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ASPECTS OF AIRSHIP DESIGN

ASPECTS OF AIRSHIP DESIGN

By:

Hans J. Kleiner

A Thesis
Submitted to the School of Graduate
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TITLE: Aspects of Airship Design

AUTHOR: Hans J. Kleiner

SUPERVISOR: Dr. J. L. Duncan

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SCOPE AND CONTENTS:

The objective of this study is to present both an update of airship design, by introducing the element of the digital computer, and the structural design of the cabin of airship CAS-1.

Various aspects of the preliminary design of an airship were subjected to refinement by use of the digital computer. These included the envelope shape, the airship static bending moment, performance characteristics such as drag, and also the pressure distribution over the envelope in both level flight and flight at angles of attack.

Another area in which extensive use was made of the digital computer involved the development of a dynamic model of the airship flying characteristics. This model, in the form of a user oriented computer programme, allows the evaluation of the flight characteristics of various design alternatives. The maneuvers specified are those required to comply with government airworthiness requirements. The initial output is intended to form part of the compliance report for CAS-1.

The final section of this thesis involves the design and analysis of the structure of the cabin of airship CAS-1. This portion of the thesis was of immediate practical value as the construction of this cabin has been completed.

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CHAPTER 1

INTRODUCTION

At the present time airships are experiencing a renewal of public interest. Technical and financial interest has also been evident for some time as shown by the proposals and feasibility studies by Gordon[5], Sonstegaard[6], Howe[7], Kleiner[4], Stinton[8], Morse[10], Jurich[9], Hecks[11], Mowforth[14], Rynish[16], Vaeth[31], and Seemann[32]. Goodyear Aerospace [17-22,30] has also carried out various studies.

What is responsible for the revived interest of engineers and transportation planners? The rebirth of the airship can be attributed to the following reasons:

1) Airships were ahead of their time in their demands upon technology. Use of computer technology might be expected to produce airships that would far exceed the performance and safety of pre World War II commercial airships.
2) Airships have better ton-mile/unit energy ratios than other airborne transportation systems. This has become of prime consideration in view of the present energy situation.
3) New materials have been developed which affect every aspect of airship construction. Plastic films, foams, and carbon fibres are among the materials

that might make significant contributions to any new airships.

4) Helium, the "safe" airship gas, is no longer a scarce gas controlled politically by only one nation.

5) Airships have several inherent attributes which airborne transportation designers strive for in other systems. These include:

(a) low levels of noise and air pollution

(b) low risk potential for fatal accidents

(c) STOL and VTOL capability

(d) long range and endurance

(e) all weather capability (when aloft)

The airship has been suggested as a possible solution for:

i) maritime patrol

ii) search and rescue

iii) airborne police work

iv) survey and exploration work

v) bulk and gaseous freight transportation

Figure 1:1 shows the sort of costs that might be achieved by airships as compared to other modes of transportation.

The development of the airship actually dates from the construction of the first elongated balloon designed by A. J. and M. N. Roberts in 1784. The envelope had an internal air cell to maintain a constant internal pressure and the airship

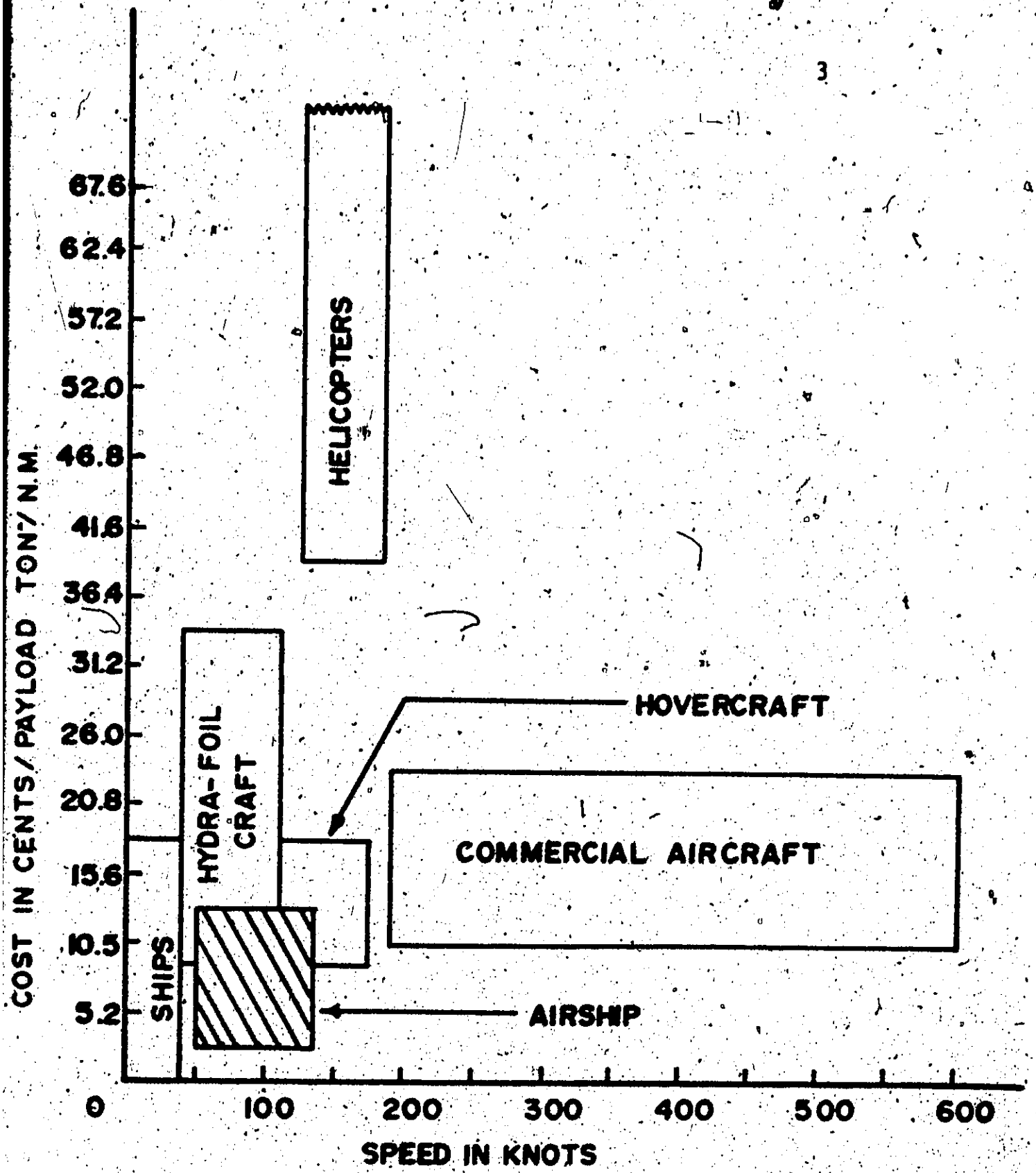


FIGURE 1.1 THE TRANSPORTATION COST SPECTRUM

was propelled and steered by means of oars. Although the vehicle was claimed to be successful, further development had to await the development of a suitable power source. Monck Mason, in 1843, tried a clockwork driven propellor and Henri Giffard, in 1852, used a steam engine on a hydrogen filled envelope and attained a speed of six miles per hour. It was not until the 1890's, with the development of the gasoline engine, that a power source, of a power to weight ratio which allowed sustained flight, was available. Santos Dumont, in France, and Count von Zeppelin, in Germany, around 1900 built and flew successful airships. The development of the airship progressed rapidly in the interval until the start of World War I. The extent of the progress can be measured by the fact that before the outbreak of the war a successful and safe commercial airship operation was already well established. It operated, in Germany, under the name of DELAG and flew three large, for their time, rigid airships.

During World War I, the airship underwent rapid development. This development had as its main aim the production of an efficient weapon system. However, this development lead to the airship becoming the first long range air transport after the termination of hostilities. The first transatlantic flight was made in 1919, and in 1928 the famous Graf Zeppelin started regularly scheduled transatlantic flights. Even larger commercial airships followed in the form of the British R100,

R101, and the German Hindenburg. The potential of the airship at this stage of development can be seen by examining the commercial payload of the 7,060,000 cubic foot airship Hindenburg. The commercial payload was 74,000 lbs. over transatlantic ranges. At the same time, the DC-3 represented the most efficient aircraft system. However, despite the promise shown, the lack of really suitable materials, design techniques, research and development funds, and the international politics of the pre-World War II era saw the demise of the large commercial rigid airships culminating in a series of accidents. Despite this, the airship, in non-rigid form, continued to give valuable service. During World War II extensive convoy escort work was done by airships. No ship was lost to submarines while under airship escort. After the war, even larger non-rigid airships were developed by the U. S. Navy to perform anti-submarine and early airborne warning duties. Interest waned, however, as airships came to be regarded as relics of an era past and in 1962 the U. S. Navy disbanded its airship service. Thus arose the present situation in which the only airships left flying in the world are those used by the Goodyear Aerospace Corporation as symbols of its corporate image.

Despite the many proposals mentioned earlier, it has been many years since a new airship has emerged from the design proposal stage to an actual piece of hardware. For one reason or another all of these proposals died a quiet death without

initiating any new design procedures or producing any advances in the multitude of areas where the incorporation of modern techniques could help provide a safe, efficient, optimum design.

This thesis, which was sponsored in part by the builders of airship CAS-1, is aimed at providing a start in the application of modern computer techniques to airship design. Two separate areas have been examined. First the computer has been used to examine the preliminary design stage. It is an ideal tool with which to cover the many alternatives available to the designer. Secondly the computer has been put to use to determine the loads on an airship by simulating the airship maneuvers which are specified in the government airworthiness regulations[3].

The final part of this thesis covers the design of the cabin structure of the airship CAS-1. The fabrication of this structure was completed during February of 1974.

It is hoped that this work will be the first of many on the subject of airships and that the interest displayed by the various individuals and agencies will produce new hardware and a new airship era.

Chapter Two Notation

x	the co-ordinate along the longitudinal axis of the airship envelope
y	the co-ordinate along the vertical axis of the envelope
L	the length of the airship
m	airship envelope shape parameter
n	airship envelope shape parameter
f	fineness ratio
C_f	friction drag coefficient
ρ	density of air (slugs/ft^3)
V	velocity (ft/sec)
$\forall$	volume of airship (ft^3)
V_K	airship velocity in knots
ν	kinematic viscosity of air (ft^2/sec)
δ_{SL}	unit lift of gas at sea level (lbs/ft^3)
CB_x	position of the center of buoyancy along the longitudinal axis
COE_x	position of the center of gravity of the envelope along the longitudinal axis
A_{CS}	the control surface area
A_H	the fixed horizontal control surface area
A_V	the fixed vertical control surface area
A_E	the elevator area
A_R	the rudder area
C	the distance between the center of buoyancy and the center of area of the total control surfaces

BM_H the hogging bending moment

BM_A the aerodynamic bending moment

P_{INT} the internal pressure of the gas containing envelope (psi)

r the perpendicular distance from the x axis

U_x the velocity component in the x direction

U_r the velocity component in the r direction

U_ϕ the velocity component in the ϕ direction

θ the angle between the radius vector and the axis of symmetry

U_θ the velocity component in the θ direction

Φ the potential function

Ψ the stream function

q the source strength per unit length

a the source length

ρ' the distance to a point from the left end of a line source

ρ'' the distance to a point from the right end of a line source

U the free stream velocity

β the transverse force coefficient

W_x the parallel velocity component in the x direction

W_r the parallel velocity component in the r direction

CHAPTER 2

PRELIMINARY DESIGN ANALYSIS

2.1 Introduction

The general concensus, in the modern day literature dealing with airships, is that any new airship appearing in the future will be of the pressure airship type (ie. non-rigid or semi-rigid). A pressure airship is an airship whose envelope shape and strength is provided by a slight internal pressure. Thus the preliminary design information presented in this chapter will apply directly to this type of airship. Some parts of the information may also apply to rigid airships, however, no special differentiation will be made.

The data presented can be segregated into four distinct areas. These are:

(i) selection of the envelope shape,

(ii) analysis of various parameters that are dependent on the envelope shape,

(iii) static shear force and bending moment analysis, and

(iv) an analysis of the pressure distribution of an envelope shape at various speeds and angles of attack.

With the aid of this data, the design of the airship shape can be made in a much more rational manner than has been the case previously.

2.2 The Envelope Shape

Most airship forms have been developed by a trial and error method, resorting to wind tunnel tests to obtain data upon which to base a decision as to the best form. Streamline shapes have sometimes been developed mathematically from the theoretical flow resulting from arbitrarily assumed systems of sinks and sources. Wind tunnel tests have not indicated any outstanding virtues in forms developed by this method. Shapes drawn by designers with a natural antitude for these matters have been as successful as any[13]. In early years shapes were often formed by simply combining various solids of revolution into a "smooth" body. Later attempts were made to fulfill various conditions with these solids, e.g., achieving a particular rate of change of curvature. The position has now been attained where mathematical expressions, capable of generating various types of bodies of revolution, are available. The value of an expression of this type is quite apparent especially if the generating function is integrable. One such mathematical form has been developed by General Mills[28], in the following manner:

A generalized shape generation equation of the form

$$y = K_1 x^n (K_2 - x) \qquad (2.1)$$

where x = the co-ordinate along the central axis, and y = the radius at a value of x, was obtained from a commonly used shape generation expression

$$y = 1/3x^{1/2}(1 - x) \qquad (2.2)$$

The constants K_1 and K_2 of equation (2.1) were then determined from the boundary conditions $y_o = 0$, $y_2 = 0$ and $y_{max.} = L/2f$, such that

$$y = \frac{(n+1)^{(n+1)}\, x^n\, (L - x)}{2\, f\, n^n\, L^n} \qquad (2.3)$$

where x = the co-ordinate along the central axis,

y = the radius of the body of revolution about the central axis at each value of x,

L = the length of the body,

f = the fineness ratio = $L/2y_{max.}$,

and n = a dimensionless parameter.

The endpoint conditions of the generated shape are given by

$$\left(\frac{dy}{dx}\right)_{x=0} = \begin{cases} \infty & 0 < n < 1 \\ 2/f & n = 1 \\ 0 & n > 1 \end{cases}$$

$$\left(\frac{dy}{dx}\right)_{x=L} = -\frac{(n+1)^{(n+1)}}{2\, f\, n^n}$$

However, the generating power of (2.3) is limited in the variety of shapes that it is possible to generate.

The introduction of another dimensionless parameter, m, into equation (2.1) results in a more general expression.

$$y = K_3\, x^n\, (K_4 - x)^m \qquad (2.4)$$

which, assuming the boundary conditions previously stated, gives upon solving for K_3 and K_4,

$$y = \frac{(n+m)^{(n+m)}\, x^n (L - x)^m}{2\, f\, n^n\, m^n\, L^{(n+m-1)}} \qquad (2.5)$$

with the boundary conditions:

$$\left(\frac{dv}{dx}\right)_{x=0} = \begin{cases} a & 0 < n < 1, \text{ all } m \\ \dfrac{(m+1)^{(m+1)}}{2\,f\,m^{m}} & n = 1, \text{ all } m \\ 0 & n > 1, \text{ all } m \end{cases}$$

$$\left(\frac{dv}{dx}\right)_{x=L} = \begin{cases} -a & 0 < m < 1, \text{ all } n \\ \dfrac{-(n+1)^{(n+1)}}{2\,f\,n^{n}} & m = 1, \text{ all } n \\ 0 & m > 1, \text{ all } n \end{cases}$$

Equation (2.5) if employed with the following conditions will generate an infinite variety of airship hull shapes.

$$m > n$$
$$0 < n < 1$$
$$0 < m < 1$$

Figure 2.1 illustrates a comparison of equation (2.5) to the Goodyear Model XZP5K Airship. Figure 2.2 illustrates a comparison of equation (2.5) to the class "C" airship shape that was much in favour during the airship era. These comparisons indicate the accuracy available when using (2.5). The three parameters which directly affect the airship shape, m, n, and f, can be varied to suit the designer.

The adaptation of (2.5) to the digital computer and modern computer plotting software permits examination of many shapes. A programme to accomplish this has been developed. The variety of shapes possible is illustrated by Figures 2.3

APPROXIMATE COMPARISON OF EQUATION $y = \frac{(n+m)^{n+m}}{2 f n^n m^m} \frac{x^n}{L^{n+m-1}} (L-x)^m$

TO GOODYEAR MODEL XZP5K AIRSHIP

f = 4.17

Figure 2.1: Approximate Comparison of Equation

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

to Goodyear Model XZP5K Airship

APPROXIMATE COMPARISON OF EQUATION $y = \frac{(n+m)^{n+m}}{2 f n^n m^m} \frac{x^n}{L^{n+m-1}}(L-x)^m$

TO CLASS "C" AIRSHIP

f = 4.19

Figure 2.2: Approximate Comparison of Equation

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

to Class "C" Airship

to 2.50 which are an output of the programme. A printout of the actual programme is given in Appendix A and should prove amenable to modification for other values of f, m, and n.

2.3 Body Configuration Dependent Parameters

The choice of envelope shape has an effect on many parameters and in turn influences which shape will finally be used. In general, it is desirable to have maximum volume for minimum weight and minimum aerodynamic drag. In actual fact the selection of a particular shape also depends on such factors as the propulsive technique, stability and control requirements, boundary layer effects, the degree of resistance to aerodynamic bending moments, and the flight profile. Although no shape can be optimum for all of the above conditions, a shape that is a satisfactory compromise must be ultimately decided upon. With the aid of (2.5) various pleasing shapes can be examined to determine which best meets the design specifications. A programme has been written which will calculate the following parameters for each shape required. An example of the type of output obtainable is given by Table 2.1.

2.3.1 Drag

One of the most important of the parameters in determining the suitability of the envelope shape is the drag.

Figures 2.3 to 2.50 to follow. They represent various envelope shapes developed by use of equation

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

Various values of f, m, and n are used.

