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INERTIA TESTS OF A 24 FOOT SINGLE KEEL PARAWING MODEL 2 REPORT NO. 2.

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By

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NASA CR-66767

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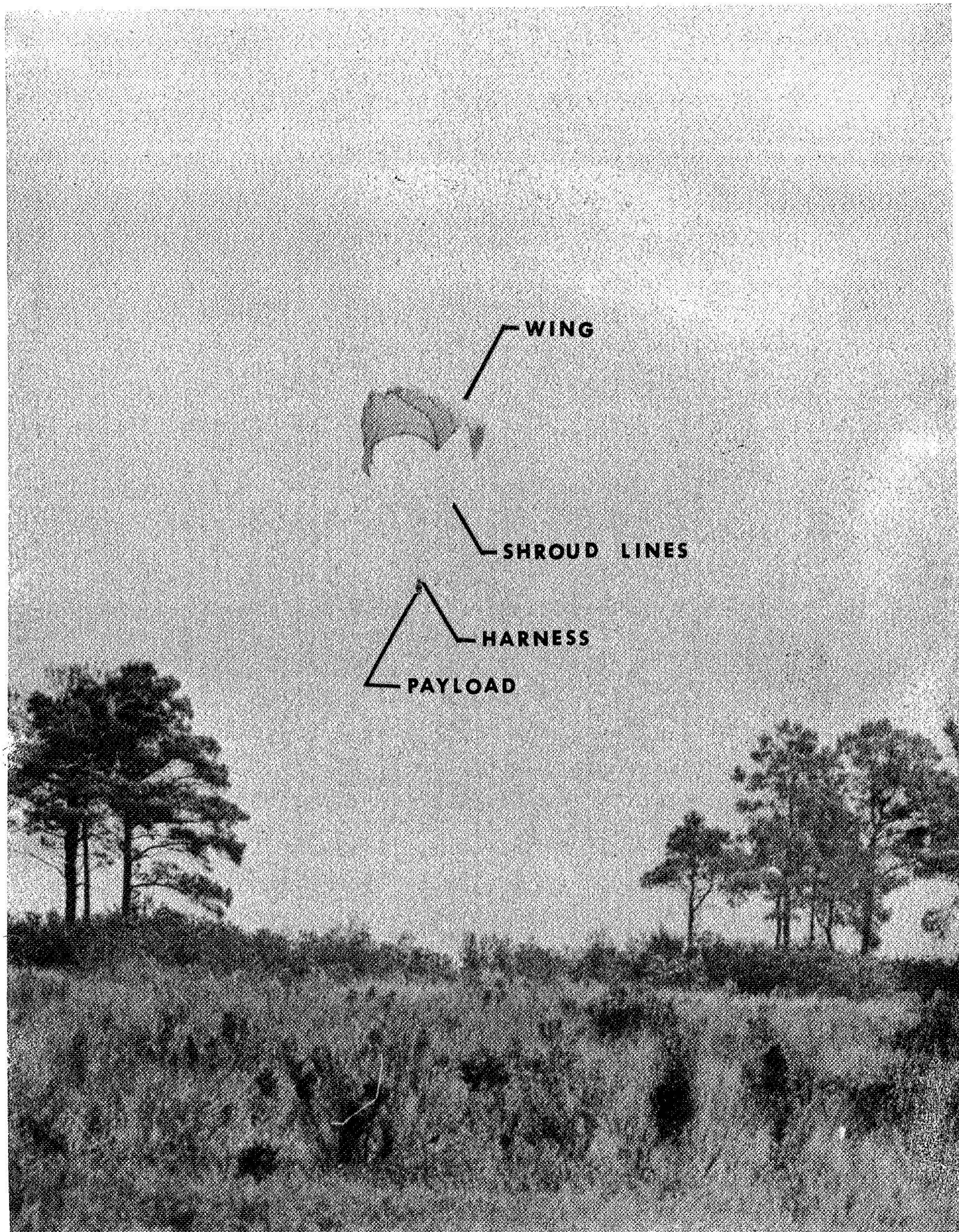


SINGLE KEEL PARAWING
FIGURE 1

FORWARD

This document has been prepared for the Langley Parawing Program Office under contract No. NAS1-6957. The main purpose of this paper is the detailed documentation of the weights, center of gravity, and inertias for a 24 ft all flexible single keel parawing,model 2. This model is part of a flight test program of a contractor, Northrop Incorporated, Ventura, California. The work was performed for the Applied Materials and Physics Division of Langley Research Center and under the technical cognizance of Mr. Sherwood Hoffman.

SUMMARY

This paper presents the mass moment of inertia tests and results of a 24 Ft. Single Keel Parawing, Model 2. This wing is part of a flight test program of a contractor, Northrop Inc.. The tests were conducted in the Langley 60 ft. vacuum sphere. The pressure and temperature inside the sphere was sea level. The wing tested was mounted on a pendulum supported frame and they were oscillated to measure periods. The data recorded consisted of stop watch times, damped oscillations on oscillograph paper, pressure and temperature in the sphere, and moisture content. The damped oscillations were measured by accelerometers mounted on the pendulum.

The wing was tested in pitch and roll. The inertias and masses of the tares and frames used, as well as the inertias for the wings alone are presented here-in. The inertias for the wing plus lines plus harness are summarized in Table 5 and Figures 12(a) and 12(b).

The inertia calculations at the harness end are taken where the harness attaches to the payload. This tie down point was selected for the inertias instead of the confluent point because it is intended that the inertia of the entire wing assembly be made readily available for use in data analysis.

All tares are subtracted from the summary data except for the apparent masses associated with the stabilizing fin of the roll test and for the transfer of trapped air inertia of the wing from the pendulum knife edge to the harness reference.

The inertia calculations are based on the parawing keel angle of 9° 17' with the horizontal. If the accrual flight angle is different, then the inertias should be rotated to obtain the correct flight data.

INTRODUCTION

This report has been prepared to document the methods, tests, and measurements of the weights, center of gravity, and moments of inertia of the 24 ft all flexible Single Keel Parawing, Model 2, for the NASA, Langley Research Center.

The tests were conducted to determine the moments of inertia of the parawing at sea level only for pitch and roll axes in the Langley 60 ft vacuum sphere. A comparison was made with data from "Report No. 1, Inertia Test of a 24 Ft Single Keel Parawing, Model 1" by LTV Aerospace Corporation. From this inertia vs. density curve, the estimate inertia vs. density curve for Model 2 was established.

The Yaw inertia was estimated from Report No. 1

In general, the shroud lines for Model 2 were about 15 percent shorter than those of Model 1. Also, Model 2 weighed 25.9 lbs. or about 3 pounds more than the first model and had about 1 percent more wing planform area.

FORMULAS

1. Inertia of Compound Pendulum (Pitch or Roll)

$$"I"_{\text{PEND KE}} = \frac{WLT^2}{4\pi^2}$$

2. Inertia of Parawing at the Knife Edge (Pitch or Roll)

$$"I"_{\text{WING KE}} = "I"_{\text{PEND KE}} - "I"_{\text{FRAME KE}} - "I"_{\text{FIN KE}} - I_{\text{TARES KE}}$$

3. Inertia of Parawing at the Center of Gravity (Pitch or Roll)

$$"I"_{\text{WING C.G.}} = "I"_{\text{WING KE}} - \frac{w}{g}(\Delta L)^2$$

4. Inertia of Parawing at the Harness (Pitch or Roll)

$$"I"_{\text{WING H}} = "I"_{\text{WING C.G.}} + \frac{w}{g}(\Delta L_H)^2$$

5. Inertia of Trifillar Pendulum (Yaw)

$$"I"_{\text{PEND}} = \frac{WT^2D^2}{16\pi^2 L_{\text{WIRES}}}$$

6. Inertia of Parawing Trifillar System (Yaw)

$$"I"_{\text{WING}} = "I"_{\text{PEND}} - "I"_{\text{FRAME}} - "I"_{\text{TARES}}$$

7. Rotation of Inertia from principal to body axis (See Sketch)

Given:

a. Inertia in Roll Axis $= I_X$

b. Inertia in Yaw Axis $= I_Z$

c. Inertia in Pitch Axis $= I_Y$

Find:

Rotate to Angle Λ

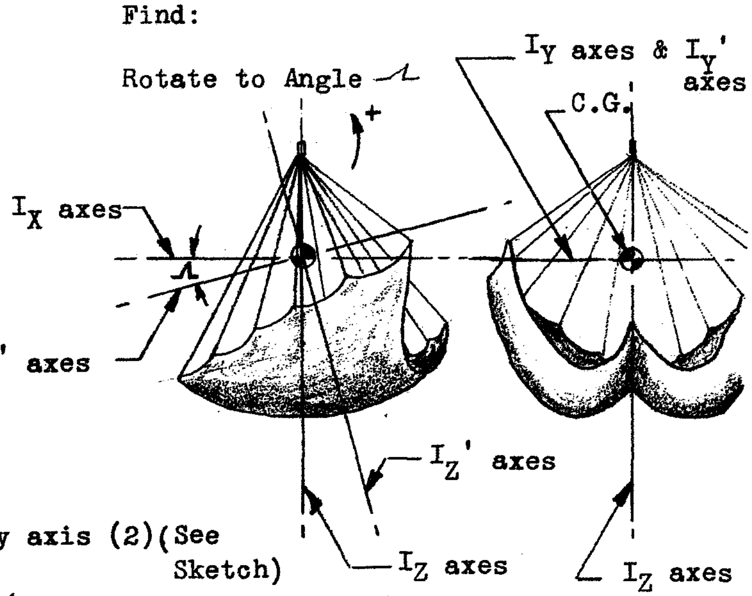
Solve:

a. $I_X' = I_X \cos^2\Lambda + I_Z \sin^2\Lambda$

b. $I_Z' = I_Z \cos^2\Lambda + I_X \sin^2\Lambda$

c. $I_Y' = I_Y$

d. $I_{ZX}' = (I_Z - I_X)\cos\Lambda \sin\Lambda$



8. Rotation from body axis (1) to body axis (2)(See Sketch)

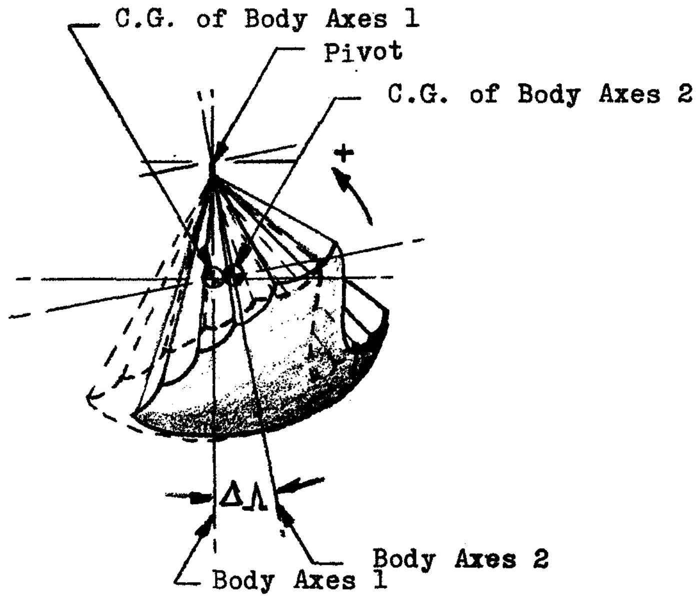
a. $I_{X_2} = I_{Z_1} \sin^2\Delta\Lambda + I_{X_1} \cos^2\Delta\Lambda - 2I_{XZ_1} \cos\Delta\Lambda \sin\Delta\Lambda$

b. $I_{Z_2} = I_{X_1} \sin^2\Delta\Lambda + I_{Z_1} \cos^2\Delta\Lambda + 2I_{XZ_1} \cos\Delta\Lambda \sin\Delta\Lambda$

c. $I_{Y_2} = I_{Y_1}$

d. $I_{XZ_2} = I_{XZ_1} (\cos^2\Delta\Lambda - \sin^2\Delta\Lambda) + (I_{X_1} - I_{Z_1}) \cos\Delta\Lambda \sin\Lambda$

