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HOT AIR BALLOON PROGRAM

PROGRESS REPORT

CONTRACT NO, NONR 1589 (05) - TASK "B"

GENERAL MILLS, INC.
MECHANICAL DIVISION

Engineering Research and Development Department
MINNEAPOLIS, MINNESOTA

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ORIG COMP 701 OPI 56 TYPE 30
ORIG CLASS 5 PAGES 64 REV CLASS ___
JUST ___ NEXT REV ___ AUTH: HR 10-2

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HOT AIR BALLOON PROGRAM

Progress Report

Prepared by

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Contract Nonr 1589(05) - Task "B"

Submitted to

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25X1

Report No. 1647
Date: January 4, 1957
Project: 55028-112

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I. INTRODUCTION

Research and development work on hot air balloons is being carried out by General Mills, Inc. under contract with the Office of Naval Research as one phase of the program covering Low Altitude Controlled Flights.

The use of hot air as a lifting gas appears desirable for some low altitude balloon applications due to the low weight and volume of the ground inflation equipment utilized. The inflation of balloons with hydrogen or helium requires a supply of gas from high pressure cylinders or a field gas generator, which are of considerable size and weight. In some cases, the application of balloons to military tasks is limited by the requirement for inflation gas and the associated shipping and handling problems. For example, the inflation of a balloon with helium for a gross lift of 350 lb requires approximately 3,500 lb of steel gas cylinders. In comparison, results of work on the present project indicate that the above load could be lifted to 5,000 ft and sustained for two hours with a total equipment weight of only 150 lb. This weight includes the fuel, tank, burner, inflation fan and controls. Longer durations could be attained by carrying more fuel and might also result from future improvements in hot air balloon design.

Although the use of hot air balloons has been considered largely for manned flight applications, non-manned, fully-automatic balloon systems may find considerable application. The use of this vehicle in short-range delivery systems could prove advantageous over systems that have been conceived in the past.

The following sections of this report cover, in detail, the research and development work which has been accomplished.

II. LIFT OF HOT AIR BALLOONS

The lift obtained in a hot air balloon is a result of the decreased density inside the envelope caused by elevated temperature. This lift is calculable by the equations:

$$\text{Lift} = V\,(\rho_a - \rho_b) \tag{2.1}$$

$$\rho_a = \frac{P_a\,M_a}{R\,T_a} \tag{2.2}$$

$$\rho_b = \frac{P_b\,M_b}{R\,T_b} \tag{2.3}$$

Where V is the balloon volume, ft^3

ρ_a is the density of ambient air, lb/ft^3

ρ_b is the density of air inside the balloon

P_a is the ambient pressure, lb/ft^2

M_a is the molecular weight of the ambient air

T_a is the temperature of the ambient air, degrees Rankine

R is the universal gas constant, 1544 ft/^oR

P_b is the pressure inside the balloon, lb/ft^2

M_b is the average molecular weight inside the balloon

T_b is the average temperature inside the balloon, ^oR.

Since the differential pressure from the inside to the outside of a balloon is extremely small compared with the absolute pressure, it is valid to let $P_a = P_b$. It has been demonstrated (see Section III) that the average molecular weight of the products of combustion is very nearly that of pure air, thereby allowing the simplification of letting $M_a = M_b$.

The lift equation then becomes:

$$\text{Lift} = \frac{V\, P_a\, M_a}{R} \left[\frac{1}{T_a} - \frac{1}{T_b}\right] \tag{2.4}$$

The unit lift of hot air (in lb/ft^3) has been calculated from Equation 2.4 and is illustrated as a function of T_a and T_b in Figure 2.1 for the sea level case. A correction factor for altitude variation is given in Figure 2.2.

An illustrative case has been taken from the above analysis, for which the operating temperatures required in three different balloons of different diameters have been plotted against gross lift at 10,000 ft MSL in the standard atmosphere. This information is shown in Figure 2.3.

Experimental measurements of lift obtained have been made during this project and satisfactorily confirm the information of Figures 2.1, 2.2 and 2.3. This work is described in Section IV.

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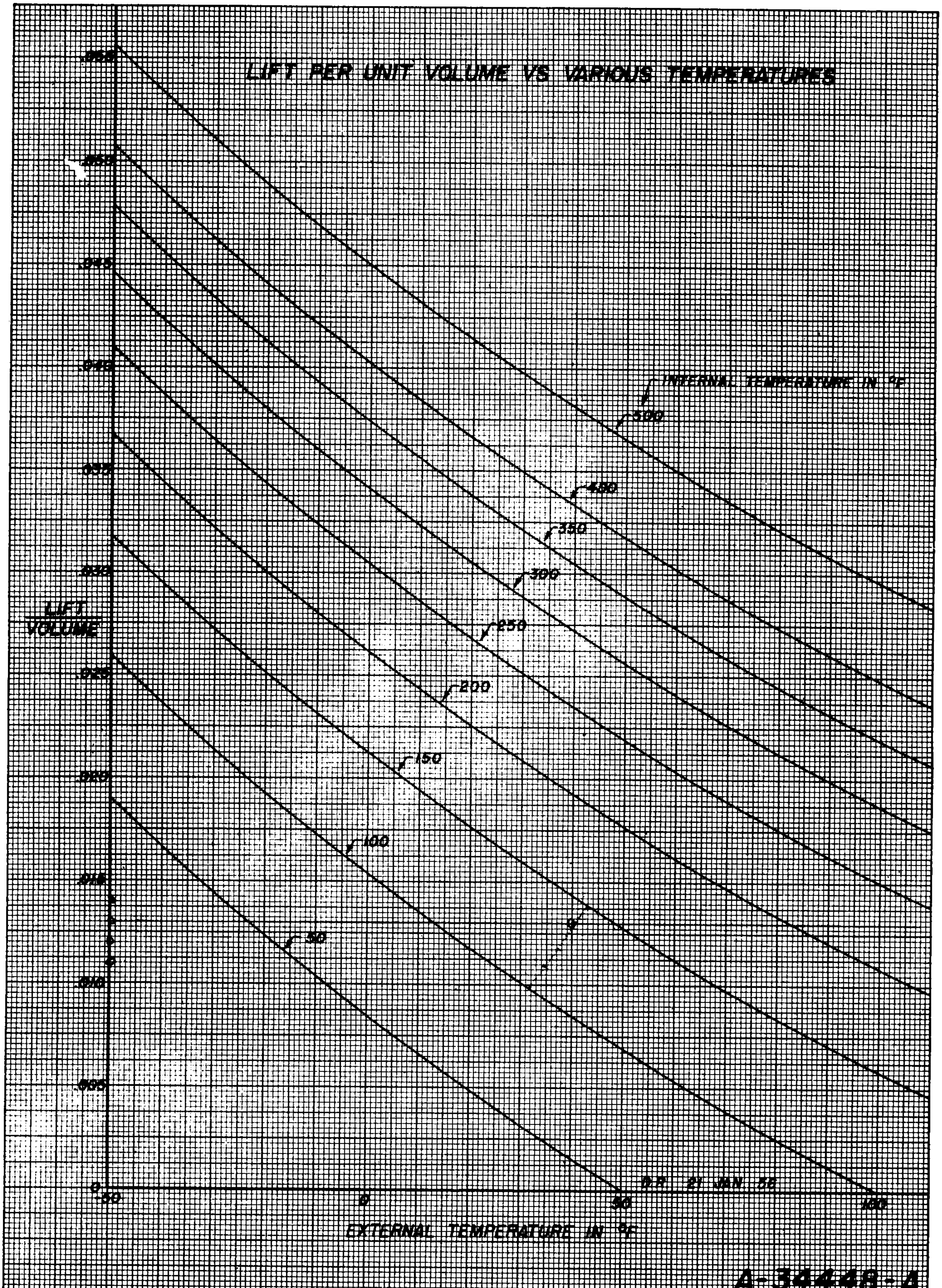

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Figure 2.1

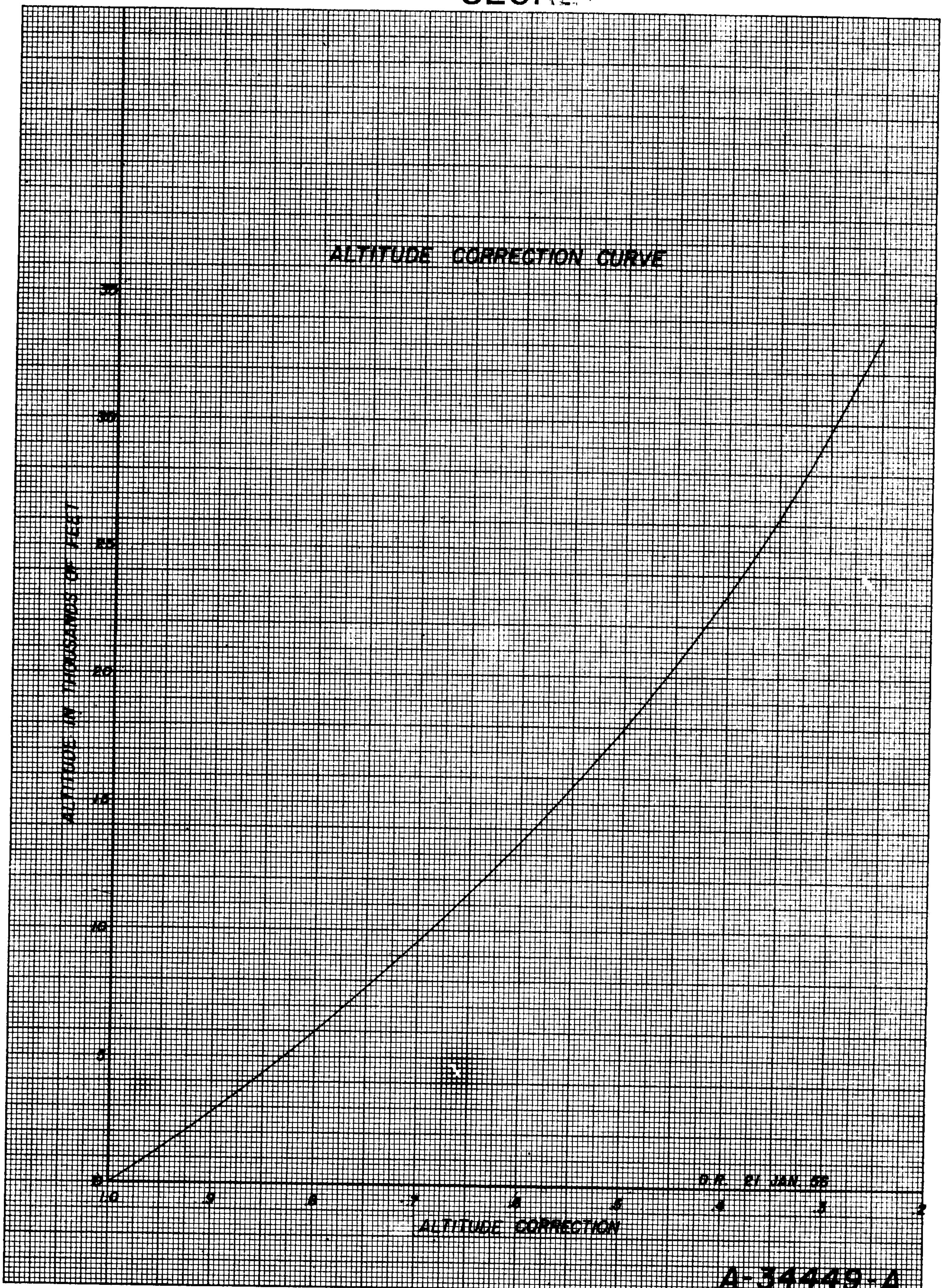

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Figure 2.2

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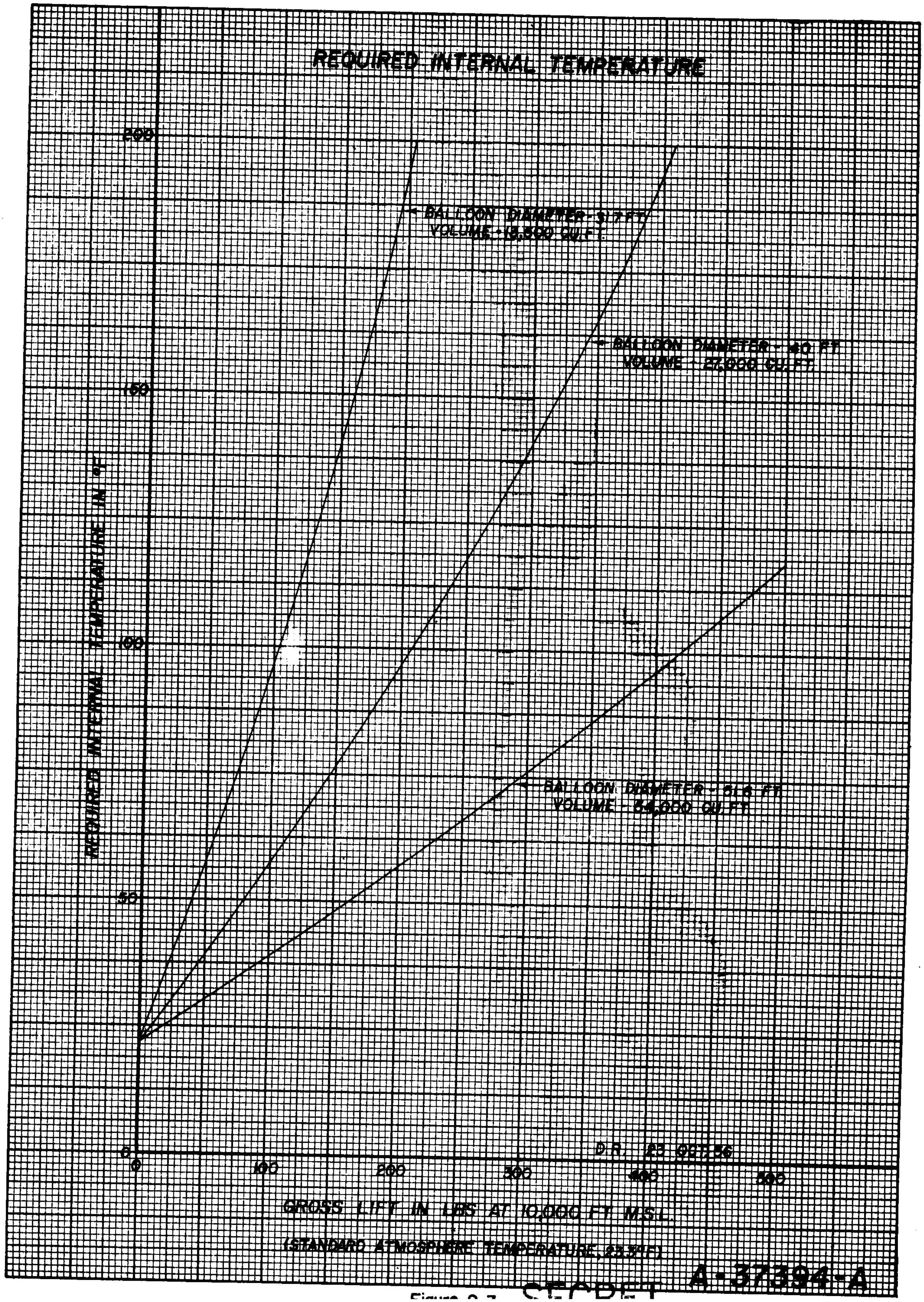

Figure 2-7

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III. FUELS AND COMBUSTION

A. Fuel Studies

Maintenance of the required internal temperature in a hot air balloon requires a continuous input of heat. The combustion of hydrocarbon fuels with atmospheric air appears to be the most satisfactory method of supplying this heat. Since the fuel must be carried on the balloon, thus reducing the payload capability, the weight of fuel required is an important consideration.

Table 3.1 lists four hydrocarbon fuels which cover the volatility range considered applicable to a hot air balloon system. No. 1 fuel oil, which is slightly less volatile than kerosene, has been taken as the lower limit for volatility. The use of No. 2 or heavier grades would only increase the complexity of the combustion equipment and also reduce reliability. Propane has been taken as the most volatile hydrocarbon fuel which would be practical to contain as a liquid in storage tanks. It has a vapor pressure of 286 psi at 130°F. The saturated hydrocarbon of next higher volatility, ethane (C_2H_6), has a critical temperature of 90°F and cannot be stored as a liquid at normal summer temperatures.

It is seen from Table 3.1 that these hydrocarbon fuels are quite similar in heating value. Heating value increases with hydrogen content, but the differences are not large. All of the fuels of Table 3.1 are considered applicable to a hot air balloon system. The high volatility of propane, which allows it to be vaporized at low temperatures in the storage tank, makes it the most desirable fuel from the standpoint of burner design. The boiling point of propane at atmospheric pressure is -31°F and that of Butane is +15°F. Gasoline and No. 1 fuel oil vaporize at higher temperatures and are not readily adaptable to systems where the fuel is vaporized in the storage tank.