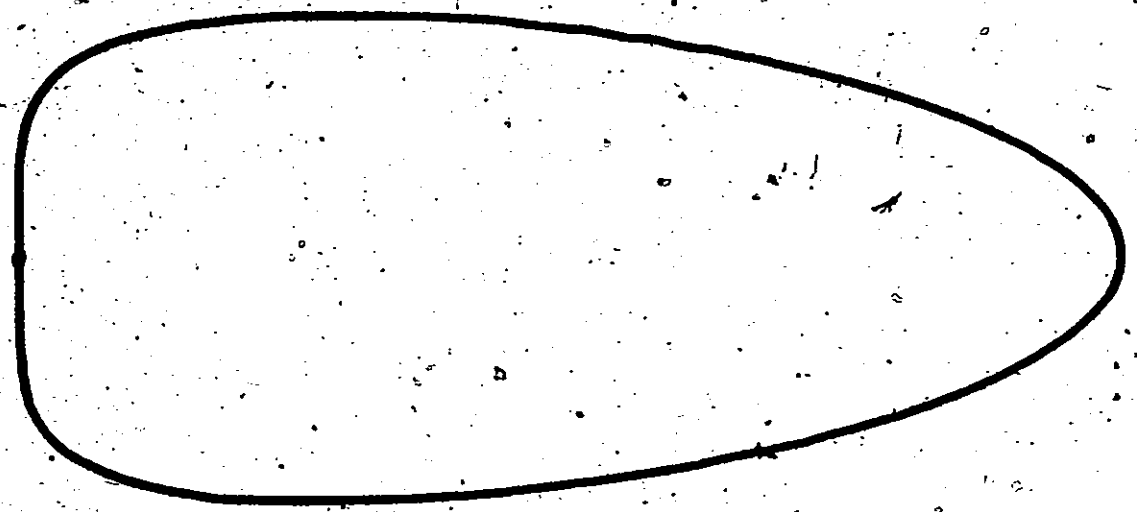


Figure 2.3: Shape of Envelope for

$n = 0.2,\ m = 0.5,\ f = 2.25$

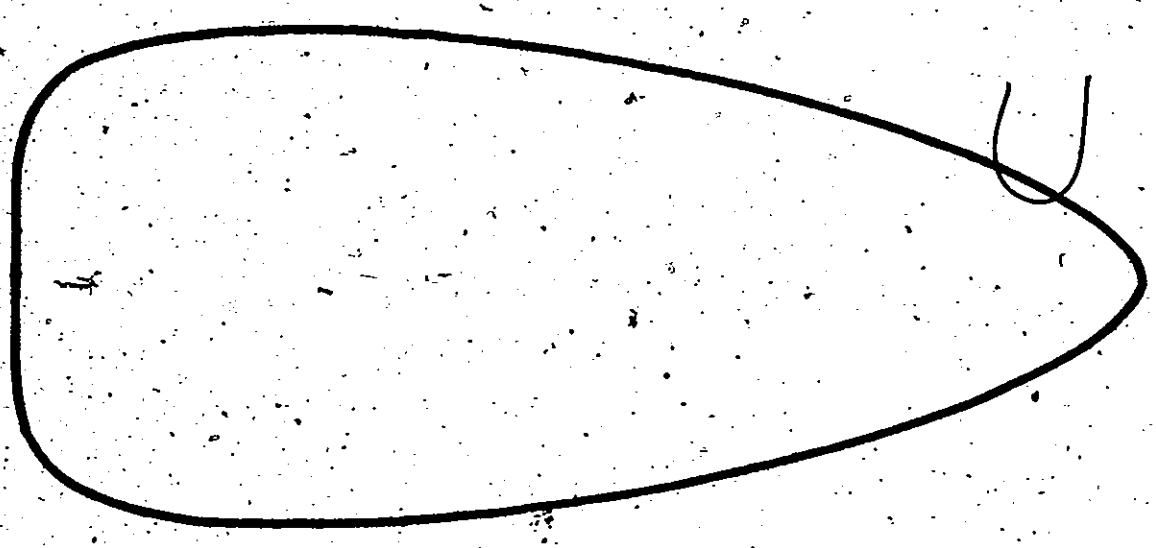


Figure 2.4: Shape of Envelope for
n = 0.2, m = 0.6, r = 2.25

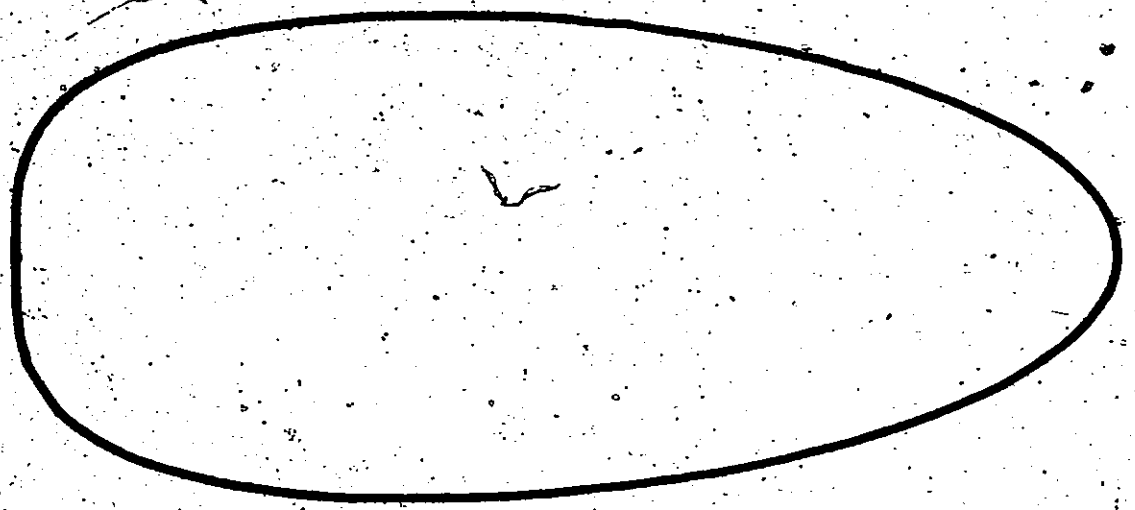


Figure 2.5: Shape of Envelope for
n = 0.3, m = 0.5 f = 2.25

Figure 2.6: Shape of Envelope for
$n = 0.3$, $m = 0.6$, $r = 2.25$

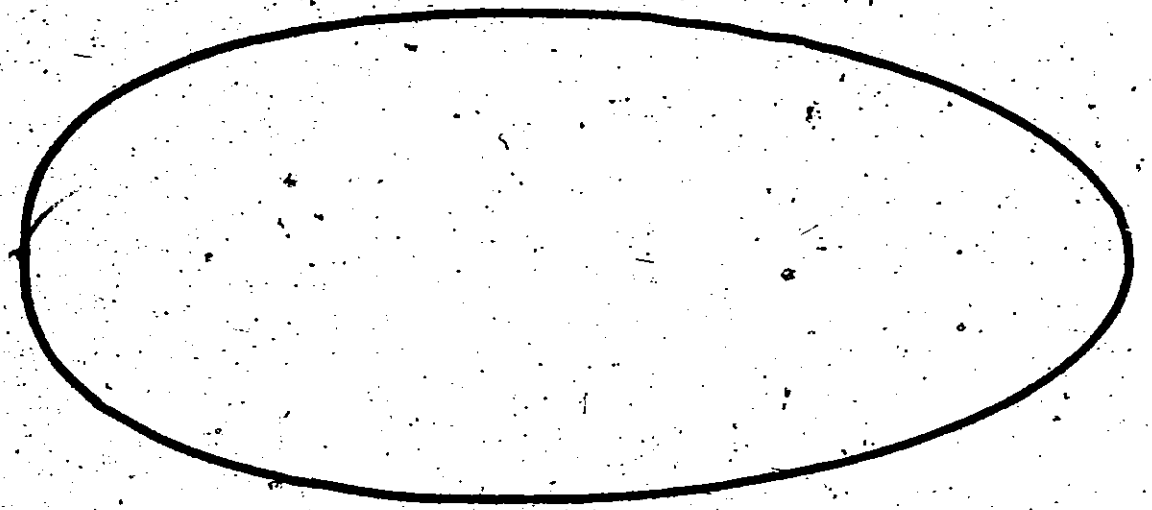


Figure 2.7: Shape of Envelope for
$n = 0.4$, $m = 0.5$, $f = 2.25$

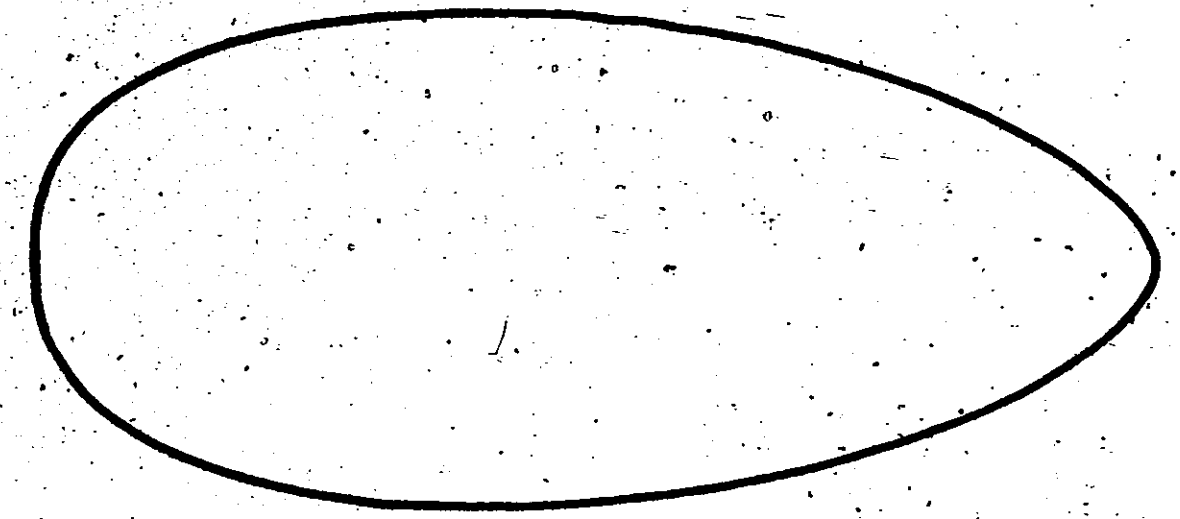


Figure 2.8: Shape of Envelope for
$n = 0.4$, $m = 0.6$, $f = 2.25$

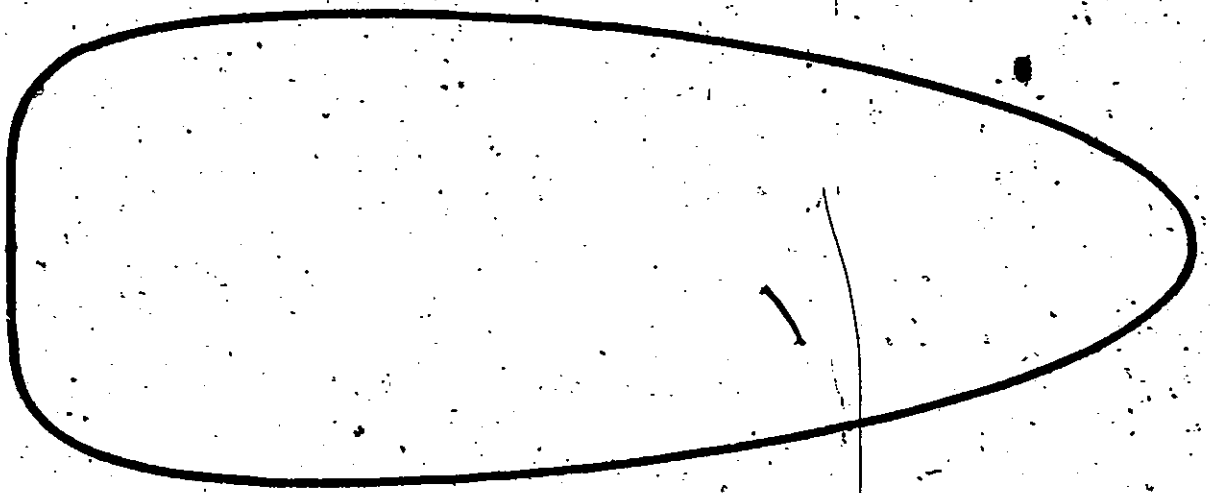


Figure 2.9: Shape of Envelope for
$n = 0.2, m = 0.5, f = 2.50$

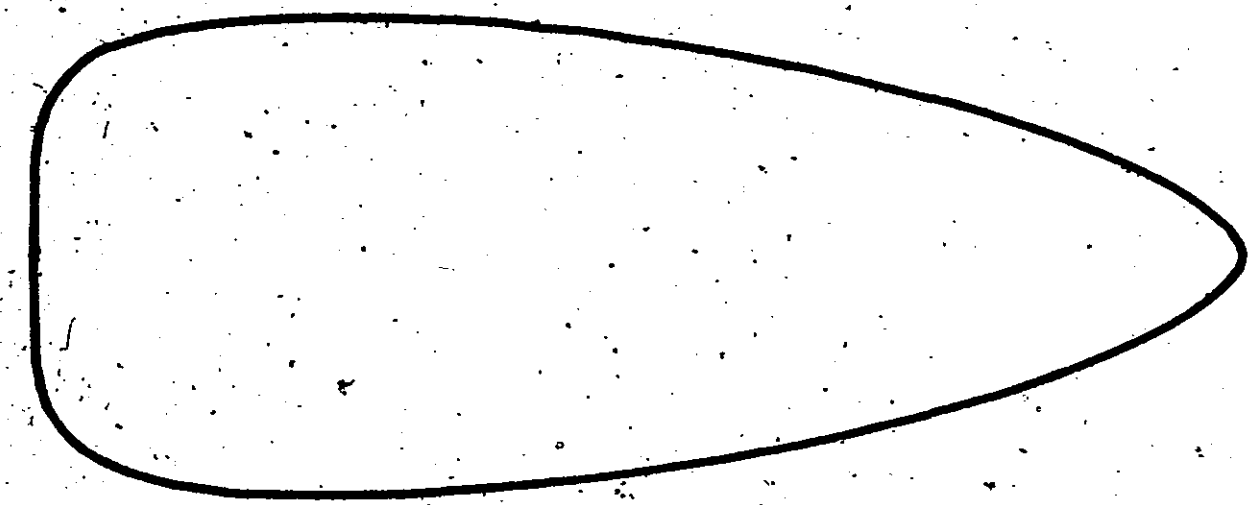


Figure 2.10: Shape of Envelope for
n = 0.2, m = 0.6, r = 2:50

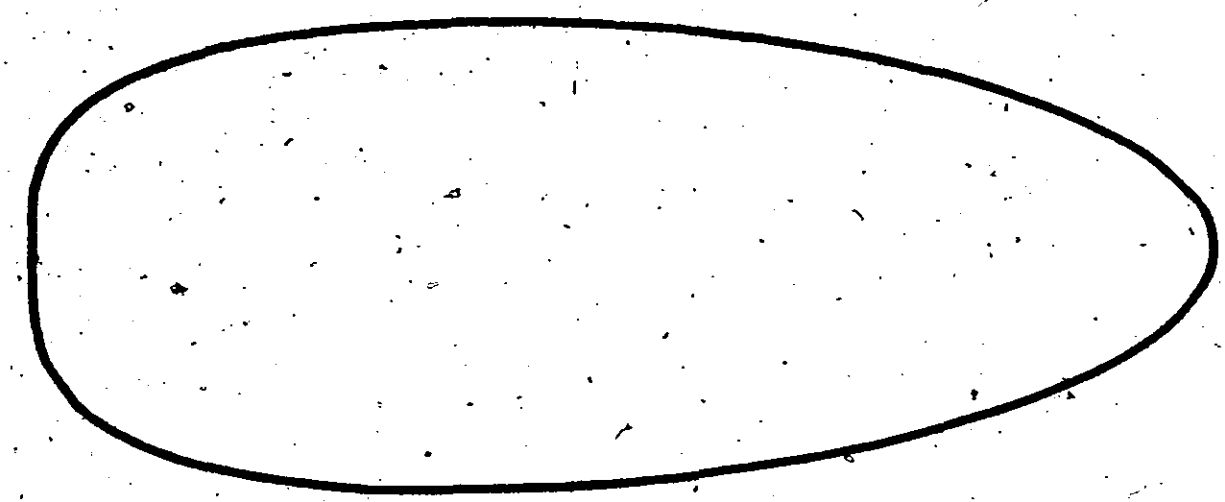


Figure 2.11: Shape of Envelope for

n = 0.3, m = 0.5, f = 2.50

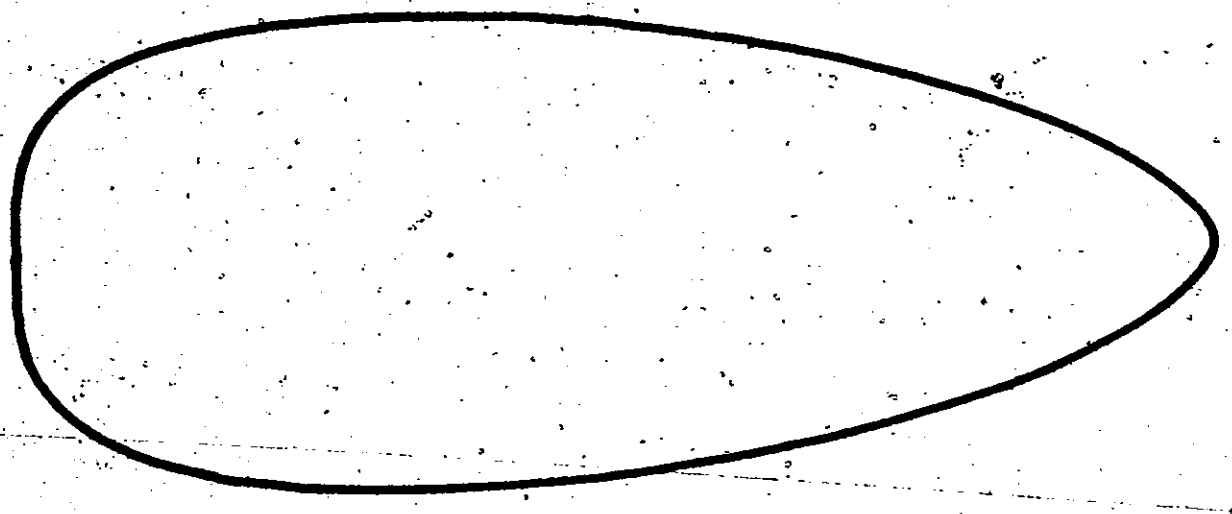


Figure 2.12: Shape of Envelope for

n = 0.3, m = 0.6, f = 2.50

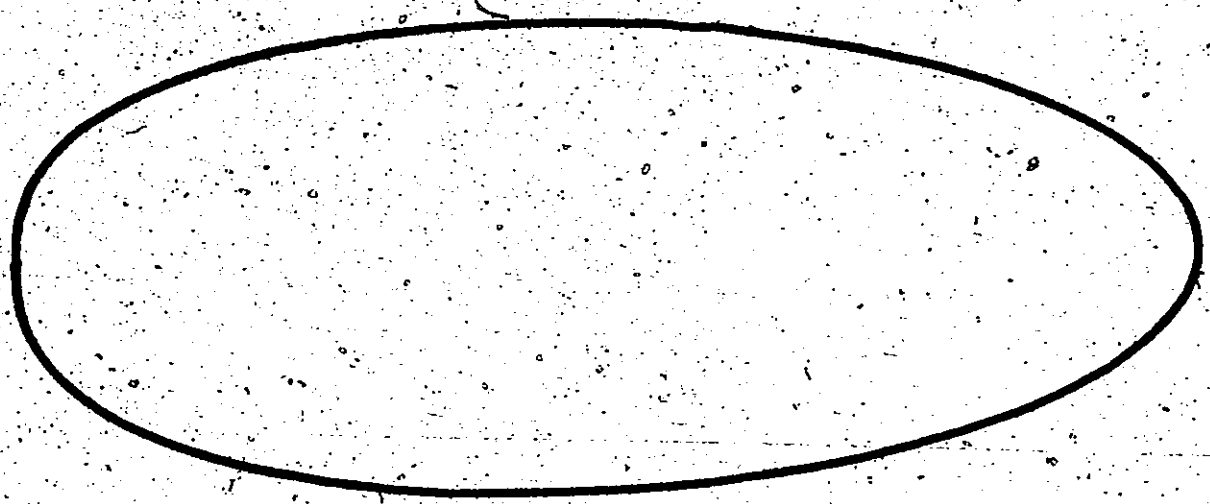


Figure 2.13: Shape of Envelope for
n = 0.4, m = 0.5, f = 2.50

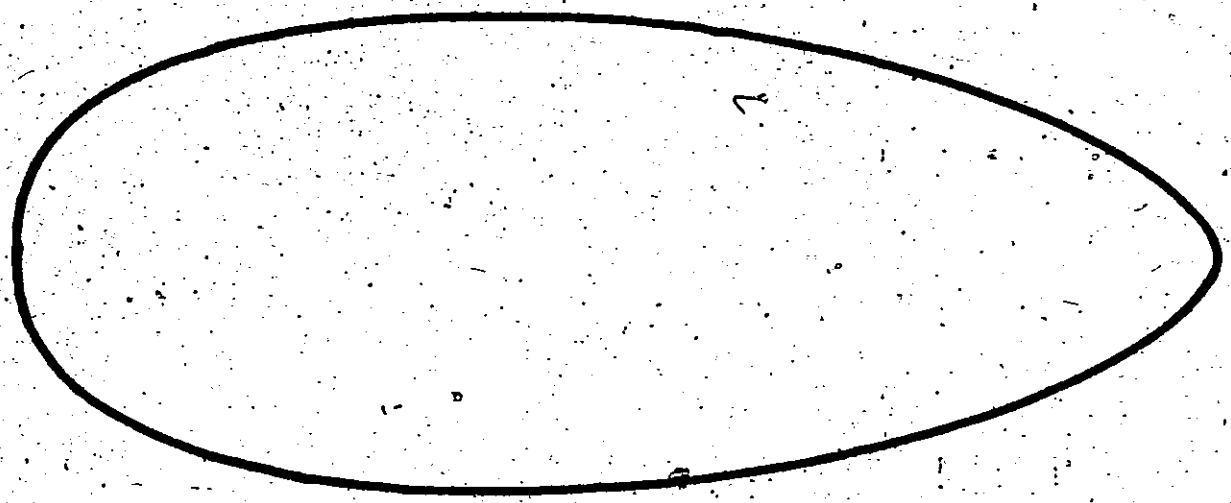


Figure 2.14: Shape of Envelope for
n = 0.4, m = 0.6, r = 2.50

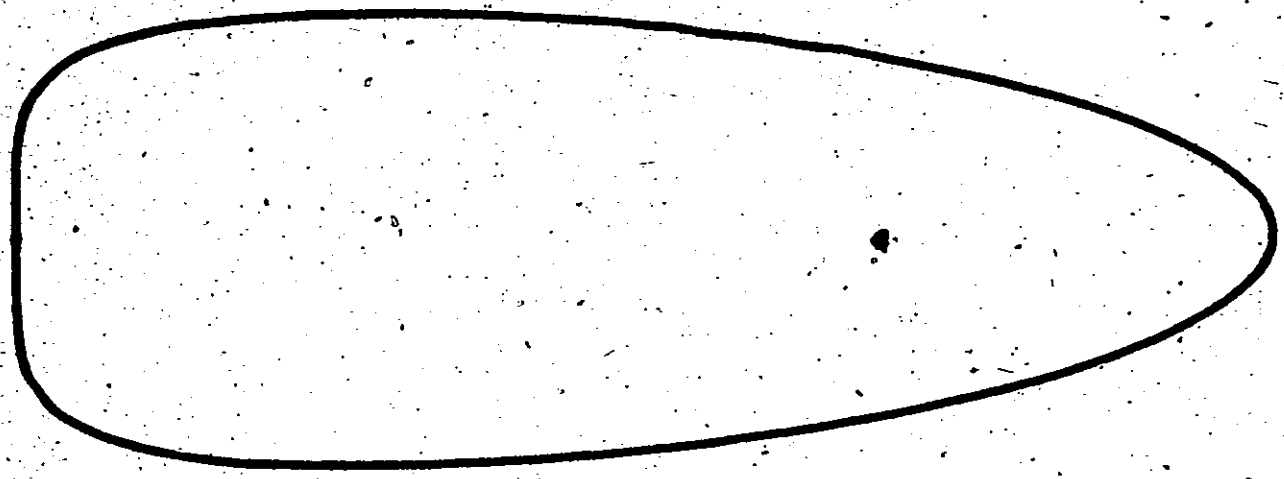


Figure 2.15: Shape of Envelope for

n = 0.2, m = 0.5, f = 2.75

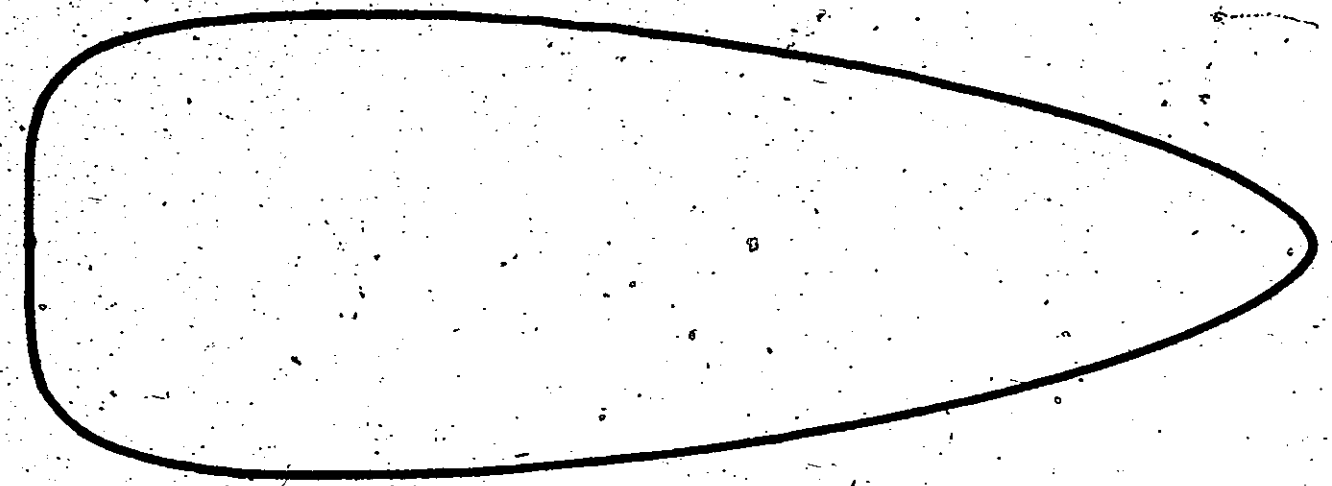


Figure 2.16: Shape of Envelope for
n = 0.2, m = 0.6, f = 2.75

Figure 2.17: Shape of Envelope for
n = 0.3, m = 0.5, f = 2.75

Figure 2.18: Shape of Envelope for
n = 0.30, m = 0.6, f = 2.75

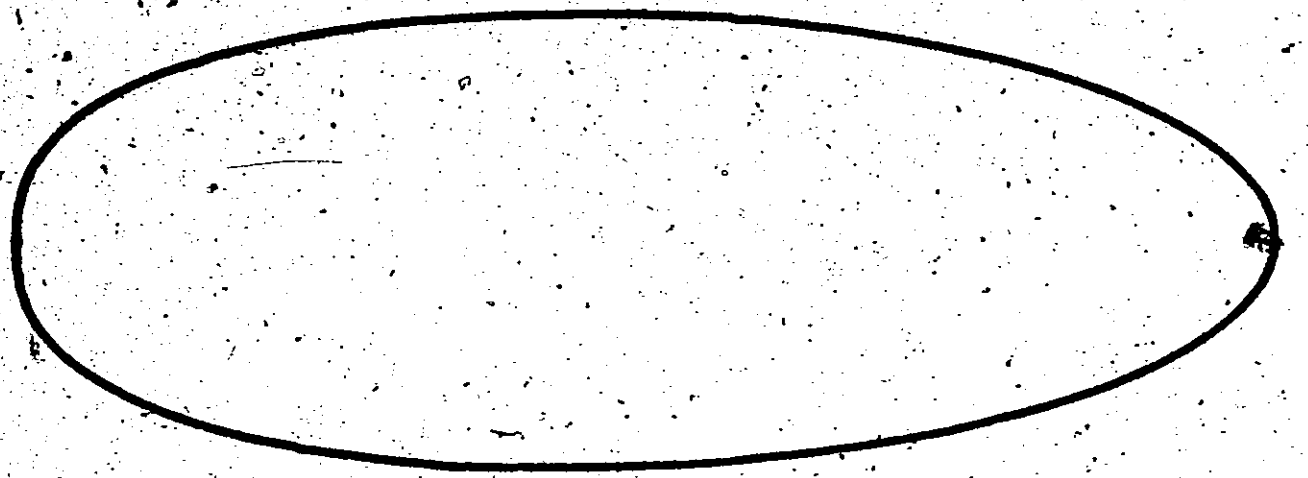


Figure 2.19: Shape of Envelope for
n = 0.400, m = 0.50, f = 2.75

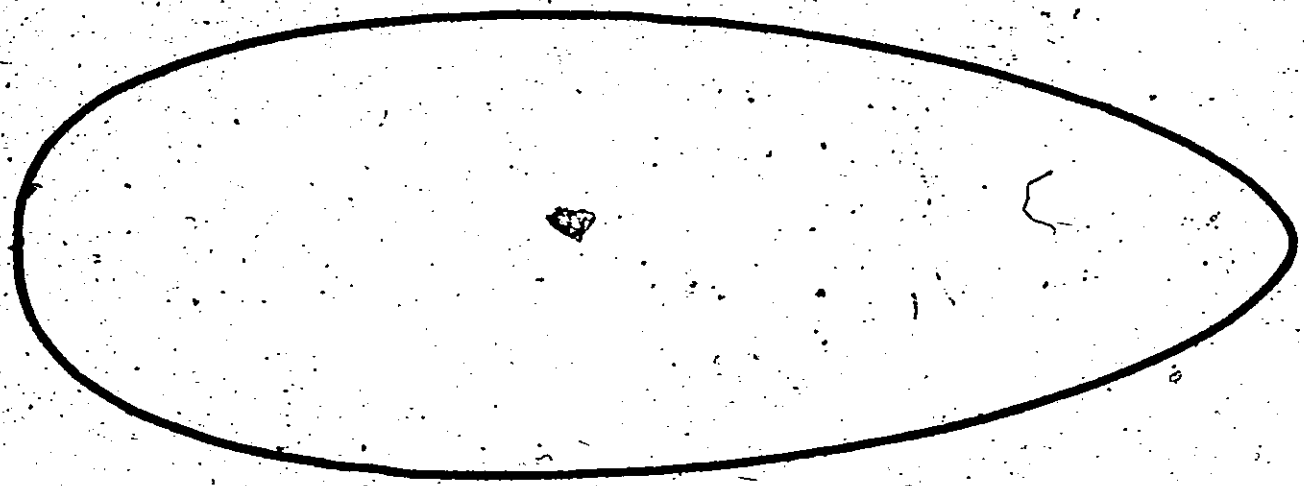


Figure 2.20: Shape of Envelope for
n = 0.4, m = 0.6, f = 2.75

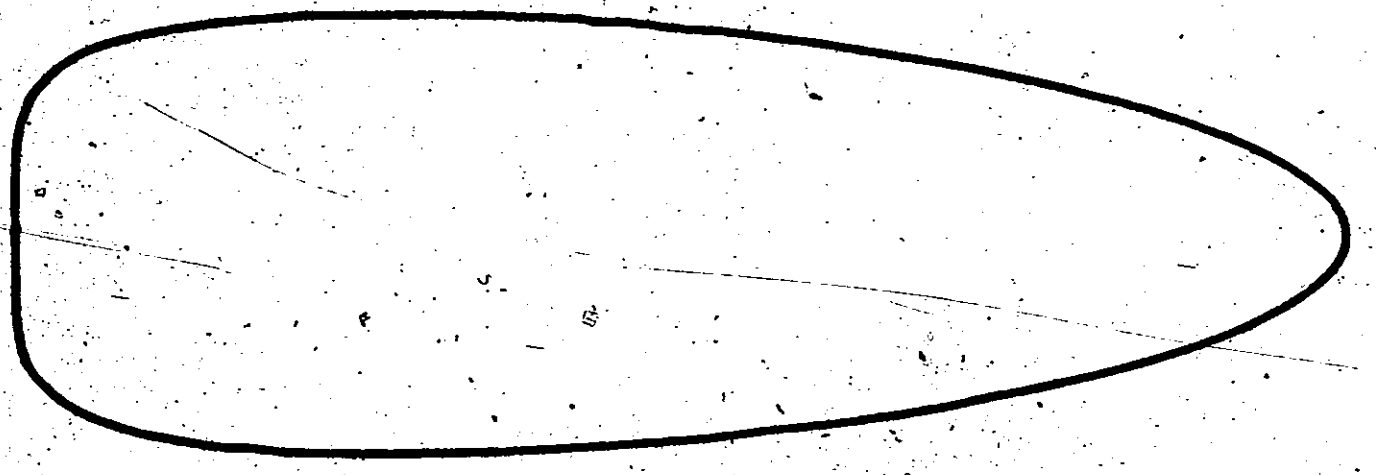


Figure 2.21: Shape of Envelope for
n = 0.2, m = 0.5, f = 3.00

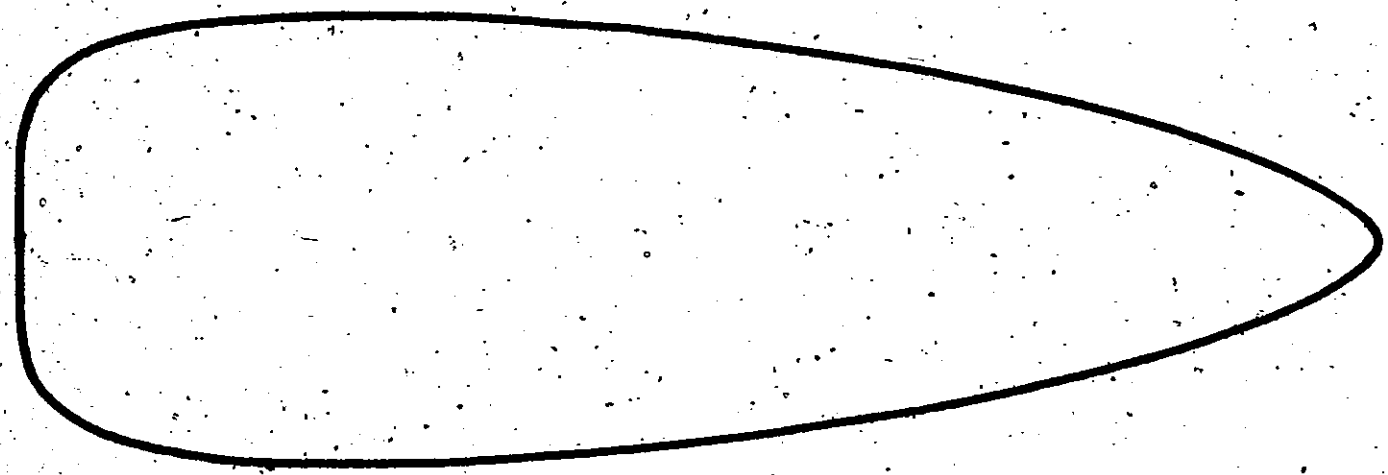


Figure 2.22: Shape of Envelope for

$n = 0.2$, $m = 0.6$, $f = 3.0$

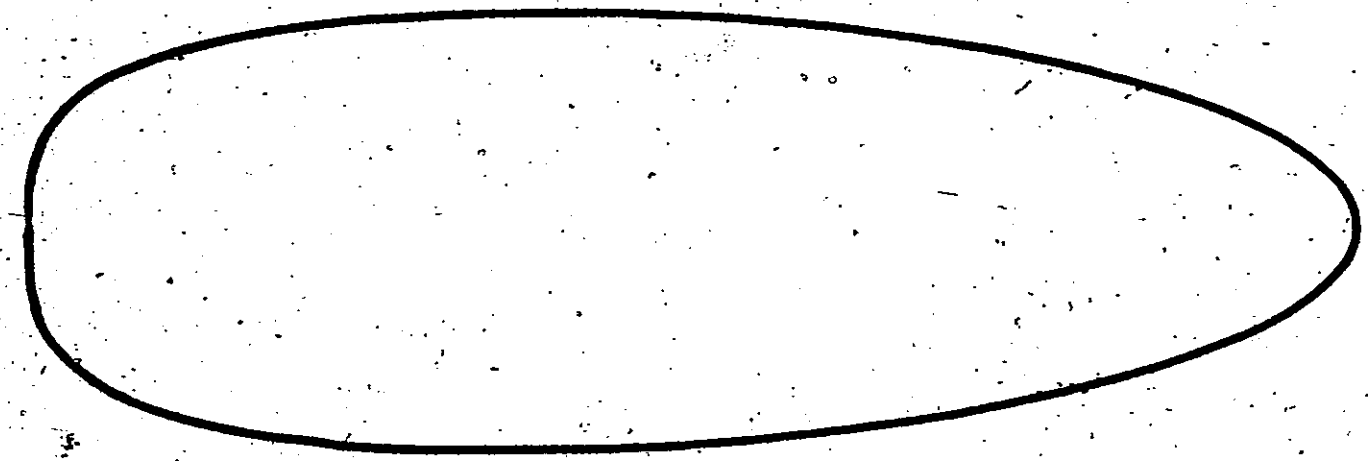


Figure 2.23: Shape of Envelope for
n = 0.3, m = 0.5, f = 3.00

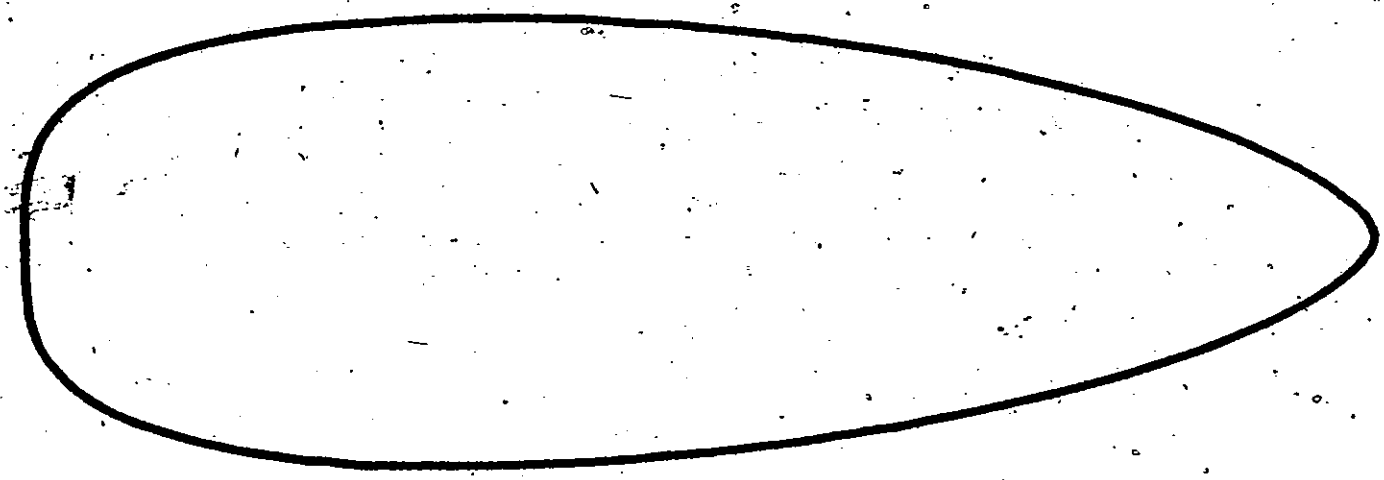


Figure 2.24: Shape of Envelope for
n = 0.3, m = 0.6, f = 3.00

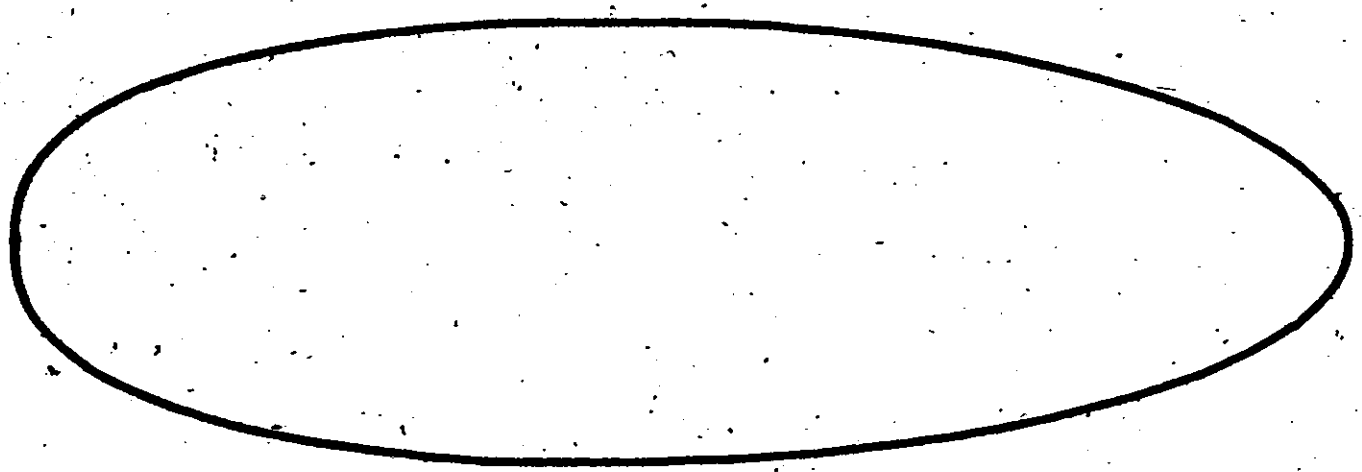


Figure 2.25: Shape of Envelope for
n = 0.400, m = 0.500, f = 3.0

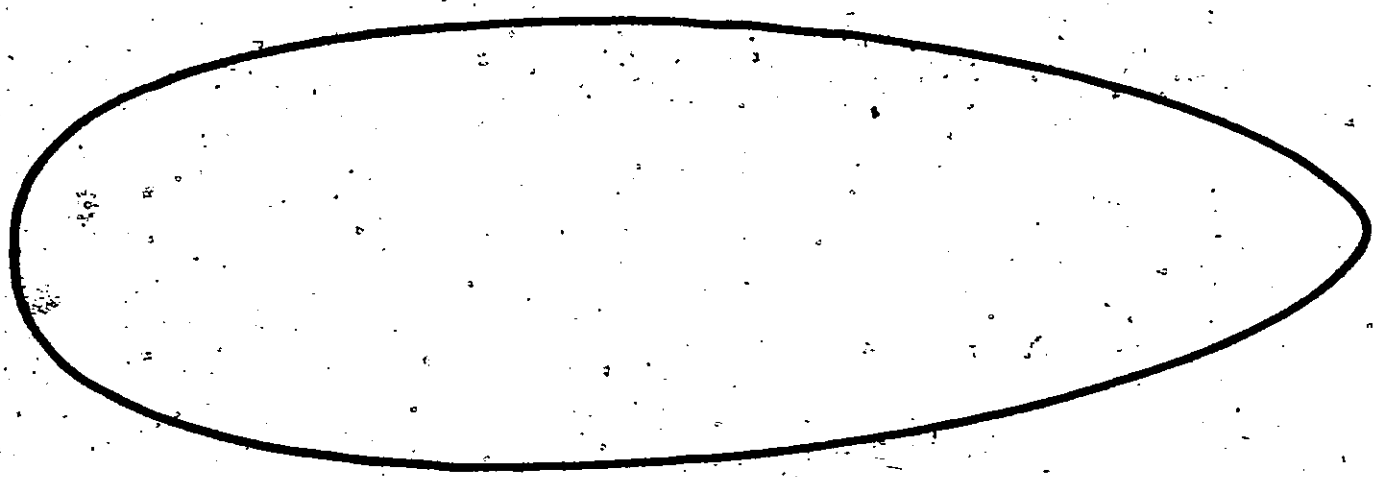


Figure 2.26: Shape of Envelope for
n = 0.4, m = 0.6, f = 3.00

Figure 2.27: Shape of Envelope for
n = 0.185, m = 0.400, f = 4.00

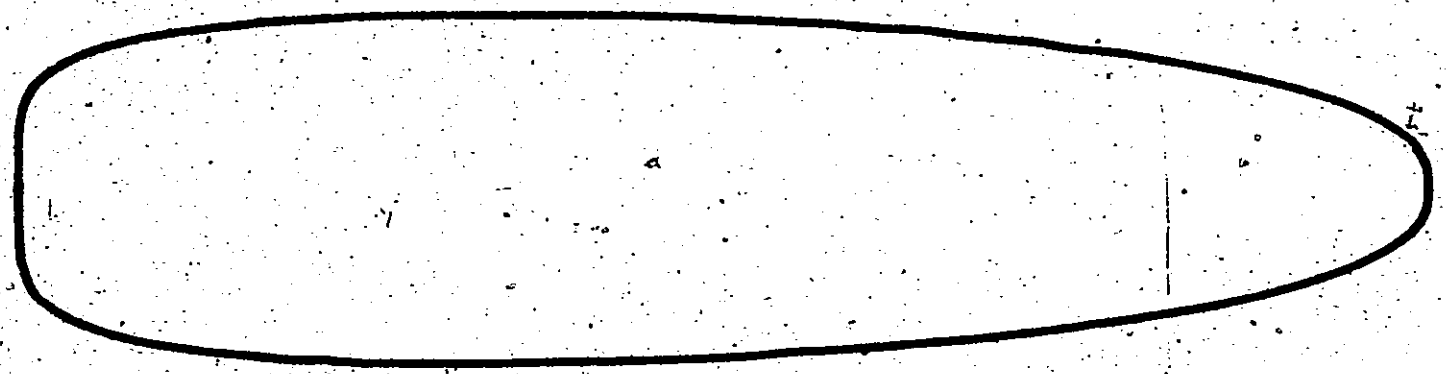


Figure 2.28: Shape of Envelope for

n = 0.200, m = 0.400, f = 4.00

Figure 2.29: Shape of Envelope for
n = 0.250, m = 0.400, f = 4.00

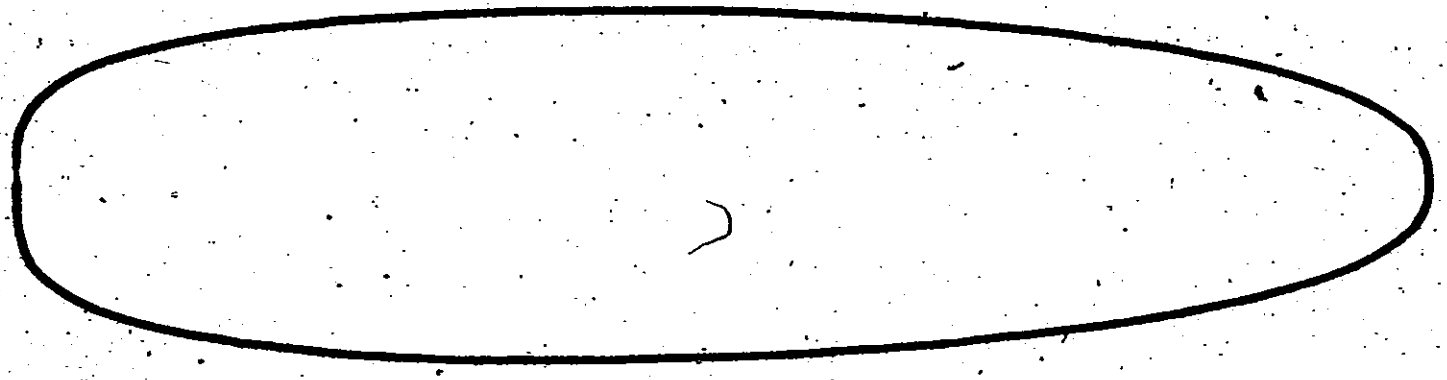


Figure 2.30: Shape of Envelope for
n = 0.275, m = 0.400, f = 4.00

Figure 2.31: Shape of Envelope for
n = 0.300, m = 0.400, r = 4.00

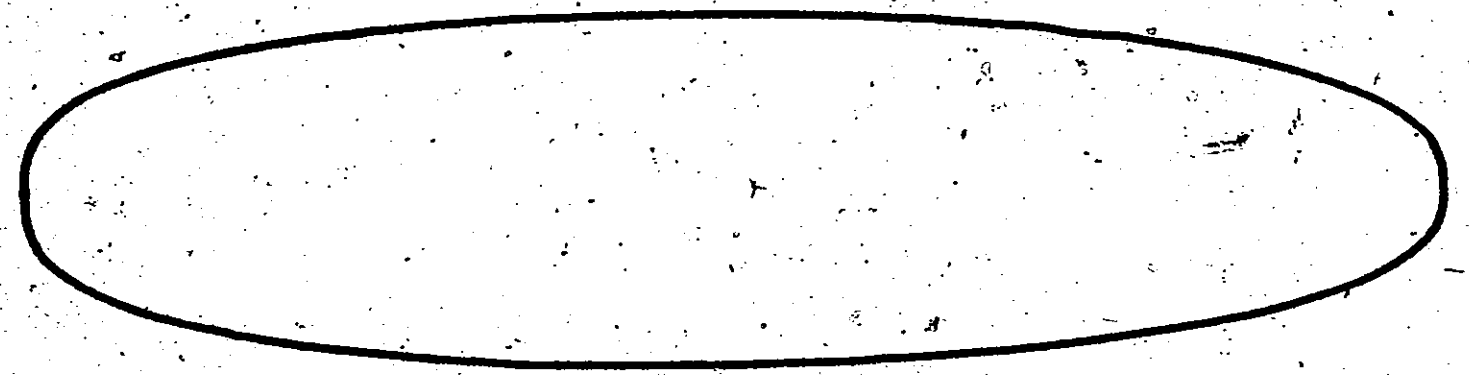


Figure 2.32: Shape of Envelope for
n = 0.350, m = 0.400, r = 4.00

Figure 2.33: Shape of Envelope for
$n = 0.375$, $m = 0.4$, $f = 4.00$

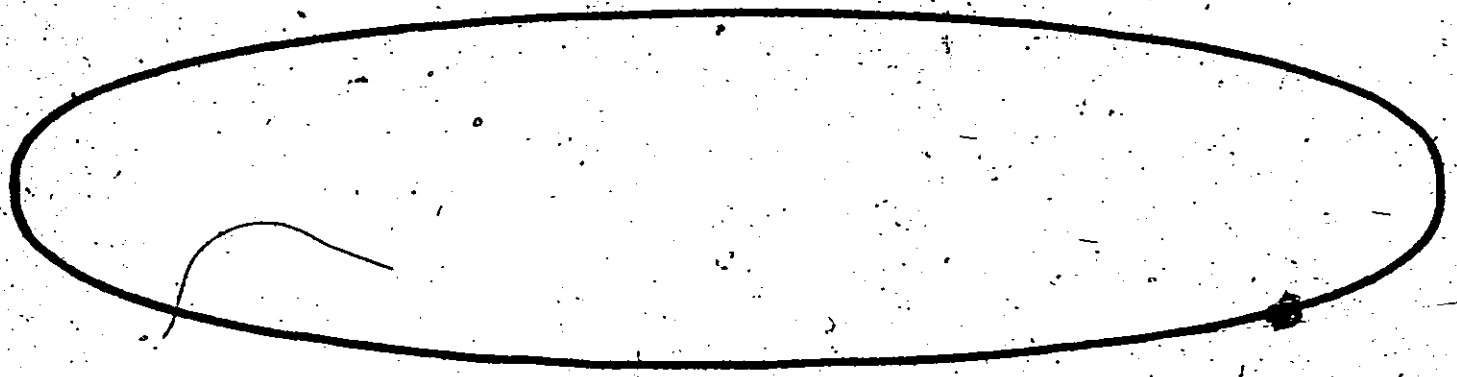


Figure 2.34: Shape of Envelope for
n = 0.400, m = 0.40, f = 4.00

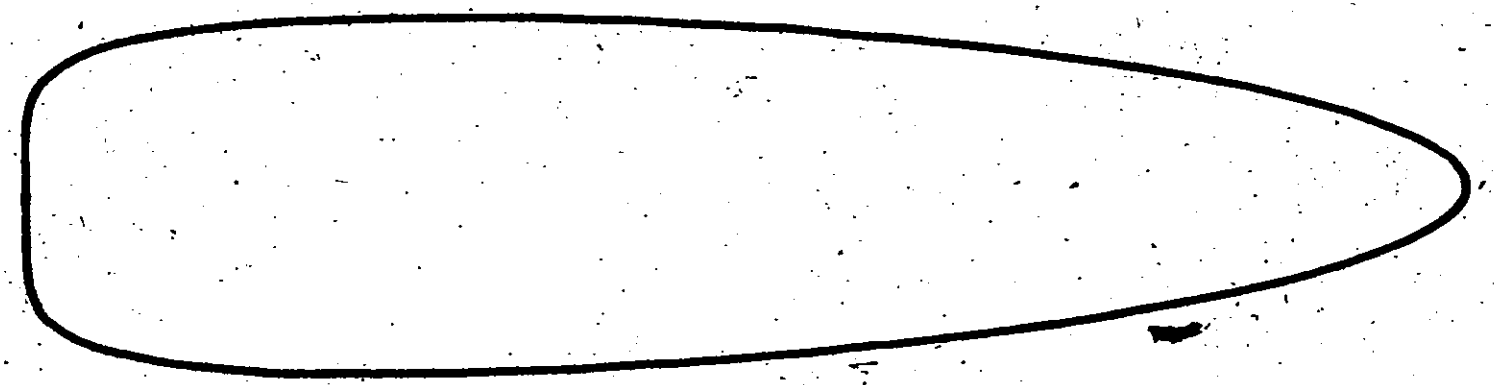


Figure 2.35: Shape of Envelope for
n = 0.185, m = 0.5, f = 4.00

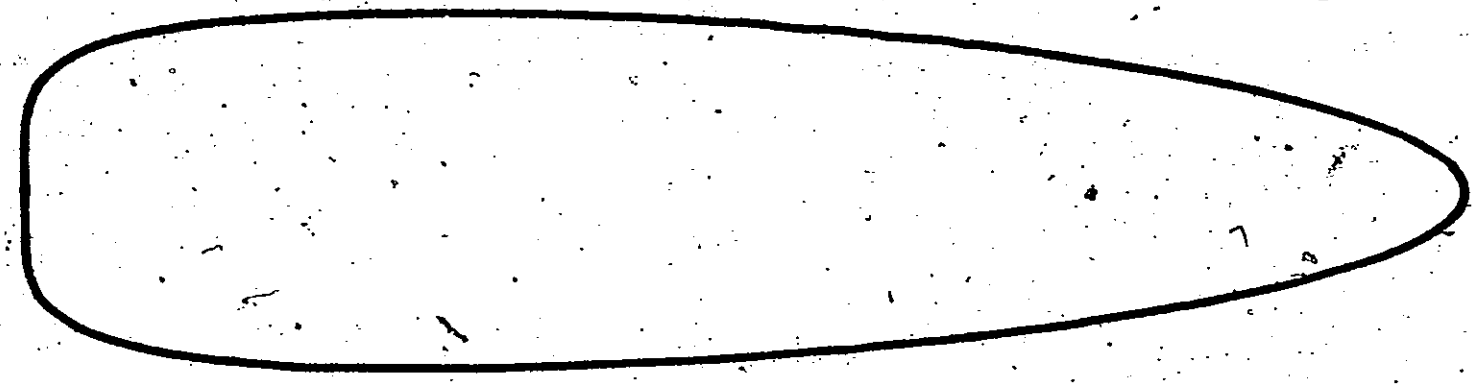


Figure 2.6: Shape of Envelope for
n = 0.200, m = 0.5, f = 4.00

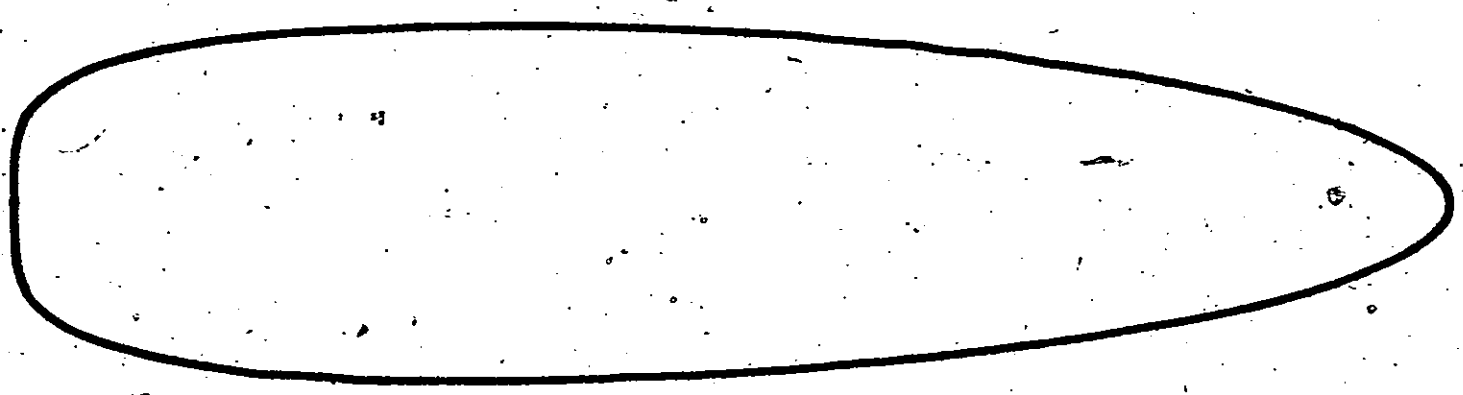


Figure 2.37: Shape of Envelope for

n = 0.25, m = 0.5, f = 4.00

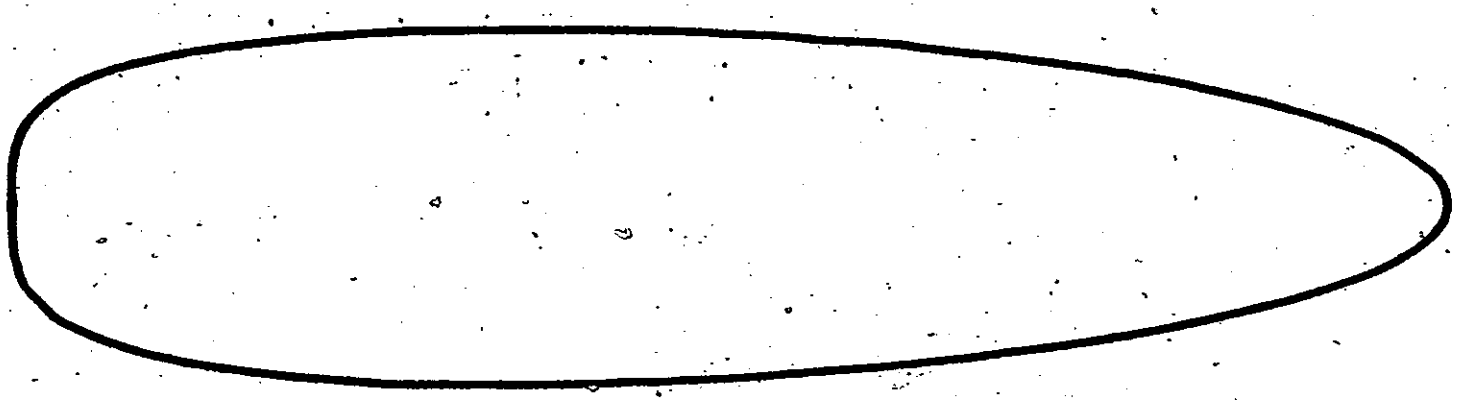


Figure 2.38: Shape of Envelope for
n = 0.275, m = 0.5, f = 4.00

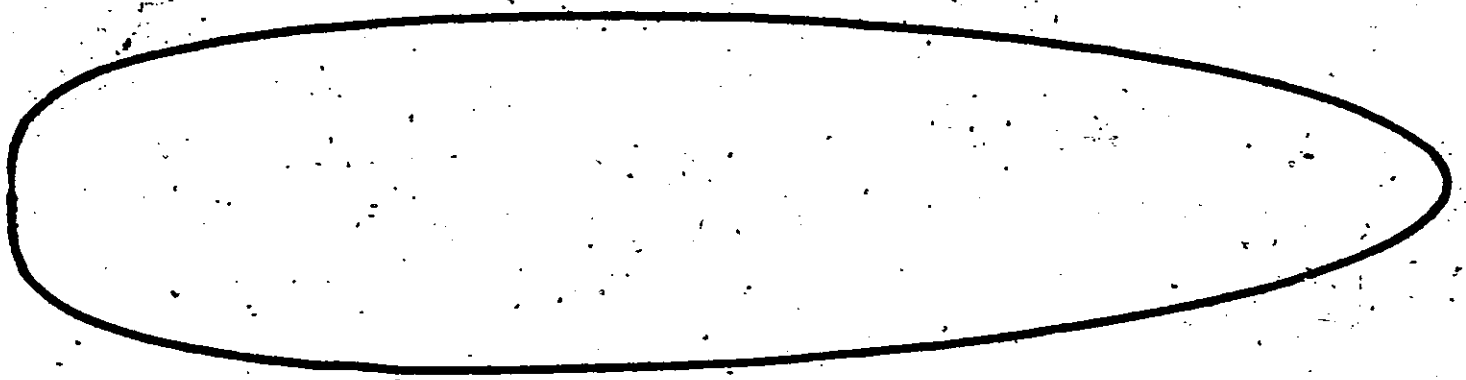


Figure 2.39: Shape of Envelope for
n = 0.300, m = 0.5, f = 4.00

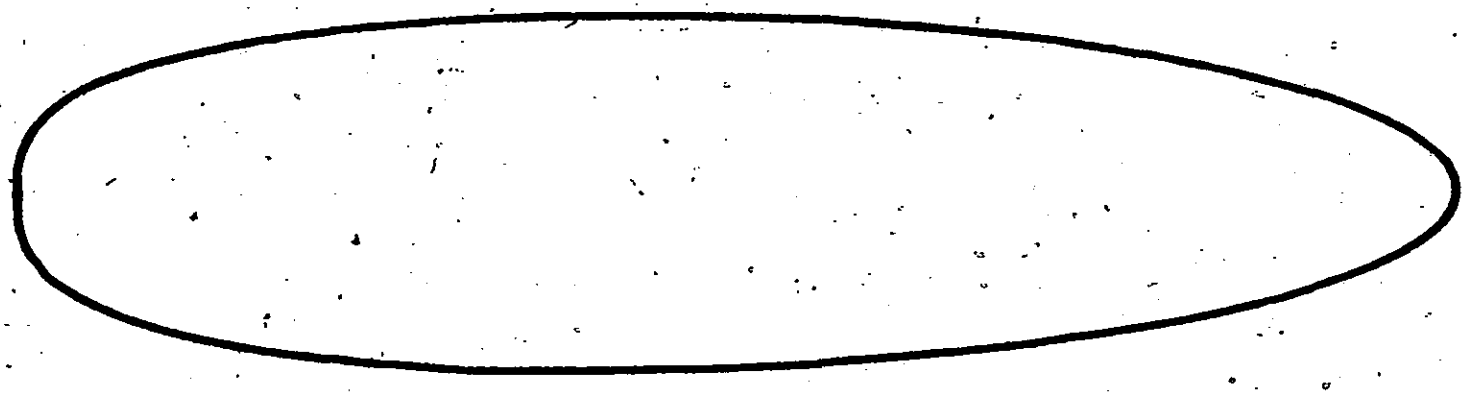


Figure 2.40: Shape of Envelope for
n = 0.350, m = 0.5, f = 4.00

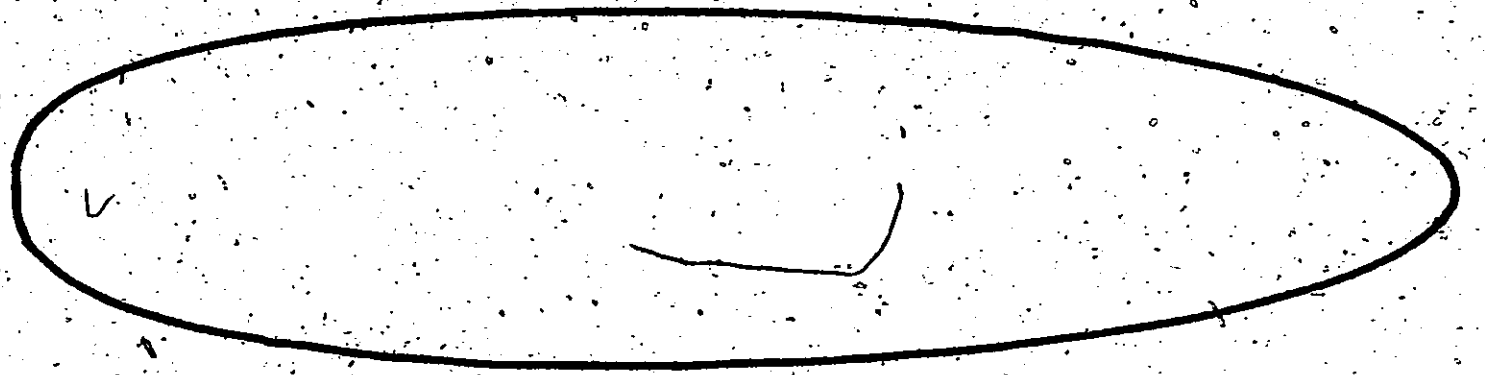


Figure 2.41: Shape of Envelope for
n = 0.375, m = 0.5, f = 4.00

Figure 2.42: Shape of Envelope for
n = 0.400, m = 0.5, f = 4.00

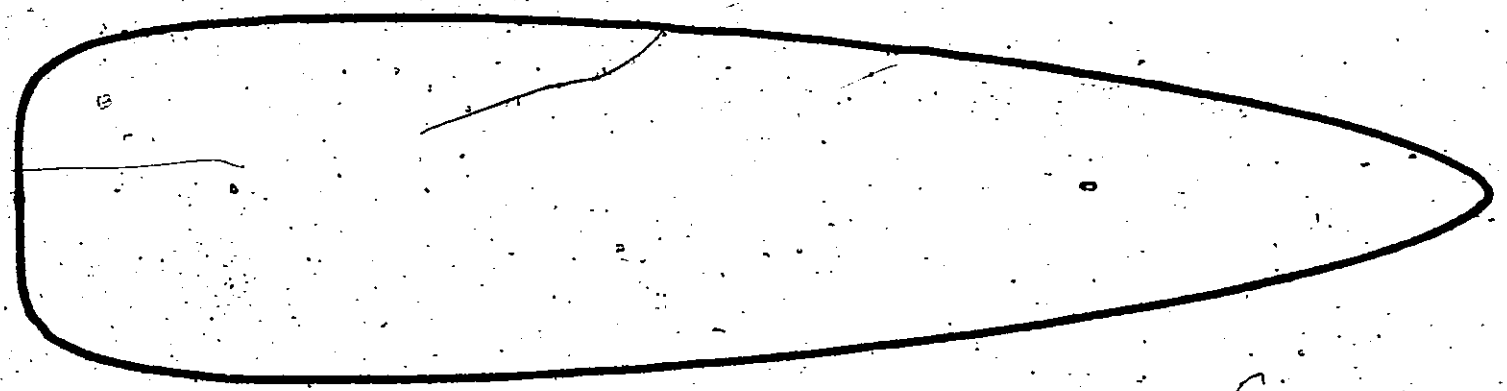


Figure 2.43: Shape of Envelope for
n = 0.185, m = 0.6, f = 4.00

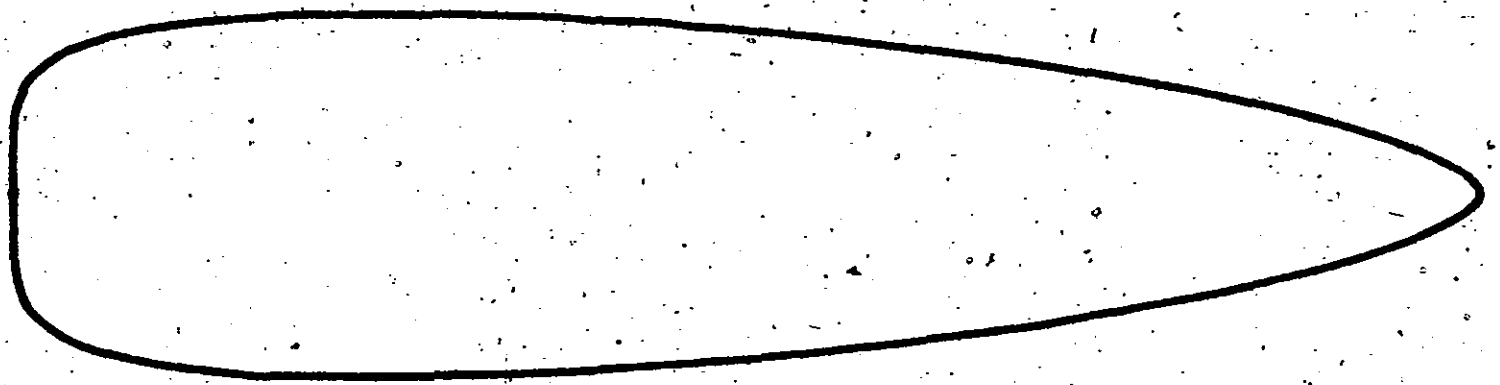


Figure 2.44: Shape of Envelope for

n = 0.200, m = 0.6, f = 4.00

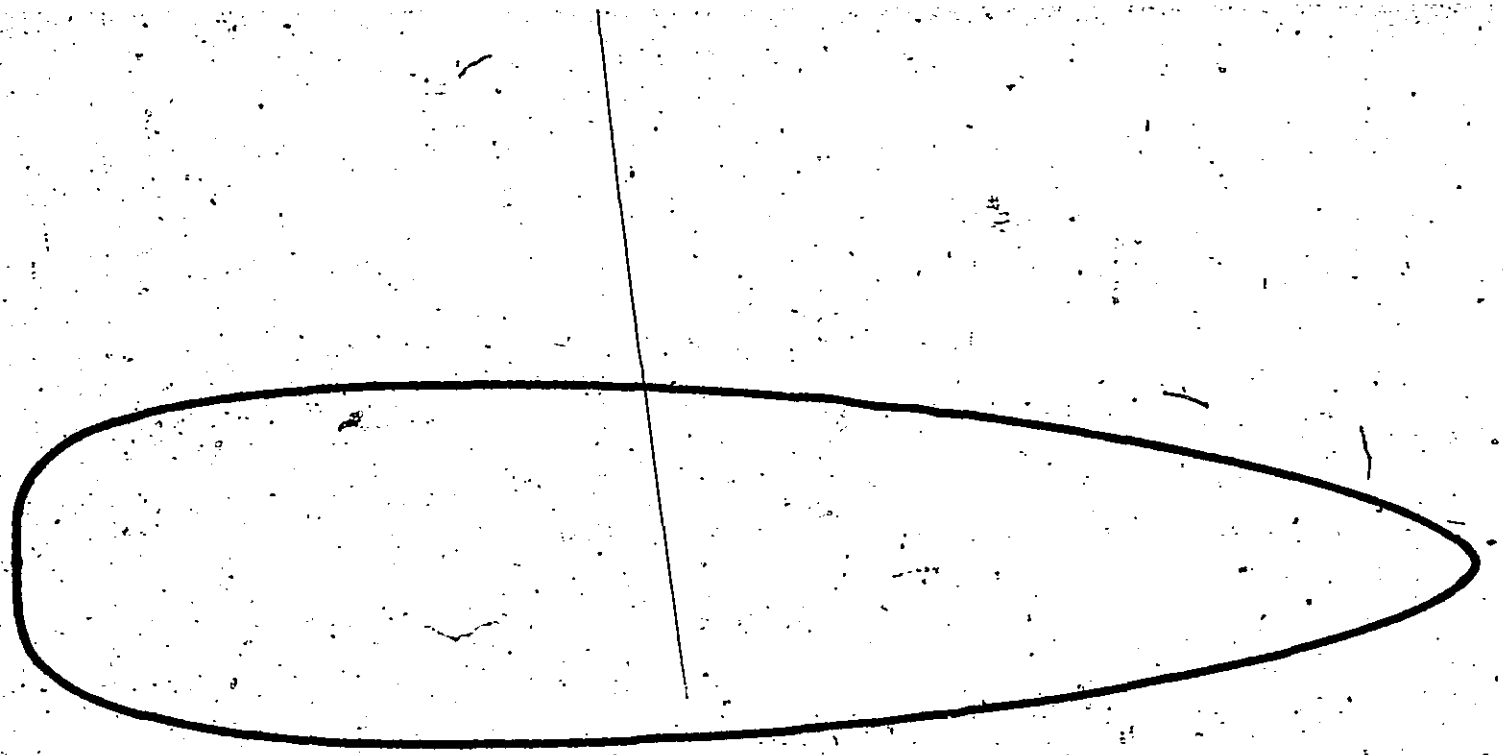


Figure 2.45: Shape of Envelope for
n = 0.275, m = 0.6, r = 4.00

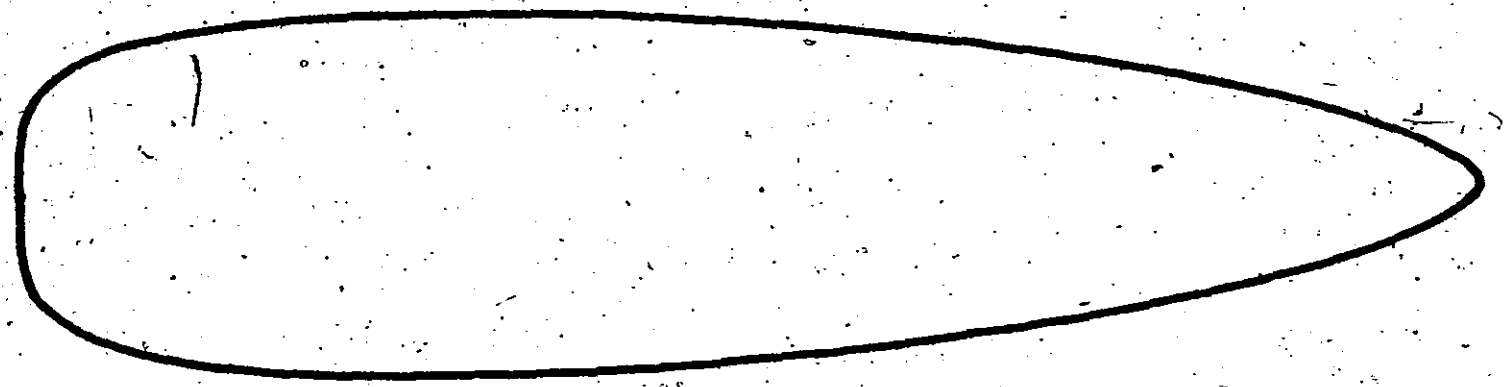


Figure 2.46: Shape of Envelope for
n = 0.250, m = 0.6, f = 4.00

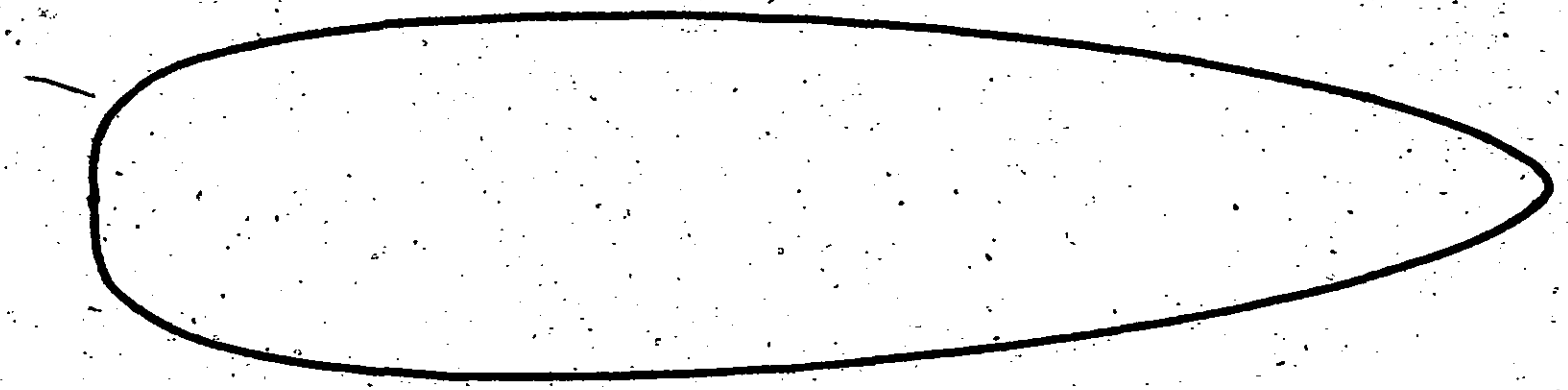


Figure 2.47: Shape of Envelope for
n = .300, m = 0.6, ζ = 4.00

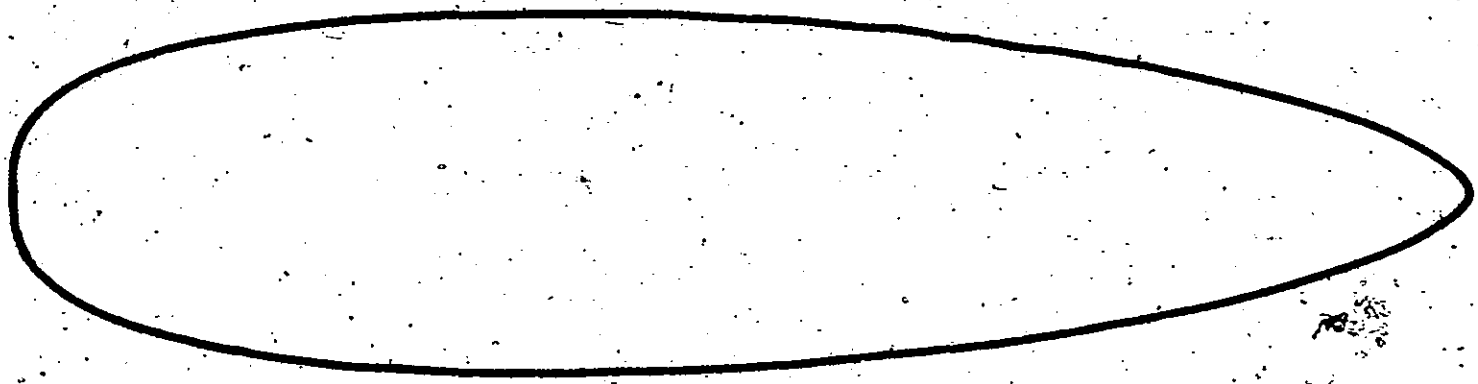


Figure 2.48: Shape of Envelope for
n = 0.350, m = 0.60, r = 4.00

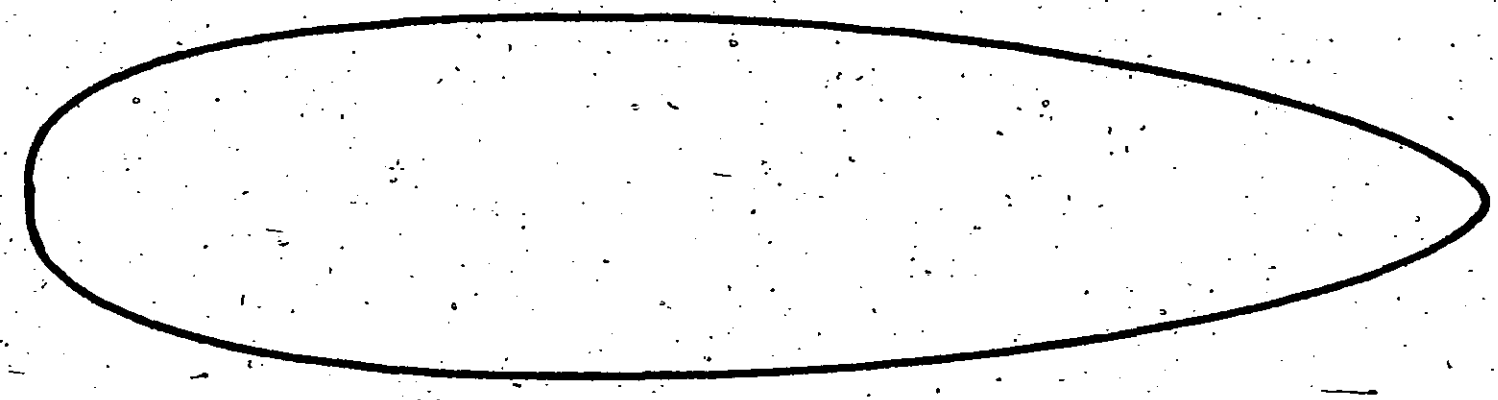


Figure 2.49: Shape of Envelope for
n = 0.375, m = 0.6, f = 4.00

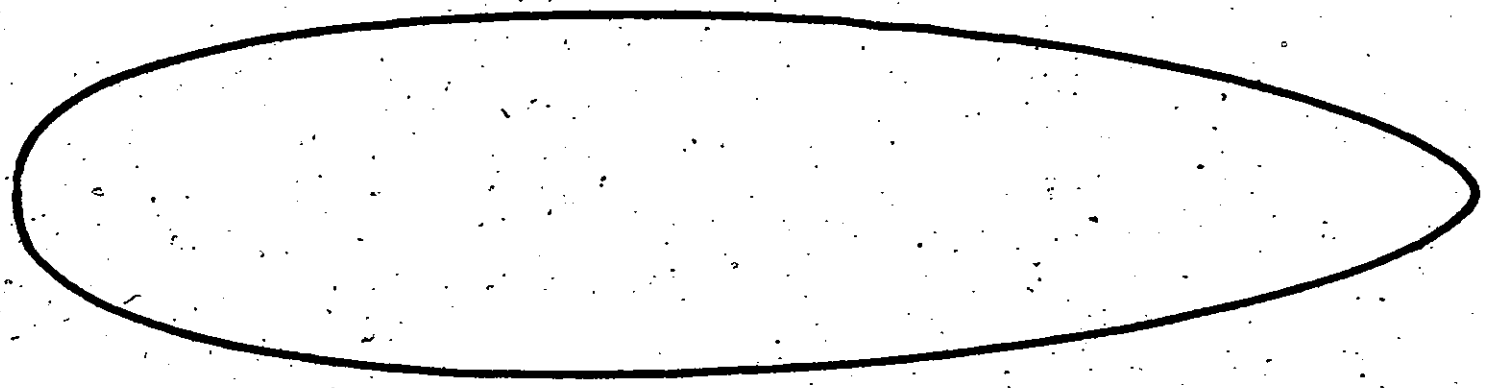


Figure 2.50: Shape of Envelope for
n = 0.4, m = 0.6, r = 4.00

TABLE 2.1: DESIGN PARAMETERS FOR VARIOUS AIRSHIP SHAPES WITH THE VELOCITY IN FEET PER SECOND = 110.000000, VOLUME IN CUBIC FEET = 91798.60 AND WITH ALL AREAS IN SQUARE FEET AND ALL DISTANCES IN FEET AND PRESSURE IS IN LBS/SQ. FT.

N	M	P	LENGTH	DRAG	ENVELOPE AREA	ENVELOPE CO.	ENVELOPE CB	HOGGING BENDING MOMENT	AERO-DYNAMIC BENDING MOMENT	MINIMUM INTERNAL PRESSURE	FIXED VERTICAL FIN AREA	FIXED HORIZONTAL CONTROL AREA	ELEVATOR AREA	RUDDER AREA	CENTRE OF TAIL SURFACE AREA LOCATION
.3	.4	2.5	100.2	1012.7	10488.0	48.3	47.2	15961.8	60957.6	4.8	493.7	383.3	144.4	72.5	77.3
.3	.5	2.5	101.8	1009.5	10483.3	47.3	45.2	16995.9	61921.8	4.7	486.1	377.3	142.2	71.4	75.8
.3	.6	2.5	103.5	1006.2	10467.1	46.4	43.6	18148.9	62946.2	4.5	478.1	371.2	139.9	70.2	74.7
.3	.7	2.5	105.2	1002.9	10441.2	45.6	42.1	19387.7	63994.0	4.4	470.3	365.1	137.6	69.1	73.7
.4	.4	2.5	101.1	1011.0	10494.0	50.5	50.5	16527.6	61490.8	4.7	489.5	379.9	143.2	71.9	80.9
.4	.5	2.5	102.3	1008.6	10490.1	49.4	48.4	17313.0	62208.6	4.6	483.8	375.6	141.5	71.1	79.2
.4	.6	2.5	103.6	1006.0	10476.0	48.4	46.6	18237.0	63022.5	4.5	477.6	370.7	139.7	70.1	77.8
.4	.7	2.5	105.0	1003.3	10453.1	47.4	45.0	19257.8	63886.5	4.4	471.1	365.7	137.8	69.2	76.6
.3	.4	3.0	113.2	875.7	11145.1	54.5	53.3	12517.2	68835.9	6.5	437.2	339.4	127.9	64.2	87.3
.3	.5	3.0	115.0	872.9	11140.1	53.4	51.1	13328.2	69924.8	6.3	430.4	334.1	125.9	63.2	85.6
.3	.6	3.0	116.9	870.1	11122.9	52.4	49.2	14232.3	71081.6	6.1	423.4	328.4	123.9	62.2	84.3
.3	.7	3.0	118.8	867.2	11095.4	51.5	47.5	15[illegible].8	72264.7	5.9	416.5	323.3	121.8	61.2	83.2
.4	.4	3.0	114.2	874.1	11151.6	57.1	57.1	12960.9	69438.0	6.4	433.4	336.5	126.8	63.7	91.4
.4	.5	3.0	115.5	872.1	11147.4	55.8	54.7	13576.8	70248.6	6.3	428.4	332.6	125.3	62.9	89.4
.4	.6	3.0	117.0	869.8	11132.4	54.6	52.6	14301.4	71167.8	6.1	422.9	328.3	123.7	62.1	87.8
.4	.7	3.0	118.6	867.5	11108.1	53.6	50.8	15101.9	72143.4	5.9	417.2	323.8	122.0	61.3	86.5
.3	.4	4.0	137.1	760.2	12266.8	66.0	64.5	8529.5	83388.8	10.6	360.9	280.2	105.6	53.0	105.7
.3	.5	4.0	139.3	757.8	12261.3	64.7	61.9	9082.1	84707.8	10.2	355.3	275.8	103.9	52.2	103.7
.3	.6	4.0	141.6	755.3	12242.4	63.5	59.6	9698.2	86109.2	9.9	349.5	271.3	102.2	51.3	102.1
.3	.7	4.0	143.9	752.8	12212.1	62.4	57.6	10360.2	87542.5	9.6	343.8	266.9	100.6	50.5	100.8
.4	.4	4.0	138.3	758.9	12273.9	69.1	69.1	8831.8	84118.2	10.4	357.8	277.7	104.7	52.6	110.7
.4	.5	4.0	139.9	757.1	12269.3	67.5	66.3	9251.5	85100.1	10.1	353.7	274.5	103.4	51.9	108.3
.4	.6	4.0	141.7	755.1	12252.8	66.1	63.8	9745.3	86213.6	9.9	349.1	271.0	102.1	51.3	106.4
.4	.7	4.0	143.7	753.1	12226.0	64.9	61.6	10290.8	87395.5	9.6	344.4	267.3	100.7	50.6	104.7

Various empirical equations have been developed over the years. Goodyear[23] for non-rigid airships suggests

$$DRAG = \frac{1}{2}\rho V\left[(.289)\left[\frac{V_K \forall^{1/3}}{\gamma}\right]^{-.154} \forall^{2/3} + 19.7 + 0.0000003\,\forall - \frac{50}{(0.00001\,\forall)}\right] \quad (2.6)$$

where ρ = density of air in slugs/ft^3

V = velocity in ft/sec.

$\forall$ = volume of the airship in ft^3

V_K = airship velocity in KNOTS

γ = kinematic viscosity of air in ft^2/sec

General Wills [28] has developed

$$DRAG = \frac{20.0^{.233}}{10^6(\delta_{SL})^{.617}} V^{1.85} L^{.617}(3.6 + \delta_{SL}\sigma) + .0025\,\sigma V^2 \quad (2.7)$$

where $\sigma = \rho/0.002377$

δ_{SL} = unit lift of the gas at sea level $\left(\frac{lbs.}{ft^3}\right)$

L = net static lift (lbs.)

Kleiner[4] has developed, based on developments by Hoerner[29],

$$DRAG = 0.5\,\rho\, V^{1.86} C_f\left(1 + \frac{1}{2f}\right)\left(4 f^{1/3} + 6\left(\frac{1}{f}\right)^{1.2} + 24\left(\frac{1}{f}\right)^{2.7}\right)\frac{\forall^{2/3}}{0.46} \quad (2.8)$$

where $C_f = \dfrac{0.074}{(VL\rho/\gamma)^{1/5}}$,

A comparison of these equations, which only predict the drag due to level flight, is shown in Figure 2.5i. It can be seem that (2.8) provides the most conservative estimate of the drag. In view of the fact that many previous airships have been underpowered (2.8) would seem to be the expression to be used. It must also be remembered that flight at any angle of attack also produces an extra drag. This need not be of concern at this stage of the design and an appropriate expression will be developed in Chapter 3.

2.3.2 Surface Area

The provision of a value for the surface area of the envelope is difficult. No exact expressions are available. General Mills[28] gives

$$A \approx \frac{\pi(n+m)^{(n+m)}}{f\, n^n\, m^m} \cdot \frac{\Gamma(n+1)\,\Gamma(m+1)}{\Gamma(n+m+2)} \cdot L^2 \qquad (2.9)$$

The area as given by (2.9) is only an approximate value and is suitable only for use over a particular range of f values. If f = 1 and (2.9) is used to find the area of a sphere, the value that results is about 20% lower than the actual value. This error decreases rapidly as the value of f increases.

2.3.3 Center of Bouyancy

The location of the center of bouyancy is of major importance to the airship designer. It is about this point

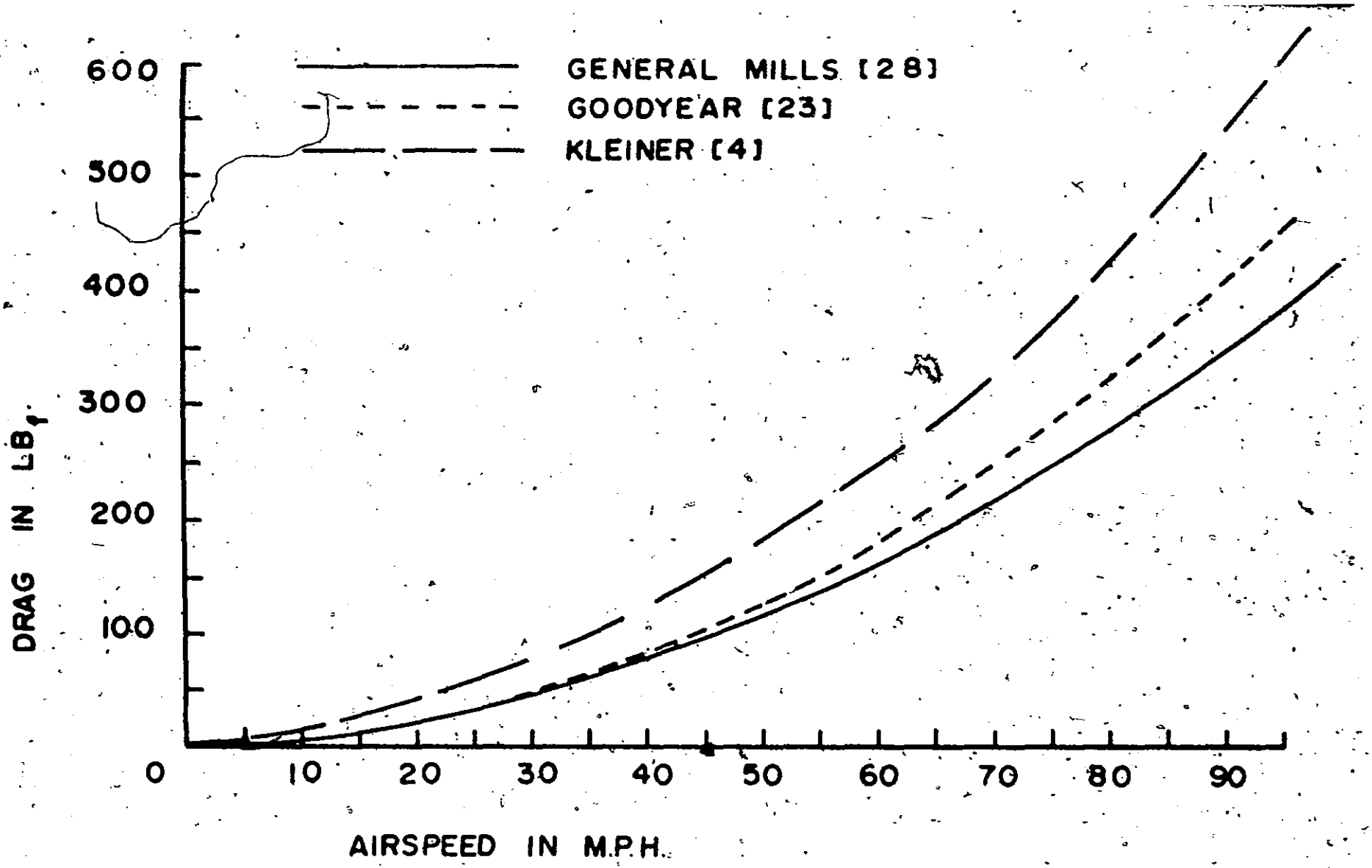


Figure 2.51: A Comparison of three Drag Equations

that the designer must balance all the other elements of the airship. An exact definition of this position is presented in Chapter 3. A convenient expression given for the position of the center of bouvance, CB_x, along the longitudinal axis by General Mills[28] is:

$$CB_x = \frac{2n + 1}{2n + 2m + 2} L. \qquad (2.10)$$

2.3.4 Center of Gravity of the Envelope

This position again is of great importance to the designer in trying to balance all the elements of the airship about the center of bouyancy. General Mills[28] gives the location of the center of gravity of the envelope, CGE_x, along the longitudinal axis as:

$$CGE_x = \frac{n + 1}{n + m + 2} L. \qquad (2.10)$$

2.3.5 Control Surfaces; Location and Size

The correct prediction of the control surface area and location is also of importance. Airships designed to date all have control surface designs based on empirical expressions. This may seem rather a crude method of design. However, as long as an airship uses no modern aerodynamic refinements such as boundary layer control or blown surfaces, there seems to be, fortunately, a large margin of control surface size within which the stability is satisfactory, for nearly all

airships built have been found to possess satisfactory stability[33]. In this case the major function of the designer is to use all possible data to design surfaces of minimum size and hence minimum weight. Several expressions have been suggested. Munk[33] suggests that A_{cs}, the control surface area, can be found from

$$A_{cs} = C_1 C_2 C_3 S_{max.} \qquad (2.12$$

where C_1, C_2, and C_3 are factors determined by secondary dimensions and $S_{max.}$ is the maximum cross-sectional area of the airship.

Burgess[13] gives

$$A_{cs} = 0.13 \nabla^{2/3} \qquad (2.12$$

and Blakemore[12] has developed an empirical method based on data from previously satisfactory designs. Figures 2.52, 2.53, and 2.54 are used to determine the correct location and size. Figure 2.52 is a plot of $\sqrt[3]{A_H L}$ and $\sqrt[3]{A_V L}$, versus $\sqrt[3]{\nabla}$. Figure 2.53 is a plot of $\sqrt[3]{A_E L}$ and $\sqrt[3]{A_R L}$ versus $\sqrt[3]{\nabla}$. Figure 2.54 is a plot of $\sqrt[3]{A \cdot C_{\nabla}}$ versus $\sqrt[3]{\nabla}$. The factors involved are:

A_H = fixed horizontal surface area

A_V = fixed vertical surface area

A_E = elevator area

A_R = rudder area

∇ = total airship volume

L = airship length

C = distance between the center of bouyancy and the

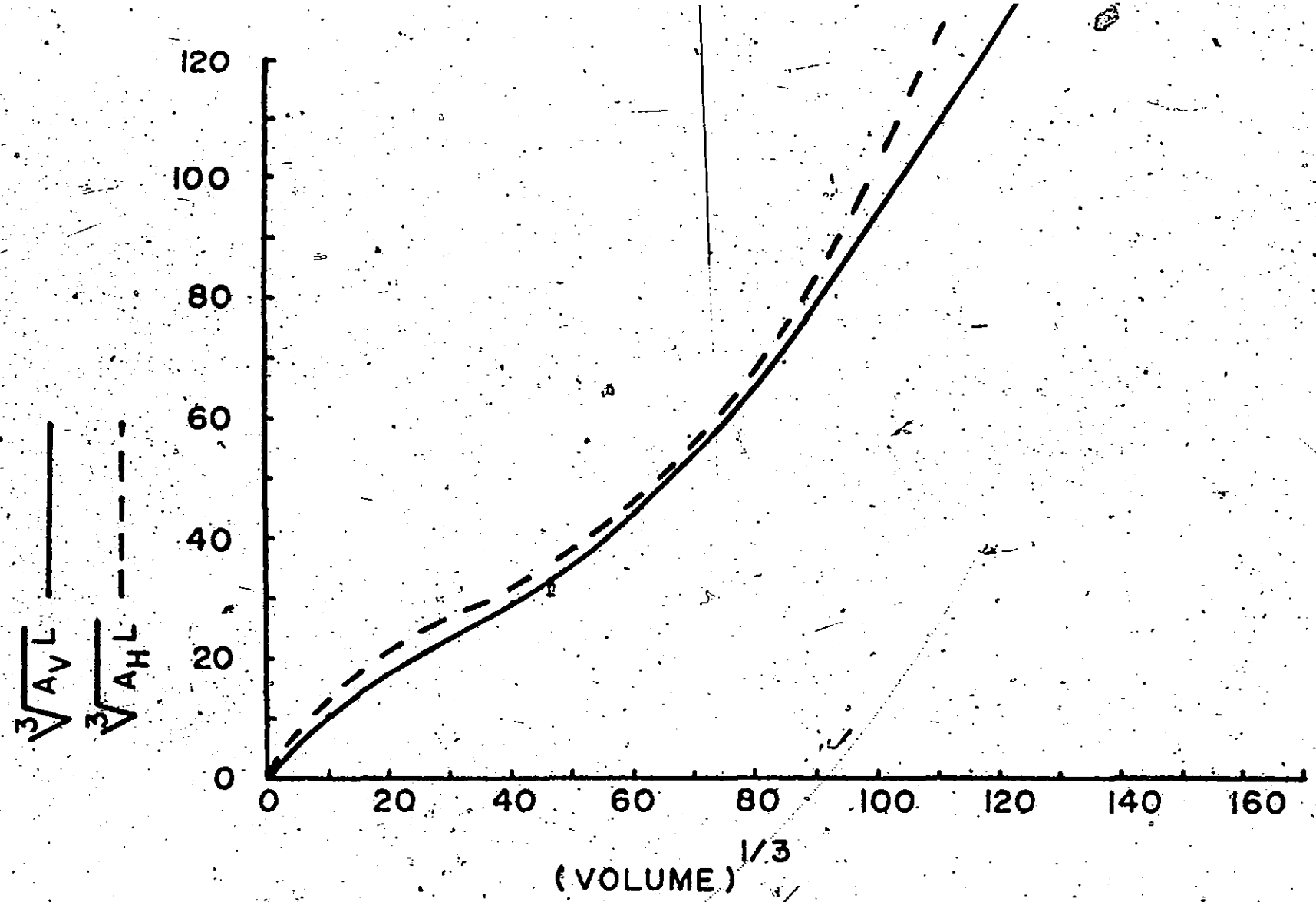


Figure 2.52: Control Surface Chart $\sqrt[3]{A_H L}$ and $\sqrt[3]{A_V L}$ vs. $\sqrt[3]{V}$

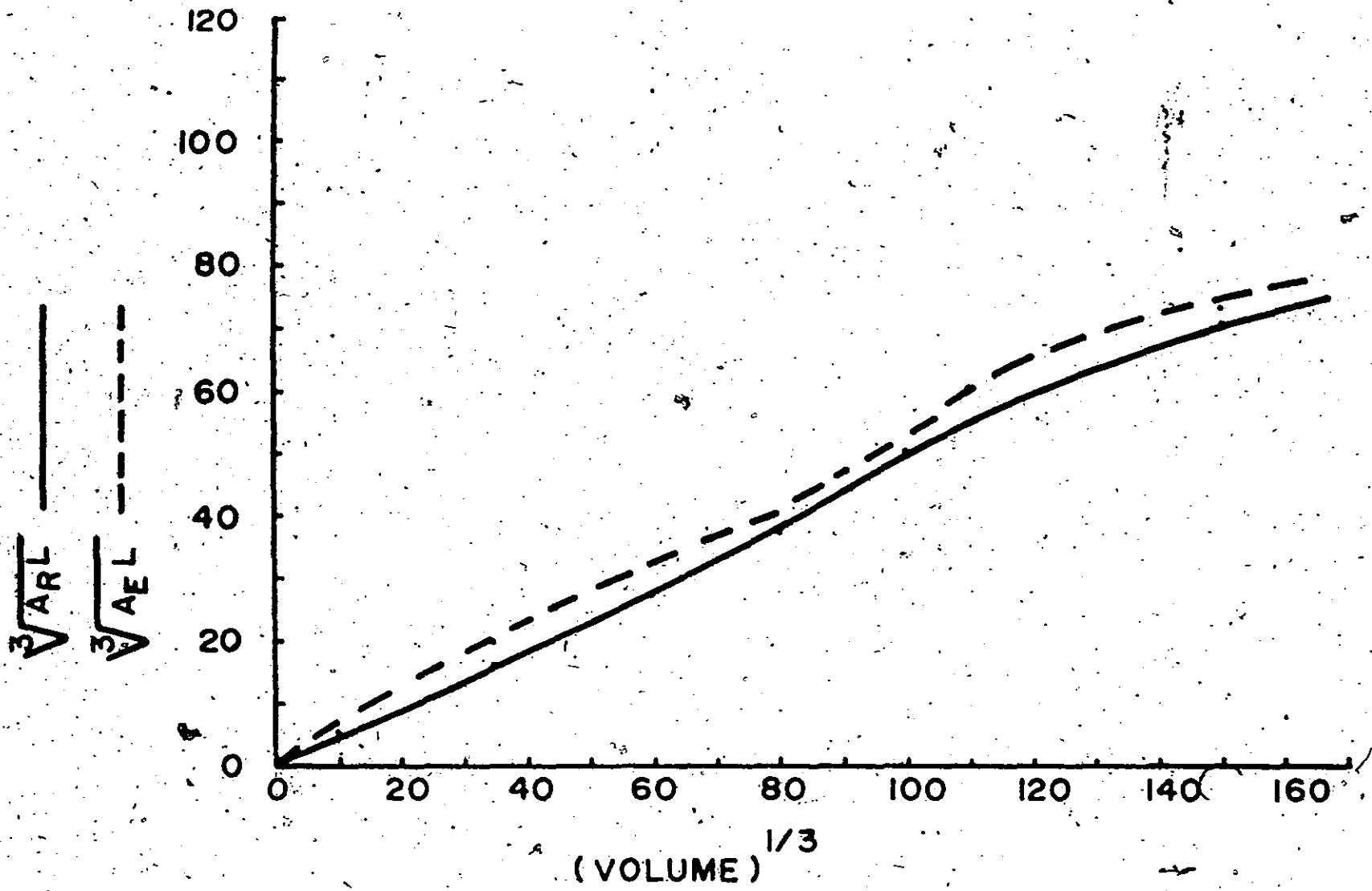


Figure 2.53: Control Surface Chart $\sqrt[3]{A_E L}$ and $\sqrt[3]{A_R L}$ vs. $\sqrt[3]{V}$

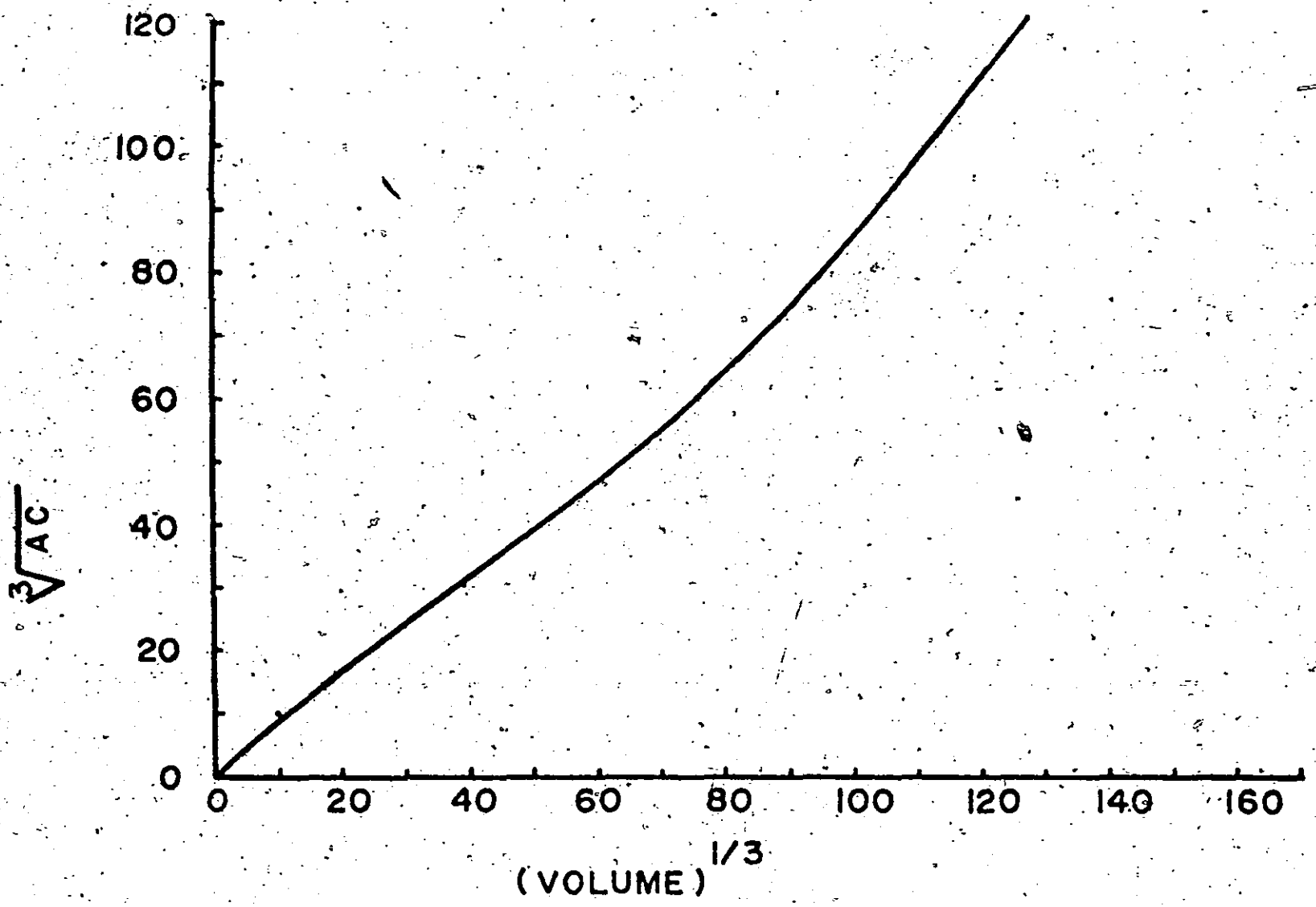


Figure 2.54: Control Surface Chart $\sqrt[3]{A.C}$ vs. $\sqrt[3]{V}$

center of area of the total surfaces

and A = total control surface area

The procedure is as follows:

1) calculate $\sqrt[3]{\forall}$

2) from the figures determine values for

$\sqrt[3]{A_H L} = e$

$\sqrt[3]{A_V L} = f$

$\sqrt[3]{A_E L} = g$

$\sqrt[3]{A_R L} = h$

$\sqrt[3]{A_C} = j$

3) then

$$A_H = e^3/L \qquad (2.13)$$

$$A_V = f^3/L \qquad (2.14)$$

$$A_E = g^3/L \qquad (2.15)$$

$$A_R = h^3/L \qquad (2.16)$$

$$C = j^3/A \qquad (2.17)$$

Satisfactory results have been achieved by this method.

2.3.6 Static Bending Moment

In airships the disposable load should be distributed such that the static bending moment is minimized. However, the airship still has a static bending moment. This bending moment is called the "Hogging Moment". This moment is due to the gas head. If h is the gas head measured upward, then a pressure due to gas head is produced. This is given by

kh where k is the unit lift of the contained gas. This pressure produces a constant longitudinal force. The pressure, due to gas head, increases toward the top of the airship and therefore the resultant of the longitudinal force acts above the airship envelope neutral axis. Consequently, a Hogging bending moment is produced, the maximum value of which is given, by Klikoff[2], for a fully inflated airship as

$$BM_H = k\pi r^3 h/4 \qquad (2.18)$$

where k = unit lift of the contained gas

r = the maximum radius of the airship

h = the head of the gas

2.3.7 Aerodynamic Bending Moment

Naatz[25] has developed an empirical expression for the maximum aerodynamic bending moment.

$$BM_A = 0.01 \rho_0 V^2 \forall^{2/3} L \qquad (2.19)$$

2.3.8 Internal Pressure

Assuming that the hogging moment as given by (2.18) resists all static bending moments, the internal pressure of the airship may then be used to resist the aerodynamic bending moment. Klikoff[2] gives:

$$P_{INT} = \frac{0.02 \rho V^2 \forall^{2/3} L}{\pi r^3} \qquad (2.20)$$

where all the parameters are as previously defined. The assumption that the hogging bending moment resists the static bending moments is reasonable for design purposes. Keeping in mind the need to achieve an airship center of gravity location, in the static condition, directly below the center of bouyancy the designer can arrange the loading to achieve a minimum total static bending moment. A programme that calculates the static loading bending moment is presented in a later section of this chapter.

2.3.9 Programme and Results

A programme to calculate the foregoing factors has been developed. Eight shapes have been examined for three different fineness ratios. The results of this investigation are presented in Table 2.1. The programme itself is to be found in APPENDIX B and can easily be modified to give the output for any shapes desired. The output can be utilized in combination with further criteria presented in later sections of this chapter, to determine the final design.

2.4 Pressure Distribution Analysis

2.4.1 Introduction

The pressure distribution over the airship envelope is one of the major considerations in determining the

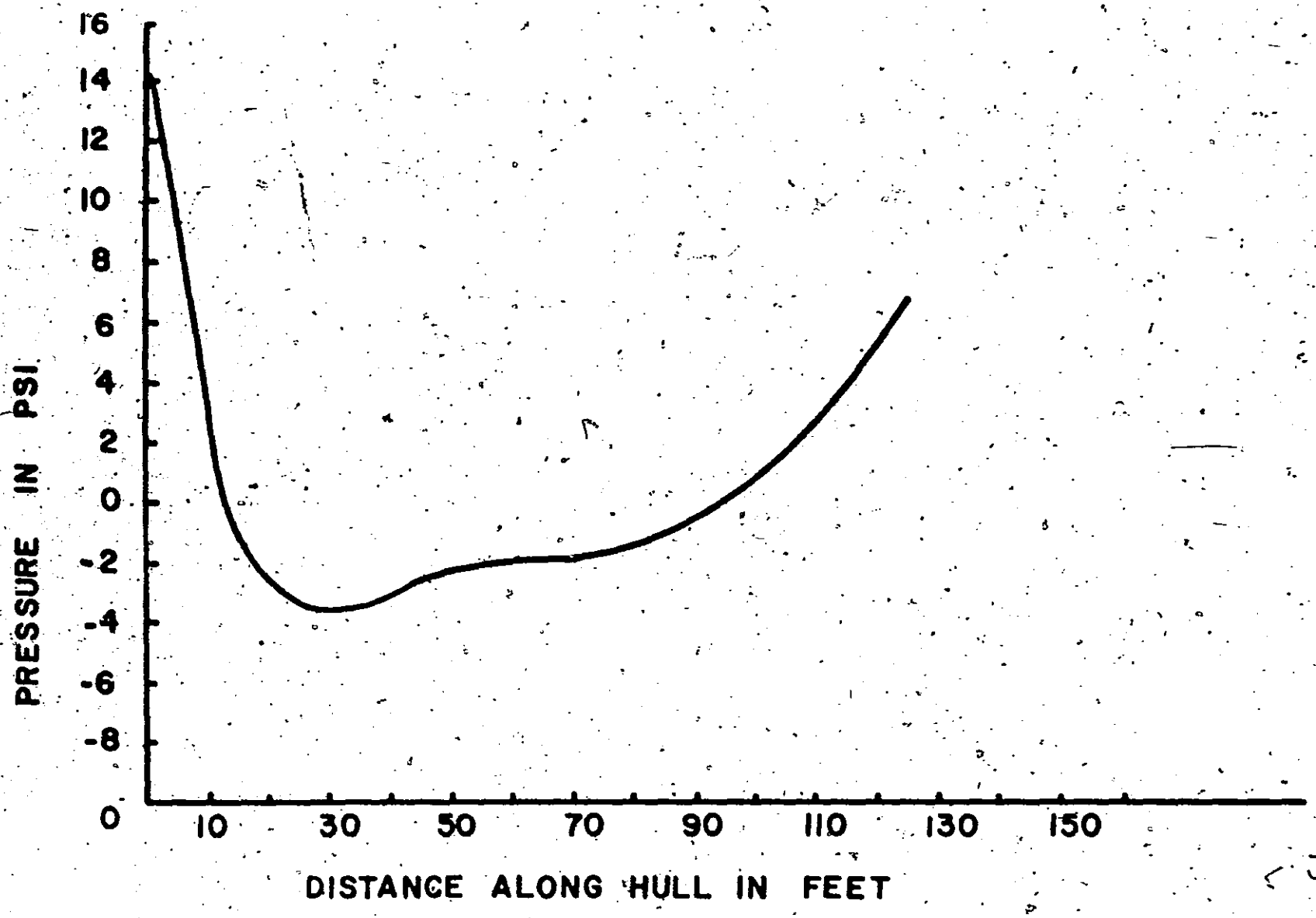


Figure 2.55: Pressure Distribution for an Airship in Level Flight
m = 0.6, n = 0.4, f = 3.00, V = 110 ft/sec.

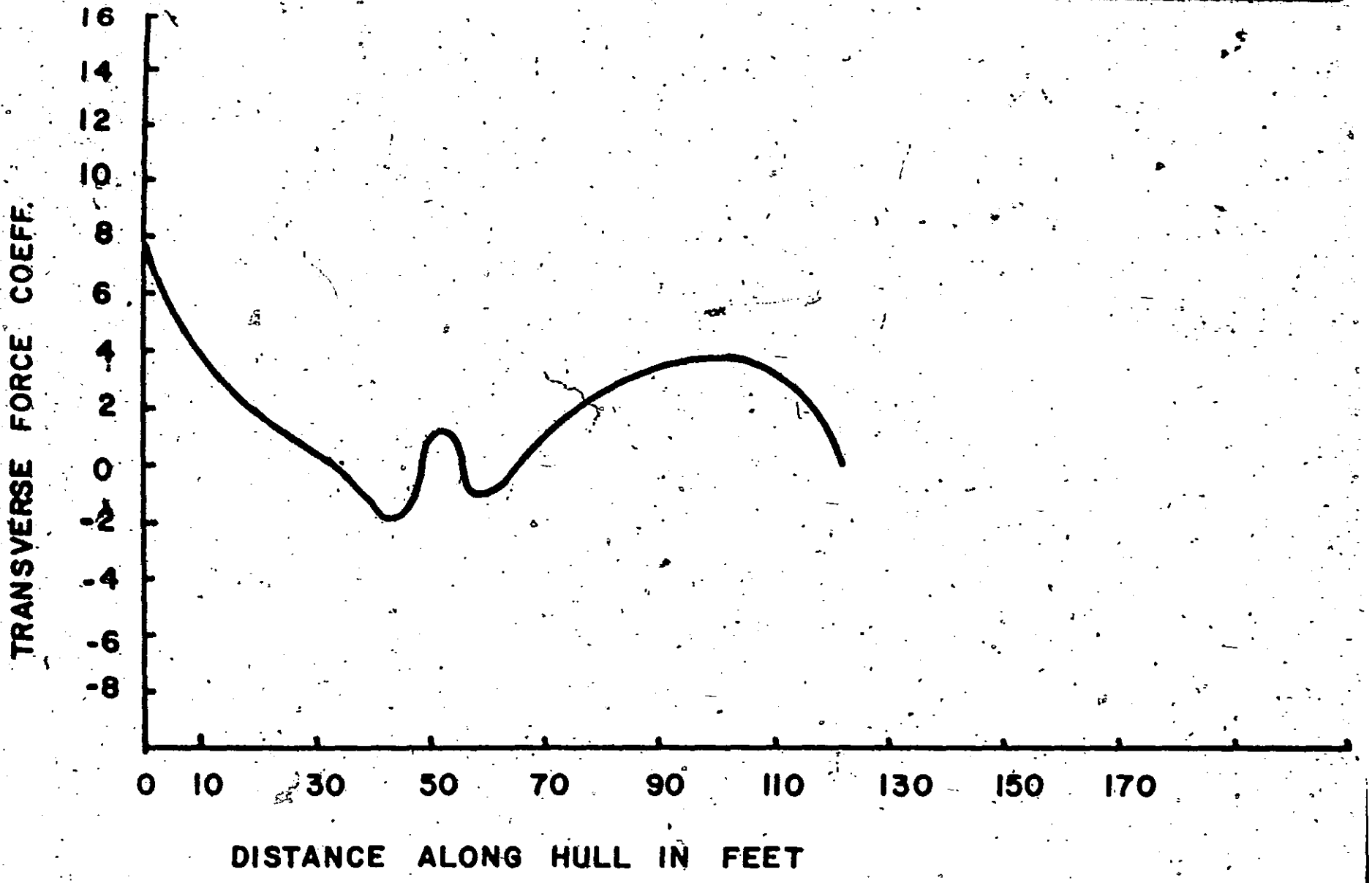


Figure 2.56: Pressure Distribution for an Airship in Non-Level Flight

m = 0.6, n = 0.4, f = 3.00, V = 110 ft/sec, α = 5.00

suitability of the shape of the hull. The information supplied by the pressure distribution is of the subjective type. It does not provide any hard data beyond the actual shape of the pressure distribution. However, from the shape of the distribution, an approximate separation point may be determined. Thus, the suitability of any shape may be determined by the comparative distance aft of the bow of the separation point. The further aft the separation point is, the more stable the airship is likely to be. The pressure distribution as calculated by Von Karman[1] is used as the basis of a computer programme which calculates the pressure distribution of any airship hull shape at any velocity and at angles of attack up to ± 10.0 degrees. The programme is listed in Appendix C and examples of the results to be obtained are illustrated by Figure 2.55 and 2.56.

2.4.2 Theodor Von Karman's Pressure Distribution on Airship Hulls

In order to understand the workings of the programme developed, a condensed version of the theory of Von Karman will be presented. Any modifications made will also be shown.

The following simplifications were made by Von Karman:

1) cabins, fins, and rudders were not considered
2) all cross-sections were represented by circular cross-sections

Two cases were calculated:

1) flow parallel to the longitudinal axis

2) flow at an angle to the longitudinal axis

Case #2 follows directly from Case #1

(a) Case #1

The flow was assumed to be produced by superposing a flow arising from a system of line sources and sinks, of differing productiveness, positioned along the longitudinal axis. The flow over the front part of the hull must be separated from that over the rear of the hull. Von Karman developed his theory for airships with long constant radius center sections and used a constant distance between the sources, or sinks, on both the bow and the stern sections. As modern airships are unlikely to have the former feature it is necessary to divide the airship hull into bow and stern sections at the point of maximum diameter and due to the difference in length between the bow and stern sections, different separation values must be used in each half.

Introducing the cylindrical co-ordinate system to be used:

x = the longitudinal axis of symmetry

r = the perpendicular distance from the x axis

ϕ = the angle of orientation of the meridian plane, as calculated from the vertical section of the body of revolution

The velocity components in these directions are:

$$U_x = \frac{\partial \phi}{\partial x}$$

$$U_r = \frac{\partial \phi}{\partial r}$$

$$U_\phi = 0$$

where ϕ is the potential function.

Using the stream function, ψ, the velocity components now read

$$U_x = \frac{1}{r}\frac{\partial \psi}{\partial r}$$

$$U_r = -\frac{1}{r}\frac{\partial \psi}{\partial x}$$

$$U_\phi = 0$$

Replacing the cylindrical co-ordinate system by a spatial polar co-ordinate system (Figure 2.57) where

ρ = the length of the radius vector

θ = the angle between the radius vector and the axis of symmetry

ϕ = the potential function

The velocity components, in the direction of the radius vector and perpendicular to it, are

$$U_\rho = \frac{\partial \phi}{\partial \rho} = \frac{1}{\rho^2 \sin\theta}\frac{\partial \psi}{\partial \theta}$$

$$U_\theta = \frac{1}{\rho}\frac{\partial \phi}{\partial \theta} = -\frac{1}{\rho \sin\theta}\frac{\partial \psi}{\partial \rho}$$

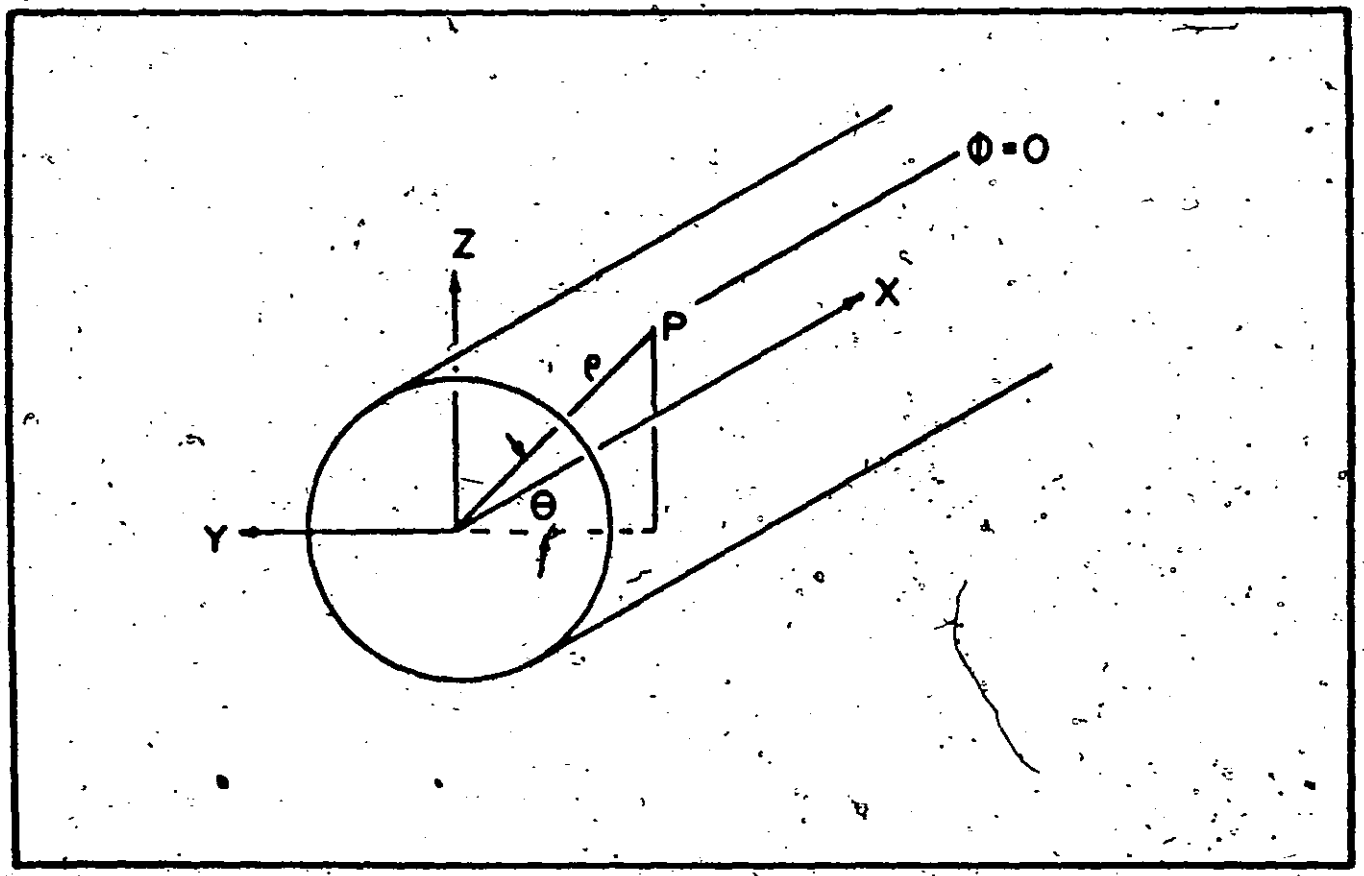


Figure 2.57: Co-ordinate Systems Used in the Analysis

The potential and stream functions, for a simple source of strength Q, read

$$\phi = -\frac{Q}{4\pi\rho}$$

$$\psi = -\frac{Q}{4\pi}(1 + \cos\theta)$$

For the remainder of the derivation:

$$Q = \sigma a$$

where σ = source strength per unit length

a = length of the source

The contribution of any element $d\xi$ to the stream function at a point P is

$$d\psi = -\frac{\sigma}{4\pi}(1 + \cos\theta)\, d\xi$$

giving

$$\psi = -\frac{\sigma}{4\pi}\int_0^a (1 + \cos\theta)\, d\xi$$

Refering to Figure 2.58

$$d\xi \cos\theta = -d\rho$$

then

$$\psi = -\frac{\sigma}{4\pi}\int_0^a (d\epsilon - d\rho)$$

Defining ρ' and ρ'' as the distance of point P from the left and right end of the line source.

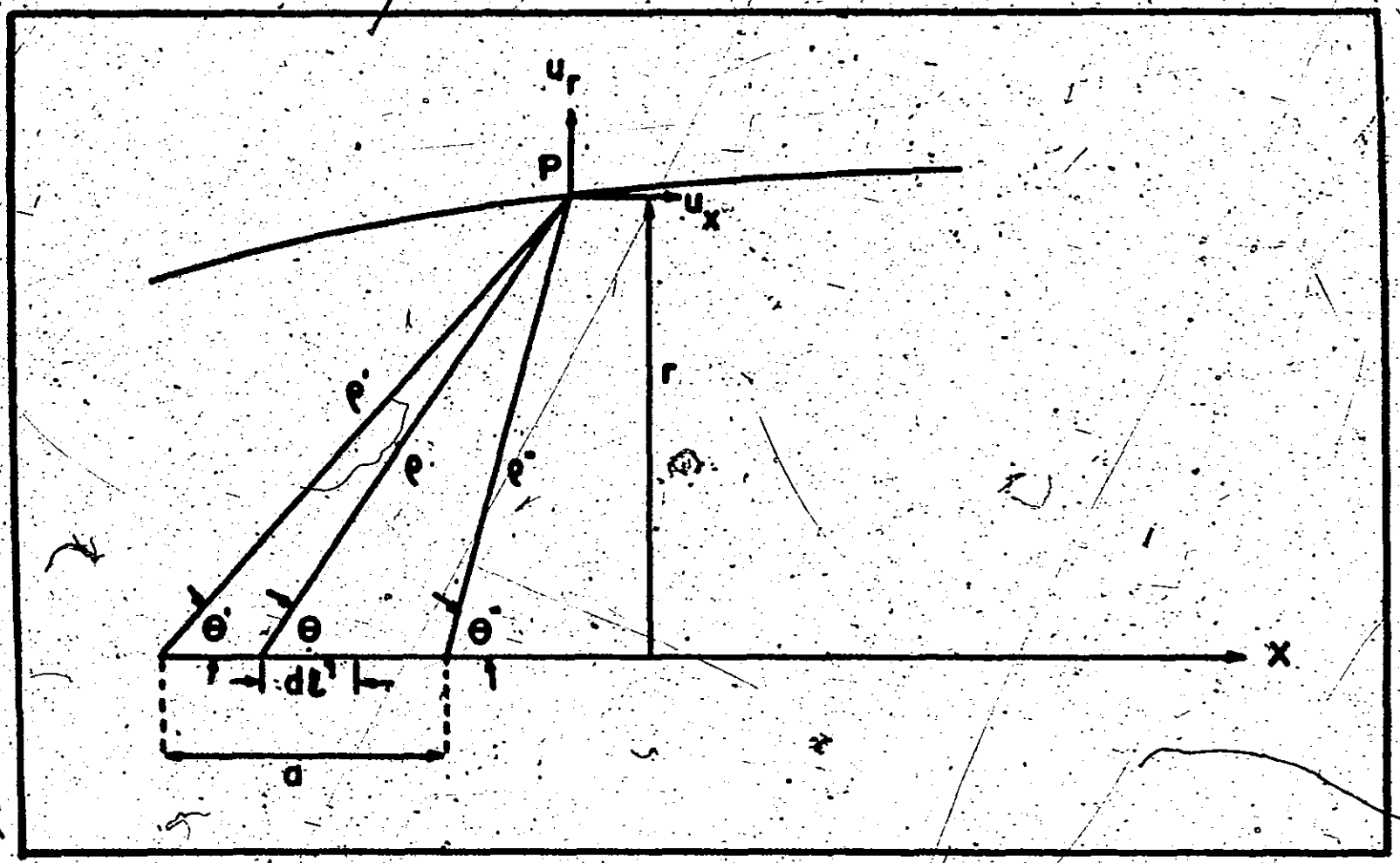


Figure 2:58: Trigonometric Relationships for a General Point Along the Hull Shape

$$\phi = -\frac{q}{4\pi}(a + \rho' - \rho'')$$

$$= -\frac{Q}{4}\left(1 + \frac{\rho' - \rho''}{a}\right)$$

The velocity components U_x and U_r become

$$U_x = \frac{Q}{4\pi ar}\left(\frac{\partial \rho''}{\partial r} - \frac{\partial \rho'}{\partial r}\right)$$

$$U_r = -\frac{Q}{4\pi ar}\left(\frac{\partial \rho''}{\partial x} - \frac{\partial \rho'}{\partial x}\right)$$

In general $\rho = \sqrt{r^2 + x^2}$ and

$$\frac{\partial \rho}{\partial r} = \sin\theta$$

$$\frac{\partial \rho}{\partial x} = \cos\theta$$

yielding

$$U_x = \frac{Q}{4\pi ar}(\sin\theta'' - \sin\theta')$$

$$U_r = -\frac{Q}{4\pi ar}(\cos\theta'' - \cos\theta')$$

Designating the distances of a given streamline point from the end points of the i^{th} line source by ρ'_i and ρ''_i

$$\phi = -\frac{Q_i}{4}\sum_{i=1}^{n}\left(1 + \frac{\rho'_i - \rho''_i}{a}\right)$$

where n is the number of sources.

The lines ϕ = constant represent streamlines and the line $\phi = 0$ yields the envelope curve. Therefore, putting $\phi = 0$ for as many points of the envelope as there are unknown line sources, a system of linear equations is obtained for the determination of Qi

$$Z_i = \frac{Q_i}{2U\pi a^2}$$

where U is the free stream velocity.

Denoting the length of the radius vectors from the end points of the i^{th} source to any point k on the envelope, a coefficient C_{ik} can be defined.

$$C_{ik} = 1 + \frac{a'_{ik} - a''_{ik}}{a}$$

The system of linear equations is

$$C_{11}Z_1 + C_{21}Z_2 + \ldots\ldots\ldots\ldots\ldots\ldots + C_{n1}Z_n = (\frac{r_1}{a})^2$$

$$C_{12}Z_1 + C_{22}Z_2 + \ldots\ldots\ldots\ldots\ldots\ldots + C_{n2}Z_n = (\frac{r_n}{a})^2$$

" " " "

$$C_{1n}Z_1 + C_{2n}Z_2 + \ldots\ldots\ldots\ldots\ldots\ldots + C_{nn}Z_n = (\frac{r_n}{a})^2$$

According to Bernoulli's equation, the pressure increase, at any point where the flow velocity is kU, is

$$\Delta P = \frac{\gamma}{2g}(1 - k^2)U^2$$

Introducing the quantity Z_i into the expressions for U_x and U_n, a value for k^2 can be obtained

$$k^2 = [1 - \frac{a}{2r_k}\sum_{i=1}^{n} Z_i(\sin\theta''_i - \sin\theta'_i)]^2 + \frac{a^2}{4r_k^2}$$

$$[\sum_{i=1}^{n} Z_i(\cos\theta''_i - \cos\theta'_i)]^2$$

ΔP = the change in the dynamic pressure

$= P - P_o$

The boundary condition is $P_o = 0$ as P_o the dynamic pressure at a a distance from the ship. Hence

$$P = \frac{\gamma}{2g}(1 - k^2)U^2$$

and for the stagnation point $k^2 = 0$

The introduction of Z_i into the expressions for U_x and U_r results in

$$U_x = U - U\frac{a}{2r_k}\sum_{i=1}^{n} Z_i(\sin\theta''_i - \sin\theta'_i)$$

$$U_r = U\frac{a}{2r_k}\sum_{i=1}^{n} Z_i(\cos\theta''_i - \cos\theta'_i)$$

These quantities are not required in this case but are necessary in the following case and for that reason are defined at this point.

(b) Case #2

The situation of oblique flow can be obtained by superposing the cases of flow at zero incidence angle and an incidence angle of ninety degrees. Flow at zero incidence angle has been investigated in the preceding section. To solve for the case of a ninety degree incidence angle, a perpendicular flow of velocity W must be assumed and the flow potential calculated using the following theorem.

"If the x axis of an x, y, z system of co-ordinates is covered with double sources whose axes are oriented in the z direction, then the flow resulting from these double sources, superposed on a parallel flow in the z direction, produces a streamline form about a body of revolution exposed to a flow at right angles to the axis of symmetry."

The principle formulae for a double source are derived as follows:

Consider a source and a sink of equal yield Q separated by a distance 2c. This gives x = y = 0 and z = ± c. The potential functions of the source and sink are

$$\phi_{(+)} = -\frac{Q}{4\pi}(x^2 + y^2 + (z - c)^2)^{-1/2}$$

$$\phi_{(-)} = \frac{Q}{4\pi}(x^2 + y^2 + (z - c)^2)^{-1/2}$$

Addition of the potential functions yields

$$\phi = -\frac{Q}{4\pi}\frac{2cz}{(x^2+y^2+z^2)^{3/2}} + \text{higher order terms}$$

The angle of inclination of any radius vector to the z axis can be designated by γ giving

$$\cos\gamma = \frac{z}{\sqrt{x^2+y^2+z^2}}$$

and $$\rho = \sqrt{x^2 + y^2 + z^2}$$

giving

$$\phi = -\frac{2Qc}{4\pi\rho^2}\cos\gamma + \text{higher order terms}$$

Letting c approach zero and Q approach infinity so that the product of 2Qc approaches a finite value M, we get

$$\phi = -\frac{M}{4\pi\rho^2}\cos\gamma,$$

the potential function for a doublet.

Superposing the parallel flow in the z direction produces flow about a sphere. The velocity component in the direction of the radius vector, ρ, is

$$W_\rho = \frac{M}{2\pi\rho^3}\cos\gamma.$$

If the parallel flow has a velocity of -W then,

$$\overline{W}_\rho = -W\cos\gamma$$

Putting

$$W_\rho + \overline{W}_\rho = 0$$

for the surface of a sphere of radius

$$\rho = \sqrt[3]{\frac{M}{2\pi W}}$$

the velocity component perpendicular to the surface of the sphere disappears. Hence, flow about a sphere is produced.

If the entire x axis is covered with these doublets of constant intensity then the flow crosswise to an infinitely long cylinder is obtained. Introducing the polar co-ordinates ρ, θ, ϕ, where θ is the angle between the radius vector and the x axis and ϕ determines the position of the meridian plane passing through the x axis then

$$\cos\gamma = \sin\theta\cos\phi$$

and

$$\phi = -\frac{M}{4\pi}\frac{\sin\theta\cos\phi}{\rho^2}.$$

$$= - \frac{\mu}{4\pi} \frac{d^2 \zeta}{dx^2} \frac{\sin\theta \cos\phi}{\rho^2}$$

Returning to Figure 2.58

$$x - \zeta = r \cot \theta$$

and $$d\zeta = \frac{r}{\sin^2\theta} d\theta$$

$$r = \rho \sin\theta$$

so that

$$d\phi = - \frac{\mu}{4\pi r} \sin\theta \, d\theta \cos\phi$$

Integrating for a constant line doublet length "a"

$$\phi = \frac{\mu}{4\pi\rho} [\cos\theta]_0^a \cos\phi$$

or indicating the angles to the left and right ends of the doublet line by θ' and θ''

$$\phi = \frac{\mu}{4\pi a} (\cos\theta'' - \cos\theta')\cos\phi$$

Integrating from $\theta = 0$ to $\theta = \pi$ yields

$$\phi = -\frac{\mu}{2\pi r} \cos\phi$$

The velocity in the r direction is

$$W_r = \frac{\mu}{2\pi r^2} \cos\phi$$

Therefore the flow around a cylinder of radius

$$r = \sqrt{\frac{\mu}{2\pi W}}$$

can be obtained by covering the cylinder axis with a doublet of moment

$$\mu = 2\pi r^2 W$$

The potential function of a system of doublets can be expressed by

$$\phi = \cos\phi\ \phi_o(\rho,\theta)$$

in which ϕ_o represents the potential function for the vertical section, $\phi=0$, and depends only on ρ and θ or x and r.

The streamline pattern in the vertical section immediately furnishes the streamline pattern and the corresponding velocity components in any meridian plane by multiplying by $\cos\phi$. The task of determining the perpendicular flow about the airship hull is, therefore, reduced to the solution of the problem in the plane $\phi=0$ (x,z plane). Following a similar method, as in Case #1, the potential function of the i^{th} source is

$$\phi_i = -\frac{\mu_i}{4\pi r}(\cos\theta'_i - \cos\theta''_i)$$

and

$$W_{xi} = \frac{\partial \phi_i}{\partial x} = \frac{\mu_i}{4\pi r}\left(\sin\theta'_i - \sin\theta''_i \frac{\partial \theta''_i}{\partial x}\right)$$

$$W_{ri} = \frac{\partial \phi_i}{\partial r} = \frac{\mu_i}{4\pi r}\left(\sin\theta'_i \frac{\partial \theta'_i}{\partial r} - \sin\theta''_i \frac{\partial \theta''_i}{\partial r}\right) + \frac{\mu_i}{4\pi r^2}(\cos\theta'_i - \cos\theta''_i)$$

where $\theta = \arctan \frac{r}{x}$

Hence

$$\frac{\partial \theta}{\partial x} = \frac{-\frac{r}{x^2}}{1 + (\frac{r}{x})^2}$$

$$\frac{\partial \theta}{\partial r} = \frac{\frac{1}{x}}{1 + (\frac{r}{x})^2}$$

and

$$\sin\theta = \frac{\frac{r}{x}}{1 + (\frac{r}{x})^2}$$

$$\cos\theta = \frac{1}{1 + (\frac{r}{x})^2}$$

Introducing

$$f(\frac{r}{x}) = \sin^3\theta$$

$$g(\frac{r}{x}) = 2\cos\theta - \cos^3\theta$$

and again designating them by f'_i or f''_i and g'_i or g''_i gives

$$W_x = \frac{1}{4\pi r^2} \sum_{i=1}^{n} u_i (f''_i - f'_i)$$

$$W_r = \frac{1}{4\pi r^2} \sum_{i=1}^{n} u_i (g'_i - g''_i)$$

The parallel flow has components

$$W_x = 0$$

$$W_r = -W$$

Let α denote the angle of inclination to the meridian plane. Then

$$\tan \alpha = \frac{W_r' + W_r}{W_x} = \frac{W_r - W}{W_x}$$

or

$$W_r - W_x \tan \alpha = W$$

giving

$$\frac{1}{4\pi r^2} \sum_{i=1}^{n} \mu_i [(x'_i - x''_i) + \tan\alpha\,(r'_i - r''_i)] = W$$

Defining Z_i as

$$Z_i = \frac{\mu_i}{4\pi a^2 W}$$

where a is the separation distance gives

$$\sum_{i=1}^{n} Z_i [(x'_i - x''_i) + \tan\alpha\,(r'_i - r''_i)] = \frac{r_i^2}{a^2}$$

If the i^{th} station of the hull were to be replaced by a portion of an infinite cylinder of radius r_i the strength of the doublet is given by

$$\mu_i = 2\pi r_i^2 W$$

or

$$z_1 = \frac{1}{2}\left(\frac{r_1}{a}\right)^2$$

The velocity components at any point k can now be expressed by

$$W_x = \frac{W}{2} I \left(\frac{r_1}{r_k}\right)^2 (f_{1k}'' - f_{1k}')$$

$$W_r = \frac{W}{2} I \left(\frac{r_1}{r_k}\right)^2 (g_{1k}' - g_{1k}'')$$

Instead of calculating the pressure distribution, Von Karman calculated a quantity, β, the "transverse force coefficient". For the purposes that we require the data, this has no effect as the shape of the pressure distribution curve and the transverse force coefficient curve are the same.

$$\beta = 2\pi r \frac{UW}{U^2 + W^2}\left(\frac{U_x W_x}{UW} + \frac{U_r W_r}{UW}\right)$$

Assuming

$$U = W = 1$$

then

$$\beta = \pi r(W_x U_x + W_r U_r)$$

where W_x, W_r, U_x and U_r are quantities that have already been defined.

2.5 Static Shear Force and Bending Moment

2.5.1 Introduction

The static shear force and static bending moment are of considerable importance in determining the suitability of

any airship design. The static shear force can be used to determine the optimum locations of the major structural components from a loading point of view. In addition, a knowledge of the static shear force can considerably aid the design of the internal suspension system of the airship. The static bending moment has its value as an indicator of the degree of optimization achieved in the location of the major structural components. The minimum bending moment indicates the optimum location.

A computer programme has been developed which enables the user to compare various designs by combuting the static shear force and bending moment given the necessary inputs. This programme is listed in APPENDIX D.

2.5.2 Programme Inputs and Sample Results

The programme as developed is user oriented and by substituting various values for the following parameters alternative designs can be evaluated.