8. Rotation of Body Axis (continued)



9. $\text{Density (Slugs/Ft}^3) = \dfrac{\text{Pressure } (\#/\text{Ft}^2)}{\text{R } (\text{Ft}^2/\text{Sec}^2 {}^\circ\text{R}) \times \text{T}^\circ\text{R}}$

10. Conversion Formulas:

a. ALTITUDE

Feet x .305 = Meters

b. INERTIA

$\text{Slugs}\cdot\text{Ft}^2 \times 1.356 = \text{Kg}\cdot\text{m}^2$

c. PRESSURE

(1) mmHg x 2.78446 = $\#/\text{Ft}^2$

(2) $\#/\text{Ft}^3 \times 47.880218 = \text{N/M}^2$

d. TEMPERATURE

(1) T°Fahrenheit + 460° = T°RANKINE

(2) T °R x .5555 = T°KELVIN

e. DENSITY

$\text{Slugs/Ft}^3 \times 515.379 = \text{Kgm/M}^3$

SYMBOLS

C.G.	Center of Gravity
K.E.	Knife Edge
T.P.	Trifilar Pendulum
D.	Diameter in Feet
ρ	Density Slugs/Ft^3
g	Gravity (32.16 Ft/sec^2)
H	Harness
ΔL_H	Length from Center of Gravity to Harness Pivot
I	Moment of Inertia in Slugs·Ft^2
L	Pendulum Length in Ft
ΔL	Length from C.G. to K.E. in Ft
R	1715 Ft^2/sec^2 °R
T°R	T°Rankine (Temp)
W	Weight in Lbs.
π	Pi (3.1416)
Σ	Summation
T	Period in sec/cyc
X	Roll Axis
Y	Pitch Axis
Z	Yaw Axis
XZ	Cross Product
X_F, Y_F, Z_F	Frame Stations, zero reference at apex
x	Distance along leading edge, ft.
θ	Linear Deflection, inches, from the oscillograph records, or deflection angle for an oscillation of the pendulum Assembly, deg
Λ	Angle between keel and horizontal reference, deg
C.B.	Counter Balance

LIST OF FIGURES

LIST OF TABLES

BIBLIOGRAPHY

1. Report No. 1 Inertia Tests of a 24 Foot Single Keel Parawing, Model 1, November 25, 1968; NASA CR-66744 by Dan O. Sumners, LTV Aerospace Corporation, Hampton, Virginia.

TABLE OF CONTENTS

SECTION 1
TEST OBJECTIVE

The purpose of this test is to establish the moments of inertia of the 24 Ft Single Keel Parawing Model 2 in the pitch and roll axes at sea level only. Yaw axes inertia is estimated.

The results of this series of tests are compared with the inertias of a 24 Ft. Single Keel Parawing Model 1. See "Report No. 1, Inertia Test of a 24 Ft. Single Keel Parawing Model 1" by Dan O. Sumners of LTV Aerospace Corporation.

SECTION 2

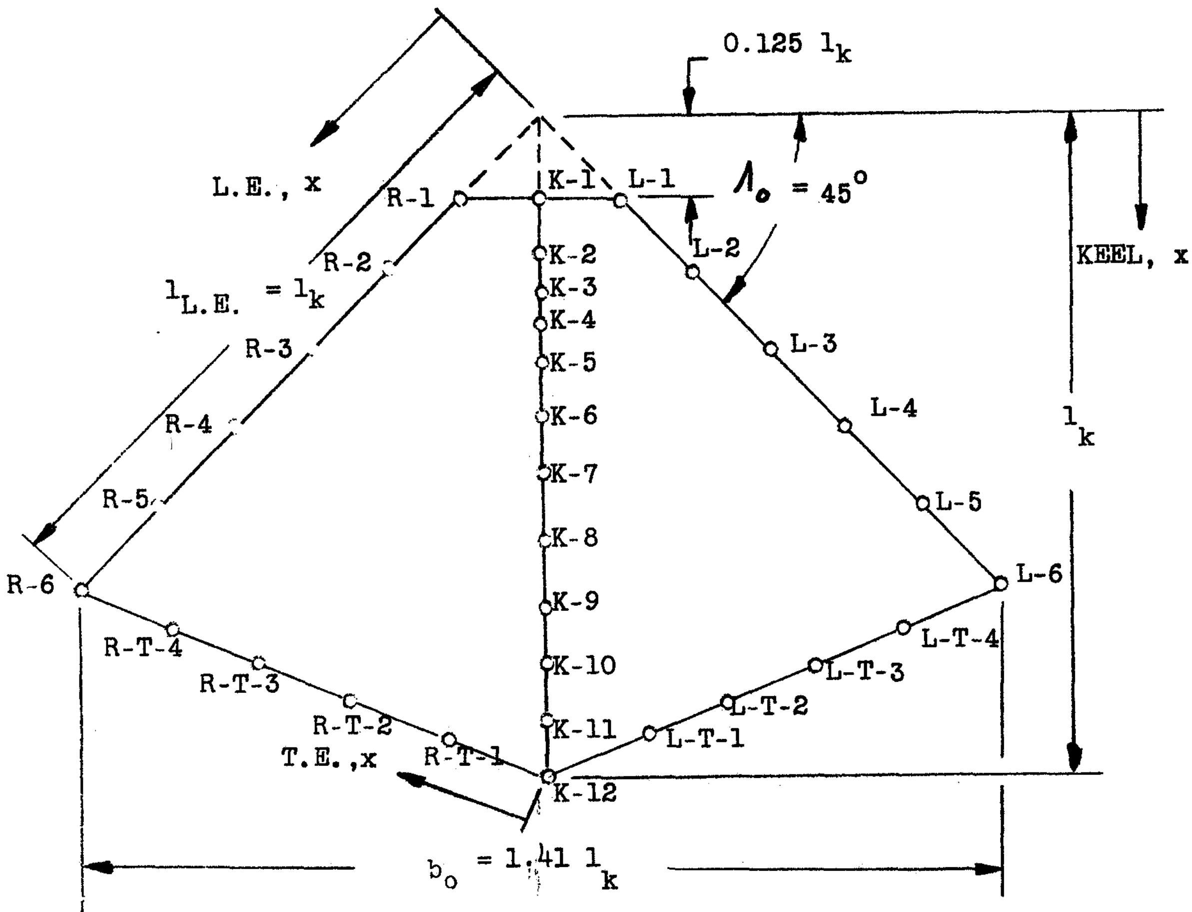
Basic engineering parawing design data:

The following figures record the design data for the 24 Ft Single-Keel Parawing, Model 2

Figure 2(a) - Fabric Design

Figure 2(b) - Shroud Line Lengths and Weights

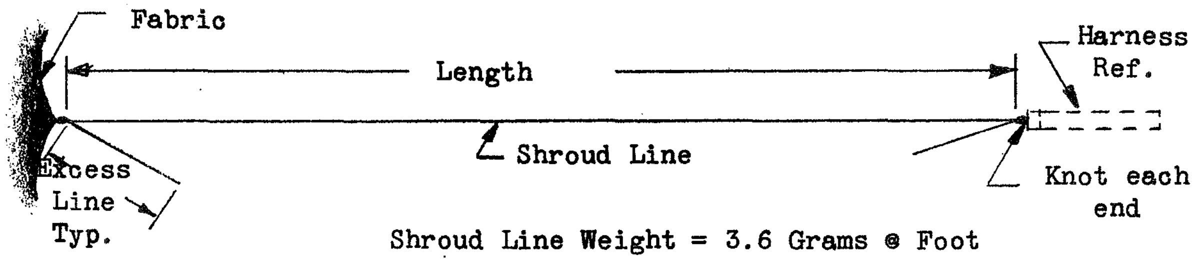
Figure 2(c) - Harness



x/l_k	x/l_k	x/l_k
KEEL	LEADING EDGE	TRAILING EDGE
x, K-1 = .125	x, L.E.-1 = .177	x, T.E.-1 = .150
x, K-2 = .210	x, L.E.-2 = .333	x, T.E.-2 = .275
x, K-3 = .291	x, L.E.-3 = .500	x, T.E.-2 = .450
x, K-4 = .333	x, L.E.-4 = .667	x, T E.-4 = .675
x, K-5 = .416	x, L.E.-5 = .833	
x, K-6 = .500	x, L.E.-6 = 1.000	
x, K-7 = .583		
x, K-8 = .667		
x, K-9 = .750		
x, K-10 = .833		
x, K-11 = .917		
x, K-12 = 1.000		

l_k = 24.0 Ft.

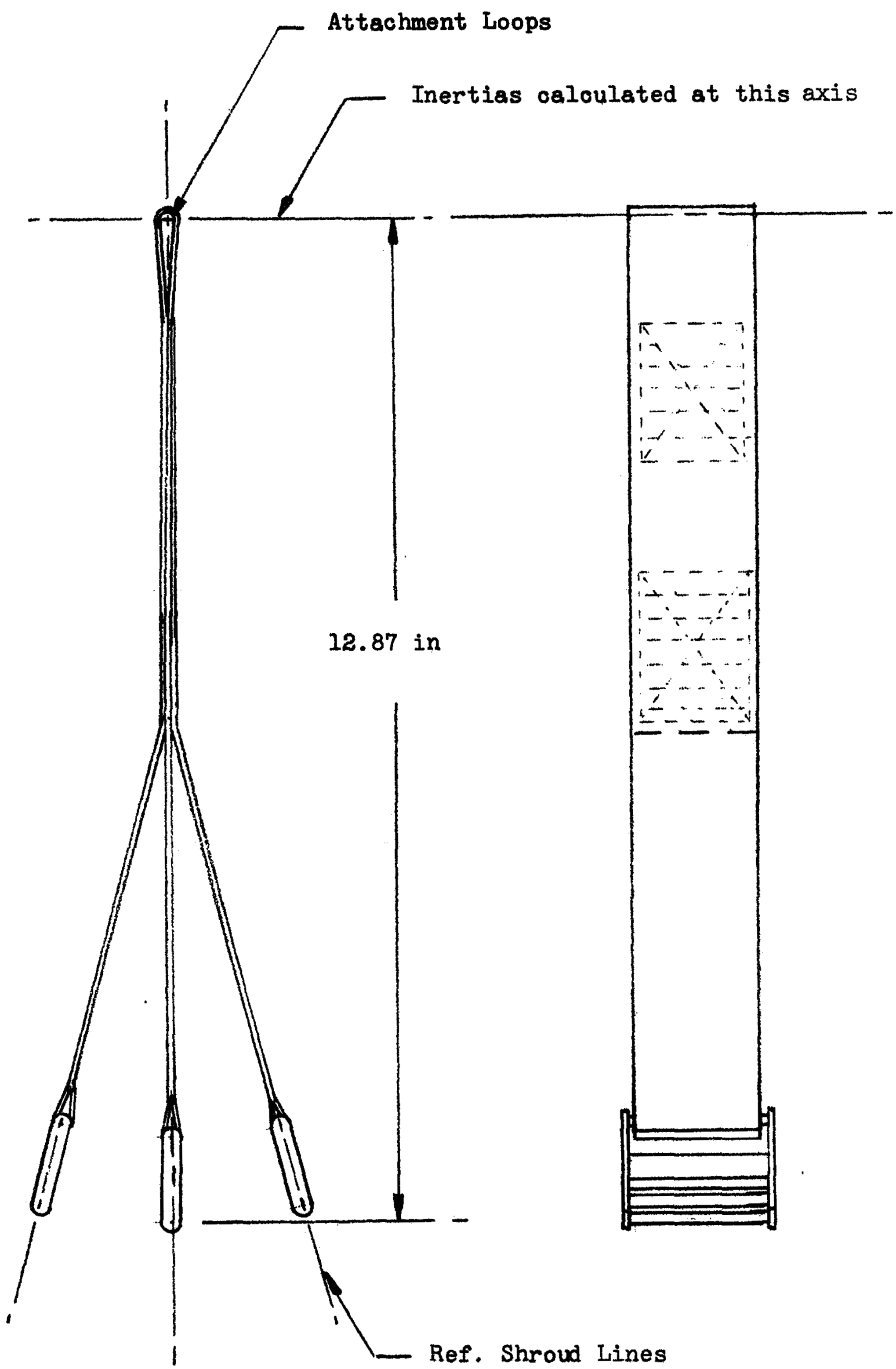
(a) Fabric Design
Figure 2 - Single Keel Parawing Design Data
Model 2, - No. 105-S NV



