N76-15048

THE DESIGN AND CONSTRUCTION OF THE CAD - 1 AIRSHIP

H. J. Kleiner*
R. Schneider**
Dr. J. L. Duncan***

ABSTRACT: This paper will deal with the background history, design philosophy and Computer application as related to the design of the envelope shape, stress calculations and flight trajectories of the CAD-1 airship, now under construction by Canadian Airship Development Corporation.

It will also outline a three-phase proposal for future development of larger cargo carrying airships.

INTRODUCTION

McMaster University's interest in airship technology and development extends back to September 1972, when three senior mechanical engineering students began a feasibility study to determine the possible use of airships to help expand Canada's northern frontiers. The three students, H. J. Kleiner, E. G. Smith, and J. Douglas, with the aid of their supervisors, Dr. J. L. Duncan, Prof. W. R. Newcombe and Dr. J. H. T. Wade, produced a four volume report. This work received fairly extensive publicity and eventually drew the attention of Mr. R. Schneider, President of Hoverjet Inc., to the abilities of McMaster University's Mechanical Engineering Department in this area.

---

* McMaster University, Hamilton, Ontario
** President, Canadian Airship Development Corporation, Thornhill, Ontario
*** Professor, McMaster University, Hamilton, Ontario

Mr. Schneider had done extensive research and studies in the field of airships since 1968, and felt that it would be possible to design and construct airships in Canada.

By the time of the first meeting between Mr. Schneider and the McMaster Group, only Mr. Kleiner, who had started work on his M.Eng. degree, and the three supervisors remained.

During the first meeting between these two groups in early February 1973, it was decided that the McMaster group would provide the engineering required to set-up the specifications for the preliminary design of a "minimum Airship" of the non-rigid type, and Mr. Schneider and his team would arrange for financing that would allow the construction of this airship at Hoverjet Inc.

Three basic objectives were envisaged as being achieved by this course of action:

(i) Commercial employment in the role of a research platform, aerial filming, and TV work, survey and S.A.R. work and aerial advertising.

(ii) Training of Air and Ground crews for future larger airships.

(iii) Provide a basis for developing Canadian design and Manufacturing skills and capabilities for larger airship projects.

To encompass the various and widely scattered groups and individuals who had expressed their willingness to provide their knowledge and services to the project, a non-profit interest group known as the Canadian Airship Study Group was formed and Mr. Schneider appointed as Co-ordinator.

By June 1973, initial financing was secured and the bulk of the design work was completed, allowing a construction start to be made in the Fall of 1973.

The airship design that emerged has no novel or radical design features, but follows established design and construction principles for pressure airships. From the design point of view, it is intended primarily to gain experience and competence in the various aspects of airship design.

The airship is 120 ft. long, with a 40 ft. maximum diameter, powered by two CONTINENTAL O - 200 aircraft engines of 100 hp each and a cruising range of 300 miles. Payload capacity of 1575 lbs. which will enable a flight crew of two and four passengers, or an equivalent cargo load to be carried.

Although the design follows conventional and established practices, advanced methods of design analysis have been employed. In addition, techniques of envelope manufacture and the materials used will embody recent developments in synthetic fibres, weaving, coating and joining methods.

As the construction of the (then) CAS - 1 progressed, it was felt that a company should be incorporated to take over from CASG and Hoverjet Inc., and oversee the construction of the present airship and lay the framework for future airship designs. Thus, early in 1974, the Canadian Airship Development Corporation was incorporated to take the functions of the CASG. The airship was re-designated as CAD-1.

This paper will describe the analysis which led to the design specifications of the CAD-1, the techniques employed in the computer aided analysis of the flight performance and loads, and the economic assessment of the present airship. Further work to be done by C.A.D.C. will also be reviewed.

DESIGN PHILOSOPHY

The preliminary studies performed were based on computer outputs which, for various fineness ratios, allowed evaluation of such parameters as:

(i)	Weights and displacement	(Fig. 1)
(ii)	Power and velocity for constant shape	(Fig. 2)
(iii)	Power and displacement	(Fig. 3)
(iv)	Power and shape for a constant velocity	
(v)	Displacement and control surface areas	

Initial evaluation of these parameters and the performance specifications which had been set, led to the selection of a shape with a fineness ratio of F = 2.25 and a volume of 70,000 cu. ft.

The shape chosen was developed from a polynomial expression originated by General Mills (*4) which allows the generation of an infinite number of shapes. The final body shape can then be chosen on a performance and aesthetic basis. The expression used for the body shape was:

$$y = \frac{[n+m]^{n+m}}{2 f n^{n} m^{m}} \cdot \frac{x^{n}}{L^{n+m-1}} \left(L - x\right)^{m}$$

where: n and m are parameters which may be altered to produce varying shapes,

f is the fineness ratio desired,

L is the overall airship length in feet,

x is the distance from the bow in feet.

The versatility of this expression is illustrated by 2.1 and 2.2 which show the relationship between the shapes generated and several known shapes.

The very low fineness ratio caused considerable worry as to possible stability problems. In order to ascertain the degree of stability of the design, a computer program was developed to calculate the pressure distribution over any airship body in both level flight and flight at varying angles of attack. The only inputs required are data relating to velocity, angle of attack and body shape. This program was derived from, and is an extension of Theodor von Karman (*1) on airship pressure distributions. The type of output produced by the programmer is shown by Fig. 3.1, the pressure distribution for the CAD-1 shape in level flight. As a result of this investigation, the fineness ratio was increased to 3.00, while at the same time the volume was raised to 90,000 cu.ft., in order to offset the weight escalation by this change and other developments. Figures 3.2 and 3.3 show the initial and final shapes that were decided upon.

It was originally intended to power CAS-1 by means of two 2-stroke inboard engines driving swivelling, ducted fans. Although this was a very light and simple arrangement, the Canadian Ministry of Transport (M.O.T.) requirements for licensing the craft and the lack of funds for a large scale certification program led to the temporary abandonment of this vectoring power system. In its place, two light aircraft engines of sufficient power, mounted in a conventional configuration, are used. This caused a substantial increase in weight.

At the same time, several discussions took place as to the Gondola (Car) design. Based on manufacturing facilities and skilled labour available, the decision was made to use a welded tubular steel structure over a fabricated aluminum structure, which, in turn, caused a further increase in weight.

The gondola load structure consists of lightweight 4130 chromemoly aircraft tubing in a conventional design arrangement. However, it was decided that the gondola design and strength was to be sufficient to provide for the possibility of future development of various propulsive methods, such as the one previously mentioned, and also allow for the testing of other systems. In addition, the use of the airship for training purposes suggested a rugged structure as the possibility of heavier than normal impact on the main wheel, which must be absorbed by the gondola structure, was high.

All these considerations made the volume increase mandatory in order to maintain the initial specified payload and performance specifications. The engineering required to design the gondola was provided by the McMaster group while the actual application engineering and construction was carried out by a group at Hoverjet under the supervision of Mr. Schneider. The primary gondola structure is illustrated in various stages of construction in Figures 4.1 and 4.2.

FLIGHT TRAJECTORY CALCULATIONS

The question of how an airship will behave when required to perform certain manoeuvres has always been one of the uncertainties of airship design. Wind tunnel experiments and model studies have been inconclusive (*5).

During the period of quantity construction of airships, designers based their decisions upon emprical data that had been gathered from previous designs. However, recent airworthiness regulations require that the forces acting during various manoeuvres be calculated and taken into account at the structural design stage. The calculations involved in this task would be very tedious and time consuming if done by hand; the problem is tractable, however, using the high speed digital computer.

The requirements that must be met are given in the "Ministry of Transport, Civil Aeronautics, Provisional Airworthiness Requirements, Airships" subpart C, Structure, sections SC. 4 (a) through SC. 4 (e) (*3).

"Manoeuvering Load Conditions.