XN - airship shape factor

XM - airship shape factor

P - airship fineness ratio

XL - airship length

N - number of 1 foot interval stations into which the airship is divided starting with 1 at the bow

CABXS - starting position of the cabin

CABXST - stopping position of the cabin

TAILXS - starting position of the tail assembly

TAILXST - stopping position of the tail assembly

SUSPXS - starting position of the internal suspension system

SUSPXST - stopping position of the internal suspension system

NOSEXST - stopping position of the bow cap

WNOSE - the bow cap weight

WCAB - the cabin weight

WTAIL - the tail weight

WEIGHT - the weight of the envelope material (oz./sq.yd)

XCCO - the position of the center of gravity of the cabin

XNCG - the position of the center of gravity of the bow cap

XTCO - the position of the center of gravity of the tail assembly

The programme assumes that all weights are distributed evenly over the distances concerned and also assumes one integral straight line ballonet. The programme has been tested for the following design parameters and the results are shown in Figure 2.59 and Figure 2.60.

XN - 0.4

XM - 0.6

R - 3.00

XL -117.0

N -118.0

SUSPXS	- 20.0
SUSPXST	- 90.0
NOSEXST	- 20.0
CABXS	- 38.6
CABXST	- 61.6
TAILXS	- 85.0
TAILXST	-100.0
WNOSE	-200.0
WCAB	-3200.0
WTAIL	-500.0
WEIGHT	- 11.40
XCCG	- 52.6
XNCG	- 10.0
XTCG	- 90.0

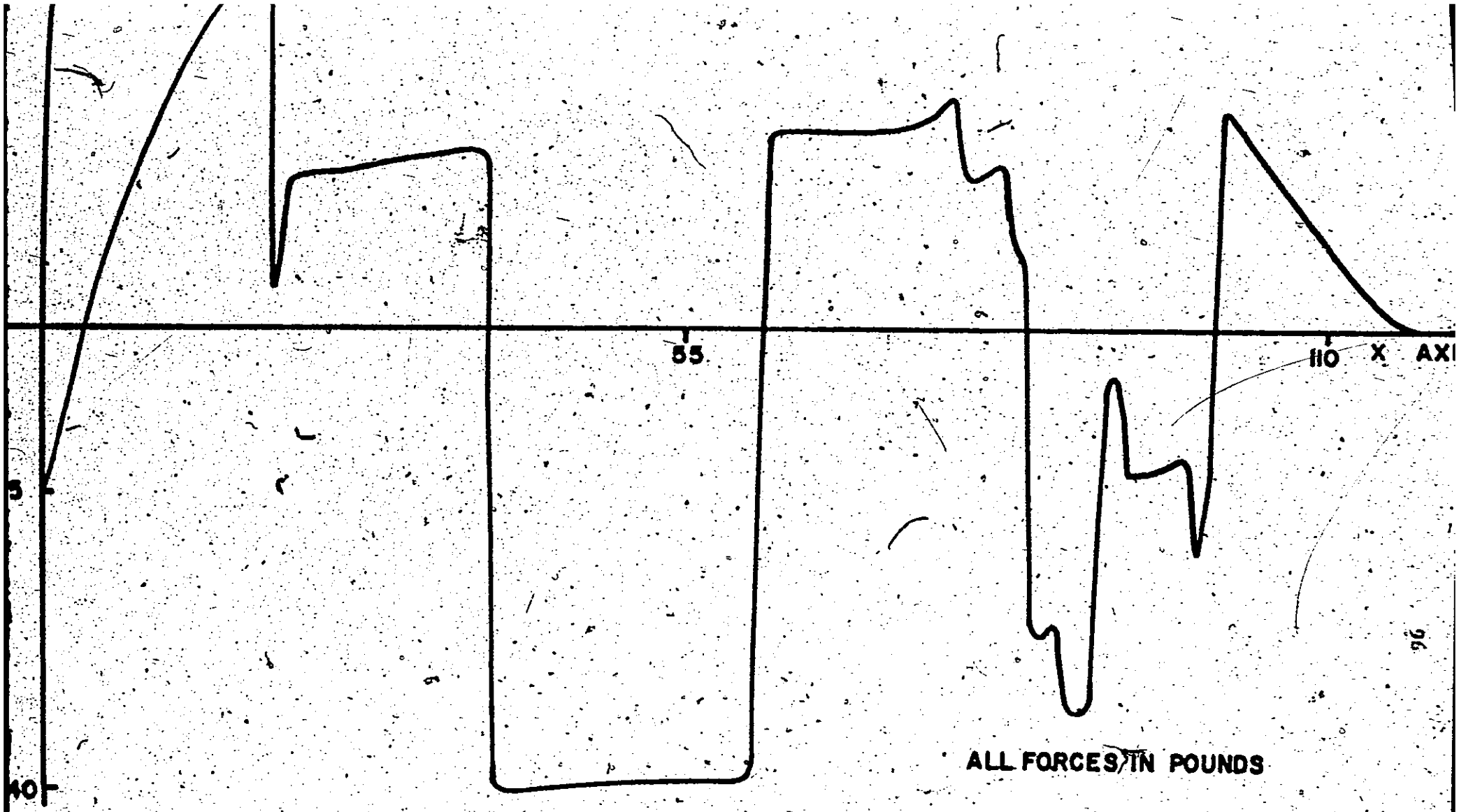
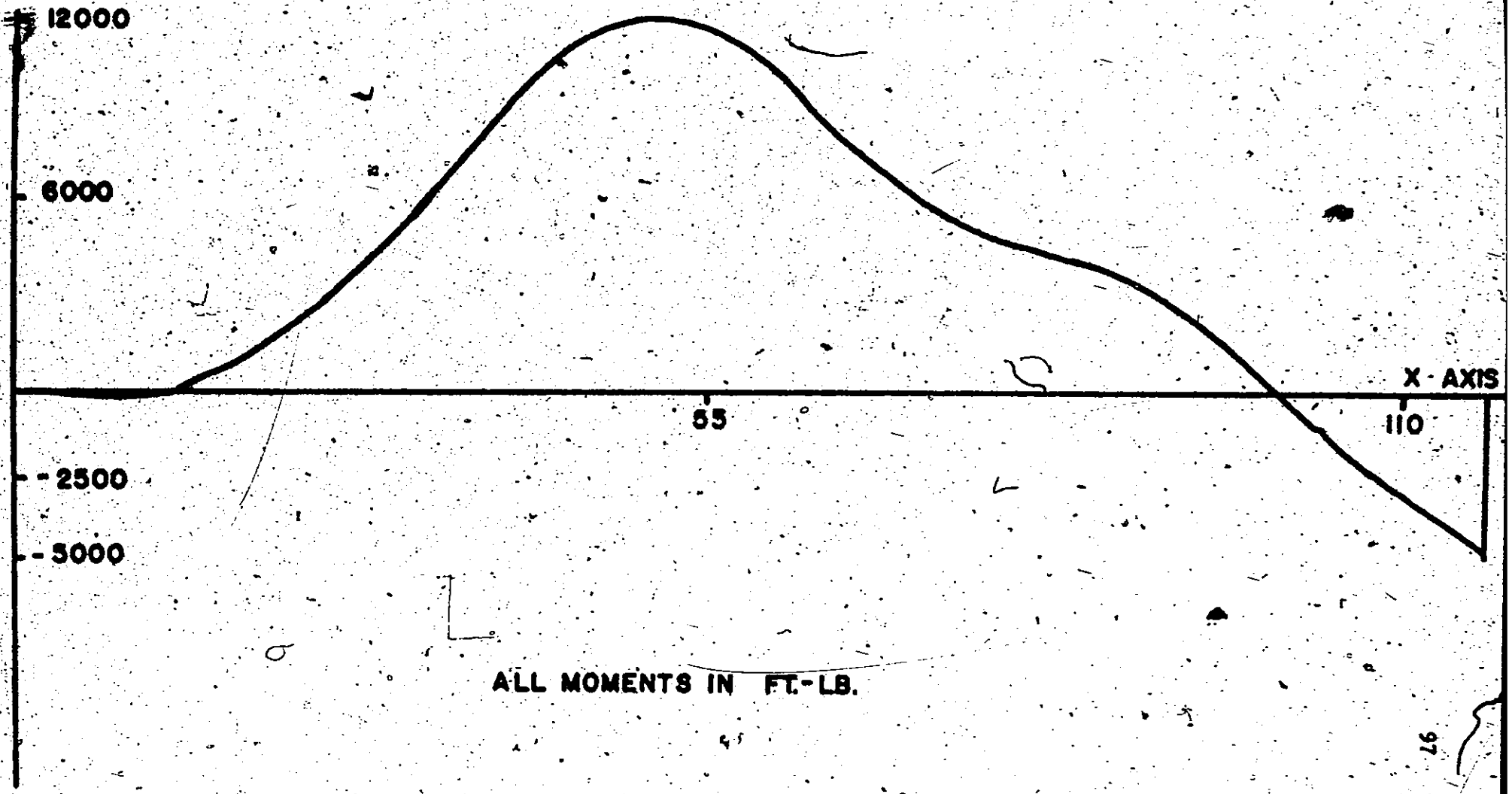


Figure 2.59: Static Shear Force Diagram



ALL MOMENTS IN FT.-LB.

Figure 2.60: Static Bending Moment Diagram

Chapter Three Notation

γ the angle of inclination

θ the angle of attack

ϕ the roll angle

ψ the yaw angle

δ the angle of rotation

V_{TOT} the total volume of the envelope

V_{BAL} the volume of the ballonets

γ_{AIR} the density of air

γ_{HE} the density of Helium

F_g the lifting gas force

F_w the weight of the airship

F_d the drag force

F_t the engine thrust force

F_L the dynamic lift force

F_S the lift force of the fixed tail surfaces

F_{ds} the drag force of the fixed tail surfaces

F_e the elevator force

F_R the rudder force

C_L the lift coefficient

C_D	the drag coefficient
$\forall$	the volume of the airship
V	the velocity of the afrship
A	the area coefficient
δ	the density of air
W	the weight of the airship.
L	the length of the airship
S	the cross sectional area
R	the radius of the turning circle
CB	the position of the center of bouyancy.
CPT	the center of pressure of the tail
CP	the center of pressure of the airship
I	the mass moment of inertia
a	the linear acceleration
α	the angular acceleration
m	the mass of the system
x_c	the position of the center of mass of the system in the x direction
y_c	the position of the center of mass of the system in the y direction
z_c	the position of the center of mass of the system in the z direction
m	airship envelope shape parameter
n	airship envelope shape parameter
f	airship fineness ratio

CHAPTER 3

COMPUTER AIDED TRAJECTORY AND LOAD CALCULATIONS

3.1 Introduction

The question of how an airship will behave when required to perform certain maneuvers has always been one of the uncertainties of airship design. Wind tunnel experiments and model studies have been inconclusive[11]. During the period of quantity construction of airships, designers based their decisions upon empirical data that had been gathered from previous designs. However, recent airworthiness regulations require that the forces acting during various maneuvers 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].

"Maneuvering Load Conditions. The airship structure shall be designed to withstand the limit loads resulting from the following maneuvering conditions, conducted at airspeed of V_D, critical statically-heavy weight, and at the centre-of-gravity location critical for each maneuver:

(a) In level flight, application of full rudder, applied at the maximum control rate attainable, until a heading of 75 degrees 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 maneuvers 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 maneuvers of SC.4(d) combined with alternatively a left and right steady-state turn."

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

3.2 Static Force and Moment Analysis

A static force and moment analysis is performed in order to reveal the forces and moments involved when an airship travels at a constant velocity. A simple unrealistic situation will be analysed first, and then extended to the real situation. The initial situation is unrealistic due to the fact that it assumes an airship in neutral bouyancy, that is with the static lift force exactly equal to the weight of the system, in level flight. This an airship cannot accomplish without use of the control system.

The analysis shown here will later be developed further in order to include acceleration effects. A full understanding of the static situation is necessary before dealing with the dynamic situation.

3.2.1 Description of Airship Axis.

An airship hull is a solid of revolution. Labelling its axis of rotation as the x axis produces the co-ordinate system illustrated in Figure 3.1. Any angular deviation of the airship, will be either pitch, yaw, or roll, or a combination of these motions.

The nomenclature related to the previously described axis system is shown in Table 3.1.

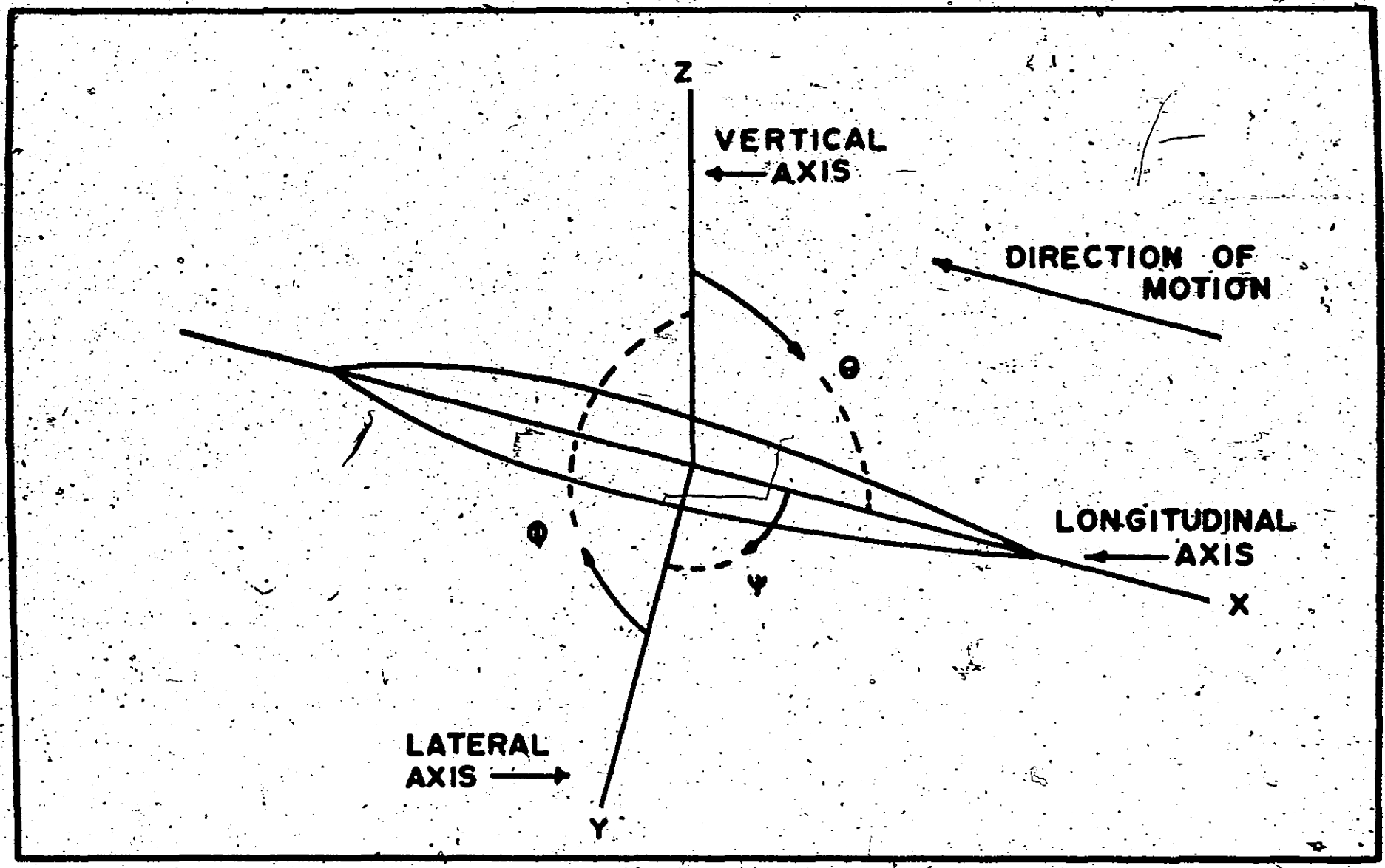


Figure 3.1: Airship Axes

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TABLE 3.1
Nomenclature

Axis		Moment about axis		Angle	Velocities		Acc.	
Designation	Symbol	Designation	Symbol	Symbol	Linear	Ang.	Linear	Ang.
Longitudinal	X	Roll	L	ϕ	VX	WX	AX	WX
Lateral	Z	Pitch	M	θ	VZ	WZ	AZ	WZ
Vertical	Y	Yaw	N	ψ	VY	WY	AY	WY

Various angles in both the pitch and yaw directions must be defined. Referenced to the moving axes of the airship three angles are required. The angle of attack in the vertical plane, with respect to the center of bouyancy, is θ and the angle of attack in the horizontal plane, once again with respect to the center of bouyancy is ϕ. The roll angle, ϕ, is also referenced to the center of bouyancy. The motion of the airship axes produces angles which are referenced to the fixed ground level axis. Motion in the X-Y plane is referenced to the X axis and produces an angle of inclination, γ. Motion in the X-Z plane produces an angle of rotation, β, with respect to the longitudinal direction. Thus the total angle of pitch is given by $\gamma + \theta$ and the total angle of yaw by $\phi + \beta$.

3.2.2 Center of Bouyancy

The center of bouyancy of an airship may be defined as the center of mass of the fluid displaced by the external shape of the envelope. This definition implies that the airship is at its ceiling altitude and the ballonets are completely deflated. If the ballonets are inflated equally, assuming fore and aft ballonets, then properly placed ballonets produce no center of mass shifts. If, however, unequally inflated ballonets are used to trim the airship, center of mass shifts will occur. The degree of inflation will have no effect on the lifting force produced by the enclosed Helium as

$$(V_{TOT} - V_{BAL}) \times (\gamma_{AIR} - \gamma_{He}) = C$$

at any altitude. The degree of inflation of the ballonets possible is a function of the altitude.

$$V_{BAL} = f(h)$$
$$= (1-x)V_{TOT}$$

where x is the ratio of the density of air at sea level to the density of air at the requisite altitude.

For an airship which is in static equilibrium the center of bouyancy should be located directly above the center of gravity of the airship and on the longitudinal axis.

3.2.3 Definitions and Assumptions

Motion of an airship in flight may be defined in terms of roll, pitch, and yaw about the longitudinal axis. An airship differs from an aircraft in that the three types of motion are independent of one another.

The following analysis will be based on the assumption that -

1) the static lift force remains constant,
2) the total weight remains constant,
3) the air speed of the airship remains constant,
4) the airship form remains unchanged,
5) the center of gravity and the center of bouyancy remain fixed with respect to the airship axes,

6) the controls remain neutral,

7) the airship moves in an ideal, incompressible, frictionless fluid.

3.2.4 Forces and Moments Acting on an Airship

An unrealistic situation will be examined first in order to establish a simple image of some of the forces and moments. Suppose an airship is travelling in neutral bouyancy, at a constant speed, with the horizontal axis co-incident with the direction of motion (angle of attack is zero), as illustrated by Figure 3.2. The forces and moments acting are as follows:

1) Forces:

(a) F_g = the force due to the lifting gas acting through the center of bouyancy, CB.

(b) F_w = the total weight of the airship acting through the center of gravity, CG.

(c) F_d = the drag force acting on the center of pressure, CP.

(d) F_t = the thrust force of the engines acting along the thrust line of the engines, CT.

2) Moments about the center of bouyancy:

(a) M_w = moment due to the weight
$= 0$

(b) M_g = moment due to the lifting gas
$= 0$

(c) M_{td} = moment due to the thrust and drag
$= T(a)$ (3.1)

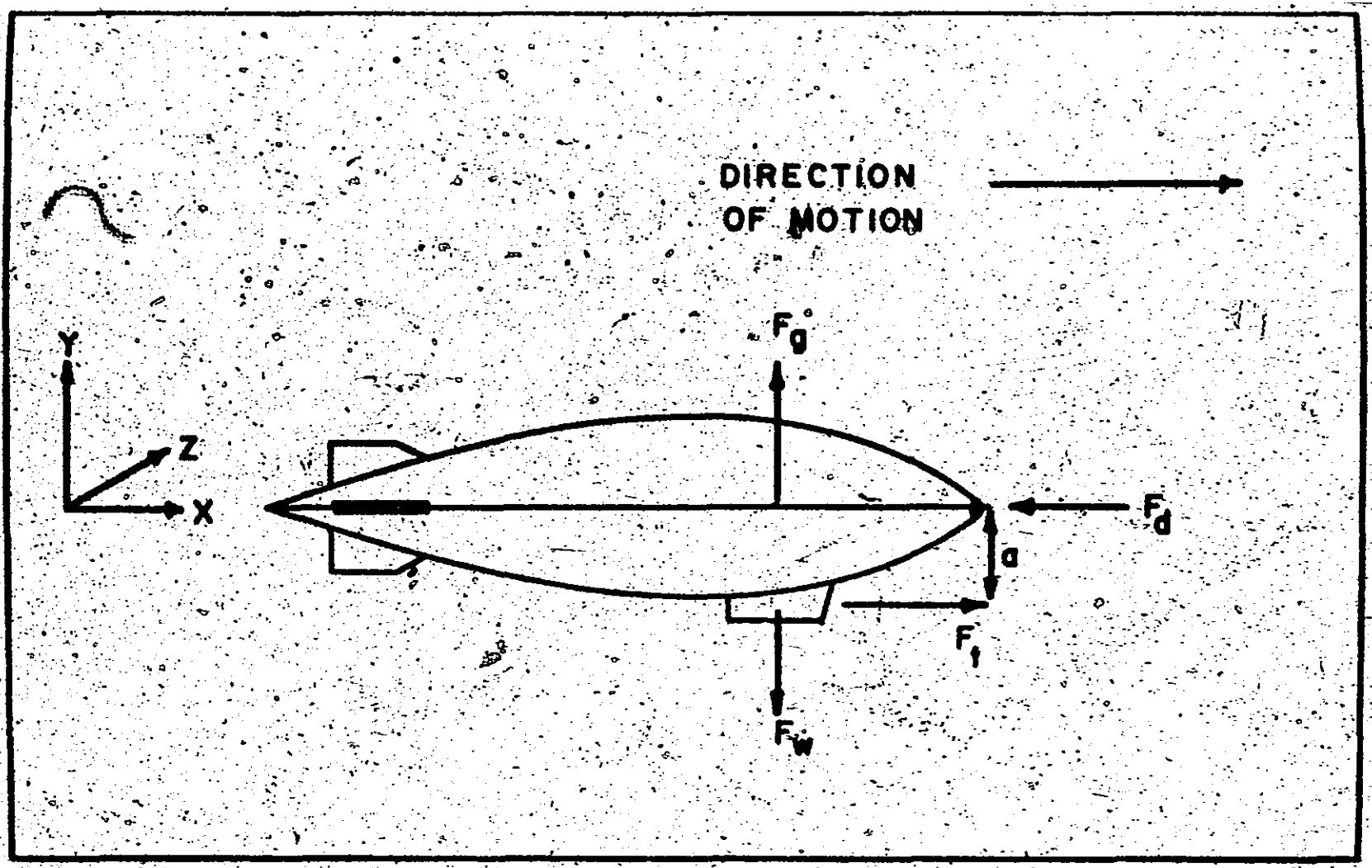

Figure 3.2: Forces Acting on an Airship
(idealized case)

where "a" is the vertical distance between the engine thrust line and the center of bouyancy.

Hence, for static equilibrium and constant velocity

$$F_g = F_w$$

$$F_d = F_b$$

However, the thrust-drag moment, M_{td}, is unbalanced and would tend to force the nose of the airship in an upward direction. In order to overcome this problem airships are trimmed nose down until a balancing moment is produced ($\theta \neq 0$). The force and moment analysis thus becomes much more complex than in the situation just described.

Six different situations can be identified depending on the static condition of the airship and its direction of inclination. These six situations are illustrated in Figure 3.3.

Case No. 1 - The airship is in neutral bouyancy flying with the nose trimmed up an angle of α. Thus, since $\theta = 0^\circ$, the airship will climb at an angle of $\gamma = \alpha$.

Case No. 2 - The airship is in neutral bouyancy flying with the nose trimmed down an angle of α. Once again $\theta = 0^\circ$ and the airship will dive at an angle of $\gamma = \alpha$.

Case No. 3 - The airship is flying statically heavy (the static lifting force is less than the total system weight) with the nose trimmed up an angle of α. Here the airship will have an angle of attack of θ and an angle of motion of γ. Thus the angle of trim α must equal $\gamma + \theta$.

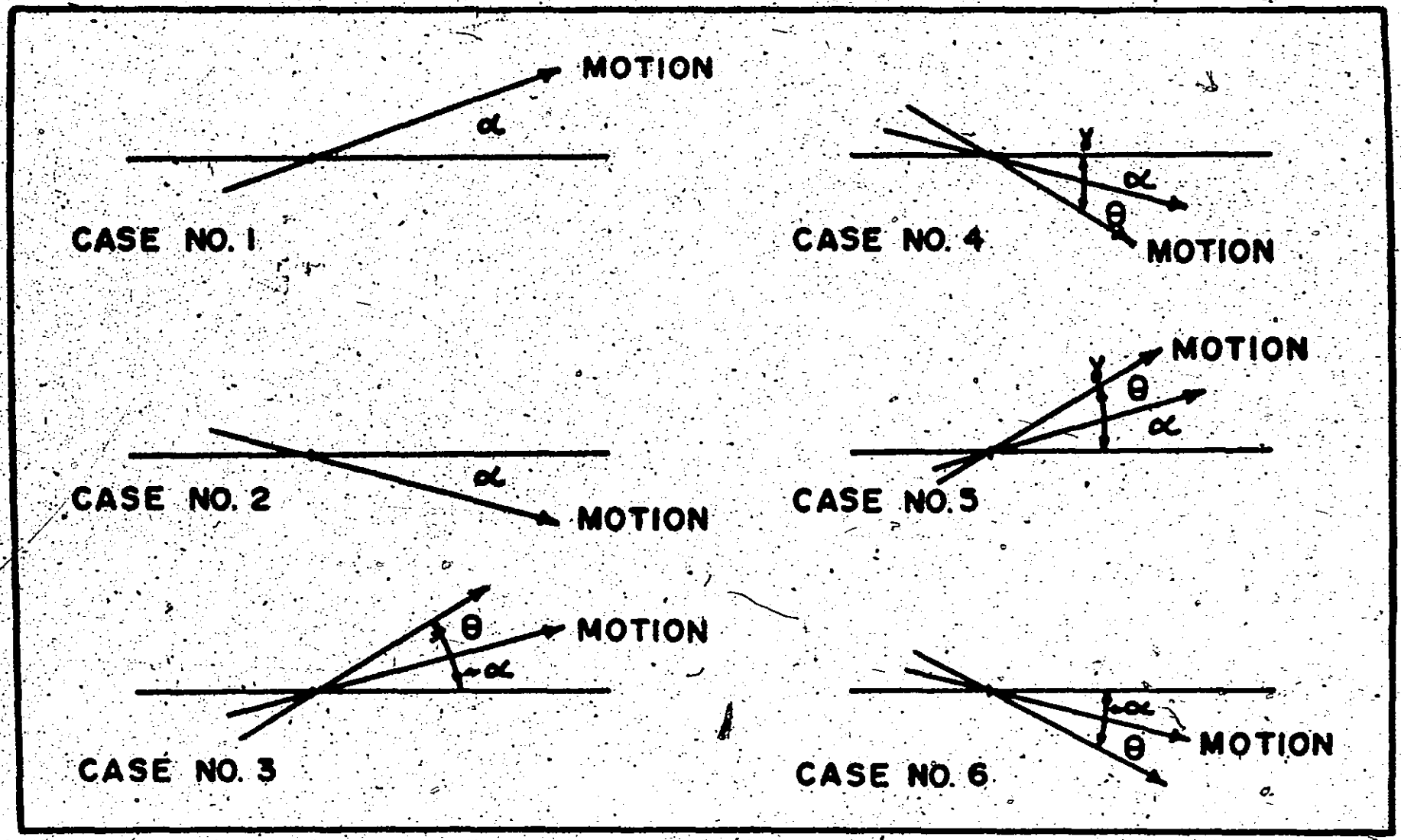

Figure 3.3: Airship Trajectories for Various Loading Conditions and Angles of Attack.

Case No. 4 - The airship is flying statically heavy with the nose trimmed down an angle of α. Here the airship will have an angle of attack of $-\theta$, and an angle of motion of $-\gamma$. Thus the angle of trim α, which can be defined as the angle between the airship longitudinal axis and the fixed horizontal axis, must equal $\gamma-\theta$ as $\gamma>\theta$ due to the heaviness of the airship.

Case No. 5 - The airship is flying statically light (the static lifting force is greater than the total system weight) with the nose trimmed up an angle of α. This case is similar to Case No. 4. The angle of motion is γ and the angle of attack is θ. Due to the lightness of the system $\gamma>\theta$ and the trim angle α must equal $\gamma-\theta$.

Case No. 6 - The airship is flying statically light, with the nose trimmed down an angle of α. The angle of attack is $-\theta$ and the angle of motion is $-\gamma$. Due to the lightness of the system $\theta>\gamma$ and the trim angle α must equal $\gamma + \theta$.

Cases 1 and 2 almost never occur and thus only four actual situations must be contemplated.

An examination of one of these cases in detail will reveal the forces and moments actually operating on an airship. Case number three is shown in Figure 3.4. Refering to this figure, a general situation can be identified. The forces and moments are:

1) Forces

(a) F_g = the force due to the lifting gas acting through the center of bouyancy, CB.

(b) F_w = the total weight of the airship acting through the center of gravity, CG

(c) F_d = the drag force acting on the airship through the center of pressure, CP.

(d) F_t = the thrust force of the engines acting along the thrust line of the engines, CT.

(e) F_L = the dynamic lift force on the hull due to flying at an angle of pitch of θ, acting through the center of pressure, CP.

(f) F_s = the lift of the fixed tail surfaces due to flying at an angle of pitch θ, acting through the center of pressure of these surfaces.

(g) F_{ds} = the drag of the tail surfaces, acting through the center of pressure of these surfaces.

(h) F_e = the force due to deployment of the elevators. This force acts through the center of pressure of the tail, CPT.

Several of these forces have been defined in the previous chapter. These include:

F_g - the lifting force due to the contained gas

F_w - the gross weight of the system

F_d - the drag force as given by[4]

F_t - the thrust force due to the engines.

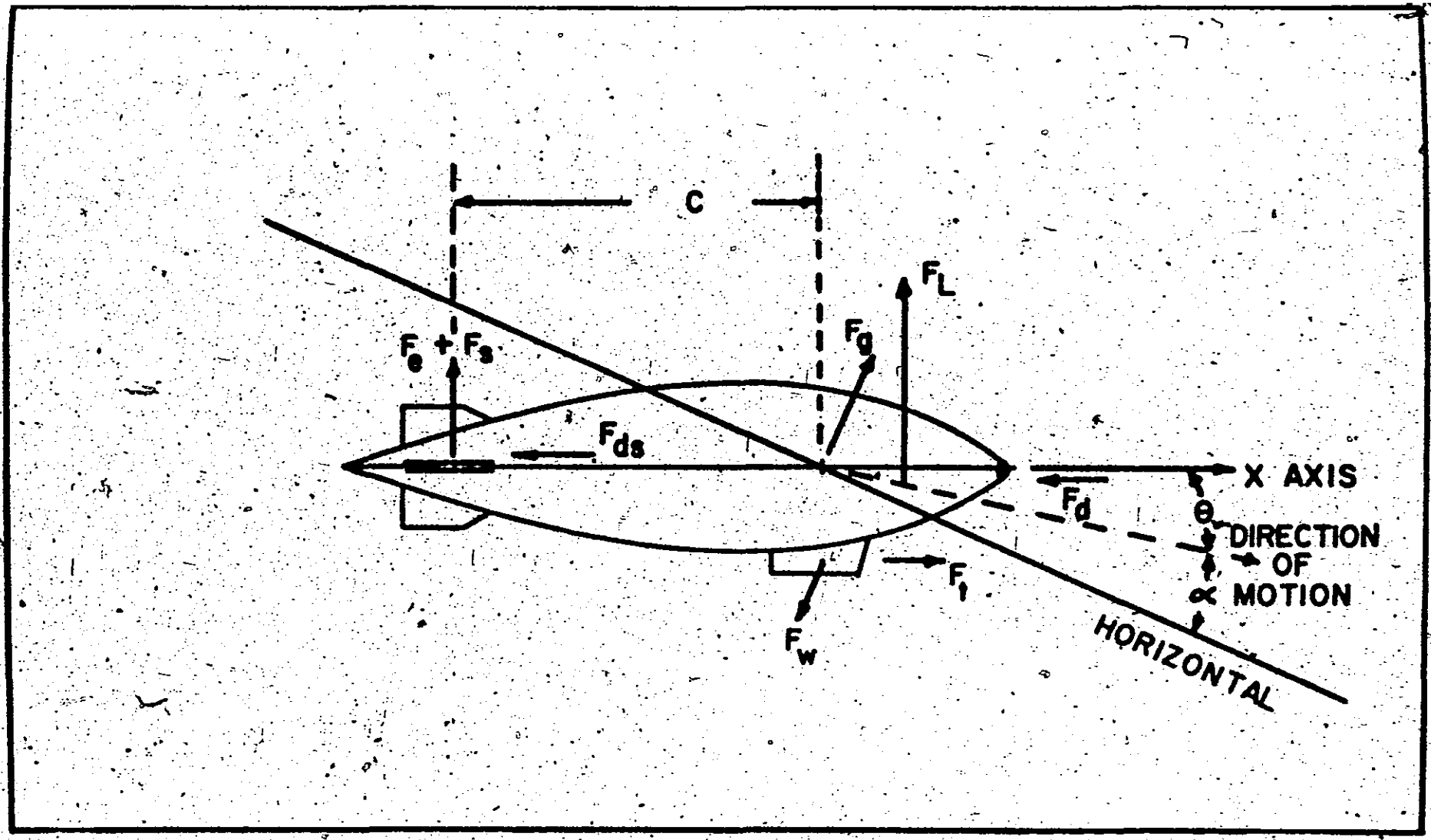

Figure 3.4: Forces Acting on an Airship for the Loading Condition of Case #3.

However, the remaining forces F_L, F_s, F_{ds}, and F_e must be defined.

(a) The dynamic lift force, F_L, occurs as a result of the symmetrical airfoil shape of the airship hull. The equation for the dynamic lift of an airship is[27]

$$F_L = \frac{1}{2} C_L \rho V^2 y^{2/3} \tag{3.3}$$

where the lift coefficient may be approximated by[28]

$$C_L = 1.25\gamma \tag{3.4}$$

and γ is the angle of pitch of the airship expressed in radians. This approximation holds up to an angle of pitch of ten degrees.

(b) The force, F_s, on the fixed tail surfaces is given by

$$F_s = \frac{1}{2} C_L \rho V^2 A \tag{3.5}$$

The lift coefficient in this case is dependent on the airfoil shape adopted for these surfaces and A is the product of the mean chord and the mean span.

(c) The drag force of the tail surfaces is determined from

$$F_{ds} = \frac{1}{2} C_D \rho V^2 A \tag{3.6}$$

and C_D is the drag coefficient for the chosen airfoil shape and A is the drag area of the airfoil.

(d) The elevator force, F_e, once again depends on the airfoil shape and is given by

$$F_e = \frac{1}{2} \rho C_L V^2 A \tag{3.7}$$

In this case C_L is the lift coefficient of the airfoil as determined with moveable surfaces. The quantities ρ, V, and

V are as defined in Chapter 2.

2) Moments about the center of bouyancy:

(a) Static righting moment

$$M_{SR} = Wh \sin(\gamma \pm \theta) \qquad (3.2)$$

where W = total weight of the airship

h = the vertical distance between the center of gravity and the center of bouyancy

(b) Engine thrust moment

$$M_{td} = T(a)$$

(c) Dynamic upsetting moment

This moment is due to the pressure difference between the two sides of the hull. It is assisted by reduced pressure on one side of the tail. These forces act in opposite directions, but as the force due to the hull is greater, the resultant is called the dynamic lift of the hull. However, both these forces cause rotation in the same direction producing the upsetting moment. The upsetting moment due to these aerodynamic forces is so great that when flying with a positive pitch angle it is necessary to hold the elevators down instead of up as would be expected. The converse applies when flying with a negative pitch angle. Munk[13] provides the expression

$$M_u = V \rho/2 V^2 (K_2 - K_1) \sin 2\theta \qquad (3.8)$$

where ∇ = the total volume of the airship in ft^3,

V = the velocity of the airship in ft/sec.,

ρ = the density of the air in slugs/ft^3,

θ = the angle of pitch,

and (K_2-K_1) = constants to correct for the fact that masses of air are carried along with the hull in both longitudinal and transverse motion. Values of K_1 and K_2 can be found in Table 3.2.

(d) Tail surface moment

This moment opposes the dynamic upsetting moment and results from the tail force generated by the tail airfoil when flying at an angle of pitch.

$$M_s = F_s \cdot C + F_{ds} \cdot C \sin(\theta) \qquad (3.10)$$

(e) Damping moment

An airship travelling along a specific path is considered as having two superimposed motions, one of translation as a whole, and one of rotation about a point. During the rotation about the point moments are produced. Suppose the nose is rising. Every part of the airship forward of the center of rotation is moving upward, while all parts to the rear of that center are moving downward. Thus an upward pressure of the air against the rear of the airship will be produced, as will a downward pressure of the air on the forward part. These forces cancel as far as longitudinal motion is concerned, but act together to give a moment to resist the existing

motion. As this moment acts only to damp out rotational moments once the forces that have caused these moments have been removed they will not enter into the analysis necessary to perform the maneuvers outlined in 3.1.

(f) Elevator Force Moment

$$M_e = F_e (CPT - CB) \qquad (3.11)$$

The elevators are not normally considered when examining the static situation. However, it is possible to be flying at such an angle of pitch that their employment is required to counter the dynamic upsetting moment.

3.2.5 Longitudinal Steady Motion

For pitch stability the sum of the restoring moments must equal the sum of the upsetting moments. Assuming no elevator deployment ($M_e = 0$)

$$M_{SR} + M_S = M_U + M_{td} \qquad (3.12)$$

Equation 4.6 holds only for the case illustrated by figure 3.4. Rearranged versions of this equation apply in the other cases. For example, during a dive, the static righting moment aids the dynamic upsetting moment and the thrust moment.

TABLE 3.2

Coefficients of Additional Mass of Ellipsoids of Various Length/ Diameter Ratios [13]

Length / Diameter	K_1	K_2	$K_2 - K_1$	K' Rotation
1.0	.500	.500	0	0
1.50	.305	.621	.316	.094
2.00	.309	.702	.493	.240
2.51	.156	.763	.607	.367
2.99	.122	.803	.681	.465
3.99	.082	.860	.778	.608
4.99	.059	.895	.836	.701
6.01	.045	.918	.873	.764
6.97	.036	.933	.897	.805
8.01	.029	.945	.916	.840
9.02	.024	.954	.930	.865
9.97	.021	.960	.939	.883
	0	1.000	1.000	1.000

NOTE: L/D is for an equivalent ellipsoid shape and is calculated from:

$$L/D = \sqrt{\frac{\pi}{6} \frac{L^3}{VOL}}$$

3.2.6 Stability in Roll

Stability in roll, which is a very difficult problem in aircraft, is not a problem in airships. The static righting moment acts also with regard to roll and since there is no dynamic upsetting moment, rolling only occurs due to side gusts against the car and envelope and due to centrifugal force when turning. The moments of these forces are immediately overcome by the large restoring moment due to the low position of the center of gravity. Rolling may be uncomfortable but there is never any danger of it reaching an excesssive value.

3.2.7 Steady Motion at a Fixed Yaw Angle

The forces and moments acting during steady motion at a fixed yaw angle present a rather more complex picture. Figure 3.5 illustrates the forces acting during this type of motion. Burgess[13] gives the following expression, derived by Dr. M. M. Munk, for the transverse aerodynamic forces acting on an airship moving at a fixed angle of yaw.

$$\frac{dF}{dx} = \frac{dS}{dx}(K_2 - K_1)V^2\rho/2 \sin 2\phi + k' V^2\rho/R\ S \cos\phi + k' V^2 \frac{\rho x}{R} \frac{dS}{dx} \cos\phi \qquad (3.13)$$

In essence, one could call this motion a steady state turn. The first term in the above equation represents the force along the hull due to the angle of yaw and is inward toward the center of the turn on the fore-body and outward on the after-body. It produces a turning moment balanced by an inward force assumed to be applied at the center of area of the fins. The second term gives a transverse force almost equal in magnitude to the

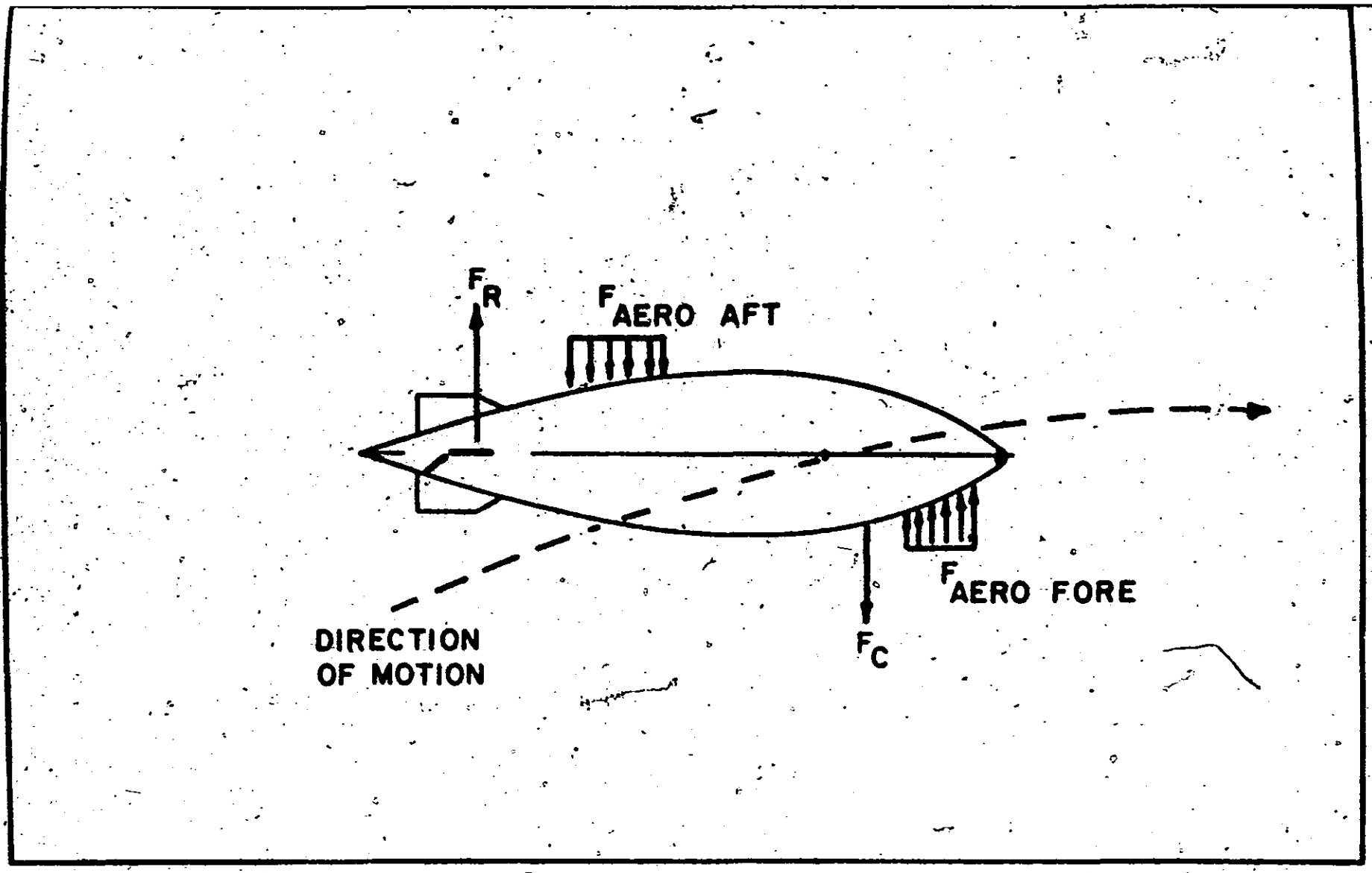

Figure 3.5: Forces Acting on an Airship at a Fixed Yaw Angle.

centrifugal force of the displaced air and distributed in the same manner, but acting inward instead of outward. The third term represents outward forces on the tapered portions of the hull, having the same resultant as the forces represented by the second term, but of opposite sign, and acting through the center of bouyancy. The sum of the second and third terms gives no resultant force or moment.

The force F_{SV} on the tail surfaces acts inwardly toward the center of the turn, and since the theoretical forces on the bare hull have no resultant force, and only a resultant moment due to integration of the first term of (3.13), F_{SV} is equal in magnitude to the centrifugal force of the ship. Thus the forces acting include

(a) The tail surface force

$$F_{SV} = -F_C = -\sum_{i=1}^{N} k' V^2 (\rho/R) S x_1 \cos\phi \qquad (3.14)$$

where k' = coefficient of additional mass due to rotation

x_1 = the distance along the longitudinal axis

S = the cross-sectional area at each value of x_1

ϕ = the angle of yaw

N = the number of stations along the x axis

and R = the radius of the turning circle related to the angle of yaw at the center of bouyancy

$$= \frac{2b}{(K_2-K_1)\sin 2\phi}$$

All other quantities are as previously described. This force must offset the aerodynamic moment of the bare hull due to the angle of yaw.

(b) The rudder force

$$F_R = \frac{1}{2} \rho C_L V^2 A \qquad (3.15)$$

where C_L = the rudder lift coefficient

A = the lift area of the tail surfaces

= airfoil chord x airfoil span

(c) The aerodynamic forces on the bare hull

These forces cancel on the fore and after body. However, an expression is required to be able to calculate the moments produced.

$$\sum_{i=1}^{N} F_{HA} = \sum_{i=1}^{N} (K_2 - K_1) \Delta S \, V^2 \, \rho/2 \, x_i \sin 2\phi = 0 \qquad (3.16)$$

This force acts through the center of pressure of the tail, CPT, and from a purely static consideration C_L would be calculated using the angle of yaw at the center of bouyancy. However, the radius of turn for an airship, unlike an airplane, is not much greater than the length of the airship. Hecks[11] suggests that a factor of four is trypical for the minimum radius. As a result the local flow direction relative to the axis of a turning airship changes considerably from the nose to the tail and hence the power of rudder is boosted. Figure (3.6) illustrates this effect. Hecks[11], once again, suggests that the effective angle of yaw of the tail surfaces is doubled. Therefore,

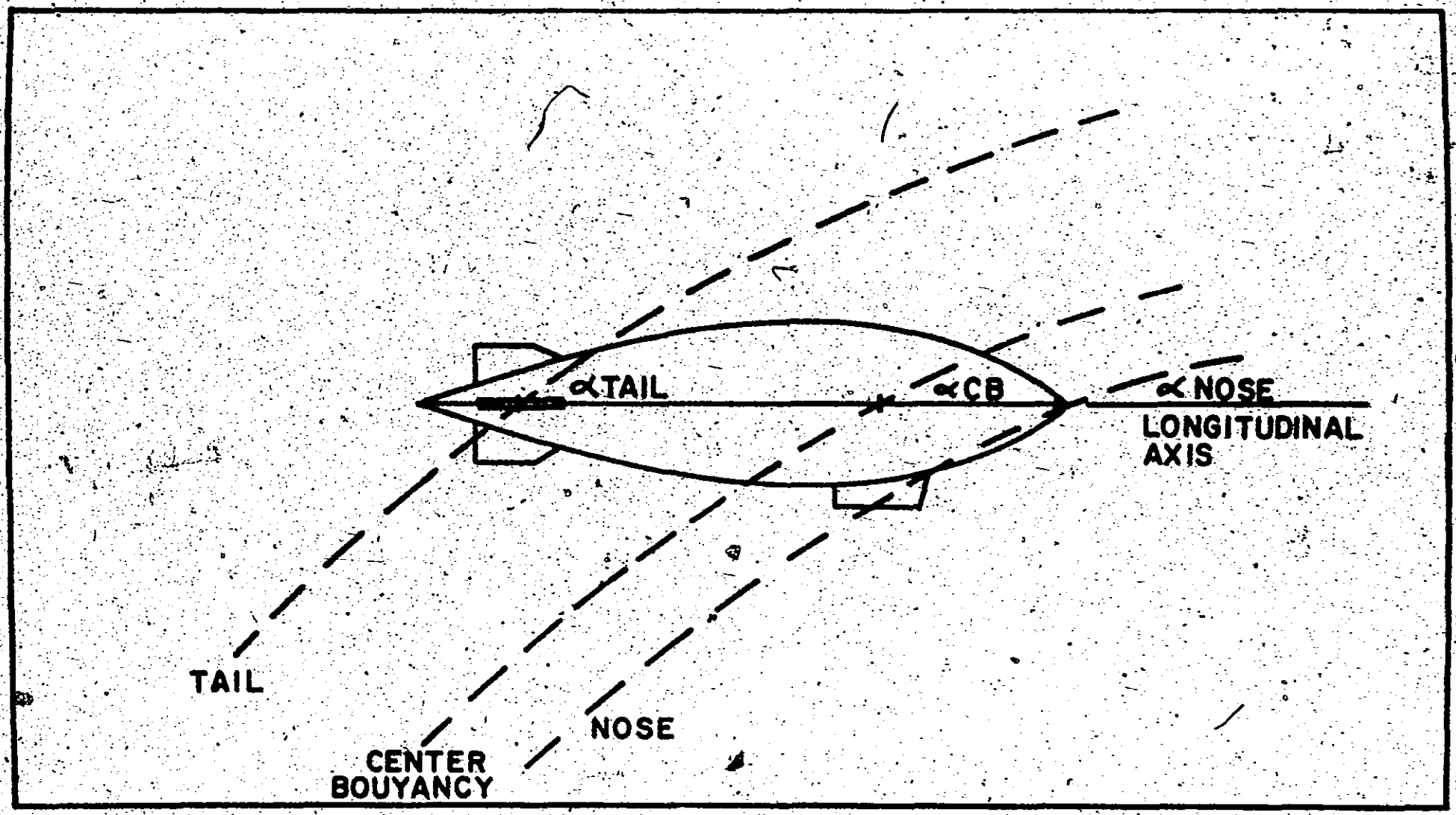

Figure 3.6: Angle of Yaw Variation Over the Airship Length

$$\phi_S = 2\,\phi_{CB} \tag{3.17}$$

The moments produced by these forces are:

(a) Aerodynamic Moment

This is the moment due to the aerodynamic forces on the bare hull.

$$M_A = \sum_{i=1}^{N} F_{HA}(CB - x_i) \tag{3.18}$$

where x_i in this case is the longitudinal distance from the center of bouyancy.

(b) Rudder Moment

Moment due to the application of the rudder

$$M_R = F_R(CPT - CB) \tag{3.19}$$

(c) Fin Moment

The moment due to part of the tail surface force opposing the aerodynamic moment.

$$M_F = -M_A \tag{3.20}$$

(d) Yawing Moment

The damping moment due to the remaining aerodynamic force after the aerodynamic moment has been compensated for.

$$M_Y = \frac{(CB - CP)}{(CPT - CB)} F_{SV} \tag{3.21}$$

Thus for steady motion at a fixed yaw angle

$$M_A + M_R = M_F + M_Y \tag{3.22}$$

The static force analysis is now complete. The forces and moments described are all for no acceleration. However, the analysis must be extended to the accelerated or dynamic situation for this is the situation most commonly encountered by the airships and required to fulfill the specifications outlined in 3.1.

3.3 Dynamic Force and Moment Analysis

The analysis developed in the previous section will now be extended to include acceleration effects. The term "acceleration effects" includes both translational and rotational motion. Rotational acceleration of airships is normally derived from control effects. Control of airships may be subdivided into two classes, directional and altitude. Before developing the equations for these control classes, a brief description of each will be given so that the reader will be familiar with the control effects.

3.3.1 Altitude Control

Altitude control is used to accomplish a change in altitude, either ascending or descending. Assume that the airship is flying in neutral trim and in static equilibrium. It is desired to climb. The elevators are raised. This action causes a rotation to occur and the airship acquires an angle of pitch θ. The moments given by (3.6) act along with the moment due to the vertical deflection of the

elevators. The application of up elevators causes a downward force on the tail surfaces. Eventually the forces due to thrust acting at an angle of $(\gamma + \theta)$, due to the dynamic lift, and due to the fixed horizontal surfaces will overcome this force. However, it should be noted that the airship actually descends a short distance before climbing due to the reaction to the initial elevator force. For this reason extreme caution should be exercised in the use of elevators near the ground. If it is desired to deacend the elevators are lowered. This causes an upward force on the tail surfaces and once again the situation previously described occurs, however with the direction of the forces and initial motion reversed. It should be noted, however, as mentioned when discussing the upsetting moment, that this moment becomes very large and thus once the desired altitude has been attained, it is necessary to climb with elevators down and to descend with the elevators up.

3.3.2 Directional Control

Directional control is attained by use of fins and rudders. It is essential to have a clear concept of the reaction of the airship to rudder control. Figure 3.7 illustrates the action of an airship during a turn and Figure 3.8 shows the action of an airship during obstacle avoidance.

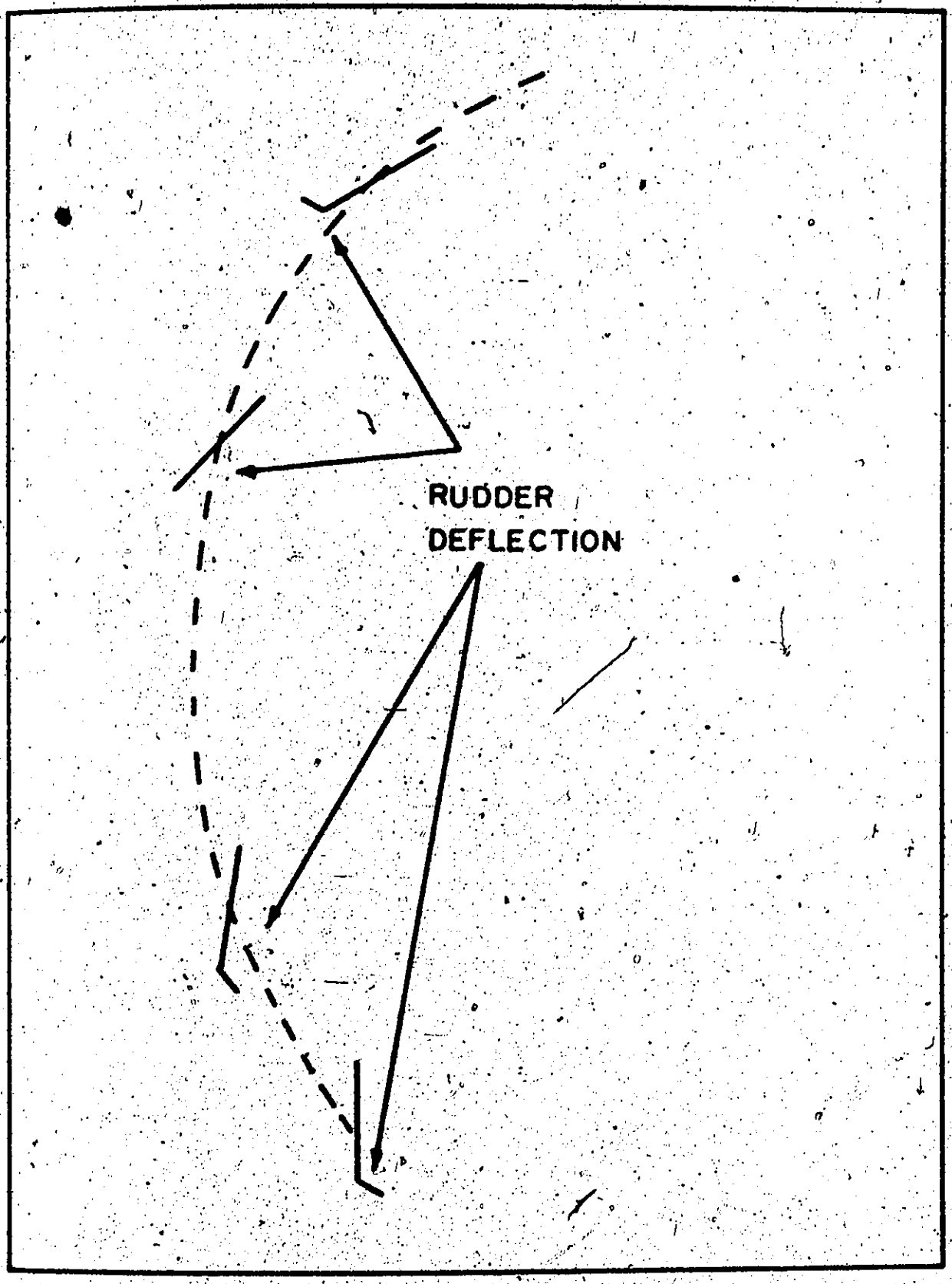

Figure 3.7: Action of an Airship During a Turn

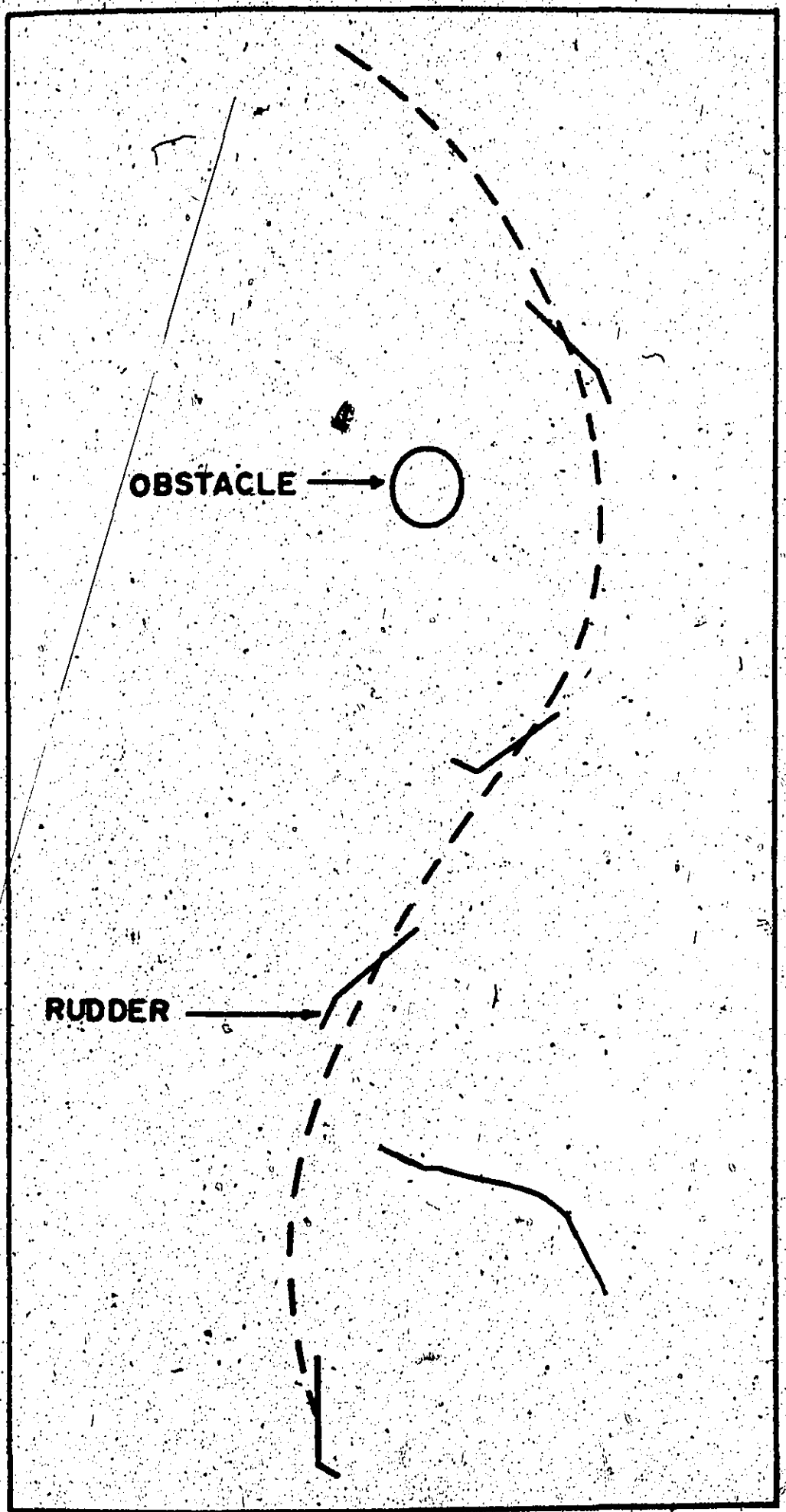

Figure 3.8: Action of an Airship During Obstacle Avoidance

When it is desired to turn to the right, the rudder is deflected to the right. This produces two effects. First an instantaneous force to the left acting on the right side of the rudder. Second, the airship rotates about its center of bouyancy such that the nose swings to the right. Thus initially the airship moves to the left and rotates to the right. The rotation of the nose to the right sets up a centrifugal force acting to the right. As the angle of yaw increases this centrifugal force increases until it is larger than the rudder force and the direction of lateral motion is to the right. However, the yaw moment is also increasing and thus the angular velocity of the airship will eventually decrease until the minimum turning radius is achieved. If the rudder is maintained in the hard right position, or even returned to the neutral position the turning will continue and in order to check this turn it is necessary to move the rudder to the hard left position. The turning radius is governed by the yaw moment and is greater for an airship of large fineness ratio than for one where this ratio is small.

3.3.3 Mechanics Equations

A rigid body having accelerated motion in space must obey the following equations;

$$\left.\begin{aligned} \Sigma F_x &= m\,a_x \\ \Sigma F_y &= m\,a_y \\ \Sigma F_z &= m\,a_z \\ \Sigma M_x &= I_x \dot{W}_x \\ \Sigma M_y &= I_y \dot{W}_y \\ \Sigma M_z &= I_z \dot{W}_z \end{aligned}\right\} \quad (3.23)$$

Where I_x, I_y, and I_z are the sums of the mass moments of inertia of the various components of the body reference to a set of axes with their origin at the center of rotation by use of the parallel axis transformation.

$$\left.\begin{aligned} I_x' &= I_x + m\,(y_c^2 + z_c^2) \\ I_y' &= I_y + m\,(x_c^2 + z_c^2) \\ I_z' &= I_z + m\,(x_c^2 + y_c^2) \end{aligned}\right\} \quad (3.24)$$

The response of an airship to an upsetting or a correcting moment is a function of the mass moment of inertia of the system. The mass moment of inertia of the system is composed of the inertial characteristics of the envelope, the enclosed gas, the payload, the propulsion devices, and any other independent major structural part. To simplify the problem the mass of several individual components of the airships have been taken as point loads acting through the center of mass of the particular component. Thus for these components:

$$I_x = 0$$

$$I_y = 0$$

$$I_z = 0$$

The parts of the airship treated in this manner include:

1) the nose cone,

2) the cabin,

3) the engines,

and 4) the tail.

This is a reasonable simplification as the actual inertia of these components will only tend to make the airship more stable than the model would indicate.

The remaining moments of inertia, those related to the envelope and the enclosed gas, will be analysed about a set of axes perpendicular to the central axes and located at $x = 0$. General Mills[28] developed a set of equations, to determine these moments of inertia, which are quite convenient to use in conjunction with a digital computer.

The mass moment of inertia of the enclosed gas is given by:

$$I_x = \frac{\pi m\,(N+M)^{4(N+M)}}{32 P^{4N} N^{4N} M^{4M}} \cdot \frac{\Gamma(4N+1)\,\Gamma(4M+1)}{\Gamma(4N+4M+2)} L^5 \qquad (3.25)$$

$$I_y = I_z = I_x + \frac{\pi m\,(N+M)^{2(N+M)}}{4 P^{2N} N^{2N} M^{2M}} \cdot \frac{\Gamma(2N+3)\,\Gamma(2M+1)}{\Gamma(2N+2M+4)} L^5 \qquad (3.26)$$

All the factors used in these equations are as defined in Chapter 2.

The mass moment of inertia of the envelope is given by:

$$I_x = \frac{\pi m\,(N+M)^{3(N+M)}}{4P^{3N}3^{3N}M^{3M}} \cdot \frac{\Gamma(3N+1)\,\Gamma(3M+1)}{\Gamma(3N+3M+2)} L^4 \qquad (3.27)$$

$$I_y = I_z = \frac{I_x}{2} + \frac{\pi m\,(N+M)^{(N+M)}}{P\,N^N\,M^M} \cdot \frac{\Gamma(N+3)\,\Gamma(M+1)}{\Gamma(N+M+4)} L^4 \qquad (3.28)$$

As these moments of inertia have been calculated with respect to a set of co-ordinate axes with their origin at the nose of the airship ($x = 0$) a transformation must be performed to a set of axes whose origin is the point about which rotation occurs. This is done using the parallel axis transformation described previously. Those components whose moment of inertia about their own axis was taken as zero must also be referenced to the rotation center using the parallel axis transformation and these will thus acquire a moment of inertia by means of the quantities

$$m(x_c^2 + y_c^2)$$

$$m(x_c^2 + z_c^2)$$

$$m(y_c^2 + z_c^2)$$

The masses used in these equations are the individual masses of the components and the mass used in the mechanics equations is the system mass.

$$m = \frac{W_{system}}{G} \qquad (3.28)$$

G being the gravitational constant and W_{system} the total weight of the airship.

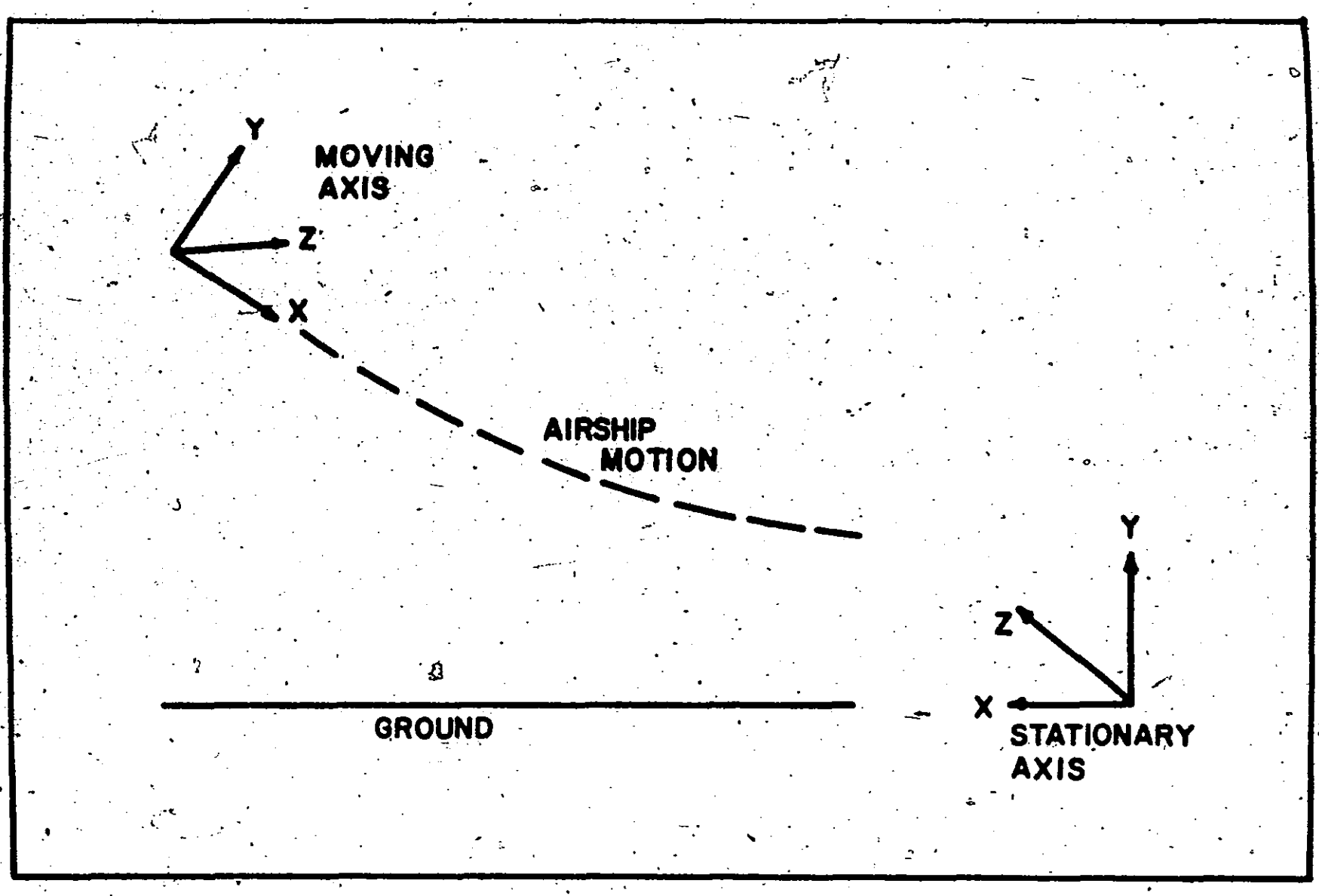

Figure 3.9: Modified Set of Axis

3.3.4 Forces and Moments Acting on the Airship

The forces and moments acting on the airship during accelerated motion are essentially similar to those discussed in the static case. However, both the linear acceleration and the angular acceleration which may occur cause the forces and angles to change continuously. Hence, when considering accelerated motion it is convenient to consider very small time increments and to consider the situations as being static within these time increments. The acceleration effects can be superposed when moving from one time interval to the next.

3.3.5 Determination of the Accelerations

Rotational and translational accelerations will be examined as the airship rotates about its center of gravity. Thus a modified set of axes is now introduced and illustrated in Figure 3.9. This new set of axes makes it possible to seperate the effects on the airship and the motion with respect to the original horizontal axes.

(a) Translational Acceleration

(1) X direction

From the mechanics equations

$$a_x = \frac{\Sigma P_x}{m} \qquad (3.30)$$

where

$$\Sigma P_x = [(P_d+P_{ds}) \cos(\gamma) + (P_L - P_R + P_S) \sin(\gamma)] \cos(\phi + \theta) + [P_C + P_R] \sin(\phi + \theta) \quad (3.31)$$

(2) Y direction

Similarly in the y direction,

$$a_y = \frac{\Sigma P_y}{m} \quad (3.32)$$

where

$$\Sigma P_y = [P_E - P_W] + P_L \cos(\gamma) + P_S \cos(\gamma) + P_e \cos(\gamma) + P_t \sin(\epsilon) - (P_d + P_{ds}) \sin(\gamma) \quad (3.33)$$

and ϵ is defined by the cases discussed in section 3.2.4.

i.e. $\epsilon = \gamma + \theta$ when climbing
$= \gamma - \theta$ when diving
} in a heavy condition,

$\epsilon = \gamma - \theta$ when climbing
$= \gamma + \theta$ when diving
} in a light condition,

and $\epsilon = 0$ in a neutral condition.

(3) Z direction

Similarly in the z direction

$$a_z = \frac{\Sigma P_z}{m} \quad (3.34)$$

where

$$\Sigma P_z = [(P_d + P_{ds}) \cos(\gamma) + (P_L + P_e + P_s) \sin(\gamma)] \sin(\phi + \theta) + [P_C + P_R] \cos(\phi + \theta). \quad (3.35)$$

NOTE: the co-ordinates x, y, z used in these equations are referenced to the fixed ground axes. When determining the velocity of the airship, and all the quantities that it affects, it is necessary to reference this to the moving axis of the airship. Hence,

$$a_{\substack{\text{Airship}\\\text{Forward}}} = \frac{(F_d + F_{ds}) + (F_w - F_L)\sin(\gamma) - F_t\cos(\gamma)}{m} \qquad (3.36)$$

and

$$V_{\substack{\text{Airship}\\\text{Forward}}} = \int_0^t a\,dt = at + V_o \,. \qquad (3.37)$$

The sum of the forces acting on the airship with respect to its co-ordinate axes are:

$$\left.\begin{aligned} \Sigma F_x &= F_d + F_{ds} - F_t \\ \Sigma F_y &= F_g - F_w + F_L + F_s + F_e \\ \Sigma F_z &= F_C + F_R \end{aligned}\right\} \qquad (3.38)$$

(b) Rotational Acceleration

(1) Rotation about the z axis

$$\dot{W}_z = \frac{\Sigma M_z}{I_z}, \qquad (3.39)$$

where

$$\Sigma M_z = M_u + M_{td} + M_{SR} + M_e + M_S . \qquad (3.40)$$

(ii) Rotation about the Y axis

$$\dot{W}_y = \frac{\Sigma M_y}{Iy} \qquad (3.41)$$

where

$$\Sigma M_y = M_A + M_R + M_F + M_y . \qquad (3.42)$$

(iii) Rotation about the x axis

As explained previously, stability in roll in airships is taken care of almost automatically. Hence acceleration about this axis will be neglected.

3.3.6 Determination of Position

The trajectories can be determined if the position can be determined at all times. Once the accelerations have been determined the velocity can be determined from

$$V = \int_{t_1}^{t_2} a\,dt = aA + V_{t_1} \qquad (3.37)$$

and hence the position referenced to some initial co-ordinate

$$P = \int_{o}^{t} V dt = \frac{1}{2} at^2 + V_o t + \rho_o \qquad (3.43)$$

where ρ_o = position at the previous time interval

V_o = velocity at the previous time interval.

The velocities and positions must be determined for the x,y and z co-ordinates. Once these co-ordinates have been obtained and evaluated to ascertain that the correct maneuvers

have been carried out it is now possible to evaluate the flight forces acting on the airship, as expressed by (3.38), and thus satisfy the initial requirements.

3.4 User Oriented Computer Programme Description

The theory which has been presented in the previous sections lends itself to adaptation to computer usage. In order to both aid the designer and to submit as part of compliance report required by the Ministry of Transport, a user oriented computer programme has been developed. This programme computes the trajectories based on the presented theory and also calculates the forces acting on the airship. The designer may change any of the listed input variables in order to examine various design possibilities. Figure 3.10 illustrates the programme set up. A complete listing of the programme is included in Appendix E. The programme does not simulate the exact conditions that prevail in the airship at various times. 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 fore-and-aft sloshing of the air in the ballonets. It is also assumed that the designer will provide two horizontal tail surfaces and two vertical tail surfaces. If this is not the case, then the quantities involving the tail forces must be suitably altered.

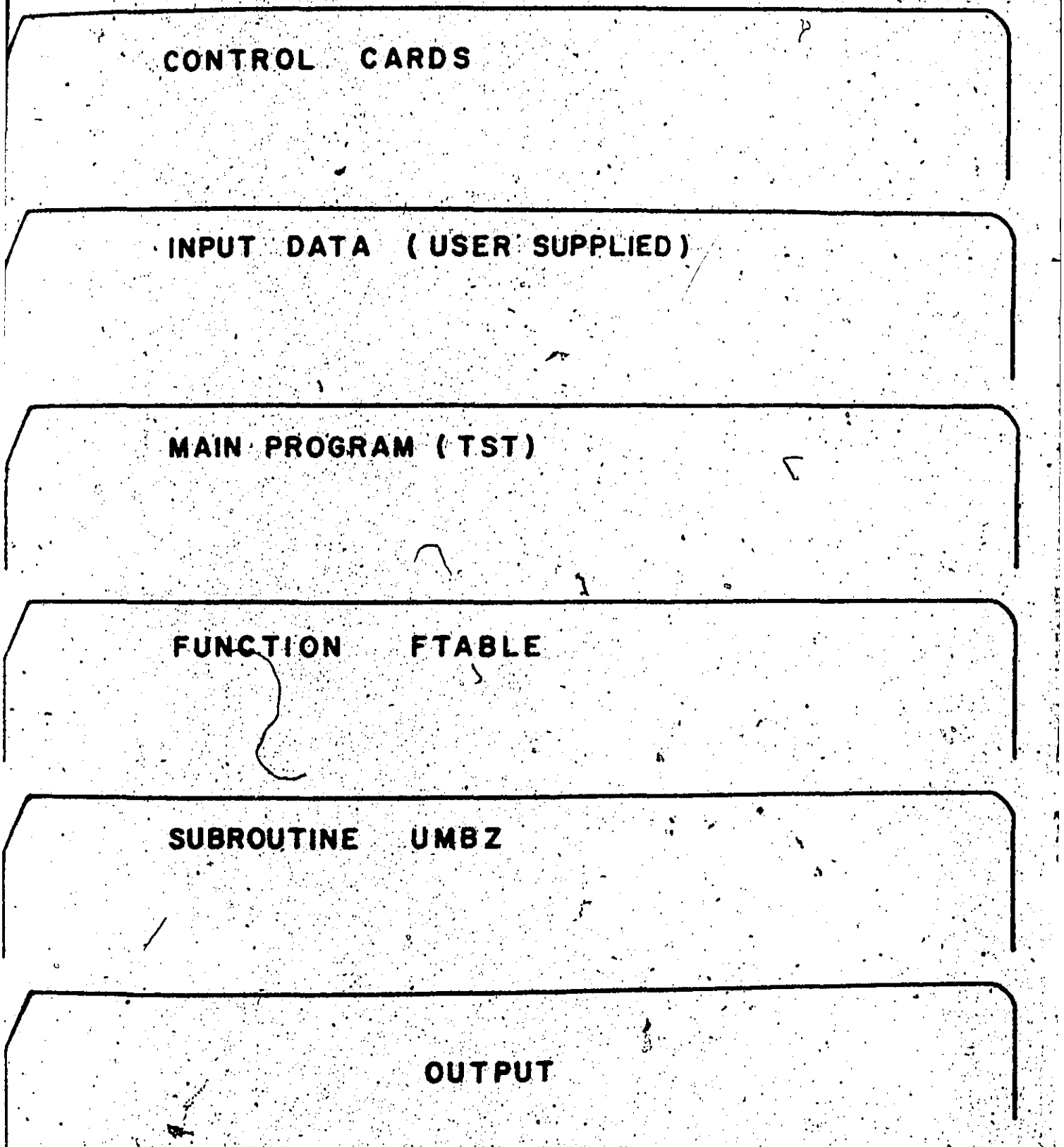

Figure 3.10: Trajectory Programme Input Deck Setup

The user input variables are as follows:

(1)	XN	Airship shape parameter N
(2)	XM	Airship shape parameter M
(3)	XL	Airship length in feet
(4)	F	Airship fineness ratio
(5)	VOL	Airship lifting gas volume in cubic feet
(6)	VOLT	Airship total volume in cubic feet
(7)	XT	Location of the center of gravity of the tail surfaces in the x direction
(8)	YT	Location of the center of gravity of the tail surfaces in the y direction
(9)	ZT	Location of the center of gravity of the tail surfaces in the z direction
(10)	XP	Location of the nose cone center of gravity in the x direction
(11)	YN	Location of the nose cone center of gravity in the y direction
(12)	ZN	Location of the nose cone center of gravity in the z direction
(13)	XE	Location of the engine center of gravity in the x direction
(14)	YE	Location of the engine center of gravity in the y direction
(15)	ZE	Location of the engine center of gravity in the z direction
(16)	XCAB	Location of the cabin center of gravity in the x direction
(17)	YCAB	Location of the cabin center of gravity in the y direction
(18)	ZCAB	Location of the cabin center of gravity in the z direction

NOTE: All these locations measured in feet from the nose of the airship

(19)	WCAB	The airship cabin weight in lbs.
(20)	WT	The tail weight in lbs.
(21)	WN	The nose weight in lbs.
(22)	EW	The engine weight in lbs.
(23)	WE	The airship envelope weight in lbs.
(24)	TOW	The airship total weight in lbs.
(25)	CHH	The average chord length of the horizontal tail surfaces in feet
(26)	CHV	The average chord length of the vertical tail surfaces in feet.
(27)	TL	The span of the horizontal surface (1) in feet
(28)	RL	The span of the vertical surface (1) in feet
(29)	DH	The maximum thickness of the airfoil in feet
(30)	CL	Airfoil lift coefficient
(31)	AL	The pitch angle corresponding to each lift coefficient
(32)	CD	Airfoil drag coefficient
(33)	AD	The pitch angle corresponding to each drag coefficient
(34)	CLD	The airfoil lift coefficient when using a flap system
(35)	ALD	The pitch angle corresponding to each lift coefficient
(36)	YMDR	The maximum descent rate in ft/sec
(37)	YMC	The maximum climb rate in ft/sec

(38) WX — The airship envelope material weight in ozs/ square yards.

