CONFIDENTIAL ~~SECRET~~

19 February 1958

MEMORANDUM FOR: Office of Logistics/Procurement Division/Military Purchase

SUBJECT : Request for Transfer of Funds [redacted] 25X1

1. The Agency intends to sponsor a continuation of research and development leading toward a small powered, lighter-than-air vehicle. The [redacted] has indicated that they will support this work with technical assistance and with funds if and when supplementary funds are available to them for fiscal year 1958. 25X1

2. It is therefore requested that funds in the amount of $80,366.00 be transferred to the [redacted] with the understanding that they will enter into a contractual agreement with [redacted] to perform work in accordance with [redacted] 11510-B, Phase I. This sum of money is a partial procurement of Phase I described in this proposal. It is expected that [redacted] will contribute the remaining funds necessary to accomplish this work but should this contribution not be forthcoming [redacted] should process the contract on a partial procurement basis with the stipulation that the remaining funds necessary to accomplish all of the technical work described for Phase I will be made available by the Agency. 25X1 25X1 25X1 25X1 25X1

3. Technical liaison with the [redacted] and with [redacted] will be provided by [redacted] Room 210, West Outbuilding, extension [redacted] 25X1 25X1 25X1 25X1

4. Charges for this work are to be made from unvouchered funds against Allotment Number 8-2502-10. This transfer should be made so that Agency interest is not revealed in [redacted] beyond those who have received security approval from the Agency security office. 25X1

[redacted] 25X1

Chief
TSS/Engineering Division

Attachments:
Proposal dtd 6 Jan 58
TSS-913-27-1448-58

APPROVED FOR THE OBLIGATION OF FUNDS:

Research Director

Date

DD/P/TSS/E[redacted]mt

~~SECRET~~ 25X1

CONFIDENTIAL

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JUST 22 NEXT REV 2010 AUTH: HR 70-2

REQUISITION AND SHIPPING INSTRUCTIONS FOR SUPPLIES AND EQUIPMENT

~~SECRET~~

PAGE 1 OF 1 PAGES

REQUISITION NO. TSS-913-27-1448-58

PROC. CHARGEABLE TO

MATERIAL COST CODE 8-2502-10

VOUCHER (OR CARGO) NO.

DATE 19 Feb 1958

SIGNATURE OF APPROVING OFFICER [redacted]

DATE REQUIRED

25X1

NAME OF CONTACT OFFICER [redacted]

TELEPHONE [redacted]

OFFICE TSS/ED

25X1

SHIPPING INSTRUCTIONS

CONSIGNEE (NAME AND DESTINATION)

TRUCK	AIR CAR.	SEA CAR.	AIR POU.	SEA POU.	COMM.	MILIT.	DIPLO.

AIR SHIPMENT JUSTIFICATION

MARKING INSTRUCTIONS

PACKING INSTRUCTIONS

EST. WEIGHT

EST. CUBE

EST. AVAILABILITY DATE

REQUESTED IN LETTER/CABLE DATED

REMARKS: (OF OPERATING DIVISION)

REMARKS: (OF STOCK CONTROL PROCESSING)

REQUISITION AND SHIPPING INSTRUCTIONS FOR SUPPLIES AND EQUIPMENT

PAGE 1 OF 1 PAGES

REQUISITION NO. TSS-913-27-1448-58

PROC. CHARGEABLE TO

MATERIAL COST CODE 8-2502-10

VOUCHER (OR CARGO) NO.

DATE 19 Feb 1958

ITEM NO.	STOCK NO.	NOMENCLATURE	PRICING AND EDITING DATA			
		It is requested that funds in the amount of $80,366.00 be transferred [redacted] [redacted] in accordance with Memo for OL/PD/Military Purchase from C/TSS/ED dated 19 Feb. 1958, Subj: Request for Transfer of Funds to the [redacted]	QUANTITY	UNIT	UNIT PRICE	EXTENSION
			RELEASED	ACTION	S-A-C	LOCATION
			QUANTITY	UNIT	UNIT PRICE	EXTENSION
			RELEASED	ACTION	S-A-C	LOCATION
			QUANTITY	UNIT	UNIT PRICE	EXTENSION
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		~~SECRET~~	QUANTITY	UNIT	UNIT PRICE	EXTENSION
			RELEASED	ACTION	S-A-C	LOCATION
			QUANTITY	UNIT	UNIT PRICE	EXTENSION
			RELEASED	ACTION	S-A-C	LOCATION

25X1

25X1

25X1

FORM NO. 88
1 FEB 55
PREVIOUS EDITIONS OF THIS FORM MAY BE USED

CONFIDENTIAL

[redacted]

25X1

ENGINEERING, RESEARCH & DEVELOPMENT

[redacted]

25X1

8268 MD-2

If enclosure (s) is/are withdrawn, (or not attached) the classification of this correspondence will be cancelled without reference to the originating authority.

25X1

[redacted]

[redacted] 25X1

January 6, 1958

[redacted] 25X1

Subject: [redacted] Proposal No. 11510-B - Small Plastic Airship 25X1

Reference: Our letter dated November 1, 1957

Gentlemen:

In response to referenced request we are pleased to submit herewith our proposal No. 11510-B entitled "Small Plastic Airship." Subject proposal supersedes proposal Nos. 11510 and 11510-A. Therefore, we have enclosed herewith our fiscal and contractual data together with a breakdown of costs and a summary thereof.

Lighter than Air vehicles have unique inherent characteristics which we believe can fulfill certain military operational requirements. Under contract [redacted] we have completed a basic LTA study. The proposed program is an outgrowth of that study and is important from the standpoint of increasing our fundamental knowledge about airships. We feel that a significant advancement in the state of the art will result, allowing the definition of other Lighter than Air systems to perform military tasks. 25X1

The estimated cost of this proposal is $325,359 plus a fixed fee of $22,775 for a total of $348,134.

Should there be any questions concerning this proposal, we will be happy to provide any additional information you feel necessary for your evaluation. We look forward to the opportunity of being of service to the Navy.

Very truly yours,

[redacted] 25X1

Contract Administrator

Approved by [redacted] 25X1

Proposal and Contract Administration

PROPOSAL NO. 11510-B

FISCAL AND CONTRACTUAL DATA

I. SCOPE

It is hereby proposed that the Mechanical Division of [redacted] 25X1 [redacted] 25X1 (hereafter referred to as the Contractor) enter into a cost-plus-fixed-fee type contract with the Government to conduct research as discussed in the enclosed Technical Discussion.

II. ESTIMATED COST

It is estimated that the cost of the proposed program will be $325,359 plus a fixed fee of $22,775 for a total of $348,134. A detailed breakdown of this amount is given in the attached cost schedule.

III. DELIVERY

It is proposed that this program will run for a period of twenty-four (24) months after receipt of an executed contract.

IV. TERMS AND CONDITIONS

A. This proposal is subject to withdrawal by the Contractor unless written acceptance thereto is received within sixty (60) days from the date specified herein.

B. Any contract resulting from this proposal shall contain the standard Exculpatory Clause entitled EXCUSABLE DELAYS found in Section 7-203.11 of the Armed Services Procurement Regulations.

C. All subject matter (including drawings, present or proposed designs, and other data or information) submitted with this proposal is incorporated herein for a study on a confidential basis, without consideration, for the sole purpose of negotiations of a possible contract. No subject matter is to be used, copied, or otherwise reproduced, or disclosed to any third party in any manner, directly or indirectly, without written approval by the Mechanical Division. All property rights, including patent rights, in any such subject matter are expressly reserved to [redacted], except to the extent otherwise provided by the specific terms of a written contract to which [redacted], is a party. 25X1 25X1

D. Net payment for work performed under any contract which may result from this proposal shall be due thirty (30) days following date of the Contractor's invoice.

E. In preparing this proposal, no allowance has been made for the working of overtime. Any premium time which is paid in connection with any overtime worked is charged to overhead, rather than directly to the contract.

F. All inventions which may result from work proposed hereunder will be the property of the Contractor. If this contract actually calls for experimental, developmental, or research work, Contractor is willing to include the standard patent rights clause (ASPR-9-107.1) in such contract.

G. Any contract resulting from this proposal will contain provision for the payment of the fixed fee as stipulated in the cost estimate and for reimbursing the Contractor for all costs incurred in the performance of this contract, in accordance with Section XV, Part 2 of Armed Services Procurement Regulations. Contract should further authorize that [redacted] 25X1 [redacted] 25X1, be authorized the use of negotiated final overhead rates with provisional reimbursement at current standard burden rates (for any department in which work is performed) with adjustment to be made to the negotiated final overhead rates as periodically determined in accordance with ASPR 3-704.1.

For the purpose of compiling our estimate of costs, G&A and Burden have been included at estimated rates which closely approximate the anticipated actual G&A and Burden.

GENERAL INFORMATION

The following information and representations are provided to supplement information contained in the discussion of Terms and Conditions.

A. [redacted] having its executive offices at Minneapolis, Minnesota. 25X1

B. The Mechanical Division of the company now employs approximately two thousand (2,000) persons. Total employees of the corporation number approximately thirteen thousand (13,000).

C. There is no agreement to pay any commission, percentage, brokerage, or contingent fee in connection with the proposed contract.

D. Individuals authorized to conduct negotiations on behalf of the Mechanical Division on the work proposed hereunder include: Mr. Z. Soucek, General Manager; Mr. E. Frank Coy, Director of Sales; Mr. Victor E. Benson, Supervisor, Proposal and Contract Administration.

E. The Mechanical Division is under cognizance of the United States Air Force for security and for Government inspection when required.

