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Lateral Characteristics of an Avro Swept Wing with and Without Tip Tanks.

7 June 1950

Signed E.B.MacC. NATIONAL RESEARCH COUNCIL Sheet 1 of 10

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UNCLASSIFIED

LATERAL CHARACTERISTICS OF AN AVRO SWEPT WING, WITH AND WITHOUT TIP TANKS

Prepared by: E.B. MacCuish

SECRET

1. INTRODUCTION

This memorandum contains the results of wind tunnel measurements of rolling moment, yawing moment, and side force, made on a model of an A. V. Roe Canada Limited swept wing, with and without tip tanks. Lift, drag and pitching moment measurements were reported in Reference 1.

2. MODEL

The pertinent model geometry is given in Figure 1.

Large spanwise cracks, one on each surface, had appeared in the model before the tests, and some distortion was indicated by the fact that with the tail sting removed the trailing edges of the two sides of the wing, at the centre, were displaced vertically about 1/8 inch.

3. RANGE OF TESTS

At R.N. = 2.2×10^6 the model, with and without tanks, was yawed from $-2°$ to $16°$ at each of six values of C_L between about zero lift and $C_{L_{max}}$. At R.N. = 3.3×10^6 measurements were made, wing alone, for the same angle of yaw range at lift coefficients of - 0.01, 0.18, 0.28 and 0.38.

4. DESCRIPTION OF TESTS

The model was assumed to be symmetrical about its horizontal centre plane, hence, to obtain the interference of the main struts, which are normally on the high pressure side of the wing, the model, with dummy struts mounted, was pitched negatively rather than inverted. The tests revealed little strut interference, but the components measured at positive angles of attack did not agree with those measured at corresponding lift coefficients in the negative angle of attack range. Further tests were made, therefore, with dummy struts mounted and the model pitched positively, to determine the effect of struts on the low pressure side of the wing. Considerable strut interference was noted in this case, but when the appropriate corrections were applied to the results obtained at negative angles of attack the above disagreement was still present. To explain this difference in the lateral force and moment components it was concluded that the model was asymmetrical.

This conclusion is based on the reasonable assumptions: that the dumm struts exactly simulate the main struts, and that the flow is uniform within the volume swept out by the model.

5. RESULTS

The results are given in Tables I to V and Figs. 2 to 12.

Yawing moment is given, as measured, about the suspension point, which was at $0.52\bar{c}$.

Rolling Moment:

The rolling moments, with and without tanks, are plotted against angle of yaw in Figs. 2 and 3. Values of l_v, measured at zero yaw are plotted in Fig. 8. The latter decreases, indicating more stability, as C_L is increased up to 0.5 where l_v begins to increase until instability is indicated above $C_L = 0.7$, wing alone, and 0.85 with tip tanks. This unstable change indicates that the lift on the leading half of the wing falls off sooner than the lift on the trailing half of the wing.

Yawing Moment:

The yawing moment measurements are plotted in Figs. 4 and 5 and values of n_v in Fig. 8. Below $C_L = 0.5$ n_v is small, but above this value, n_v rapidly becomes positive, indicating directional stability. At $C_L \approx 0.9$, however, n_v becomes negative. This is due to the reduction in induced drag of the leading tip associated with the early fall-off of lift. At the three highest lift coefficients the curves of $C_n - \psi$ have radically departed from linearity at the large angles of yaw.

Side Force:

The side force results are plotted in Figs. 6 and 7, and values of y_v in Fig. 9. In general, y_v is positive. As in the case of l_v and n_v, y_v is measured at $\psi = 0°$ and at the higher angles of attack C_y tends to be non-linear with ψ.

Effect of Wing Asymmetry:

By comparing the measurements made in the positive angle of attack range with those made in the negative range, the effect of model asymmetry can be seen. Appreciable changes are noticeable in n_v and y_v, but l_v is not affected much. The model asymmetry is not very important, therefore, because in the complete aircraft the vertical tail and fuselage provide the major contribution to n_v and y_v. The results show, however, the extreme sensitivity of the wing to small departures from horizontal symmetry.

Effect of Tip Tanks:

A definite increase in effective dihedral due to tip tanks is evident from Fig. 8 where l_v is seen to be more negative with tanks than without. Furthermore the change from a negative value of l_v to a positive one takes place at a greater value of C_L. This is apparently due to an end plate effect of the tanks.

The effect of tanks on n_v is not as pronounced as in the case of l_v. In general, n_v is more positive with tanks on.

The presence of tip tanks makes y_v more negative as would be expected from a consideration of side area.

6. CONCLUSIONS

1. The lateral components measured when the model was pitched positively did not agree with those measured when the model was pitched negatively. The differences are concluded to be due to a lack of horizontal symmetry in the model. Cracks had appeared in the surfaces of the model and some distortion was evident. Because the rolling moments showed fair agreement, this is not very important when the complete model is considered, the fuselage and vertical tail providing the major contributions to n_v and y_v. The results do show, however, the extreme sensitivity of the lateral components of the wing to apparently small departures from symmetry. In future to prove more directly the presence or absence of symmetry a model should be pitched positively in one position and then turned over and pitched positively again.

2. The values of l_v and n_v indicate increasing stability up to values of C_L between 0.7 and 0.9, where they change sign and indicate instability. The values of y_v are in general positive. The curves of C_l, C_n and C_y against ψ become non-linear as the model is pitched above the angle of attack at which the tip stall begins.

3. The presence of tip tanks increases the effective dihedral, increases the directional stability about the $0.52\bar{c}$ point, and makes y_v more negative.

7. REFERENCES

1. E.B. MacCuish — Lift, Drag and Pitching Moment Characteristics of aModel of an A. V. Roe Swept Wing With and Without Tip Tanks. Aerodynamics Memo 5684-2.

NOTATION

$$C_L = \frac{\text{lift}}{\frac{1}{2}\rho V^2 S}$$

$$C_y = \frac{\text{side force}}{\frac{1}{2}\rho V^2 S}$$

$$C_l = \frac{\text{rolling moment}}{\frac{1}{2}\rho V^2 Sb}$$

$$C_n = \frac{\text{yawing moment}}{\frac{1}{2}\rho V^2 Sb}$$

ψ - angle of yaw

β - angle of sideslip $= -\psi$

$$l_v = \left.\frac{dC_l}{d\beta}\right|_{\psi=0} \text{ per radian}$$

$$n_v = \left.\frac{dC_n}{d\beta}\right|_{\psi=0} \text{ per radian}$$

$$y_v = \frac{1}{2}\left.\frac{dC_y}{d\beta}\right|_{\psi=0} \text{ per radian}$$

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TABLE I

Wing Alone R.N. = 2.2×10^6

Positive α Range

C_l

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	.001	0	0	-.001	0	0	-.001	-.002
.20	-.001	-.001	.001	.001	.003	.004	.005	.007
.45	-.002	-.001	.001	.003	.005	.008	.011	.014
.71	-.002	-.003	.003	-.002	0	.002	.004	.008
.90	0	-.005	-.009	-.012	-.015	-.017	-.013	-.011
.98	-.003	-.008	-.015	-.020	-.027	-.031	-.034	-.036

C_n

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	-.0001	.0000	-.0001	-.0002	-.0003	-.0002	-.0004	-.0006
.20	.0001	-.0001	-.0002	-.0003	-.0005	-.0006	-.0010	-.0012
.45	-.0001	-.0001	-.0002	-.0001	-.0010	-.0013	-.0023	-.0030
.71	.0018	-.0005	-.0021	-.0029	-.0037	-.0039	-.0050	-.0067
.90	.0009	.0007	.0011	.0013	.0009	.0002	-.0041	-.0068
.98	-.0010	.0013	.0019	.0044	.0070	.0086	.0083	.0048

C_y

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	.0005	.0006	.0007	.0009	.0011	.0011	.0013	.0017
.20	.0007	.0008	.0005	.0001	.0000	.0000	-.0003	-.0003
.45	.0032	.0013	-.0006	-.0017	-.0025	-.0035	-.0051	-.0069
.71	-.0003	.0031	.0035	.0007	-.0019	-.0066	-.0155	-.0241
.90	.0038	.0029	.0016	.0001	-.0023	-.0080	-.0332	-.0481
.98	.0108	.0019	-.0060	-.0122	-.0170	-.0244	-.0392	-.0524