Optionally the user may also introduce the following quantities:

(39) XXIN — The mass moment of inertia of the airship nose - x direction

(40) YYIN — The mass moment of inertia of the airship nose - y direction

(41) ZZIN — The mass moment of inertia of the airship nose - z direction

(42) XXIC — The mass moment of inertia of the cabin - x direction

(43) YYIC — The mass moment of inertia of the cabin - y direction

(44) ZZIC — The mass moment of inertia of the cabin - z direction

(45) XXITA — The mass moment of inertia of the tail surfaces - x direction

(46) YYITA — The mass moment of inertia of the tail surfaces - y direction

(47) ZZITA — The mass moment of inertia of the tail surfaces - z direction

(48) XXIE — The mass moment of inertia of the engines - x direction

(49) YYIE — The mass moment of inertia of the engines - y direction

(50) ZZIE — The mass moment of inertia of the engines - z direction

These quantities unless specifically otherwise defined are set to 0 by the programme. The input quantities should be entered into the programme via data cards placed after the appropriate comment cards.

For example variable (24) TOW should be entered after the cards;

WEIGHT DATA

```
DATA TOW/6000.0/
DATA .....
```

3.5 Programme Results

The programme has been used to evaluate the CANADIAN AIRSHIP DEVELOPMENT CORPORATION design CAS-1 in order to file a compliance report as required by the Ministry of Transport regulations. Table 3.3 presents the input quantities. Table 3.4 presents selected trajectories as well as the matching angles and velocities, both linear and angular. Finally Table 3.5 presents the same selected trajectories and the corresponding forces in the x, y, and z directions. Figures 3.11 through 3.15 illustrate several of the trajectories calculated by the programme.

TABLE 3.3: COMPUTER TRAJECTORY TEST INPUT VARIABLES

Quantity	Value
XN	0.4
XM	0.6
XL	117.0
F	3.0
VOL	80087
VOLT	91000
XT	93.0
YT	0.0
ZT	25.0
XP	5.0
XN	0.0
ZN	0.0
XE	52.6
YE	-25.0
ZE	20.0
XCAB	48.8
YCAB	-25.0
ZCAB	0.0
WCAB	3274.0
WT	500.0
WN	200.0
EW	400.0
WE	922.0
TOW	5400.0
CHH	17.2
CHV	12.0
TL	14.0
RL	15.0
DH	2.0
WX	11.40
YMDR	40.0
YMC	40.0

AL 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0

AD 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0

ALD -14.0, -12.0, -10.0, -8.0,.....0.0, 2.0,....10.0

CL 0.1, 0.2, 0.3, 0.4,....1.0

CD 0.0092, 0.0095, 0.010, 0.0119, 0.0120, 0.0130, 0.0145, 0.0166, 0.0200

CLD -0.4, 0.0, 0.25, 0.48, 0.70, 0.95, 1.15, 1.35, 1.55, 1.75, 1.95, 2.10, 1.98

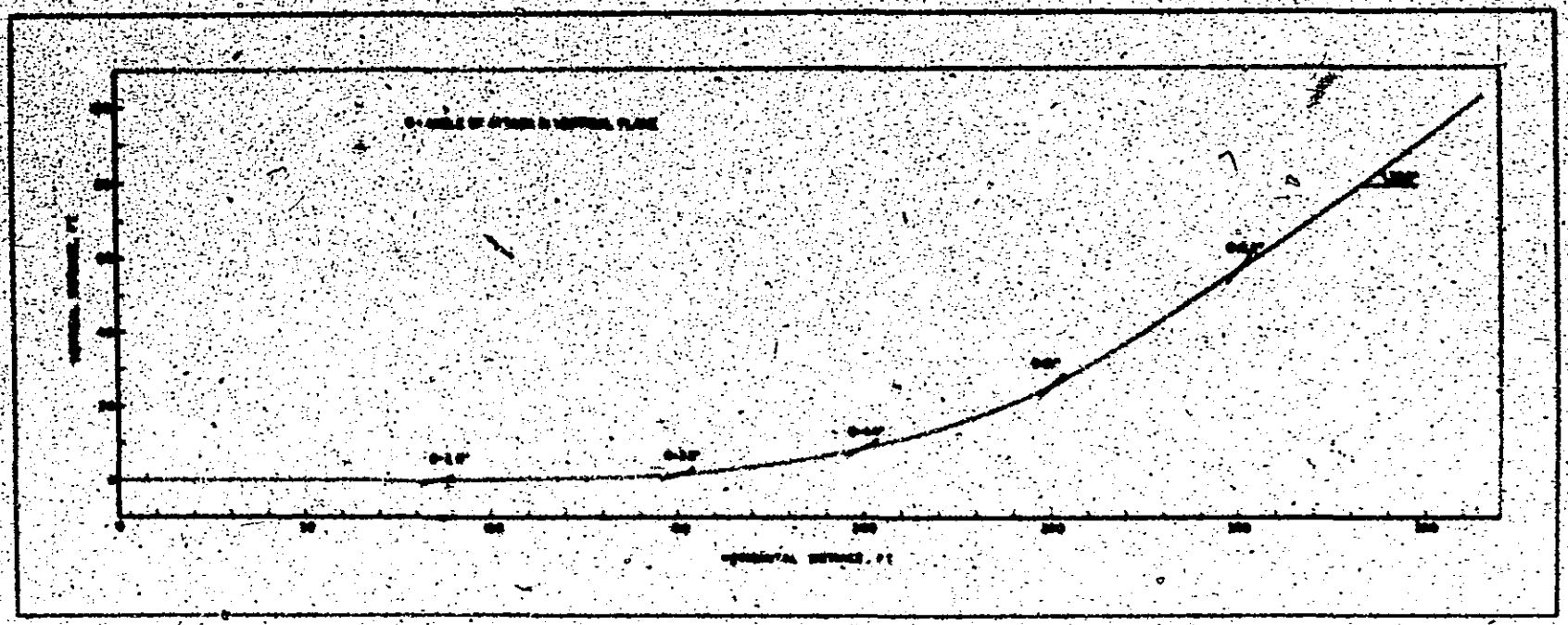

Figure 3.11: Graphical Illustration of the Programme Output-Take-off Trajectory

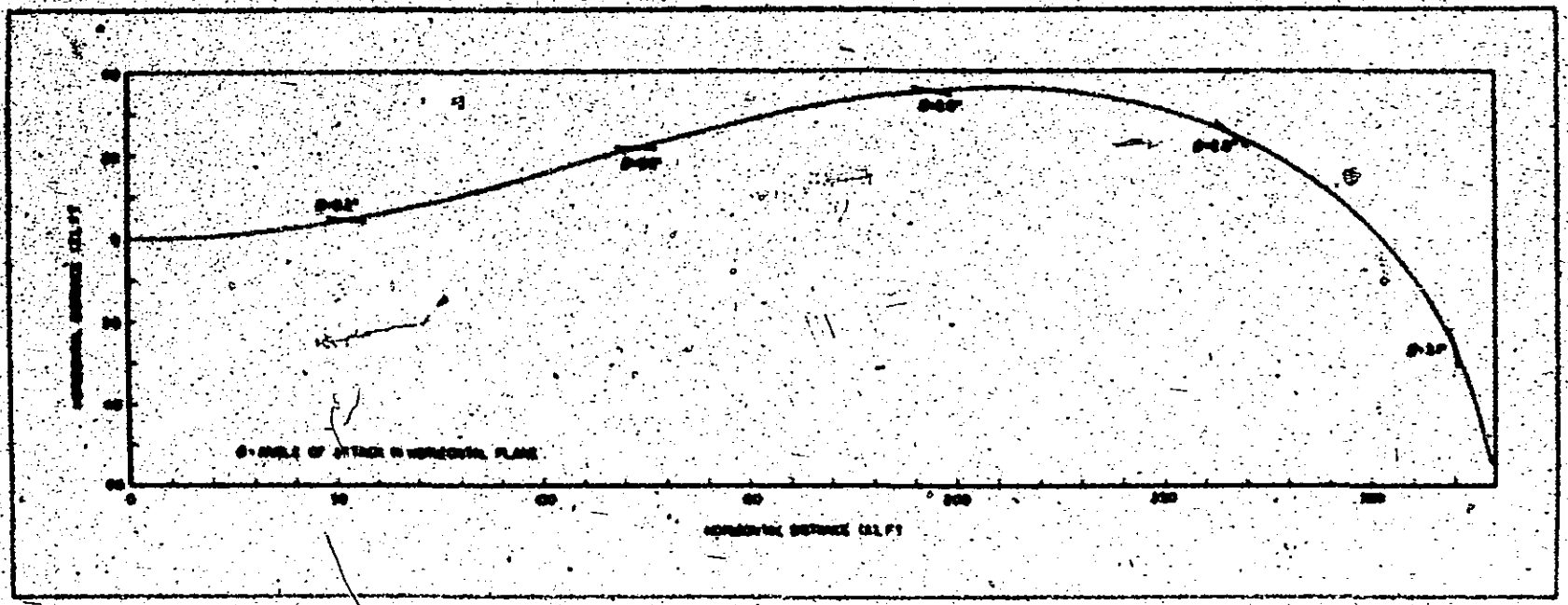

Figure 3.12: Graphical Illustration of the Programme Output- Full Rudder Until a 75° Turn Achieved

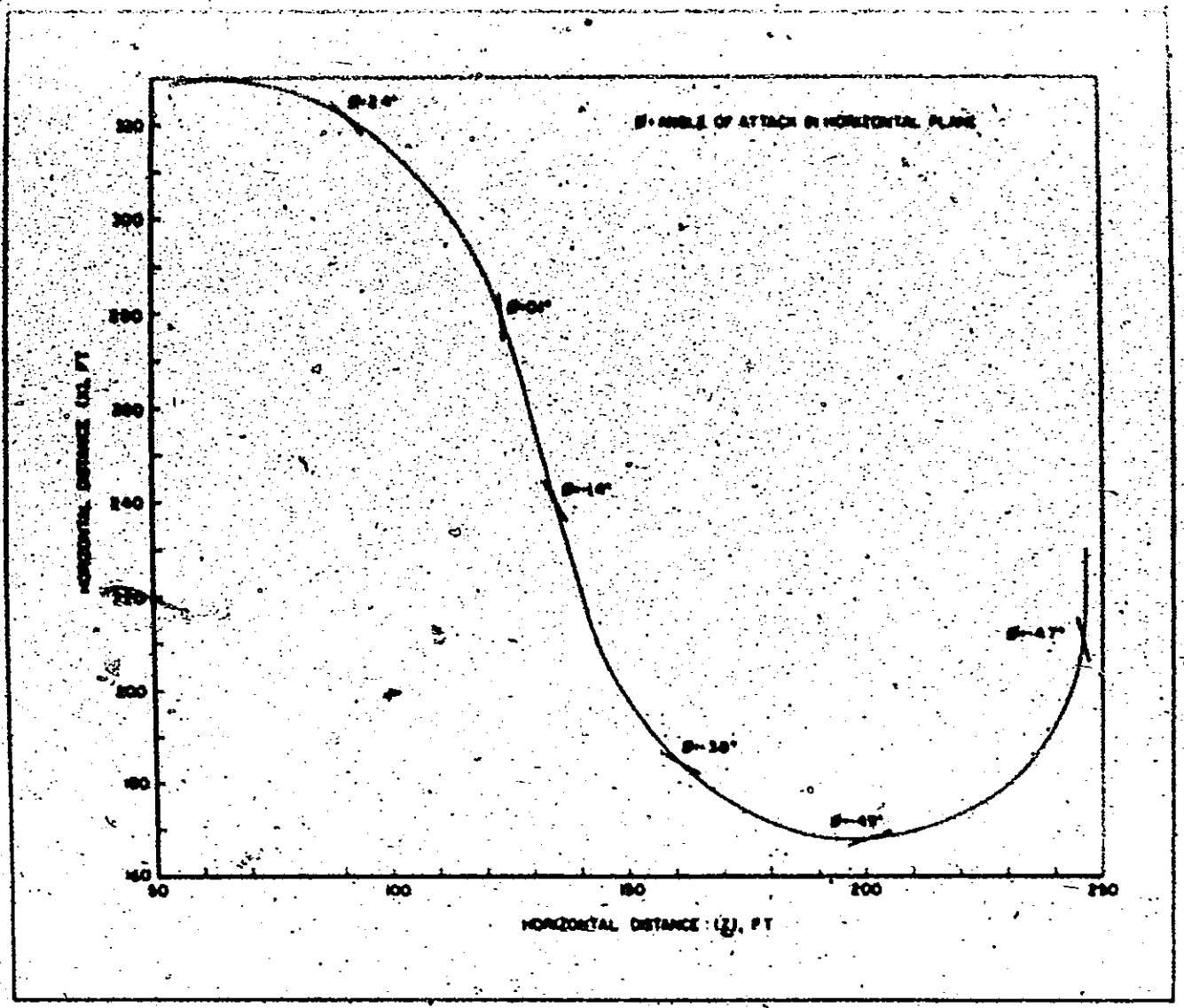

Figure 3.13: Graphical Illustration of the Programme Output- Full Opposite Rudder Until the Original Heading Regained

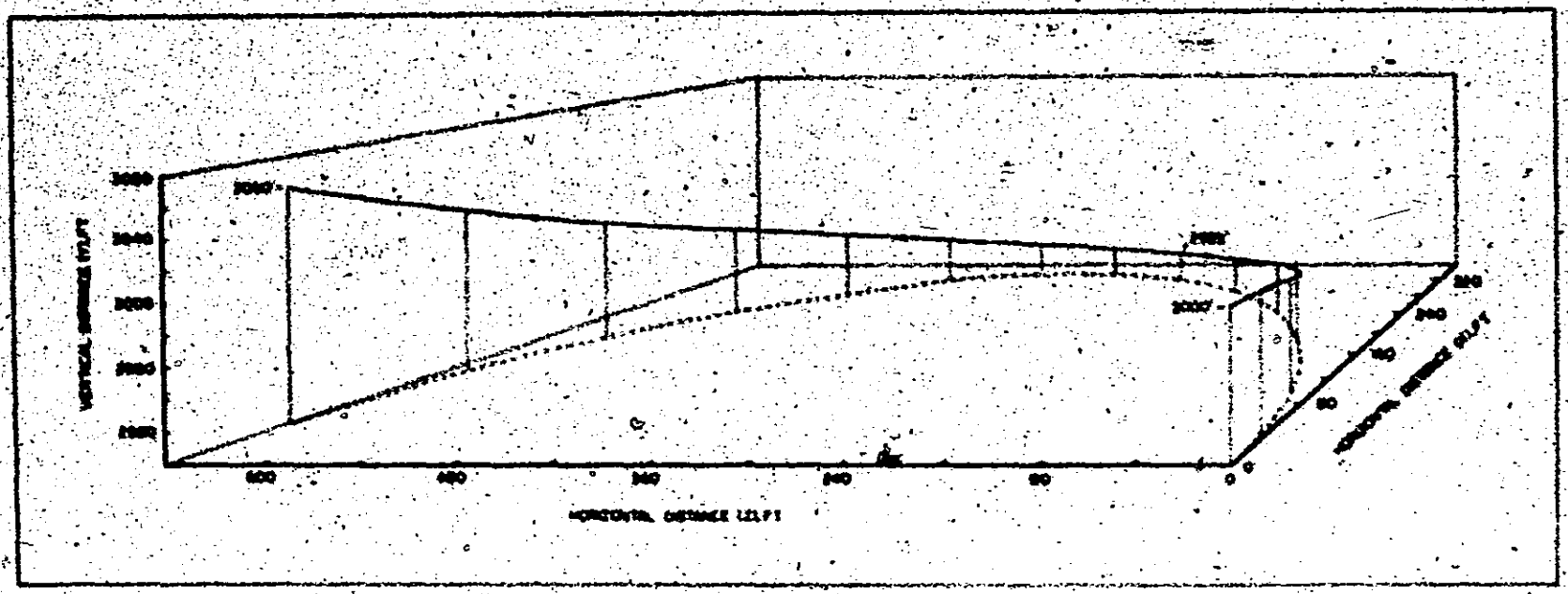

Figure 3.14: Graphical Illustration of the Programme Output- Full-up Elevators and a Steady State Turn From 0 to 180 degrees

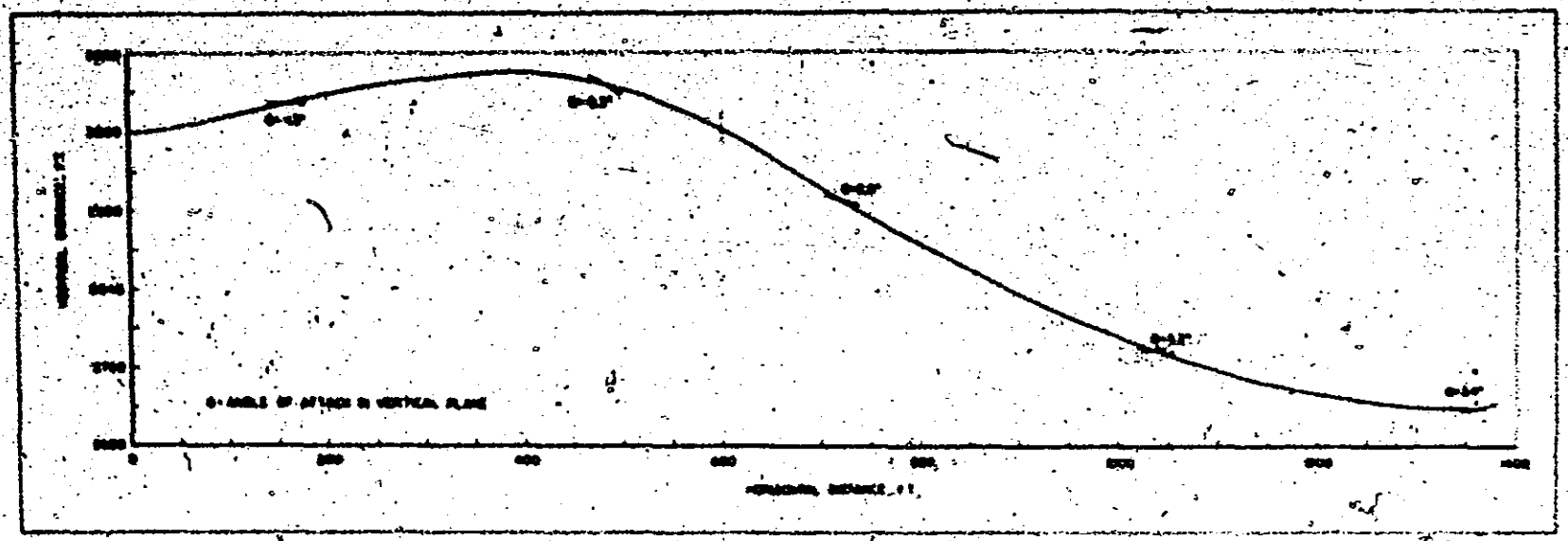

Figure 3.15: Graphical Illustration of the Programme Output-Full Down Elevator Until Maximum Descent Rate Achieved and Then Full Up Elevator Until Descent Rate Equals Zero

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	γ	φ	β
TAKE OFF AND CLIMB OVER 100 FT. OBSTACLE									
-.025	0.000	0.000	-.253	-1.812	0.000	0.000	0.000	0.000	0.000
-.005	0.000	0.000	-.053	0.000	0.000	.000	0.000	0.000	0.000
-.012	0.000	0.000	-.063	0.000	0.000	.000	0.000	0.000	0.000
-.022	0.000	0.000	-.115	0.000	0.000	.001	0.000	0.000	0.000
-.035	0.000	0.000	-.149	0.000	0.000	.001	0.000	0.000	0.000
-.052	0.000	0.000	-.185	0.000	0.000	.001	0.000	0.000	0.000
-.072	0.000	0.000	-.224	0.000	0.000	.002	0.000	0.000	0.000
-.097	0.000	0.000	-.266	0.000	0.000	.002	0.000	0.000	0.000
-.126	0.000	0.000	-.312	0.000	0.000	.003	0.000	0.000	0.000
-.159	0.000	0.000	-.363	0.000	0.000	.004	0.000	0.000	0.000
-.198	0.000	0.000	-.419	0.000	0.000	.005	0.000	0.000	0.000
-.243	0.000	0.000	-.482	0.000	0.000	.006	0.000	0.000	0.000
-.295	0.000	0.000	-.554	0.000	0.000	.007	0.000	0.000	0.000
-.356	0.000	0.000	-.639	0.000	0.000	.009	0.000	0.000	0.000
-.426	0.000	0.000	-.740	0.000	0.000	.010	0.000	0.000	0.000
-.504	0.000	0.000	-.860	0.000	0.000	.012	0.000	0.000	0.000
-.599	0.000	0.000	-1.035	0.000	0.000	.014	0.000	0.000	0.000
-.715	0.000	0.000	-1.268	0.000	0.000	.017	0.000	0.000	0.000
-.869	0.000	0.000	-1.794	0.000	0.000	.021	0.000	0.000	0.000
-1.074	0.000	0.000	-2.300	0.000	0.000	.028	0.000	0.000	0.000
-1.329	0.000	0.000	-2.806	0.000	0.000	.032	0.000	0.000	0.000
-1.635	0.000	0.000	-3.311	0.000	0.000	.039	0.000	0.000	0.000
-1.992	0.000	0.000	-3.816	0.000	0.000	.048	0.000	0.000	0.000
-2.398	0.000	0.000	-4.320	0.000	0.000	.058	0.000	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	ψ	φ	β
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x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Y	φ	B
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-[illegible]	[illegible]	[illegible]	-[illegible]	0.000	0.000	2.0[illegible]	0.000	0.000	0.000
-91.127	.001	0.000	-24.276	.011	0.000	2.104	.010	0.000	0.000
-[illegible]	.004	0.000	-27.717	.039	0.000	2.211	.032	0.000	0.000
-97.[illegible]	.009	0.000	-30.198	.066	0.000	2.300	.096	0.000	0.000
-100.10[illegible]	.017	0.000	-30.592	.116	0.000	2.369	.173	0.000	0.000
-103.189	.032	0.000	-31.066	.177	0.000	2.4[illegible]	.272	0.000	0.000
-106.313	.051	0.000	-31.657	.253	0.000	2.513	.395	0.000	0.000
-109.400	.083	0.000	-31.885	.360	0.000	2.591	.540	0.000	0.000
-112.490	.123	0.000	-32.300	.461	0.000	2.653	.709	0.000	0.000
-115.942	.178	0.000	-32.718	.573	0.000	2.720	.902	0.000	0.000
-119.[illegible]	[illegible]	0.000	-33.[illegible]	.717	0.000	2.7[illegible]	1.1[illegible]	0.000	0.000
-122.[illegible]	[illegible]	0.000	-33.[illegible]	.871	0.000	2.871	1.361	0.000	0.000
-125.[illegible]	[illegible]	0.000	-34.[illegible]	1.067	0.000	2.947	1.628	0.000	0.000
-128.[illegible]	[illegible]	0.000	-34.471	1.262	0.000	3.022	1.919	0.000	0.000
-132.[illegible]	.[illegible]	0.000	-34.7[illegible]	1.457	0.000	3.097	2.216	0.000	0.000
-136.310	.626	0.000	-35.181	1.691	0.000	3.174	2.579	0.000	0.000
-139.853	1.002	0.000	-35.560	1.967	0.000	3.250	2.967	0.000	0.000
-143.420	1.2[illegible]	0.000	-35.[illegible]	2.294	0.000	3.324	3.361	0.000	0.000
-147.[illegible]	1.460	0.000	-36.295	2.622	0.000	3.400	3.[illegible]	0.000	0.000
-150.685	1.716	0.000	-36.653	2.863	0.000	3.476	4.209	0.000	0.000
-154.309	2.018	0.000	-37.012	3.100	0.000	3.553	4.660	0.000	0.000
-158.087	2.356	0.000	-37.356	3.[illegible]	0.000	3.62[illegible]	5.103	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Y	φ	B
-161.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.700	6.711	0.000	[illegible]
-165.[illegible]	[illegible]	[illegible]	-38.[illegible]16	4.362	0.000	3.700	6.260	0.000	0.000
-169.[illegible]	[illegible]	0.000	-38.325	4.802	0.000	3.[illegible]	6.848	0.000	0.000
-173.[illegible]	[illegible]	0.000	-38.[illegible]	5.[illegible]	0.000	3.[illegible]	7.[illegible]	0.000	0.000
-177.[illegible]	[illegible]	0.000	-38.[illegible]	5.760	0.000	4.[illegible]	8.[illegible]	0.000	0.000
-181.[illegible]	5.269	0.000	-39.179	6.271	0.000	4.079	8.760	0.000	0.000
-185.[illegible]	5.91[illegible]	0.000	-39.436	6.811	0.000	4.152	9.[illegible]	0.000	0.000
-188.956	6.624	0.000	-39.672	7.376	0.000	4.2[illegible]	10.172	0.000	0.000
-192.[illegible]	7.390	0.000	-39.8[illegible]	7.9[illegible]	0.000	4.2[illegible]	10.[illegible]	0.000	0.000
-196.934	[illegible].217	0.000	-40.095	8.542	0.000	4.367	11.695	0.000	0.000
-210.952	9.1[illegible]	0.000	-40.278	9.[illegible]	0.000	4.4[illegible]	12.408	0.000	0.000
-20[illegible]	10.06[illegible]	0.000	-40.[illegible]	9.[illegible]	0.000	4.5[illegible]	1[illegible].327	0.000	0.000
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-213.10[illegible]	[illegible]	[illegible]	-40.[illegible]17	11.[illegible]	0.000	[illegible]	1[illegible].0[illegible]	0.000	0.000
-217.[illegible]	[illegible]	[illegible]	-40.[illegible]	12.0[illegible]	0.000	4.70[illegible]	15.[illegible]	0.000	0.000
-221.[illegible]	[illegible]	[illegible]	-40.[illegible]	12.[illegible]	[illegible]	4.765	16.[illegible]	0.000	0.000
-225.[illegible]	[illegible]	[illegible]	-40.[illegible]	13.[illegible]	[illegible]	4.[illegible]	17.[illegible]	0.000	0.000
-229.[illegible]	[illegible].462	0.000	-40.914	14.[illegible]	0.000	4.[illegible]	18.[illegible]	0.000	0.000
-233.[illegible]	[illegible].780	0.000	-40.901	15.166	0.000	4.942	19.[illegible]	0.000	0.000
-237.617	[illegible].342	0.000	-40.[illegible]	16.[illegible]	0.000	4.[illegible]	20.[illegible]	0.000	0.000
-241.[illegible]	[illegible]	0.000	-40.7[illegible]	16.[illegible]	0.000	5.050	[illegible].[illegible]	0.000	0.000
-245.77[illegible]	[illegible].727	0.000	-40.[illegible]1	17.[illegible]	0.000	5.099	23.125	0.000	0.000
-249.811	[illegible].588	0.000	-40.167	1[illegible].374	0.000	5.1[illegible]	[illegible].747	0.000	0.000
-253.802	[illegible].600	0.000	-39.6[illegible]	20.[illegible]	0.000	5.163	[illegible].770	0.000	0.000
-257.[illegible]	[illegible]	[illegible]	-3[illegible]	[illegible].323	[illegible]	5.216	[illegible].763	0.000	[illegible]
-261.[illegible]15	[illegible]	[illegible]	-[illegible].976	[illegible]	[illegible]	5.216	[illegible].717	0.000	[illegible]
-265.[illegible]	[illegible].469	[illegible]	-38.614	[illegible].[illegible]11	[illegible]	5.[illegible]	[illegible]	[illegible]	[illegible]

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	γ	φ	β
-2[illegible]	[illegible]	[illegible]	-[illegible]	24.[illegible]	[illegible]	5.216	31.474	0.000	[illegible]
-273.[illegible]	[illegible]	[illegible]	-[illegible]	24.517	[illegible]	5.216	32.149	0.000	0.000
-277.122	[illegible]	[illegible]	-[illegible]	24.769	0.000	5.216	32.315	0.000	0.000
-281.[illegible]	[illegible]	0.000	-39.201	25.025	0.000	5.216	32.4[illegible]	0.000	0.000
-28[illegible]	[illegible]	0.000	-39.[illegible]	25.265	0.000	5.216	32.64[illegible]	0.000	0.000
-288.[illegible]	[illegible]	0.000	-39.[illegible]	25.549	0.000	5.216	32.842	0.000	0.000
-292.[illegible]	[illegible]	0.000	-39.[illegible]	25.817	0.000	5.216	33.070	0.000	0.000
-296.[illegible]	[illegible]	0.000	-39.7[illegible]	26.089	0.000	5.216	33.224	0.000	0.000
-30[illegible]	[illegible]	0.000	-40.[illegible]	26.364	0.000	5.216	33.423	0.000	0.000
-30[illegible]	[illegible]	[illegible]	-[illegible]	26.643	0.000	5.216	33.628	0.000	[illegible]
-30[illegible]	[illegible]	0.000	-40.[illegible]	26.925	0.000	5.216	33.837	0.000	0.000
-312.[illegible]	[illegible]	0.000	-40.127	27.211	0.000	5.216	34.051	0.000	0.000
-316.[illegible]	[illegible]	0.000	-40.[illegible]	27.500	0.000	5.216	34.270	0.000	0.000
-3[illegible]	[illegible]	0.000	-40.363	27.791	0.000	5.216	34.494	0.000	0.000
-324.[illegible]	[illegible]	0.000	-40.382	28.086	0.000	5.216	34.722	0.000	0.000
-328.[illegible]	[illegible]	0.000	-40.[illegible]	28.384	0.000	5.216	34.954	0.000	0.000
-332.[illegible]	[illegible]	0.000	-40.725	28.686	0.000	5.216	35.190	0.000	0.000
-337.[illegible]	[illegible]	0.000	-40.[illegible]	28.987	0.000	5.216	35.430	0.000	0.000
-341.[illegible]	[illegible]	0.000	-40.[illegible]	29.293	0.000	5.216	35.675	0.000	0.000
-345.[illegible]	[illegible]	0.000	-40.[illegible]	29.60[illegible]	0.000	5.216	35.923	0.000	0.000
-349.[illegible]	[illegible]	0.000	-40.[illegible]	29.911	0.000	5.216	36.176	0.000	0.000
-353.[illegible]	[illegible]	0.000	-40.787	30.223	0.000	5.216	36.429	0.000	0.000
-357.[illegible]	[illegible]	0.000	-40.[illegible]	30.538	0.000	5.216	36.688	0.000	0.000
-361.[illegible]	[illegible]	0.000	-40.[illegible]	30.855	0.000	5.216	36.949	0.000	0.000
-365.[illegible]	[illegible]	0.000	-40.[illegible]	31.173	0.000	5.216	37.214	0.000	0.000
MANEUVER	[illegible]								

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Ψ	Φ	β
FULL RUDDER UNTIL 75 DEGREE TURN MADE									
0.000	3000.00	0.000	-88.000	0.000	0.000	-.022	0.000	0.000	0.000
-8.808	3000.00	-.133	-88.155	.121	-2.666	-.023	.039	.005	-.868
-17.624	3000.00	-.533	-88.272	.241	-5.324	-.023	.117	.021	-2.595
-26.458	3000.00	-1.196	-88.309	.359	-7.937	-.023	.194	.047	-4.207
-35.287	3000.00	-2.116	-88.272	.475	-10.468	-.023	.269	.083	-5.954
-44.109	3000.00	-3.284	-88.173	.590	-12.879	-.023	.343	.130	-7.541
-52.919	3000.00	-4.684	-88.025	.703	-15.133	-.023	.415	.187	-9.038
-61.713	3000.00	-6.301	-87.846	.814	-17.197	-.023	.486	.253	-10.422
-70.488	3000.00	-8.112	-87.655	.924	-19.035	-.022	.556	.328	-11.671
-79.244	3000.00	-10.095	-87.473	1.032	-20.618	-.022	.624	.412	-12.764
-87.984	3000.00	-12.222	-87.321	1.139	-21.915	-.022	.692	.504	-13.683
-96.711	3000.00	-14.462	-87.214	1.244	-22.901	-.022	.758	.604	-14.408
-105.430	3000.00	-16.785	-87.177	1.340	-23.549	-.022	.823	.711	-14.922
-114.150	3000.00	-19.154	-87.224	1.450	-23.836	-.022	.887	.824	-15.208
-122.880	3000.00	-21.533	-87.367	1.551	-23.741	-.022	.951	.943	-15.251
-131.629	3000.00	-23.882	-87.611	1.651	-23.244	-.022	1.013	1.068	-15.038
-140.407	3000.00	-26.161	-87.957	1.749	-22.327	-.022	1.074	1.199	-14.558
-149.225	3000.00	-28.326	-88.395	1.846	-20.973	-.022	1.135	1.323	-13.802
-158.090	3000.00	-30.333	-88.913	1.941	-19.167	-.022	1.194	1.455	-12.763
-167.010	3000.00	-32.136	-89.485	2.035	-16.896	-.022	1.252	1.588	-11.434
-175.988	3000.00	-33.688	-90.081	2.128	-14.149	-.022	1.309	1.720	-9.814
-185.025	3000.00	-34.942	-90.659	2.220	-10.921	-.021	1.366	1.852	-7.901
-194.117	3000.00	-35.848	-91.172	2.310	-7.208	-.021	1.421	1.982	-5.696
-203.254	3000.00	-36.359	-91.564	2.399	-3.014	-.021	1.475	2.109	-3.203
-212.421	3000.00	-36.427	-91.773	2.487	1.651	-.021	1.528	2.232	-.426
-221.596	3000.00	-36.007	-91.729	2.574	6.766	-.021	1.579	2.350	2.628

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	ψ	φ	β
-230.750	3000.00	-35.051	-91.302	2.660	18.304	-.021	1.630	2.463	5.949
-239.648	3000.00	-33.527	-86.548	2.744	111.222	-.021	1.679	2.569	9.528
-248.546	3000.00	-31.392	-84.365	2.820	24.470	-.021	1.726	2.667	13.352
-257.694	3000.00	-29.020	-87.546	2.910	30.981	-.021	1.773	2.757	17.408
-266.335	3000.00	-25.187	-85.224	2.991	37.679	-.021	1.818	2.839	21.679
-274.707	3000.00	-21.074	-82.204	3.071	44.479	-.021	1.863	2.910	26.149
-282.742	3000.00	-16.292	-78.497	3.150	51.263	-.020	1.906	2.971	30.799
-290.371	3000.00	-10.632	-74.081	3.228	57.942	-.020	1.948	3.021	35.611
-297.522	3000.00	-4.715	-68.953	3.305	64.348	-.020	1.989	3.060	40.562
-304.126	3000.00	2.031	-63.130	3.381	70.590	-.020	2.029	3.088	45.631
-310.116	3000.00	9.367	-56.654	3.456	76.194	-.020	2.068	3.101	50.796
-315.428	3000.00	17.242	-49.586	3.529	81.318	-.020	2.107	3.103	56.029
-320.008	3000.00	25.598	-42.018	3.602	85.801	-.020	2.144	3.092	61.304
-323.810	3000.00	34.367	-34.032	3.674	89.58	-.020	2.181	3.069	66.591
-326.799	3000.00	43.474	-25.762	3.745	92.571	-.020	2.218	3.034	71.862
-328.954	3000.00	52.841	-17.328	3.815	94.778	-.020	2.253	2.985	77.086
MANOEUVER	COMPLETE								

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Y	ϕ	β
FULL RUDDER UNTIL BACK ON ORIGINAL HEADING									
-328.954	3000.00	52.041	-17.329	3.815	94.778	-.020	2.253	2.985	77.086
-329.809	3000.00	62.469	-.236	3.885	91.706	-.019	2.282	2.906	84.971
-328.866	3000.00	72.278	18.211	3.953	98.395	-.019	2.279	2.780	95.420
-326.165	3000.00	81.986	36.205	4.019	95.764	-.019	2.265	2.609	105.710
-321.687	3000.00	91.278	53.358	4.085	90.072	-.019	2.251	2.379	115.790
-315.576	3000.00	99.870	68.868	4.150	81.773	-.019	2.237	2.108	125.486
-308.028	3000.00	107.540	82.096	4.214	71.612	-.019	2.227	1.784	134.612
-299.290	3000.00	114.148	92.655	4.277	60.552	-.019	2.221	1.418	142.972
-289.634	3000.00	119.659	100.466	4.340	49.661	-.019	2.220	1.011	150.363
-279.324	3000.00	124.141	105.747	4.401	39.079	-.019	2.227	.567	156.585
-268.590	3000.00	127.759	108.923	4.462	32.396	-.019	2.242	.094	161.450
-257.618	3000.00	130.758	110.511	4.523	27.573	-.019	2.263	-.402	164.798
-246.546	3000.00	133.413	110.937	4.583	25.935	-.018	2.290	-.912	166.500
-235.417	3000.00	136.115	110.439	4.642	27.690	-.018	2.320	-1.430	166.467
-224.505	3000.00	139.142	109.004	4.701	32.868	-.018	2.351	-1.945	164.656
-213.740	3000.00	142.854	106.306	4.758	41.358	-.018	2.380	-2.450	161.061
-203.339	3000.00	147.570	101.700	4.815	52.966	-.018	2.402	-2.935	155.686
-193.540	3000.00	153.580	94.292	4.872	67.230	-.018	2.414	-3.392	148.556
-184.674	3000.00	161.109	83.018	4.927	83.345	-.018	2.413	-3.813	139.732
-177.187	3000.00	170.282	66.725	4.981	100.126	-.018	2.397	-4.188	129.286
-171.633	3000.00	181.081	44.351	5.034	115.856	-.018	2.362	-4.508	117.275
-168.657	3000.00	193.283	15.174	5.085	128.172	-.018	2.308	-4.765	103.761
-168.940	3000.00	206.392	-20.832	5.134	134.016	-.018	2.233	-4.946	88.869
-173.108	3000.00	219.580	-62.525	5.182	129.739	-.018	2.137	-5.040	72.498
-181.586	3000.00	231.640	-107.041	5.226	111.474	-.018	2.023	-5.034	54.972
-194.401	3000.00	[illegible]	[illegible]	5.265	75.365	[illegible]	[illegible]	[illegible]	[illegible]

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Ψ	φ	β
-210.951	3000.00	245.911	-181.735	5.300	22.003	-.018	1.754	-4.658	16.496
-229.421	3000.00	244.627	-145.663	5.327	-47.671	-.018	1.610	-4.255	-3.893
MANOEUVER	COMPLETE								

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Y	ϕ	β
PULL DOWN	ELEVATOR	UNTIL MAX	DESCENT RATE	ACHIEVED					
0.000	3000.000	0.000	-88.000	0.000	0.000	-.022	0.000	0.000	0.000
-8.806	3000.164	0.000	-88.134	3.956	0.000	-.089	1.092	0.000	0.000
-17.631	3000.672	0.000	-88.311	6.722	0.000	-.048	3.270	0.000	0.000
-26.476	3001.512	0.000	-88.465	10.089	0.000	-.080	5.435	0.000	0.000
-35.324	3002.684	0.000	-88.610	13.452	0.000	-.125	7.576	0.000	0.000
-44.194	3004.202	0.000	-88.769	16.800	0.000	-.183	9.683	0.000	0.000
-53.076	3006.048	0.000	-88.919	20.126	0.000	-.253	11.746	0.000	0.000
-61.977	3008.225	0.000	-89.067	23.427	0.000	-.337	13.754	0.000	0.000
-70.890	3010.553	0.000	-89.193	23.142	0.000	-.426	14.645	0.000	0.000
-79.816	3012.852	0.000	-89.318	22.842	0.000	-.514	14.453	0.000	0.000
-88.754	3015.121	0.000	-89.436	22.518	0.000	-.601	14.246	0.000	0.000
-97.703	3017.365	0.000	-89.554	22.170	0.000	-.688	14.025	0.000	0.000
-106.664	3019.553	0.000	-89.670	21.797	0.000	-.774	13.790	0.000	0.000
-115.637	3021.713	0.000	-89.786	21.400	0.000	-.859	13.541	0.000	0.000
-124.621	3023.832	0.000	-89.901	20.980	0.000	-.944	13.278	0.000	0.000
-133.617	3025.908	0.000	-90.015	20.535	0.000	-1.029	13.000	0.000	0.000
-142.624	3027.938	0.000	-90.127	20.067	0.000	-1.114	12.708	0.000	0.000
-151.643	3029.920	0.000	-90.239	19.575	0.000	-1.199	12.402	0.000	0.000
-160.672	3031.852	0.000	-90.349	19.060	0.000	-1.283	12.082	0.000	0.000
-169.712	3033.731	0.000	-90.458	18.521	0.000	-1.368	11.748	0.000	0.000
-178.764	3035.555	0.000	-90.566	17.958	0.000	-1.453	11.399	0.000	0.000
-187.826	3037.321	0.000	-90.673	17.372	0.000	-1.539	11.036	0.000	0.000
-196.898	3039.020	0.000	-90.778	16.762	0.000	-1.625	10.659	0.000	0.000
-205.981	3040.673	0.000	-90.881	16.128	0.000	-1.711	10.268	0.000	0.000
-215.074	3042.253	0.000	-90.983	15.471	0.000	-1.798	9.862	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	ψ	φ	β
-224.171	3043.766	0.000	-91.083	14.789	0.000	-1.886	9.441	0.000	0.000
-233.291	3045.209	0.000	-91.181	14.083	0.000	-1.974	9.006	0.000	0.000
-242.414	3046.581	0.000	-91.278	13.353	0.000	-2.064	8.556	0.000	0.000
-251.540	3047.879	0.000	-91.372	12.597	0.000	-2.154	8.090	0.000	0.000
-260.668	3049.099	0.000	-91.464	11.817	0.000	-2.246	7.610	0.000	0.000
-269.839	3050.241	0.000	-91.555	11.012	0.000	-2.339	7.114	0.000	0.000
-279.001	3051.358	0.000	-91.690	11.333	0.000	-2.438	6.956	0.000	0.000
-288.176	3052.500	0.000	-91.817	11.499	0.000	-2.546	7.096	0.000	0.000
-297.364	3053.669	0.000	-91.937	11.494	0.000	-2.659	7.136	0.000	0.000
-306.563	3054.789	0.000	-92.047	11.309	0.000	-2.777	7.069	0.000	0.000
-315.773	3055.902	0.000	-92.147	10.935	0.000	-2.900	6.889	0.000	0.000
-324.992	3056.966	0.000	-92.235	10.363	0.000	-3.028	6.592	0.000	0.000
-334.219	3057.964	0.000	-92.311	9.590	0.000	-3.159	6.174	0.000	0.000
-343.454	3058.875	0.000	-92.374	8.619	0.000	-3.293	5.634	0.000	0.000
-352.694	3059.678	0.000	-92.424	7.445	0.000	-3.430	4.970	0.000	0.000
-361.938	3060.363	0.000	-92.458	6.065	0.000	-3.570	4.181	0.000	0.000
-371.184	3060.880	0.000	-92.476	4.476	0.000	-3.711	3.264	0.000	0.000
-380.432	3061.234	0.000	-92.477	2.678	0.000	-3.854	2.216	0.000	0.000
-389.679	3061.405	0.000	-92.459	.667	0.000	-3.997	1.037	0.000	0.000
-398.923	3061.361	0.000	-92.421	-1.556	0.000	-4.141	-.275	0.000	0.000
-408.178	3061.084	0.000	-92.617	-3.983	0.000	-4.284	-1.715	0.000	0.000
-417.456	3060.554	0.000	-92.889	-6.452	0.000	-4.427	-3.282	0.000	0.000
-426.753	3059.741	0.000	-93.040	-9.567	0.000	-4.570	-4.988	0.000	0.000
-436.060	3058.626	0.000	-93.111	-12.733	0.000	-4.711	-6.835	0.000	0.000
-445.370	3057.182	0.000	-93.079	-16.151	0.000	-4.850	-8.823	0.000	0.000
-454.670	3055.383	0.000	-92.921	-19.822	0.000	-4.987	-10.952	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	ψ	φ	β
-463.446	3057.205	0.000	-92.609	-23.745	0.000	-5.120	-13.222	0.000	0.000
-473.265	3050.779	0.000	-92.563	-24.762	0.000	-5.250	-14.687	0.000	0.000
-482.456	3044.245	0.000	-92.472	-25.919	0.000	-5.250	-15.325	0.000	0.000
-491.698	3045.545	0.000	-92.364	-27.079	0.000	-5.250	-16.007	0.000	0.000
-500.929	3042.829	0.000	-92.249	-28.242	0.000	-5.250	-16.690	0.000	0.000
-510.148	3039.047	0.000	-92.116	-29.407	0.000	-5.250	-17.373	0.000	0.000
-519.352	3036.148	0.000	-91.969	-30.575	0.000	-5.250	-18.057	0.000	0.000
-528.541	3033.832	0.000	-91.807	-31.745	0.000	-5.250	-18.742	0.000	0.000
-537.712	3030.599	0.000	-91.631	-32.918	0.000	-5.250	-19.428	0.000	0.000
-546.866	3027.248	0.000	-91.440	-34.092	0.000	-5.250	-20.114	0.000	0.000
-556.000	3023.780	0.000	-91.235	-35.268	0.000	-5.250	-20.802	0.000	0.000
-565.112	3020.195	0.000	-91.014	-36.445	0.000	-5.250	-21.490	0.000	0.000
-574.202	3016.491	0.000	-90.779	-37.623	0.000	-5.250	-22.179	0.000	0.000
-583.267	3012.670	0.000	-90.528	-38.803	0.000	-5.250	-22.869	0.000	0.000
-592.307	3008.730	0.000	-90.263	439.984	0.000	-5.250	-23.559	0.000	0.000
-601.319	3004.673	0.000	-89.982	-41.165	0.000	-5.250	-24.250	0.000	0.000
MANOEUVER	COMPLETE								

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Ψ	φ	β
PULL UP ELEVATOR UNTIL DESCENT RATE = 0									
-601.314	3004.673	0.000	-89.962	-41.165	0.000	-5.250	-24.250	0.000	0.000
-610.185	3000.156	0.000	-87.330	-44.194	0.000	-2.473	-23.017	0.000	0.000
-618.737	2995.924	0.000	-83.716	-47.425	0.000	2.494	-31.953	0.000	0.000
-627.101	2991.058	0.000	-83.574	-47.894	0.000	5.188	-34.597	0.000	0.000
-635.493	2986.298	0.000	-84.249	-47.303	0.000	5.135	-34.484	0.000	0.000
-643.949	2977.595	0.000	-84.882	-46.756	0.000	4.734	-34.012	0.000	0.000
-652.559	2972.061	0.000	-87.319	-43.939	0.000	3.559	-32.751	0.000	0.000
-661.343	2966.725	0.000	-88.350	-42.768	0.000	2.198	-31.292	0.000	0.000
-670.154	2961.400	0.000	-87.879	-43.728	0.000	2.175	-31.160	0.000	0.000
-678.917	2955.978	0.000	-87.384	-44.727	0.000	2.902	-31.766	0.000	0.000
-687.670	2950.515	0.000	-87.682	-44.532	0.000	3.256	-31.985	0.000	0.000
-696.473	2945.099	0.000	-88.371	-43.788	0.000	3.035	-31.618	0.000	0.000
-705.333	2939.741	0.000	-88.816	-43.372	0.000	2.752	-31.180	0.000	0.000
-714.220	2934.401	0.000	-88.943	-43.415	0.000	2.749	-31.011	0.000	0.000
-723.121	2929.058	0.000	-89.065	-43.463	0.000	2.913	-30.997	0.000	0.000
-732.043	2923.723	0.000	-89.369	-43.237	0.000	2.999	-30.894	0.000	0.000
-741.000	2918.417	0.000	-89.770	-42.864	0.000	2.958	-30.653	0.000	0.000
-749.994	2913.146	0.000	-90.122	-42.556	0.000	2.902	-30.387	0.000	0.000
-759.021	2907.902	0.000	-90.409	-42.339	0.000	2.910	-30.174	0.000	0.000
-768.076	2902.674	0.000	-90.705	-42.106	0.000	2.956	-29.986	0.000	0.000
-777.164	2897.485	0.000	-91.048	-41.792	0.000	2.982	-29.769	0.000	0.000
-786.287	2892.323	0.000	-91.419	-41.430	0.000	2.978	-29.512	0.000	0.000
-795.448	2887.196	0.000	-91.783	-41.071	0.000	2.973	-29.242	0.000	0.000
-804.644	2882.109	0.000	-92.139	-40.717	0.000	2.962	-28.976	0.000	0.000
-813.876	2877.056	0.000	-92.503	-40.343	0.000	3.000	-28.708	0.000	0.000
-823.165	2872.062	0.000	-92.883	-39.935	0.000	3.117	-28.426	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	γ	φ	β.
-832.453	2867.070	0.000	-93.273	-49.502	0.000	3.019	-28.123	0.000	0.000
-841.600	2862.142	0.000	-93.666	-49.054	0.000	3.025	-27.812	0.000	0.000
-851.186	2857.760	0.000	-94.063	-48.591	0.000	3.034	-27.494	0.000	0.000
-860.613	2852.425	0.000	-94.465	-48.107	0.000	3.046	-27.167	0.000	0.000
-870.060	2847.640	0.000	-94.875	-47.600	0.000	3.056	-26.829	0.000	0.000
-879.588	2842.907	0.000	-95.291	-47.071	0.000	3.064	-26.479	0.000	0.000
-889.138	2838.227	0.000	-95.711	-46.522	0.000	3.073	-26.119	0.000	0.000
-898.730	2833.603	0.000	-96.134	-45.954	0.000	3.082	-25.749	0.000	0.000
-908.365	2829.037	0.000	-96.562	-45.364	0.000	3.091	-25.369	0.000	0.000
-918.043	2824.531	0.000	-96.994	-44.754	0.000	3.100	-24.979	0.000	0.000
-927.764	2820.088	0.000	-97.429	-44.121	0.000	3.109	-24.579	0.000	0.000
-937.529	2815.708	0.000	-97.867	-43.468	0.000	3.117	-24.168	0.000	0.000
-947.337	2811.395	0.000	-98.307	-42.793	0.000	3.126	-23.748	0.000	0.000
-957.190	2807.150	0.000	-98.749	-42.098	0.000	3.135	-23.318	0.000	0.000
-967.087	2802.977	0.000	-99.192	-41.380	0.000	3.143	-22.878	0.000	0.000
-977.029	2798.876	0.000	-99.637	-40.641	0.000	3.152	-22.429	0.000	0.000
-987.015	2794.849	0.000	-100.081	-39.880	0.000	3.160	-21.969	0.000	0.000
-997.045	2790.901	0.000	-100.526	-39.098	0.000	3.168	-21.500	0.000	0.000
-1007.120	2787.031	0.000	-100.970	-38.294	0.000	3.177	-21.022	0.000	0.000
-1017.239	2783.243	0.000	-101.413	-37.468	0.000	3.185	-20.534	0.000	0.000
-1027.402	2779.538	0.000	-101.854	-36.620	0.000	3.193	-20.036	0.000	0.000
-1037.610	2775.920	0.000	-102.293	-35.751	0.000	3.201	-19.529	0.000	0.000
-1047.861	2772.389	0.000	-102.730	-34.859	0.000	3.209	-19.013	0.000	0.000
-1058.156	2768.949	0.000	-103.163	-33.946	0.000	3.217	-18.488	0.000	0.000
-1068.493	2765.601	0.000	-103.592	-33.011	0.000	3.225	-17.953	0.000	0.000
-1078.874	2762.348	0.000	-104.017	-32.054	0.000	3.232	-17.410	0.000	0.000
-1089.297	2759.192	0.000	-104.437	-31.075	0.000	3.240	-16.857	0.000	0.000

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Y	ψ	β
-1099.761	2756.134	0.000	-104.852	-30.074	0.000	3.248	-16.295	0.000	0.000
-1110.267	2753.178	0.000	-105.260	-29.052	0.000	3.255	-15.725	0.000	0.000
-1120.613	2750.325	0.000	-105.661	-28.008	0.000	3.262	-15.145	0.000	0.000
-1131.399	2747.577	0.000	-106.055	-26.942	0.000	3.270	-14.557	0.000	0.000
-1142.623	2744.937	0.000	-106.441	-25.855	0.000	3.277	-13.961	0.000	0.000
-1152.686	2742.407	0.000	-106.818	-24.747	0.000	3.284	-13.355	0.000	0.000
-1163.386	2739.989	0.000	-107.186	-23.618	0.000	3.291	-12.741	0.000	0.000
-1174.123	2737.685	0.000	-107.544	-22.467	0.000	3.298	-12.119	0.000	0.000
-1184.895	2735.497	0.000	-107.892	-21.295	0.000	3.305	-11.488	0.000	0.000
-1195.701	2733.427	0.000	-108.228	-20.103	0.000	3.312	-10.849	0.000	0.000
-1206.540	2731.477	0.000	-108.553	-18.890	0.000	3.319	-10.202	0.000	0.000
-1217.411	2729.650	0.000	-108.865	-17.657	0.000	3.325	-9.547	0.000	0.000
-1228.312	2727.947	0.000	-109.164	-16.403	0.000	3.332	-8.883	0.000	0.000
-1239.243	2726.370	0.000	-109.449	-15.130	0.000	3.338	-8.212	0.000	0.000
-1250.201	2724.922	0.000	-109.719	-13.837	0.000	3.345	-7.533	0.000	0.000
-1261.186	2723.604	0.000	-109.975	-12.525	0.000	3.351	-6.846	0.000	0.000
-1272.195	2722.418	0.000	-110.215	-11.193	0.000	3.357	-6.151	0.000	0.000
-1283.228	2721.366	0.000	-110.439	-9.843	0.000	3.363	-5.449	0.000	0.000
-1294.282	2720.450	0.000	-110.645	-8.475	0.000	3.369	-4.739	0.000	0.000
-1305.356	2719.672	0.000	-110.834	-7.088	0.000	3.375	-4.021	0.000	0.000
-1316.448	2719.033	0.000	-111.005	-5.684	0.000	3.381	-3.297	0.000	0.000
-1327.556	2718.536	0.000	-111.157	-4.262	0.000	3.387	-2.565	0.000	0.000
-1338.678	2718.182	0.000	-111.289	-2.824	0.000	3.393	-1.826	0.000	0.000
-1349.813	2717.972	0.000	-111.401	-1.369	0.000	3.398	-1.079	0.000	0.000
-1360.958	2717.909	0.000	-111.493	.102	0.000	3.404	-.326	0.000	0.000
-1372.111	2717.993	0.000	-111.563	1.588	0.000	4.169	.434	0.000	0.000
MANOEUVER	COMPLETE								

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	γ	ψ	β
STEADY STATE TURN FROM 0-180 DEGREES									
0.000	3000.00	0.000	-88.000	0.000	0.000	-.022	0.000	0.000	0.000
-8.797	3000.00	-.110	-87.933	.121	2.317	-.023	.039	1.645	.755
-17.585	3000.00	.463	-87.836	.241	4.632	-.023	.118	1.645	2.265
-26.361	3000.00	1.042	-87.679	.359	6.944	-.023	.195	1.645	3.776
-35.118	3000.00	1.852	-87.460	.475	9.252	-.023	.272	1.645	5.286
-43.850	3000.00	2.892	-87.180	.590	11.552	-.023	.347	1.645	6.797
-52.551	3000.00	4.162	-86.840	.704	13.845	-.023	.422	1.645	8.307
-61.215	3000.00	5.661	-86.440	.815	16.127	-.023	.495	1.645	9.818
-69.836	3000.00	7.387	-85.979	.925	18.399	-.022	.567	1.645	11.329
-78.408	3000.00	9.340	-85.459	1.034	20.657	-.022	.639	1.645	12.840
-86.925	3000.00	11.518	-84.880	1.141	22.901	-.022	.709	1.645	14.351
-95.381	3000.00	13.919	-84.242	1.247	25.129	-.022	.778	1.645	15.863
-103.770	3000.00	16.543	-83.545	1.351	27.340	-.022	.847	1.645	17.374
-112.087	3000.00	19.388	-82.790	1.453	29.531	-.022	.914	1.645	18.885
-120.325	3000.00	22.448	-81.977	1.555	31.701	-.022	.981	1.645	20.397
-128.479	3000.00	25.725	-81.108	1.655	33.850	-.022	1.047	1.645	21.908
-136.544	3000.00	29.216	-80.182	1.753	35.974	-.022	1.111	1.645	23.420
-144.513	3000.00	32.919	-79.201	1.850	38.074	-.022	1.175	1.645	24.932
-152.381	3000.00	36.830	-78.165	1.946	40.147	-.022	1.238	1.645	26.444
-160.143	3000.00	40.947	-77.074	2.041	42.192	-.022	1.300	1.645	27.956
-167.793	3000.00	45.267	-75.930	2.134	44.207	-.021	1.362	1.645	29.468
-175.327	3000.00	49.787	-74.733	2.226	46.192	-.021	1.422	1.645	30.980
-182.737	3000.00	54.503	-73.484	2.317	48.144	-.021	1.482	1.645	32.492
-190.021	3000.00	59.414	-72.184	2.406	50.062	-.021	1.541	1.645	34.004
-197.172	3000.00	64.519	-70.834	2.495	51.946	-.021	1.599	1.645	35.517

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	γ	ψ	β
-204.185	3000.00	69.401	-69.434	2.582	53.794	-.021	1.656	1.645	37.029
-211.056	3000.00	75.271	-67.987	2.668	55.603	-.021	1.713	1.645	38.542
-217.780	3000.00	80.920	-66.492	2.753	57.374	-.021	1.769	1.645	40.055
-224.352	3000.00	86.344	-64.971	2.836	59.105	-.020	1.824	1.645	41.567
-230.768	3000.00	91.539	-63.304	2.919	60.795	-.020	1.878	1.645	43.080
-237.023	3000.00	96.501	-61.734	3.000	62.442	-.020	1.932	1.645	44.593
-243.112	3000.00	101.229	-60.061	3.081	64.046	-.020	1.985	1.645	46.106
-249.033	3000.00	105.720	-58.346	3.160	65.605	-.020	2.037	1.645	47.619
-254.780	3000.00	109.973	-56.591	3.239	67.118	-.020	2.088	1.645	49.133
-260.349	3000.00	113.986	-54.796	3.316	68.584	-.020	2.139	1.645	50.646
-265.737	3000.00	117.756	-52.963	3.392	70.003	-.019	2.189	1.645	52.159
-270.940	3000.00	121.281	-51.093	3.467	71.372	-.019	2.239	1.645	53.673
-275.954	3000.00	124.559	-49.188	3.541	72.692	-.019	2.288	1.645	55.187
-280.776	3000.00	127.588	-47.249	3.615	73.961	-.019	2.336	1.645	56.700
-285.402	3000.00	130.367	-45.277	3.687	75.178	-.019	2.384	1.645	58.214
-289.829	3000.00	132.894	-43.273	3.758	76.343	-.019	2.430	1.645	59.728
-294.055	3000.00	135.169	-41.239	3.829	77.456	-.019	2.477	1.645	61.242
-298.076	3000.00	137.189	-39.177	3.898	78.512	-.019	2.523	1.645	62.756
-301.889	3000.00	138.955	-37.088	3.967	79.514	-.018	2.568	1.645	64.270
-305.492	3000.00	140.464	-34.972	4.034	80.461	-.018	2.612	1.645	65.784
-308.882	3000.00	141.715	-32.833	4.101	81.352	-.018	2.656	1.645	67.299
-312.058	3000.00	142.707	-30.670	4.167	82.186	-.018	2.700	1.645	68.813
-315.015	3000.00	143.439	-28.487	4.232	82.963	-.018	2.742	1.645	70.328
-317.754	3000.00	143.911	-26.284	4.296	83.681	-.018	2.785	1.645	71.842
-320.271	3000.00	144.122	-24.062	4.359	84.341	-.018	2.826	1.645	73.357
-322.566	3000.00	144.073	-21.824	4.422	84.943	-.017	2.868	1.645	74.872

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Υ	Ψ	β
-324.635	3000.00	258.328	-19.570	4.483	85.484	-.017	2.908	1.645	76.387
-326.479	3000.00	266.901	-17.304	4.544	85.967	-.017	2.948	1.645	77.902
-328.095	3000.00	275.518	-15.025	4.604	86.389	-.017	2.988	1.645	79.417
-329.483	3000.00	284.175	-12.736	4.664	86.750	-.017	3.027	1.645	80.932
-330.642	3000.00	292.865	-10.438	4.722	87.051	-.017	3.066	1.645	82.447
-331.570	3000.00	301.583	-8.133	4.780	87.292	-.017	3.104	1.645	83.963
-332.268	3000.00	310.321	-5.822	4.837	87.471	-.016	3.141	1.645	85.478
-332.735	3000.00	319.074	-3.507	4.893	87.589	-.016	3.178	1.645	86.994
-332.970	3000.00	327.835	-1.190	4.949	87.646	-.016	3.215	1.645	88.509
-332.973	3000.00	336.600	1.127	5.004	87.642	-.016	3.251	1.645	90.025
-332.744	3000.00	345.361	3.444	5.058	87.576	-.016	3.287	1.645	91.541
-332.284	3000.00	354.112	5.758	5.111	87.449	-.016	3.322	1.645	93.057
-331.593	3000.00	362.847	8.068	5.164	87.261	-.016	3.357	1.645	94.573
-330.671	3000.00	371.561	10.372	5.216	87.012	-.015	3.391	1.645	96.089
-329.519	3000.00	380.247	12.669	5.267	86.702	-.015	3.425	1.645	97.605
-328.138	3000.00	388.898	14.956	5.318	86.331	-.015	3.459	1.645	99.121
-326.528	3000.00	397.510	17.234	5.368	85.901	-.015	3.492	1.645	100.637
-324.691	3000.00	406.075	19.499	5.417	85.410	-.015	3.524	1.645	102.154
-322.626	3000.00	414.589	21.750	5.466	84.859	-.015	3.557	1.645	103.670
-320.342	3000.00	423.044	23.986	5.514	84.249	-.015	3.588	1.645	105.187
-317.833	3000.00	431.436	26.205	5.562	83.580	-.015	3.620	1.645	106.704
-315.102	3000.00	439.757	28.405	5.609	82.852	-.014	3.651	1.645	108.221
-312.153	3000.00	448.003	30.585	5.655	82.067	-.014	3.681	1.645	109.737
-308.986	3000.00	456.168	32.744	5.701	81.224	-.014	3.712	1.645	111.254
-305.605	3000.00	464.245	34.880	5.746	80.324	-.014	3.741	1.645	112.771
-302.011	3000.0	472.230	36.991	5.790	79.368	-.014	3.771	1.645	114.289

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Ψ	Φ	β
-248.208	3000.00	480.116	39.077	5.895	78.357	-.014	3.800	1.645	115.806
-244.197	3000.00	487.899	41.134	5.878	77.291	-.014	3.829	1.645	117.323
-249.983	3000.00	495.572	43.163	5.921	76.170	-.013	3.857	1.645	118.841
-255.566	3000.00	503.130	45.162	5.963	74.997	-.013	3.885	1.645	120.358
-260.952	3000.00	510.568	47.128	6.005	73.771	-.013	3.913	1.645	121.876
-276.142	3000.00	517.882	49.062	6.046	72.493	-.013	3.940	1.645	123.393
-271.141	3000.00	525.066	50.961	6.087	71.164	-.013	3.967	1.645	124.911
-265.952	3000.00	532.112	52.824	6.128	69.786	-.013	3.994	1.645	126.429
-260.578	3000.00	539.019	54.650	6.167	68.359	-.013	4.020	1.645	127.947
-255.024	3000.00	545.781	56.438	6.207	66.884	-.012	4.046	1.645	129.465
-249.293	3000.00	552.394	58.186	6.246	65.362	-.012	4.072	1.645	130.983
-243.389	3000.00	558.851	59.893	6.284	63.795	-.012	4.097	1.645	132.501
-237.316	3000.00	565.150	61.558	6.322	62.182	-.012	4.122	1.645	134.020
-231.079	3000.00	571.286	63.179	6.359	60.527	-.012	4.147	1.645	135.538
-224.683	3000.00	577.254	64.756	6.396	58.829	-.012	4.172	1.645	137.057
-218.130	3000.00	583.049	66.288	6.432	57.089	-.012	4.196	1.645	138.575
-211.427	3000.00	588.669	67.773	6.468	55.310	-.012	4.220	1.645	140.094
-204.578	3000.00	594.110	69.211	6.504	53.492	-.011	4.243	1.645	141.613
-197.588	3000.00	599.366	70.599	6.539	51.637	-.011	4.267	1.645	143.132
-190.461	3000.00	604.435	71.938	6.574	49.745	-.011	4.290	1.645	144.650
-183.203	3000.00	609.313	73.227	6.608	47.819	-.011	4.312	1.645	146.169
-175.816	3000.00	613.997	74.464	6.642	45.859	-.011	4.335	1.645	147.689
-168.312	3000.00	618.484	75.649	6.676	43.867	-.011	4.357	1.645	149.208
-160.691	3000.00	622.769	76.780	6.709	41.845	-.011	4.379	1.645	150.727
-152.959	3000.00	626.851	77.858	6.741	39.793	-.010	4.401	1.645	152.246
-145.122	3000.00	630.726	78.880	6.773	37.713	-.010	4.422	1.645	153.766

x ft.	y ft.	z ft.	Vx ft/sec	Vy ft/sec	Vz ft/sec	θ	Ψ	Φ	β
-137.146	3000.00	634.392	79.848	6.805	35.607	-.010	4.443	1.645	155.286
-129.155	3000.00	637.846	80.749	6.837	33.476	-.010	4.464	1.645	156.805
-121.037	3000.00	641.086	81.613	6.868	31.322	-.010	4.485	1.645	158.325
-112.836	3000.00	644.110	82.410	6.899	29.145	-.010	4.505	1.645	159.845
-104.558	3000.00	646.914	83.149	6.929	26.949	-.010	4.525	1.645	161.365
-96.209	3000.00	649.498	83.829	6.959	24.733	-.009	4.545	1.645	162.885
-87.795	3000.00	651.860	84.451	6.989	22.500	-.009	4.565	1.645	164.405
-79.322	3000.00	653.996	85.013	7.018	20.252	-.009	4.584	1.645	165.925
-70.795	3000.00	655.910	85.515	7.047	17.990	-.009	4.604	1.645	167.445
-62.222	3000.00	657.595	85.957	7.075	15.715	-.009	4.623	1.645	168.966
-53.607	3000.00	659.052	86.338	7.104	13.429	-.009	4.641	1.645	170.486
MANOEUVER	CONTE TF								

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
TAKE OFF AND CLIMB OVER 100 F. OBSTACLE					
-.025	0.000	0.000	-.001	0.000	0.000
-.005	0.000	0.000	47.221	-304.119	0.000
-.012	0.000	0.000	49.997	-304.119	0.000
-.022	0.000	0.000	53.119	-304.119	0.000
-.035	0.000	0.000	56.657	-304.119	0.000
-.052	0.000	0.000	60.699	-304.119	0.000
-.072	0.000	0.000	65.363	-304.119	0.000
-.097	0.000	0.000	70.804	-304.119	0.000
-.126	0.000	0.000	77.234	-304.119	0.000
-.159	0.000	0.000	84.949	-304.119	0.000
-.198	0.000	0.000	94.379	-304.119	0.000
-.243	0.000	0.000	106.167	-304.119	0.000
-.295	0.000	0.000	121.324	-304.119	0.000
-.355	0.000	0.000	141.535	-304.119	0.000
-.424	0.000	0.000	169.833	-304.118	0.000
-.504	0.000	0.000	212.287	-304.118	0.000
-.599	0.000	0.000	283.056	-304.117	0.000
-.715	0.000	0.000	424.628	-304.116	0.000
-.869	0.000	0.000	849.465	-304.114	0.000
-1.107	0.000	0.000	849.072	-304.100	0.000
-1.329	0.000	0.000	848.599	-304.096	0.000
-1.635	0.000	0.000	848.052	-304.076	0.000
-1.992	0.000	0.000	847.436	-304.046	0.000
-2.398	0.000	0.000	846.755	-304.001	0.000
-2.856				-303.944	
-3.364				-303.877	
-3.921				-303.794	
-4.526				-303.696	
-5.180				-303.578	
-5.881				-303.441	

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-6.455	[illegible]	[illegible]	[illegible]	-302.825	0.000
-7.444	[illegible]	[illegible]	[illegible]	-302.654	0.000
-8.323	[illegible]	[illegible]	[illegible]	-302.004	0.000
-9.231	[illegible]	[illegible]	[illegible]	-301.470	0.000
-10.195	[illegible]	[illegible]	[illegible]	-301.440	0.000
-11.170	[illegible]	[illegible]	[illegible]	-301.183	0.000
-12.259	[illegible]	[illegible]	[illegible]	-299.364	0.000
-13.303	[illegible]	[illegible]	[illegible]	-298.244	0.000
-14.32	[illegible]	[illegible]	[illegible]	-297.137	0.000
-15.121	[illegible]	[illegible]	[illegible]	-295.850	0.000
-16.041	[illegible]	[illegible]	[illegible]	-294.400	0.000
-16.934	[illegible]	[illegible]	[illegible]	-292.775	0.000
-17.942	[illegible]	[illegible]	[illegible]	-291.047	0.000
-18.944	[illegible]	[illegible]	[illegible]	-289.309	0.000
-19.941	[illegible]	[illegible]	[illegible]	-287.645	0.000
-20.943	[illegible]	[illegible]	[illegible]	-286.141	0.000
-21.940	[illegible]	[illegible]	[illegible]	-284.779	0.000
-22.940	[illegible]	[illegible]	[illegible]	-283.549	0.000
-23.940	[illegible]	[illegible]	[illegible]	-282.433	0.000
-24.940	[illegible]	[illegible]	[illegible]	-281.423	0.000
-25.940	[illegible]	[illegible]	[illegible]	-280.509	0.000
-26.940	[illegible]	[illegible]	[illegible]	-279.683	0.000
-27.940	[illegible]	[illegible]	[illegible]	-278.938	0.000
-28.940	[illegible]	[illegible]	[illegible]	-278.266	0.000
-29.940	[illegible]	[illegible]	[illegible]	-277.660	0.000
-30.940	[illegible]	[illegible]	[illegible]	-277.114	0.000
-31.940	[illegible]	[illegible]	[illegible]	-276.623	0.000
-32.940	[illegible]	[illegible]	[illegible]	-276.180	0.000
-33.940	[illegible]	[illegible]	[illegible]	-275.781	0.000
-34.940	[illegible]	[illegible]	[illegible]	-275.422	0.000
-35.940	[illegible]	[illegible]	[illegible]	-275.098	0.000
-36.940	[illegible]	[illegible]	[illegible]	-274.805	0.000
-37.940	[illegible]	[illegible]	[illegible]	-274.541	0.000
-38.940	[illegible]	[illegible]	[illegible]	-274.302	0.000
-39.940	[illegible]	[illegible]	[illegible]	-274.086	0.000
-40.940	[illegible]	[illegible]	[illegible]	-273.891	0.000
-41.940	[illegible]	[illegible]	[illegible]	-273.715	0.000
-42.940	[illegible]	[illegible]	[illegible]	-273.556	0.000
-43.940	[illegible]	[illegible]	[illegible]	-273.413	0.000
-44.940	[illegible]	[illegible]	[illegible]	-273.284	0.000
-45.940	[illegible]	[illegible]	[illegible]	-273.168	0.000
-46.940	[illegible]	[illegible]	[illegible]	-273.063	0.000
-47.940	[illegible]	[illegible]	[illegible]	-272.968	0.000
-48.940	[illegible]	[illegible]	[illegible]	-272.882	0.000
-49.940	[illegible]	[illegible]	[illegible]	-272.804	0.000
-50.940	[illegible]	[illegible]	[illegible]	-272.734	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-52.241	.000	0.000	111.11	-206.123	0.000
-54.[illegible]	.[illegible]	[illegible]	[illegible]	-197.400	0.000
-54.77	.000	0.000	[illegible]	-184.143	0.000
-54.[illegible]	.[illegible]	0.000	[illegible]	-174.319	0.000
-51.[illegible]	.000	0.000	[illegible]	-167.902	0.000
-46.[illegible]	.000	0.000	114.052	-159.000	0.000
-46.[illegible]	.000	0.000	114.113	-145.249	0.000
-49.139	.000	0.000	114.400	-132.972	0.000
-41.129	.000	0.000	112.141	-120.036	0.000
-34.34[illegible]	.000	0.000	149.193	-106.423	0.000
-27.[illegible]	.000	0.000	147.424	-92.117	0.000
-19.77[illegible]	.000	0.000	[illegible]	-77.098	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	-[illegible]	[illegible]
-[illegible]	.[illegible]	[illegible]	[illegible]	-[illegible]	[illegible]
-[illegible]	.[illegible]	[illegible]	[illegible]	-27.6[illegible]	[illegible]
-[illegible]	.[illegible]	0.000	[illegible]	-[illegible]	[illegible]
-[illegible]	.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-[illegible]	.[illegible]	[illegible]	[illegible]	-2.470	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	49.713	0.000
-[illegible]	.[illegible]	0.000	[illegible]	70.603	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-[illegible]	.[illegible]	0.000	[illegible]	115.439	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	139.[illegible]	0.000
-[illegible]	.[illegible]	0.000	[illegible]	[illegible]	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-122.[illegible]	.[illegible]	0.000	[illegible]	[illegible]	[illegible]
-[illegible]	.[illegible]	[illegible]	[illegible]	244.151	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	271.251	0.000
-[illegible]	.[illegible]	[illegible]	[illegible]	[illegible]	0.000
-[illegible]	.[illegible]	0.000	[illegible]	329.[illegible]	0.000
-[illegible]	[illegible]	[illegible]	[illegible]	361.329	0.000
-[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-197.37	1.000	0.000	711.727	923.753	0.000
-150.565	1.711	0.000	709.115	884.811	0.000
-104.387	2.415	0.000	706.513	846.206	0.000
-158.067	3.355	0.000	704.512	824.492	0.000
-151.437	3.773	0.000	703.451	805.450	0.000
-145.423	4.141	0.000	702.727	787.950	0.000
-139.442	4.463	0.000	702.352	831.255	0.000
-173.285	4.747	0.000	702.305	816.411	0.000
-127.108	4.995	0.000	702.588	705.281	0.000
-121.176	5.209	0.000	703.205	794.813	0.000
-115.201	5.391	0.000	704.170	781.163	0.000
-109.256	5.543	0.000	705.493	819.470	0.000
-103.334	5.667	0.000	707.188	808.479	0.000
-197.434	5.767	0.000	709.265	897.529	0.000
-91.552	5.843	0.000	711.737	936.750	0.000
-85.688	5.896	0.000	714.615	976.056	0.000
-79.844	5.928	0.000	717.911	1015.473	0.000
-213.103	5.941	0.000	721.636	1055.021	0.000
-217.177	5.936	0.000	725.801	1095.727	0.000
-211.476	5.917	0.000	730.419	1136.614	0.000
-205.396	5.885	0.000	735.501	1177.701	0.000
-199.539	5.842	0.000	741.060	1219.011	0.000
-233.925	5.788	0.000	747.109	1260.564	0.000
-227.411	5.726	0.000	753.662	1302.380	0.000
-221.053	5.657	0.000	760.732	1344.480	0.000
-245.77	5.582	0.000	768.333	1386.883	0.000
-249.511	5.502	0.000	776.479	1429.608	0.000
-253.302	5.418	0.000	785.184	1472.674	0.000
-257.143	5.331	0.000	794.462	1516.100	0.000
-261.035	5.242	0.000	804.328	1559.904	0.000
-264.977	5.151	0.000	814.797	1604.104	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-2[illegible].134	[illegible].863	[illegible].000	[illegible].1[illegible]	134.104	0.000
-213.263	[illegible].113	[illegible].000	[illegible]	115.990	0.000
-217.122	[illegible].761	[illegible].000	[illegible]	125.589	0.000
-2[illegible].137	[illegible].251	[illegible].000	[illegible]	133.755	0.000
-2[illegible].[illegible]02	[illegible].792	[illegible].000	[illegible]	143.134	0.000
-2[illegible].[illegible]02	[illegible].411	[illegible].000	[illegible]	152.208	0.000
-242.[illegible]33	[illegible].982	[illegible].000	[illegible]	161.233	0.000
-2[illegible].[illegible]23	[illegible].478	[illegible].000	[illegible]	169.948	0.000
-3[illegible].[illegible]46	[illegible].[illegible]0[illegible]	[illegible].000	[illegible]	178.447	0.000
-3[illegible].[illegible]08	[illegible].[illegible]76	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]82	[illegible].[illegible]29	[illegible].000	[illegible]	[illegible]	[illegible]
-312.79	[illegible].[illegible]36	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]07	[illegible].[illegible]71	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]33	[illegible].[illegible]05	[illegible].000	[illegible]	[illegible]	[illegible]
-32[illegible].[illegible]37	[illegible].[illegible]43	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]09	[illegible].[illegible]25	[illegible].000	[illegible]	[illegible]	[illegible]
-33[illegible].[illegible]54	[illegible].[illegible]67	[illegible].000	[illegible]	[illegible]	[illegible]
-33[illegible].[illegible]14	[illegible].[illegible]50	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]16	[illegible].[illegible]48	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]43	[illegible].[illegible]83	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]13	[illegible].[illegible]82	[illegible].000	[illegible]	[illegible]	[illegible]
-[illegible].[illegible]	[illegible].[illegible]	[illegible].000	[illegible]	27[illegible].740	[illegible]
-3[illegible].[illegible]70	[illegible].[illegible]80	[illegible].000	[illegible]	-27[illegible].75[illegible]	[illegible]
-3[illegible].[illegible]	[illegible].[illegible]	[illegible].000	[illegible]	[illegible]	[illegible]
-3[illegible].[illegible]	[illegible].[illegible]	[illegible].000	[illegible]	[illegible]	[illegible]

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
FULL RUDDER UNTIL 75 DEGREE TURN MADE					
0.000	3000.00	0.000	0.000	0.0	0.000
-8.808	3000.00	-.133	249.704	0.0	-4474.901
-17.629	3000.00	-.533	263.459	0.0	-4465.669
-26.458	3000.00	-1.196	260.789	0.0	-4401.878
-35.287	3000.00	-2.119	258.120	0.0	-4278.032
-44.109	3000.00	-3.284	255.476	0.0	-4093.559
-52.919	3000.00	-4.684	257.877	0.0	-3848.413
-61.713	3000.00	-6.301	250.343	0.0	-3543.123
-70.488	3000.00	-8.112	247.890	0.0	-3178.817
-79.244	3000.00	-10.095	245.530	0.0	-2757.237
-87.984	3000.00	-12.222	243.271	0.0	-2280.732
-96.711	3000.00	-14.462	231.640	0.0	-1752.236
-105.430	3000.00	-16.785	229.980	0.0	-1175.095
-114.150	3000.00	-19.158	228.435	0.0	-553.540
-122.880	3000.00	-21.533	226.996	0.0	108.054
-131.629	3000.00	-23.882	225.644	0.0	804.982
-140.407	3000.00	-26.161	224.339	0.0	1532.294
-149.225	3000.00	-28.326	223.053	0.0	2284.880
-158.090	3000.00	-30.333	221.770	0.0	3057.544
-167.010	3000.00	-32.135	220.456	0.0	3845.067
-175.988	3000.00	-33.688	219.035	0.0	4642.263
-185.025	3000.00	-34.942	217.244	0.0	5443.995
-194.117	3000.00	-35.548	215.430	0.0	6245.205
-203.259	3000.00	-36.359	213.467	0.0	7040.907
-212.421	3000.00	-36.427	211.572	0.0	7826.169
-221.596	3000.00	-36.007	209.522	0.0	8596.106
-230.750	3000.00	-35.054	207.269	0.0	9345.799
-239.848	3000.00	-33.527	204.809	0.0	10070.270
-248.846	3000.00	-31.392	202.069	0.0	10764.450
-257.694	3000.00	-28.620	199.100	0.0	11423.152

