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General Mills
MECHANICAL DIVISION
2003 EAST HENNEPIN AVENUE • MINNEAPOLIS 13, MINNESOTA • FEDERAL 2-7481

February 6, 1959

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GENERAL MILLS
Subject: GMI Unsolicited Proposal No. E-1106 - Low Altitude Airship

Gentlemen:

General Mills, Inc. is pleased to submit herewith five (5) copies of our unsolicited proposal No. E-1106 for a low altitude airship.

We have elected to submit budgetary costs for your planning purposes; however we would be happy to submit a complete breakdown of costs if you so deem it necessary at this time. The estimated cost to design and develop a system in accordance with the technical discussion is $100,000. A budgetary figure for each vehicle in quantities of twenty (20) is $7,400 which includes $1,400 for batteries. The hardware items and batteries on the airship are reusable if they are recovered undamaged. We anticipate this recovery for at least 80 percent of the flights thereby reducing the total cost of the twenty units. One set of ground equipment will be required for each launch point which will include IR, transmitters, etc. costing approximately $5,000.

If you have any questions during your evaluation of subject proposal, please feel free to contact us and we will be happy to forward any additional information you may require.

Very truly yours,

Mechanical Division of
GENERAL MILLS, INC.

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MECHANICAL DIVISION General Mills

TO WIDER WORLDS — THROUGH INTENSIVE RESEARCH • CREATIVE ENGINEERING • PRECISION MANUFACTURING

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February 3, 1959

LOW ALTITUDE AIRSHIP

Technical Proposal E-1106

Prepared by:

Mechanical Division of
GENERAL MILLS, INC.
1620 Central Avenue
Minneapolis 13, Minnesota

This document consists of 52 pages, and is number 3 of 13 copies.

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LOW ALTITUDE AIRSHIP

Technical Proposal

I. INTRODUCTION

This document is an unsolicited proposal for the development of an automatic package delivery airship system. General Mills, Inc. believes that a requirement for such a system exists, and this proposal defines our approach to the development of the system.

A. Background

In December 1958, General Mills, Inc. (GMI) determined that a requirement may exist for an automatic package delivery airship system. This system should be capable of being transported in a small motor vehicle to a launch point, of being inflated and launched in the field, and would deliver a 25 pound payload to a remote area and then return to the vicinity of the launch point.

1. Detailed Requirements

The airship should possess the following flight requirements:

Payload	25 pounds
Range (launch point to target)	1 mile minimum 5 miles maximum
Maximum airspeed	20 knots
Altitude (maximum)	2,000 feet MSL
Launch Altitude	0-1500 feet MSL

The airship will operate silently to prevent audible detection, and it will be colored to provide minimum visual detectability. The weight and helium content of the airship will be held to a minimum consistent with the load carrying requirements to facilitate field launching by a small crew. The entire airship system will be transportable in a small truck.

2. Typical Mission

A possible mission of the system may be as follows: A crew in a small truck drives to a field location near a closed danger area. They stop, remove the airship from the truck, inflate it and ready the simple guidance system. The payload is attached, the motors are started, and the airship takes off. It rises 500 feet above the terrain, silently crosses a danger area and then descends to low level. It flies a few feet (25) above terrain until it reaches the desired destination. The payload is then released and the airship rises 500 feet and returns to the vicinity of the launch point. This operation is illustrated in Figure 1.

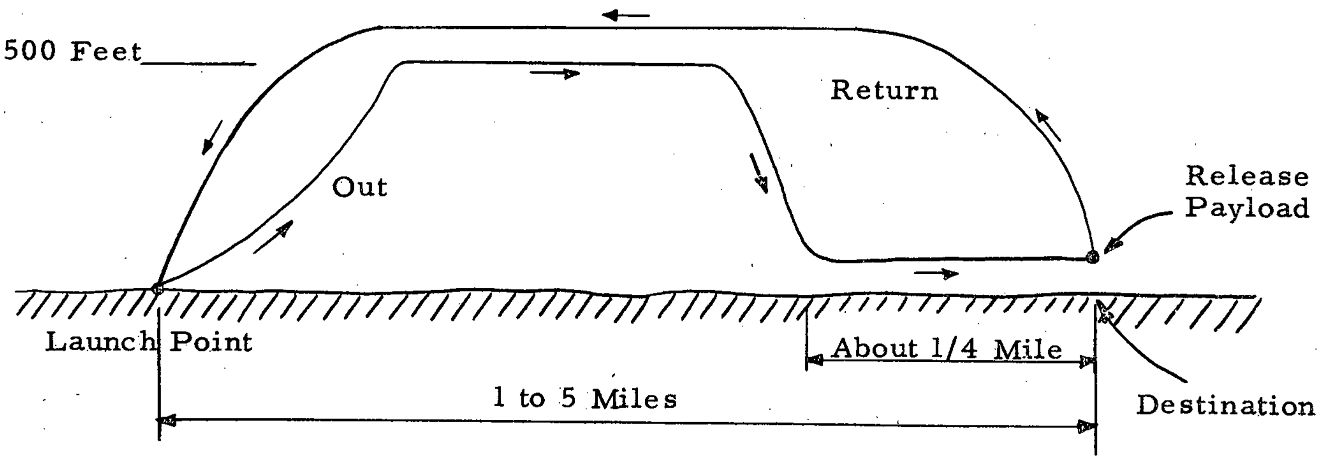


Figure 1. Mission Profile

The navigation requirements for the airship are simple because the destination or target is long and narrow, such as a road. We can assume that navigation within a 30 degree wedge is satisfactory, as sketched below.

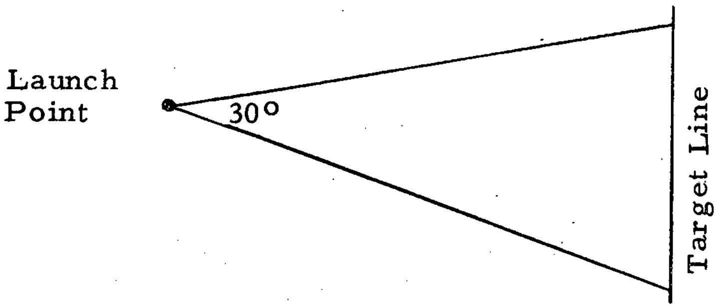


Figure 2. Horizontal Flight Path Limits

The airship need not return precisely to the launch point; however, it should return across the danger area and it is desirable that it be located and recovered.

It has been indicated that experienced personnel will be utilizing the equipment involved in this system, and that such personnel have handled and inflated polyethylene balloons under field conditions.

Line-of-sight radio command control guidance of the airship is permissible, if such is required.

B. System Description

This paragraph contains a general description of the proposed system. The configuration of this system has been established on the basis of our limited knowledge of the application and operational requirements of the system, and it is possible that a more detailed understanding of these requirements will make an alternate system more desirable. This is particularly true of the airship guidance system. A more detailed technical discussion, including alternate versions which were considered, will be found in later paragraphs of this proposal.

The configuration of the proposed system is shown in Figure 3. The airship has the following characteristics:

Length	34 feet
Diameter	11 feet
Gross Volume (including tail fins)	2330 cubic feet
Helium Volume	2190 cubic feet (sea level)
Balloon System Weight	102 pounds (not including payload)
Material	2 mil polyethylene
Propulsion	Two 1/2 HP DC motors 2 foot diameter propellers
Speed	20 knots

Side mounting of the motors permits azimuth control and keeps the propellers away from vegetation and personnel. The vertical fin has been placed above to keep it out of the way also. The fins are pressurized with helium.

The "gondola" suspended below the airship contains the payload, the altitude control rope (drop-line), the ballast, the guidance and control system and

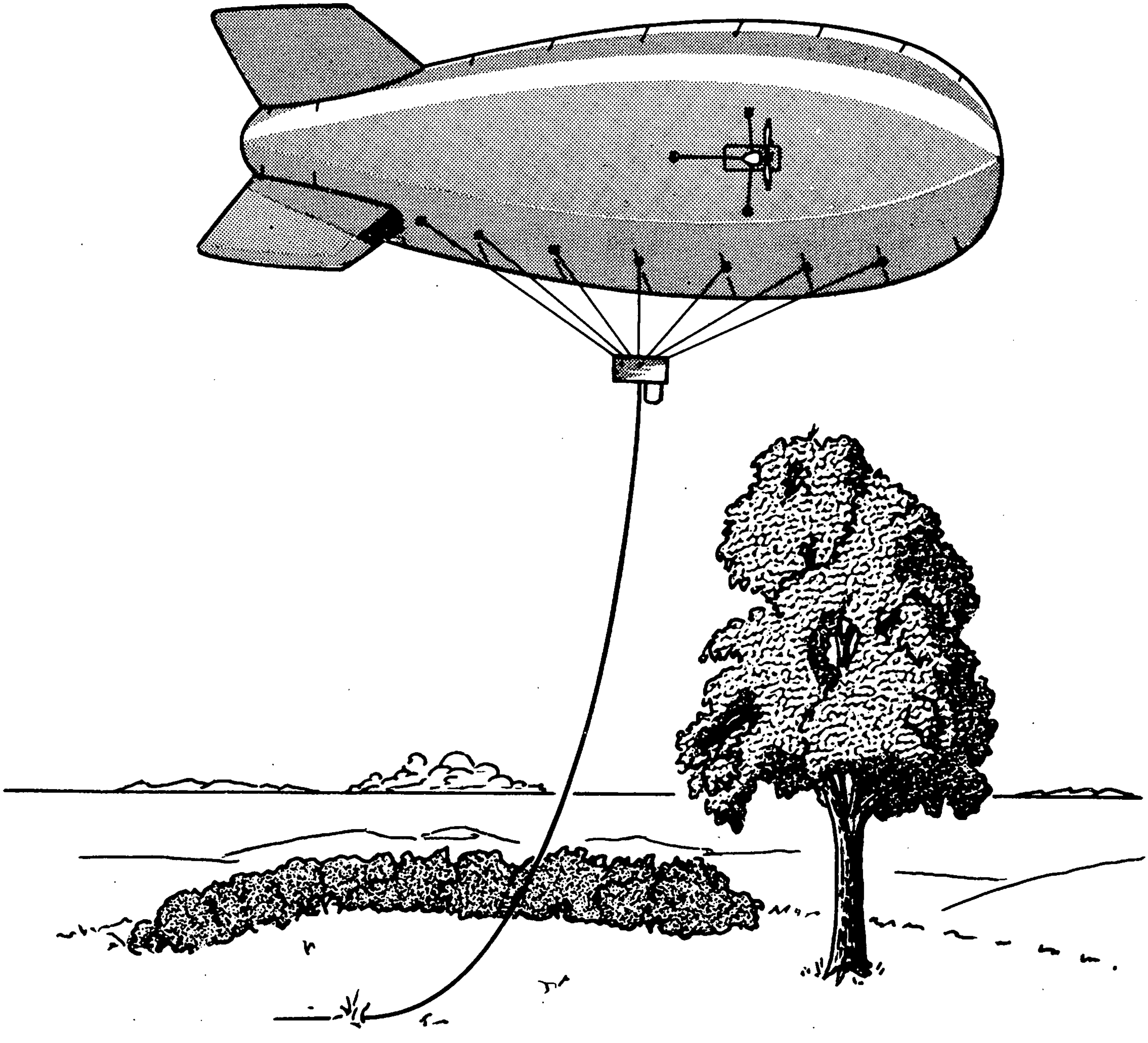


Figure 3. Low Altitude Guided Airship

the batteries. The gondola is made of cloth and is suspended by nylon harness lines. Such construction reduces packaging problems and aids portability.

The airship system will contain a simple guidance system which will establish the proper ground track for the airship at altitude. Changes of direction of flight are accomplished by turning the side mounted motors on and off, thereby eliminating the need for movable control surfaces. Provisions will also be included to allow the ground crew to track the progress of the airship constantly as long as it is within line-of-sight. We believe that this capability is necessary to speed the mission and thus help insure its success.

The elements of the guidance system are:

1) Altitude, sensed by a pressure altimeter and controlled at high altitude by valving helium or dropping ballasts. At low altitude, the drop-line maintains terrain clearance.
2) Direction, sensed by a compass in the airship.
3) Ground track, sensed by tracking the vehicle with an infra-red "sniperscope" or IR viewers which are commercially available. To aid in tracking, the vehicle will carry an infra-red light, which will be shielded to prevent radiation in all directions. Range to the airship can be measured by using two "sniperscopes" and by triangulating with the aid of a small navigation plotter.

Ground track will be corrected after launching by a command radio link which directs a corrected azimuth heading to the airship. Once established as a directional memory, the airship will continue to fly this heading until the payload is released.

Upon release of the payload, the airship rises to 500 feet above terrain and heading command is transmitted which returns the vehicle to the launch area.

If it were possible to assume that operation would occur only under very light wind conditions, then the guidance system can be greatly simplified. No means of determining ground track would be necessary. The airborne guidance system would include a compass to maintain heading, and airship descent would be initiated by a simple timer instead of by radio command.

C. System Capabilities

The system described herein can be launched under field conditions. Unpacking, assembly and inflation can be accomplished by 2 or 3 men in 1 hour or less. Although a top speed of 20 knots should permit operation in winds up to 15 mph, field inflation should not be attempted if surface winds are in excess of 10 mph. Surface winds at night are usually low, and nighttime operation should be possible most of the time.

The airship with 33 pounds of silver cell batteries has a duration of about 60 minutes. This duration will theoretically permit delivery to a line 5 miles from launch point and will permit return with head or tail winds as high as 17 mph, (assuming perfect guidance) and winds as high as 21 mph at 90 degrees to the flight path. This operation is shown in Figure 4. With no wind at all, the 5 mile mission can be accomplished in 26 minutes, and a 1 mile mission in about 5 minutes.

The normal mission should be complete, including inflation, flight and recovery, in less than 2 hours. This time may be divided as follows:

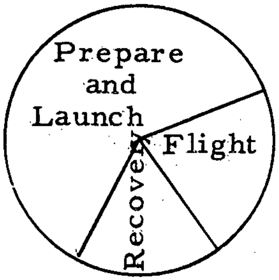


Figure 5. Distribution of Operational Effort

The above is based on a reasonable expectation of 60 minutes for assembly, inflation, operational check, and launch; 30 minutes for flight (both ways); and 20 minutes for recovery.

Operation of the airship will be quiet, and the infra-red light will not be visible to the naked eye. This, coupled with small size of the vehicle, will minimize the probability of detection.

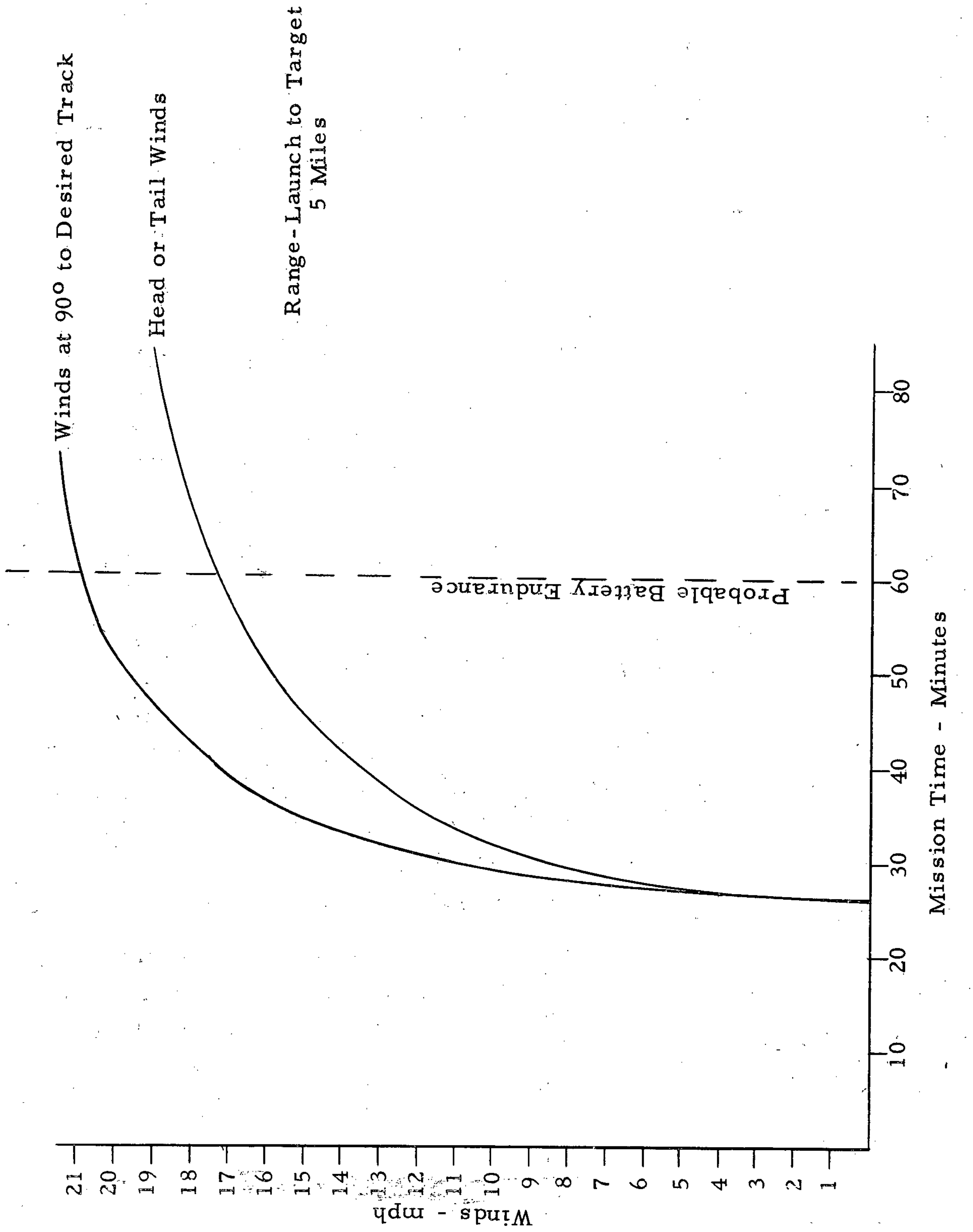


Figure 4. Mission Time for Various Winds

II. TECHNICAL DISCUSSION

A. Design Considerations

The basic criteria used in the design of this airship are high reliability, ease of launching and flying, and a low unit cost. Therefore, the system components will be items which are proven and which are commercially available rather than components which must be developed.

1. Design Parameters

a. Envelope Shape

The navy Class "C" shape with a 3 to 1 fineness ratio has been selected for the envelope shape. GMI has used this shape for its captive balloons, a number of which were in the same volume range as this airship, and has found it to be highly satisfactory. It has a low drag coefficient, a high volume-to-surface area ratio, and has a favorable position of the center of buoyancy.

b. Envelope and Tail Material

The general requirements for the materials are 1) low elongation, 2) low gas permeability, 3) high strength-to-weight ratio, and 4) abrasion and handling injury resistance. The material elongation must be held to a minimum to prevent shape distortion and subsequent deterioration of the envelopes aerodynamic characteristics. Low gas permeability losses give the balloon a longer flight time, while a high strength-to-weight ratio allows a relatively smaller gross envelope volume for a given payload because less lifting gas is required to lift the envelope. The material must be tough to prevent leaks from developing during normal handling procedures.

A two-mil polyethylene film most adequately meets the specifications and will be used. Polyethylene is recommended instead of Mylar because polyethylene is much easier to fabricate and Mylar has such a very low tear resistance.

c. Tail Surfaces

An ellipsoid has its stable direction of translation through the atmosphere when its shortest axis lies tangent to its path. This results in the body tending to turn broadside to the direction of movement through the fluid medium and results in the maximum drag or energy being dissipated into the slipstream. Therefore, airships are fitted with stabilizing fins to produce a moment counteracting this tendency of streamlined bodies of revolution to turn broadside to the wind. The attachment of fins near the aft-end of the airship which are parallel to the major axis of the airship results in their having a restoring moment which is minimum when the wind flow is parallel to the major axis and which increases rapidly as the flow is displaced from this axis. The fins also disturb the theoretical pressure distribution around the hull allowing the production of some stabilizing forces on the hull itself.

The desired airship flight characteristics must be specified and the tail efficiency defined before the actual tail fin area can be specified. If the tail fins are too small, the airship will have the tendency to turn broadside to its direction of translation which means that power would always have to be expended to bring the airship back to the desired course. If the tail fins are too large, the airship will be so stable that it cannot be maneuvered without expending a great deal of power.

The efficiency of the tail fins is a function of their aerodynamic characteristics and their placement on the envelope. A rigid fin such as an airplane wing can be made so that it has a high restoring force through small angles of displacement. Such a fin should not be packaged with the balloon envelope because of the danger of it punching holes in the envelope during shipping. It would probably have to be mounted on the envelope in the field after the airship has been inflated. An inflatable fin can be made which does not have as effective aerodynamic properties, but which possesses certain other advantages. Inflated fins are recommended for the following reasons:

1) Lower weight.
2) May be fastened to the envelope at the factory.

3) Simplifies ground handling during inflation.
4) The base of the fin may be made relatively broad reducing the stress in the envelope with a minimum weight penalty.

The force acting on the tail fins produces a moment of torque which tends to rotate the airship about its center of rotation. Therefore, as the length of the moment arm increases, the forces acting on the fins may be reduced. Because the center of rotation is near the middle of the balloon, the fins should be placed as far aft as practical.

A review of references 1, 2 and 3 and the analysis in this report on maneuverability indicates that a tail surface projected area of .5 (balloon envelope volume)$^{2/3}$ divided equally into an inverted "Y" form tail and placed as shown in Figure 3 is satisfactory for the recommended inflated tails.

