

T.N. 432  
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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 432  
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DRAG TESTS OF 4/9-SCALE MODEL ENGINE NACELLES  
WITH VARIOUS COWLINGS

By Ray Windler  
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October, 1932

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SUMMARY

Results are given for drag tests of 4/9-scale model radial air-cooled engine nacelles made as a part of a general investigation of wing-nacelle-propeller interference. A small nacelle of the type commonly used with exposed engine cylinders was tested with various forms of cowling over the cylinders. The effects of cowling-ring position and of angle of ring chord to the thrust line were investigated. An N.A.C.A. cowled nacelle and a smooth body were also tested.

The results are given at 50, 75, and 100 miles per hour for  $-5^{\circ}$ ,  $0^{\circ}$ ,  $5^{\circ}$ ,  $10^{\circ}$ , and  $15^{\circ}$  angle of pitch.

INTRODUCTION

Models of two air-cooled engine nacelles with various cowlings have been tested in the propeller-research tunnel of the National Advisory Committee for Aeronautics as a part of a general investigation of wing-nacelle-propeller interference. Although the addition of nacelles to an airplane generally introduces interference problems, it is considered advisable to give the results of the drag tests of the nacelles alone without interference in this report as a contribution to general information on aerodynamic resistance. It should be borne in mind that these results were obtained with the propeller removed. The reader is referred to the reports on the general program (reference 1 and others to be published in the near future) for the practical application of nacelles to airplanes. (See also references 2, 3, and 4.) The results of drag tests on a number of small model nacelles are already available. The close check of two of the 4/9-scale combinations tested with full-scale results gives assurance that the values

obtained for the other combinations, especially with the ring cowlings, should be close to those for the full-scale condition. This check is attributed to the large scale (4/9) of the present models and the fairly accurate reproduction of engine details.

Two nacelles were used. The first was similar to the conventional types which have exposed cylinders; the second was a larger one which, when used with a hood, constituted an N.A.C.A. cowled nacelle. Both nacelles were 4/9-scale models of Wright J-5 engine nacelles reported in reference 3, and were tested with various types of cowling over the engine, which was reproduced in considerable detail. A smooth body (without engine cylinders) was also tested. Test results are given in pounds drag of the models at several air speeds up to 100 miles per hour.

#### APPARATUS AND METHODS

A description of the 20-foot propeller-research tunnel and methods of testing may be found in reference 5. The nacelles were supported by tubes attached to the regular airfoil supports. (See fig. 1.) To these tubes were attached short arms bolted to the end of the vertical supports. Suitable holes in the arms permitted the angle of pitch to be adjusted to the desired values. With this arrangement it was not necessary to use a sting and therefore the tare drag was reduced. In making the tare-drag tests the nacelles were supported by wires free of the tubes.

Figure 2 shows the nacelles used and gives their principal dimensions. The larger nacelle had a maximum diameter approximately equal to that of the engine. This nacelle was tested both with the hood (ring) in place and with it removed, the former arrangement constituting an N.A.C.A. cowled nacelle. The conventional nacelle (hereafter called small nacelle) had a small diameter back of the cylinders and a little over half the fin area of the cylinders exposed. This nacelle was tested with the cylinders exposed and with the hood as previously used on the N.A.C.A. cowled nacelle as well as with various forms of ring cowlings. A smooth body without engine cylinders was also tested as it had been used in the general program.

The various ring cowlings are shown in Figure 3 and are of two types. The first includes three wide, thin, fixed-angle rings designated Nos. 1, 2, and 3. The angles between the ring chords and the thrust lines are  $0^\circ$ ,  $-3^\circ$ , and  $-6.3^\circ$ , respectively. These rings were all of approximately 9-inch chord and the maximum thickness/chord ratio was approximately 0.05 for ring No. 1 and 0.07 for rings Nos. 2 and 3. All three of the rings were tested in the same two fore-and-aft positions on the engine and the  $-6.3^\circ$  ring was also tested in a more forward position. (See fig. 4 for ring positions.) Tests of these three fixed-angle rings agreed with flight tests (reference 4) in that the angle of chord to thrust line had a marked effect on the results obtained. The variable-angle ring as shown in Figure 3 was then constructed. This polygonal ring of nine sides had a 6-inch chord and a maximum thickness/chord ratio of approximately 0.10. The chord angle could be adjusted from  $0^\circ$  to  $-15^\circ$ . The design of this ring was based on a study of the tests of reference 6.

The two positions in which the variable-angle ring was tested are given in Figure 4. In the rear position it was tested with the chord set  $0^\circ$ ,  $-5^\circ$ ,  $-8^\circ$ ,  $-10^\circ$ , and  $-15^\circ$  to the thrust line. The  $-8^\circ$  setting was found to be the best and this angle only was used in the tests in the forward position.

All the combinations except one were tested at  $-5^\circ$ ,  $0^\circ$ ,  $5^\circ$ ,  $10^\circ$ , and  $15^\circ$  angle of pitch. Figure 1 shows most of these combinations as mounted for tests. Readings were taken from which the dynamic pressure and drag could be obtained. Tare-drag tests at the above angles of pitch provided suitable data for computing the net drag.

## RESULTS

The net drags of all the combinations tested are given in Tables I, II, and III at 50, 75, and 100 miles per hour for  $-5^\circ$ ,  $0^\circ$ ,  $5^\circ$ ,  $10^\circ$ , and  $15^\circ$  angle of pitch. The results for 100 miles per hour are plotted in Figures 5 to 9, inclusive. Figures 7 and 9 show the effect on drag of the angle of the cowling-ring chord to the thrust line. Figure 10 gives the net drag, in pounds, of full-size Wright J-5 engine nacelles obtained by scaling up these model results. The relative drag of the different nacelles and engine cowlings at the three different air speeds is practically

the same; since the percentage accuracy is the greatest at 100 miles per hour, the discussion following has been taken from the results at this speed only.

The results that are given have been taken from faired curves and are believed to be accurate to within  $\pm 0.2$  pound as the average deviation of the test points from the faired curves did not exceed this amount.

## DISCUSSION

### Effect of Body Shape and N.A.C.A. Hood

Table I and Figure 5 give the results for the nacelles exclusive of the ring cowlings tested on the small nacelle. The following savings in drag were obtained at  $0^\circ$  angle of pitch: increasing the diameter back of the engine cylinders reduced the drag 25 per cent when the cylinders were exposed and 57 per cent when a hood was used; using a hood reduced the drag 39 per cent on the small nacelle and 65 per cent on the large one; increasing the diameter and using a hood (N.A.C.A. cowled nacelle) reduced the drag 74 per cent. With the following two exceptions, these savings were practically independent of angle of pitch up to and including  $15^\circ$ . When the hood was employed, enlarging the diameter decreased the drag 43 per cent at  $15^\circ$  angle of pitch as against 57 per cent at  $0^\circ$ . Likewise, if both the diameter was increased and the hood was employed (N.A.C.A. cowled nacelle), the drag relative to that of the small nacelle with exposed cylinders was reduced only 62 per cent at  $15^\circ$  as against 74 per cent at  $0^\circ$ . These results also show that using the hood is more effective in reducing the drag than increasing the diameter behind the cylinders and that increasing the diameter behind the cylinders is more effective when a hood is employed than when the cylinders are exposed. These results are in agreement with the full-scale tests of references 2 and 3.