Shroud Line Weight = 3.6 Grams @ Foot
Weight of All Shroud Lines = 6.8379 Lbs

SHROUD LINE IDENTIFICATION	LINE LENGTH FT.	LINE WEIGHT LBS.	AVG. TWO (2) KNOT WEIGHT LBS.	AVG. TWO (2) EXCESS LINE WT. LBS.	TOTAL WEIGHT OF LINE LBS.
LEADING EDGE LINES					
L-1 or R-1	26.0	.206	.006	.0159	.2279
L-2 or R-2	24.75	.196	.006	.0159	.2179
L-3 or R-3	23.7	.188	.006	.0159	.2009
L-4 or R-4	22.0	.175	.006	.0159	.1969
L-5 or R-5	20.85	.1655	.006	.0159	.1874
L-6 or R-6	18.75	.1488	.006	.0159	.1707
KEEL LINES					
K-1	25.0	.2359	.006	.0159	.2578
K-2	25.55	.203	.006	.0159	.2249
K-3	25.8	.2048	.006	.0159	.2267
K-4	25.3	.201	.006	.0159	.2229
K-5	24.7	.196	.006	.0159	.2179
K-6	24.5	.194	.006	.0159	.2159
K-7	24.5	.194	.006	.0159	.2159
K-8	24.5	.194	.006	.0159	.2159
K-9	24.5	.194	.006	.0159	.2159
K-10	24.141	.192	.006	.0159	.2139
K-11	22.333	.177	.006	.0159	.1989
K-12	20.750	.1646	.006	.0159	.1865
TRAILING EDGE LINES					
L-T-1 or R-T-1	26.166	.2079	.006	.0159	.2298
L-T-2 or T-T-2	27.416	.2176	.006	.0159	.2395
L-T-3 or R-T-3	26.50	.210	.006	.0159	.2319
L-T-4 or R-T-4	22.5	.1786	.006	.0159	.2005

(b) - Shroud Lines Design
Figure 2 - Continued



(c) Harness Design
Figure 2 - Concluded

SECTION 3
TEST PROCEDURE

24 Ft. Single Keel **Parawing, Model 2** - Weight and Center of Gravity

A. Bundale Parawing assembly (Parawing, Shroud Lines, and Harness) and weigh on scales. 25.9 LBS

B. Center of Gravity of Parawing by Board Method (See Figure 3)

1. Suspend a board, approximately one (1) inch thick, 6 inches wide and 37 Ft. 2½ inches long parallel to floor with three (3) scales.
   See Figure No. 3.

2. Record weight of each scale and their location from end of board.
   Scale 1 12.0# Scale 2 16.9# Scale 3 10.3#

3. Stretch Parawing flat on the floor and pull all shroud lines straight from harness to attachment with sail, stretch the sail in the same manner and fold until Parawing is in a bundle with shroud lines straight.

4. Place Parawing on board without changing location of scales. Record distance of harness from end of board, and new weight of each scale.
   Scale 1 26.3# Scale 2 22.5# Scale 3 16.3#

5. Take moments about end of board for wing and board. Weight of board and Parawing = 65.1 LBS.

$$\Sigma \text{MOM} = 0$$
$$W_{TOTAL}\,(L'') = W_1 L_1 + W_2 L_2 + W_3 L_3$$
$$65.1\#\,(L'') = 22.5(79.5'') + 16.3\#(256.5'') + 26.3\#(373.5'')$$
$$L = 242.5921 \text{ inches}$$

6. Take moments about end of board for board alone.
   Weight of board = 39.2 LBS.

$$W_{BOARD}\,(L) = W_{B_1} L_1 + W_{B_2} L_2 + W_{B_3} L_3$$
$$39.2\,(L) = 16.9\#(79.5'') + 10.3\#(256.5'') + 12.0\#(373.5'')$$
$$L = 216.0076 \text{ inches}$$

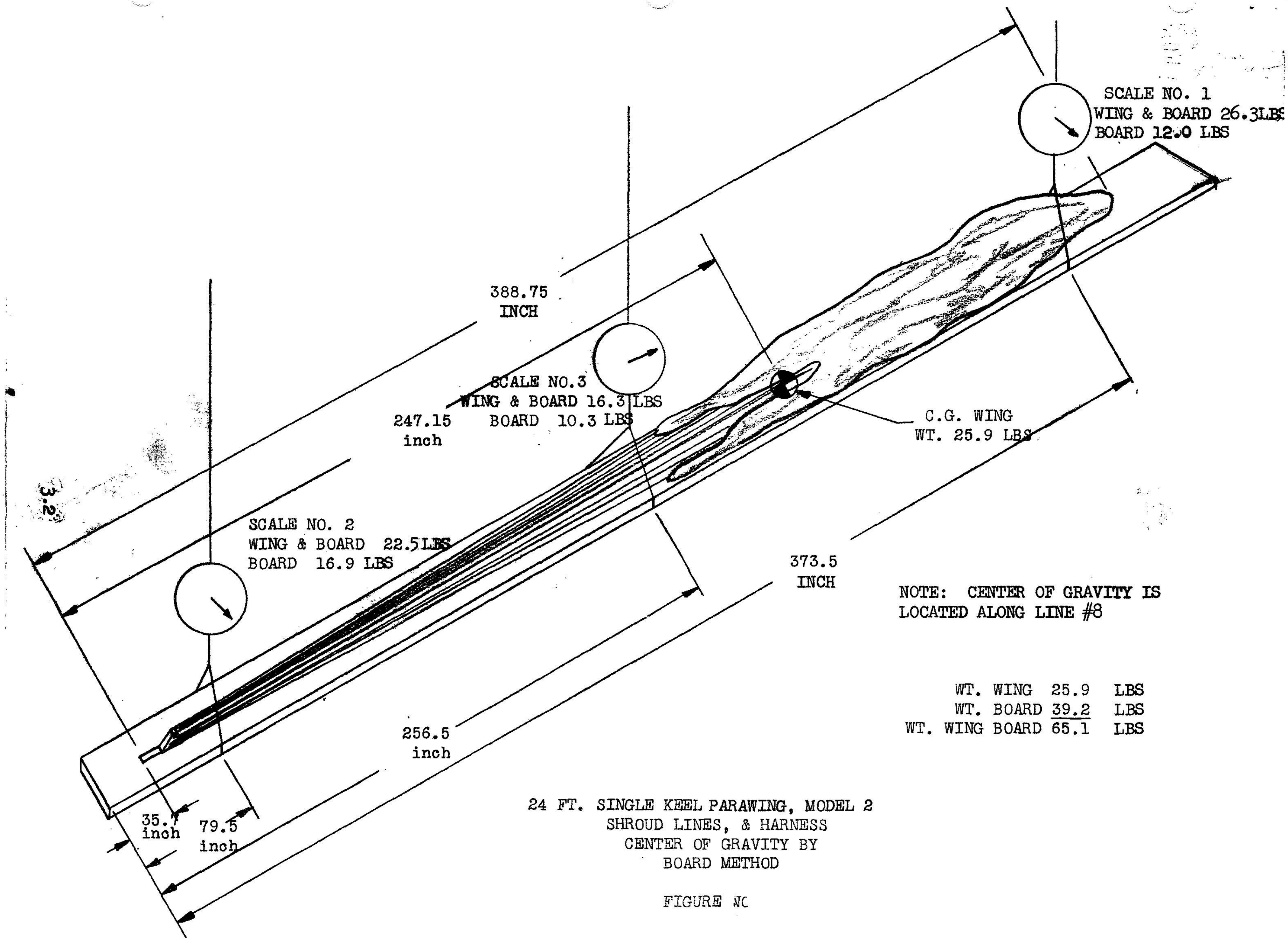
7. Take moments for wing alone.
   Weight of wing = 25.9 LBS

$$W_{WING}\,(L) = W_T(\Delta L_T) - W_B(\Delta L_B)$$
$$25.9\,(L) = 65.1\#(242.6'') - 39.2\#(216.008'')$$
$$L = 282.8473 \text{ inches}$$