The airship structure shall be designed to withstand the limit loads resulting from the following manoeuvering conditions, conducted at airspeed of V_D, critical statically-heavy weight, and at the centre-of-gravity location critical for each manoeuvre:

(a) In level flight, application of full rudder, applied at the maximum control rate attainable, until a heading of 75° off the original heading is attained, followed by immediate application of full opposite rudder, applied at the maximum control rate attainable to original heading. The effects of overcontrol shall be taken into account.

(b) In level flight, maintain a steady-state turn with rudder fully deflected in the direction of turn.

(c) The manoeuvres of SC. 1(a) through SC. 1(b) combined with full-up elevator, applied at the maximum control rate attainable, and alternatively, with full-down elevator, similarly applied.

(d) In level flight, apply full-down elevator at maximum control rate attainable until the specified maximum rate of descent is obtained followed immediately by full-up elevator at maximum control rate until rate of descent equals zero. The effects of overcontrol shall be taken into account.

(e) The manoeuvers of SC.4(d) combined with alternatively a left and right steady-state turn."

The theory needed to provide the trajectories dictated by these manoeuvres was examined and a user-oriented computer package which has been developed will be described.

This work constituted a major part of Mr. Kleiner's M.Eng. thesis (*2).

Once the required trajectories have been achieved the resulting loads on the airship are calculated by the programme. The theory used in developing the programme was based mainly on empirical equations. The programme does not simulate the exact conditions that prevail in the airship. To simplify matters, the ballonets were considered to be fully deflated at all times. Thus, center of gravity shifts, due to various degrees of inflation, were neglected as were axial shifts of the center of gravity due to the fore-and-aft of the air in the ballonets. The results achieved by the programme are illustrated by Figures 5.1 through 5.5. Only a portion of the manoeuvres required are illustrated here, however, the results achieved are readily apparent.

The manoeuvres presented are:

(1) Fig. 5.1 Graphical illustration of the programme output-take-off trajectory.

(2) Fig. 5.2 Graphical illustration of the programme output-full rudder until a 75° turn has been achieved.

(3) Fig. 5.3 Graphical illustration of the programme output-full opposite rudder until the original heading regained.

(4) Fig. 5.4 Graphical illustration of the programme output-full up elevators and a steady state turn from 0 - 180 degrees.

(5) Fig. 5.5 Graphical illustration of the programme output-full down elevators until maximum descend rate achieved and then full up elevators until descend rate equals zero.

It is also hoped that these results will provide a basis on which to check the output of the work presently being carried out by Mr. H. Sharpe of the University of Toronto Aerospace Institute for CADC, on modern stability analysis and control systems evaluation for airships.

The computer design package previously mentioned is very simple to operate and requires only that the designer input the physical characteristics of the design. The trajectories and the loads incurred will be the resultant output. This package has been tested for several designs and has performed satisfactorily.

ENVELOPE MATERIAL

The selection of the envelope material presented several interesting alternatives. Initially, it was hoped that the envelope could be built of metal, a la ZMC-2, or perhaps a plastic-foam laminate.

Whatever the advantages of these materials, one major obstacle prevented their use, cost. The term "cost" includes both the large amount of engineering time required as well as the actual costs of material and construction. The use of the more established airship envelope material as used on the Goodyear airships was felt to be a last resort as cost and weight were felt to be much too high. Also, construction of an envelope of this type and material required skilled labour, not presently available. Hence, after surveying the alternative materials available, a decision was made in favour of the new Dupont "Kevlar-29" fibre. The material is woven in a "Trigon" (triaxial) fabric, polyurethane coated and UV retardent added in the process. Material weight is 8.5 oz. per square yard.

Induction sealing of all envelope seams will replace conventional sewing. Seams are taped inside and outside. This process provides a major saving in labour.

So far, no major obstacles have been encountered, neither in the engineering or construction of the airship. Work progresses very well with the construction of the envelope and control surfaces as the next step.

FUTURE PROGRAM

Based on the work so far, a future development program has been worked out between McMaster University and Canadian Airship Development Corporation and submitted to the Canadian Government and potential future users of large cargo carrying Airships.

PROPOSAL

This proposal has been prepared in the anticipation that the LTA vehicle technology so far developed will be recognized as a sound contribution to a method of Cargo Transportation capable of servicing the northern areas of Canada.

A consortium of interests is proposed so that the contributions of expertise in the technical, operational and economic areas can be included in the overall project development besides providing some financial support for the project.

In view of the developments in LTA vehicle technology in the USA and Europe, it is considered that Canada does have both the potential and technical capability to develop its own LTA vehicles especially for areas where there are a wide range of natural resources and climatic and terrain conditions which make normal modes of transportation extremely difficult.

DEVELOPMENT PROGRAM

Since the formation of CADC work has started on what could be a three phase program; the program will start with the current small scale activities and move toward the larger scale, potentially economic vehicles and actual freight operations. The program will be directed at developing the technological expertise to design and build airships which are not only reliable but efficient (in their design) and at the same time provide real data on operations from which better operating forecasts can be made.

The program has three identifiable phases:

(1) The first can be planned and costed in detail immediately.

(2) Financial requirements for the second phase can only be determined by the work done in the first phase, although an approximate estimate has been prepared.

(3) No attempt is made to determine the cost of the third phase, but the general objectives and some of the possible means are stated.

Before detailing the three phases, an outline is given of the groups who might be interested in forming a consortium to develop LTA vehicle technology and then establish an operating organization as a transportation function in Canada.

ECONOMICS

The economics using Lighter Than Air transportation vehicles has not been developed as there is no reliable history on which to base manufacturing and operating costs.

There are, however, some interesting comparisons on the costs of:

(a) very large aircargo aircraft, and
(b) the costs of LTA vehicles.

In the case of (a), the initial manufacturing costs are extremely high. Under normal operating conditions large airstrips, navigation systems, refuelling facilities and maintenance support must be provided. There is sufficient data available to at least estimate costs per mile in the aircraft mode of cargo movement.

In the case of (b), the manufacturing costs are much less, and will not require the complicated design inherent in aircraft. LTA vehicles will not require the extensive runways with their continual maintenance expense, will operate with a less sophisticated navigation system and the turn around maintenance will be much less. It is also anticipated that development into full service would be accelerated through LTA vehicles.

Comparison of fuel and other secondary costs would also appear to be in favour of the LTA vehicles.

It is recognized that the speed difference between the two vehicles is a big factor but against this could be considered the possibility of intermediate staging posts which could readily be established for LTA Cargo Carriers.

The economics of the LTA operations would be part of the consortium study.

THE CONSORTIUM

The eventual scale of the venture, and its inherent risks are such that the total program should involve a consortium of interests. For the sake of brevity in this proposal, these are identified in the following manner.

Government Agencies

It is suggested that the Department of Industry, Trade and Commerce would invite the appropriate Branches in other relevant Departments such as the Ministry of Transport, the Ministry of Indian and Northern Affairs and the Ministry of State for Science and Technology to evaluate their interests in supporting the project. The Science Council and the National Research Council should also be invited to participate in discussions.

Discussions have already been held with the Canadian Transport Commission and the Transport Development Agency who have encouraged continuation of the project since it was first introduced to them.

Carriers

The two principal Canadian carriers with extensive transportation experience, Canadian National and Canadian Pacific Railways, would be invited to contribute their own proposals for the operation and economic assessments of airships related to transportation demands in areas of Canada not serviced by their own systems. Additional freight carriers both surface and air, specializing in northern transportation could also be invited to contribute in long range planning, i.e. Air Canada, C.P. Air, Nordair, Transair, Wardair.

Aircraft Manufacturers

Such companies as DeHavilland, Canadair & Douglas could be involved in the future design and fabrication of the airship and companies like CAE, Aviation Electric interested in the flight instrumentation and controls.

Constructors

The Canadian Airship Development Corporation (CADC) has designed and is constructing an airship - CAD-1 which is 120 feet long to carry a payload of 1,500 lbs. and be operational by the Spring of 1975.

