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ROYAL AIRCRAFT ESTABLISHMENT

Farnborough, Hants.

WIND TUNNEL TESTS ON THE EXHAUST INTERFERENCE DRAG OF A MERLIN UNIVERSAL POWER PLANT INSTALLED ON A WING

PART II - WITH SLIPSTREAM

by

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Item No: 8A IV

SUMMARY

Previous tests on exhaust interference without slipstream have been extended to include the effects of propeller both with and without exhausts. The tests covered a range of three up-and-down positions of the nacelle with two settings of thrust line to chord line.

Except at high C_L (above 0.8) slipstream has little effect on exhaust interference, apart from that for exhausts in the highest position tested where there is an increase in interference drag equivalent to 20% to 30% of the exhaust thrust. At $C_L = 0.9$ the interference for lower exhaust positions is increased by some 20% thrust.

The effect of exhausts is small compared with that of the propeller slipstream. As the propeller is lowered relative to the wing, the slipstream interference increases rapidly. With the propeller 13% chord below the chord line the interference is 50 lb. at 100 f.p.s. per nacelle for an engine power of 800 B.H.P. at $C_L = 0.8$. Allowing for scale effect up to a Reynolds number fifteen times the model value, it is estimated that some 60% of this effect will remain.

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1 Introduction

The programme of tests described in Part I[1] of this report, concerning the interference effects of a line of exhausts on a nacelle installed on a wing at fairly high C_L, has been extended here to include the effects of propeller slipstream both with and without exhausts. Since the previous tests indicated that the fore-and-aft position of the power plant was a secondary variable, a range of up-and-down positions only was tested. A further variable was introduced by having available two different settings of the propeller thrust line to the wing chord.

2 Description of Apparatus

2.1 General

The 1/5 scale model wing and nacelles used were the same as in Part I, apart from the modifications to the power plant necessitated by fitting the propeller. The previous complication of providing airflow round the exhausts to represent flame damping was dispensed with, the intake in the nose of the power plant being removed and replaced by a fairing.

The same notation has been used to define the nacelles, "A" meaning midwing, "B" semi-dropped and "C" dropped. The tests were confined to the rear position of the fore-and-aft range, i.e. position "3". Two up-and-down positions of the exhausts were available with each nacelle arrangement. The exhaust flow was represented by compressed air fed into the model through the end of the wing. Provision was made for altering the thrust line to wing chord line angle from the previous -5° to 0°, by the insertion of a wedge at the rear of the power plant.

Model details are given in Table 1.

2.2 Propeller Installation

A general arrangement drawing showing the installation of the 6 H.P. electric motor is given in Fig. 1. A larger motor would have been an advantage but 6 H.P. was the most which could be accommodated in the nacelle. In order to fit the motor it was necessary to reduce the size of the exhaust manifolds.

The motor was pivoted freely inside a case attached to the model. The propeller torque was measured on an auxiliary balance on the tunnel roof, from which a wire led to an arm attached to the rear of the motor and projecting outside the model. Adjustable stops connected to warning lights on the balance were fitted to control the range of movement of the torque arm. This was done to avoid changes in torque zero caused by the out-of-balance moment of the motor. The setting found to be most convenient gave about 0.1 in. movement of the end of the torque arm (9 ins. long). Mercury cups were fitted in the model to avoid any constraint upon the motor by the current leads. The current was fed into the model through the stability weight wires which were led into mercury cups outside the tunnel.

Details of the propeller are given in Fig. 2.

3 Tests

3.1 Calibrations

The exhaust thrust calibration described in Part I (made on nacelle alone at zero wind speed) was repeated because of the modification to the exhaust manifolds.

A calibration of the propeller comprising thrust and torque measurements was also made on the nacelle without wing.

3.2 Interference

The main tests were made at a wind speed of 120 ft./sec. For the most part they were limited to two incidences corresponding to C_L of roughly 0.7 and 0.9. At each incidence measurements were made with and without exhaust flow, and with and without propeller. One propeller pitch setting only was used, 30° at 0.7 radius.

The measurements made for each condition were:-

(1) Lift
(2) Drag
(3) Pressure drop across orifice plate (exhaust supply)
(4) Static pressure before orifice plate
(5) Exhaust total head in manifolds
(6) Exhaust total temperature
(7) Propeller torque
(8) Propeller rotational speed

The various propeller-nacelle-exhaust combinations tested are listed in the following table and illustrated in Fig. 2.

Nacelle	Exhaust Position	Thrust line setting to wing chord
A3 (- 5)	high	-5°
A3 (0)	high	0°
A3 (- 5)	low	-5°
B3 (-5)	high	-5°
C3 (-5)	high	-5°
C3 (0)	high	0°

4 Analysis

As in Part I an ideal exhaust thrust t_I, found from the thrust measured on the nacelle alone at zero wind speed, has been used. Similarly an ideal propeller thrust, T_I (power absorbed divided by forward speed) has been defined. The reason for the use of T_I rather than the normal power or torque coefficient is merely for convenience in the analysis. From these ideal thrusts a series of efficiencies and interference drags are defined as follows:-

(a) Exhaust efficiency =
(Drag of wing + nacelle + propeller without exhausts
- drag of wing + nacelle + propeller with exhaust flow*)
$\div\ t_I$

Exhaust interference drag =
t_I - (Drag of wing + nacelle + propeller without exhaust
- drag of wing + nacelle + propeller with exhaust flow at the same lift).

* The immediate results from the tunnel are given at constant incidence but the final results are corrected to constant lift.

(b) Propeller net efficiency =
(Drag of wing + nacelle - drag of wing + nacelle with propeller operating*) $\div T_I$

Propeller interference drag =
Thrust of propeller measured on nacelle alone at given power - (Drag of wing + nacelle - drag of wing + nacelle at the same lift with propeller operating at the same power)

(c) Overall net efficiency =
(Drag of wing + nacelle - drag of wing + nacelle with exhaust flow and propeller operating*) $\div T_I + t_I$

(d) Propeller propulsive efficiency =
(Drag of wing - drag of wing + nacelle at the same lift with propeller operating) $\div T_I$

Nacelle + propeller interference drag =
Thrust of propeller measured on nacelle alone at given power - (drag of wing - drag of wing + nacelle at the same lift with propeller operating at the same power)

(e) Overall propulsive efficiency =
(Drag of wing - drag of wing + nacelle at the same lift with exhaust flow and propeller operating) $\div T_I + t_I$

Nacelle + propeller + exhaust interference drag =
Thrust of propeller measured on nacelle alone + t_I for given power - (drag of wing - drag of wing + nacelle at the same lift with exhaust flow and propeller operating at the same power)

The measured efficiencies have been corrected to propulsive efficiencies on a four-engined aircraft of aspect ratio 10. The convenient result of the exhaust efficiency being independent of exhaust thrust, as found in Part I, no longer holds with slipstream, and analysis has therefore been confined to obtaining the exhaust efficiency at definite values of engine power.

The corrections are the same as in Part I, with the addition of corrections due to the propeller lift changes. The propeller lift change has been split into three parts caused by:-

(1) the increased velocity in the slipstream,

(2) the propeller side force[2],

(3) the propeller thrust component.

The slipstream lift increment (after being corrected for change in wing aspect ratio in the slipstream from model to full scale[3]) has been added to the nacelle lift change. The other two components of the propeller lift change have been added to the total lift change to find the change of wing induced drag. As with the nacelle induced drag, the slipstream induced drag has been assumed to be the same on the aircraft as on the infinite aspect ratio wing.

* The immediate results from the tunnel are given at constant incidence but the final results are corrected to constant lift.

5 Degree of Accuracy

With the experimental arrangement used it is difficult to attain a high degree of accuracy because of the large drag of the wing itself. In general the drag readings are accurate to ± 2 lb. full scale at 100 f.p.s. The propeller efficiencies are therefore subject to an error of roughly ± 1%, and the exhaust efficiencies to ± 10%. This means further that there is a possible error of ± 8 lb. in the final values of interference drag.

6 Results and Discussion

6.1 Presentation of Results

The measurements are tabulated in Tables 2, 3, 4. In Fig. 4 contours of constant net overall efficiency are plotted. From these the overall thrust efficiency of the slipstream-exhaust combination can be read off, for any values of propeller and exhaust thrust, for each of the six nacelle arrangements tested, and at either of the two C_L values.

More detailed analysis is contained in Table 5 and Figs. 5-9, where values of the separate efficiencies and corresponding interference drags are given; and plotted against the height relative to wing chord of exhausts, nacelle, or propeller, whichever is appropriate.

Results for nacelle C3, for which case a bigger range of C_L was used, are plotted against C_L in Figs. 10 and 11.

6.2 Exhaust Efficiency

The main result (Fig.5) is the drop of 20% - 30% in efficiency, for exhausts well above the wing, compared with the results without propeller, which give no interference in this position. The effect may be caused by the rotation of the slipstream carrying the exhaust on one side of the nacelle down into a less favourable position. In terms of interference drag the loss is equivalent to 3 or 4 lb. at 100 ft./sec. per nacelle, at a C_L of 0.8 and an engine power of 800 B.H.P.

For lower exhaust positions the effect of the propeller is appreciable only at the higher incidence. Fig. 11, where the results for nacelle C3 are plotted against C_L, emphasises this effect.