The drag of the smooth body was 8.6 pounds at  $0^\circ$  pitch. This value seems rather excessive as it is practically the same as the drag of a sphere whose diameter is equal to the maximum diameter of the body. An examination of Figure 2 reveals the fact that although this body is by no means an ideally streamline shape, one would hardly expect it to have as high a drag as that measured.

## Effect of Rings

There is a popular belief that almost any kind of a ring cowling will reduce the drag of a radial engine. The fallacy of this belief for the condition without a propeller is shown by the results obtained with rings Nos. 1 and 2 and with the variable-angle ring set  $0^\circ$ . At  $0^\circ$  angle of pitch these rings increased the drag over that with the cylinders exposed. Ring No. 3 in the best location reduced the drag 7.5 pounds or 25 per cent. The effect of the fore-and-aft position of the rings is shown in Figure 6 and it will be observed that moving the ring forward increased the drag with rings Nos. 1 and 2, and reduced the drag with ring No. 3. Figure 7, in which the values of drag are replotted to show the effect of ring-chord angle to the thrust line for the three rings in position No. 3, shows that further reduction could be expected if the ring-chord angle were increased. These results, which are also given in Table II, indicate that the fore-and-aft location of the ring affects the drag to a slight extent but that the angle of the ring chord to the thrust line is a more decisive factor in drag reduction.

The results with the variable-angle ring will be found in Table III and Figures 8 and 9. In the rear position the optimum angle of chord increased with the angle of pitch as shown in Figure 9. The  $-8^\circ$  chord angle was selected and run in the forward position where the drag was found to be slightly lower than in the rear one. (See Table III and fig. 8.) With this optimum angle and position the drag was reduced 38 per cent over that with the cylinders exposed. None of the other angles were tried in the forward position.

## Comparison of Rings and N.A.C.A. Hood

The following comparison is made between the rings and the N.A.C.A. Hood which was tested on the small nacelle as a matter of interest. With the hood, and the rings in position No. 1, the leading edge of the cylinder cowling was  $5\frac{3}{4}$  inches ahead of the center line of the cylinders. (See figs. 2 and 4.) This was the maximum forward location that could be used and have clearance for the propeller at high pitch settings. With the variable-angle ring set  $-8^\circ$  in position No. 1 the drag was 18.7 pounds at  $0^\circ$  angle of

pitch, which is only 0.2 pound higher than with the hood; therefore, there is little choice between the two for cruising or high speed. However, the drag increased more rapidly with the ring than with the hood as the angle of pitch was increased until at  $15^\circ$  it was almost  $1\frac{1}{2}$  times that with the hood. Hence the hood appeared to be the better cowling for general-purpose use. Subsequent tests of wing-nacelle combinations have verified this both with the propeller operating and with it removed. (Reference 1.)

Since tests with the small nacelle showed that the N.A.C.A. hood was superior to all of the rings tested, the rings were not tested on the large nacelle.

#### Effect of Angle of Pitch

All the combinations show the usual increase in drag with angle of pitch. A systematic analysis reveals the interesting fact that the lower the drag of the combination at  $0^\circ$  pitch the higher is the percentage increase in drag as the angle of pitch is increased. The combination which had the lowest drag at  $0^\circ$  pitch had, however, the lowest drag throughout the entire pitch range.

#### Agreement with Full-Scale Tests

The full-scale drags at  $0^\circ$  angle of pitch of all the combinations tested as obtained by scaling up these model tests are given in Figure 10. Results of some previous full-scale wind-tunnel drag tests on J-5 engine nacelles are given in reference 3. The following table giving the drag (in pounds) at 100 miles per hour shows a close agreement between the  $4/9$ -scale model tests reported herein and those full-scale tests.

Nacelle	Full-scale drag ref. 3 pounds	Model drag $(4/9)^2$ pounds
Small nacelle - exposed cylinders	155	153
N.A.C.A. nacelle	43	40

## Other Considerations

In the general program of wing-nacelle-propeller interference, propeller tests, especially with tandem propellers, have shown that the propulsive efficiency is affected by the angle of the ring chord to the thrust line. This effect is presumably caused by the fact that the slipstream of the propeller changes the direction of air flow over the ring and consequently the drag. It has been found that the cowling that gives the lowest drag without the propeller is not always the best combination when used with a propeller. This is a partial explanation of why some cowlings have been known to increase the drag with the propeller removed in tunnel tests but have shown increases in speed when tested in free flight. At least it is evident that a nacelle cowling should not be selected entirely from a consideration of drag and that it is necessary to consider the complete power unit including nacelle and propeller.

Langley Memorial Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., September 22, 1932.

## REFERENCES

1. Wood, Donald H.: Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. II. Thick Wing - Various Radial-Engine Cowlings - Tractor Propeller. T.R. No. 436, N.A.C.A., 1932.
2. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine-I. T.R. No. 313, N.A.C.A., 1929.
3. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine-II. T.R. No. 314, N.A.C.A., 1929.
4. Gough, Melvin N.: Effect of the Angular Position of the Section of a Ring Cowling on the High Speed of an XF7C-1 Airplane. T.N. No. 355, N.A.C.A., 1930.
5. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 300, N.A.C.A., 1928.
6. Townend, H. C. H.: Reduction of Drag of Radial Engines by the Attachment of Rings of Aerofoil Sections, Including Interference Experiments of an Allied Nature, with Some Further Applications. R. & M. No. 1267, British A.R.C., 1929.

TABLE I. Net Drag of Various Nacelles  
(Values in pounds)

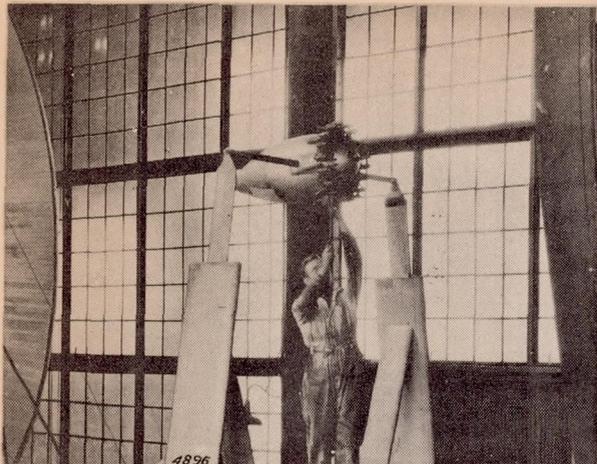
Angle of pitch degrees	Smooth body	Small nacelle with exposed cylinders	Small nacelle with N.A.C.A. hood	Large nacelle with exposed cylinders	Large nacelle with N.A.C.A. hood
$q = 6.4 \text{ lb./sq.ft.}, 50 \text{ m.p.h.}$					
-5	1.9	8.6	4.6	--	3.8
0	2.2	7.8	4.6	6.0	2.2
5	2.2	8.5	5.5	6.0	2.5
10	2.6	9.0	6.1	7.0	3.1
15	3.0	9.6	6.4	-	4.0
$q = 14.4 \text{ lb./sq.ft.}, 75 \text{ m.p.h.}$					
-5	4.2	18.7	10.9	-	4.9
0	4.9	17.1	10.4	13.5	4.6
5	4.9	17.7	10.9	13.3	5.3
10	5.8	18.9	12.0	15.1	6.0
15	8.0	19.9	13.1	-	7.6
$q = 25.6 \text{ lb./sq.ft.}, 100 \text{ m.p.h.}$					
-5	7.3	33.2	19.9	-	7.2
0	8.6	30.2	18.5	22.8	7.9
5	8.8	30.9	18.6	23.4	8.4
10	10.4	33.0	20.3	25.5	9.4
15	14.3	34.3	22.6	-	12.9

