FREE LIFT AT SURFACE 160 LBS = 12.5%
(INCLUDING 100 LBS IN TOW BALLOON)

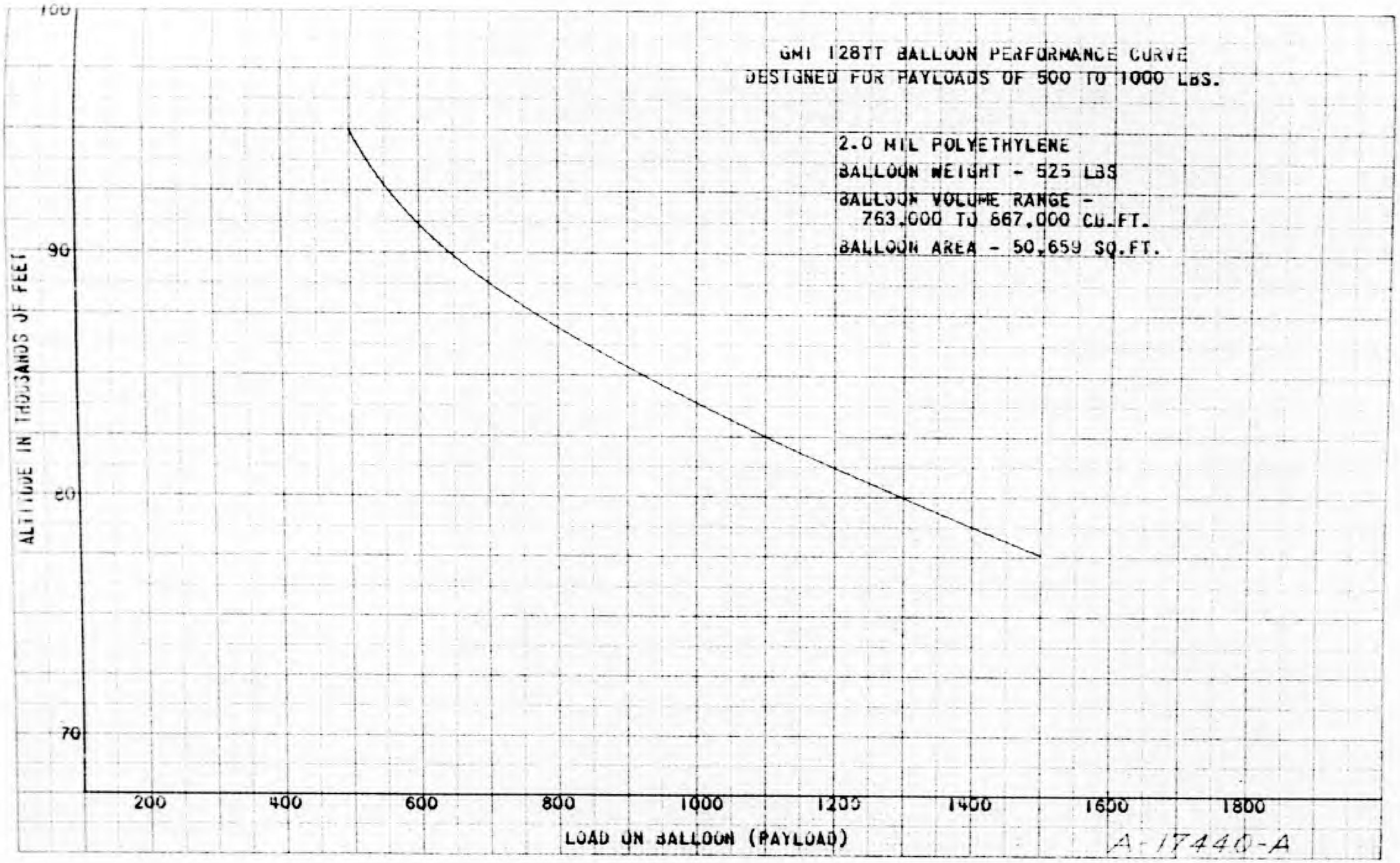
BALLOON TYPE	NUMBER	MATERIAL	WEIGHT
3.2×10⁶ CU.FT. TAILORED TAPELESS	1	ARL#333	850LBS

GENERAL MILLS INC., ENGINEERING RESEARCH AND DEVELOPMENT DEPARTMENT, MINNEAPOLIS, MINNESOTA

A-21519-C

JUL 6 1955

APPENDIX B



A-17440-A

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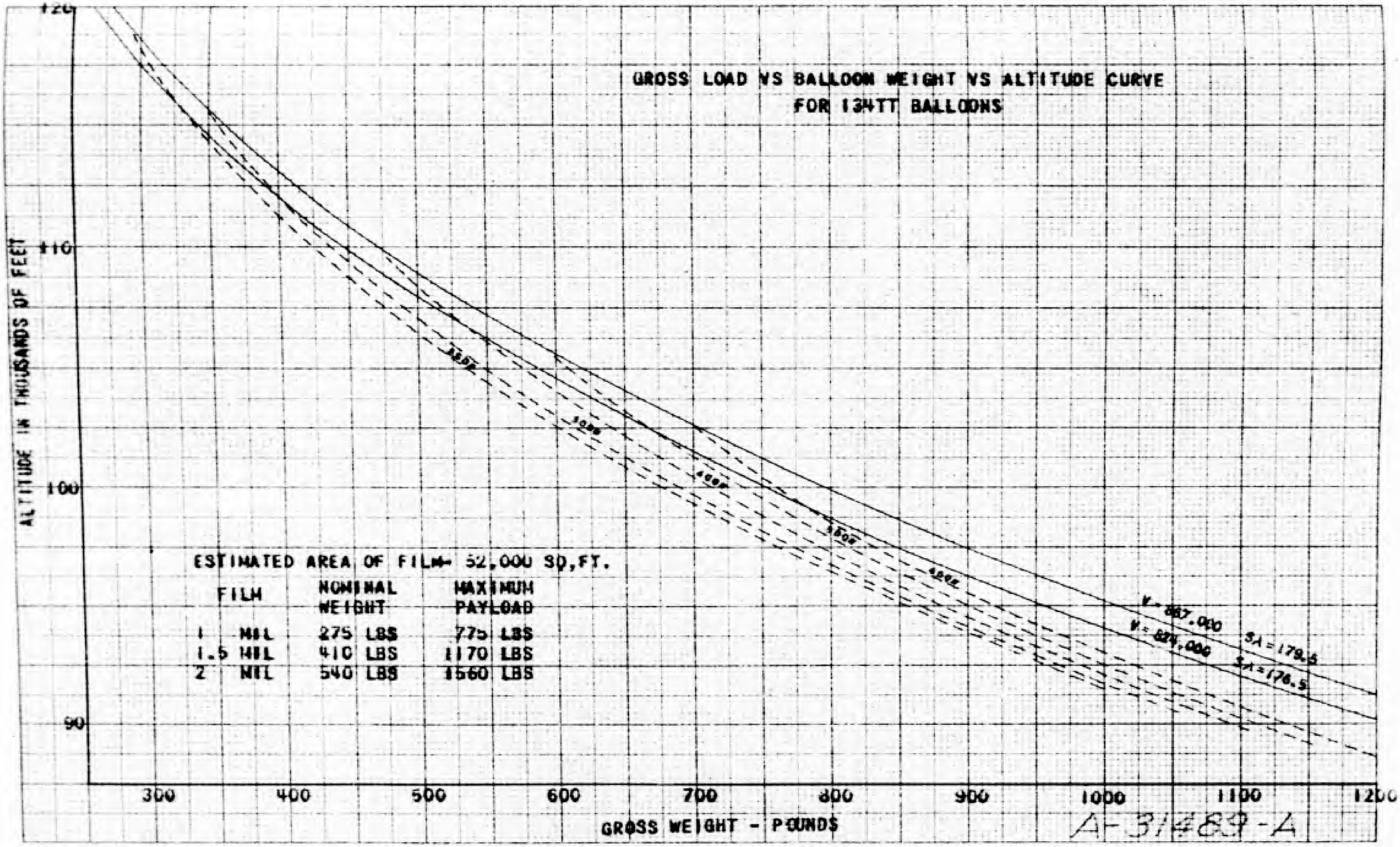