6.3 Propeller Efficiency

The propeller net efficiency as a function of J is given in Table 4 as the net overall efficiency with zero exhaust flow. Taking the particular condition of 800 B.H.P. (per engine) on a four engined aircraft, whose particulars are given in Table 1, Fig. 6 shows the propulsive efficiency (i.e. taking into account also the nacelle drag) as a function of nacelle height relative to the wing chord leading edge (see Fig. 2 for illustration of this parameter). The high efficiencies of 75-80% for central or partly dropped nacelles indicate that at high C_L the slipstream is mostly carried clear over the top of the wing, which is therefore relatively free from interference drag. With the thrust line 5° down to wing chord a rapid fall in efficiency is found when the nacelle is dropped more than 10% chord, the slipstream being then carried into the wing. By tipping up the nose of the power plant through 5°, from the engine bulkhead forward (see Fig. 2), this decrease is avoided within the range of nacelle heights investigated, as Fig. 6 shows.

These results are interpreted in terms of interference drag in the curves of Fig. 7.

For the nacelle C3 (-5), dropped 16% chord below central (fig. 2), the interference drag at C_L = 0.8 is about 50 lb. full scale at 100 ft./sec. for an engine power of 800 B.H.P. The effect is therefore much larger than the observed changes in interference drag of the exhausts. Allowing for scale effect up to a Reynolds number fifteen times the model value, it is estimated that the propeller interference would be reduced to about 60% of the above value. By tipping up the front of the nacelle through 5° (thereby raising the propeller a distance equal to 4½% of the chord) the interference on the model is reduced to zero.

The results suggest that the vertical position of the propeller is the most important variable in determining the degree of interference. To check this, the interference drag is shown in Fig. 8 plotted against distance of the propeller centre below the projected wing chord (see Fig. 2 for illustration of the parameter). For this purpose the propeller interference alone (i.e. excluding changes of nacelle drag) is plotted. Within the experimental accuracy, it is conceivable that the points at a given C_L lie on a single curve, independently of the inclination of the thrust line. The results are not conclusive, however, and it is probable that a separate effect of thrust line inclination exists.

From Fig. 6 it seems that the optimum position of the nacelle with inclined thrust line is about 5% dropped if designing for a C_L of 0.9, and central if designing for a C_L of 0.7. For lower values of C_L, still higher nacelle positions would be required to ensure the slipstream being carried over the wing. Alternatively the lower positions tested might then be suitable for directing the slipstream under the wing. Fig. 10, giving results for nacelle C3 (lowest position) over an extended C_L range, shows that below C_L = 0.4 the effect of tipping up the nacelle nose disappears. A fuller series of tests is required before accurate conclusions can be drawn. We may note that the interference effects at lower C_L values will in general be of smaller magnitude on account of both the reduced circulation and also a smaller slipstream velocity factor.

6.4 Overall Efficiency

The overall effect of nacelle, propeller and exhaust, at constant lift on a four-engined aircraft, is given as an efficiency in Table 5, and plotted as interference drag against nacelle height in Fig. 9. The optimum heights suggested in the previous paragraph are little affected by addition of the exhaust interference (c.f. Figs. 7 and 9).

7 Conclusions

7.1 Exhaust Interference

For the highest exhaust position tested (central nacelle), the exhaust efficiency (i.e. the ratio of exhaust thrust realised to the ideal thrust obtained on a nacelle without wing) is decreased by 20 - 30% by a representative slipstream at a lift coefficient of about 0.8. This is equivalent to an interference drag of 3 - 4 lb. at 100 ft./sec. for an engine power of 800 B.H.P. At C_L = 0.9 the effect is appreciable over the whole range of nacelle heights tested.

7.2 Propeller Interference

The interference effects of the exhaust flow are small compared with those which the propeller slipstream can cause. As the nacelle with thrust line 5° down to chord is dropped beyond 10% chord from the central position, the interference of the slipstream increases rapidly; such that when the nacelle is 16½% chord below central, the interference drag as measured is 50 lb. full scale at 100 ft./sec. for an engine power of 800 B.H.P. at $C_L = 0.8$. At fifteen times the model Reynolds Number the effect would probably be about 60% of this.

By tipping up the front of the nacelle from the engine bulkhead forwards, to make the thrust line parallel to the chord, the interference for the same rear nacelle position is reduced to zero. The effect depends largely on the height of the propeller centre relative to the wing chord, but the inclination of the thrust line probably also affects the result.

If in future installations designed for cruising at high lift coefficient the propeller centre is more than 10% chord below the chord line, it would be advisable to make more extensive tests to check the interference effects. At present this seems hardly likely in view of the general trend to gas turbine installations involving power plants of smaller diameter, and higher cruising speeds.

References

Ref.No.	Author	Title, etc.
1	Winter, Dorward	Wind Tunnel Tests on the Exhaust Interference Drag of a Merlin Universal Power Plant installed on a Wing. Part I - Without Slipstream. R.A.E. Report No. Aero.2087. October, 1945. A.R.C. Report No. 9495.
2	Walker, Levacic	Wind Tunnel Measurements of the Forces on Inclined Propellers. R.A.E. Report No. Aero.2024. April, 1945.
3	Smelt, Davies	Estimation of Increase in Lift due to Slipstream. R. & M.1788. February, 1937.

Attached:

Table I - V
Drgs. 19230S - 19240S

Circulation:

C.S.(A)		A.D.R.D.L.1	- 2
D.G.S.R.(A)		A.D.R.D.L.2	- 2
D.S.R.(A)		D.Eng.R.D.	
A.D.A.R.D.(Res)		D.D.A.R.D.(Civ.)	
A.D.S.R.(Records)	- Action copy	D.D.R.D.(Perf.)	
D.A.R.D.		A. & A.E.E.	
P.D.T.D.		M.A.E.E.	
R.T.P.(T.I.B.)	- 110+1	A.R.C.(for Engine Sub-Com.)	- 30
D.T.R.D.			
D.D.A.R.D.(Serv.)			

Table I

Model Details

(Dimensions are full scale)

Model Scale 1:5

Wing:-	
Span	57.58 ft.
Chord	12.17 ft.
Area	700.5 sq.ft.
Section	NACA 2420
Nacelles:-	
Maximum Diameter	55.8 ins.
Distance of nacelle ℄ below chord l.e. A	0
B	7.2% chord
C	16.4% chord
Distance of nacelle nose ahead wing l.e.	65.4% chord
Propeller:-	
Diameter	13.5 ft.
Number of blades	4
Solidity at 0.7 radius	0.126
Pitch setting at 0.7 radius	30°
Angle between thrust line and wing chord	0° and -5°
Height of thrust line above power plant ℄	7.6% chord
Distance of propeller ℄ ahead wing l.e.	52.5% chord
Exhausts:-	
Total exit area	40.5 sq.ins.
Distance of exhaust ℄ above chord l.e. for high exhaust position A	12.0% chord
B	4.8% chord
C	-4.4% chord
Height difference between high and low exhaust positions	7.5% chord
Distance of rear exhaust exit ahead wing l.e.	10.3% chord
Assumed Characteristics of Four-engined Aircraft:-	
Wing area	1400 sq.ft.
Aspect ratio	10
Wing loading	45 lb./sq.ft.
Exhaust exit area (manifolds)	25 sq.ins.

Table II

Propeller Calibration on Nacelle Alone

Tunnel speed f.p.s.	Propeller J	k_Q	k_T	η	Ideal propeller thrust lb. f.s. at 100 f.p.s.
120	1.470	0.00502	0.00216	0.101	43.1
	1.433	0.00632	0.00903	0.326	58.6
	1.396	0.00790	0.01669	0.469	79.2
	1.361	0.00959	0.02845	0.643	103.7
	1.330	0.01232	0.0402	0.693	142.9
	1.299	0.01297	0.0454	0.723	161.5
	1.266	0.01479	0.0546	0.743	198.8
	1.234	0.01669	0.0615	0.724	242.2
	1.207	0.01795	0.0713	0.762	278.4
	1.168	0.01976	0.0869	0.818	337.8
	1.144	0.02065	0.0884	0.730	376.2
80	1.151	0.0194	0.0806	0.762	346.6
	1.119	0.0216	0.0930	0.767	419.0
	1.083	0.0228	0.1013	0.767	489.8
	1.049	0.0229	0.1056	0.769	537.7
	1.021	0.0248	0.1164	0.764	635.0
	0.995	0.0252	0.1205	0.758	697.2

Table III

Lift and Drag for Wing Alone

Tunnel speed 120 f.p.s.

α°	-0.4	0.5	1.5	2.6	3.65	4.7	5.75	6.75	7.85
C_L	0.086	0.188	0.291	0.394	0.494	0.593	0.691	0.782	0.878
Drag lb.f.s. at 100 f.p.s.	125.5	132.8	141.2	149.8	164.1	178.7	197.2	216.4	241.3

Table IV

Results for Nacelles on Wing With and Without Propeller and Exhausts

Tunnel Speed 120 f.p.s.