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-266.335	3000.00	-25.187	195.959	0.0	12041.088
-274.707	3000.00	-21.074	192.864	0.0	12612.893
-282.742	3000.00	-16.292	189.254	0.0	13133.168
-290.371	3000.00	-10.932	185.744	0.0	13596.545
-297.522	3000.00	-4.715	182.156	0.0	14001.777
-304.126	3000.00	2.031	178.521	0.0	14343.273
-310.116	3000.00	9.367	174.885	0.0	14610.762
-315.428	3000.00	17.242	171.277	0.0	14799.785
-320.008	3000.00	25.598	167.727	0.0	14906.410
-323.810	3000.00	34.367	164.264	0.0	14927.368
-326.799	3000.00	43.474	160.915	0.0	14860.142
-328.954	3000.00	52.841	157.705	0.0	14703.041
MANOEUVER	COMPLETE				

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
PULL RUDDER UNTIL BACK ON ORIGINAL HEADING					
-328.[illegible]	3000.00	52.041	157.705	0.0	14703.041
-324.809	3000.00	62.447	154.944	0.0	29955.413
-328.[illegible]	3000.00	72.278	137.428	0.0	30194.092
-326.165	3000.00	81.986	109.825	0.0	30495.760
-321.687	3000.00	91.278	81.462	0.0	30293.378
-315.576	3000.00	99.870	52.634	0.0	29494.180
-308.028	3000.00	107.540	24.416	0.0	27986.680
-299.249	3000.00	114.148	-1.066	0.0	25680.931
-289.634	3000.00	119.659	-22.811	0.0	22531.355
-279.324	3000.00	124.141	-40.645	0.0	18556.768
-268.590	3000.00	127.759	-53.401	0.0	13847.942
-257.610	3000.00	130.759	-63.503	0.0	8557.655
-246.546	3000.00	133.413	-68.844	0.0	2873.691
-235.417	3000.00	136.115	-65.315	0.0	-3021.144
-224.505	3000.00	139.142	-64.857	0.0	-8977.000
-213.740	3000.00	142.454	-66.440	0.0	-14903.640
-203.339	3000.00	147.570	-69.629	0.0	-20902.085
-193.540	3000.00	153.580	-78.501	0.0	-26898.453
-184.674	3000.00	161.119	-95.138	0.0	-32904.618
-177.187	3000.00	170.282	-121.706	0.0	-39117.008
-171.633	3000.00	181.081	-160.951	0.0	-45737.338
-168.657	3000.00	193.283	-215.977	0.0	-52988.886
-168.940	3000.00	206.392	-290.571	0.0	-61126.167
-173.108	3000.00	219.580	-390.137	0.0	-70429.757
-181.586	3000.00	231.640	-521.318	0.0	-81137.864
-194.401	3000.00	241.012	-691.971	0.0	-93287.692
-210.951	3000.00	245.911	-910.953	0.0	-106522.392
-229.861	3000.00	244.627	-1187.702	0.0	-119727.914
MANOEUVER	COMPLETE				

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
PULL DOWN	ELEVATOR UNTIL MAX		DESCENT RATE	ACHIEVED	
0.000	3000.000	0.000	0.000	0.000	0.000
-8.000	3000.184	0.000	259.769	5633.216	0.000
-17.631	3002.672	0.000	257.298	5648.498	0.000
-26.479	3001.512	0.000	253.399	5652.186	0.000
-35.324	3002.694	0.000	247.951	5643.679	0.000
-44.194	3004.207	0.000	241.066	5621.191	0.000
-53.078	3006.046	0.000	232.708	5582.783	0.000
-61.977	3008.275	0.000	223.099	5523.864	0.000
-70.890	3010.553	0.000	212.080	-459.799	0.000
-79.816	3012.852	0.000	210.995	-501.225	0.000
-88.754	3015.121	0.000	200.733	-542.178	0.000
-97.703	3017.355	0.000	200.115	-582.785	0.000
-106.664	3019.563	0.000	199.543	-623.105	0.000
-115.637	3021.713	0.000	199.010	-663.173	0.000
-124.621	3023.832	0.000	198.530	-703.025	0.000
-133.617	3025.908	0.000	198.082	-742.698	0.000
-142.624	3027.938	0.000	197.663	-782.231	0.000
-151.643	3029.920	0.000	197.264	-821.662	0.000
-160.672	3031.852	0.000	196.892	-861.033	0.000
-169.712	3033.731	0.000	196.546	-900.384	0.000
-178.764	3035.555	0.000	196.220	-939.757	0.000
-187.826	3037.321	0.000	195.910	-979.198	0.000
-196.898	3039.026	0.000	195.580	-1018.749	0.000
-205.981	3040.673	0.000	195.123	-1058.458	0.000
-215.074	3042.253	0.000	194.698	-1098.371	0.000
-224.174	3043.766	0.000	194.271	-1138.538	0.000
-233.291	3045.209	0.000	193.835	-1179.009	0.000
-242.414	3046.581	0.000	193.385	-1219.836	0.000
-251.546	3047.879	0.000	193.140	-1261.075	0.000
-260.688	3049.099	0.000	192.734	-1302.784	0.000
-269.839	3050.241	0.000	192.390	-1345.022	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-279.001	3051.354	0.000	192.009	547.612	0.000
-288.178	3052.500	0.000	187.394	-280.574	0.000
-297.364	3053.649	0.000	186.978	.730	0.000
-306.563	3054.799	0.000	184.781	-301.886	0.000
-315.773	3055.902	0.000	182.900	-614.698	0.000
-324.992	3056.946	0.000	181.349	-950.944	0.000
-334.219	3057.964	0.000	180.109	-1289.617	0.000
-343.455	3058.975	0.000	179.118	-1622.607	0.000
-352.694	3059.978	0.000	178.370	-1962.938	0.000
-361.938	3061.353	0.000	177.822	-2309.024	0.000
-371.184	3060.980	0.000	177.349	-2659.454	0.000
-380.432	3061.234	0.000	176.862	-3013.071	0.000
-389.679	3061.405	0.000	176.296	-3369.053	0.000
-398.923	3061.341	0.000	175.522	-3726.997	0.000
-408.178	3061.084	0.000	174.181	-4093.825	0.000
-417.456	3060.552	0.000	168.446	-4491.685	0.000
-426.753	3059.741	0.000	162.207	-4897.468	0.000
-436.060	3058.626	0.000	155.415	-5312.013	0.000
-445.370	3057.142	0.000	140.031	-5734.977	0.000
-454.670	3055.343	0.000	120.010	-6160.015	0.000
-463.946	3053.205	0.000	131.331	-6604.756	0.000
-473.205	3051.779	0.000	121.937	-1703.423	0.000
-482.456	3050.245	0.000	117.382	-1949.894	0.000
-491.698	3048.545	0.000	114.581	-1952.358	0.000
-500.929	3046.829	0.000	111.754	-1959.893	0.000
-510.148	3045.047	0.000	108.911	-1967.476	0.000
-519.352	3043.248	0.000	106.053	-1975.106	0.000
-528.541	3041.432	0.000	103.180	-1982.782	0.000
-537.712	3039.599	0.000	100.291	-1990.506	0.000
-546.866	3037.748	0.000	97.387	-1998.276	0.000
-556.000	3035.880	0.000	94.467	-2006.092	0.000
-565.117	3033.995	0.000	91.533	-2013.954	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-574.202	3016.491	0.000	80.583	-2021.842	0.000
-558.267	3012.676	0.000	85.619	-2029.815	0.000
-542.307	3008.773	0.000	82.640	-2037.814	0.000
-526.314	3004.773	0.000	-79.647	-2045.857	0.000
MANEUVER	COMPLETE				

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
PULL UP ELEVATOR UNTIL DESCENT RATE = 0.					
-631.319	3044.673	0.000	79.647	-2045.857	0.000
-618.185	3000.154	0.000	76.639	-1426.435	0.000
-618.737	2994.924	0.000	92.985	-1513.865	0.000
-627.101	2989.058	0.000	76.554	-837.648	0.000
-635.493	2983.210	0.000	41.561	1414.589	0.000
-643.944	2977.595	0.000	39.424	1315.510	0.000
-652.559	2972.041	0.000	42.746	6179.337	0.000
-661.343	2966.725	0.000	51.992	2550.349	0.000
-670.154	2961.400	0.000	60.828	-1829.933	0.000
-678.917	2955.978	0.000	59.790	-1909.272	0.000
-687.670	2950.515	0.000	52.686	500.991	0.000
-696.473	2944.999	0.000	47.211	1633.102	0.000
-705.333	2939.741	0.000	46.954	943.117	0.000
-714.220	2934.491	0.000	47.427	6.563	0.000
-723.121	2929.058	0.000	45.764	-4.170	0.000
-732.043	2923.793	0.000	42.589	548.643	0.000
-741.000	2918.417	0.000	39.892	842.662	0.000
-749.994	2913.140	0.000	38.271	706.181	0.000
-759.021	2907.902	0.000	36.868	519.378	0.000
-768.070	2902.679	0.000	34.972	544.985	0.000
-777.164	2897.485	0.000	32.734	706.552	0.000
-786.287	2892.323	0.000	30.623	798.125	0.000
-795.448	2887.198	0.000	28.765	789.982	0.000
-804.644	2882.109	0.000	26.955	773.576	0.000
-813.870	2877.056	0.000	25.030	809.420	0.000
-823.145	2872.042	0.000	23.031	873.190	0.000
-832.453	2867.070	0.000	21.001	917.578	0.000
-841.800	2862.142	0.000	19.154	941.116	0.000
-851.184	2857.260	0.000	17.204	965.059	0.000
-860.613	2852.425	0.000	15.345	1000.266	0.000
-870.080	2847.640	0.000	13.417	1040.530	0.000
-879.588	2842.907	0.000	11.503	1077.089	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-899.138	2838.227	0.000	9.609	1109.112	0.000
-898.730	2833.603	0.000	7.725	1140.900	0.000
-908.365	2829.037	0.000	5.841	1174.927	0.000
-918.043	2824.531	0.000	3.961	1210.040	0.000
-927.764	2820.088	0.000	2.091	1244.360	0.000
-937.529	2815.708	0.000	.232	1277.615	0.000
-947.337	2811.395	0.000	-1.617	1310.690	0.000
-957.190	2807.150	0.000	-3.459	1344.138	0.000
-967.087	2802.977	0.000	-5.293	1377.733	0.000
-977.029	2798.876	0.000	-7.116	1411.067	0.000
-987.015	2794.849	0.000	-8.929	1444.061	0.000
-997.045	2790.901	0.000	-10.732	1476.897	0.000
-1007.120	2787.031	0.000	-12.524	1508.694	0.000
-1017.239	2783.243	0.000	-14.305	1542.404	0.000
-1027.402	2779.536	0.000	-16.075	1574.932	0.000
-1037.610	2775.920	0.000	-17.833	1607.254	0.000
-1047.861	2772.389	0.000	-19.579	1639.404	0.000
-1058.156	2768.949	0.000	-21.313	1671.405	0.000
-1068.493	2765.601	0.000	-23.034	1703.241	0.000
-1078.874	2762.346	0.000	-24.742	1734.887	0.000
-1089.297	2759.192	0.000	-26.436	1766.332	0.000
-1099.761	2756.134	0.000	-28.117	1797.578	0.000
-1110.267	2753.178	0.000	-29.783	1828.627	0.000
-1120.814	2750.325	0.000	-31.435	1859.469	0.000
-1131.398	2747.577	0.000	-33.072	1890.094	0.000
-1142.023	2744.937	0.000	-34.693	1920.495	0.000
-1152.686	2742.407	0.000	-36.298	1950.668	0.000
-1163.386	2739.989	0.000	-37.888	1980.607	0.000
-1174.123	2737.685	0.000	-39.461	2010.305	0.000
-1184.895	2735.497	0.000	-41.017	2039.756	0.000
-1195.701	2733.427	0.000	-42.555	2068.953	0.000
-1206.540	2731.477	0.000	-44.076	2097.890	0.000

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-1217.411	2729.650	0.000	-45.579	2126.561	0.000
-1228.312	2721.447	0.000	-47.063	2154.959	0.000
-1239.243	2726.370	0.000	-48.526	2183.079	0.000
-1250.201	2720.422	0.000	-49.976	2210.914	0.000
-1261.189	2723.604	0.000	-51.401	2238.456	0.000
-1272.195	2722.418	0.000	-52.807	2265.705	0.000
-1283.220	2721.366	0.000	-54.193	2292.649	0.000
-1294.262	2720.450	0.000	-55.558	2319.283	0.000
-1305.356	2719.672	0.000	-56.902	2345.603	0.000
-1316.448	2719.033	0.000	-58.225	2371.601	0.000
-1327.556	2718.536	0.000	-59.525	2397.272	0.000
-1338.678	2718.182	0.000	-60.803	2422.611	0.000
-1349.813	2717.972	0.000	-62.058	2447.611	0.000
-1360.956	2717.909	0.000	-63.290	2472.268	0.000
-1372.111	2717.993	0.000	-64.499	2496.575	0.000
MANOEUVER COMPLET					

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
STEADY STATE TURN FROM 0-180 DEGREES					
0.000	3000.00	0.000	0.000	0.0	0.000
-8.791	3000.00	.410	259.769	0.0	3889.759
-17.585	3000.00	.463	254.343	0.0	3889.759
-26.381	3000.00	1.042	254.401	0.0	3889.759
-35.118	3000.00	1.852	254.458	0.0	3889.759
-43.850	3000.00	2.852	254.513	0.0	3889.759
-52.551	3000.00	4.102	254.566	0.0	3889.759
-61.215	3000.00	5.661	254.618	0.0	3889.759
-69.835	3000.00	7.387	254.669	0.0	3889.759
-78.400	3000.00	9.340	254.718	0.0	3889.759
-86.925	3000.00	11.518	254.765	0.0	3889.759
-95.381	3000.00	13.919	254.811	0.0	3889.759
-103.770	3000.00	16.543	254.856	0.0	3889.759
-112.087	3000.00	19.388	254.900	0.0	3889.759
-120.325	3000.00	22.448	254.943	0.0	3889.759
-128.479	3000.00	25.725	254.984	0.0	3889.759
-136.544	3000.00	29.216	255.025	0.0	3889.759
-144.513	3000.00	32.919	255.064	0.0	3889.759
-152.381	3000.00	36.830	255.103	0.0	3889.759
-160.143	3000.00	40.947	255.141	0.0	3889.759
-167.793	3000.00	45.267	255.177	0.0	3889.759
-175.327	3000.00	49.787	255.214	0.0	3889.759
-182.737	3000.00	54.503	255.249	0.0	3889.759
-190.021	3000.00	59.414	255.283	0.0	3889.759
-197.172	3000.00	64.514	255.317	0.0	3889.759
-204.185	3000.00	69.801	255.350	0.0	3889.759
-211.056	3000.00	75.271	255.383	0.0	3889.759
-217.784	3000.00	80.920	255.414	0.0	3889.759
-224.352	3000.00	86.744	255.446	0.0	3889.759
-230.768	3000.00	92.739	255.476	0.0	3889.759

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-237.023	3000.00	98.901	255.507	0.0	3889.759
-243.112	3000.00	105.425	255.536	0.0	3889.759
-249.033	3000.00	111.704	255.566	0.0	3889.759
-254.780	3000.00	118.344	255.594	0.0	3889.759
-260.349	3000.00	125.129	255.623	0.0	3889.759
-265.737	3000.00	132.054	255.651	0.0	3889.759
-270.940	3000.00	139.127	255.678	0.0	3889.759
-275.954	3000.00	146.330	255.706	0.0	3889.759
-280.776	3000.00	153.663	255.733	0.0	3889.759
-285.402	3000.00	161.120	255.759	0.0	3889.759
-289.829	3000.00	168.696	255.786	0.0	3889.759
-294.055	3000.00	176.389	255.812	0.0	3889.759
-298.076	3000.00	184.184	255.838	0.0	3889.759
-301.889	3000.00	192.085	255.863	0.0	3889.759
-305.494	3000.00	200.084	255.889	0.0	3889.759
-308.882	3000.00	208.175	255.914	0.0	3889.759
-312.058	3000.00	216.352	255.939	0.0	3889.759
-315.015	3000.00	224.609	255.964	0.0	3889.759
-317.754	3000.00	232.941	255.989	0.0	3889.759
-320.271	3000.00	241.342	256.014	0.0	3889.759
-322.566	3000.00	249.807	256.038	0.0	3889.759
-324.635	3000.00	258.329	256.063	0.0	3889.759
-326.479	3000.00	266.901	256.087	0.0	3889.759
-328.095	3000.00	275.518	256.112	0.0	3889.759
-329.483	3000.00	284.175	256.136	0.0	3889.759
-330.642	3000.00	292.865	256.161	0.0	3889.759
-331.570	3000.00	301.583	256.185	0.0	3889.759
-332.268	3000.00	310.321	256.209	0.0	3889.759
-332.735	3000.00	319.074	256.233	0.0	3889.759
-332.970	3000.00	327.835	256.258	0.0	3889.759
-332.973	3000.00	336.600	256.282	0.0	3889.759
-332.744	3000.00	345.361	256.306	0.0	3889.759

TABLE 3.5: SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-332.284	3000.00	354.112	256.331	0.0	3889.759
-331.593	3000.00	362.841	256.355	0.0	3889.759
-330.471	3000.00	371.561	256.379	0.0	3889.759
-329.514	3000.00	380.247	256.404	0.0	3889.759
-328.136	3000.00	388.898	256.429	0.0	3889.759
-326.520	3000.00	397.510	256.453	0.0	3889.759
-324.691	3000.00	406.075	256.478	0.0	3889.759
-322.664	3000.00	414.589	256.503	0.0	3889.759
-320.342	3000.00	423.044	256.527	0.0	3889.759
-317.433	3000.00	431.436	256.552	0.0	3889.759
-315.102	3000.00	439.757	256.577	0.0	3889.759
-312.153	3000.00	448.003	256.603	0.0	3889.759
-308.986	3000.00	456.168	256.628	0.0	3889.759
-305.605	3000.00	464.245	256.653	0.0	3889.759
-302.011	3000.00	472.230	256.679	0.0	3889.759
-298.208	3000.00	480.116	256.704	0.0	3889.759
-294.197	3000.00	487.899	256.730	0.0	3889.759
-289.983	3000.00	495.572	256.756	0.0	3889.759
-285.566	3000.00	503.130	256.782	0.0	3889.759
-280.952	3000.00	510.568	256.808	0.0	3889.759
-276.142	3000.00	517.882	256.834	0.0	3889.759
-271.141	3000.00	525.066	256.860	0.0	3889.759
-265.952	3000.00	532.112	256.887	0.0	3889.759
-260.578	3000.00	539.019	256.914	0.0	3889.759
-255.024	3000.00	545.781	256.940	0.0	3889.759
-249.293	3000.00	552.394	256.967	0.0	3889.759
-243.389	3000.00	558.851	256.994	0.0	3889.759
-237.316	3000.00	565.150	257.022	0.0	3889.759
-231.079	3000.00	571.286	257.049	0.0	3889.759
-224.683	3000.00	577.254	257.077	0.0	3889.759
-218.130	3000.00	583.049	257.104	0.0	3889.759
-211.427	3000.00	588.669	257.132	0.0	3889.759

TABLE 3.5; SELECTED TRAJECTORIES AND FORCES

x ft.	y ft.	z ft.	Fx	Fy	Fz
-204.578	3000.00	594.110	257.160	0.0	3889.759
-197.588	3000.00	599.366	257.188	0.0	3889.759
-190.601	3000.00	604.435	257.217	0.0	3889.759
-183.203	3000.00	609.319	257.245	0.0	3889.759
-175.810	3000.00	613.997	257.274	0.0	3889.759
-168.316	3000.00	618.484	257.303	0.0	3889.759
-160.691	3000.00	622.769	257.332	0.0	3889.759
-152.956	3000.00	626.851	257.361	0.0	3889.759
-145.122	3000.00	630.726	257.390	0.0	3889.759
-137.186	3000.00	634.392	257.420	0.0	3889.759
-129.155	3000.00	637.846	257.449	0.0	3889.759
-121.037	3000.00	641.088	257.474	0.0	3889.759
-112.836	3000.00	644.110	257.509	0.0	3889.759
-104.554	3000.00	646.910	257.539	0.0	3889.759
-96.209	3000.00	649.478	257.569	0.0	3889.759
-87.795	3000.00	651.810	257.600	0.0	3889.759
-79.322	3000.00	653.948	257.630	0.0	3889.759
-70.795	3000.00	655.910	257.661	0.0	3889.759
-62.222	3000.00	657.595	257.692	0.0	3889.759
-53.607	3000.00	659.052	257.723	0.0	3889.759
MANOEUVER	COMP ETC				

CHAPTER 4

CAS-1 CABIN STRUCTURE DESIGN

4.1 Introduction

In addition to the theoretical and programming work undertaken, this thesis, also provides the design and analysis of the cabin structure of airship CAS-1. The specifications as to cabin dimensions were provided by CASG (Canadian Airship Study Group , subsequently Canadian Airship Development Corporation). The loading requirements,which the structure was to meet, were partially specified by Ministry of Transport, Civil Aeronautics, Provisional Airworthiness Requirements, Airships[3], sections SC. 2(a), SC.2(b), and SC.11

The design philosphy for the cabin are incorporated in the following considerations:

(1) The final configuration of the engine supports could not be determined at the time of the design

(2) Considerable strength was to be built into the structure in order to permit subsequent modification for testing of various engine support configurations.

(3) An attempt was to be made to provide under floor strength and compressive strength in the verticals in order to provide reasonable protection inside the cabin in case of accidental impact.

(4) Due to airscrew clearance requirements, with respect to both the ground and the envelope, the cabin must be higher than needed for accommodation. This provided the basis for the decision to provide a deep floor structure providing good floor strength and generous space for other requirements such as ballast containment, handling cables, and fuel tanks.

The cabin structure can be separated into two distinct sections each of which must withstand certain loading conditions. Figure 4.1 illustrates the total cabin with both side and front views. The lower cabin structure (below the floor level), illustrated in Figure 4.2, is required to withstand the loading imposed by landing on the single main wheel at a specified sink rate. However, two other conditions should also be examined.

(1) the static condition occuring when the airship is at rest on its single landing wheel

(2) the rigging condition occuring when the cabin is separated from the airship and is resting on four removeable castors.

The upper cabin structure, illustrated in Figure 4.3, can itself be divided into two distinct sections. The transverse sections are required to withstand the loading imposed by the internal catenary system. The longitudinal sections are required to withstand the loading due to the external suspension system and due to the force imparted by the engines.

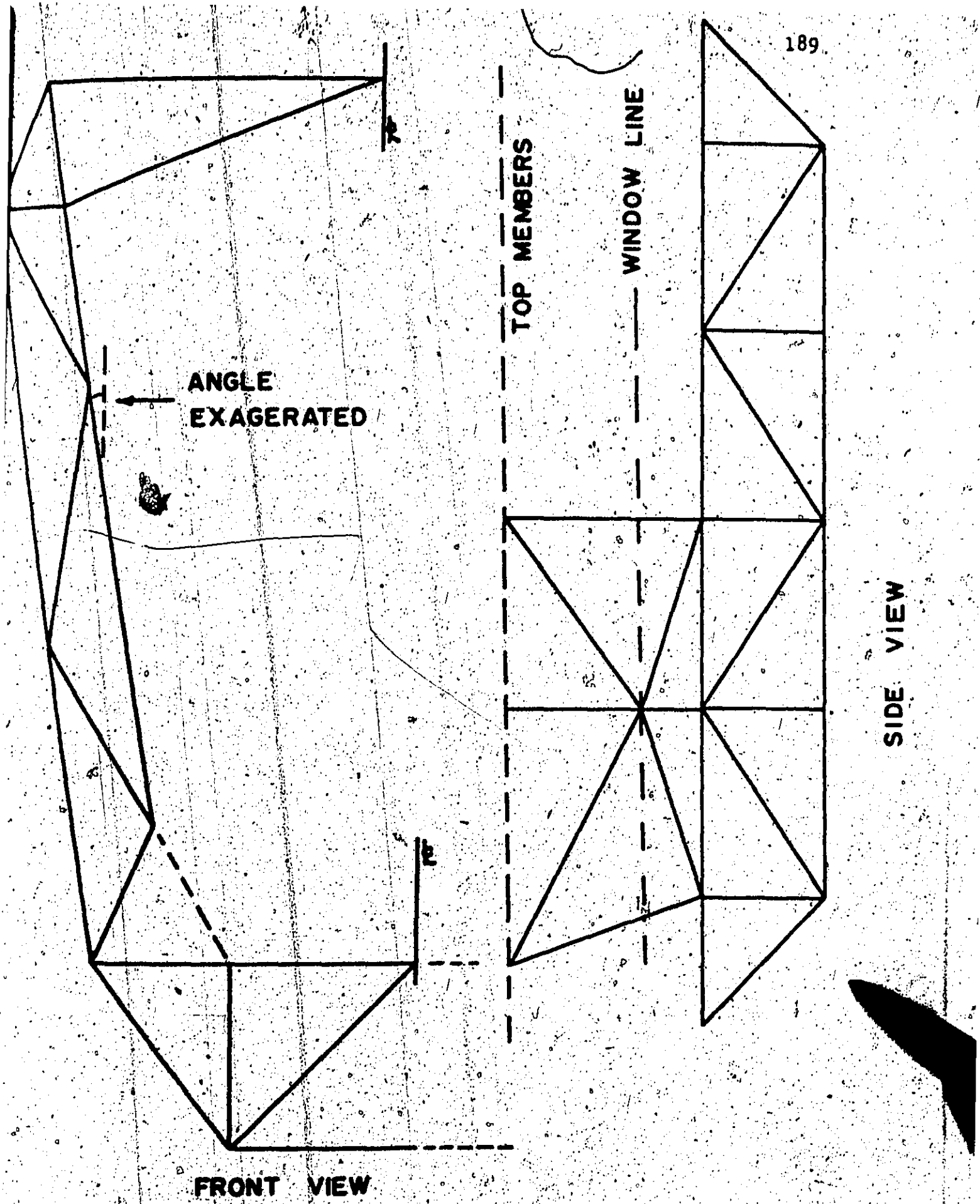


Figure 4.1: Cabin Structure Illustration
Front and Side View

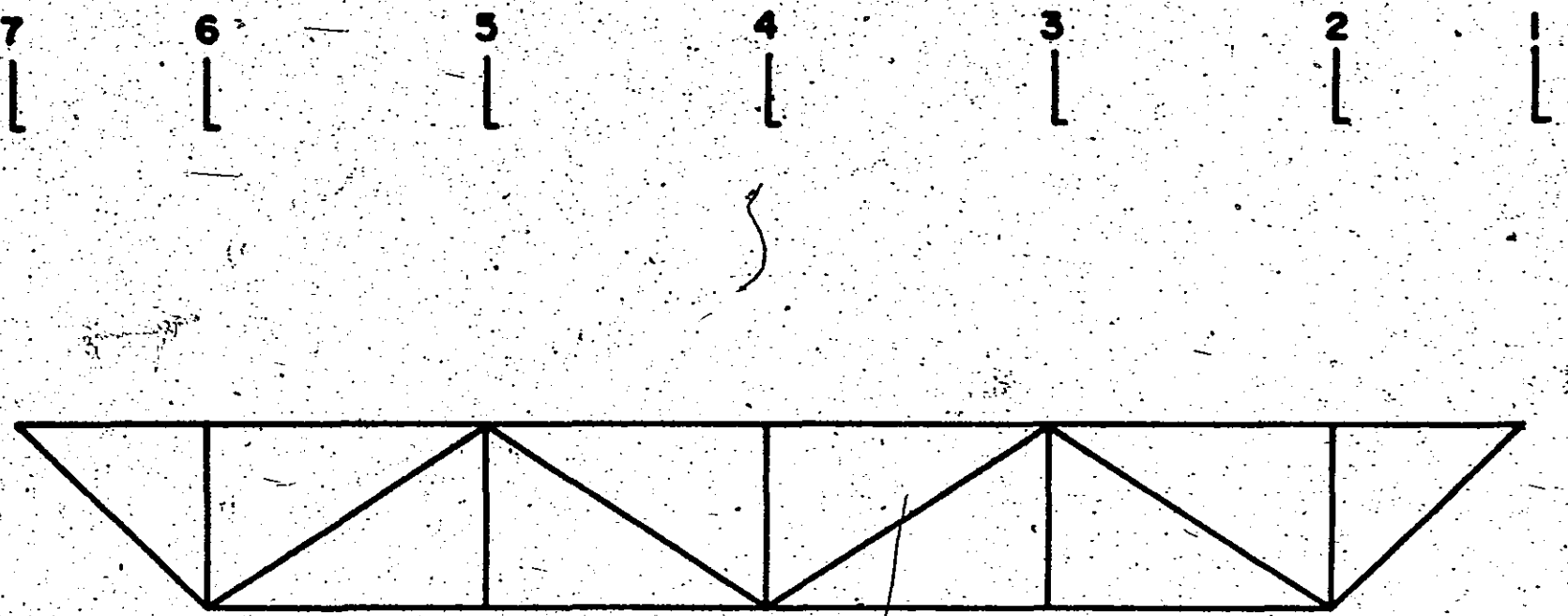


Figure 4.2: Lower Cabin Structure

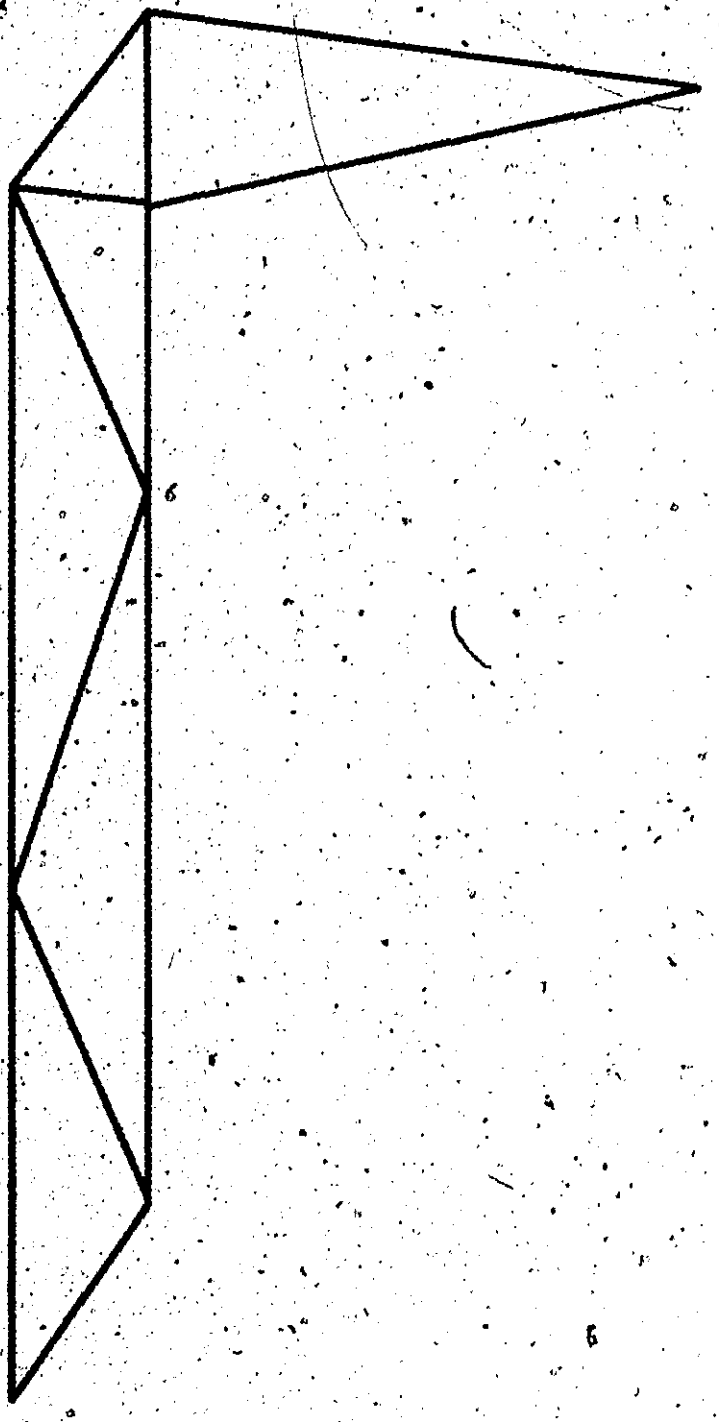


Figure 4.3: Upper Cabin Structure

4.2 Upper Transverse Section Loading Analysis

The transverse upper cabin structure has three major transverse sections. Each section provides two attachment points for the internal suspension system. The cabin weight is usually taken 60% on the internal suspension system and 40% on the external suspension system. However, for the purposes of this analysis 100% of the cabin weight will be taken on the internal suspension system. This will tend to provide a conservative design. Another simplification involves the static engine weight input. The condition is illustrated by Figure 4.4. The struts shown in the illustration are in tension in both the static and the dynamic situation. Refering to Figure 4.5 it can be seen that the tension in the strut will reduce the load in the transverse structure.

The worst condition that occurs is the inflight dynamic loading. The assumption of a rigid body consisting of the engines, outriggers, and underfloor structure allows an analysis to be performed. The total torque of the engines is 382 foot-pounds. The resultant situation is illustrated by Figure 4.6. From static considerations

$$C_V = B_V$$

$$C_H = B_H$$

and from a moment analysis performed about point A

$$D_V = \frac{385}{5} = 76 \text{ pounds}$$

$$D_H = 1 \text{ pound}$$

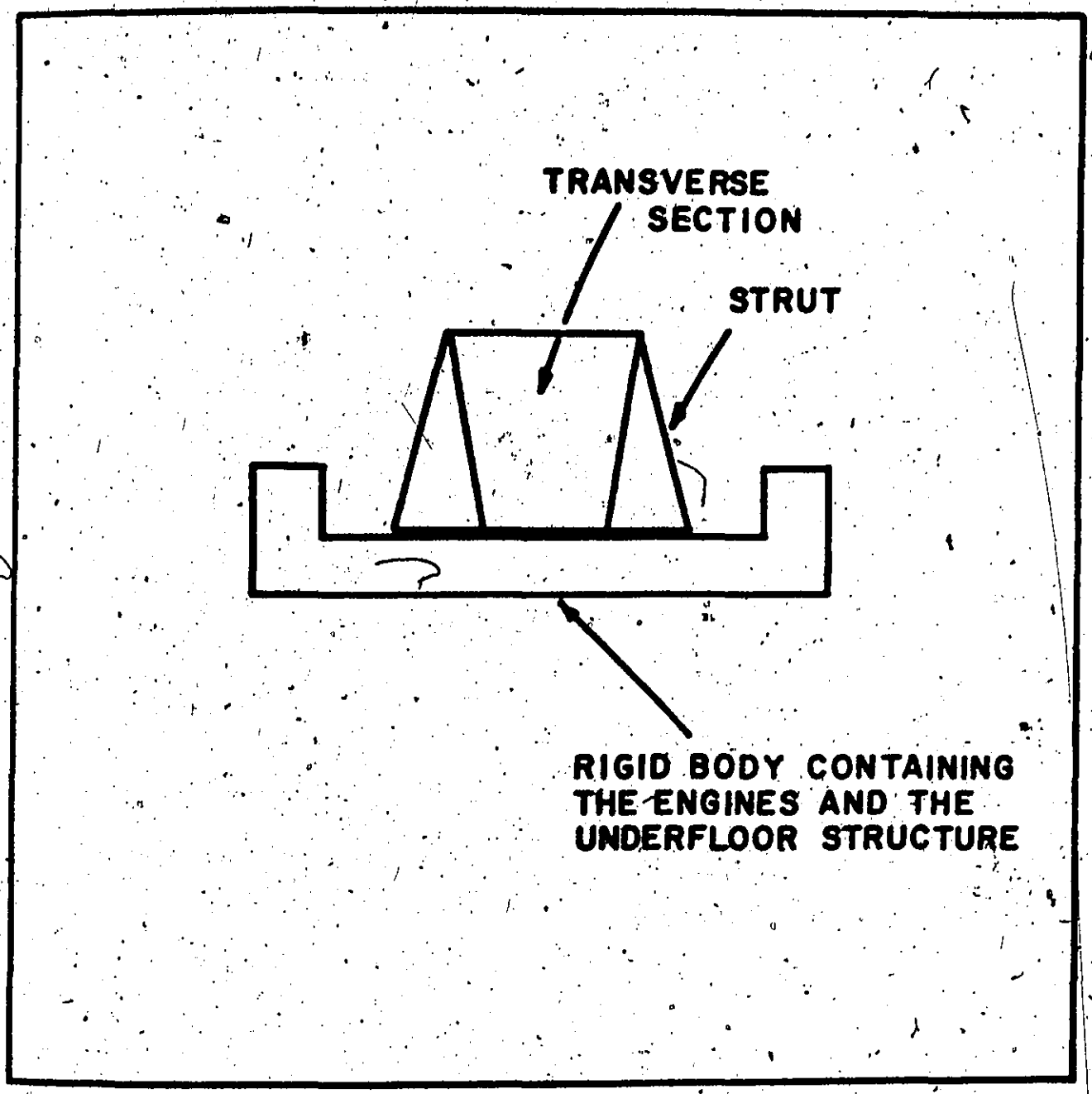


Figure 4.4: Engine Attachment Idealization

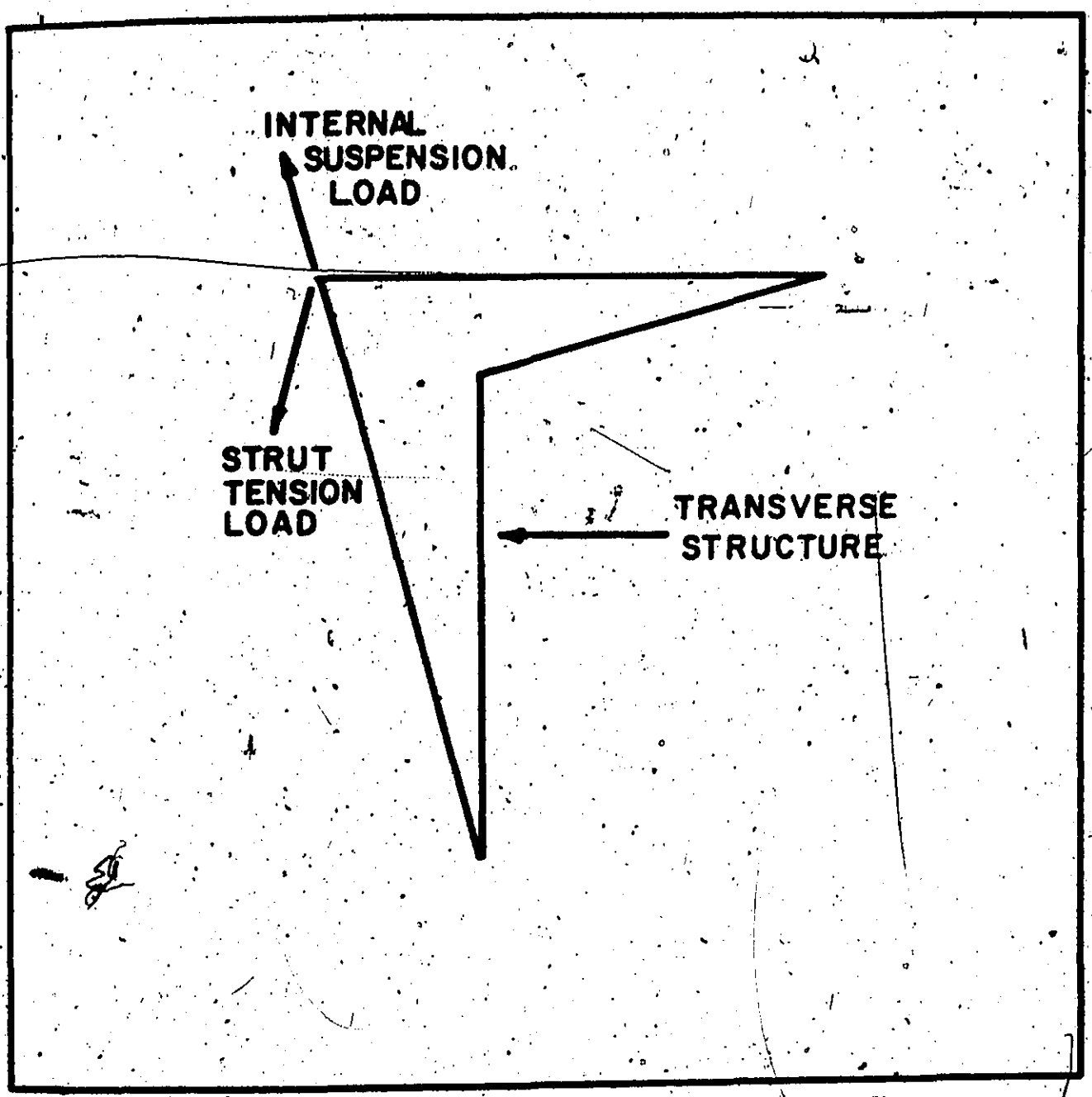


Figure 8.5: Engine Static Weight Input Arrangement

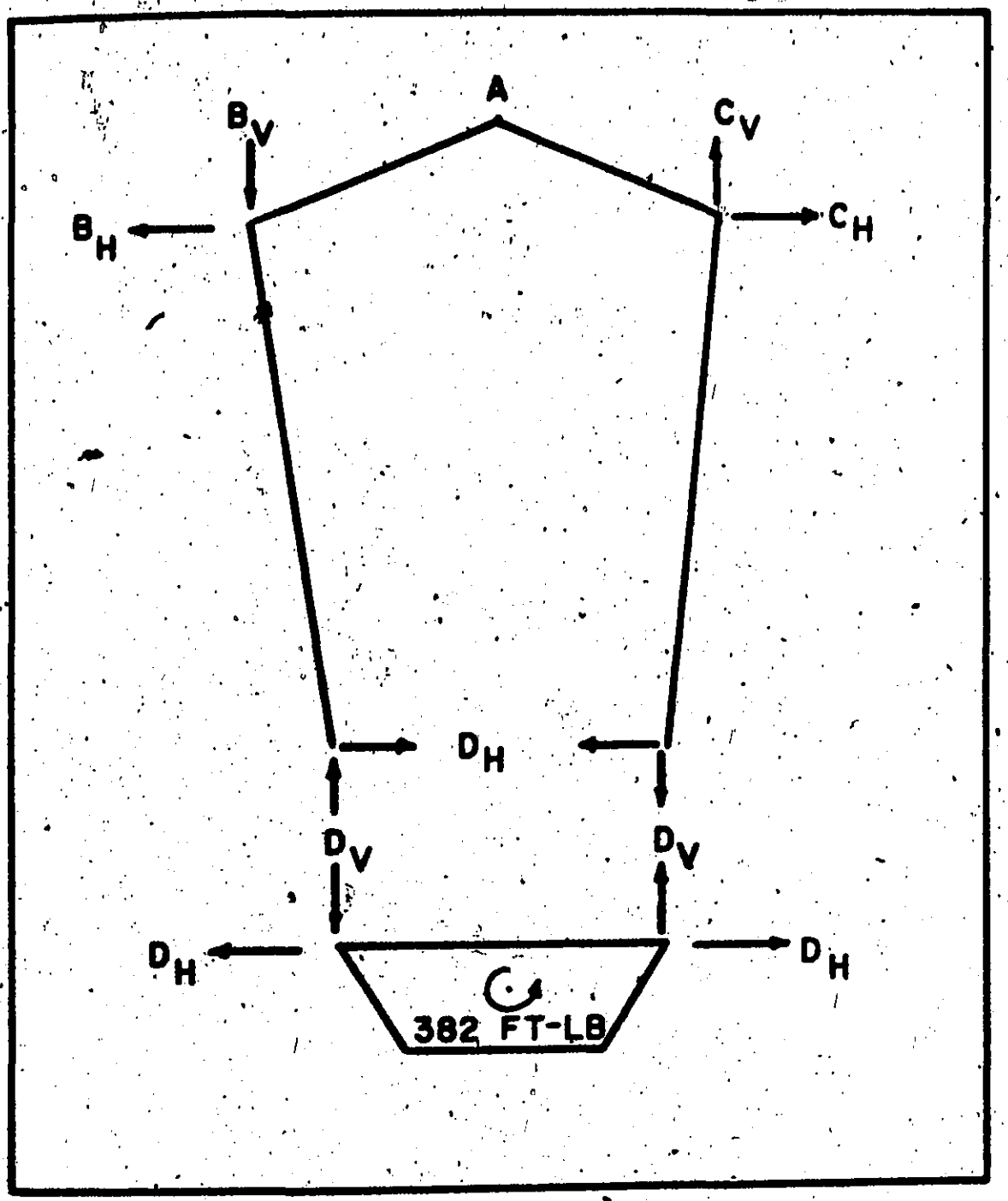


Figure 4.6: Engine Static Weight Input

These are the additional forces produced by the engine torque. These forces must be divided between the three transverse sections in the same proportion as the static cabin weight is proportioned to the internal suspension system.

The analysis of the internal suspension system loads is based on the assumption, as previously stated, that 100% of the static cabin weight is carried by the system. The system is symmetrical about the longitudinal center line of the cabin. The total cabin weight is taken as 3200 pounds. The free body diagram of the system is shown by Figure 4.7. The suspension cables will have load cells in order to allow the loads in the cables to be set at any desired quantity. Hence all combinations of tensions are possible if they obey the following conditions,

$$\Sigma F_V = 0 \qquad (4.1)$$

$$\Sigma F_H = 0 \qquad (4.2)$$

$$\Sigma M_{CG} = 0 \qquad (4.3)$$

Some arbitrary choices must be made in order to solve the system shown by Figure 4.7. The following quantities were, therefore, arbitrarily chosen,

$$B_V = 750 \text{ pounds}$$

$$\beta = 75 \text{ degrees}$$

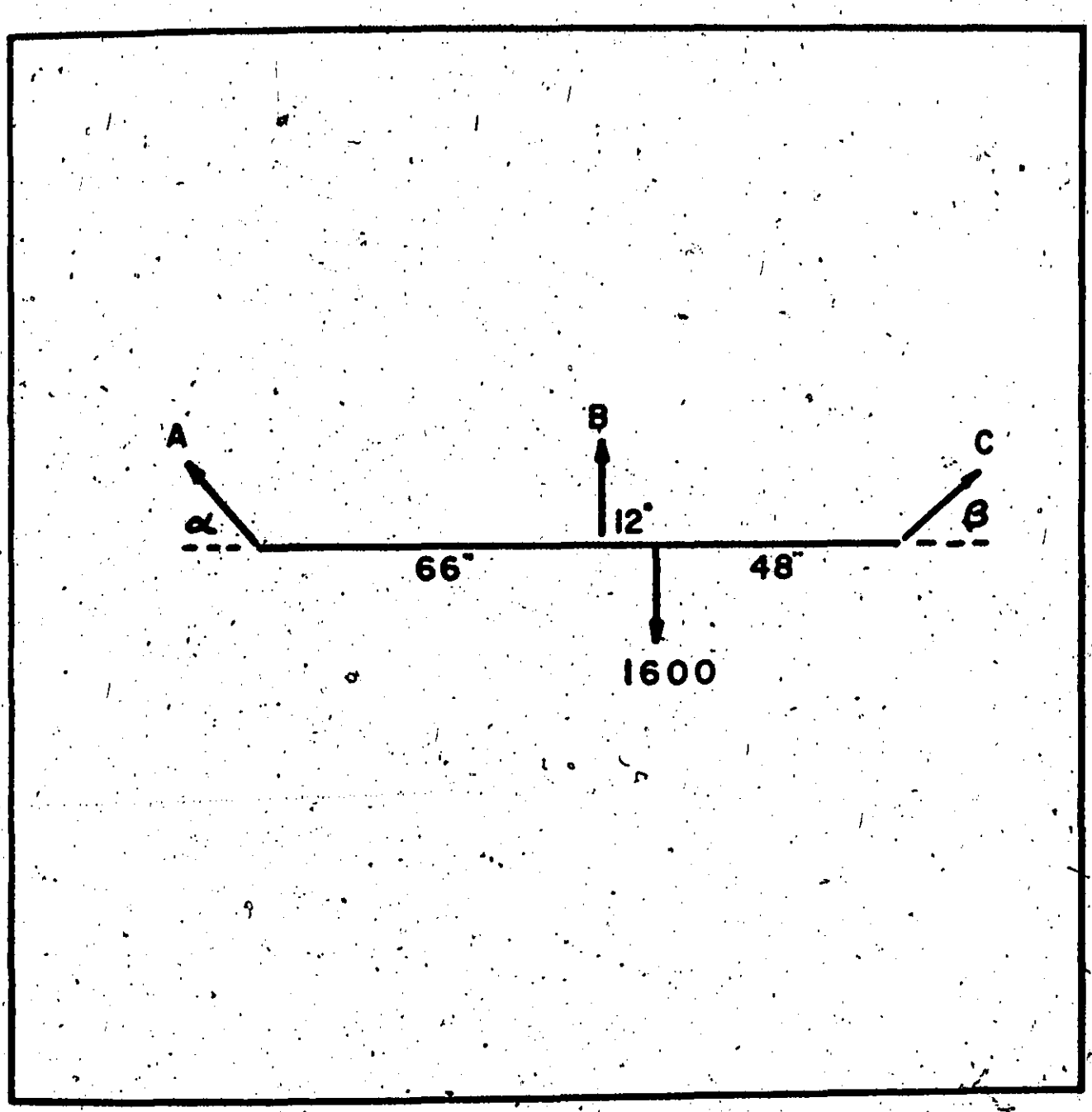


Figure 4.7: System Free Body Diagram

Refering to the free body diagram, the following equations can be formulated.

$$A \sin\alpha + 750 + C\sin 75 - 1600 = 0 \qquad (4.1)$$

$$A \cos\alpha - C\cos 75 = 0 \qquad (4.2)$$

$$A \sin\alpha \times 66 + 750 \times 12 - C\sin 75 \times 48 = 0 \qquad (4.3)$$

From this system of equations, the following results can be obtained.

$C = 590$ pounds

$A = 318$ pounds

$B = 750$ pounds

$\alpha = 61.5$ degrees

$\beta = 75$ degrees

However, for the purposes of this analysis, only the vertical components have significance.

$A_V = 280$ pounds

$B_V = 750$ pounds

$C_V = 570$ pounds

The loads on the structure can be resolved into six components. These components, illustrated along with the basic structural design in Figure 4.8, are

(1) F_{VI} the vertical load due to the static tension of the suspension cable plus or minus a force due to the engine torque

(2) F_{HI} the horizontal load due to the static tension of the suspension cable plus a force due to the engine torque

(3) F_{VII} the vertical balancing force

(4) F_{HII} the horizontal balancing force

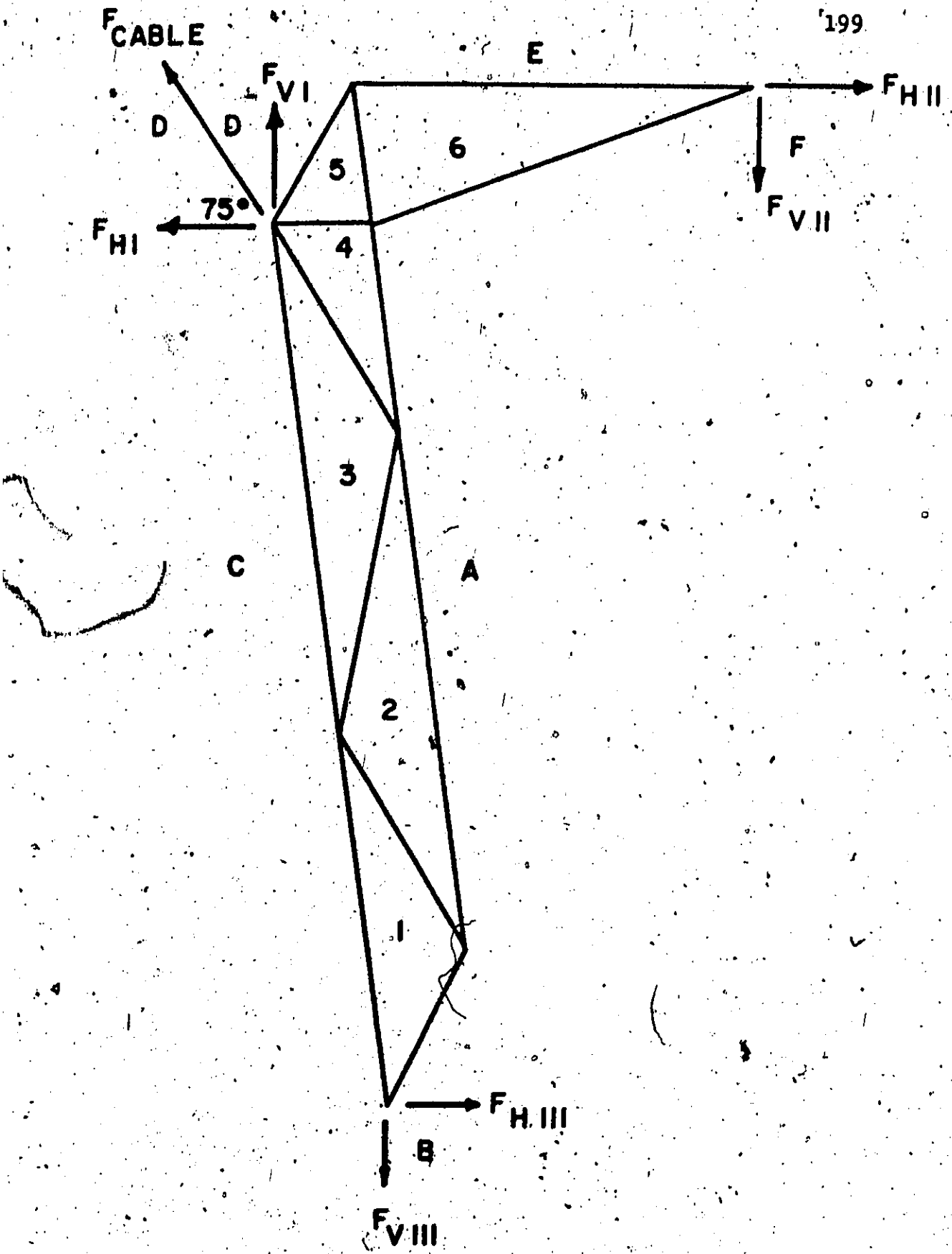


Figure 4.8: Transverse Structure Load Components

(5) F_{VIII} the vertical load due to the static tension of the suspension cable plus or minus a force due to the engine torque

(6) F_{HIII} the horizontal force due to the above and obtained by considering moments about the cabin center line.

These loads can be determined for each transverse section. In order to simplify the design the decision was made to use a common size tubing in all the transverse structural sections. Hence, only the maximum loading, which occurs in section B, was considered and the total dynamic loading of the engines was also assumed to be taken in this one section. The suspension cables were assumed to have an inclination of 75 degrees to the horizontal, as shown in Figure 4.8, and the resulting loading is given by Table 4.1. The loading situations are shown in Figure 4.9 and Figure 4.10, while the graphical analysis used to solve the problem is presented in Figures 4.11 and 4.12. Table 4.2 presents the loads obtained from the analysis and also the ultimate design load. The ultimate design load was taken to be the larger of the left side or right side loads and a safety factor of two was applied.

One further situation must be considered. This is the situation which can occur due to wind gusts hitting the cabin side on. The result of such an occurance is shown in Figure 4.13. If the quantity

$$W \sin\alpha = \text{maximum}$$

is arbitrarily chosen to be 750 pounds then α, the gust swing angle, can be calculated to be 30 degrees.

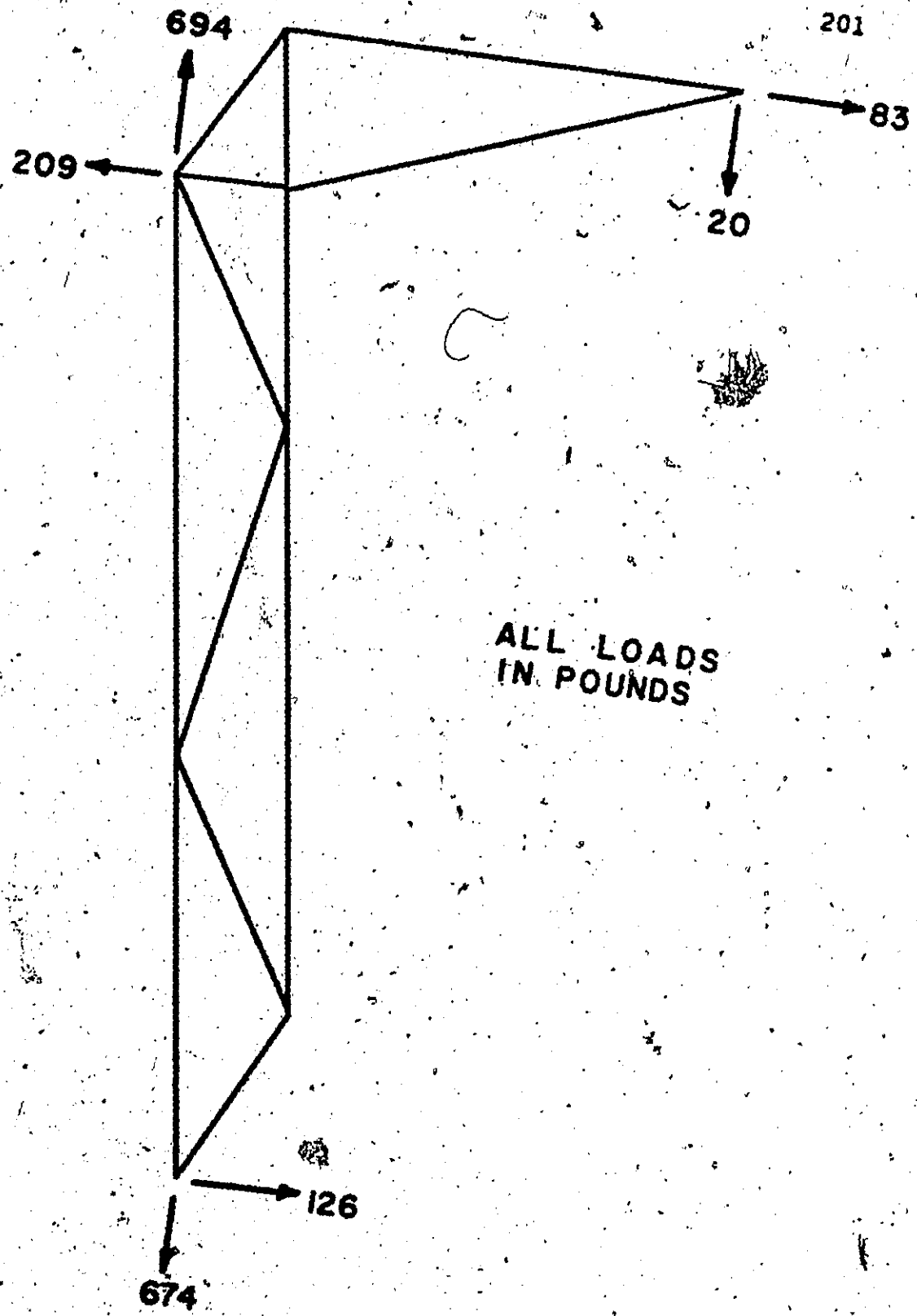


Figure 4.9: Transverse Structure Left Loading Diagram

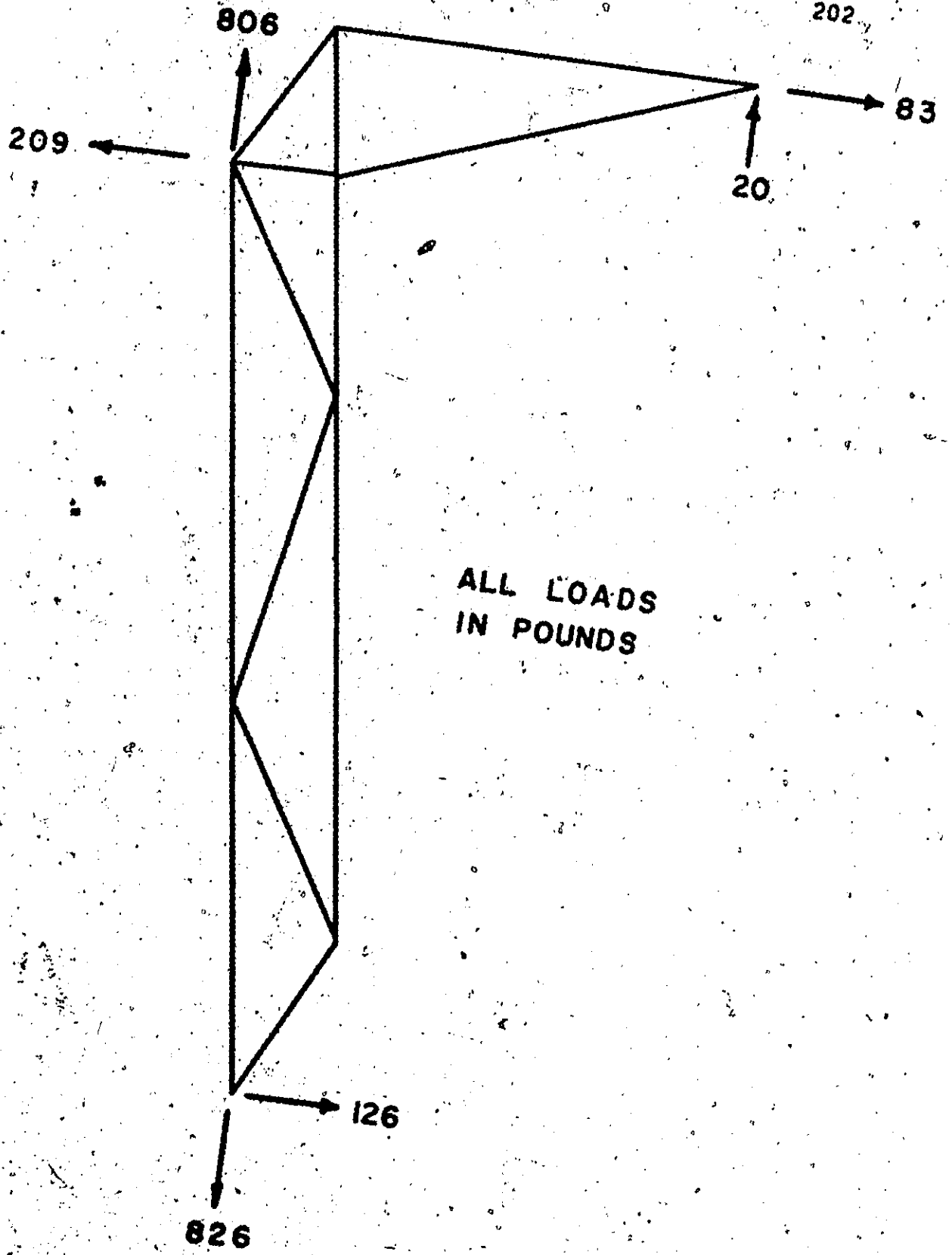


Figure 4.10: Transverse Structure Right Loading Diagram

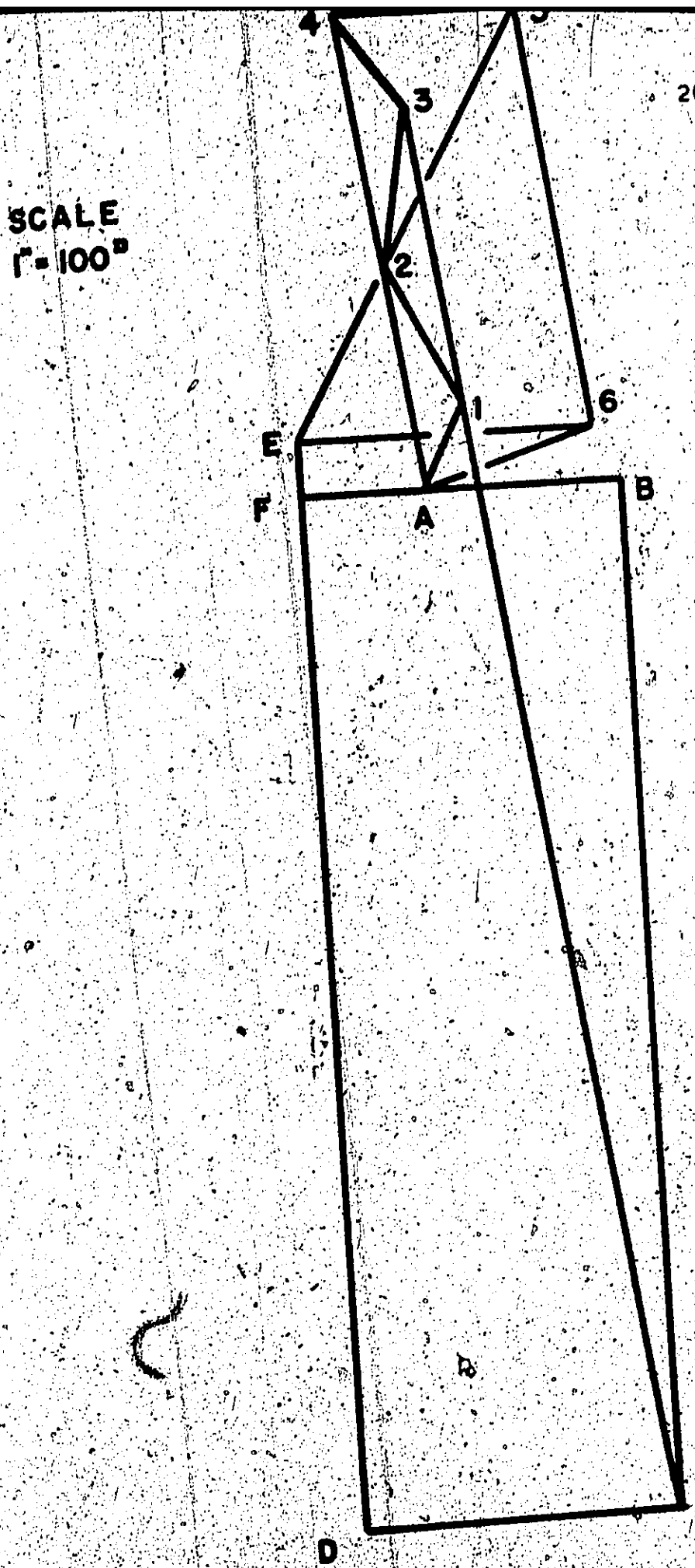
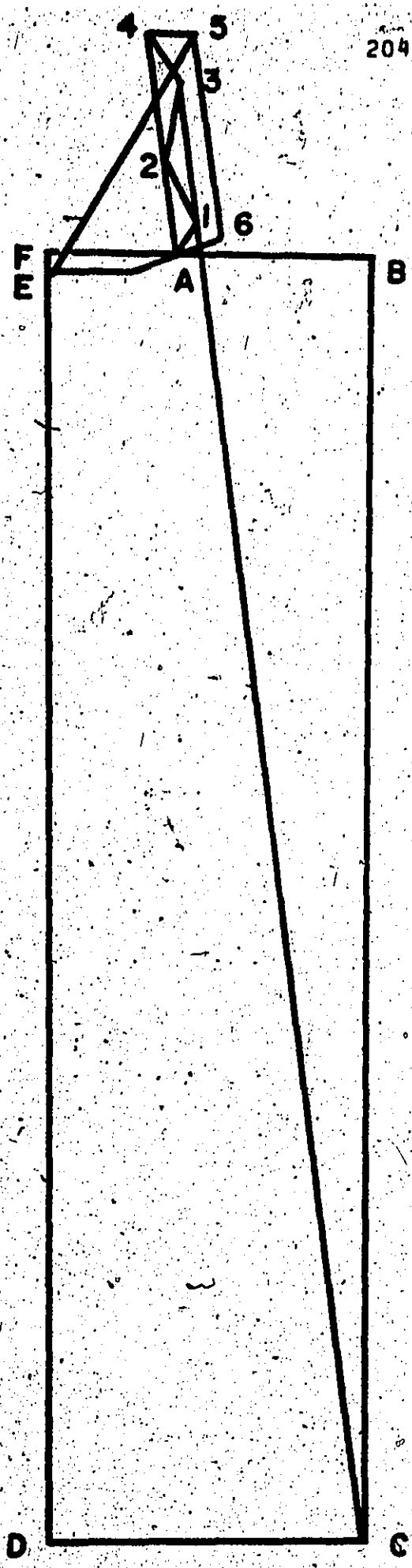


Figure 4.11: Graphical Analysis Left Transverse Structure



SCALE
1" = 100'

Figure 4.12: Graphical Analysis Right Transverse Structure

The division of this load into the various loads required for the structural analysis is given by Figure 4.14. The loading diagrams for these loads are presented in Figure 4.15 and Figure 4.16, and the graphical analysis, performed to obtain the loads in each member, is presented in Figure 4.17 and Figure 4.18.

The worst possible situation, and perhaps an unrealistic one, occurs when the above loading is combined with the previous loading using superposition. The results of such a combination, in terms of ultimate loads, is presented in Table 4.2(a). From the results presented in this table the structural members, required for the transverse sections, can be determined.

4.3 Upper Side Members Loading Analysis

The structure in this analysis must withstand various forces which can be combined into two basic situations, involving climb and dive maneuvers, constituting the extreme boundaries of the flight enevelope. The structural configuration, shown in Figure 4.19, must withstand the following forces :

(1) the weight of the cabin at the center of gravity location (3200 pounds),

(2) the trust force of the engines (480 pounds per engine)

(3) the forces due to a 30 degree dive

(4) the forces due to a 30 degree upwards inclination

Cases 1, 2 and 3 can be combined into one situation and Cases 1 and 4 can be combined into another situation.