SCHEDULE I

Summary of Costs

Phase I	$ 88,491
Phase II	137,666
Phase III	60,926
Total	287,083
10 percent Contingency on Phases II and III	19,859
Total Estimated Cost	306,942
G&A @ 6 percent	18,417
	325,359
Fixed Fee @ 7 percent	22,775
Total Selling Price	$348,134

* Helium for tests in Phases II and III	GFE
Portable Mooring Mast	GFE
Large, Hangar-type building for inflation tests	GFE

SCHEDULE II

Direct Labor:			
Research			
Principal & Senior Engineer	5,226 hrs. @ $4.10	$21,427	
Associate & Junior Engineer	3,114 hrs. @ $2.90	9,031	
Technician "A"	1,038 hrs. @ $2.20	2,284	
			$32,742
ERD Model Shop			
Machinist	300 hrs. @ $2.60		780
Balloon Operations			
Principal & Senior Engineer	300 hrs. @ $3.85	$ 1,155	
Technician	500 hrs. @ $2.00	1,000	
			2,155
Balloon Production			
Principal & Senior Engineer	480 hrs. @ $3.85	$ 1,848	
Technician	860 hrs. @ $1.90	1,634	
			3,482
Technical Editing			
Editor	100 hrs. @ $3.10		310
Burden:			
Research	9,378 hrs. @ $3.30	$30,947	
Balloon Operations	800 hrs. @ $2.15	1,720	
ERD Model Shop	300 hrs. @ $2.90	870	
Balloon Production	1,340 hrs. @ $2.75	3,685	
			$37,222
Other Expenses:			
Travel		$ 3,000	
Materials		6,400	
Consultant		2,400	
			11,800
Total Cost Less G&A and Fixed Fee Phase I			$88,491

SCHEDULE III

Phase II

Labor:			
Research Department			
Principal or Senior Scientist	4,671 hrs. @ $4.10		$19,151
Balloon Manufacturing Department			
Senior Engineer	3,700 hrs. @ $3.85	$14,245	
Development Engineer	600 hrs. @ $3.45	2,070	
Draftsmen	1,500 hrs. @ $2.65	3,975	
			$20,290
Balloon Operations Department			
Senior Engineer	4,050 hrs. @ $3.85	15,593	
Draftsmen	1,600 hrs. @ $2.25	3,600	
Technicians	2,800 hrs. @ $2.00	5,600	$24,793
Burden:			
Research Department	4,671 hrs. @ $3.30	$15,414	
Balloon Manufacturing Dept.	5,800 hrs. @ $2.75	15,950	
Balloon Operations Department	8,450 hrs. @ $2.15	18,168	
			$49,532
Material and Fabrication Costs			23,900
Total Cost Less G&A and Fixed Fee Phase II			$137,666

SCHEDULE IV

Phase III			
Labor:			
Research Department			
Principal and Senior Engineers	2,076 hrs. @ $4.10	$8,512	
Balloon Manufacturing Dept.			
Senior Engineer	1,000 hrs. @ $3.85	3,850	
Balloon Operations Dept.			
Senior Engineer	1,100 hrs. @ $3.85	$4,235	
Draftsman	200 hrs. @ $2.25	450	
Technicians	2,550 hrs. @ $2.00	5,100	
			$22,147
Burden:			
Research Department	2,076 hrs. @ $3.30	$6,851	
Balloon Manufacturing Dept.	1,000 hrs. @ $2.75	2,750	
Balloon Operations Dept.	3,850 hrs. @ $2.15	8,278	
			17,879
Material and Fabrication			20,900
Total Cost Less G&A and Fixed Fee Phase III			$60,926

CONFIDENTIAL

33703

This document consists of 13 pages and is number 2 of 15 copies, series – , and the following — attachments.

January 6, 1958

Proposal 11510-B

SMALL PLASTIC AIRSHIP

Prepared for

[redacted] 25X1

Prepared by [redacted] 25X1
Technical Specialist

Approved by: [redacted] 25X1

[redacted] 25X1

CONFIDENTIAL

PREFACE

Recent Soviet rocket and submarine accomplishments make it imperative that the free world develop suitable intelligence and defense systems as rapidly as possible.

ICBM detection by infrared and other more recently developed techniques at stratospheric levels, as well as submarine detection by passive and active sonar at sea level, are of primary importance. The detection equipment in both cases requires a suitable vehicle.

There is a real need for an economical solution to the vehicle problem, a solution which is compatible with the operational requirements of the future. Lighter-than-air vehicles, in general, have unique, inherent features such as long flight duration, hovering capability, low cost, vibrationless and quiet operation, as well as the ability to house large radar antennas without aerodynamic penalty.

Lighter-than-air system descriptions have been plagued by the lack of reliable fundamental knowledge concerning vehicle performance. Such elementary considerations as the optimum length-to-diameter ratio are not established. Predicted durations can be in error by as much as a factor of five. Knowledge gained from the proposed program will be invaluable for future system specification, and the airship resulting from this work can be considered as a working model for vehicles having advanced capabilities such as pictured in Figures 1 through 3.