Nacelle: Exhaust position: Thrust line setting to wing chord	α^o	C_L	Drag	Measured Thrust	Measured Lift Change	Ideal Propeller Thrust	Ideal Exhaust Thrust	Propeller J	Exhaust Flow lb./sec. f.s.	Net Overall Efficiency
			lb. f.s. at 100 f.p.s.							
A3 high -5°	5.75	0.692	223.3	0	0	0	0	No prop	0	
				20.9	-17	63.5	0	1.470	0	0.329
				43.9	83	64.6	27.3		5.3	0.478
				104.8	125	64.1	157.6		14.1	0.473
				157.0	125	200.4	0	1.283	0	0.783
				275.3	225	199.8	157.9		14.1	0.770
				322.1	-58	405.4	0	1.147	0	0.795
				331.5	158	401.6	28.8		5.5	0.770
				385.9	217	391.5	157.6		14.1	0.703
	7.85	0.877	282.6	0	0	0	0	No prop	0	
				20.3	300	88.3	0	1.463	0	0.230
				46.3	341	88.3	26.1		5.3	0.405
				169.5	450	86.9	158.3		14.1	0.690
				164.6	350	209.3	0	1.293	0	0.788
				181.8	433	209.0	27.0		5.4	0.770
				273.3	425	207.5	158.8		14.1	0.746
				299.2	492	398.4	0	1.156	0	0.752
				303.7	500	397.4	25.1		5.2	0.719
				377.8	525	386.1	157.3		14.1	0.696
A3 low -5°	5.75	0.702	230.2	0	0	0	0	No prop	0	
				42.2	50	77.0	0	1.445	0	0.548
				67.9	108	78.1	27.0		5.3	0.646
				181.9	366	77.0	156.9		14.2	0.777
				187.3	92	230.8	0	1.269	0	0.811
				203.4	142	225.5	26.5		5.3	0.807
				316.2	358	219.9	159.5		14.3	0.833
				338.7	183	415.6	0	1.137	0	0.815
				362.3	216	415.2	28.3		5.5	0.818
				463.9	358	414.5	157.3		14.2	0.812
	7.85	0.879	280.1	0	0	0	0	No prop	0	
				41.8	183	87.2	0	1.435	0	0.480
				58.6	200	84.7	25.4		5.2	0.533
				181.3	392	86.4	160.0		14.3	0.736
				163.9	266	214.2	0	1.269	0	0.765
				191.1	300	217.6	27.2		5.4	0.781
				300.0	425	212.6	158.5		14.3	0.809
				310.2	392	398.4	0	1.139	0	0.778
				326.7	433	395.9	27.7		5.4	0.771
				400.6	500	392.1	158.3		14.2	0.728

contd.

Table IV (contd.)

Nacelle: Exhaust position: Thrust line setting to wing chord	α^o	C_L	Drag	Measured Thrust	Measured Lift Change	Ideal Propeller Thrust	Ideal Exhaust Thrust	Propeller J	Exhaust Flow lb./sec. f.s.	Net Overall Efficiency
			lb. f.s. at 100 f.p.s.							
A3 high 0°	5.75	0.700	221.6	0	0	0	0	No prop	0	
				30.9	83	84.5	0	1.439	0	0.366
				50.1	142	82.0	28.1		5.4	0.455
				171.6	250	80.6	158.7		14.2	0.717
				155.1	142	216.3	0	1.273	0	0.717
				174.3	192	214.8	28.0		5.5	0.718
				291.6	316	213.5	158.6		14.2	0.784
				311.5	208	411.7	0	1.141	0	0.757
				329.1	250	408.9	26.9		5.3	0.755
				388.0	366	405.1	159.2		14.2	0.688
	7.85	0.882	283.6	0	0	0	0	No prop	0	
				38.7	175	96.8	0	1.437	0	0.400
				62.3	175	96.5	26.6		5.3	0.506
				177.0	258	95.4	159.5		14.3	0.694
				167.8	200	230.7	0	1.271	0	0.727
				186.6	258	229.8	25.6		5.3	0.731
				289.4	325	227.9	158.6		14.2	0.749
				312.7	308	414.8	0	1.140	0	0.754
				323.6	341	414.8	27.6		5.5	0.731
				388.7	375	409.9	157.4		14.1	0.685
B3 high -5°	5.75	0.678	205.0	0	0	0	0	No prop	0	
				25.2	-50	74.4	0	1.447	0	0.339
				44.8	241	70.3	28.9		5.4	0.452
				155.2	350	67.6	162.2		14.4	0.675
				146.6	108	210.5	0	1.280	0	0.696
				171.0	175	211.5	26.5		5.2	0.718
				286.5	375	211.5	160.7		14.3	0.769
				311.4	200	400.2	0	1.149	0	0.777
				332.1	192	398.5	27.0		5.3	0.780
				421.4	400	397.8	163.1		14.5	0.734
	7.85	0.857	254.1	0	0	0	0	No prop	0	
				40.7	142	82.6	0	1.439	0	0.493
				48.0	200	82.3	28.7		5.5	0.433
				163.6	408	80.1	162.6		14.4	0.675
				153.5	233	217.2	0	1.273	0	0.707
				168.0	258	212.2	27.0		5.3	0.702
				285.2	450	221.0	159.0		14.2	0.751
				305.9	308	402.6	0	1.145	0	0.760
				317.8	333	396.4	26.6		5.3	0.751
				375.0	516	391.8	160		14.2	0.680

contd.

Table IV (contd.)

Nacelle: Exhaust Position: Thrust line setting to wing chord	α^{o}	C_L	Drag	Measured Thrust	Measured Lift Change	Ideal Propeller Thrust	Ideal Exhaust Thrust	Propeller J	Exhaust Flow lb./sec. f.s.	Net Overall Efficiency
			lb. f.s. at 100 f.p.s.							
C3	-0.45	0.068	152.4	0	0	0	0	No prop	0	
high				23.8	-216	57.4	0	1.469	0	0.415
-5°				49.5	-250	57.1	27.5		5.3	0.585
				69.7	-350	55.5	71.0		9.0	0.551
				88.6	-375	55.2	106.3		11.3	0.549
				152.6	-216	200.4	0	1.289	0	0.761
				170.1	-275	195.5	28.1		5.3	0.761
				198.8	-383	195.2	74.0		9.1	0.739
				217.9	-417	195.2	105.7		11.2	0.724
				298.5	-318	380.6	0	1.156	0	0.784
				317.7	-318	384.7	27.8		5.3	0.770
				330.9	-391	385.0	73.9		9.1	0.721
				341.1	-441	382.6	105.9		11.2	0.699
	1.4	0.244	158.9	0	0	0	0	No prop	0	
				18.6	75	54.0	0	1.472	0	0.344
				33.8	25	54.0	28.0		5.3	0.412
				58.7	17	50.5	75.8		9.2	0.465
				68.2	17	49.1	108.3		11.3	0.433
				91.7	17	50.5	158.5		14.1	0.439
				142.5	25	189.8	0	1.298	0	0.750
				154.5	58	182.4	28.5		5.3	0.733
				182.0	0	188.0	76.3		9.2	0.688
				197.3	-8	188.0	104.2		11.1	0.675
				212.4	-17	186.7	156.6		14.0	0.619
				273.5	8	386.0	0	1.163	0	0.708
				282.1	-8	382.6	28.3		5.3	0.686
				294.8	-17	381.3	75.1		9.2	0.646
				302.1	-42	381.0	109.0		11.4	0.617
				309.8	-67	370.6	157.4		14.1	0.587
	3.6	0.454	181.2	0	0	0	0	No prop	0	
				24.7	-33	59.9	0	1.466	0	0.412
				47.8	0	56.9	31.9		5.9	0.538
				66.2	58	55.8	73.6		9.0	0.515
				106.9	108	54.5	159.7		14.2	0.498
				123.1	108	54.8	220.8		17.2	0.447
				142.2	-25	195.0	0	1.292	0	0.730
				155.3	17	195.0	27.7		5.2	0.698
				161.4	50	189.8	74.1		9.1	0.612
				180.1	92	188.9	158.0		14.1	0.520
				191.3	92	188.9	220.8		17.2	0.467
				253.2	-17	391.9	0	1.156	0	0.646
				259.1	17	386.8	28.2		5.3	0.621
				265.3	67	379.9	75.7		9.2	0.583
				275.8	75	380.2	157.8		14.1	0.513
				287.3	83	377.1	220.8		17.2	0.481

contd.

Table IV (contd.)

Nacelle: Exhaust Position: Thrust line setting to wing chord	α°	C_L	Drag	Measured Thrust	Measured Lift Change	Ideal Propeller Thrust	Ideal Exhaust Thrust	Propeller J	Exhaust Flow lb./sec. f.s.	Net Overall Efficiency
			lb. f.s. at 100 f.p.s.							
C3 high -5° (contd.)	5.7	0.659	214.0	0	0	0	0	No prop	0	
				31.4	-42	62.6	0	1.466	0	0.502
				50.5	0	62.3	27.5		5.2	0.562
				58.3	108	61.3	74.6		9.1	0.429
				69.2	158	60.7	163.9		14.4	0.308
				79.9	225	58.8	221.0		17.2	0.286
				109.0	0	194.6	0	1.297	0	0.560
				122.9	58	189.0	27.8		5.2	0.567
				125.4	100	194.6	73.8		9.0	0.468
				140.0	183	192.7	159.0		14.1	0.399
				147.9	250	193.0	221.8		17.2	0.356
				248.4	108	394.3	0	1.147	0	0.631
				259.7	108	392.6	28.2		5.3	0.618
				266.6	167	395.7	77.2		9.3	0.564
				274.0	250	381.5	161.9		14.3	0.505
				301.4	316	391.2	223.9		17.3	0.491
	7.8	0.844	249.6	0	0	0	0	No prop	0	
				24.5	117	64.7	0	1.481	0	0.379
				57.5	167	62.5	68.9		8.6	0.437
				95.7	300	60.9	165.5		14.4	0.423
				110.3	392	60.9	219.8		17.0	0.394
				127.7	175	203.3	0	1.308	0	0.628
				139.3	208	201.7	75.5		9.1	0.503
				152.1	342	201.7	163.9		14.3	0.416
				156.4	383	191.1	218.9		17.0	0.382
				224.4	83	393.0	0	1.153	0	0.571
				243.6	108	391.2	74.2		9.1	0.524
				254.9	242	389.2	166.3		14.5	0.459
				261.0	250	397.7	221.5		17.2	0.422
C3 high 0°	5.7	0.656	207.8	0	0	0	0	No prop	0	
				42.8	108	92.0	0	1.451	0	0.465
				61.7	108	91.7	29.1		5.4	0.511
				121.3	275	89.0	7.3		14.1	0.492
				168.4	142	224.6	0	1.283	0	0.749
				187.2	142	222.1	27.6		5.2	0.750
				245.9	300	221.8	159.6		14.2	0.644
				313.5	233	410.9	0	1.150	0	0.763
				336.1	200	410.2	28.7		5.3	0.766
				388.9	358	402.6	159.1		14.1	0.692
	7.8	0.846	250.2	0	0	0	0	No prop	0	
				33.2	158	98.5	0	1.449	0	0.337
				49.5	142	99.3	26.7		5.2	0.393
				115.7	142	101.2	159.5		14.2	0.443
				172.5	233	243.3	0	1.282	0	0.709
				186.9	208	243.0	28.6		5.3	0.688
				237.9	383	239.9	158.2		14.1	0.597
				300.9	342	414.7	0	1.149	0	0.726
				316.7	333	408.8	27.1		5.2	0.727
				345.1	408	404.7	161.3		14.3	0.610

