HINGE MOMENTS

Thesis by

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HINGE MOMENTS

Introduction

The matter herein presented represents the results of an investigation on hinge moments of ailerons on a 1/12.5 scale model of a main wing airfoil of the XP3D-1 Navy Patrol Boat[1)].

The data obtained were then employed in the calculation of stick forces due to aileron moments on the full scale airplane, the calculations covering a flying range of eighty to one hundred eighty miles per hour.

Description of Apparatus

The aileron was a 1/12.5 scale model of a main wing airfoil of the XP3D-1 Navy Patrol Boat having the N.A.C.A. #2218 airfoil section at the root and the N.A.C.A. #2211½ airfoil section at the tip. Aspect ratio equals 6.97 and span 91.25 inches (232 cm.). The aileron span was 24 inches (60.96 cm.) and the aileron mean chord was 2.395 inches (6.077 cm.). Aileron area was 370.446 cm.^{2}.

The aileron was hinged to the wing by three ball bearing hinges spaced as shown in the figure.

Measurements were made at various angles of attack, the wing chord being set at an angle of 5° to the fuselage axis.

The investigations were conducted in the wind tunnel at the Guggenheim Aeronautics Laboratory at the California Institute of Technology[2)].

[1)] The XP3D-1 - The Navy Patrol Boat designed and being built by the Douglas Aircraft Company, Inc., Santa Monica, California.

[2)] cf. C.B. Millikan and A.L. Klein: "Description and Calibration of the 10 ft. wind tunnel at the California Institute of Technology", Transactions of A.S.M.E., Aeronautical Engineering, (1932-33).

The principle of measuring aileron hinge moments by means of the differential pressure on two orifices is an adaptation of the measuring device as developed and used in the measurement of the drag of a sphere[3].

The apparatus consists essentially of a moment arm bearing an oxygen jet. (Figure 1). The arm is rigidly secured to the aileron at one end and held in position by a relatively rigid spring at the other.

A gap of .015" exists between the moving block which carries the jet of the moment arm and a fixed block having two orifices. Compressed oxygen is supplied to the orifice block from a gas cylinder through a standard pressure regulating unit.

A difference in pressure is measured on the manometer directly connected to the orifices in the fixed block depending on the position of the movable jet relative to the fixed orifices. That is, as a load is applied to the aileron, a proportional movement of the arm causes a movement of the jet relative to the orifices with a corresponding variation in the differential air pressure in the orifices.

Calibration of the device is made by application of known moments. Corresponding deflections are read on the manometer.

The moments caused by the wind loads in an actual run are then obtained by reading the manometer deflections and picking off the corresponding values of moment from the calibration curve.

The device is a new application of the principle and considerable experimental work was done in adapting the device for the measurement of hinge moments.

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[3] cf. C.B. Millikan and A.L. Klein: "Effect of Turbulence", Aircraft Engineering, August 1933.

Experimental data obtained as a result of the first runs with the device were not reliable. The results were due in a large measure to the more or less crude construction of the parts together with unsatisfactory means of securing the parts rigidly. A systematic investigation of the possible causes of the discrepancies was therefore undertaken.

Three springs were used during the investigation. Originally a transverse flat spring secured at both ends was used. With this setup the moment arm attached at the midspan. The difficulty of securing this type of spring rigidly,together with difficulty in adjusting same, made its use unsatisfactory.

The above spring was replaced by a round hairpin spring (.087"), which was held securely in the wing in an adjustable block at one end and in the moment arm at the other.

While results were considerably improved, difficulty in reproduction of data still prevailed.

The setup was further modified by soldering all parts where connections were made, in order to eliminate slipping. Calibration could now be reproduced with considerably improved results, although a drift persisted in the data.

As a final modification of the apparatus a loop was introduced in the hairpin spring.

By heating the tunnel to an approximate equilibrium temperature before commencing a run, it was found that more consistent results were obtained. By this procedure the effect of temperature change was reduced to a minimum.

During the experiment it was noted that an error was introduced in the manometer reading, resulting from tunnel air. This error varied with aileron angle. Examination disclosed the fact that with the tunnel running, air was blowing into the orifices. This difficulty was corrected by shielding the orifices with wax.

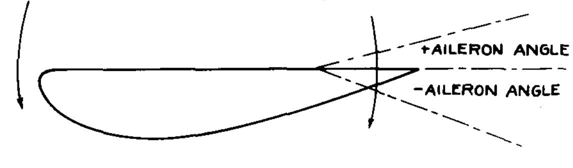
A vibrator operated by compressed air was installed in the model in order to minimize the effect of friction on the aileron hinges. Special attention was directed toward the cleanliness of the bearings.

It is believed that the data obtained from the final setup are quite consistent.

Observations were made at wind velocities of 123 and 143 miles per hour.

The following convention was used in designating moments, (Fig. 2):

A moment tending to produce clockwise rotation as viewed from the pilot's seat is considered positive. All values refer to an aileron on the right wing.



AIRFOIL INVERTED
FIG. 2

Reduction of Observations

The ~~calibration~~ calculation of the hinge moment from the net moments obtained from applying the deflections resulting from the wind loads to the calibration curve, is made as follows:

All results are reduced to the form of dimensionless coefficients.

$$C_H = \frac{M}{qSt}$$

C = hinge moment

M = moment in gm. cm. as measured on the aileron

q = $\frac{1}{2}\rho V^2$ = kinetic energy (a measure of velocity)

S = area of aileron in $cm.^2$

t = mean chord of aileron

b = span of aileron

ρ = mass density of air

For the aileron used in this investigation, the following constant is employed:

$$C_H = \frac{M}{qSt} = \frac{M}{q(370.45)(6.077)} = \frac{M}{2248.61(q)} = \frac{.000442\ M}{q}$$

Figures A and B represent the value of hinge moment coefficient plotted against "Angle of Attack" and "Aileron Setting" respectively. The values of C_H plotted, represent the average value obtained for any particular setup, a total of about sixty runs having been made. The small variation of values obtained on successive runs may be noted from typical data sheets.

Calculation of Stick Forces on Full Scale Airplane

The following method was employed in calculating the stick forces resulting from the aileron moments at various speeds:

A value of l_w, (wing loading), equals $\frac{\text{Lift of Airplane}}{\text{Wing Area}}$ equals $\frac{20013\#}{1296}$ = 15.45, where weight = lift = 20013# and wing area = 1296 $ft.^2$

From $l_w = \frac{1}{2}\rho V^2 C_L$, the value of $C_L = \frac{l_w}{\frac{1}{2}\rho V^2}$, where ρ = density of air standard conditions and "V" is expressed in feet per second. For the value of C_L obtained for each value of "V", the corresponding angle of attack is obtained from the curve of Lift Coefficient vs. Angle of Attack[4]. Fig. 6.

The coefficient of hinge moment "C_H" was then obtained for the angle of attack corresponding to the Lift Coefficient for the respective velocities of the airplane in miles per hour.

The value of "C_H" was substituted in the formula:

$$C_H = \frac{M}{qSt}$$

where C_H = hinge moment coefficient
q = "q" in lbs./ft.^{2} for particular V in m.p.h.
S = aileron area (actual airplane)
t = mean aileron chord (actual airplane)

The moment on the aileron of the full scale airplane, therefore, is given by: $M = C_H \quad q \quad S \quad t$. The values of aileron moments for a one to one differential were calculated and plotted (Figs. 3, 4 and 5).

Since the differential of the aileron movement in the actual plane is not one to one, it was necessary to calculate the values of the moments from the aileron angles resulting from the differential employed in the XP3D-1. Fig. 7 is the curve of aileron angle vs. the wheel angle for the XP3D-1. From this figure was obtained the negative angle of one aileron corresponding to the positive angle of the opposite aileron.

The aileron moment was then calculated for a particular aileron setting. The value obtained was then corrected in the order of the ratio obtained from figure 8, Curve of Ratio of Aileron Moment to Wheel Moment.

Fig. 9 summarizes the hinge moment investigation and represents curves of the Wheel Moment plotted against velocity in miles per hour for the XP3D-1. The aileron angle in actual flight will be small, while a large portion of the range covered by Fig. 7 represents conditions not encountered in flight, the results are of interest and are included herewith.

Assuming the control wheel in the cockpit of the XP3D-1 to have a diameter of twelve inches, the total force in lbs. that it will be necessary for the pilot to apply to the circumference of the wheel in order to obtain a particular aileron angle will be numerically equal to the moment.

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[4] cf. Report 127, page 23, fig. 4, by C.B. Millikan and A.L. Klein

The author wishes to thank Dr. Th. von Kármán, Director of the Guggenheim Aeronautics Laboratory at the California Institute of Technology for the opportunity of making the research and for his helpful suggestions. The research was suggested and carried out under the direction of Dr. A. L. Klein.

Acknowledgment is also due to Dr. A. L. Klein for his numerous helpful suggestions, and to W. H. Bowen who cooperated in the research.