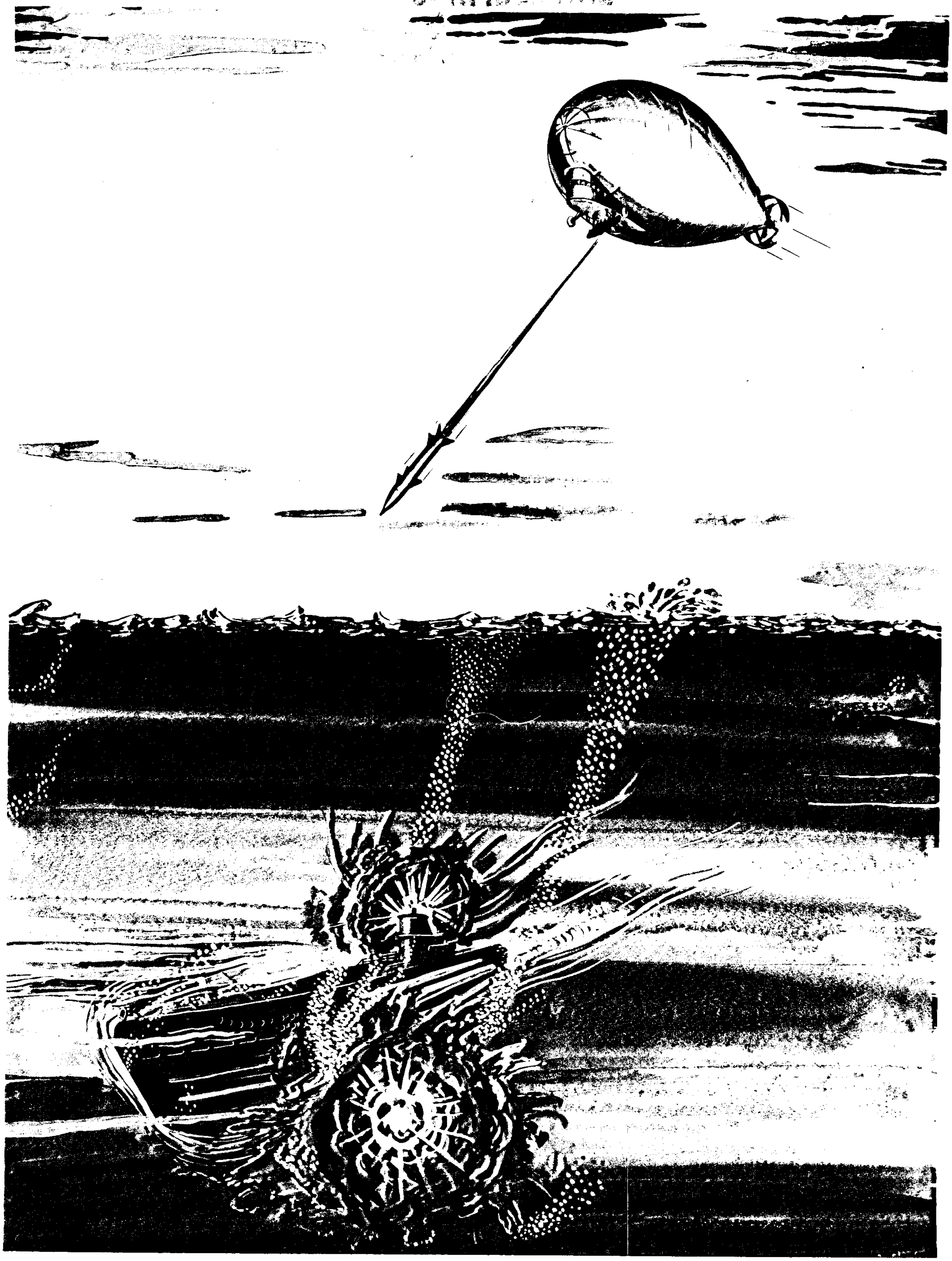

Figure 1. Airship Engaged in ASW Mission

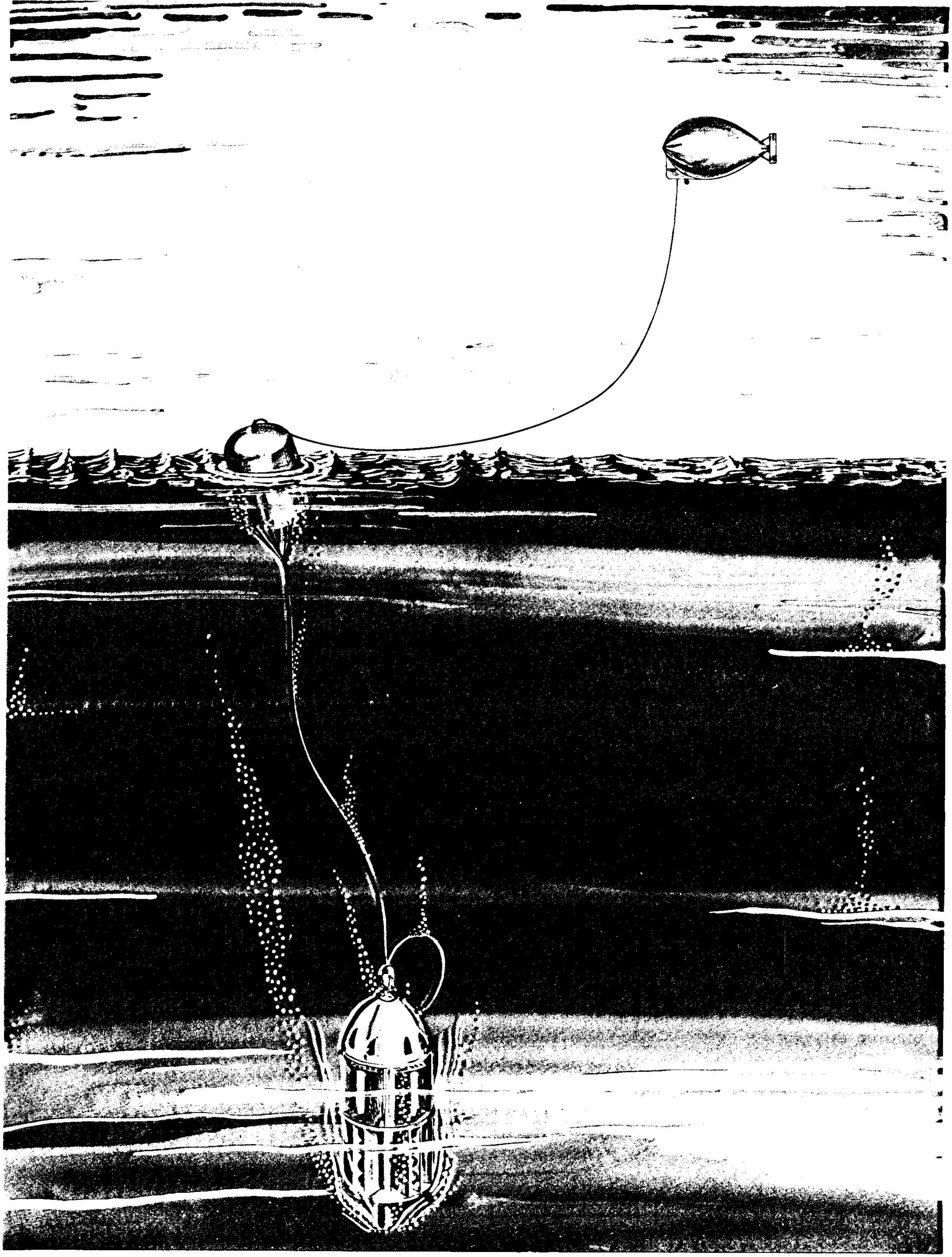

Figure 2. Airship Utilizing Sonar Equipment

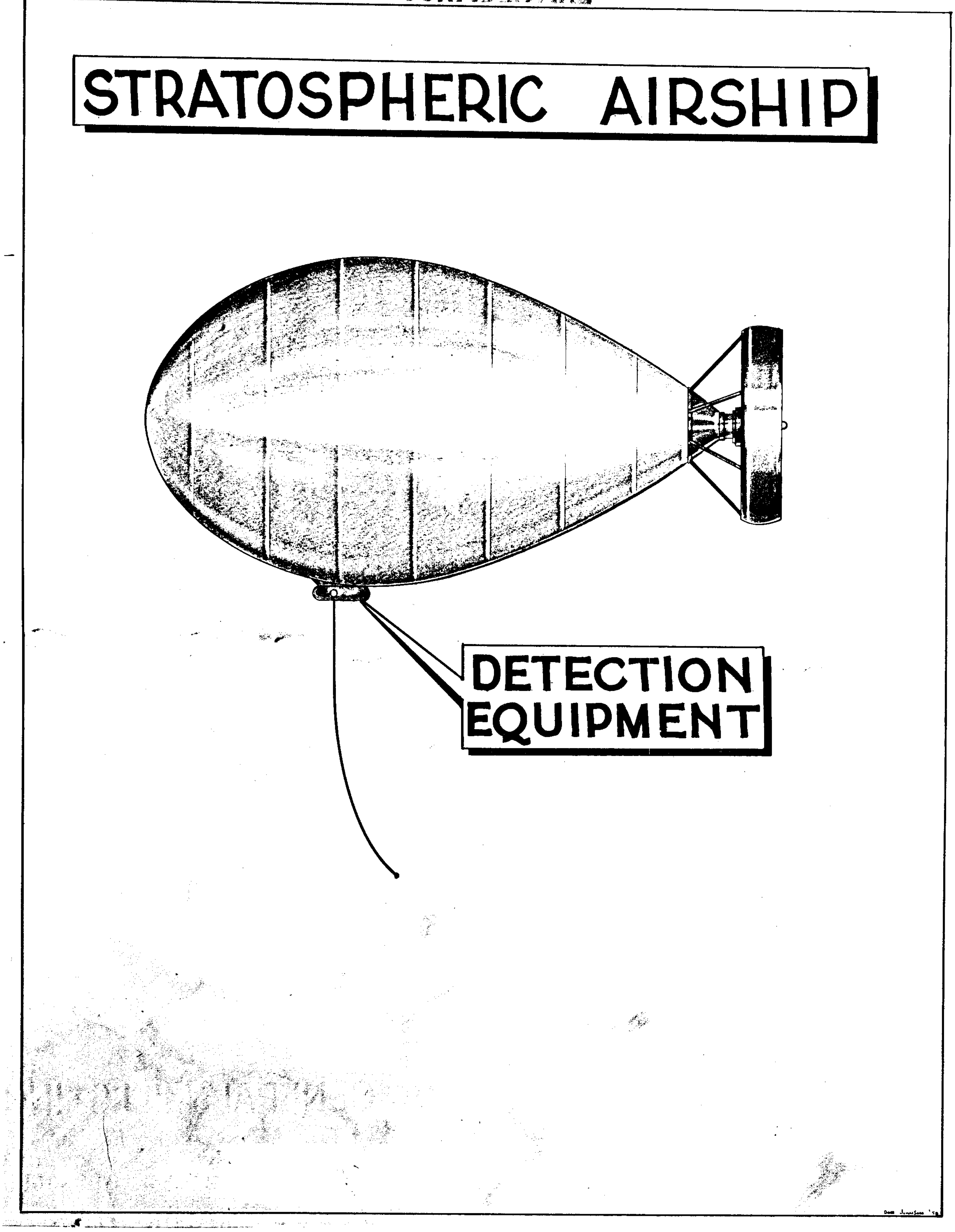

Figure 3. An Airship as a Stratospheric Platform

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LIST OF ILLUSTRATIONS

I. OBJECTIVE

In a broad sense, the objective of this proposal is to demonstrate unique features of powered lighter-than-air vehicles which can lead to stratospheric airships capable of performing defense and intelligence missions beyond the capability of other aircraft types. Advanced techniques capable of substantially increasing the performance of present airships, such as the ASW ship, will also be demonstrated.

Specifically, the objective of this proposal is to outline a two-year program of work, culminating in the delivery of a small plastic airship designed for a specific mission. This work in an outgrowth of the program initiated under [redacted]. The work to date has been conducted 25X1 on a very broad basis, applicable to the LTA field as a whole without limitations as to size, altitude, endurance, etc. Our approach is based on sound fundamental principles and laws rather than on convention. This type of approach, coupled with recent technological advances, will allow a considerable growth in LTA capability, of which this proposal is a part.

II. INTRODUCTION

Although the powered lighter-than-air field has received considerable attention since its inception in the nineteenth century, the full impact of recent technological advances has yet to be realized.

Significant advances have occurred in boundary layer theory[1,2], aircraft propulsion[3], gas barrier materials[4], mathematical and computer techniques in areas of pressure beam mechanics[5], stability and control[6], and in describing the physical properties of streamlined bodies of revolution[7]. Apart from these advances appears an area of configuration arrangement offering noteworthy features (Figure 1).

In light of these recent advances, it is not surprising to discover that the available data on powered airships, although voluminous, fits no natural pattern. Very little is known about the real reasons for favorable results in some cases and for less favorable results in others. The best results obtained thus far have been obtained largely by a process of trial and error. The results of such developments are available only in the form of designs with specific geometric properties and not in the form of laws or facts that are responsible for the results.

The airship has certain unique capabilities which have not been fully exploited. It is not necessarily limited to low altitudes; stratospheric ships, taking advantage of light wind and fair weather conditions, require very nominal amounts of energy to ramain on station for several days. Unlike the airplane, the duration of an airship can be indefinitely extended as the speed is decreased, a feature compatible or required for many detection schemes.

Thrust and power requirements can be further reduced by airflow control methods, resulting in prolonged flight profiles. For ASW ships, in addition to the need for a fast crusing speed, it is necessary to have a highly maneuverable ship with a controllable hovering capability under all wind conditions. The boundary layer concept of fluid flow, as well as solutions to the dynamic equations of motion, are now providing the fundamental laws from which such a capability can be achieved.

To insure a maximum advancement of the state of the art, a strong emphasis will be placed on a research approach. The program will consist of three phases:

Phase I - Research, Theoretical and Experimental
Phase II - Development and Testing
Phase III - Final Design, Acceptance Tests and Delivery.

The program will be carried out by coordinated effort of the various capabilities within the Mechanical Division of [redacted] Phase I will be carried out primarily by the Research Department, while substantial amounts of Phases II and III will be conducted by the Balloon Department. Direct responsibility for all phases of the program, however, will be retained by the Research Department. 25X1

III. DESIGN OBJECTIVES

The requirements for this vehicle are unique in several respects. A portion of the flight will be unpowered and the vehicle must be capable of maneuvering close to the ground while the payload is decreased by as much as two-thirds. It is desired that the vehicle be field-inflatible with a minimum of personnel and equipment. A high degree of flight stability, as well as excellent maneuvering capabilities, is considered essential. Performance and operational requirements are listed below:

1.	Payload, pilot, passenger and/or luggage	400 lb
2.	Cruising altitude	7,000 ft MSL
3.	Free ballooning capability	2 hours
4.	Crusing range at zero wind velocity	100 miles
5.	Minimum speed at sea level	50 knots
6.	Field-inflatible in 15 knots surface wind.	

IV. PROPULSIVE ENERGY REQUIREMENTS

A basic problem common to most powered lighter-than-air missions is to propel a configuration with a maximum ratio of volume to weight through the atmosphere with a minimum expenditure of fuel and a maximum degree of directional stability and control.

Although considerable work has been conducted to individually optimize airship components, we believe it is essential to consider the airship structure together with its propelling, stabilizing and controlling devices as a unit. Components should be designed and arranged so as to complement rather than to interfere with each other.

The analysis of the problem to approach an optimum configuration for the task will include giving consideration to such basic parameters as:

A. Shape and fineness ratio for:
   1. Size reduction
   2. Increased resistance to applied aerodynamic bending loads.

B. Boundary layer suction for:
   1. Over-all energy requirement reduction
   2. Directional stabilization
   3. Directional control.

C. Conventional as well as rear propulsion for increased efficiency and controllability.

D. Ring tail and shrouded propeller versus conventional fins for:
   1. Thrust augmentation, particularly at low speed
   2. Flow improvement around hull
   3. Propeller efficiency increase and/or weight reduction of

stabilizing surfaces

4. Structural strength increase

5. Increased directional stability and control, especially at or near hovering conditions.

E. Engine air requirements (for cooling and combustion) and their possible relation to boundary-sucked air.

There appear to be several configurations worthy of investigation in the early phases of this program. Some of these are:

1. Small fineness ratio:

   a. Aft-propelled by ducted propeller serving also as the stabilizer

   b. Some distributed boundary layer suction

   c. Boundary layer air used for engine intake or cooling purposes.

2. Larger fineness ratio:

   Same as (1) (a) above.