Table V

Propulsive Efficiency and Interference Drag Corrected to Constant Lift on Four-engined Aircraft

Nacelle: Exhaust position: Thrust line setting to wing chord	C_L	Engine Power B.H.P.	Propulsive Efficiency No exhausts	Propulsive Efficiency With exhausts	Exhaust Efficiency	Interference drag per nacelle lb. f.s. at 100 f.p.s. Nacelle + propeller	Nacelle + propeller + exhausts	Propeller
A3 high -5°	0.691	800	0.77	0.77	0.82	-3	0	-14
		1000	0.78	0.78	0.79	-3	2	-14
		1200	0.78	0.76	0.60	-3	12	-14
	0.878	800	0.77	0.76	0.64	0	8	-18
A3 low -5°	0.691	800	0.79	0.79	0.78	-8	-5	-19
		1000	0.80	0.81	0.84	-12	-8	-22
		1200	0.80	0.81	0.86	-13	-8	-24
	0.878	800	0.77	0.77	0.81	0	4	-19
A3 high 0°	0.691	800	0.72	0.72	0.69	9	14	-2
		1000	0.75	0.75	0.75	6	12	-5
		1200	0.75	0.75	0.73	6	16	-4
	0.878	800	0.75	0.74	0.66	8	15	-10
B3 high -5°	0.691	800	0.72	0.73	0.88	8	10	4
		1000	0.76	0.77	0.85	1	5	-2
		1200	0.77	0.78	0.85	-2	4	-5
	0.878	800	0.78	0.78	0.75	-4	1	-6
C3 high -5°	0.280	800	0.18	0.22	0.64	15	17	-1
		1000	0.28	0.33	0.69	22	25	6
		1200	0.38	0.42	0.71	25	29	9
	0.492	800	0.64	0.64	0.62	11	15	7
		1000	0.70	0.68	0.52	7	16	3
		1200	0.71	0.68	0.39	8	24	4
	0.687	800	0.60	0.60	0.61	39	46	43
		1000	0.61	0.61	0.59	49	59	53
		1200	0.62	0.62	0.63	54	67	58
	0.872	800	0.62	0.60	0.24	52	67	56
C3 high 0°	0.687	800	0.79	0.79	0.77	-8	-4	-4
		1000	0.80	0.79	0.69	-10	-2	-6
		1200	0.79	0.78	0.67	-8	4	-4
	0.872	800	0.78	0.76	0.54	-2	7	2

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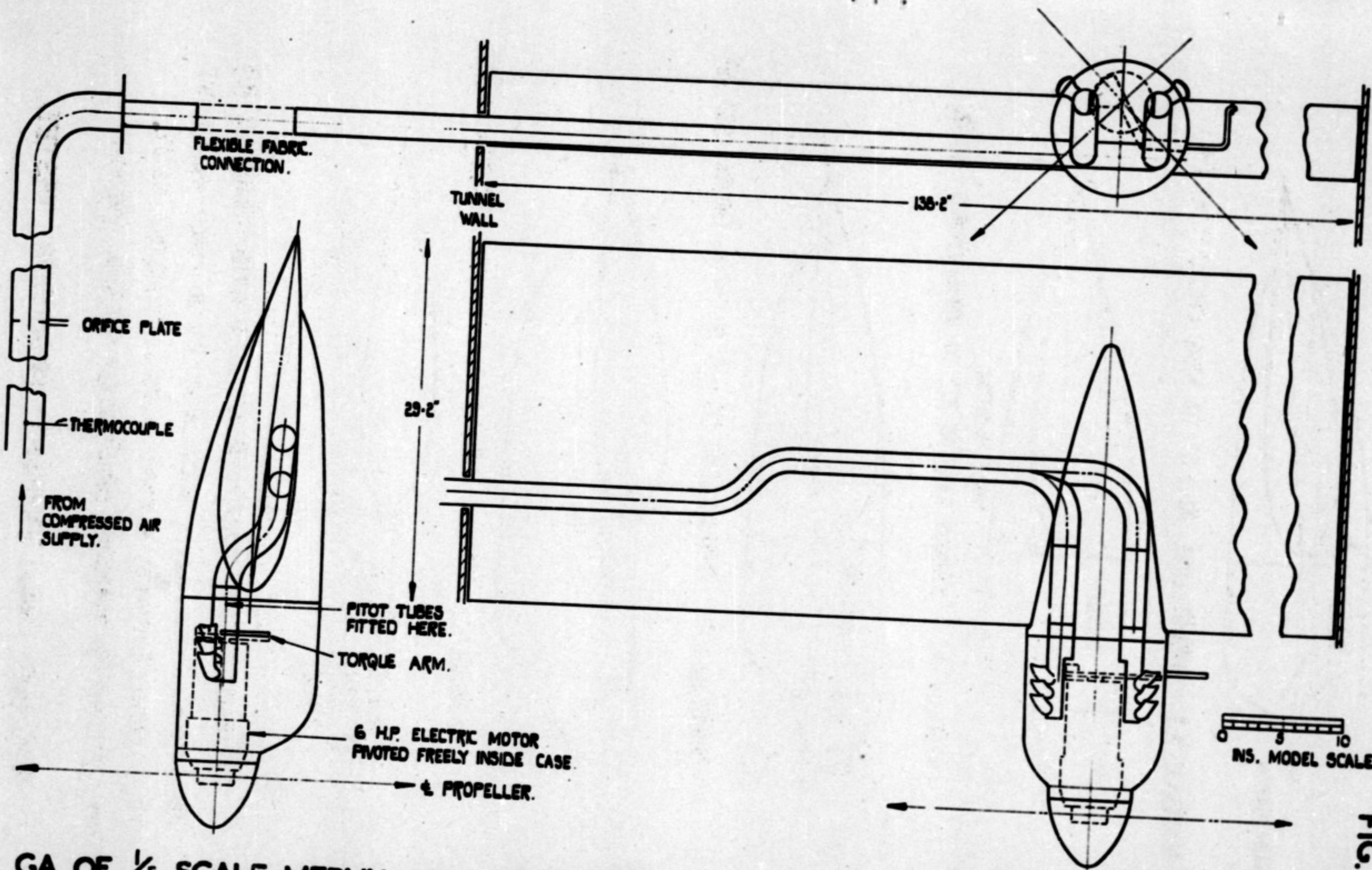
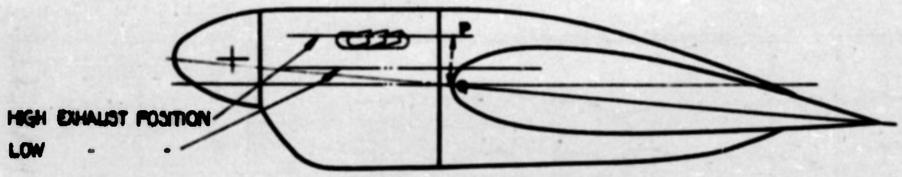
FIG. 1

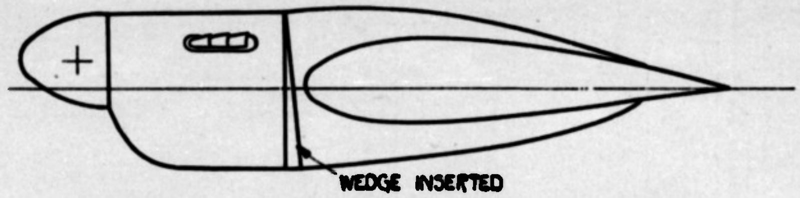


GA. OF 1/5 SCALE MERLIN U.P.P. MODEL WITH EXHAUSTS & PROPELLER (MID-WING NACELLE)