8. Dimension from harness to center of gravity of Parawing.

$$\begin{array}{r} 282.8473 \\ -\ 35.70 \\ \hline 247.15 \end{array}$$ inches

9. By Design of Parawing center of gravity is near shroud line no. 8.



NOTE: CENTER OF GRAVITY IS LOCATED ALONG LINE #8

WT. WING	25.9	LBS
WT. BOARD	39.2	LBS
WT. WING BOARD	65.1	LBS

24 FT. SINGLE KEEL PARAWING, MODEL 2
SHROUD LINES, & HARNESS
CENTER OF GRAVITY BY
BOARD METHOD

FIGURE NO

SECTION 4
TARES

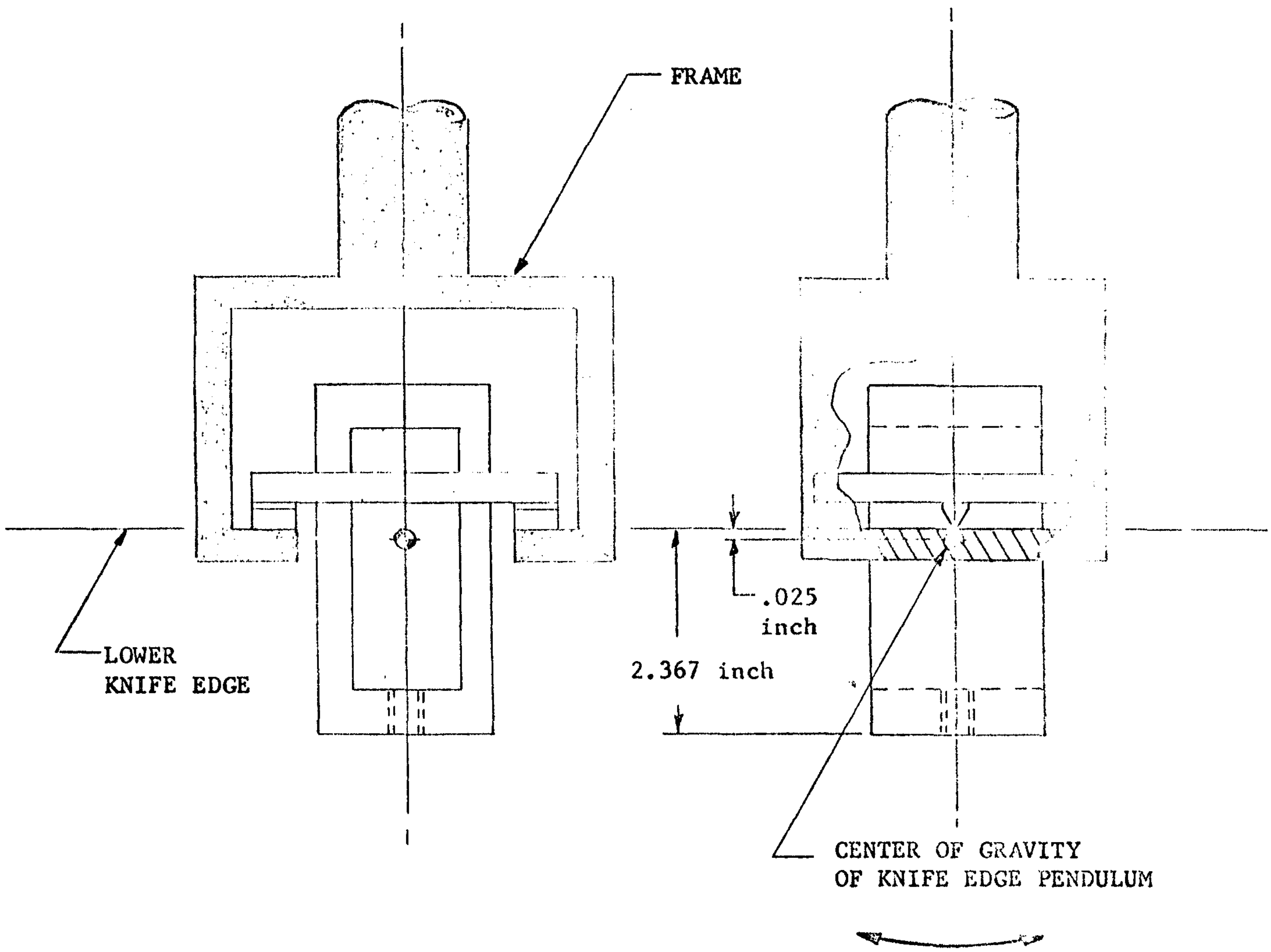
24 Ft Single Keel Parawing, Model 2 - Tares

A. Pendulum tares are listed as follows:

1. Standard knife edge is used with all pendulum tares; lower knife edge only. (See Figure 4)

2. 6 ft extension tares used in pitch and roll pendulum test for inertia. (See Figure 5)

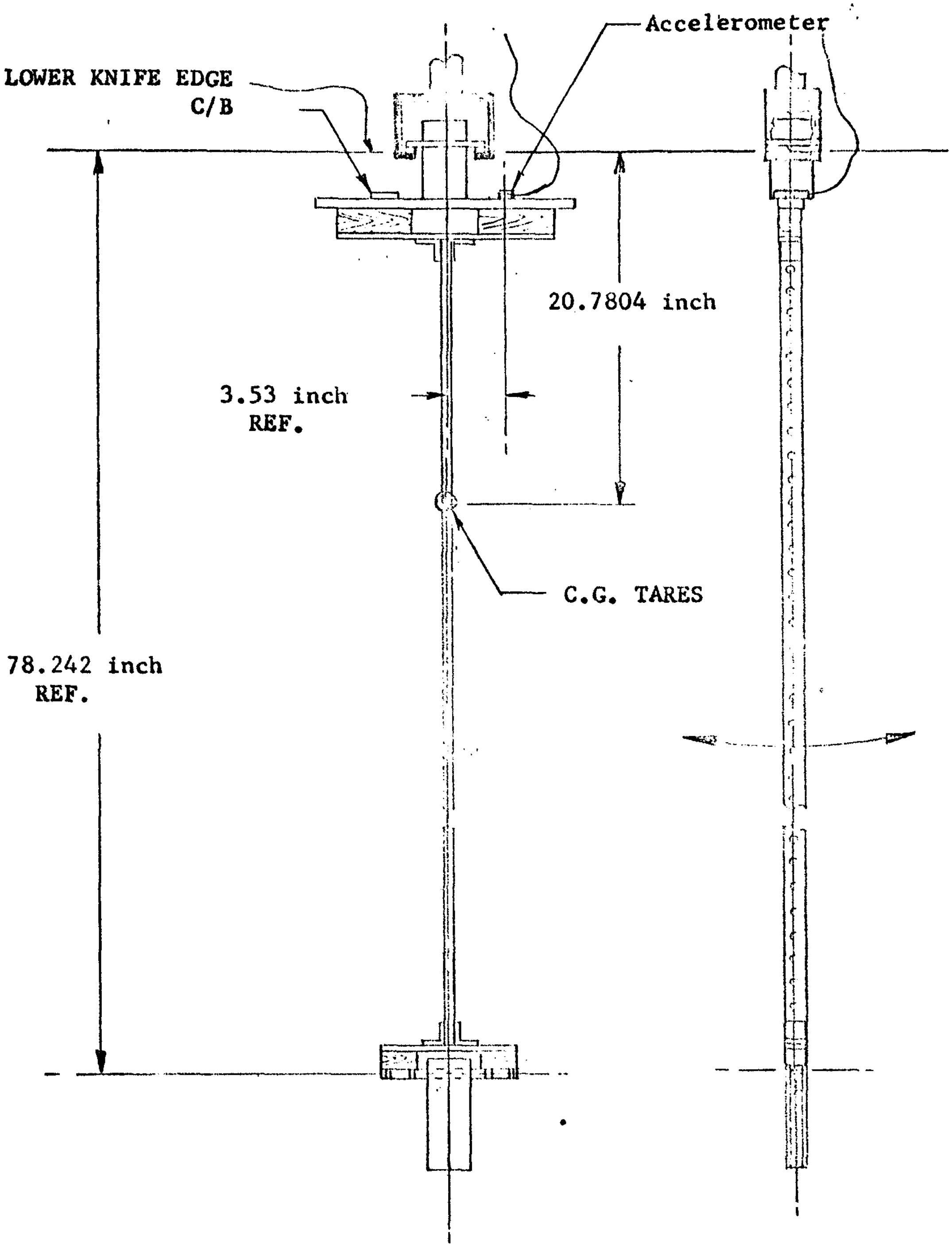
WEIGHT = 7.851 LBS
INERTIA = .0025 FT-LBS sec^2
"T"AVG = 2.49 sec/cyc



STANDARD KNIFE EDGE PENDULUM
LOWER KNIFE EDGE
FIGURE 4

COMBINED C.G. TO KNIFE EDGE = 20.7804 INCH OR 1.7317 FT.
TOTAL WEIGHT = 16.3822 LBS.

"T" AVG	=	2.5556 sec/cyc
$"T"^2$ AVG	=	6.53109 sec^2/cyc^2
"I" TARES K.E.	=	4.69325 slugg ft^2
"I" TARES C.G.	=	3.1656 slugs ft^2



SET UP C
LOWER KNIFE EDGE
6 FT. EXTENSION
TARES
FIGURE 5

SECTION 5

FRAME

24 Ft. Single Keel Frame - Weight, Center of Gravity, and Moments of Inertia

A. Frame Data Derived from Report No. 1

1. Weight - 23.45 lbs.
2. Center of Gravity - Z sta = 0
   (Station in inches) - Y sta = +1.99
   - X sta = 96.0
3. Frame moments of inertia about center of gravity with keel parallel to floor.

   Pitch = 16.92256 slugs·ft^2
   Roll = 20.23297 slugs·ft^2
   Yaw = 26.45905 slugs·ft^2

B. Frame Data Rotated for this Test

1. Weight - Same
2. Center of Gravity - Same
3. Frame Moments of Inertia about Center of Gravity with Keel rotated $9^\circ 17'$ to floor, which was the reference inclination.

   (a) Pitch inertia at center of gravity, I_Y.
   16.92256 slugs·ft^2 (same)

   (b) Roll inertia at center of gravity, I_X.
   $"I"_{FRAME\ C.G.} = "I"_{ROLL} (\cos^2\Lambda) + "I"_{YAW} (\sin^2\Lambda)$
   $"I"_{FRAME\ C.G.} = 20.23297\ (.98690)^2 + (26.45905)(.16132)^2$
   $"I"_{FRAME\ C.G.} = 20.394878$ slugs·ft^2 (estimated)

   (c) Yaw inertia at center of gravity, I_Z.
   $"I"_{FRAME\ C.G.} = "I"_{YAW} (\cos^2\Lambda) + "I"_{ROLL} (\sin^2\Lambda)$
   $"I"_{FRAME\ C.G.} = 26.45905\ (.97397)^2 + 20.23297\ (.16132)^2$
   $"I"_{FRAME\ C.G.} = 26.296822$ slugs·ft^2 (estimated)

   (d) Cross-products: the Z axis of the frame was aligned with the vertical axis of the pendulum knife edge making $I_{XZ\ FRAME\ C.G.} \cong 0$. For a $9^\circ 17'$ rotation, $I_{XZ\ FRAME} = (I_Z - I_X) \cos\Lambda \sin\Lambda$, $I_{XZ\ FRAME} = (26.296 - 20.395)(.97397)(.16132)$, $I_{XZ\ FRAME} = .927$ slugs·ft^2.

SECTION 6
OSCILLATION DEVICE

Solenoid Oscillation Device
See Figure 6

A. Purpose:

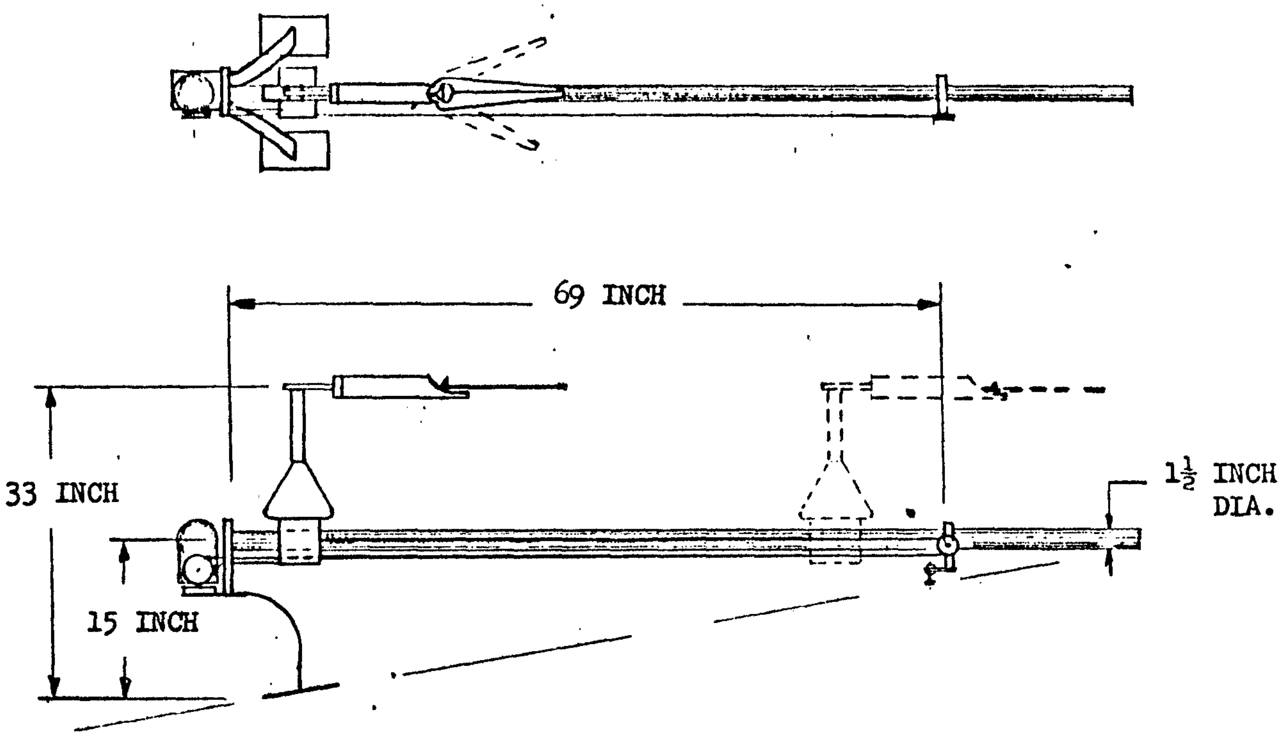
To oscillate pendulum assembly inside 60 ft sphere for both pitch and roll tests.