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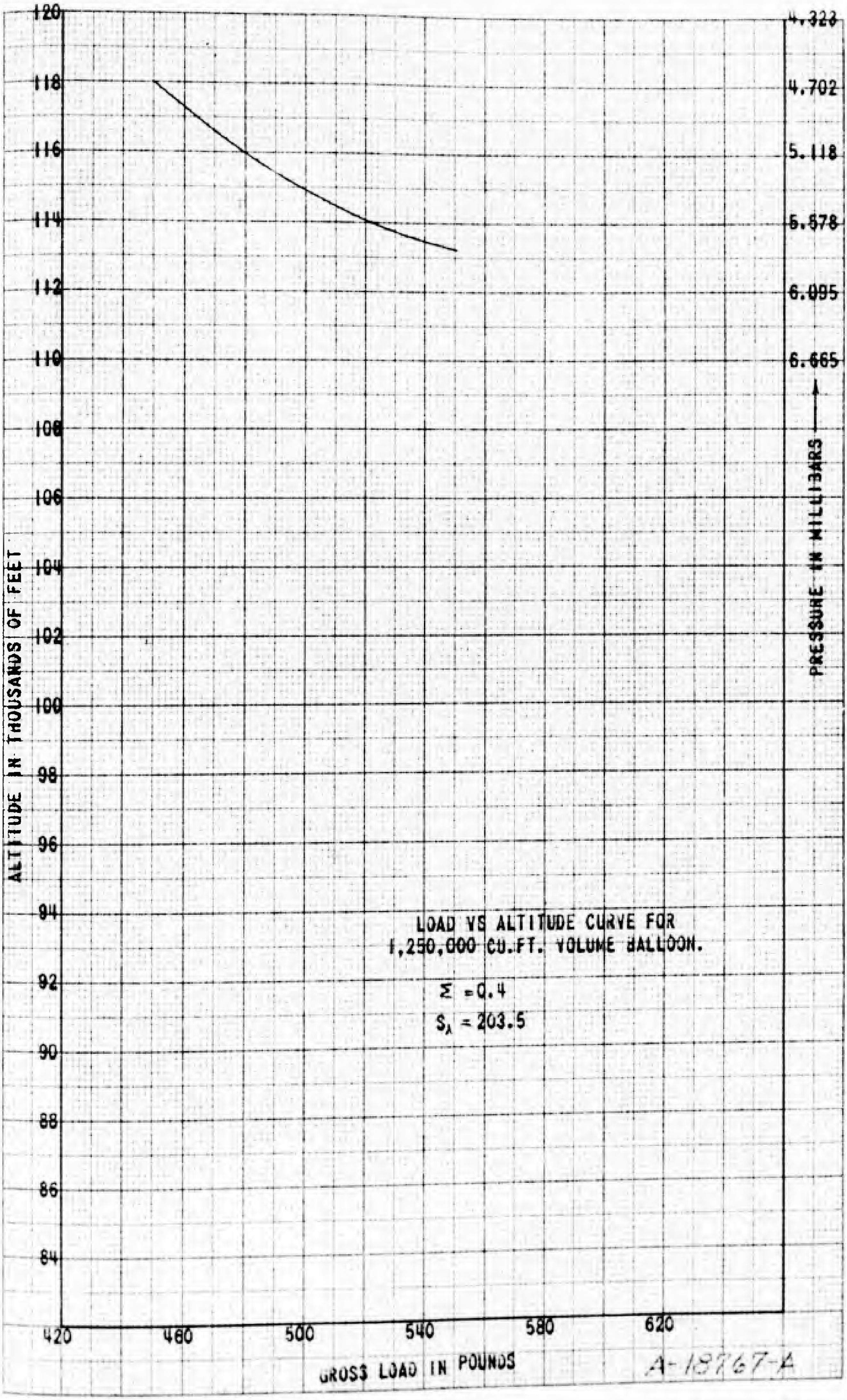


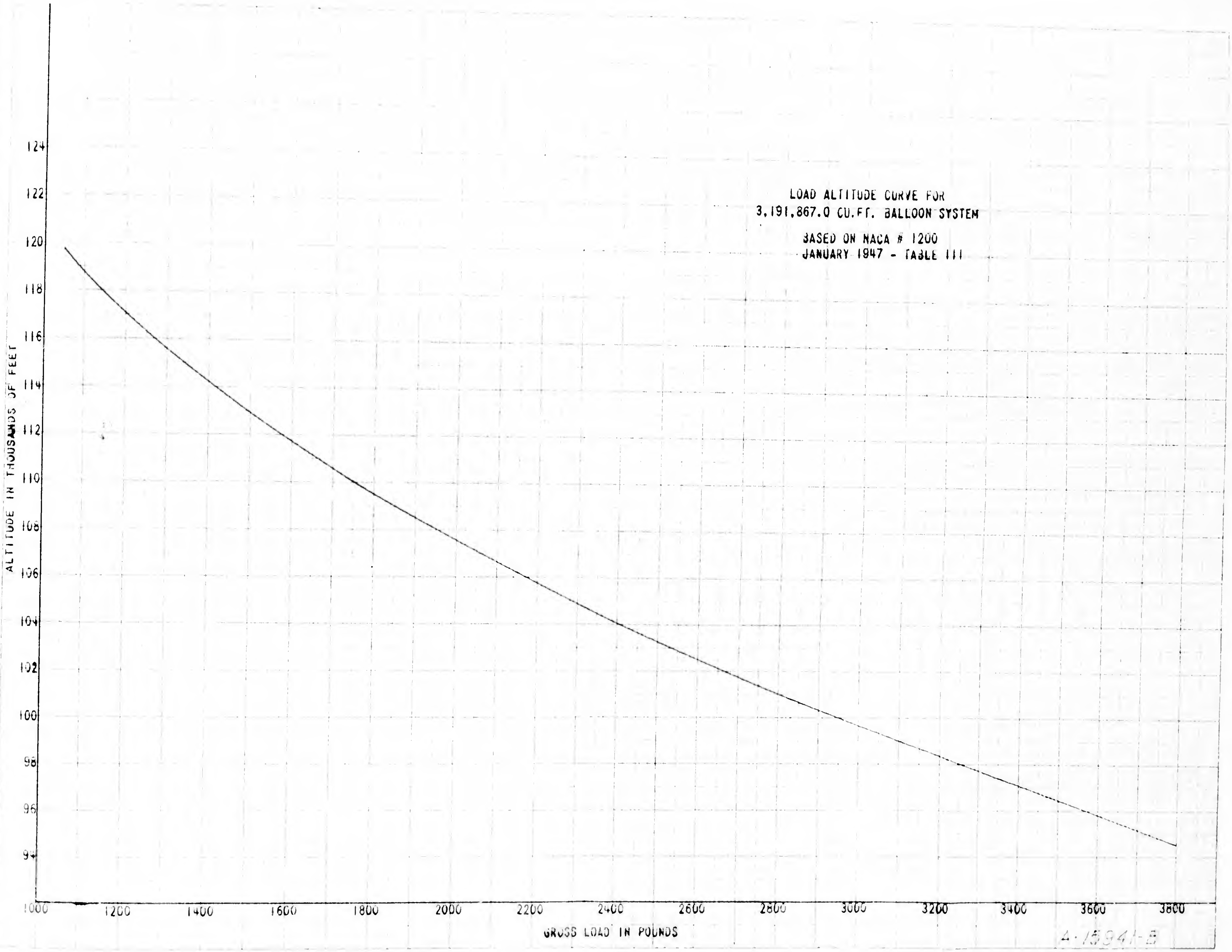
LOAD VS ALTITUDE CURVE FOR
1,250,000 CU.FT. VOLUME BALLOON.

$\Sigma = 0.4$

$S_A = 203.5$

A-18767-A

JUL 6 1955



LOAD ALTITUDE CURVE FOR
3,191,867.0 CU.FT. BALLOON SYSTEM

BASED ON NACA # 1200
JANUARY 1947 - TABLE III

A-15941-B

JUL 6 1955

APPENDIX C

TABLE C-1

BALLOON FLIGHT PERFORMANCE DATA
TYPE 134 TT BALLOONS

Balloon Number	Flight Number	Date Flown	Launch Site *	Launch Time (CST)	Balloon Weight, Lbs	Payload, Lbs	Gross Weight, Lbs	Theoretical Ceiling, Ft.	Maximum Alt. Attained, Ft	Rate of Rise, Ft/Min
1	1230	5 Oct 54	1	0642	473	399	872	95,650	96,300	484
2	1255	12 Nov 54	1	0715	469	369	838	96,550	98,000	568
3	1253	10 Nov 54	1	0701	464	375	839	96,500	5,800	327
4	1273	19 Dec 54	1	0859	487	346	833	96,800	98,000	635
5	1262	22 Nov 54	1	0652	473	379	852	96,250	94,750	716
6	1279	29 Dec 54	1	0818	473	373	846	96,400	95,000	543
7	1294	30 Jan 55	1	0953	403	416	819	96,750	32,500	754
8	1317	15 Feb 55	1	0921	398	396	794	97,400	94,700	558
9	1318	22 Feb 55	1	0908	407	224	631	103,000	38,200	549
10	1311	15 Feb 55	2	0905	413	204	617	103,500	19,000	443
11	1320	1 Mar 55	1	0901	423	216	639	102,800	37,000	656
12	1306	9 Mar 55	2	0723	542	411	953	93,800	92,800	705
13	1310	18 Mar 55	2	0719	542	414	956	93,850	42,400	

* 1 = U of Minn. airport
2 = Huron, S. D. airport

TABLE C-2

BALLOON FLIGHT PERFORMANCE DATA
TYPE 79N BALLOON

Balloon Number	Flight Number	Date Flown	Launch Site *	Launch Time (CST)	Balloon Weight, Lbs	Payload, Lbs	Gross Weight, Lbs	Theoretical Ceiling, Ft	Maximum Alt. Attained, Ft	Rate of Rise, Ft/Min
31	1043	9 Aug 53	1	0644	227	304	531	80,100	79,500	786
32	1046	15 Aug 53	1	0504	216	348	564	78,800	79,400	536
37	1060	20 Aug 53	1	0619	184	281	475	82,400	81,450	867
39	1061	23 Aug 53	1	0559	171	345	516	80,700	Failed	937
40	1063	15 Sept 53	1	0644.5	171	300	471	82,600	82,500	813
41	1062	10 Sept 53	1	0544	191	305	496	81,500	81,400	832
42	1064	24 Sept 53	1	1054	194	303	497	81,500	81,000	770
43	1066	9 Oct 53	1	0605	191	304	495	81,500	82,400	638
47	1067	15 Oct 53	1	0702	192	334	526	80,300	81,000	745
66	1069	5 Nov 53	1	0736	200	282	482	82,100	81,900	878
68	1093	6 Jan 54	1	0728	244	271	515	80,700	82,000	812
69	1089	9 Dec 53	1	0751	242	267	509	81,000	80,500	874
91	1096	28 Jan 54	3	0903	196	350	546	79,500	80,000	617

TABLE C-2 (Cont.)