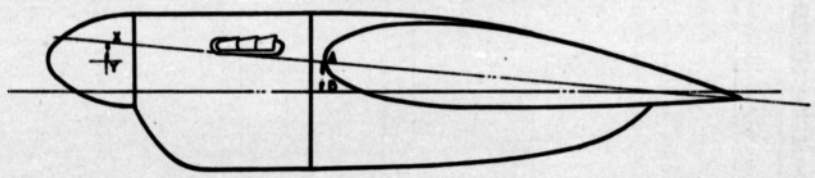
FIG. 2



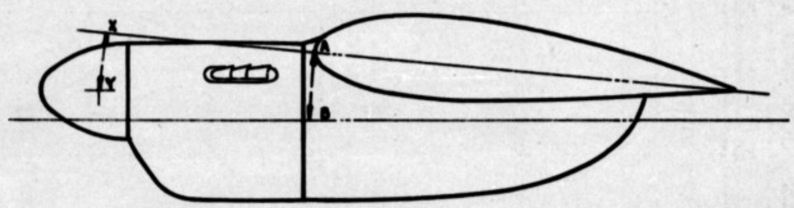
NACELLE A3 : THRUST LINE AT -5° TO WING CHORD : A3 (-5)



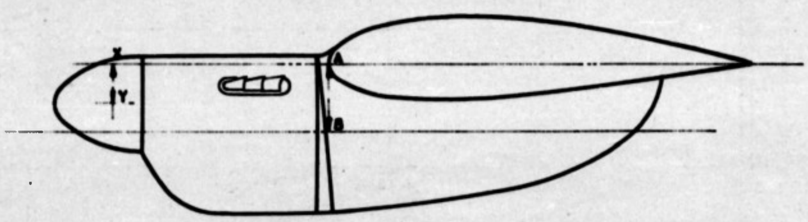
NACELLE A3 : THRUST LINE AT 0° TO WING CHORD : A3 (0)



NACELLE B3 : THRUST LINE AT -5° TO WING CHORD : B3 (-5)



NACELLE C3 : THRUST LINE AT -5° TO WING CHORD : C3 (-5)



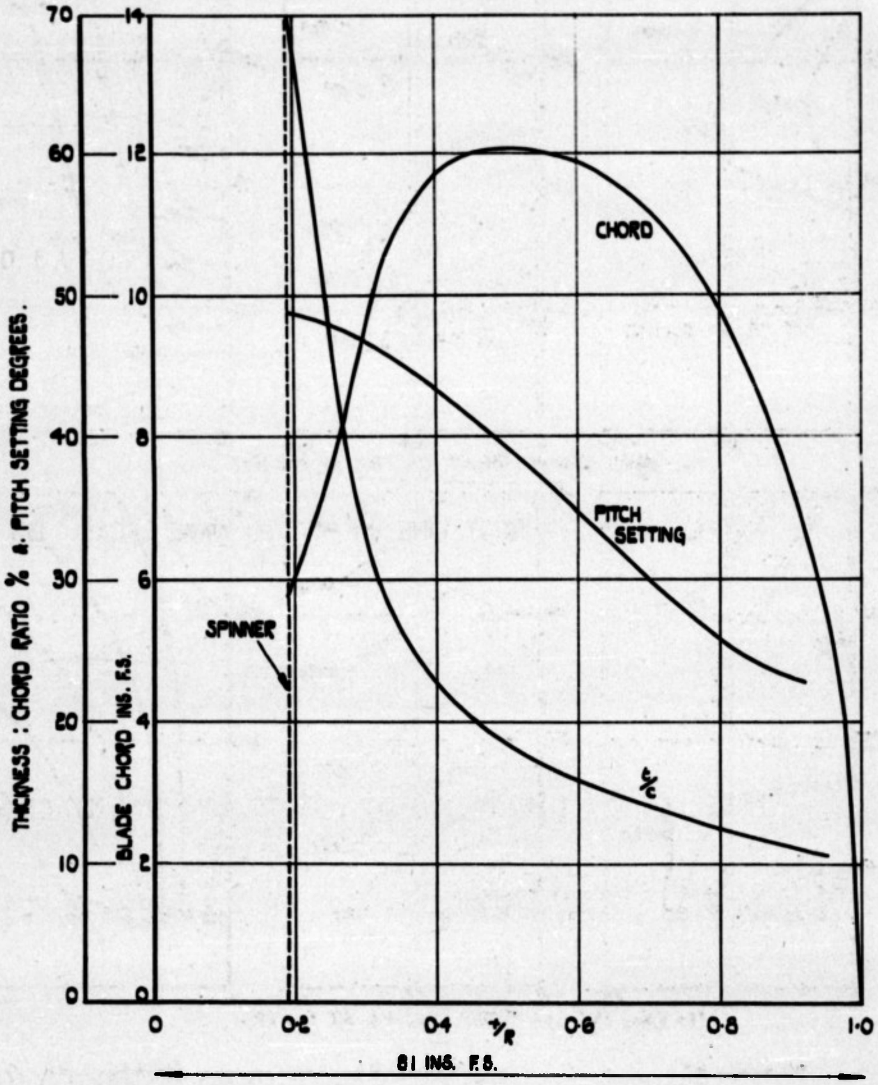
NACELLE C3 : THRUST LINE AT 0° TO WING CHORD : C3 (0)

AB = DISTANCE OF NACELLE ℄ BELOW CHORD LEADING EDGE (FIGS. 6,7,9)

P.Q. = DISTANCE OF EXHAUST ℄ ABOVE CHORD LEADING EDGE (FIG. 5)

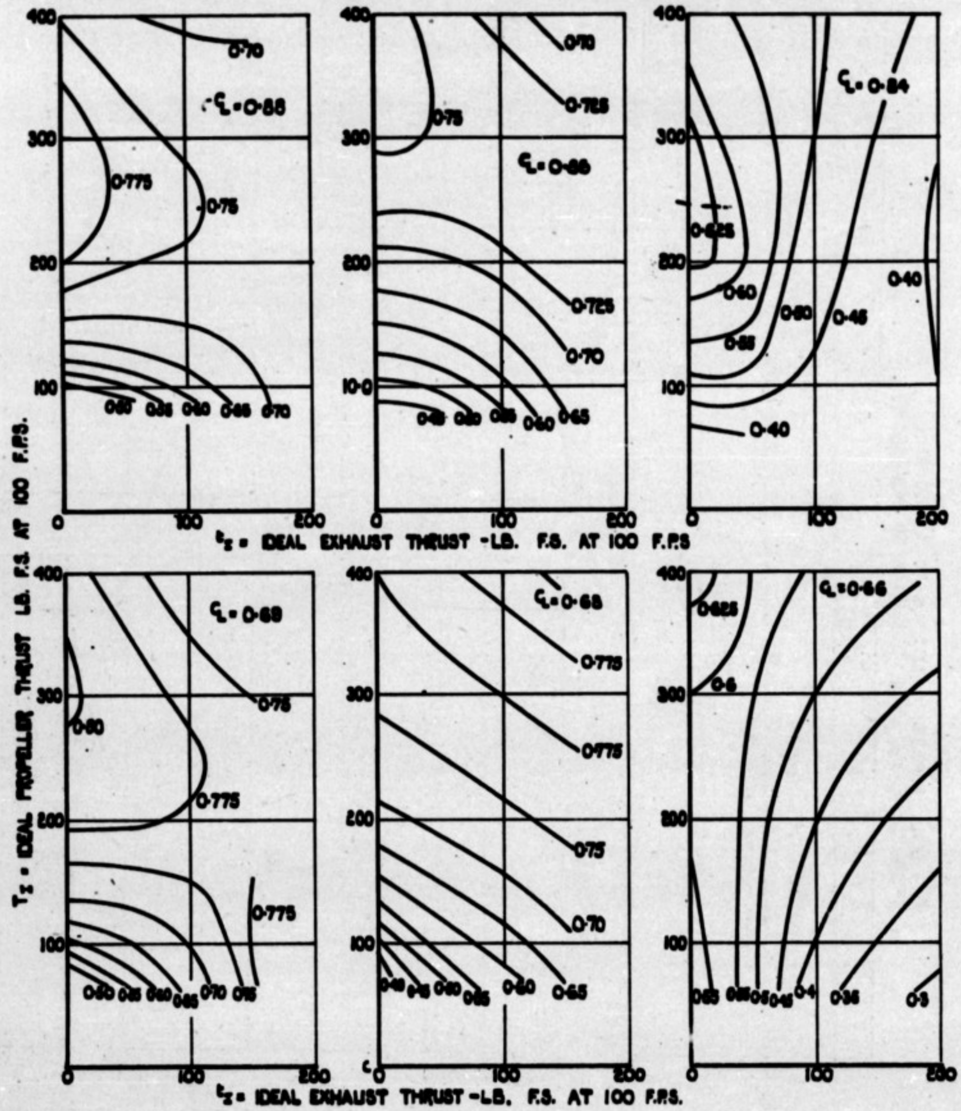
X.Y. = DISTANCE OF PROPELLER CENTRE BELOW WING CHORD (FIG. 8)

NACELLE AND EXHAUST POSITIONS TESTED.



DETAILS OF PROPELLER (4 BLADED.)

