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EXPERIMENTS WITH INTUBED PROPELLERS

By L. Stipa

L'Aerotecnica, August, 1931

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EXPERIMENTS WITH INTUBED PROPELLERS\*

By L. Stipa

SUMMARY

The writer, following his article published in the April, 1931 number of L'Aerotecnica, under the title of "Ala a Turbina" (turbine wing), illustrates the results of the experiments with his new method of propulsion and explains its advantages. In describing the experiments with propellers operated in conjunction with a Venturi tube forming the only fuselage of the "turbine wing," it is necessary to use a different name from the preceding one.

WIND TUNNEL TESTS WITH PROPELLER ROTATING  
AT A FIXED POINT

The above-mentioned article explains how the inside shape of the longitudinal section of the Venturi-tube fuselage is of capital importance for the success of the experiments. Three types of tubes were designed (fig. 1) by varying the inside shape and, in the third type, also the outside shape, which gave different experimental results.

These fuselage tubes were made on a 1:5 scale. It was necessary to adopt such a large scale because the dimensions of the tube had to correspond to the size of the propeller. Experimenters know that results obtained with a propeller model having a diameter of less than 50 cm (about 20 in.) are not reliable. Hence, the scale of the propeller model being given, the scale of the fuselage model followed.

Moreover, since the fuselage had to be attached to the arms of the wind-tunnel balance, it had to be very

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\*"Esperienze con Eliche Intubate." L'Aerotecnica (Rome), August, 1931, pp. 923-953.

light. In fact, it was made of sheet aluminum and did not weigh over 10 kg (22 lb.). (Fig. 2.) The large size of the fuselage model created difficulties in the wind-tunnel tests, which will be considered later.

Two propellers were chosen for the wind-tunnel tests: one from the seaplane C R 20, the other from the S 59. These two propellers differ chiefly in pitch, the C R 20 propeller having a pitch of 0.472 m (1.55 ft.) and a diameter of 0.48 m (1.57 ft.), while the propeller of the S 59 has a pitch of 0.41 m (1.35 ft.) and a diameter of 0.5205 m (1.71 ft.).

The following tests were made with each propeller:

1. Propeller alone;
2. " in presence of Venturi-tube fuselage;
3. " integral with " " "
4. Resistance of Venturi-tube fuselage at different revolution speeds of the propeller.

The first test was made by attaching the propeller to the arm of the balance of the tunnel propellers, with the determination of the thrust T.m. developed by the propeller and of the power W.m. absorbed by the propeller at different revolution speeds of the propeller.

The thrust was measured in kilograms and the power in kilogram-meters. The results for both propellers are given in Table I.

TABLE I

Propeller of C R 20				Propeller of S 59			
r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	<u>T.m.</u> W.m.	r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	<u>T.m.</u> W.m.
2600	24.67	1.410	0.0571	2600	25.92	2.125	0.082
3000	32.61	1.950	0.0598	3000	37.4	2.775	0.0742
3400	47.65	2.550	0.0537	3400	48.1	3.550	0.0723
3800	67.30	3.185	0.0472	3800	73.7	4.425	0.060
4200	91.85	3.950	0.0430	4200	99.4	5.400	0.0543
4600	121.0	4.795	0.0396	4600	129	6.410	0.0500
5000	160.6	5.730	0.0356	5000	163	7.425	0.0455

kgm x 7.23298 = ft.-lb.

kg x 2.20462 = lb.

The second test was made by attaching the propeller as above and placing behind it the Venturi-tube fuselage (fig. 3), which was attached to the wind-tunnel walls. The same data were determined for both propellers as given in Table II. These data were obtained with the modified Venturi-tube fuselage (2d series of tests).

TABLE II

Propeller of C R 20				Propeller of S 59			
r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	$\frac{T.m.}{W.m.}$	r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	$\frac{T.m.}{W.m.}$
2200	9.29	0.775	0.0834	2200	9.54	1.100	0.1153
2600	16.69	1.225	0.0733	2600	21.45	1.875	0.0874
3000	27.0	1.700	0.0630	3000	33.70	2.550	0.0756
3400	40.26	2.250	0.0558	3400	49.24	3.325	0.0675
3800	56.36	2.875	0.0510	3800	67.91	4.200	0.0618
4200	76.85	3.550	0.0460	4200	92.63	5.100	0.0550
4600	100.86	4.265	0.0422	4600	121.67	6.100	0.0500
5000	128.87	5.025	0.0390				

The third test was made by attaching the propeller alone to the balance and securing firmly to the same arm the Venturi-tube fuselage, so as to measure on the balance the thrust resulting from the traction of the propeller and from the resistance of the Venturi-tube fuselage. (Fig. 4.)

Analogous data were determined by varying the r.p.m. of the propeller. The results are given in Table III and refer to the modified Venturi-tube fuselage, which was used in the second series of experiments.

TABLE III

Propeller of C R 20				Propeller of S 59			
r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	<u>T.m.</u> W.m.	r.p.m. of pro- peller	W.m. Power ab- sorbed by pro- peller kgm	T.m. Thrust pro- duced by pro- peller kg	<u>T.m.</u> W.m.
1800	5.25	0.825	0.157	3000	36.86	3.175	0.0861
2200	9.49	1.250	0.13	3400	51.37	4.037	0.0786
2600	17.23	1.750	0.101	3800	75.19	5.050	0.0709
3000	27.60	2.350	0.0851	4200	95.0	6.125	0.0644
3400	40.21	3.075	0.0764	4600	125.49	7.437	0.0592
3800	58.74	3.850	0.0655	4800	146.30	8.150	0.0557
4200	78.44	4.712	0.0600				
4600	104.24	5.650	0.0542				

The data for the C R 20 propeller are plotted in Figure 5 and for the S 59 in Figure 6. In order to be better able to determine the difference between the various thrusts and powers under the three different conditions, it was thought best to determine the ratio between the thrust and the power at different revolution speeds. This ratio is given in the fourth column of Table III and plotted in Figures 7 and 8 for propellers C R 20 and S 59, respectively. The results clearly indicate the advantage of the propeller integral with the Venturi-tube fuselage over the propeller alone and in the presence of the Venturi-tube fuselage.

As to what caused the greater traction and the less power absorbed by the propeller integral with the Venturi-tube fuselage with respect to the propeller alone, it was obviously the reaction (not resistance) of the Venturi-tube fuselage, which was confirmed by the fourth test. In this test the propeller alone was attached to the wind-tunnel balance. This balance was secured, however, in a position of stability in such a way as not to be affected by the propeller thrust. The fuselage was mounted near the propeller, as already shown, but suspended from a different balance, so as to make it possible to vary its fore-and-aft position according to whether there was a resistance or a reaction. (Fig. 9.)

By varying the propeller r.p.m. from a minimum to a maximum, a reaction was always obtained, the values of which are given in Table IV and plotted in Figure 10.

TABLE IV

Propeller r.p.m.	1844	2208	2620	3010	3374	3766	4170
Resistance in grams (reaction)	-202	-300	-423	-562	-690	-832	-985

Figure 10 also contains the curve for the reaction obtained from the unmodified Venturi-tube fuselage with the C R 20 propeller.

The greater reaction was obtained with the modified fuselage and the S 59 propeller (second series of experiments). This reaction is equal to the difference between the thrust obtained with the propeller integral with the fuselage and the thrust of the same propeller in the presence of the same fuselage. Hence, it is possible, for the difference between analogous thrusts, to determine also the reaction obtained with this fuselage and the C R 20 propeller. (Fig. 5.)

These data clearly demonstrate the effect of the inside shape of the fuselage, since a slight variation of the latter produces very different results. This effect will be still more clearly shown in the following account of the wind-tunnel tests.

#### WIND-TUNNEL TESTS

These tests were made with the same C R 20 and S 59 propellers, as follows:

1. Propeller alone with wind velocities of 15 and 20 m (49.2 and 65.6 ft.) per second;
2. Propeller in presence of Venturi-tube fuselage with wind velocities of 15 and 20 m per second;
3. Propeller integral with Venturi-tube fuselage with wind velocities of 15 and 20 m per second;

4. Resistance of Venturi-tube fuselage from varying the wind velocity;

5. Resistance of Venturi-tube fuselage with wind of 20 m/s at different propeller r.p.m.;

6. C R 20 propeller integral with C R 20 fuselage.

For brevity, only the results obtained with a wind velocity of 20 m (65.6 ft.) per second are given, since the results obtained with the wind velocity of 15 m (49 ft.) per second are analogous to the former.

Tests 2, 3, 4 and 5 were each made three times with the unmodified Venturi-tube fuselage (first series of experiments), with the modified fuselage (second series), and with the second modification (third series), as shown in Figure 1. The propeller maintained the position indicated in Figure 11.

Returning to the experiments with the propeller rotating at a fixed point, the excessive dimensions of the Venturi-tube fuselage have already been noted. The velocity of the air in the tunnel was measured at a certain distance upstream from the model (fig. 11), and, if the model was very large, it diminished the free section of the air passage and consequently increased the velocity.

In our case, the diameter of the tunnel at the model is 2 m (6.56 ft.) with a section of 3.1416 m<sup>2</sup> (33.82 sq.ft.). The model of the Venturi-tube fuselage (second series) has a parasite section of 0.28 m<sup>2</sup> (3.01 sq.ft.). The wind velocity of 20 m/s, measured upstream in correspondence with the model, is  $20 \times 3.1416 / 2.8616 = 22$ , or an increase of 10%. It should be borne in mind that the resistance also increases with the square of the velocity, but this increase is disregarded in the following calculations. Hence, the values of  $\gamma = V/ND$  and of the efficiency  $\eta = \tau \gamma / \chi$  are both increased 10% for the propeller integral with the Venturi-tube fuselage.