The CAD-1 would be used for initial training and operations and is committed by CADC for their own evaluations. A second model using the same design and configuration could be built and be operating by the Summer of 1975 for use by the consortium.

It is inevitable that other developments for larger airships with carrying capacities of 300 - 500 tons will require other aircraft manufacturers to be part of the consortium for engineering, design and construction of the larger airships.

The Centre for Applied Research and Engineering Design, Incorporated (CARED) at McMaster University would provide the project management and administration to coordinate the activities of the Consortium in Phase I and prepare the estimates for Phase II at a negotiated contract cost.

THE PROJECT

Phase I

This Phase can be conveniently divided into three sections:

Operating and Training

The purpose is to obtain experience with a small, pressure type airship (blemp) operating in various areas of Canada. A nucleus of both ground and air crews would be developed which would be sufficient size to man operations in the next phase of the program. The airship would be of the CAD-1 type:

120 ft. long, 1,500 lbs. payload

The first airship of this type will be ready for operations early in 1975, however, it is fully committed in another area under an existing operating contract with the Canadian Airship Development Corporation. It is suggested that a second airship of this type be constructed and purchased as part of this project and this could probably be available by the Summer of 1975. This would then be operated for a period of 18 months in this phase of the program.

Application Assessment

Investigations of the applications, economic assessments and feasibility of transportation development for a larger airship to be constructed in Phase II would be carried out jointly by the government and the consortium. The developed data would be continuously fed into the third activity in Phase I.

Engineering Design

A detailed design and cost estimate would be produced for an airship to be constructed in Phase II. This would still be a pressurized type of about 300 ft. overall length with a payload of 15 to 20 tons. For convenience, this type would be called CAD-2. The design activity for CAD-2 will be headed by Canadian Airship Development Corporation (CADC). The objective will be to complete the design by the end of 1975, so that Phase I can be completed by the middle of 1976 with detailed plans, targets and cost estimates prepared for Phase II.

An estimate of costs in Phase I is as follows:

Purchase of CAD-1 type airship	$ 600,000.
Cost of operating and crew training for 18 months	300,000.
Applications investigation and transport systems evaluation	80,000.
Design of CAD-2 and associated research projects	160,000.
Project administration costs	96,000.
TOTAL PROJECTED COST:	$ 1,236,000.

Phase II

The detailed program would be proposed as the result of the experience gained in Phase I. However, it is intended that operating tests and training with the CAD-1 type airship would continue while the larger CAD-2 type was being constructed.

This Phase would include the operating of the larger airship (CAD-2) with some time spent on scheduled freight movements. It is unlikely this airship would be an economic carrier except in exceptional circumstances, but it would enable realistic operational trials to be made which could influence the economics in the next Phase of the program.

No detailed extimate of the cost of Phase II is attempted, although, the CAD-2 airship would probably cost approximately $3 million and the overall cost of Phase II would be about $5 million. The CAD-2 airship should be operating by the end of 1976 and Phase II concluded at the end of 1977.

The design team would continue during Phase II on the preliminary design of an economically feasible commercial vehicle.

Phase III

The objective in Phase III will be to complete the detail design and to construct a prototype of an economical commercial carrier based on the experience and data obtained in Phases I and II.

The configuration and method of manufacture cannot be determined at the present time, although it seems likely that this would have a payload of about 300 to 500 tons. (It will be observed that in each successive type of airship in the program, the payload increases by a multiplication factor of between 10 and 20, and this is thought to be the maximum jump which is reasonable to make).

The eventual prototype could be a metal-skinned airship, but it is anticipated that many of the features in the vehicle itself and in ground handling and operating will have evolved naturally (as is normal in sound engineering projects) from what has been developed in the earlier Phases.

REFERENCES:

(*1) Von Karman, T., "Calculation of Pressure Distribution on Airship Hulls", NACA Technical Memorandum No. 574, (1927).

(*2) Kleiner, H.J., "Aspects of Airship Design", M. Eng. Thesis, McMaster University, (1974).

(*3) Ministry of Transport, Civil Aeronautics, Provisional Airworthiness Requirements, Airships.

(*4) Anderson, A.A., Erickson, M.L., Frochlich, H.E., Henjum, H.E., Schwoebel, R.L., Stone, V.H., Torgeson, W.L., "Lighter-than-Air Concepts Study", Final Report Nonr 1589 (07), General Mills, Inc., Minneapolis, Minnesota (1960).

(*5) Hecks, K., "Pressure Airships: a review", Aeronautical Journal, November (1972), pp. 647-656.