TABLE II

Wing Alone R.N. = 2.2 x 10^6

Negative α Range

C_l

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	-.001	0	-.001	-.001	-.001	-.001	-.002	-.001
.20	-.002	-.001	.001	.002	.002	.002	.004	.006
.45	-.002	-.002	-.001	.001	.002	.003	.005	.009
.71	-.003	-.002	-.002	.000	.000	.000	.002	.006
.90	-.002	-.007	-.011	-.014	-.014	-.019	-.023	-.022
.98	-.002	-.006	-.012	-.016	-.021	-.025	-.034	-.035

C_n

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	-.0002	.0000	.0000	.0000	-.0001	-.0002	-.0004	-.0007
.20	.0001	.0001	-.0002	-.0003	-.0004	-.0006	-.0009	-.0013
.45	.0002	.0012	.0015	.0013	.0010	.0007	.0001	-.0004
.71	.0012	.0006	.0000	-.0001	-.0011	-.0021	-.0042	-.0067
.90	.0001	.0010	.0016	.0023	.0016	.0010	.0012	-.0005
.98	-.0010	.0001	.0026	.0038	.0069	.0088	.0091	.0075

C_y

C_L \ ψ	-2	0	2	4	6	8	12	16
-.03	.0005	.0006	.0007	.0008	.0005	.0008	.0014	.0015
.20	-.0002	-.0001	-.0005	-.0007	-.0007	-.0005	-.0004	-.0001
.45	.0006	-.0043	-.0069	-.0090	-.0089	-.0095	-.0113	-.0136
.71	-.0025	-.0037	-.0077	-.0129	-.0152	-.0180	-.0266	-.0340
.90	.0005	-.0027	-.0034	-.0067	-.0101	-.0167	-.0273	-.0375
.98	.0052	-.0031	-.0071	-.0141	-.0187	-.0281	-.0474	-.0694

TABLE III

Wing with Tip Tanks R.N. = 2.2×10^6

Positive α Range

C_l

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	.000	.001	.000	.001	-.001	-.001	-.003	.000
.23	-.003	-.001	.002	.003	.004	.005	.006	.009
.49	-.004	-.001	.002	.005	.009	.008	.014	.017
.74	-.005	-.002	.000	.001	.005	.005	.008	.012
.91	-.002	-.005	-.007	-.012	-.010	-.013	-.006	-.009
.97	-.004	-.006	-.010	-.015	-.017	-.022	-.023	-.021

C_n

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	-.0001	.0005	.0002	.0003	.0003	.0004	.0004	.0005
.23	.0001	.0005	.0000	.0001	.0002	.0001	-.0002	-.0002
.49	.0004	.0004	-.0007	-.0009	-.0012	-.0016	-.0027	-.0032
.74	.0012	.0005	-.0014	-.0030	-.0038	-.0041	-.0056	-.0060
.91	.0011	.0014	.0007	.0006	-.0002	-.0019	-.0054	-.0069
.97	-.0013	.0003	.0015	.0024	.0034	.0039	.0027	.0012

C_y

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	.0006	.0005	.0009	.0012	.0016	.0020	.0034	.0054
.23	.0004	.0002	.0004	.0006	.0007	.0010	.0024	.0042
.49	.0023	.0017	.0012	.0006	.0000	-.0002	.0006	.0019
.74	.0024	.0023	.0019	.0039	.0011	-.0029	-.0085	-.0144
.91	.0026	.0017	.0026	.0046	.0035	.0005	-.0222	-.0225
.97	.0060	.0007	.0019	-.0033	-.0045	-.0082	-.0167	-.0262

TABLE IV

Wing with Tip Tanks   R.N. = 2.2×10^6

Negative α Range

C_l

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	.001	.000	.000	-.001	-.002	.000	-.001	-.004
.23	-.002	-.002	.000	.002	.003	.003	.007	.004
.49	-.005	-.002	.001	.005	.006	.008	.008	.012
.74	-.007	-.004	-.002	.001	.001	.003	.007	.005
.91	-.006	-.007	-.011	-.011	-.015	-.013	-.016	-.020
.97	-.004	-.006	-.010	-.014	-.017	-.022	-.022	-.020

C_n

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	-.0001	.0005	.0001	.0002	.0003	.0004	.0004	.0001
.23	.0001	.0006	.0001	.0001	.0001	.0001	-.0001	-.0007
.49	.0009	.0010	.0003	.0000	-.0002	-.0005	-.0012	-.0025
.74	.0014	.0009	.0004	-.0015	-.0019	-.0026	-.0043	-.0065
.91	.0006	.0011	.0004	.0007	-.0004	-.0009	-.0005	-.0021
.97	-.0004	.0013	.0014	.0030	.0045	.0050	.0041	.0024

C_y

C_L \ ψ	-2	0	2	4	6	8	12	16
-.02	.0005	.0006	.0009	.0011	.0018	.0019	.0032	.0051
.23	.0001	.0004	.0005	.0006	.0006	.0009	.0022	.0043
.49	-.0008	-.0032	-.0040	-.0044	-.0058	-.0057	-.0050	-.0028
.74	.0009	-.0042	-.0099	-.0078	-.0118	-.0147	-.0193	-.0221
.91	.0004	.0002	-.0012	-.0038	-.0045	-.0075	-.0128	-.0388
.97	.0045	.0024	-.0018	-.0050	-.0086	-.0130	-.0267	-.0382

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TABLE V

Wing Alone R.N. = 3.3×10^6

Positive α Range

C_l

C_L \ ψ	-2	0	2	4	6	8	12	16
-.01	.001	.000	.000	.000	.000	.000	.000	.000
.18	-.001	-.001	.001	.001	.002	.003	.005	.007
.28	-.002	.000	.001	.003	.004	.005	.008	.011
.38	-.005	-.001	.001	.003	.005	.007	.011	.014