Propane requires a heat input for vaporization of slightly less than one per cent of its heating value. In some cases, this heat is obtained by natural heat transfer through the walls of the tank from the atmosphere. If the demand for vaporized fuel is high and the surface area is small, additional heat must be added to vaporize the liquid. In the propane burner described in Section VII, a small burner provides heat for this purpose.

Storage tanks for these fuels are discussed in Section V. Figure 5.3 illustrates the weight of the tank and fuel required for various quantities of energy storage.

TABLE 3.1

HYDROCARBON FUELS

Fuel	Per Cent H_2	Higher Heating Value	Formula
Propane	18.2	21,560 BTU/lb	C_3H_8
Butane	17.25	21,180	C_4H_{10}
Gasoline	15.8	20,500	C_8H_{18}
No. 1 Fuel Oil	14.0	19,750	---

B. Molecular Weight and Dew Point of Products

Consideration has been given to selection of the most advantageous method of transferring the heat to the air inside the balloon. The two alternatives are (1) allowing the products of combustion to enter the balloon directly, or, (2) making use of a heat exchanger which transfers heat from the products to the air in the balloon, thereby allowing discharge of the products directly overboard. Further examination shows that the first of these alternatives is the most simple and results in the lowest equipment weight without any penalty in lifting capability. Calculations have been made of the average molecular weight of the products of combustion of hydrocarbon fuels with various amounts of air. These point out that, if the steam formed by combustion of the hydrogen is retained in the superheated state, the total mixture of air, nitrogen, carbon dioxide and steam is slightly buoyant with respect to air at the same temperature. The average molecular weights resulting from these calculations are shown in Figure 3.1.

A sample calculation illustrating the basis of Figure 3.1 is given below:

The products[1] formed by the combustion of one pound of propane with 100 per cent excess air are:

Item		Weight (lb)
CO_2		3.00
H_2O		1.64
N_2		12.02
Air		15.65
	Total	32.31

The volumes occupied by each item at the arbitrary standard sea level condition, with a temperature of 59°F and a pressure of 2116 psf, are determined from the perfect gas law:

$$V = \frac{W(1544)T}{M\,P} = \frac{W}{M}\,\frac{(1544)(519)}{2116} = 379\,\frac{W}{M} \qquad (3.1)$$

These volumes are:

$$\text{for } CO_2,\ V = \frac{379(3.00)}{44} = 25.8\ ft^3$$

$$\text{for } H_2O,\ V = \frac{379(1.64)}{18} = 134.5 \text{ ft}^3$$

$$\text{for } N_2,\ V = \frac{379 \times 12.02}{28} = 162.5 \text{ ft}^3$$

$$\text{for Air},\ V = \frac{379 \times 15.65}{28.97} = 204.5 \text{ ft}^3$$

$$\text{Total Volume} = 427.3 \text{ ft}^3$$

$$\text{Average Molecular Weight} = \frac{379W}{V} = \frac{379(32.31)}{427.3} = 28.66$$

This value, which is lower than the molecular weight of air (28.97), is valid only if the water vapor remains in the superheated form. The dew point of the combustion products may be determined by a method similar to that above, in which the water vapor specific volume is calculated, thereby fixing the saturation temperature. For the case illustrated above, the water vapor specific volume is 260 ft^3/lb and the dew point is 111°F. Dew point values for these fuels at different air mixtures are given in Figure 3.2. Dew point values in Figure 3.2 fall below 100°F at 200 per cent excess air. Calculations of balloon wall temperature in Section IV indicate that it will be practical to maintain wall temperatures above 100°F, thus assuring freedom from condensation inside the balloon.

C. Combustion Efficiency

Fuel supplied to the burner must release heat which will pass through the balloon walls at a rate adequate to maintain the required temperature within the balloon. There are two possibilities for inefficiency in this process:

1. Incomplete combustion - If all of the hydrogen is not burned to water and all the carbon is not burned to CO_2, a loss of energy is involved.

MOLECULAR WEIGHT OF COMBUSTION PRODUCTS

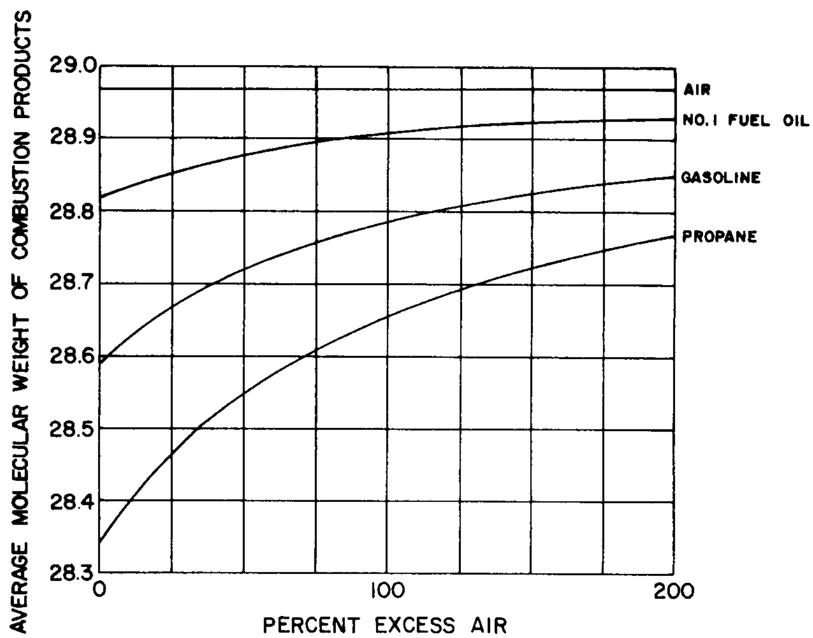


Figure 3.1

DEW POINT OF COMBUSTION PRODUCTS

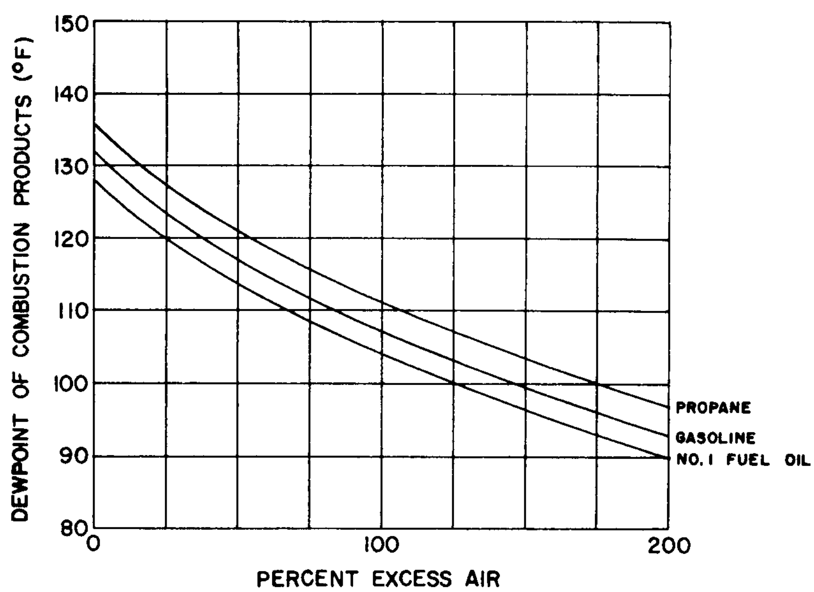


Figure 3.2

2. Ventilation loss - If some of the heat released by the fuel is not transferred through the balloon film but leaves in a stream of hot gases passing through a ventilation port, a loss of energy is involved.

1. Incomplete Combustion

The hydrocarbon fuels considered in this work are propane, butane, gasoline and No. 1 fuel oil. These fuels have all been used in industrial equipment and burners have been developed in which complete combustion is assured. Incomplete combustion results in production of carbon monoxide. This situation cannot be tolerated in, for example, domestic heating equipment. Precautions are therefore taken in the design of these burners to eliminate the possibility of creating carbon monoxide. The primary consideration is to provide adequate excess air for combustion. The amount required depends upon burner design and fuel properties. Gaseous fuels, such as propane and butane, require less excess air than liquid fuels because they are more easily mixed with air. Burners for gaseous fuels can operate without danger of incomplete combustion with excess air quantities below 100 per cent, and those for the liquid fuels can reliably produce complete combustion with less than 150 per cent excess air. Satisfactory burners for the gaseous fuels are more simple than those for liquid fuels because the fuel atomization requirement is not present.

It is concluded from the above considerations that a burner for application to a hot air balloon must be designed to produce complete combustion. Operation in the zone of incomplete combustion would introduce additional practical problems of luminous flames in gaseous burners and smoke production with liquid fuels.

2. Ventilation Loss

Continuous efficient operation of a burner requires that new air be supplied and combustion products removed at an equal rate. The flow of combustion products from a balloon at elevated temperature represents an inefficiency in the system. The amount of loss may be determined by the equation[2] below:

$$V = W_g C_p \Delta T + 9 W_h (1089 + 0.455 \Delta T) \tag{3.2}$$

where

V is the ventilation loss Btu/hr

W_g is the mass flow of combustion products, lb/hr

C_p is the specific heat of the products Btu/lb-°F

ΔT is the temperature difference from the inside to outside of the balloon

W_h is the weight fraction of hydrogen in the fuel, lb/lb.

The quantity of heat leaving the system through the balloon wall is:

$$Q = U A \Delta T \tag{3.3}$$

where

Q is the heat flow, Btu/hr

U is the over-all coefficient of heat transfer, Btu/hr-ft^2-°F

A is the balloon surface area, ft^2

ΔT is the temperature difference from the inside to outside of the balloon.

The quantity of heat released by the fuel is:

$$H = W_f \Delta H_f \tag{3.4}$$

where

H is the heat release, Btu/hr

W_f is the mass flow rate of fuel, lb/hr

ΔH_f is the higher heating value of the fuel, Btu/lb.

The energy balance for the system, with nomenclature as defined above, is the following:

$$H = Q + V \tag{3.5}$$

The combustion efficiency, based on zero carbon monoxide, is:

$$\eta c = \frac{Q}{H} = \frac{H - V}{H} \tag{3.6}$$

In order to evaluate the items of Equations 3.2 through 3.6, determination must be made of W_g, the mass flow rate of the combustion products. In experimental work this is most conveniently accomplished by volumetric analyses of the products of combustion with an Orsat Analyzer. The measurement of CO_2, O_2 and CO defines[1,b] W_g/W_f for a given fuel of known composition:

$$\frac{W_g}{W_f} = \frac{11\ CO_2 + 8\ O_2 + 7\ (CO + N_2)}{3\ (CO_2 + CO)} \tag{3.7}$$

where CO_2, O_2, CO and N_2 designations are whole number percentages of constituents from an Orsat analysis.

The excess air may be calculated from the composition of the combustion products and that of the fuel by Equation 3.8:

$$\text{Per cent excess air} = \frac{0.21\left[\frac{w_c}{CO_2} + 3\ (w_h - 0.125\ w_o)\right]}{\left[w_c + 3\ (w_h - 0.125\ w_o)\right]} \tag{3.8}$$

where

w_c is the weight fraction of carbon in the fuel, lb/lb

w_h is the weight fraction of hydrogen in the fuel, lb/lb

W_O is the weight location of oxygen in the fuel, lb/lb

CO_2 is the whole number percentage of volume from the Orsat.

Orsat readings which correspond to excess air quantities from zero to 200 per cent are given in Figure 3.3 for propane, gasoline and No. 1 fuel oil. Combustion efficiencies, based on zero carbon monoxide, are shown as a function of excess air and temperature differential in Figure 3.4. These graphs allow convenient evaluation of performance from the Orsat analysis.

It is seen from Figure 3.4 that combustion efficiency is relatively high for all excess air values below 200 per cent. Therefore it appears that it will be advantageous to operate with approximately 200 per cent excess air to insure complete combustion and to reduce the dew point, since the penalty is not severe.

EXCESS AIR VS CO_2 CONCENTRATION

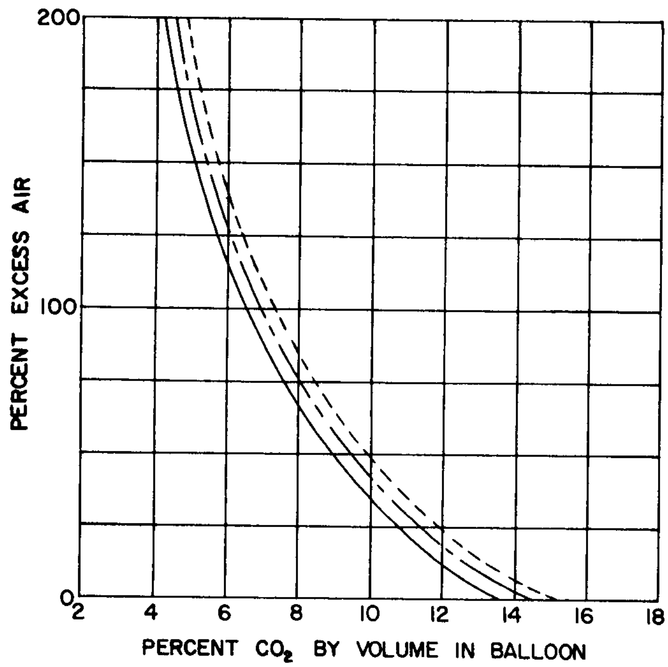


Figure 3.3

VENTILATION HEAT LOSSES

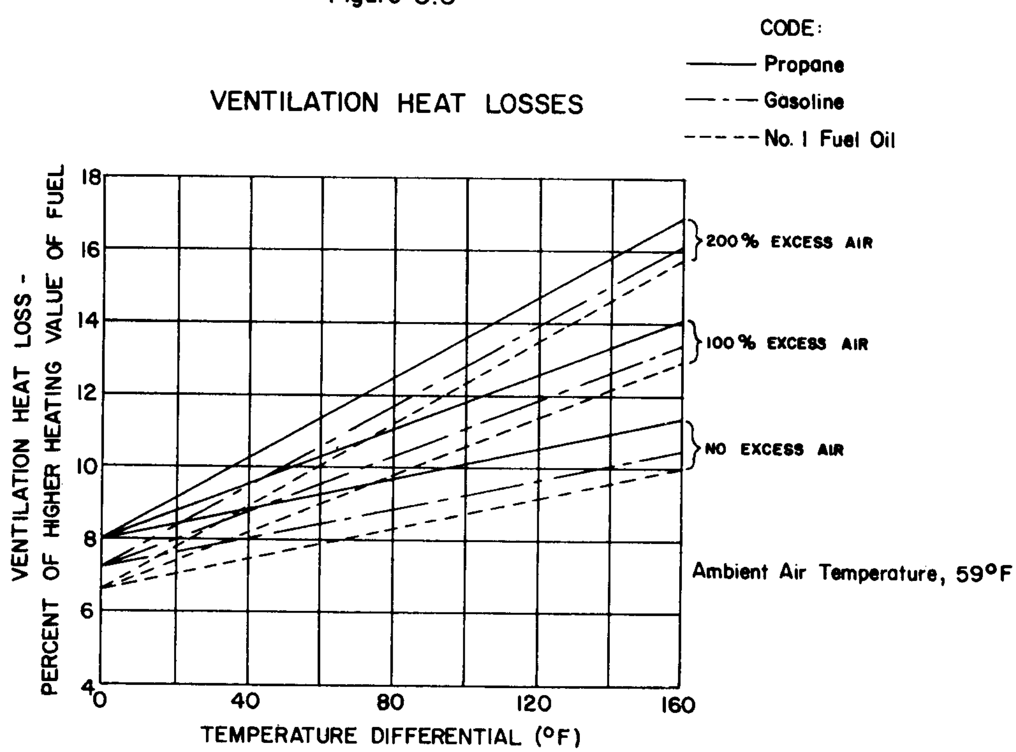


Figure 3.4

IV. HEAT LOSS

A. Analysis

The total heat loss from a hot air balloon is the sum of the heat flowing through the balloon film plus that leaving the balloon by ventilation. The ventilation losses are relatively small (less than 20 per cent of the fuel input) and are readily determined by the method presented in Section III. The heat loss through the balloon film is of major significance.

Heat is transferred from the warm gases inside the balloon to the balloon wall by a combination of the three heat transfer modes: radiation, convection and conduction. It passes through the balloon material by conduction and is again transferred to the surrounding air by a combination of all three modes.

This situation is similar to the case of heat transfer between any two gases separated by a thin membrane. It has been useful, in similar problems, to define an over-all coefficient of heat transfer, U, having the engineering units of Btu/hr-ft^2-$^\circ$F, since the heat flow in this type of problem has been found to be linear with temperature differential:

$$U = \frac{Q}{A \Delta T} \tag{4.1}$$

where

Q is the total heat flow, Btu/hr

A is the total area of the film, ft^2

ΔT is the temperature differential between the two gases, $^\circ$F.