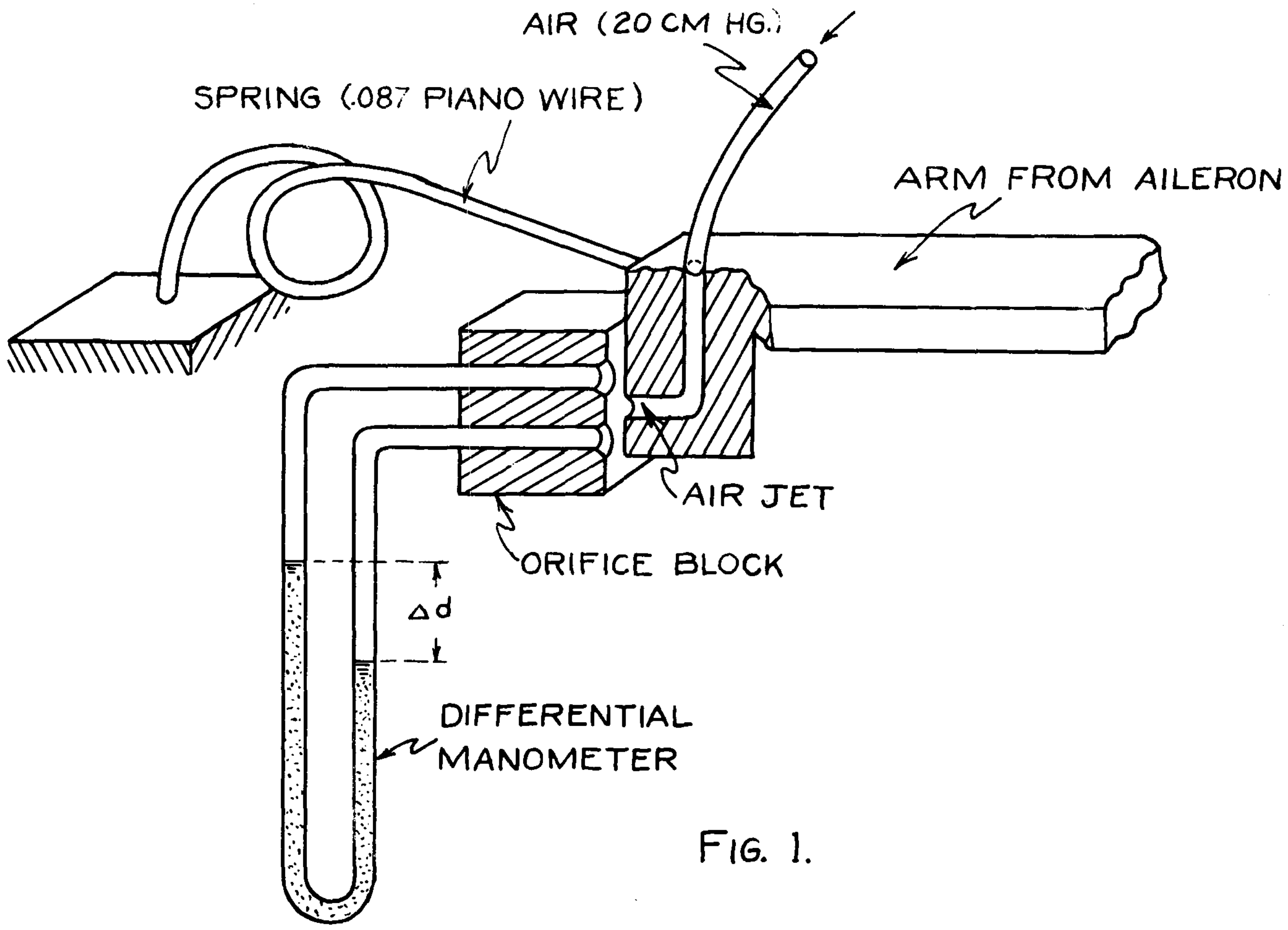
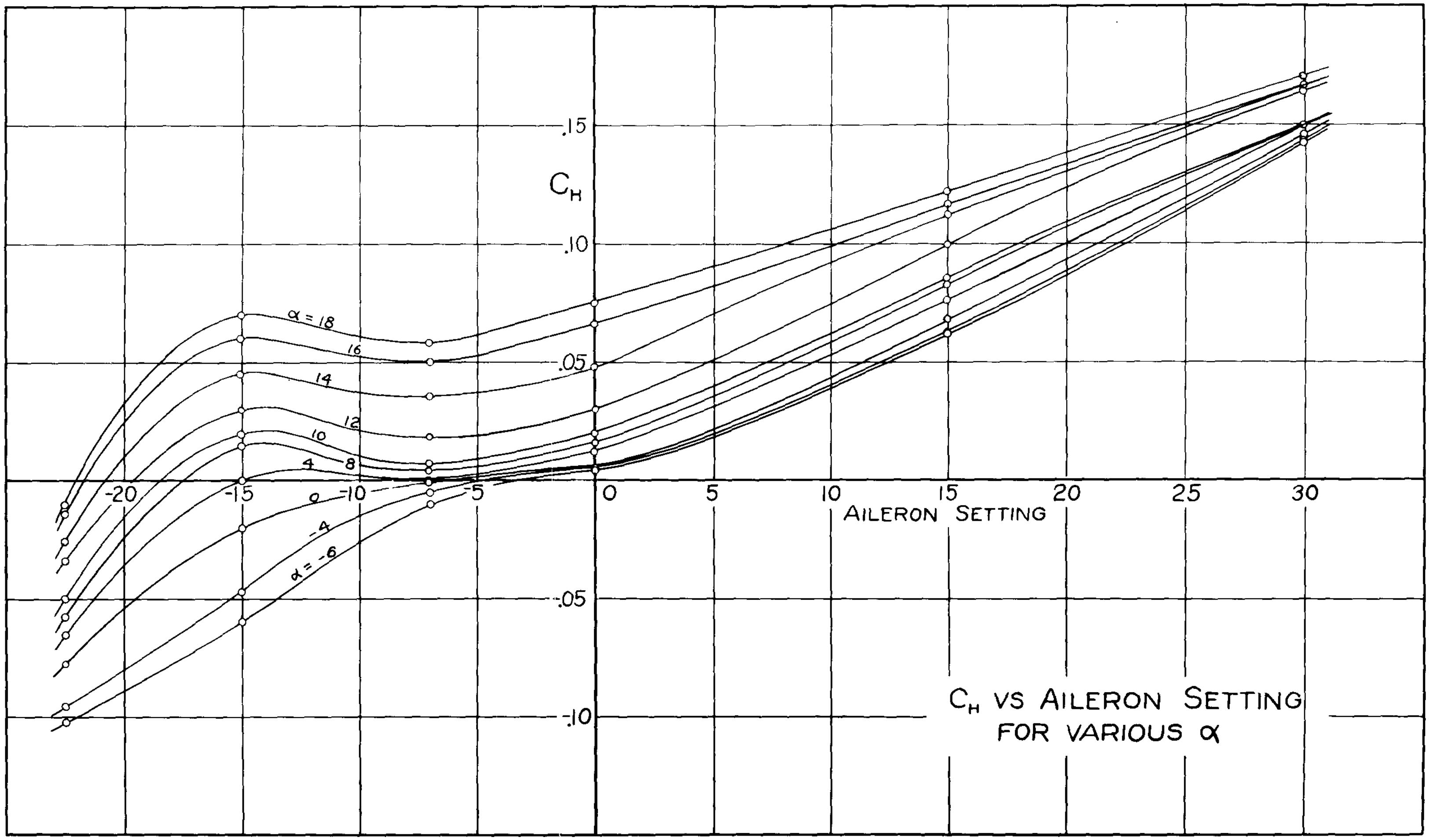
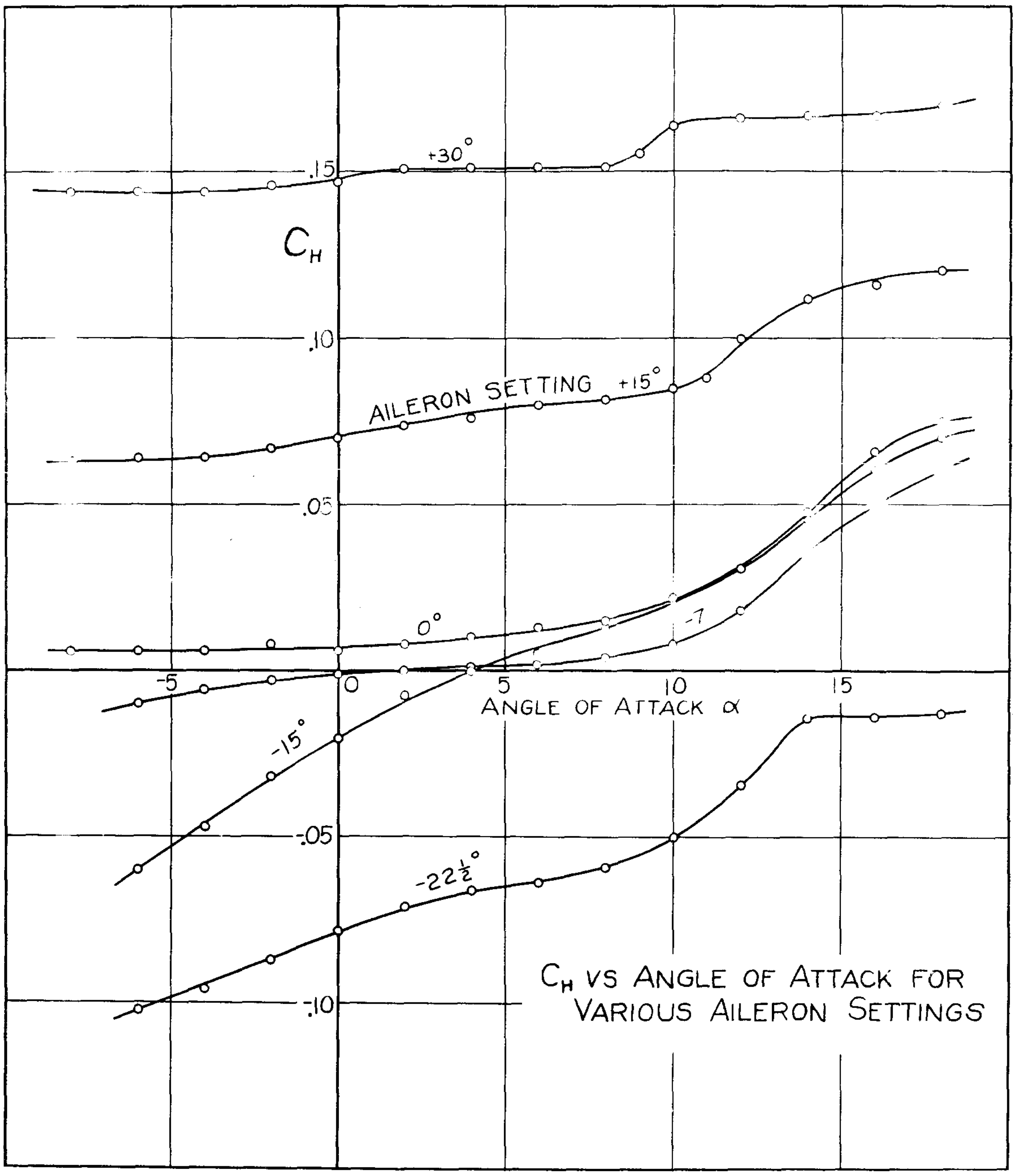