In Figures 12 and 13, there are plotted the results of tests 1, 2 and 3 with propellers C R 20 and S 59, respectively, and with the modified Venturi-tube fuselage (second series). These curves show how the efficiency of the propeller is increased by the presence of the Venturi-tube fuselage in both these cases.

The efficiency of the propeller integral with the fuselage also includes the total resistance of the fuselage. Moreover, the above-mentioned 10% must be added.

Figures 14 and 15 show the effect of the inside shape of the fuselage on the characteristics of the C R 20 and S 59 propellers integral with the unmodified fuselage (first series). The maximum efficiencies are much inferior to those obtained with the modified fuselage.

In experiment No. 4 for both the modified and unmodified fuselage, the resistances are plotted in Figure 16 for an increase in the wind velocity from 10 to 30 m (32.8 to 98.4 ft.) per second. Note the great reduction in the resistance of the modified fuselage as compared with the resistance of the unmodified fuselage.

In test No. 5 we obtain the resistances of the same two fuselages with a wind velocity of 20 m/s and varying propeller r.p.m. Note here also the great reduction in the resistance of the modified fuselage (fig. 17) and the different course of the curve.

In order to make a practical comparison of the characteristics of the propeller C R 20 integral with the Venturi-tube fuselage, it is intended to make the same propeller integral with the model of the fuselage of the C R 20 seaplane. The fuselage of the C R 20 seaplane consisted of one central hull (fig. 18), to which were attached all the other parts (struts, landing gear, wings, etc.) covered by the propeller. (Fig. 19.)

In order to obtain the most unfavorable conditions, there was purposely chosen the C R 20 pursuit seaplane, the finest obtainable, while for comparison there was selected another airplane of less favorable characteristics. The characteristics of the propeller C R 20 integral with the fuselage of the seaplane C R 20 are plotted in Figure 20. In this figure and in comparison with these characteristics, there are plotted the curves for the same propeller integral with the Venturi-tube fuselage.

If, as already mentioned, the 10% correction is made in the efficiency curve of the C R 20 propeller integral with the Venturi-tube fuselage, there is found a decisive advantage of the latter, in that its efficiency is greater up to  $\gamma = 0.45$ . Above this value of  $\gamma$ , however, the maximum efficiency is slightly less, but remains near-

ly constant over a large range of  $\gamma$ . This always without taking account of the increased resistance due to the increased wind velocity near the model.

The difficult take-off of the transatlantic seaplanes S 55 from Bolama is remembered. Difficulty is still experienced in taking off from the Libyan Desert. The difficulty can be greatly reduced by this method, because the propeller traction or thrust is greatly increased and the absorbed power reduced at the velocity of the take-off.

In this connection it may also be affirmed that it is not necessary to reduce the revolutions of the variable pitch propeller, if the propeller is intubed, consequently reducing the size of the parts and the weight of the engine and increasing the reliability of functioning.

I now take the liberty to make an observation regarding the system which yields the characteristic curves of the C R 20 and S 59 propellers integral with the Venturi-tube fuselage. This observation regards the method by which the values of  $\gamma = V/ND$  are obtained.  $D$  is constant.  $V$  is fixed and remains constant during the whole test. On the other hand,  $N$  varies from the minimum to the maximum value permitted by the wind-tunnel balance.

The  $\gamma$ , thus obtained, is valid for isolated propellers and for propellers in the presence of or integral with a normal fuselage swept by the slipstream, because the entire fuselage is exposed to the wind velocity  $V$  increased by the velocity of the slipstream.

In the case of the Venturi-tube fuselage, only the inside is under the above conditions, while the outside is always exposed to a velocity  $V$  of the wind, which is constant and fixed from the beginning of the experiment. As is well known, this velocity induces on the fuselage a certain resistance of constant value for the duration of the experiment.

Figure 10 shows that the effective thrust due to the fuselage increases as the revolution speed of the propeller increases. Hence the propeller must be given a suitable speed because it must overcome the drag of the outside portion.

But such conditions do not occur in practice. An airplane starts from a speed of zero and increases gradually up to its maximum speed. The propeller r.p.m. also increases, but much more slowly than the speed of the airplane, because this increase is due simply to the fact that the propeller rotating at a fixed point brakes the engine and prevents it from developing its full power. The variation in the r.p.m. cannot amount to more than 100 or possibly 150 and is therefore almost negligible.

However,  $\gamma$  should be obtained by varying  $V$  and by slightly varying (or even keeping constant) the propeller r.p.m., for the purpose of simulating, in so far as possible, the actual operating conditions of the propeller.

Tests were made with the propeller integral with the Venturi-tube fuselage, with constant  $N$  and variable  $V$ . The results are shown in Figure 21 (third series of experiments), as compared with corresponding data obtained by varying the r.p.m. The difference is obvious and shows that my observations were correct. Nevertheless, it no longer seems possible, in the study of the present craft, to apply Renard's law of similitude, obtained by varying the r.p.m. but it must be obtained instead by varying the velocity of the air current.

In order to determine the greater efficiency of the propeller integral with the fuselage, it is well to consider the following points:

1. The experiments showed the resistance of the Venturi-tube fuselage at different wind velocities and, in particular, a resistance of 0.7 kg (1.54 lb.) (second series) (fig. 16) at a velocity of 20 m/s (65.6 ft./sec.).

2. From the experiments we determine the thrust, the power absorbed and the efficiency of each of the two propellers, the C R 20 and the S 59, integral with the modified Venturi-tube fuselage. (Figs. 12 and 13.)

3. The effective thrust of both propellers in said condition is the sum of the resultant thrust, measured by the tunnel balance, and of the resistance of the Venturi tube at the given wind velocity.

This, because in order to obtain a positive propeller thrust, it must first overcome the resistance of the

Venturi-tube fuselage. Moreover, it is desirable to keep the resistance of the fuselage constant at different propeller speeds, because its increase or decrease is due to the effect of the rotation of the propeller and therefore is the effect of the propeller itself. In an airplane we have  $S = R$  ( $S =$  propeller thrust and  $R =$  airplane resistance or drag).

In the experiments integral with the Venturi-tube fuselage, we obtained a thrust difference between the total propeller thrust and the resistance of the fuselage, i.e.,  $P = S - R$  ( $P =$  thrust measured on the balance). Hence the total effective thrust of the propeller is  $S = P + R$ . These corrections of the thrust and hence of the efficiency are given in Table V. Apparently, there is no variation in the power absorbed.

TABLE V

## Propeller of Seaplane C R 20

Propeller r.p.m.	Thrust on balance kg	Total thrust kg	$\gamma$	$\tau$	$\chi$	$\eta$
3200	0.700	1.400	0.777	0.0744	0.063	0.9168
3600	1.262	1.962	0.691	0.0824	0.066	0.8637
4000	1.937	2.637	0.622	0.0898	0.067	0.836
4400	2.675	3.375	0.565	0.0946	0.0699	0.765
4800	3.525	4.225	0.518	0.0999	0.0717	0.721
5200	4.512	5.212	0.470	0.105	0.0719	0.686

## Propeller of Seaplane S 59

Propeller r.p.m.	Thrust on balance kg	Total thrust kg	$\gamma$	$\tau$	$\chi$	$\eta$
3000	0.625	1.325	0.774	0.0572	0.0465	0.952
3400	1.325	2.025	0.684	0.068	0.0524	0.882
3800	2.150	2.850	0.611	0.0765	0.0559	0.837
4200	3.037	3.737	0.553	0.0840	0.057	0.8129
4600	4.025	4.725	0.505	0.0869	0.0568	0.7726
5000	5.062	5.762	0.464	0.0897	0.0577	0.721

kg  $\times$  2.20462 = lb.

These data, measured in curves and superposed in Figures 12 and 13, are also plotted in Figures 22 and 23, on which is shown the increased efficiency of the propeller integral with the Venturi-tube fuselage (by subtracting the fuselage resistance), as compared with the same alone and in the presence of the fuselage. The fuselage resistance forms part of the total resistance and hence of the total efficiency of the entire craft. We will therefore examine, in a future article, the experimental efficiency results obtained with the complete turbine wing. Other very useful applications can be made of the principle of the turbine wing.

If there are openings in the sides of the Venturi-tube fuselage (figs. 24 and 25) ending near the narrowest section of the tube, where the negative pressure is the greatest, a reversal of the air flow is obtained. If this reversal is forward, it increases the thrust (fig. 24); if upward, it increases the lift. Experiments will soon be instituted in this connection. At present we have the following conclusions:

1. The efficiency of a propeller in the presence of a Venturi-tube fuselage is greater than that of an isolated propeller;

2. The efficiency of a propeller integral with a Venturi-tube fuselage is greater than that of an isolated propeller or of a propeller in the presence of the same fuselage;

3. The Venturi-tube fuselage, when the propeller is running, offers no resistance, but produces a thrust (reaction), which increases the propeller thrust, as shown by Figure 10;

4. The functioning of the propeller is greatly affected by the inside shape of the Venturi-tube fuselage.

Translation by Dwight M. Miner,  
National Advisory Committee  
for Aeronautics.