Another concept that has been applied to this problem is that of total thermal resistance, R_T, which is the reciprocal of U. The total thermal resistance in this case is considered to consist of that of a film of air on each side of the membrane plus the membrane itself. In equation form:

$$U = \frac{1}{R_T} = \frac{1}{\frac{1}{f_a} + \frac{X}{K} + \frac{1}{f_b}} \tag{4.2}$$

where

f_a is the conductance of the first "film", Btu/hr-ft^2-^{o}F

f_b is the conductance of the second "film", Btu/hr-ft^2-^{o}F

X is the thickness of the membrane, ft

K' is the thermal conductivity of the membrane material, Btu-ft/hr-ft^2-^{o}F

For thin membranes the $\frac{X}{K}$ term drops out. This is the case with balloon materials in the range of 1 to 10 mils thick. The computed value of the conductance for a 2-mil polyethylene film is 1,160 Btu/hr-ft^2-^{o}F, demonstrating a negligible thermal resistance.

An important conclusion at this point is that the heat loss from a single-membrane balloon is independent of the material. This fact has been confirmed experimentally in that the heat loss from 7-ft diameter polyethylene and Mylar balloons was found to be the same.

The heat transfer across the air "film" on each side of the membrane is therefore the major consideration. Actual values of f_a or f_b are known to be strongly dependent upon air velocity and surface emissivity and to a lesser degree upon air density and temperature difference. The effects of the more important variables, air velocity and surface emissivity, have been determined through work in connection with the heating of buildings. For non-metallic materials, the infrared emissivity is approximately 0.90. The film coefficients f_a and f_b have a value[2b] of 1.65 Btu/hr-ft^2-^{o}F in this case.

For a relative air motion of 5 mph, f_a increases to 3.0 Btu/hr-ft^2-°F for normal temperature ranges. The corresponding values for a single-wall balloon are 0.82 and 1.06 Btu/hr-ft^2-°F. From this same work, the conductance of a stagnant air space (between two membranes) is 1.18 Btu/hr-ft^2-°F, near room temperature.

The foregoing statements indicate a possible advantage in fabricating a balloon out of several layers of material, thereby creating air spaces of significant thermal resistance. With a two-layer balloon having one air space, the U value for zero wind is 0.485 Btu/hr-ft^2-°F, and, with a 5-mph relative wind, U equals 0.56 Btu/hr-ft^2-°F. Extending this analysis to a three-layer balloon with two air spaces, the U values are 0.34 and 0.38 Btu/hr-ft^2-°F for the zero and 5-mph examples respectively.

Fabrication of multilayer balloons in which an effective air space is achieved has not been accomplished to date. However, it is expected that significant reductions in heat loss could be accomplished by this method.

Calculations of heat required have been made for a sample balloon of 27,000-cu ft volume, with a gross lift of 350 lb. The required internal temperatures for this constant lift are shown as a function of altitude in Figure 4.1. These values are based on the NACA standard atmosphere. The equations used in this calculation are given in Section II.

Calculations have been made of the fixed quantity of heat required to warm the initial inflation air to the operating temperature and to counteract the cooling tendency produced by the expansion during ascent. These values are given in Figure 4.2. In evaluating the heating requirement caused by the ascent, the standard dry adiabatic lapse rate has been used. The values of Figure 4.2 represent 3 to 5 lb of fuel, an amount which is significant

BALLOON AIR TEMPERATURE REQUIRED FOR CONSTANT LIFT

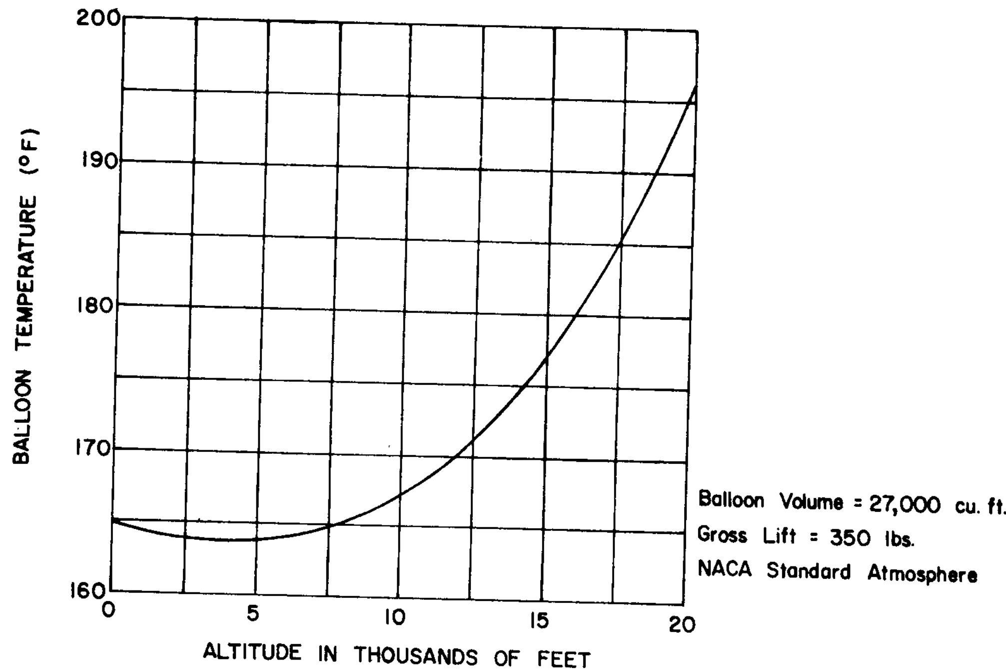


Figure 4.1

TOTAL HEAT REQUIRED TO HEAT INITIAL INFLATION AIR AND MAINTAIN TEMPERATURES OF FIGURE 4.1 DURING EXPANSION ON ASCENT (DOES NOT INCLUDE BALLOON HEAT LOSS)

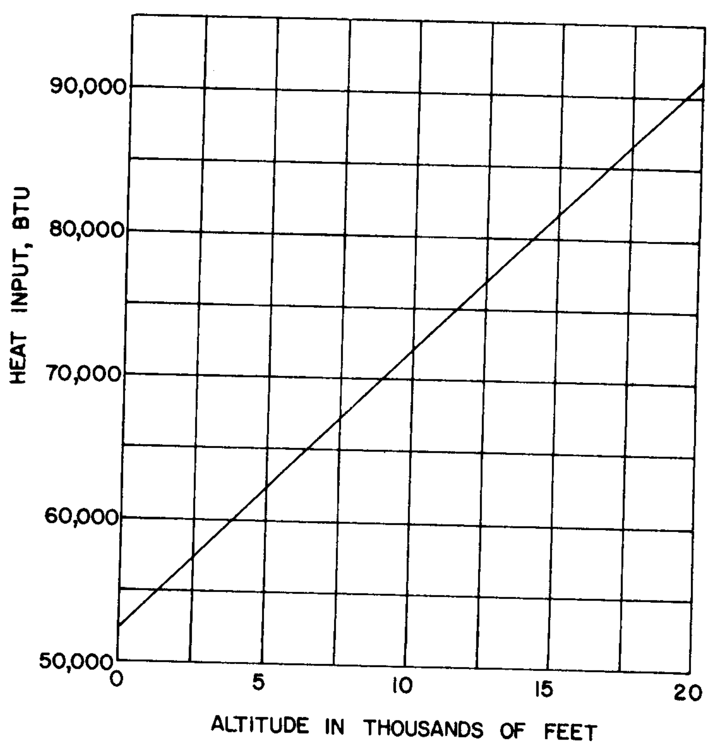


Figure 4.2

but not large compared with the expected fuel load of 30 to 70 lb.

Values of continuous heat loss are determined as a function of altitude for single, double and triple-layer balloons at operating temperatures as shown in Figure 4.1. These values are given in Figures 4.3, 4.4 and 4.5. They are all based on calculated U coefficients as described above.

The balloon wall temperatures expected in this example are given in Figure 4.6 for a double-layer balloon and Figure 4.7 for a triple-layer balloon. Surface temperatures for a single-layer balloon will be nearly equally removed from the internal and external temperatures.

Referring to Section V, the energy storage capacities in Figure 5.3 can be correlated with the heat input requirement described above. In order to provide a two-hour flight duration at 5,000 ft for a 27,000-cu ft balloon with 350 lb gross lift, the following amounts of energy must be supplied:

Initial Inflation and Ascent (Figure 4.2)	62,000 Btu
Climb at 440 ft/min (Figure 4.3)	99,000 Btu
Floating for Two Hours at 5,000 ft, zero wind (Fig. 4.3)	860,000 Btu
Total Energy to Start of Descent	1,021,000 Btu

The fuel requirements during the descent period are dependent upon the control method used. It is possible that no further addition of heat would be required. Figure 5.3 indicates that a total weight of 81 lb for tank and fuel (with propane) would provide a useful output of 1,200,000 Btu, a value which provides a small safety factor in the above example.

B. Experiments

Several controlled experiments were performed with small balloons (7-ft diameter) to determine the U values for hot air balloons. In addition, estimates were made from earlier inflations of 20, 30 and 39-ft balloons.