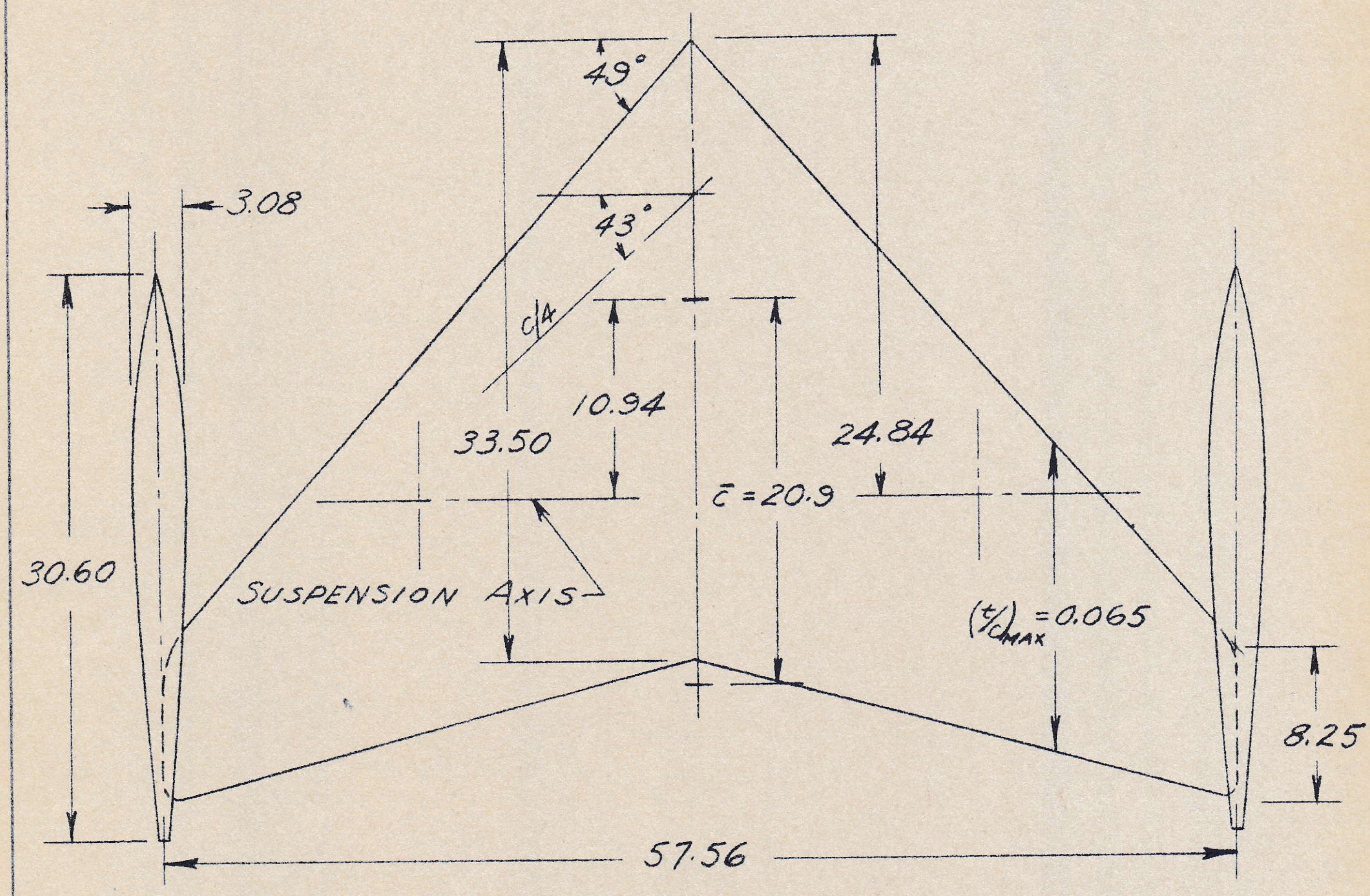
C_n

C_L \ ψ	-2	0	2	4	6	8	12	16
-.01	.0001	.0001	.0000	-.0001	-.0001	-.002	.0000	-.0004
.18	.0001	.0000	-.0001	-.0003	-.0004	-.0005	-.0008	-.0011
.28	.0002	.0000	-.0003	-.0003	-.0008	-.0010	-.0015	-.0020
.38	.0004	.0000	-.0005	-.0009	-.0013	-.0017	-.0023	-.0032

C_y

C_L \ ψ	-2	0	2	4	6	8	12	16
-.01	-.0001	-.0001	-.0001	.0000	.0003	.0006	.0005	.0008
.18	.0003	.0001	.0000	-.0001	-.0002	-.0002	-.0001	.0001
.28	.0006	.0003	.0001	-.0002	-.0003	-.0005	-.0007	-.0007
.38	.0008	.0003	-.0002	-.0006	-.0011	-.0014	-.0024	-.0022

FIG 1



SCALE - 1" = 10"

AREA $S = 8.34$ SQ. FT.

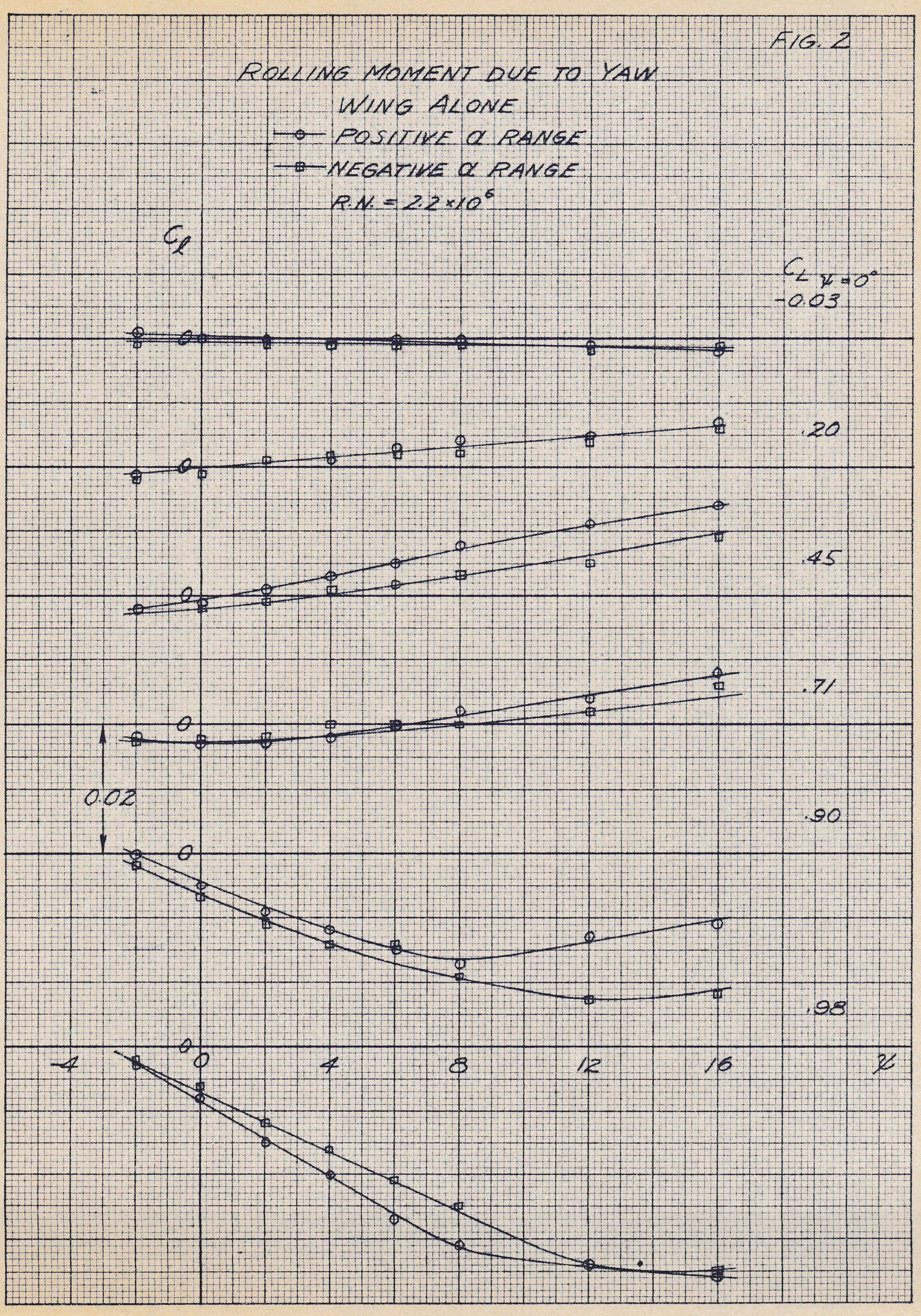
MEAN CHORD $\bar{c} = \frac{S}{b} = 1.75$ FT.

TAPER RATIO $\lambda = 0.246$

ASPECT RATIO $A = 2.76$

MEASURED MODEL DIMENSIONS

FIG. 2



ROLLING MOMENT DUE TO YAW
WING ALONE
POSITIVE α RANGE
NEGATIVE α RANGE
R.N. = 2.2×10⁶
C_l
C_L ψ=0°
-0.03
.20
.45
.71
.90
.98
0.02
0
-4
0
4
8
12
16
ψ