FIG. 4



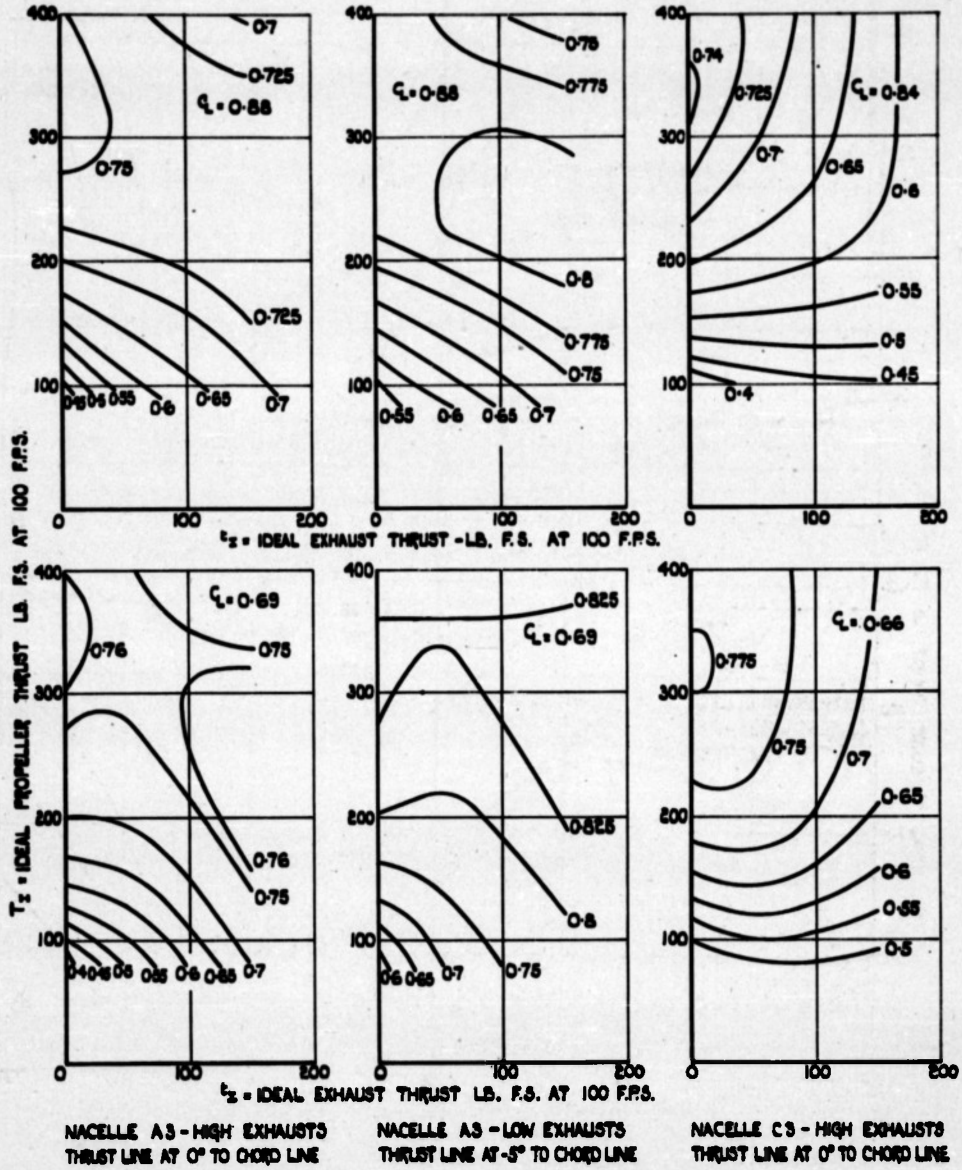
NACELLE A3 NACELLE B3 NACELLE C3

NACELLE WITH THRUST LINE AT -5° TO CHORD LINE — HIGH EXHAUST POSITION

CONTOURS OF NET OVERALL EFFICIENCY FOR INFINITE ASPECT RATIO.

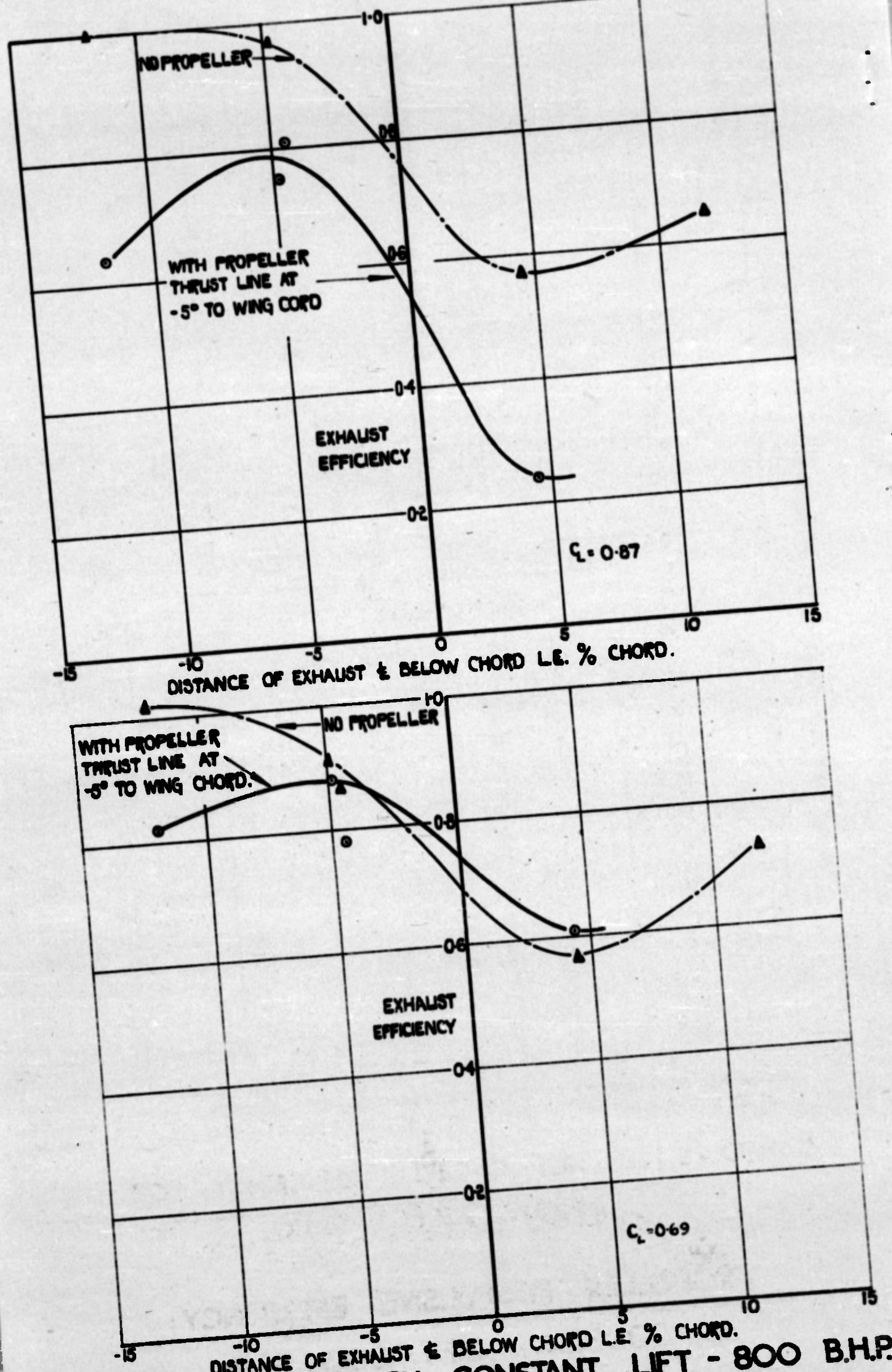
No 19234 8

REPORT AERO 2087A
FIG. 4. (CONT.)



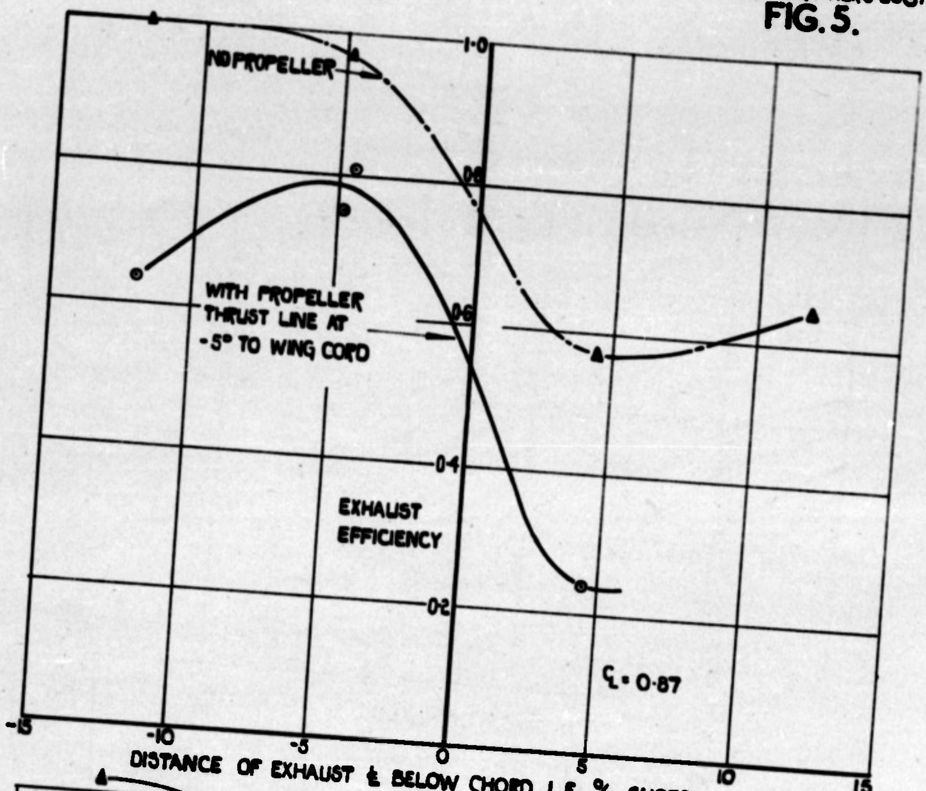
CONTOURS OF NET OVERALL EFFICIENCY FOR INFINITE ASPECT RATIO.