3. Large fineness ratio: (4.2 to 1)

   a. Stabilized by boundary layer control, eliminating the need for fins (as suggested by Dr. August Raspet)

   b. Conventional engine location

4. Conventional arrangement with or without distributed boundary layer suction.

The components involved in the configurations of (1) and (2) are arranged to complement each other. Although the magnitude of the over-all reduction in drag is difficult to estimate, the arrangement presents a form of ideal propulsion called boundary layer propulsion. Configurations of (3) and (4) minimize balance and flow separation difficulties.

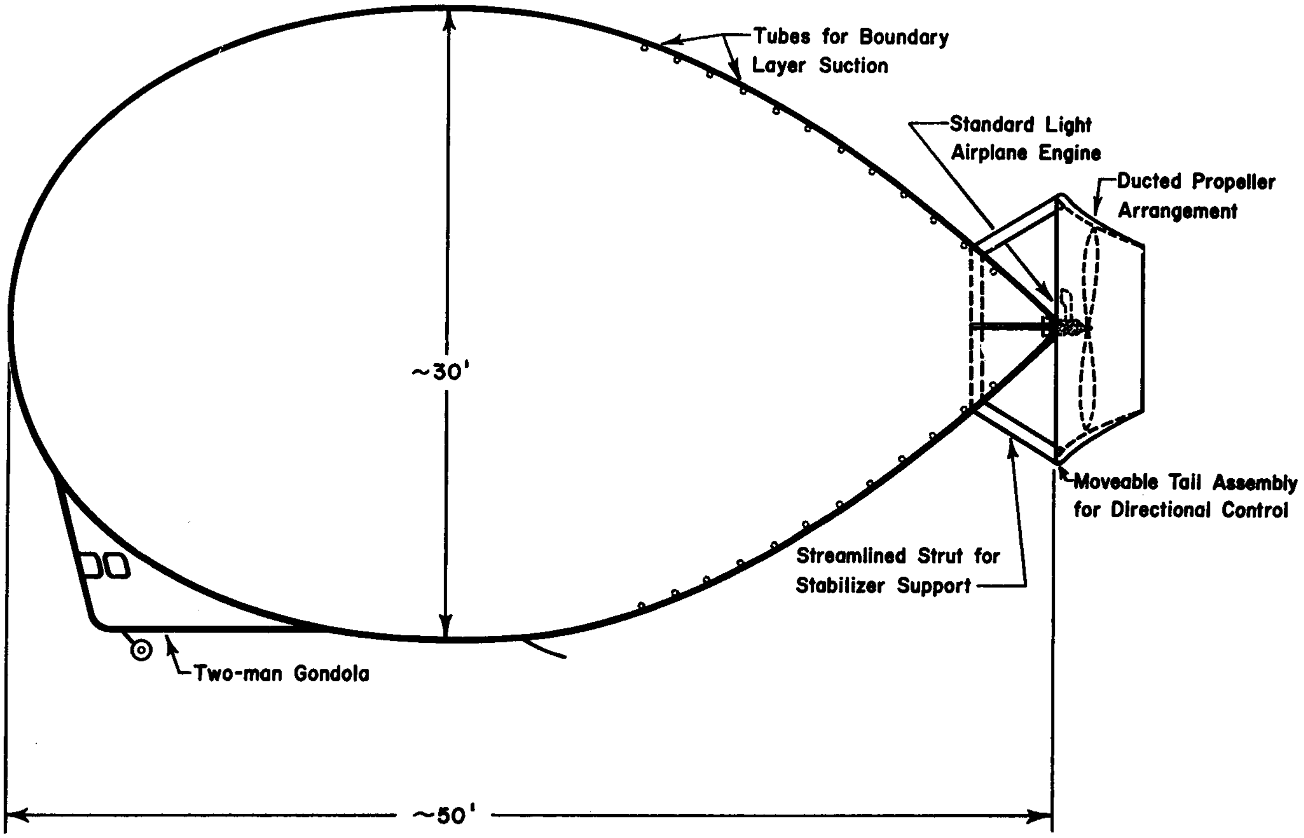
Boundary layer control is intimately involved in all four suggested configurations. Reductions in drag have to be closely measured against the increased complication to determine the degree of usefulness. Unfortunately, the theories are not verified at Reynolds numbers corresponding to those of a full-size airship. Measurements are being conducted on other programs, and these results when they become available, as well as theoretical predictions and measurements on this program, will be applied to this analysis.

A list of apparent advantages for configurations (1) and (2) is presented below. The full potential of configuration (3) can only be estimated after more progress has been made on programs now underway, particularly those at Mississippi State College under Dr. August Raspet.

The degree of departure from the conventional shape of configuration (4) toward the short "fat" shape of configurations (1) and (2) will be evaluated in terms of its advantages as well as the complications involved in preventing flow separation. A series of shapes between these two extremes will be analyzed theoretically for their over-all advantages prior to the selection of a given shape for detailed investigation and preliminary design purposes. On the assumption that flow separation can be prevented, at no great penalty, by distributed suction on a shape such as presented in Figure 4, the following advantages are to be gained:

1. Propeller thrust is combined with stabilizing control surfaces to give low speed controllability at and near hovering conditions. This feature is especially needed in ASW missions.

POSSIBLE CONFIGURATION FOR SMALL PLASTIC AIRSHIP



Approximate Volume, 20,000-25,000 cu.ft.

Figure 4

2. A properly designed stern rotor has the capability of recovering kinetic energy from the wake[8], thus reducing the over-all energy requirement.

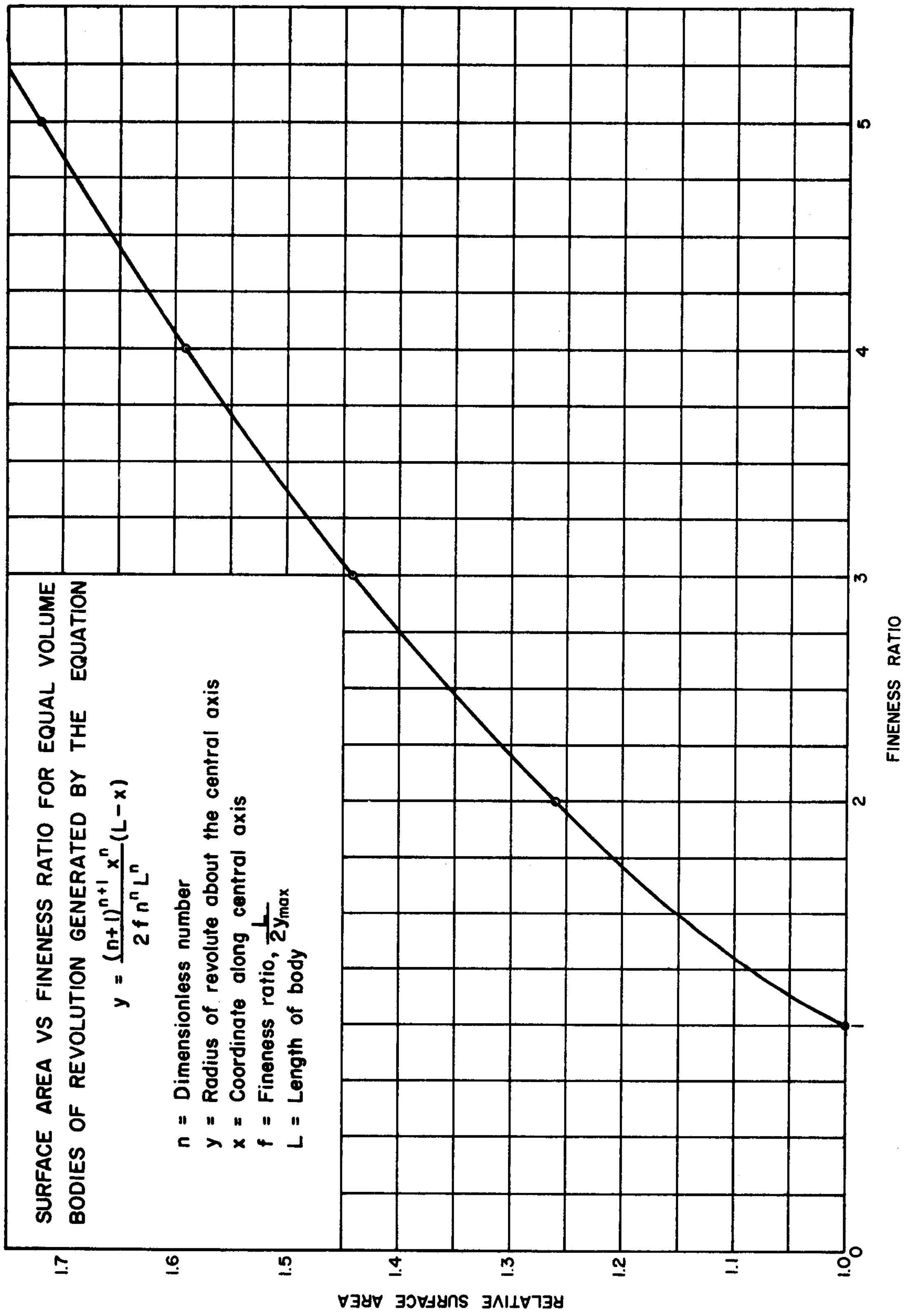
3. When the flow separation is prevented, the drag of an airship is largely a function of the ship's surface area. (Figure 5 shows the relationship between the relative surface area and the fineness ratio for equal volumes of a body of revolution.) This reduction in surface area results in both drag and size reduction, which in turn reduces the propeller, engine and fuel requirements, with a further decrease in size of the envelope necessary to lift them.

4. The lift of a ring air foil has twice the lift of an elliptic flat plate that spans a diameter and has a quarter of the area[9]. It operates outside the ship's boundary layer with a resulting increase in effectiveness. A recent NACA Report[10] has described the testing of five annular airfoils showing comparisons with Ribner's theoretical analysis.

5. A ring tail can be designed to superimpose a favorable pressure gradient on the rear of the hull which retards boundary layer growth and reduces drag. Care must be taken in ring tail design, however, as some ring tails have resulted in an increased drag[11].

6. The ring tail can be used to increase the mass flow through the propeller, with a net result of a gain in thrust without a loss in efficiency.