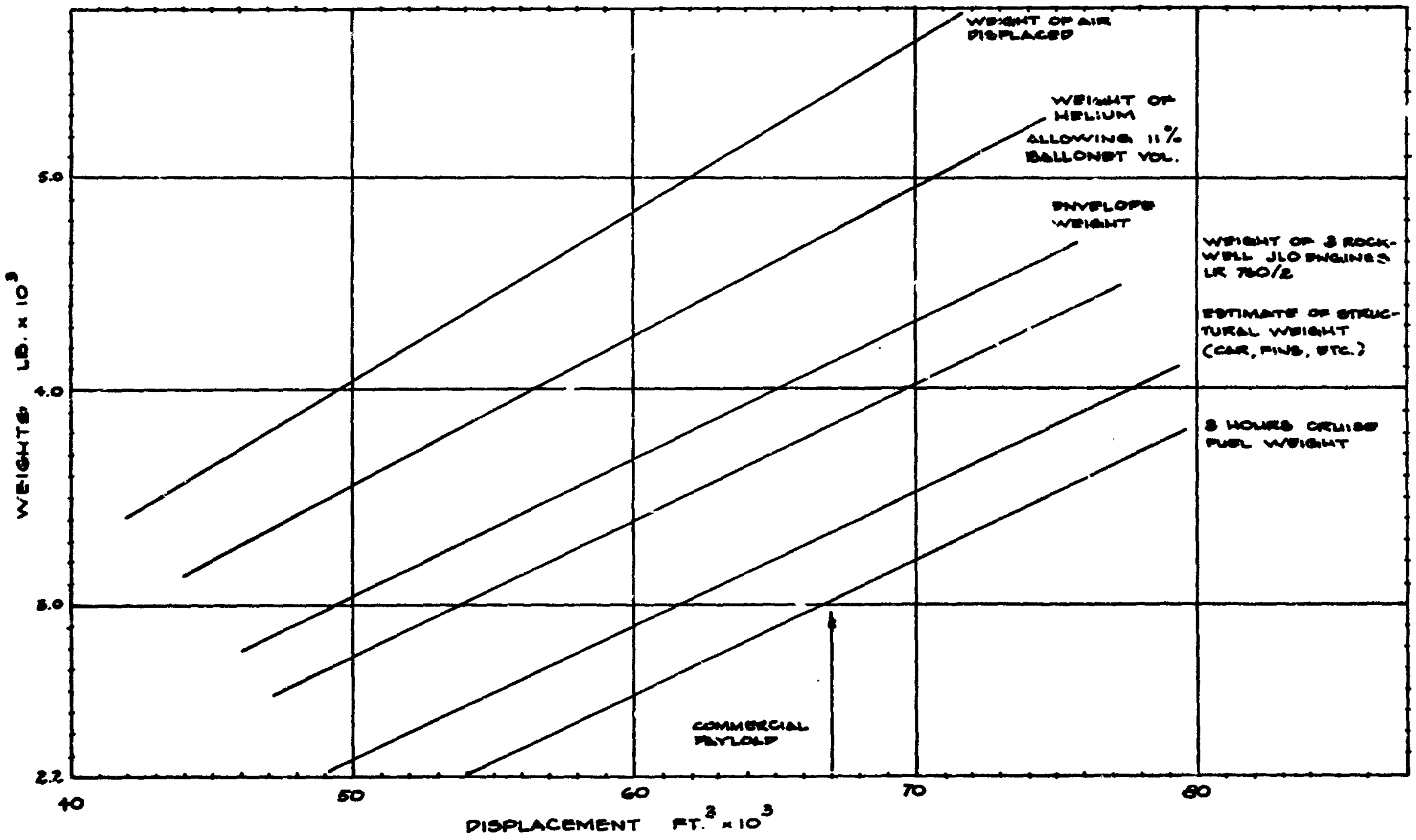

FIG. 1 WEIGHT v. DISPLACEMENT

F = 2.50 V = 60 MPH
N = 0.2 M = 0.6

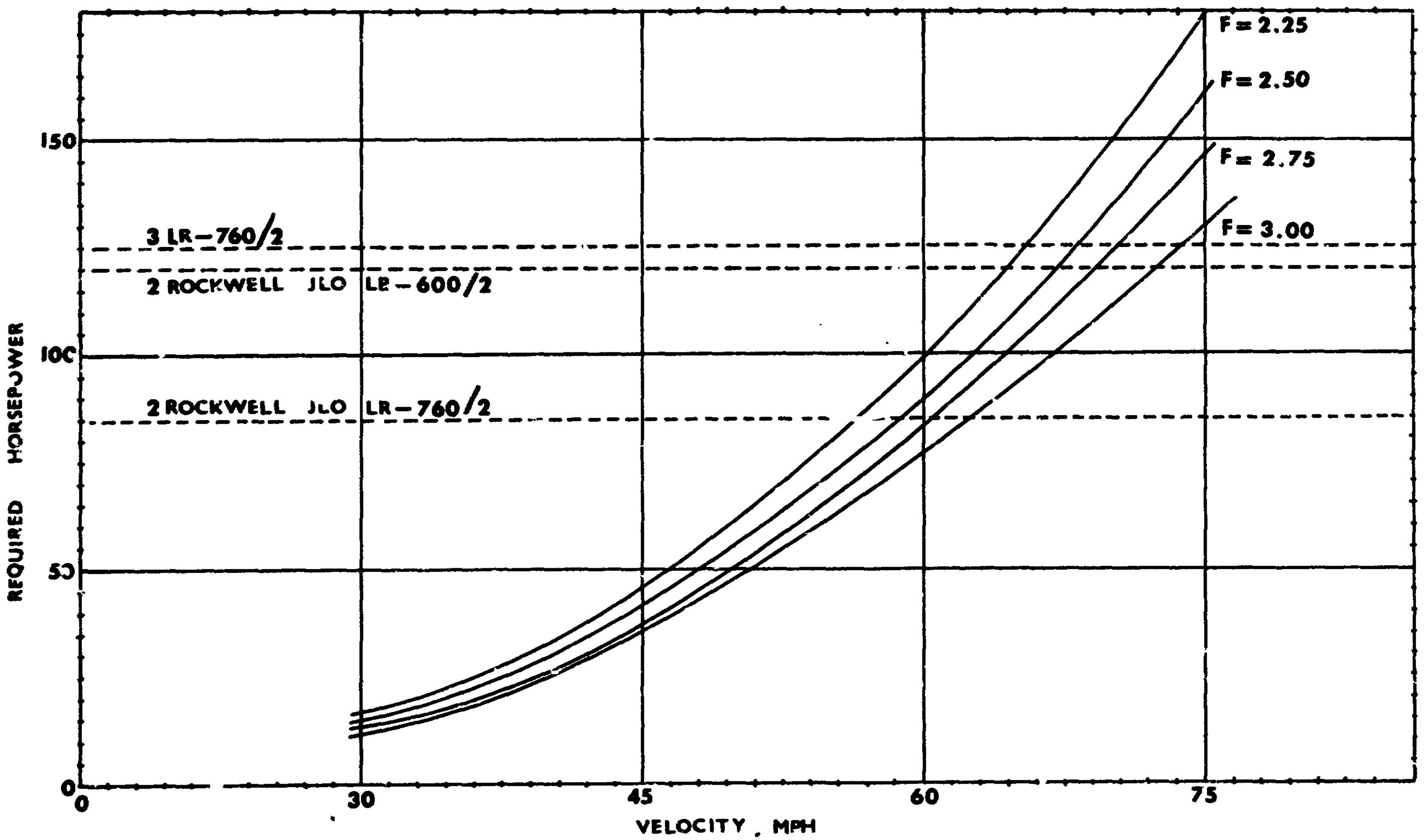

FIG. 2 REQUIRED ENGINE HP v. MAXIMUM VELOCITY
VOLUME = 70,000 CUBIC FEET
N = 0.2 M = 0.6

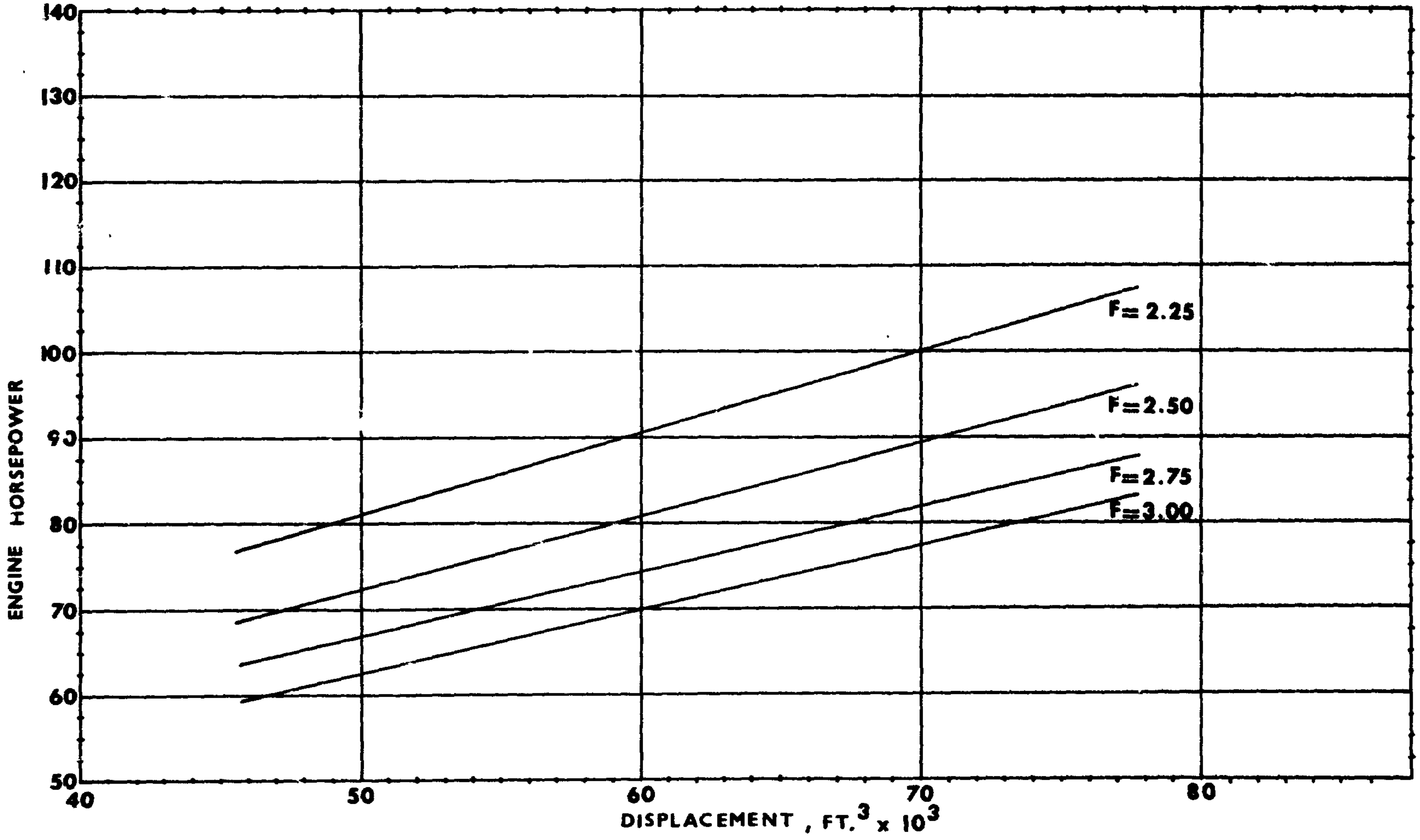

FIG. 3 REQUIRED ENGINE HORSEPOWER v. DISPLACEMENT

V= 60 MPH N=0.2 M =0.6

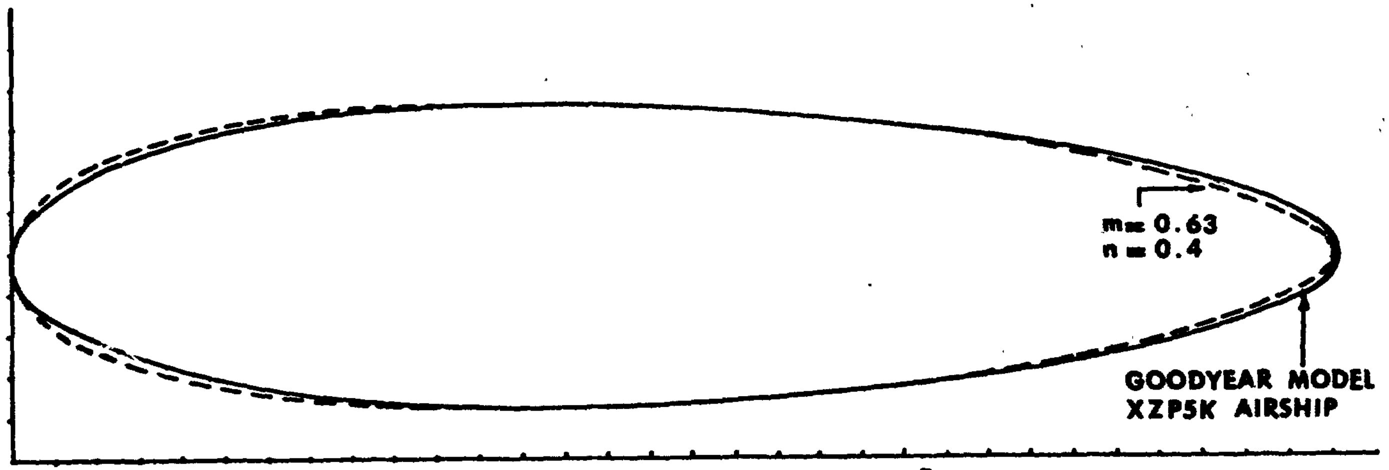