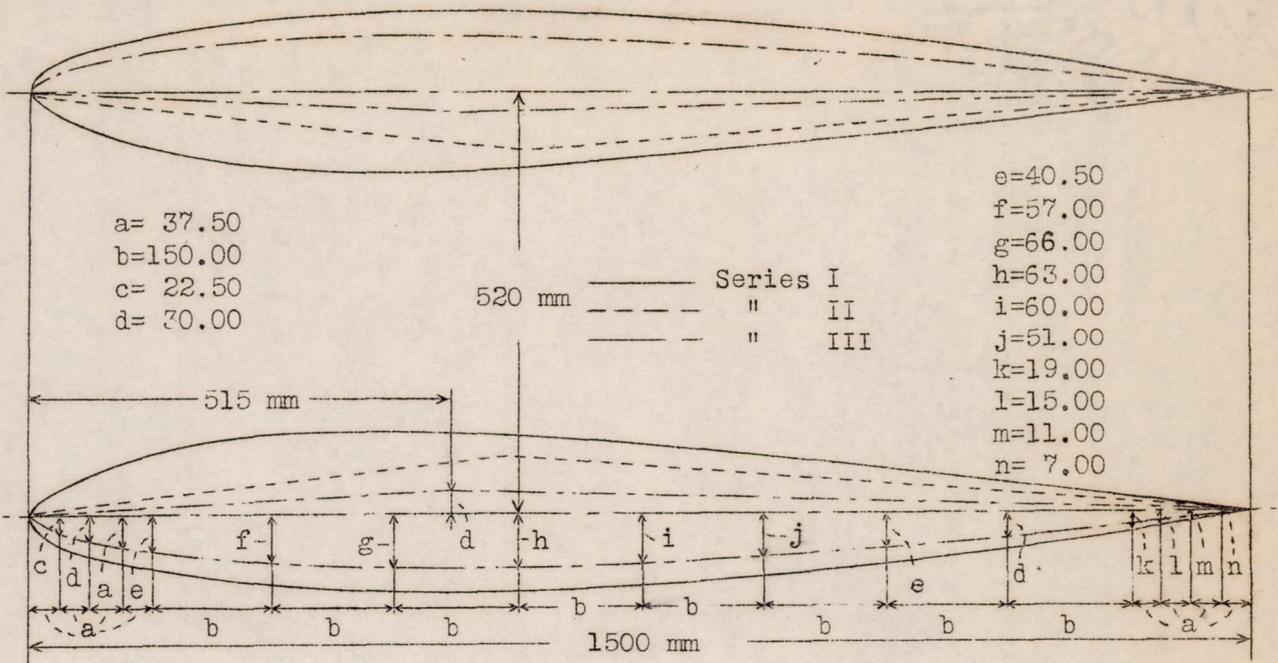


Fig. 1 Tube having inside shape of venturi tube and outside shape of wing profile. Scale 1.5 of the model. Longitudinal section.