AIR (20 CM HG.)
SPRING (.087 PIANO WIRE)
ARM FROM AILERON
AIR JET
ORIFICE BLOCK
Δd
DIFFERENTIAL
MANOMETER

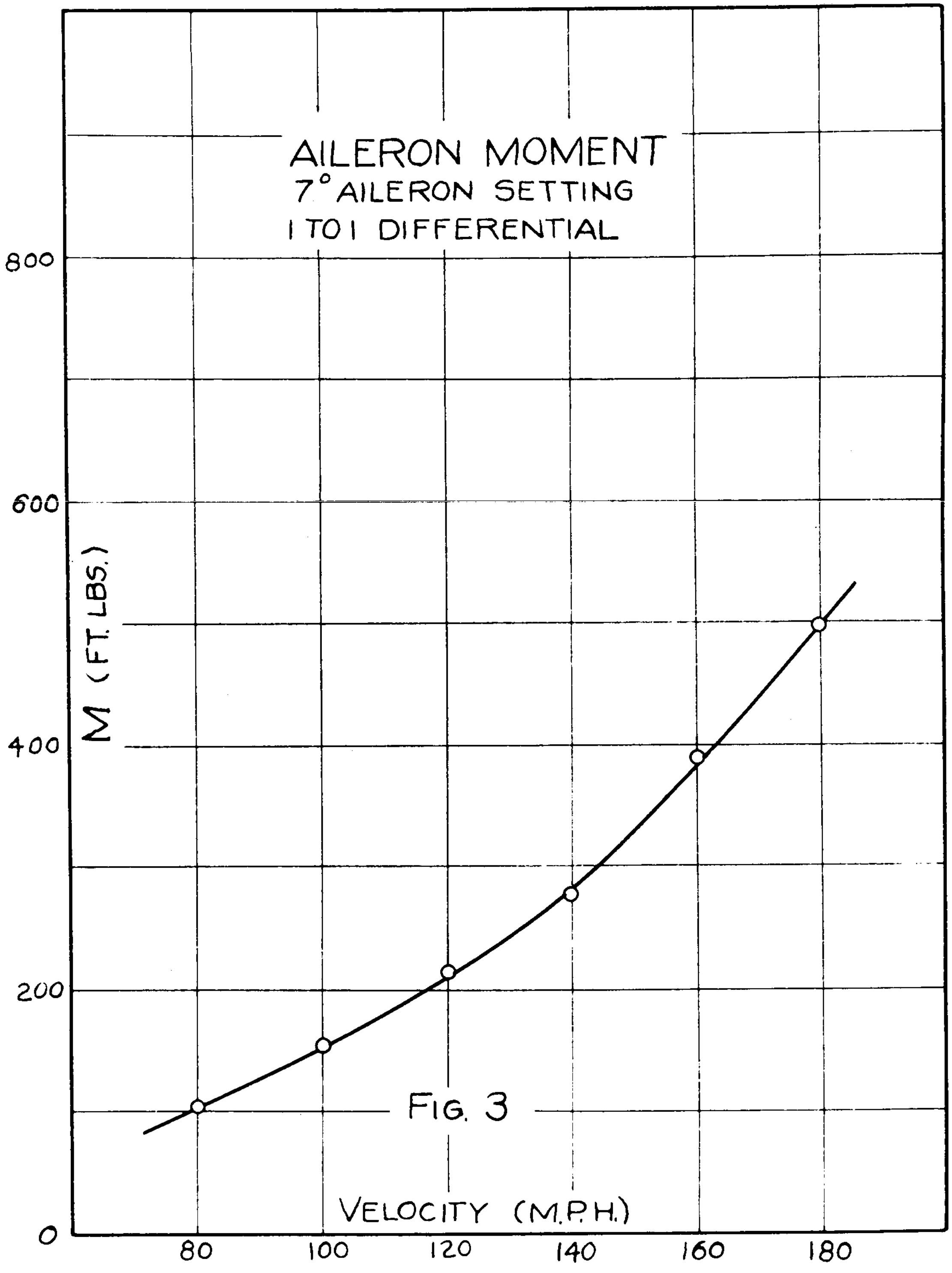
FIG. 1.



C_H VS AILERON SETTING FOR VARIOUS α



C_H vs Angle of Attack for Various Aileron Settings



AILERON MOMENT
7° AILERON SETTING
1 TO 1 DIFFERENTIAL

FIG. 3

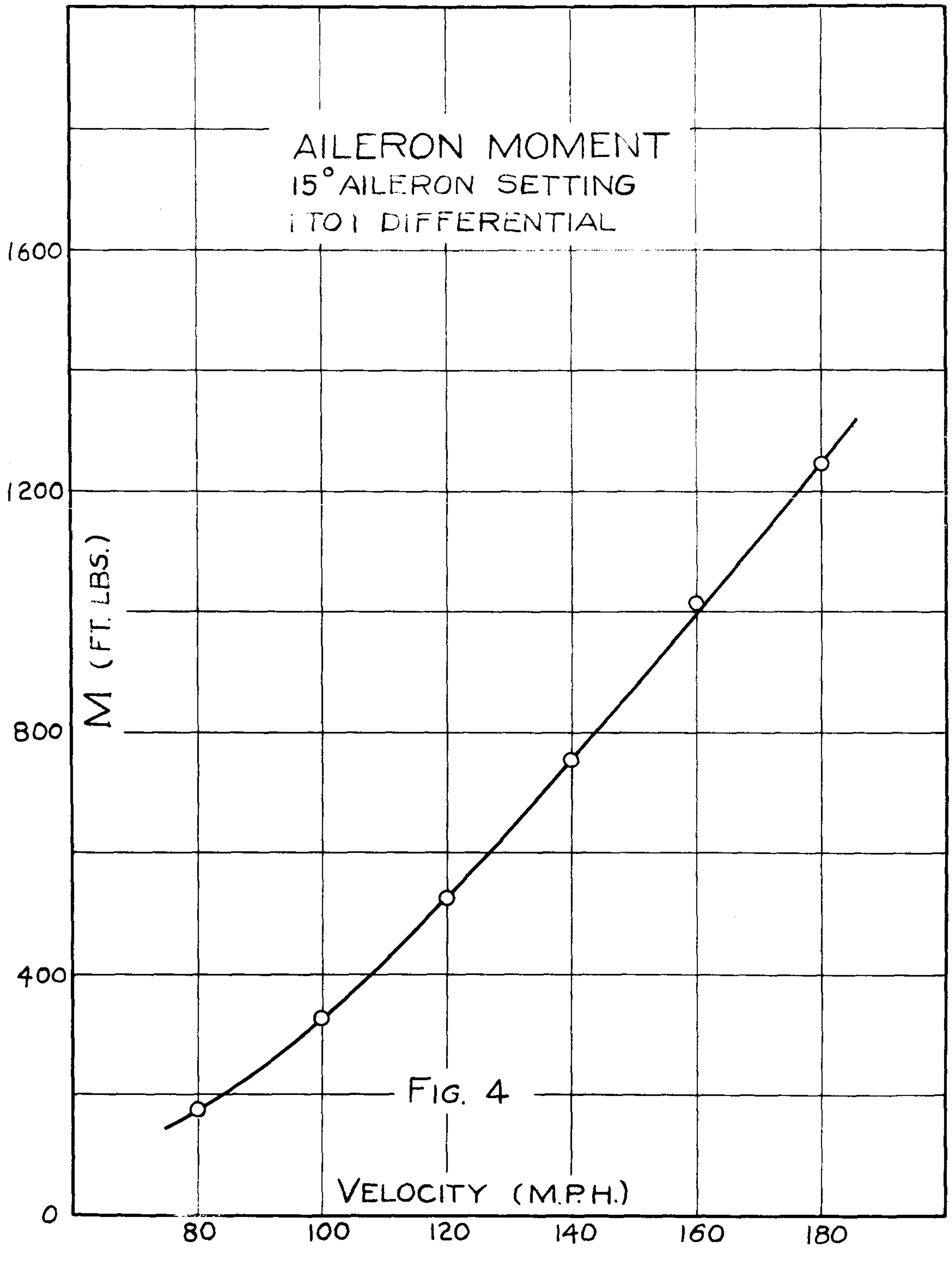

AILERON MOMENT
15° AILERON SETTING
1 TO 1 DIFFERENTIAL
1600
1200
800
400
0
M (FT. LBS.)
80
100
120
140
160
180
VELOCITY (M.P.H.)