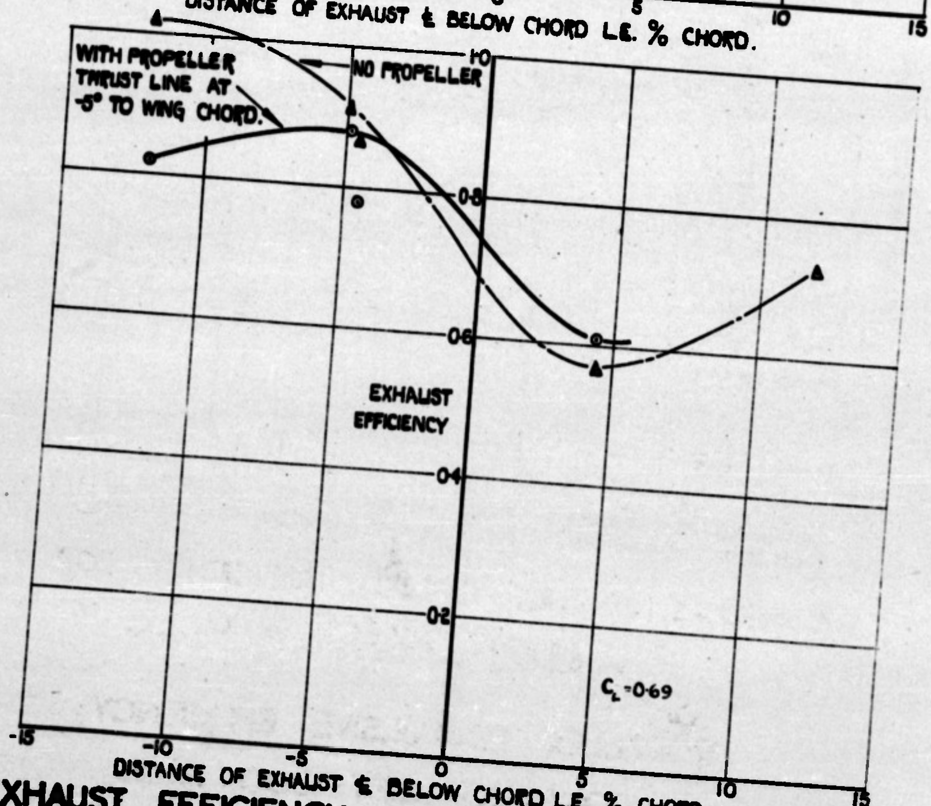
FIG. 5.



EXHAUST EFFICIENCY - CONSTANT LIFT - 800 B.H.P.

FIG. 5.

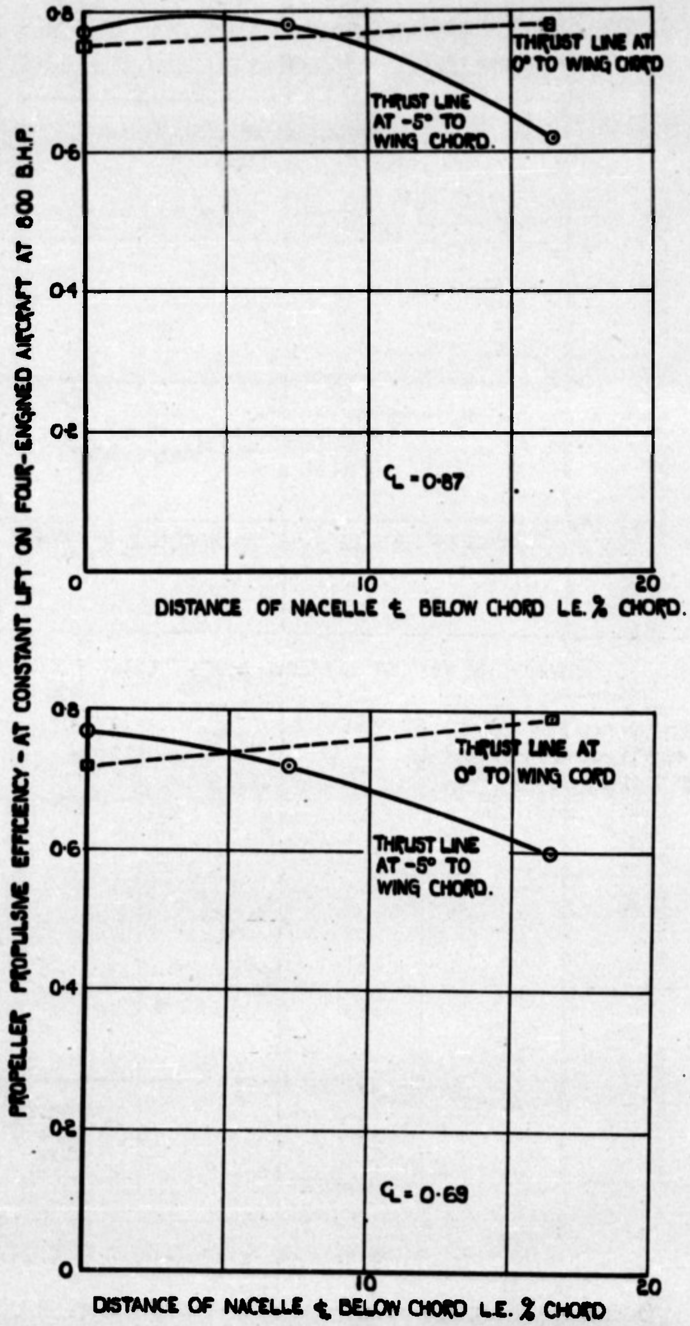




EXHAUST EFFICIENCY - CONSTANT LIFT - 800 B.H.P.

REPORT AERO 2087A.

FIG. 6



PROPELLER PROPULSIVE EFFICIENCY.

- CONSTANT LIFT 800 - B.H.P.

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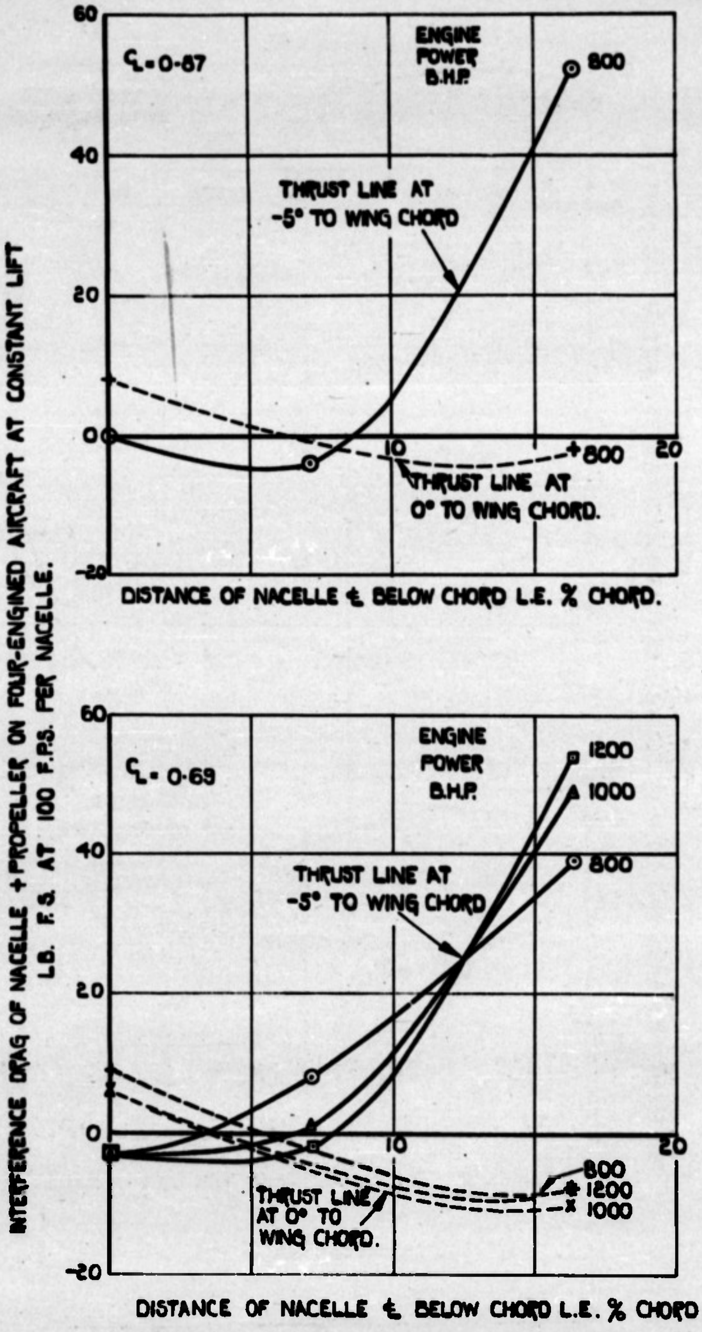
FIG.7.