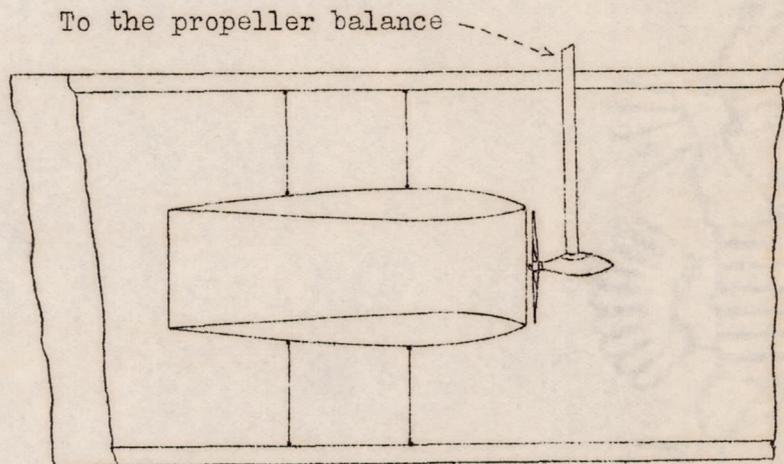


Fig. 3

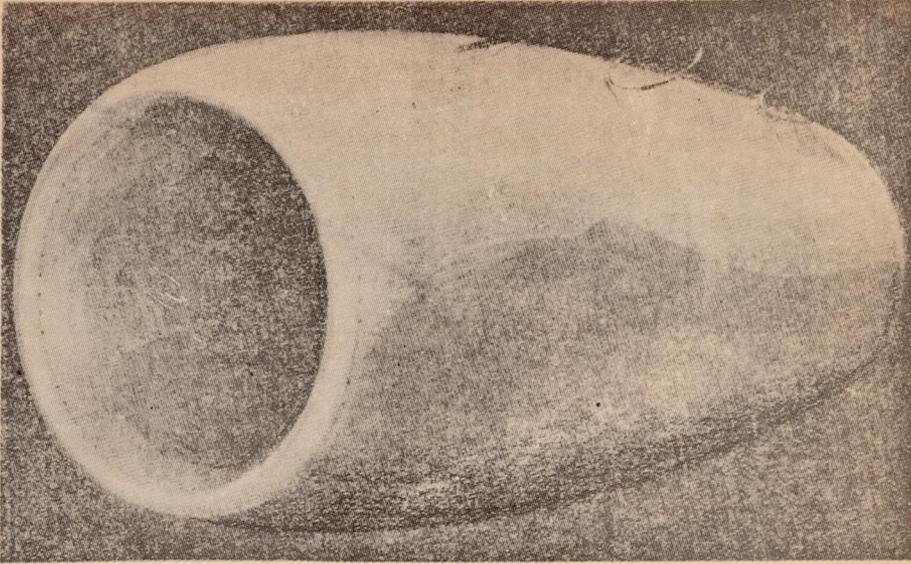


Fig.2

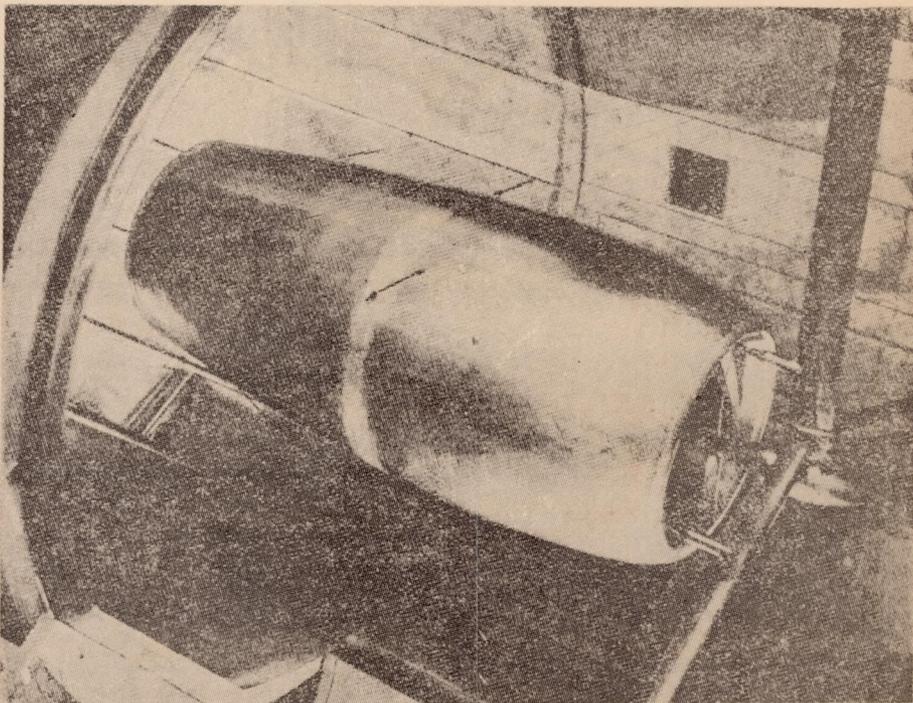


Fig.4

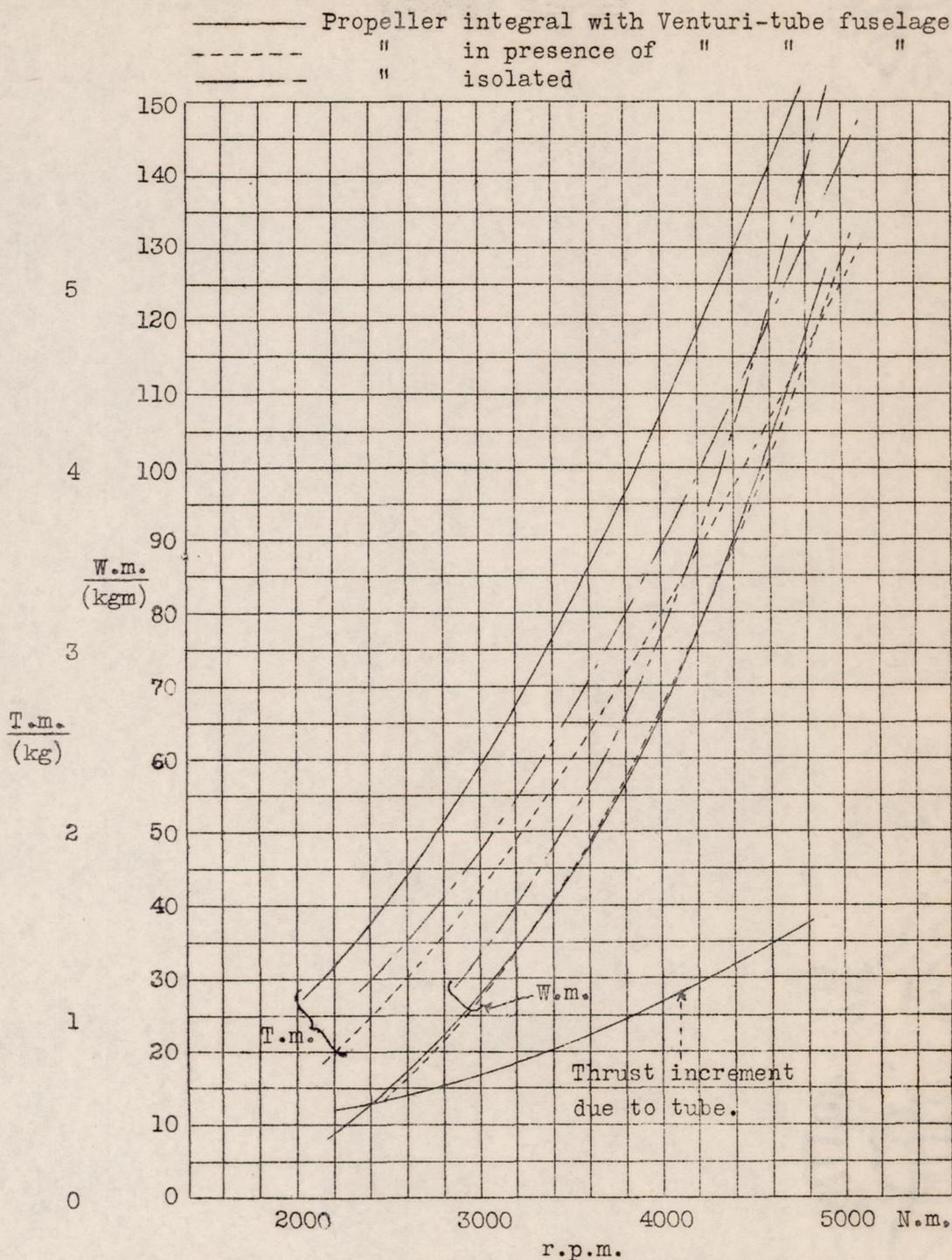


Fig. 5 "Stipa" intubed propeller (Series II) Propeller of seaplane CR 20. Thrust and power of propeller rotating at a fixed point.

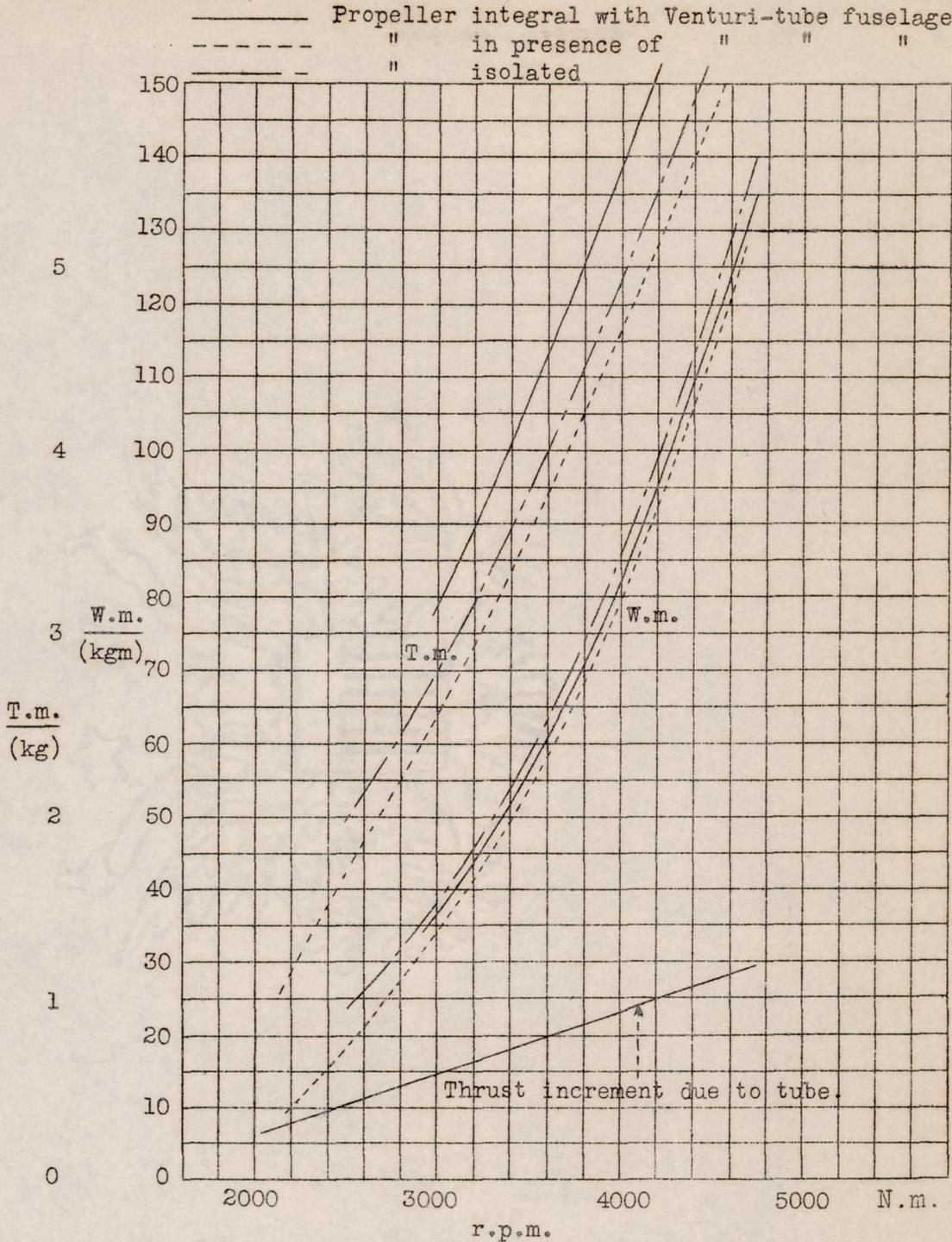


Fig.6 "Stipa" intubed propeller (Series II) Propeller of seaplane S 59. Thrust and power of propeller rotating at a fixed point.

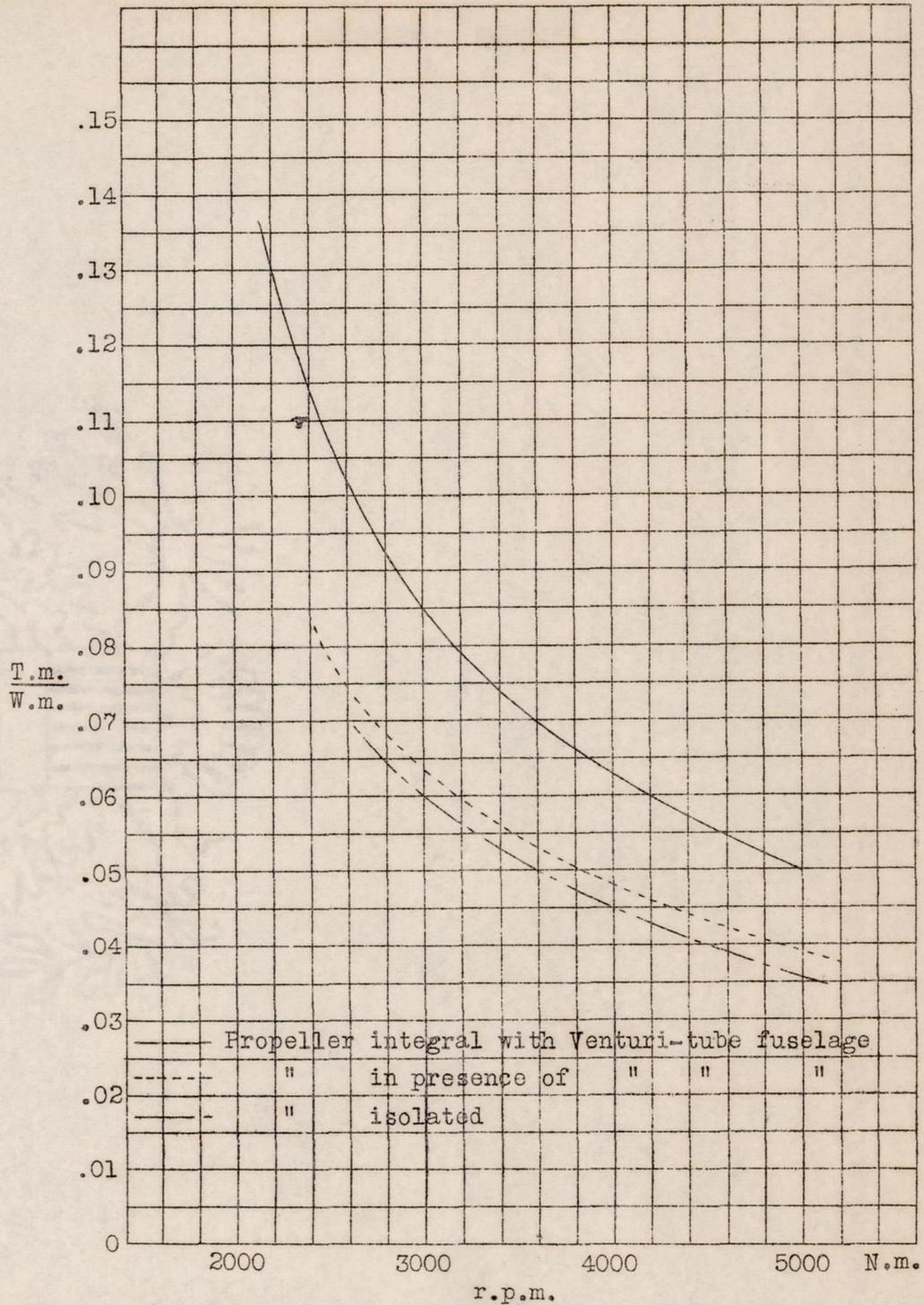


Fig. 7 "Stipa" intubed propeller (Series II) Propeller of seaplane CR 20. Thrust and power of propeller rotating at a fixed point.