HEAT LOSS FOR SINGLE WALL BALLOON AT TEMPERATURES OF FIGURE 4.1

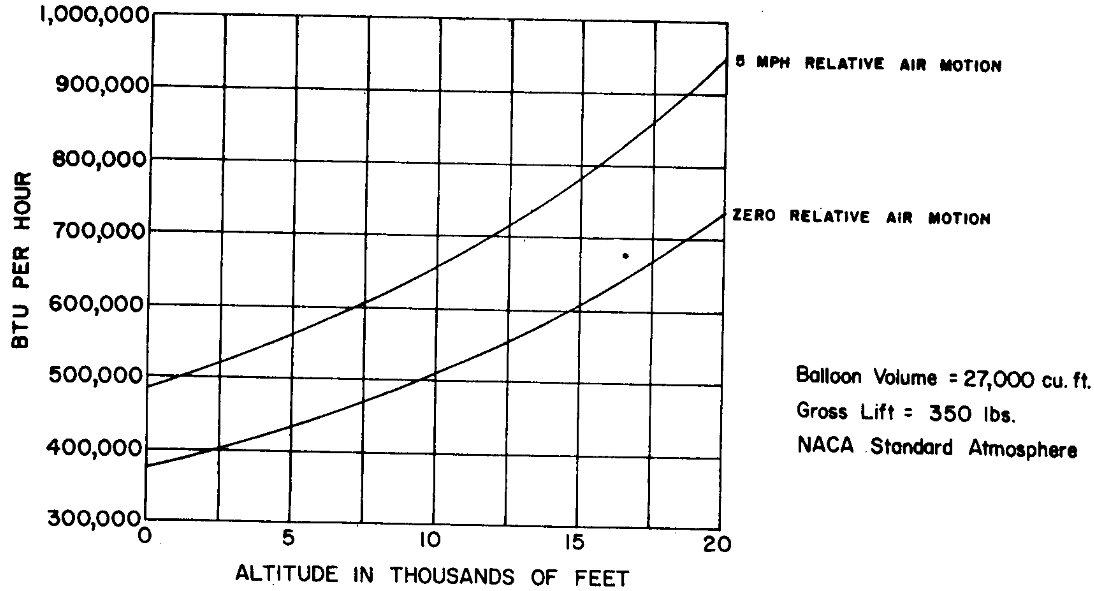


Figure 4.3

HEAT LOSS FOR DOUBLE WALL BALLOON AT TEMPERATURES OF FIGURE 4.1

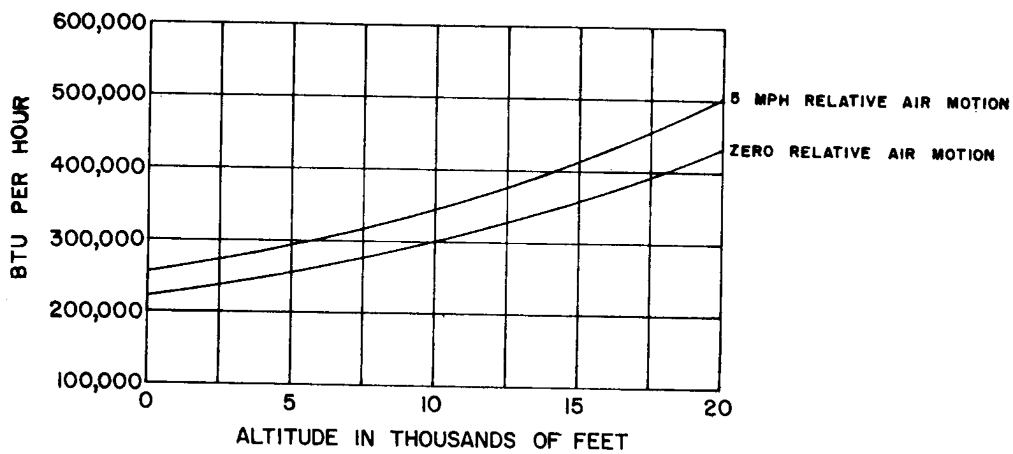


Figure 4.4

HEAT LOSS FOR TRIPLE WALL BALLOON AT TEMPERATURES OF FIGURE 4.1

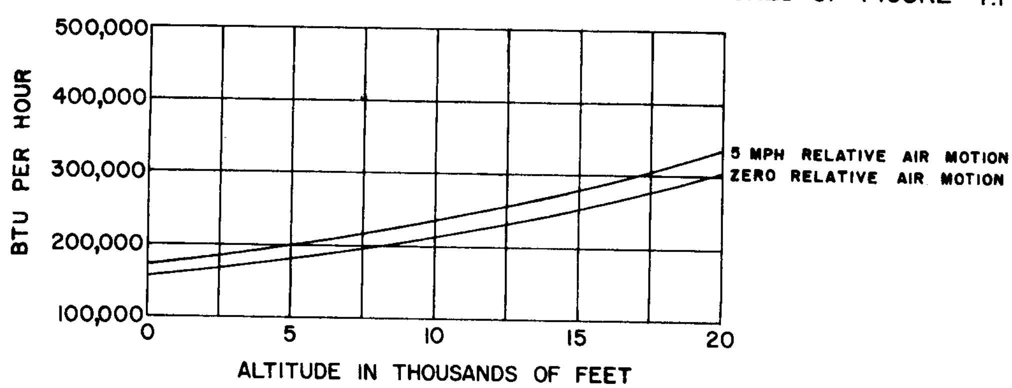


Figure 4.5

WALL TEMPERATURES FOR DOUBLE WALL BALLOON
AT INTERNAL TEMPERATURES OF FIGURE 4.1

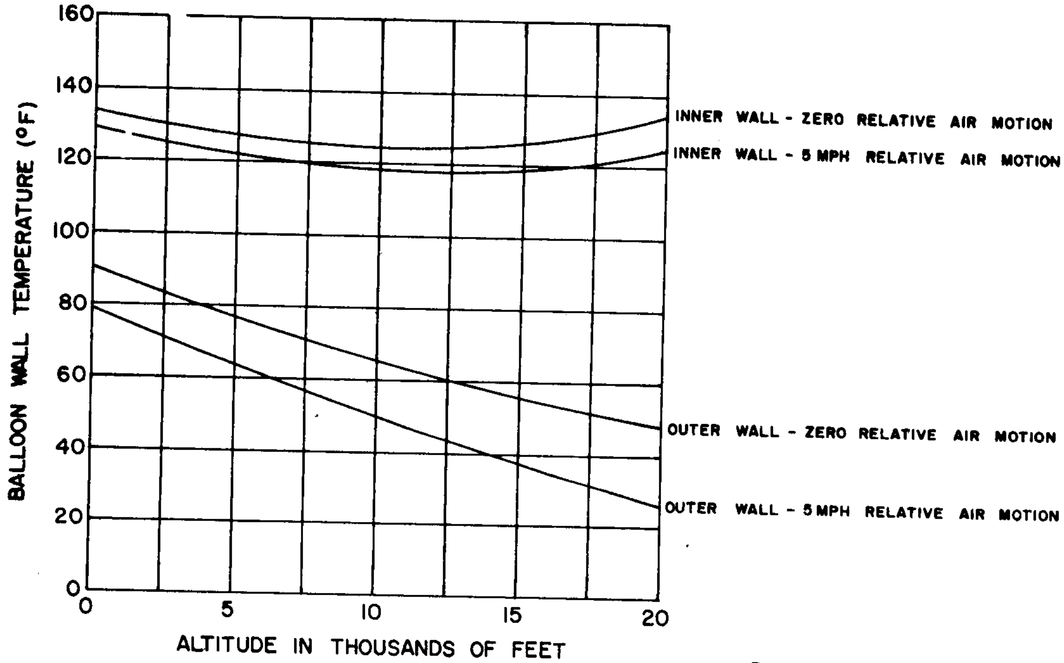


Figure 4.6

Balloon Volume = 27,000 cu. ft.
Gross Lift = 350 lbs.
NACA Standard Atmosphere

WALL TEMPERATURES FOR TRIPLE WALL BALLOON
AT INTERNAL TEMPERATURES OF FIGURE 4.1

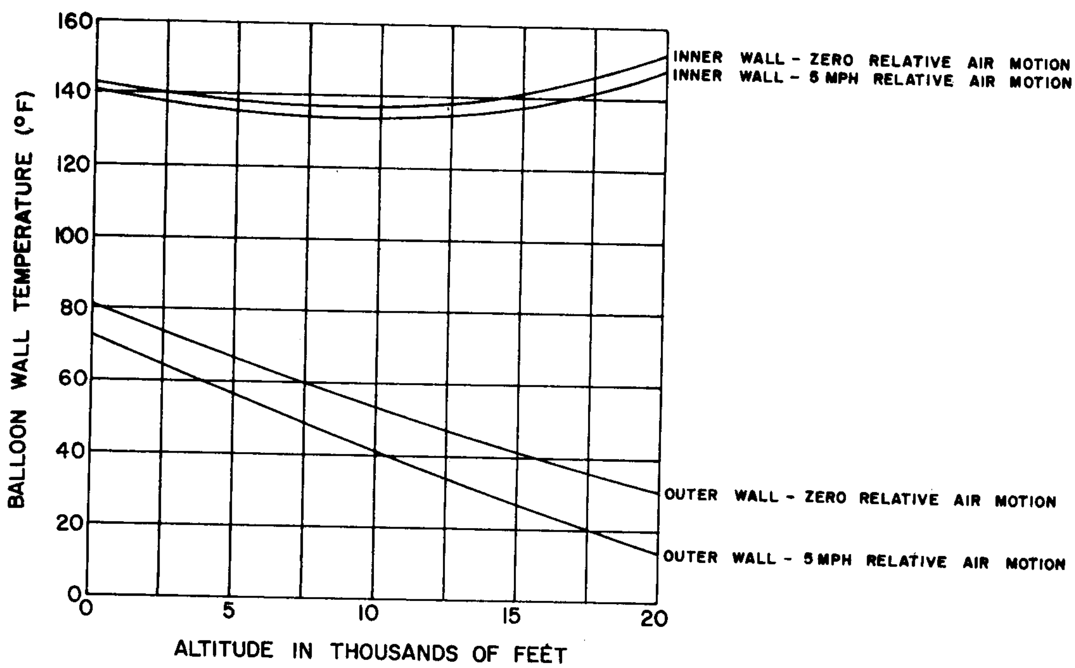


Figure 4.7

Table 4.1 summarizes tests of single-layer balloons. The lift values agree with the graphs of Section II. The heat transfer values are in general agreement with the value of 0.82 used in the above calculations. Tests with the 7-ft balloon resulted in an average coefficient U of 1.067 Btu/hr-ft^2-^{o}F, which is considerably higher than those found in other tests. This is due primarily to the very great temperature difference which was required in these tests to produce measurable lifts in the small balloons.

Table 4.2 presents more detailed information for five tests on a single-layer Mylar balloon. This data points to an increase in the U value with increased temperature differentials.

These tests were conducted, as shown in Figure 4.8, utilizing propane bunsen-type burners. Fuel consumption was measured with a calibrated orifice-manometer combination, and lift was determined by changes in the reading of a balance. Chemical analysis of the products of combustion was made with an Orsat Analyzer. Figure 4.9 presents the temperature distributions determined by a thermocouple probe. Mean temperatures and measured lift are correlated with theoretical lift values. Very good agreement was found.

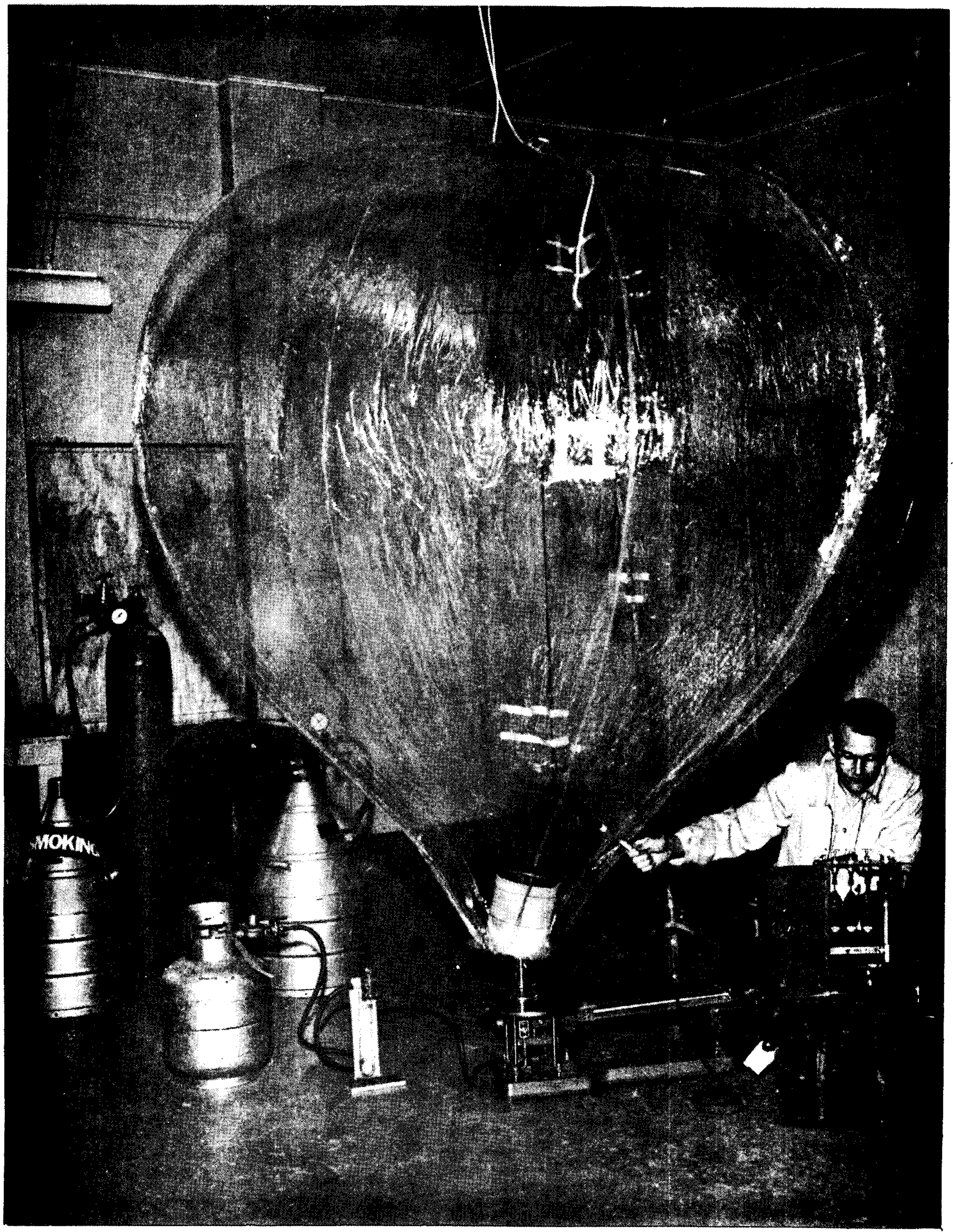
Ventilation losses (from a 6-in. diameter vent port in the side of the balloon) were determined from the measured internal and external temperatures and the Orsat analysis by making use of the equations in Section III.

A 7-ft diameter, double-layer, polyethylene balloon and a similar Mylar balloon were fabricated. These were made by sealing tubular gores together and gathering the ends to form a cylinder balloon. A small quantity of air was placed in the tubes to separate the two walls. This method was not entirely satisfactory in that the air collected in the top and bottom of the gores, leaving the layers in contact with each other in the center. An

TABLE 4.1

SUMMARY OF UNIT HEAT LOSS VALUES - EXPERIMENTS WITH HOT AIR BALLOONS

Balloon Size	ΔT	Lift Lb/Ft^3	U $Btu/hr\text{-}ft^2\text{-}{}^\circ F$
7 ft	151°F	0.0160	1.067
20 ft	50°F	0.00355	0.854
30 ft	43.7°F	0.0033	0.748
39 ft	75°F	0.00926	0.776



TEST CONFIGURATION FOR LIFT MEASUREMENTS
FIGURE 4.8

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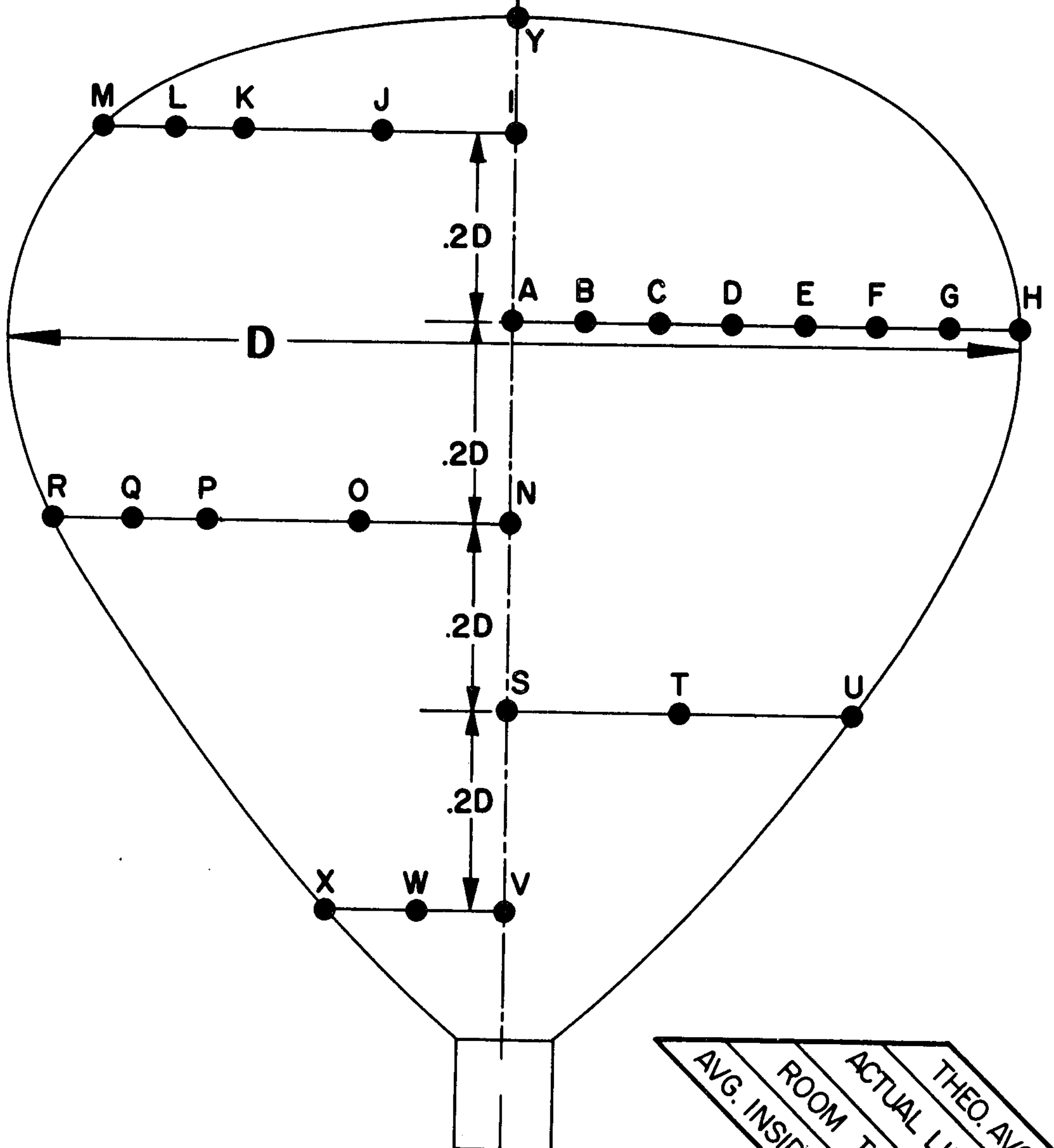


TEST No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
	TEMPERATURE																								
1	212	211	213	183	210	211	208	161	207	206	204	200	154	205	214	211	211	193	203	192	147	344	188	162	203
2	227	226	226	229	228	232	229	190	236	236	196	189	182	255	241	236	229	204	212	211	188	214	204	160	206
3	257	257	256	257	258	258	252	213	278	277	269	257	212	269	267	262	257	192	239	232	207	272	217	182	247
4	236	244	241	245	245	245	240	181	258	258	260	272	230	255	255	245	225	190	241	226	185	250	200	175	231
5	235	235	236	235	239	245	243	226	255	254	257	257	242	236	255	243	234	225	328	229	235	452	230	183	225
6	278	280	283	277	292	279	292	205	301	295	296	293	206	269	266	270	269	202	265	261	255	266	245	200	261

AVG. INSIDE TEMP.	ROOM TEMP.	ACTUAL LIFT LB/FT3	THEO. AVG. TEMP.
212	76	.0131	185
224	82	.0143	210
257	82	.0173	250
244	80	.0163	220
258	85	.0155	230
278	84	.0183	270

NOTE: ALL TEMPERATURES ARE FAHRENHEIT

FIGURE - 4.9.

BALLOON TEMPERATURE DISTRIBUTION

estimated 30 to 50 per cent of the area was acting as a single-wall balloon.

The U values obtained from the polyethylene balloon are shown in Table 4.3, and those pertaining to the Mylar balloon are given in Table 4.4. These U coefficients are somewhat lower than those of Table 4.2 for the single-layer balloon. However, they do not reflect the expected improvement corresponding to an effective double-layer balloon, due to the fabrication difficulties discussed above.

The combined results presented in Section II, III and IV indicate that, from the point of view of minimum fuel consumption, operation with relatively low temperature differentials and large balloons will be advantageous. This is true because the area to volume ratio decreases with increased size, and the heat transfer coefficient, U, decreases moderately with reduced temperature differential.

A further conclusion from the investigation of heat loss is that ordinary single-wall balloons may be expected to have U values between 0.75 and 1.1 Btu/hr-ft^2-$^{\circ}$F over a range of temperature differences from 50°F to 150°F.

TABLE 4.2

RESULTS OF HEAT LOSS TESTS OF 7-FT SINGLE-WALL BALLOON

Reading No.	ΔT ^{o}F	Orsat Analysis $\%CO_2$	$\%O_2$	$\%CO$	$\%N_2$	Ventilation Heat Loss BTU/hr	Heat Input BTU/hr	Heat Loss Through Walls of Balloon BTU/hr	Area of Balloon Ft^2	U Value BTU/hr-ft^2-^{o}F
1	125	1.9	16.8	0.6	80.7	3,888	19,600	15,712	140	0.899
2	135	3.8	14.3	0.5	81.4	3,640	23,000	20,360	140	1.022
3	151	2.8	16.0	0.6	80.6	4,719	28,300	23,581	140	1.188
4	164	3.4	14.9	0.5	81.2	5,940	32,400	26,460	140	1.115
5	182	3.7	14.9	0.6	80.8	6,380	34,700	28,320	140	1.110

TABLE 4.3

RESULTS OF HEAT LOSS TESTS OF 7-FT DOUBLE-WALL POLYETHYLENE BALLOON
(Material thickness 0.0015 inch)

Reading No.	ΔT ^{o}F	Orsat Anlysis $\%CO_2$	$\%O_2$	$\%CO$	$\%N_2$	Ventilation Heat Loss BTU/hr	Heat Input BTU/hr	Heat Loss Through Walls of Balloon BTU/hr	Area of Balloon Ft^2	U Value BTU/hr-ft^2-^{o}F
1	87.6	--	--	--	--	1,549	10,500	8,951	147.5	0.694
2	84.0	3.2	15.0	0.0	81.8	1,589	11,000	9,411	147.5	0.760
3	85.0	--	--	--	--	1,530	10,500	8,970	147.5	0.716

TABLE 4.4

RESULTS OF HEAT LOSS TESTS OF 7-FT DOUBLE-WALL MYLAR BALLOON
(Material thickness 0.0005 inch)

Reading No.	ΔT °F	Orsat Analysis %CO_2	%O_2	%CO	%N_2	Ventilation Heat Loss BTU/hr	Heat Input BTU/hr	Heat Loss Through Walls of Balloon BTU/hr	Area of Balloon Ft^2	U Value BTU/hr-ft^2-°F
1	49.5	1.4	17.4	0.0	81.2	1,035	6,000	4,965	148	0.679
2	68.4	1.4	17.4	0.0	81.2	1,735	9,000	7,265	148	0.719
3	90.0	2.0	16.0	0.0	82.0	2,290	12,300	10,010	148	0.753
4	98.1	1.6	16.2	0.0	82.2	3,248	13,500	10,252	148	0.707
5	119.9	2.0	15.8	0.0	82.2	3,805	17,300	13,495	148	0.760
6	127.8	1.5	16.1	0.0	82.4	5,246	19,000	13,754	148	0.729
7	136.0	3.0	14.0	0.0	83.0	3,840	20,500	16,660	148	0.824
8	152.9	3.5	14.3	0.0	82.2	4,600	24,800	20,200	148	0.895
9	167.4	3.4	14.7	0.0	81.9	5,460	27,500	22,040	148	0.891
10	177.4	3.2	14.4	0.0	82.4	6,118	29,000	22,882	148	0.872
11	191.2	3.4	14.3	0.0	82.3	6,900	32,000	25,100	148	0.887
12	196.2	3.5	14.3	0.0	82.2	7,210	33,500	26,290	148	0.906
13	203.5	3.8	13.6	0.0	82.6	7,310	35,000	27,690	148	0.920
14	209.7	3.5	14.3	0.0	82.2	8,040	36,500	28,460	148	0.917

V. FUEL STORAGE

Tanks for storage of fuel for continuous heat supply have been studied. Analyses pertaining to storage tank weight have been made, based on a spherical shape. This shape has the most advantageous area to volume ratio and can be used for a field unit.