TABLE II. Net Drag of Small Nacelle  
with Fixed-Angle Rings  
(Values in pounds)

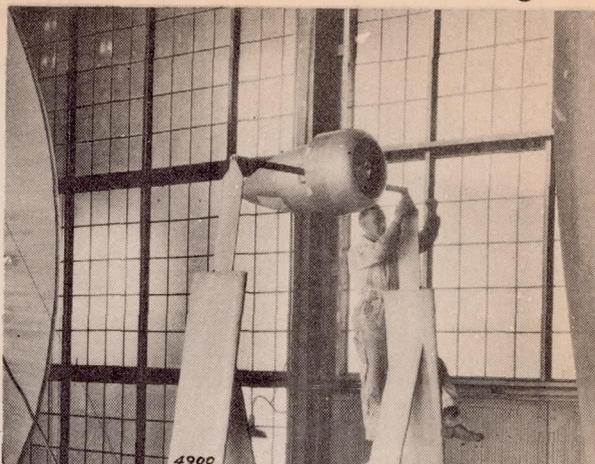
Angle of pitch degrees	Ring No. 1		Ring No. 2		Ring No. 3		
	Pos. No. 2	Pos. No. 3	Pos. No. 2	Pos. No. 3	Pos. No. 1	Pos. No. 2	Pos. No. 3
	q = 6.4 lb./sq.ft., 50 m.p.h.						
-5	10.0	10.4	8.2	8.2	7.0	6.6	7.1
0	10.5	9.7	7.6	7.8	6.0	6.0	6.3
5	10.5	9.5	7.3	8.0	6.0	6.3	6.9
10	10.8	9.5	8.2	8.4	7.0	7.7	7.9
15	10.9	10.2	9.0	9.1	8.6	8.8	9.6
	q = 14.4 lb./sq.ft., 75 m.p.h.						
-5	22.1	22.1	18.6	18.4	15.2	14.9	15.5
0	22.5	21.4	17.6	17.5	13.0	13.5	14.0
5	22.7	21.3	17.6	17.5	13.3	14.3	15.9
10	22.3	21.3	18.5	18.2	15.5	16.6	17.5
15	23.4	22.7	20.2	20.5	18.5	19.5	20.5
	q = 25.6 lb./sq.ft., 100 m.p.h.						
-5	38.6	38.5	33.0	32.6	26.7	26.6	26.5
0	39.1	37.5	32.6	31.1	22.7	23.8	24.9
5	37.6	37.5	31.5	30.9	23.5	25.3	27.0
10	38.2	36.8	32.7	32.2	27.5	28.8	30.1
15	40.4	40.0	36.1	36.5	32.4	33.9	35.7

TABLE III. Net Drag of Small Nacelle  
with Variable-Angle Ring  
(Values in pounds)

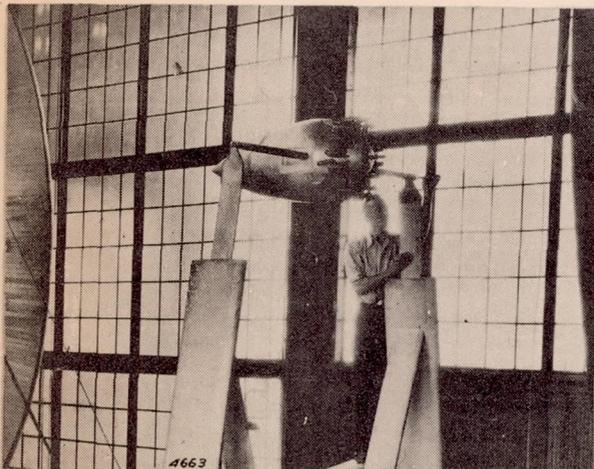
Angle of pitch degrees	Pos. No. 1	P o s i t i o n    No. 2				
	Set -8°	Set 0°	Set -5°	Set -8°	Set -10°	Set -15°
	q = 6.4 lb./sq.ft., 50 m.p.h.					
-5	5.6	8.9	6.1	6.0	5.6	6.9
0	5.2	8.5	5.0	5.5	5.5	6.4
5	5.7	8.9	5.9	5.6	5.4	6.9
10	6.6	8.3	6.7	7.5	6.5	6.5
15	7.8	9.3	8.4	8.4	8.1	8.1
	q = 14.4 lb./sq.ft., 75 m.p.h.					
-5	12.5	19.8	13.4	12.5	12.6	6.9
0	10.9	20.0	11.0	11.5	11.6	6.4
5	11.6	19.3	13.1	12.4	11.9	6.9
10	14.5	18.4	15.4	15.1	13.9	6.5
15	17.4	20.5	18.2	18.1	17.3	8.1
	q = 25.6 lb./sq.ft., 100 m.p.h.					
-5	21.1	34.9	22.7	21.9	22.9	26.0
0	18.7	36.1	19.0	19.8	20.1	25.2
5	19.9	33.7	23.3	21.8	20.8	25.1
10	25.6	32.5	27.5	25.5	24.2	25.7
15	30.5	36.4	32.0	31.7	30.6	30.4