The tails will be inflated with helium and pressurized to the same pressure as the envelope by having free circulation between the tails and the envelope. The estimated volume of the tail fins is 110 cubic feet.

d. Pressurization

The airship must be pressurized to prevent deformation by the dynamic pressure of the air and bending moments produced by the payload and propulsion system. The common method of maintaining a constant pressure differential between the lifting gas and the outside air is by using a ballonet. A ballonet is a compartment within the airship envelope which may be inflated or deflated with air, thus varying the volume occupied, and hence, the pressure of the lifting gas. As the airship rises, the pressure of the external air decreases so that air must be evacuated from the ballonet to allow the lifting gas to expand and reduce pressure. The converse is true when the airship descends. A more complete discussion of this problem is included in the static stability and the altitude control sections of the proposal.

---

1. Bairstow, L. Applied Aerodynamics Second Edition, New York, Longmans, Sreen, and Company, 1939.
2. Burgess, C. P. Airship Design, New York, Ronald Press, 1927.
3. Blackemore, T. L. Pressure Airships, New York, Ronald Press, 1927.

The ballonet will be pressurized by a two blower system with each blower stalling at 1/2 inch of water pressure. One small blower will operate continuously to maintain the pressure in the ballonet to overcome leaks and minor changes in altitude. This blower will have a flow rate from 0 to 200 CFM. During the valving operation, a larger blower will operate to place air in the ballonet at the same rate that helium is being valved. This blower will have a capacity of about 700 CFM. An airtight flap-type valve will lie over the top of this large blower when it is not operating to prevent air loss from the ballonet. The valve will be gravity operated for closing while the pressure generated from the blower will open the valve during operation. See Figure 6 for the blower arrangements.

e. Airship Volume

The airship must have a large enough volume of helium to support its weight buoyantly at the maximum design altitude. Since the airship must fly to an altitude of 2000 feet MSL, the required volume may be calculated from the relationship: system weight = airship volume times helium buoyant lift, pounds per cubic foot.

The following is an estimated breakdown for the system.

Payload and release mechanism	25 pounds	5
Propulsion system	20 pounds	20
Navigation and controls	16 pounds	16
Wiring	3 pounds	3
Drop line and ballast	20 pounds	10
Batteries, including rack	33 pounds	[illegible]
Ballonet blowers, helium valve	7 pounds	7
Balloon weight, including harness, ballonet, etc.	$.1201 \text{ vol}^{2/3}$ pounds	

The lift of helium at 2000 feet based on the NACA standard atmosphere is .0622 pounds per cubic foot. As previously stated, the volume of the tail fins is about 110 cubic feet, hence they will have a lift of about 7 pounds. The volume relationship may now be expressed as $.0622 \text{ vol} = .1201 \text{ vol}^{2/3} + 117$. Therefore, the minimum balloon volume is 2220 cubic feet. The length of

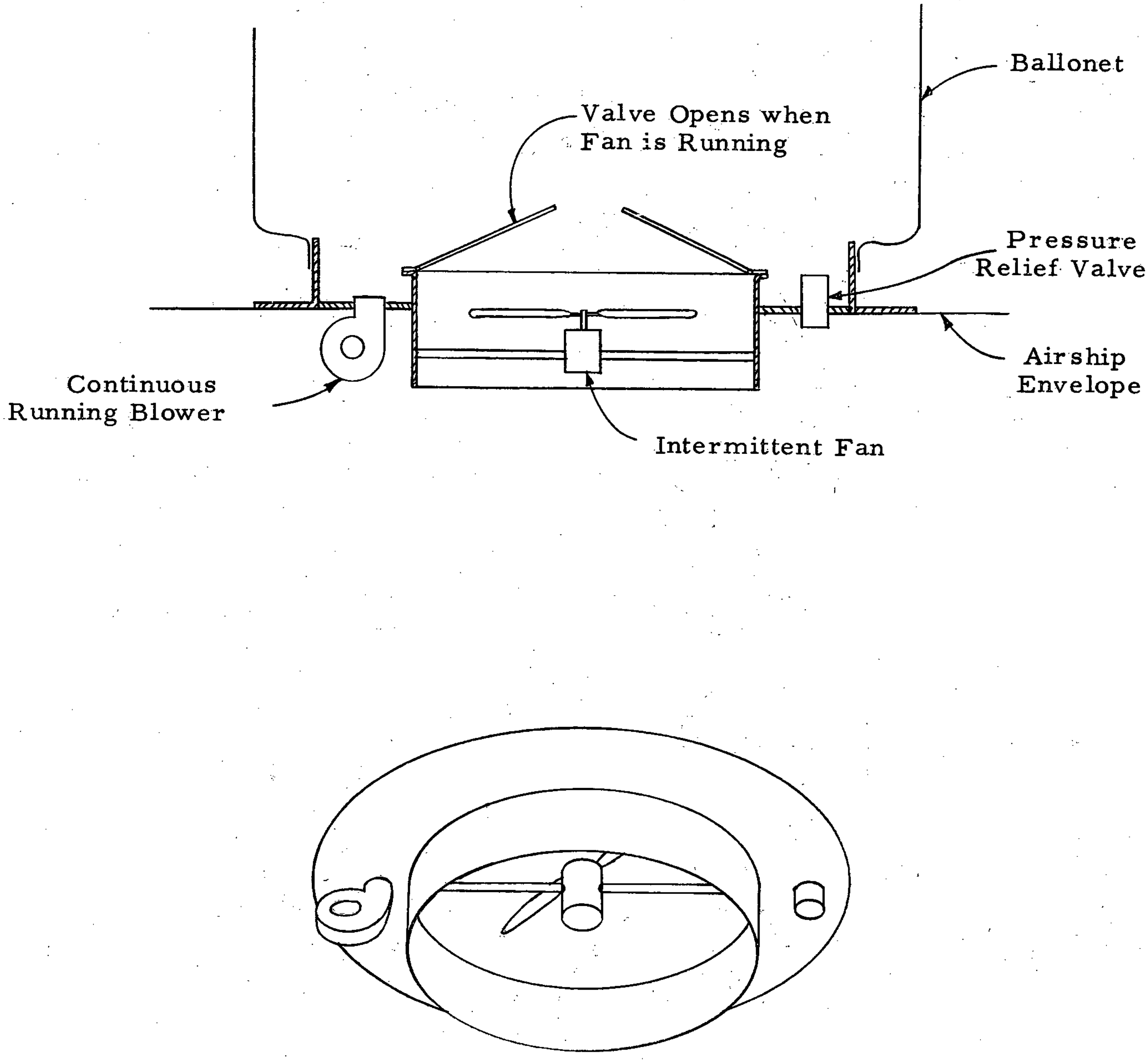


Figure 6. Ballonet Pressurizing System

this balloon is 34 feet and the maximum diameter 11.3 feet. The estimated balloon weight is 20.4 pounds.

f. Static Stability Considerations

The airship is in equilibrium when the sum of the external moments is equal to zero.

The balloon's position when it is in equilibrium is significant because any transient forces acting on the balloon will result in perturbations about this position. For the present case, the two most significant components of the airship's position are its angle of attack and its altitude above the ground.

(1) Airship Angle of Attack - The angle of attack of the airship is defined as the angle between the major axis of the airship and the wind or relative motion of the atmosphere. The drag of the airship is minimum when this angle is zero and it increases by a factor of the angle squared as the airship is displaced from this position. Therefore, the airship flies at a zero angle of attack, it will result in the minimum dissipation of power to complete the mission.

The major forces acting on the airship are the buoyancy of the lifting gas and the gravity forces acting in the vertical plane and the drag and the thrust acting in the horizontal plane. (The airship is symmetrical and proper tail fins will be applied so that there will be no aerodynamic pitching or yawing moments at zero angle of attack.) For steady state flight, the thrust equals the drag, so the moments from the horizontal forces can be made equal to zero by placing the propulsion force at the same level as the effective center of drag of the airship. The moments from the vertical forces will be zero if the center of buoyancy is directly above the center of gravity of the system. The gravity forces on the airship change when ballast is dropped and when the payload is released so these or any other varying weights should be placed directly below the center of gravity to avoid shifts in the position of the C. G.

When loads are dropped, the buoyant forces must be reduced to maintain airship equilibrium. Buoyancy is reduced by valving helium. As helium is valved, air is forced into the ballonet to maintain a pressure differential across the envelope. Since the center of buoyancy is defined as the point where the sum of the moments of the lifting gas is equal to zero, the helium released and the air added to the ballonet must be symmetrically placed with respect to the C. G. This will be accomplished by placing a cylindrical ballonet in the airship with the major axis on a line passing through the center of gravity and the center of buoyancy (See Figure 7).

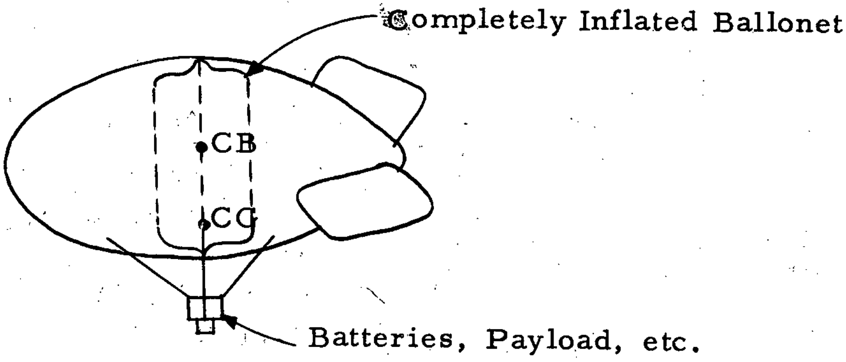


Figure 7. Ballonet Placement

Based on preliminary estimates, the center of buoyancy of the proposed system is 15. 8 feet from the nose and along the center line of the airship. The center of gravity is also 15. 8 feet from the nose and 6. 9 feet below the center line before the load is dropped, and 5. 8 feet below after the load has been dropped.

With the center of gravity located below the center of buoyance at zero angle of attack, the system acts as a pendulum with the center of buoyancy as the pivot point (See Figure 8). The weight of the airship system gives a restoring moment of $N = wL \sin\alpha$ if it is displaced from its equilibrium position tending to return the airship to its zero angle of attack position.

(2) Airship Altitude - The airship maintains altitude in the atmosphere by the buoyance principle. If the weight of the displaced air is equal to the weight of the airship, the vertical forces will be in equilibrium

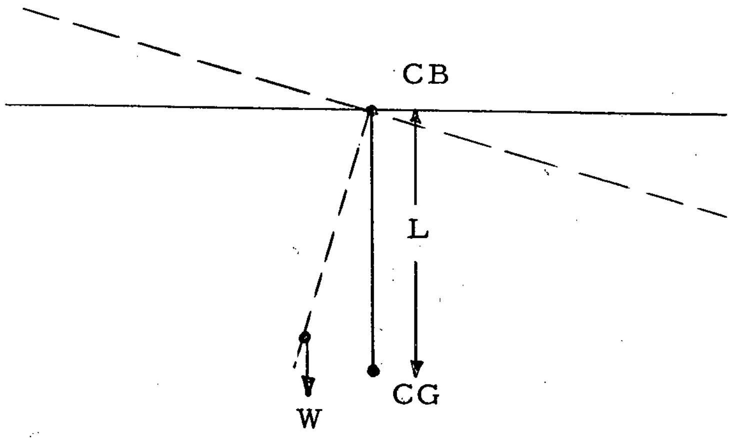


Figure 8. Static Stability

and the airship will remain at its present altitude. If the weight of air displaced exceeds the airship weight, it will rise; and if the airship weight exceeds the weight of the displaced air, it will descend.

Obviously, the airship gets its buoyant lift from the fact that a cubic foot of helium gas weighs less than a cubic foot of air at the same temperature and pressure. Therefore, the buoyant lift of the airship may be lowered by valving off helium into the free air and replacing the helium by air in the ballonet. This method allows the volume of the airship to remain constant while varying the lift.

(a) Ballonet Volume - The ballonet must have enough volume so that an adequate amount of air may be inserted to pressurize the airship at all points on the flight profile. The maximum helium volume in the airship is 2220 cubic feet. This volume exists when the airship is at 2000 feet MSL on the way to the target area. The minimum helium volume occurs as the airship approaches the ground when it returns to the launch area. If this area is at sea level, the volume at this point is approximately 1420 cubic feet; therefore, the ballonet must have a volume of 800 cubic feet.

(b) Helium Valving Rates - Helium must be valved 4 times on a flight mission. The airship will have excess free lift when it is released from the launch point and after is has dropped the payload. It must lose lift to approach the ground at the target area and again when it returns to the launch site. The valving rate can be specified as the rate required to cause the airship to come into equilibrium before it rises more than 500 feet after it has dropped the 25 pound payload, the time of maximum free lift.

The airship obeys Newton's second law or $F = ma$ where

m = effective mass of the airship; includes airship mass plus entrained air; slugs

a = acceleration; ft per sec^2

F = free lift minus drag where drag may be expressed as KV^2; pounds

If helium is valved at a constant rate of volume, the decrease in free lift is given by $F - ct$, if thermodynamic effects are neglected, where F is the initial free lift, c is the valving rate in pound lift per sec, and t is time in seconds. The differential equations of motion then become:

$$m\frac{dv}{dt} + KV^2 = F - ct$$

or

$$m\frac{d^2h}{dt^2} + K\left(\frac{dh}{dt}\right)^2 = F - ct$$

where

h = balloon altitude, feet

V = balloon velocity, FPS

K = balloon drag factor

Neither of these equations can be solved in terms of elementary functions because of their non-linearity, so they must be evaluated on a computer or by numerical methods. The following section shows a numerical analysis for 2 cases showing the flight profiles with a valving rate of 3/4 pounds per second.

This rate proves satisfactory and will be used as present design criteria. This rate of valving and the exact length of time the valve must remain open at each position in the flight profile will be solved on our analog computer during the engineering phase of the proposed program.

The valving rates are quite critical for a satisfactory ascent and descent profile, and the valve must be accurately calibrated. The proposed system consists of an orifice and an electrically driven valve. They are mounted as shown in Figure 9. The large blower on the ballonet will start to function as the valve is opened so that the pressure differential across the orifice is constant. This constant pressure principle allows calibration tests to be run in the laboratory to determine the optimum orifice size and shape.

(c) Altitude Control Ballast - The flight profile of this system requires that the balloon fly at varying altitudes, and some type of ballast system will be required to facilitate an abrupt change in rate of descent to prevent collision with terrain. Fortunately, the application of the system results in the disposal of part of the gross load at a time that additional altitude or free lift is required, and ballast is not required at this point of operation. The ballast system will be controlled by an automatic activating device. The preliminary design of the system allows 9 pounds of weight for the ballast.

The simplest system would consist of a small tank containing a liquid ballast such as water, kerosene or any other available liquid. The dropping of this ballast would be controlled by an electric solenoid valve that would be activated by the altitude control circuit. To avoid over control, this ballast would be released through a restricted orifice of a size determined from experimental testing of the system. (See Figure 9A).

An alternate to the liquid ballast system would be one utilizing steel or lead shot for ballast. This system requires that the ballast material be clean and completely free of any foreign matter to prevent any stoppage or malfunction of the control valve. With this system, ballast would have to be furnished as part of the field package and would be contained in sealed, moisture proof containers. This system also would use an electric solenoid valve to regulate the flow of ballast.

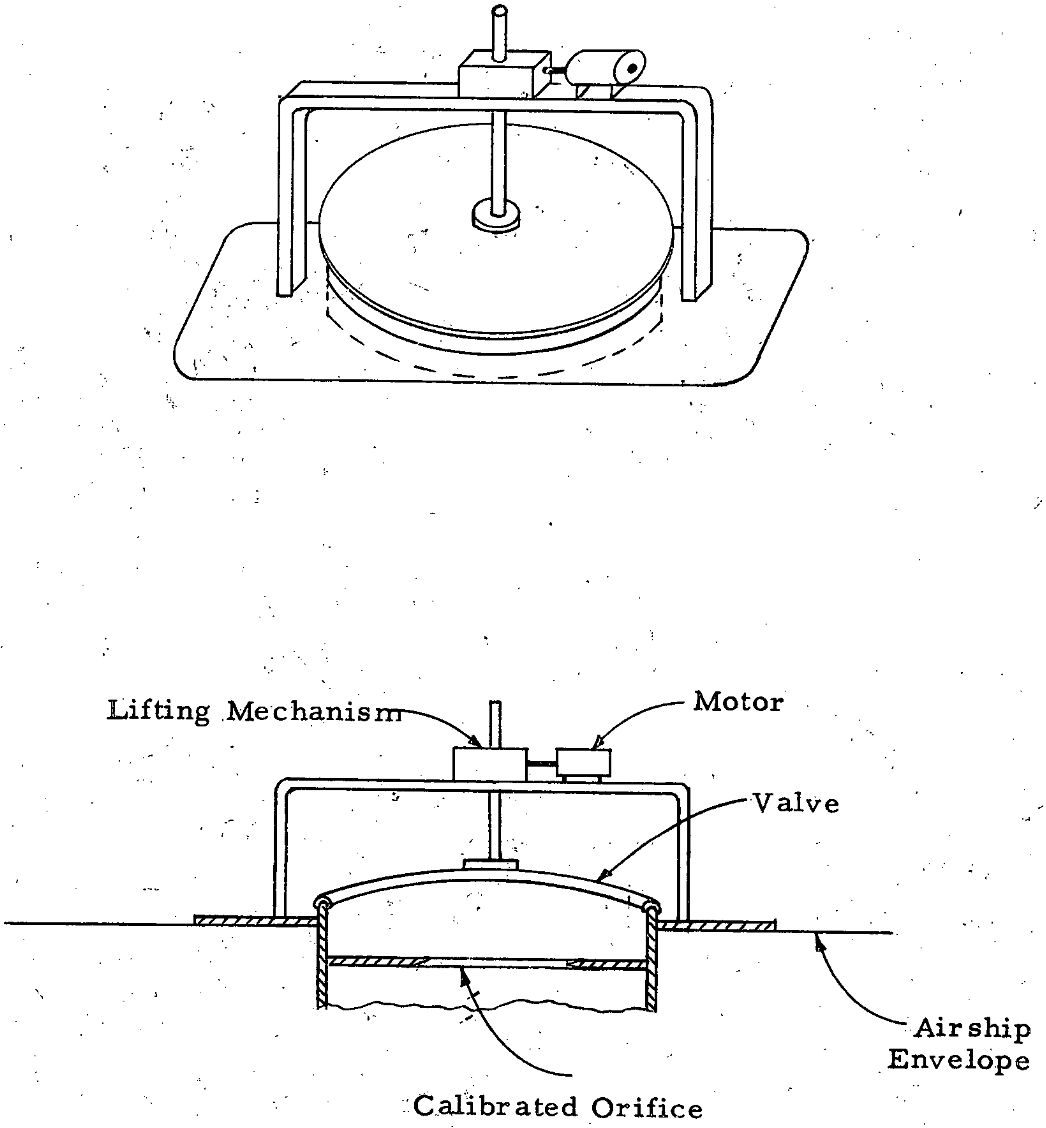


Figure 9. Helium Exhaust Valve

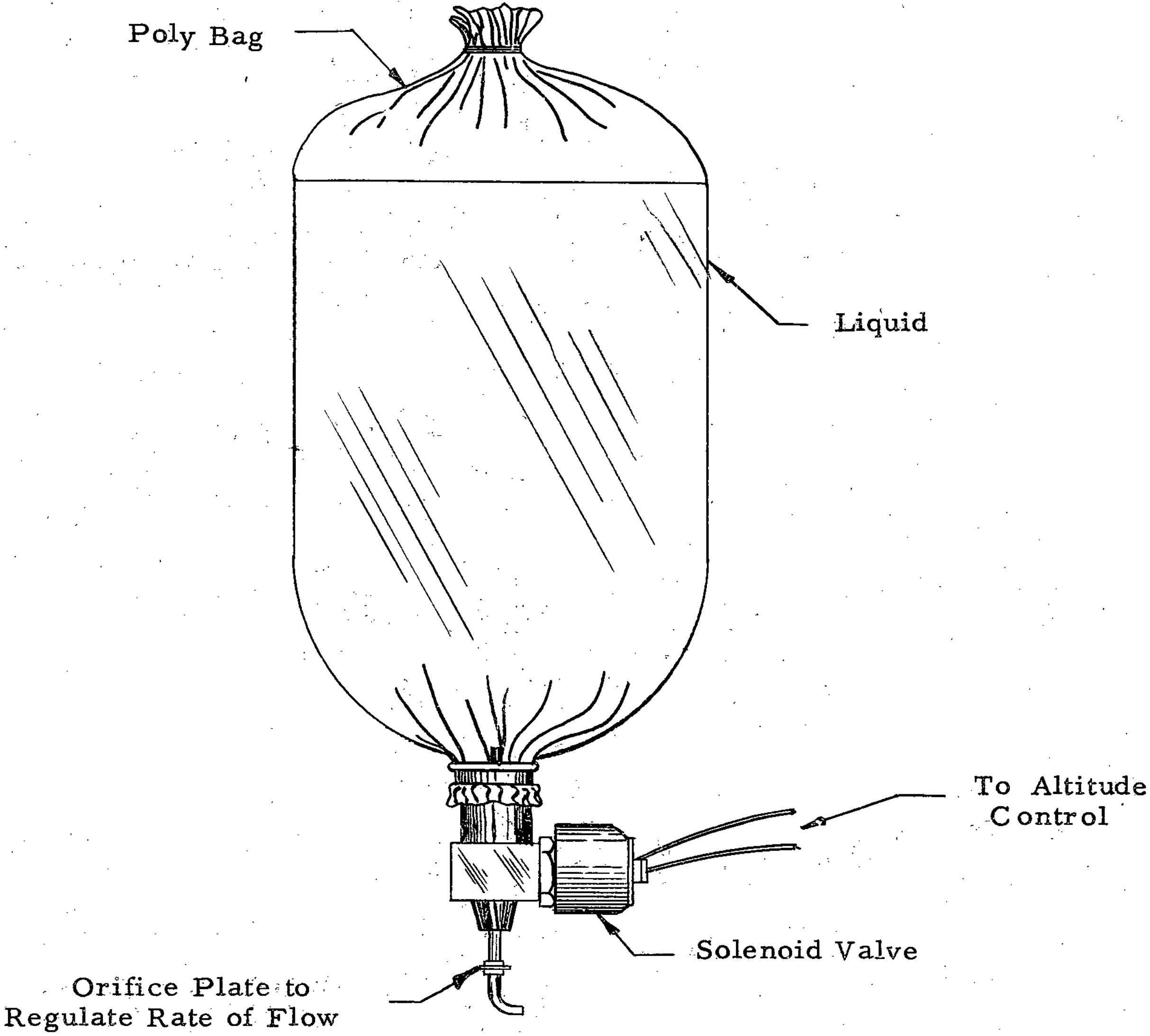


Figure 9A. Liquid Ballast System

(d) Drop Line - The use of a drop line or drag rope is common for very low altitude balloon flights. This allows a balloon to float at a near constant low level without the use of large quantities of ballast to correct for small changes in altitude. This method is not practical in areas that are forested or covered by brush or hedges because of the possibility that the rope may become tangled and stop the progress of the balloon. By proper selection of the drag rope material, this probability may be minimized but cannot be eliminated entirely. Tentatively, the drop line is 50 feet long and consists of a light, hollow plastic tube which will be shot loaded to a 5 pound weight in the center and at the lower end. This method presents a more decisive force in controlling the airship's variations than a line with a uniform weight.