7. The propeller, like the ring tail, superimposes a favorable pressure gradient on the rear of the hull which retards boundary layer growth and reduces drag. When the propeller is ducted, the pressure increment forward of the propeller is large and the pressure back of the



SURFACE AREA VS FINENESS RATIO FOR EQUAL VOLUME BODIES OF REVOLUTION GENERATED BY THE EQUATION

$$y = \frac{(n+1)^{n+1} x^n}{2 f n^n L^n}(L-x)$$

n = Dimensionless number
y = Radius of revolute about the central axis
x = Coordinate along central axis
f = Fineness ratio, $\frac{L}{2y_{max}}$
L = Length of body

Figure 5

propeller is nearly constant[12]. Bell Aircraft has recently summarized the "state of the art" of ducted propellers. Their work, completed under a Navy contract, will be useful in this program[13].

8. The ring acts as an end plate to the propeller blades and thus reduces the falling off in thrust toward the tips. The space between the blade and the ring must be kept small. The ducted propeller would have much broader blades toward the tips, with a possible appreciable increased propeller efficiency. Ordinarily, the main consequence of the ring would be the increased skin friction drag on the ring. By proper propeller and fairing design, however, this loss will not be appreciable. This loss also must be somewhat discounted in this case because the ring eliminates the conventional tail surfaces and their high drag contributions. In one example[14], the ring and plate effect increased the efficiency by 11 percent.

9. By proper ring design, the forces interacting between the ring and the propeller can increase the efficiency by another increment. In the above mentioned example, this amounted to approximately eight percent.

10. Variable pitch propeller blades are required when the external rate of variance changes appreciably with flight speed. The presence of the fairing or ring makes it possible to keep the rate of advance actually experienced by the propeller more nearly constant, thus reducing the requirement for variable pitch blades. This beneficial effect arises from the fact that the velocity increment due to the ring is more pronounced at lower flight speeds.

11. The increase in static thrust for a ducted propeller can

be spectacular[15], which, of course, is important in takeoff and landing, particularly from fields not considered airports. It is also important in tight maneuvers such as those necessary in anti-submarine warfare.

12. The ducted propeller allows the use of a smaller diameter and engine weight, resulting in a smaller size airship.

13. The ring surrounding the propeller is a safety feature, possibly of importance in field operations.

14. It is common practice to define the resistance to aerodynamic bending loads by the formula:

$$f = \frac{R^3 \pi \Delta P}{2\ell}$$

where:

f = resisting force

ℓ = length of the ship

R = largest radius

ΔP = pressure differential.

From this it can be seen that a ship of lower fineness ratio is ordinarily a much stronger ship, or, conversely, the ship can be made smaller for the same strength.

15. As the fineness ratio is decreased a reduction in profile area is experienced. This in turn reduces the aerodynamic forces acting on the ship.

16. The aerodynamic loads on the stabilizing surfaces can be better absorbed by a ring tail configuration, which is inherently a superior type structure as compared to a cantilevered fin-type.

17. A smaller ship has an increased structural efficiency[16]. A higher percentage of the gross load will be in payload.

18. In ships of high fineness ratio the requirement for strength in the diagonal direction of the airship fabric becomes important[17]. For woven fabrics this is a direct weight penalty amounting to as much as one-third the envelope weight. For shapes of smaller fineness ratio this strength requirement is reduced. Since plastic films usually have some strength in all directions, a large envelope weight saving may be possible.

19. The large favorable pressure gradient on the front portion of the hull has the potential of moving the point of instability further aft[18], resulting in a laminar flow over a larger portion of the hull. Other shapes having specified pressure distribution[19] may offer additional advantages.

The arrangement offers some advantages regarding boundary layer suction. It is possible that air requirements of the engine can be combined beneficially with the suction requirements of the boundary layer.

The problems in weight and balance do not appear to be insurmountable. Present day lightweight, high-strength materials, as well as advanced stress analysis techniques and strain measuring devices, make such an arrangement appear feasible. Several engines suitable for rear installation are currently available.

Care must be exercised in defining a configuration which will be stable for both moored and flight conditions.

Other difficulties that may be encountered are incompatibilities between propeller diameter requirements and ring diameter requirements. Another important unknown at this time is the effect of the hull on the velocity of the air flowing into the propeller. Once these items are determined, however, there are numerous parameters to be adjusted and compromised. Different techniques to replace conventional moveable control surfaces will be investigated. It is expected that inflatible pressure beams can be substituted for this purpose and will be the subject of considerable model as well as theoretical work.

It is realized that other programs evaluating ring tails and rear engine installations have been conducted. Reports on all of these programs have not been received. The reports reviewed to date[20,21,22] indicate the desirability of further investigation of these features.

V. FLUID DYNAMICS

A. Summary

The drag values for airships have been obtained experimentally either by full scale deceleration tests or by wind tunnel methods. Large discrepancies have appeared in these data[23], due largely to a lack of understanding ofthe boundary layer mechanism which is sensitive to free air turbulence, surface roughness and the Reynolds number.

The boundary layer concept of aerodynamics allows an insight into the mechanism of fluid resistance to motions of a body. The resistance of a smooth body of revolution is due almost entirely to the viscous action of the fluid, which results in energy dissipation in three principal ways:

1. The shearing stress or skin friction at the hull surface imparts a velocity to the air, appearing finally as kinetic energy in the wake.

2. The viscous action of the fluid causes the growth of a boundary layer which is first laminar, then turbulent. The extreme length of airships causes this boundary layer to become very thick on the after portions of the hull. Inside the boundary layer, fluid particles are in motion, causing turbulence and eddies to appear, with an eventual loss of energy in the form of heat.

3. Flow separation generally occurs on the after portion of the airship body, producing large vortices and eddies and reversal of air flow at the hull surface and inboard sections of the control surfaces. These air turbulences are finally dissipated, also in the form of heat.

There are, in general, at least five ways to decrease the energy required to propel an airship:

1. Preserve laminar flow as long as possible; Figure 6 shows a comparison

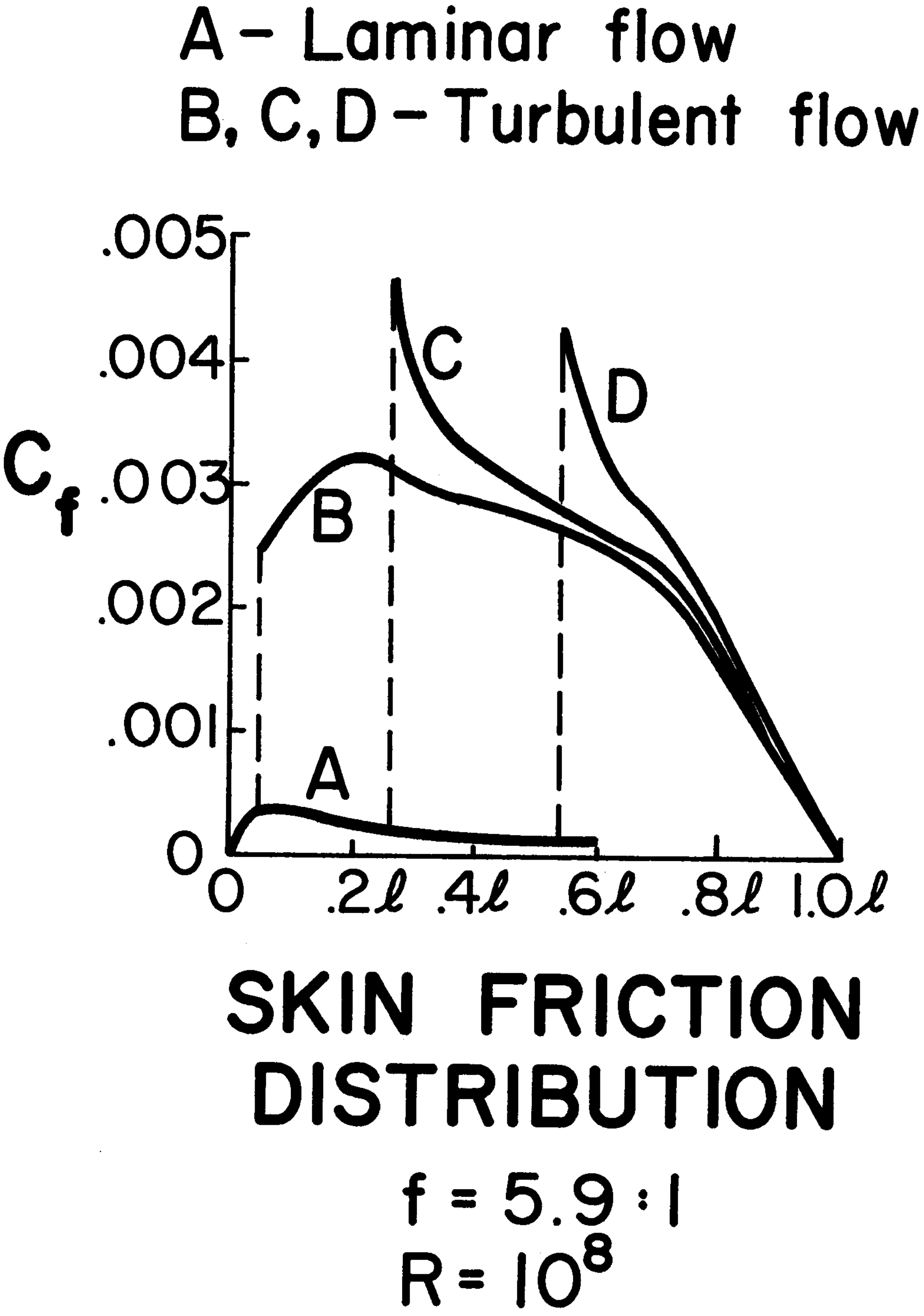


Figure 6. Laminar and Turbulent Skin Friction

between laminar and turbulent friction for a body of revolution of 5.9 fineness ratio.

2. Select a shape in which the shearing stress is not excessive.
3. Reduce the surface area to a minimum.
4. Recover as much kinetic energy from the wake as possible.
5. Prevent flow separation, an example of which for a divergent channel is presented in Figure 7.

H. Schlichting has computed the point of instability for a laminar flow on four bodies of various fineness ratios from 1 to 8. It is interesting to note that at high Reynolds number this point is furtherest aft for the lowest fineness ratio. K. Wieghardt has computed the laminar shearing stress for the same four fineness ratios and has plotted the shearing stress for each. Interestingly, the longer bodies had very high shear near the front while the "fatter" bodies' maximum shear was considerably less and further aft. The total shear for each of the four bodies was about equal.