Tanks having internal volumetric capacity of 1,000, 2,000 and 3,000 cu inches have been used in illustrative calculations. Their respective diameters are 12.5, 15.6 and 18 inches and their respective capacities in U. S. gallons are 4.33, 8.66 and 12.99.

Four high-strength materials have been studied for this application. They are stainless steel (No. 316), aluminum (615-T4), glass fiber, and the aluminum alloy 56S-H38.

Tank weight values[3] have been calculated from the following calculations, pertaining to a thin hollow sphere:

$$t = \frac{2S}{P_r} \tag{5.1}$$

where

t is the wall thickness, inches

S is the allowable unit stress, psi

P is the design internal, psig

r is the internal radius of the sphere, inches.

$$r = \sqrt[3]{\frac{3V}{4\pi}} \tag{5.2}$$

where

r is the internal radius of the sphere, inches

V is the internal volume of the sphere, in^3.

$$dV = 4\pi r^2 \, dr \tag{5.3}$$

where

dV is the volume between the inner and outer surfaces of the tank, in^3

r is the internal radius, inches

$dr = t$, the tank thickness, inches.

$$W_t = dV \rho \tag{5.4}$$

where

W_t is the weight of the tank shell, pounds

ρ is the density of the tank material, lb /in^3.

$$\eta_t = \frac{100 \, W_f}{W_f + W_t} \tag{5.5}$$

where

η_t is the tank efficiency, per cent

W_f is the weight of the fuel, pounds

W_t is the weight of the tank, pounds.

The weight of tanks, based on the above equations, is directly related to the storage pressure. Exceptions to this statement occur with low pressure fuels where pressure is no longer the design criterion and minimum thicknesses for structural integrity are used. Figure 5.1 shows calculated weights for 1,000, 2,000 and 3,000-cu inch tanks at working pressures to 1,000 psig. Stresses are based on a safety factor of 2.0, referred to the yield point of the material.

Propane is the most volatile fuel which was considered in detail. It has a vapor pressure of 286 psia at 130°F. From Figure 5.1, the corresponding weight for a 3,000 in^3 tank would be 5 to 12 lb, depending upon the material selected. Tank efficiencies, based on a fuel of density equal to propane, are shown in Figure 5.2. A tank efficiency of 82 to 92 per cent would be expected (at a design pressure of 286 psi).

The weight of a spherical tank and the fuel for a given energy storage capacity are shown in Figure 5.3. The material is No. 316 stainless steel. A combustion efficiency of 85 per cent (as defined in Section III) has been assumed. The quantities of energy storage in Figure 5.3 are correlated with expected duration in Section IV. Figure 5.3 illustrates the great similarity of the several hydrocarbon fuels when compared on the storage weight basis. Selection of fuels will, therefore, be based primarily on other considerations, of which controllability of combustion is the most significant.

The major conclusion from the analysis of fuel tanks is that adequate lightweight tanks can be made which will contribute only slightly to the weight of the over-all hot air balloon system.

WEIGHT OF SPHERICAL TANKS WITH SAFETY FACTOR OF 2.0

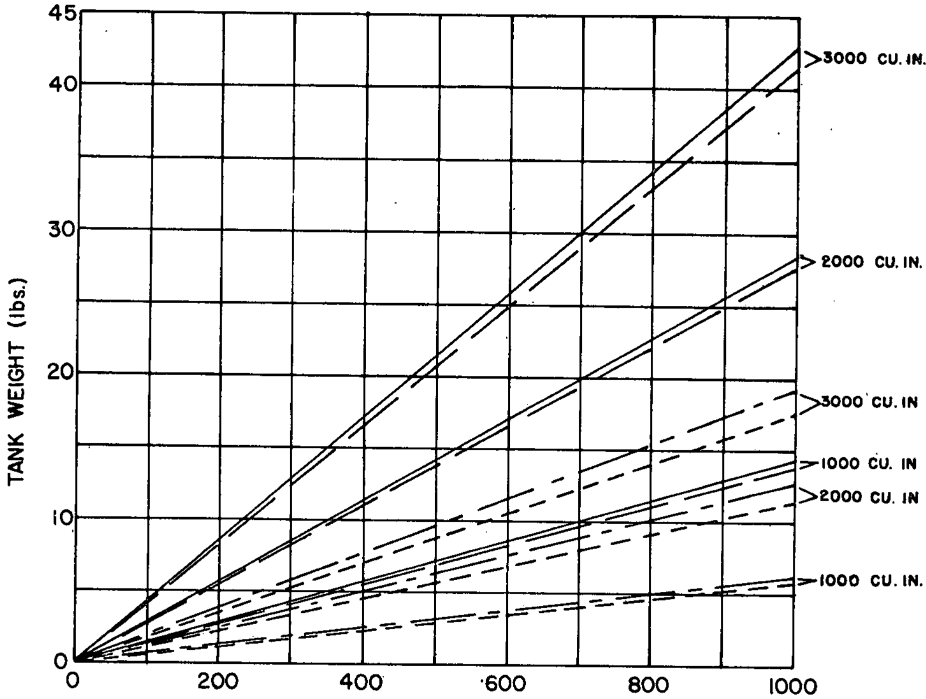
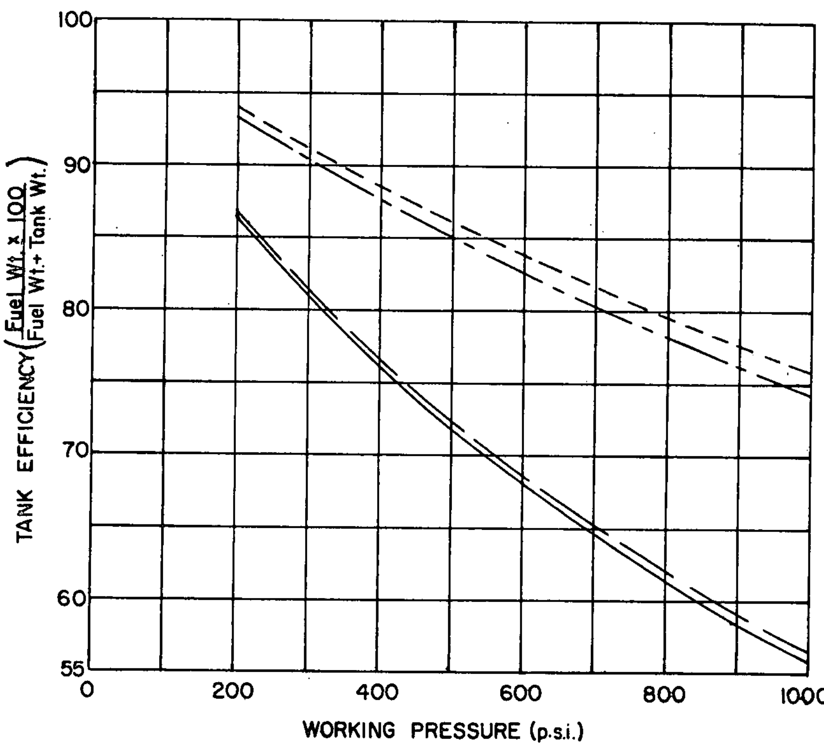


Figure 5.1

CODE:

- Stainless Steel (316)
- Aluminum (56S-H38)
- Aluminum (61S-T4)
- Glass Fiber

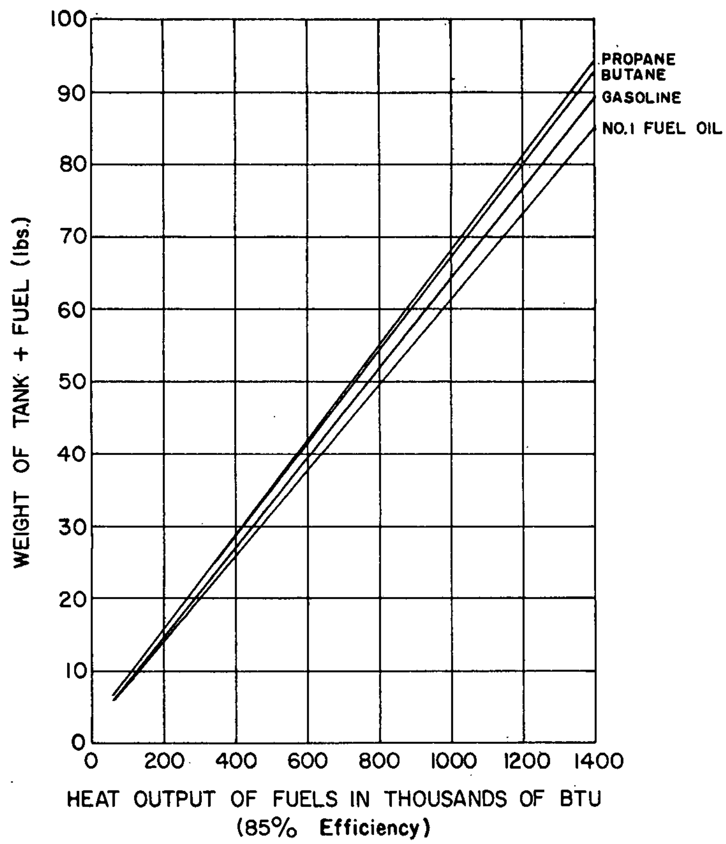
EFFICIENCY OF SPHERICAL TANKS



Fuel Density equal to Propane
Tank Volume, 3000 cu. in.

Figure 5.2

ENERGY STORAGE IN SPHERICAL FUEL TANKS



Assuming

Minimum tank wall thickness of 0.040" for propane and butane

Minimum tank wall thickness of 0.030" for gasoline

Spherical tanks - 0.80 volume factor applied to propane and butane

Material, stainless steel

Figure 5.3

VI. INFLATION

The operation of a hot air balloon requires an initial inflation with air. It has been found that the natural induction of air by the operation of the burner is not sufficient to fill the balloon. Inflation of the balloon by some powered means is required. The purpose of this section of the report is to describe the analysis and experimental work which led to the selection of prototype hardward to meet the above requirements, as described in Section VII.

A. General Analysis

A balloon volume of 27,000 ft^3 was taken as a nominal maximum value and an inflation duct of 15-in. diameter was arbitrarily selected as a practical design limit. Inflation rates consistent with filling times of 40, 30, 20 and 10 minutes were considered. The above assumptions resulted in inflation velocity values which then made possible the calculation of velocity head and air horsepower values. Formulas [2c,2d] used in this analysis are given below:

$$Q = AV \tag{6.1}$$

where

Q is the volume flow rate, ft^3/min

A is the free inflation duct area, ft^2

V is the average velocity, ft/min.

$$h_v = \left(\frac{V}{4005}\right)^2 \tag{6.2}$$

where

h_v is the velocity head, inches of water

V is the average velocity, ft/min

4005 is a constant, evaluated for normal sea level conditions.

$$P = \frac{QH}{6350} \qquad (6.3)$$

where

P is the volume rate of flow, ft^3/min

H is the total head, inches of water

6350 is a constant evaluated for normal sea level air.

It was assumed that the inflation duct would have a re-entrant entrance and an abrupt exit. From reference 4 this combination results in the equation:

$$H = 1.85\, h_v \qquad (6.4)$$

The magnitude of the total head, H, may be reduced by aerodynamic design of the entrance. However, it is questionable that the additional cost of an entrance of this type could be justified, for a semi-expendable field unit.

Further assumptions were made for the case in which inflation could be accomplished by an electrically-driven fan. An adiabatic fan efficiency of 60 per cent and a motor efficiency of 50 per cent were arbitrarily set. Over-all efficiency of the combination is 30 per cent. Results are given in Table 6.1.

It can be seen from Table 6.1 that the power requirements are quite low and an electrically-driven inflation fan is reasonable. Other possibilities for delivering these quantities of power to a fan were also considered. Specifically considered were the use of an internal combustion engine (as built for models) and the application of a hand crank through a gear train.

TABLE 6.1

POWER REQUIRED FOR INFLATION

Inflation Time (min)	Q (Ft^3/min)	V (Ft/min)	h_v (in.H_2O)	H (in.H_2O)	P (HP)	Shaft HP 60% Eff. (HP)	Motor HP 50% Eff. (HP)
40	674	548	0.019	0.035	0.0037	0.00617	0.01234
30	900	732	0.034	0.063	0.0089	0.0148	0.0296
20	1350	1100	0.075	0.139	0.0295	0.0492	0.0984
10	2700	2200	0.300	0.555	0.236	0.393	0.786

Model engines capable of delivering power throughout the range of Table 6.1 are readily available and represent a highly-developed, lightweight, compact power source. The primary disadvantage of the model internal combustion engine is its questionable starting reliability in the field. Experience indicates that this power source would be somewhat less reliable than the electric motor when compared on the basis of starting the unit after lengthy storage. Other special problems associated with this motive unit are the requirement of a special fuel and the lack of good speed control. Both of these latter difficulties could be overcome if there were future incentive to use this motive unit.

Reference 2e indicates that a man can exert energy at a rate of 90,000 ft lb/hr (0.0454 HP) for a considerable length of time, the duration being dependent upon the atmospheric conditions. At an effective temperature of 105°F the expected duration would be approximately one-half hour. At lower temperatures this duration increases significantly. Referring to Table 6.1, expenditure of energy at this rate would result in an inflation time slightly more than 20 minutes. In comparing this method with the use of an electrically-driven fan, it is concluded that it could serve as an emergency method in case of electrical system failure.

B. Experimental Work

Because of the need for a relatively high-volume flow rate with low pressure differential, an axial flow-type fan appeared most suitable. In order than an electric motor have minimum weight, a high shaft speed was considered a desirable feature. This combination defines a low torque requirement for the motor. It was found that small wooden propellers made for model airplane work had these desirable characteristics.

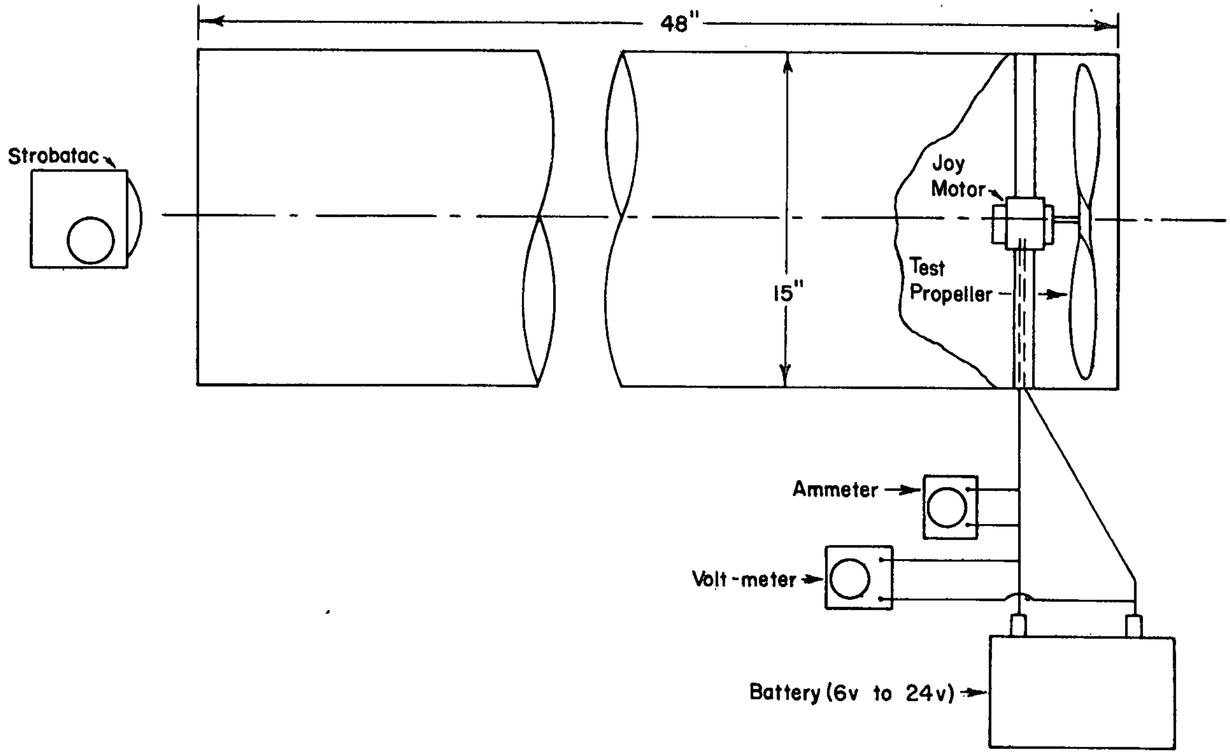
Tests were run on several of these propellers having various diameters and pitch angles. During the tests the propellers were driven by a direct current aircraft-type motor operating from a 12-volt wet cell. The test unit was mounted in a 14.5-in. diameter duct, as illustrated in Figure 6.1. Motor power input was measured by voltmeter and ammeter, speed by a stroboscopic tachometer, and air velocity by a vane anemometer. Results of these tests are given in Table 6.2.