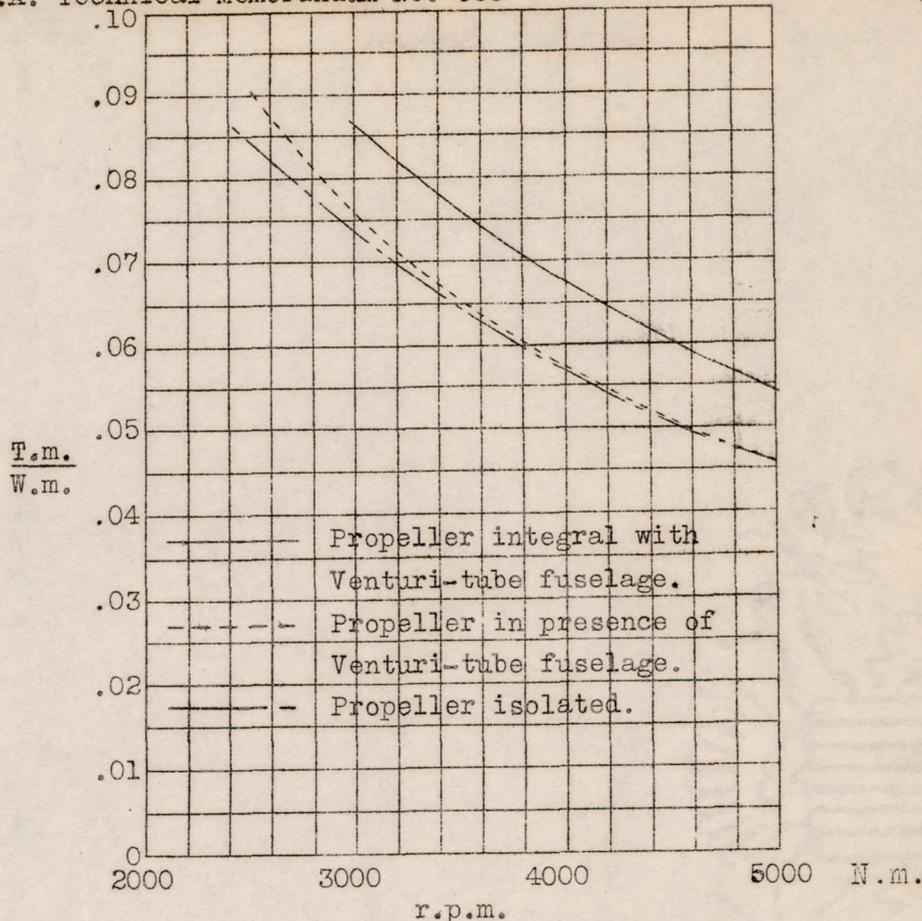


Fig. 8 "Stipa" intubed propeller (Series II). Propeller of seaplane S 59. Thrust and power of propeller rotating at a fixed point.

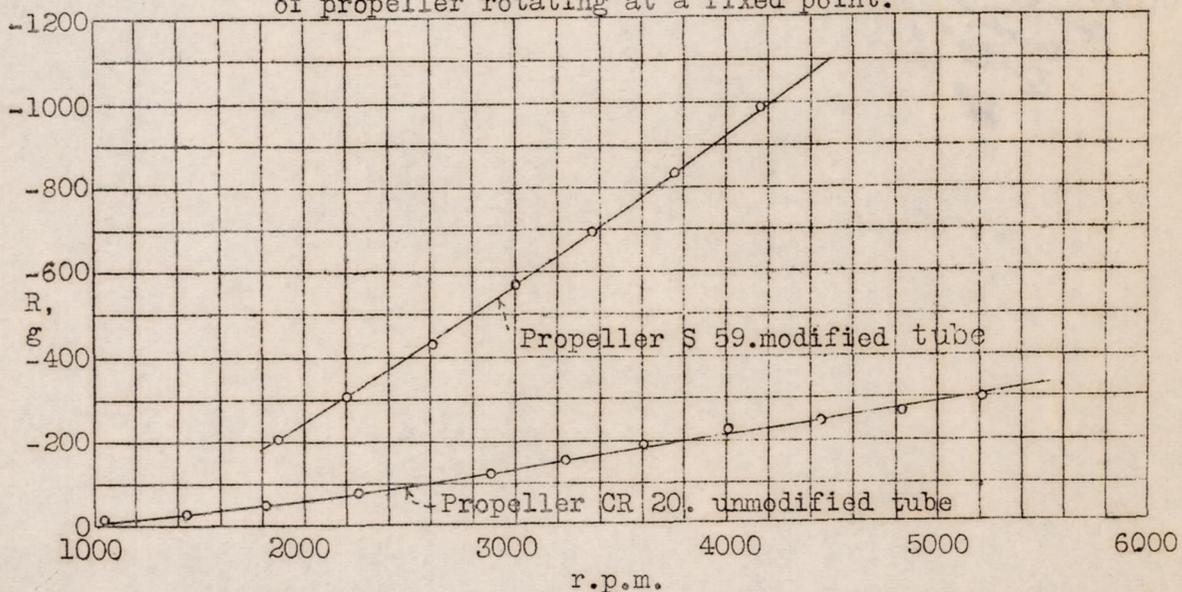


Fig. 10 Stipa's experiments (Series II). Negative resistance (reaction) of tube at different propeller r.p.m.  $V=0$  m/sec.

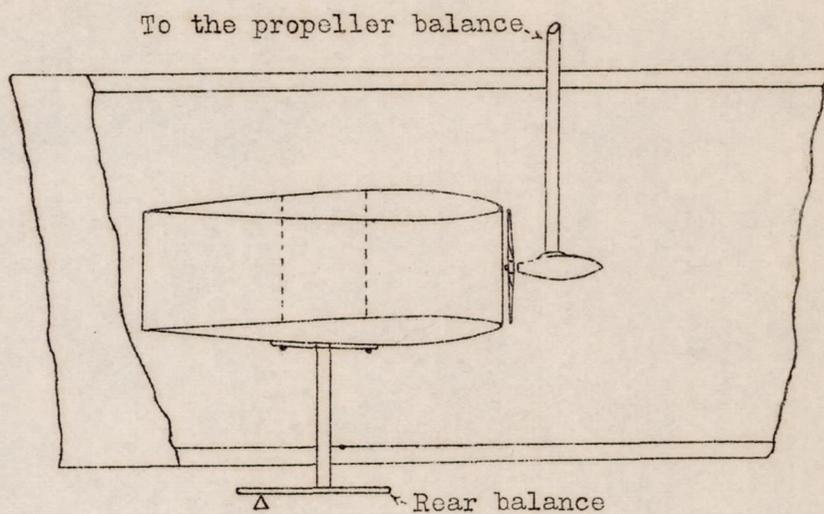


Fig. 9

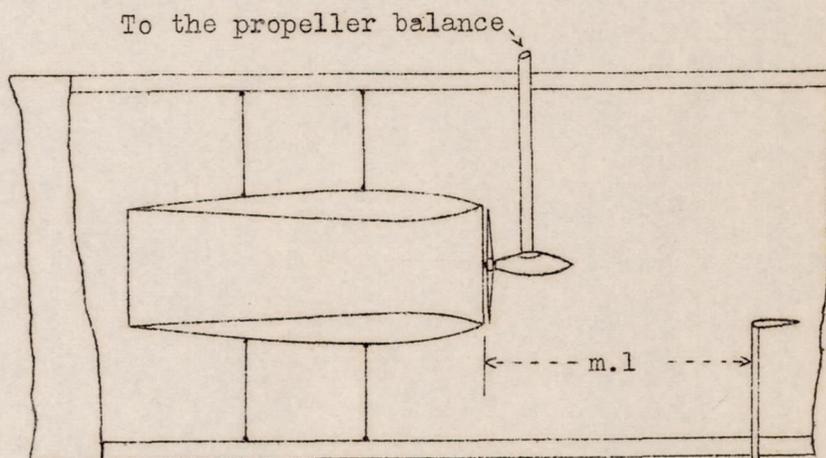


Fig. 11

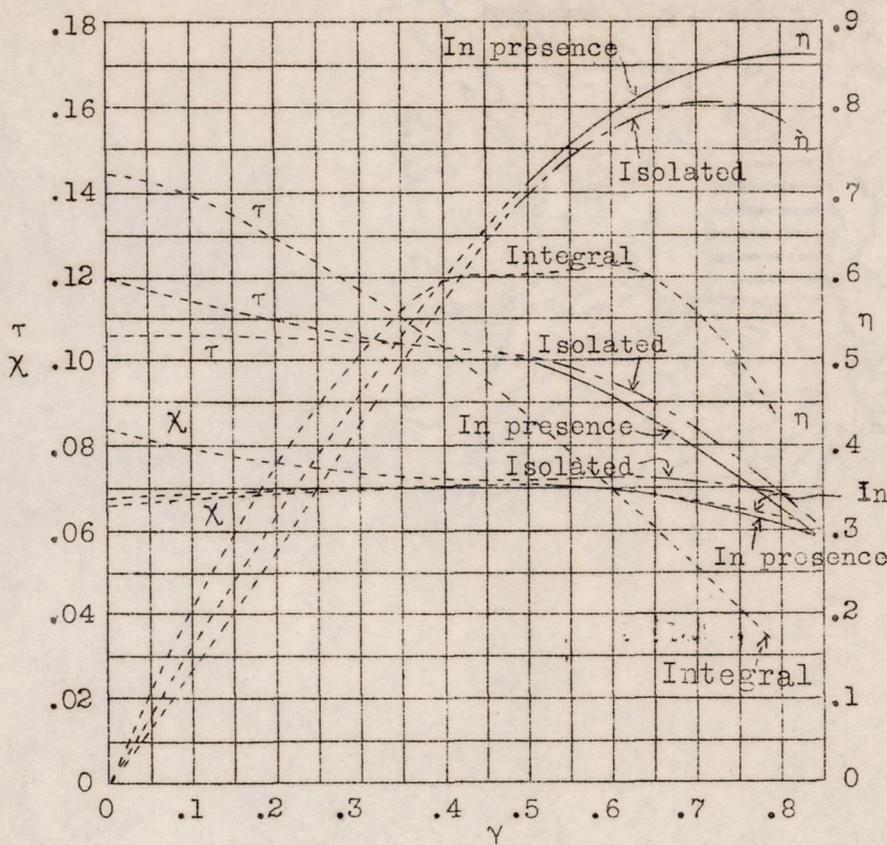


Fig.12 "Stipa" intubed propeller (Series II) Propeller of seaplane CR 20 V = 20 m/sec.