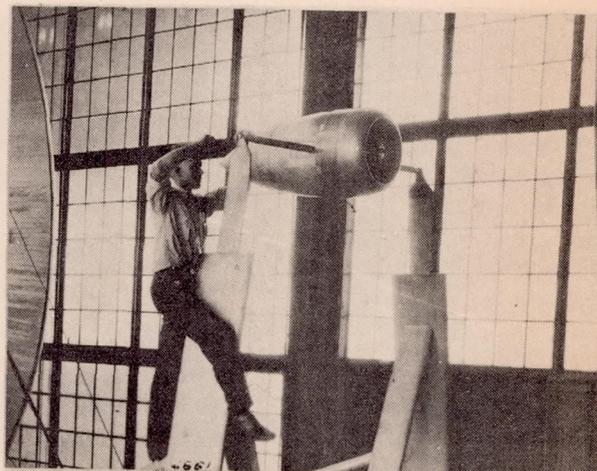
A, Small nacelle with exposed cylinders



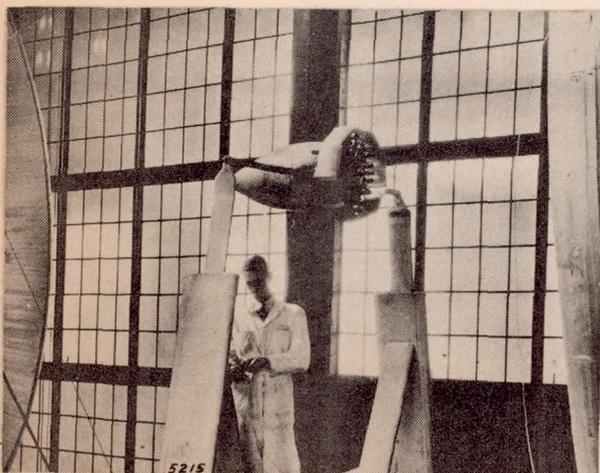
B, Small nacelle with N.A.C.A. hood



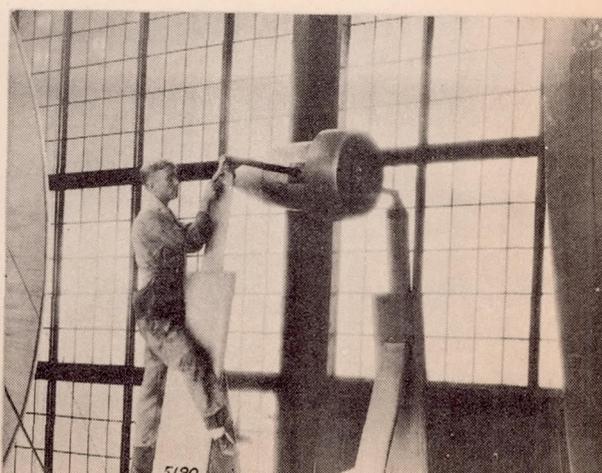
C, N.A.C.A. nacelle with hood cowling removed



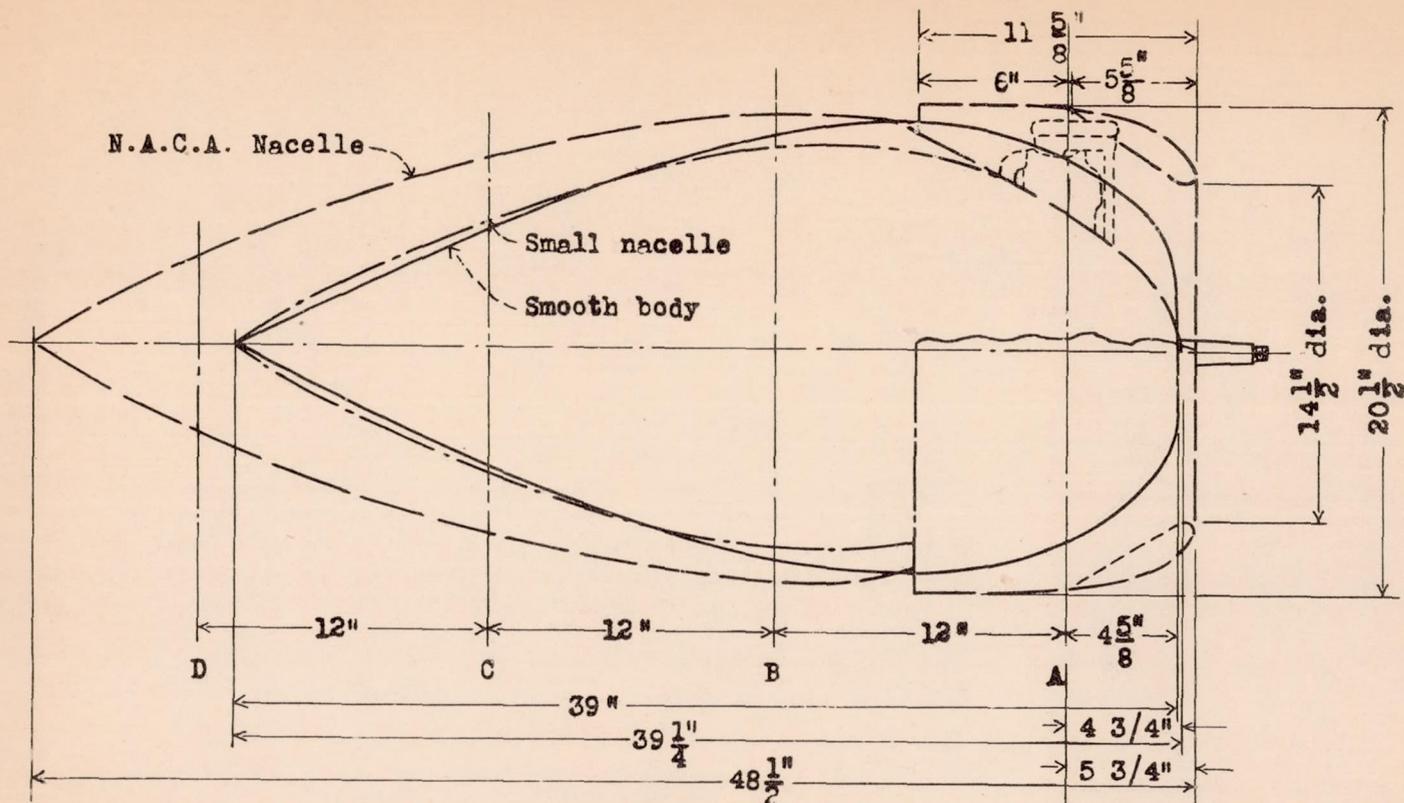
D, N.A.C.A. nacelle



E, Small nacelle with variable-angle ring



F, Small nacelle with ring No.3 in position No.2



	Diameter - inches				
	Sta. A	Sta. B	Sta. C	Sta. D	Max.
Small nacelle	11 1/2	16 5/8	10 1/2	—	16 3/4
N.A.C.A. nacelle	11 1/2	19 3/8	15 3/4	7 1/2	19 1/2
Smooth body	15	17 3/4	9 3/4	—	19

Fig. 2

⊙ Cylinders

Note: Dummy engine not used with smooth body.