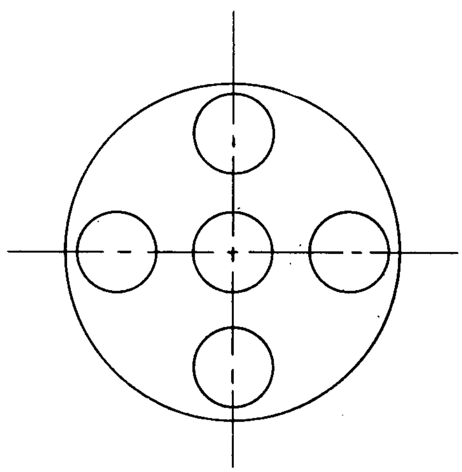
TABLE 6.2

PROPELLER PERFORMANCE
(Motor Voltage - 12V)

Propeller Diam.	& Pitch	Current (amps)	Speed (rpm)	Air Vel. (ft/min)	Air Flow (cfm)	Inflation Time for 27,000 ft^3 (min)	Over-all Eff. of Fan & Motor (%)
12"	5	4.17	3870	898	1100	24.5	22.8
12"	8	4.90	3200	967	1185	22.8	24.4
14"	6	4.90	3200	1046	1280	25.4	30.9
14"	8	5.75	3200	862	1060	21.2	14.8

INFLATION FAN TEST CONFIGURATION





Cross section of test duct showing anemometer positions

Figure 6.1

The performance of the 14-in. diameter propeller with 6-in. pitch was found to be most efficient and was therefore recommended for use in the prototype burner-inflation assembly.

Further tests were made on operation of the electric motor and propeller with dry cell batteries. Battery drain tests were made with various combinations of 6-volt dry cells (Burgess F4BP). It was found that six of these cells connected to supply a nominal 18 volts resulted in an inflation time of 30 minutes for a 27,000-cu ft balloon. Six cells connected so as to provide a nominal 12 volts resulted in an inflation time of 35 minutes, and four cells connected to provide 12 volts resulted in an inflation time of 38 minutes. Voltage, current and speed as a function of time are shown in Figures 6.2, 6.3 and 6.4.

Since these batteries weigh approximately 1-1/4 lb each, the use of a pack of six weighing 7-1/2 lb appears to be a very practical solution to the inflation problem. Wet-type 12-volt batteries, weighing 15 lb and used in light airplanes, are available which would reduce the inflation time to approximately 25 minutes.

A preliminary performance test was run on a "McCoy 60" model aircraft engine. This motor is rated at 1.32 HP at 17,000 rpm, which is somewhat higher than the range of values in Table 6.1. When operating with a 14-in. propeller, it delivered 4,000 cfm, a rate which corresponds to an inflation time for a 27,000-cu ft balloon of approximately 7 minutes. This rate of inflation is higher than that obtained with the electrical system and points to the use of this type of motive unit in cases where extremely rapid inflation is required.

BATTERY DRAINAGE TESTS

SIX BATTERIES (BURGESS F4BP) OPEN CIRCUIT VOLTAGE, 18V

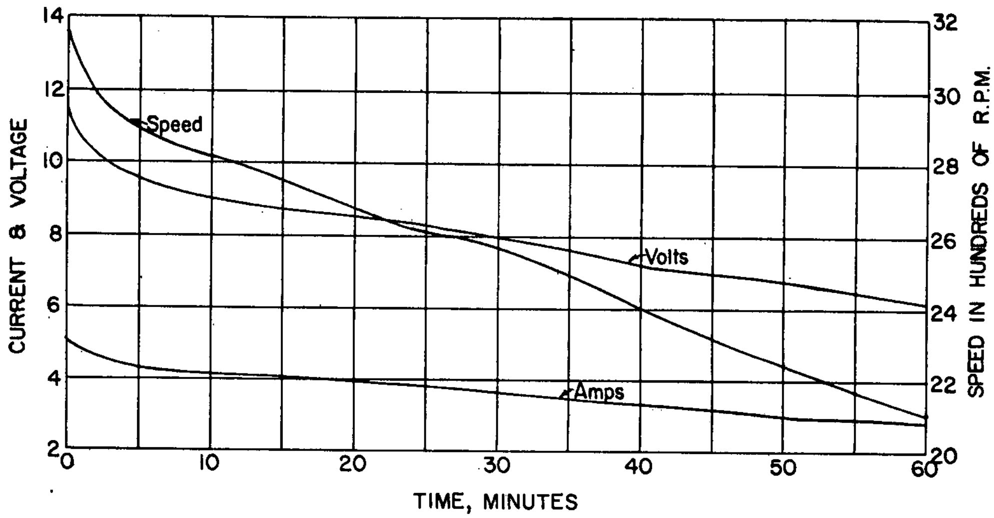


Figure 6.2

BATTERY DRAINAGE TESTS

SIX BATTERIES (BURGESS F4BP) OPEN CIRCUIT VOLTAGE, 12V

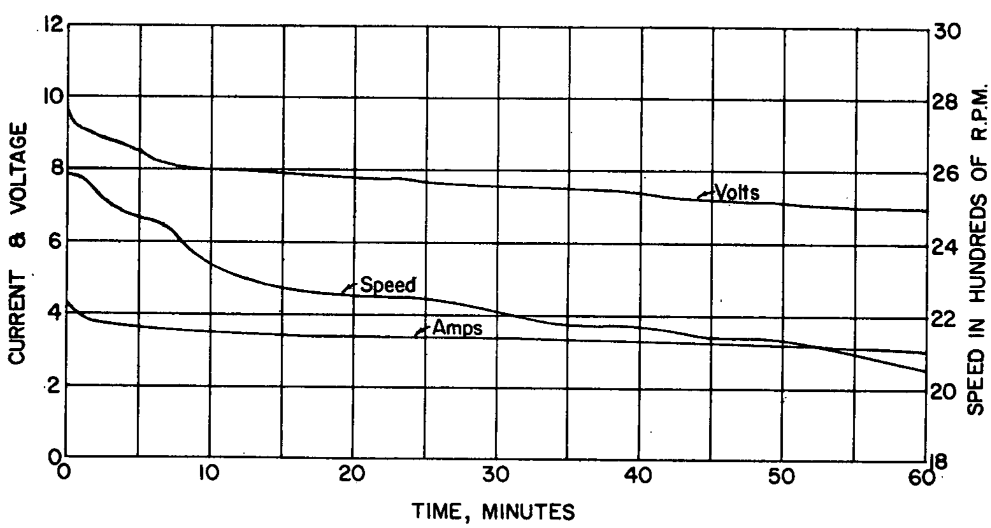


Figure 6.3

BATTERY DRAINAGE TESTS

FOUR BATTERIES (BURGESS F4BP) OPEN CIRCUIT VOLTAGE, 12V

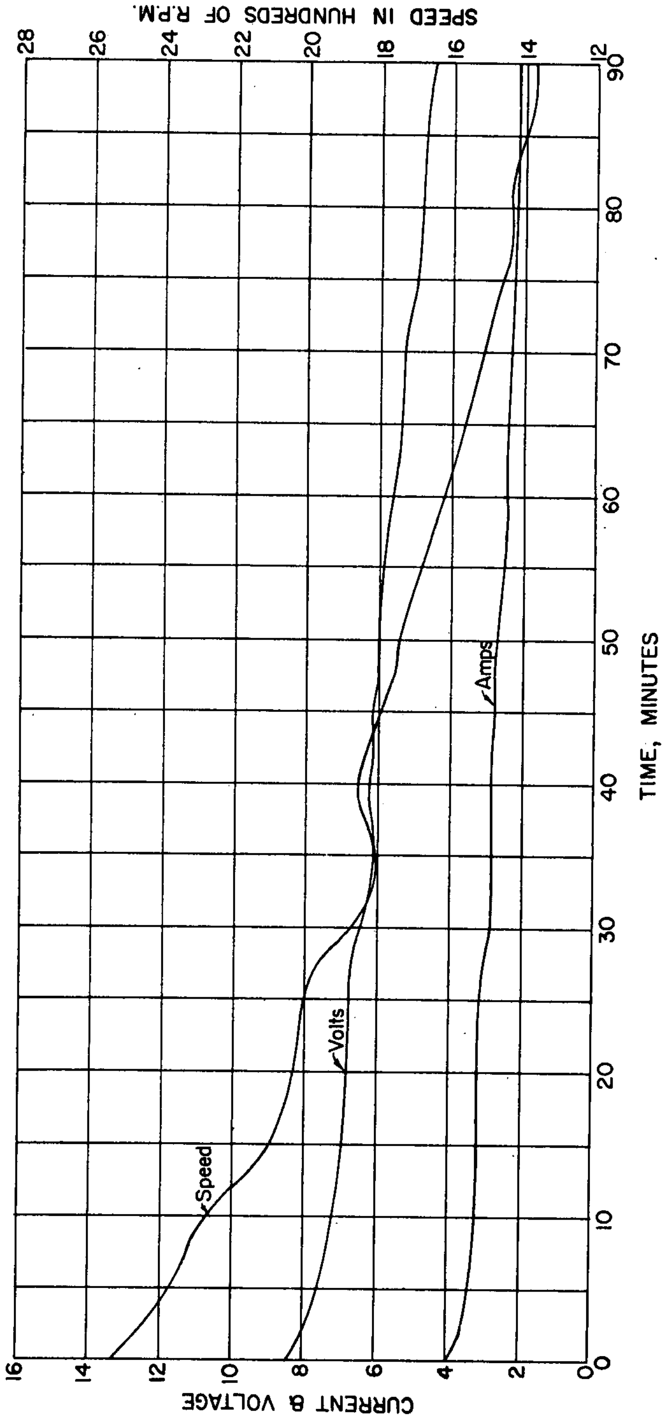


Figure 6.4

VII. PROTOTYPE BURNER ASSEMBLY

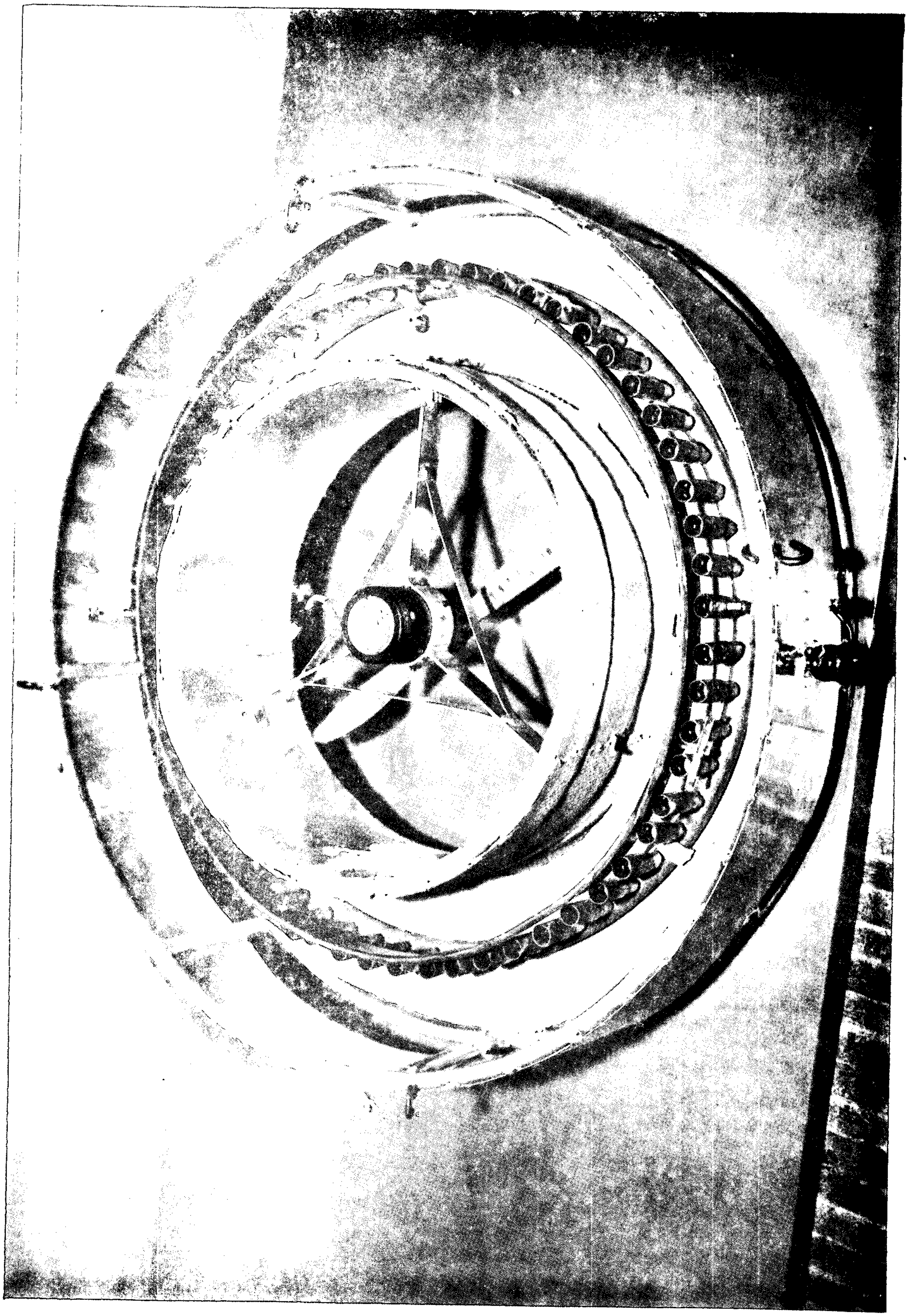
A prototype burner and inflation assembly has been constructed for this project. This unit is designed to provide a continuous, controllable heat input to the balloon as well as incorporating the initial inflation equipment. The assembly is shown as viewed from the top in Figure 7.1 and as viewed from the bottom in Figure 7.2. Figure 7.6 shows the over-all dimensions of the assembly. The prototype burner assembly consists of the following components:

1. Inflation fan and motor
2. Fuel tank (Propane)
3. Ignition system
4. Main burner
5. Tank heater
6. Relief and pressure regulating valves.

The total weight of the entire protype assembly excluding the fuel supply is 59 lb.

A. Inflation Fan and Motor

The inflation fan and motor are mounted in the assembly on a detachable spider frame. The motor is a direct-current compound-wound unit made by the Joy Manufacturing Company and is the motive unit for their fan model number X-702-29A. The fan blade is a wooden model-aircraft propeller 14-inches in diameter with a 6-in. pitch and bears the "Rite Pitch" trade name. Power consumption of this combination is 60 watts at 12 volts and its air flow rate is 1,280 cu ft/min. The resultant inflation time for a 27,000-cu ft balloon is 21 minutes.