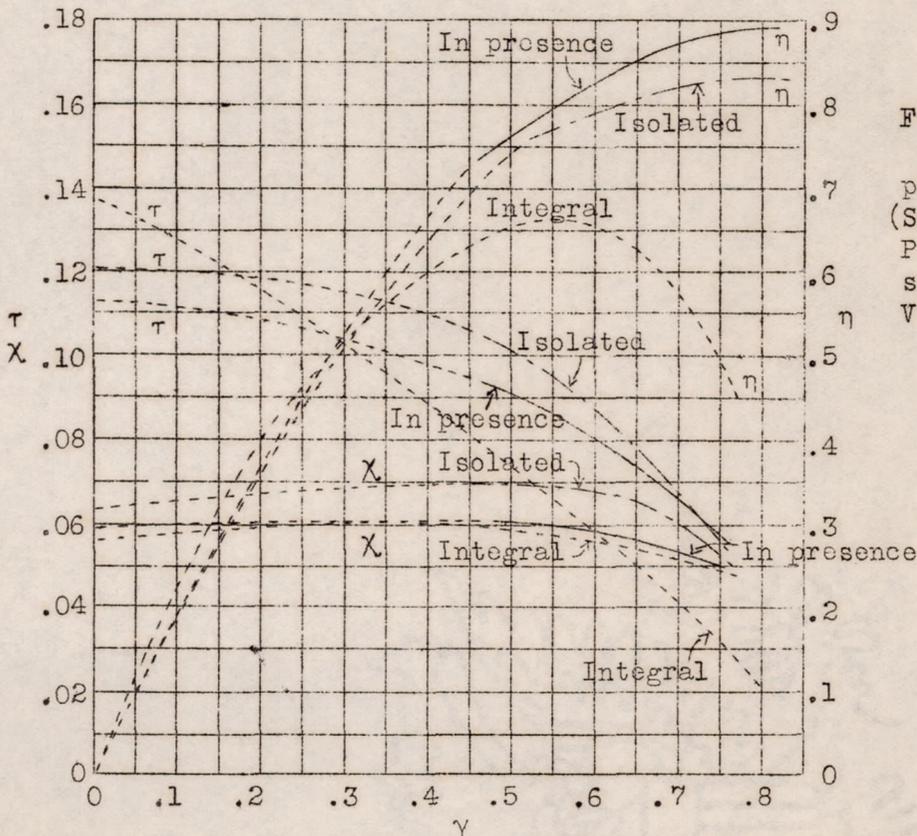


Fig.13 "Stipa" intubed propeller (Series II) Propeller of seaplane S 59 V = 20 m/sec.

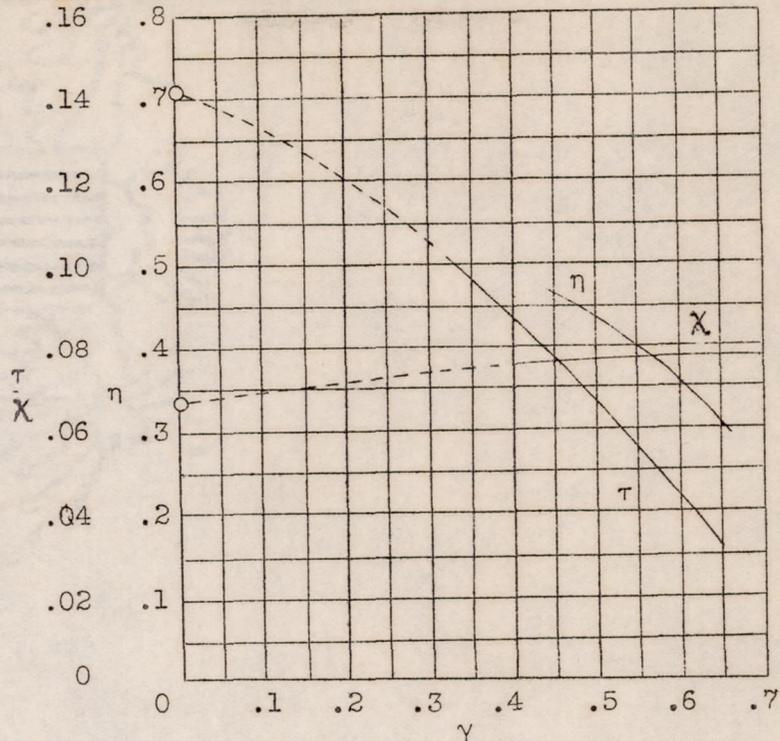


Fig. 14 Model CR 20 integral with tube  $D=0.48$  m  
 $V=20$  m/sec.

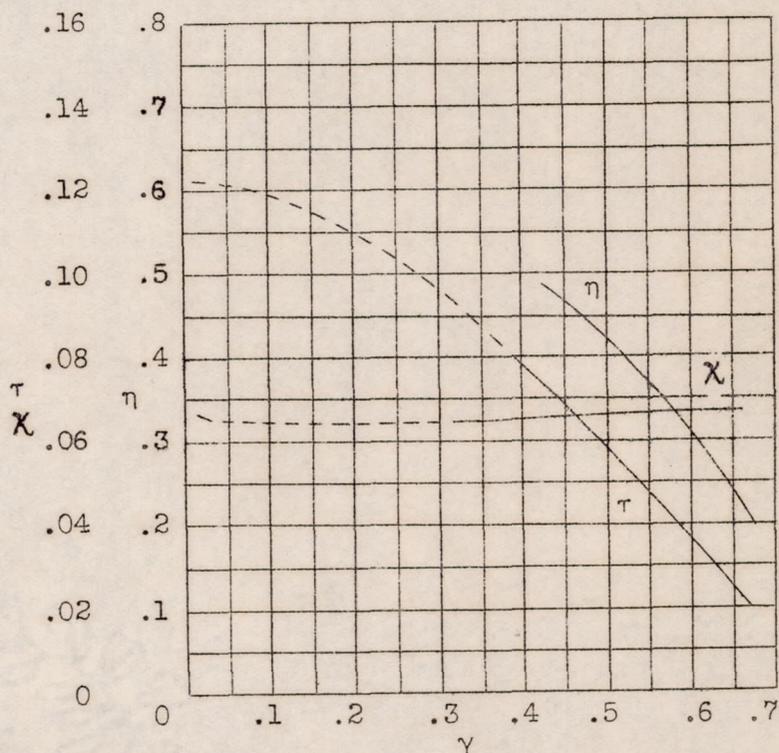


Fig. 15 Model S 59 integral with tube  $D=0.5205$  m  
 $V=20$  m/sec.