Another major reason for using a drag rope for this application is to provide a handling line to aid in launch and recovery of the vehicle. It is mandatory that the airborne system return to its launch area for recovery, and the use of a drop line would make the recovery more certain.

(e) Analysis - Figure 10 shows the resulting altitude and velocity-versus-time curve for the 500 foot descent approach to the position for dropping the payload. To start the descent, helium is valved from the airship at a rate of 3/4 lb/sec for the first 16 seconds. During this period, the loss of helium creates the necessary force to accelerate the airship downward. After the valving is stopped, the airship reaches an equilibrium velocity of 8.4 ft/sec. When it has descended to an altitude of 100 feet, a ballast of 9 lbs is dropped to lower the descent velocity. To reduce this velocity to zero, a 50 foot drop line is utilized. The drop line is a light, hollow plastic tube of negligible weight with 5 lb masses located at its middle and end positions. As the drop line touches the ground, the airship experiences a reduction in weight of 5 lbs and the velocity is reduced from 5.6 ft/sec to 4.1 ft/sec in 5 seconds. Then the second 5 lb mass touches the ground with the resultant effect of reducing the descent velocity to zero at an altitude of 17 feet above the ground. This maneuver takes approximately 80 seconds.

Figure 11 shows the resulting altitude and velocity-versus-time curve after the payload has been dropped. When the payload is dropped, the airship experiences an upward accelerating force due to the excess lift. To stop this

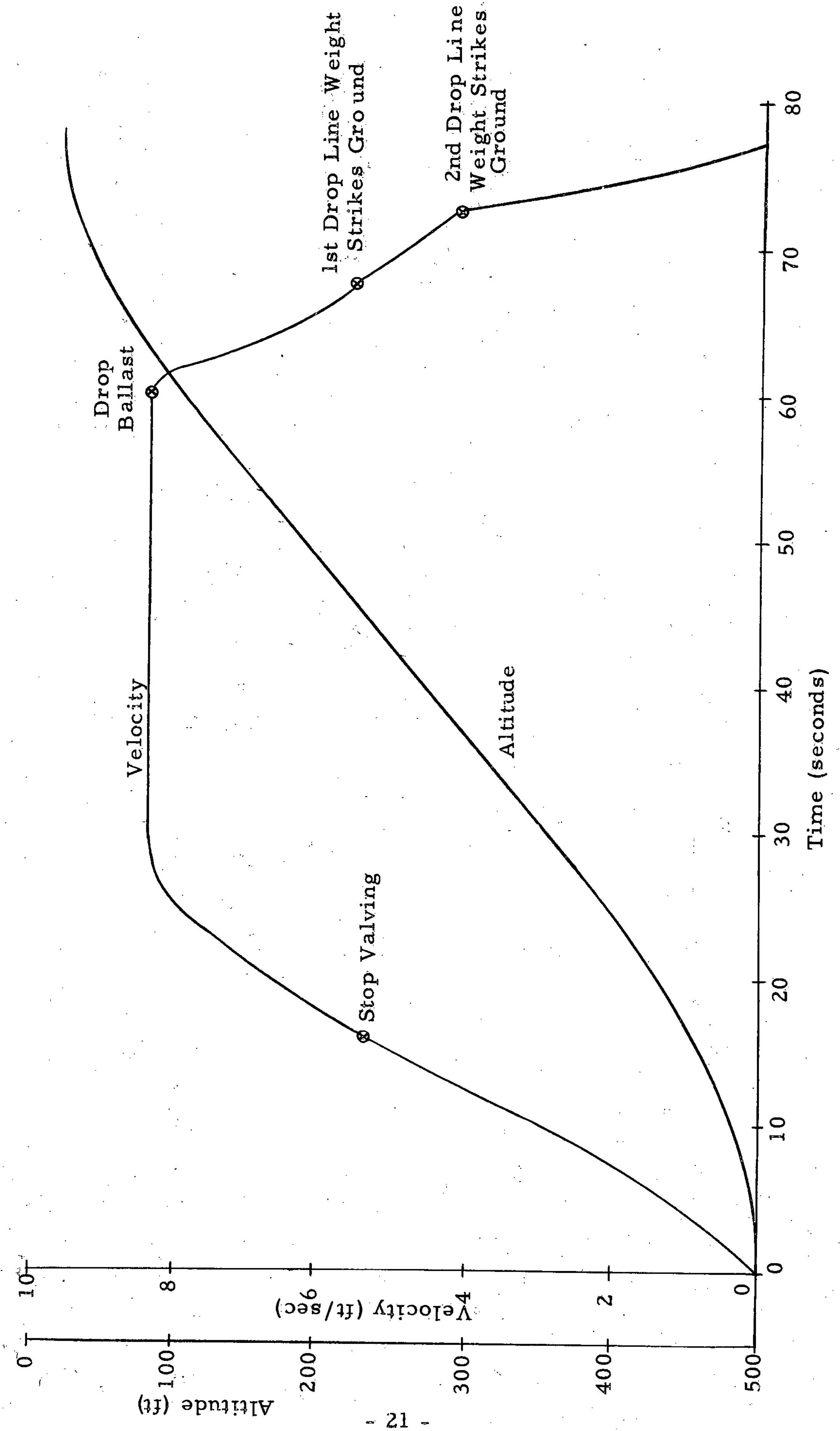


Figure 10. Descent Curve

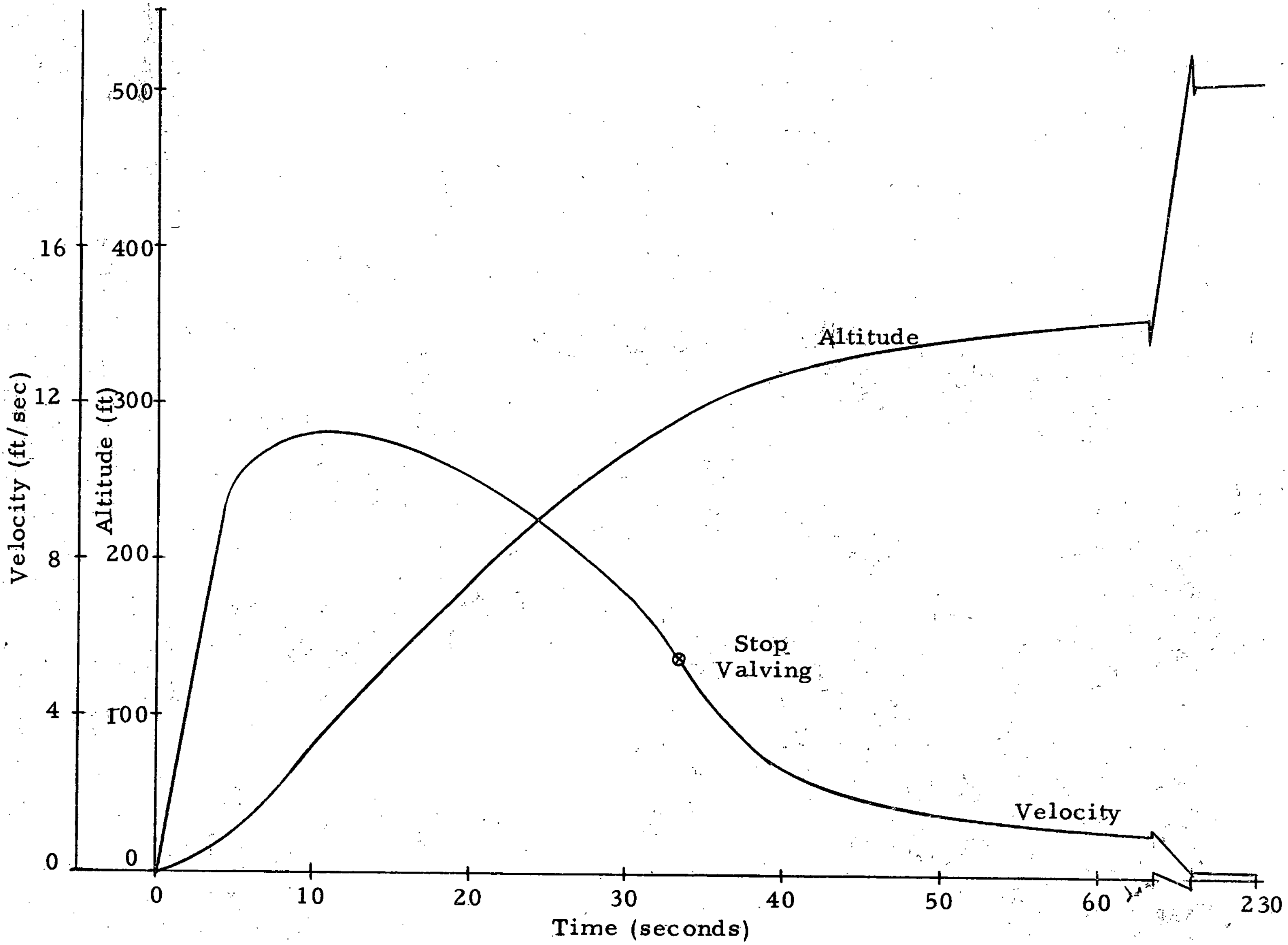


Figure 11. Ascent Curve

ascent, helium is valved from the airship at the rate of 3/4 lb/sec for 33.3 seconds. After the valving stops, the ascent velocity is reduced to zero by the opposing drag force at an altitude of 500 feet in 230 seconds.

The graphs were plotted by solving the following differential equation:

$$m\frac{dv}{dt} + Kv^2 = F - ct \qquad \text{(See Page 16)}$$

If the term (f-ct) is assumed constant over small time intervals, the following solution can be used:

$$V = \sqrt{F/K}\,\tanh\sqrt{\frac{TK}{m}} + \text{constant}$$

This equation was solved numerically, assuming F to be constant over 5 second intervals.

2. Propulsion System

Before a propulsion system can be specified, the requirements of the system must be known. The first of these requirements to be investigated is the thrust needed to propel the airship at a speed of 20 knots.

$$\text{Balloon Drag} = C_D \frac{\rho V^2}{2} \text{vol}^{2/3}$$

C_D = drag coefficient

ρ = air density, slugs/feet^3

V = airship velocity, fps

vol = airship volume, feet^3

$$C_D \approx .05$$

$$\frac{\rho V^2}{2} = 1.3 \text{ lb/ft}^2 \text{ (velocity of 20 knots)}$$

$$\mathrm{vol}^{2/3} = (2220)^{2/3} = 170$$

$$\mathrm{drag} = (.05)\,(1.3)\,(170) = 11 \text{ pounds}$$

Since the thrust must equal the drag

$$T = 11 \text{ pounds.}$$

The required propulsion system must therefore be capable of producing a total thrust of 11 pounds. The two systems which have been considered are a propeller system and rocket or jet system. Some of the factors that enter into the evaluation of the two are efficiency, heat, visibility, noise, cost and controllability. The advantages of a propeller system indicate that it would be more practical for the application in question. Cost, which is an important determining factor, would be extremely high for developing a rocket system, and at the low velocities required, the efficiency of such a system would be lower than that of a propeller system. In addition, a rocket would produce excess heat which would be detrimental to the fabric of the airship. If rocket engines were used they would have to be mounted at an unreasonable distance from the surface of the ship. The glow from the rocket would make it easily visible during night flights and the noise produced would also aid in the detection of the vehicle.

A propeller system can be developed which will be of relatively low cost as compared to a rocket development and will be difficult to detect both visually and aurally during night flights.

a. Propeller Analysis

Based on the momentum theory, a small propeller of the model aircraft type would have the following characteristics.

$$T = A \rho V_d (V_s - V_o) \tag{1}$$

where

T = thrust, pounds
A = propeller area, feet^2

ρ = air density, slug/feet^3
V_d = airship speed, fps
V_s = slipstream velocity, fps
V_o = free stream velocity, fps

Let $V_o = V_d$

if the prop radius r, = 1 foot; T = 5.5 pounds; and V_d = 33.8 fps.

$$V_s = \frac{T}{A \quad V_d} - V_o = \frac{5.5}{(1)^2\ (.00238)\ (33.8)} + 33.8 = 55.6 \text{ fps.}$$

$$\text{Efficiency} \cong \frac{V_d}{V_s \quad V_d} \cong \frac{67.6}{89.4} \cong 75.5\%$$

For a propeller running at 6000 rpm and V_s = 55.6 fps, the advance should be .55 ft/turn or 6.66 inches/turn.

The effective hp required is given by

$$H_p = \frac{T \times V_d}{550}$$

$$HP = \frac{11\ (20)\ (1.69)}{550} = .675 \text{ HP}$$

If two propellers are used, each propeller must supply,

$$\frac{.675}{2} = .338 \text{ HP}$$

The momentum theory neglects energy losses resulting from vorticies in the slipstream. If some allowance is made for these losses and the propellers are assumed to be 67.5% efficient, then the motor

$$hp = \frac{.338}{.675} = .50 \text{ HP}$$

b. Motors

The motors used to drive the propellers can be either internal combustion or electric. An internal combustion engine would be heavier than an electric motor at the low horsepower needed and would also present special problems. A clutch might have to be used between the propeller and engine to facilitate maneuvering the airship since the engine could not be turned off during flight. A muffler system would also be needed to reduce the noise. All factors point to an electric motor as the power source for driving the propellers. Such a motor would be quiet running, light weight, and easy to control for maneuvering.

One difficulty in using electric motors is that of finding a satisfactory source of power. If the motors are assumed to 60% efficient,

$$\text{Power required} = \frac{2 \times .5}{.6} = 1.67 \text{ HP} = 1245 \text{ watts}$$

A table of some of the batteries considered is shown below.

Type	Weight (lb)	Nominal Voltage	Capacity Amp. Hrs.	Watt Hours Per lb.	Lb. Per 24 V	Watt Hours Per Dollar
Lead Acid	15	12	12 @ 5 hr rate	9.6	30	4.83
Lead Acid	51	12	70 @ 20 hr rate	16.47	102	43.80
Silver Zinc	.825	1.51	20 @ 10 hr rate	36.6	13.2	.95
Silver Zinc	1.766	1.51	60 @ 10 hr rate	51.3	28.3	1.15
Silver Cadium	2.565	1.10	70 @ 13 hr rate	30	56.4	.89

Since a battery with the greatest watt hours per pound is needed, the second silver zinc battery would probably have to be used. The weight for a 27 volt system would be 3/1.8 pounds. The watt hours available are

$$31.8 \times 51.3 = 1630 \text{ watt hours}$$

This would be enough to handle the motor requirements and the requirements of the navigation and control equipment for approximately one hour. The disadvantage of this battery is its relatively high cost.

c. Motor Mounting

The next point to consider is the mounting of the motors. The simplest method would be to mount two motors, one on each side of the airship along an axis passing through the center of gravity. This method would produce a better static balance than if the motors were mounted elsewhere. If they were mounted beneath the ship they would possibly interfere with the fastening of the payload. Also, by placing the motors on each side, a greater torque will be available for turning since they will be at a greater distance from the center of the ship than if they had been mounted underneath.

The proposed method of mounting is shown in Figure 12. The center of each motor should be approximately 15 inches from the skin of the airship to provide proper clearance for the propeller. The method of mounting the motor must be such that the complete unit can be easily and safely packaged and that the airship can be quickly launched with the least amount of adjustments being made in the field. These requirements are in addition to the requirement that the motor be mounted as rigidly and securely as possible.

To meet this last requirement, the motor should be supported by at least three cables. The three cables will be oriented as shown in Figure 12, two providing vertical support and one providing horizontal support. The motor will be attached to two aluminum tubular beams, which in turn will be attached to a thin aluminum plate fastened to the skin. The purpose of this plate is to hold the motor away from the airship. The area of the plate shall be such that the internal pressure will provide an outward force sufficient to offset the inward force due to the motor weight and mounting cables.

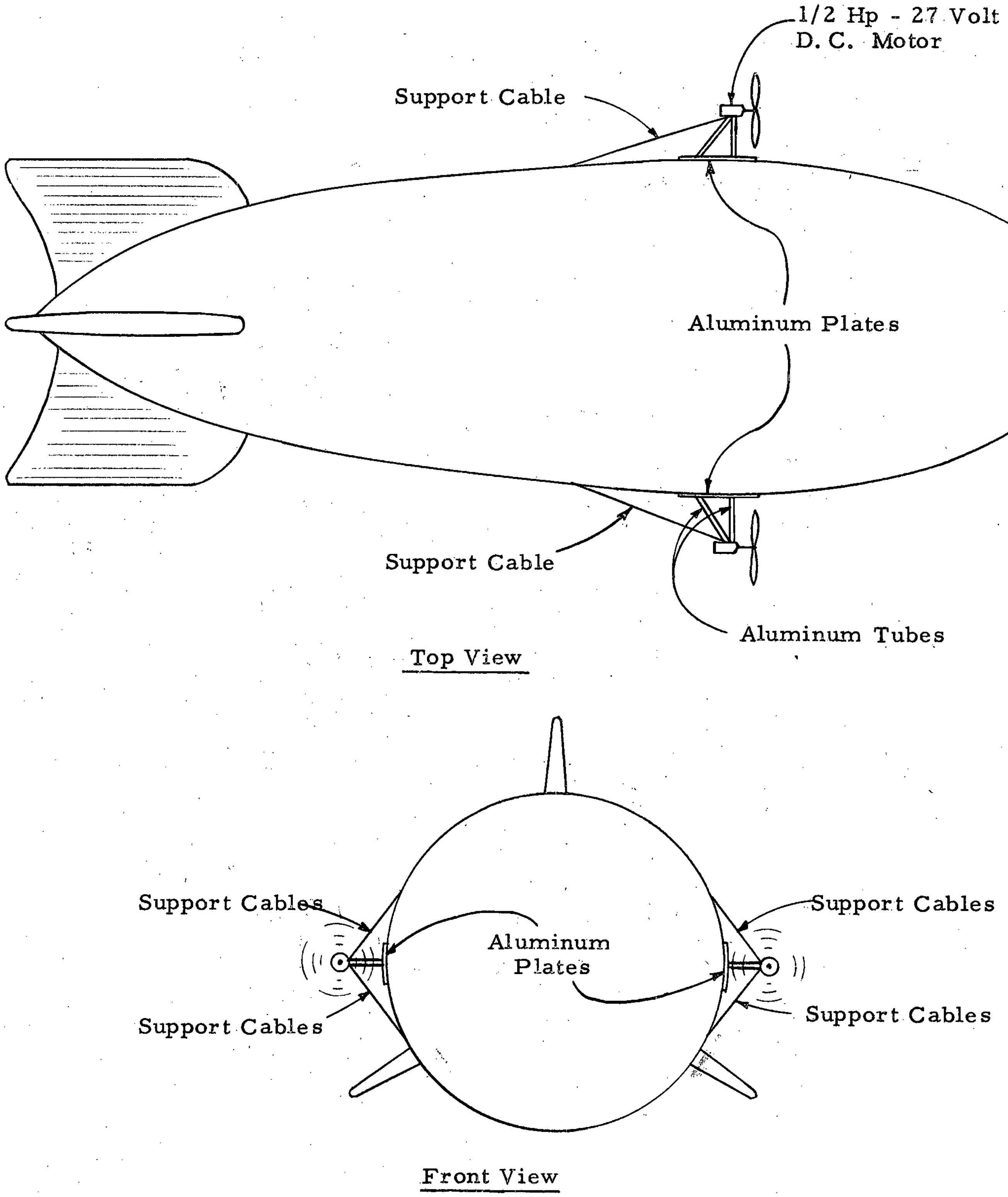
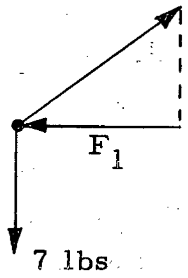


Figure 12. Motor Mounting Method

With the dimensions given, a pressure differential of 1" of water and a motor thrust of 5.50 pounds, the required plate area can be calculated. The weight of the motor cables and tubing is taken as 7 pounds.