BURNER ASSEMBLY – TOP VIEW
FIGURE 7.1

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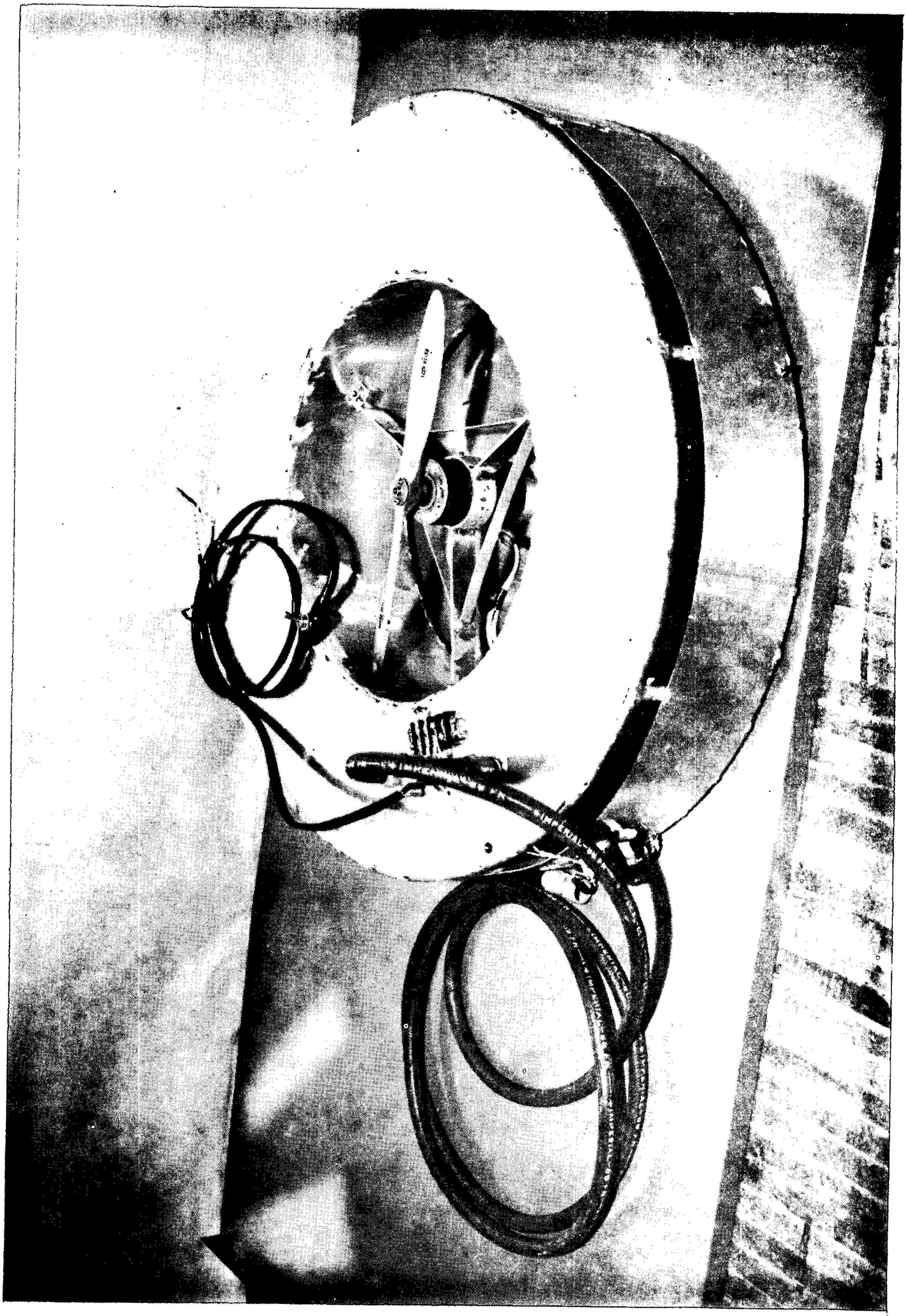

BURNER ASSEMBLY - BOTTOM VIEW
FIGURE 7.2

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B. Fuel Tank (Propane)

The fuel tank selected for the prototype unit is a standard (military) low-pressure-breathing oxygen tank made of stainless steel with banded construction. Its volumetric capacity is 2,100 cu in. with a design working pressure of 400 psig. This tank has been fitted with an internal dip tube of 3/8-in. diameter copper to facilitate use of the tank in a horizontal position. Gaseous fuel is drawn off the top without danger of liquid carryover. The tank is equipped with a pressure relief valve set at 375 psig.

This oxygen tank was used in the prototype model because of its general suitability, having approximately the desired capacity and an ample safety factor for use with propane. The tank is less efficient weightwise than those discussed in Section V because of its elongated shape (cylinder with hemispheric ends) and its high design working pressure. This tank holds approximately 35 lb of propane.

C. Ignition System

An electrical spark-type ignition system is incorporated in the prototype model to provide remote ignition and a reliable method of relighting the burner during flight. This ignition system utilizes two model sizes of spark plugs which are provided with intermittent high voltage through separate ignition coils energized by a relay. The electrical diagram for this system is shown in Figure 7.7. Photographs of the completed unit are shown in Figures 7.3 and 7.4. The ignition system provides instantaneous lighting of the main burner unit.

D. Main Burner

The main burner unit is designed to operate on high pressure propane throughout a pressure range from 5 to 100 lb psig. The ring for the burner

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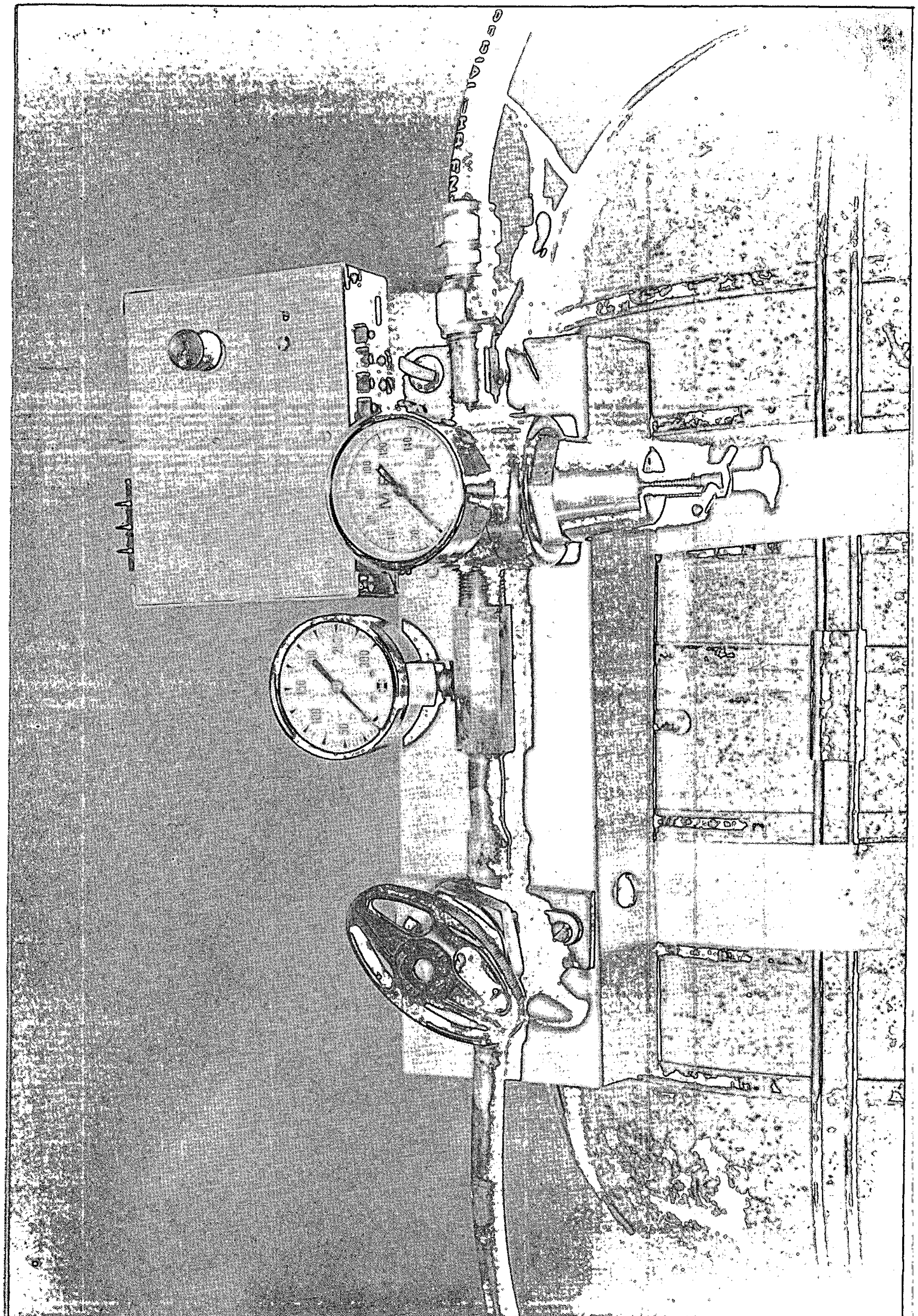

BURNER CONTROLS WITH IGNITION CONTROL BOX

FIGURE 7.3

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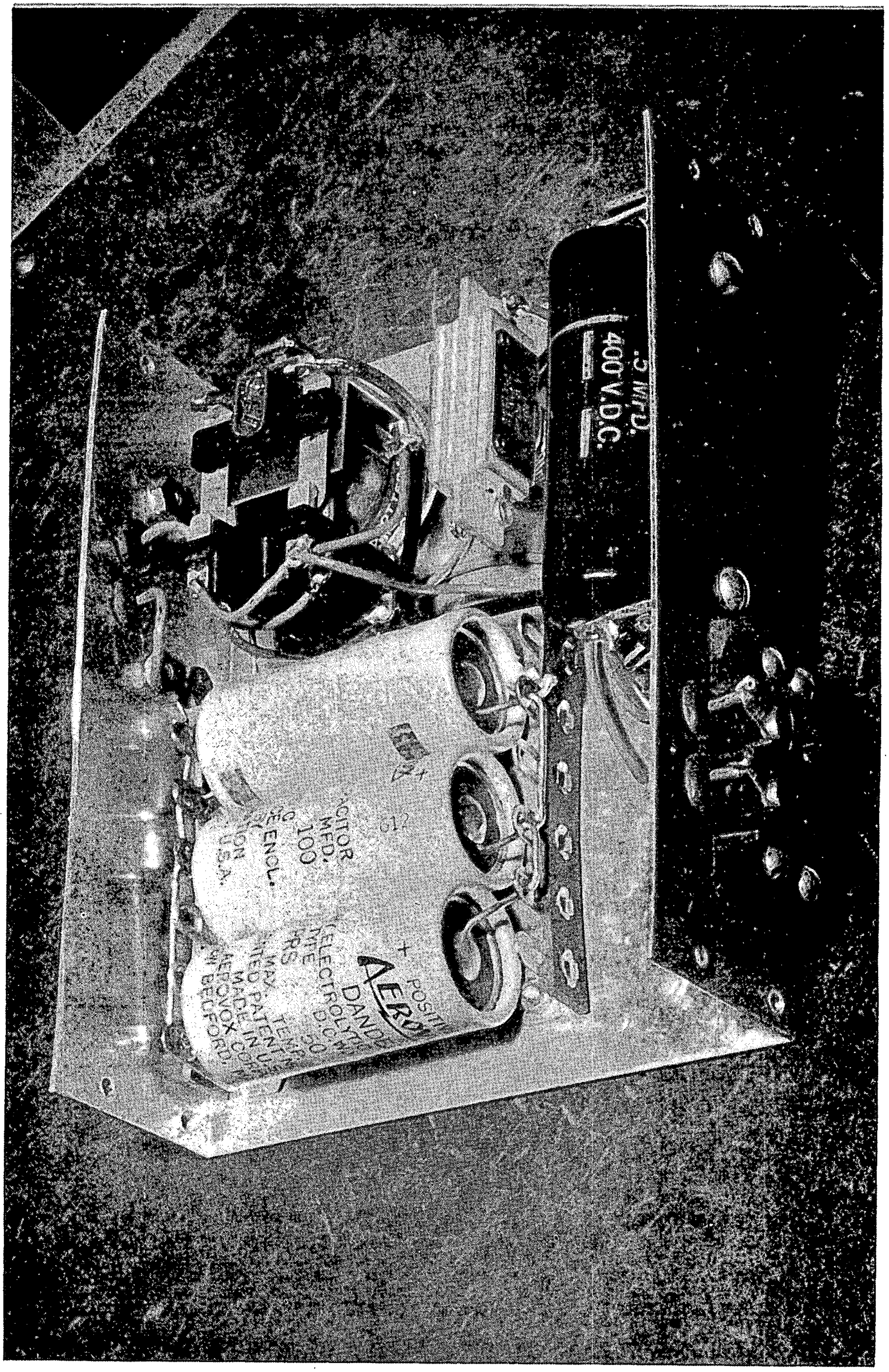


BURNER IGNITION CONTROL BOX

FIGURE 7.4

has 60 separate combustion heads, each of which induces small quantities of air. The burner heads are a commercial item (No. 1352-BU) manufactured by Otto Bernz, Inc. Mounting nipples of brass tubing are silver-soldered into a hard copper manifold. This design was selected in order to minimize manifold size and weight and yield efficient operation of a wide range of fuel input rates.

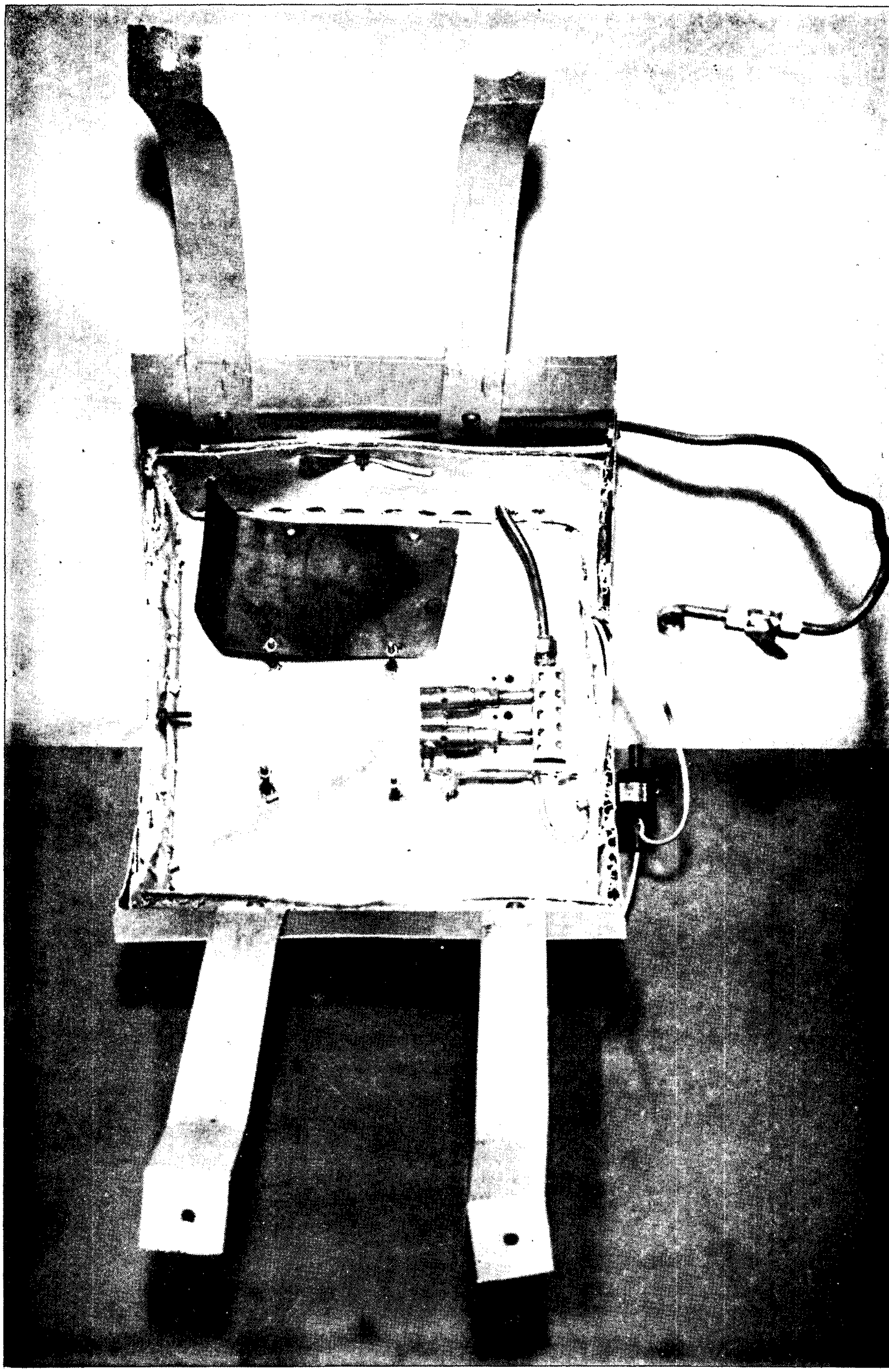
It was found experimentally that a stainless steel collector ring is necessary to insure instantaneous ignition of all of the burner heads. This unit provides a communicating channel for the gas at the time of ignition.

The burner is calibrated for fuel consumption rate versus manifold pressure by measurement of fuel weight loss over known time intervals. These fuel consumption values are given in Table 7.1.

The burner is mounted in a housing made of aluminum. This housing serves as a windshield and mounting structure for the inflation fan and motor. The burner is insulated from the housing by sheets of corrugated asbestos. Rings are provided on the upper surface of the frame for attaching the burner to the balloon.

E. Tank Heater

The continuous evaporation of the liquid propane requires an input of heat which is greater than that obtainable from the surrounding air. This need is met by a small propane burner tank heater containing two high-pressure propane burners of the same type as the main burner, mounted in a shield or enclosure as shown in Figure 7.5. Heat from the products of combustion is transferred to the tank by natural convection. A stainless steel radiation shield is provided by means of the burner and tank to prevent local overheating.



TANK HEATER BURNER ASSEMBLY WITH BAFFLE REMOVED

FIGURE 7.5

Since, the requirement for heat input to the fuel varies directly with the consumption of the main burner, it is desirable to connect the tank heater in parallel with the main burner. By this method, linear modulation of the tank heater with demand is accomplished.

F. Relief and Pressure Regulating Valve

The tank relief valve is a Superior No. 1032B-X-1 set at 375 psig. This valve is a combination filling valve and pressure release.