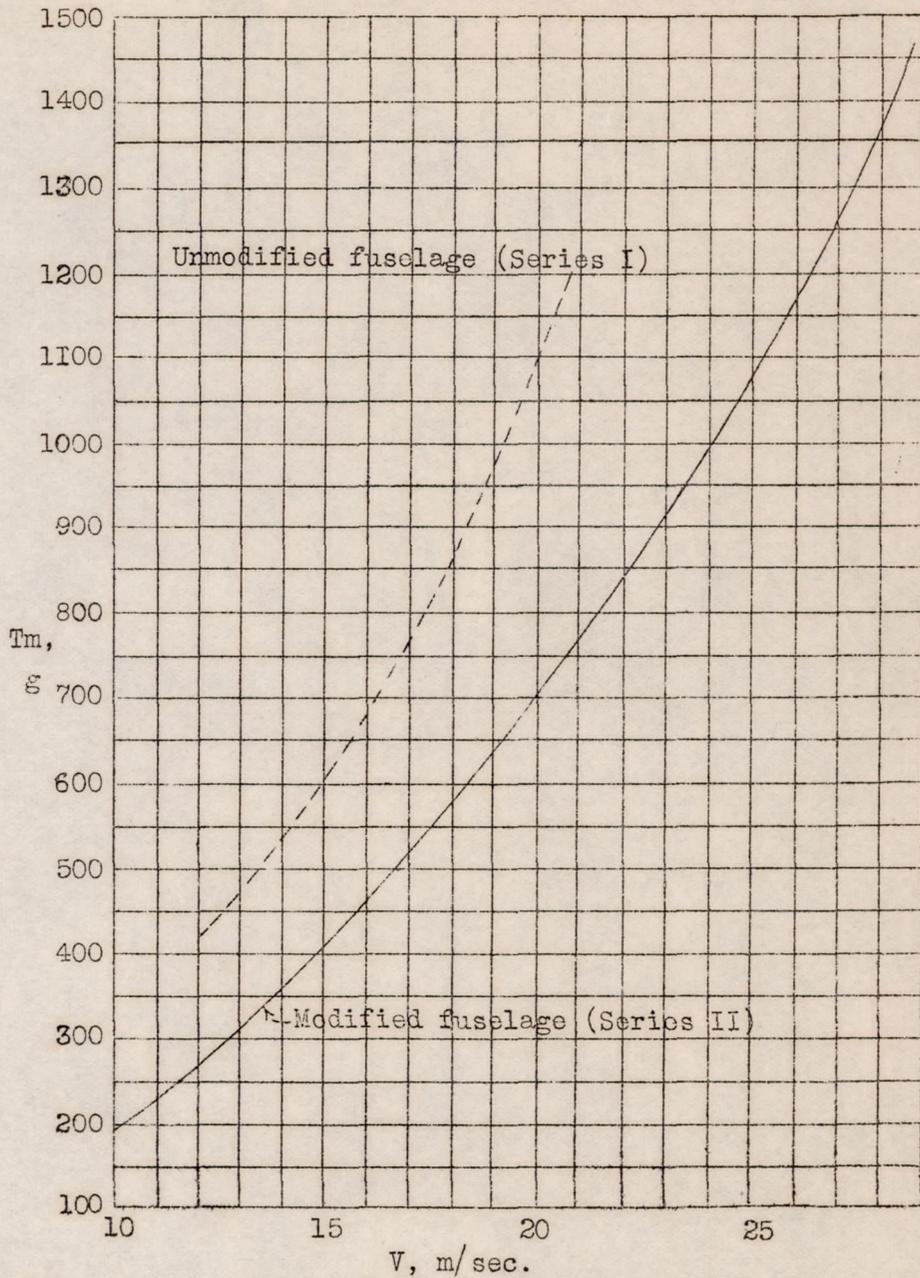


Fig. 16 Resistance of Venturi-tube fuselage.  
"Stipa" intube propeller (Series II)

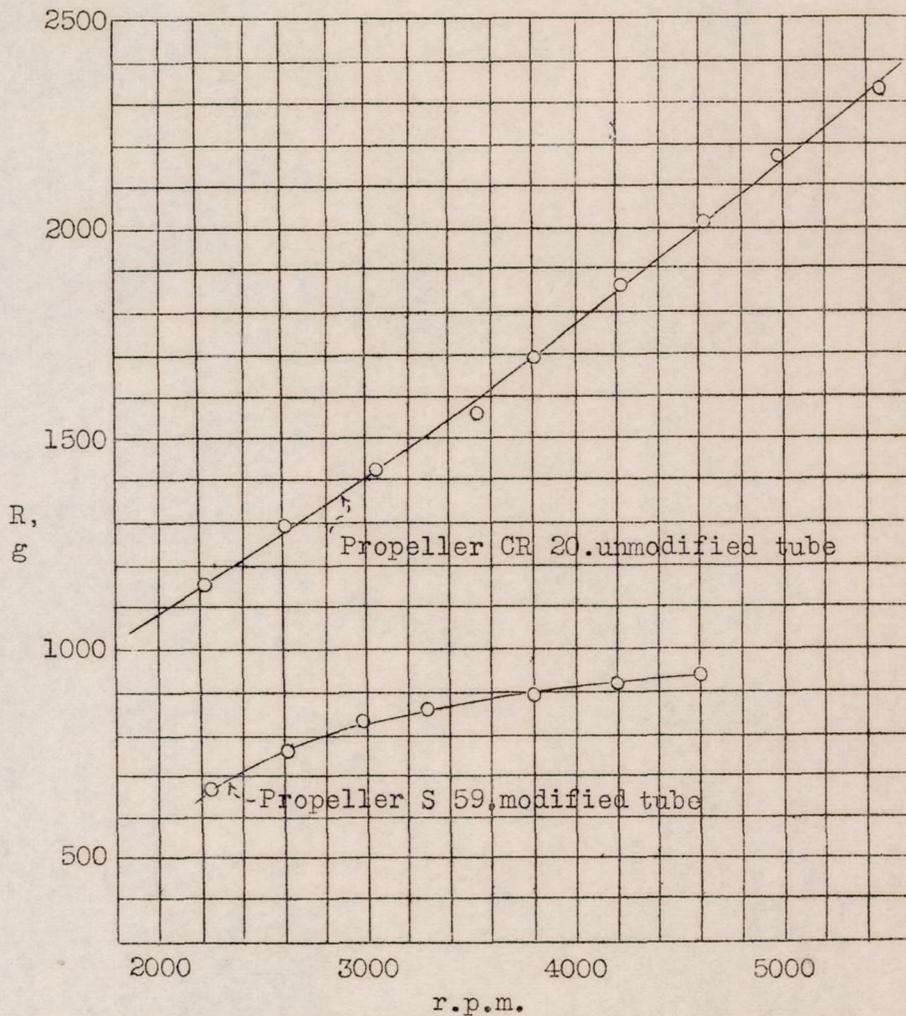


Fig. 17 Stipa's experiments. Resistance of tube (in grams) at different propeller r.p.m.  $V=20$  m/sec.

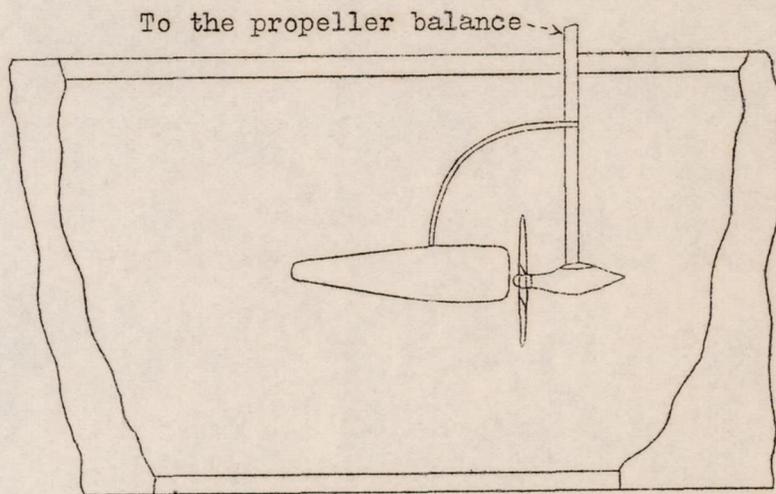


Fig. 18

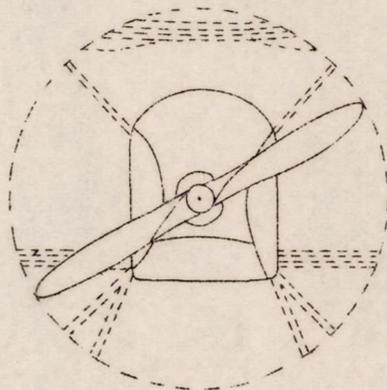
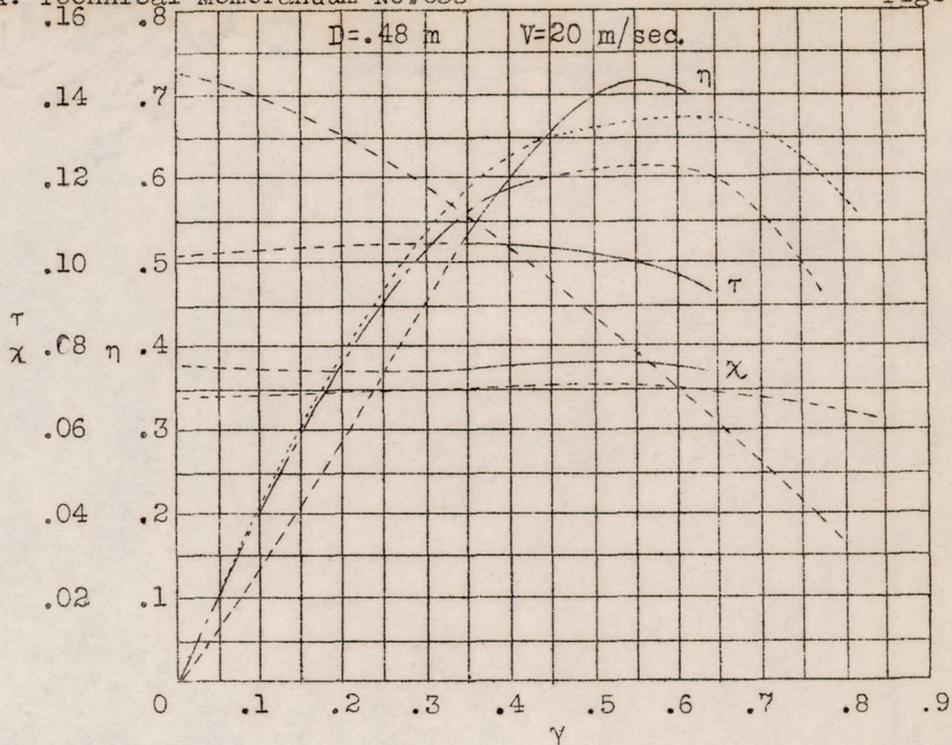


Fig. 19



————— Fuselage CR 20  
 - - - - - Tube  
 ..... Tube for corrected velocity

Fig. 20 Propeller of seaplane CR 20, integral with fuselage.