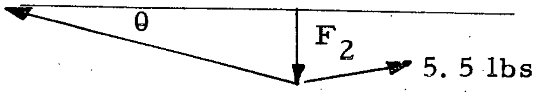
Force due to weight of motor:



δ = 54 degrees

$$F_1 = \frac{7}{\tan 54^\circ} = 5.05 \text{ pounds}$$

Force due to thrust of motor:



θ = 14.5 degrees

$$F_2 = 5.5 \tan 14.5^\circ = 1.42 \text{ pounds}$$

$$\text{Total force} = F_1 + F_2 = 6.47 \text{ pounds}$$

$$P_o = 1 \text{ inch of water} = .0361 \text{ psi}$$

$$\text{Plate area} = \frac{F_T}{P_o} = \frac{6.47}{.0361} = 179 \text{ in}^2$$

To have a sufficient factor of safety, the plate area should be at least 250 in^2. It is suggested the plate be approximately 10 inches high and 25 inches long. A rectangular shape such as this will provide additional support in the direction of the axis of the airship.

The motor cannot be too difficult to package. Likewise, the plates cannot be mounted at the launch site since too much valuable time would be consumed. The best arrangement from both points of view is to have a combination of the two.

The manner in which this is accomplished is to attach the aluminum plates to the airship at the factory. This could be done by using a pressure sensitive fiber tape. The aluminum plates would have two sockets welded to them into which the aluminum tubes would fit. The airship could then be easily packaged with only the plates attached. The motors can be packaged separately along with the tubes, cables, and propellers. The tubing and cables would be attached to the motor at the factory.

When the vehicle is unpacked in the field, the motor can then be mounted and readied in a few short steps by first placing the aluminum tubes into the sockets on the plates and securing them by pinning or bolting. The cables would then be attached to the airship and the propellers would be fastened. The final step would be to connect the electrical system to the motors.

d. Flight Duration

The total flight duration should be one hour or less since the batteries will last that long when the motors are running continuously and the other equipment is in intermittent operation. The airship will be capable of traveling at a velocity of 20 knots. The total flight time depends upon the velocity and direction of existing winds but with a 15 knot wind, a flight to a destination 5 miles away and a return to the starting point can be made in less than 1 hour regardless of wind direction. A plot of flight duration versus direction of a 15 knot wind is shown in Figure 13. This plot is based on a straight line flight, which means the vehicle is pointed in the proper direction, and then maintains a 20 knot velocity output. This will not occur in the actual case because of variations in the wind velocity and direction. With a condition of no wind the total flight time is .434 hours.

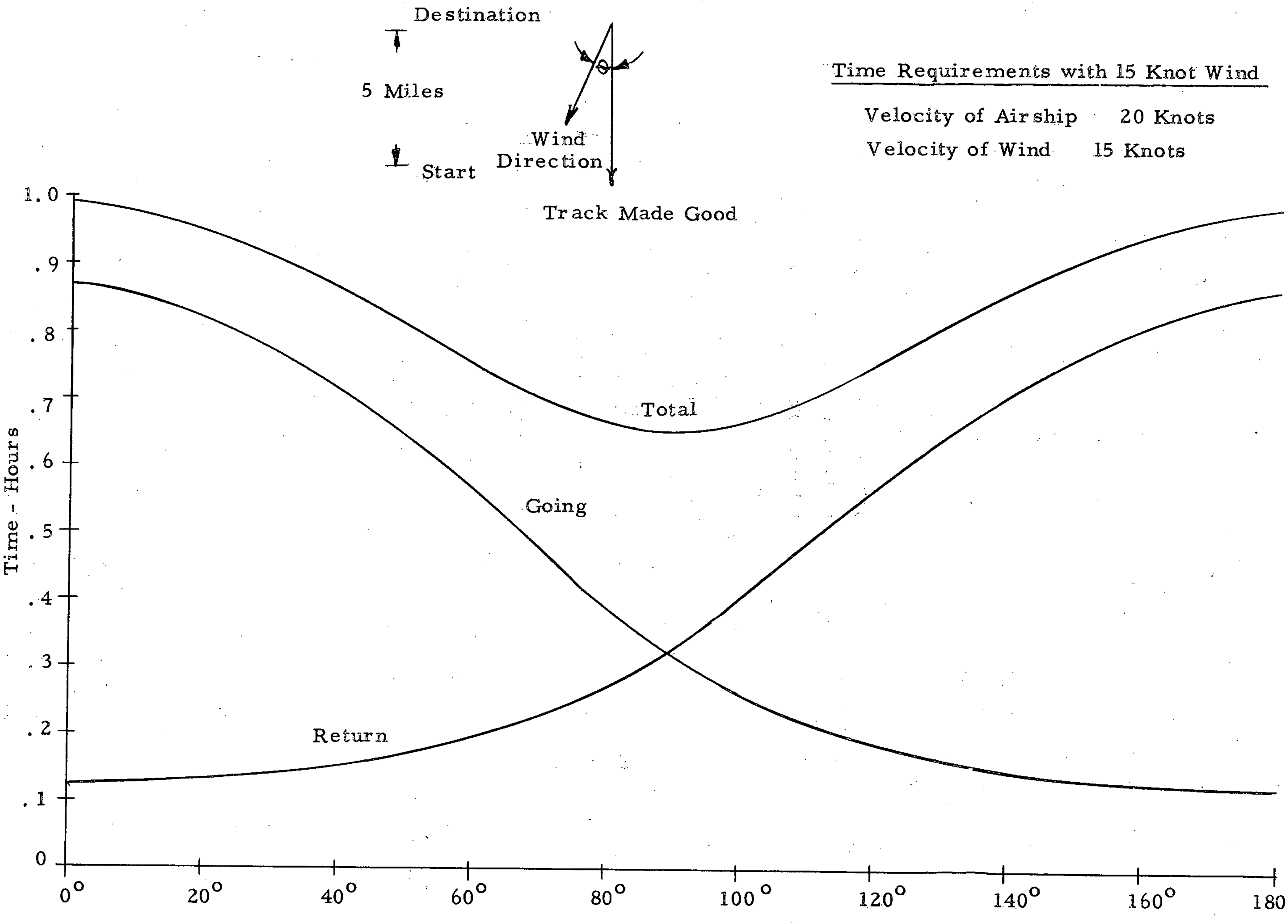


Figure 13. Flight Duration vs. Wind Direction

It is thus apparent that before a launching of the airship is made, the existing wind conditions must be known to insure the possibility of a successful flight.

3. Maneuverability

When the airship is flying on a straight, unaccelerated flight path, all forces acting on the vehicle are in static equilibrium. In order to curve the flight path, this equilibrium must be upset in such a way that the resulting unbalanced forces operate perpendicular to the flight path. Various methods can be employed to supply the force or torque required to curve the flight path, and several schemes are discussed in later paragraphs.

The acceleration of the airship in response to the unbalanced forces perpendicular to the flight path results in a curvature of the flight path and a rotation of the airship about the Y axis. This rotation produces damping moments which tend to stop the rotation, and which require additional torque to produce the desired curvature. This damping effect, caused by the angular velocity of the airship about its Y axis, gives it additional stability over unaccelerated flight conditions.

The following equations (see appendix) can be utilized to determine the turning radius as a function of required torque for the proposed airship configuration:

$$\theta = n/K\, t + \frac{n\,I}{K^2}\, e^{-(K/I)t} - n\,I/K^2$$

$$\dot{\theta} = n/K \left[1 - e^{-(K/I)t}\right]$$

$$R = v/2\,\dot{\theta}$$

where:

n = required torque, ft. lbs.
K = damping term, ft. lb. sec.
I = total moment of inertia, ft. lb. sec. ^{2}
θ = angle of yaw, radians

The results of the above equations are shown in Figures 14, 15 and 16. (It should be noted that these curves were developed on the assumption of a horizontal turn with the forward and angular velocities remaining constant.) From these curves the time required to turn 180 degrees, the angular velocity, and the radius of turn for a particular velocity and torque can be obtained.

From the preceeding equations, it can be shown that, other things being equal, this radius is proportional to the velocity squared. Thus:

$$\frac{R_2}{R_1} \cong \left(\frac{V_2}{V_1}\right)^2$$

This relationship concludes that in order to minimize the turning radius, the forward velocity should be reduced.

Of the various devices which could be used to produce the unbalanced force necessary to cause a curved flight path, the following are considered practical from a design standpoint:

1) Movable surfaces
2) Rotatable aft propellers
3) Propeller controls

A movable surface in the form of a rudder could be attached to the trailing edge of the top fin of the inverted Y tail configuration. By deflecting the rudder, the pressure variation over the fin is changed, creating the necessary force to turn the airship. The fins of the proposed airship are pressurized and are, therefore, subjected to deflection for relatively light air loads. As the rudder is deflected, the dynamic pressure of the air will create a pitching moment tending to twist the fin. This moment varies with the speed squared, and thus, as the speed increases, the fin twists in a direction tending to reduce the turning moment. At low speeds, the torque produced by the rudder, unless it is prohibitively large, is insufficient to produce the required turning radius.

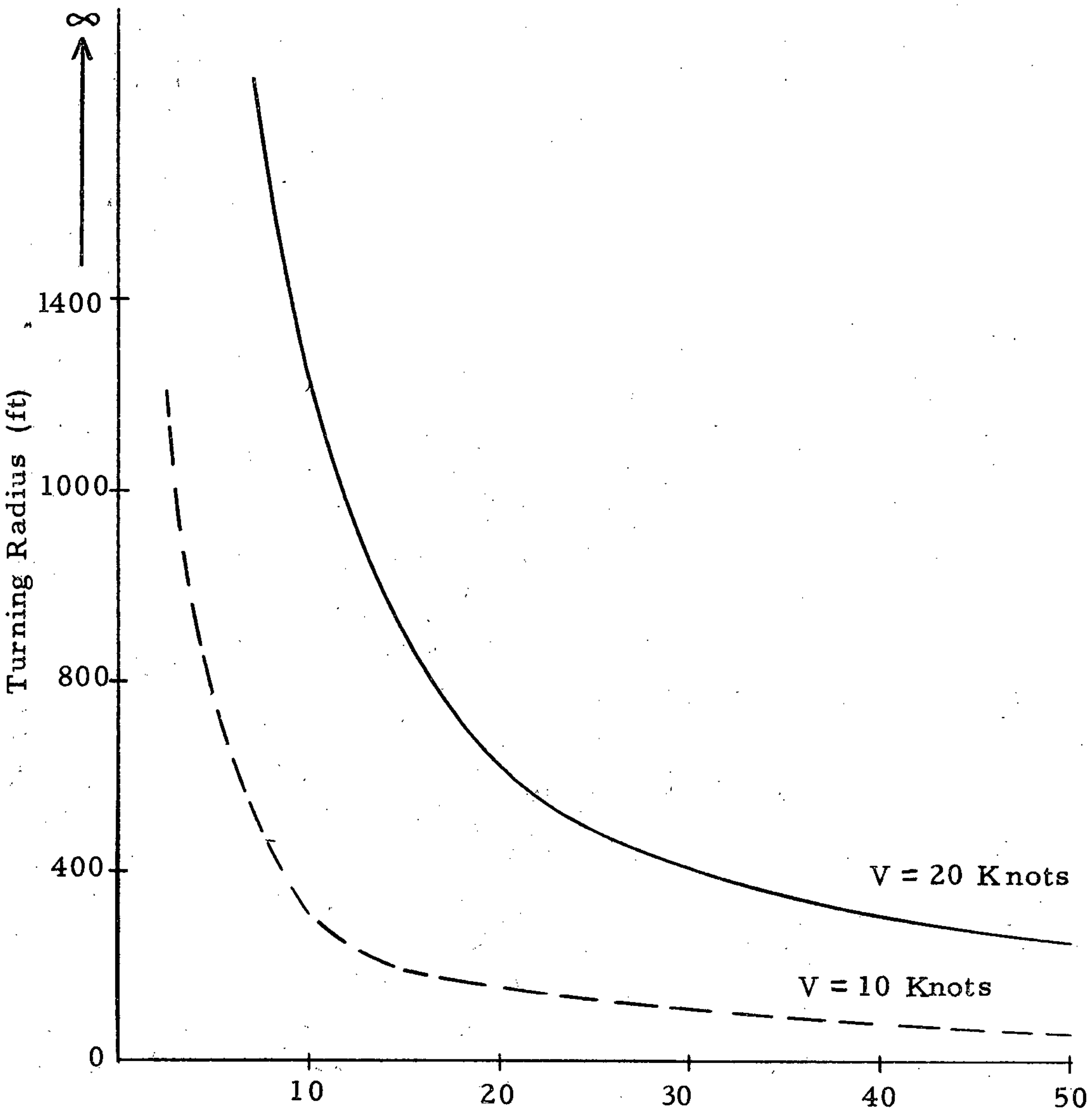


Figure 14. Turning Radius as a Function of Torque and Forward Velocity

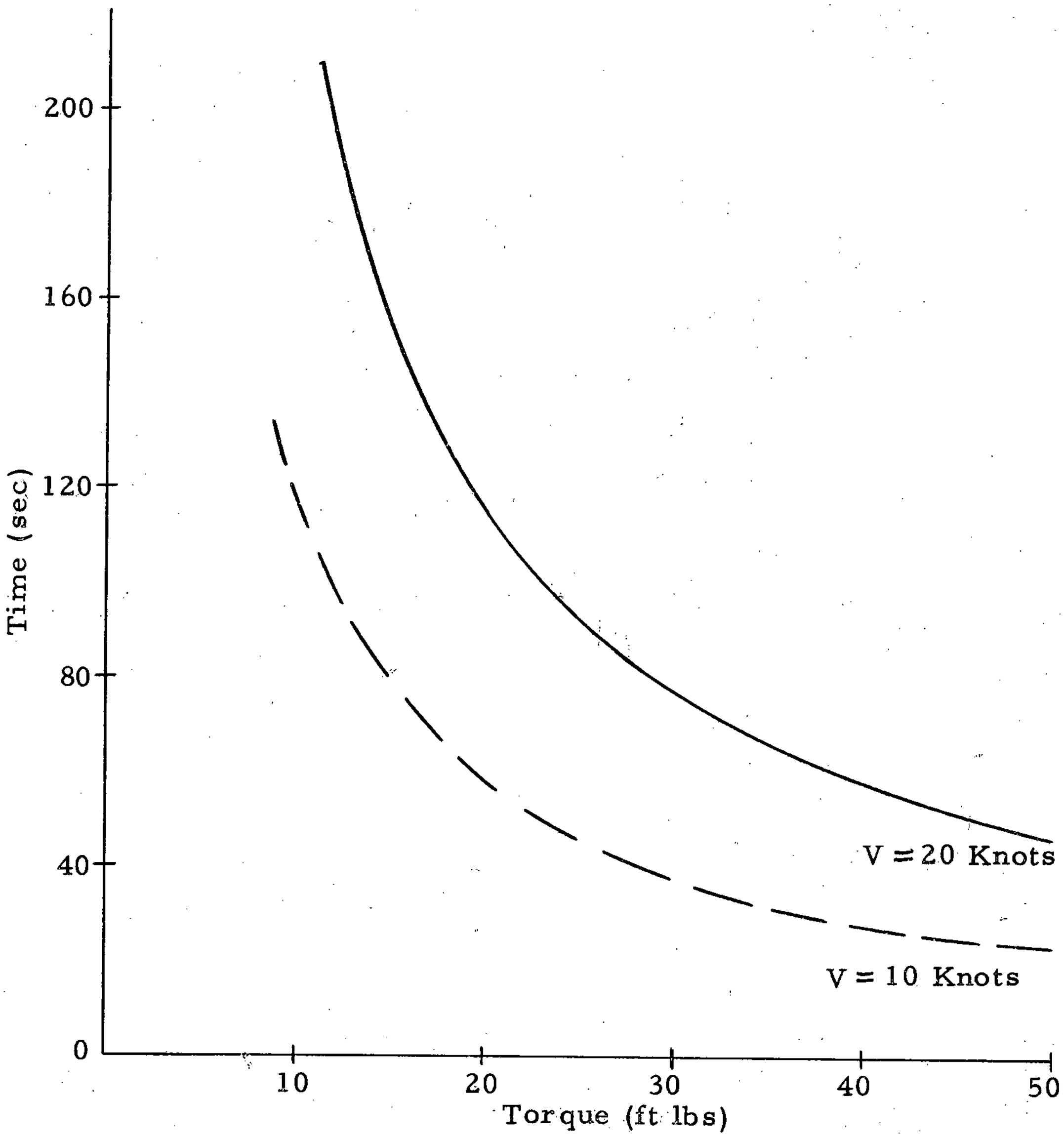


Figure 15. Turning Time as a Function of Torque and Forward Velocity to Turn 180°

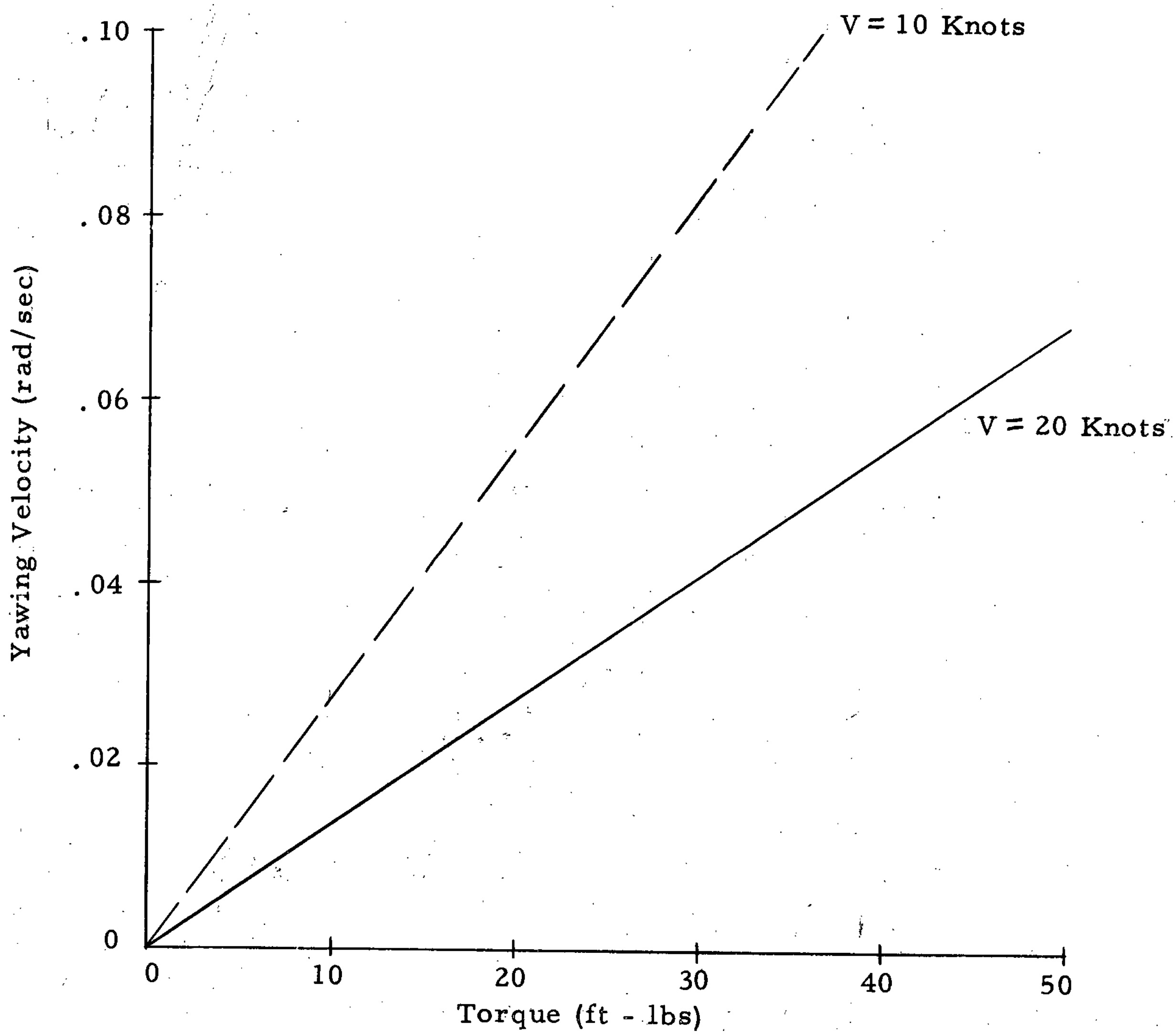


Figure 16. Turning Rate (rad/sec) as a Function of Torque and Forward Velocity

All control surfaces are more effective at high speeds, since the forces acting on the surfaces vary as the square of the velocity. To take advantage of the increased velocity of the propeller slipstream, a movable surface could be positioned immediately behind the propeller. Proper deflection of these surfaces would create the required torque to turn the airship. Using this scheme to curve the flight path, the following configurations would utilize the largest moment arm and contribute the maximum torque:

1) Two propellers positioned one on each side of the maximum diameter section.

2) A propeller positioned on the aft end.