TABLE 4.1: Section Loading

Force	LEFT			RIGHT		
	Static	Dynamic	Total	Static	Dynamic	Total
P_{VI}	750	-56	694	750	56	806
P_{HI}	202	7	209	202	7	209
P_{VII}		20	20		20	20
P_{HII}	77	6	83	77	6	83
P_{VIII}	750	-76	674	750	76	826
P_{HIII}	125	1	126	125	1	126

TABLE 4.2

Member Loads Level Condition

Member	Length	Left Side	T / C	Right Side	T / C	Ultimate Load	T / C
A1	15	65	C	25	C	130	C
A2	42.5	140	C	60	C	280	C
A4	17	315	C	140	C	630	C
A6	33.5	120	C	30	T	240	C
C1	30.8	740	T	860	T	1720	T
C3	42.5	930	T	940	T	1880	T
E5	13.5	315	T	180	T	630	T
E6	33.5	195	T	50	T	390	T
12	20.5	90	T	40	T	180	T
23	25	110	C	50	C	220	C
34	20.5	80	T	40	T	160	T
45	8.5	115	C	30	C	230	C
56	11.5	280	C	130	C	560	C

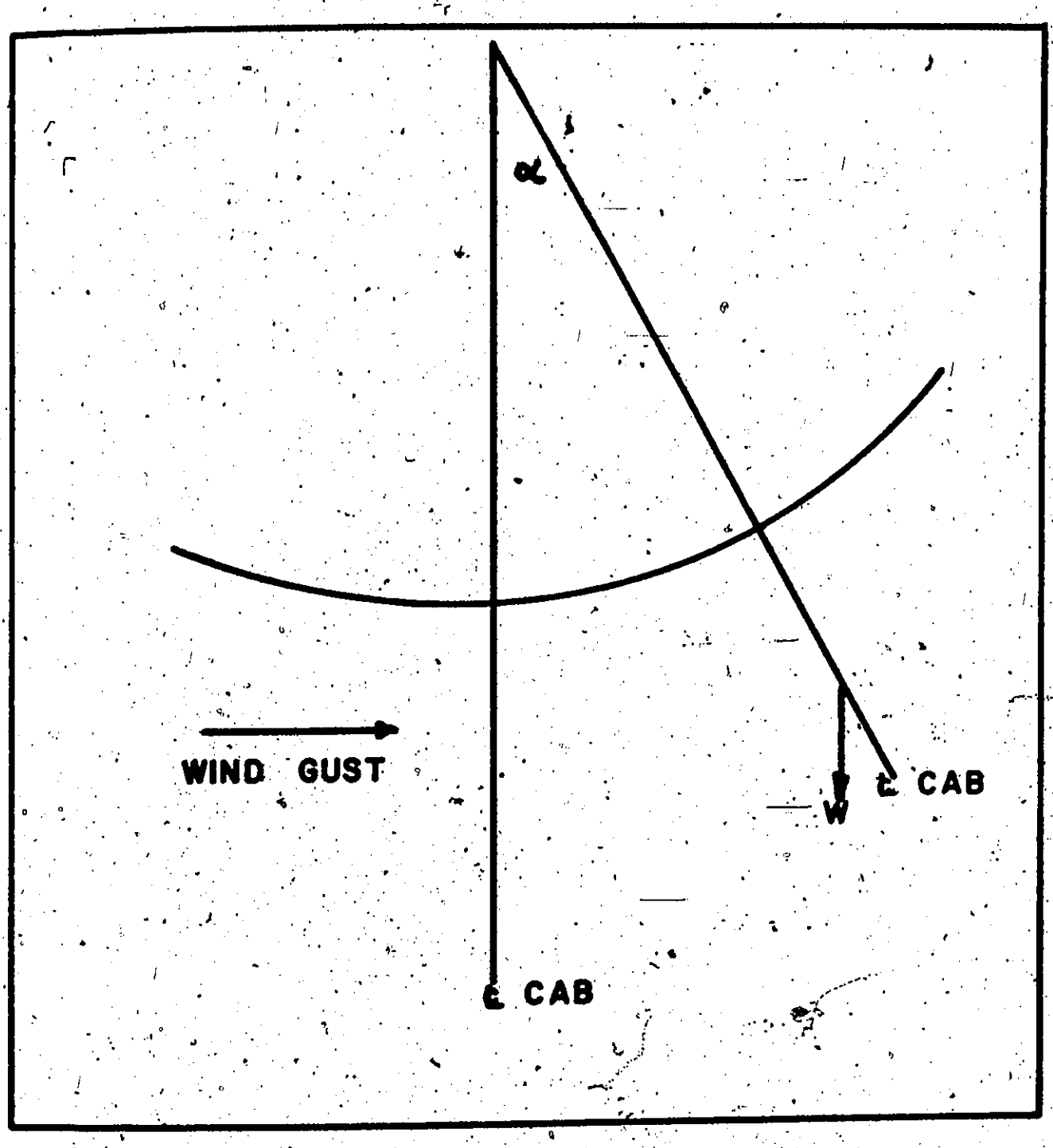


Figure 4.13: Wind Gust Situation

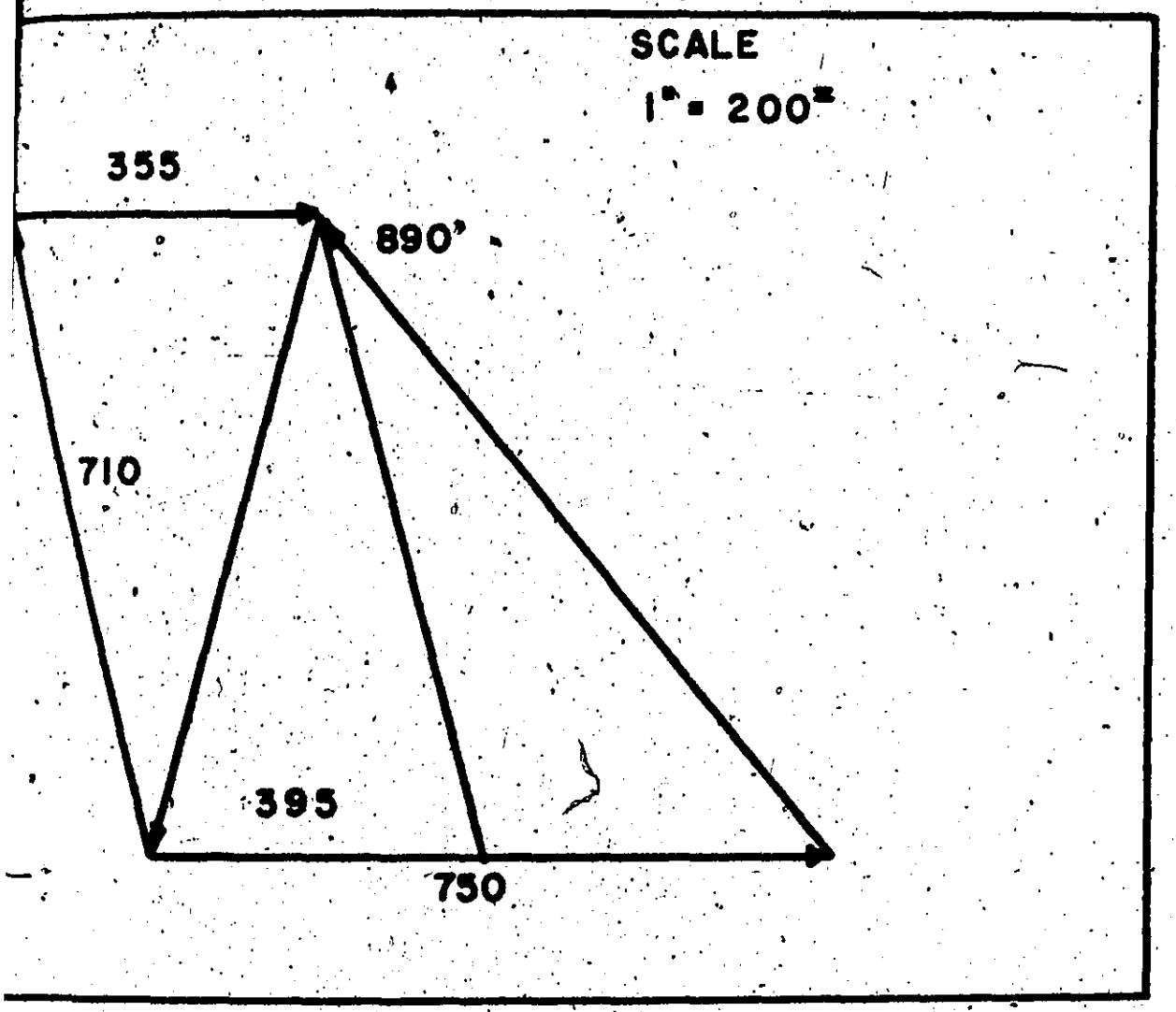


Figure 4.14: Load Analysis Gust Situation

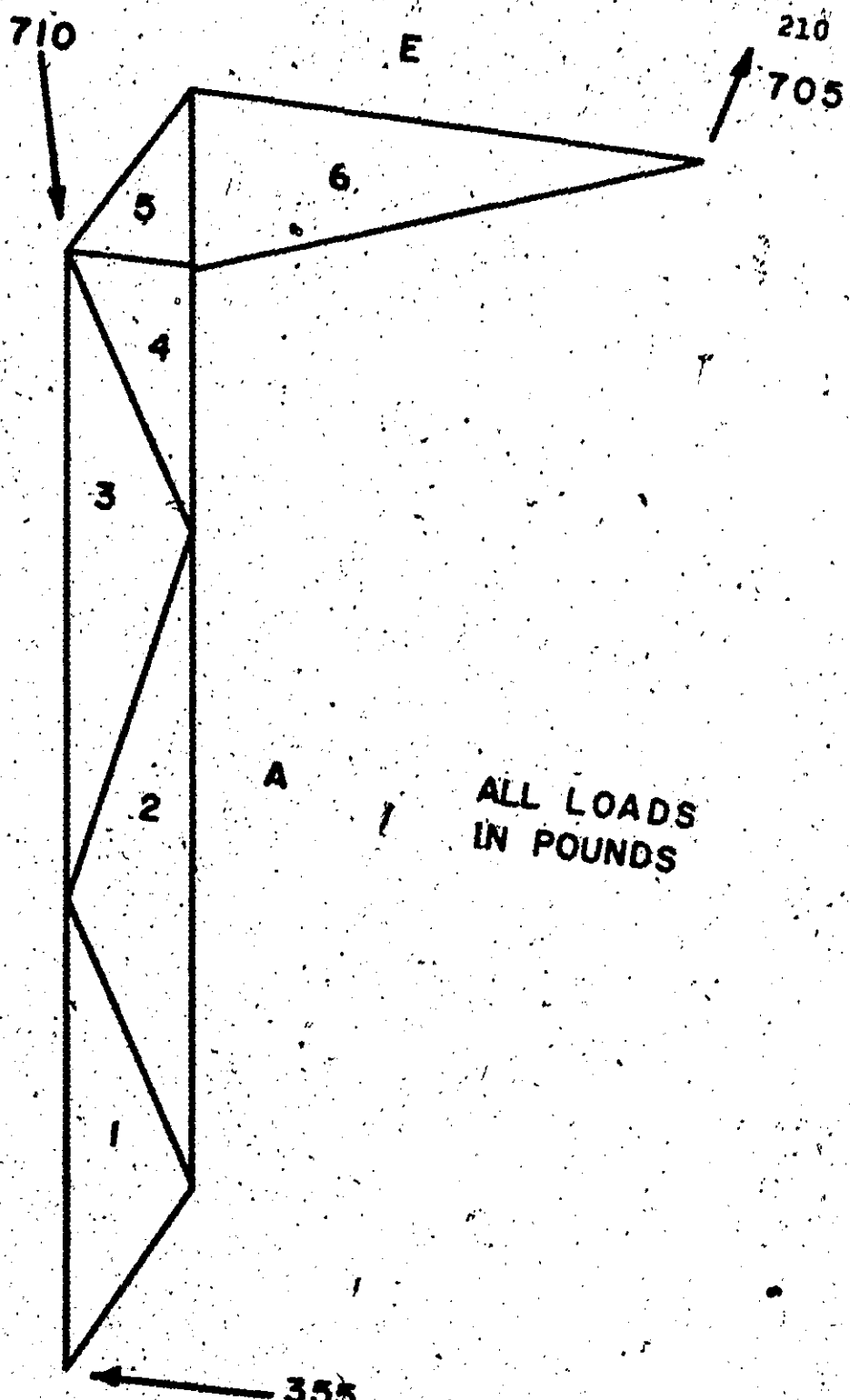


Figure 4.15: Gust Loading Left Transverse Structure

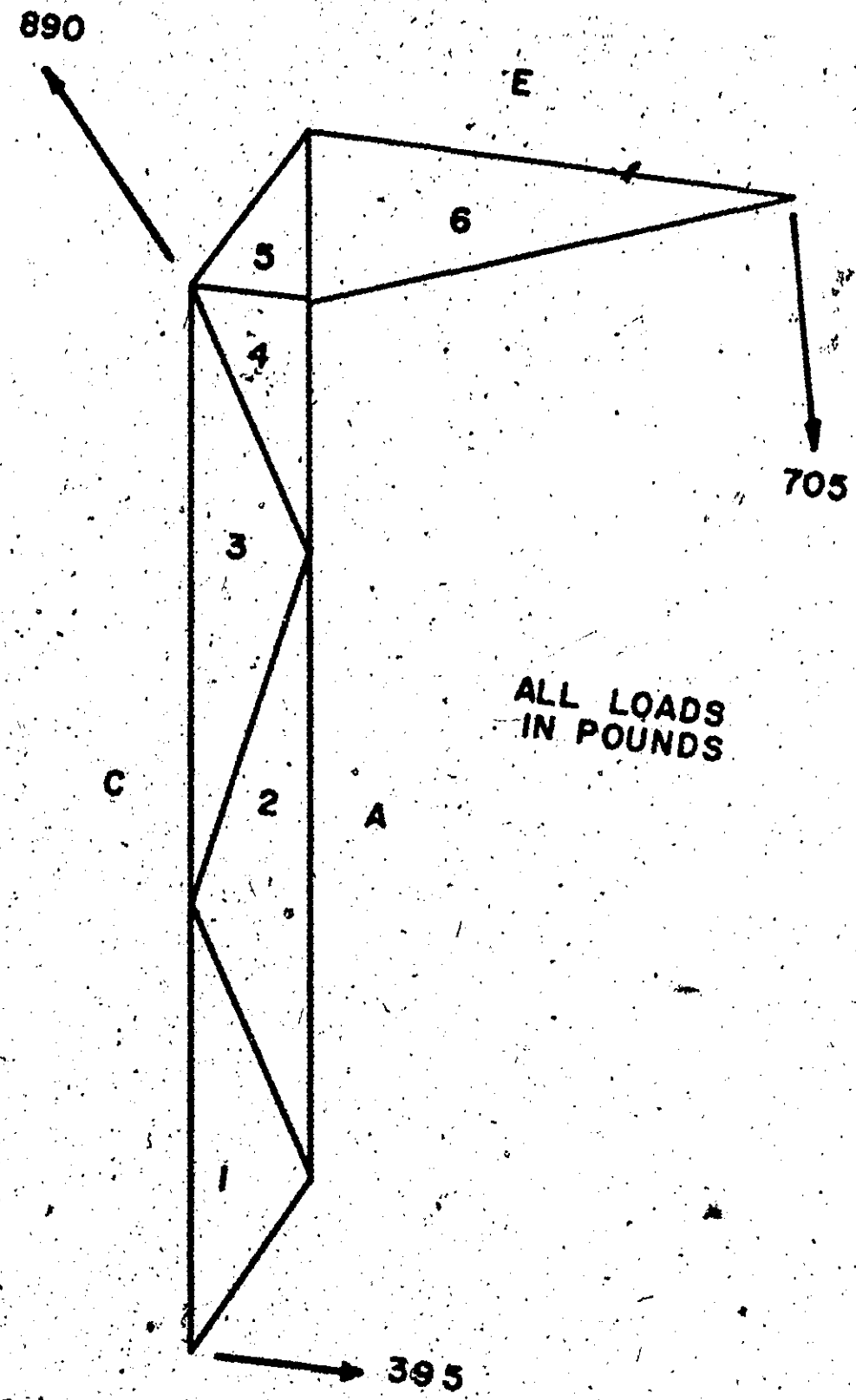
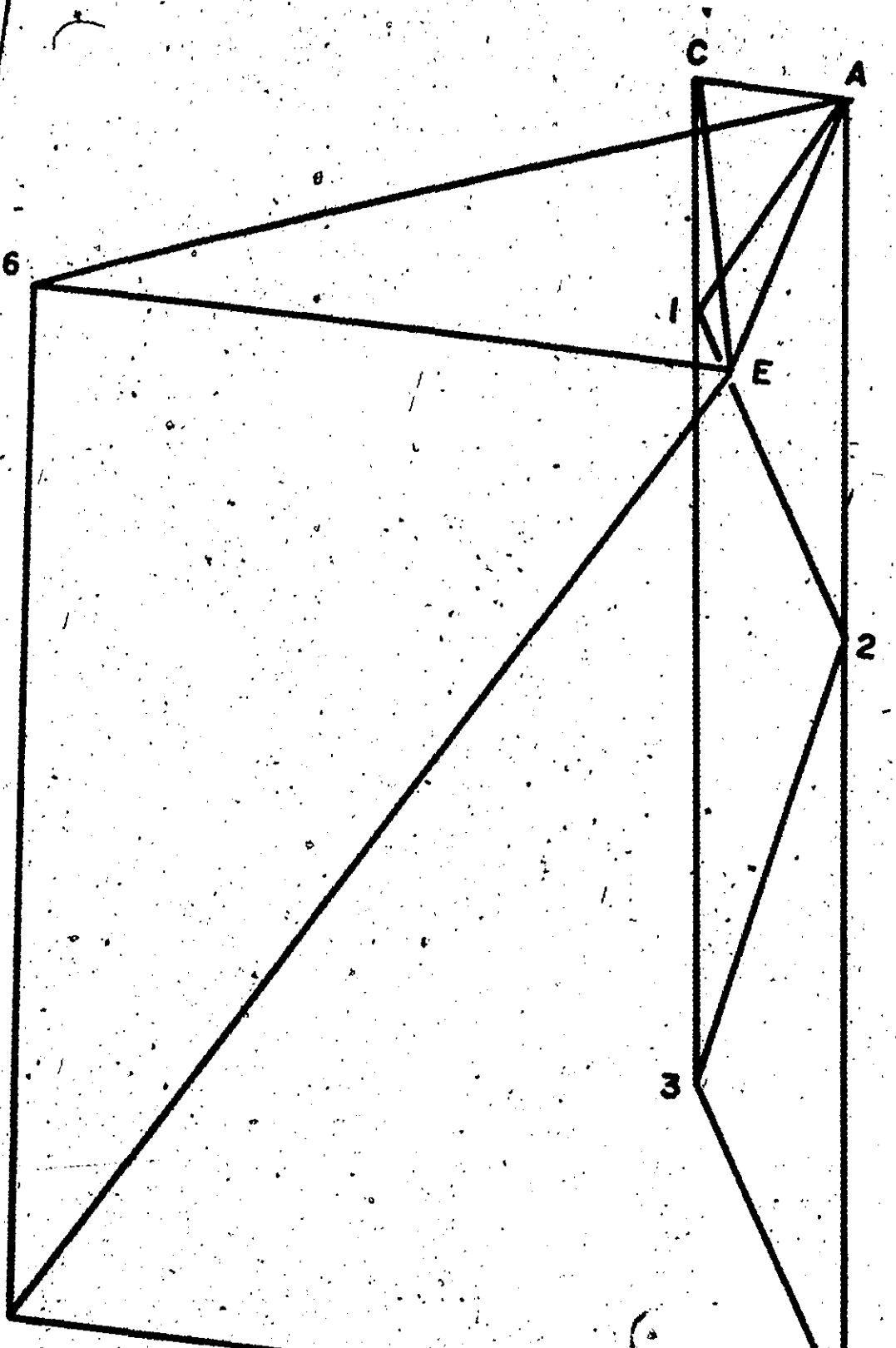
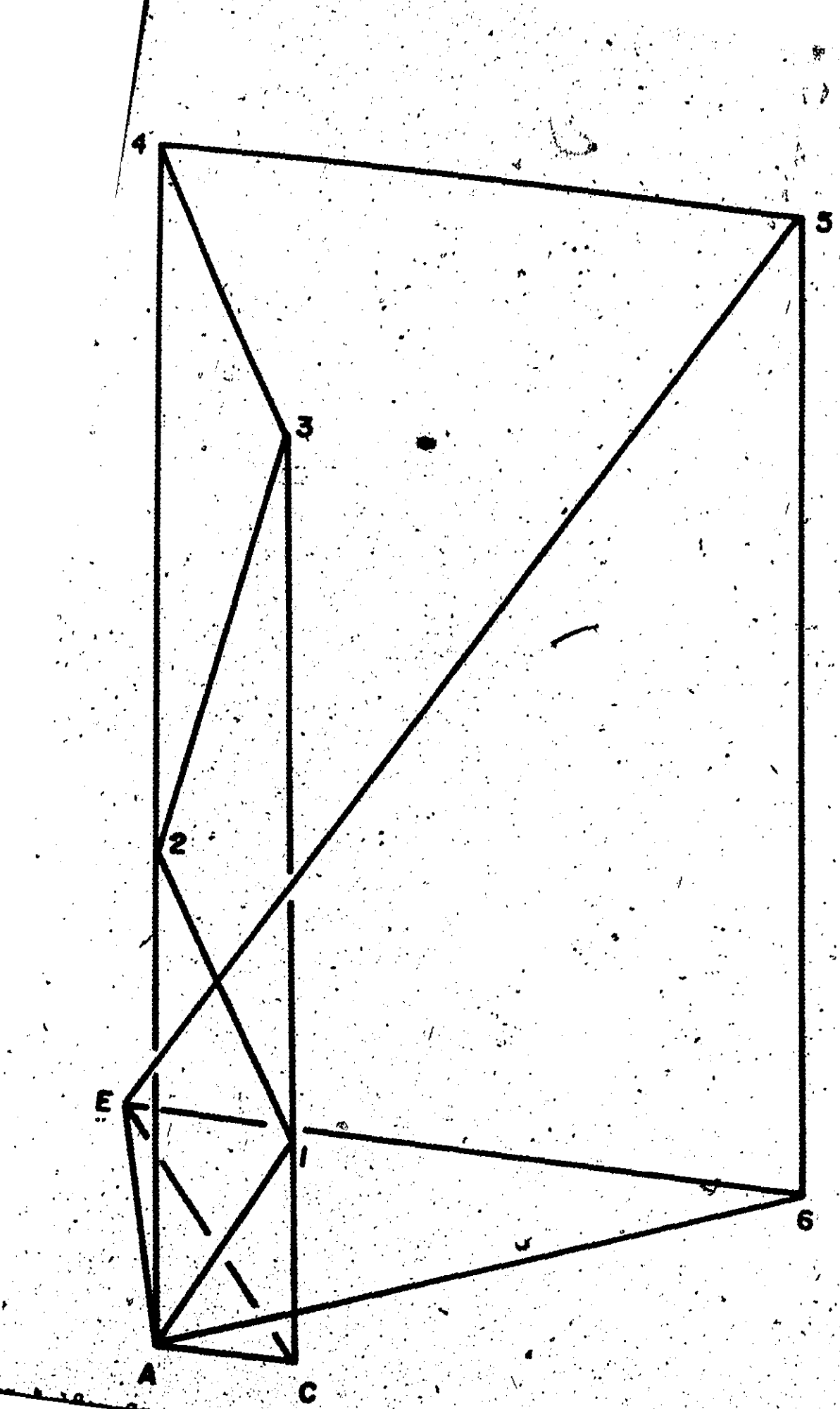


Figure 4.16: Gust Loading Right Transverse Structure



SCALE
1" = 400"

Figure 4.17: Graphical Analysis Gust Condition Left Transverse Structure



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1" = 400'

Cost Condition Right Transve

TABLE 4.2(a)

Combined Side Force and Level Condition Loads
(Ultimate Loads)

Member	Length	Left				Right			
		Side	Dynamic	Total	T C	Side	Dynamic	Total	T C
A1	15	1280T	130C	1150	T	1440	130	1570	C
A2	42.5	2640T	280C	2360	T	2920	280	3200	C
A4	17	6480T	630C	5850	T	7000	630	7630	C
A6	33.5	4160T	240C	3920	T	3840	240	4080	C
C1	30.5	1120C	1720T	600	T	1280	1720	3000	T
C3	42.5	4920C	1880T	3040	C	5400	1880	7280	T
E5	13.5	5840C	630T	5210	C	6400	630	7030	T
E6	33.5	3600C	390T	3210	C	4000	390	4390	T
12	20.5	1760C	180T	1580	C	1920	180	2100	T
23	25	2280T	220C	2060	T	2440	220	2660	C
34	20.5	1760C	160T	1600	C	1920	160	2080	T
45	8.5	4120T	230C	3890	T	3760	230	3990	C
56	11.5	5040T	560C	5480	T	5680	560	6240	C

4.3.1 Basic Case 1

This situation combines the full weight at the center of gravity with full engine thrust and a thirty degree dive. The free body diagram illustrating this situation is shown in Figure 4.20.

The value of B_V remains as determined in the previous analysis as it cannot resist any couples. An analysis of the vertical forces and the moments about the center of gravity implies that a negative cable force is produced at A. This is unrealistic. The most that can happen is that $A_V=0$ which implies that the cable is slack. Assuming $A_V=0$, the following analysis can be performed.

$$\Sigma F_V = 0 \qquad B_V + C_V = 1600$$

$$\Sigma M_{CG} = 0 \qquad 1280 \times 72 - B_V \times 12 - C_V \times 66 = 0$$

The above equations give

$$C_V = 1351 \text{ pounds}$$

$$B_V = 249 \text{ pounds}$$

The loading situation thus produced is illustrated by Figure 4.21 and the idealized situation used to solve for the member loadings is shown by Figure 4.22. This situation is conservative as the real number will have smaller forces than the idealized member. The results for those members to be analysed in this section are presented in Table 4.3.

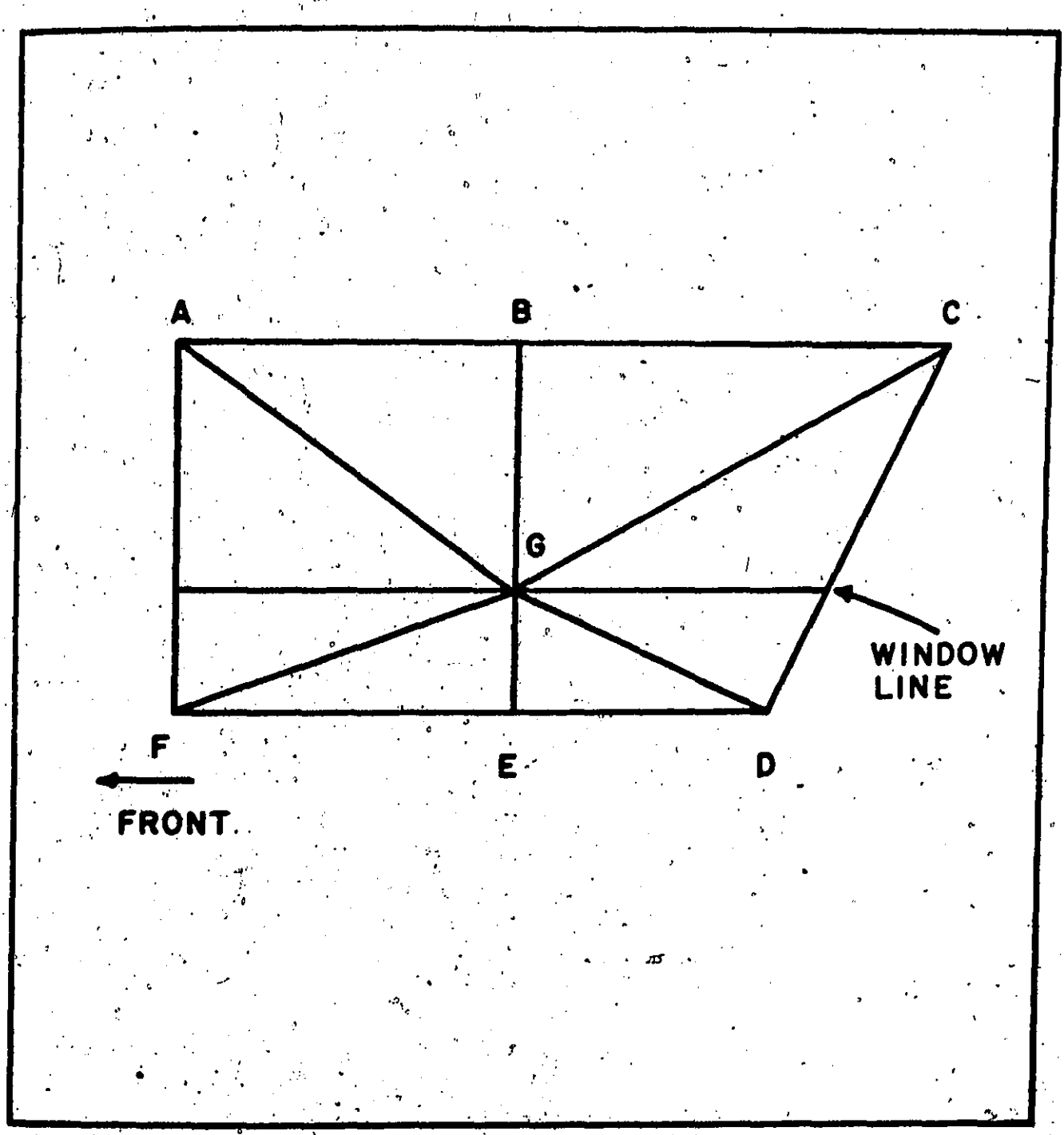


Figure 4.19: Upper Side Structure

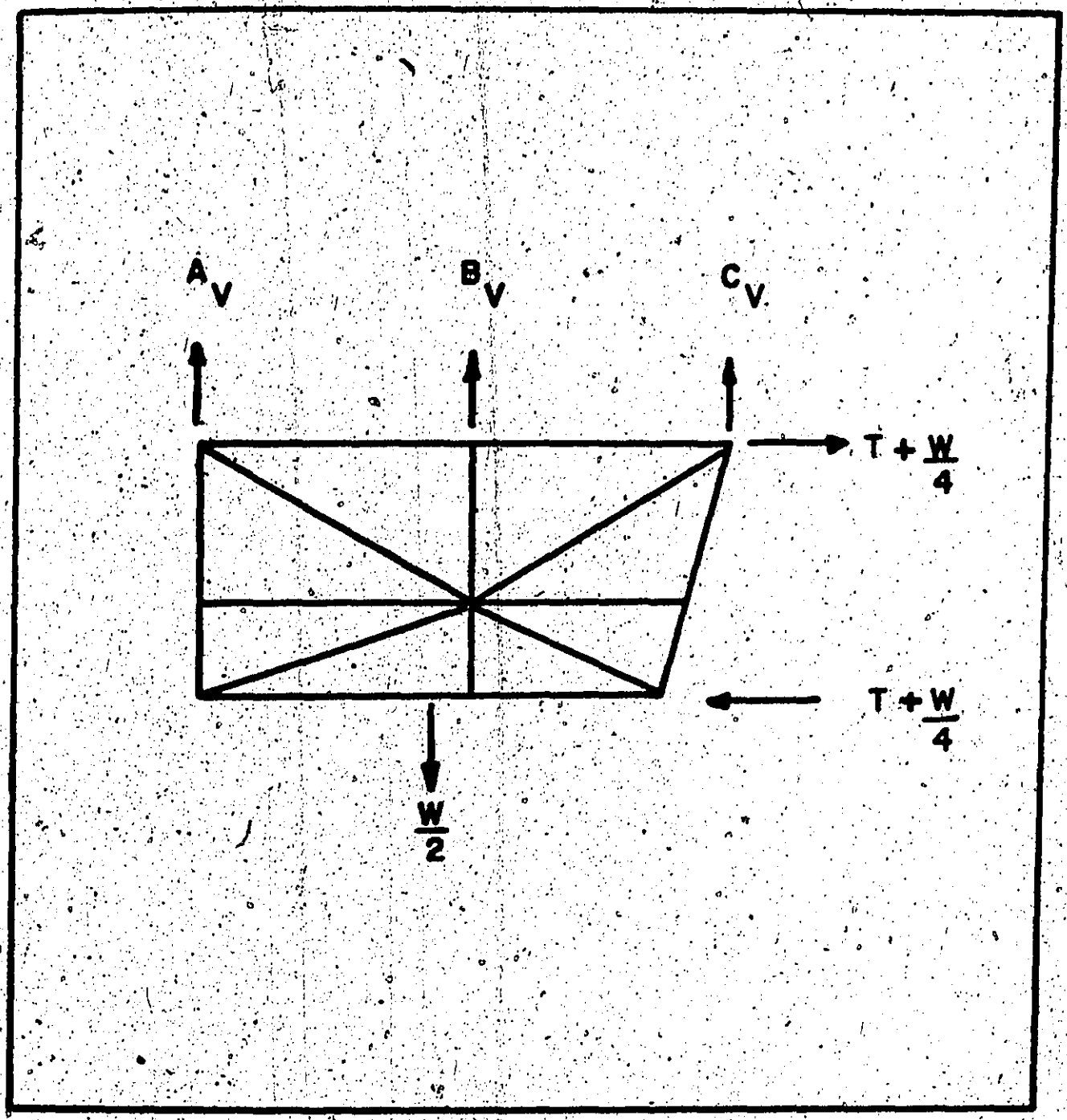


Figure 4.20: Upper Side Structure Loading Situation

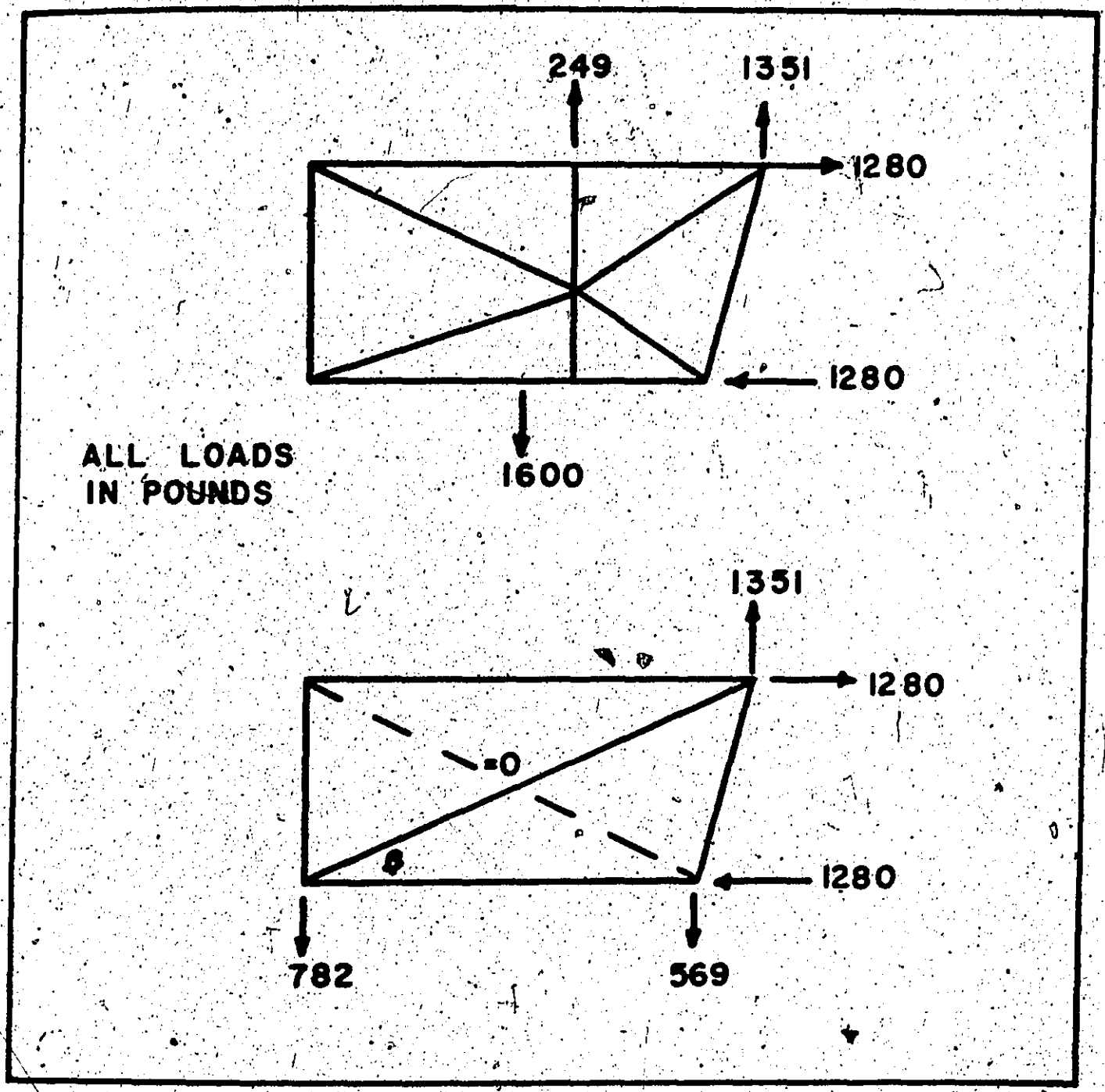


Figure 4.21: Upper Side Structure Actual Loading Basic Case 1

Figure 4.22: Upper Side Structure Idealized Loading Basic Case 1

TABLE 4.3

Upper Side Structure Loading

Member	Load x 2 (lbs.)	T C
AG	1710	T
GD	1710	T
FG	2910	T
GC	2910	T
AJ	1600	T
CK	2560	T

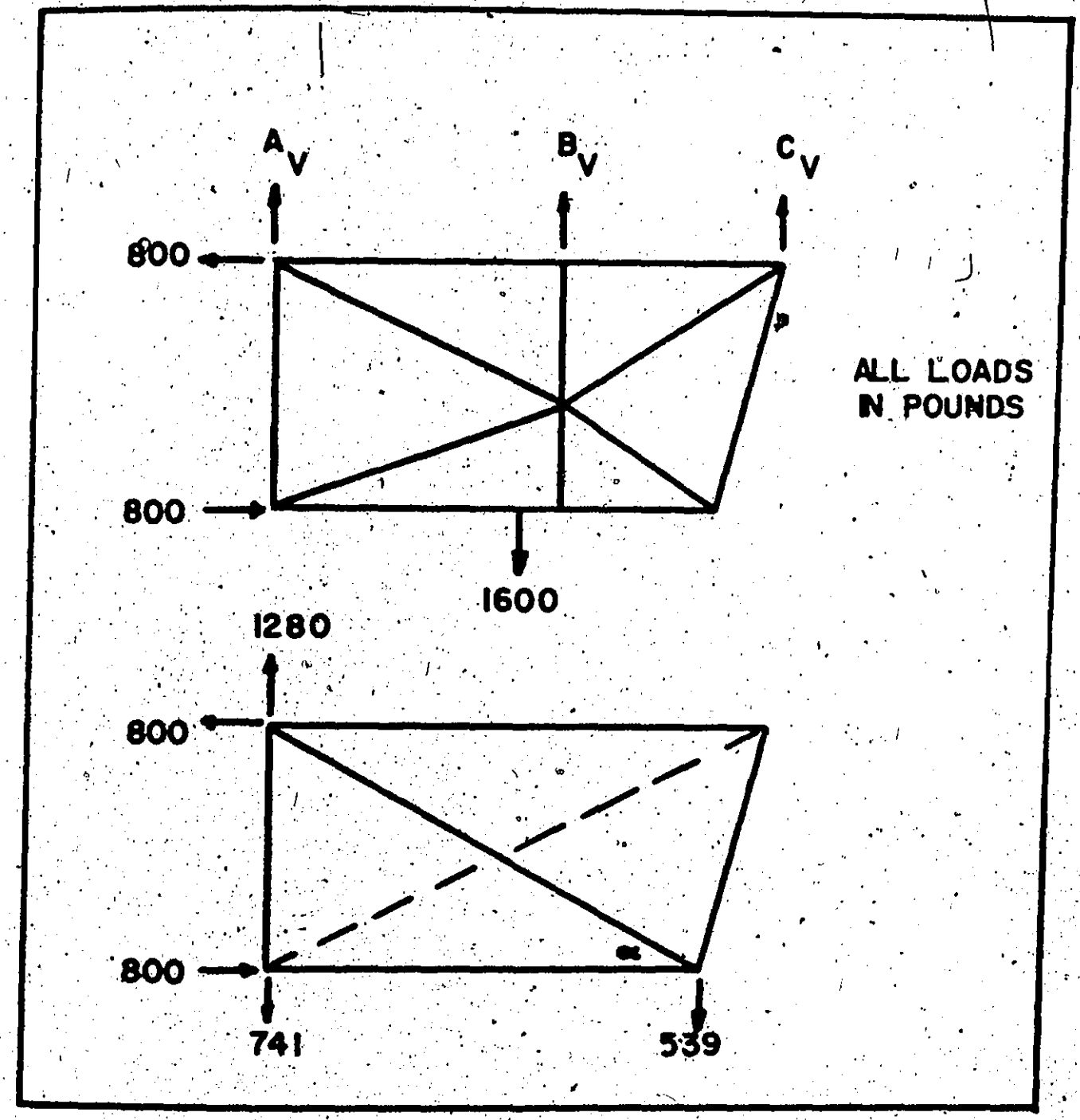


Figure 4.23: Upper Side Structure Actual Loading Basic Case 2

Figure 4.24: Upper Side Structure Idealized Loading Basic Case 2

4.4.2 Basic Case #2

In this case the full weight at the center of gravity is combined with a thirty degree upwards inclination. The free body diagram is illustrated by Figure 4.23. Conditions similar to the previous situation prevail. Again an idealized situation is solved. The loading of this idealization is shown in Figure 4.24. Assuming $C_V = 0$, the force and moment analysis can once again be performed.

$$\Sigma F_V = 0 \qquad A_V + B_V = 1600$$

$$\Sigma M_{CG} = 0 \qquad 800 \times 72 + B_V \times 12 - A_V \times 48 = 0$$

The above equations yielded

$$A_V = 1280 \text{ pounds}$$

$$B_V = 320 \text{ pounds}$$

The results for those members to be analysed in this section, are also presented in Table 4.3. Several members shown in Figure 4.19 have no design structural function and are used only for truss integrity. In order to size these members the decision was made to use as much common sized material as possible. Boundary condition loading was used to estimate if the material size was satisfactory.

4.4 Underfloor Structure Loading Analysis

The underfloor structure can be divided into two major segments. One segment consists of a longitudinal truss system as illustrated

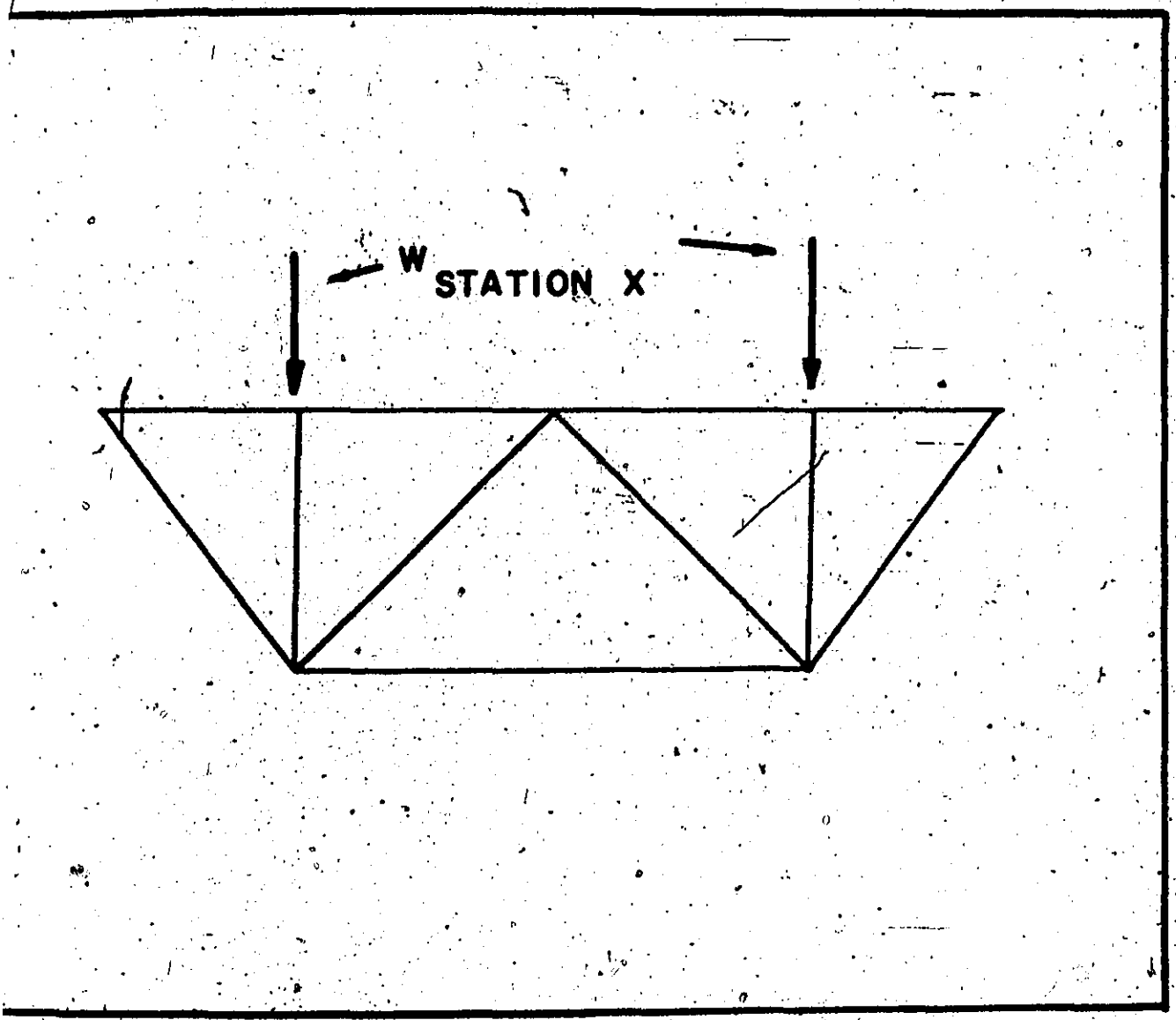


Figure 4.25: Transverse Truss Configuration

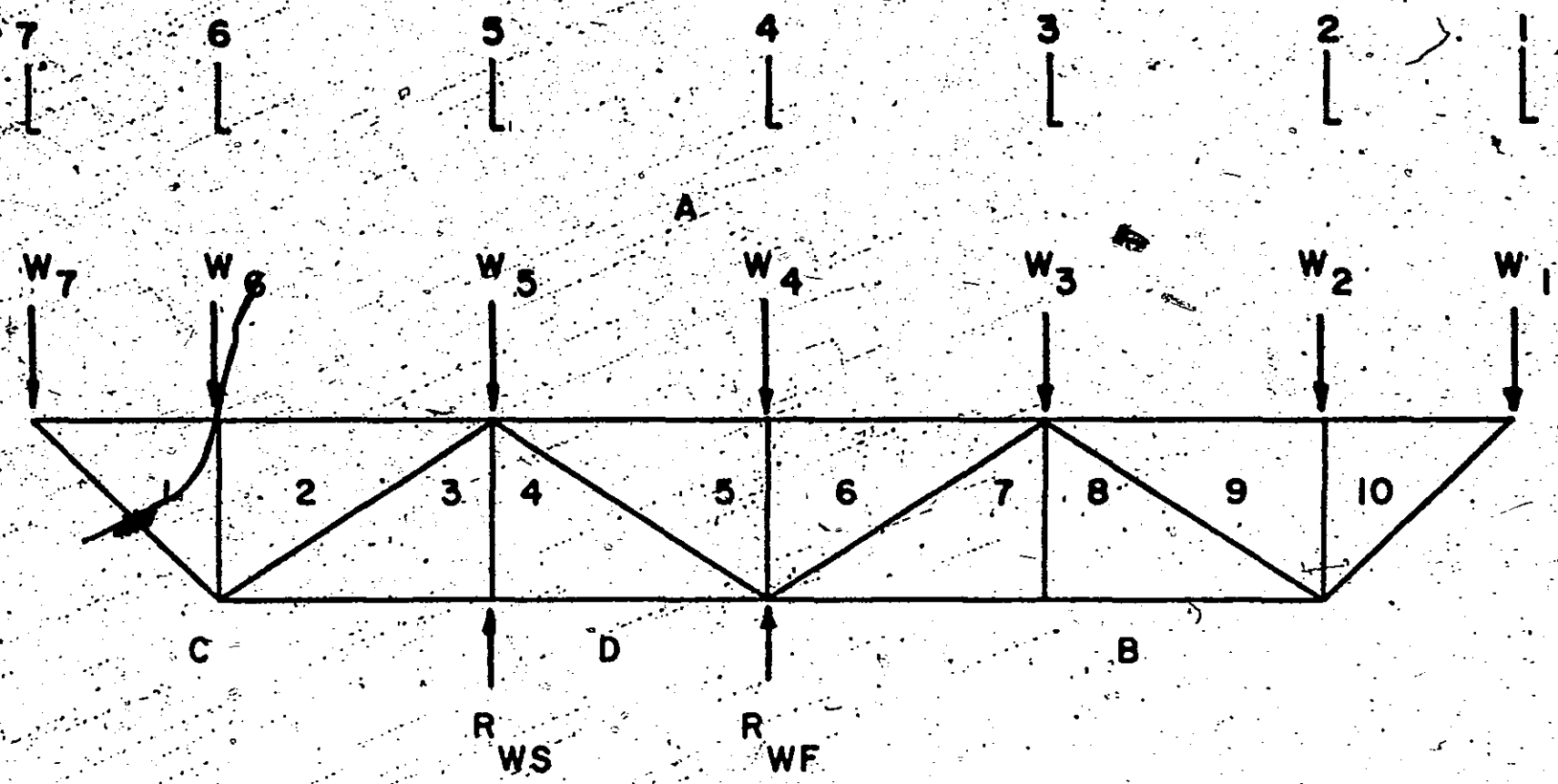


Figure 4.26: Longitudinal Truss Configuration

in Figure 4.25. The second segment is made up of the transverse truss systems that join the longitudinal truss in five positions. The transverse truss configuration is illustrated by Figure 4.25. As previously stated, the longitudinal structure must be examined for three support conditions. The transverse sections must be examined individually as the loading condition of each varies.

4.4.1 Longitudinal Truss Structure Static Condition

Assume that the full weight of the cabin is resting on the landing gear. The design calls for the wheel to be located one foot forward of the horizontal center of gravity position of the cabin. This center of gravity position corresponds to station number five as shown in Figure 4.26. In this configuration, the cabin will maintain a horizontal attitude.

The weight of the cabin and its payload can be split into the weight catagories listed in Table 4.4. These weights can now be distributed over the seven stations shown in Figure 4.26. The distribution of the weights is arbitrary as far as the structural and payload weights are concerned. Only the weight of the fuel must be specifically located in such a manner that the center of gravity position previously specified is attained. The location of these weights in relation to the transverse sections is shown by Figure 4.27. The location of the fuel is obtained by means of a moment balance. Table 4.5 gives the arbitrary distribution of the other weights. Using these values the following moment balance was performed.

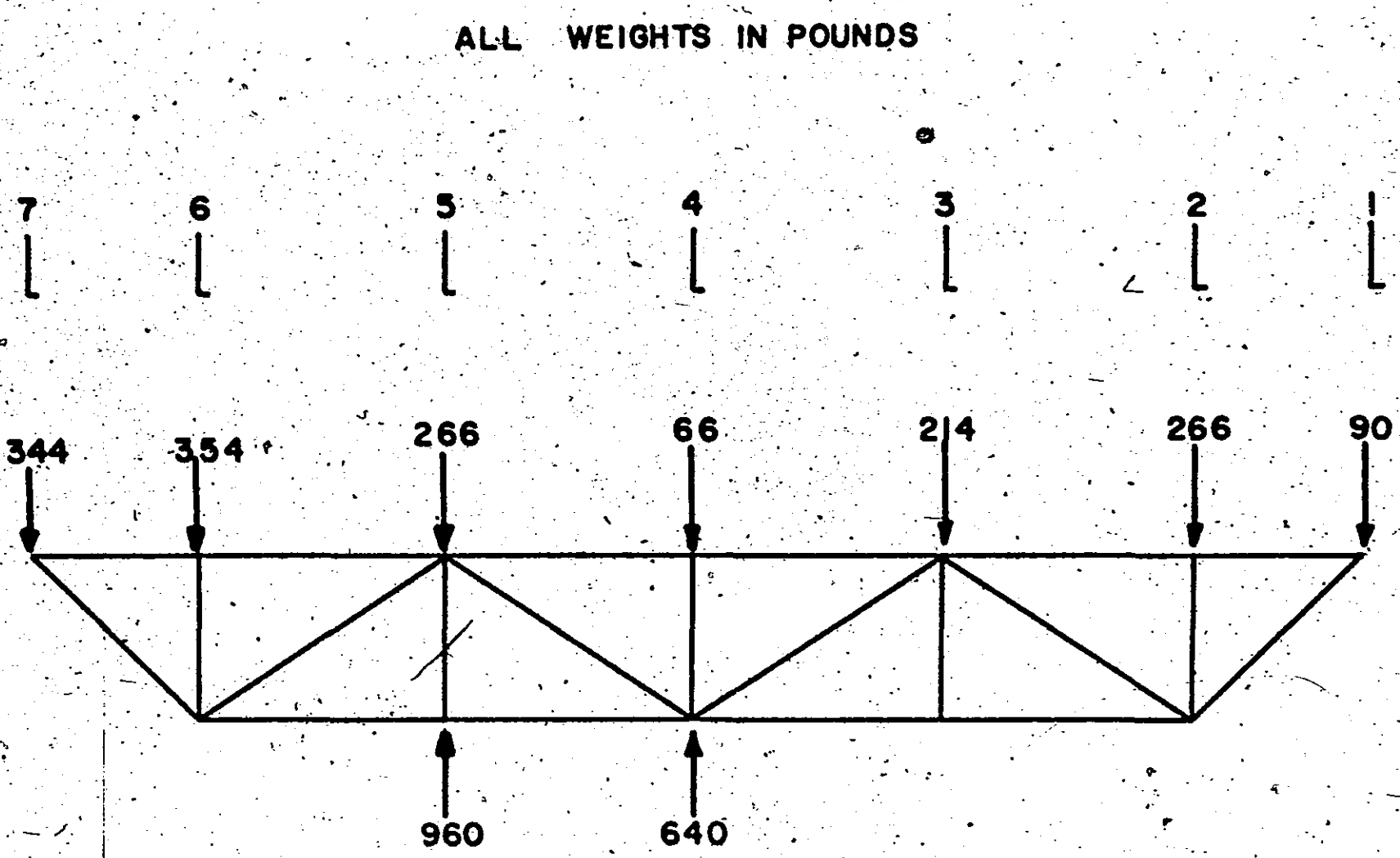


Figure 4.27: Longitudinal Truss Loading

Table 4.4

Airship Load Distribution

engines	200 pounds per side
outriggers	50
pilots (2)	200
passengers (2)	200
above floor structure	240
below floor structure	160
floor and equipment on floor	300
fuel	250
	1600

TABLE 4.5

Load Distribution on Underfloor Structure

Category	Weights on Station (lbs.)						
	1	2	3	4	5	6	7
Above floor structure	48		48		48	48	48
Below floor structure	22	23	23	23	23	23	23
Floor & equipment	20	43	43	43	43	65	43
Pilots (2)		200					
Passengers			100			100	
Engines					132	68	
Outriggers					20	30	
Sub Total	90	266	214	66	266	334	114
Fuel (used as Bal. Wt.)						20	230
Total	90	266	214	66	266	354	344

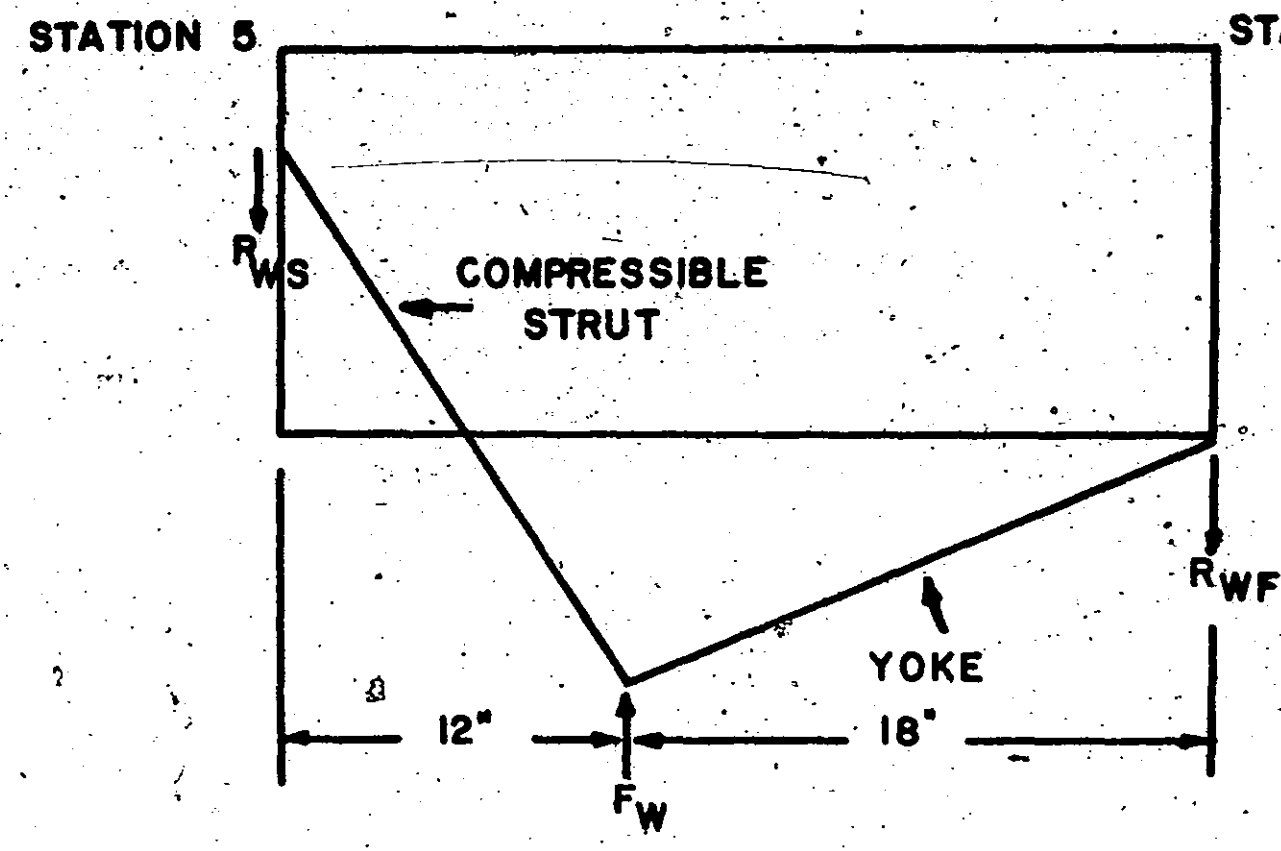


Figure 4.28: Landing Gear Arrangement

$\therefore \Sigma M_{CG} = 0$

CCW		CW	
90 x 99 =	8910	266 x 12 =	3192
266 x 78 =	20748	344 x 42 =	14028
214 x 48 =	10272	114 x 67 =	7638
66 x 18 =	1188		
	41118		24858

$\therefore$ net moment = 16260

$\therefore$ the fuel weight must be distributed between stations 6 and 7 so as to produce a clockwise moment of 16260.

230 x 67 =	15410
20 x 42 =	840
	16250

$\therefore$ at station 6 add 20 pounds

at station 7 add 230 pounds

The total weight acting at each station after the fuel weight allocation is also given in Table 4.5. The landing gear arrangement is illustrated by Figure 4.28. It should be noted that not all the weights shown act in the vertical sense in reality and hence some of the stations have a horizontal component of force. These, however, are small and have thus been ignored. The reaction forces that the landing gear applies at stations 4 and 5, can now be obtained.

Refering to Figure 4.28 a force and moment balance must be obtained.

$\Sigma P_y = 0$ $\qquad R_{WS} + R_{WP} = P_W$

and $\Sigma M_{PW} = 0$ $\qquad R_{WS} \times 12 - R_{WP} \times 18 = 0$

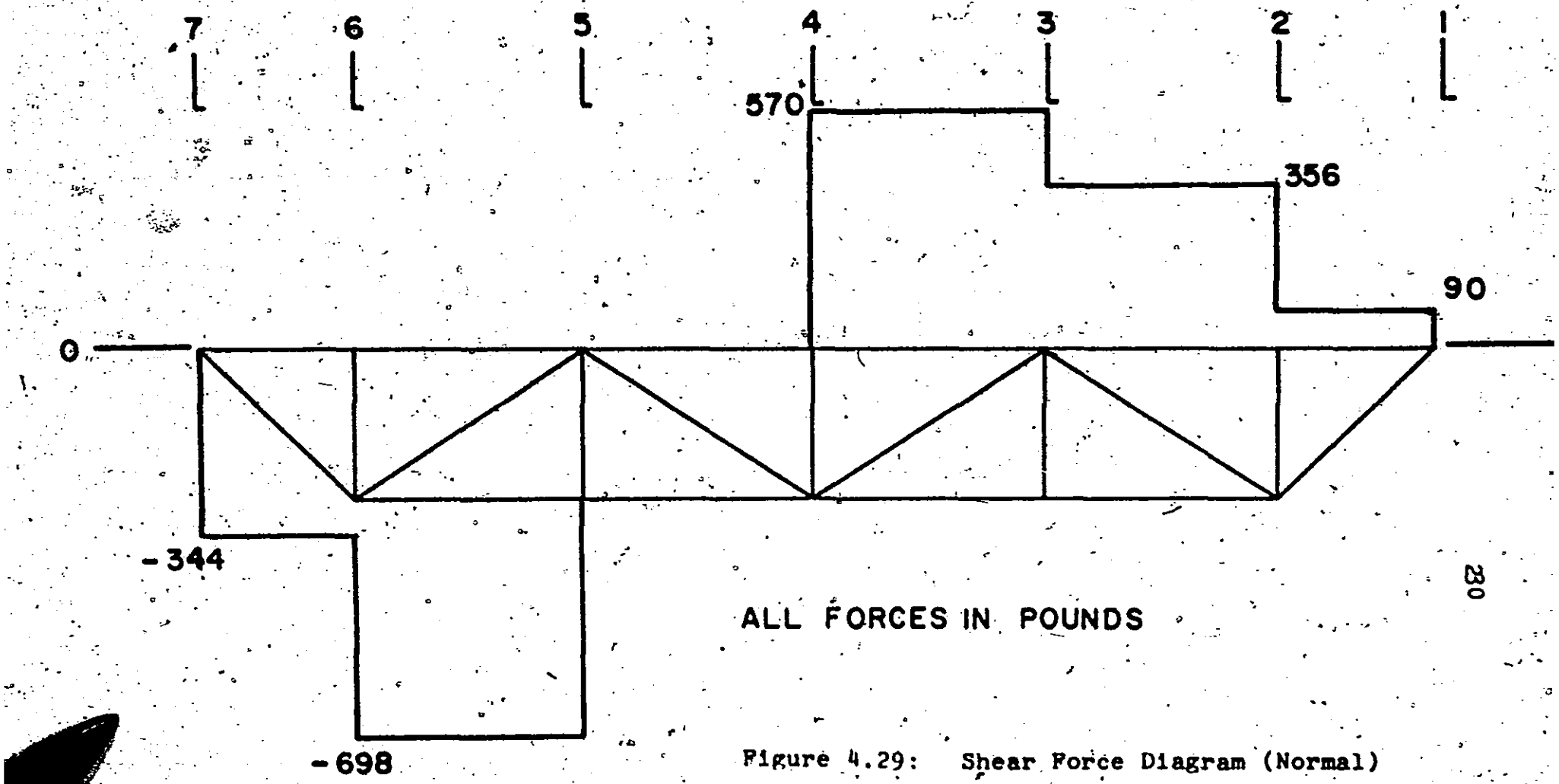


Figure 4.29: Shear Force Diagram (Normal)

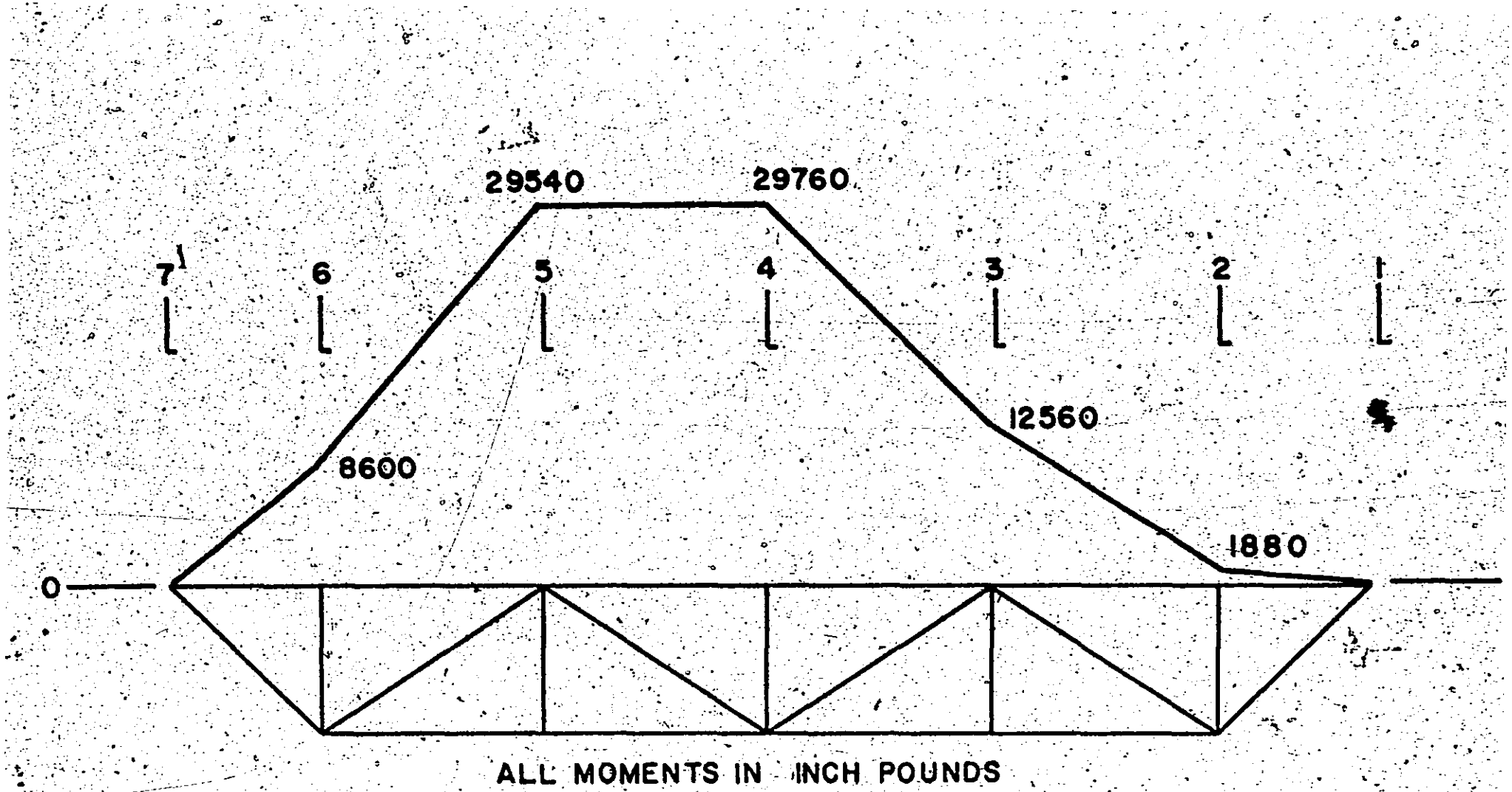


Figure 4.30: Bending Moment Diagram (Normal)

Solution of these relationships gives values of:

$R_{WS} = 0.6\ P_W = 960$ pounds

$R_{WP} = 0.4\ P_W = 640$ pounds

Combining these values with the loads imposed on each station, a shear force diagram, as illustrated by Figure 4.29, may be attained. The bending moment, in inch pounds, at any point along the structure may be described by:

$$M = 344x + 354(x-25) + 266(x-55) - 960(x-55) + 66(x-85) - 640(x-85) + 214(x-115) + 266(x-145) + 90(x-166)$$

where x is the distance of the load from the longitudinal center of gravity position and if $(x-y) < 0$ then $(x-y) = 0$. The resulting bending moment diagram is described by Figure 4.30. Using the bending moment diagram and the shear force diagram the loads on the members may be determined. These loads are given in Table 4.6. Note that a safety factor of two has been incorporated when moving from the static load to the design load. This exceeds the safety factor of 1.5 that is specified in the airworthiness requirements[3].

4.4.2 Longitudinal Truss Structure Static Castored Condition

For purposes of ground movement when not attached to the envelope, the cabin is fitted with removable castors at stations 2 and 6. Retaining the loadings as given in the previous analysis then the reactions at the castors can be calculated by means of a force and moment balance to be

TABLE 4.6

Longitudinal Underfloor Structure Static Loading

Member	Length (inches)	Static Load (lbs.)	Design Load (lbs.)	T C
A1	25	478	956	T
A2	30	478	956	T
A5	30	1640	3280	T
A6	30	1640	3280	T
A9	30	105	210	T
A10	21	105	210	T
B10	34	139	278	C
B8	30	698	1396	C
B7	30	698	1396	C
D4	30	1640	3280	C
C3	30	1640	3280	C
C1	35	590	1180	C
12	18	354	708	C
23	45	1745	3490	T
34	18	960	1920	C
45	45	0		
56	18	66	132	C
67	45	1425	2850	C
78	18	0		
89	45	890	1780	T
910	18	266	532	C

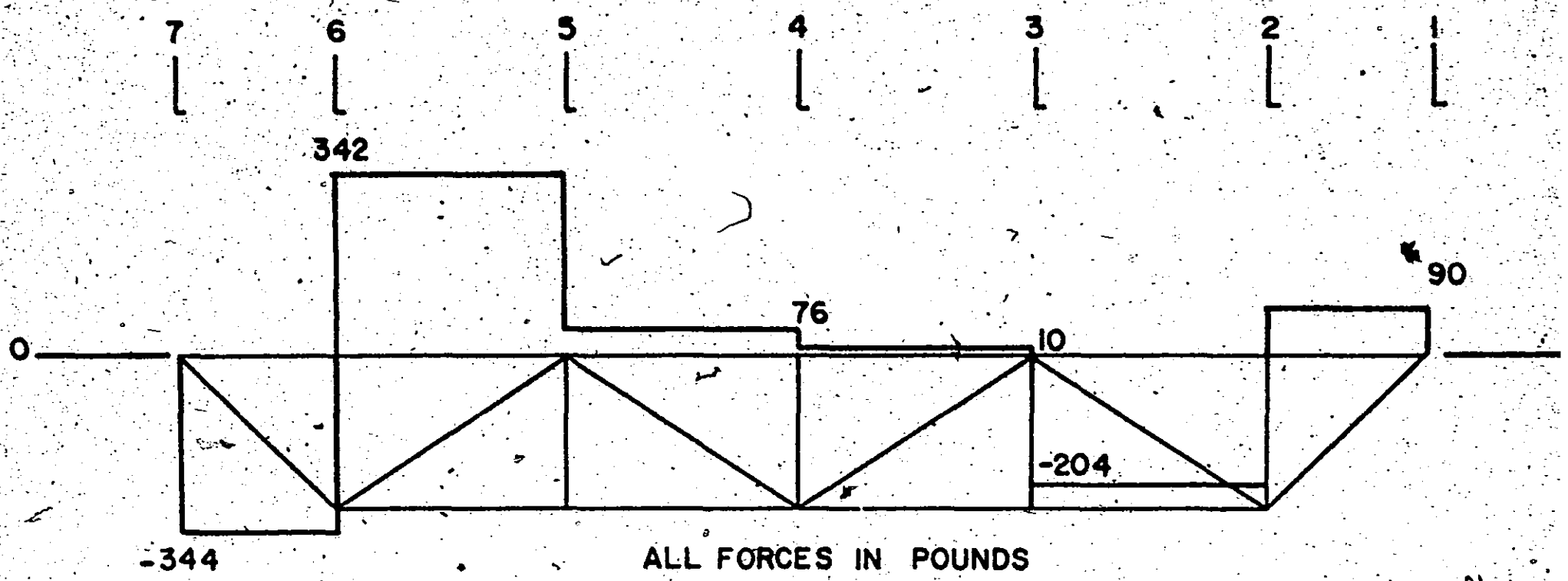
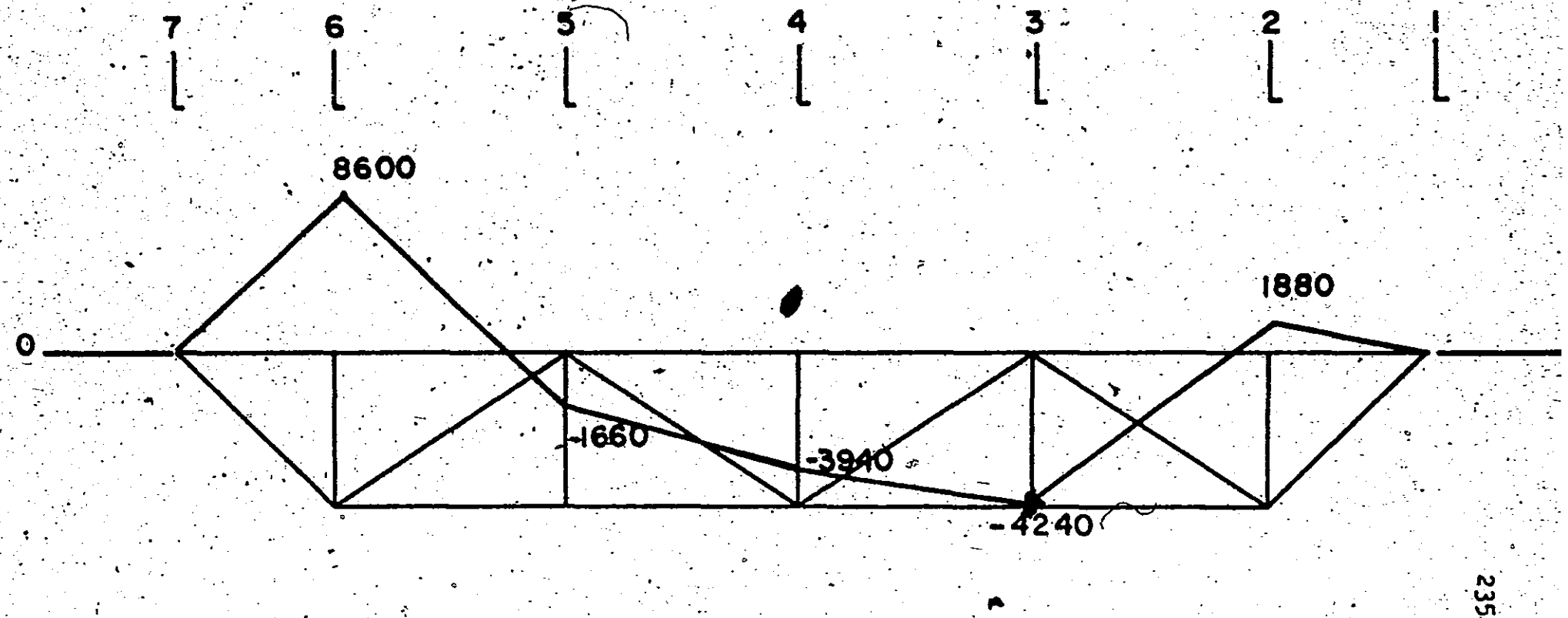


Figure 4.31: Shear Force Diagram (Castored)



ALL MOMENTS IN INCH POUNDS

Figure 4.32: Bending Moment Diagram (Castored)

R_2 = 560 pounds

and R_6 = 1040 pounds

The shear force diagram for the loading condition is shown by Figure 4.31. Once again the bending moment at any point along the length is given by

$$M = 344x + 354(x-25) - 1040(x-25) + 266(x-55) + 66(x-85) + 214(x-115) + 266(x-145) - 560(x-145) + 90(x-166)$$

where the same conditions apply as in the previous moment expression. The result of this expression is given by Figure 4.32.

The loading of the members, as calculated from the shear force and moment values, is given in Table 4.7.

4.4.3 Longitudinal Truss Structure Dynamic Condition

The case of the dynamic loading due to landing at some sink rate can be considered by assuming that the wheel force at this sink rate would be some multiple of the static wheel force. If a multiple of two is chosen, then the wheel force, P_W, would be equal to 6400 pounds. The sink rate necessary to achieve this loading can be calculated using the following expressions.

$$\delta_{max} = \delta_w + \delta_s \quad (4.4)$$

$$P_W = k\,\delta_{max} \quad (4.5)$$

$$K.E. = 1/2(w/g)v^2 \quad (4.6)$$

and

$$E.A. = 1/2k\,\delta^2_{max} \quad (4.7)$$

TABLE 4.7

Longitudinal Underfloor Structure Static Loading
(on castors)

Member	Load	Design Load	T C	Section A Design Load	T C
A1	478	956	T	956	T
A2	478	956	T	956	T
A5	219	438	C	3280	T
A6	219	438	C	3280	T
A9	105	210	T	210	T
A10	105	210	T	210	T
B10	139	278	C	278	C
B8	235	470	T	1396	C
B7	235	470	T	1396	C
D4	92	184	T	3280	C
C3	92	184	C	3280	C
C1	590	1180	C	1180	C
12	354	708	C	708	C
23	855	1710	C	3490	T
34	0			1920	C
45	190	380	T		
56	66	132	C	132	C
67	25	50	C	2850	C
78	0				
89	510	1020	C	1780	T
910	266	532	C	532	C

where

δ_w = the deflection possible in the landing gear wheel in inches

δ_s = the deflection possible in the strut in inches

K.E. = the kinetic energy of the system

E.A. = the energy that the system can absorb

Substituting from (4.4) for k in (4.7) and equating (4.6) and (4.7) gives

$$v = \frac{F_W \times g \times \delta_{max}}{W} \qquad (4.8)$$

where

g = the gravitational constant

W = the weight of the cabin

For our design

W = 3200 pounds

g = 32

δ_w = 1 inch

δ_s = 9 inches

and F_W = 6400 pounds

This gives a value of the sink rate upon substitution in (4.8) for a multiple of two, of 7.3 ft/sec. The government airworthiness requirements[3] specify a design sink rate of "not less than 3 ft/sec". Clearly a multiple of two times the static main wheel condition is satisfactory for this design purpose. Table 4.8 gives the dynamic loading and the dynamic design load of each member. The dynamic design load incorporates the previously stated safety factor of two.

TABLE 4.8

Longitudinal Underfloor Structure Dynamic Loading

Member	Design Load A	T / C	Design Load B	T / C	Dynamic Load Design	T / C
A1	956	T	956	T	1912	T
A2	956	T	956	T	1912	T
A5	3280	T	438	C	6560	T
A6	3280	T	438	C	6560	T
A9	210	T	210	T	420	T
A10	210	T	210	T	420	T
B10	278	C	278	C	556	C
B8	1396	C	470	T	2792	C
B7	1396	C	470	T	2792	C
D4	3280	C	184	T	6560	C
C3	3280	C	184	C	6560	C
C1	1180	C	1180	C	2360	C
12	708	C	708	C	1416	C
23	3490	T	1710	C	6980	T
34	1920	C	0		3840	C
45	0		380	T	0	
56	132	C	132	C	264	C
67	2850	C	50	C	5700	C
78	0		0		0	
89	1780	T	1020	C	3560	T
910	532	C	532	C	1064	C

A comparison of the values for the design loads of the members as given by Table 4.6, Table 4.7 and Table 4.8 respectively shows that the design loads to be used for the side truss members are those of Table 4.8

4.4.4 Underfloor Structure Transverse Sections

The underfloor structure consists of two longitudinal truss systems joined by transverse sections at stations 2, 3, 4, 5, and 6. These five sections can be separated into three distinct groups having different design loading conditions.

(i) Sections at stations 5 and 6

Station 5 contains the rear landing gear attachment and hence must withstand the dynamic landing situation. Station 6 must also withstand heavy loads carried over from station 5. Therefore, the same loading will be assumed in both sections. If P_W = 6400 then the loading of these stations is

$$R_{WS} = 0.6\ P_W = 3840 \text{ pounds}$$

distributed as illustrated in Figure 4.33. The graphical analysis used to solve for the member loads, given in Table 4.9, is illustrated by Figure 4.34.

(ii) Sections at stations 4 and 3

Station 4 contains the forward landing gear attachment and thus the loading of this section, and also section 3, for the reasons expressed previously, is dictated by the dynamic landing condition,

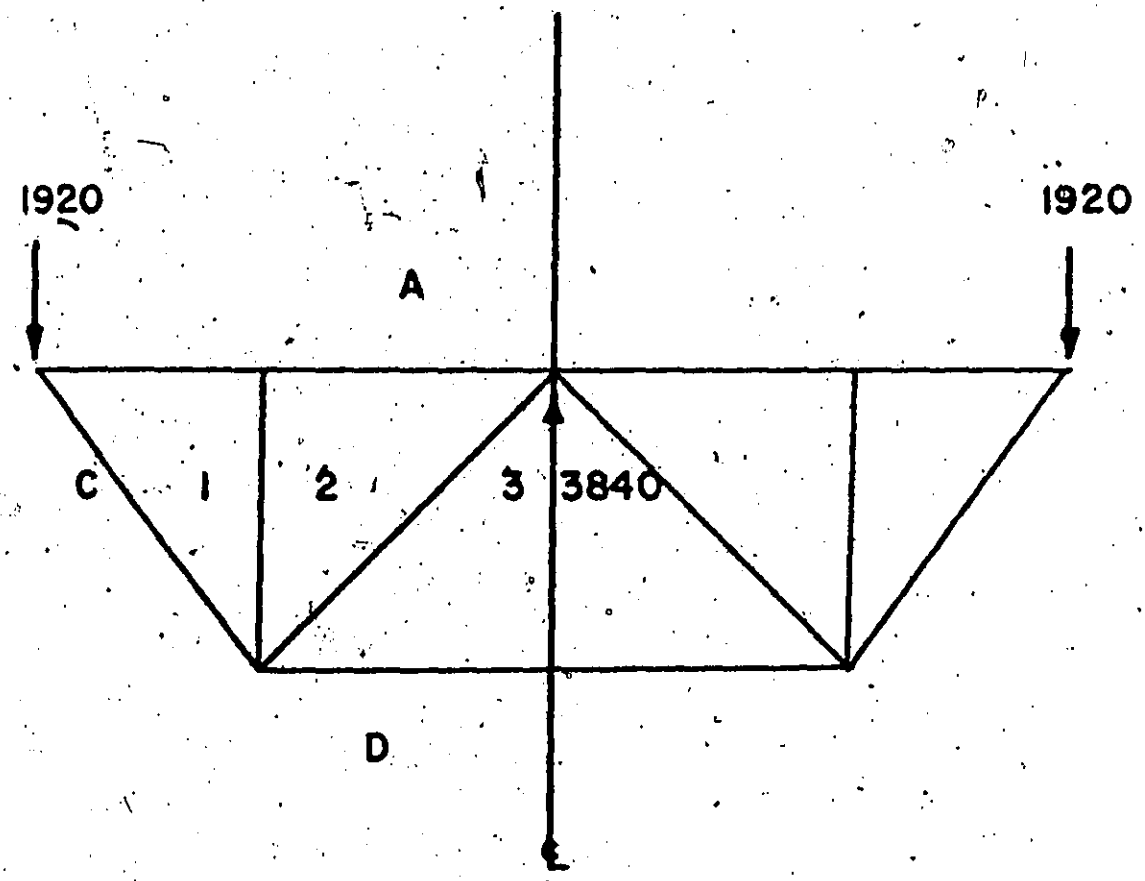
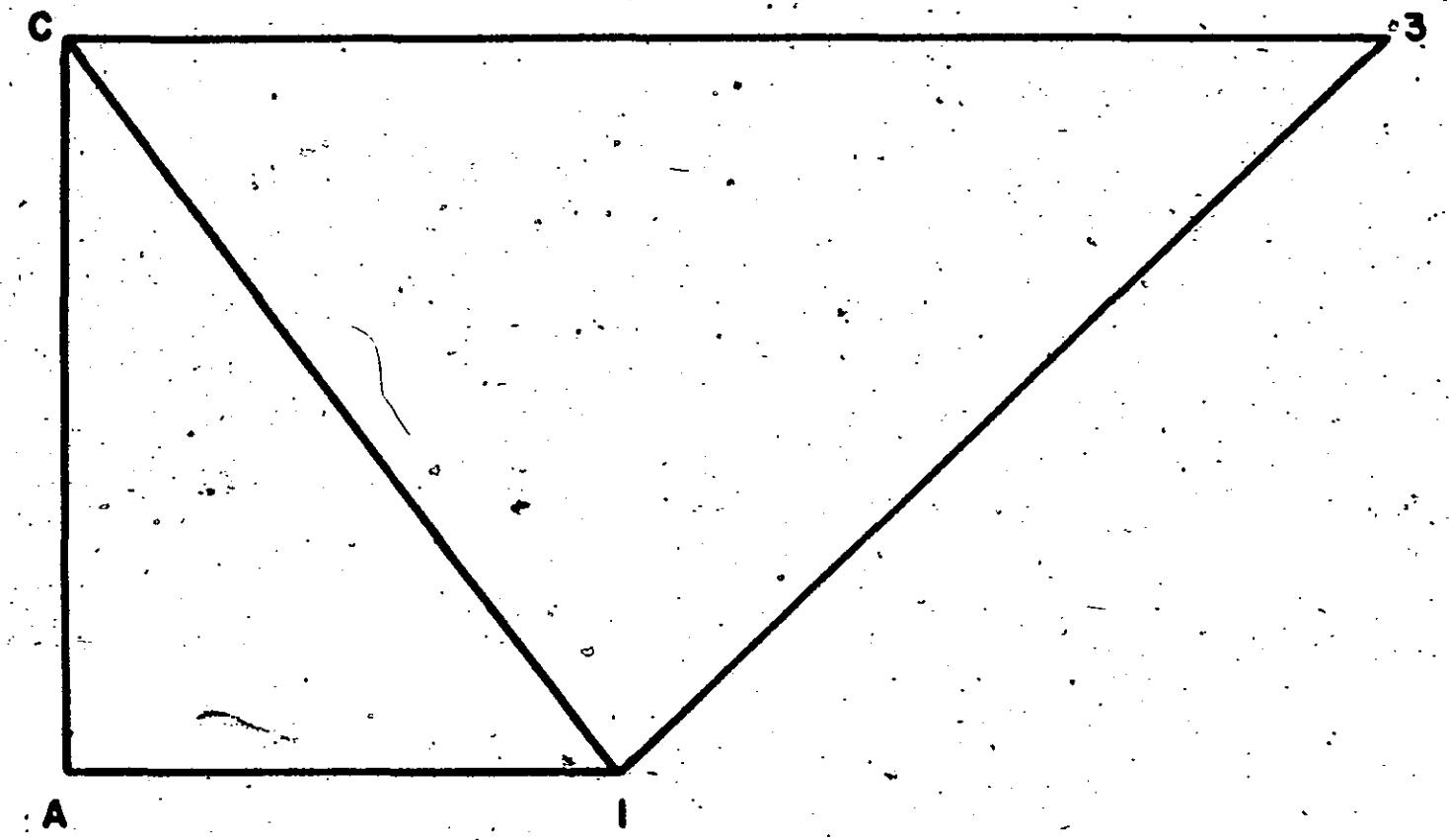


Figure 4,33: Transverse Section Loading.



SCALE 1" = 500'

Figure 4.34: Graphical Analysis of Transverse Section

TABLE 4.9

Transverse Section Loads

Member	Length	Load	Design Load	T C
A1	13.5	1425	2850	T
A2	18	1425	2850	T
A4	18	1425	2850	T
A5	13.5	1425	2850	T
B5	22.5	2405	4810	C
C1	22.5	2405	4810	C
D3	36	3345	6690	C
12	18			
23	25	2700	5400	T
34	25	2700	5400	T
45	18			
A1	13.5	425	850	T
A2	18	425	850	T
A4	18	425	850	T
A5	13.5	425	850	T
B5	22.5	715	1430	C
C3	36.0	425	850	T
D1	22.5	715	1430	C
12	18			
23	25	0		
34	25	0		
45	18			
A1	13.5	970	1940	T
A2	18.0	970	1940	T
A4	18.0	970	1940	T
A5	13.5	970	1940	T
B5	22.5	1630	3260	C
C3	36.0	970	1940	T
D1	22.5	1630	3260	C
12	18			
23	25	0		
34	25	0		
45	18			

$R_{WP} = 0.4\ P_W = 2560$ pounds

As the configuration is the same in all the transverse sections, the member loads are just a multiple of those attained in (i) These member loads are also given in Table 4.9.

(iii) Section at station 2

The maximum loading situation at station 2 is dictated by the condition of the cabin resting on castors. This loading has previously been determined as

$$R_2 = 560 \text{ pounds}$$

Hence the member loads are again a multiple of (i) and are also given in Table 4.9.