BALLOON FLIGHT PERFORMANCE DATA
TYPE 79N BALLOON

Balloon Number	Flight Number	Date Flown	Launch Site *	Launch Time, (CST)	Balloon Weight, Lbs	Payload, Lbs	Gross Weight, Lbs	Theoretical Ceiling, Ft	Maximum Alt. Attained, Ft	Rate of Rise, Ft/Min
93	1167	19 Aug 54	1	0503	194	330	524	80,400	81,000	783
94	1160B	8 July 54	1	0354	196	295	491	81,700	81,800	798
95	1100	16 Feb 54	3	0743	191	340	531	80,100	79,000	716
96	1229	22 Sept 54	1	0604	184	368	552	79,300	79,100	785
97	1228	20 Sept 54	1	0604	182	374	556	79,100	79,000	797
98	1232	15 Oct 54	2	0820	182	359	541	79,700	79,500	855
99	1234	20 Oct 54	1	0635	192	360	552	79,300	79,400	762
102	1269	6 Dec 54	1	0735	190	356	546	79,500	79,400	685
103	1285	13 Jan 55	1	0825	143	344	487	81,900	79,900	564
105	1293	30 Jan 55	1	0834	170	350	520	80,500	80,000	663
111	1313	14 Feb 55	1	0845	172	340	512	80,800	45,100	578
112	1316	15 Feb 55	1	0857	219	347	566	78,700	78,800	627
116	1305	9 Mar 55	2	0843	223	372	595	77,700	Failed	735
119	1308	16 Mar 55	2	0725	219	360	579	78,200	77,700	655

* 1 = U of Minn. airport
2 = Huron, S. D. airport
3 = Pierre, S. D. airport

TABLE C-3

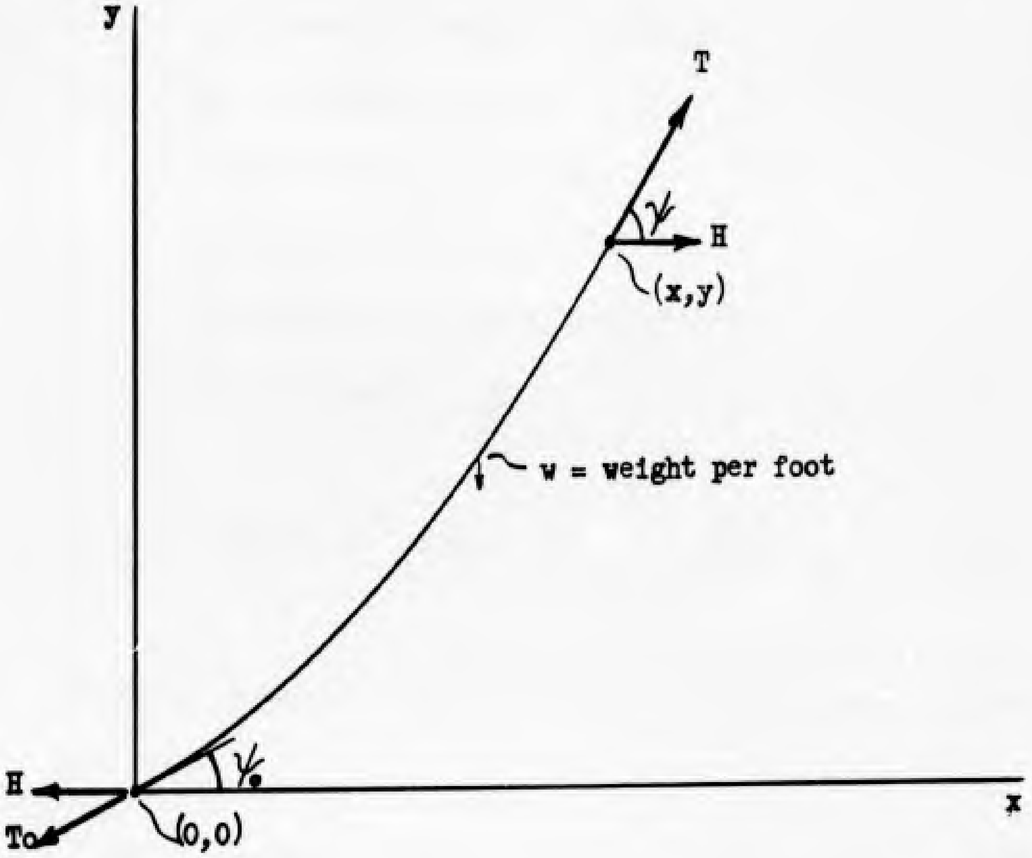
BALLOON FLIGHT PERFORMANCE DATA

Balloon Type	Balloon Number	Flight Number	Date Flown	Launch Site *	Launch Time (CST)	Balloon Weight,Lbs	Payload,Lbs	Gross Weight,Lbs	Theoretical Ceiling,Ft	Maximum Altitude Attained,Ft	Rate of Rise,Ft/Min
1161	28	1115	8 April 54	2	0533	420	376	796	96,000	96,300	372
1161	31	1122	31 March 54	1	0706	395	693	1088	89,700	89,450	497
1265TT	1	1119	22 June 54	1	0423	402	349	751	98,300	98,000	753

1. U of Minn. Airport
2. Pierre, S. D. Airport

APPENDIX D

SOLUTION OF CATENARY FOR BALLOON TIE LINE



The diagram above shows the forces present for a section of a catenary. The equations defining the force relationships as developed by Campbell* for the case when the points of support are on the same level are summarized below. The following notation is used.

---

* Campbell, J. W., An Introduction to Mechanics, Pitman Publishing Corp., N. Y., 1947, pp. 233-263

x = span (distance between balloons)

s = total length of catenary

q = sag

T = tension at supports (balloons)

H = horizontal tension

w = weight per unit length

ψ = inclination at end

c = depth of directrix below vertex

u = a parameter = $\frac{x}{2c}$

$$\frac{s}{x} = \frac{\sinh u}{u} \qquad \text{(D-1)} \qquad\qquad \frac{2H}{wx} = \frac{1}{u} \qquad \text{(D-2)}$$

$$\frac{2q}{x} = \frac{\cosh u - 1}{u} \qquad \text{(D-3)} \qquad\qquad \frac{2q}{s} = \tanh \frac{u}{2} \qquad \text{(D-4)}$$

$$\frac{2T}{wx} = \frac{\cosh u}{u} \qquad \text{(D-5)} \qquad\qquad \frac{ws}{2T} = \tanh u \qquad \text{(D-6)}$$

$$\tan \psi = \sinh u \qquad \text{(D-7)} \qquad\qquad \frac{T}{T - wq} = \cosh u \qquad \text{(D-8)}$$

$$T = H + wq \qquad \text{(D-9)}$$

A sample calculation similar to those made in preparing the data for Figures 4 and 5 is presented below:

Given: x = 1000 ft

s = 1025 ft

w = 0.0091 lb per ft

Unknown: H

The parameter, u, is first determined using equation (D-1) and Table C* from Campbell for the function, $\frac{\sinh u}{u}$

$$\frac{s}{x} = \frac{\sinh u}{u}$$

$$\frac{1025}{1000} = \frac{\sinh u}{u}$$

$$1.025 = \frac{\sinh u}{u}$$

$u = .386$ (From Table C)

The horizontal tension is then obtained from equation (D-2)

$$\frac{2\,H}{w\,x} = \frac{1}{u}$$

$$H = \frac{w\,x}{2\,u}$$

$$H = \frac{(.0091)\,1000}{2\,(.386)}$$

$$H = 11.8 \text{ lb}$$

---

* Campbell, op. cit., p. 354

APPENDIX E

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

IN REPLY REFER TO
ONR:461:MDR:eew

CONFIDENTIAL

Ser 0735

13 MAY 1955

Mr. Marvin A. Sandgren
General Mills, Incorporated
Mechanical Division
Engineering Research & Development Department
2003 East Hennepin Avenue
Minneapolis 13, Minnesota

Dear Mr. Sandgren:

With regard to your recent request to ASTIA of 11 April, and letters of 12 April and 29 April to this Office requesting information on low thrust rocket motors, we are enclosing herewith a Confidential engineering report prepared for this Office by Reaction Motors, Incorporated. As you can note on the cover, this is the Air Branch file copy and it will be appreciated if you will return this after it has served your purpose for the feasibility study under Contract Nonr 1589(02).

A preliminary investigation has been made of other possible sources of low thrust sustained rocket power. Mr. Bessio of the Bureau of Aeronautics (SI-53) has been contacted and has recommended the rocket engine contained in the Reaction Motors, Inc. report as the one best suited to your needs. It should be pointed out that its low temperature characteristics are not good. However, by providing a proper source of heating this rocket should perform satisfactorily. There are other propellants, some of which are costly, some of which are dangerous; all are in the research and experimental stage. If details are desired they can be obtained by contacting Mr. Bessio.

The most recent general specifications of the RMI low thrust rocket are as follows: (a) thrust - 30 pounds, (b) weight - 1 pound, (c) fuel - consumes 25 pounds of fuel per hour per pound of thrust.

It is hoped the above information will be of value in your study.

Sincerely yours,

W. C. Fortune
W. C. FORTUNE
CAPTAIN, USN
Head, Air Branch
By direction of
Chief of Naval Research

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APPENDIX F

ANALYSIS OF THE BALLOON "SEA ANCHOR" SYSTEM

The arrangement shown in Figure F-1 represents a balloon system in which several balloons are tied together with nylon lines which hang in the form of catenaries. The balloon at the left end of the line is floating sufficiently below the others so that it is in an air mass which is moving at a lower velocity than that at the upper level. As a result there will be relative motion of air past all balloons. The aerodynamic drag will produce forces which will keep the balloons separated. By adjusting the length of the various catenaries, the horizontal separation can be made equal for all balloons on the upper level.