With the propellers positioned at the section of maximum diameter, the most efficient control surface would be a flat plate. This arises from consideration of the forces acting on the surface. From Figure 17, it is observed that the moment contributed by the drag is much larger than that contributed by the lift component. Since this surface must be designed to create maximum drag, a flat plate, utilizing turbulence and eddy flow, would be practical. However, the deflection of this surface would merely cancel the thrust of the corresponding propeller, resulting in a "sluggish" system.

With a propeller positioned at the aft section, a symmetrical airfoil would give best results. From Figure 17, it is observed that the lift component is the major force contributing to the required torque. If a flat plate were used, as the airstream strikes against the inclined plate, turbulence and eddy currents would destroy the lift and increase the drag. Since the drag force does not contribute to the turning moment, it must be minimized. Thus, a symmetrical airfoil, limited to a plus or minus 16 degree deflection, would be practical.

From the calculations given below, it is shown that for a particular torque, more control surface area is required when the propellers are located at the section of maximum diameter than at the tail, primarily because of the difference in the moment arms.

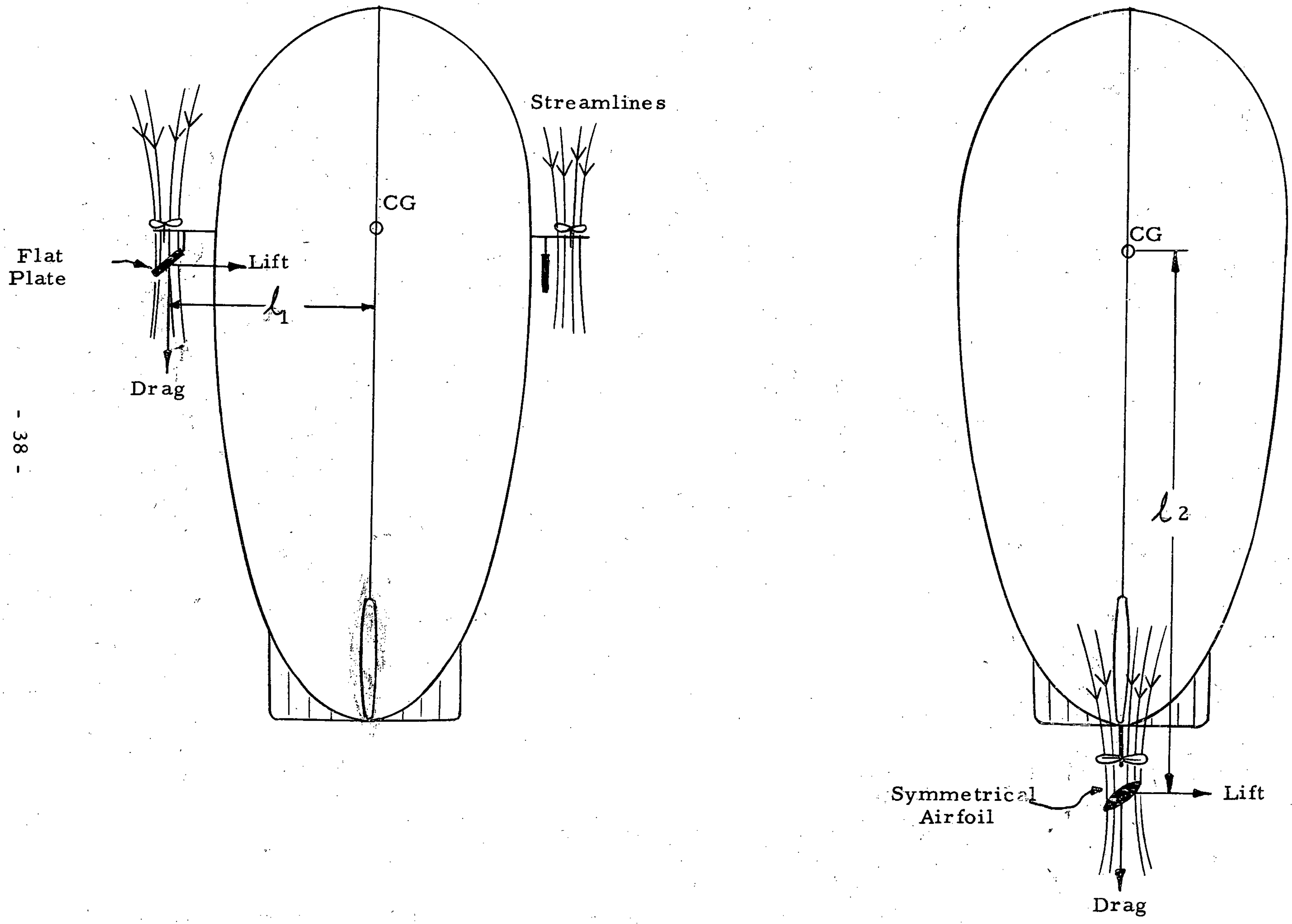


Figure 17. Slipstream Diverting Devices for Heading Control

From Figure 17,

$$\begin{cases} n_1 = D\ell_1, = C_D \, \rho/2 \, S_1 V^2 \, \ell_1 = (1.28) \, \rho/2 \, S_1 V^2 \, (6) \\ n_2 = L\,\ell_1 = C_L \, \rho/2 \, S_2 V^2 \, \ell_2 = (1.6) \, \rho/_2 \, S_2 V^2 \, (18) \end{cases}$$

where:

C_D = drag coefficient for a flat plate 1.28
C_L = lift coefficient for a typical airfoil 1.6
ρ = density of air
S_1, S_2 = required areas
V = velocity of airship
ℓ_1, ℓ_2 = respective lever arms

Thus, for a given torque:

$$n_1 = n_2$$

$$(6)\ (1.28)\ \rho/2 \, S_1 V^2 = (1.6) \, \rho/2 \, S_2 V^2 \ (18)$$

$$\frac{S_1}{S_2} = \frac{(1.6)(18)}{(6)(1.28)} = 3.75$$

In either case, this system, besides increasing the total weight of the airship and reducing its payload, requires an additional power supply to activate the surface and hold it in place. Also, the drag of these surfaces reduces the efficiency and over-all performance of the airship.

A propeller positioned aft of the airship would eliminate these inefficient control surfaces. Using the moment arms as a criteria, this scheme would supply the maximum torque possible, resulting in the minimum radius of turn. However, when the propeller is positioned for maximum torque (see Figure 18), the air flow strikes it in its plane of rotation, causing a very inefficient system. Also, the auxiliary equipment necessary for such a configuration would add considerable weight and complexity to the airship.

The third possible method is to apply propeller controls. To produce the necessary force to curve the flight path, the thrust of the propeller is decreased by reducing its rotational speed. With this arrangement, it is possible to obtain a maximum torque of 30 ft. lbs. by stopping the required propeller. Utilizing this torque, the following results are obtained:

reversible prop?

$V_{Forward}$	Minimum Turning Radius	Time to turn 180°
20 Knots	400'	77 sec
10 Knots	100'	38 sec

This system combines the advantages of efficiency, lightweight, low cost, and simplicity, and because of these benefits it was selected.

C. Navigation and Controls

The preceding paragraphs have considered the basic airship design, its propulsion system and the mechanisms for steering and altitude control. This section is devoted to the system necessary to impart the required guidance information to the steering and altitude controlling mechanisms. To satisfy the operational requirements of the airship, it will be necessary to control the heading of the airship, the cruising altitude and the point at which the airship begins its descent prior to dropping the payload. It will also be necessary to control the airship so that it returns to the launching area. The general design objectives of the control system are simplicity, reliability and low cost.

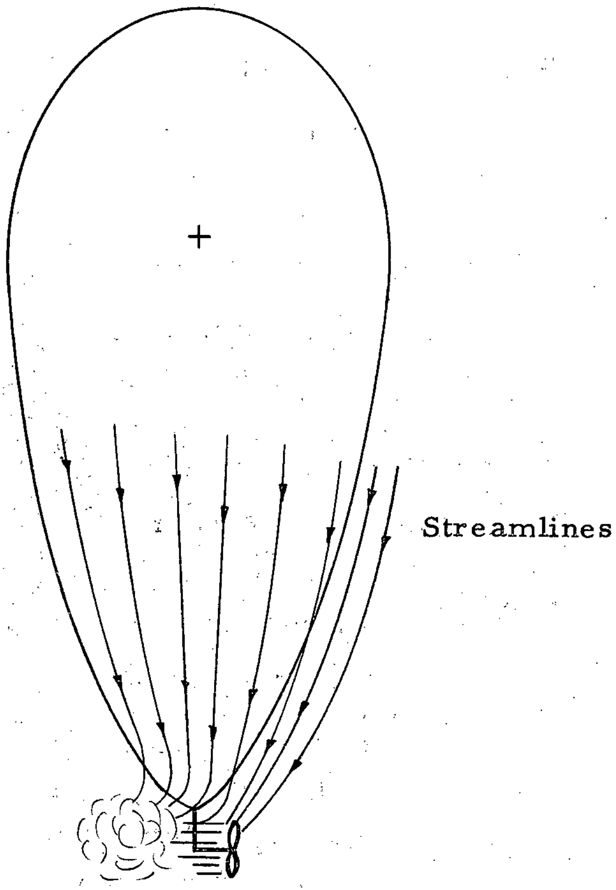


Figure 18. Aft Propeller In Heading Control

In operation the airship will be required to perform the following:

1) Ascend to a cruising altitude
2) Cruise to a predetermined point
3) Descend to a low altitude
4) Cruise at a low altitude
5) Release the payload
6) Ascend to a cruising altitude
7) Fly to the vicinity of the launching point
8) Descend

A number of different control systems are suitable to this application, and each system possesses certain advantages and disadvantages. A few of these possible control systems are discussed in the following paragraphs.

1. Preset System

With this system, the various parameters of heading, elevation and range are preset prior to launching the airship. Figure 19 is a block diagram of this system. A magnetic compass is employed as a reference for the airship steering system. The magnetic compass has a synchrotel output device which is connected to two control transformers. The shaft of one control transformer is set to the desired heading for the airship on the outbound course. The shaft of the second control transformer is set to the heading for the return course. The output of the control transformer is a voltage with an amplitude proportional to the error in the heading of the airship from the reference heading. The phase of the error signal with respect to a reference voltage indicates the direction in which the airship is off course. The error signal is supplied to a phase sensitive rectifier which operates a polarized relay. If the airship is on the desired course, the output of the phase sensitive rectifier is zero and the polarized relay operates one set of contacts for a left error, and the other set of contacts for a right error. The relay contacts, in turn, control motor contactors which control the flow of current from the

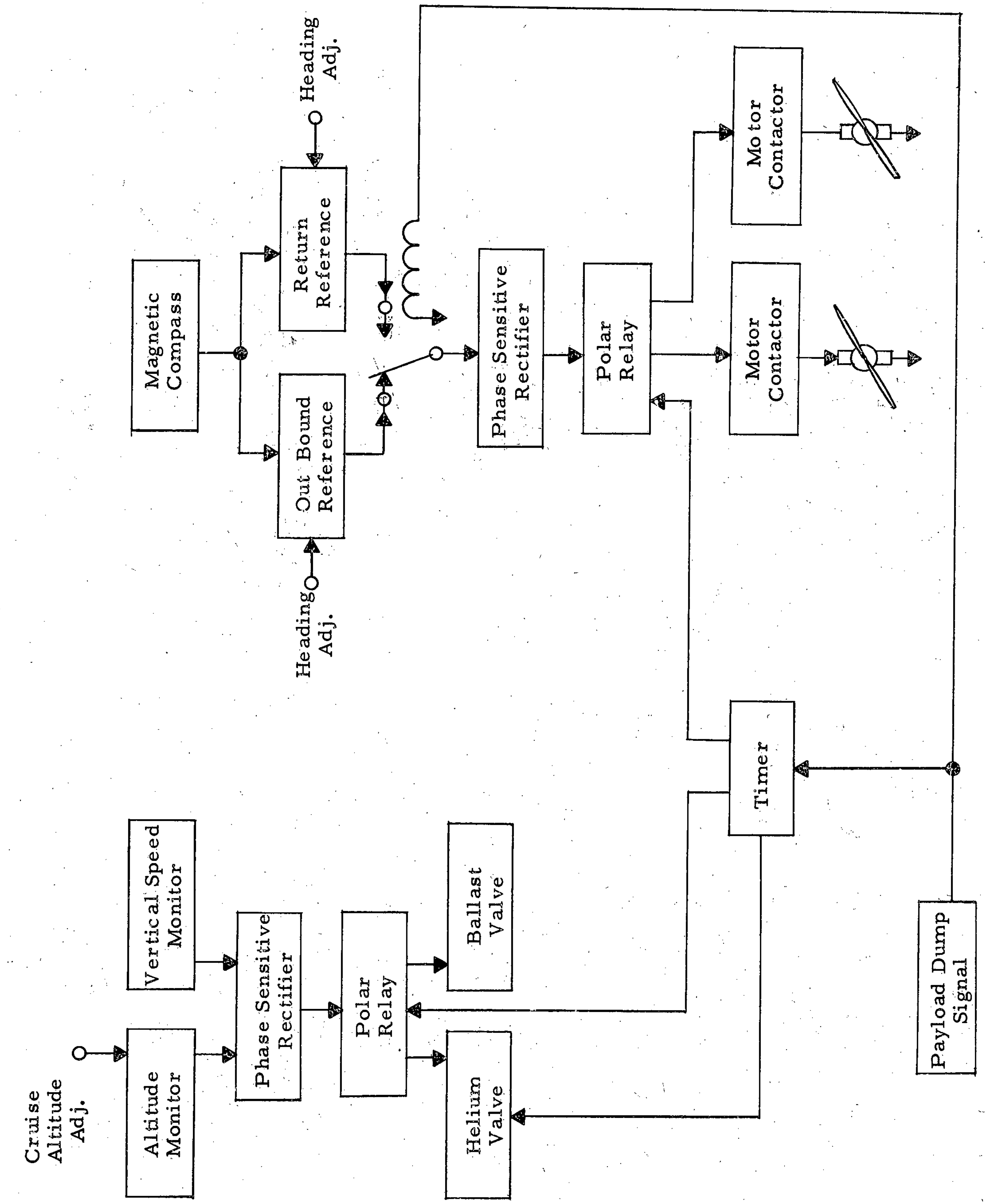


Figure 19. Preset Airship Control System

battery to the drive motors. Thus, if the airship is off course to the left, the right motor is stopped until the heading error is corrected, at which time, the right motor resumes operation.

The altitude control for the airship employs an altitude monitor which is preset on the ground to the desired cruising altitude. A vertical speed indicator is also employed to optimize the altitude control. The output of the altitude monitor and the vertical speed indicator are combined and sent to a phase sensitive rectifier which operates a polarized relay. In this case the two sets of contacts on the relay are connected to a helium valve and to a ballast valve. To maintain the preset altitude, helium is valved off to cause the airship to descend and ballast is dropped to allow the airship to rise. A timing device which is preset prior to launching the airship determines the sequence and duration of the various phases of flight such as the time at which the steering system begins operation, the time at which the altitude system begins operation and the time at which the airship is caused to descend to the low cruising altitude. These various times will have to be calculated on the basis of desired flight path, estimated wind speed and estimated wind direction over the flight path of the airship.

As soon as the payload is released, a signal causes the steering system to switch over to the return course heading and causes the altitude system to begin valving helium for a preset length of time to compensate for the loss of the payload. Upon reaching cruising altitude, the regular altitude control system takes over. The final operation of the timer is to cause the airship to descend to the launch point after completing the return course.

The advantage of this system is that it requires no control communications during the flight of the airship. The accuracy of the system is dependent upon the ability of the ground crew to estimate wind speed and direction accurately along the path of the airship and to estimate the pertinent times to be set into the timer.

2. Command System

A command system for controlling the airship involves two links -- an information link and a command link. Figure 20 shows a block diagram

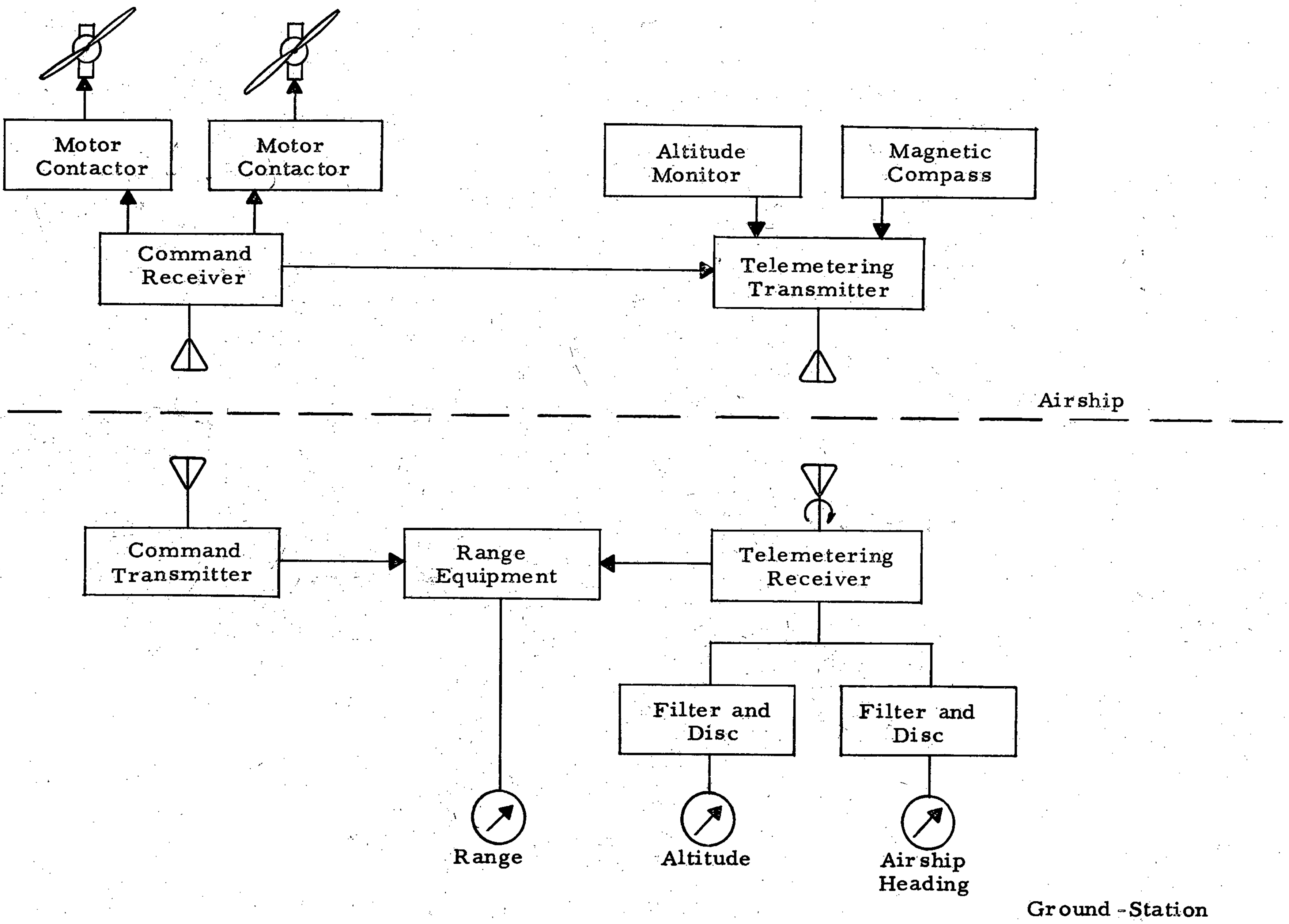


Figure 20. Command Airship Control System

of the command system. In this system the magnetic compass output is transmitted to the launch point with a telemetering transmitter. An altitude monitor in the airship produces a signal proportional to altitude, and this information also is transmitted to the ground station by the telemetering transmitter. A receiver on the ground picks up the transmitted signal with a directional antenna. The receiver detects the transmitted signal and displays heading and altitude information on a pair of meters at the ground station. The directional antenna is rotated for maximum signal, and the bearing of the airship relative to the ground station is determined by the position of the antenna. Knowing the heading of the airship, the altitude, and the bearing of the airship from the ground station, the ground station personnel can transmit appropriate commands to the airship with a command transmitter. A command receiver in the airship receives the signals and operates appropriate relays to control the drive motors and the helium and ballast valves.

To measure the range to the airship, both the command and information links are used. From the ground station, a reference tone is transmitted through the command transmitter to the airship where it is picked up by the command receiver. The output of the receiver is then filtered appropriately and sent to the telemetering transmitter. The telemetering transmitter then transmits the reference tone back to the ground station receiver, and a phase angle meter compares the phase of the received tone with that of the transmitted tone. The phase shift between the return signal and the transmitted signal is a direct function of the range between the airship and the ground station. Time delays in the various equipments can be compensated by adjustments at the ground station prior to launching the airship.

Other means of determining airship bearing from the ground station and the range between airship and ground station are feasible. For example, an infrared optical system could be used to determine the relative bearing and the range to the airship providing a suitable infrared source was carried on the airship.

The principal advantage of the command system is that ground station personnel can transmit corrections to the airship and can compensate for changes in wind speed and direction from those values measured at the time of launch. The disadvantage of the system is that it requires considerable equipment in operation by the ground personnel during the flight of the airship. Also it requires 2-way communication while the airship is cruising at low altitude.