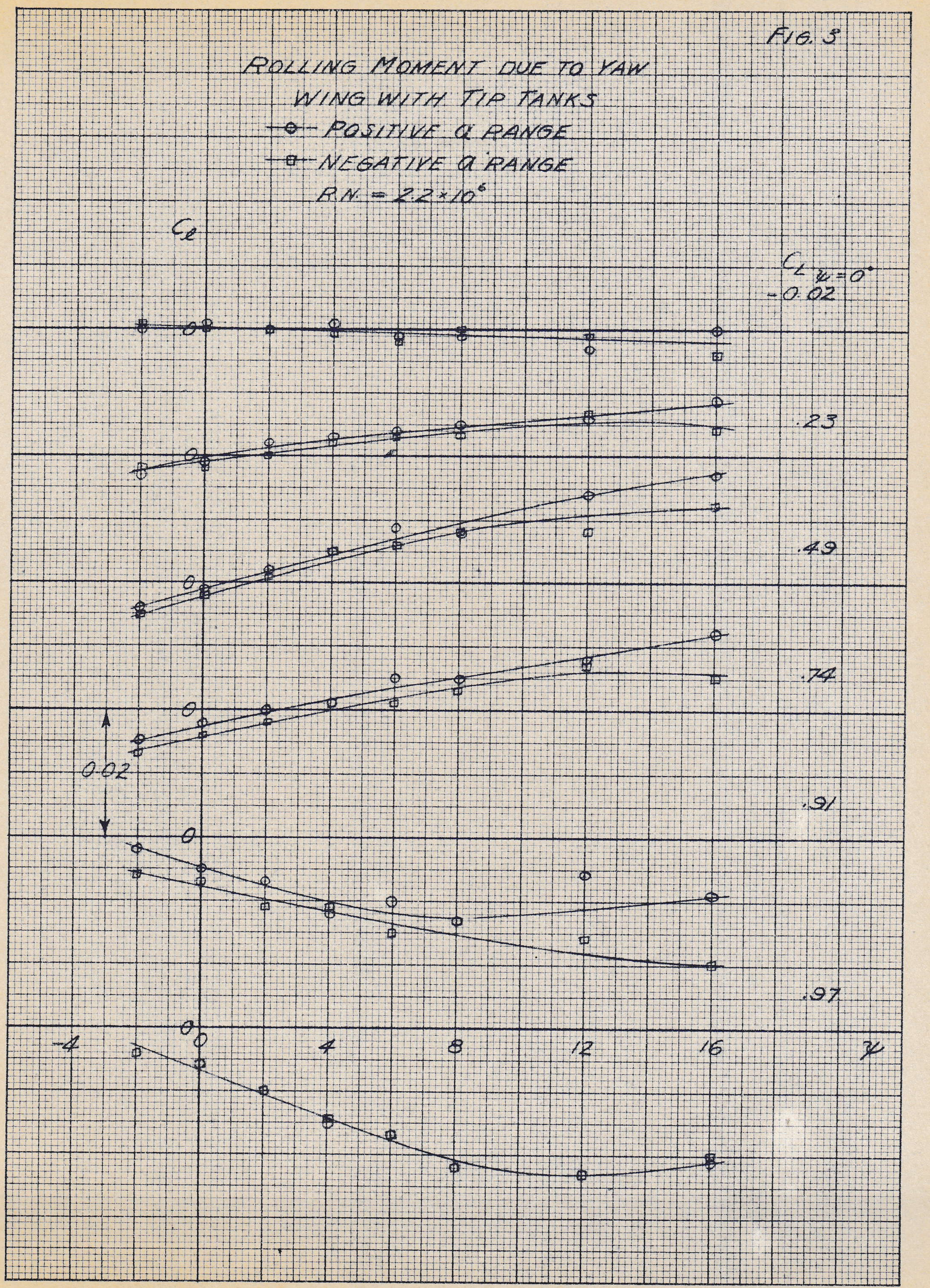
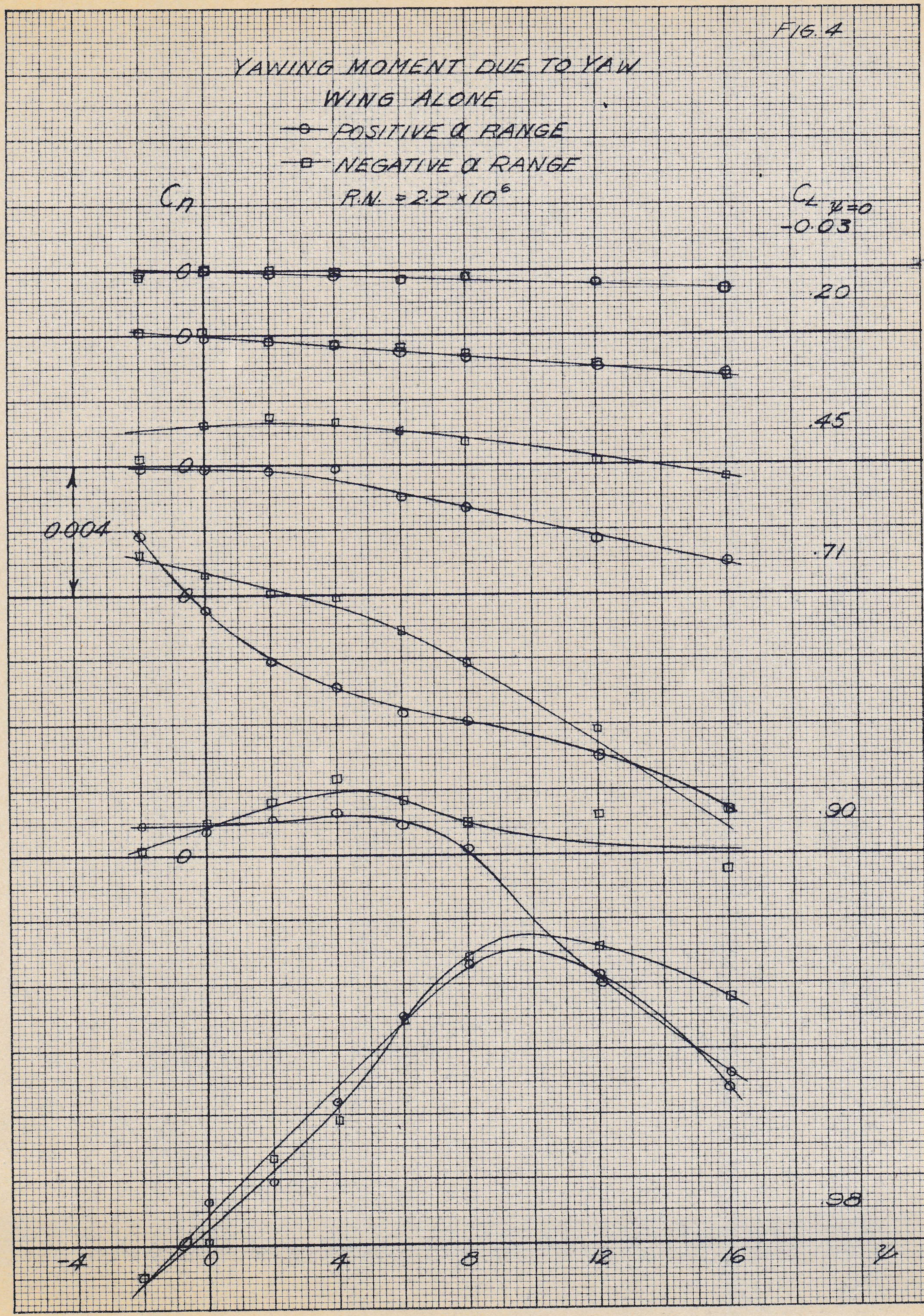


FIG. 3
ROLLING MOMENT DUE TO YAW
WING WITH TIP TANKS
POSITIVE α RANGE
NEGATIVE α RANGE
R.N. = 2.2×10⁶
C_l
$C_{L\,\psi=0°}$
-0.02
.23
.49
.74
.91
.97
0.02
0
-4
4
8
12
16
ψ



KEUFFEL & ESSER CO., N. Y. NO. 359-11
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U. S. A.