FIG. 2.1 APPROXIMATE COMPARISON OF EQUATION $Y = \frac{\left[1+m\right]^{n+m}}{2f\,n^{n}m^{m}} \cdot \frac{x^{n}}{L^{n+m-1}}\left[L-x\right]^{m}$

TO GOODYEAR MODEL XZP5K AIRSHIP, $f = 4.17$

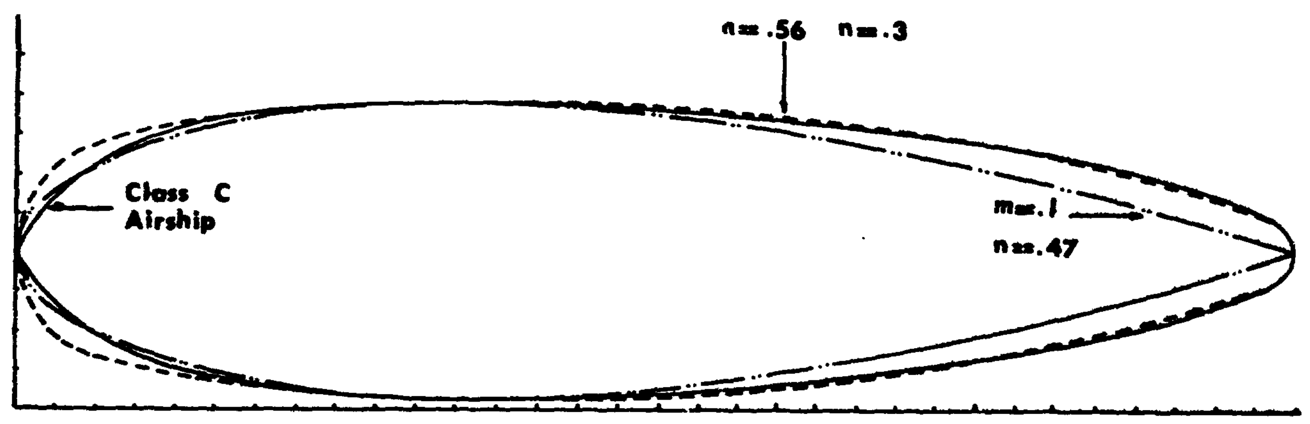

FIG. 2.2 APPROXIMATE COMPARISON OF EQUATION $Y = \frac{\left[n+m\right]^{n+m}}{2 f n^{n} m^{m}} \cdot \frac{x^{n}}{L^{n+m-1}} \left[L - x\right]^{m}$