FIG. 4

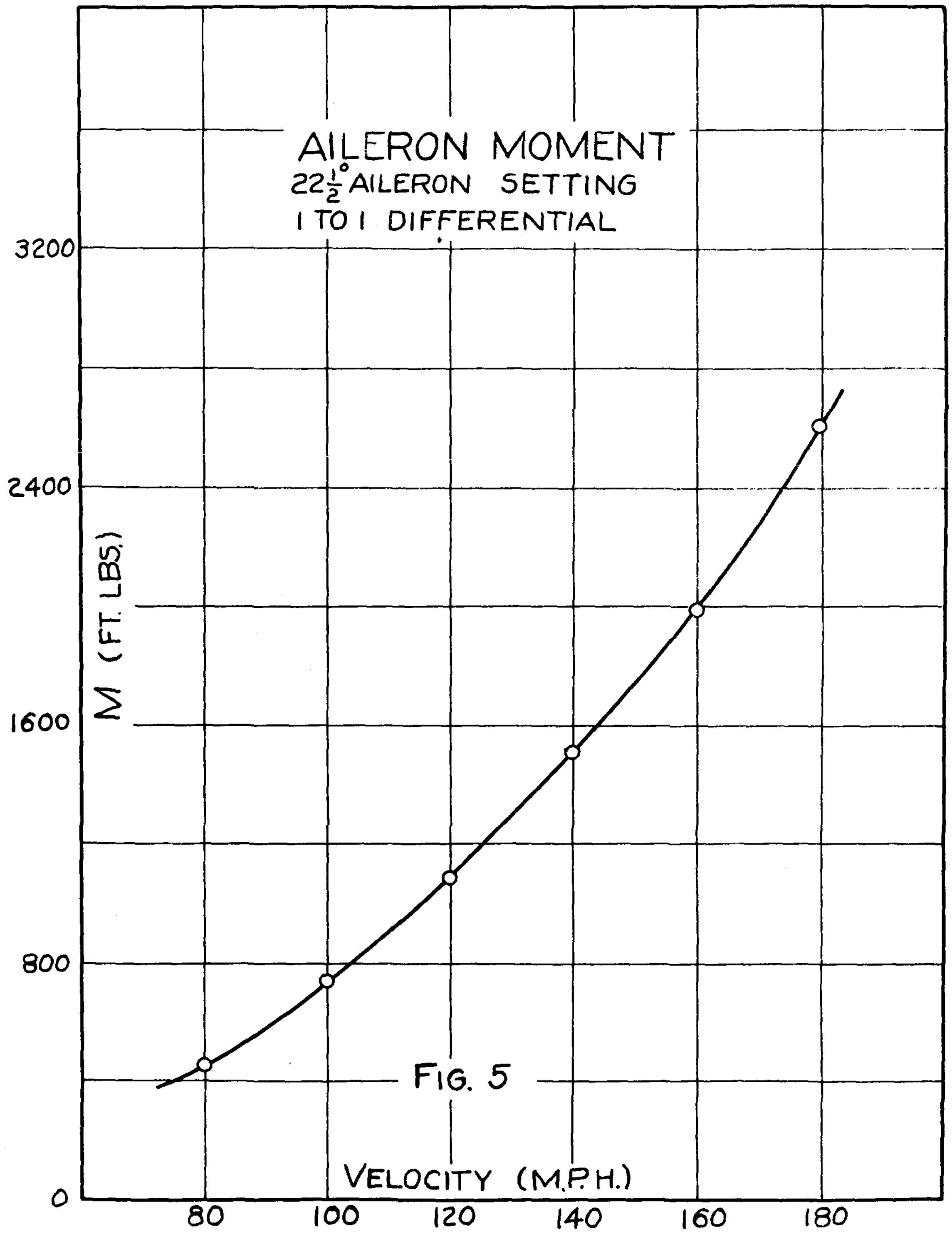
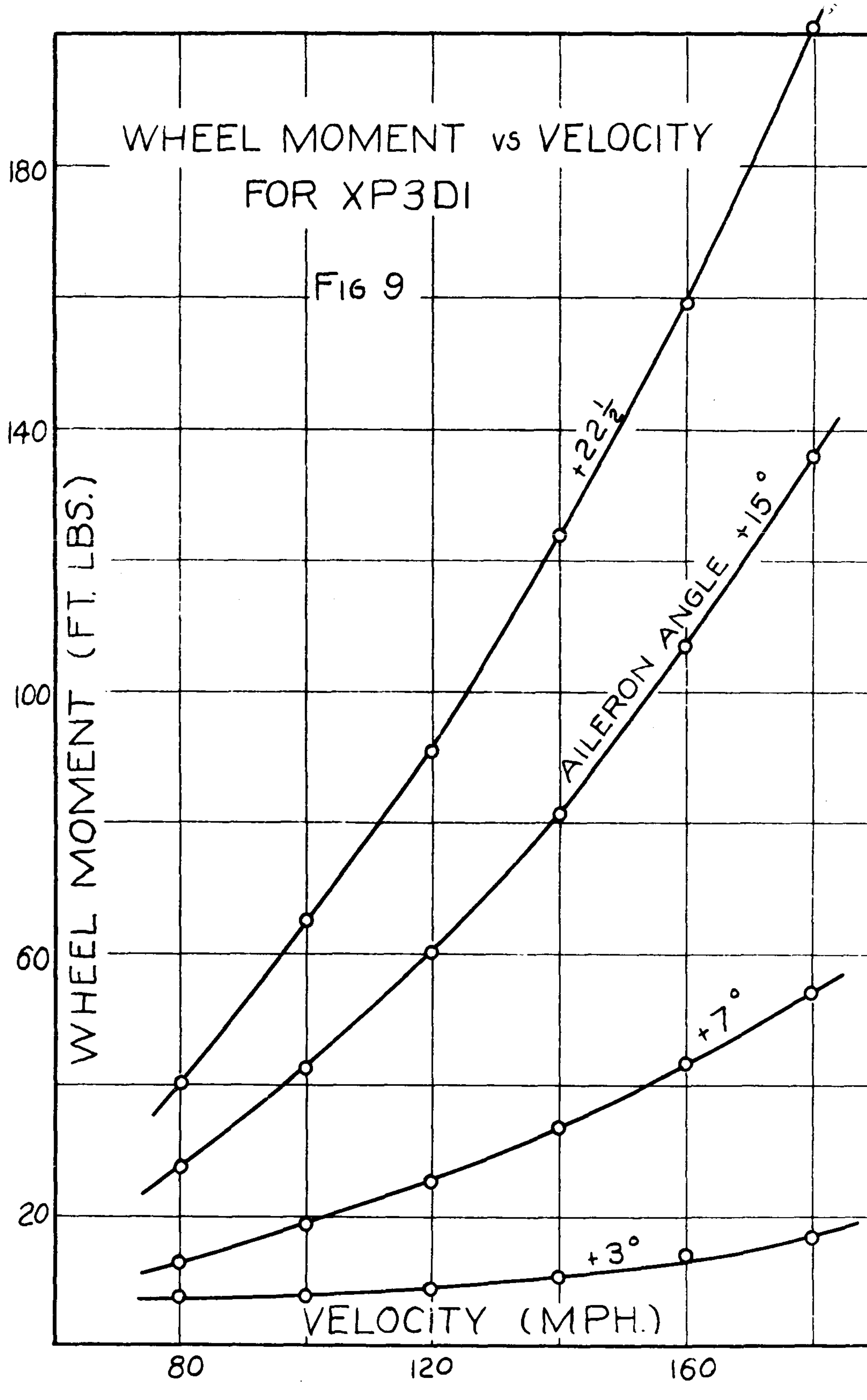

AILERON MOMENT
$22\frac{1}{2}°$ AILERON SETTING
1 TO 1 DIFFERENTIAL
M (FT. LBS.)
3200
2400
1600
800
0
VELOCITY (M.P.H.)
80
100
120
140
160
180

FIG. 5



WHEEL MOMENT vs VELOCITY FOR XP3D1

FIG 9

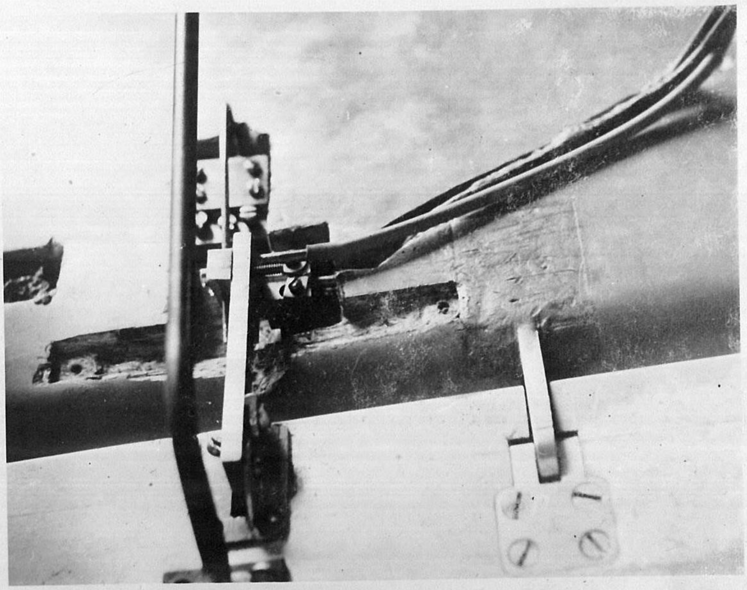


FIG. 8

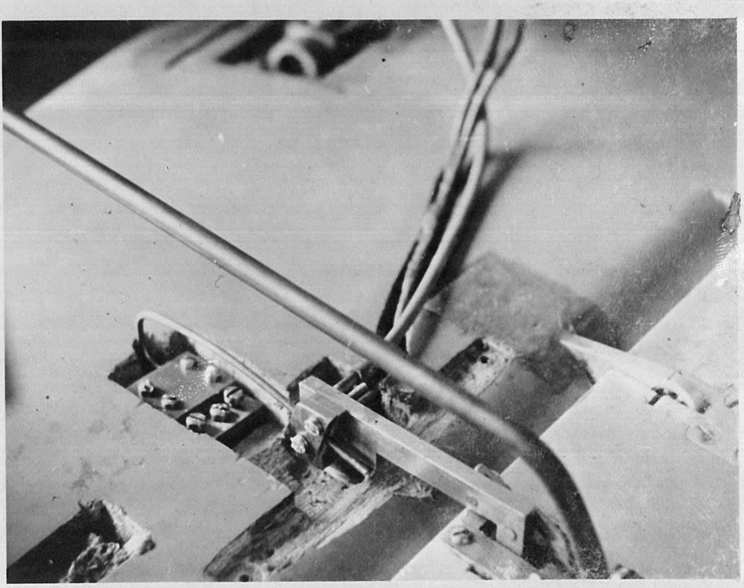


FIG. 9

Figures (8 & 9) - View of setup showing the original spring

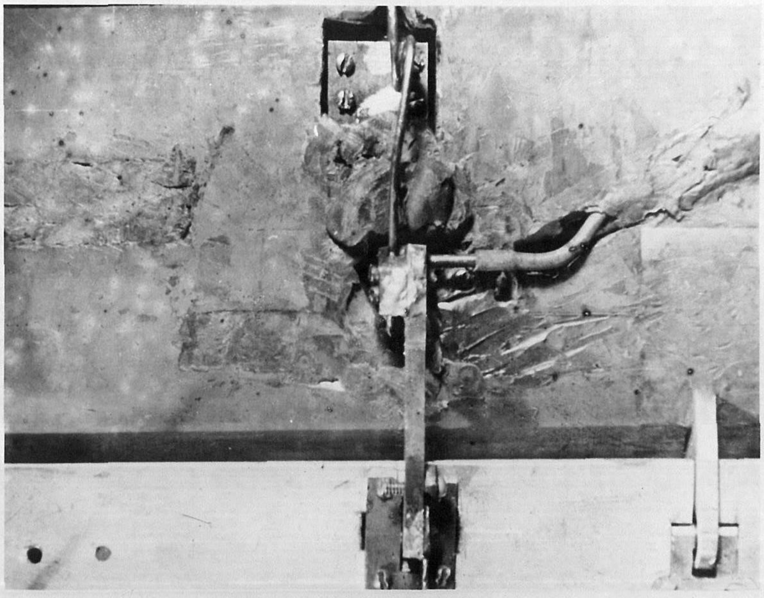


FIG. 10

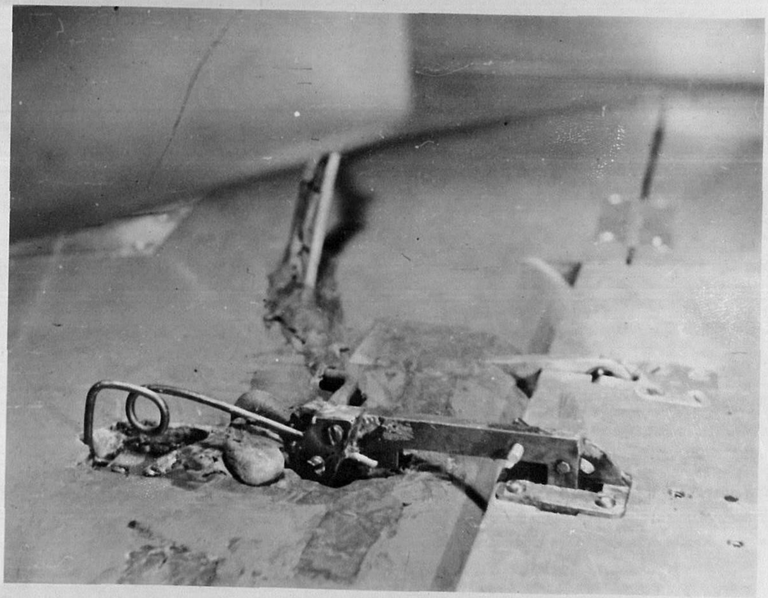


FIG. 11

Final setup showing modified hairpin spring. The investigations were conducted with the setups as shown.