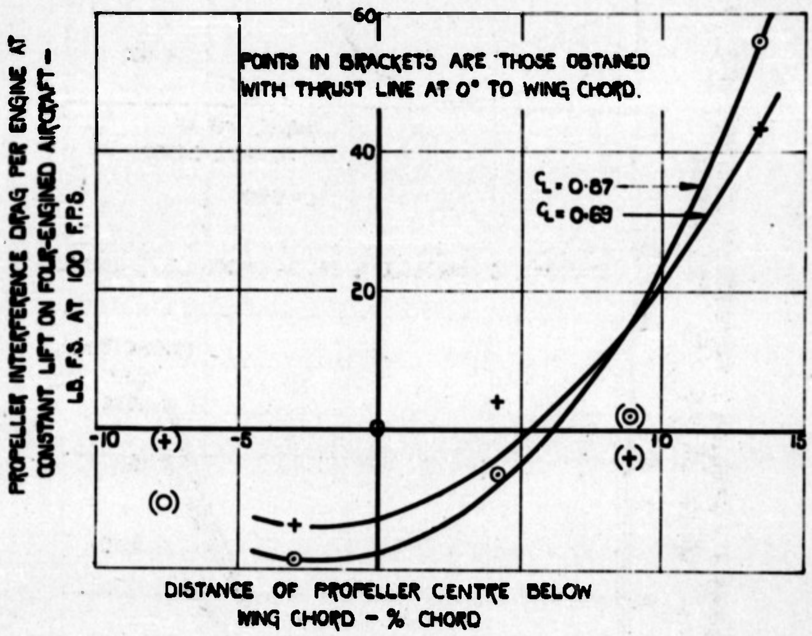


NACELLE + PROPELLER INTERFERENCE DRAG.

No 19238 S.

REPORT AERO 2067A

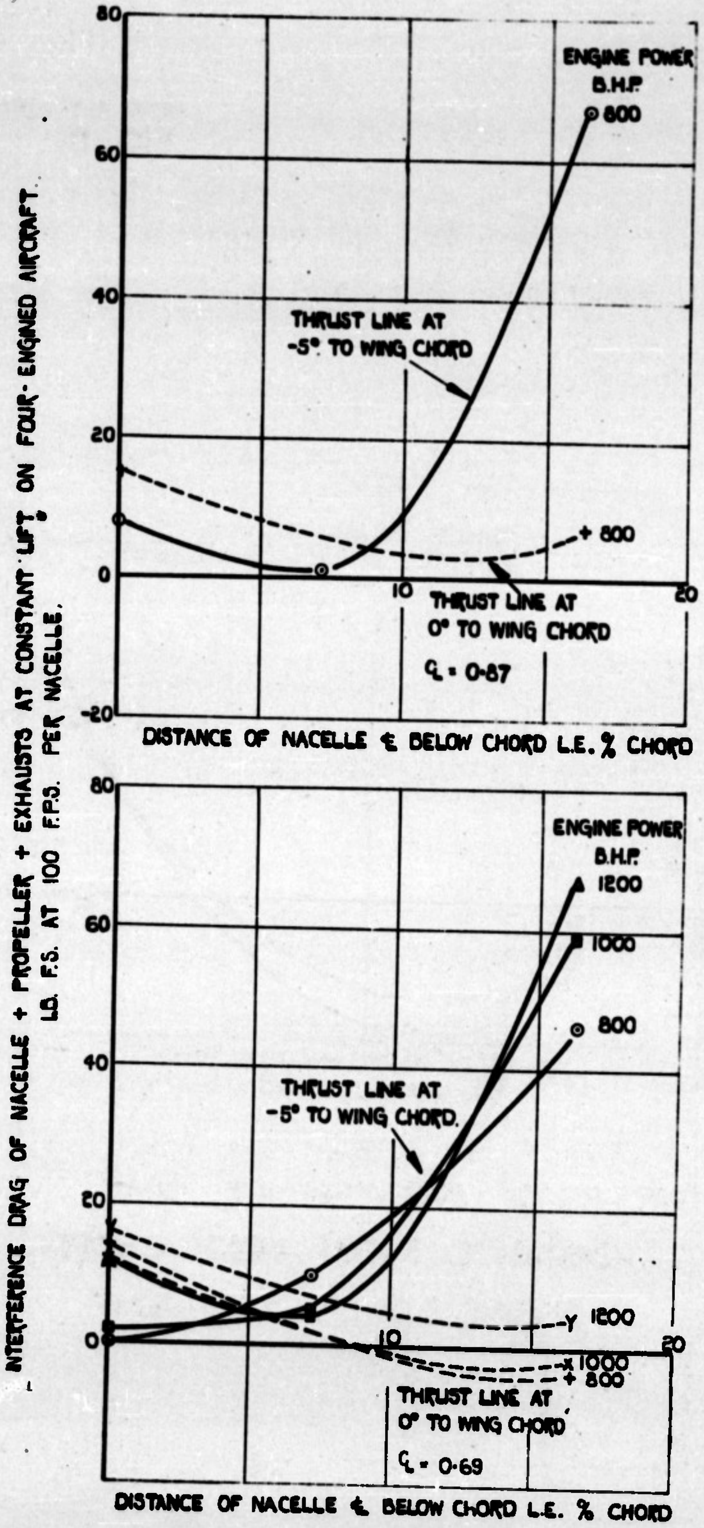
FIG. 8.



PROPELLER INTERFERENCE DRAG V.S. DISTANCE FROM WING CHORD

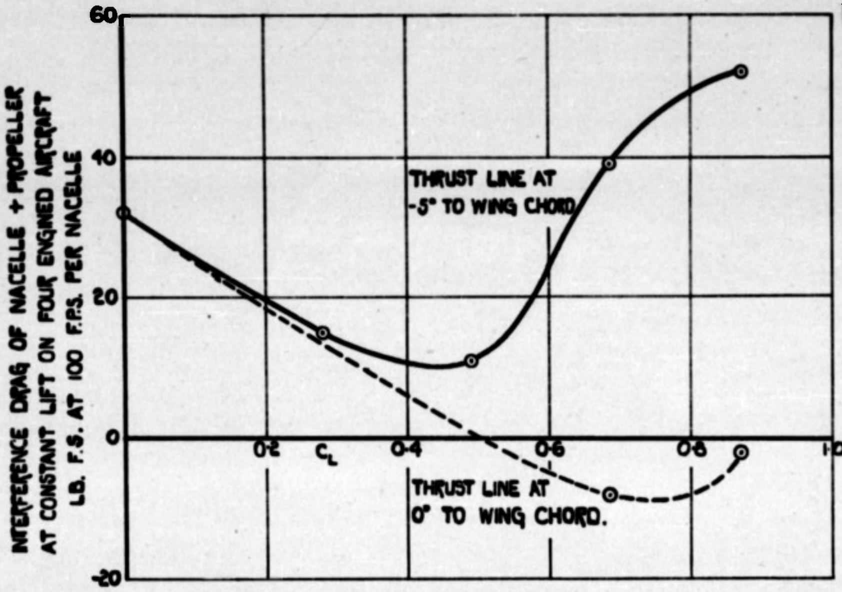
ENGINE POWER = 800 B.H.P.

FIG. 9.



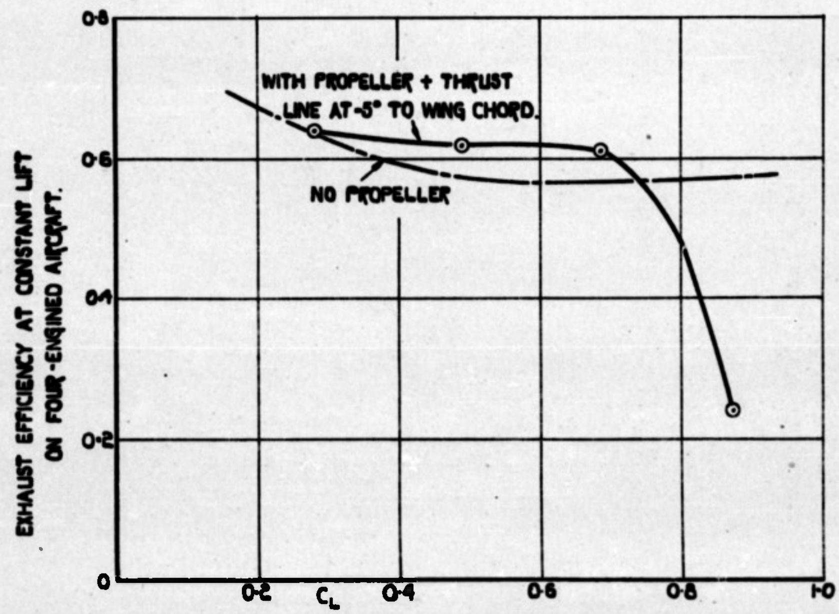
OVERALL INTERFERENCE DRAG

FIG. 10



NACELLE + PROPELLER INTERFERENCE DRAG-NACELLE C3
ENGINE POWER = 800 B.H.P.

FIG. 11.



EXHAUST EFFICIENCY - NACELLE C3 -
HIGH EXHAUSTS - 800 B.H.P.

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TITLE:	Wind Tunnel Tests on the Exhaust Interference Drag of a Merlin Universal Power Plant Installed on a Wing - Part II - With Slipstream
AUTHOR(S)	Winter, K. G.; Dorwood, J.
ORIG. AGENCY	Royal Aircraft Establishment, Farnborough, Hants
PUBLISHED BY	(Same)

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DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Aug' 46	Restr.	Gt. Brit.	English	26	tables, graphs

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