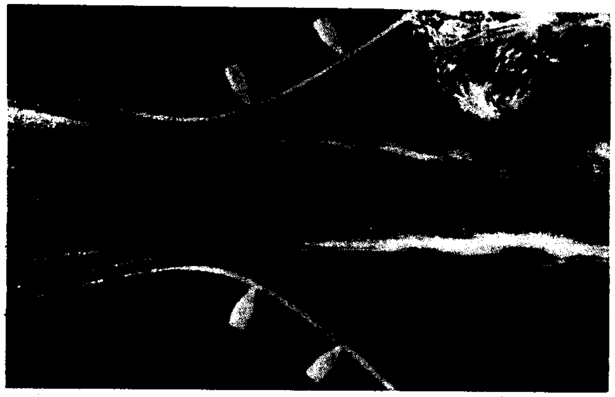
From the standpoint of minimum surface area, the sphere of course would be the best, with increasing area as the fineness ratio increases as shown in Figure 5.

A properly designed stern rotor will have the ability of converting kinetic energy in the wake into useful propulsion thrust.

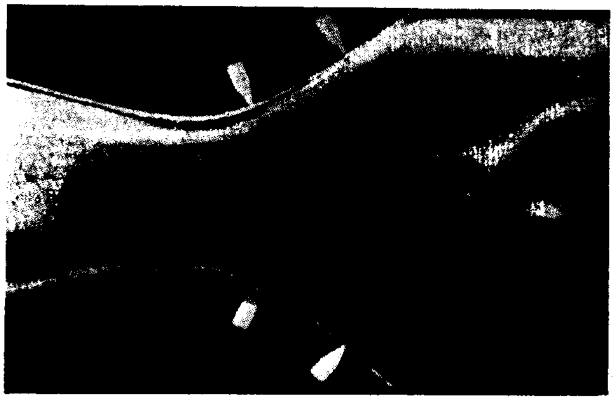
Flow separation is aggravated with shorter fineness ratios. Boundary layer suction, ring stabilizers, and stern propulsion will aid in the prevention of separation and the final design will depend heavily upon the ease with which the flow can be made to follow the ships' contour.

B. Boundary Layer Theory

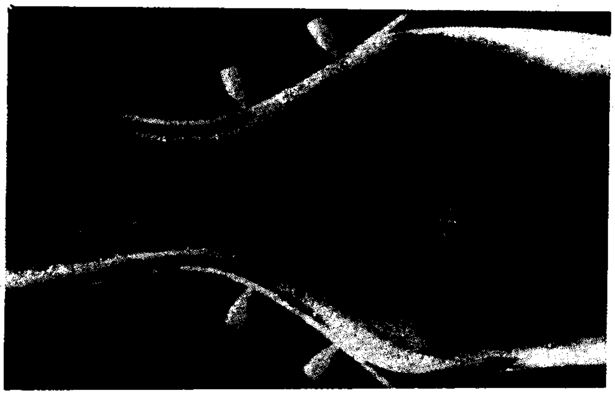
It has been established by reliable experiments that fluids like water



Flow with separation in a highly divergent channel, from Prandtl-Tietjens



Flow with boundary layer suction on upper wall of highly divergent channel



Flow with boundary layer suction on both walls of highly divergent channel

Figure 7. Flow Separation Prevention

and air never slide on the surface of the body; what happens is that the final fluid layer immediately in contact with the body is attached to it and all the friction of fluids with solid bodies is therefore an internal friction of the fluid. Theory and experiment agree in indicating that the transition from the velocity of the body to that of the stream, in such a case, takes place in a thin layer of the fluid, which is so much the thinner the less the viscosity.

On a body of revolution the air particles impinge at the stagnation point and form a laminar-type boundary layer as they progress up the forward portion of the body to lower pressures. Energy is transmitted from the body to the fluid. Transition to turbulent flow occurs over an interval at some distance from the nose, which is dependent upon such parameters as:

1. Local Reynolds number
2. Surface roughness
3. Magnitude of the pressure gradient
4. Degree of air stream turbulence.

Turbulent flows are usually treated from the Reynolds number viewpoint. This considers the turbulent flow to consist of a mean flow upon which a fluctuation flow of much smaller magnitude is superimposed. After the combined mean and fluctuation quantities are substituted into the Navier Stokes equations of motion for viscous flow, appropriate time averages of the resulting flow lead to the Reynolds equations of motion. The lack of analytical relations for the Reynolds stresses has made the theoretical treatment of turbulent flow difficult.

Whereas laminar boundary layers are well defined theoretically, turbulent boundary layer theories rely upon empirical data. A method for calculating the turbulent boundary layer on a body of revolution is presented in Chapter 22 of Reference 1. This method has been devised by E. Truckenbrodt by utilizing the energy integral equations. Unique in this method is the explicit expression for the energy transformed into heat by turbulence in the boundary layer. His method incorporates experimental results obtained by I. Rotta in establishing a relation between the energy thickness and displacement thickness of the boundary layer. Also deduced from this work is a simple expression for the heat dissipation energy which allows the energy integral equation to be integrated. From this an expression for the momentum thickness is obtained.

The advantage in using E. Truckenbrodt's method lies in the fact that only simple quadratures are required in the process and that no derivatives of the ideal, potential velocity function are needed. The method also presents a clearer physical insight into the processes taking place.

Another method is presented by Granville[24]. Unfortunately, these methods utilize certain assumptions which have never been verified by in-flight boundary layer measurements on airships.

It is essential that theoretical work be verified by detailed experimentation as extrapolation of the available information can be misleading. It is anticipated that detailed boundary layer profile measurements will be conducted in the field on a full scale captive-balloon model having the airship shape and stabilizing method selected by theoretical analysis of the factors involved, as previously mentioned. Prior to this effort, however, a review of the boundary layer work conducted by Northrup Aircraft

Corporation, and particularly the tests conducted on bodies of revolution in the low turbulence NACA wind tunnel at Moffet Field, California, will be made for possible applicability to this program.

It is expected that the boundary layer investigations conducted by the Aerophysics Department of Mississippi State College[25] under Dr. Raspet will be of considerable value in planning and executing this program, particularly with respect to the experimental technique employed and its relation to the various theoretical treatments.

Effective boundary layer control is a subtle type endeavor. Minor amounts, properly performed, can reap great advantages, whereas much effort incorrectly conducted can end in penalty rather than reward. To allow effective boundary layer control to take place it is necessary that the airflow around the body be completely understood, before and after suction.

Once the boundary layer profile is established for varuous stations of a given shape and configuration, intelligent estimates of the location, amount and distribution of suction can be made. According to Cornish[26], the suction velocity is determined by an equation of the type:

$$V_o = (H + 2)\,\Theta U' + \rho\Theta\,'U - \frac{\tau_o}{\rho U}$$

where:

H = boundary layer shape parameter

Θ = boundary layer momentum thickness

U = local velocity

τ_o = local wall shearing stress

ρ = mass density.

Therefore, the suction velocity should be governed by reducing the momentum thickness without letting the local shearing stress get too high, i.e., low suction velocities largely distributed are preferable to concentrated large suction velocities.

The final degree of boundary layer suction must be evaluated in terms of added complication and weight as well as reduction of over-all energy requirements and control advantages.

C. Electric Analogy Tank

The pressure distribution around a body is required for boundary layer analysis. Although potential flow theory is adequate for obtaining pressure distributions about simple shapes, it is expected that the three-dimensional electric analogy tank will be useful in obtaining pressure distributions about bodies with stabilizing surfaces and propelling devices attached. The model will have to be of sufficient size to reduce meniscus difficulties.

The electric analogy tank consists of an insulated trough partially filled with an electrolyte, usually a weak electrolyte such as ordinary water. An electric field is introduced into the tank by suitably placed electrodes. When a body is placedin the field, the body's effect on the field can be measured by a probe, tracing lines of constant voltage, which are also the streamlines surrounding the body. Detailed analysis of the flow surrounding any shape can be made. Such analysis can explain the superiority of one shape or configuration over another. One will probably be able to deduce criteria leading to optimum aerodynamic performance. It is possible also to study the effect of a propeller and a ring tail combination on the flow surrounding an airship configuration. The lift curve is found by varying the angle of attack. In these cases it is necessary to adjust the trailing-edge streamline to conform with the boundary conditions of smooth flow.

Use of the tank combines the visual advantages of a smoke tunnel with thos of a high speed computer. In many instances it can solve problems that are impossible to solve by other techniques. Since the tank simulates perfect fluid theory, its limitations are largely the same as the perfect fluid theory. It is necessary to utilize viscous drag theory in combination with the tank to obtain resistance data. Progress to date at [redacted] has resulted 25X1 in setting up the analogy tank and computer for three-dimensional bodies of revolution. Test runs have been made on bodies of known pressure distribution. The streamlines plotted by the computer compare very favorably with known data[27].

Brower has recently established a method of obtaining the normal force on a body of revolution by use of the electric analogy tank[28]. This is a rather unique solution, since the perfect fluid theory has traditionally been plagued by D'Alembert's paradox that a body pointed at both ends immersed in an inviscid fluid stream inclined to the body axis sustains no force. Brower refined Von Karman's original work by applying the theory to one model, having a fineness ratio of six. This accounts for a vortex system, which is responsible for a normal force being generated. He recommends this technique in those cases where one shape is to be thoroughly investigated.

D. Stability Analysis

The aerodynamic characteristics of a lighter-than-air vehicle are of fundamental importance in performing a static and dynamic stability analysis since both upsetting and stabilizing forces and moments are aerodynamic in nature.

Lift, drag, pitching moments, sideforce, yawing moments, rotary lift and rotary moment characteristics are all necessary for these computations. Static stability and equilibrium conditions for the moored or free flight condition of a ligher-than-air captive vehicle can be mathematically determined by solving the three equations, listed below, simultaneously[29]:

1. Vertical forces

$$L \cos\beta + D \sin\beta + (B - W) = T \cos\theta$$

2. Horizontal forces:

$$D \cos\beta - L \sin\beta = T \sin\theta$$

3. Moments about C.G. (Center of Gravity):

$$\Delta Y \quad D \cos(\alpha - \sigma) - L \sin(\alpha - \sigma) \quad +$$

$$(M_a)_{CB} - \Delta Y_B \sin(\phi - \sigma) - T\ell_T = M_{CG}$$

where:

L = lift, lb

D = drag, lb

B = static buoyancy, lbs

W = gross weight, lb

T = cable tension, lb

$(M_a)_{CB}$ = aerodynamic moment about Center of Buoyancy, ft-lb

M_{CG} = moment about Center of Gravity, ft-lb

ℓT = dynamic moment arm of tail lift with respect to C.G.