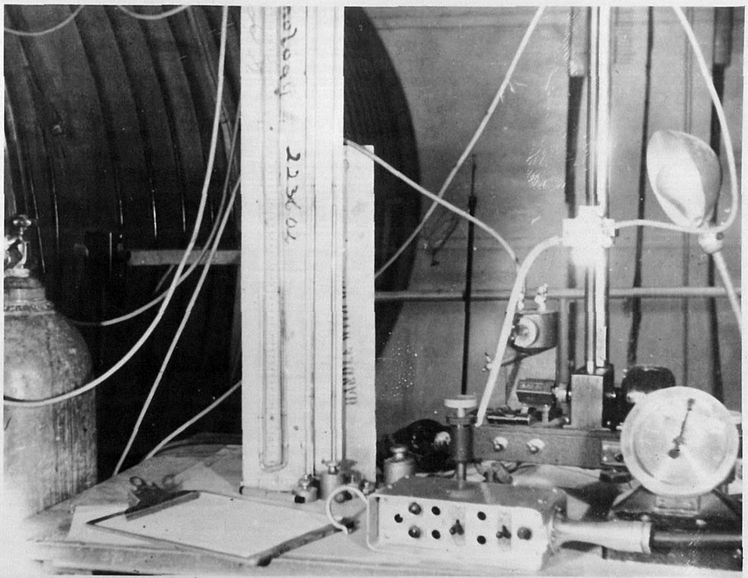


FIG. 12

View of instruments

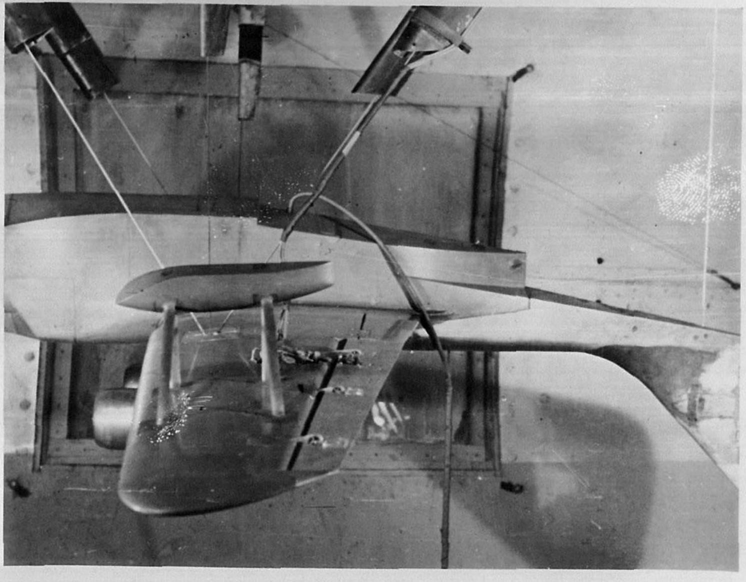


FIG. 13

The XP3D-1 model in the wind tunnel ready for test

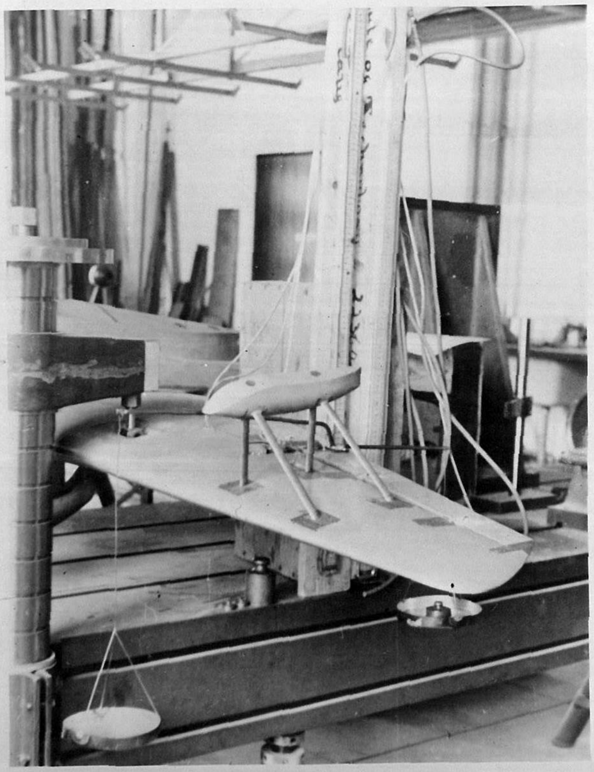


FIG. 14

View of the model showing setup for calibration before placing the model in the wind tunnel.

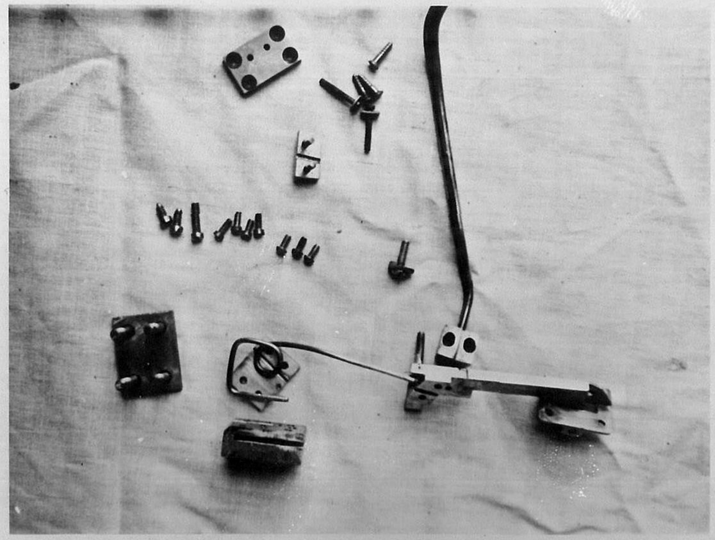


FIG. 15

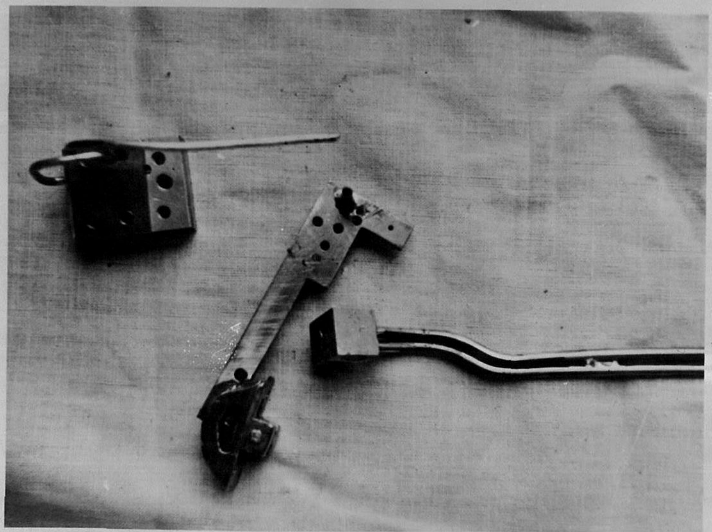


FIG. 16

Figures 15 and 16. Views of Orifice Block, Lever Arm (Moveable Jet), and Spring, Disassembled.