The notation used in Figure F-1 is as follows:

R = aerodynamic drag on the balloon

H = horizontal tension in the catenary

V = wind velocity

It is assumed that V_2 is greater than V_1.

The horizontal forces acting at each support point can be equated as follows assuming that all balloons on the upper level are the same size.

$$\text{At (a)}, \; H_1 = R_1 = 5\,R_2 \qquad \text{(F-1)}$$

$$\text{At (b)}, \; H_1 = R_2 + H_2 = 5\,R_2 \qquad \text{(F-2)}$$

$$\text{At (c)}, \; H_2 = R_2 + H_3 = 4\,R_2 \qquad \text{(F-3)}$$

$$\text{At (d)}, \; H_3 = R_2 + H_4 = 3\,R_2 \qquad \text{(F-4)}$$

$$\text{At (e)}, \; H_4 = R_2 + H_5 = 2\,R_2 \qquad \text{(F-5)}$$

$$\text{At (f)}, \; H_5 = R_2 \qquad \text{(F-6)}$$

The aerodynamic drag forces, R_1 and R_2, can be determined from the

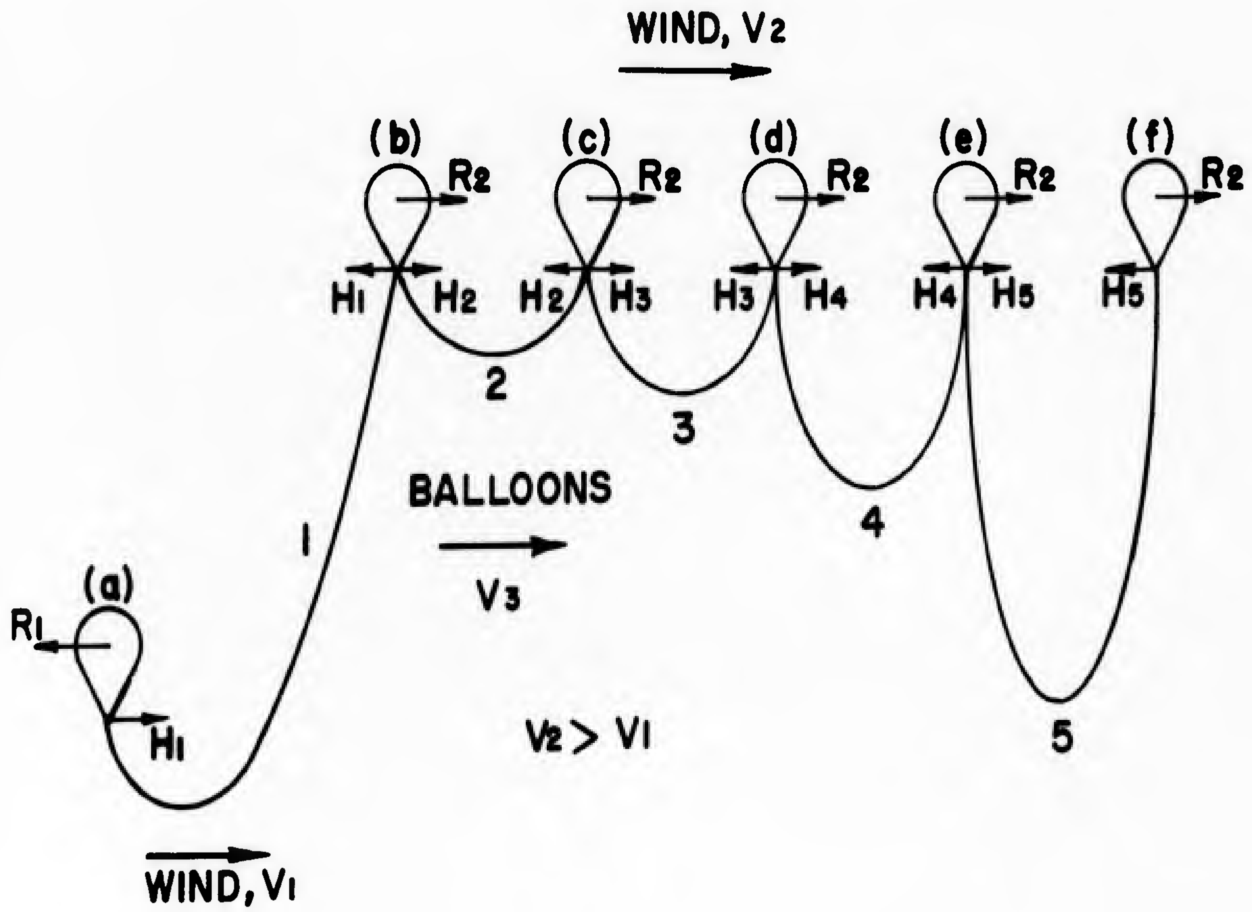

WIND, V_2
(b)
(c)
(d)
(e)
(f)
R_2
H_1
H_2
H_3
H_4
H_5
2
3
4
5
1
BALLOONS
V_3
(a)
R_1
H_1
$V_2 > V_1$
WIND, V_1

FIGURE F-1

standard equation:

$$R = \frac{1}{2} \frac{\rho}{g_c} A C_d V^2 \tag{F-7}$$

where:

ρ = air density, lb_m per cu ft

g_c = dimensional conversion factor = $32.2 \frac{lb_f}{lb_m} \frac{ft}{sec^2}$

A = profile area of the balloon, sq ft

C_d = drag coefficient = 0.7 for balloon

V = velocity, ft per sec

At station (a)

$$R_1 = \frac{1}{2} \frac{\rho_1}{g_c} A_1 C_d (V_3 - V_1)^2 \tag{F-8}$$

and at stations (b) through (f)

$$R_2 = \frac{1}{2} \frac{\rho_2}{g_c} A_2 C_d (V_2 - V_3)^2 \tag{F-9}$$

APPENDIX G

SOLUTION OF POTENTIAL REQUIRED TO PRODUCE A GIVEN REPULSION FORCE BETWEEN IDENTICAL SPHERICAL CONDUCTORS

Smythe* presents a problem in which it must be shown that the repulsion force between two equal spheres of radius "a", with their centers a distance "c" apart, and charged to the same potential V, is given by the following equation:

$$F = 2\pi\epsilon V^2 \sum_{n=1}^{\infty} (-1)^{n+1} (\coth\beta - n \coth n\beta) \operatorname{csch} n\beta \qquad \text{(G-1)}$$

where $$\cosh\beta = \frac{1}{2} \frac{c}{a} \qquad \text{(G-2)}$$

and ϵ = capacitivity

For air $\epsilon \approx 8.85 \times 10^{-12}$ farads per meter

Equation (G-1) can be used to determine the potential required to produce a given repulsion force between two balloons. For this problem the balloons are assumed to be spheres 110 ft in diameter; the center distance is 1000 ft; and the required repulsion force is 1.5 lb.

In equation (G-1), when V is in volts and ϵ in farads per meter, F is joules per meter. Since the force is given as 1.5 lb and since

$$1 \frac{\text{joule}}{\text{meter}} = 0.102 \text{ kilogram}$$

and

$$1 \text{ kilogram} = 2.2 \text{ lb}$$

$$F = \frac{1.5}{2.2 \times 0.102} = 6.68 \frac{\text{joules}}{\text{meter}}$$

Next it will be necessary to evaluate a sufficient number of terms in the series involving the hyperbolic functions. The parameter, β, can be determined from the definition, equation (G-2):

---

* Smythe, William R., Static and Dynamic Electricity, McGraw-Hill, N.Y., 1950, pp. 118-121 and p. 202 (problem 28).

$$\cosh \beta = \frac{1}{2}\ \frac{c}{a} = \frac{1000}{2 \times 55} = 9.09091$$

$$\beta = 2.8926$$

$$\coth \beta = 1.00617$$

The first four terms are evaluated in the following table:

n	$n\beta$	coth $n\beta$	n coth $n\beta$	cothβ -n coth $n\beta$	csch $n\beta$	$(-1)^{n+1}$	n th term
1	2.8926	1.00617	1.00617	0.00000		+1	0.00000
2	5.7852	1.00000	2.00000	- 0.99383	0.00615	-1	0.00611
3	8.6778	1.00000	3.00000	- 1.99383	0.00017	+1	0.00034
4	11.5704	1.00000	4.00000	- 2.99383	0.00001	-1	0.00002

$$\sum_{n=1}^{\infty} = 0.00579$$

Substituting the values for F, ϵ and Σ in equation (G-1) gives

$$6.68 = 2\pi 8.85 \times 10^{-12}\ V^2\ (.00579)$$

$$V = \left(\frac{6.68 \times 10^{12}}{2 \times 8.85 \times .00579} \right)^{1/2}$$

$$V = (20.75 \times 10^{12})^{1/2}$$

$$V = 4.56 \times 10^6 \text{ volts}$$

The charge on a sphere of radius "a" is given by

$$Q = 4 \pi \epsilon a V \quad \text{coulomb}$$

$$= 4 \pi \times 8.85 \times 10^{-12} \times \frac{55}{3.281} \times 4.56 \times 10^6 \quad \text{(F-3)}$$