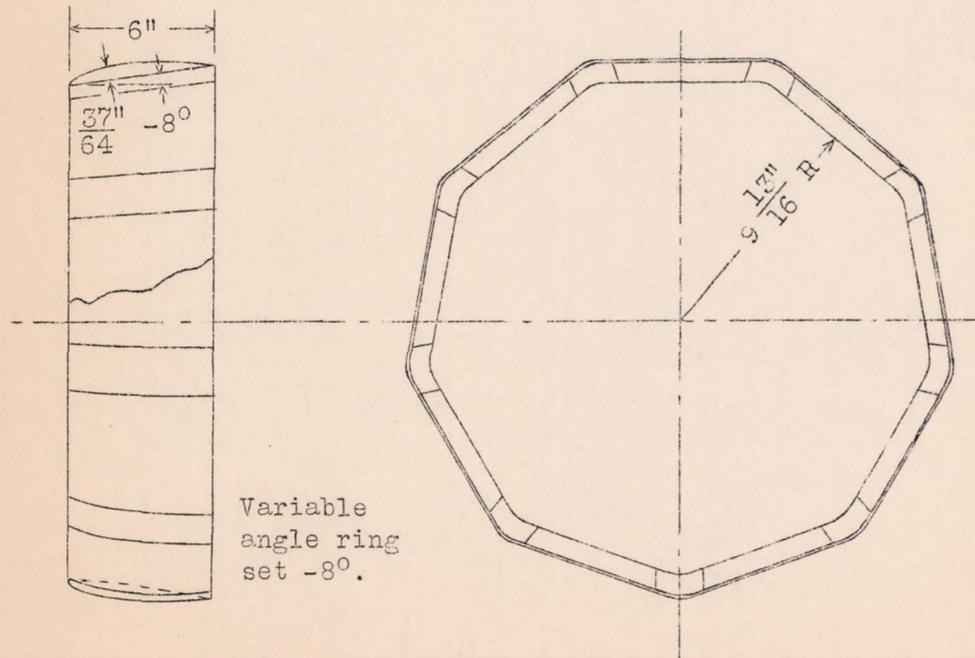
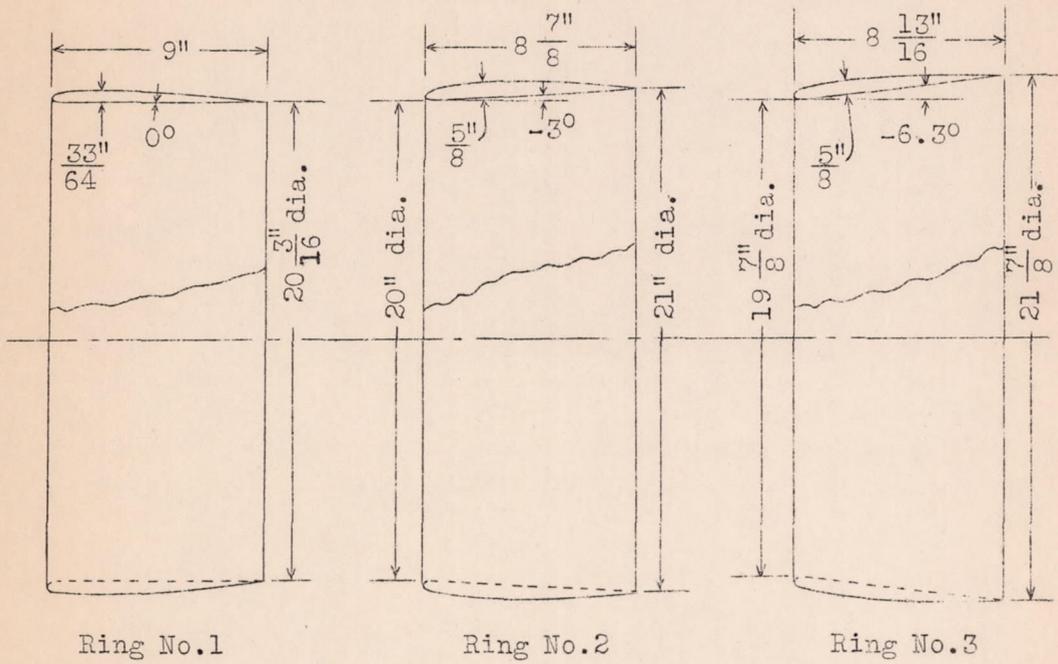


Fig.3 Ring cowlings.