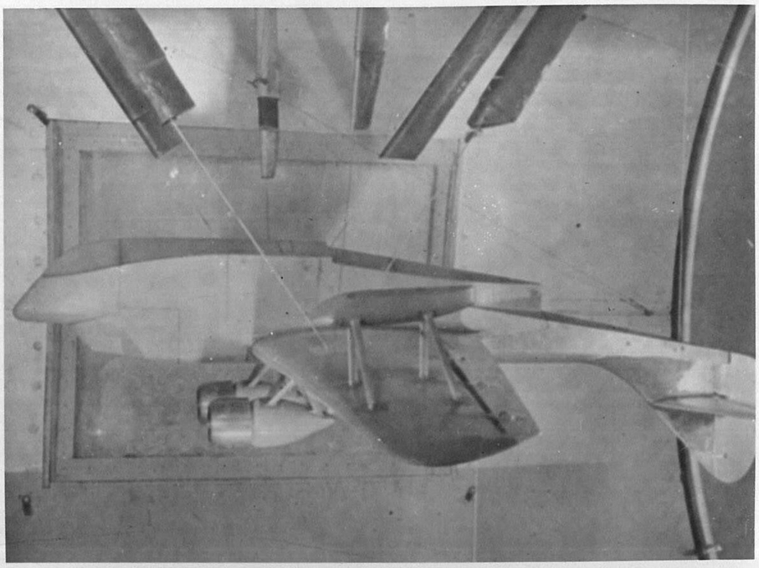


FIG. 17

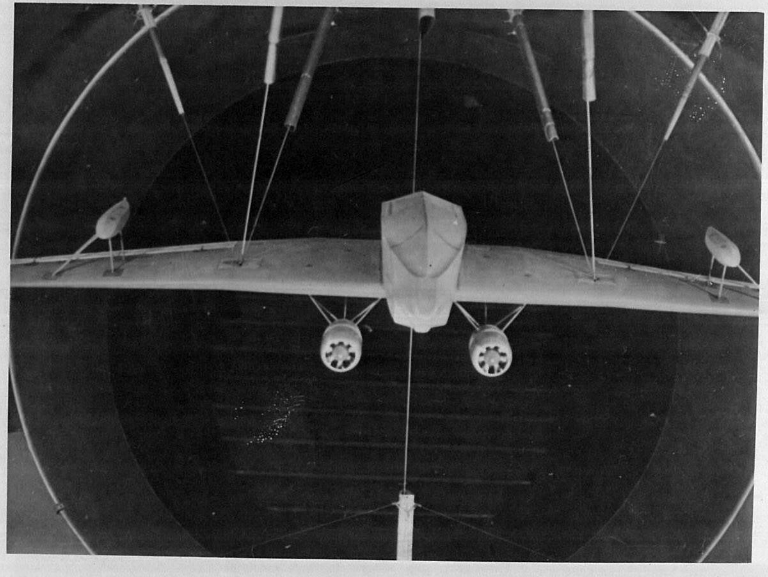
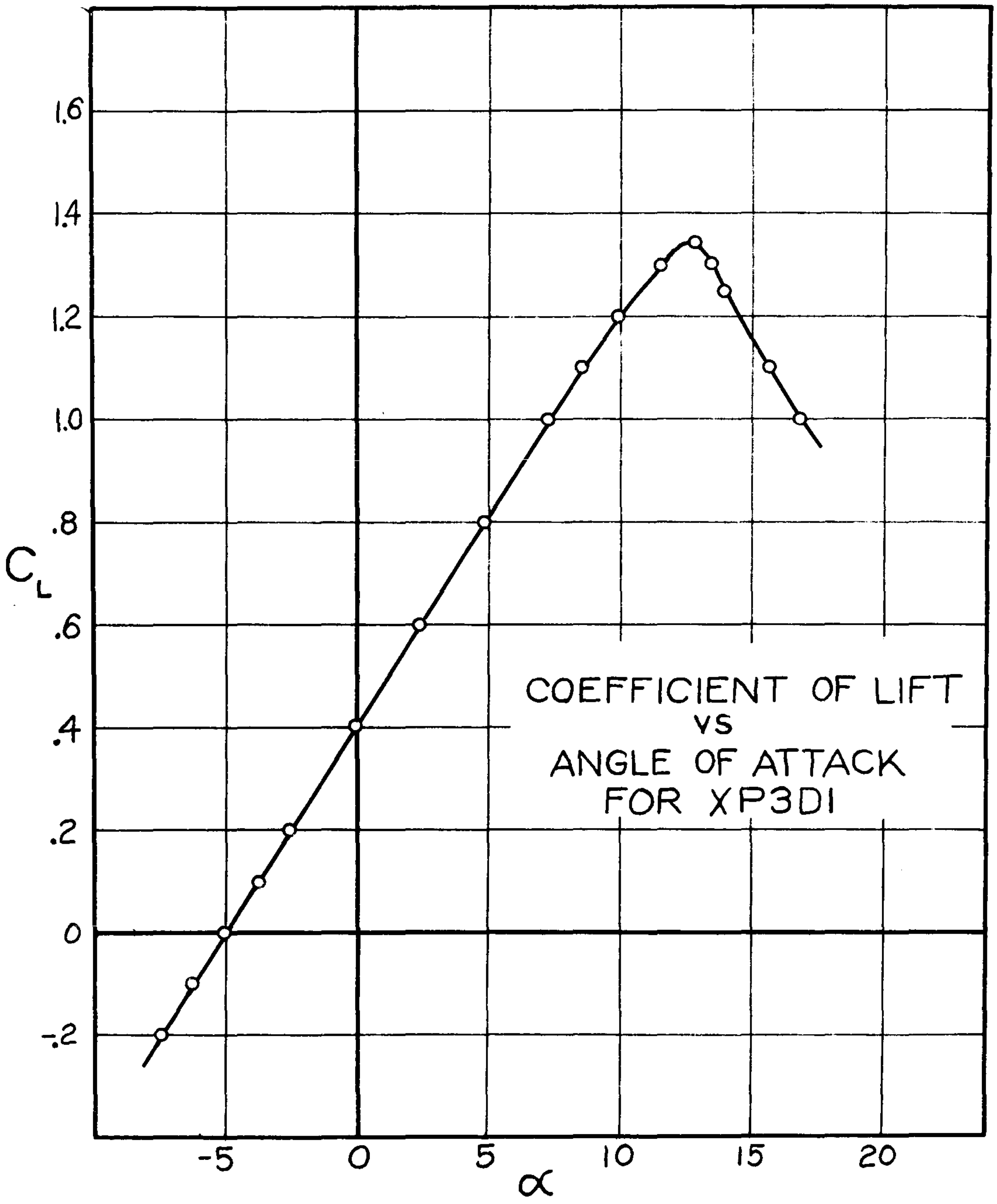
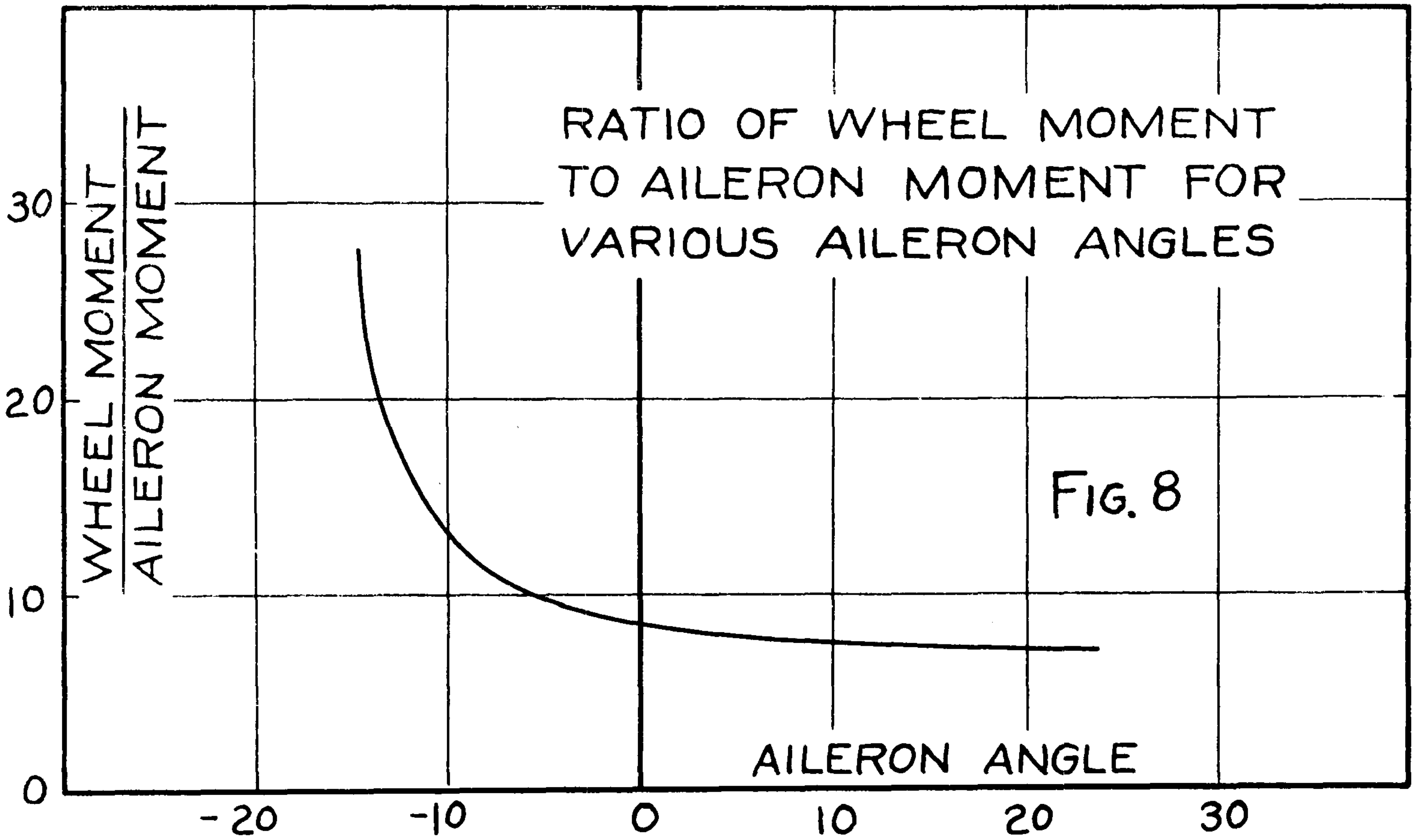


FIG. 18

Figures 17 and 18. Views of the XP3D-1 Rigged in the Wind Tunnel.


COEFFICIENT OF LIFT
VS
ANGLE OF ATTACK
FOR XP3D1
C_L
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-.2
-5
0
5
10
15
20
α