3. Command/Preset System

The command/preset system combines features of both the preset system and the command system discussed earlier. Figure 21 shows a block diagram of the system. In this system, a magnetic compass with a synchrotel output is connected to a control transformer, and the shaft of the control transformer is adjusted to the desired heading before launch. Once in flight, the heading reference can be changed by command from the ground station. As in the preset system the control transformer output provides an error voltage resulting in the control of the right or left motor.

Altitude control may be either automatic as in the preset system, or by direct control of the helium and ballast valves as in the command system.

Information of heading and altitude is telemetered back to the ground. A range reference tone transmitted from the ground to the command receiver is re-transmitted to the ground with a telemetering transmitter.

The descent phase prior to dropping the payload is commanded from the ground station. An indication of the payload release is telemeterd back to the land station so that the return course heading can be commanded. Once the airship is returned to the vicinity of the launching point, a command is given to cause the ship to return to earth. The prime advantage of this system is its flexibility. Should any of the automatic systems fail, the ground station personnel can take over control of the airship by direct command link, and this would be an advantage should it be necessary to abort the mission.

4. Other Systems

A number of other systems could be used, including beam riding or simultaneous lobe comparison techniques. These involve the use of considerably

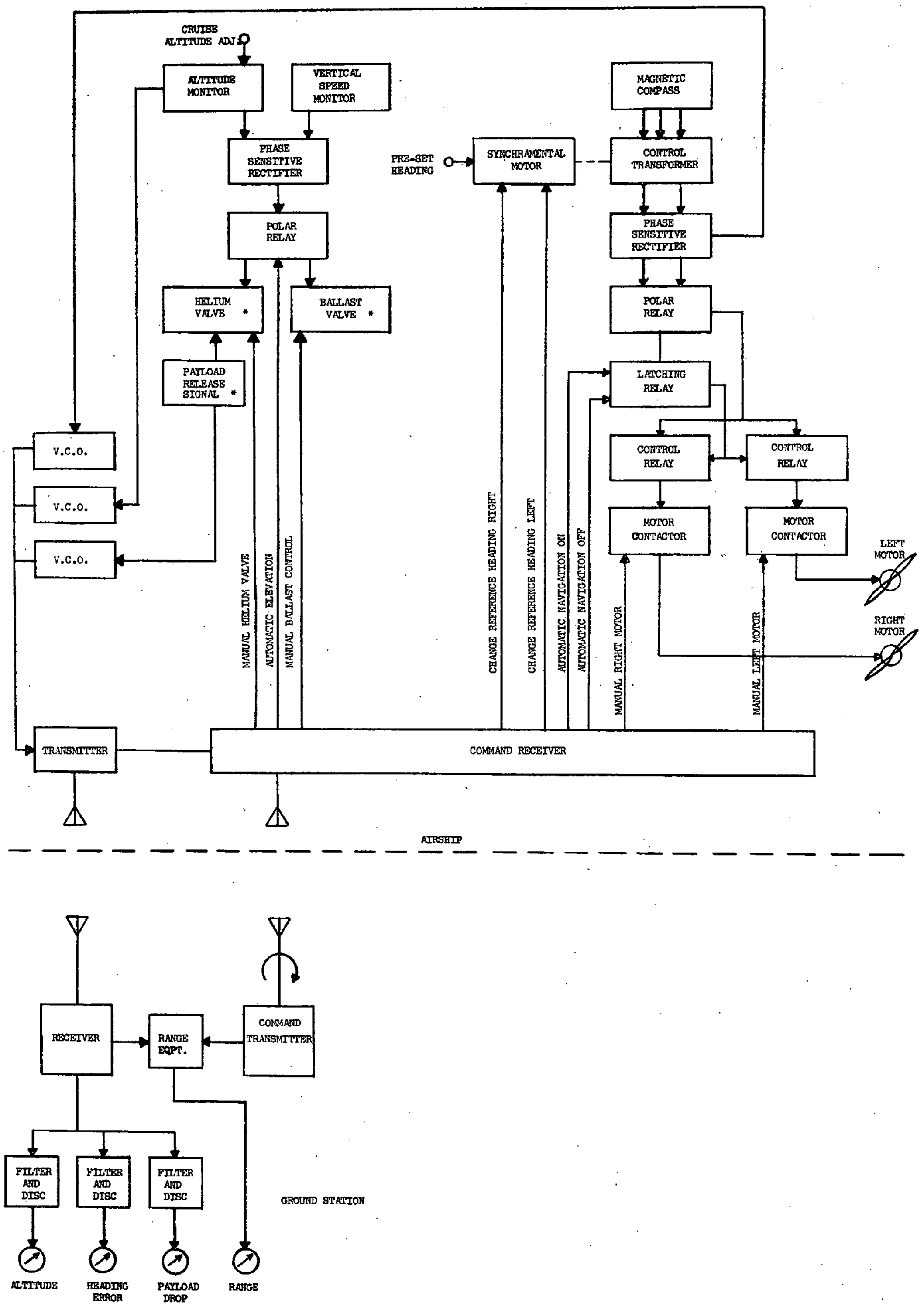


Figure 21. Command/Preset Airship Control System.

more complex ground and airborne equipment and hence will not be described in detail, however, they will be given consideration during the design phase of the program.

5. Prototype Airship Navigation and Control System

The following is a description of the system to be used in the prototype airship. It features simplicity and flexibility. Figure 22 is a block diagram of the system. This system is a combination of the preset and the command systems described earlier.

In this system the ground station personnel have complete control over the airship by means of a command transmitter. In addition, a magnetic compass aboard the airship serves as a heading reference, and the desired heading is preset into the system. During flight, an operator at station A observes the IR beacon on the airship through his IR viewer. With his viewer set to the desired flight path, he can determine if the airship is going off course, and he can jog the reference heading in the airship either left or right with the command transmitter.

The cruising altitude is controlled by a system using aneroid sensors and helium and ballast valves such as that used in the preset system.

The operator at station B also observes the IR beacon on the airship. When the relative bearing of the airship from station B reaches a precalculated value, the automatic altitude control is removed by a radio command and a timer programs the helium and ballast valves to bring the ship down to the low altitude drop level.

Once the airship begins the descent phase, it can operate without ground command and steers the last commanded reference heading. The drop rope holds the airship at an equilibrium altitude. Once the payload drops, the helium valve opens for a preset period of time and then the regular altitude control begins functioning. The return course heading is commanded by the operator at station A upon seeing the airship return to altitude. Operator A observes the airship during its return flight and transmits course corrections as before.

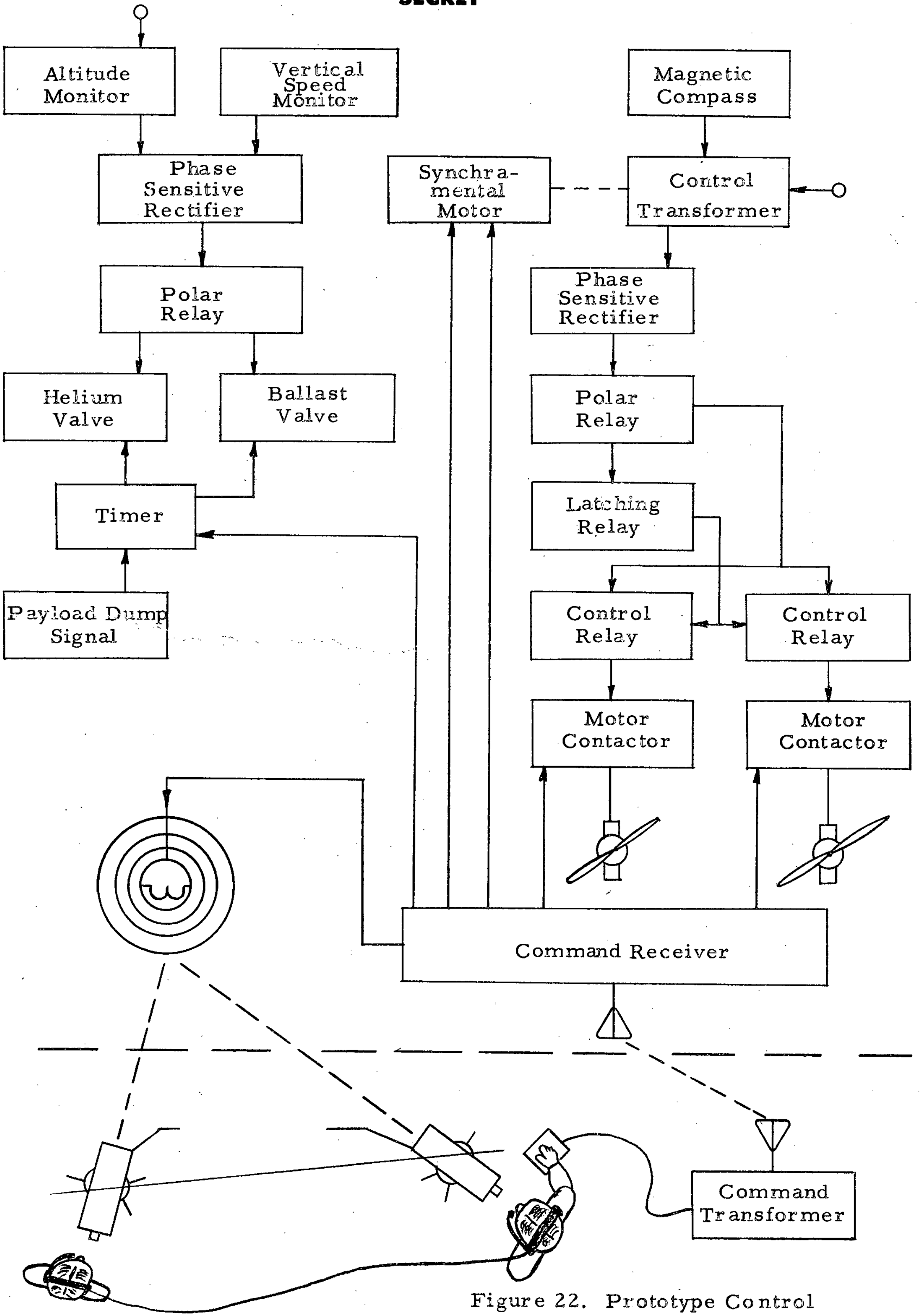


Figure 22. Prototype Control System

Upon reaching the launching area, the helium is valved off and the motors are stopped by radio command.

This system is reasonably simple to operate under the expected conditions of a mission. All of the automatic controls can be disconnected and direct command given from the ground station. Since the airship is not radiating radio signals, it cannot be tracked by D/F stations. The operating radio frequency, power and ground antenna size can be chosen to give optimum insurance against detection.

D. Operations

Operational problems are minimized for this system because of the small size of the balloon. This system can be transported complete with inflation gas by a jeep or other similar small vehicle.

The inflation gas for this system can be contained in 10 standard, 220 cu. ft. helium cylinders. These cylinders form the major part of the operational equipment.

Additional equipment will include the following:

1) Cylinder manifold with gage
2) Inflation hose and diffuser
3) Ground cloth (15 x 40 ft.)
4) Handling lines
5) Ground control instrumentation for control of flight
6) 0-100 lb. spring scale

A balloon as small as this may be successfully launched by a crew of three or four men depending on surface wind conditions.

1. Launching Procedure

1) The helium requirements are determined and the cylinders gaged at the staging or supply area to insure that sufficient helium will be provided at the launch site.

2) The launch site must be a cleared area at least as large as the ground cloth.

3) The ground cloth is spread so that its longest dimension will be along the direction of the wind.

4) The balloon is removed from its box and is spread out so that its nose points into the wind. (Launchings should not generally be considered in surface winds in excess of 15 mph.)

5) The inflation gas cylinders are manifolded together and the inflation hose and diffuser connected to the inflation tube on balloon.

6) The balloon is inflated with sufficient gas to lift the complete airborne system as determined with the spring scale.

7) The tail and ballonet blowers are started to pressurize the tails and the balloon envelope.

8) Attach load and make final check out of the control system.

9) Release balloon for flight.

After completion of mission, the balloon will be returned to the general launch area for recovery. When the balloon reaches this area it will be deflated and the controls and other hardware recovered.

2. Guidance Procedure

The ground guidance equipment should be checked prior to the mission. The transmitter will be tested for power output and frequency, and the infra-red viewers will be examined for satisfactory operation.

Two men are required to operate the guidance system after the airship is aloft. The first man measures the azimuth angle to the airship with an infra-red viewer and controls ground track by commanding right and left corrections with the command transmitter. The second man, located some distance away, tracks the airship with a second infra-red viewer and measures the azimuth angle to the airship. With a known base line between the two viewers, the azimuth angles define the position of the airship.

The length of the base line between the two veiwers can be established by one of two methods.

1) The two observing positions can be established with map coordinates, or:

2) The second man can be displaced from the first man by a distance measured with a line.

In the first case, communication between the observers could be established with a "walkie-talkie" radio. In the second, the measuring line could be a telephone line which would serve the dual purpose of communications. The azimuth of the base line would be obtained by supplying the second viewer with an infra-red light source, and then sighting on that source from the first viewer.

A compass or sighting on stars with a transit will give north reference. In our present concept, this optical sight is mounted on the same tripod as the infra-red viewer.

After the "descend" signal is given to the airship, the second viewer is no longer required. This operator can be returning to the vehicle while the airship is proceeding on its mission.

III. . PROGRAM AND SCHEDULE

A. General

The program necessary to deliver a satisfactory working model of this low altitude airship covers 9 months time. A summary of this schedule is shown in Figure 23. More detailed schedules are shown in Figures 24 and 25.

Basically, we believe that two models of the airborne guidance system must be fabricated -- one an experimental breadboard and the other a deliverable prototype. We also forsee the fabrication of six balloons, one being the final and deliverable model. All six balloons will not be complete; the first five consisting mainly of the plastic fabrication. We anticipate that all five will be damaged during the flight tests. It is expected that the hardware such as motors, etc. will be recovered and reused on the others.

The ground guidance equipment is expected to be modified, existing equipment, either purchased or GFE. Only one model should be necessary for the development program.

As the schedule shows, we anticipate an extensive flight test program. This is required to adjust the design and performance of the airship and guidance system and to insure its satisfactory operation under field conditions.

In addition to the ground guidance equipment, there will be a minority of ropes and hoses, a ground cloth, and a suitable container. This is called "ground equipment" in Figure 25. It will be fabricated in time for the flight tests and will be subject to minor additions and modifications as we learn more during the flights.

The delivery of the equipment can be followed 30 days later by a technical report.

B. Program on Guidance and Control

The program of guidance and control equipment is based on the fabrication of a breadboard model and testing, followed by the design, fabrication and test of the prototype. The program is detailed in Figure 24 and explained below:

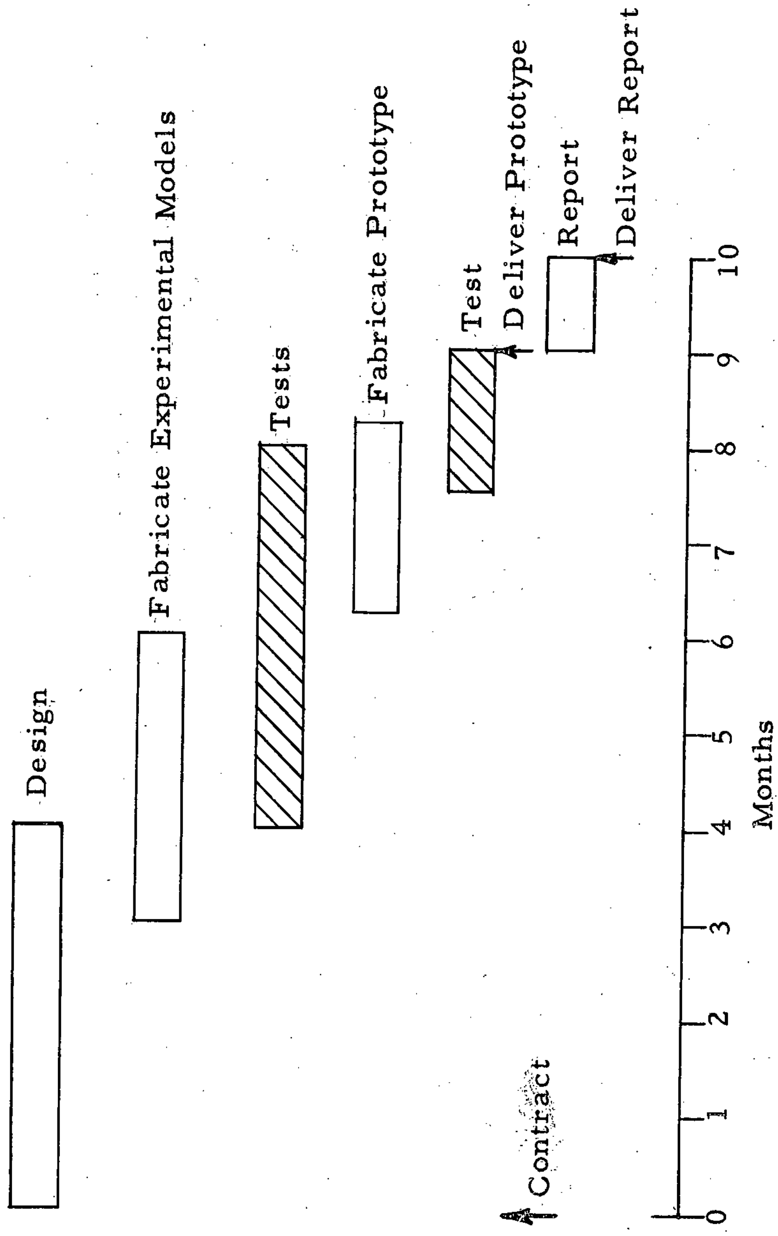


Figure 23. Summary of Program Schedule

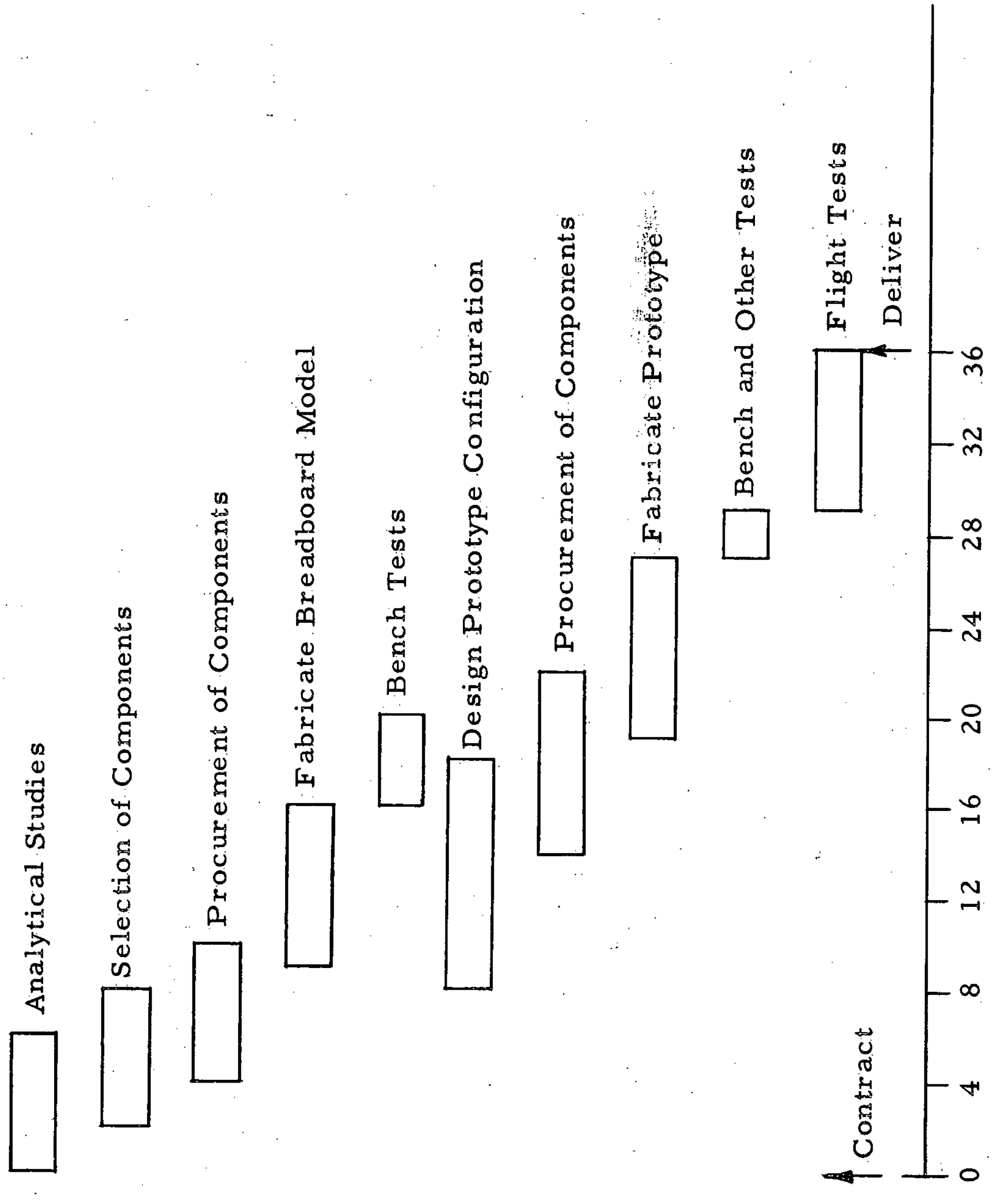


Figure 24. Schedule - Guidance and Control Equipment

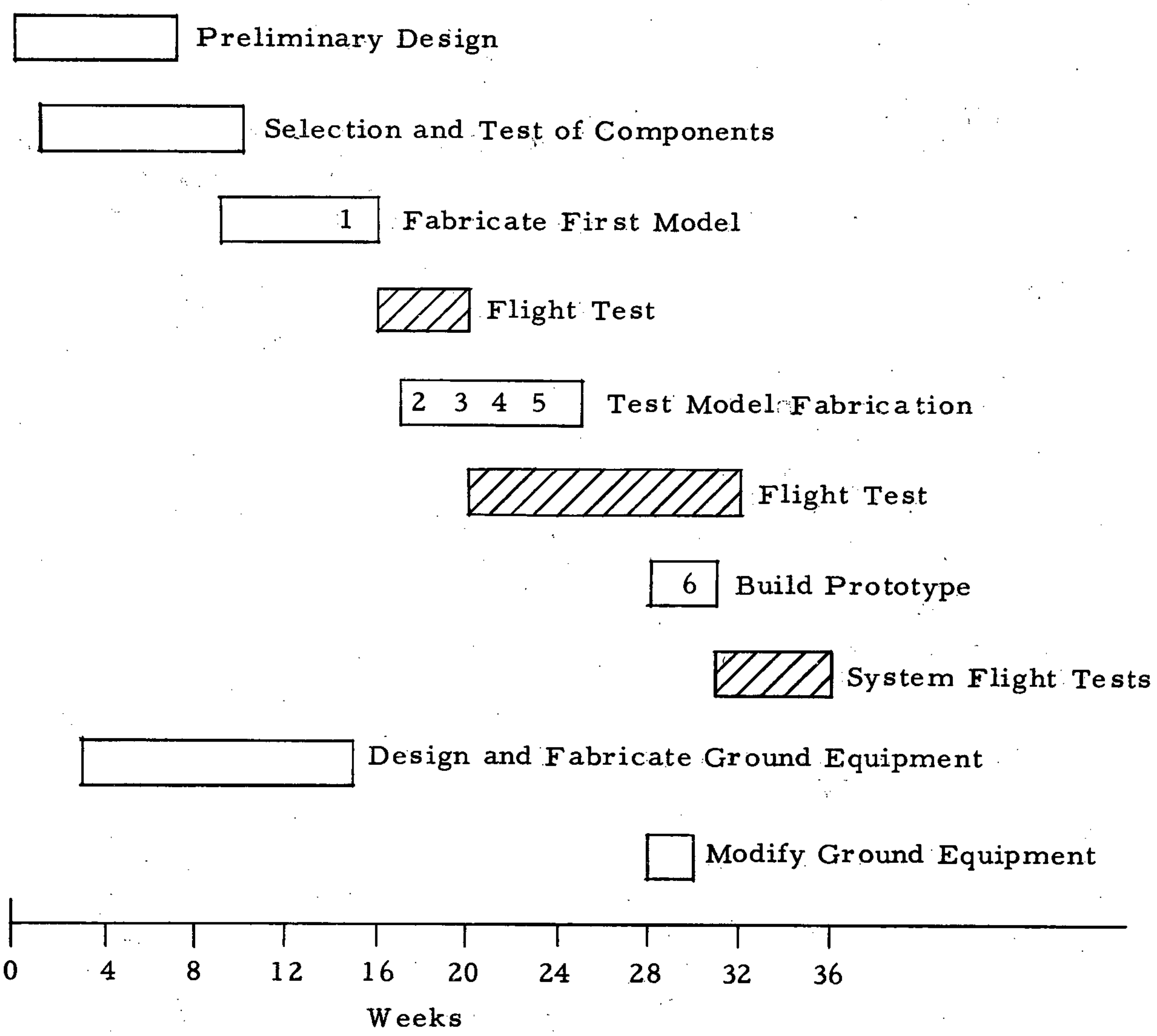


Figure 25. Schedule - Vehicle and Ground Equipment

Analytical Studies

The guidance function is reviewed with the customer to make sure we have the correct requirements. Possible GFE equipments are considered. Some REAC studies are performed to study the closed loop performance of the vehicle and guidance and control equipment in azimuth and elevation. Gust effects are considered. The compass requirements are determined.

Selection of Components

This phase involves writing of brief specifications and determination of tolerances on components, discussion with vendors, and determining the applicability of existing equipment. The problem here is not so much of finding equipment and components that will do the job, but rather finding satisfactory <u>low cost</u> components.

Procurement of Components

Once components are located, 6 weeks should be adequate allowance for delivery.

Fabricate Breadboard Model

The sensors, relays, controls, motors and propellers are assembled into an operating model for bench performance tests.

Bench Test

The breadboard model is checked for electrical and mechanical operation. Measurements are made on sensors.

Design Prototype Configurations

The information gained in the design and test of the breadboard model, and the data from vehicle flight tests which utilized components of the control equipment permits the design of the prototype system and its proper packaging.

Procurement of Components

This time is allowed for delivery from suppliers and fabrication in the model shop.

Fabricate Prototype

The prototype is fabricated, using a limited amount of engineering drawings.

Bench and Other Tests

The prototype is checked for functional operation and given a limited environmental check. Certain sensors should operate properly (altitude) and the equipment should withstand a fair temperature range and the vibration and handling during transport.

Flight Tests

The prototype vehicle and guidance system are assembled and checked together as a system. A mission is simulated.

C. Program on Vehicle

A detailed schedule of the program for the development of the vehicle and associated ground equipment is shown in Figure 25. The following work is anticipated during the various phases of the system.

Preliminary Design

Stress, aerodynamic configurations, weight and balances, electrical power required, helium valve rates, ballonet fan sizes and flow rates, vertical turning rates, acceptable propeller noise, selection of envelope material are all typical of the problems to be considered here.

Selection and Test of Components

Actual motors, propellers, valves, and other components will be selected based on consideration of their characteristics and will be tested. Thrust tests will be made. Propellers will be checked on a truck to determine optimum rpm at cruise speed. A volume calibration will be made on helium valve.

Flight Test

The first vehicle will be inflated and flight tested initially in a hangar. Harnessing will be checked and the vehicle put in limited motion utilizing various portions of the control equipment as they become available. Maintenance of pressure by ballonet fan will be checked.

Other Models

Four additional experimental models will be fabricated, each one embodying successive changes as design knowledge improves. These models will be successively utilized and expended during the tests.

Flight Tests

Models will be flown outdoors, weather permitting. Rise rates, altitude control, drag coefficient, maneuverability, operation of ballast system and other information will be obtained.

Build Prototype

A prototype vehicle utilizing prototype hardware will be constructed based on information obtained from the design and construction of experimental models.

System Flight Tests

The final prototype model with the final prototype guidance system will be checked by performing a simulated mission.

Design and Fabricate Ground Equipment

During this time the auxiliary equipment will either be designed and fabricated or located within our existing inventory. This consists of tie down ropes, hoses, valves, container and other things necessary to conduct the flight tests and permit proper operation of the delivered prototype. Flight test instrumentation will be fabricated at the same time.

Modify Ground Equipment

The ground equipment which was assembled for the flight tests will be modified and changed to make it suitable for use during the test of the prototype. No ground equipment (except guidance) will be delivered.

IV. PROGRAM ORGANIZATION

The proposed project will be carried out under the direction of personnel of the Engineering Department. Services of personnel from the Balloon and Research Departments will be enlisted as necessary. A simplified organization chart of the Mechanical Division of General Mills is shown in Figure 26. The chart shows the relationship of this project to the existing organizations of the Engineering and Balloon Departments. The blocks in the project organization which are duplicated as heavy blocks within the division organization indicate where most of the effort will occur.

The project will be under the direction of the Special Vehicle Systems Group in the Systems Engineering Laboratory of the Engineering Department of the Mechanical Division.

The Special Vehicle Systems Group is a new organization that has been and is being introduced to old and potentially new customers and users of General Mills' balloons and services. This group is staffed with personnel formerly with the Research Department who have done preliminary design on balloon vehicles and with system engineers from the Engineering Department. This group is located in Plant 5 of the Mechanical Division and thus has access to the facilities of the Engineering and Research Departments and to the services of several hundred scientists, engineers and technicians working there. The function of this group is to be responsible for designs of new balloon systems which involve the use of more than just a gas bag, such as power plants, instrumentation, payloads, dynamics, guidance, control, special effects, etc.

Since this program involves the use of a power plant, guidance, and dynamics, it will be directed by the Special Vehicle Systems group. All preliminary vehicle design, guidance and control design, analysis using REAC and digital computers, and analysis of test data will be done by this group. Certain ground equipment and airborne instrumentation and flight operations and equipment associated therewith will be designed and fabricated

by the group at Plant 6 under J. Swisher. Construction of the production vehicle and the early models including detailed design will be done at Plant 7. General Mills has successfully used this organization and method of operating on previous projects.

V. FACILITIES AND EXPERIENCE

The facilities and experience required for the completion of the proposed airship program fall into three categories:

Balloons -- Guidance -- Radio Communications

The Mechanical Division of General Mills, Inc. is ideally suited to this program because it possesses an engineering staff experienced in all three areas, and it has laboratories and manufacturing facilities already engaged in similar work.

It is impossible in a short discussion to describe all facilities of the Mechanical Division which may be useful in the proposed program. Aside from the purchase of standard parts and devices, General Mills, Inc. is completely independent of outside suppliers for a program of this type and this magnitude. The entire program will be handled within the framework of our existing organization.

A. Balloon Facilities and Experience

The facilities of the Balloon Department of the Mechanical Division encompass three areas -- Design Engineering, which is engaged in the design and construction of balloons and balloon flight control and data collection equipment; Plastic Film Fabrication, which handles a vast array of balloon production jobs; and Flight Operations, which handles the flight preparation, launching and tracking of GMI balloons. All three of these activities are staffed with experienced experts, and are generously supplied with electronic, mechanical, and plastic film manufacturing equipment.

1. Design Engineering

This group possesses broad experience in the fields of electrical, mechanical and aeronautical engineering coupled with a sound background in physics related to balloon applications. Its accomplishments include design of such components as preset-timed controls, remote controls, telemetering devices, automatic cutdown devices for terminating flights, barographs for determining time-altitude data, baracoders and transmitters for relaying data to ground sites, and a variety of other specialized instruments and devices for specific applications.

The services of two shops are available to this group. A well equipped instrument development shop is capable of constructing and testing both electrical and mechanical prototype units, and a machine and welding shop fabricates special fittings and components dictated by a particular design need.

2. Plastic Film Fabrication

The capabilities and facilities of the film fabrication group for handling a vast array of production jobs are second to none. This group has produced balloons in every configuration from hundreds of thousands of small Pillow Balloons® such as those used for dropping propaganda leaflets behind the Iron Curtain, to gigantic 212 foot diameter balloons of 3,750,000 cubic foot capacity used for upper altitude research and high altitude rocket launching. In fact, Figure 27 shows a more elaborately constructed "AEROCAP" balloon which closely resembles the configuration and dimensions of the airship proposed in this document.

The plastic film fabrication group has combined four important ingredients necessary to the production of plastic balloons: flexibility, speed, efficiency, and painstaking care. The inspection, production control and methods sections have integrated their efforts in such a way as to guarantee the customer maximum product reliability.

3. Flight Operations

Flight operations has a threefold activity: 1) flight preparation, 2) inflation and launching, and 3) tracking and recovery. This group has at its disposal modern direction finding radio equipment, recovery trucks and both single and multi-engine aircraft for tracking.

B. Guidance Facilities and Experience

Aside from the facilities of the Balloon Department, the Engineering Department of the Mechanical Division operates a Guidance and Navigation Laboratory which is engaged in the development of precision electronic, electromechanical, and mechanical analog devices for use in missile guidance

Figure 27. "Aerocap" Balloon Similar to Proposed Airship

systems, bombing and navigation computers and other types of guidance and control systems used in missile and aircraft installations. Although this work is far more complex and detailed than the requirements of the guidance system for the proposed airship, the experience and the fabrication facilities of this laboratory may be of value in developing the optimum airship guidance system. The engineers of the Guidance and Navigation Laboratory are experienced in the requisites of any airborne guidance system: namely, accuracy, low cost, reliability, light weight, and low power consumption.

The Guidance and Navigation Laboratory is also staffed with personnel who are engaged in the development of complex surveying and automatic tracking systems. These personnel are well qualified in the fields of optics and infra-red radiation. Again, while the complexity of their work exceeds the requirements of the tracking system for the proposed airship, their experience will be helpful in formulating the optimum tracking system.

C. Radio Communications

The Engineering Department operates a Communications and Controls laboratory which has broad experience and facilities in radio and microwave communications, and in control systems. The services of this group are available to assist in the development of radio command and radio range systems for the proposed airship.

D. Additional Facilities

The Computer Laboratory of the Engineering Department possesses a Reeves C400 (REAC) analog computer which will be helpful in achieving an optimum airship design, and which will aid in the analysis of flight control devices.

E. Additional Experience

During the past decade plastic balloons have evolved from experimental toys to highly reliable scientific stratoplatforms. Innumerable military operational and research programs currently employ balloons. General Mills, Inc. has been at the forefront of this work for many years, and has developed a wide variety of balloons for a multitude of applications.

In response to continuing and widespread requirements to suspend scientific equipment or advertising material at relatively low (a few thousand feet) altitudes and in average meteorological conditions, GMI has accomplished the successful design, construction and operation of aerodynamically shaped, lighter-than-air captive vehicles. These vehicles, sold under the trade mark "AEROCAP", are aerodynamically shaped with tail fins.

Units up to 39 feet in length have been successfully operated and have proven themselves reliable at altitudes up to 1500 feet above terrain in winds of up to 40 knots. The "AEROCAP" Balloon deploys itself almost vertically above the mooring point throughout a wide range of wind conditions. A brief flight was made with one of these units to an altitude of 4500 feet above terrain with no difficulty experienced. Rapid progress has witnessed flights of units up to 65 feet in length, fabrication of vehicles more than 130 feet long, and development of balloons in excess of 200 feet capable of 20,000 lbs. lift.

VI. PERSONNEL RESUMES

The following pages contain resumes of personnel who will be assigned to the Low Altitude Airship project.

APPENDIX A

Sound Detection

A test was conducted by General Mills to determine the sound intensity of a 2 foot propeller rotating at 6000 rpm. The test was made indoors in a large room where the original sound-pressure level (SPL) was recorded as 55 decibels (db). The reference point for the SPL is .0002 microbar. The power level (PWL) is also given in decibels and has a reference point of 10^{-13} watts. The relationship between SPL and PWL is given below:

$$PWL = SPL + 20 \log_{10} r + 10.5 \qquad (1)$$

where:

PWL and SPL are in decibels

r = the distance in feet from the sound source to the point where the SPL is measured.

If the SPL is measured at a point r_1, the SPL at a point r_2 can then be predicted from equation (1).

$$SPL_2 = SPL_1 - 20 \log_{10} \frac{r_2}{r_1} \qquad (2)$$

The sound intensity of the 2 foot propeller rotating at 5900 rpm was recorded by a General Radio Co. sound-survey meter placed 2-1/2 feet from the propeller. The SPL reading recorded was 83 Db. Because the test was run near a wall, the reading obtained is slightly higher than the actual reading due to sound reflections. A correction factor of -2 Db was used to compensate for the room reflections. The SPL reading at 2-1/2 feet is then given as 83-2 = 81 Db. Since the airship will be flying at an altitude of 500 ft the sound intensity at that distance should be known.

$$SPL_2 = SPL_1 - 20 \log_{10} \frac{r_2}{r_1}$$

$$= 81 - 20 \log_{10} \frac{500}{2.5}$$

$$= 81 - 46 = 35 \text{ Db.}$$

A SPL of 35 DB is classified as a faint sound and is equivalent to a quiet residential area or a quiet home. This 35 Db SPL occurs directly below the airship. At any other ground station the SPL will decrease as the distance from the airship increases.

The loudness level is somewhat different from the sound-pressure level. It is the SPL at a frequency of 1000 cycles per second. The units of loudness level are phons. Sounds of various frequencies are compared to a sound of equivalent loudness at a frequency of 1000 cps. In the case of a propeller rotating at 5900 rpm, the frequency of the sound waves would be approximately 200 cps. A SPL of 35 Db at 200 cps is equivalent to 14 Db at 1000 cps, or a loudness level of 14 phons. About 50 percent of the population can hear sounds that exceed 20 phons and the percentage decreases rapidly as the loudness level drops below 20 phons.

The results of the test indicate that the proposed airship would not be easily detectable due to noise. Although the test was not made under actual conditions or even under ideal conditions, it is believed that a fairly representative value of sound intensity was obtained.

Figures A1 and A2 show the sound-pressure level and loudness level as a function of propeller rpm.