The remaining terms appearing these equations are defined in Figure 8 and apply to a moored captive balloon. For the free flight condition many of the terms are zero and a thrust term must be added. The results obtained from the solution of these equations apply to the ideal case of steady-state

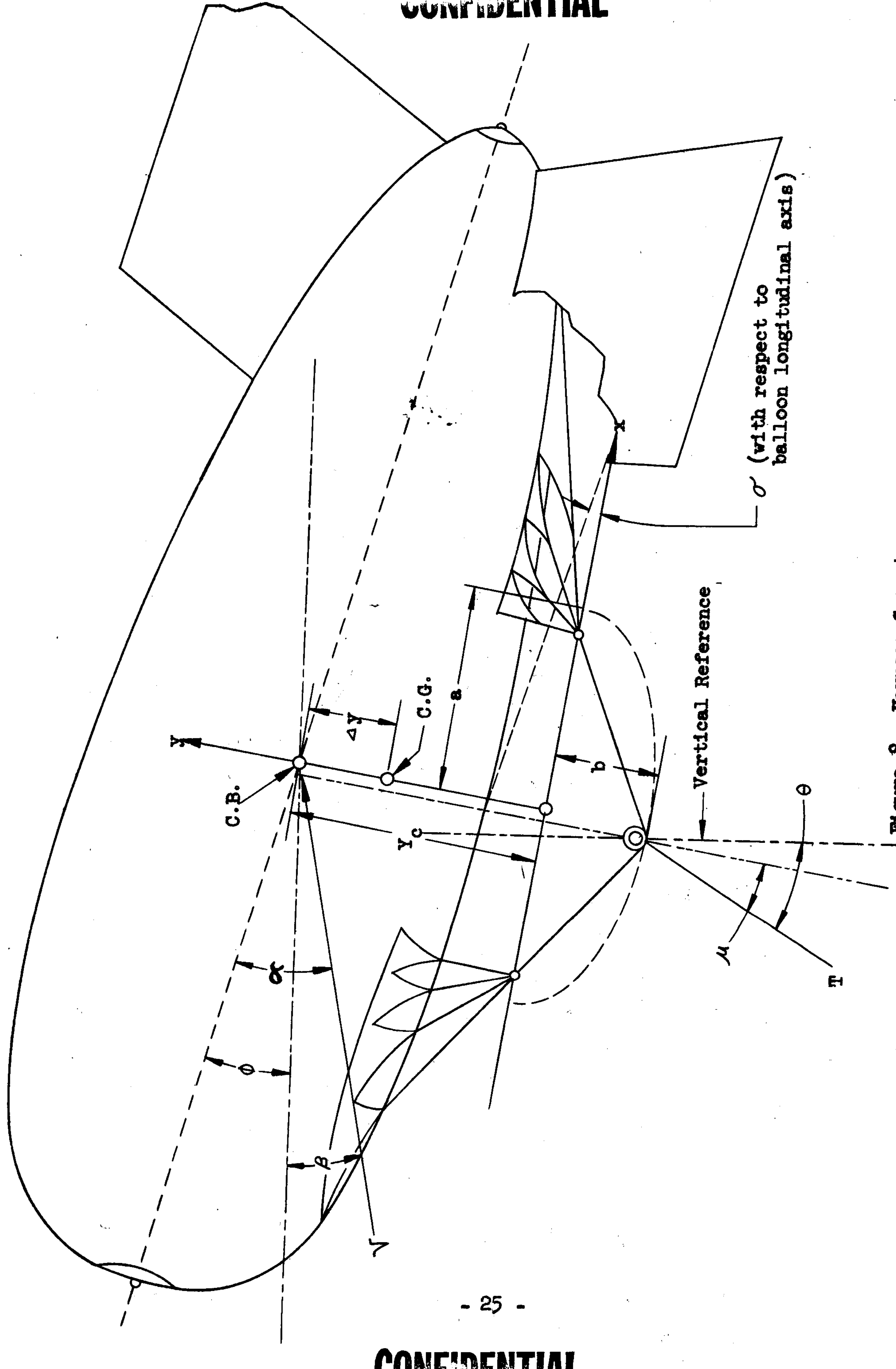


Figure 8. Harness Geometry

wind conditions. It is also necessary to investigate the dynamic response to time-variable wind currents and gusts superimposed upon the steady wind current. For small displacements from the equilibrium condition, the pitching motion of the ship must satisfy an equation of the type:

$$I_e \ddot{\phi} + m'' \dot{\phi} + m_1' \alpha + m_2' \phi = M_g (t)$$

where:

I_e = effective moment of inertia of the balloon in pitch, including virtual inertia of the envelope and fins

m_1' = slope of the aerodynamic pitching moment versus α at α_t

m_2' = metacentric stabilizing moment coefficient

m'' = rotary derivation of pitching moment due to rate of pitch

ϕ and α are small angular displacements from the quilibrium balloon altitude

M_g = pitching moment due to aerodynamic forces acting during the gust.

A similar analysis can be made for the ship in yawing motion. One important factor in lighter-than-air work is the large virtual inertia.

A mathematical stability analysis will be made as a part of the predesign analysis. In this manner it is possible to predict the effect of component designs of different or unusual arrangements as well as to define the control necessary for flight maneuvers.

VI. STRUCTURAL REQUIREMENTS

Careful analysis will be carried out to determine the static and dynamic forces applied to the envelope. A model of the vehicle will be built and evaluation of fabric strain will be made. The work conducted to date at [redacted] under the title of Pressure Beam Mechanics will prove useful for this application. The findings of Zannoni, et al.[30], will also be of value. An operating pressure will be specified to provide adequate resistance to the envelope bending moments caused by static buoyancy, component weight, and aerodynamic forces in flight. Material exposure tests have been carried out and are reported in the final report[31]. Two or three of these materials will be selected early in the program for further weathering tests. A material for the envelope will then be selected in view of these findings.

The vehicle will be provided with one or more ballonets, which are separate, internal air chambers. Multiple ballonets may have certain desirable trim and pitch control features. The main purpose of the ballonet is to allow the lifting gas to expand or contract without changing the size or shape of the main envelope. The expansions or contractions are caused by changes in atmospheric pressure, temperature and the vehicle altitude. The size, shape, location and ballonet material will be specified from these findings.

Past experience has shown that pressurization by centrifugal blowers is a desirable method. This type of blower, equipped with forwardly inclined vanes, has a characteristic of providing constant pressure at minimum power. Available aircraft-type equipment will be reviewed and optimum equipment will be selected.

VII. SPECIAL PROBLEM AREAS

A. Field Handling and Inflation

Special consideration will be given in the preliminary design to minimize field inflation and launching difficulties. Provisions for mooring the vehicle during this period will be provided. It is expected that shroud techniques can be developed to facilitate inflation for high wind launchings. Figures 9 and 10 show the shroud technique as applied to free balloon launchings for high wind conditions. Component selection and design for the vehicle will be influenced by the requirements of this type launching.

B. Controllability

Several new ideas regarding controllability of the airship have been advanced. It is expected that small laboratory models will be constructed to verify certain aerodynamic properties. Theoretical work, entitled "Inflatible Muscles," conducted in the first phase of the program will be beneficial in the analysis of these ideas.

C. Other Lighter-Than-Air Systems

The staff will be available to consult, discuss, and make prelimimary estimates and calculations involving other lighter-than-air tasks. Figures 11 and 12 show two lighter-than-air vehicles which are used for specific task objectives.