TO CLASS C AIRSHIP , $f = 4.19$

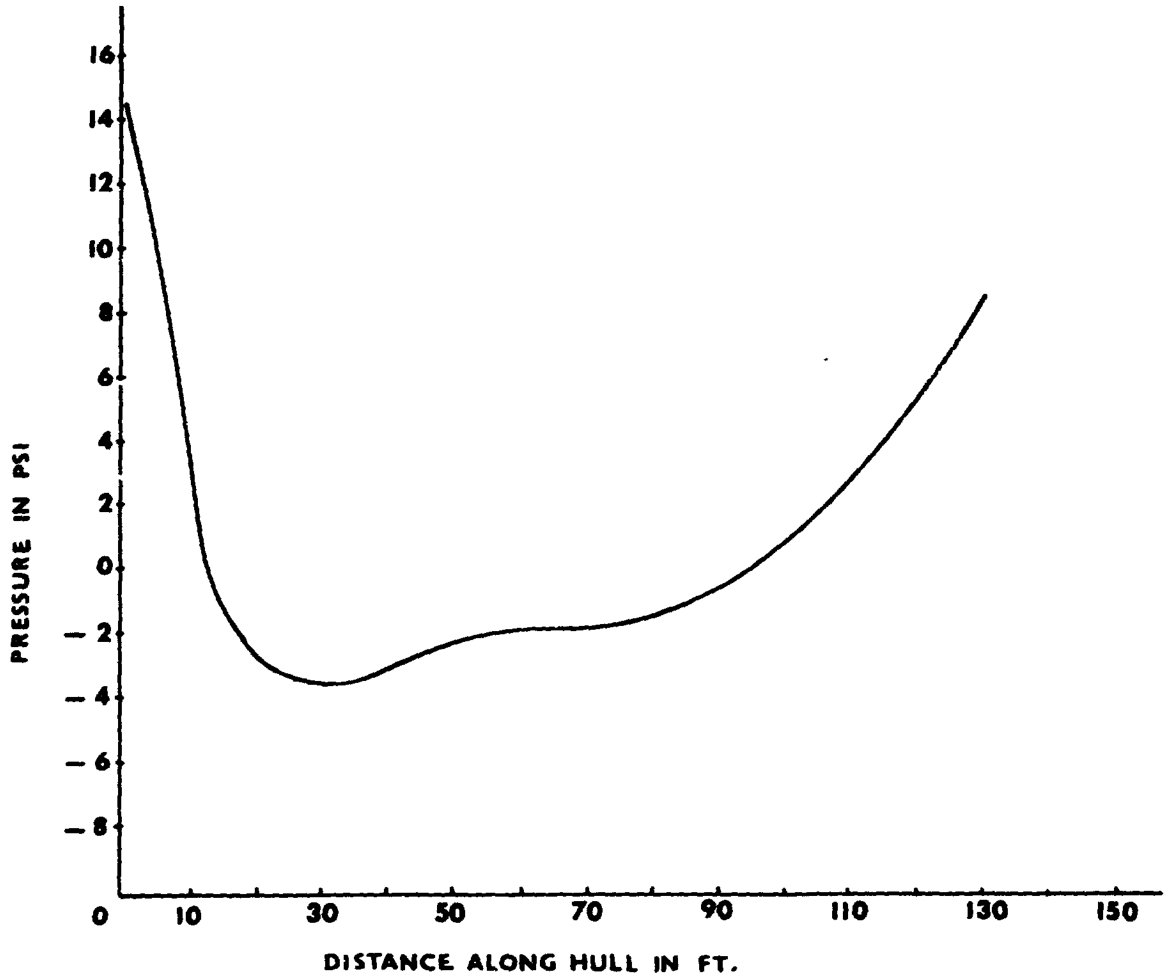

FIG. 3.1 PRESSURE DISTRIBUTION FOR AN AIRSHIP IN LEVEL FLIGHT

$m = 0.6$ $V = 110$ fps
$n = 0.4$ $f = 3.00$

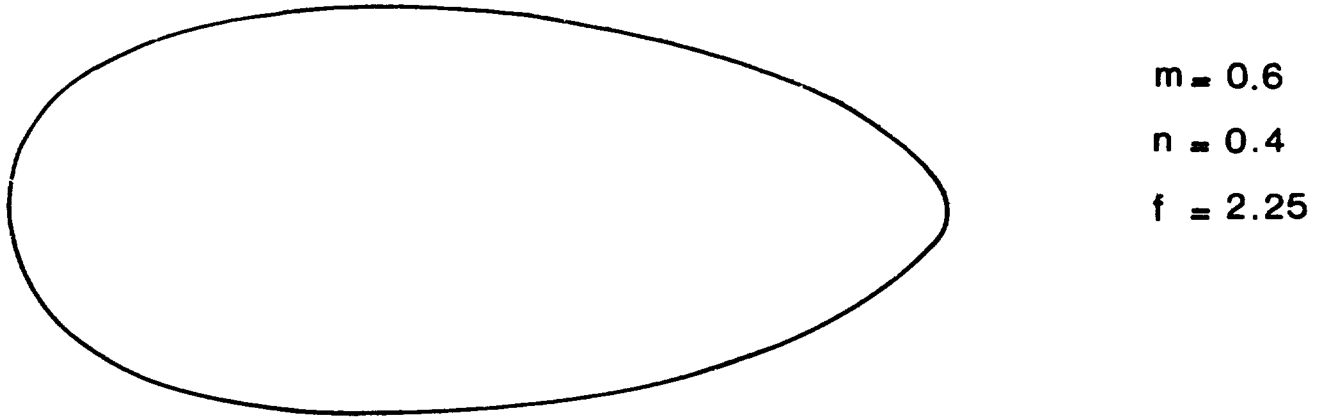

FIG. 3.2 INITIAL SHAPE OF ENVELOPE

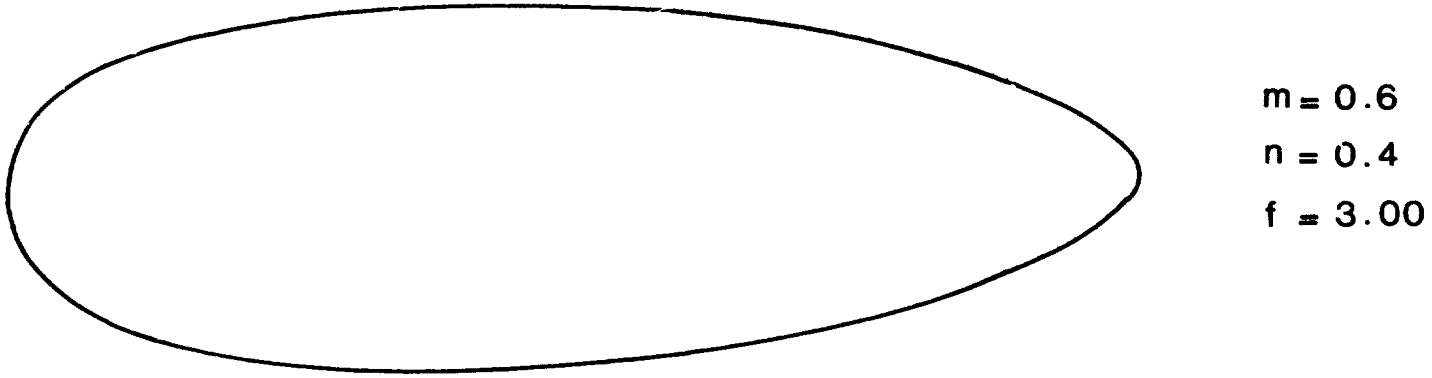

FIG. 3.3 FINAL SHAPE OF ENVELOPE