$$= \underline{8.5 \times 10^{-3}} \quad \text{coulomb}$$

The work in joules is

$$W = Q V$$

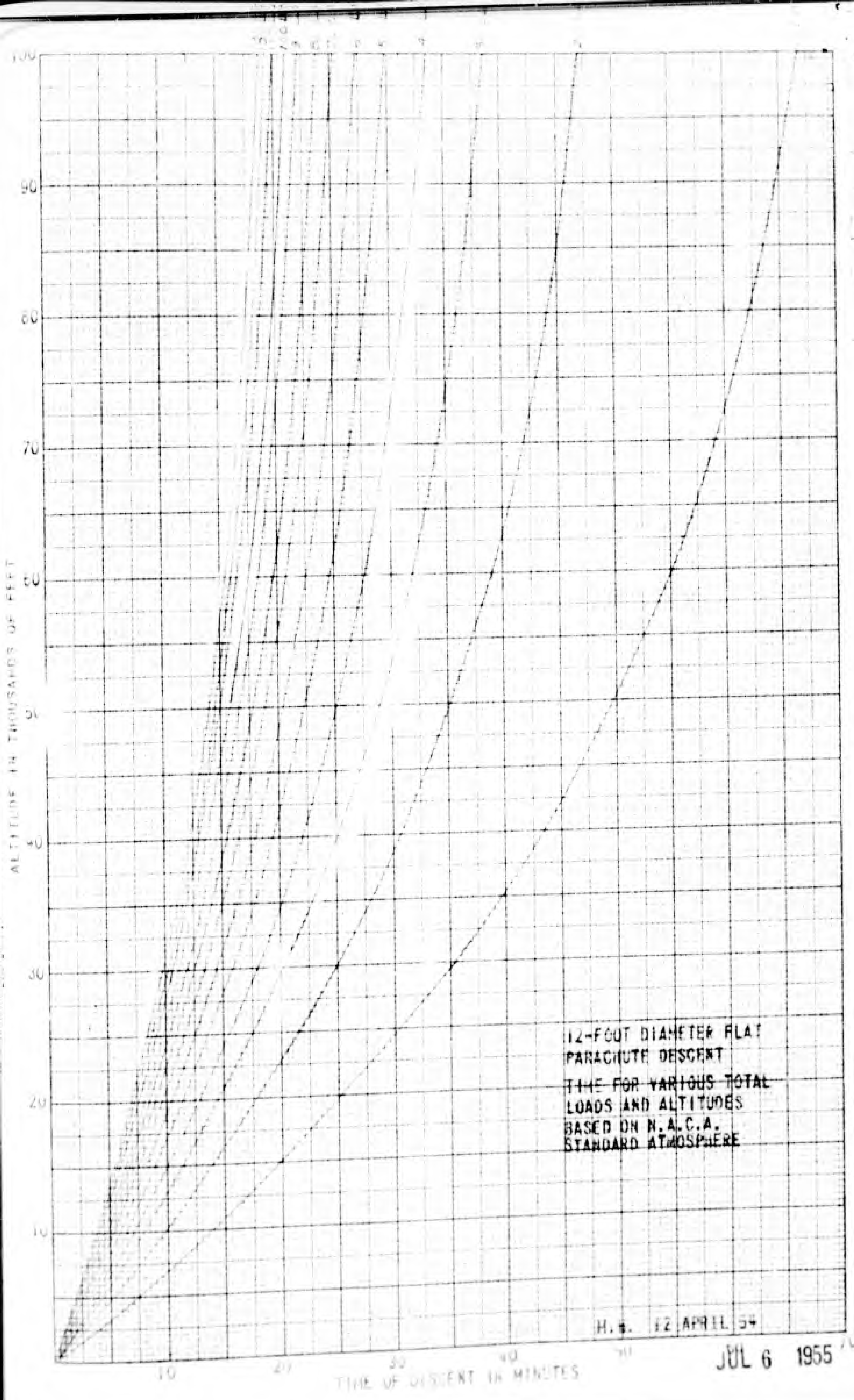
$$= 8.5 \times 10^{-3} \times 4.56 \times 10^6$$

$$= \underline{3.88 \times 10^4} \quad \text{joules}$$

or

$$W = .7376 \times 3.88 \times 10^4 = \underline{2.86 \times 10^4} \text{ ft lb}$$