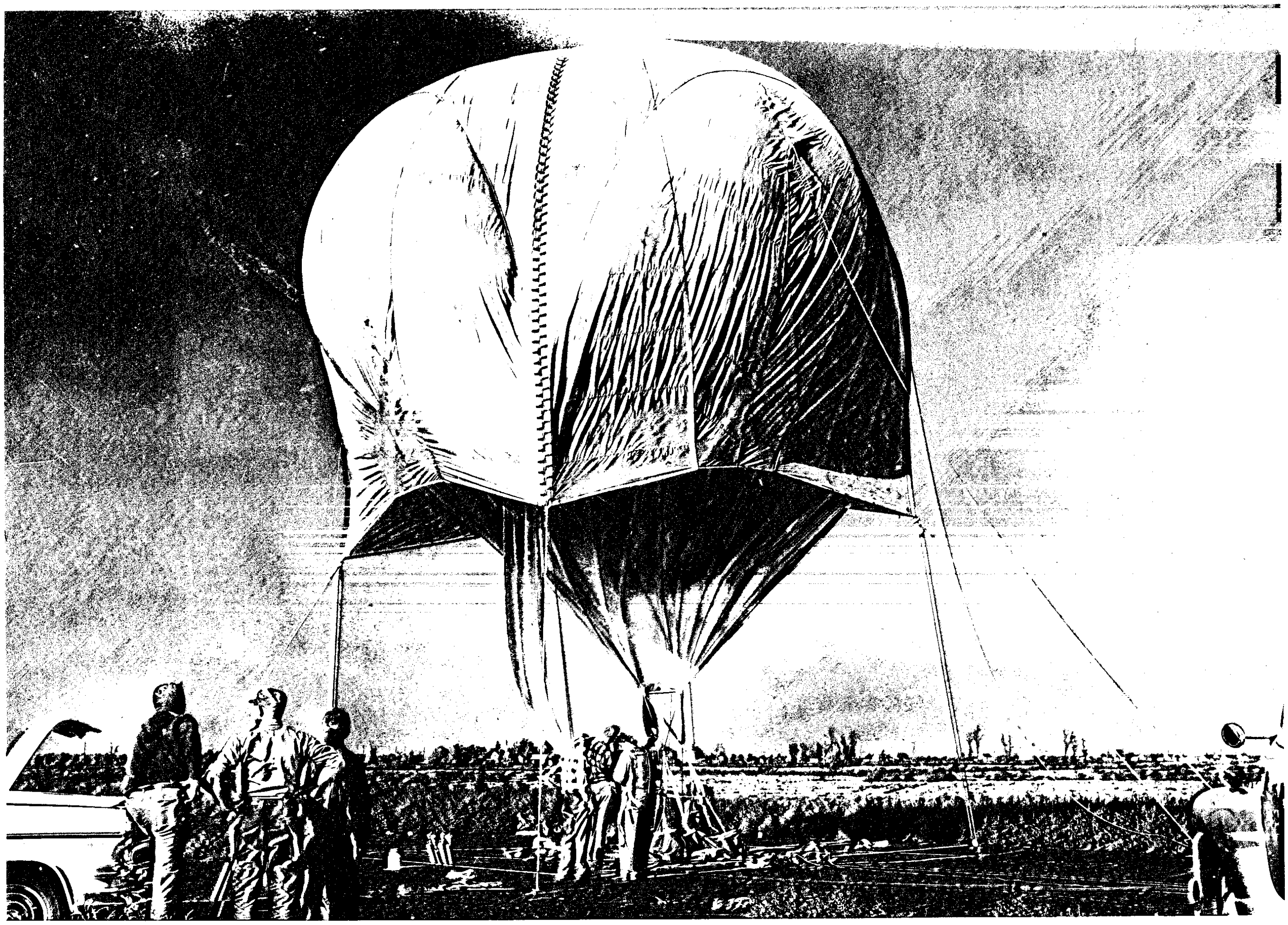


Figure 9. Shroud in Place, Protecting Balloon from Wind During Inflation Process

Figure 10. Shroud Being Removed

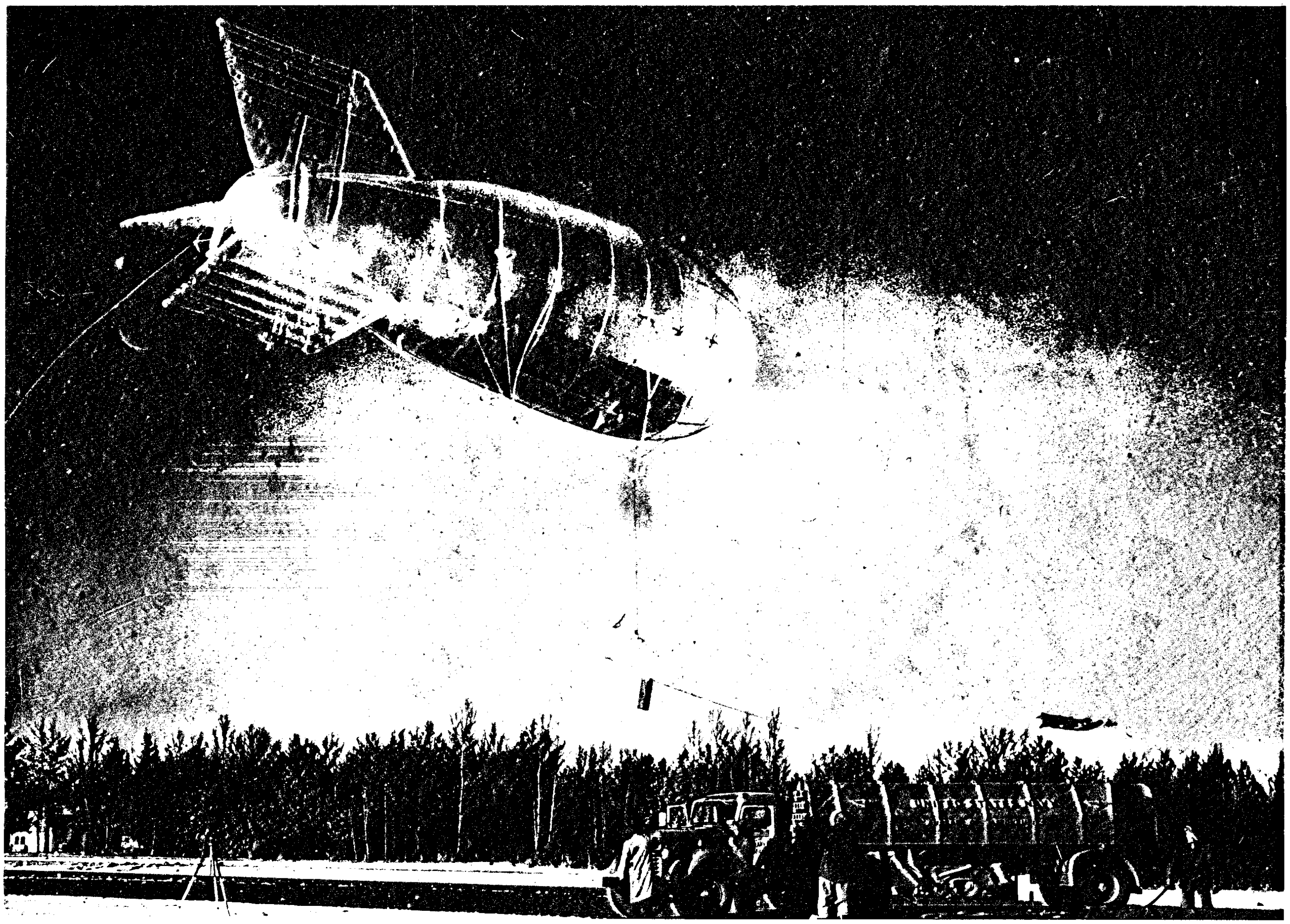


Figure 11. Model 13-5-8

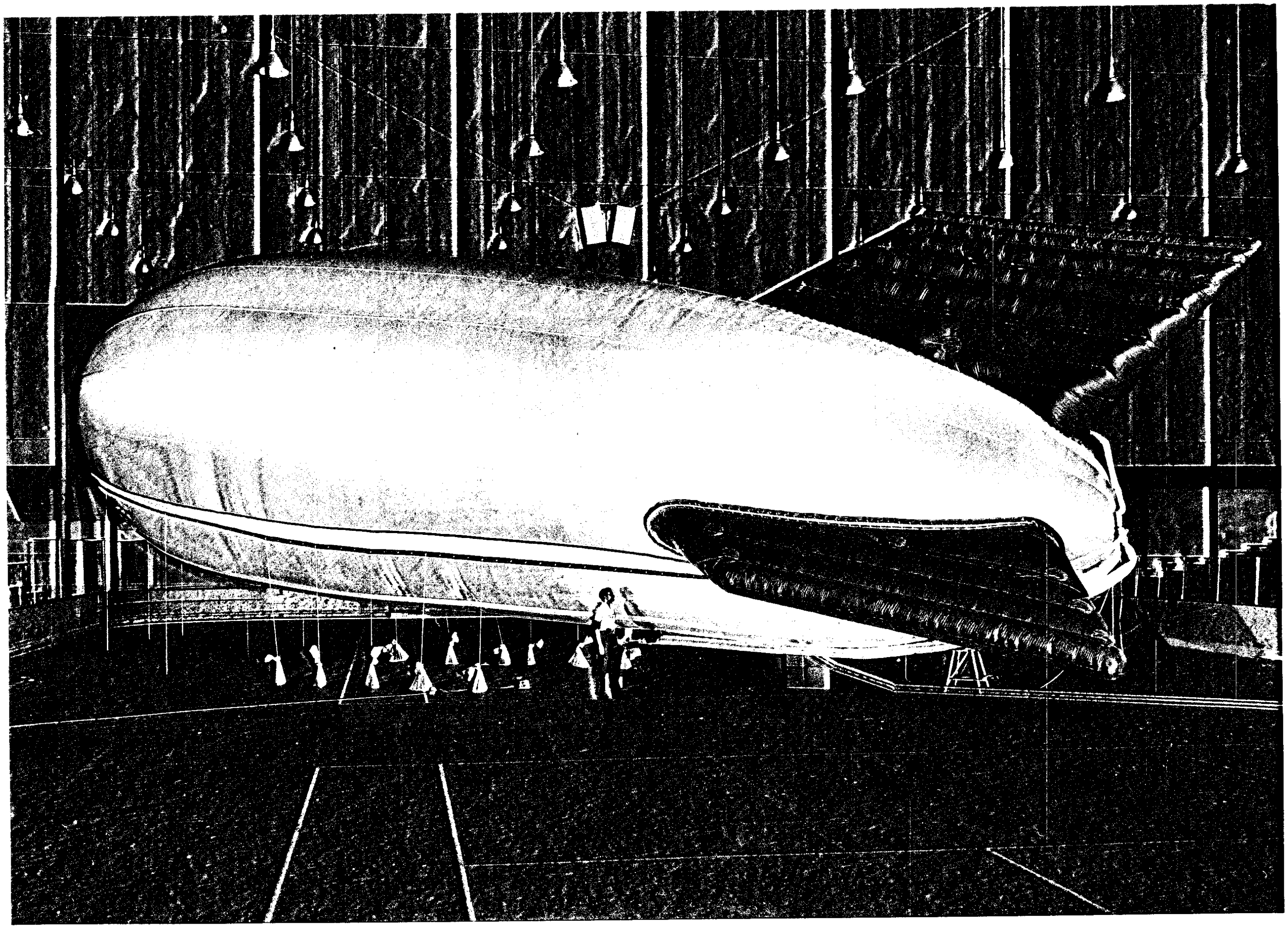


Figure 12. Model 21-S-8

VIII. PROPOSED PROGRAM

A. Phase I

The research phase of the program will be organized to take full advantage of a combined theoretical and experimental approach. Extensive boundary layer work has been conducted by Dr. Pfenniger at Northrop Aircraft Co., Dr. August Raspet at Mississippi State College, and Professor Hazen at Princeton. To fully utilize the results of their work several trips will be made.

During the research phase, laboratory work will be verified by model experimentation. The type of experimentation will depend heavily upon the personal experience and recommendations of previous boundary layer researchers. There is strong evidence that wind tunnel turbulence masks the phenomena being investigated. The low turbulence tunnel at Moffitt Field may be the answer to this difficulty, as personnel there have recently been conducting boundary layer tests on bodies of revolution for Dr. Pfenniger.

Phase I of the program will result in the preparation of a preliminary design report for a small plastic airship, the design objectives of which are discussed in Section III. One year is estimated to be required for this work.

B. Phase II

This phase of the proposed program is a developmental and testing phase. It will include the preparation of sufficiently detailed drawings for fabricating the first design model. This design will be based on the preliminary drawings from Phase I.

The completed vehicle will then undergo inflation and flight tests. The initial inflation tests will be conducted in an area protected from the wind, preferably in a large, hangar-type building. The initial flight tests will be conducted during relatively calm days and a portable mooring mast will be required during the initial flight tests to permit its re-use on successive days without deflation. As the ground crews and pilots become more experienced with the vehicle, tests will be conducted under varying wind conditions to test the vehicle's compliance with the design objectives outlined in Phase I of this program. During the inflation and flight tests minor vehicle modifications may be made.

The final drawings will incorporate corrections and/or modifications of deficiencies discovered during the manufacturing and testing periods.

C. Phase III

This phase of the proposed program will include the construction of a prototype vehicle from the final drawing in Phase II, flight tests, and delivery to the sponsoring agency. The flight tests will be conducted in the presence of personnel from the sponsoring agency and will be conducted to determine the vehicle's compliance with the design objectives outlined in Phase I of this program. Phases II and III are estimated to require an additional year.

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