A manually-adjustable pressure regulator has been selected to allow modulation of the manifold pressure between 3 and 130 psig. This unit is a "M-B Model R-G" automatic pressure-reducing and regulating valve which maintains constant downstream pressure with variable upstream pressure.

TABLE 7.1

CALIBRATION OF MAIN BURNER

Manifold Pressure Psig	Heating Rate BTU/hr
10	85,000
20	155,000
30	225,000
40	280,000
50	345,000
60	410,000
70	470,000
80	530,000

OUTLINE DRAWING OF PROTOTYPE ASSEMBLY

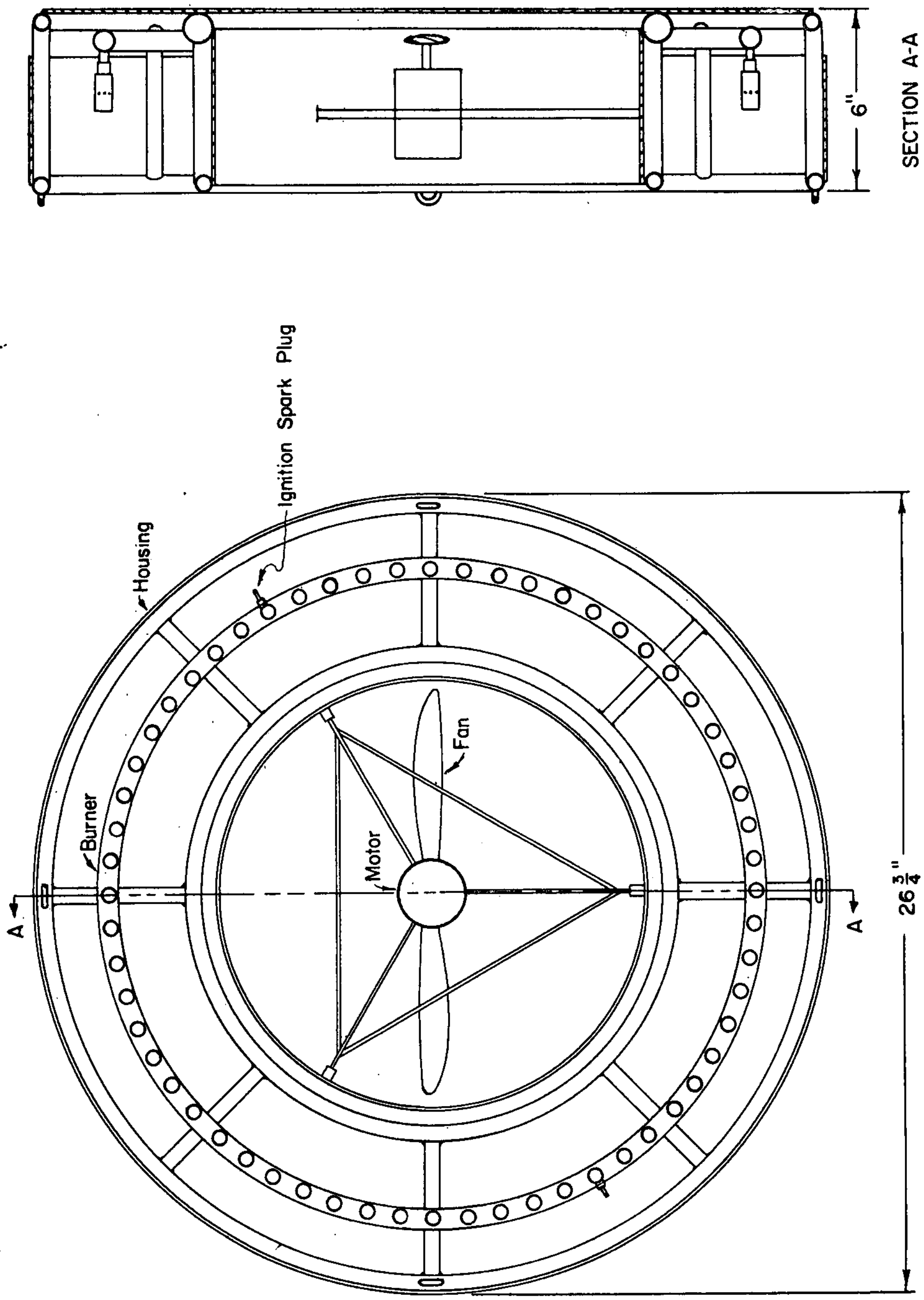


Figure 7.6

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CIRCUIT DIAGRAM
ELECTRIC IGNITION SYSTEM

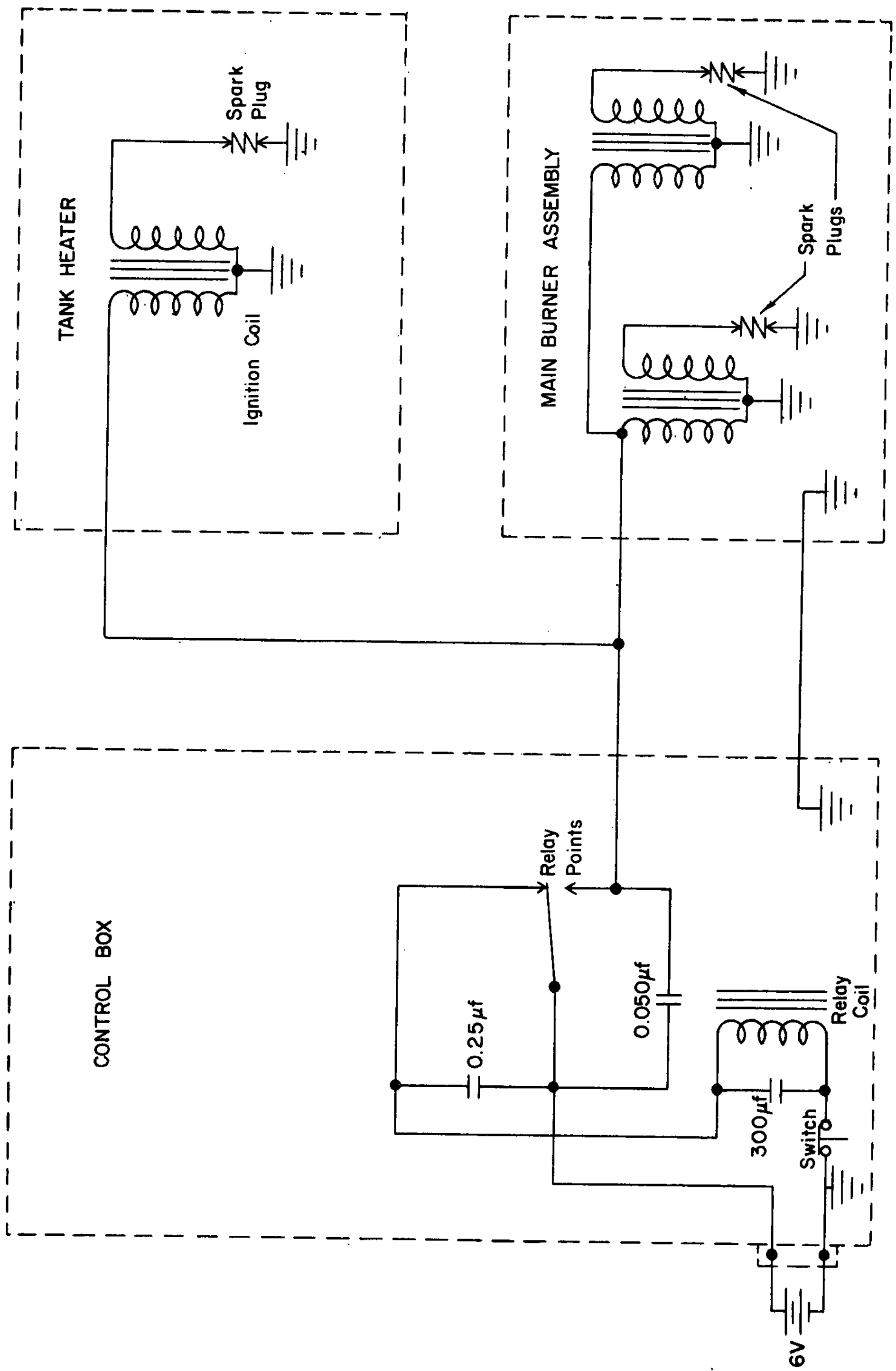

Figure 7.7

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VIII. CONTROL OF HOT AIR BALLOONS

Control of the lift in a hot air balloon will be required, particularly in manned operations. Three possibilities have been considered:

1. Valving of hot air from the top of the balloon
2. Drawing air from the bottom of the balloon by reversing the inflation fan
3. Modulating the fuel input to the burner.

A. Valving

Calculations have been made of the valving areas required for lift loss rates up to 20 lb/min. These are shown in Figure 8.1. Valving areas equivalent to circular openings 6 to 18-inches in diameter result.

Figure 8.1 is based on the assumption that a 27,000-ft^3 balloon operates at a constant lift of 350 lb at altitudes from sea level to 15,000 ft by maintaining the required internal temperature. At every altitude the density difference between inside and outside is 0.01296 lb/ft^3. The required rate of air flow for a lift loss rate of 20 lb/min is 25.7 ft^3/sec. Low lift loss rates require proportionally lower air flow rates.

Flow in this case is incompressible, and the equation below is valid:

$$Q = CA\sqrt{2gh} \tag{8.1}$$

where

Q is the flow rate, ft^3/sec

C is the orifice coefficient (assumed 0.60)

A is the free flow area, ft^2

g is the acceleration of gravity ft/sec^2

h is the motive head, ft.

The motive head, h, can be determined from the height of the valve above the zero pressure level as follows:

$$h = \frac{(\rho_a - \rho_b) L}{\rho_b} \tag{8.2}$$

where

ρ_a is the density outside the balloon, lb/ft^3

ρ_b is the density inside the balloon, lb/ft^3

L is the height of the valve above the zero pressure level, ft.

B. Reversing Inflation Fan

The inflation fan used in the prototype unit handles 1,280 cfm. This corresponds to a lift loss rate of 16.6 lb/min following the analysis above. The possibility has occurred of reversing this fan so as to draw air from the balloon for control purposes, thereby eliminating need for a valve in the top.

C. Modulating Fuel Input

Modulation of the fuel input to the burner appears to have merit as a control technique. The prototype assembly described in Section VII is capable of operating over a range of 10 per cent to 100 per cent of its full capacity, thereby allowing control of the lift. The dynamic response of the system to this type of control is not reliably calculable, however, and must be determined by field experiment.

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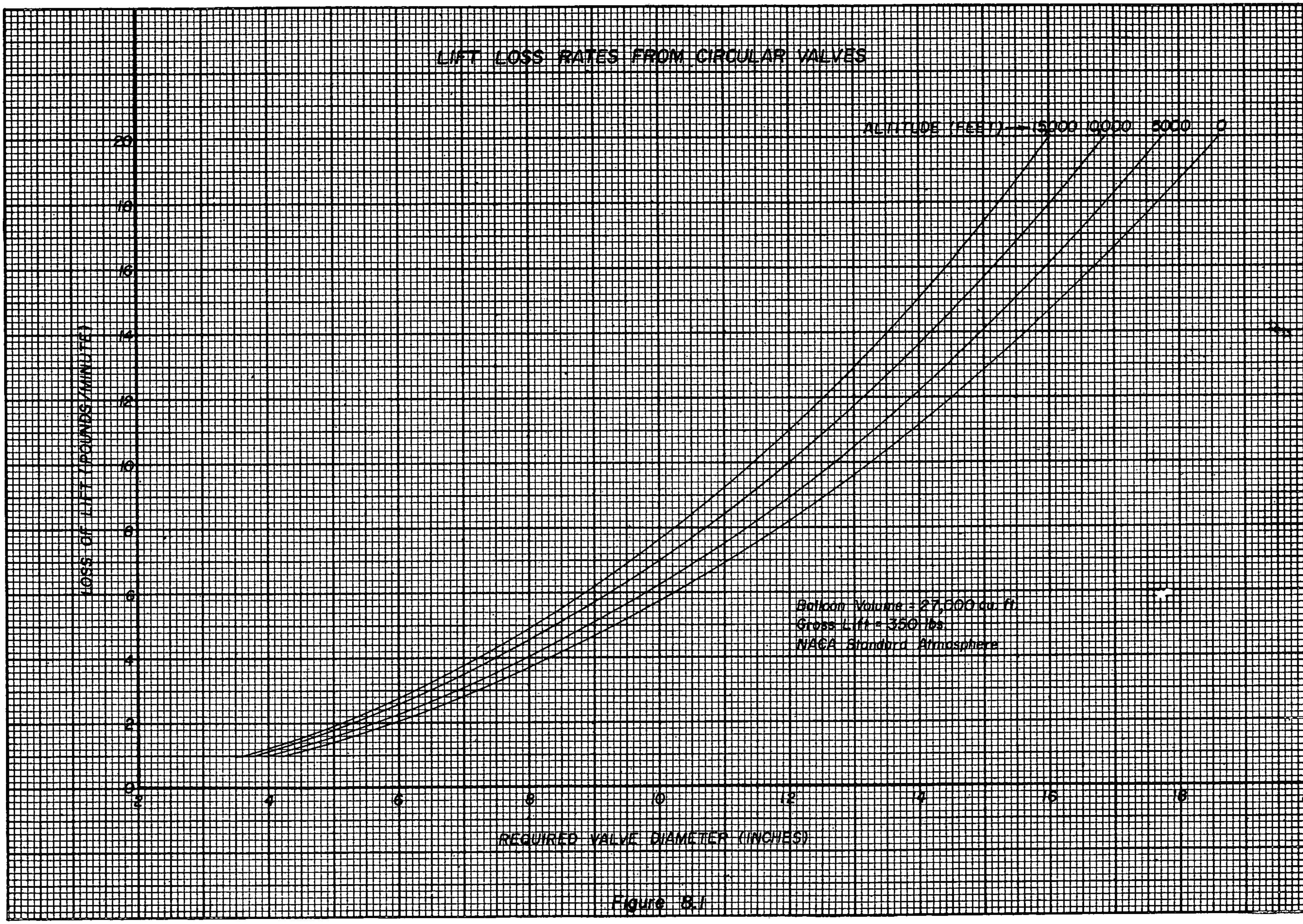

Figure 8.1

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IX. CONCLUSIONS

From the work covered in this report, several conclusions are drawn. These are given below:

1. The lift produced in a hot air balloon is consistent with the classic theory of buoyancy. The graphical solutions of Section II provide accurate determination of lift and required balloon size.

2. Maximum surface temperature occurs at the apex of the balloon and is approximately equal to the average internal air temperature as shown in Figure 4.9. This means that, even though the general surface temperature is considerably lower than the internal air temperature, the balloon must be capable of withstanding an actual film temperature equal to the design average internal air temperature. Mylar is a more satisfactory balloon material than polyethylene because of its higher maximum operating temperature. Mylar balloons should be satisfactory for temperatures up to 250°F and polyethylene should be limited to a temperature of 150°F.

3. Heat loss through the balloon film can be closely predicted by the method outlined in Section IV. Fuel input must be greater than the heat loss through the film plus ventilation heat loss, as evaluated in Section III.

4. The most satisfactory fuel for a hot air balloon is Propane, which can be contained as a liquid and burned in the gaseous form. This fuel allows broad modulation of the fuel input with relatively simple, lightweight equipment.

5. Combustion mixtures involving approximately 200 per cent excess air are recommended to insure complete combustion and to maintain a low dew point within the balloon.

6. Electric ignition systems can successfully provide remote-controlled re-lighting of the burner with a low-weight dry battery power source.

7. Initial installation of a man-carrying hot air balloon can successfully be accomplished in approximately 30 minutes with an electrically-driven inflation fan, similar to the type used in the prototype, with a dry battery power-pack weighing 7.5 lb.

8. A duration of two hours at 5,000 feet is considered compatible with a 27,000-ft manned-balloon system utilizing a propane fuel system, as discussed in Section IV.

9. The field of multilayer balloons holds promise of reducing the fuel consumption from that of a single-layer balloon. Double-wall balloons were built (see Section IV) which showed moderate improvements. Reductions in heat loss more nearly consistent with the theoretical analysis should be obtainable if a successful method of separating the layers is found.

X. REFERENCES

1. Marks, L. S., Mechanical Engineers' Handbook, Fifth Edition, McGraw-Hill, New York, 1951, (a) p. 343, (b) p. 348.

2. Heating Ventilating Air Conditioning Guide, Volume 33, American Society of Heating and Air Conditioning Engineers Inc., New York, 1955, (a) p. 356, (b) p. 174-179, (c) p. 735, (d) p. 759, (e) p. 117.

3. Timoshenko, S., Strength of Materials, Part I, Second Edition, D. Van Nostrand Co., New York, 1940, p. 42.

4. Carrier, W. H., Cherne, R. E., and Grant, W. A., Modern Air Conditioning, Heating and Ventilating, Pitman, New York, 1940, p. 235.

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