4.5 Summary

The loading which each member of the structure is subjected to, has been determined and tabulated in Tables 4.2, 4.3, 4.8, and 4.9. These loads are for the most part determined in an extremely conservative manner and use a safety factor higher than specified. Hence any inaccuracies due to assumptions made in the analysis should not prove serious. The loading as tabulated, was used to determine structural member sizes for the construction of the cabin. This construction has been completed and the structure as built is illustrated by Figures 4.35 through 4. 36. The calculated structural weight for the members, as per the loading requirements, was 280 pounds and the actual final weight as constructed was 316

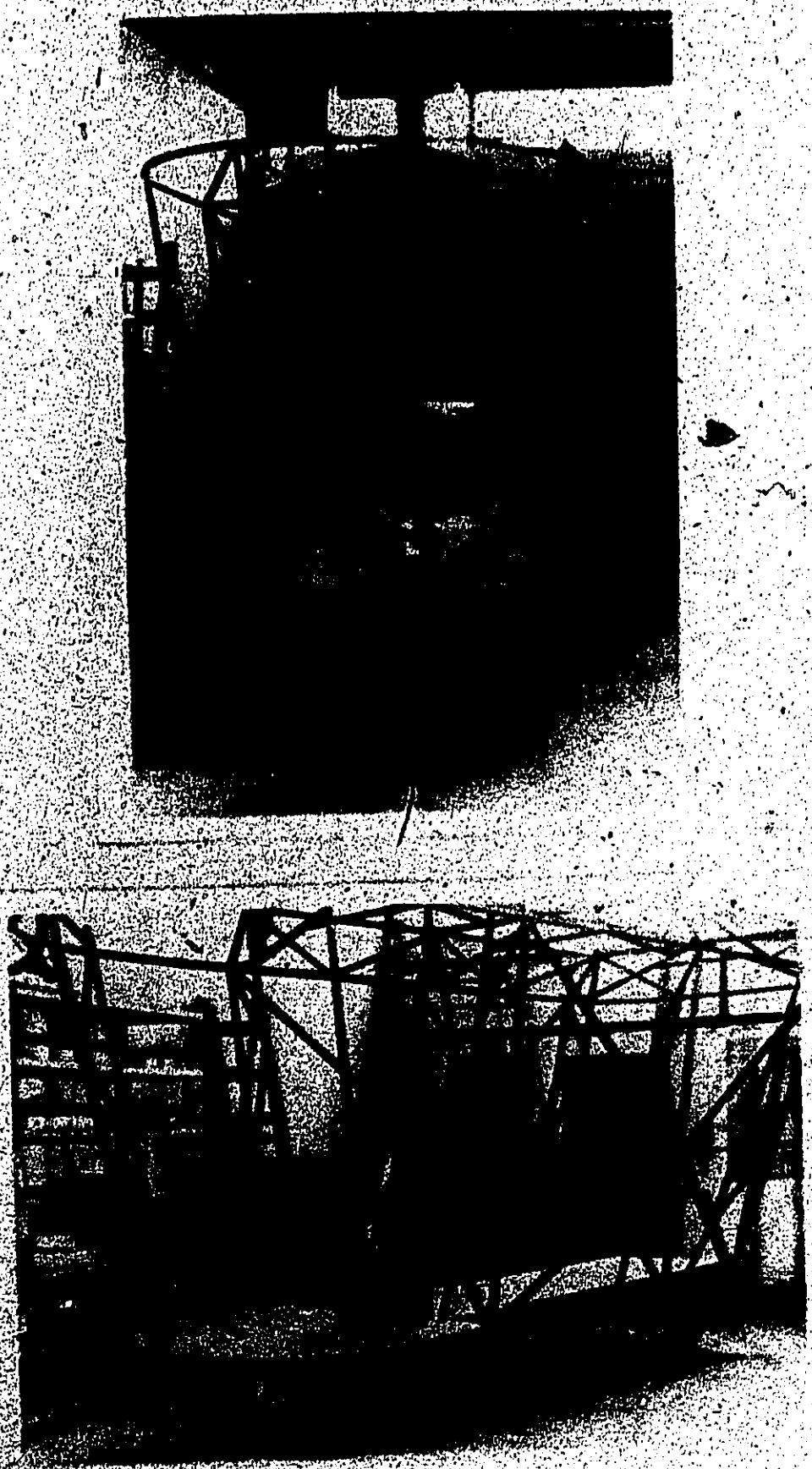


Figure 3.35: Cabin Structure as Completed

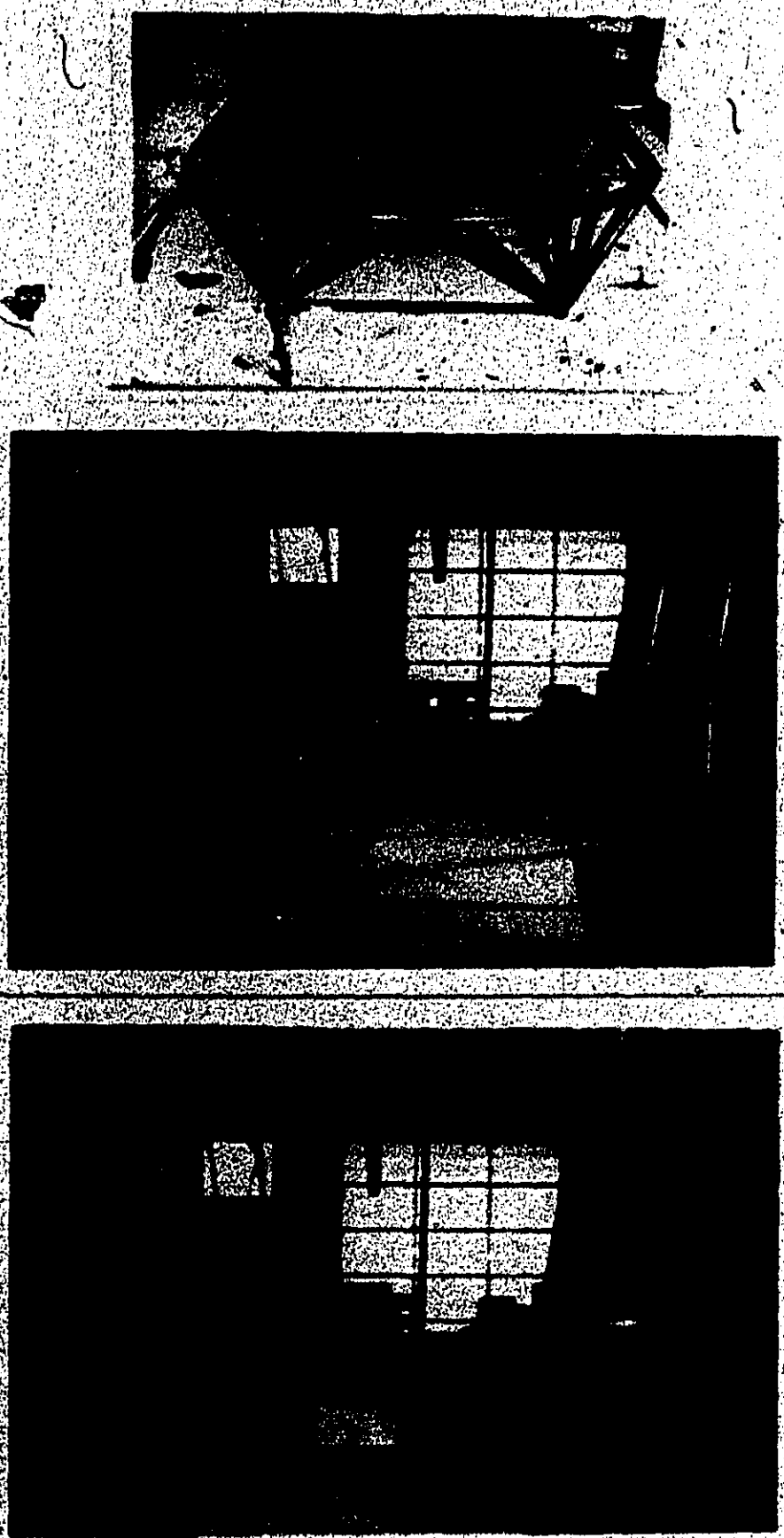


Figure 4.36: Cabin Structure During Construction

pounds. This weight increase is mainly due to inclusion of several members for non-structural (i.e. shaping of exterior) purposes.

It is anticipated that operating experience will lead to some simplification of the cabin structure.

CHAPTER 5

Conclusions

This work has examined several aspects of airship design. The areas covered include:

(A) Preliminary Design Evaluation

- (i) shape
- (ii) aerodynamics
- (iii) structural considerations
- (iv) pressure distribution

(B) Trajectory and Inflight Load Determination

(C) Gondola Structural Design.

The first two catagories involved computer aided design and user oriented design packages have been developed.

The results achieved in the gondola structural design have been used to construct the actual gondola for CAS-1, an airship under construction by the Canadian Airship Development Corporation. Output from the computer design packages has been used to establish the design parameters for CAS-1 and the trajectory results can be used in the compliance report required by the Ministry of Transport. The output from the trajectory program will also be used to check the results of a highly theoretical mathematical model now being developed by the University of Toronto to analyse various aerodynamic effects.

Much work remains to be done in the airship field before it as a transportation system reachs a technological level equal to that having been obtained by other transportation systems.

Areas of immediate importance include:

(1) aerodynamics. Any improvement in the manouverability of the airship would be greatly welcomed.

(2) trim and ballast systems. Improvements are necessary in this area in order to achieve an efficient transportation system.

(3) propulsion systems.

(4) cargo handling systems.

(5) avionics systems.

It is hoped that this work will be the first of many in this field and that the airship revival effort will continue and grow.

APPENDIX A

PROGRAMME FOR ENVELOPE SHAPES

```
      [illegible] (INPUT,OUTPUT,PLOT,[illegible]=OUTPUT,TAPE8=PLOT)
      [illegible] (INPUT,OUTPUT,PLOT,[illegible]=OUTPUT,TAPE8=PLOT)
C
C  *****************************************************************
C  *                                                               *
C* *                                                               *
C*     THIS PROGRAM CALCULATES THE CONTOURS OF AIRSHIP HULLS FOR   *
C*     VARIOUS PARAMETERS AND THEN PLOTS THESE CONTOURS ON 24 BY   *
C*     22 INCH DRAFTING PAPER. THE PARAMETERS INVOLVED ARE FROM THE *
C*     GENERAL HULLS STUDY. THE BASIC SHAPE WILL NOT CHANGE EVEN IF *
C*     THE VOLUME IS CHANGED. THEREFORE ONLY ONE VALUE OF THE VOLUME *
C*     WILL HAVE TO BE FED INTO THE PROGRAM.                        *
C*                                                                 *
C  *                                                               *
C  *****************************************************************
C
C
C     PROGRAM NOTATION
C
C     F=AIRSHIP FINENESS RATIO
C     D=THE MAXIMUM AIRSHIP DIAMETER (FT)
C     XN1 A PARAMETER USED IN DETERMINING THE HULL SHAPE
C     XN2 A PARAMETER USED IN DETERMINING THE HULL SHAPE
C     XL=THE TOTAL AIRSHIP LENGTH (FT)
C     VL IS THE AIRSHIP VOLUME IN FT**3
C
C
C     FIN1=THE INITIAL FINENESS RATIO
C
C     THESE VALUES ARE TO BE INCREMENTED
C
C
      DIMENSION XL(3), XN(2), X[illegible](2), X(313), Y(313), F(4), XPAR(10), YPA
     1R(10), [illegible]
C
      INTEGER TEXT(72)
C
C     INPUT DATA
C
      XN(1)=[illegible]
      XN(2)=[illegible]
C
      IJ=0
C
      IL=1
C
      VL=73000
C
C
      TEXT(1)=[illegible]
      TEXT(2)=[illegible]
```

```
      TEXT(53)=[illegible]
      TEXT(54)=[illegible]
      TEXT(55)=[illegible]
      TEXT(56)=[illegible]
      TEXT(57)=[illegible]
      TEXT(58)=[illegible]
      TEXT(59)=[illegible]
      TEXT(60)=[illegible]
      TEXT(61)=[illegible]
      TEXT(62)=[illegible]
      TEXT(63)=[illegible]
      TEXT(64)=[illegible]
      TEXT(65)=[illegible]
      TEXT(66)=[illegible]
      TEXT(67)=[illegible]
      TEXT(68)=[illegible]
      TEXT(69)=[illegible]
      TEXT(70)=[illegible]
      TEXT(71)=[illegible]
      TEXT(72)=[illegible]
C
C     FINENESS RATIO INCREMENTED IN STEPS OF 0.25
C
      FINI=2.25
      DO 2 KKK=1,40
      LLL=KKK-1
      IF (KKK.EQ.1) F(KKK)=FINI
      IF (KKK.EQ.1) GO TO 1
      F(KKK)=F(LLL)+0.25
    1 CONTINUE
C
C     THE VALUES OF XN AND YN ARE VARIED IN ORDER TO DETERMINE THE BEST
C     SHAPE
C
      DO 6 II=1,2
      IF (II.EQ.1) XN(II)=0.5
      IF (II.EQ.2) XN(II)=0.6
      DO 5 K=1,3
      IF (K.EQ.1) YN(K)=0.2
      IF (K.EQ.2) YN(K)=0.3
      IF (K.EQ.3) YN(K)=0.4
      YN=YN(K)
      XN=XN(II)
C
C     CALCULATION OF THE [illegible] LENGTH
C
      Z=((XN+YN)**(YN+XN))/(2.0*F(KKK)*((YN)**YN)*((XN)**XN))
      W=(3.1416*(XN+YN)**(2.0*(XN+YN)))/(4.0*(F(KKK)**2)*(YN**(2.0*YN))*(X
     1N**(2.0*XN)))
```

```
[illegible]
C
C     [illegible] APPROXIMATION TO THE VOLUME INTEGRAL
C
      [illegible]
      XX=2.*[illegible]
      YY=2.*YY[illegible]
      ZZ=2.*[illegible]
      CALL GAMMA (XX,GX,[illegible])
      CALL GAMMA (YY,IX,[illegible])
      CALL GAMMA (ZZ,ZY,[illegible])
      [illegible]
      XL(K)=[illegible]**
      DO 3 J=1,[illegible]
      M=J-1
      JJ=[illegible]
      DC=XL(K)/[illegible]
      CC=XL(2)/[illegible]
      DD=CS/2.[illegible]
      AA=([illegible])/2.[illegible]
      IF (J.[illegible].1) X(J)=[illegible]
      IF (J.[illegible]) [illegible]
      IF (J.[illegible].2) X(J)=[illegible]
      IF (J.[illegible]) X(J)=[illegible]
      IF (J.[illegible]) X(J)=[illegible]
      IF (J.[illegible]) X(J)=[illegible]
      IF (J.LT.[illegible]) GO TO [illegible]
      IF (J.GT.[illegible]) X(J)=X(M)+AA
      IF (J.GT.[illegible]) GO TO 2
      IF (J.GT.[illegible]) X(J)=X(M)[illegible]
      IF (J.GT.[illegible]) GO TO 2
      X(J)=X(M)+([illegible])
C
C     CALCULATION OF THE AIRSHIP CONTOURS
C
    2 Y(J)=(Z/([illegible](K)**([illegible])))*((X(J))**VN)*(ABS(XL(K)-X(J)))**V[illegible]
      Y(JJ)=-Y(J)
      Y(IJ)=X(J)
      CONTINUE
C
      IJ=IJ+1
C
C     CALCULATION OF THE AIRSHIP MAXIMUM DIAMETER
C
      D=XL(K)/F([illegible])
C
C     PLOTTING DATA
C
C
      DO 4 NN=1,[illegible]
      [illegible]
```

```
      YI=II+1
    4 CONTINUE
    C
      IF (IJ.EQ.1) YPAR(2)=12.
      IF (IJ.EQ.2) YPAR(1)=13.
      IF (IJ.EQ.3) YPAR(1)=17.
      IF (IJ.EQ.1) YPAR(1)=1.5
      IF (IJ.EQ.3) YPAR(3)=1.
      IF (IJ.EQ.2) YPAR(3)=1.
      YPAR(4)=1.
      YPAR(5)=2.
      YPAR(7)=1.
      YPAR(9)=1.
      YPAR(10)=1.0
      XPAR(1)=1.
      XPAR(2)=8.
      XPAR(3)=1.
      XPAR(4)=XPAR(6)
      XPAR(5)=4.
      XPAR(7)=1.
      XPAR(9)=1.
      XPAR(10)=.05
      KODE=1
    C
      IF (IJ.EQ.2) IJ=1
    C
    C PLOTTING SUBROUTINES
    C
      CALL NAME (17,12)
      CALL SCALE (IT,XT,YT,XPAR,YPAR)
      CALL PLOT (X,Y,IS,XPAR,YPAR,KODE)
      CALL PAPER
    5 CONTINUE
    6 CONTINUE
    7 CONTINUE
    C
      STOP
      END
```

```
      PROGRAM 1(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
C
C     ******************************************************************
C     *                                                                *
C     *  THIS PROGRAM CALCULATES THE CONTOURS OF AIRSHIP HULLS FOR     *
C     *  VARIOUS PARAMETERS AND THEN PLOTS THESE CONTOURS ON 2A BY     *
C     *  22 INCH DRAFTING PAPER. THE PARAMETERS INVOLVED ARE FROM THE  *
C     *  GENERAL MILLS STUDY. THE BASIC SHAPE WILL NOT CHANGE EVEN IF  *
C     *  THE VOLUME IS CHANGED. THEREFORE ONLY ONE VALUE OF THE VOLUME *
C     *  WILL HAVE TO BE FED INTO THE PROGRAM.                         *
C     *                                                                *
C     ******************************************************************
C
C     PROGRAM NOTATION
C
C     F=AIRSHIP FINENESS RATIO
C     D=THE MAXIMUM AIRSHIP DIAMETER ( FT )
C     XN= A PARAMETER USED IN DETERMINING THE HULL SHAPE
C     XM= A PARAMETER USED IN DETERMINING THE HULL SHAPE
C     XL=THE TOTAL AIRSHIP LENGTH ( FT )
C     VL IS THE AIRSHIP VOLUME IN FT**3
C
C     FINT=THE INITIAL FINENESS RATIO
C     THESE VALUES ARE TO BE INCREMENTED
C
      DIMENSION XL(8), XN(8), XM(3), X(310), Y(310), F(4), XPAR(10), YPA
     1R(10), IEXT(3), ME(2)
      DIMENSION ZY(5), ZX(5)
      INTEGER TEXT(72)
C
C     INPUT DATA
C
      ME(1)=10H KLEINER H
      ME(2)=10H.J.
C
      IJ=0
C
      IL=1
C
      VL=50000.0
C
      ZY(1)=0.0
      ZY(2)=127.5
```

```
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE4=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
      ZY(3)=127.5
      ZY(4)=0.0
      ZY(5)=0.0
      ZX(1)=0.0
      ZX(2)=0.0
      ZX(3)=165.0
      ZX(4)=105.0
      ZX(5)=0.0
C
      TEXT(1)=10HN=0.185 A
      TEXT(2)=10HN=0.4 , F=
      TEXT(3)=10H4.00
      TEXT(4)=10HF=0.200 ,
      TEXT(5)=10HN=0.4 , F=
      TEXT(6)=10H4.00
      TEXT(7)=10HN=0.250 ,
      TEXT(8)=10HN=0.4 , F=
      TEXT(9)=10H4.00
      TEXT(10)=10HN=0.275 ,
      TEXT(11)=10H N=0.4 , F
      TEXT(12)=10H=4.00
      TEXT(13)=10HN=0.300 ,
      TEXT(14)=10H N=0.4 , F
      TEXT(15)=10H=4.00
      TEXT(16)=10HN=0.350 ,
      TEXT(17)=10H N=0.4 , F
      TEXT(18)=10H=4.00
      TEXT(19)=10HN=0.375 ,
      TEXT(20)=10H N=0.4 , F
      TEXT(21)=10H=4.00
      TEXT(22)=10HN=0.400 ,
      TEXT(23)=10H N=0.4 , F
      TEXT(24)=10H=4.00
      TEXT(25)=10HN=0.185 ,
      TEXT(26)=10H N=0.5 , F
      TEXT(27)=10H=4.00
      TEXT(28)=10HN=0.200 ,
      TEXT(29)=10H N=0.5 , F
      TEXT(30)=10H=4.00
      TEXT(31)=10HN=0.250 ,
      TEXT(32)=10H N=0.5 , F
      TEXT(33)=10H=4.00
      TEXT(34)=10HN=0.275 ,
      TEXT(35)=10H N=0.5 , F
      TEXT(36)=10H=4.00
      TEXT(37)=10HN=0.300 ,
      TEXT(38)=10H N=0.5 , F
      TEXT(39)=10H=4.00
      TEXT(40)=10HN=0.350 ,
      TEXT(41)=10H N=0.5 , F
```

```
T I C PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)                PAGE  6
      TEXT(42)=10H=4.00                                                          A  101
      TEXT(43)=10HN=0.375 ,                                                      A  102
      TEXT(44)=10H M=0.5 , F                                                     A  103
      TEXT(45)=10H=4.00                                                          A  104
      TEXT(46)=10HN=0.400 ,                                                      A  105
      TEXT(47)=10H M=0.5 , F                                                     A  106
      TEXT(48)=10H=4.00                                                          A  107
      TEXT(49)=10HN=0.185 ,                                                      A  108
      TEXT(50)=10H M=0.6 , F                                                     A  109
      TEXT(51)=10H=4.00                                                          A  110
      TEXT(52)=10HN=0.200 ,                                                      A  111
      TEXT(53)=10H M=0.6 , F                                                     A  112
      TEXT(54)=10H=4.00                                                          A  113
      TEXT(55)=10HN=0.250 ,                                                      A  114
      TEXT(56)=10H M=0.6 , F                                                     A  115
      TEXT(57)=10H=4.00                                                          A  116
      TEXT(58)=10HN=0.275 ,                                                      A  117
      TEXT(59)=10H M=0.6 , F                                                     A  118
      TEXT(60)=10H=4.00                                                          A  119
      TEXT(61)=10HN=0.300 ,                                                      A  120
      TEXT(62)=10H M=0.6 , F                                                     A  121
      TEXT(63)=10H=4.00                                                          A  122
      TEXT(64)=10HN=0.350 ,                                                      A  123
      TEXT(65)=10H M=0.6 , F                                                     A  124
      TEXT(66)=10H=4.00                                                          A  125
      TEXT(67)=10HN=0.375 ,                                                      A  126
      TEXT(68)=10H M=0.6 , F                                                     A  127
      TEXT(69)=10H=4.00                                                          A  128
      TEXT(70)=10HN=0.400 ,                                                      A  129
      TEXT(71)=10H M=0.6 , F                                                     A  130
      TEXT(72)=10H=4.00                                                          A  131
C                                                                                A  132
CCCC  FINENESS RATIO DEFINED                                                     A  133
C                                                                                A  134
      KKK=1                                                                      A  135
      F(KKK)=4.00                                                                A  136
C                                                                                A  137
CCC   THE VALUES OF XN AND XM ARE VARIED IN ORDER TO DETERMINE THE BEST          A  138
      SHAPE                                                                      A  139
C                                                                                A  140
      DO 5 II=1,3                                                                A  141
C                                                                                A  142
      IF (II.EQ.1) XM(II)=0.4                                                    A  143
      IF (II.EQ.2) XM(II)=0.5                                                    A  144
      IF (II.EQ.3) XM(II)=0.6                                                    A  145
C                                                                                A  146
      DO 4 K=1,8                                                                 A  147
C                                                                                A  148
                                                                                 A  149
                                                                                 A  150
```

```
      IF (K.EQ.1) XN(K)=0.125                                          A  151
      IF (K.EQ.2) XN(K)=0.2                                            A  152
      IF (K.EQ.3) XN(K)=0.25                                           A  153
      IF (K.EQ.4) XN(K)=0.275                                          A  154
      IF (K.EQ.5) XN(K)=0.3                                            A  155
      IF (K.EQ.6) XN(K)=0.35                                           A  156
      IF (K.EQ.7) XN(K)=0.375                                          A  157
      IF (K.EQ.8) XN(K)=0.4                                            A  158
C                                                                      A  159
      YN=XN(K)                                                         A  160
      YM=XM(II)                                                        A  161
C                                                                      A  162
CC    CALCULATION OF THE AIRSHIP LENGTH                                A  163
C                                                                      A  164
      Z=((YN+YM)**(YN+YM))/(2.0*F(KKK)*((YN)**YN)*((YM)**YM))          A  165
      W=(3.1A*(YN+YN)**(2.0*(YN+YM)))/(4.0*(F(KKK)**2)*(YN**(2.0*YN))*(Y A  166
     1M**(2.0*YM)))                                                    A  167
C                                                                      A  168
CC    USE GAMMA APPROXIMATION TO THE VOLUME INTEGRAL                   A  169
C                                                                      A  170
      B=0.33                                                           A  171
      XX=2.0*YN+1.0                                                    A  172
      YY=2.0*YM+1.0                                                    A  173
      ZZ=2.0*YN+2.0*YM+2.0                                             A  174
      CALL GAMMA (XX,GX,IER)                                           A  175
      CALL GAMMA (YY,TX,IER)                                           A  176
      CALL GAMMA (ZZ,SX,IER)                                           A  177
      U=(GX*TX)/SX                                                     A  178
      XL(K)=(VL/(W*U))**B                                              A  179
      DO 2 J=1,155                                                     A  180
      N=J-1                                                            A  181
      JJ=310-N                                                         A  182
      DD=XL(K)/10000.0                                                 A  183
      CC=XL(K)/100.0                                                   A  184
      BB=CC/25.0                                                       A  185
      AA=(CC-DD)/25.0                                                  A  186
      IF (J.EQ.1) X(J)=0.0                                             A  187
      IF (J.EQ.1) GO TO 1                                              A  188
      IF (J.EQ.2) X(J)=0.01                                            A  189
      IF (J.EQ.3) X(J)=0.05                                            A  190
      IF (J.EQ.4) X(J)=0.075                                           A  191
      IF (J.EQ.5) X(J)=0.10                                            A  192
      IF (J.LT.6) GO TO 1                                              A  193
      IF (J.GT.5.AND.J.LT.31) X(J)=X(N)+AA                             A  194
      IF (J.GT.5.AND.J.LT.31) GO TO 1                                  A  195
      IF (J.GT.130) X(J)=X(N)+BB                                       A  196
      IF (J.GT.130) GO TO 1                                            A  197
      X(J)=X(N)+(CC-2.0*DD)                                            A  198
C                                                                      A  199
C     CALCULATION OF THE AIRSHIP CONTOURS                              A  200
```

```
      PROGRAM T1(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
C
    1 Y(J)=(Z/(XL(K))**(YN*YM-1.0))*((X(J))**YN)*(ABS(XL(K)-X(J)))**YM
      Y(JJ)=-Y(J)
      X(JJ)=X(J)
    2 CONTINUE
C
      IJ=IJ+1
CCC
CCC   CALCULATION OF THE AIRSHIP MAXIMUM DIAMETER
C
      D=XL(K)/F(KKK)
CCCC
CCCC  PLOTTING DATA
C
      DO 3 NN=1,3
      ITEXT(NN)=TEXT(IL)
      IL=IL+1
    3 CONTINUE
C
      IF (IJ.EQ.1) XPAR(1)=1.0
      IF (IJ.EQ.2) XPAR(1)=13.0
      IF (IJ.EQ.1) XPAR(2)=27.0
      IF (IJ.EQ.2) XPAR(2)=14.0
      IF (IJ.EQ.1) XPAR(3)=1.0
      IF (IJ.EQ.2) XPAR(3)=1.0
      XPAR(4)=15.0
      XPAR(5)=0.0
      XPAR(7)=1.0
      XPAR(9)=1.0
      XPAR(10)=10.0
      YPAR(1)=1.0
      YPAR(2)=20.0
      YPAR(3)=11.0
      YPAR(4)=XPAR(4)
      YPAR(5)=6.0
      YPAR(7)=1.0
      YPAR(9)=0.0
      YPAR(10)=0.50
      COUNT=5
      KODE=0
C
      IF (IJ.EQ.2) IJ=0
CCC
CCC   PLOTTING SUBROUTINES
C
      CALL NAME (ME,12)
      CALL SCRIBE (ITEXT,22,XPAR,YPAR)
      CALL LINE (ZX,ZY,COUNT,XPAR,YPAR,KODE)
      CALL FREE (X,Y,310,XPAR,YPAR,KODE)
```

```
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
      CALL PAPAD                                                        A 251
      CONTINUE                                                          A 252
C     CONTINUE                                                          A 253
C                                                                       A 254
      STOP                                                              A 255
      END                                                               A 256
```

APPENDIX B

PROGRAMME FOR BODY DEPENDENT PARAMETERS

```
      PROGRAM TST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     ******************************************************************
C     *                                                                *
C     *  A PROGRAM TO CALCULATE PRELIMINARY DESIGN PARAMETERS OF       *
C     *  VARIOUS AIRSHIP SHAPES. THESE PARAMETERS ARE TO BE USED       *
C     *  TO DECIDE ON THE ENVELOPE SHAPE OF THE FINAL DESIGN.          *
C     *  TWENTY FOUR DESIGNS WILL BE EXAMINED. THE DESIGNS             *
C     *  WILL CONSIST OF EIGHT SHAPES AND EACH SHAPE WILL BE           *
C     *  EXAMINED FOR THREE VALUES OF FINENESS RATIO.                  *
C     *                                                                *
C     *  THE OUTPUT WILL CONSIST OF                                    *
C     *                                                                *
C     *    (1) SHAPE PARAMETERS                                        *
C     *    (2) VELOCITY                                                *
C     *    (3) INTERNAL PRESSURE REQUIRED                              *
C     *    (4) CENTER OF BOUYANCY LOCATION                             *
C     *    (5) ENVELOPE CENTER OF GRAVITY LOCATION                     *
C     *    (6) ENVELOPE SURFACE AREA                                   *
C     *    (7) DRAG                                                    *
C     *    (8) TAIL SURFACE SIZE AND LOCATION                          *
C     *    (9) AERODYNAMIC BENDING MOMENT                              *
C     *    (10) HOGGING MOMENT                                         *
C     *                                                                *
C     ******************************************************************
C
C     USER INPUT DATA
C
C     VOL  THE VOLUME OF THE AIRSHIP IN FT**3
C     VEL  THE VELOCITY OF THE AIRSHIP IN FT/SEC
C     ROE  THE DENSITY OF THE AIR IN SLUGS/FT**3
C     XMU  THE DYNAMIC VISCOSITY OF THE AIR IN SLUGS/FT-SEC
C     XN   AN AIRSHIP ENVELOPE SHAPE FACTOR
C     XM   AN AIRSHIP ENVELOPE SHAPE FACTOR
C     F    THE AIRSHIP FINENESS RATIO
C
      DIMENSION F(3),XN(2),XM(4),CRV(13),E1(13),E2(13),E3(13),F4(13),A1(
     113)
C
C     INPUT DATA
C
      DATA F / 2.50,3.00,4.00 /
      DATA XN / 0.3,0.4 /
      DATA XM / 0.4,0.5,0.6,0.7 /
      DATA VEL,VOL,ROE,XMU / 110.0,91798.6,0.002378,3.639E-07 /
C
C     CONTROL SURFACE DATA
```

```
      DATA CRV / 0.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0,80.0,90.0,100.0,
     1110.0,120.0 /
      DATA E1 / 0.0,12.0,21.0,28.0,35.0,40.0,48.0,57.0,68.0,78.0,90.0,10
     10.0,113.0 /
      DATA E2 / 0.0,9.0,17.0,24.0,31.0,39.0,47.0,56.0,65.0,75.0,85.0,95.
     10,105.0 /
      DATA E3 / 0.0,8.0,14.0,19.0,23.0,27.0,30.0,35.0,40.0,46.0,52.0,60.
     10,65.0 /
      DATA E4 / 0.0,6.0,10.0,15.0,18.0,22.0,27.0,32.0,37.0,43.0,50.0,57.
     10,63.0 /
      DATA A1 / 0.0,10.0,17.0,23.0,30.0,36.0,44.0,53.0,62.0,72.0,83.0,94
     1.0,104.0 /
C
C     IJ=0
C
C     DO 1 I=1,3
C     DO 2 II=1,2
C     DO 3 III=1,4
C
C     CALCULATION OF THE AIRSHIP LENGTH
C
      XX=2.0*XN(II)+1.0
      YY=2.0*XM(III)+1.0
      ZZ=2.0*XN(II)+2.0*XM(III)+2.0
C
      CALL GAMMA (XX,GX,IER)
      CALL GAMMA (YY,TX,IER)
      CALL GAMMA (ZZ,SX,IER)
C
      U=(GX*TX)/SX
      B=1.0/3.0
C
      W=(3.14**(XN(III)+XN(II))**(2.0*(XN(III)+XM(III))))/(4.0*4F(I)**2)*(
     1XN(II)**(2.0*XN(II)))*(XN(III)**(2.0*XM(III)))
C
      XL=(VOL/(W*U))**B
C
C     CALCULATION OF THE DRAG
C
      CF=0.074/(VEL*XL*ROE/XMU)**0.2
C
      A=(1.0+0.5/F(I))
C
      T=1.86
C
      BHDR=0.5*ROE*VEL**T*(CF*A*(4.0*(F(I)**B)+6.0*((1.0/F(I))**1.2)+24.
     10*((1.0/F(I))**2.))*VOL**0.67
C
      DRAG=BHDR/0.35
```

```
      C
      C     CALCULATION OF THE CENTER OF BOUYANCY
      C
      CBX=(2.0*XN(II)+1.0)/(2.0*XN(II)+2.0*XM(III)+2.0)*XL
      C
      C     CALCULATION OF THE ENVELOPE SURFACE AREA
      C
      YY=XN(II)+1.0
      YX=XM(III)+1.0
      ZX=XN(II)+XM(III)+2.0
      C
      CALL GAMMA (XY,XG,IER)
      CALL GAMMA (YX,XT,IER)
      CALL GAMMA (ZX,XS,IER)
      C
      ZY=(XG*XT)/XS
      C
      ESA=(3.14*(XN(II)+XM(III))**(XN(II)+XM(III)))/(F(I)*XN(II)**XN(II)
     1*XM(III)**XM(III))*ZY*XL**2
      C
      C     CALCULATION OF THE ENVELOPE CENTER OF GRAVITY
      C
      CGEA=(XN(II)+1.0)/(XN(II)+XM(III)+2.0)*XL
      C
      C     CALCULATION OF THE HOGGING BENDING MOMENT
      C
      R=XL/(2.0*F(I))
      H=2.0*R
      BMH=0.063*3.14*R**3*H/4.0
      C
      C     CALCULATION OF THE AERODYNAMIC BENDING MOMENT
      C
      BMA=0.01*ROE*VEL**2*VOL**0.67*XL
      C
      C     CALCULATION OF THE INTERNAL PRESSURE REQUIRED
      C
      PINT=BMA*2.0/(3.14*R**3)
      C
      C     CALCULATION OF THE CONTROL SURFACES
      C
      C     FIXED HORIZONTAL SURFACE AREA
```

```
      ACHV=VOL**0.33
      AH=FTABLE(CRV,E1,ACRV,13)**3./XL
C
C     FIXED VERTICAL SURFACE AREA
C
      AV=FTABLE(CRV,E2,ACRV,13)**3.0/XL
C
C     ELEVATOR AREA
C
      AE=FTABLE(CRV,E3,ACRV,13)**3.0/XL
C
C     RUDDER AREA
C
      AR=FTABLE(CRV,E4,ACRV,13)**3.0/XL
C
C     DISTANCE AFT OF THE CENTER OF BOUYANCY
C
      AT=AR+AE+AH+AV
      SCX=FTABLE(CRV,A1,ACRV,13)**3.0/AT
C
C     LOCATION OF THE TAIL CENTER OF AREA
C
      XSC=CRX+SCX
C
C     DATA OUTPUT
C
      IJ=IJ+1
      IF (IJ .EQ. 1) WRITE (6,4)
      WRITE (6,5) XN(III),XM(III),F(I),XL,DRAG,ESA,CGEX,CRX,BMH,BMA,PINT,
     1AH,AV,AE,AR,XSC
      CONTINUE
      CONTINUE
      CONTINUE
      WRITE (6,6) VEL,VOL
C
```

```
      4   FORMAT (1H1,1X,*    N          M          F          XL        DRAG      E. AREA
     1E. CG     CB        RMM       RMA       PINT       MFSA       VFSA       EA
     2 RA       CSCA*)
      5   FORMAT (1H0,1X,16( F7.1,1X ))
      6   FORMAT (1HU,1X,*VELOCITY IN FEET PER SECOND = *,F10.6,5X,*VOLUME I
     1N CUBIC FEET = *,F10.2//1X,*AREAS ARE IN SQUARE FEET AND DISTANCES
     2 ARE IN FEET*)
C
      STOP
      END
```

```
      FUNCTION FTABLE ( VAR , FUNC , XX , M )
C
C     VAR=DISCRETE TABULAR VALUES OF THE VARIABLE
C     FUNC=DISCRETE TABULAR VALUES OF THE FUNCTION
C     XX=GIVEN VALUE OF THE VARIABLE
C     M=NUMBER OF STATIONS OR TABLE VALUES
C     FTABLE=INTERPOLATED VALUE OF FUNCTION CORRESPONDING TO XX
C
      DIMENSION VAR(1),FUNC(1)
C
      NEND=M-1
C
      DO 10 I=1,NEND
C
      INT=I
C
      IF(XX.GT.VAR(I).AND.XX.LE.VAR(I+1)) GO TO 11
C
   10 CONTINUE
C
   11 FTABLE=FUNC(INT)+(XX-VAR(INT))*(FUNC(INT+1)-FUNC(INT))/(VAR(INT+1)
     1-VAR(INT))
C
      RETURN
      END
```

APPENDIX C

PROGRAMME FOR PRESSURE DISTRIBUTION

```
      PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C*****************************************************************
C*                                                               *
C* A PROGRAM THAT CALCULATES THE PRESSURE DISTRIBUTION FOR ANY   *
C* GIVEN AIRSHIP SHAPE.  THE ONLY USER INPUTS BEING THE RADIUS   *
C* OF THE HULL AT EACH SOURCE OR SINK AND THE NUMBER AND SEPERATION *
C* DISTANCE OF THESE. THIS PROGRAM IS FOR ANGLE OF ATTACK SUCH   *
C* AS IS SPECIFIED BY THE USER. THE PROGRAM MUST BE READ IN TWICE. *
C* THE FRONT HALF OF THE SHAPE IS DONE FIRST, THE BACK HALF IS DONE *
C* THE SECOND TIME, THE POINT OF DIFFERENTIATION IS THE POINT OF *
C* MAXIMUM DIAMETER.                                             *
C*                                                               *
C*****************************************************************
C
C  THE USER MUST INPUT THE FOLLOWING QUANTITIES
C
C  N   THE NUMBER OF STATIONS THAT THE PRESSURE DISTRIBUTION IS
C      REQUIRED AT. THE NUMBER OF STATIONS SHOULD BE THE SAME IN
C      EACH HALF OF THE HULL.
C
C  R   THE RADIUS OF THE ENVELOPE IN FEET AT EACH STATION. THE
C      VALUES OF R ARE READ IN BACKWARDS (IE. TAIL TO NOSE)
C      FOR THE SECOND RUN.
C
C  A   THE SEPERATION OF THE STATIONS IN FEET. THE SEPERATION
C      DISTANCE USED FOR EACH HALF OF THE HULL MAY BE DIFFERENT
C      AND NO PARTICULAR VALUE IS SPECIFIED
C
C  RHO THE DENSITY OF THE AIR IN SLUGS PER CUBIC FOOT
C
C  VEL THE AIRSHIP VELOCITY IN FEET PER SECOND.
C
C  ALPHA THE AIRSHIP ANGLE OF ATTACK IN DEGREES.
C
C  USER MUST DIMENSION THE FOLLOWING QUANTITIES
C
C  C(N,N)
C  S(N)
C  R(N)
C  XX(N)
C  CC(N)
C  DD(N)
C  XP(N)
C  RCCP(N,N)
C  RCCDP(N,N)
```

```
      SINTP(N,N)                                                        A   51
      SINTDP(N,N)                                                       A   52
      COSTP(N,N)                                                        A   53
      COSTDP(N,N)                                                       A   54
      B(N,N)                                                            A   55
      G(N,N)                                                            A   56
      XX(N,N)                                                           A   57
      XX(N,N)                                                           A   58
      FX(N,N)                                                           A   59
      GX(N,N)                                                           A   60
      BETA(N)                                                           A   61
      UX(N)                                                             A   62
      UP(N)                                                             A   63
      WX(N)                                                             A   64
      WP(N)                                                             A   65
                                                                        A   66
      DIMENSION C(7,7), F(7), KK(7), P(7), CC(7), DD(7), XP(7), BOEP(7,7 A   67
     1), BOEDP(7,7), SINTP(7,7), SINTDP(7,7), COSTP(7,7), COSTDP(7,7), F A   68
     2(7,7), G(7,7), XX(7,7), FX(7,7), GX(7,7), XX(7,7), BETA(7), UX(7), A   69
     3 UP(7), WX(7), WP(7)                                              A   70
                                                                        A   71
                                                                        A   72
      DEFINING THE VELOCITY AND THE ANGLE OF ATTACK PARAMETERS          A   73
                                                                        A   74
                                                                        A   75
      READ (5,17) N                                                     A   76
      READ (5,17) I                                                     A   77
      READ (5,14) A                                                     A   78
      READ (5,14) BOE                                                   A   79
      READ (5,14) VEL                                                   A   80
      READ (5,14) ALPHA                                                 A   81
                                                                        A   82
                                                                        A   83
      II=2                                                              A   84
      IF (ALPHA.GT...0) II=1                                            A   85
                                                                        A   86
      CALCULATION OF THE PRESSURE AT THE ROW ( DYNAMIC PRESSURE )       A   87
                                                                        A   88
      PR=0.5*BOE*VEL**2                                                 A   89
                                                                        A   90
      CALCULATION OF SOURCE AND SINK STRENGTHS                          A   91
                                                                        A   92
      DO 5 I=1,N                                                        A   93
      DO 4 J=1,N                                                        A   94
```

```
      I=J
C     CALCULATION OF RADII
C
      IF (I.NE.J) GO TO 1
      ROSP(I,J)=SQRT(P(J)**2.0+(A/2.0)**2.0)
    1 ROSP(I,J)=ROSP(I,J)
C
C     CALCULATION OF THE ANGLES
C
      SINTP(I,J)=P(J)/ROSP(I,J)
      SINTOP(I,J)=SINTP(I,J)
      COSTP(I,J)=(A/2.0)/ROSP(I,J)
      COSTOP(I,J)=-COSTP(I,J)
C
C     CALCULATION OF THE UNSYMMETRICAL FLOW PARAMETERS
C
```

```
A  101
A  102
A  103
A  104
A  105
A  106
A  107
A  108
A  109
A  110
A  111
A  112
A  113
A  114
A  115
A  116
A  117
A  118
A  119
```

```
      XX(I,J)=A
      XT=R(J)/XX(I,J)

C
      F(I,J)=XT**3./((1.+.2*XT**2.)**(3./2.))
      G(I,J)=2.*XT**2.*(1.+.7/((1.+.2*XT**2.)**(3./2.)))

C
      FX(I,J)=F(I,J)
      GX(I,J)=G(I,J)

      GO TO 3

C
C     I .LT. J
C     CALCULATION OF THE RADII

      IF (I.GT.J) GO TO 2
      ROEP(I,J)=SQRT((R(J)**2.)+((J-I)*A+(A/2.0))**2.0)
      ROEDP(I,J)=SQRT((R(J)**2.0)+((J-I)*A-(A/2.0))**2.0)

C     CALCULATION OF THE ANGLES

      SINTP(I,J)=R(J)/ROEP(I,J)
      SINTDP(I,J)=R(J)/ROEDP(I,J)
      COSTP(I,J)=((J-I)*A+A/2.)/ROEP(I,J)
      COSTDP(I,J)=((J-I)*A-A/2.)/ROEDP(I,J)

C     CALCULATION OF THE UNSYMMETRICAL FLOW PARAMETERS

      XX(I,J)=(J-I)*A+A/2.0
```

```
      XX(I,J)=(J-I)*A-A/2.0                                              A  151
      XT=R(J)/XX(I,J)                                                    A  152
      XTT=R(J)/XY(I,J)                                                   A  153
C                                                                        A  154
      F(I,J)=XT**3./((1.0+XT**2.0)**(3.0/2.0))                           A  155
      G(I,J)=2.0*XT**2.0+1.0/((1.0+XT**2.0)**(3.0/2.0))                  A  156
      FX(I,J)=XTT**3./((1.0+XTT**2.0)**(3.0/2.0))                        A  157
      GX(I,J)=2.0*XTT**2.0+1.0/((1.0+XTT**2.0)**(3.0/2.0))               A  158
C                                                                        A  159
      GO TO 3                                                            A  160
C                                                                        A  161
      I .GT. J                                                           A  162
C     CALCULATION OF THE RADII                                           A  163
C                                                                        A  164
      ROEP(I,J)=SQRT(R(J)**2.0+((I-J)*A-A/2.0)**2.0)                     A  165
      ROEDP(I,J)=SQRT(R(J)**2.0+((I-J)*A+A/2.0)**2.0)                    A  166
C                                                                        A  167
C     CALCULATION OF THE ANGLES                                          A  168
C                                                                        A  169
      SINTP(I,J)=R(J)/ROEP(I,J)                                          A  170
      SINTDP(I,J)=R(J)/ROEDP(I,J)                                        A  171
      COSTP(I,J)=((J-I)*A+A/2.0)/ROEP(I,J)                               A  172
      COSTDP(I,J)=((J-I)*A-A/2.0)/ROEDP(I,J)                             A  173
C                                                                        A  174
C     CALCULATION OF THE UNSYMMETRICAL FLOW PARAMETERS                   A  175
C                                                                        A  176
      XX(I,J)=(I-J)*A-A/2.0                                              A  177
      XY(I,J)=(I-J)*A+A/2.0                                              A  178
      XT=R(J)/XX(I,J)                                                    A  179
      XTT=R(J)/XY(I,J)                                                   A  180
C                                                                        A  181
      F(I,J)=XT**3./((1.0+XT**2.0)**(3.0/2.0))                           A  182
      G(I,J)=2.0*XT**2.0+1.0/((1.0+XT**2.0)**(3.0/2.0))                  A  183
      FX(I,J)=XTT**3./((1.0+XTT**2.0)**(3.0/2.0))                        A  184
      GX(I,J)=2.0*XTT**2.0+1.0/((1.0+XTT**2.0)**(3.0/2.0))               A  185
C                                                                        A  186
C     COEFFICIENTS FOR SIMULTANEOUS EQUATIONS                            A  187
C                                                                        A  188
      CONTINUE                                                           A  189
      C(J,I)=1.0+((ROEP(I,J)-ROEDP(I,J))/A)                              A  190
C                                                                        A  191
      CONTINUE                                                           A  192
C                                                                        A  193
C     RIGHT HAND SIDE COEFFICIENTS                                       A  194
C                                                                        A  195
C                                                                        A  196
C                                                                        A  197
C                                                                        A  198
C                                                                        A  199
C                                                                        A  200
```

```
      R(I)=(R(I)/A)**2.0
      CONTINUE

C     SOLVING SIMULTANEOUS EQUATIONS
      CALL SIMQ (C,B,N,KS)
      WRITE (6,17) KS

C     SOLVING FOR PRESSURE DISTRIBUTION

      WRITE (6,21)

      DO 6 I=1,N
      WRITE (6,20) I,B(I)
    6 CONTINUE

      WRITE (6,22)

      DO 8 J=1,N

      EE=0.0
      FF=0.0

      DO 7 I=1,N

      CC(I)=B(I)*(SINTDP(J,I)-SINTP(J,I))
      DD(I)=B(I)*(COSTDP(J,I)-COSTP(J,I))

      EE=EE+CC(I)
      FF=FF+DD(I)

    7 CONTINUE

      AA=A/(2.0*R(J))
      BB=(A**2.0)/(4.0*R(J)**2.0)
      XK(J)=SQRT(ABS(1.0-AA*EE)**2.0+ABS(BB*FF)**2.0)

      XP(J)=RHO/2.0*(1.0-XK(J)**2.0)*VEL**2.0

      WRITE (6,20) J,XK(J)

    8 CONTINUE
      IF (T1.EQ.1) GO TO 10
```

```
      WRITE (6,24)
      WRITE (6,26) VEL,ALPHA
      WRITE (6,23) DD
C
      DO 9 J=1,N
C
      WRITE (6,20) J,XP(J)
      CONTINUE
C
10    CONTINUE
      IF (II.NE.1) GO TO 16
C
C     CALCULATION OF THE TRANSVERSE FORCE COEFFICIENT
C
      VVL=1.0
C
C     CALCULATION OF THE TANGENTIAL AND RADIAL VELOCITIES
C
C     HORIZONTAL
C
      DO 11 J=1,N
      UX(J)=VVL-VVL*(A/(2.0*R(J)))**EE
      UR(J)=VVL*(A/(2.0*R(J)))**FF
11    CONTINUE
C
C     VERTICAL
C
      DO 13 J=1,N
C
      SS=0.0
      TT=0.0
C
      DO 12 I=1,N
C
      ST=(R(I)/R(J))**2.0*(F(I,J)-FX(I,J))
      TS=(R(I)/R(J))**2.0*(G(I,J)-GX(I,J))
C
      SS=ST+SS
      TT=TS+TT
```

```
C
12    CONTINUE
C
      UX(J)=(VVL/2.0)*SS
      UR(J)=(VVL/2.0)*TT
C
13    CONTINUE
CCCCCC
      CONVERTING ANGLE TO RADIANS
CCCCCC
      RADNS=6.29*ALPHA/180.0
CCCCCC
      TRANSVERSE FORCE COEFFICIENT
CCCCCC
      DO 14 J=1,N
C     BETA(J)=3.14*R(J)*(UX(J)*WX(J)+UR(J)*WR(J))*SIN(RADNS)
C
14    CONTINUE
C
      WRITE (6,25)
      WRITE (6,26) VEL,ALPHA
C
      DO 15 I=1,N
C
C     WRITE (6,20) I,BETA(I)
C
15    CONTINUE
C
16    CONTINUE
CCCCC
C
      STOP
C
17    FORMAT (I6)
18    FORMAT (F10.9)
19    FORMAT (F10.6)
20    FORMAT (1H0,17HVALUE AT STATION ,4X,I4,10X,F20.10)
21    FORMAT (1H1,25HSOURCE AND SINK STRENGTHS)
22    FORMAT (1H1,20HVALUE OF VARIABLE K )
23    FORMAT (1H0,1X,*DYNAMIC PRESSURE = *,F10.5)
24    FORMAT (1H1,53HVALUE OF THE PRESSURE DISTRIBUTION AT EACH POINT R(
     1))
25    FORMAT (1H1,53HVALUE OF THE TR.FORCE DISTRIBUTION AT EACH POINT R(
     1))
```

```
26    FORMAT (1H0,1X,1 HVELOCITY =,F7.2,2X,6HFT/SEC//1X,17HANGLE OF ATTA   A 351
     1CK =,F5.2,2X,7H DEGREES)                                             A 352
      END                                                                  A 353-
```

APPENDIX D

PROGRAMME FOR STATIC SHEAR FORCE AND BENDING MOMENT

```
T I D Y                                                                  PAGE    1
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
C     PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
C*****************************************************************
C                                                                *
C     A PROGRAM TO EVALUATE THE DESIGN OF AN AIRSHIP. THE PROGRAM*
C     ALLOWS THE POSITIONING OF VARIOUS PARAMETERS BY THE USER.  *
C     THE PROGRAM ASSUMES THAT ALL THE FORCES ACTING ON THE AIRSHIP*
C     CAN BE REPRESENTED AS ACTING ON A BEAM.                    *
C                                                                *
C*****************************************************************
C
C
C    USER INPUT VARIABLES
C
C
C    XN      SHAPE FACTOR
C    XM      SHAPE FACTOR
C    F       FINENESS RATIO
C    XL      AIRSHIP LENGTH
C    N       NUMBER OF STATIONS THE AIRSHIP IS DIVIDED INTO STARTING
C    WITH
C       1 AT THE BOW
C    XX      THE DISTANCE BETWEEN THE STATIONS
C    BALXS   THE STARTING POSITION OF THE BALLONETS
C    BALXST  THE STOPPING POSITION OF THE BALLONETS
C    CABXS   THE STARTING POSITION OF THE CABIN
C    CABXST  THE STOPPING POSITION OF THE CABIN
C    TAILXS  THE STARTING POSITION OF THE TAIL ASSEMBLY
C    TAILXST THE STOPPING POSITION OF THE TAIL ASSEMBLY
C    SUSPXS  THE STARTING POSITION OF THE SUSPENSION
C    SUSPXST THE STOPPING POSITION OF THE SUSPENSION
C    WNOSE   THE NOSE CAP WEIGHT
C    WCAB    THE CABIN WEIGHT
C    WTAIL   THE TAIL ASSEMBLY WEIGHT
C    WEIGHT  THE WEIGHT OF THE ENVELOPE MATERIAL (OZ. PER SQ. YD.)
C    XCCG    POSITION OF THE CG OF THE CABIN
C    XNCG    POSITION OF THE CG OF THE NOSE CAP
C    XTCG    POSITION OF THE CG OF THE TAIL ASSEMBLY
C
C
C    USER MUST DIMENSION THE FOLLOWING QUANTITIES
C
C
C    Y(N)
C    VOL(N-1)
C    SURFA(N-1)
C    SLIFT(N-1)
C    WSURF(N-1)
C    XLIFT(N-1)
C    X(N-1)
```

```
* T I D Y *
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)                PAGE    1
C     ZZ(N-1)                                                                       A   51
C     AA(N-1)                                                                       A   52
C     PVOL(N-1)                                                                     A   53
C     PSA(N-1)                                                                      A   54
C     WTBA(N-1)                                                                     A   55
C     WTBF(N-1)                                                                     A   56
C     TOTL(N-1)                                                                     A   57
C     XMOMT(N-1)                                                                    A   58
C     XZ(N-1)                                                                       A   59
C                                                                                   A   60
      DIMENSION Y(118), VOL(117), SLIFT(117), WSURF(117), SUREA(117)                A   61
      DIMENSION XLIFT(117)                                                          A   62
      DIMENSION X(200), ZZ(200), AA(200), PVOL(200), PSA(200), WTBA(200)            A   63
     1, WTBF(200)                                                                   A   64
      DIMENSION TOTL(117), XMOMT(117), XZ(117)                                      A   65
C                                                                                   A   66
      REAL NOSEXST                                                                  A   67
C                                                                                   A   68
C     USER INPUT DATA                                                               A   69
C                                                                                   A   70
      DATA XM,XN,XX,N,AL,F/0.6,0.4,1.0,118,117.0,3.00/                              A   71
      DATA WEIGHT/11.40/                                                            A   72
      DATA CAB,WTAIL,NOSE/3200.0,500.0,200.0/                                       A   73
      DATA ACCG,XNCG,XTCG/52.6,10.0,90.0/                                           A   74
      DATA EPS/0.1/                                                                 A   75
      DATA DR/11.4/                                                                 A   76
      DATA SUSPXS,SUSPXST,NOSEXS,NOSEXST,CABXS,CABXST,TAILXS,TAILXST/20.0,90.0,     A   77
     120.0,39.6,61.6,85.0,100.0/                                                    A   78
C                                                                                   A   79
C     CALCULATING THE DENSITY OF AIR IN LBS/FT**3                                   A   80
C                                                                                   A   81
      DA=0.002378*32.174                                                            A   82
C                                                                                   A   83
C     CALCULATING THE VOLUME (G.M. EQUATION )                                       A   84
C                                                                                   A   85
      A=3.14*(XN+XM)**(2.0*(XM+XN))/(4.0*F**2.0*(XN**(2.0*XN))*(XM**(2.0            A   86
     1*XM)))                                                                        A   87
C                                                                                   A   88
C     THE GAMA APPROXIMATION IS USED TO SOLVE THE INTEGRAL                          A   89
C                                                                                   A   90
      B=2.0*XN+1.0                                                                  A   91
```

```
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)
      C=2.0*XM+1.0                                                          A  101
      D=2.0*XM+2.0*AN+2.0                                                   A  102
C                                                                           A  103
      CALL GAMMA (B,E,IER)                                                  A  104
      WRITE (6,7) IER                                                       A  105
      CALL GAMMA (C,G,IER)                                                  A  106
      WRITE (6,7) IER                                                       A  107
      CALL GAMMA (D,H,IER)                                                  A  108
      WRITE (6,7) IER                                                       A  109
C                                                                           A  110
C                                                                           A  111
      Z=E*G/H                                                               A  112
C                                                                           A  113
      VTOT=A*Z*XL**3.0                                                      A  114
C                                                                           A  115
      WRITE (6,8)                                                           A  116
C                                                                           A  117
      WRITE (6,9) VTOT                                                      A  118
C                                                                           A  119
      CALL VOLAPRX (XN,XM,XX,N,XL,F,VOL,Y)                                  A  120
C                                                                           A  121
      V=0.0                                                                 A  122
C                                                                           A  123
      M=N-1                                                                 A  124
C                                                                           A  125
      DO 1 I=1,N                                                            A  126
C                                                                           A  127
      WRITE (6,10) Y(I),I                                                   A  128
C                                                                           A  129
    1 CONTINUE                                                              A  130
C                                                                           A  131
      WRITE (6,8)                                                           A  132
C                                                                           A  133
      DO 2 I=1,M                                                            A  134
C                                                                           A  135
      WRITE (6,11) I,VOL(I)                                                 A  136
C                                                                           A  137
      V=V+VOL(I)                                                            A  138
    2 CONTINUE                                                              A  139
C                                                                           A  140
      WRITE (6,12) V                                                        A  141
C                                                                           A  142
C                                                                           A  143
C                                                                           A  144
C     CONVERTING WEIGHT INTO LBS/SQ. FT.                                    A  145
C                                                                           A  146
C                                                                           A  147
C                                                                           A  148
C                                                                           A  149
C                                                                           A  150
```

```
C
      S=W*EIGHT/(9.0*16.0)                                              A  151
      DHF=DA/(9.0*16.0)                                                 A  152
C                                                                       A  153
      CALL ENVST (Y,VOL,M,N,SLIFT,WSURF,SURFA,SL,SA,W,SW,XX)            A  154
C                                                                       A  155
      WRITE (6,8)                                                       A  156
C                                                                       A  157
      DO 3 I=1,M                                                        A  158
C                                                                       A  159
      WRITE (6,13) SLIFT(I),WSURF(I),SURFA(I),I                         A  160
    3 CONTINUE                                                          A  161
      WRITE (6,14) SL,SA,W                                              A  162
C                                                                       A  163
C                                                                       A  164
C                                                                       A  165
C                                                                       A  166
C                                                                       A  167
C                                                                       A  168
C                                                                       A  169
C                                                                       A  170
C                                                                       A  171
C                                                                       A  172
C                                                                       A  173
C                                                                       A  174
C                                                                       A  175
C                                                                       A  176
C                                                                       A  177
C                                                                       A  178
C                                                                       A  179
C                                                                       A  180
C                                                                       A  181
C                                                                       A  182
C                                                                       A  183
C                                                                       A  184
C                                                                       A  185
C                                                                       A  186
C                                                                       A  187
C                                                                       A  188
C                                                                       A  189
C                                                                       A  190
C                                                                       A  191
C                                                                       A  192
C                                                                       A  193
C                                                                       A  194
C                                                                       A  195
C                                                                       A  196
C                                                                       A  197
C                                                                       A  198
C                                                                       A  199
C                                                                       A  200
```

DETERMINING THE BALLONET CHARACTERISTICS

```
      CALL BAIAPRX (XM,XN,AL,F,DA,DBF,EPS,PVOL,PSA,WTBA,WTBF,VVV,SS,XS,X
     IF,CGB,X,ZZ,AA)
```

TOTAL BALLONET WEIGHT

```
      WBB=DBF*SS
      WRITE (6,15) WBB
```

DETERMINING THE CG POSITION

```
      CALL CGPOS (XM,XN,XCB,XECG,XCCG,XNCG,XTCG,XASCG,XL,W,WCAR,WTAIL,WN
     1OSE,CGB,SS,DBF)
      WRITE (6,8)
      WRITE (6,16) XCB,XECG,XASCG
```

DETERMINING THE NET LIFT

```
      PROGRAM T(INPUT,OUTPUT,PLT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3=PLT)                    PAGE  3 11
      WRITE (6,8)                                                                        A  201
C                                                                                        A  202
      TLIFT=0.0                                                                          A  203
C                                                                                        A  204
      XD=1.0                                                                             A  205
C                                                                                        A  206
      L=1                                                                                A  207
C                                                                                        A  208
      DO 6 I=1,M                                                                         A  209
C                                                                                        A  210
      IF (XD.LT.XS.OR.XD.GT.XF) GO TO 4                                                  A  211
C                                                                                        A  212
      XLIFT(I)=SLIFT(I)-(PVOL(L)*0.063)                                                  A  213
C                                                                                        A  214
      L=L+1                                                                              A  215
C                                                                                        A  216
      GO TO 5                                                                            A  217
C                                                                                        A  218
    4 XLIFT(I)=SLIFT(I)                                                                  A  219
C                                                                                        A  220
    5 XD=XD+XX                                                                           A  221
C                                                                                        A  222
      TLIFT=TLIFT+XLIFT(I)                                                               A  223
C                                                                                        A  224
      WRITE (6,17) I,XLIFT(I)                                                            A  225
C                                                                                        A  226
    6 CONTINUE                                                                           A  227
C                                                                                        A  228
      WRITE (6,18) TLIFT                                                                 A  229
C                                                                                        A  230
C                                                                                        A  231
C                                                                                        A  232
C     DETERMINING THE TOTAL NET BOUYANCY                                                 A  233
C                                                                                        A  234
C                                                                                        A  235
      BALXS=XS                                                                           A  236
      BALXST=XF                                                                          A  237
C                                                                                        A  238
      CALL LOADIST (M,NOSEXST,BALXS,BALXST,WTBA,WTBF,CABXS,CABXST,TAILXS                 A  239
     1,TAILXST,SLIFT,WSURF,WNOSE,WCAB,WTAIL,XX,TOTL,SUSPXS,SUSPXST)                      A  240
C                                                                                        A  241
C                                                                                        A  242
C     DETERMINING THE STATIC MOMENT DISTRIBUTION                                         A  243
C                                                                                        A  244
C                                                                                        A  245
      CALL XMOM (XX,TOTL,XMOMI,XZ,M)                                                     A  246
C                                                                                        A  247
      STOP                                                                               A  248
C                                                                                        A  249
                                                                                         A  250
```

```
      7    FORMAT (10X,4HIEN=,I5)                                                    A 251
      8    FORMAT (1H1)                                                              A 252
      9    FORMAT (10X,14HTOTAL VOLUME =,F20.10)                                     A 253
     10    FORMAT (5X,13HRADIUS (FT) =,F10.5,5X,12HSTATION NO. ,5X,I6)               A 254
     11    FORMAT (5X,11HSTATION NO.,,4X,I4,10X,7HVOLUME=,F20.10,4X,5HFT**3)         A 255
     12    FORMAT (5X,14HTOTAL VOLUME =,F20.10)                                      A 256
     13    FORMAT (5X,10HLIFT(LBS)=,F10.2,5X,23HENVELOPE WEIGHT (LBS) =,F10.2        A 257
     1,5X,22HSURFACE AREA (FT**2) =,F10.2,5X,I4)                                    A 258
     14    FORMAT (5X,11HTOTAL LIFT=,F10.2,5X,19HTOTAL SURFACE AREA=,F10.2,5X        A 259
     1,10HENVELOPE WEIGHT=,F10.2)                                                   A 260
     15    FORMAT (5X,26HWEIGHT OF BALLONET (LBS) =,F10.5)                           A 261
     16    FORMAT (5X,25HCENTER OF BOUYANCY (FT) =,F10.5,5XF18HENVELOPE CG (F        A 262
     1T) =,F10.5,5X,17HAIRSHIP CG (FT) =,F10.5)                                     A 263
     17    FORMAT (5X,11HSTATION NO.,,4A,I4,10X,16HNET LIFT (LBS) =,4X,F20.10)       A 264
     18    FORMAT (5X,22HTOTAL NET LIFT (LBS) =,F10.4)                               A 265
           END                                                                       A 266
```

```
      SUBROUTINE VOLAPHX (AN,AM,AA,N,XL,F,VOL,Y)
C
C     THIS SUBROUTINE APPROXIMATES THE VOLUME OF AN AIRSHIP SHAPE BY
C     USING
C     CIRCULAR CONE SEGMENTS.
C
      DIMENSION Y(1), VOL(1)
C
C     CALCULATING THE RADIUS AT THE FRONT AND THE BACK OF THE SEGMENT
C
      X=0.0
      DO 1 I=1,N
      XJ=X+AA
      Y(I)=((XN+XM)**(XN+XM)*A**XN*(XL-XJ)**XM)/(2.0*F*XN**XN*XM**XM*XL**
     1(XN+XM-1.0))
      X=XJ
    1 CONTINUE
C
C     CALCULATION OF THE VOLUME
C
      DO 2 I=2,N
      J=I-1
      VOL(J)=0.33*3.14*AA*(Y(I)**2.0+Y(I)*Y(J)+Y(J)**2.0)
    2 CONTINUE
      RETURN
      END
```

```
* T I D Y *                                                                    PAGE  16
      SUBROUTINE COPOS (XM,XN,XCH,XECG,XCCG,XNCG,XTCG,XASCG,XL,W,WCAB,WT
      SUBROUTINE COPOS (XM,XN,XCH,XECG,XCCG,XNCG,XTCG,XASCG,XL,W,WCAB,WT
     1AIL,WNOSE,CGB,SS,DBF)
C
C
C        THIS SUBROUTINE FINDS THE POSITION OF THE CENTER
C        OF GRAVITY ( ALONG THE X AXIS ) OF THE GAS VOLUME
C        AND THE ENVELOPE. ALSO THE POSITION OF THE TOTAL CG
C        OF THE AIRSHIP IS DETERMINED.
C
C     DETERMINING THE CB AND THE ENVELOPE CG
C
      XCB=(2.0*XN+1.0)*XL/(2.0*XM+2.0*XN+2.0)
      XECG=(XN+1.0)*XL/(XN+XM+2.0)
C
C     DETERMINING THE TOTAL AIRSHIP CG
C
      WBB=SS*DBF
C
C     TAKING MOMENTS ABOUT THE CB
C
      XXXXX=(XNCG-XCB)*WNOSE+(XCCG-XCB)*WCAB+(XECG-XCB)*W+(XTCG-XCB)*WTA
     1IL+(CGB-XCB)*WBB
      YYY=W+WCAB+WTAIL+WNOSE+WBB
C
      XASCG=XXXXX/YYY+XCB
C
      RETURN
      END
```

```
C  ENVST
      SUBROUTINE ENVST (Y,VOL,M,N,SLIFT,WSURF,SURFA,SL,SA,W,SW,XX)
      SUBROUTINE ENVST (Y,VOL,M,N,SLIFT,WSURF,SURFA,SL,SA,W,SW,XX)
C
C
C        THIS SUBROUTINE CALCULATES THE LIFT , SURFACE AREA , AND THE
C        WEIGHT OF THE ENVELOPE.
C
      DIMENSION VOL(1), Y(1), SLIFT(1), WSURF(1), SURFA(1)
C
C        DEFINING THE LIFT OF HELIUM
C
      XLIFT=0.063
C
C        DEFINING THE LIFT OF EACH STATION
C
      SL=0.0
      DO 1 I=1,M
      SLIFT(I)=VOL(I)*XLIFT
      SL=SL+SLIFT(I)
    1 CONTINUE
C
C        DEFINING THE SURFACE AREA AND THE WEIGHT OF THE ENVELOPE
C
      W=0.0
      SA=0.0
      DO 2 I=1,M
      J=I+1
      AA=0.0
      IF (Y(I).LT.Y(J)) AA=Y(J)-Y(I)
      IF (Y(I).GT.Y(J)) AA=Y(I)-Y(J)
      SURFA(I)=3.14*(Y(I)+Y(J))*SQRT(XX**2.0+AA**2.0)
      SA=SA+SURFA(I)
      WSURF(I)=SW*SURFA(I)
```

```
      SUBROUTINE LAYER (Y,VOL,H,N,SLIFT,NSURF,SURFA,S[illegible]SA,W,SW,XX)
C
      WW=W*NSURF(I)
C
C2    CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE HALAPHX (AM,AN,AL,F,AO,FO,EPS,PVOL,PSA,WTBA,WTBF,VOL,SA
      SUBROUTINE HALAPHX (AM,AN,AL,F,AO,FO,EPS,PVOL,PSA,WTBA,WTBF,VOL,SA   1
     1,XS,XF,CGB,X,Z,A)                                                    2
C                                                                          3
CCCCCC                                                                     4
      THIS SUBROUTINE CALCULATES CHARACTERISTICS OF AN AIR BALLONET SUCH    5
      AS VOLUME VOL,INSIDE SURFACE AREA SA,CENTER OF GRAVITY CGB,INSIDE    6
      AIR WEIGHT WTBA,INSIDE FABRIC WEIGHT WTBF                            7
C                                                                          8
C                                                                          9
      DIMENSION X(1), Y(200), Z(1), A(1), PVOL(1), PSA(1), WTBA(1), WTBF   10
     1(1)                                                                  11
C                                                                          12
      XS=.0                                                                13
      XF=XL                                                                14
      DX=1.                                                                15
      DDX=2.                                                               16
      DO 5 K=1,20                                                          17
C     WRITE (6,7)                                                          18
CC                                                                         19
      XS=XS+DDX                                                            20
      XF=XF-DDX                                                            21
      N=XF-XS                                                              22
      DO 1 I=1,N                                                           23
      IF (I.EQ.1) X(I)=XS+1.                                               24
      IF (I.GT.1) X(I)=X(I-1)+1.                                           25
      Y(I)=((XN+XM)**(XN+XM)*X(I)**XN*(XL-X(I))**XM)/(2.**F*XN**XN*XM**XM  26
     1*XL**(XN+XM-1.))                                                     27
    1 CONTINUE                                                             28
      A(1)=.0                                                              29
      Z(1)=.0                                                              30
      M=N-1                                                                31
      DO 2 I=2,M                                                           32
      IF (Y(I).LE.Y(1)) GO TO 3                                            33
      Z(I)=2.*SQRT(Y(1)**2-Y(I)**2)                                        34
      THETA=2.*ACOS(Y(I)/Y(1))                                             35
      A(I)=.5*Y(1)**2*(2.*THETA-SIN(THETA))                                36
    2 CONTINUE                                                             37
    3 VOL=.0                                                               38
      M=I-1                                                                39
      A(I)=.0                                                              40
      Z(I)=.0                                                              41
      TWTBA=.0                                                             42
      SA=.0                                                                43
      WRITE (6,8)                                                          44
      DO 4 I=1,M                                                           45
      PVOL(I)=(A(I)+A(I+1))/2.*DX                                          46
      WTBA(I)=PVOL(I)*AO                                                   47
      PSA(I)=(Z(I)+Z(I+1))*DX                                              48
```

```
* T I D Y *
      SUBROUTINE BALAPHX (A,AN,AL,F,AD,FD,EPS,PVOL,PSA,WTRA,WTBF,VOL,SA      PAGE   24
      WTBF(I)=PSA(I)*FD                                                          51
      VOL=VOL+PVOL(I)                                                            52
      WRITE (6,9) PVOL(I),PSA(I),WTBA(I),WTBF(I)                                 53
      TWTHA=TWTHA+WTRA(I)*(X(I)+X(I+1))/2.                                       54
      SA=SA+PSA(I)                                                               55
    4 CONTINUE                                                                   56
      CGB=TWTHA/VOL/AD                                                           57
      WRITE (6,10) VOL,SA,AS,XF,CGB                                              58
      ERROR=(ABS(10000.-VOL)/VOL)                                                59
      IF (ERROR.LT.EPS) GO TO 6                                                  60
    5 CONTINUE                                                                   61
      RETURN                                                                     62
C                                                                                63
    7 FORMAT (1H1)                                                               64
    8 FORMAT (5X,'ELEMENT VOLUME ',2X,'ELEMENT AREA ',2X,'AIR WEIGHT/ELE         65
     1MENT',2X,'FABRIC WEIGHT/ELEMENT ',//)                                      66
    9 FORMAT (2X,4F15.1)                                                         67
   10 FORMAT (/5X,'TOTAL VOLUME=',F8.1,4X,'TOTAL BALLONET SURFACE AREA=         68
     1 ',F8.1,'START X=',F5.1,2X,'FINAL X=',F5.1,3X,'CENTER OF GRAVITY=        69
     2 ',F5.1//)                                                               70
      END                                                                        71
```

```
      SUBROUTINE LOADIST (N,NOSEXST,BALXS,BALXST,WTRA,WTBF,CABXS,CABXST,
     SUBROUTINE LOADIST (N,NOSEXST,BALXS,BALXST,WTRA,WTBF,CABXS,CABXST,
     1TAILAS,TAILXST,SLIFT,WSURF,WNOSE,WCAR,WTAIL,XX,TOTL,SUSPXS,SUSPXST
     2)
C
      DIMENSION TOTL(1), SLIFT(1), WSURF(1), WTRA(1), WTBF(1)
      DIMENSION K(117)
      DIMENSION XAR(5), YAR(5)
      DIMENSION TEXT(2)
      DIMENSION XPAR(5), YPAR(5)
      DIMENSION X(117)
C
      REAL NOSEXST
C
      INTEGER COUNT
C
CCCCC
CCCCC   THIS SUBROUTINE DETERMINES THE FORM OF THE FINAL DISTRIBUTED
CCCCC   LOAD OF THE AIRSHIP.
CCCCC
      TEXT(1)=10HKLEINER ,
      TEXT(2)=10HM.J.
      XPAR(1)=1.0
      XPAR(2)=16.0
      XPAR(3)=2.0
      XPAR(4)=10.0
      XPAR(5)=0.0
      YPAR(1)=1.0
      YPAR(2)=11.0
      YPAR(3)=6.0
      YPAR(4)=10.0
      YPAR(5)=1.0
      XAR(1)=-XPAR(4)
      XAR(2)=-XPAR(4)
      XAR(3)=14.0*XPAR(4)
      XAR(4)=14.0*XPAR(4)
      XAR(5)=-XPAR(4)
      YAR(1)=-5.0*YPAR(4)
      YAR(2)=4.0*YPAR(4)
      YAR(3)=4.0*YPAR(4)
      YAR(4)=-5.0*YPAR(4)
      YAR(5)=-5.0*YPAR(4)
      KOUE=0
      COUNT=14
CCCCC
CCCCC DISTRIBUTING THE KNOWN LOADS
CCCCC
C     NOSE LOAD
```

```
C
C
      DWN=WNOSE/NOSEXST
C
C
C     CABIN LOAD
C     DISTRIBUTED  60 PER CENT ON THE SUSPENSION AND
C                40 PER CENT ON THE CABIN FAIRING
C
C
      DWC=0.4*WCAB/(CABXST-CABXS)
C
      DWS=0.6*WCAB/(SUSPXST-SUSPXS)
C
C
C     TAIL LOAD
C
C
      DWT=WTAIL/(TAILXST-TAILXS)
C
C
C     THE DISTRIBUTION OF THE BOUYANCY IS KNOWN FROM PREVIOUS
C     SUBROUTINES.
C     ALSO KNOWN IS THE ENVELOPE WEIGHT DISTRIBUTION AND THE
C     DISTRIBUTION
C     DUE TO THE BALLONETTS.
C
C
C     FINAL LIFT DISTRIBUTION
C
C
      WRITE (6,15)
C
C
      XXX=1.0
C
      L=1
C
      DO 14 I=1,M
C
      X(I)=XXX
C
      YY=SLIFT(I)-WSURF(I)
C
      IF (XXX.LE.NOSEXST.AND.XXX.LT.BALXS.AND.XXX.LT.SUSPXS) GO TO 1
C
      IF (XXX.LE.NOSEXST.AND.XXX.LT.BALXST.AND.XXX.LT.SUSPXS) GO TO 2
C
      IF (XXX.LE.NOSEXST.AND.XXX.LE.BALXST.AND.XXX.LE.SUSPXST) GO TO 3
C
```

```
      SUBROUTINE LOADIST (M,NOSEXST,BALXS,BALXST,WTBA,WTBF,CABXS,CABXST,
C     IF (XXX.GT.NOSEXST.AND.XXX.LE.BALXST.AND.XXX.LT.SUSPXS) GO TO 4
C     IF (XXX.GT.BALXS.AND.XXX.GT.SUSPXS.AND.XXX.LT.CABXS) GO TO 5
C     IF (XXX.GT.BALXS.AND.XXX.GT.SUSPXS.AND.XXX.LE.CABXST) GO TO 6
C     IF (XXX.GT.BALXS.AND.XXX.GT.SUSPXS.AND.XXX.GT.CABXST.AND.XXX.LT.TA
     1ILXS) GO TO 7
C     IF (XXX.LE.SUSPXST.AND.XXX.GE.TAILXS.AND.XXX.LE.BALXST) GO TO 12
C     IF (XXX.LE.BALXST.AND.XXX.GT.TAILXS) GO TO 9
C     IF (XXX.GT.BALXS.AND.XXX.GT.SUSPXST.AND.XXX.GT.CABXST.AND.XXX.LT.T
     1AILXS) GO TO 8
C     IF (XXX.GT.TAILXS.AND.XXX.LE.TAILXST) GO TO 10
C     IF (XXX.GT.TAILXST) GO TO 11
C
C1    TOTL(I)=YY-DWN
      K(I)=2
      GO TO 13
C
C2    TOTL(I)=YY-DWN-WTBA(L)-WTBF(L)
      L=L+1
      K(I)=3
      GO TO 13
C
C3    TOTL(I)=YY-DWN-WTBA(L)-WTBF(L)-DWS
      L=L+1
      K(I)=4
      GO TO 13
C
C4    TOTL(I)=YY-WTBA(L)-WTBF(L)
      L=L+1
      K(I)=5
      GO TO 13
C
C5    TOTL(I)=YY-WTBA(L)-WTBF(L)-DWS
      L=L+1
      K(I)=6
      GO TO 13
C
C6    TOTL(I)=YY-WTBA(L)-WTBF(L)-DWS-DWC
      L=L+1
      K(I)=7
      GO TO 13
C
```

```
      SUBROUTINE LOADINT (MSNOSLAST,BALAS,BALAST,WTBA,WTBF,CABAS,CABAST,
    7 TOTL(I)=YY-WTBA(L)-WTBF(L)-DWS                                        F  151
      L=L+1                                                                 F  152
      K(I)=8                                                                F  153
      GO TO 13                                                              F  154
C                                                                           F  155
    8 TOTL(I)=YY-WTBA(L)-WTBF(L)                                            F  156
      L=L+1                                                                 F  157
      K(I)=13                                                               F  158
      GO TO 13                                                              F  159
C                                                                           F  160
    9 TOTL(I)=YY-WTBA(L)-WTBF(L)-DWT                                        F  161
      L=L+1                                                                 F  162
      K(I)=10                                                               F  163
      GO TO 13                                                              F  164
C                                                                           F  165
   10 TOTL(I)=YY-DWT                                                        F  166
      K(I)=1                                                                F  167
      GO TO 13                                                              F  168
C                                                                           F  169
   11 TOTL(I)=YY                                                            F  170
      K(I)=12                                                               F  171
      GO TO 13                                                              F  172
C                                                                           F  173
   12 TOTL(I)=YY-DWT-WTBF(L)-WTBA(L)-DWS                                    F  174
      L=L+1                                                                 F  175
      K(I)=16                                                               F  176
      GO TO 13                                                              F  177
C                                                                           F  178
   13 XXX=XXX+XX                                                            F  179
C                                                                           F  180
      WRITE (6,16) I,TOTL(I),K(I)                                           F  181
C                                                                           F  182
CC                                                                          F  183
   14 CONTINUE                                                              F  184
C                                                                           F  185
      CALL NAME (TEXT,COUNT)                                                F  186
      COUNT=5                                                               F  187
      CALL LINE (XAR,YAR,COUNT,XPAR,YPAR,KODE)                              F  188
      COUNT=117                                                             F  189
      CALL FREE (X,TOTL,COUNT,XPAR,YPAR,KODE)                               F  190
      CALL PAPAD                                                            F  191
C                                                                           F  192
      RETURN                                                                F  193
C                                                                           F  194
   15 FORMAT (1H1)                                                          F  195
   16 FORMAT (5X,11HSTATION NO.,I10,16HTOTAL NET LIFT =,F20.5,I10)          F  196
      END                                                                   F  197
```

```
      SUBROUTINE XMOM (XX,TOTL,XMOMT,XZ,M)
C
C     A SUBROUTINE TO CALCULATE THE MOMENTS OF A DISTRIBUTED LOAD
C
      DIMENSION TOTL(1), XMOMT(1), XZ(1)
      DIMENSION XAR(5), YAR(5)
      DIMENSION TEXT(2)
      DIMENSION XPAR(5), YPAR(5)
      DIMENSION X(117)
C
      INTEGER COUNT
C
C     THIS SUBROUTINE WILL NOT WORK UNLESS THERE ARE MORE THAN
C     THREE FUNCTION VALUES TO INTEGRATE
C
      TEXT(1)=10HKLEINER
      TEXT(2)=10HH.J.
      XPAR(1)=1.0
      XPAR(2)=16.0
      XPAR(3)=2.0
      XPAR(4)=10.0
      XPAR(5)=0.0
      YPAR(1)=1.0
      YPAR(2)=11.0
      YPAR(3)=6.0
      YPAR(4)=4000.0
      YPAR(5)=1.0
      XAR(1)=-XPAR(4)
      XAR(2)=-XPAR(4)
      XAR(3)=14.0*XPAR(4)
      XAR(4)=14.0*XPAR(4)
      XAR(5)=-XPAR(4)
      YAR(1)=-5.0*YPAR(4)
      YAR(2)=4.0*YPAR(4)
      YAR(3)=4.0*YPAR(4)
      YAR(4)=-5.0*YPAR(4)
      YAR(5)=-5.0*YPAR(4)
      KODE=0
      COUNT=14
C
      NCIM=M
C
      CALL QSF (XX,TOTL,XZ,NCIM)
C
      CALL QSF (XX,XZ,XMOMT,NCIM).
C
```

```
      WRITE (6,2)
C     DO 1 I=1,NCIM
C     X(I)=I
C     WRITE (6,3) I,XMOMT(I)
C1    CONTINUE
CC
      CALL NAME (TEXT,COUNT)
      COUNT=5
      CALL LINE (XAR,YAR,COUNT,XPAR,YPAR,KODE)
      COUNT=117
      CALL FREE (X,XMOMT,COUNT,XPAR,YPAR,KODE)
      CALL PAPAD
C     RETURN
C2    FORMAT (1H1)
3     FORMAT (5X,11HSTATION NO.,I10,17HMOMENT (FT-LBS) =,F20.5)
      END
```