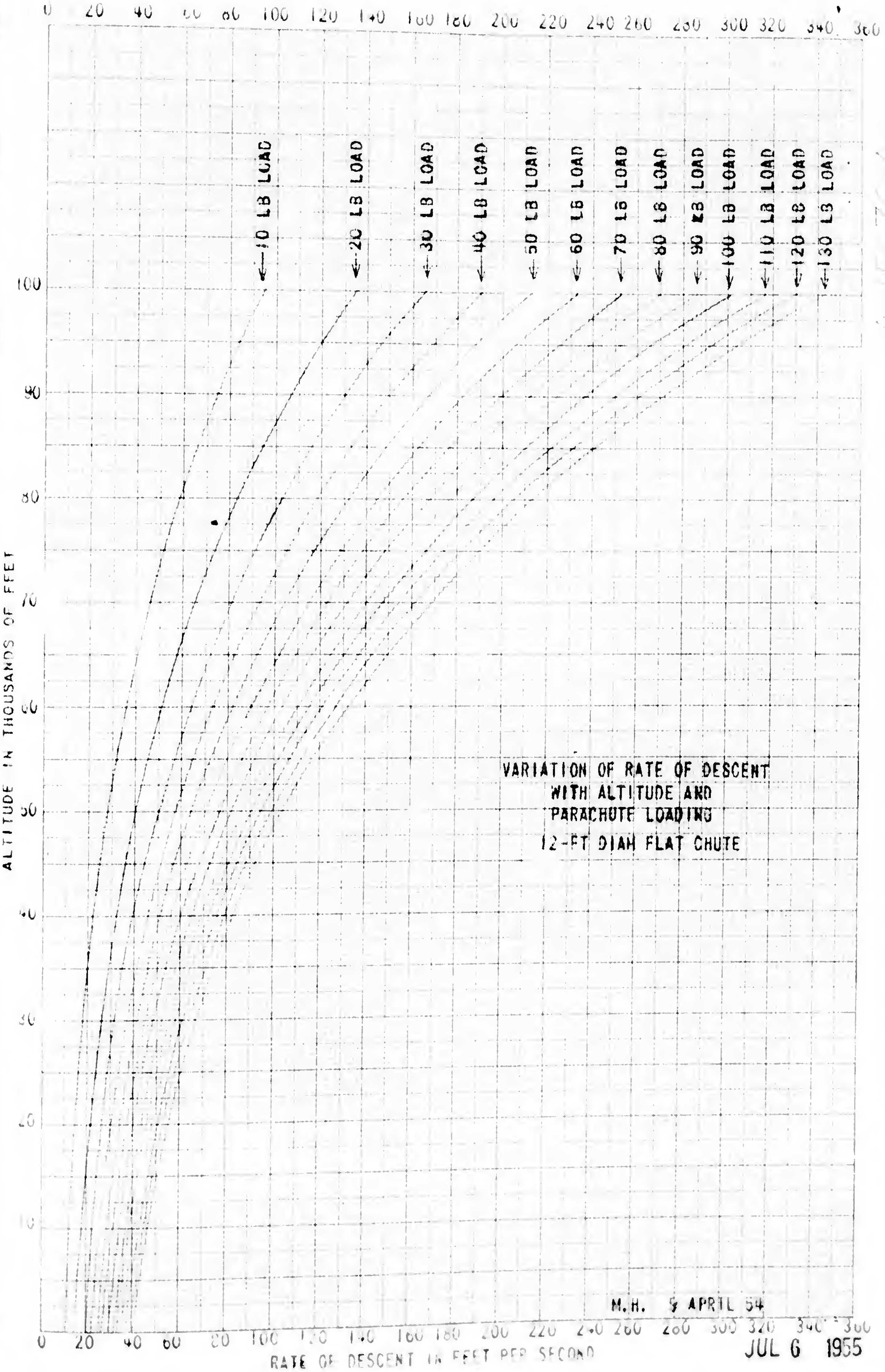
APPENDIX H



12-FOOT DIAMETER FLAT
PARACHUTE DESCENT

TIME FOR VARIOUS TOTAL
LOADS AND ALTITUDES
BASED ON N.A.C.A.
STANDARD ATMOSPHERE

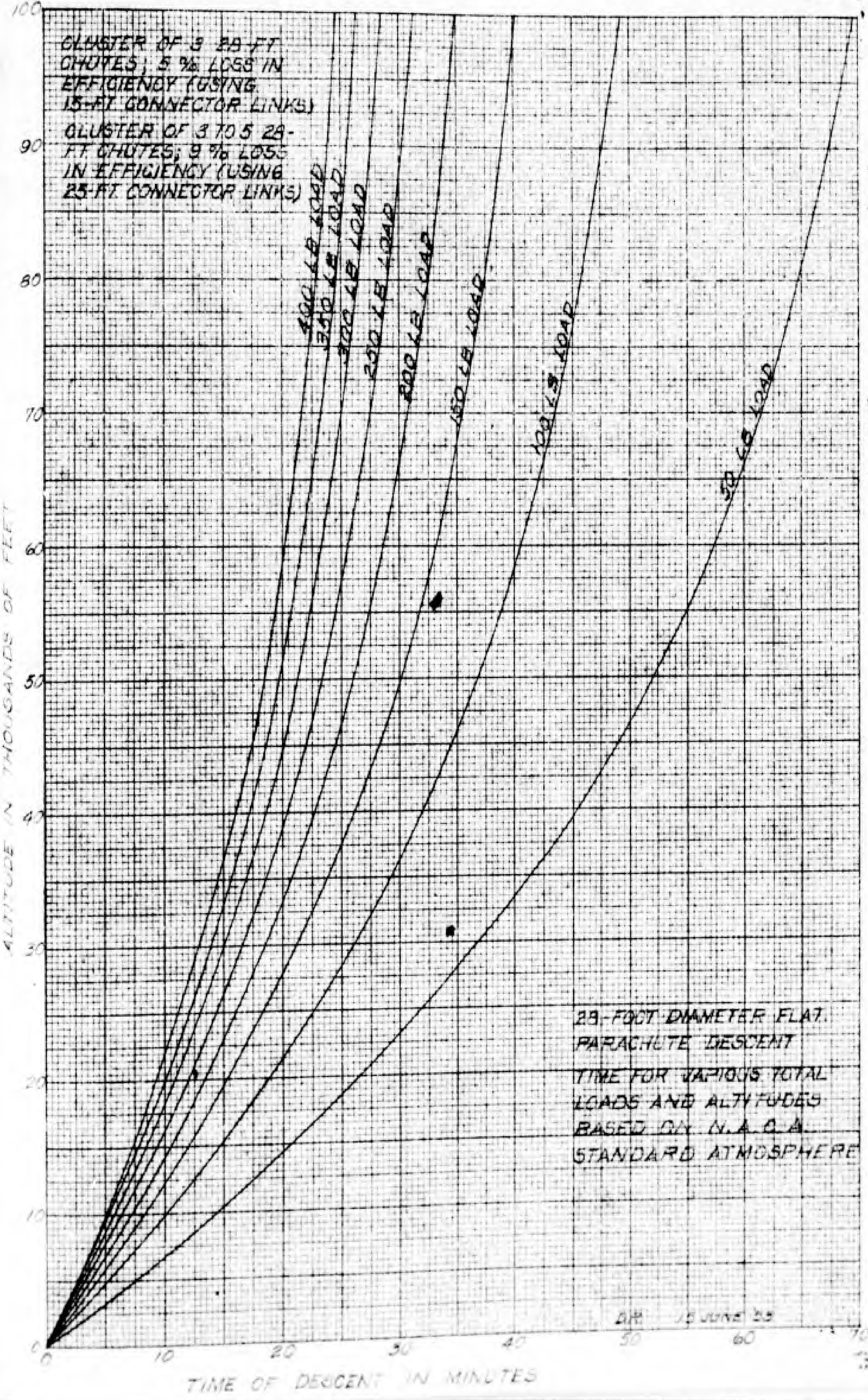
H.W. 12 APRIL 54



VARIATION OF RATE OF DESCENT
WITH ALTITUDE AND
PARACHUTE LOADING
12-FT DIAM FLAT CHUTE

M.H. 9 APRIL 54

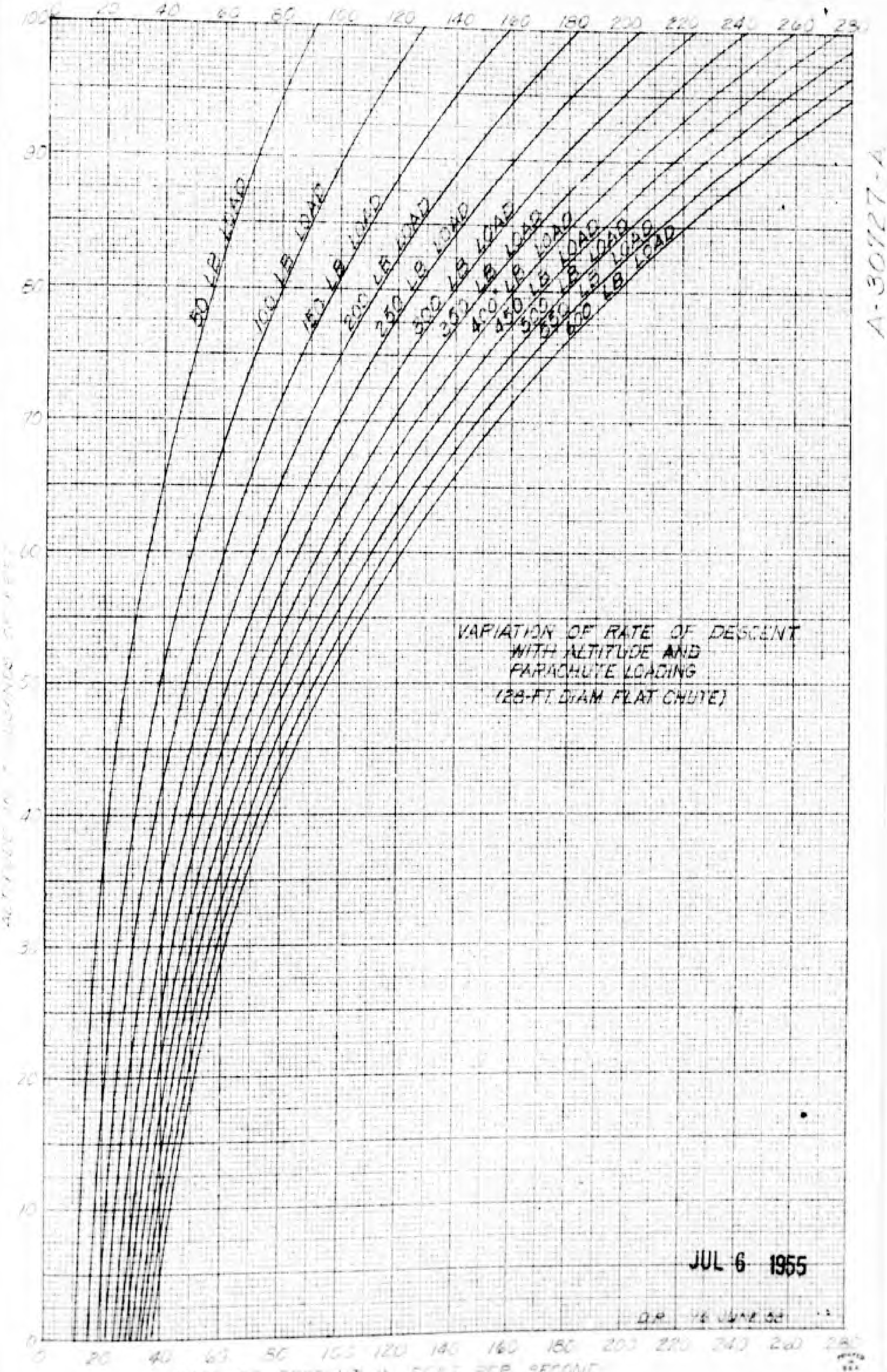
JUL 6 1955



28-FOOT DIAMETER FLAT PARACHUTE DESCENT TIME FOR VARIOUS TOTAL LOADS AND ALTITUDES BASED ON N.A.C.A. STANDARD ATMOSPHERE

A-30726-A

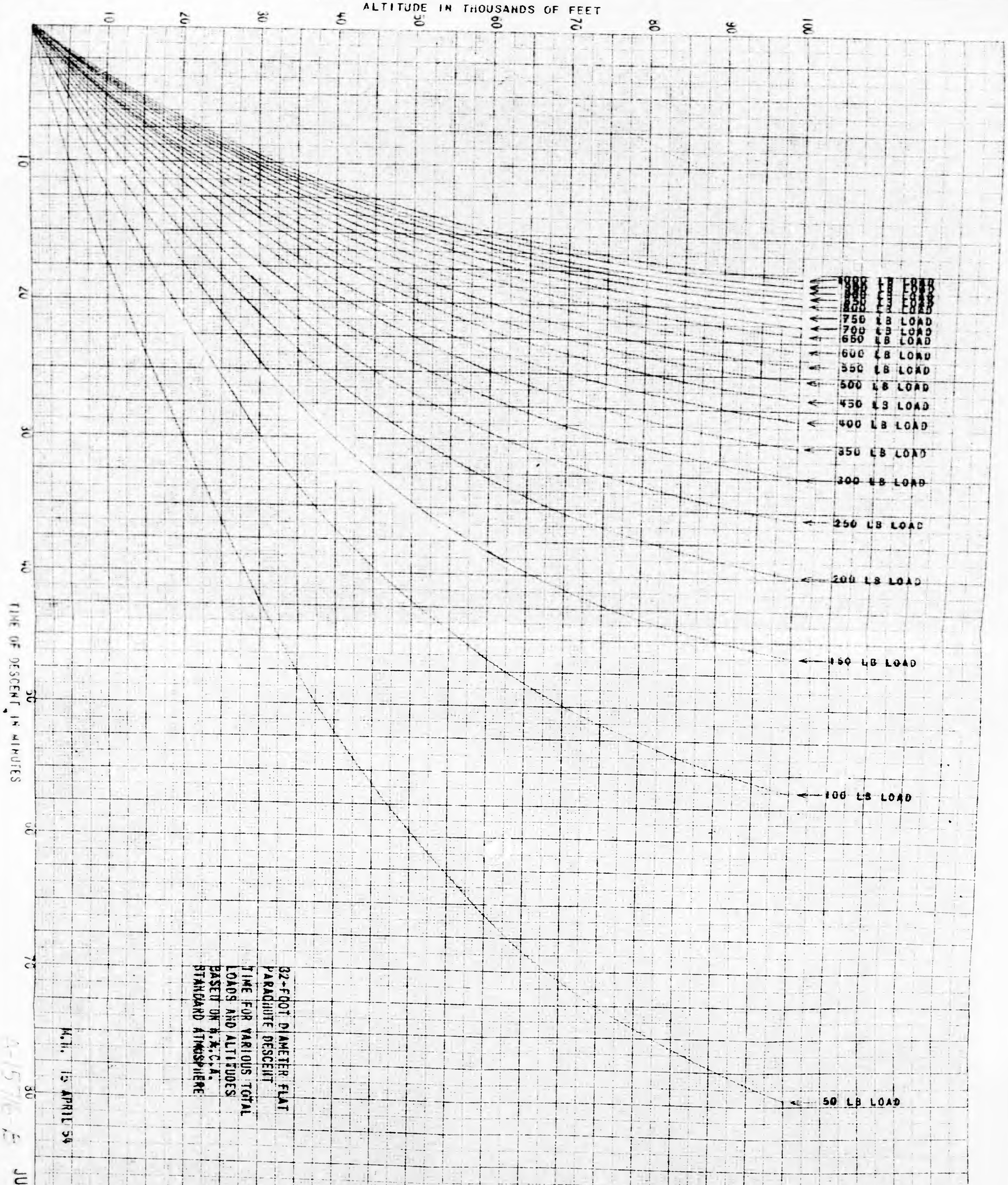
JUL 6 1955



VARIATION OF RATE OF DESCENT
WITH ALTITUDE AND
PARACHUTE LOADING
(28-FT DIAM FLAT CHUTE)