Figure : 4.1 Cabin Structure During Construction

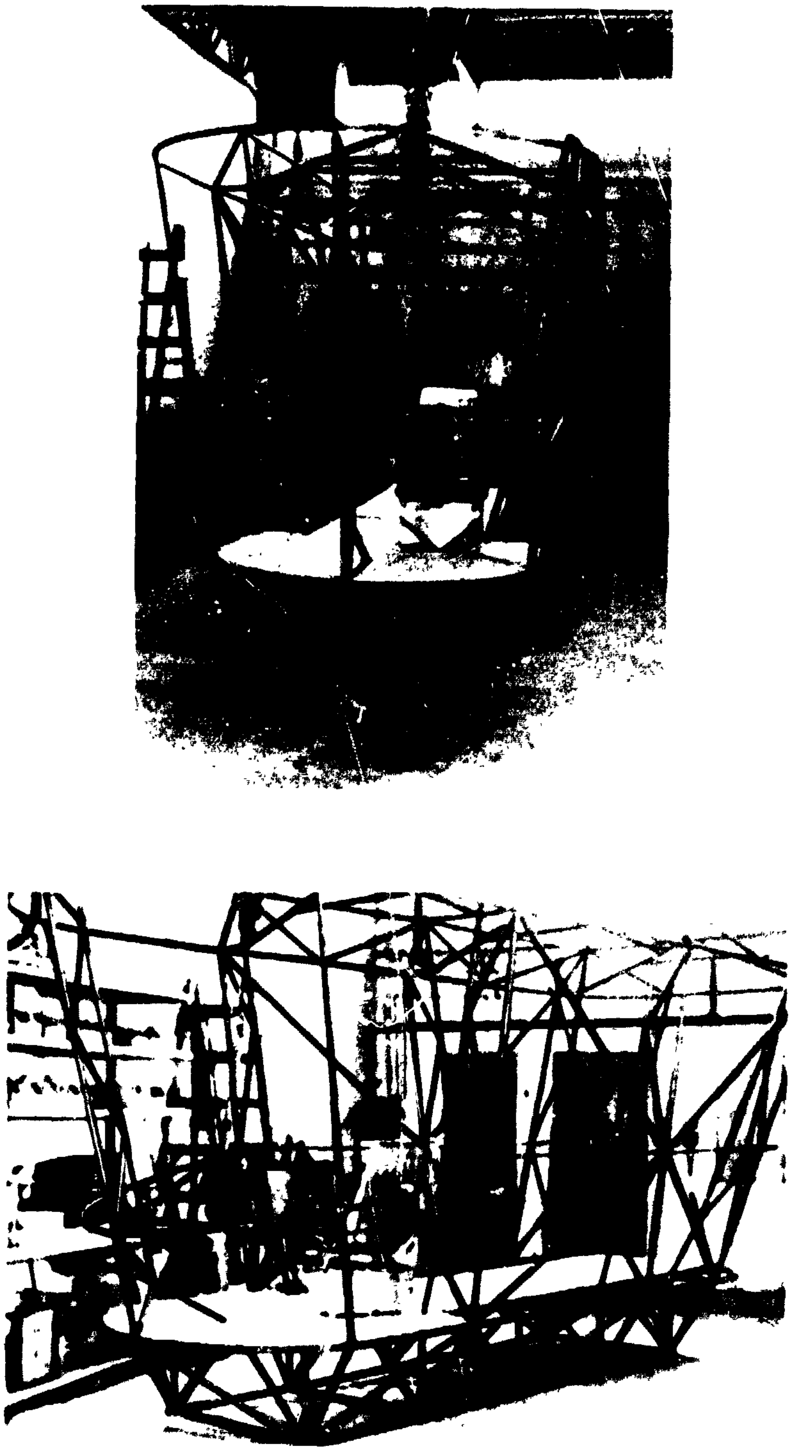

Figure: 4.2   Cabin Structure as Completed

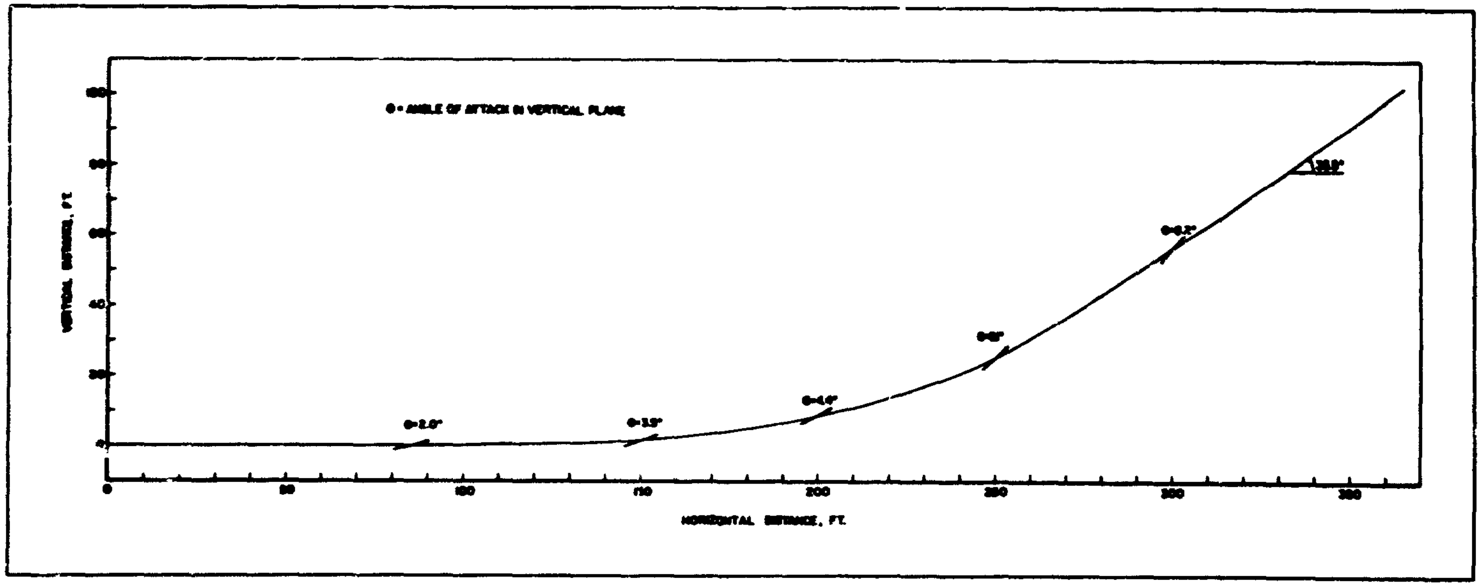

FIG. 5.1 TAKE — OFF TRAJECTORY

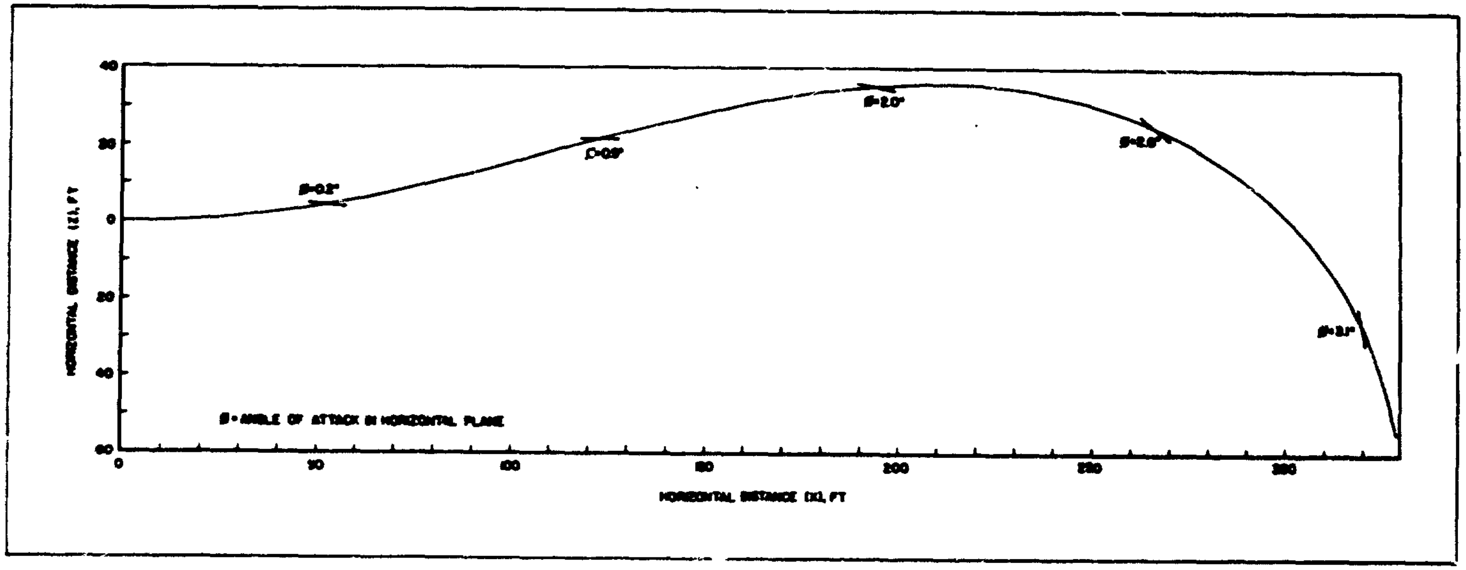

FIG. 5.2 FULL RUDDER UNTIL A 75° TURN HAS BEEN ACHIEVED

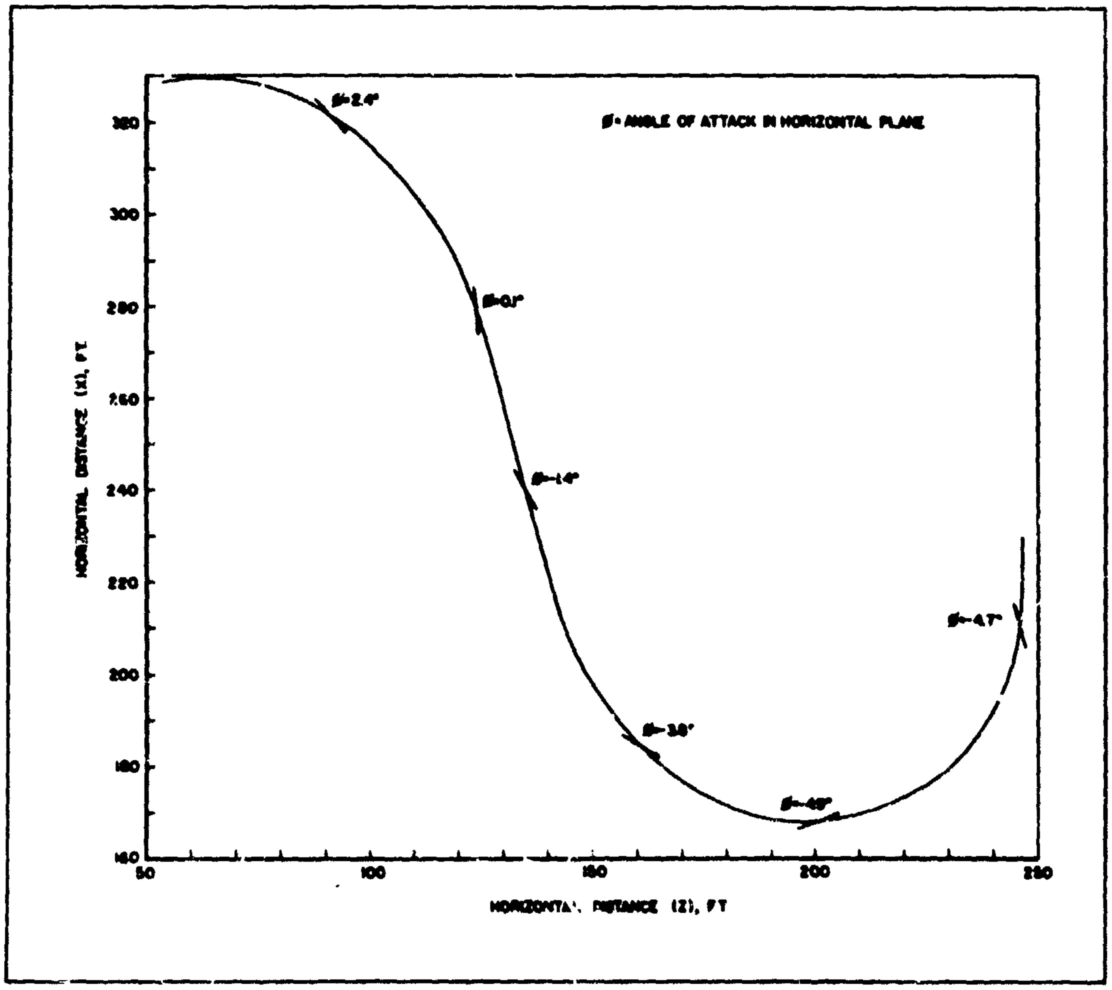