APPENDIX E

PROGRAMME FOR AIRSHIP TRAJECTORIES

```
* T I O Y *
                PROGRAM IST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                PAGE  1
      PROGRAM IST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                          A    1
C                                                                                 A    2
C                                                                                 A    3
C     ****************************************************************            A    4
C     *                                                              *            A    5
C     *  A PROGRAM TO DETERMINE THE FORCES ACTING ON AN AIR-         *            A    6
C     *  SHIP DURING SPECIFIC MANEUVERS. THESE MANEUVERS ARE         *            A    7
C     *  SPECIFIED MAINLY BY THE MINISTRY OF TRANSPORT ,             *            A    8
C     *  PROVISIONAL AIRWORTHINESS REQUIREMENTS SC J(A) THROUGH      *            A    9
C     *  SC 4(E). THE MANEUVERS PERFORMED ARE                        *            A   10
C     *  (1) TAKE OFF AND CLIMB OVER A 50 FOOT OBSTACLE              *            A   11
C     *  (2) FULL RUDDER UNTIL A 75 DEGREE TURN HAS BEEN MADE        *            A   12
C     *  (3) FULL OPPOSITE RUDDER UNTIL THE ORIGINAL HEADING IS      *            A   13
C     *      ONCE AGAIN ATTAINED                                     *            A   14
C     *  (4) STEADY STATE TURN FROM 0-180 DEGREES                    *            A   15
C     *  (5) FULL UP ELEVATORS AND FULL RUDDER UNTIL A 75 DEGREE     *            A   16
C     *      TURN HAS BEEN MADE                                      *            A   17
C     *  (6) FULL UP ELEVATORS AND FULL OPPOSITE RUDDER UNTIL BACK   *            A   18
C     *      ON THE ORIGINAL HEADING                                 *            A   19
C     *  (7) FULL DOWN ELEVATORS AND FULL RUDDER  UNTIL A 75 DEGREE  *            A   20
C     *      TURN HAS BEEN MADE                                      *            A   21
C     *  (8) FULL DOWN ELEVATORS AND FULL OPPOSITE RUDDER UNTIL      *            A   22
C     *      BACK ON THE ORIGINAL HEADING                            *            A   23
C     *  (9) FULL UP ELEVATORS AND A STEADY STATE TURN FROM          *            A   24
C     *      0-180 DEGREES                                           *            A   25
C     *  (10) FULL DOWN ELEVATORS AND A STEADY STATE TURN            *            A   26
C     *       FROM 0-180 DEGREES                                     *            A   27
C     *  (11) FULL DOWN ELEVATORS UNTIL THE MAXIMUM DESCENT RATE     *            A   28
C     *       HAS BEEN ACHIEVED                                      *            A   29
C     *  (12) FULL UP ELEVATORS UNTIL THE DESCENT RATE IS ZERO       *            A   30
C     *  (13) FULL UP ELEVATORS UNTIL THE MAXIMUM CLIMB RATE OCCURS  *            A   31
C     *       DURING A STEADY STATE TURN                             *            A   32
C     *  (14) FULL DOWN ELEVATORS UNTIL THE CLIMB RATE IS ZERO       *            A   33
C     *       DURING A STEADY STATE TURN                             *            A   34
C     *                                                              *            A   35
C     ****************************************************************            A   36
C                                                                                 A   37
C     INPUT VARIABLES                                                             A   38
C     USER SUPPLIED                                                               A   39
C                                                                                 A   40
C                                                                                 A   41
C     SHAPE VARIABLES                                                             A   42
C                                                                                 A   43
C                                                                                 A   44
C     XN AIRSHIP SHAPE PARAMETER                                                  A   45
C     XM AIRSHIP SHAPE PARAMETER                                                  A   46
C     XL AIRSHIP LENGTH  FT.                                                      A   47
C     F  AIRSHIP FINENESS RATIO                                                   A   48
C     VOL THE LIFTING GAS VOLUME OF THE AIRSHIP                                   A   49
C                                                                                 A   50
```

```
C     VOLT THE TOTAL ENVELOPE VOLUME OF THE AIRSHIP  FT**3
C
C     LOCATION VARIABLES
C
C       XCAB THE CABIN CG LOCATION ALONG THE X AXIS
C       YCAB THE CABIN CG LOCATION ALONG THE Y AXIS
C       ZCAB THE CABIN CG LOCATION ALONG THE Z AXIS
C       XT THE LOCATION OF THE TAIL CG ALONG THE X AXIS
C       YT THE LOCATION OF THE TAIL CG ALONG THE Y AXIS
C       ZT THE LOCATION OF THE TAIL CG ALONG THE Z AXIS
C       XN THE LOCATION OF THE NOSE CONE CG ALONG THE X AXIS
C       YN THE LOCATION OF THE NOSE CONE CG ALONG THE Y AXIS
C       ZN THE LOCATION OF THE NOSE CONE CG ALONG THE Z AXIS
C       XE THE ENGINE CG LOCATION ALONG THE X AXIS
C       YE THE ENGINE CG LOCATION ALONG THE Y AXIS
C       ZE THE ENGINE CG LOCATION ALONG THE Z AXIS
C
C     WEIGHT VARIABLES
C
C       WCAB THE CABIN WEIGHT OF THE AIRSHIP
C       WT THE TAIL WEIGHT OF THE AIRSHIP
C       WN THE WEIGHT OF THE AIRSHIP NOSE REINFORCEMENT
C       EW THE ENGINE WEIGHT
C       WE THE AIRSHIP ENVELOPE WEIGHT
C       WX WEIGHT OF THE ENVELOPE MATERIAL   OZS./YD.**2
C       TOW THE AIRSHIP TOTAL WEIGHT DURING THE MANEUVERS
C
C     TAIL CHARACTERISTICS
C
C       CHH  AVERAGE HORIZONTAL CHORD LENGTH
C       TL   TAIL SURFACE (I) SPAN
C       CHV  AVERAGE VERTICAL CHORD LENGTH
C       RL   RUDDER (I) SPAN
C       DH   MAXIMUM THICKNESS OF THE AIRFOIL
C
C     AIRFOIL COEFFICIENT DATA
C
C       CLD FLAP DEFLECTED LIFT COEFFICIENT
C       CL  LIFT COEFFICIENT
C       CD  DRAG COEFFICIENT
C       AL  ANGLE FOR CL
C       AD  ANGLE FOR CD
C       ALD ANGLE FOR CLD
C
C     CLIMB AND DESCENT CHARACTERISTICS
C
C       YMDR  MAXIMUM DESCENT RATE  FT/SEC
C       YMC   MAXIMUM CLIMB RATE  FT/SEC
C
C     OPTIONAL USER SUPPLIED VARIABLES
```

```
C
C     MASS MOMENTS OF INERTIA
C
C       XXIN  THE MASS MOMENT OF INERTIA OF THE TAIL  X DIRECTION
C       YYIN  THE MASS MOMENT OF INERTIA OF THE TAIL  Y DIRECTION
C       ZZIN  THE MASS MOMENT OF INERTIA OF THE TAIL  Z DIRECTION
C       XXIC  THE MASS MOMENT OF INERTIA OF THE CABIN  X DIRECTION
C       YYIC  THE MASS MOMENT OF INERTIA OF THE CABIN  Y DIRECTION
C       ZZIC  THE MASS MOMENT OF INERTIA OF THE CABIN  Z DIRECTION
C       XXITA  THE MASS MOMENT OF INERTIA OF THE TAIL SURFACES X DIRECTION
C       YYITA  THE MASS MOMENT OF INERTIA OF THE TAIL SURFACES Y DIRECTION
C       ZZITA  THE MASS MOMENT OF INERTIA OF THE TAIL SURFACES Z DIRECTION
C       XXIE  THE MASS MOMENT OF INERTIA OF THE ENGINES  X DIRECTION
C       YYIE  THE MASS MOMENT OF INERTIA OF THE ENGINES  Y DIRECTION
C       ZZIE  THE MASS MOMENT OF INERTIA OF THE ENGINES  Z DIRECTION
C
C     INTERNALLY GENERATED ANGLES
C
C     INPUT ANGLES
C
C       PHI  INITIAL ANGLE BETWEEN THE Z AND THE X AXES
C       THETA  INITIAL ANGLE OF ATTACK
C       ALPHA  INITIAL ANGLE OF MOTION REFERENCED TO THE X-Z PLANE
C       YAW  INITIAL ANGLE OF MOTION REFERENCED TO THE X-Y PLANE
C
      DIMENSION CL(10), CD(9), AL(10), AD(9)
      DIMENSION XK(12), XK2(12), DXK(12), XKP(12), FR(12)
      DIMENSION ZT(2), ZE(2)
      DIMENSION CLD(13), ALD(13)
      DIMENSION Y2(117)
      COMMON /AV/ YMDR,YMC
C
C     INPUT DATA
C
C     SHAPE DATA
C
      DATA XN,XM,XL,F/0.4,0.6,117.0,3.00/
      DATA VOL,VOLT/80887.0,91000.0/
C
C     WEIGHT DATA
C
```

```
* T I D Y *
      PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                MAIN  17
      DATA WCAB,WT,WN,WW,WE/3274.0,500.0,200.0,400.0,922.0/                  A  151
      DATA TOW/5400.0/                                                       A  152
      DATA WX/11.40/                                                         A  153
C                                                                            A  154
C     DIMENSION DATA                                                         A  155
C                                                                            A  156
      DATA XCAB,XT,XF,XE/48.8,93.0,5.0,52.6/                                 A  157
      DATA YCAB,YT,YN,YE/-25.0,0.0,0.0,-25.0/                                A  158
      DATA ZCAB,ZT(1),ZT(2),ZN,ZE(1),ZE(2)/0.0,25.0,-25.0,0.0,20.0,-20.0     A  159
     1/                                                                      A  160
C                                                                            A  161
C     MASS MOMENT OF INERTIA DATA                                            A  162
C                                                                            A  163
      DATA XXIN,XXIC,XXITA,XXIE/0.0,0.0,0.0,0.0/                             A  164
      DATA YYIN,YYIC,YYITA,YYIE/0.0,0.0,0.0,0.0/                             A  165
      DATA ZZIN,ZZIC,ZZITA,ZZIE/0.0,0.0,0.0,0.0/                             A  166
C                                                                            A  167
C     INITIALIZATION DATA                                                    A  168
C                                                                            A  169
      DATA XINT,YINT,ZINT,TINT,VFINT,VYINT,VZINT/0.0,0.0,0.0,0.0,0.0,0.0,0.0 A  170
     1,0.0/                                                                  A  171
      DATA ANGV/0.0/                                                         A  172
C                                                                            A  173
C     CONSTANTS                                                              A  174
C                                                                            A  175
      DATA G,DELT/32.174,0.1/                                                A  176
C                                                                            A  177
C     ENGINE THRUST DATA                                                     A  178
C                                                                            A  179
      DATA POW/850.0/                                                        A  180
C                                                                            A  181
C     TAIL DATA                                                              A  182
C                                                                            A  183
      DATA CHH,CHV,TL,DH,RL/17.2,12.0,14.0,2.0,15.0/                         A  184
C                                                                            A  185
C     INITIAL ANGLE DATA                                                     A  186
C                                                                            A  187
```

```
* T I D Y *          PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)          PAGE  30
C
      DATA PHI,THETA,ALPHA/0.0,0.0,0.0/                                          A 201
      DATA YAW/0.0/                                                              A 202
C                                                                                A 203
C     CLIMB AND DESCENT DATA                                                     A 204
C                                                                                A 205
      DATA YMDR,YMC/40.0,40.0/                                                   A 206
C                                                                                A 207
C     COEFFICIENT DATA                                                           A 208
C                                                                                A 209
      DATA XK1/0.500,0.305,0.209,0.156,0.122,0.082,0.059,0.045,0.036,0.0         A 210
     129,0.024,0.021/                                                            A 211
      DATA XK2/0.500,0.621,0.702,0.763,0.803,0.860,0.895,0.918,0.933,0.9         A 212
     145,0.954,0.960/                                                            A 213
      DATA DXK/0.000,0.316,0.493,0.607,0.681,0.778,0.836,0.873,0.897,0.9         A 214
     116,0.930,0.939/                                                            A 215
      DATA XKP/0.000,0.094,0.240,0.367,0.465,0.608,0.701,0.764,0.805,0.8         A 216
     140,0.865,0.883/                                                            A 217
      DATA FR/1.00,1.50,2.00,2.51,2.99,3.99,4.99,6.01,6.97,8.01,9.02,9.9         A 218
     17/                                                                         A 219
C                                                                                A 220
      DATA CL/0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/                           A 221
      DATA CD/0.0092,0.0095,0.010,0.0119,0.012,0.013,0.0145,0.0166,0.020         A 222
     1/                                                                          A 223
      DATA CLD/-0.4,0.0,0.25,0.48,0.70,0.95,1.15,1.35,1.55,1.75,1.95,2.1         A 224
     10,1.98/                                                                    A 225
      DATA ALD/-14.0,-12.0,-10.0,-8.0,-6.0,-4.0,-2.0,0.0,2.0,4.0,6.0,8.0        A 226
     1,10.0/                                                                     A 227
      DATA AL/1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0/                          A 228
      DATA AD/1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0/                               A 229
C                                                                                A 230
C     CALCULATION OF THE RADIUS AT ONE FOOT INTERVALS                            A 231
C                                                                                A 232
      XA=0.0                                                                     A 233
C                                                                                A 234
      DO 1 II=1,117                                                              A 235
C                                                                                A 236
      XA=XA+1.0                                                                  A 237
C                                                                                A 238
      SR=((XN+XM)**(XN+XM)*XA**XN*(XL-XA)**XM)/(2.0*F*XN**XN*XM**XM*XL**         A 239
     1(XN+XM-1.0))                                                               A 240
C                                                                                A 241
      Y2(II)=SR                                                                  A 242
```

```
C     CONTINUE                                                          A 251
                                                                        A 252
C     CALCULATION OF GAS MASS                                           A 253
                                                                        A 254
      WGM=0.000177*2.2/0.03532                                          A 255
C     GASM=WGM*VOL                                                      A 256
                                                                        A 257
C     POINT OF APPLICATION                                              A 258
                                                                        A 259
      XG=(2.0*XN+1.0)*XL/(2.0*XN+2.0*XM+2.0)                            A 260
      YG=0.0                                                            A 261
      ZG=0.0                                                            A 262
                                                                        A 263
C     CENTER OF PRESSURE LOCATION                                       A 264
                                                                        A 265
      XCP=XL*0.25                                                       A 266
      YCP=0.0                                                           A 267
      ZCP=0.0                                                           A 268
C     XP=XCP                                                            A 269
                                                                        A 270
C     COUNTER                                                           A 271
                                                                        A 272
      IST=0                                                             A 273
      IJ=0                                                              A 274
      I=1                                                               A 275
      K=0                                                               A 276
      KOUNT=0                                                           A 277
      IZ=0                                                              A 278
                                                                        A 279
C     CALCULATION OF THE CENTER OF BOUYANCY                             A 280
                                                                        A 281
      XCB=((2.0*XN+1.0)/(2.0*XN+2.0*XM+2.0))*XL                         A 282
      YCB=0.0                                                           A 283
      ZCB=0.0                                                           A 284
C                                                                       A 285
C     CALCULATION OF THE ENVELOPE CG.                                   A 286
```

```
C                                                                       A 301
C                                                                       A 302
      XCGE=((XN+1.0)/(XN+XM+2.0))*XL                                    A 303
      YCGE=0.0                                                          A 304
      ZCGE=0.0                                                          A 305
C                                                                       A 306
CCCCC                                                                   A 307
CCCCC CALCULATION OF THE MASS MOMENT OF INERTIA OF THE ENVELOPE         A 308
CCCCC AND THE MASS MOMENT OF INERTIA OF THE ENCLOSED GAS                A 309
CCCCC                                                                   A 310
C                                                                       A 311
      W=WX/(9.0*16.0*32.174)                                            A 312
C                                                                       A 313
      AA=(3.0*XN+1.0)                                                   A 314
      BB=(3.0*XM+1.0)                                                   A 315
      CC=(3.0*XN+3.0*XM+2.0)                                            A 316
      DD=(XN+3.0)                                                       A 317
      EE=(XM+1.0)                                                       A 318
      FF=(XN+XM+4.0)                                                    A 319
      GG=(4.0*XN+1.0)                                                   A 320
      HH=(4.0*XM+1.0)                                                   A 321
      OO=(4.0*XN+4.0*XM+2.0)                                            A 322
      PP=(2.0*XN+3.0)                                                   A 323
      QQ=(2.0*XM+1.0)                                                   A 324
      RR=(2.0*XN+2.0*XM+4.0)                                            A 325
C                                                                       A 326
      CALL GAMMA (AA,AB,IER)                                            A 327
      WRITE (6,91) IER                                                  A 328
      CALL GAMMA (BB,BA,IER)                                            A 329
      WRITE (6,91) IER                                                  A 330
      CALL GAMMA (CC,CA,IER)                                            A 331
      WRITE (6,91) IER                                                  A 332
      CALL GAMMA (DD,DA,IER)                                            A 333
      WRITE (6,91) IER                                                  A 334
      CALL GAMMA (EE,EA,IER)                                            A 335
      WRITE (6,91) IER                                                  A 336
      CALL GAMMA (FF,FA,IER)                                            A 337
      WRITE (6,91) IER                                                  A 338
      CALL GAMMA (GG,GA,IER)                                            A 339
      WRITE (6,91) IER                                                  A 340
      CALL GAMMA (HH,HA,IER)                                            A 341
      WRITE (6,91) IER                                                  A 342
      CALL GAMMA (OO,OA,IER)                                            A 343
      WRITE (6,91) IER                                                  A 344
      CALL GAMMA (PP,PA,IER)                                            A 345
      WRITE (6,91) IER                                                  A 346
      CALL GAMMA (QQ,QA,IER)                                            A 347
      WRITE (6,91) IER                                                  A 348
      CALL GAMMA (RR,RA,IER)                                            A 349
      WRITE (6,91) IER                                                  A 350
```

```
C
C     X-AXIS
C
      XXI=((3.14*W*(XN*XM)**(3.0*(XN*XM)))/(4.0*F**3.0*AN**(3.0*XN)*XM**
     1(3.0*XM)))*(AB*BA/CA)*XL**4.0
C     XXIG=3.14*WGM*(XN*XM)**(4.0*(XN*XM))/(32.0*F**4*XN**(4.0*XN)*XM**(
     14.0*XM))*(GA*HA/DA)*XL**5
C
C     Y-AXIS
C
      YYI=XXI/2.0*((3.14*W*(XN*XM)**(XN*XM))/(F*XN**XN*XM**XM))*(DA*EA/F
     1A)*XL**4.0
C     YYIG=XXIG*3.14*WGM*(XN*XM)**(2.0*(XN*XM))/(4.0*F**2*XN**(2.0*XN)*X
     1M**(2.0*XM))*(PA*QA/RA)*XL**5
C
C     Z-AXIS
C
      ZZI=YYI
C     ZZIG=YYIG
C
C     CALCULATION OF THE BOUYANCY FORCE
C
      BFX=0.0
      BFY=0.063*VOL
      BFZ=0.0
C
C     CALCULATION OF CG
C
C     TAKING MOMENTS ABOUT CENTER OF BOUYANCY
C
C     X DIRECTION
C
      XX=(XF-XCB)*WN*(XCAB-XCB)*WCAB*(XT-XCB)*WT*(XE-XCB)*EW*(XCGE-XCB)*
     1WE
C
```

A 351 A 352 A 353 A 354 A 355 A 356 A 357 A 358 A 359 A 360 A 361 A 362 A 363 A 364 A 365 A 366 A 367 A 368 A 369 A 370 A 371 A 372 A 373 A 374 A 375 A 376 A 377 A 378 A 379 A 380 A 381 A 382 A 383 A 384 A 385 A 386 A 387 A 388 A 389 A 390 A 391 A 392 A 393 A 394 A 395 A 396 A 397 A 398 A 399 A 400

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* T I D Y *      PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      XXX=WN+WCAB+WT+WE+EW                                                A 401
      XCG=XX/XXX+XCB                                                      A 402
C                                                                         A 403
C     Y DIRECTION                                                         A 404
C                                                                         A 405
      YY=(YN-YCB)*WN+(YCAB-YCB)*WCAB+(YT-YCB)*WT+(YE-YCB)*EW+(YCGE-YCB)*  A 406
     1WE                                                                  A 407
      YYY=WN+WCAB+WT+EW+WE                                                A 408
C                                                                         A 409
      YCG=YY/YYY                                                          A 410
C                                                                         A 411
C     Z DIRECTION                                                         A 412
C                                                                         A 413
      ZZ=(ZN-ZCB)*WN+(ZCAB-ZCB)*WCAB+(ZT(1)-ZCB)*WT/2.0+(ZT(2)-ZCB)*WT/2 A 414
     1.0+(ZE(1)-ZCB)*EW/2.0+(ZE(2)-ZCB)*EW/2.0+(ZCGE-ZCB)*WE              A 415
      ZZZ=YYY                                                             A 416
C                                                                         A 417
      ZCG=ZZ/ZZZ                                                          A 418
C                                                                         A 419
C     CALCULATION OF THE TOTAL MASS MOMENT OF INERTIA ABOUT THE CG        A 420
C                                                                         A 421
C     NOSE COMPONENT                                                      A 422
C                                                                         A 423
      XXIPN=XXIN+WN/G*((YN-YCB)**2+(ZN-ZCB)**2)                           A 424
      YYIPN=YYIN+WN/G*((ZN-ZCB)**2+(XF-XCB)**2)                           A 425
      ZZIPN=ZZIN+WN/G*((YN-YCB)**2+(XF-XCB)**2)                           A 426
C                                                                         A 427
C     CABIN COMPONENT                                                     A 428
C                                                                         A 429
      XXIPC=XXIC+WCAB/G*((YCAB-YCB)**2+(ZCAB-ZCB)**2)                     A 430
      YYIPC=YYIC+((ZCAB-ZCB)**2+(XCAB-XCB)**2)*WCAB/G                     A 431
      ZZIPC=ZZIC+((XCAB-XCB)**2+(YCAB-YCB)**2)*WCAB/G                     A 432
C                                                                         A 433
C     TAIL ASSEMBLY COMPONENT                                             A 434
C                                                                         A 435
      XXIPT=XXITA+(YT-YCB)**2+(ZT(1)-ZCB)**2)*WT/G                        A 436
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      YYIPT=YYITA*WT/G*((ZT(1)-ZCB)**2+(XT-XCB)**2)                     A 451
      ZZIPT=ZZITA*WT/G*((XT-XCB)**2+(YT-YCB)**2)                        A 452
C                                                                       A 453
C     ENGINE COMPONENT                                                  A 454
C                                                                       A 455
C                                                                       A 456
C                                                                       A 457
      XXIPE=XXIE*EW/(G)*((YE-YCB)**2+(ZE(1)-ZCB)**2)                    A 458
      YYIPE=YYIE*EW/(G)*((ZE(1)-ZCB)**2+(XE-XCB)**2)                    A 459
      ZZIPE=ZZIE*EW/(G)*((XE-XCB)**2+(YE-YCB)**2)                       A 460
C                                                                       A 461
C                                                                       A 462
      XXIT=XXIPN+XXIPT+XXIPC+XXIPE+XXI+WE/G*(YCB**2+ZCB**2)+XXIG+WGM/G*( A 463
     1YCB**2+ZCB**2)                                                    A 464
      YYIT=YYIPN+YYIPT+YYIPC+YYIPE+YYI+WE/G*(XCB**2+ZCB**2)+YYIG+WGM/G*( A 465
     1XCB**2+ZCB**2)                                                    A 466
      ZZIT=ZZIPN+ZZIPT+ZZIPC+ZZIPE+ZZI+WE/G*(XCB**2+YCB**2)+ZZIG+WGM/G*( A 467
     1YCB**2+XCB**2)                                                    A 468
C                                                                       A 469
C                                                                       A 470
C     DETERMINATION OF TAKE-OFF MASS                                    A 471
C                                                                       A 472
C                                                                       A 473
      TM=TOW/G                                                          A 474
C     IF (K.GT.0) GO TO 2                                               A 475
C                                                                       A 476
C                                                                       A 477
C     SMOOTH APPLICATION OF POWER FOR TAKE OFF                          A 478
C                                                                       A 479
C                                                                       A 480
      J=20                                                              A 481
C     IF (I.EQ.1) POX=POW/20                                            A 482
C                                                                       A 483
C                                                                       A 484
C     ACCELERATION IN THE F DIRECTION DUE TO THE SUDDEN APPLICATION OF  A 485
C     POWER                                                             A 486
C                                                                       A 487
C                                                                       A 488
C                                                                       A 489
      ACCF=-POX/TM                                                      A 490
C                                                                       A 491
C                                                                       A 492
C     SIMILARLY IN THE Y DIRECTION                                      A 493
C                                                                       A 494
C                                                                       A 495
C                                                                       A 496
      ACCY=-(TOW-BFY)/TM                                                A 497
C                                                                       A 498
C     CALCULATION OF THE FIRST POINT OF THE TRAJECTORY                  A 499
C                                                                       A 500
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C                                                                       A  501
C                                                                       A  502
C     DEFINING THE ANGLE IN RADIANS                                     A  503
C                                                                       A  504
C                                                                       A  505
      THETAR=THETA*3.14/180.0                                           A  506
      ALPHAR=ALPHA*.14/180.0                                            A  507
      PHIR=PHI*3.14/180.0                                               A  508
      YAWR=YAW*3.14/180.0                                               A  509
C                                                                       A  510
      DELTAY=0.0                                                        A  511
      Z=0.0                                                             A  512
C                                                                       A  513
C     CONTINUE                                                          A  514
C                                                                       A  515
      BETAR=0.0                                                         A  516
C                                                                       A  517
      ROE=0.002378                                                      A  518
C                                                                       A  519
      IF (K.GT.0) GO TO 3                                               A  520
C                                                                       A  521
      T=TINT+DELT                                                       A  522
C                                                                       A  523
      VF=VFINT+ACCF*DELT                                                A  524
      VY=VYINT+ACCY*DELT                                                A  525
C                                                                       A  526
      IF (ACCY.LT.0.0) VY=VYINT                                         A  527
C                                                                       A  528
      VX=VF*COS(PHIR)                                                   A  529
      VZ=VF*SIN(PHIR)                                                   A  530
      VD=VF                                                             A  531
C                                                                       A  532
      ACCX=ACCF*COS(PHIR)                                               A  533
      ACCZ=ACCF*SIN(PHIR)                                               A  534
C                                                                       A  535
      X=XINT+ACCX*DELT**2/2.0                                           A  536
      Y=YINT+ACCY*DELT**2/2.0                                           A  537
C                                                                       A  538
      IF (ACCY.LT.0.0) Y=YINT                                           A  539
C                                                                       A  540
      X1=X                                                              A  541
      Y1=Y                                                              A  542
      Z1=Z                                                              A  543
C                                                                       A  544
C     CONTINUE                                                          A  545
C                                                                       A  546
C     CONTINUE                                                          A  547
C                                                                       A  548
C     DEFINING COEFFICIENTS REQUIRED TO CALCULATE THE UNBALANCED MOMENT A  549
C                                                                       A  550
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* T I D Y *    PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                    PAGE  45
C
C     DELTA K                                                                    A  551
C                                                                                A  552
      XFR=SQRT(3.14/6.0*XL**3/VOLT)                                              A  553
      DYK=FTABLE(FR,DXK,XFR,12)                                                  A  554
C                                                                                A  555
C     K PRIME                                                                    A  556
C                                                                                A  557
      XK=FTABLE(FR,XKP,XFR,12)                                                   A  558
C                                                                                A  559
C     TAIL LIFT COEFFICIENT                                                      A  560
C                                                                                A  561
      ABSTA=ABS(THETA)*2.0                                                       A  562
      ABSTY=YAW*2.0                                                              A  563
      CLT1=FTABLE(AL,CL,ABSTY,10)                                                A  564
      CLT=FTABLE(AL,CL,ABSTA,10)                                                 A  565
C     IF (ABSTA.GT.10.0) CLT=0.0                                                 A  566
      IF (BETAR.GT.10.0) CLT=0.0                                                 A  567
      IF (THETA.LT.0.0) CLT=-CLT                                                 A  568
C                                                                                A  569
C     TAIL DRAG COEFFICIENT                                                      A  570
C                                                                                A  571
      IF (THETA.EQ.0.0) GO TO 5                                                  A  572
      CDT=FTABLE(AD,CD,ABSTA,9)                                                  A  573
      GO TO 6                                                                    A  574
    5 CDT=0.0                                                                    A  575
    6 CONTINUE                                                                   A  576
      ABY=ABS(YAW)*2.0                                                           A  577
      IF (YAW.EQ.0.0) GO TO 7                                                    A  578
      CDT1=FTABLE(AD,CD,ABY,9)                                                   A  579
                                                                                 A  580
                                                                                 A  581
                                                                                 A  582
                                                                                 A  583
                                                                                 A  584
                                                                                 A  585
                                                                                 A  586
                                                                                 A  587
                                                                                 A  588
                                                                                 A  589
                                                                                 A  590
                                                                                 A  591
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                                                                                 A  593
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                                                                                 A  597
                                                                                 A  598
                                                                                 A  599
                                                                                 A  600
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C
      GO TO 8
C
    7 CDT1=0.0
    8 CONTINUE
CCCCC
CCCCC DEFINING DRAG AND LIFT AREAS
CCCCC
      AVCL=CHH*TL
      ADR=DH*TL
      ADRR=DH*RL
      AHCL=CHV*RL
CC
      IF ((K.GT.0).AND.(I.EQ.1)) GO TO 64
C
      DRTY=CDT*ROE*VD**2*AUH+CDT1*ROE*VD**2*ADHR
      FLTY=CLT*ROE*VD**2*AVCL
      FLTW=CLT1*ROE*VD**2*AHCL
CC
CCC   DEFINING THE ANGLE MODES
CC
      IF ((TOW.GT.BFY).AND.(DELTAY.LT.0.0)) BTR=ALPHAR-THETAR
      IF ((TOW.GT.BFY).AND.(DELTAY.GT.0.0)) BTR=ALPHAR+THETAR
      IF ((TOW.LT.BFY).AND.(DELTAY.LT.0.0)) BTR=ALPHAR+THETAR
      IF ((TOW.LT.BFY).AND.(DELTAY.GT.0.0)) BTR=ALPHAR-THETAR
C
      IF (DELTAY.EQ.0.0) BTR=THETAR
C
      KK=K+1
C
      GO TO (11,11,11,11,9,9,10,10,9,10,10,11,9,11), KK
C
    9 CONTINUE
C
      IF (DELTAY.LT.0.0) BTR=THETAR
C
      GO TO 11
C
   10 CONTINUE
C
      IF (DELTAY.GT.0.0) BTR=THETAR
C
   11 CONTINUE
C
      IF (I.GT.1) GO TO 12
```

```
C                                                                       A 651
      CALL UMBZ (TOW,PUX,ROE,VF,THETAR,ALPHAR,VOLT,DYK,YCB,YE,YCG,FLTY,D  A 652
     1RTY,XT,XCB,UBM)                                                   A 653
C                                                                       A 654
      ANGACC=UBM/ZZIT                                                   A 655
      ANGV=ANGACC*DELT+ANGV                                             A 656
      THETAR=THETAR+0.5*ANGACC*DELT**2+ANGV*DELT                        A 657
C                                                                       A 658
      ANGACZ=0.0                                                        A 659
      ANGVZ=0.0                                                         A 660
      YAWR=0.0                                                          A 661
C                                                                       A 662
C                                                                       A 663
      I=I+1                                                             A 664
C                                                                       A 665
      WRITE (6,115)                                                     A 666
      WRITE (6,116)                                                     A 667
      WRITE (6,119)                                                     A 668
      WRITE (6,118) VX,VY,VZ,ACCX,ACCY,ACCZ,PHI,YAW,ALPHA,THETA,X,Y,Z   A 669
C                                                                       A 670
C                                                                       A 671
12    CONTINUE                                                          A 672
C                                                                       A 673
      IF (I.LT.J) POX=POW/(J-I)                                         A 674
      IF (I.GE.J) POX=POW                                               A 675
C                                                                       A 676
CCCCC                                                                   A 677
CCCCC CALCULATION OF THE CONTROL SURFACES FORCE                         A 678
CCCCC                                                                   A 679
CCCCC                                                                   A 680
CCCCC ELEVATORS                                                         A 681
CCCCC                                                                   A 682
      ANGACC=UBM/ZZIT                                                   A 683
      AAA1=ANGACC                                                       A 684
C                                                                       A 685
      IF (ABS(VD).GE.44.0) GO TO 13                                     A 686
      IF (ABS(VD).LT.44.0) AFE=0.0                                      A 687
      GO TO 25                                                          A 688
C                                                                       A 689
13    CONTINUE                                                          A 690
C                                                                       A 691
      GO TO (14,17,17,17,18,18,21,21,18,21,21,18,18,21,24), KK          A 692
C                                                                       A 693
CCCCC                                                                   A 694
CCCCC TAKE OFF                                                          A 695
CCCCC                                                                   A 696
C                                                                       A 697
14    CONTINUE                                                          A 698
C                                                                       A 699
                                                                        A 700
```

```
C     CALCULATION OF THE MAXIMUM ELEVATOR FORCE POSSIBLE                A 701
C                                                                       A 702
      CLE=FTABLE(ALO,CLO,ABSTA,13)                                      A 703
C                                                                       A 704
      AFEM=CLE*ROE*VD**2*AVCL                                           A 705
C                                                                       A 706
C     REDUCE TO/OR KEEP ACCELERATION (ANGULAR) AT ZERO                  A 707
C                                                                       A 708
      AFE1=UBM/(XT-XCB)                                                 A 709
C                                                                       A 710
      ANGAC1=-AFE1*(XT-XCB)/ZZIT                                        A 711
C                                                                       A 712
      IF (ANGV.EQ.0.0) ANGAC2=0.0                                       A 713
      IF (ANGV.EQ.0.0) AFE2=0.0                                         A 714
      IF (ANGV.EQ.0.0) GO TO 15                                         A 715
      IF (IJ.GT.0) GO TO 16                                             A 716
C                                                                       A 717
C     CALCULATE THE REMAINING ELEVATOR FORCE AVAILABLE                  A 718
C                                                                       A 719
      EFR=AFEM-AFE1                                                     A 720
C                                                                       A 721
C     REDUCE ANGULAR VELOCITY TO ZERO IN ONE SECOND                     A 722
C                                                                       A 723
      ANGAC2=-ANGV/(10.0*DELT)                                          A 724
C                                                                       A 725
      AFE2=-ANGAC2*ZZIT/(XT-XCB)                                        A 726
C                                                                       A 727
      IF (ABS(AFE2).GT.ABS(EFR)) ANGAC2=-EFR*(XT-XCB)/ZZIT              A 728
      IF (ABS(AFE2).GT.ABS(EFR)) AFE2=EFR                               A 729
C                                                                       A 730
      IJ=1                                                              A 731
C                                                                       A 732
      GO TO 16                                                          A 733
C                                                                       A 734
15    IJ=0                                                              A 735
C                                                                       A 736
16    CONTINUE                                                          A 737
C                                                                       A 738
      AFE=AFE1+AFE2                                                     A 739
C                                                                       A 740
      ANGACC=AAA1+ANGAC1+ANGAC2                                         A 741
C                                                                       A 742
      IF (ABS(ANGACC).LT.0.00001) ANGACC=0.0                            A 743
                                                                        A 744
                                                                        A 745
                                                                        A 746
                                                                        A 747
                                                                        A 748
                                                                        A 749
                                                                        A 750
```

```
C       GO TO 25                                                          A  751
C                                                                         A  752
C       ELEVATORS ONLY IN USE TO KEEP A CONSTANT ATTITUDE                 A  753
C                                                                         A  754
C                                                                         A  755
C                                                                         A  756
C                                                                         A  757
17      CONTINUE                                                          A  758
C       CALL UMRZ (TOW,POX,ROE,VD,THETAR,ATR,VOLT,DYK,YCG,YE,YCG,FLTY,DHTY A  759
     1,XT,XCB,UBM)                                                        A  760
C       AFE=UBM/(XT-XCB)                                                  A  761
C       ANGACC=AAA1-(AFE*(XT-XCB)/ZZIT)                                   A  762
C       IF (ABS(ANGACC).LT.0.000011 ANGACC=0.0                            A  763
C       GO TO 25                                                          A  764
C                                                                         A  765
C                                                                         A  766
C       ELEVATORS UP                                                      A  767
C                                                                         A  768
C                                                                         A  769
18      CONTINUE                                                          A  770
C       IKY=IKY+1                                                         A  771
C       AEU=-THETA*2.0                                                    A  772
C       IF ((AEU.GT.10.0).OR.(AEU.LT.-14.0)) GO TO 19                     A  773
C       CLE=FTABLE(ALD,CLD,AEU,13)                                        A  774
C       GO TO 20                                                          A  775
C                                                                         A  776
19      CONTINUE                                                          A  777
C       IF (AEU.GT.10.0) CLE=CLD(13)                                      A  778
        IF (AEU.LT.-14.0) CLE=0.0                                         A  779
C                                                                         A  780
20      CONTINUE                                                          A  781
C       IF (BETAR.GT.10.0) CLE=0.0                                        A  782
C       AFEM=CLE*ROE*VD**2*AVCL                                           A  783
        AFE=-AFEM                                                         A  784
C       ANGACC=AAA1-(AFE*(XT-XCB)/ZZIT)                                   A  785
C                                                                         A  786
                                                                          A  787
                                                                          A  788
                                                                          A  789
                                                                          A  790
                                                                          A  791
                                                                          A  792
                                                                          A  793
                                                                          A  794
                                                                          A  795
                                                                          A  796
                                                                          A  797
                                                                          A  798
                                                                          A  799
                                                                          A  800
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C  * T I D Y *    PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                    PAGE  10
      GO TO 25                                                                          A  801
C                                                                                       A  802
C                                                                                       A  803
C     ELEVATORS DOWN                                                                    A  804
C                                                                                       A  805
C                                                                                       A  806
   21 CONTINUE                                                                          A  807
C     IKY=IKY+1                                                                         A  808
C     AEU=THETA*2.0                                                                     A  809
C     IF ((AEU.GT.10.0).OR.(AEU.LT.-14.0)) GO TO 22                                     A  810
C     CLE=FTABLE(ALD,CLD,AEU,13)                                                        A  811
C     GO TO 23                                                                          A  812
   22 CONTINUE                                                                          A  813
C     IF (AEU.GT.10.0) CLE=CLD(13)                                                      A  814
      IF (AEU.LT.-14.0) CLE=0.0                                                         A  815
   23 CONTINUE                                                                          A  816
C     IF (BETAR.GT.10.0) CLE=0.0                                                        A  817
C     AFEM=CLE*ROE*VD**2*AVCL                                                           A  818
      AFE=AFEM                                                                          A  819
C     ANGACC=AAA1-(AFE*(XT-XCB)/ZZIT)                                                   A  820
C     GO TO 25                                                                          A  821
C                                                                                       A  822
   24 CONTINUE                                                                          A  823
C     GO TO 84                                                                          A  824
   25 CONTINUE                                                                          A  825
C                                                                                       A  826
C                                                                                       A  827
C     RUDDERS                                                                           A  828
C                                                                                       A  829
      KK=K+1                                                                            A  830
C     GO TO (26,27,28,34,27,28,27,28,34,34,26,26,34,34,26), KK                          A  831
C                                                                                       A  832
C                                                                                       A  833
```

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* I D Y *        PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                    PAGE  6
C       RUDDER NOT IN USE                                                              A  851
C                                                                                      A  852
C                                                                                      A  853
C     26  CONTINUE                                                                     A  854
C                                                                                      A  855
        AFR=0.0                                                                        A  856
        XIM8=0.0                                                                       A  857
C       GO TO 30                                                                       A  858
C                                                                                      A  859
C       LEFT AND RIGHT RUDDER                                                          A  860
C                                                                                      A  861
C     27  CONTINUE                                                                     A  862
C                                                                                      A  863
        TYAW=2.0*YAW                                                                   A  864
        CLR=FTABLE(ALD,CLD,TYAW,13)                                                    A  865
        AFR=-CLR*ROE*VO**2*AHCL                                                        A  866
C       GO TO 29                                                                       A  867
C                                                                                      A  868
C     28  CONTINUE                                                                     A  869
C                                                                                      A  870
        TYAW=2.0*YAW                                                                   A  871
        CLR=FTABLE(ALD,CLD,TYAW,13)                                                    A  872
        AFR=CLR*ROE*VO**2*AHCL                                                         A  873
C       GO TO 29                                                                       A  874
C                                                                                      A  875
C     29  CONTINUE                                                                     A  876
C                                                                                      A  877
C       CALCULATING FIN AND AERODYNAMIC FORCES                                         A  878
C                                                                                      A  879
C                                                                                      A  880
C       AERODYNAMIC FORCE                                                              A  881
C                                                                                      A  882
C                                                                                      A  883
        XA=0.0                                                                         A  884
        XIM9=0.0                                                                       A  885
        XIM8=0.0                                                                       A  886
C                                                                                      A  887
C       CALCULATION OF THE TURNING RADIUS AT EACH TIME INTERVAL                        A  888
C                                                                                      A  889
C                                                                                      A  890
        IF (YAWR.EQ.0.0) GO TO 31                                                      A  891
     30 CONTINUE                                                                       A  892
        R1=2.0*(XT-XCB)/(DYK*SIN(2.0*YAWR))                                            A  893
                                                                                       A  894
                                                                                       A  895
                                                                                       A  896
                                                                                       A  897
                                                                                       A  898
                                                                                       A  899
                                                                                       A  900
```

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      GO TO 32                                                          A 901
   31 CONTINUE                                                          A 902
      R1=1.0E12                                                         A 903
   32 CONTINUE                                                          A 904
C                                                                       A 905
      DO 33 II=1,117                                                    A 906
C                                                                       A 907
      XA=XA+1.0                                                         A 908
      CSA=3.14*Y2(II)**2                                                A 909
C                                                                       A 910
      XIM1=XK*VD**2*ROE*CSA*COS(YAWR)/(2.0*R1)                          A 911
      XIM2=XIM1*XA                                                      A 912
      XIM8=XIM8+XIM2                                                    A 913
C                                                                       A 914
      IF ((K.EQ.3).OR.(K.EQ.8).OR.(K.EQ.9)) GO TO 36                    A 915
      IF ((K.EQ.12).OR.(K.EQ.13)) GO TO 36                              A 916
C                                                                       A 917
   33 CONTINUE                                                          A 918
CCC                                                                     A 919
      GO TO 38                                                          A 920
CCCCC                                                                   A 921
      STEADY STATE TURN                                                 A 922
CCCCC                                                                   A 923
   34 CONTINUE                                                          A 924
CCCCCCCCC                                                               A 925
      STEADY STATE TURN OCCURS WHEN THE YAW MOMENT IS EQUAL TO THE      A 926
      RUDDER                                                            A 927
      MOMENT                                                            A 928
CCCCCCCCC                                                               A 929
      IF (YAWD.LT.100.) GO TO 37                                        A 930
C                                                                       A 931
   35 YAWR=YAWR+0.0001                                                  A 932
C                                                                       A 933
      GO TO 30                                                          A 934
C                                                                       A 935
   36 CONTINUE                                                          A 936
CCCCCCC                                                                 A 937
      CALCULATING YAW FORCE                                             A 938
CCCCCCC                                                                 A 939
      YAWF=(XCB-XP)/(XT-XCB)*XIM8                                       A 940
C                                                                       A 941
CCC                                                                     A 942
      CALCULATING THE RUDDER FORCE                                      A 943
```

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* T I D Y *                PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)          PAGE  51
C
C
      YAW=YAWR*180.0/3.14                                                          A  951
      TYAW=2.0*YAW                                                                 A  952
      CLR=FTAHLE(ALO,CLO,TYAW,13)                                                  A  953
      AFR=-CLR*ROE*VU**2*AMCL                                                      A  954
      YAWD=ABS(-AFR-YAWF)                                                          A  955
      IF (YAWD.GT.100.) GO TO 35                                                   A  956
C37   CONTINUE                                                                     A  957
C38   CONTINUE                                                                     A  958
CCCCC                                                                              A  959
CCCCC SUM OF THE FORCES ACTING ON THE AIRSHIP                                      A  960
CCCCC                                                                              A  961
CCCCC HORIZONTAL                                                                   A  962
CCCCC                                                                              A  963
CCCCC DRAG EQUATIONS                                                               A  964
CCCCC                                                                              A  965
      ROE=0.002378                                                                 A  966
C     SIG=ROE/0.002378                                                             A  967
CCCCC                                                                              A  968
CCCCC DRAG DUE TO LEVEL FLIGHT                                                     A  969
CCCCC                                                                              A  970
      XMU=3.639E-7                                                                 A  971
C     CF=0.074/(((ABS(VD)*XL*ROE)/XMU)**0.2)                                       A  972
C     A=(1.0+0.5/F)                                                                A  973
C     BHDR=0.5*ROE*ABS(VD)**1.86*(CF*A*(4.0*(F**0.33)+6.0*((1.0/F)**1.2)           A  974
     1+24.0*((1.0/F)**2.7))*VOLT**0.97)                                            A  975
C     DRAGO=BHDR/0.35                                                              A  976
CCCCC                                                                              A  977
CCCCC CALCULATION OF THE LIFT COEFFICIENT                                          A  978
CCCCC                                                                              A  979
      CLA=1.25*THETAR                                                              A  980
C     IF (ABS(THETA).GT.14.0) CLA=0.0                                              A  981
C                                                                                  A  982
                                                                                   A  983
                                                                                   A  984
                                                                                   A  985
                                                                                   A  986
                                                                                   A  987
                                                                                   A  988
                                                                                   A  989
                                                                                   A  990
                                                                                   A  991
                                                                                   A  992
                                                                                   A  993
                                                                                   A  994
                                                                                   A  995
                                                                                   A  996
                                                                                   A  997
                                                                                   A  998
                                                                                   A  999
                                                                                   A1000
```

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C     LIFT FORCE DUE TO ANGLE OF ATTACK                                  A1001
C                                                                        A1002
C                                                                        A1003
      DLF=CLA*ROE/2.0*VD**2*VOLT**0.67                                   A1004
C                                                                        A1005
C     DRAG DUE TO ANGLE OF ATTACK                                        A1006
C                                                                        A1007
C                                                                        A1008
C                                                                        A1009
      DRAGL=4.0*ABS(DLF)**1.67/(ABS(VD)**1.33*VOLT**0.44*S10**0.67)      A1010
C                                                                        A1011
C     TOTAL DRAG                                                         A1012
C                                                                        A1013
C                                                                        A1014
C                                                                        A1015
C                                                                        A1016
      DRAG=DRAGO+DRAGL                                                   A1017
C                                                                        A1018
C                                                                        A1019
      FACH=(DRAG*DRTY)*COS(BTR)-POX*COS(BTR)+DLF*SIN(BTR)-FLTY*SIN(BTR)* A1020
     1AFE*SIN(BTR)                                                       A1021
C                                                                        A1022
C     FACZ=AFR*XIMB                                                      A1023
C                                                                        A1024
C                                                                        A1025
C     VERTICAL                                                           A1026
C                                                                        A1027
C                                                                        A1028
      FACV=BFY-TOW+DLF*COS(BTR)+FLTY*COS(BTR)+AFE*COS(BTR)+POX*SIN(BTR)- A1029
     1(DRAG*DRTY)*SIN(BTR)                                               A1030
C                                                                        A1031
C     IF (IST.EQ.1) GO TO 39                                             A1032
C                                                                        A1033
C     GO TO 40                                                           A1034
C                                                                        A1035
C39   CONTINUE                                                           A1036
C                                                                        A1037
      FACH=-FACH                                                         A1038
      FACZ=-FACZ                                                         A1039
C40   CONTINUE                                                           A1040
C                                                                        A1041
C                                                                        A1042
C                                                                        A1043
C     ACCELERATION CALCULATIONS IN THE GENERAL CASE                      A1044
C                                                                        A1045
C                                                                        A1046
C     NO LINEAR ACCELERATION DURING A STEADY STATE TURN                  A1047
C                                                                        A1048
C                                                                        A1049
      GO TO (42,42,42,41,42,42,42,42,41,41,42,42,41,41), KK              A1050
```

```
C                                                                    A1051
41    CONTINUE                                                       A1052
C                                                                    A1053
      ACCF=0.0                                                       A1054
C                                                                    A1055
      GO TO 43                                                       A1056
C                                                                    A1057
42    CONTINUE                                                       A1058
C                                                                    A1059
      ACCF=FACH/TM                                                   A1060
C                                                                    A1061
43    CONTINUE                                                       A1062
C                                                                    A1063
      ACCY=FACV/TM                                                   A1064
C                                                                    A1065
      ACCX=ACCF*COS(PHIR+YA*R)+(FACZ/TM)*SIN(PHIR+YA*R)              A1066
      ACCZ=ACCF*SIN(PHIR+YA*R)+(FACZ/TM)*COS(PHIR+YA*R)              A1067
C                                                                    A1068
CCCC  TRAJECTORY CALCULATIONS                                        A1069
CCCC                                                                 A1070
C                                                                    A1071
      X=X+ACCX*DELT**2/2.0+VX*DELT                                   A1072
      Y=Y+ACCY*DELT**2/2.0+VY*DELT                                   A1073
      Z=Z+ACCZ*DELT**2/2.0+VZ*DELT                                   A1074
C                                                                    A1075
      IF ((ACCY.LE.0.0).AND.(Y.LE.0.0)) Y=0.0                        A1076
C                                                                    A1077
      IF (IST.EQ.0) DX=X1-X                                          A1078
      IF (IST.EQ.1) DX=X-X1                                          A1079
C                                                                    A1080
      DY=ABS(Y-Y1)                                                   A1081
      DZ=ABS(Z1-Z)                                                   A1082
C                                                                    A1083
      DELTAY=Y-Y1                                                    A1084
      DELTAZ=Z-Z1                                                    A1085
C                                                                    A1086
      DX1=SQRT(ABS(X1-X)**2+ABS(Z1-Z)**2)                            A1087
C                                                                    A1088
      X1=X                                                           A1089
      Y1=Y                                                           A1090
      Z1=Z                                                           A1091
C                                                                    A1092
CCCC  VELOCITY CALCULATIONS                                          A1093
CCCC                                                                 A1094
C                                                                    A1095
      VX=VX+ACCX*DELT                                                A1096
      VZ=VZ+ACCZ*DELT                                                A1097
      VY=VY+ACCY*DELT                                                A1098
                                                                     A1099
                                                                     A1100
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C
      IF ((ACCY.LE.0.0).AND.(Y.LE.0.0)) VY=0.0                          A1101
C                                                                       A1102
      VD=SQRT(VX**2+VY**2+VZ**2)                                        A1103
C                                                                       A1104
C                                                                       A1105
C     ANGLE CALCULATIONS                                                A1106
C                                                                       A1107
C                                                                       A1108
      ALP1=ALPHAR                                                       A1109
C                                                                       A1110
      IF (PHI.GT.179.0) GO TO 44                                        A1111
C                                                                       A1112
      ALPHAR=ATAN2(DY,DX1)                                              A1113
      PHIR=ATAN2(DZ,DX)                                                 A1114
C                                                                       A1115
      GO TO 45                                                          A1116
C                                                                       A1117
44    CONTINUE                                                          A1118
C                                                                       A1119
      IST=1                                                             A1120
C                                                                       A1121
      PHI=0.0                                                           A1122
      PHIR=0.0                                                          A1123
C                                                                       A1124
45    CONTINUE                                                          A1125
C                                                                       A1126
C                                                                       A1127
      IF (PHI.GT.90.0) GO TO 46                                         A1128
C                                                                       A1129
      IF ((DELTAZ.LT.0.0).AND.(IST.NE.1)) PHIR=-PHIR                    A1130
C                                                                       A1131
46    CONTINUE                                                          A1132
C                                                                       A1133
      IF (DELTAY.LT.0.0) ALPHAR=-ALPHAR                                 A1134
C                                                                       A1135
      DALP=ALPHAR-ALP1                                                  A1136
C                                                                       A1137
      IF ((K.EQ.4).OR.(K.EQ.5).OR.(K.EQ.8).OR.(K.EQ.12)) GO TO 47       A1138
C                                                                       A1139
      IF ((K.EQ.6).OR.(K.EQ.7).OR.(K.EQ.9).OR.(K.EQ.10)) GO TO 48       A1140
C                                                                       A1141
      BETAR=0.0                                                         A1142
C                                                                       A1143
      GO TO 49                                                          A1144
C                                                                       A1145
47    CONTINUE                                                          A1146
C                                                                       A1147
      IF (DELTAY.LT.0.0) BETAR=THETA-ALPHA                              A1148
C                                                                       A1149
                                                                        A1150
```

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      IF (DELTAY.GT.0.0) BETAR=0.0                                      A1151
C     GO TO 49                                                          A1152
C                                                                       A1153
48    CONTINUE                                                          A1154
C     IF (DELTAY.GT.0.0) BETAR=ALPHA-THETA                              A1155
C     IF (DELTAY.LT.0.0) BETAR=0.0                                      A1156
C                                                                       A1157
49    CONTINUE                                                          A1158
C                                                                       A1159
C     ANGLE CALCULATIONS                                                A1160
C                                                                       A1161
      CALL UNBZ (TOW,POX,HOE,VD,THETAR,BTR,VOLT,DYK,YCB,YE,YCG,FLTY,DRTY A1162
     1,XT,XCB,UBM)                                                      A1163
C     IF (ABS(VD).GE.44.0) GO TO 50                                     A1164
C     ANGACC=UBM/ZZIT                                                   A1165
C                                                                       A1166
50    CONTINUE                                                          A1167
C     ANGV1=ANGV                                                        A1168
C                                                                       A1169
      IF ((KK.EQ.14).OR.(KK.EQ.12)) GO TO 51                            A1170
C     IF (ABS(THETA).GT.5.2) GO TO 55                                   A1171
C                                                                       A1172
51    CONTINUE                                                          A1173
C                                                                       A1174
      IF (KK.EQ.12) GO TO 52                                            A1175
      IF (KK.EQ.14) GO TO 53                                            A1176
C     GO TO 54                                                          A1177
C                                                                       A1178
52    CONTINUE                                                          A1179
C     IF (THETA.LT.5.2) GO TO 54                                        A1180
C     GO TO 55                                                          A1181
C                                                                       A1182
53    CONTINUE                                                          A1183
C     IF (THETA.GT.-5.2) GO TO 54                                       A1184
C     GO TO 55                                                          A1185
                                                                        A1186
                                                                        A1187
                                                                        A1188
                                                                        A1189
                                                                        A1190
                                                                        A1191
                                                                        A1192
                                                                        A1193
                                                                        A1194
                                                                        A1195
                                                                        A1196
                                                                        A1197
                                                                        A1198
                                                                        A1199
                                                                        A1200
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```
C                                                                       A1201
54    CONTINUE                                                          A1202
C                                                                       A1203
      TH1=THETAR                                                        A1204
C                                                                       A1205
      THETAR=THETAR+0.5*ANGACC*DELT**2+ANGV*DELT                        A1206
      ANGV=ANGACC*DELT+ANGV                                             A1207
C                                                                       A1208
      DTH=THETAR-TH1                                                    A1209
C                                                                       A1210
C                                                                       A1211
CCCCC PULL OUT FROM CLIMB OR DIVE                                       A1212
CCCCC                                                                   A1213
C                                                                       A1214
      IF ((DELTAY.LT.0.0).AND.(K.EQ.11)) THETAR=THETAL-(-DTH*DALP)      A1215
      IF ((DELTAY.GT.0.0).AND.(K.EQ.13)) THETAR=THETAL-(-DTH*DALP)      A1216
C                                                                       A1217
      GO TO 56                                                          A1218
C                                                                       A1219
55    CONTINUE                                                          A1220
C                                                                       A1221
      ANGACC=0.0                                                        A1222
      ANGV=0.0                                                          A1223
C                                                                       A1224
56    CONTINUE                                                          A1225
C                                                                       A1226
      DANGV=ANGV-ANGV1                                                  A1227
C                                                                       A1228
      IF ((ABS(ANGV).LT.0.0005).AND.(DANGV.LT.0.0)) ANGV=0.0            A1229
C                                                                       A1230
C     IF ((K.EQ.3).OR.(K.EQ.8).OR.(K.EQ.9)) GO TO 57                    A1231
C                                                                       A1232
      ANGACZ=(-AFR-(XCB-XP)/(XT-XCB)*XIMB)*(XT-XCB)/YYIT                A1233
      YAWR=YAWR+0.5*ANGACZ*DELT**2+ANGVZ*DELT                           A1234
      ANGVZ=ANGACZ*DELT+ANGVZ                                           A1235
C                                                                       A1236
57    CONTINUE                                                          A1237
CCCCC ANGLE IN DEGREES                                                  A1238
CCCCC                                                                   A1239
C                                                                       A1240
      ALPHA=ALPHAR*180.0/3.14                                           A1241
C                                                                       A1242
      THETA=THETAR*180.0/3.14                                           A1243
C                                                                       A1244
      PHI=PHIR*180.0/3.14                                               A1245
C                                                                       A1246
      YAW=YAWR*180.0/3.14                                               A1247
C                                                                       A1248
      T=T+DELT                                                          A1249
                                                                        A1250
```

```
C
      I=I+1                                                          A1251
C                                                                    A1252
C     SUM OF THE FORCES ACTING ON THE AIRSHIP                        A1253
C                                                                    A1254
C                                                                    A1255
C     X DIRECTION                                                    A1256
C                                                                    A1257
      SUMFX=POX-DRAG-DRTY                                            A1258
C                                                                    A1259
C     Y DIRECTION                                                    A1260
C                                                                    A1261
      SUMFY=BFY-TOW+FLTY+AFE+DLF                                     A1262
C                                                                    A1263
C     Z DIRECTION                                                    A1264
C                                                                    A1265
      SUMFZ=XIMB+AFR                                                 A1266
C                                                                    A1267
      K1=K                                                           A1268
C                                                                    A1269
C                                                                    A1270
C     TEST FOR COMPLETION OF MANEUVER                                A1271
C                                                                    A1272
C                                                                    A1273
      GO TO (62,62,62,62,62,62,62,62,62,62,59,61,58,60), KK          A1274
C                                                                    A1275
58    YMAXC=DELTAY*10.0                                              A1276
59    YMAXDR=-DELTAY*10.0                                            A1277
60    CR=DELTAY*10.0                                                 A1278
61    DSR=-DELTAY*10.0                                               A1279
C                                                                    A1280
62    CONTINUE                                                       A1281
C                                                                    A1282
      CALL TEST (PHI,K,YMAXDR,DSR,Y,YMAXC,CR)                       A1283
C                                                                    A1284
      IF (K1.EQ.K) GO TO 83                                          A1285
C                                                                    A1286
      ILY=1                                                          A1287
      GO TO 83                                                       A1288
C                                                                    A1289
63    CONTINUE                                                       A1290
C                                                                    A1291
      KK=K+1                                                         A1292
C                                                                    A1293
      GO TO (64,67,64,64,67,64,67,64,64,64,67,64,67,67), K           A1294
C                                                                    A1295
64    CONTINUE                                                       A1296
C                                                                    A1297
      Y=3000.0                                                       A1298
      X=0.0                                                          A1299
                                                                     A1300
```

```
      PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                    A1301
      Z=0.0                                                                 A1302
      T=0.0                                                                 A1303
      THETAR=0.0673                                                         A1304
      ALPHAR=0.0                                                            A1305
      PHIR=0.0                                                              A1306
      YAWR=0.0                                                              A1307
      BTR=THETAR                                                            A1308
      POX=POW                                                               A1309
      VD=-88.0                                                              A1310
      ANGV=0.0                                                              A1311
      ANGVZ=0.0                                                             A1312
      ANGACZ=0.0                                                            A1313
      VX=VD                                                                 A1314
      VY=0.0                                                                A1315
      VZ=0.0                                                                A1316
      ACCX=0.0                                                              A1317
      ACCY=0.0                                                              A1318
      ACCZ=0.0                                                              A1319
      YAW=0.0                                                               A1320
      ALPHA=0.0                                                             A1321
      PHI=0.0                                                               A1322
      BETAR=0.0                                                             A1323
      YAWD=1.0E04                                                           A1324
      XIMR=0.0                                                              A1325
      SUMFX=0.0                                                             A1326
      SUMFY=0.0                                                             A1327
      SUMFZ=0.0                                                             A1328
C                                                                           A1329
C     CALCULATION TO DETERMINE THETA SUCH THAT THE VERTICAL FORCE IS        A1330
C     ZERO                                                                  A1331
C                                                                           A1332
      FS=BFY-TOW                                                            A1333
65    PV=POX*SIN(THETAR)                                                    A1334
      CLA=1.25*THETAR                                                       A1335
      QLF=CLA*ROE*VD**2*VOLT**0.67/2.0                                      A1336
      CDT1=0.0                                                              A1337
C                                                                           A1338
      THETA=180.0*THETAR/3.14                                               A1339
C                                                                           A1340
      ABSTA=ABS(THETA)                                                      A1341
      CDT=FTABLE(AD,CD,ABSTA,9)                                             A1342
      CLT=FTABLE(AL,CL,ABSTA,10)                                            A1343
C                                                                           A1344
      IF (THETA.LT.0.0) CLT=-CLT                                            A1345
C                                                                           A1346
      FLTY=CLT*ROE*VD**2*AVCL                                               A1347
      DRTY=CDT*ROE*VD**2*ADR+CDT1*ROE*VD**2*AURR                            A1348
C                                                                           A1349
      CALL UMBZ (TOW,POX,ROE,VD,THETAR,BTR,VOLT,DYK,YCB,YE,YCG,FLTY,DRTY    A1350
     1,XT,XCB,UBM)
```

```
C
      AFE=UBM/(XT-XCB)                                                  A1351
      AFC=DLF*FLTY*AFE                                                  A1352
      FAV=AFC*FS*PV                                                     A1353
      IF (ABS(FAV).LT.1.) GO TO 66                                      A1354
      IF (FAV.GT.0.0) THETAR=THETAR-0.001                               A1355
      IF (FAV.LT.0.0) THETAR=THETAR+0.00001                             A1356
      GO TO 65                                                          A1357
C                                                                       A1358
66    CONTINUE                                                          A1359
C                                                                       A1360
      ANGACC=UBM/ZZIT                                                   A1361
C                                                                       A1362
C                                                                       A1363
      THETA=THETAR*180.0/3.14                                           A1364
C                                                                       A1365
      DELTAY=0.0                                                        A1366
      XI=X                                                              A1367
      YI=Y                                                              A1368
      ZI=Z                                                              A1369
      I=I+1                                                             A1370
      KK=K+1                                                            A1371
67    CONTINUE                                                          A1372
C                                                                       A1373
      IF ((K.EQ.11).OR.(K.EQ.13)) ANGV=0.0                              A1374
C                                                                       A1375
      IST=0                                                             A1376
      IKY=0                                                             A1377
      ILY=0                                                             A1378
C                                                                       A1379
      THETAL=THETAR                                                     A1380
CCCCC                                                                   A1381
CCCCC                                                                   A1382
CCCCC WRITE APPROPRIATE HEADINGS                                        A1383
CCCCC                                                                   A1384
CCCCC                                                                   A1385
      GO TO (68,69,70,71,72,73,74,75,76,77,78,79,80,81,82), KK          A1386
C                                                                       A1387
68    CONTINUE                                                          A1388
      GO TO 83                                                          A1389
69    CONTINUE                                                          A1390
      WRITE (6,134)                                                     A1391
      WRITE (6,115)                                                     A1392
      WRITE (6,116)                                                     A1393
      WRITE (6,120)                                                     A1394
      GO TO 83                                                          A1395
70    CONTINUE                                                          A1396
      WRITE (6,134)                                                     A1397
      WRITE (6,115)                                                     A1398
      WRITE (6,116)                                                     A1399
                                                                        A1400
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      WRITE (6,121)
      GO TO 83
71    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,122)
      GO TO 83
72    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,123)
      GO TO 83
73    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,124)
      GO TO 83
74    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,125)
      GO TO 83
75    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,126)
      GO TO 83
76    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,127)
      GO TO 83
77    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,128)
      GO TO 83
78    CONTINUE
      WRITE (6,134)
      WRITE (6,115)
      WRITE (6,116)
      WRITE (6,129)
      GO TO 83
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      PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                A1451
   79 CONTINUE                                                          A1452
      WRITE (6,134)                                                     A1453
      WRITE (6,115)                                                     A1454
      WRITE (6,116)                                                     A1455
      WRITE (6,130)                                                     A1456
      GO TO 83                                                          A1457
   80 CONTINUE                                                          A1458
      WRITE (6,134)                                                     A1459
      WRITE (6,115)                                                     A1460
      WRITE (6,116)                                                     A1461
      WRITE (6,131)                                                     A1462
      GO TO 83                                                          A1463
   81 CONTINUE                                                          A1464
      WRITE (6,134)                                                     A1465
      WRITE (6,115)                                                     A1466
      WRITE (6,116)                                                     A1467
      WRITE (6,132)                                                     A1468
      GO TO 83                                                          A1469
   82 CONTINUE                                                          A1470
      WRITE (6,134)                                                     A1471
      WRITE (6,133)                                                     A1472
C     GO TO 84                                                          A1473
C                                                                       A1474
   83 CONTINUE                                                          A1475
C                                                                       A1476
C     THETAL=THETAR                                                     A1477
C                                                                       A1478
C     KOUNT=KOUNT+1                                                     A1479
C                                                                       A1480
C     IF (MOD(KOUNT,12).EQ.0) WRITE (6,117)                             A1481
C                                                                       A1482
      WRITE (6,118) VX,VY,VZ,ACCX,ACCY,ACCZ,PHI,YAW,ALPHA,THETA,X,Y,Z   A1483
      WRITE (6,135) SUMFX,SUMFY,SUMFZ                                   A1484
C                                                                       A1485
C     IF (ILY.EQ.1) GO TO 63                                            A1486
C                                                                       A1487
C     IF (K.EQ.14) GO TO 84                                             A1488
C                                                                       A1489
C     GO TO 4                                                           A1490
C                                                                       A1491
   84 CONTINUE                                                          A1492
CC                                                                      A1493
CC    DATA OUTPUT                                                       A1494
CC                                                                      A1495
C                                                                       A1496
      WRITE (6,85)                                                      A1497
      WRITE (6,86) XCB                                                  A1498
      WRITE (6,92) YCB                                                  A1499
                                                                        A1500
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* T I D Y *                PROGRAM TST(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                PAGE  6
      WRITE (6,93) ZCB                                                                      A1501
      WRITE (6,87) XCGE                                                                     A1502
      WRITE (6,94) YCGE                                                                     A1503
      WRITE (6,95) ZCGE                                                                     A1504
      WRITE (6,96) XCG                                                                      A1505
      WRITE (6,97) YCG                                                                      A1506
      WRITE (6,98) ZCG                                                                      A1507
      WRITE (6,88) XXI                                                                      A1508
      WRITE (6,89) YYI                                                                      A1509
      WRITE (6,90) ZZI                                                                      A1510
      WRITE (6,109) XXIG                                                                    A1511
      WRITE (6,110) YYIG                                                                    A1512
      WRITE (6,111) ZZIG                                                                    A1513
      WRITE (6,105) GASM                                                                    A1514
      WRITE (6,99) XG                                                                       A1515
      WRITE (6,100) YG                                                                      A1516
      WRITE (6,101) ZG                                                                      A1517
      WRITE (6,102) BFX                                                                     A1518
      WRITE (6,103) BFY                                                                     A1519
      WRITE (6,104) BFZ                                                                     A1520
      WRITE (6,112) XCP                                                                     A1521
      WRITE (6,113) YCP                                                                     A1522
      WRITE (6,114) ZCP                                                                     A1523
      WRITE (6,106) XXIT                                                                    A1524
      WRITE (6,107) YYIT                                                                    A1525
      WRITE (6,108) ZZIT                                                                    A1526
C                                                                                           A1527
C                                                                                           A1528
      STOP                                                                                  A1529
C                                                                                           A1530
C                                                                                           A1531
   85 FORMAT (1H1,1X,28HENVELOPE PHYSICAL PARAMETERS)                                       A1532
   86 FORMAT (1H0,1X,20HCENTER OF BOUYANCY =,F20.10,2X,3HFT.,6X,1HX)                        A1533
   87 FORMAT (1H0,1X,28HENVELOPE CENTER OF GRAVITY =,F20.10,2X,6HFT.   X)                   A1534
   88 FORMAT (1H0,1X,40HMASS MOMENT OF INERTIA (X) OF ENVELOPE =,F20.10)                    A1535
   89 FORMAT (1H0,1X,40HMASS MOMENT OF INERTIA (Y) OF ENVELOPE =,F20.10)                    A1536
   90 FORMAT (1H0,1X,40HMASS MOMENT OF INERTIA (Z) OF ENVELOPE =,F20.10)                    A1537
   91 FORMAT (1H0,1X,15)                                                                    A1538
   93 FORMAT (1H0,1X,20HCENTER OF BOUYANCY =,F20.10,2X,3HFT.,6X,1HY)                        A1539
   94 FORMAT (1H0,1X,20HCENTER OF BOUYANCY =,F20.10,2X,3HFT.,6X,1HZ)                        A1540
   95 FORMAT (1H0,1X,28HENVELOPE CENTER OF GRAVITY =,F20.10,2X,6HFT.   Y)                   A1541
   96 FORMAT (1H0,1X,28HENVELOPE CENTER OF GRAVITY =,F20.10,2X,6HFT.   Z)                   A1542
   97 FORMAT (1H0,1X,33HTOTAL AIRSHIP CENTER OF GRAVITY =,F20.10,6X,1HX)                    A1543
   98 FORMAT (1H0,1X,33HTOTAL AIRSHIP CENTER OF GRAVITY =,F20.10,6X,1HY)                    A1544
   99 FORMAT (1H0,1X,33HTOTAL AIRSHIP CENTER OF GRAVITY =,F20.10,6X,1HZ)                    A1545
  100 FORMAT (1H0,1X,34HPOINT OF APPLICATION OF GAS MASS =,F20.10,6X,6HF                    A1546
     1T   X)                                                                               A1547
  100 FORMAT (1H0,1X,34HPOINT OF APPLICATION OF GAS MASS =,F20.10,6X,6HF                    A1548
                                                                                            A1549
                                                                                            A1550
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```
     1T    Y)                                                                    A1551
101  FORMAT (1H0,1X,34HPOINT OF APPLICATION OF GAS MASS =,F20.10,6X,6HF          A1552
     1T    Z)                                                                    A1553
102  FORMAT (1H0,1X,16HBOUYANCY FORCE =,F20.10,6X,7HLBF    X)                    A1554
103  FORMAT (1H0,1X,16HBOUYANCY FORCE =,F20.10,6X,7HLBF    Y)                    A1555
104  FORMAT (1H0,1X,16HBOUYANCY FORCE =,F20.10,6X,7HLBF    Z)                    A1556
105  FORMAT (1H0,1X,25HMASS OF THE LIFTING GAS =,F20.10,6X,3HLBM)                A1557
106  FORMAT (1H0,1X,38HTOTAL AIRSHIP MASS MOMENT OF INERTIA =,F20.10,6X          A1558
     1,1HX)                                                                    A1559
107  FORMAT (1H0,1X,38HTOTAL AIRSHIP MASS MOMENT OF INERTIA =,F20.10,6X          A1560
     1,1HY)                                                                    A1561
108  FORMAT (1H0,1X,38HTOTAL AIRSHIP MASS MOMENT OF INERTIA =,F20.10,6X          A1562
     1,1HZ)                                                                    A1563
109  FORMAT (1H0,1X,34HMASS MOMENT OF INERTIA OF THE GAS (X) =,F20.10)           A1564
110  FORMAT (1H0,1X,34HMASS MOMENT OF INERTIA OF THE GAS (Y) =,F20.10)           A1565
111  FORMAT (1H0,1X,34HMASS MOMENT OF INERTIA OF THE GAS (Z) =,F20.10)           A1566
112  FORMAT (1H0,1X,44HLOCATION OF AIRSHIP CENTER OF PRESSURE (X) =,F20          A1567
     1.10,5X,3HFT.)                                                            A1568
113  FORMAT (1H0,1X,44HLOCATION OF AIRSHIP CENTER OF PRESSURE (Y) =,F20          A1569
     1.10,5X,3HFT.)                                                            A1570
114  FORMAT (1H0,1X,44HLOCATION OF AIRSHIP CENTER OF PRESSURE (Z) =,F20          A1571
     1.10,5X,3HFT.)                                                            A1572
115  FORMAT (1H1)                                                              A1573
116  FORMAT (1H0,1X,*     VX          VY          VZ          AX          AY     A1574
     1      AZ          PHI         YAW         ALPHA       THETA         X     A1575
     2Y          Z          *)                                                 A1576
117  FORMAT (1H1,1X,*     VX          VY          VZ          AX          AY     A1577
     1      AZ          PHI         YAW         ALPHA       THETA         X     A1578
     2Y          Z          *)                                                 A1579
118  FORMAT (1H0,1X,13F10.3)                                                   A1580
119  FORMAT (1H0,1X,39HTAKE OFF AND CLIMB OVER 50-FT. OBSTACLE)                A1581
120  FORMAT (1H0,1X,37HFULL RUDDER UNTIL 75 DEGREE TURN MADE)                  A1582
121  FORMAT (1H0,1X,42HFULL RUDDER UNTIL BACK ON ORIGINAL HEADING)             A1583
122  FORMAT (1H0,1X,37HSTEADY STATE TURN FROM 0-180  DEGREES)                  A1584
123  FORMAT (1H0,1X,58HFULL UP ELEVATOR AND FULL RUDDER UNTIL 75 DEGREE        A1585
     1 TURN MADE)                                                              A1586
124  FORMAT (1H0,1X,64HFULL UP ELEVATOR AND FULL RUDDER UNTIL BACK ON O        A1587
     1RIGINAL HEADING)                                                         A1588
125  FORMAT (1H0,1X,60HFULL DOWN ELEVATOR AND FULL RUDDER UNTIL 75 DEGR        A1589
     1EE TURN MADE)                                                            A1590
126  FORMAT (1H0,1X,66HFULL DOWN ELEVATOR AND FULL RUDDER UNTIL BACK ON        A1591
     1 ORIGINAL HEADING)                                                       A1592
127  FORMAT (1H0,1X,54HSTEADY STATE TURN FROM 0-180  DEGREES FULL UP EL        A1593
     1EVATOR)                                                                  A1594
128  FORMAT (1H0,1X,56HSTEADY STATE TURN FROM 0-180' DEGREES FULL DOWN.        A1595
     1ELEVATOR)                                                                A1596
129  FORMAT (1H0,1X,50HFULL DOWN ELEVATOR UNTIL MAX DESCENT RATE ACHIEV        A1597
     1ED)                                                                      A1598
130  FORMAT (1H0,1X,39HFULL UP ELEVATOR UNTIL DESCENT RATE = 0)                A1599
131  FORMAT (1H0,1X,57HSTEADY STATE TURN AND CLIMB UNTIL MAX CLIMB RATE        A1600
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     1 ACHIEVED)                                                                A1601
 132  FORMAT (1H0,1X,61HSTEADY STATE TURN AND PULL DOWN ELEVATOR UNTIL C        A1602
     1 (INW RATE = 0)                                                           A1603
                                                                                A1604
 133  FORMAT (1H0,1X,7HLANDING)                                                 A1605
 134  FORMAT (1H0,1X,* MANOEUVER  COMPLETE *)                                   A1606
 135  FORMAT (1H0,* SUM FX = *,F20.6,* SUM FY = *,F20.6,* SUM FZ = *,F20        A1607
     1 .6)                                                                      A1608-
      END
```

```
      FUNCTION FTABLE (VAR,FUNC,XX,M)                                    1
C     VAR=DISCRETE TABULAR VALUES OF THE VARIABLE                        2
C     FUNC=DISCRETE TABULAR VALUES OF THE FUNCTION                       3
C     XX=GIVEN VALUE OF THE VARIABLE                                     4
C     M=NUMBER OF STATIONS OR TABLE VALUES                               5
C     FTABLE=INTERPOLATED VALUE OF FUNCTION CORRESPONDING TO XX          6
C                                                                        7
      DIMENSION VAR(1), FUNC(1)                                          8
C                                                                        9
      NEND=M-1                                                          10
C                                                                       11
      DO 1 I=1,NEND                                                     12
C                                                                       13
      INT=I                                                             14
C                                                                       15
      IF (XX.GT.VAR(I).AND.XX.LE.VAR(I+1)) GO TO 2                      16
C                                                                       17
    1 CONTINUE                                                          18
C                                                                       19
    2 FTABLE=FUNC(INT)+(XX-VAR(INT))*(FUNC(INT+1)-FUNC(INT))/(VAR(INT+1)20
     1-VAR(INT))                                                        21
C                                                                       22
      RETURN                                                            23
      END                                                               24
```

```
*TIDY*
      SUBROUTINE UMBZ (TOW,POX,ROE,VF,THETAR,ANGLR,VOLT,DYK,YCB,YCE,YCG,
      SUBROUTINE UMBZ (TOW,POX,ROE,VF,THETAR,ANGLR,VOLT,DYK,YCB,YCE,YCG,
     1FLTY,DRTY,XCGT,XCB,UBM)
C
C     CALCULATION OF THE MOMENTS ACTING ON AN AIRSHIP DURING X-Y PLANE
C     MOVEMENT
C
C     STATIC RIGHTING MOMENT
C
      H=YCB-YCG
      RH=TOW*H*SIN(ANGLR)
C
C     ENGINE THRUST MOMENT
C
      TH=POX*(YCB-YCE)
C
C     DYNAMIC UPSETTING MOMENT
C
      DUM=VOLT*ROE/2.0*VF**2*DYK*SIN(2.0*THETAR)
C
C     TAIL SURFACE MOMENT
C
      ARM=XCGT-XCB
      TSMY=FLTY*ARM+DRTY*ARM*SIN(THETAR)
C
      UBM=DUM+TH-RH-TSMY
C
      RETURN
C
      END
```

```
      SUBROUTINE TEST (PHI,K,YMAXDR,DSR,Y,YMAXC,CR)
      SUBROUTINE TEST (PHI,K,YMAXDR,DSR,Y,YMAXC,CR)
C
C     THIS SUBROUTINE TESTS TO SEE WHICH OPERATION MODE IS APPLICABLE
C
      COMMON /XV/ YMDR,YMC
C     KK=K+1
C     GO TO (1,2,3,3,2,3,2,3,3,3,4,5,6,7), KK
C1    IF (Y.GE.100.0) K=KK
      RETURN
C2    IF (PHI.GE.75.0) K=KK
      RETURN
C3    IF ((PHI.LE.0.0).OR.(PHI.GE.170.0)) K=KK
      RETURN
C4    IF (YMAXDR.GE.YMDR) K=KK
      RETURN
C5    IF (DSR.LE.0.0) K=KK
      RETURN
C6    IF (YMAXC.GE.YMC) K=KK
      RETURN
C7    IF (CR.LE.0.0) K=KK
C     RETURN
C     END
```

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