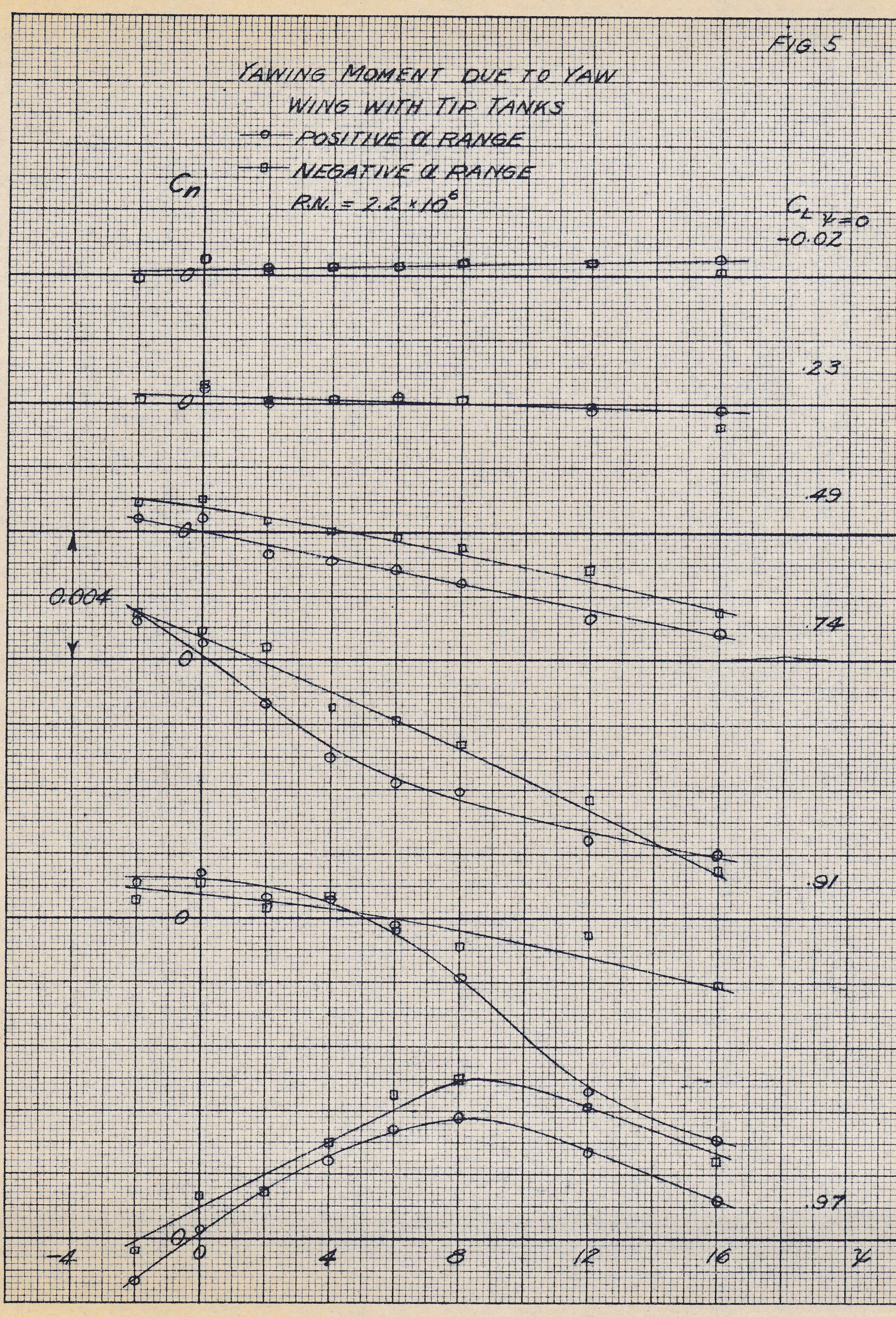


FIG. 5
YAWING MOMENT DUE TO YAW
WING WITH TIP TANKS
POSITIVE α RANGE
NEGATIVE α RANGE
R.N. = 2.2 × 10^6
C_n
C_L ψ=0
-0.02
.23
.49
.74
.91
.97
0.004
-4
0
4
8
12
16
ψ

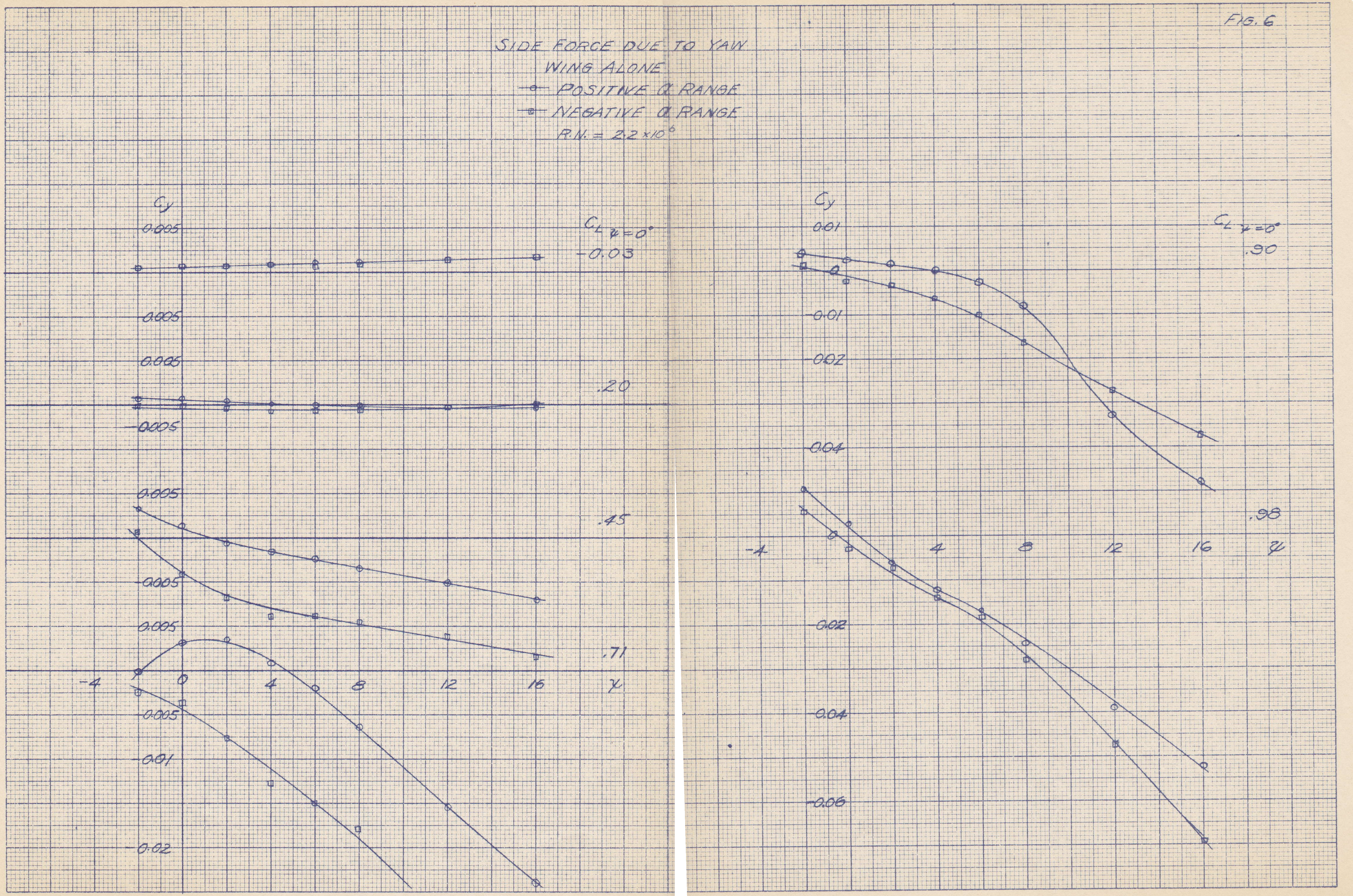


FIG. 6
SIDE FORCE DUE TO YAW
WING ALONE
POSITIVE α RANGE
NEGATIVE α RANGE
R.N. = 2.2 × 10^6
Cy
$C_{L\ \psi=0°}$
-0.03
.20
.45
.71
.90
.98
ψ