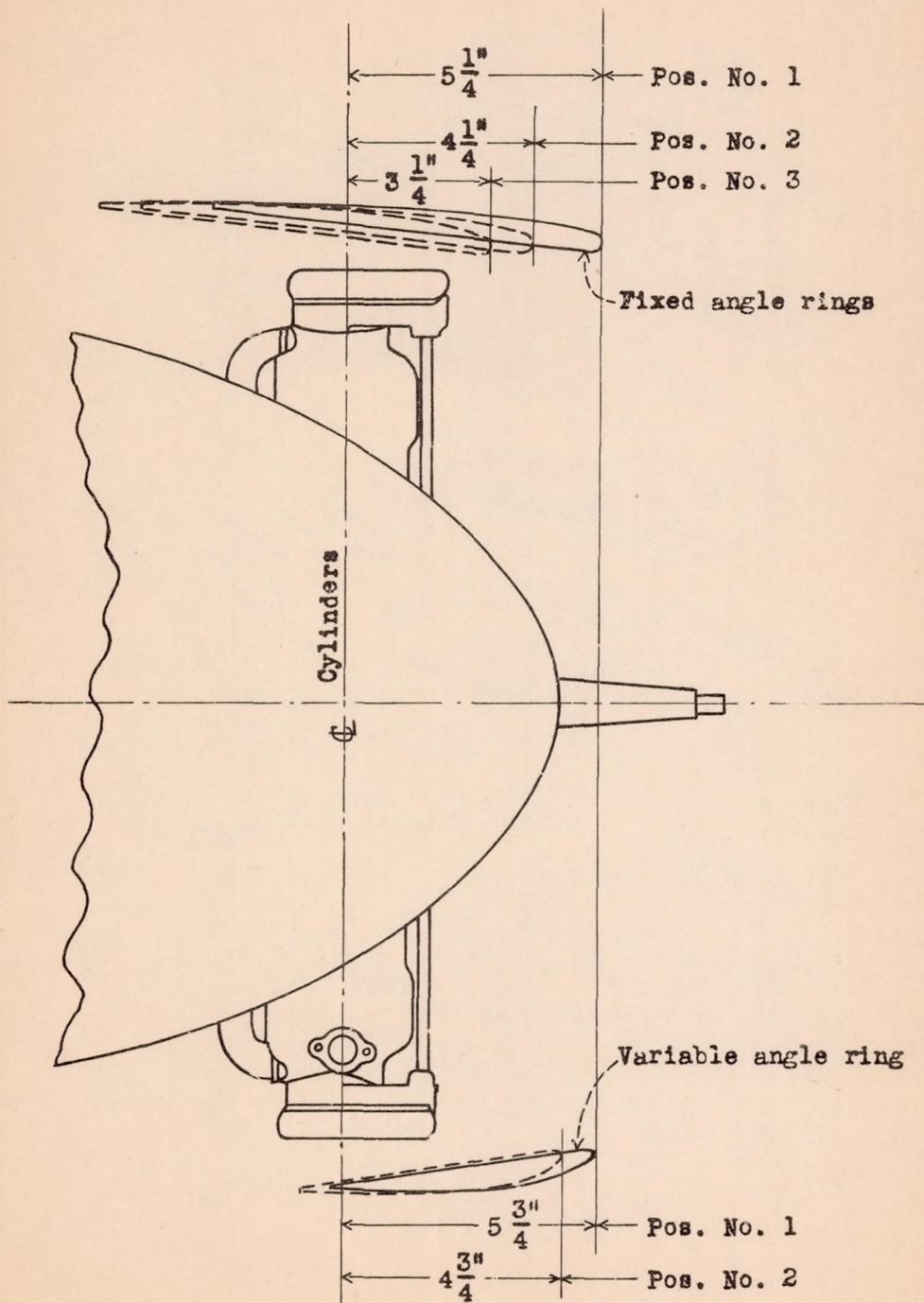


Fig. 4

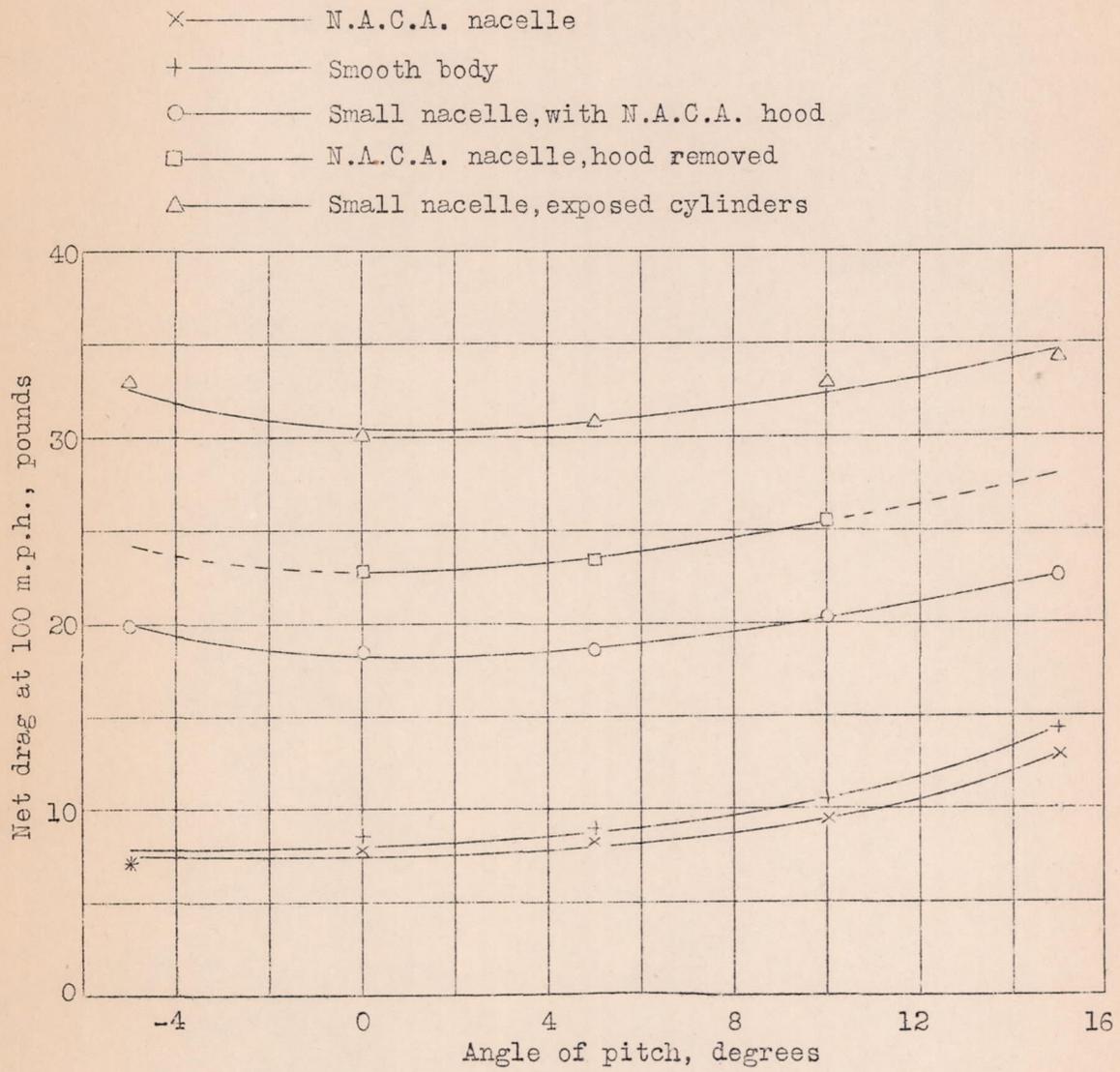


Fig.5 Change in drag with angle of pitch. (Various nacelles)

- a, Ring No.1 ( $0^{\circ}$ )
- b, " No.2 ( $-3^{\circ}$ )
- c, " No.3 ( $-6.3^{\circ}$ )

- ——— Position No.1
- × ——— " No.2
- ——— " No.3

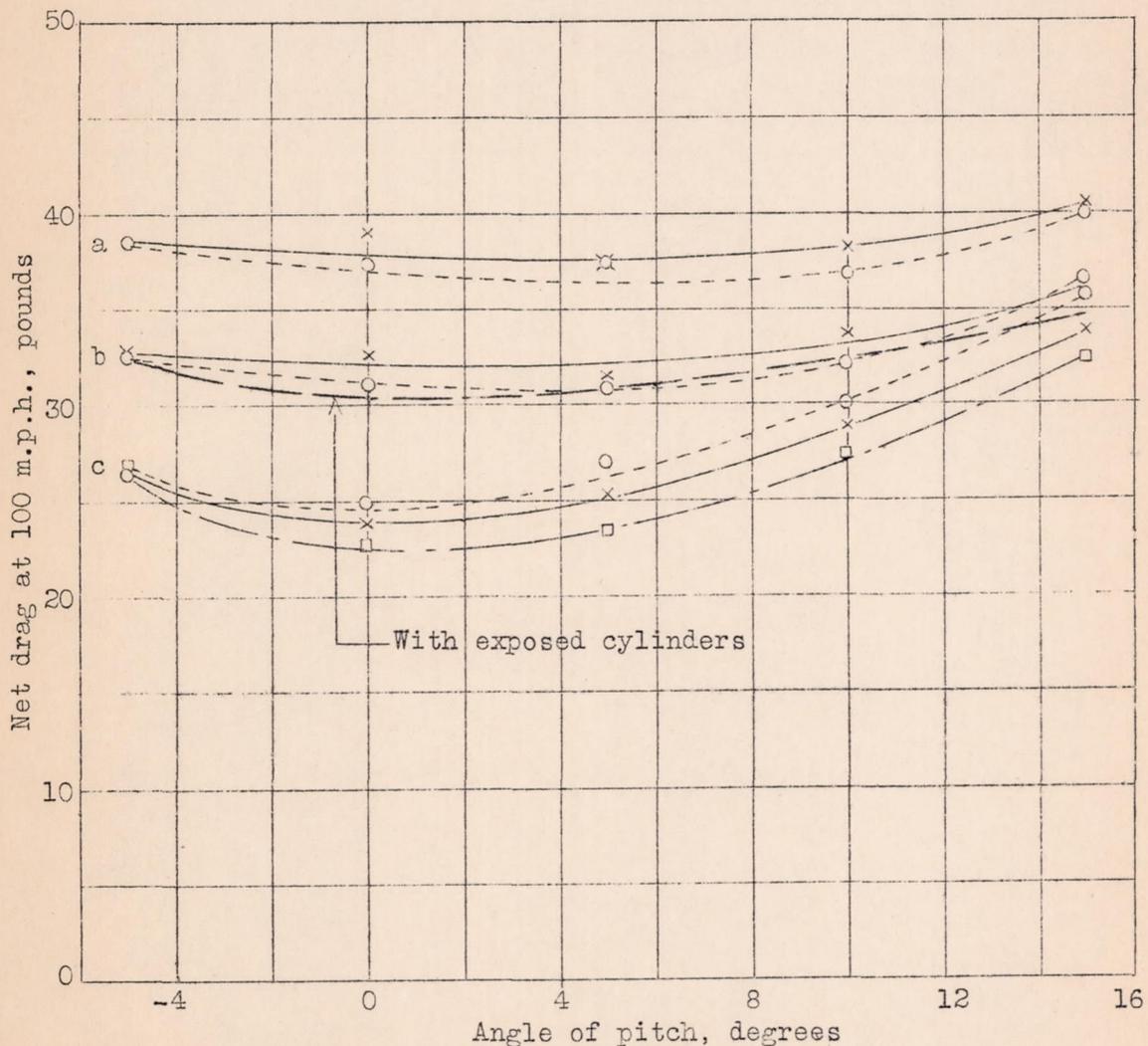


Fig.6 Drag of small nacelle with three fixed-angle rings in three positions.