B. Operated from second floor control room of sphere.

C. Description:

1. Consists of two scissor arms actuated by a solenoid to hole or release a line attached parawing.

2. Scissor assembly is moved forward or backward on a rod by a system of cables activated by a variable speed motor with reverse direction control.



SOLENOID OSCILLATING DEVICE
FIGURE 6

SECTION 7

FIN

FIN FOR ROLL TEST INSIDE 60 FT SPHERE

A. Purpose (See Figure 7) is to equalize air resistance of parawing pendulum assembly which has a tendency to yaw without the fin.

B. Fin is attached to forward keel shroud lines located to balance sail area of aft portion of parawing.

C. Fin is made of .004 thick plastic.

FIN
WEIGHT = .5467 LBS
AREA = 30.68 FT^2
THICKNESS = .004 in
INERTIA C.G. = .04489 $SLUGS \cdot FT^2$

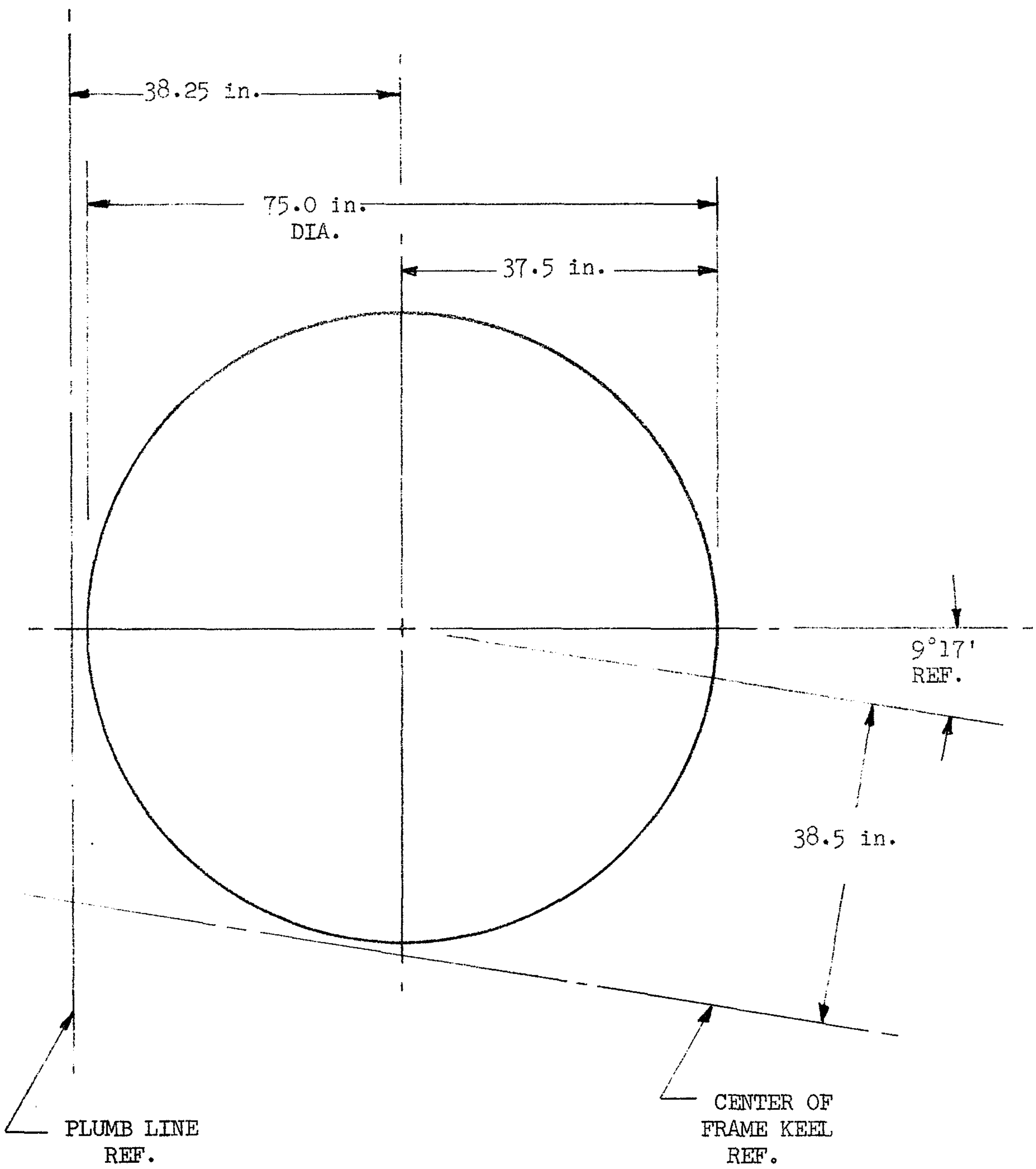


FIGURE 7 - FIN FOR ROLL TEST ONLY.

SECTION 8
PENDULUM TESTS

24 Ft Single Keel Parawing, Model 2 - Pendulum Test.
Pitch and Roll Periods.

The following Pendulum Tests were conducted to determine the periods for pitch and roll tests for each assembly at sea level altitude. The test was conducted in the 60 ft sphere with the 6 ft extension; lower knife edge, tares; 24 ft single keel frame, 24 ft single keel parawing; and fin used in roll only.

The pendulum periods are used to calculate the moments of inertia. The stop watch periods and linear deflection records, for each individual pendulum test, follows each test description.

Figure 8 is a photograph of the Langley 60 ft vacuum sphere facility. Figure 9 shows the parawing assembly in the sphere with a stabilizing fin for roll test.