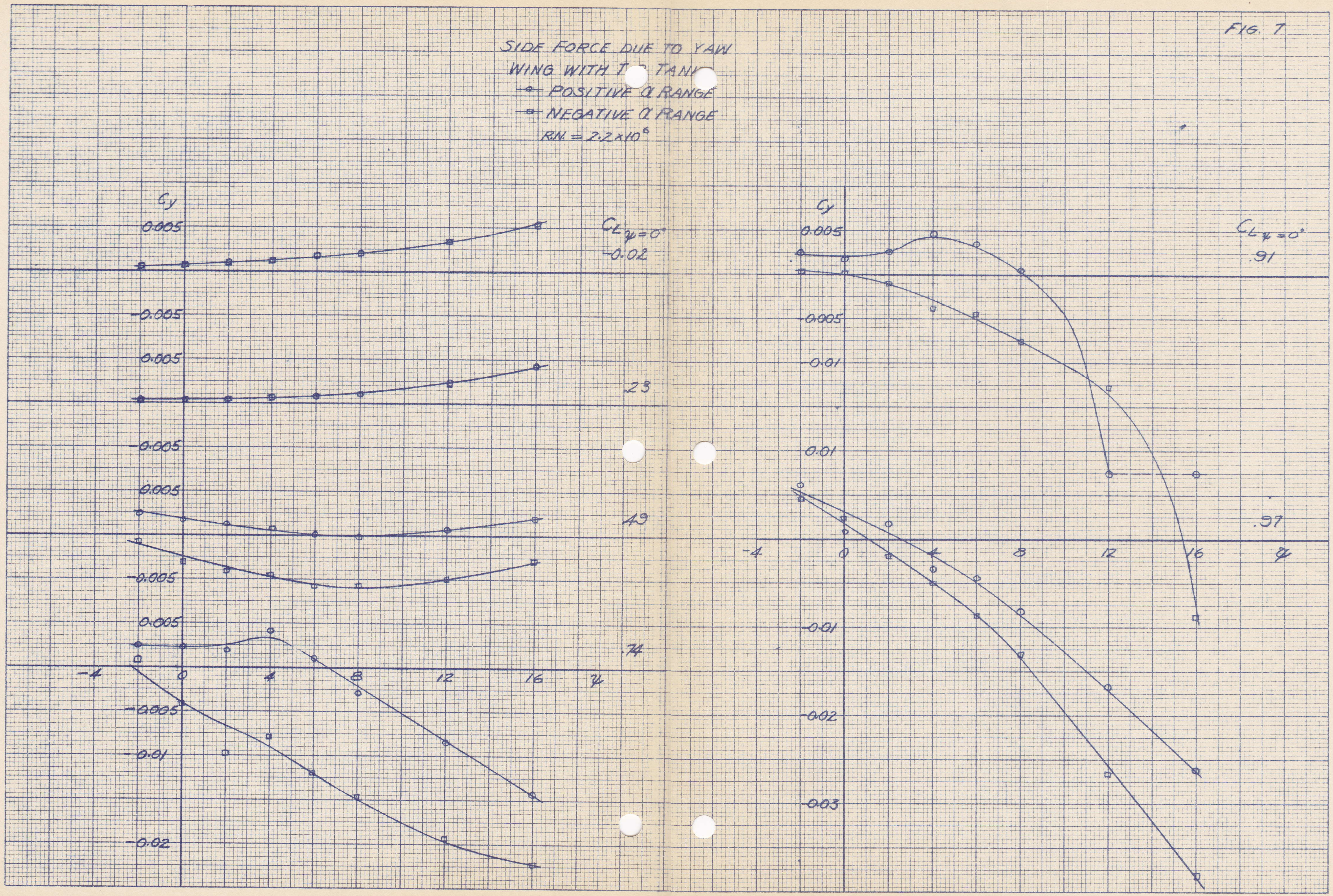


FIG. 7
SIDE FORCE DUE TO YAW
WING WITH TIP TANKS
POSITIVE α RANGE
NEGATIVE α RANGE
RN = 2.2×10^6
Cy
$C_{L_{\psi=0°}}$
-0.02
.23
.49
.74
.91
.97
0.005
-0.005
-0.01
-0.02
-0.03
-4
0
4
8
12
16
ψ

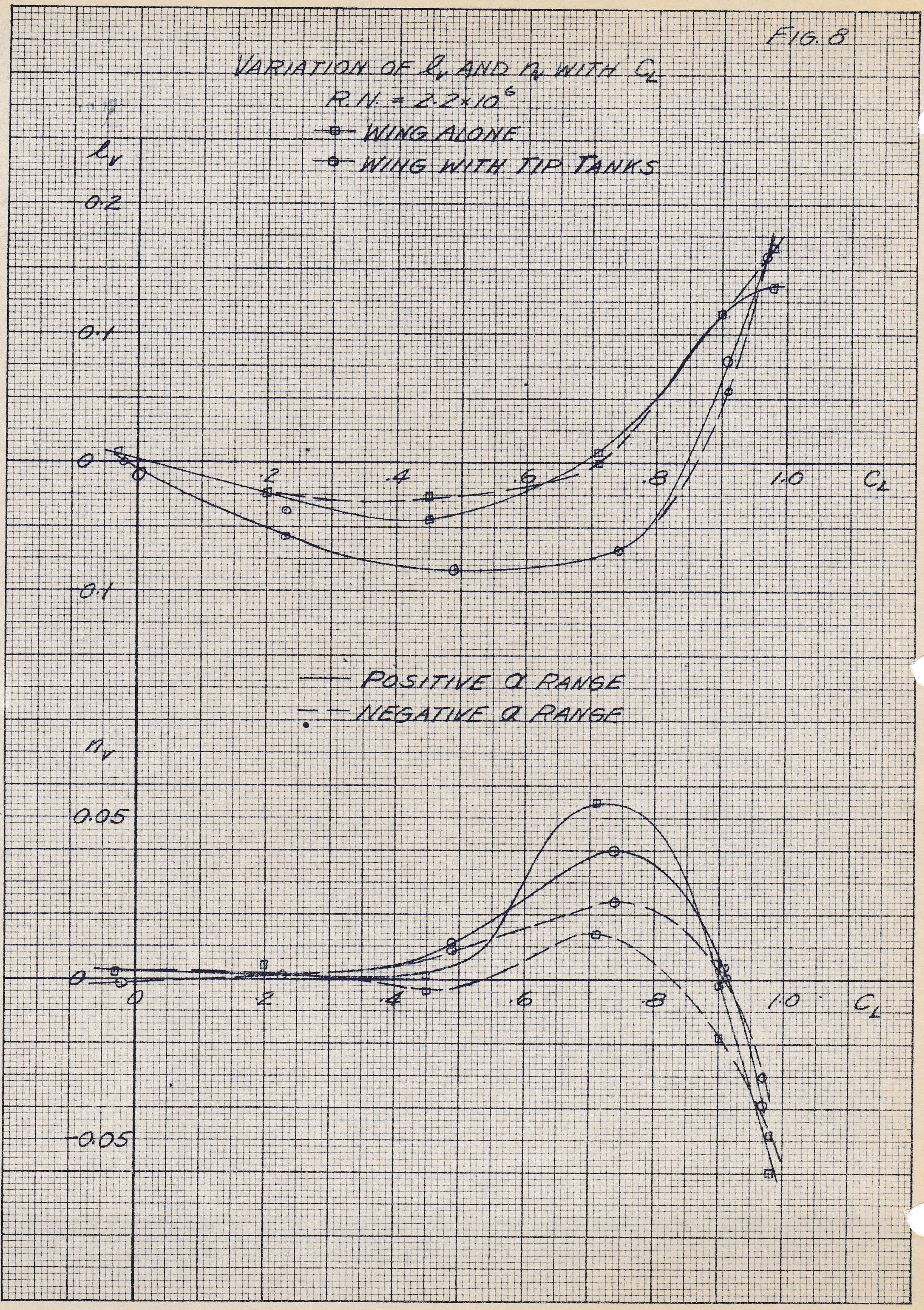


FIG. 8
VARIATION OF l_v AND n_v WITH C_L
R.N. = 2.2×10^6
WING ALONE
WING WITH TIP TANKS
l_v
0.2
0.1
0
0.1
.2
.4
.6
.8
1.0
C_L
POSITIVE α RANGE
NEGATIVE α RANGE
n_v
0.05
0
-0.05