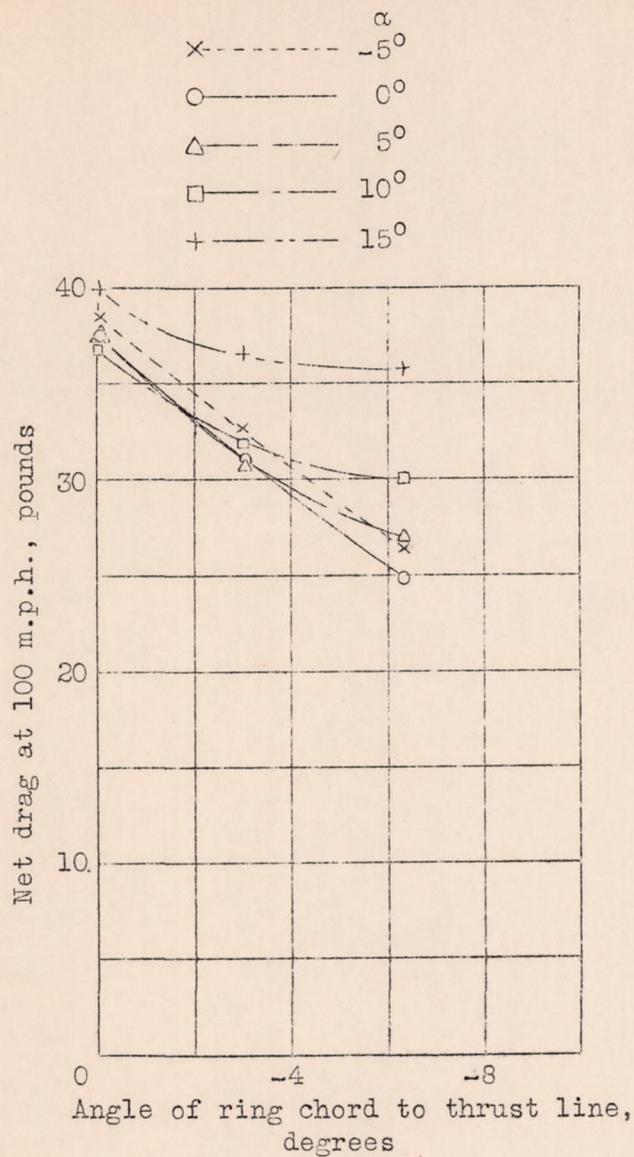


Fig.7 Effect of angle of chord to thrust line on drag. (Small nacelle with rings Nos.1,2, and 3 in position No.2).

	Ring chord setting in degrees	Ring position
x ———	0	2
o - - - -	-5	2
△ ———	-8	2
□ - - - -	-10	2
⊙ - - - -	-15	2
+ - - - -	-8	1

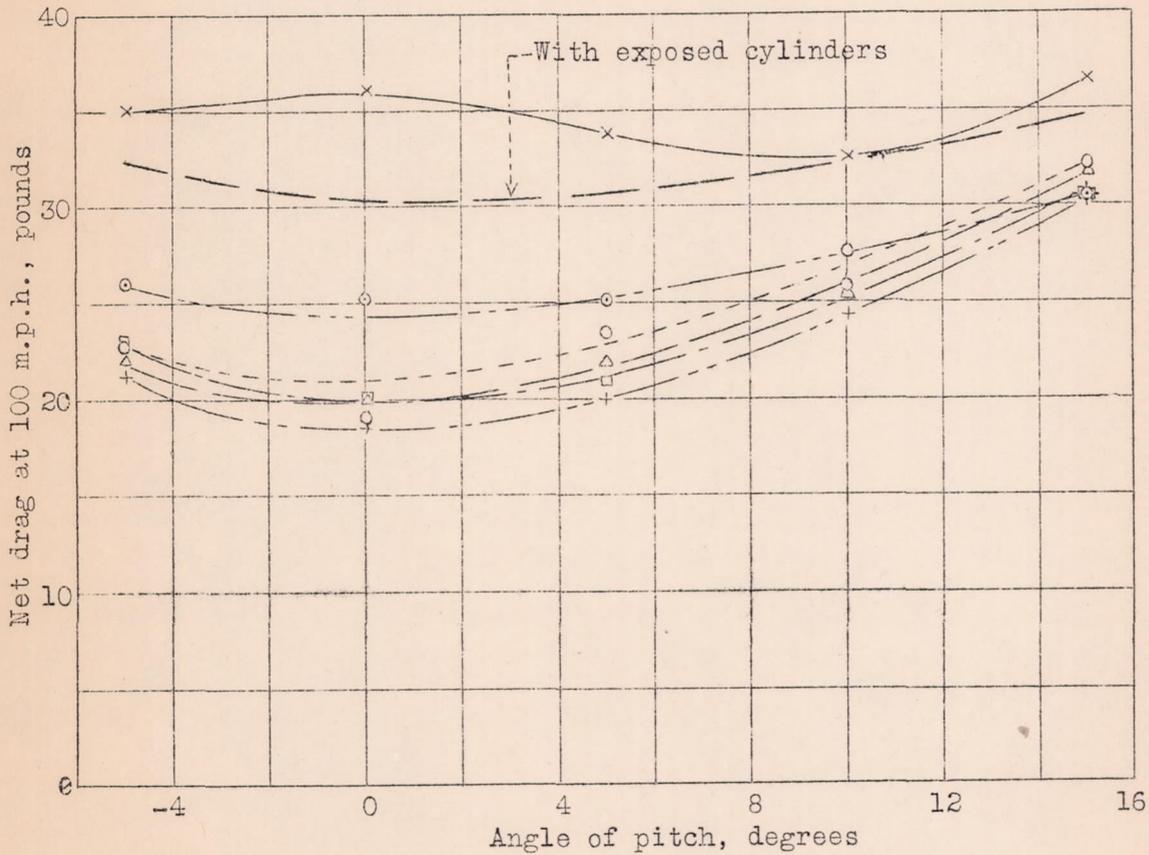


Fig.8 Change in drag with angle of pitch. (Small nacelle with variable-angle ring.)