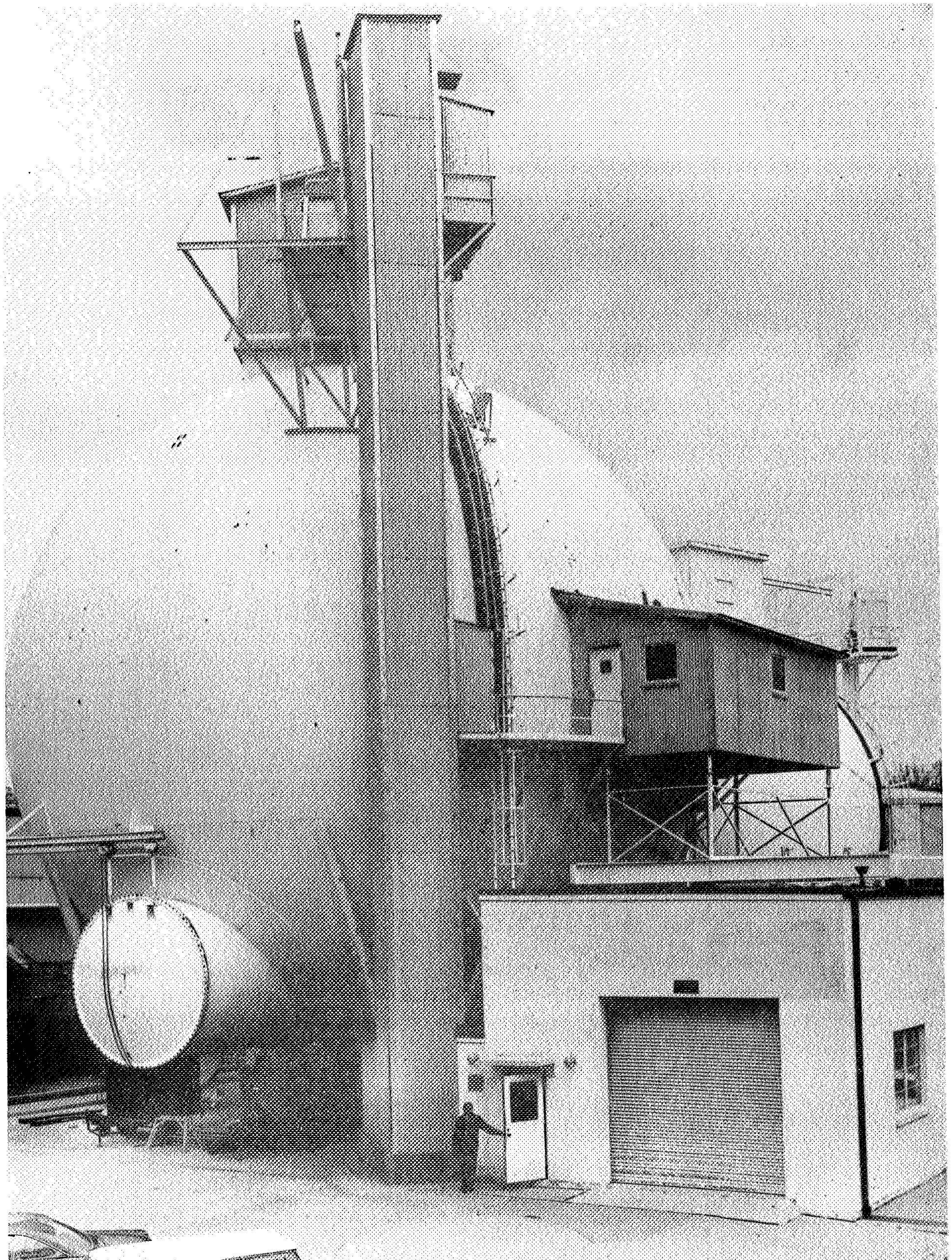


FIGURE 8 - 60 FT DIAMETER VACUUM SPHERE

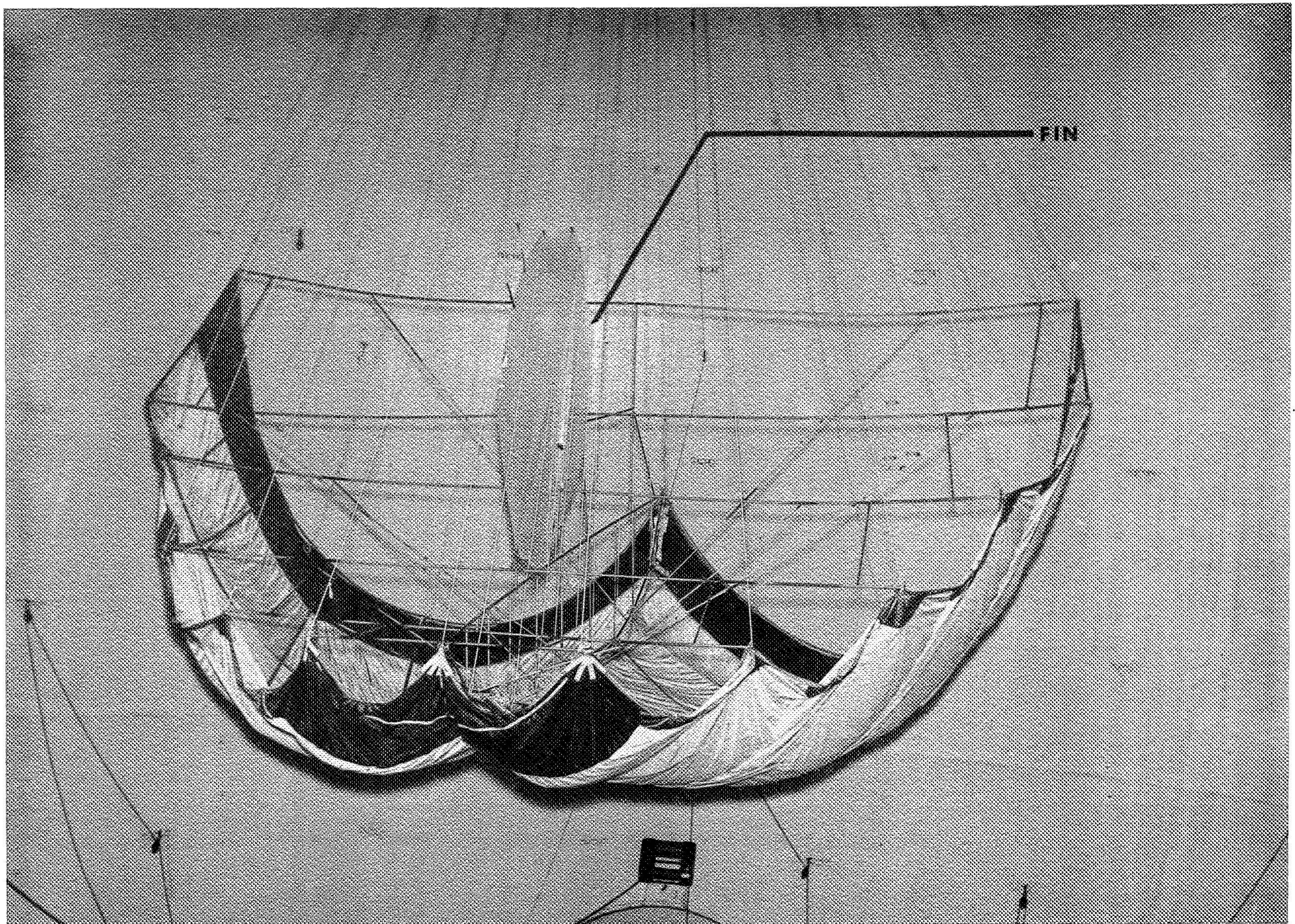


FIGURE 9 - A 24 FT SINGLE KEEL PARAWING, MODEL 2,
PENDULUM TEST
ROLL WITH FIN

SECTION 8
PENDULUM TEST NO. 1
OUTLINE

Pendulum Test - 24 Ft Single Keel **Parawing, Model 2**, Shroud Lines, Harness, Frame, and Tares.

PITCH INERTIA "6FT" EXT. TARES
(Figure 10)

A. EQUIPMENT
   1. Tares (Figure 5) - 6 Ft Ext. Set-up C Lower Knife Edge.
   2. Parawing Assembly.
   3. Frame (24 Ft Single Keel).
   4. Two (2) Accelerometers, "3G", installed on Tares for oscillation, Quick Look and Permenant Record.
   5. Solenoid Oscillating Device.
   6. Plumb Bob Attached to 50 Ft. Tape.
   7. Hoist.

B. TEST CONDUCTED AT THE FOLLOWING ALTITUDE:

Altitude	Pressure	Temperature
Sea Level	760 mmHg	530°R

C. TEST SET-UP PROCEDURE FOR TEST NO. 1
   1. Assemble Frame and Suspend Approximately One (1) Ft. Above Floor Inside Sphere.
   2. Attach Parawing to Frame.
   3. Attach Harness to Hoist and Lift Parawing to Five (5) Ft. Above Floor.
   4. Measure Points on Parawing to Floor for Keel Angle.
      (a) FWD Keel to Floor 41 inches
      (b) AFT Keel to Floor 72 inches
      (c) Angle of Keel to Floor 9°17'
   5. Hoist Assembly to Top of Sphere and Install Tares; 6 Ft. Ext., Set-up C, Lower Knife Edge.
   6. Install Accelerometers, (two), on Tares.
   7. Install Oscillating Device and Pull Line.
   8. Test Oscillation of Pendulum in Pitch Plane.
   9. Drop Plumb Line and Measure Distance From Knife Edge to Frame, 33.516 Ft.
   10. Pull Assembly AFT Three (3) Feet with Solenoid Oscillating Device, Hold Position until Settled and Steady. Release and After a Smooth Swing is Noted, Two people with Stop-Watches take Cycle Counts. Run Oscillograph Records one minute at .25"/sec.
   11. Repeat No. 10 for Three (3) Tests.

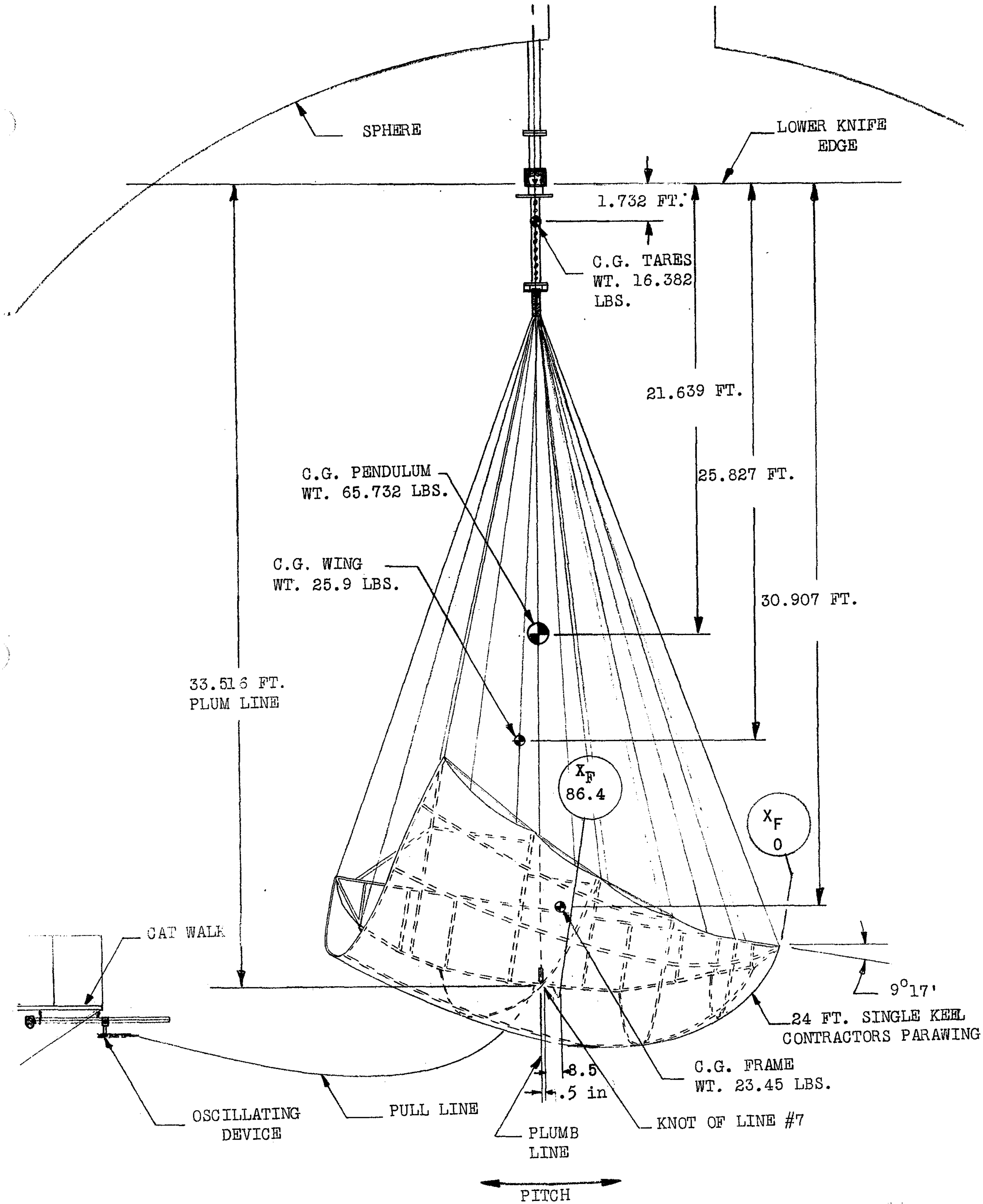


FIGURE 10.- PITCH PENDULUM, 6 FT, LOWER KNIFE EDGE, 24 FT SINGLE KEEL PARAWING, MODEL 2

TABLE 1
24 FT. SINGLE KEEL
FARAWING, MODEL 2
SHROUD LINES, & HARNESS,
TARES & FRAME IN 60 FT. SPHERE
PENDULUM TEST
STOP WATCH RECORD
PITCH

TEST NO. 1-6 FT. EXT. OSC RECORD NO. 7875 to 78 PITCH

ALTITUDE Sea Level PRESSURE 760 mmHg TEMPERATURE $530^{\circ}R$

TEST NO.	CYCLES	STOP WATCH NO. 1JM	STOP WATCH NO. 2NH	T sec/cyc AVE.
1	5	33.2 sec	33.2 sec	
2	5	33.0	33.1	
3	5	33.1	33.1	

$$30 \overline{)\begin{array}{r}198.7\\198.7\end{array}} \quad 6.6233 = \text{"T" avg. } \frac{\text{sec}}{\text{cyc}}$$

TABLE 2
24 FT SINGLE KEEL PARAWING,
MODEL 2, INERTIA TESTS

Test No. 1, Run No. 07875 76,77,78, Date 10/10/68

Wing NV 24' Single K, Mode Pitch Pend. 6 Ft.

Press. 760 mmHg, Alt. S. L. Time Scale Factor 4.0 sec/in

Temp. $70^{o}F$, Amplitude Factor 2.141 deg/in

PEAKS	θ_{max}, in	$\left(\frac{\theta}{\theta_{0\,max}}\right)$	
0	.680	1.0	
1	.495	.728	
2	.375	.551	
3	.300	.441	
4	.245	.360	
5	.208	.305	
6	.175	.257	
7	.145	.213	
8			
9			
10			

Time for n cycles = 11.52 in = 46.08 sec

n = 7

T = 6.583 sec/cycle

SECTION 8
PENDULUM TEST NO. 2
OUTLINE

Pendulum Test - 24 Ft Single Keel Parawing, Model 2, Shroud Lines, Harness, Frame, and Tares.

ROLL INERTIA "6 FT" EXT TARES
(Figure 11)

A. EQUIPMENT
   1. Fin - 75 inch diameter. (Figure 7)
   2. All other equipment to be the same as for Test No. 1.

B. TEST CONDUCTED AT THE FOLLOWING ALTITUDES:

Altitude	Pressure	Temperature
Sea Level	760 mmHg	$530^{\circ}R$

C. TEST SET-UP PROCEDURE FOR TEST NO. 2
   1. Add fin per Figure 7.
   2. Rotate pendulum assembly 90° at attack point with base on knife edge.
   3. Relocate pull line at bottom of parawing.
   4. Same as for Test No. 1.