FIG. 9

VARIATION OF y_v WITH C_L

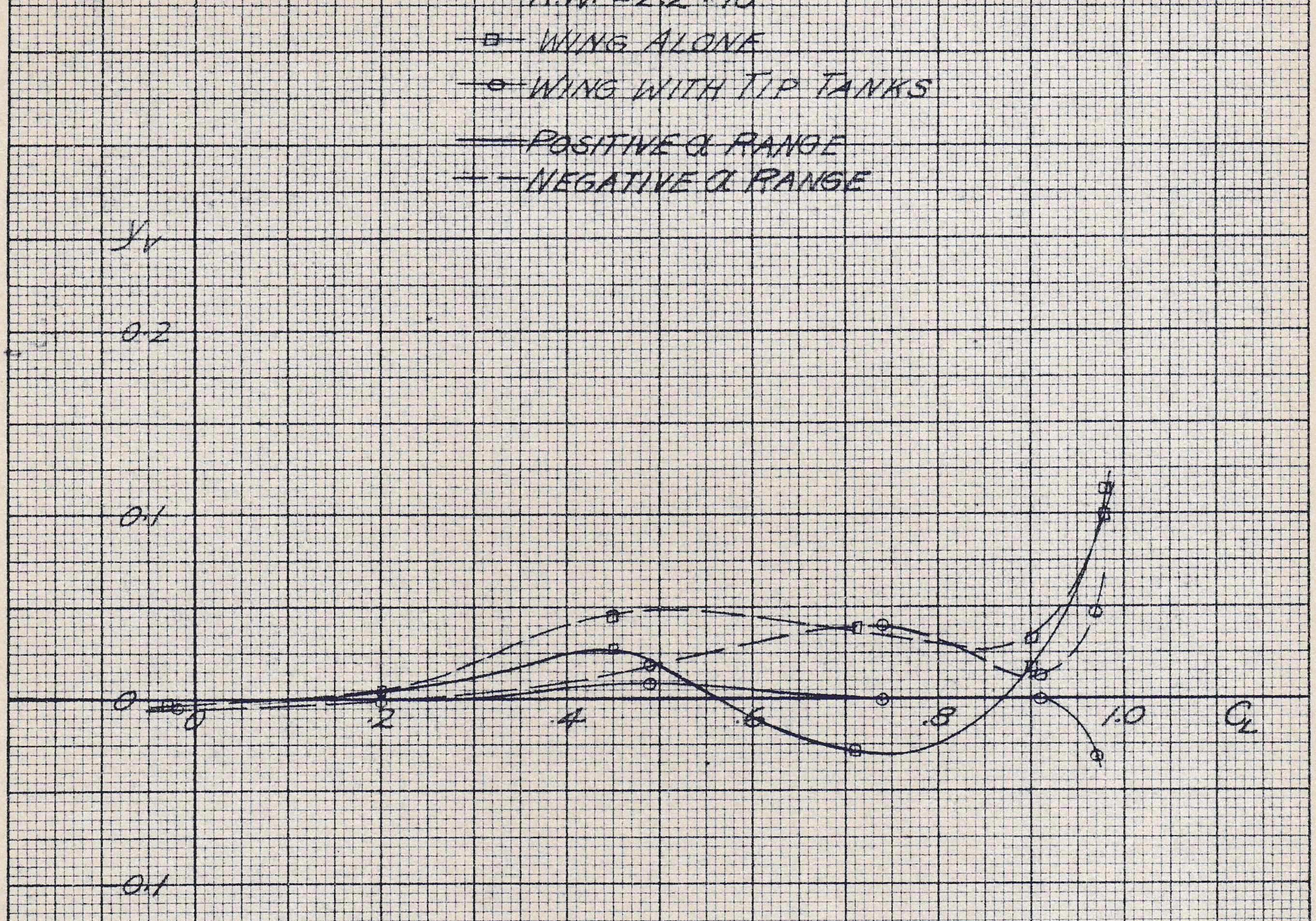
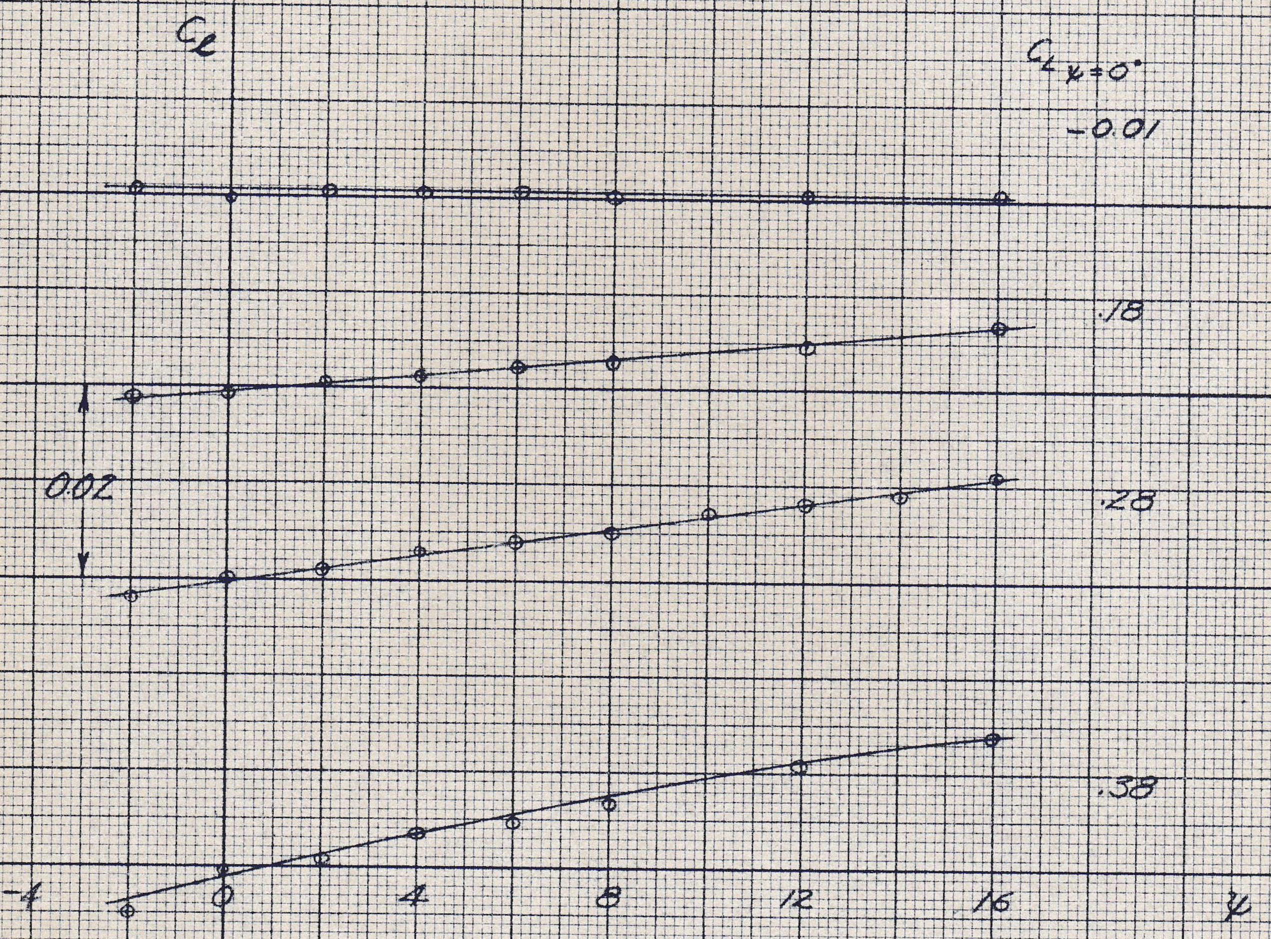