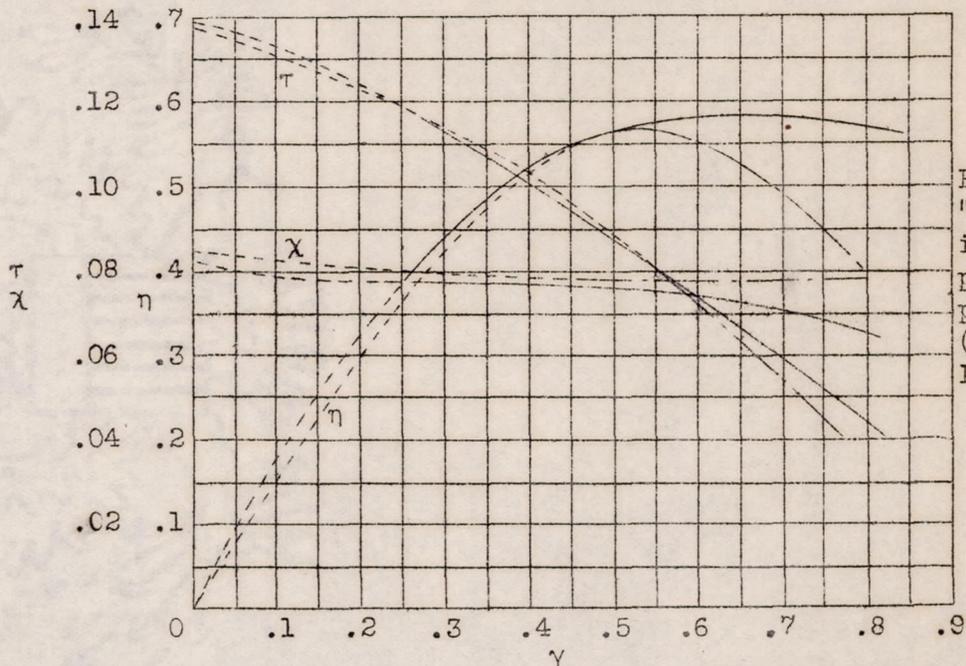
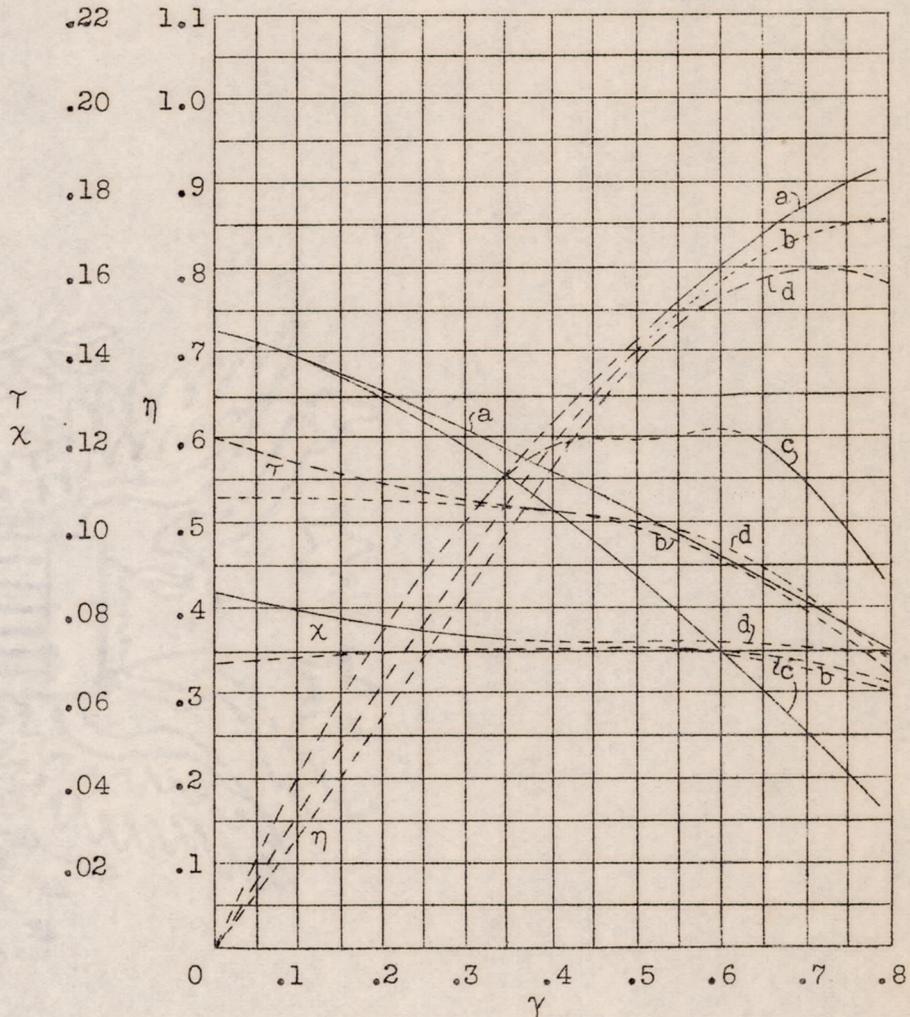


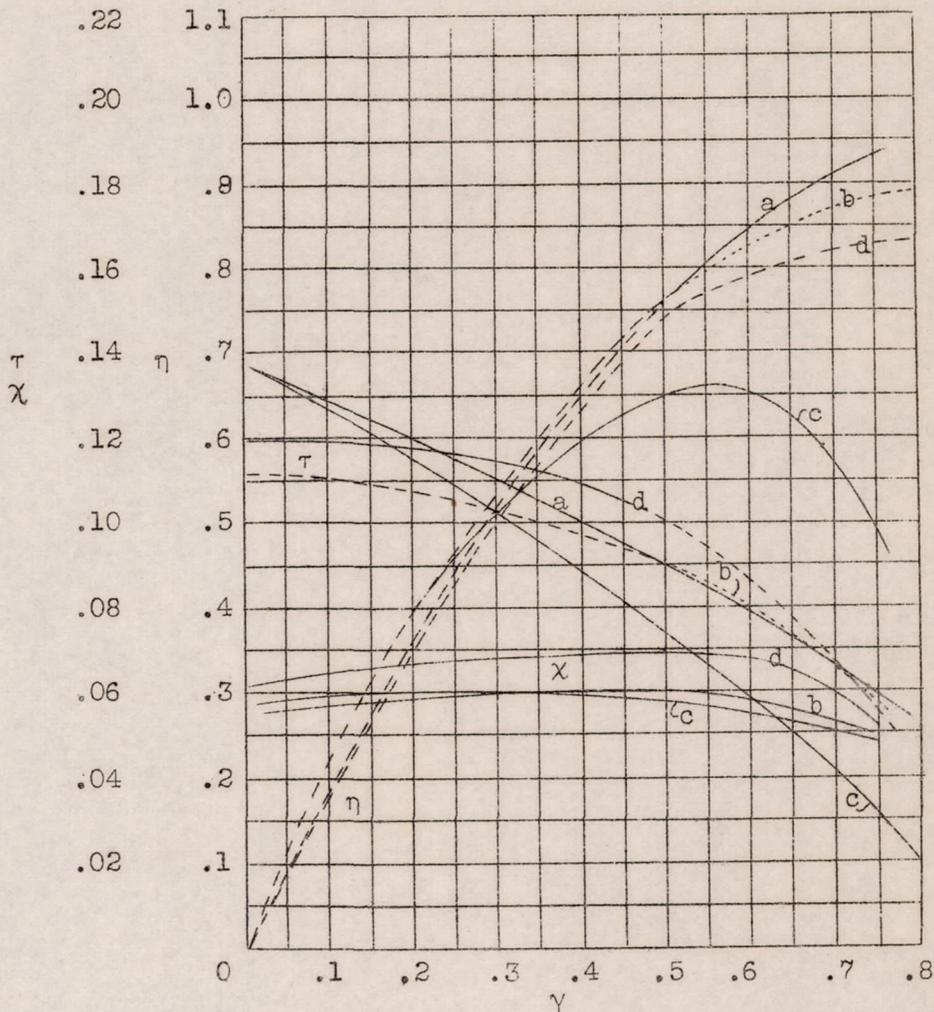
Fig. 21 "Stipa" intubed propeller (Series III).

- - - - - Propeller of seaplane CR 20 integral with tube ( $V = 20 \text{ m/sec}$ )  
 ————— " " " " " " " " ( $N.m. = 4600$ )



a, Integral derived resistance, isolated tube. b, In presence. c, Integral. d, Alone

Fig.22 "Stipa" intubed propeller (Series II). Propeller of scaplane CR 20 ( $V=20$  m/sec.)



a, Integral derived resistance, isolated tube. b, In presence  
 c, Integral. d, Alone.

Fig.23 "Stipa" intubed propeller (Series II). Propeller of  
 seaplane S 59 (V=20 m/sec.)

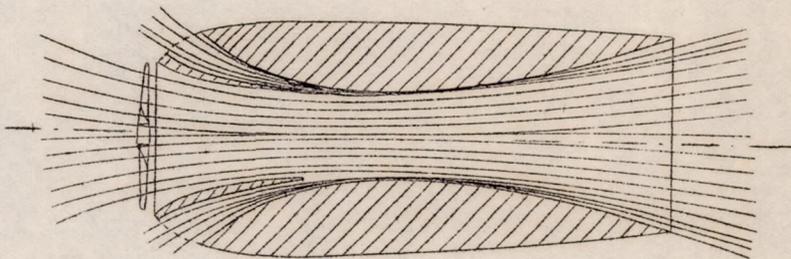


Fig. 24

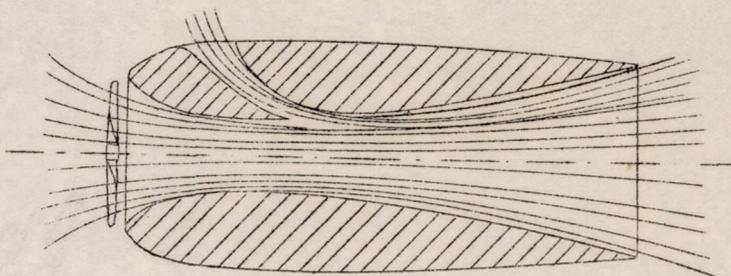


Fig. 25