A-30727-A

JUL 6 1955

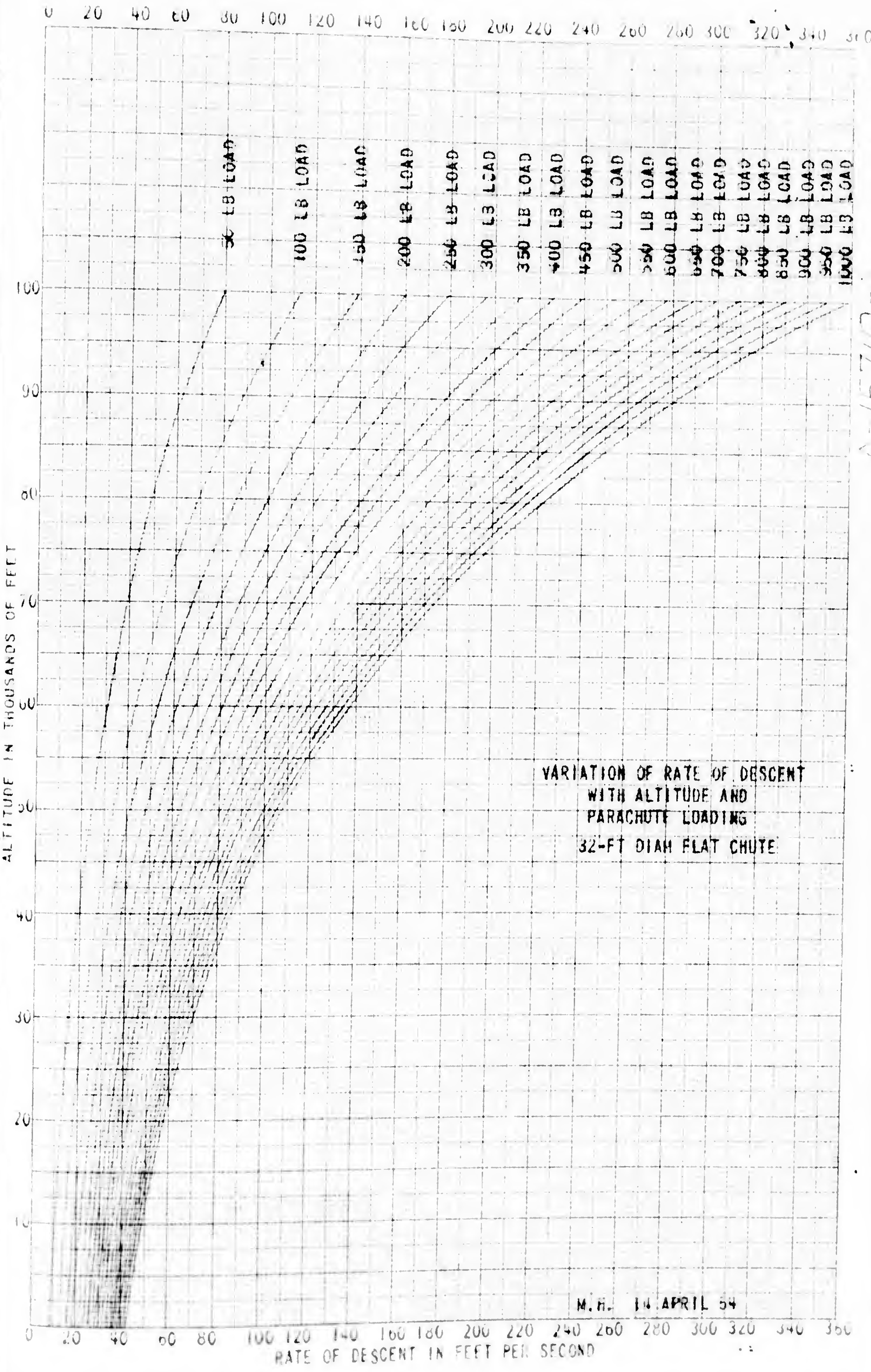


32-FOOT DIAMETER FLAT
PARACHUTE DESCENT
TIME FOR VARIOUS TOTAL
LOADS AND ALTITUDES
BASED ON N.A.C.A.
STANDARD ATMOSPHERE

M.H. 15 APRIL 54

A-15 No-5

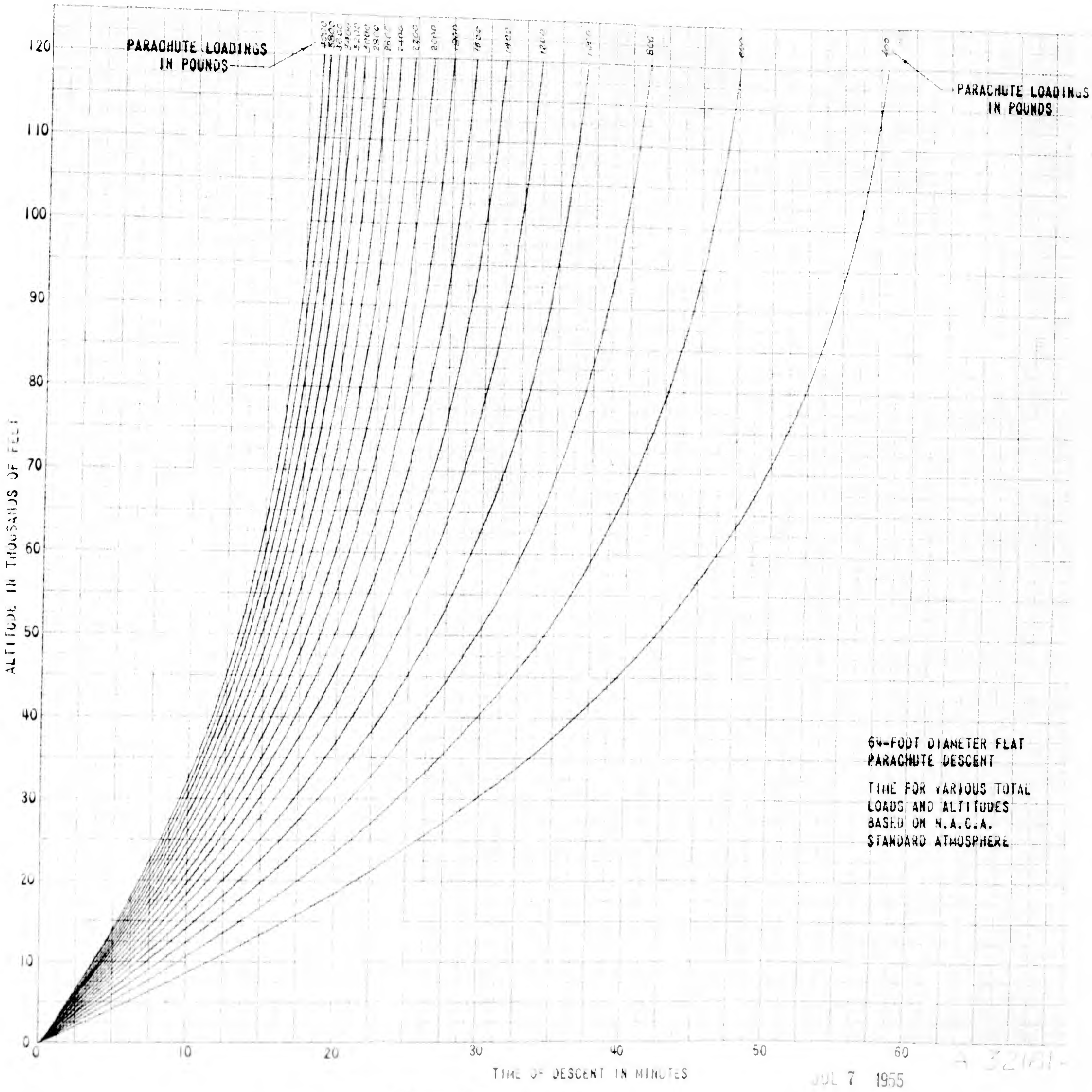
JUL 7 1955



VARIATION OF RATE OF DESCENT
WITH ALTITUDE AND
PARACHUTE LOADING
32-FT DIAM FLAT CHUTE

M.H. 14 APRIL 54

A-15710

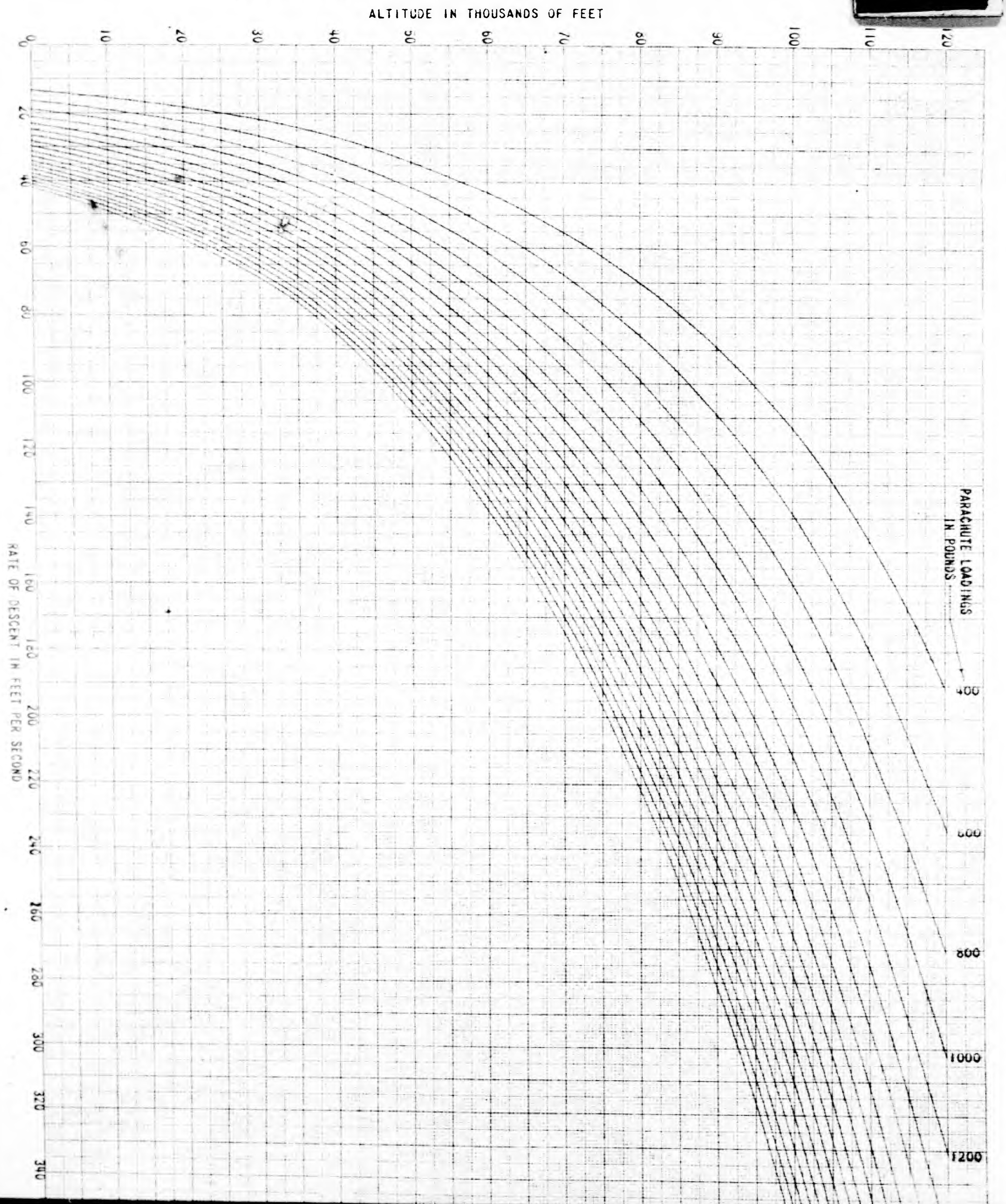


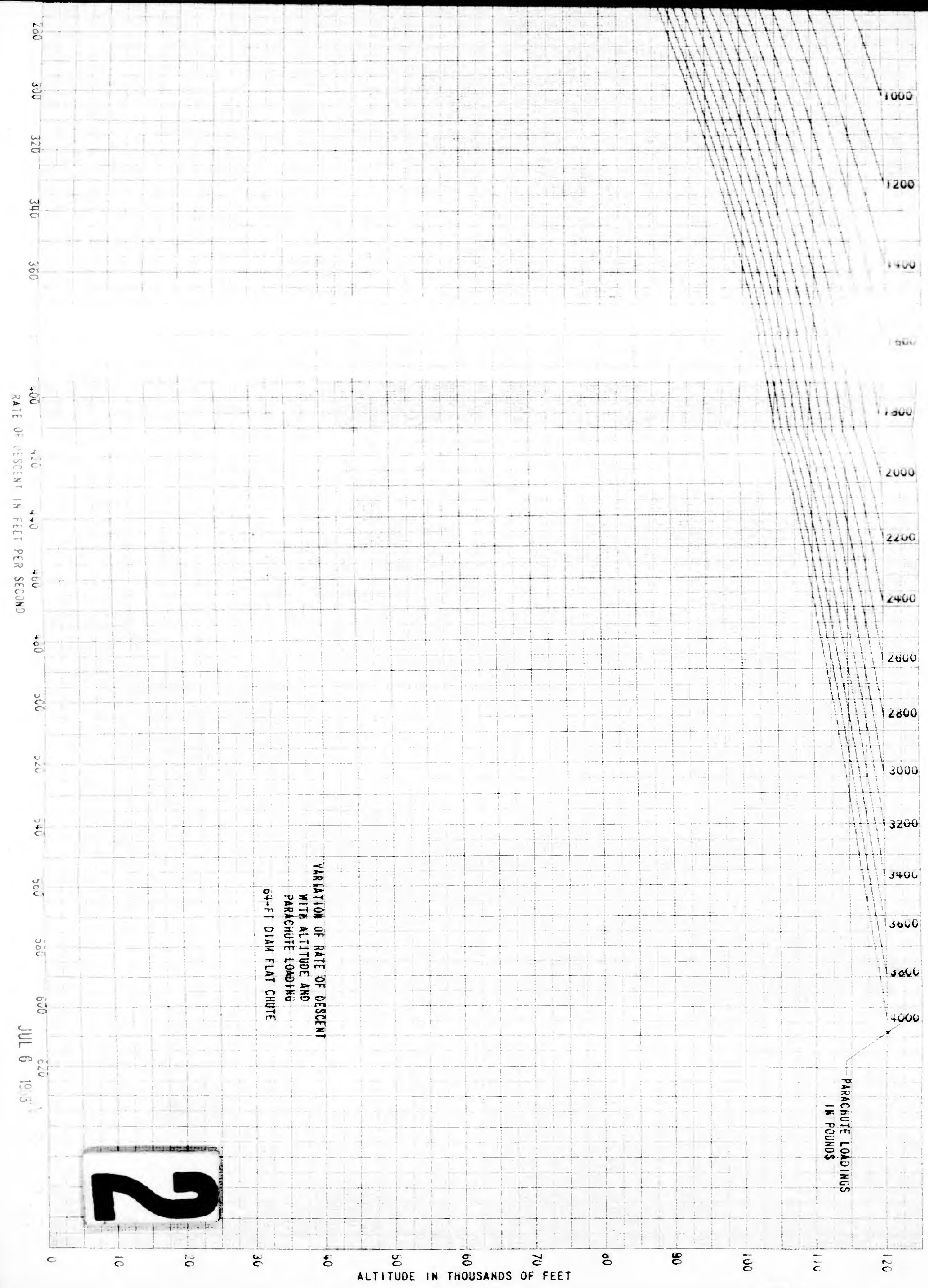
64-FOOT DIAMETER FLAT
PARACHUTE DESCENT

TIME FOR VARIOUS TOTAL
LOADS AND ALTITUDES
BASED ON N.A.C.A.
STANDARD ATMOSPHERE

JUL 7 1955

A 32181


ALTITUDE IN THOUSANDS OF FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
RATE OF DESCENT IN FEET PER SECOND
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
PARACHUTE LOADINGS IN POUNDS
400
600
800
1000
1200



VARIATION OF RATE OF DESCENT WITH ALTITUDE AND PARACHUTE LOADING 64-FT DIAM FLAT CHUTE

APPENDIX I

TABLE I-1

Strength and Weight Specifications* for Small Flexible Corrosion-Resistant Steel Cable