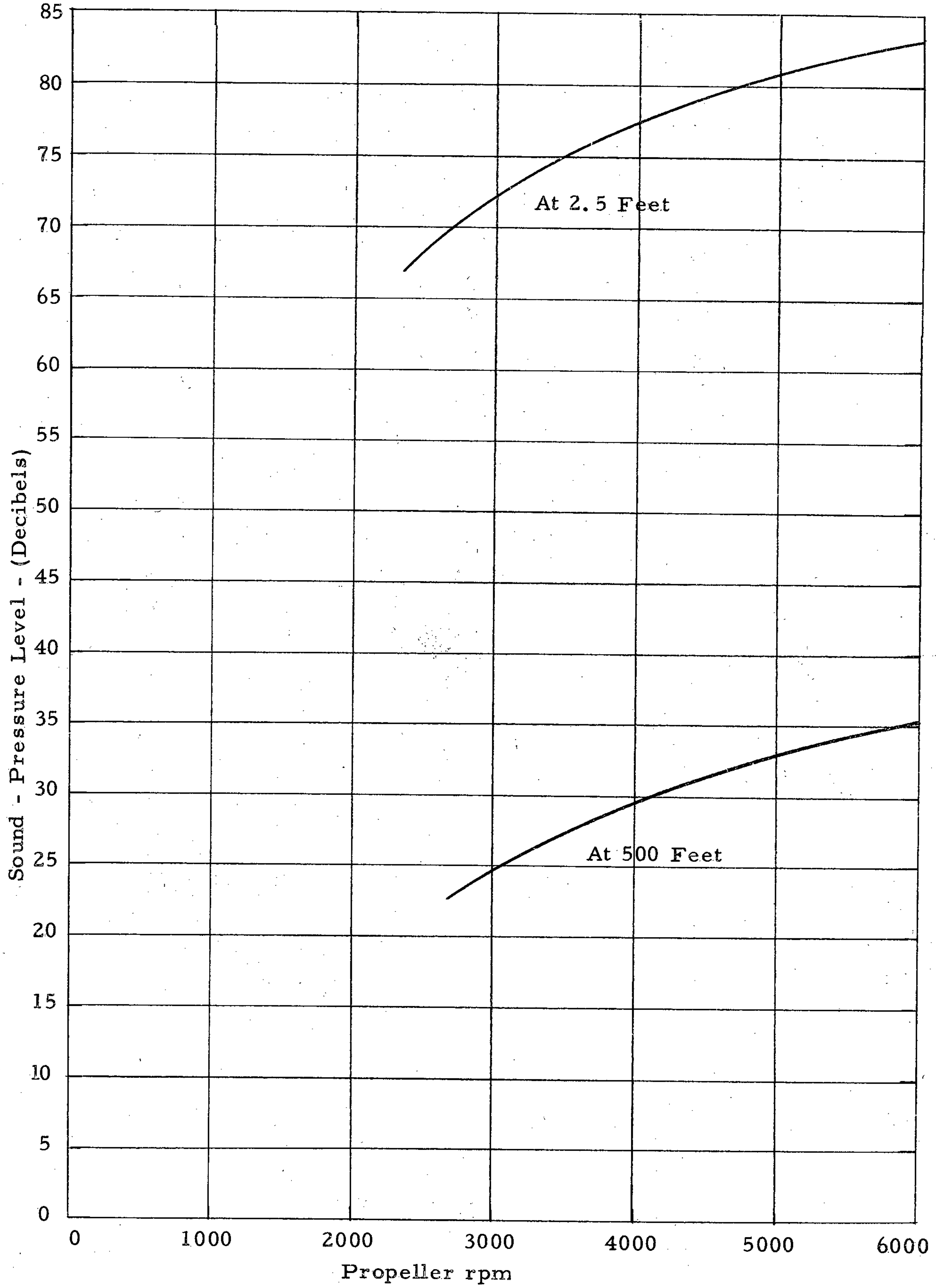


Figure A1. Sound Intensity vs. Propeller Speed

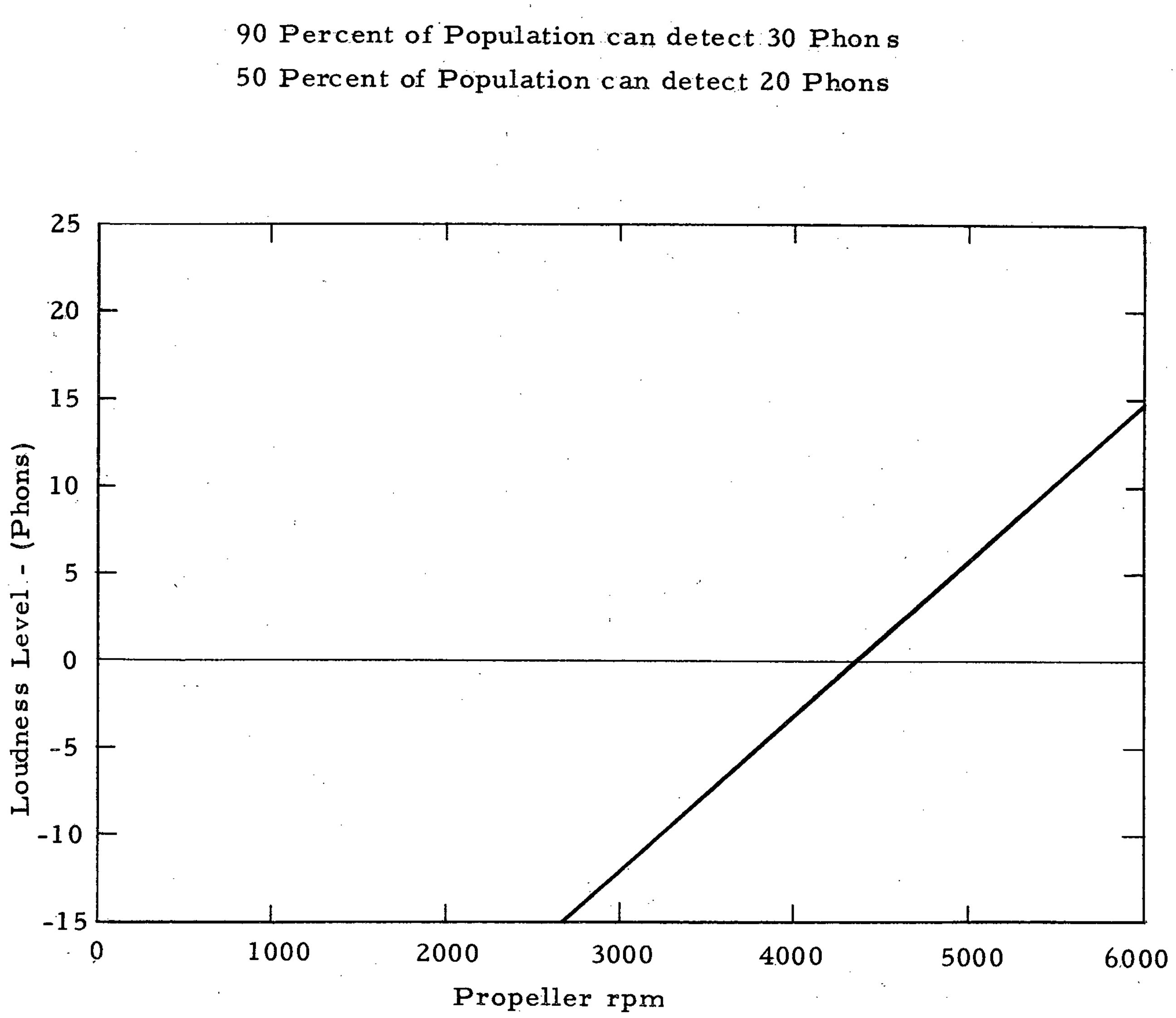
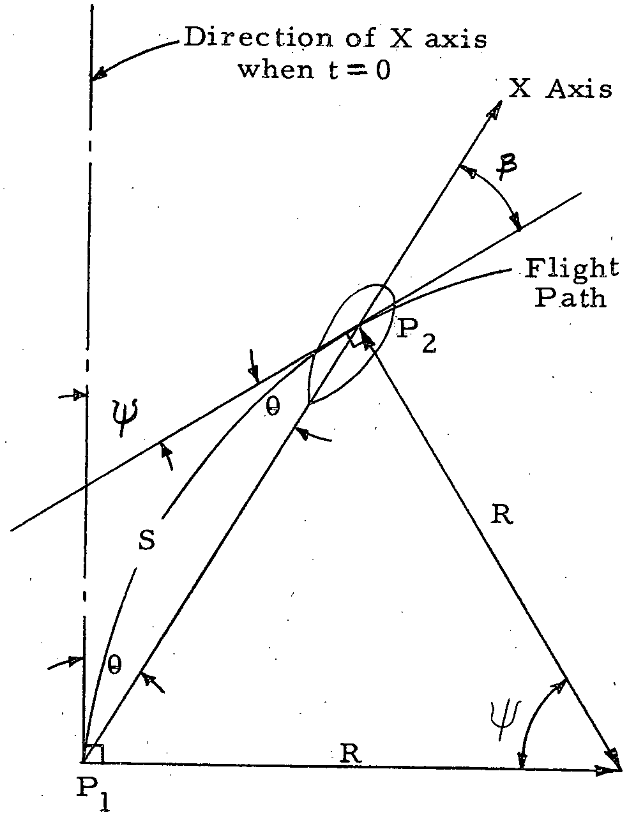


Figure A2. Loudness Level vs Propeller RPM at Distance of 500 Feet

APPENDIX B

Equations of Maneuverability



where:

R = radius of turn, feet
P_1 = position of airship at t 0
P_2 = position of airship at t t
θ = angle of yaw
β = angle of sideslip
S = distance which airship has moved in time t along circle
ψ = angle between positions P_1 and P_2
V = forward velocity, fps

From trigonometry:

$$ds = R d\psi \tag{1}$$

Rearranging:

$$R = \frac{ds}{d\psi} = \frac{ds/dt}{d\psi/dt} \tag{2}$$

However, from the geometry of the figure:

$$2\theta = \psi \tag{3}$$

Taking the derivative with respect to time:

$$\frac{2d\theta}{dt} = \frac{d\psi}{dt} \qquad (4)$$

Upon substitution of (4) into (2)

$$R = \frac{V}{2\dot{\theta}} \qquad (5)$$

The required yawing velocity, $\dot{\theta}$, can be obtained from a differential equation developed from dynamic considerations.

$$n - K\dot{\theta} = I\ddot{\theta} \qquad (6)$$

where:

n = torque, ft lbs
K = damping turn, ft lb sec
I = total moment of inertia, ft lb $\sec^2$
θ = angle of yaw, radians

Rearranging

$$\ddot{\theta} = \frac{n}{I} - \frac{K}{I}\dot{\theta} = -\frac{K}{I}\left[\dot{\theta} - \frac{n}{K}\right]$$

Thus

$$\frac{\ddot{\theta}}{\left[\dot{\theta} - \frac{n}{K}\right]} = -\frac{K}{I}$$

Equivalent integral form

$$\int \frac{a\left[\dot{\theta} - h/K\right]}{\left[\dot{\theta} - n/K\right]} = -K/I \int at$$

Solving

$$\log(\dot{\theta} - n/K) = -C\,\frac{K}{I}\,t$$

or

$$\dot{\theta} - n/K = C\,e^{-(K/I)t}$$

Evaluating C

at $t = 0$

$\theta = 0$

$C = -n/K$

Thus

$$\dot{\theta} = n/K\left[1 - e^{-(K/I)t}\right] \qquad (7)$$

Equivalent integral form

$$\int dt = n/K \int \left[1 - e^{-(K/I)t}\right] dt$$

Solving

$$\theta = n/K\left[t + \frac{e^{-(K/I)t}}{K/I}\right] + C$$

or

$$\theta = n/K\,(t + I/K\,e^{-(K/I)t}) + C$$

Evaluating C

at $t = 0$

$\theta = 0$

$\therefore C = -nI/K^2$

Thus

$$\theta = n/K\,t + n\,I/K^2\,e^{-(K/I)t} - n\,I/K^2 \qquad (8)$$

APPENDIX C

Solutions of Airships Vertical Motion

The free lift of an airship must be changed 4 times to successfully complete its mission. To determine the relationship between the various parameters after the free lift has been changed, the following differential was obtained from Newton's second law and was programmed for a REAC:

$$M \frac{d^2h}{dt^2} + K\left(\frac{dL}{dt}\right)^2 = f - at$$

where:

M	airship mass, slugs
k	drag term, slugs/ft
f	free lift, lbs
a	valving rate, lbs/sec
t	valving time, sec
h	altitude, ft.

When the airship reaches the desired position and drops its payload, it experiences an upward acceleration due to the excess free lift. To stop this ascent, helium is valved from the airship at a constant rate until $f - at = 0$. Then the drag force reduces this ascent velocity to zero at the required altitude.

Figures A3, A4, and A5 show the results of the above procedure from 18 REAC solutions. These results were obtained from the above differential equation, assuming $m = 5.5$ slugs and varying the parameters, k, a, and f. From these figures, it is observed that the valving rate adjustment is very critical to reach the desired altitude, since the other parameters are relatively fixed for a particular configuration.

These curves were plotted to show how the various parameters affect the desired altitude and peak velocity. For an analysis of our configuration, see Figures 10 and 11 of Section 3-B.

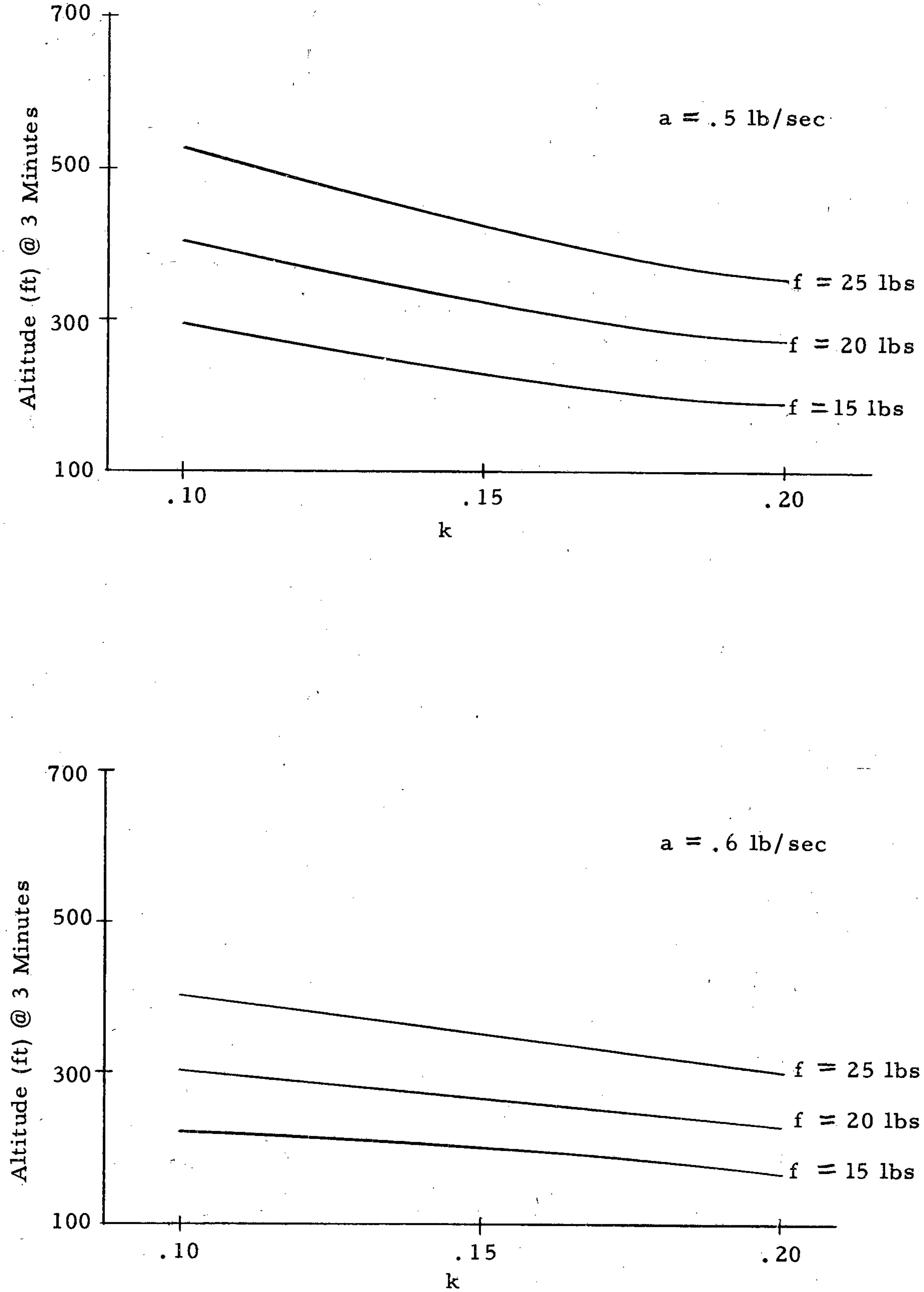


Figure A3. Altitude Variation

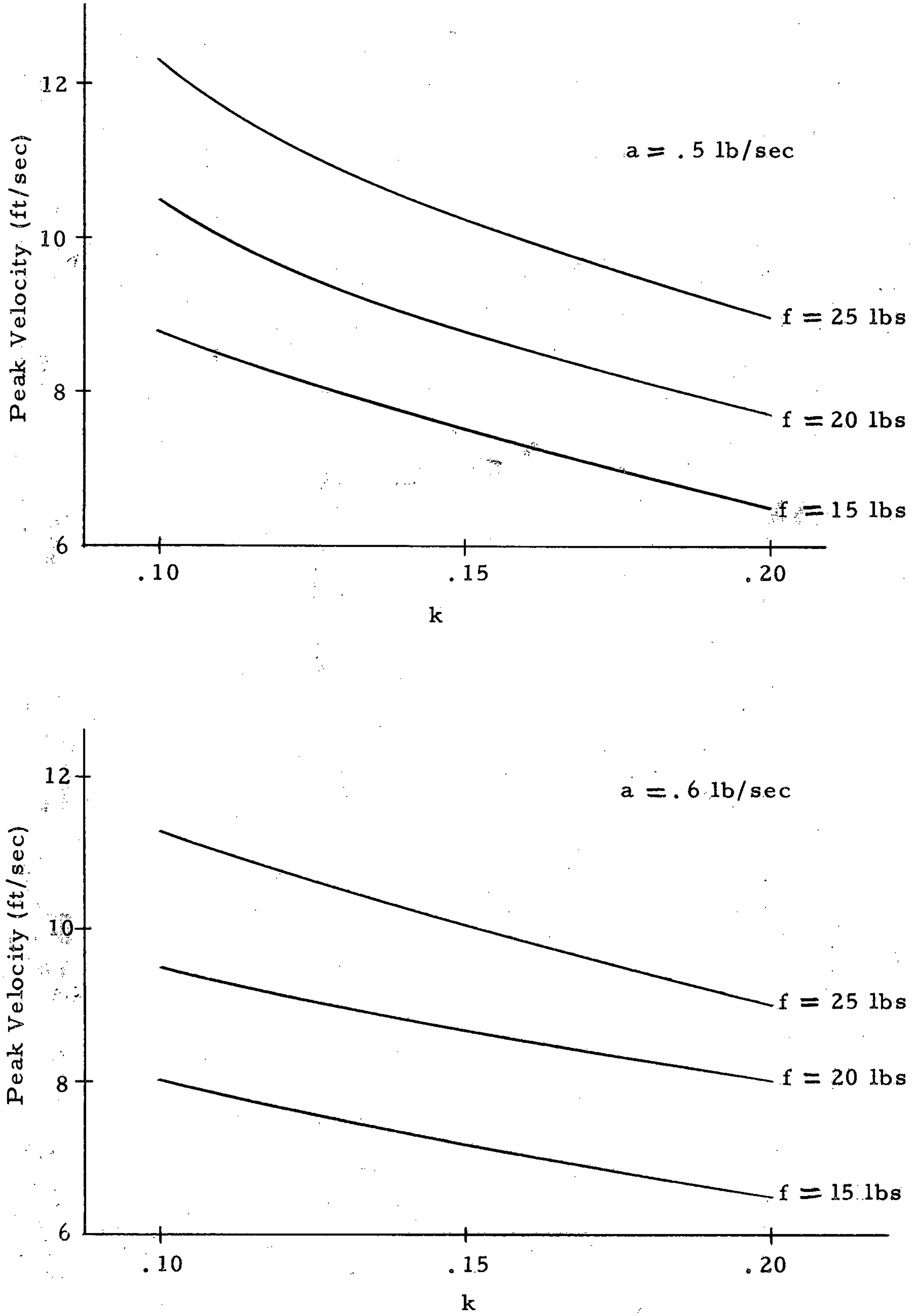
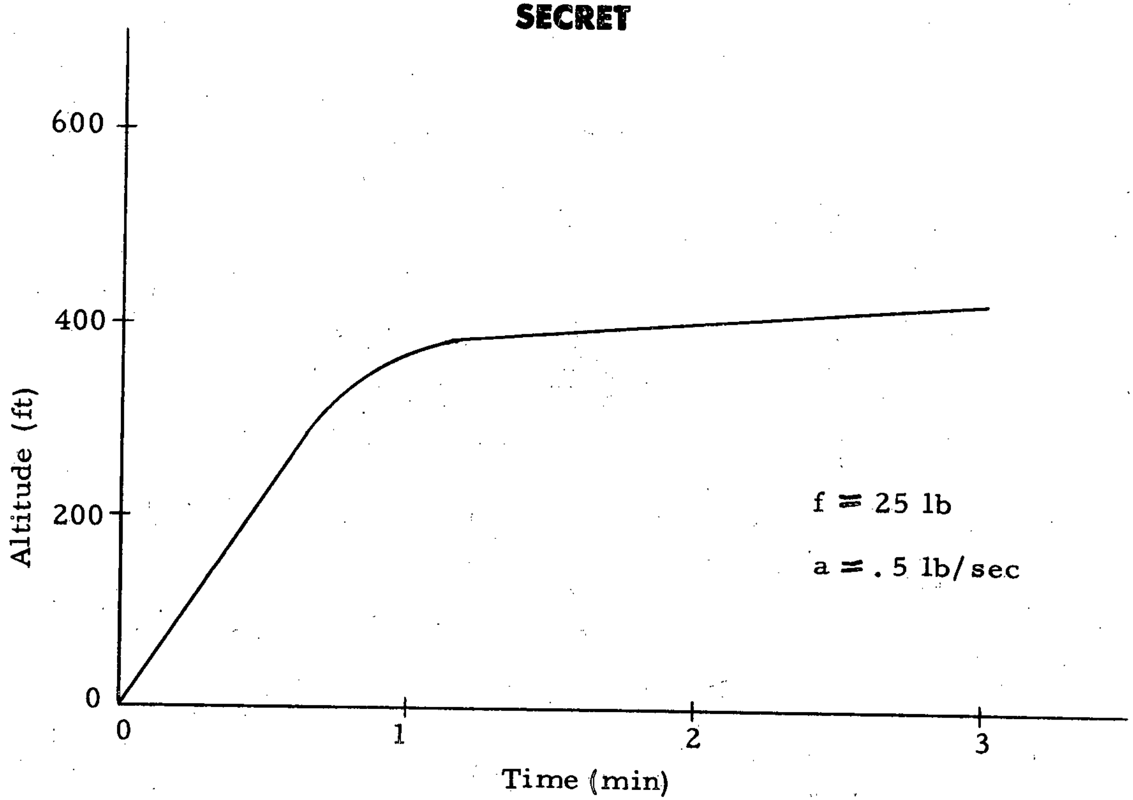


Figure A4. Peak Velocity Variation



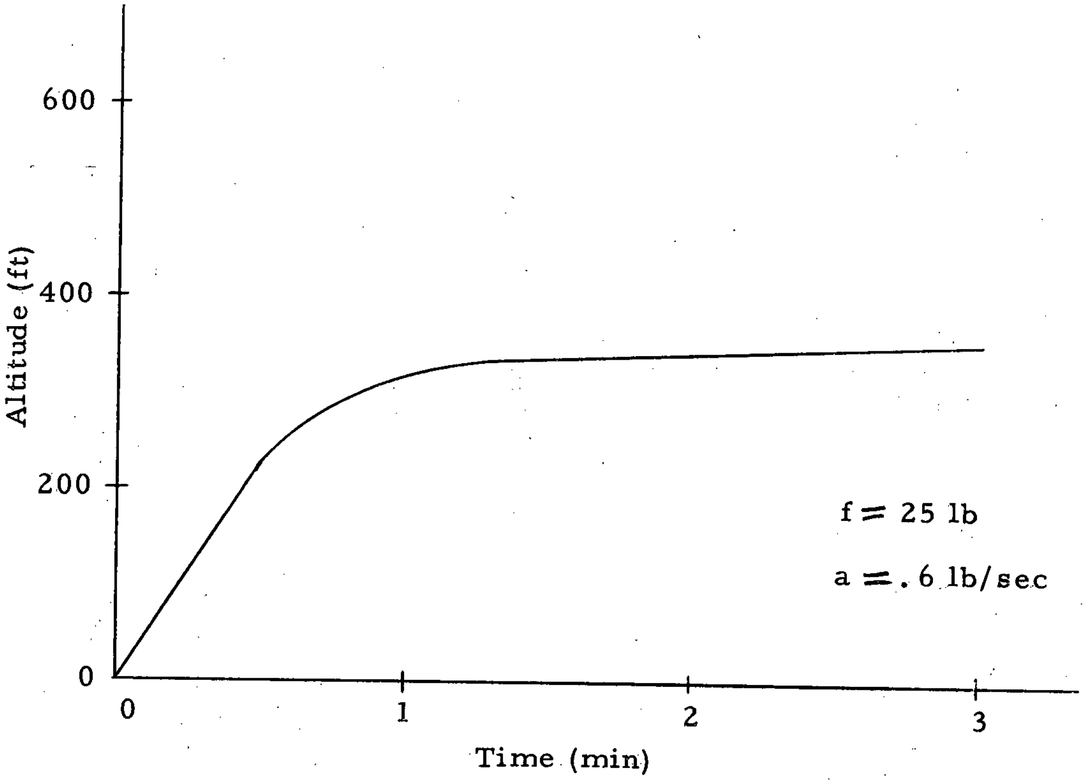


Figure A5. Altitude Variation with Time