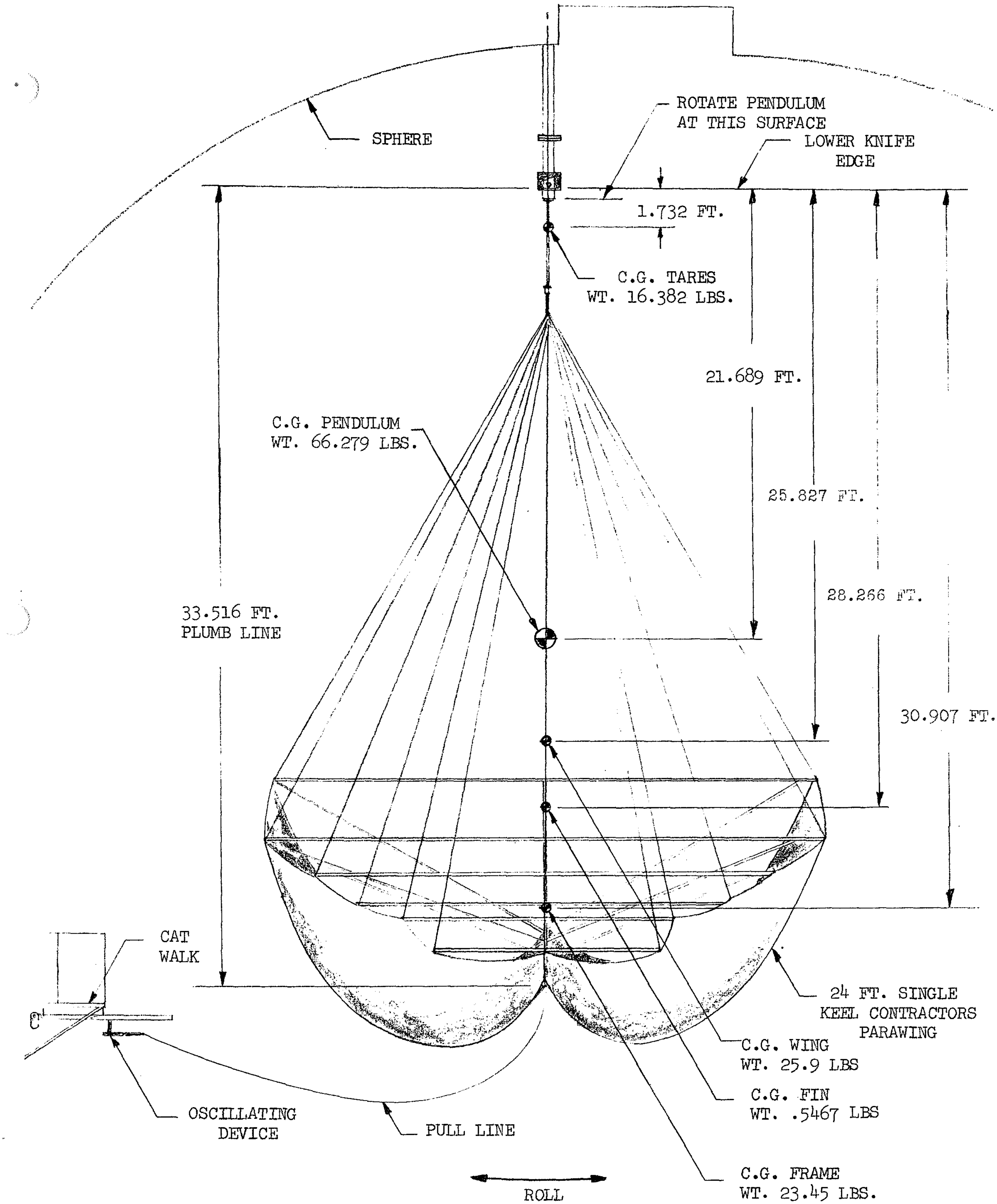


FIGURE 11 - ROLL PENDULUM, 6FT. EXT., LOWER KNIFE EDGE,
24 FT. SINGLE KEEL PARAWING, MODEL 2

TABLE 3
24 FT. SINGLE KEEL
PARAWING, MODEL 2
SHROUD LINES, & HARNESS,
TARES, & FRAME IN 60 FT. SPHERE
PENDULUM TEST
STOP WATCH RECORD
ROLL

TEST NO. 2-6Ft. Ext. OSC. RECORD NO. 7880 to 83 ROLL

ALTITUDE Sea Level PRESSURE 760 mmHg TEMPERATURE 530°R

TEST NO.	CYCLES	STOP WATCH No. 1JN	STOP WATCH No. 2NH	
1	3	24.4sec	24.4 sec	
2	3	24.6	24.3	
3	3	24.2	24.2	

$18 \overline{)146.1} = 8.1166$ = "T" avg. $\frac{sec}{cyc}$

TABLE 4
24 FT SINGLE KEEL PARAWING,
MODEL 2, INERTIA TESTS
07880

Test No. 2 , Run No. 81,82,83 Date 10/10/68

Wing NV 24' Single K , Mode Roll Pend. 6 Ft.

Press. 760 mmHg , Alt. S. L. , Time Scale Factor 4.0 sec/in

Temp. 70°F , Amplitude Factor 2.141 deg/in

PEAKS	θ_{max}, in	$\left(\frac{\theta}{\theta_o}\right)_{max}$	
0	.505	1.0	
1	.260	.515	
2	.160	.317	
3	.110	.218	
4	.083	.163	
5	.060	.119	
6			
7			
8			
9			
10			

Time for n cycles = 10.30 in = 41.21 sec

n = 5

T = 8.24 sec/cycle

8.10

SECTION 9

TEST DATA AND INERTIAS

This section contains the period and inertia summary for both pendulum tests conducted in the 60 ft. sphere. Table 5 records all environmental data: date, pressure, temperature, density, and moisture content of air, related to each test. The table also records the following inertias:

1. Inertia of pendulum at the knife edge
2. Inertia of Parawing at the knife edge
3. Inertia of Parawing at the center of gravity
4. Inertia of Parawing at the harness

Sample calculations are shown for computing density and inertia for Test No. 2, roll, (6 ft. ext. tares). The methods apply for all compound pendulum tests. Yaw inertia was estimated using the sea level period for the 24 ft. Single Keel Parawing in Report No. 1 and the mass and center of gravity of model 2. The actual yaw period may be less than shown resulting in a lower inertia at the harness.

The average curves, Figure 12(a) and 12(b), record the calculated points at 760 mmHg pressure for the model 2 parawing. The solid lines are the average curves in pitch and roll axis for the model 1 parawing taken from Report No. 1. The dotted lines are the estimated inertia vs density average curve for model 2.

The inertia calculation at the harness end are taken where the harness loop is located (see Fig. 2c). This tie down point was selected for the inertias instead of the confluent point because it is intended that the inertia of the entire wing assembly be made readily available for use in data analysis. It should be noted, that the plumb line is the vertical reference for these results. Calculation showed that the vertical axis through the center of gravity of the wing was rotated only 48 minutes counter clockwise from the point of the plumb line. This gives a value of I_{XZ} of about -1.3 slugs$\cdot$ft^2. This result was confirmed by an analytical program which was set up by the Flexible Wing Section of Full Scale Research Division for the calculation of inertias in a vacuum.

All tares are subtracted from the summary data except for the apparent masses associated with the stabilizing fin of the roll test and for the transfer of trapped air inertia of the wing from the pendulum knife edge to the harness reference. The trapped air inertias are approximately equal to those for model 1 (ref. 1) since both wings were simular. This latter correction is out of the scope of this paper and, therefore, has not been made.

The inertia estimates in figure 12(a) and 12(b) were extrapolated approximately 18,000 ft. altitude only. Another test point should be established in the lower density environment before the estimated inertia curves can be completed with any degree of accuracy.

Sample Calculations Pendulum Test No. 2, Roll

1. Density

    Given:

    1. Pressure = 760 mmHg
    2. Temperature = 530°R
    3. R_{AIR} = 1715 FT^2/sec^2 °R

    Find: Density

    Formula:

    $$\rho = \text{Pressure } \#/Ft^2 \;/\; R\ Ft^2/sec^2\ {}^\circ R$$

    $$\rho = 760 \times 2.78446/1715 \times 530^\circ R$$

    $$\rho = .00232816 \text{ slugs}/ft^3$$

2. Density Altitude = 700 feet.

Sample Calcualations Pendulum Test No. 2, Roll

Inertias: (Figure 11)
Given:

Weights	
Parawing Weight	25 lbs.
Frame Weight	23.45 lbs.
Tares Weight	16.3822 lbs.
Fin Weight	.5467 lbs.
Combination Weight	66.2789 lbs.

Roll Inertia	
"I"$_{\text{FRAME C.G.}}$	20.3949 slug·ft^2
"I"$_{\text{TARES K.E.}}$	4.69325 slugs·ft^2
"I"$_{\text{FIN C.G.}}$	.04490 slugs·ft^2

Length of Knife Edge	
Parawing C.G. to K.E.	25.827 Ft
Frame C.G. to K.E.	30.907 Ft
Fin C.G. to K.E.	28.2656 Ft
Parawing C.G. to Harness	15.167 Ft
Combination C.G. to K.E.	2.6885 Ft

Period Based on Oscillograph Record		
Period	"T"	8.24 sec/cyc
	"T"	67.8976 sec/cyc

Sample Calculations Pendulum Test No. 2, Roll
(Continued)

Find: @ Sea Level Altitude for Roll Axis

1. Fin inertia at knife edge
2. Frame inertia at knife edge
3. Pendulum inertia at knife edge
4. Parawing inertia at knife edge
5. Parawing inertia at center of gravity
6. Parawing inertia at harness end.

1. Fin Inertia at Knife Edge (Roll)

$$"I"_{FIN\ K.E.} = "I"_{FIN\ C.G.} + \frac{w}{g}(\Delta L)^2$$

$$"I"_{FIN\ K.E.} = .04489 + \frac{.5467}{32.16}(27.26558)^2$$

$$"I"_{FIN\ K.E.} = 12.682 \text{ slugs}\cdot\text{ft}^2$$

2. Frame Inertia at Knife Edge (Roll)

$$"I"_{FRAME\ K.E.} = "I"_{FRAME\ C.G.} + \frac{w}{g}(\Delta L)^2$$

$$"I"_{FRAME\ K.E.} = 20.394878 + \frac{23.45}{32.16}(30.90669)^2$$

$$"I"_{FRAME\ K.E.} = 716.915178 \text{ slugs}\cdot\text{ft}^2$$

3. Pendulum Inertia at Knife Edge

$$"I"_{PEND\ K.E.} = \frac{WLT^2}{4\pi^2}$$

$$"I"_{PEND\ K.E.} = \frac{(66.2789)(21.689)(8.24)^2}{39.478}$$

$$"I"_{PEND\ K.E.} = 2472.37 \text{ slugs}\cdot\text{ft}^2$$

4. PARAWING INERTIA AT KNIFE EDGE

$$"I"_{WING\ K.E.} = "I"_{PEND\ K.E.} - "I"_{TARES\ K.E.} - "I"_{FRAME\ K.E.} - "I"_{FIN\ K.E.}$$

$$"I"_{WING\ K.E.} = 2472.374 - 4.693 - 716.9152 - 12.6824$$

$$"I"_{WING\ K.E.} = 1738.08 \text{ slugs}\cdot\text{ft}^2$$

5. Parawing Inertia at Center of Gravity

$$"I"_{WING\ C.G.} = "I"_{WING\ K.E.} - \frac{w}{g}(\Delta L)^2$$

$$"I"_{WING\ C.G.} = 1738.08 - \frac{25.9}{32.16}(25.827)^2$$

$$"I"_{WING\ C.G.} = 1200.89 \text{ slugs}\cdot\text{ft}^2$$

6. Parawing Inertia at Harness

$$"I"_{WING\ H} = "I"_{WING\ C.G.} + \frac{W}{g} (\Delta L_H)^2$$

$$"I"_{WING\ H} = 1200.89 + \frac{25.9}{32.16} (15.167)^2$$

$$"I"_{WING\ H} = 1386.19 \text{ slugs} \cdot \text{ft}^2$$

TABLE 5

24 FT. SINGLE KEEL PARAWING, MODEL 2,
FABRIC, SHROUD LINES, & HARNESS
PENDULUM TEST IN THE 60 FT. SPHERE
PENDULUM ASSEMBLY INCLUDES WING, FRAME & TARES
6 FT. EXT. LOWER KNIFE EDGE