Diameter, In.	Type	Minimum Breaking Strength, lbs	Approximate Weight, lb/100 ft
1/32	3 x 7	110	0.16
1/16	7 x 7	480	0.75
3/32	7 x 7	920	1.60
1/8	7 x 19	1760	2.90
5/32	7 x 19	2400	4.50
3/16	7 x 19	3700	6.50

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*MIL-C-5424(1), 18 Feb., 1949, "Cable; Steel (Corrosion-Resisting) Flexible, Preformed (For Aeronautical Use)

TABLE I-2

Strength and Weight Specifications* for Nylon Cord

Type	Minimum Breaking Strength, lbs	Minimum Elongation, Per Cent	Yards per Pound of Cord	Weight, lb/ft
I (MIL-C-5040)	100	30	350	0.000952
II "	375	30	105	0.00317
III "	550	30	75	0.00444
I (MIL-C-7515)	400	20	110	0.00303
II "	550	20	85	0.00392
III "	750	20	50	0.00667
IV "	1000	20	40	0.00833
V "	1500	20	25	0.0133
VI "	2000	20	20	0.0167
VII "	2400	20	15	0.0222
VIII "	3000	20	12	0.0278
IX "	4000	20	9	0.0371
X "	5000	20	7.5	0.0444

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* MIL-C-5040A (ASG), 15 July 1953, "Cord, Nylon" and
MIL-C-7515 (USAF), 27 June 1952, "Cord, Nylon, Coreless"