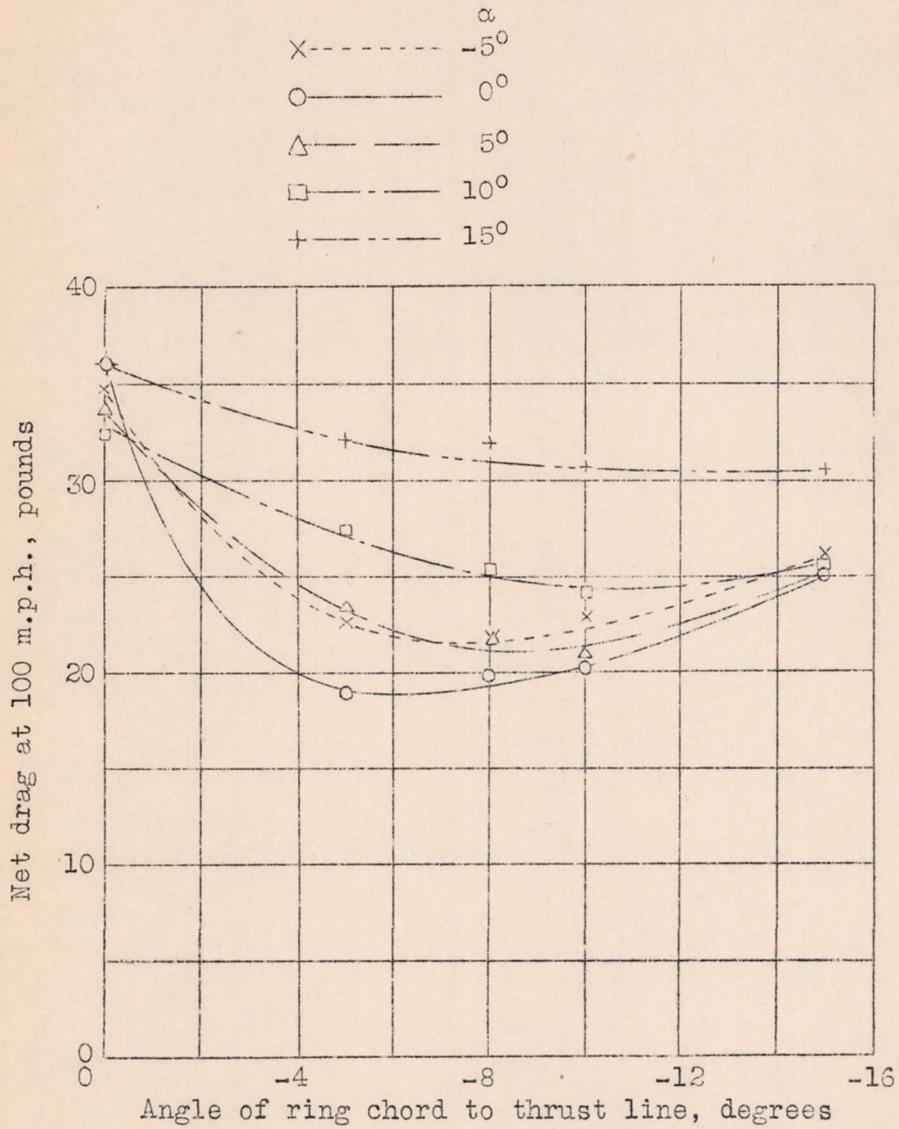


Fig.9 Effect of angle of chord to thrust line on drag. (Small nacelle with variable-angle ring in position No.2)

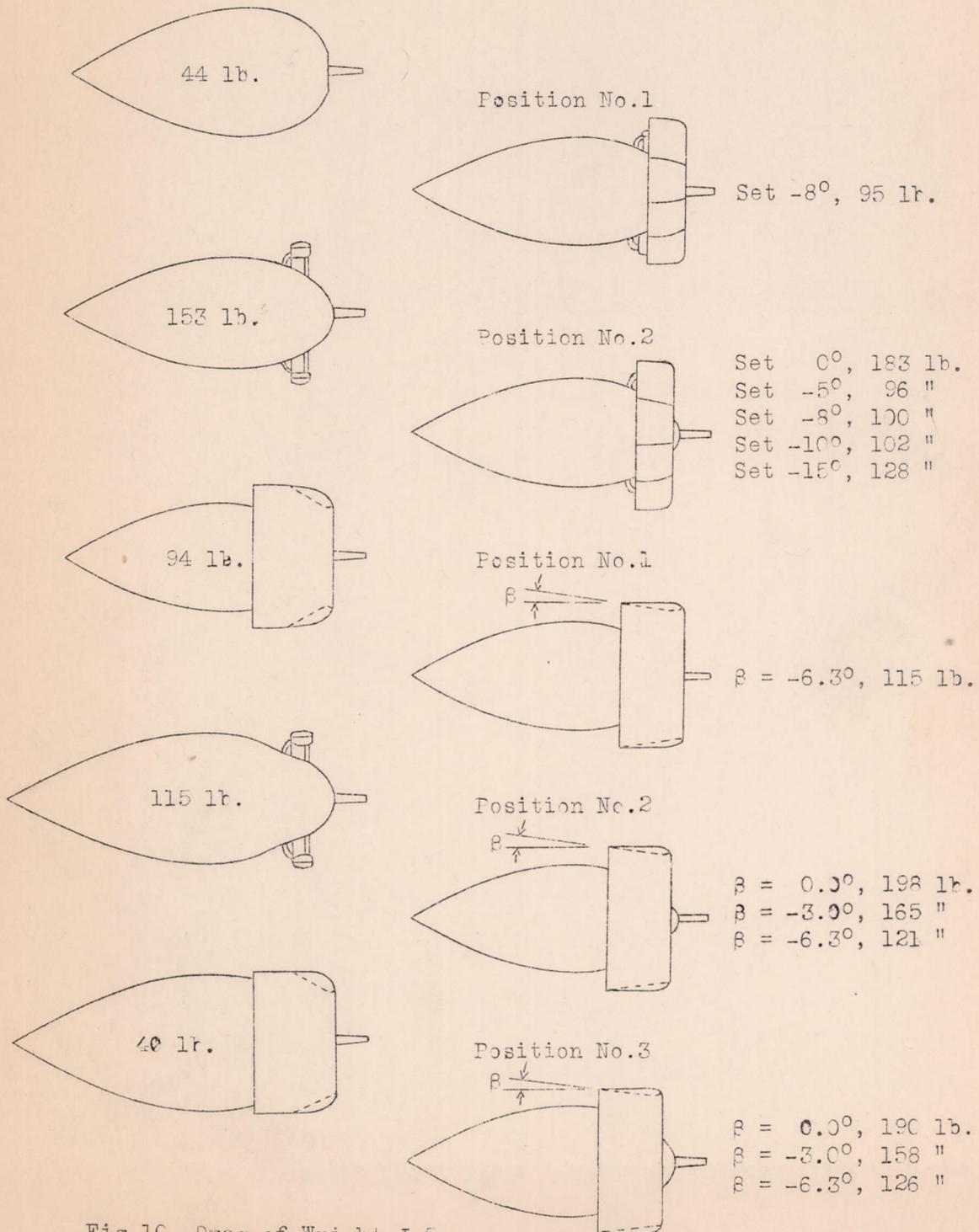


Fig.10 Drag of Wright J-5 engine nacelles.

(Drag at 100 m.p.h. - scaled up from 4/9-scale model tests).