RATIO OF WHEEL MOMENT TO AILERON MOMENT FOR VARIOUS AILERON ANGLES

FIG. 8

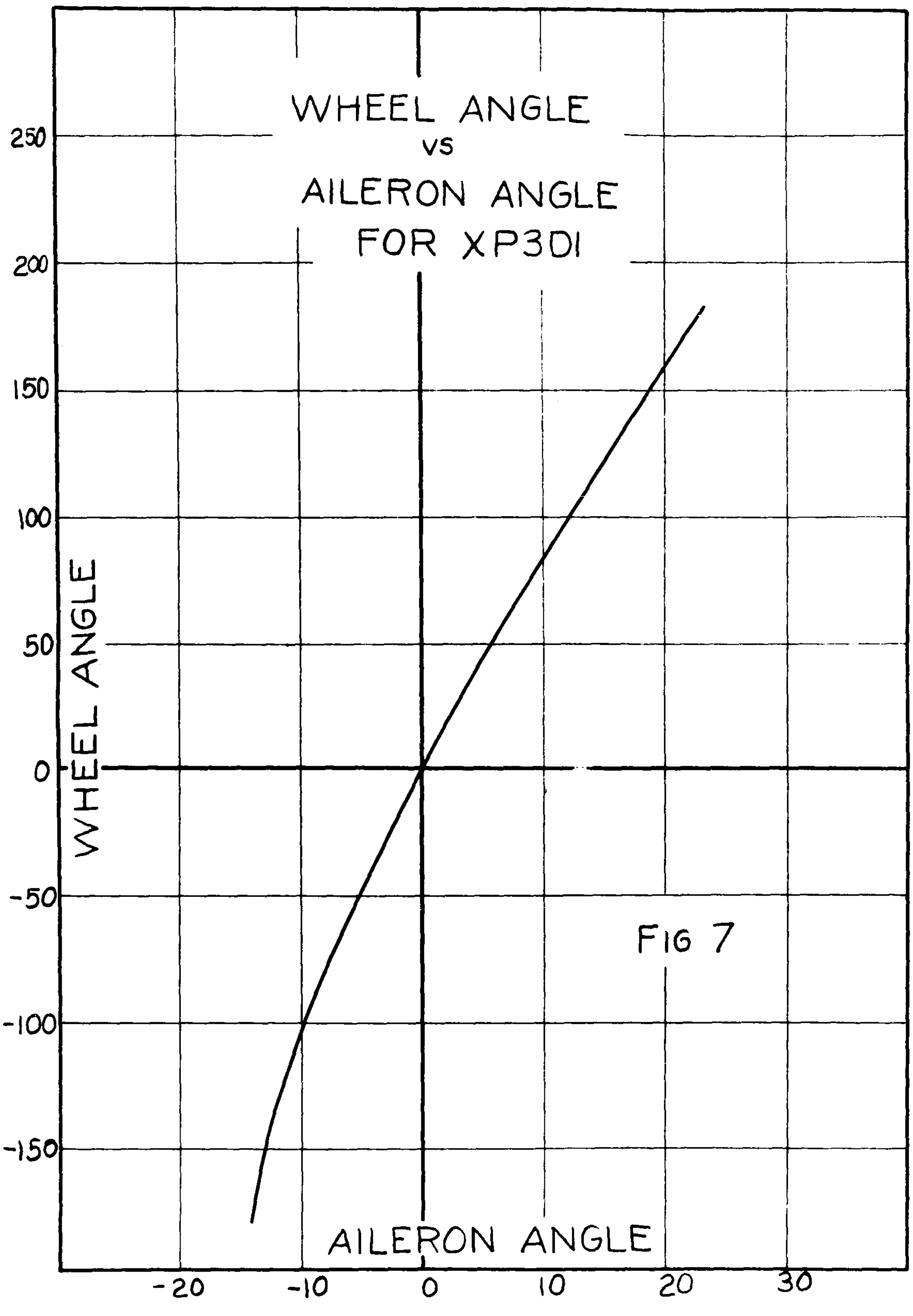

WHEEL ANGLE
VS
AILERON ANGLE
FOR XP3D1
WHEEL ANGLE
AILERON ANGLE
250
200
150
100
50
0
-50
-100
-150
-20
-10
0
10
20
30

FIG 7

TABLE OF "q" FOR VARIOUS AIR SPEEDS

Airspeed m.p.h.	Impact pressure in lbs./ft.^{2} One std. atmosphere = 2116.8 #/ft^2 = q	S × t	qSt
60	9.229	155.1	1430
80	16.405	155.1	2540
100	25.677	155.1	3980
120	37.065	155.1	5740
140	50.570	155.1	7830
160	66.214	155.1	10280
180	84.037	155.1	13030

MODEL CONSTANTS

Aileron Area (Full Scale) = 62.3 ft.^{2} (Each aileron)
(Model Scale) = 370.446 cm.^{2}

Aileron Span (Full Scale) = 300 in.
(Model Scale) = 24 in.
= 60.96 cm.

Aileron Mean Chord (Full Scale) = 2.49 ft.
(Model Scale) = 60.77 cm.

ANGLE OF ATTACK CORRESPONDING TO LIFT COEFFICIENT FOR VARIOUS SPEEDS

Weight of Plane = 20013 lbs.

Wing Area (S) = 1296 ft.^{2}

$$\ell_w = \frac{1}{2}\rho V^2 C_L \qquad C_L = \frac{2\ell_w}{\rho V^2} = \frac{\ell_w}{\rho/_2\, V^2}$$

$$\ell_w = \frac{20013}{1296} = 15.45 \qquad \rho = .002378 \text{ (std)}$$

$$C_L = \frac{20013}{1296} \Big/ .001189\,(\text{mph})^2\,(1.47)^2$$

m.p.h.	80	100	120	140	160	180
C_L	0.94	0.602	0.416	0.307	0.235	.186
α corresponding	+6.6°	+2.4°	+0.1°	-1.2°	-2.0°	-2.6°

Experiment Aileron Hinge Moments

Setup Aileron ∓ 30°

Run 20

h_f = 15.000

γ_f = 1.116

air pressure = 22.1 cm. Hg.

Calibration

— arm = 9.00" = 20.86 cm.

Positive moments only:

W grams	d	d	average d	Δ d	M
0	40.7	40.7	40.7		
20	39.7	39.6	39.65	1.05	457.0
50	38.0	37.9	37.95	2.75	1143.0
100	35.2	35.0	35.1	5.6	2286.0
150	32.3	31.9	32.1	8.6	3430.0
200	38.7	28.7	28.7	12.0	4570.0
250	25.9	25.8	25.85	14.85	5710.0
300	23.2	23.2	23.2	17.5	6850.0
350	21.0		21.0	19.7	7990.0

t_1 = 27.0°

t_2 = 28.3°

α_u	$d_\downarrow$	$d^\uparrow$	aver. d	Δ d	M	C_{M_W}
0	40.7	40.6	40.65	0		
-8	26.0	26.0	26.00	14.65	5780	.1435
-6	26.1	26.2	26.15	14.50	5710	.1415
-2	26.0	26.0	26.00	14.65	5780	.1435
0	25.7	25.8	25.75	14.90	5890	.1461
4	25.5	25.4	25.45	15.20	6000	.149
8	25.3	25.4	25.35	15.30	6050	.1500
10	25.4	25.6	25.5	15.15	5990	.1488
11	24.7	24.7	24.7	15.95	6300	.1563
12	23.9	23.9	23.9	16.75	6625	.1642
14	23.8	23.6	23.7	16.95	6700	.166
16	23.7	23.5	23.6	17.05	6740	.167
18	23.1		23.1	17.55	6950	.172

t_1 = 27.0°

t_2 = 29.0°

α_d	$d_\downarrow$	$d^\uparrow$	aver. d	Δ d	M	C_{M_W}
0	40.7	40.5	40.60			
-8	26.0	26.1	26.05	14.55	5760	.143
-6	26.2	26.2	26.20	14.40	5680	.141
-2	26.0	26.0	26.00	14.60	5750	.1425
0	25.8	25.9	25.85	14.75	5820	.144
4	25.6	25.5	25.55	15.05	5940	.1475
8	25.5	25.5	25.50	15.10	5950	.148
10	25.5	25.5	25.50	15.10	5950	.148
11	24.7	24.8	24.75	15.85	6250	.155
12	24.0	24.0	24.00	16.60	6550	.1625
14	24.0	23.7	23.85	16.85	6650	.165
16	23.8	23.6	23.70	16.90	6690	.166
18	23.2		23.20	17.40	6870	.170

Experiment Aileron Hinge Moment

Setup Aileron -7°

Run 30

$h_f = 15.000$

$\gamma_f = 1.118$

air pressure = 22.1 cm.Hg.

Calibration

- arm = 12.20" = 30.99 cm.

+ arm = 9.47" = 24.05 cm.

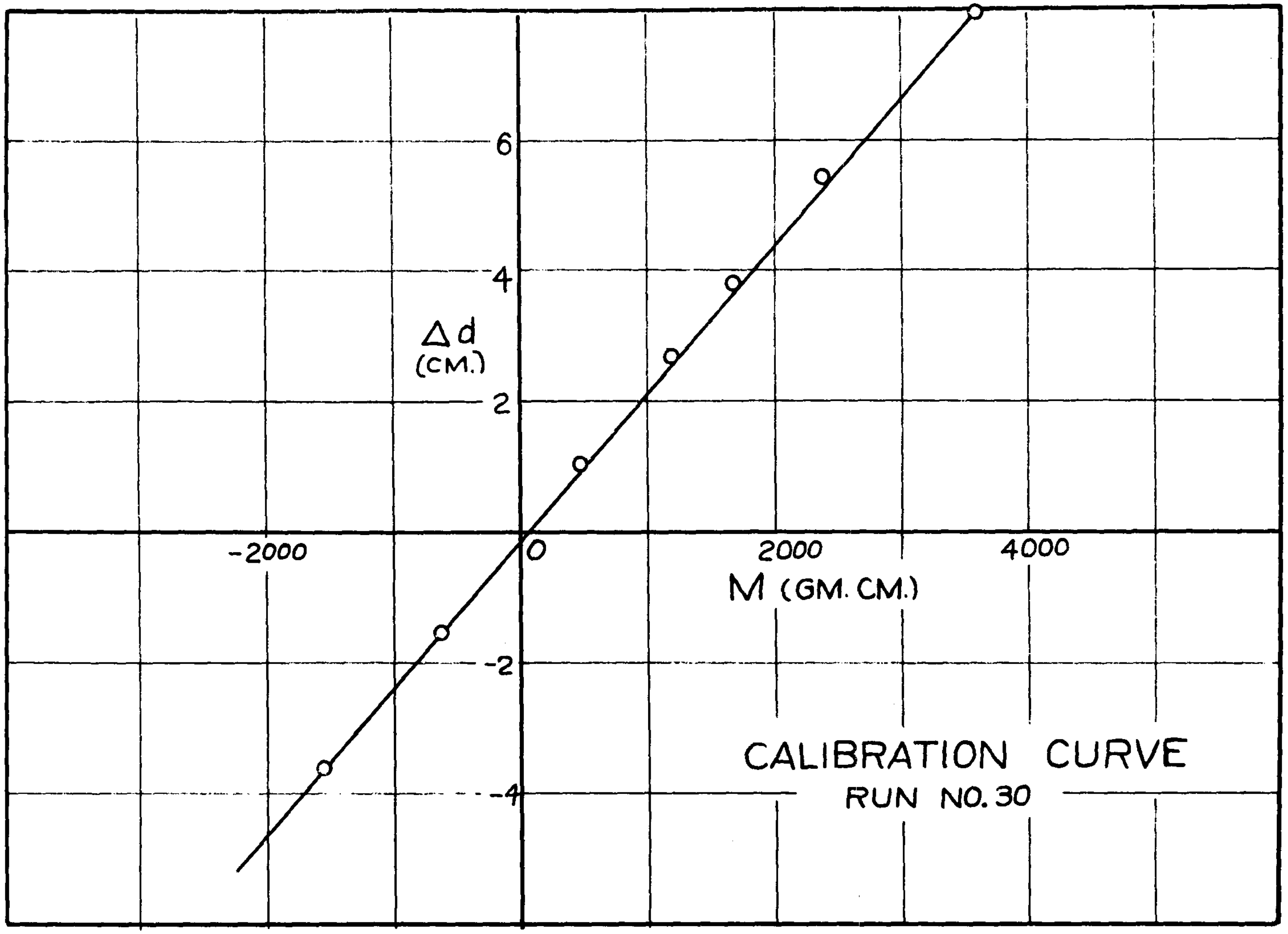
	W grams	d	d	average d	d	M
Positive moments:	0	44.6	44.6	44.6	0	
	20	43.5	43.5	43.5	1.1	481
	50	41.95	41.8	41.87	2.73	1202
	70	40.85	40.7	40.77	3.83	1682
	100	39.15	39.1	39.12	5.48	2400
	150	36.6		36.6	8.0	3603
Negative moments:	0	44.6	44.6	44.6	0	0
	20	46.1	46.1	46.1	1.5	619.6
	50	48.2	48.1	48.15	3.55	1550