TEST DATA AND CALCULATED INERTIAS

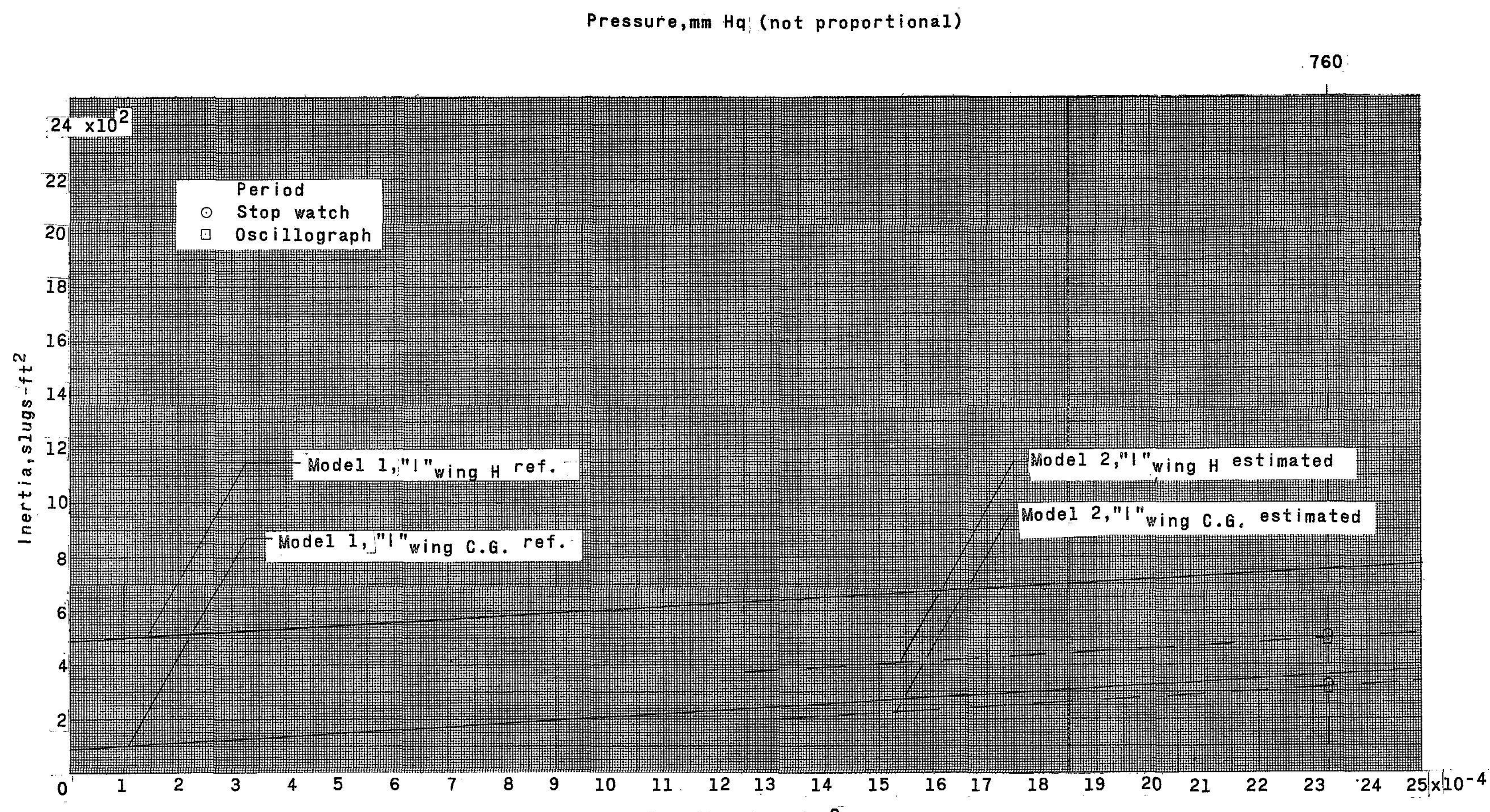
DATE	TEST NO.	PRES. mmHg	ALTITUDE FT.	TEMP. °RANKIN	DENSITY SLUGS/FT^3	MOIST* GR/1#AIR	PERIOD OSC**	PERIOD S.W.***	"I" WING KE SLUGS·FT^2	"I" WING CG SLUGS·FT^2	"I" WING CG$_2$ SLUGS·FT^2	"I" WING H SLUGS·FT^2
OCT. 10 1968	1 PITCH	760	0	530°R	.00232816	70	6.583		1561.00	842.87	305.69	489.64
								6.623	1580.02	861.88	324.70	508.66
OCT. 10 1968	2 ROLL	760	0	530°R	.00232816	70	8.240		2472.37	1738.08	1200.89	1386.19
								8.117	2398.88	1664.59	1127.39	1312.65
SEE NOTE	YAW	760	0	529°R	.00233202	70						
							EST.	33.372	67.37		33.04	33.04

NOTE:

1. Yaw tests were not conducted. The figures shown are an estimate based on Model 1, 24 ft. single keel. Yaw test, tolerance for estimated yaw period, ±1.0 sec/cyc, and tolerance for inertias, ±4.0 slugs·ft^2.

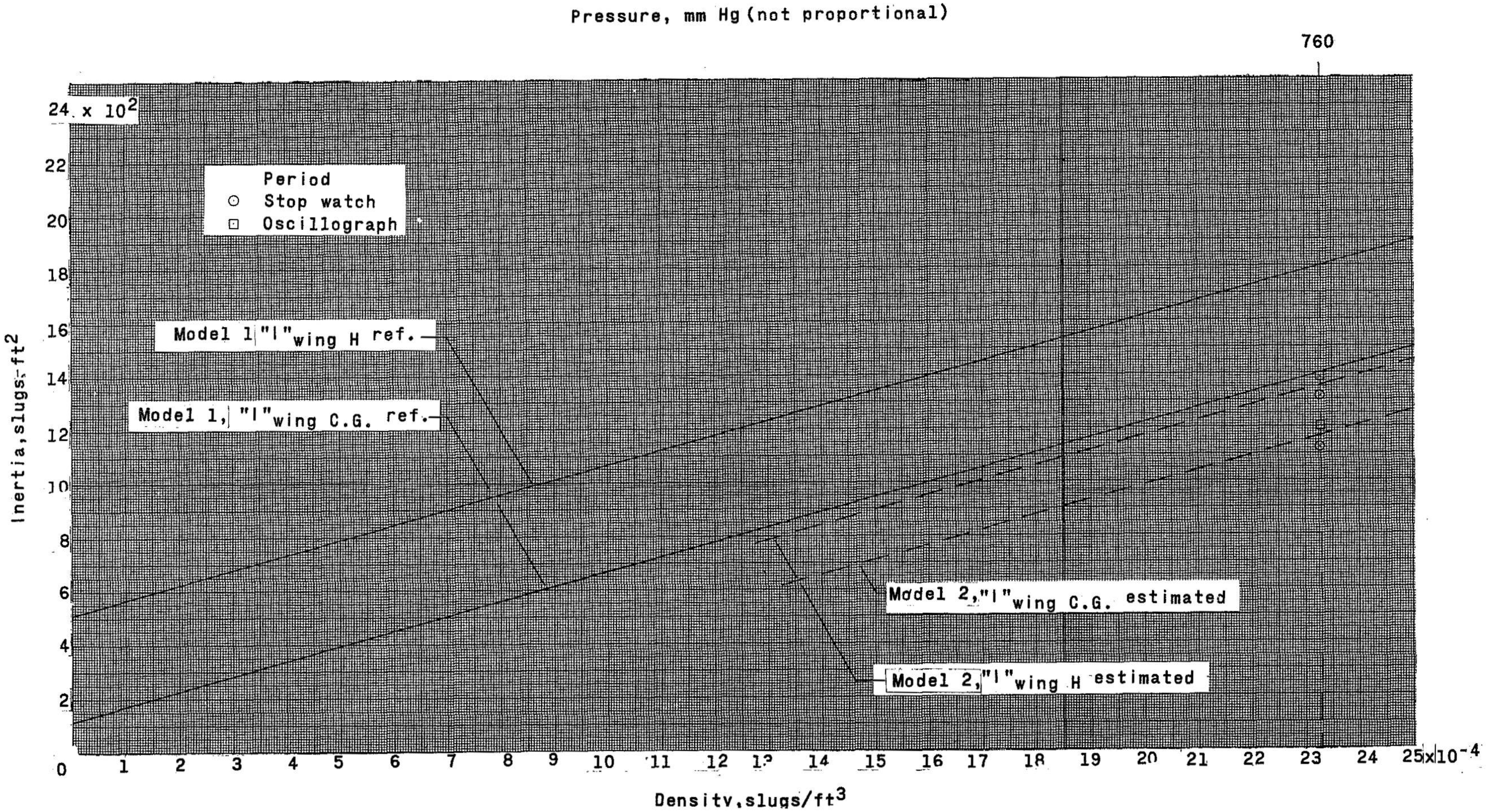
2. $I_{XZ} = -1.3$ slugs·ft^2 reference to the plumb line, the vertical axis is the plumb line for the wing and frame and tares and is rotated about the pivot, 48 minutes counter clockwise from the axis of the isolated wing.

* Grains/1#Air - Weight of water vapor in one pound of dry air
** OSC. Period, sec/cyc - Oscillograph Record
*** S.W. Period, sec/cyc - Stop Watch Record
**** H - Harness



(a) Pitch

Figure 12.- Moments of inertia vs density curves of 24 ft. single keel parawing + lines + harness, Model 2.



(b) Roll

Figure 12.- Concluded.

SECTION 10

DISCUSSION OF ACCURACY

A. The accuracy of measurements relative to mean values are estimated to be as follows:

1.	Center of gravity location	.166 ft.
2.	Stop watch period (5 cycles)	.1 sec/cyc.
3.	Oscillograph record period (7 cycles)	.05 sec/cyc.
4.	Moment of inertia about knife edge	20 $slugs \cdot ft^2$
5.	Moment of inertia about harness	20 $slugs \cdot ft^2$
6.	Moment of inertia about center of gravity	20 $slugs \cdot ft^2$
7.	Sphere pressure	2%
8.	Sphere temperature	2%

B. The inertia calculations are based on the parawing keel angle of 9^{o} 17' with the horizontal. If the accrual flight angle is different, then the inertias should be rotated to obtain the correct flight data.

Cross products of inertia, I_{XZ}, are required to accurately rotate the reference axis. The cross-products were calculated for vacuum conditions and are believed quite accurate, since good agreement was obtained between the measured and calculated moments of inertia in pitch, roll, and yaw for no air.

SECTION 11

The data contained in this report is recorded in English units. Table 6 shows the data converted into metric units.

TABLE 6

DATA CONVERSION FROM ENGLISH SYSTEM
TO METRIC SYSTEM

(a) Temperature

English System		Metric System	
(°F) Fahrenheit	(°R) Rankine	(°K) Kelvin	(°C) Centigrade
69°	529°	38.33°	20.55°
70°	530°	38.89°	21.11°

(b) Pressure

Gage Reading		Metric System	
mmHg	Related Altitude Ft.	Newtons/Meters^2	Related Altitude Meters
760	Sea Level	101,323.6	Sea Level

(c) Density

English System		Metric System	
Slugs/Ft^3	Related Altitude Ft.	Kgm/m^3	Related Altitude Meters
.00232816	700	1.1998477	213.5
.00233202	700	1.20118741	213.5

SECTION 12

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