FIG. 5.3 FULL OPPOSITE RUDDER UNTIL THE ORIGINAL HEADING REGAINED

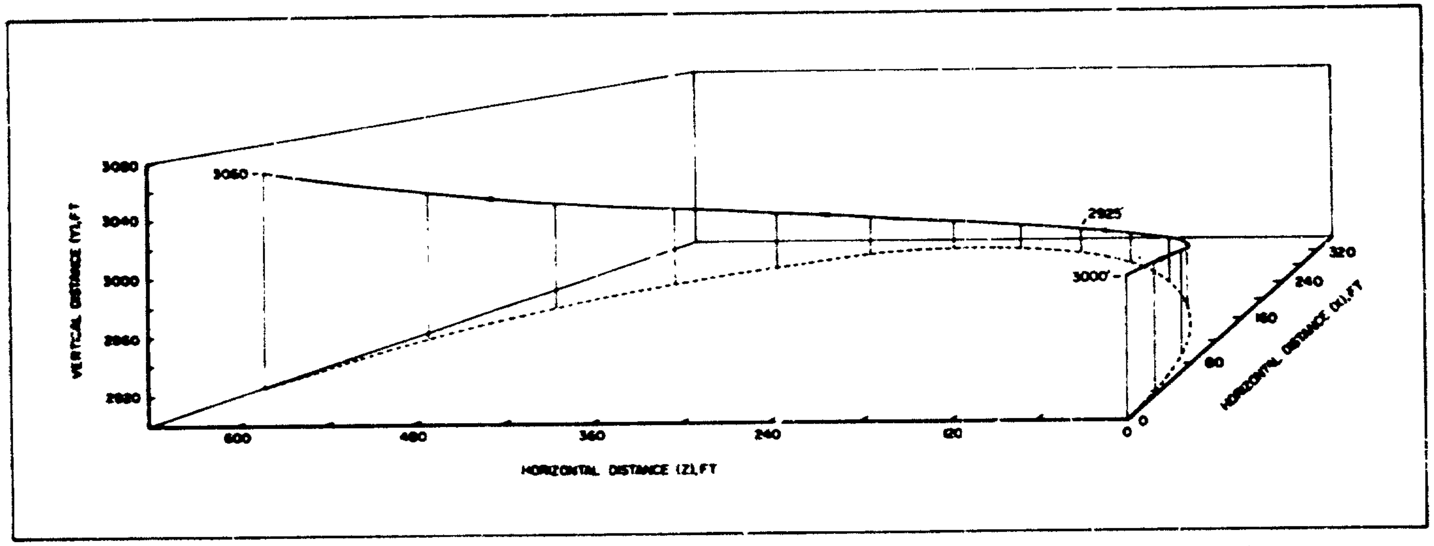

FIG. 5.4 FULL UP ELEVATORS AND A STEADY STATE TURN FROM 0° TO 180°

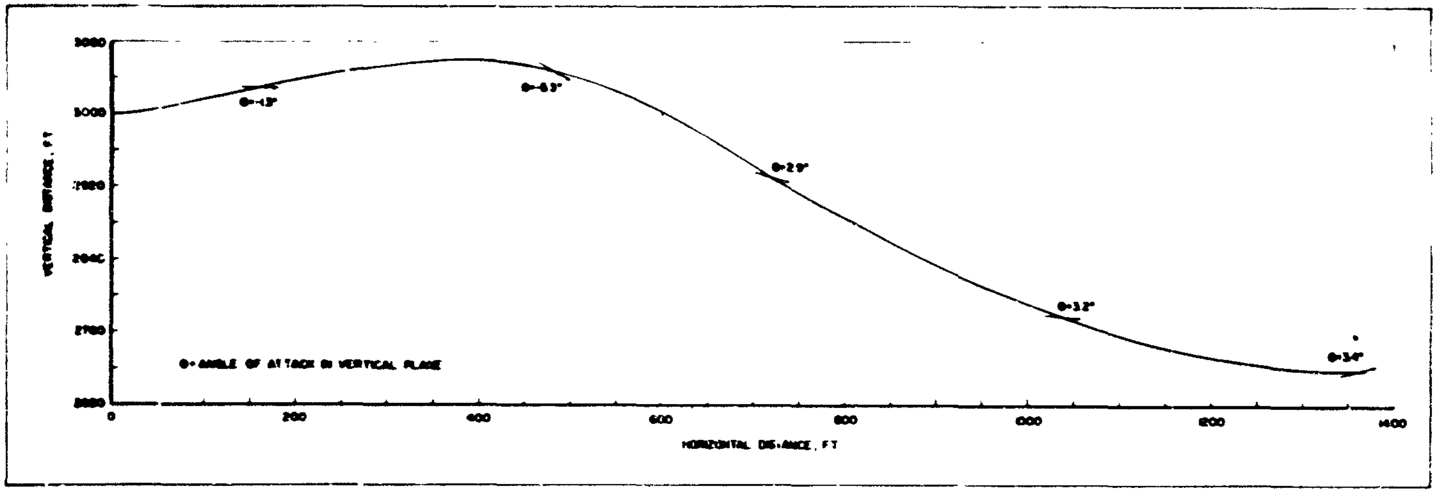

FIG. 5.5 FULL DOWN ELEVATORS UNTIL MAXIMUM DESCENT RATE ACHIEVED AND THEN FULL UP ELEVATORS UNTIL DESCENT RATE EQUALS ZERO