FIG. 10

ROLLING MOMENT DUE TO YAW
WING ALONE
POSITIVE α RANGE
R.N. = 3.3 × 10^6



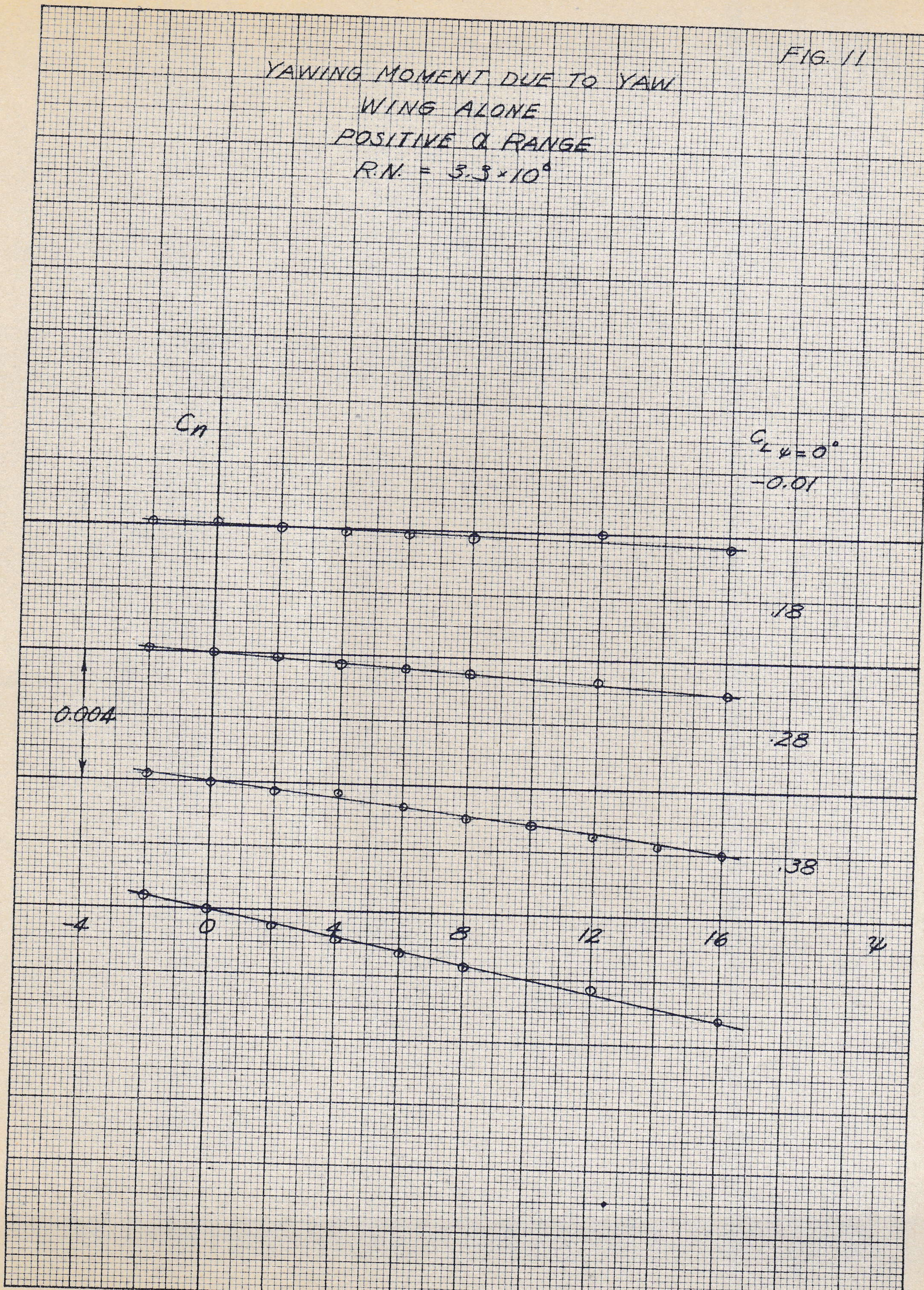
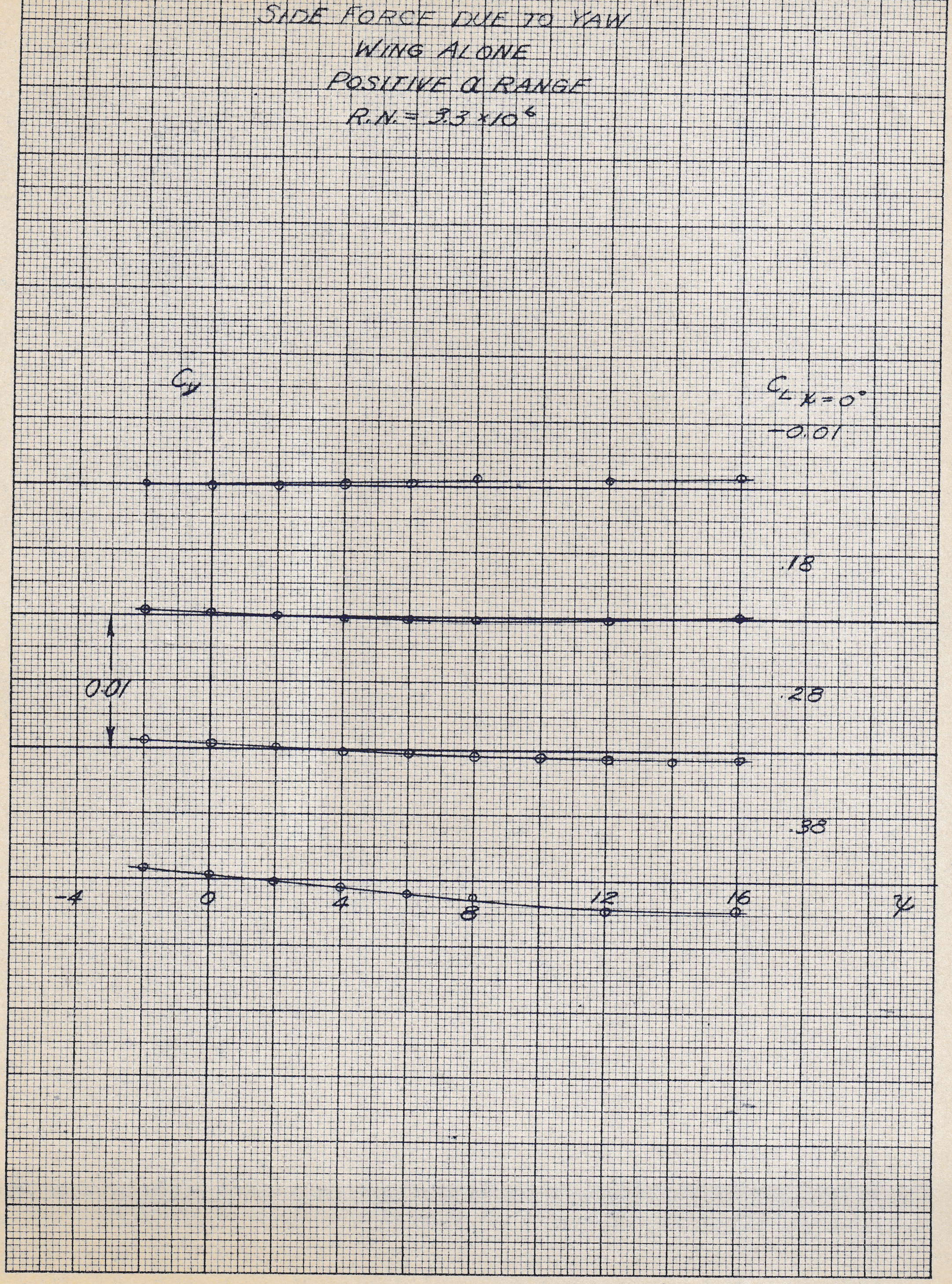


FIG. 11
YAWING MOMENT DUE TO YAW
WING ALONE
POSITIVE α RANGE
R.N. = 3.3 × 10⁶
Cn
C_L ψ=0°
-0.01
.18
.28
.38
0.004
-4
0
4
8
12
16
ψ

FIG. 12



SIDE FORCE DUE TO YAW
WING ALONE
POSITIVE α RANGE
R.N. = 3.3 × 10^6
C_y
C_L ψ = 0°
-0.01
.18
.28
.38
0.01
-4
0
4
8
12
16
ψ