$t_1 = 25.2^{\circ}$

$t_2 = 26.5^{\circ}$

α_u	d ↓	d ↑	Aver. d	Δd	M	C_H
0	44.7	44.7	44.7	0		
-6	45.5	45.5	45.5	-0.8	-350	-.0087
-4	45.2	45.2	45.2	-0.5	-200	-.0050
-2	45.0	45.0	45.0	-0.3	-120	-.0030
0	44.85	44.85	44.85	-0.15	- 50	-.0012
2	44.7	44.75	44.72	-0.02	- 0	- 0
4	44.6	44.6	44.6	0.1	50	.0012
6	44.5	44.5	44.5	0.2	100	.0025
8	44.3	44.3	44.3	0.4	200	.0050
10	43.95	44.0	43.97	0.73	330	.0082
12	43.0	43.1	43.05	1.65	730	.0181
14	41.3	41.3	41.3	3.4	1500	.0372
16	40.2	40.2	40.2	4.5	2000	.0497
18	39.4		39.4	5.3	2350	.0583

α_u	d ↓	d ↑	Aver. d	Δd	M	C_H
0	44.25	44.3	44.27	0		
-6	45.15	45.1	45.12	- .85	-370	-.0092
-4	44.8	44.8	44.8	- .53	-200	-.0050
-2	44.6	44.5	44.55	- .28	-120	-.0029
0	44.5	44.4	44.45	- .18	- 60	-.0010
2	44.4	44.3	44.35	- .08	- 40	-.0009
4	44.3	44.2	44.25	0	0	0
6	44.2	44.1	44.15	.10	50	.0012
8	44.0	43.9	43.95	.30	140	.0035
10	43.65	43.6	43.62	.63	300	.0075
12	42.8	42.7	42.75	1.50	670	.0166
14	41.0	41.0	41.0	3.25	1430	.0355
16	39.7	39.7	39.7	4.55	2025	.0502
18	38.9-		38.9	5.35	2380	.0591



CALIBRATION CURVE

RUN NO. 30

CALCULATION OF WHEEL MOMENT FOR ONE TO ONE DIFFERENTIAL

+7° Aileron Angle

Miles per Hour	80	100	120	140	160	180
qSt	2540	3980	5740	7830	10280	13030
Angle of Attack	6.6	2.4	.1	-1.2	-2	-2.6
$C_{H(7^o)}$	.044	.039	.0365	.035	.034	.034
$M_{7^o} = C_H qSt$	112	156	209	274	350	434
$C_{H(-7^o)}$	.0025	.0005	-.001	-.002	-.003	-.004
$M_{(-7^o)} = C_H qSt$	6.35	1.9	-5.74	-15.6	-30.8	52.2
$M_{(7)}$	112	156.0	209.0	274.0	350.0	434.0
$M = (M_{7^o}) - (M_{-7^o})$	105.65	154.1	214.7	239.6	380.8	486.2

+ 15° Aileron Angle

$C_{H(15^o)}$	.0805	.075	.071	.068	.067	.066
$M_{(15^o)} = C_H qSt$	204	299	407	533	687	861
$C_{H(-15^o)}$	.009	-.007	-.020	-.028	-.032	-.037
$M_{(-15^o)} = C_H qSt$	+ 25.4	-27.9	- 114	- 219	- 328	- 481
$M_{(15^o)}$	204	299	407	533	687	861
$M = (M_{15^o}) - (M_{-15^o})$	178.6	326.9	527	752	1015	1342

+22½° Aileron Angle

$C_{H(22\frac{1}{2}^o)}$	.115	.113	.109	.107	.106	.105
$M_{(22\frac{1}{2}^o)} = C_H qSt$	292	450	625	838	1088	1370
$C_{H(-22\frac{1}{2}^o)}$	-.062	-.071	-.078	-.084	-.087	-.089
$M_{(-22\frac{1}{2}^o)} = C_H qSt$	-157.5	- 281	- 440	- 662	- 894	-1220
$M_{(22\frac{1}{2}^o)}$	292	450	625	838	1088	1370
$M = M_{(22\frac{1}{2}^o)} - M_{(-22\frac{1}{2}^o)}$	449.5	731	1074	1500	1982	2590

CALCULATION OF WHEEL MOMENT FOR +15° AILERON ANGLE

Miles per Hour	80	100	120	140	160	180
qSt	2540	3980	5740	7830	10280	13030
Angle of Attack	6.6°	2.4°	0.1°	-1.2°	-2°	-2.6°
C_H (15°)	.0805	.075	.071	.068	.067	.066
$M_A = C_H qSt$ (15°)	204	299	407	533	687	861
$M_V = C_H qSt \text{ x } \frac{1}{7.1}$ (15°)	28.8	42.1	57.2	75	97	121
C_H (-11.3°)	.0073	-.001	-.0075	-.012	-.015	-.017
$M_A = C_H qSt$ (-11.3°)	18.5	-3.98	43.1	94.0	154	221
$M_V = C_H qSt \text{ x } \frac{1}{15}$ (-11.3°)	1.2	- .3	- 2.9	- 6.3	-10.3	-14.8
M_V (+15°)	28.8	42.1	57.2	75	97	121
M_V (-11.3°)	+1.2	- .3	- 2.9	- 6.3	-10.3	-14.8
$M_V = M_{V(+15°)} - M_{V(-11.3°)}$	27.6	42.4	60.1	81.3	107.3	135.8

CALCULATION OF WHEEL MOMENT FOR +3° AILERON ANGLE

Miles per Hour	80	100	120	140	160	180
qSt	2540	3980	5740	7830	10280	13030
Angle of Attack	6.6°	2.4°	0.1°	-1.2°	-2°	-2.6°
C_H (3°)	.027	.0183	.0145	.013	.0125	.0120
$M_A = C_H qSt$ (3°)	68.5	73.5	80.4	102	129	156.5
$M_V = C_H qSt \text{ x } \frac{1}{7}$ (3°)	9.8	10.5	11.9	14.5	18.4	22.3
C_H (-2.7°)	.0083	.0050	.0043	.004	.0038	.0035
$M_A = C_H qSt$ (-2.7°)	21.1	19.9	24.7	31.3	39.0	45.6
$M_V = C_H qSt \text{ x } \frac{1}{9}$ (-2.7°)	2.3	2.2	2.8	3.5	4.3	5.1
M_V(+3°)	9.8	10.5	11.9	14.5	18.4	22.3
M_V(-2.7°)	2.3	2.2	2.8	3.5	4.3	5.1
$M_V = M_{V(+3°)} - M_{V(-2.7°)}$	7.5	8.3	9.1	11.0	14.1	17.2

CALCULATION OF WHEEL MOMENT[1] FOR $+22\frac{1}{2}^\circ$ AILERON ANGLE

Miles per Hour	80	100	120	140	160	180
qSt	2540	3980	5740	7830	10280	13030
Angle of Attack	6.6°	2.4°	0.1°	-1.2°	-2°	-2.6°
C_H $(22\frac{1}{2}^\circ)$	.115	.113	.109	.107	.106	.105
$^*M_A = C_H qSt$ $(22\frac{1}{2}^\circ)$	292	450	625	838	1088	1370
$^{**}M_W = C_H qSt \times \frac{1}{7}$ $(22\frac{1}{2}^\circ)$	41.7	64.3	88.3	120	154	196
C_H (-14°)	.010	-.005	-.017	-.023	-.029	-.033
$M_A = C_H qSt$ (-14°)	25.4	-19.9	-97.5	-180.5	- 298	- 430
$M_W = C_H qSt \times \frac{1}{23}$ (-14°)	1.27	- .85	-2.72	-3.65	-4.73	-5.97
M_W $(+22\frac{1}{2}^\circ)$	41.7	64.3	88.3	120	154	196
M_W (-14°)	1.27	- .85	-2.72	-3.65	-4.73	-5.97
$M_W = M_{W(+22\frac{1}{2}^\circ)} - M_{W(-14^\circ)}$	40.43	65.15	91.02	123.65	158.73	201.97

*Aileron Moment
**Wheel Moment

[1] For actual plane

CALCULATION OF WHEEL MOMENT FOR $+7^\circ$ AILERON ANGLE

Miles per Hour	80	100	120	140	160	180
qSt	2540	3980	5740	7830	10280	13030
Angle of Attack	6.6°	2.4°	0.1°	-1.2°	-2°	-2.6°
C_H (7°)	.044	.039	.0365	.035	.034	.034
$M_A = C_H qSt$ (7°)	112	156	209	274	350	434
$M_W = C_H qSt \times \frac{1}{7.6}$ (7°)	14.8	20.5	27.5	36.1	46.1	57.1
C_H (-4°)	.006	.0033	.0031	.0028	.0025	.0021
$M_A = C_H qSt$ (-4°)	15.3	13.2	17.8	22.0	25.8	27.4
$M_W = C_H qSt \times \frac{1}{9.4}$ (-4°)	1.6	1.4	1.9	2.3	2.7	2.9
M_W $(+7^\circ)$	14.8	20.5	27.5	36.1	46.1	57.1
M_W (-4°)	1.6	1.4	1.9	2.3	2.7	2.9
$M_W = M_{W(+7^\circ)} - M_{W(-4^\circ)}$	13.2	19.1	25.6	33.8	43.4	54.2