C.P. No. 21
10925
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Effect of Propeller Thrust on Downwash and Velocity at Tailplane

Data from Low Speed Tunnel Tests

By

A. Spence, B.Sc.

LONDON: HIS MAJESTY'S STATIONERY OFFICE

1950

Price 1s. 6d. net.

C.P. No.21

Report No. Aero.2218

August, 1947.

ROYAL AIRCRAFT ESTABLISHMENT

The Effect of Propeller Thrust on Downwash and Velocity at Tailplane - A Collection of Data from Low Speed Wind Tunnel Tests

by

A.Spence, B.Sc.

SUMMARY

The results of low-speed wind tunnel model tests on longitudinal stability of five models have been analysed to give the effects of propeller thrust on the angle of downwash and the velocity at the tailplane.

No attempt at detailed generalisation of the results has been made at this stage. The results do, however, give an indication of the magnitude of the effects and show some of the more important variables.

LIST OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1 Introduction

In R.& M.1488[1], a collection was made of the data then available on the effect of slipstream on the downwash and velocity at the tailplane. In view of the current importance of longitudinal stability with propellers, a further collection of more recent data has been made and is given in the present report. This forms an interim stage in an attempt to estimate the effects of slipstream on longitudinal stability.

The data are extracted from the results of low-speed wind tunnel model tests made at the Royal Aircraft Establishment in the No.1 $11\frac{1}{2}$ ft. × $8\frac{1}{2}$ ft. tunnel. In all cases the propellers were driven by electric motors housed inside the models.

2 Method of Analysis

2.1 Downwash at tailplane

The method of analysis of the results is necessarily less direct than that employed in Ref.1. This is because only one tailsetting was used for tests with propellers. The ratio (a_2/a_1) of $dc_m/d\eta$ to $dc_m/d\eta_T$ is obtained for the model without propellers and is assumed to be the same with propellers. Two methods of obtaining the mean effective angle of downwash at the tailplane are available as follows:-

(a) If the pitching moment with tail is the same as that without tail at a constant incidence α for a tailsetting η_T (to wing chord) and an elevator angle η, then the angle of downwash, ε, is given by

$$\varepsilon = \alpha + \eta_T + (a_2/a_1)\,\eta .$$

(b) If at constant incidence α, the change of pitching moment caused by the tail at a setting η_T with elevators at 0° is ΔC_{m_T}, then a tailsetting

$$\eta_T - \Delta C_{m_T} \div \left[(a_1/a_2) \times (dc_m/d\eta)\right]$$

would give zero tail load provided that the tail lift is in the linear range. Hence the downwash angle is

$$\varepsilon = \alpha + \eta_T - \Delta C_{m_T} \div \left[(a_1/a_2) \times (dc_m/d\eta)\right].$$

Each of these methods is used where it is the more convenient. In calculating changes of downwash angle, values at zero propeller thrust are used as datum.

2.2 Velocity at tailplane

The effect of thrust on the mean effective velocity at the tailplane is obtained by comparing the value of $dc_m/d\eta$ in a particular condition with that at zero thrust. These values at zero thrust agree closely with corresponding values without propellers and show no appreciable or consistent variation with incidence.

A mean value over a wide incidence range (usually from zero lift nearly up to the stall) is therefore used as datum in calculating the effect of propeller thrust. As in Ref.1, the results are expressed in the form of a velocity increment factor, b. If the mean velocity at the tailplane is U at zero thrust and U(1+b) with thrust, then

$$(1+b)^2 = (dc_m/d\eta) \div (dc_m/d\eta \text{ at zero thrust}).$$

3 Notes on the Data Used and the Presentation of Results

The data are taken from tests on the longitudinal stability of five models, as follows:-

Model	G.A.Drawing	No. of prop. units	Reference
Aeroplane A	Fig.1	1	-
Hornet	Fig.3	2	2,3
Sturgeon	Fig.4	2	4
Aeroplane B	Fig.5	4	-
Saunders-Roe 10/46	Fig.7	6	

The Reynolds numbers of the tests (based on the standard mean chord of the wing in each case) are given in the following table.

Model	Reynolds No. ÷ 10^6	
	$T_c = 0$*	Highest T_c used
Aeroplane A	1.2	0.6
Hornet	1.2	0.6
Sturgeon	1.1	0.55
Aeroplane B	0.75	0.35
Saunders-Roe 10/46	0.45	0.45

Relevant model details are given in Table I and general arrangement drawings are shown in Figs.1, 3, 4, 5 and 7.

3.1 Comparison of various modes of propeller rotation on the Hornet

The tests on the Hornet model[2,3] included several modes of propeller rotation:-

(a) both propellers right hand -

(b) "handed" with tips coming up in the middle -

(c) "handed" with tips going down in the middle -

(d) contra-rotating

For all except the contra-rotating propellers, only one value of the propeller thrust coefficient, T_c, was used at each incidence, i.e. the T_c corresponding to full throttle power at the particular trimmed lift coefficient. The downwash angles are therefore plotted in Fig.[illegible] against incidence, values of T_c being given alongside the points plotted.

* T_c = Propeller propulsive thrust ÷ $\rho V^2 D^2$ (D = prop. diameter).

The corresponding velocity increments at the tailplane are shown in Fig. 9.

3.2 Contra-rotating propellers

All five models were tested with contra-rotating propellers. In every case several values of T_c were used at each incidence and the downwash and velocity increments are plotted against thrust coefficient in Fig. 10, lines at constant incidence being drawn. Thumb-nail plan views of the models are added for convenience.

It should be noted that in the cases of the Hornet and Sturgeon, the tests with slipstream were made with the louvers of the wing leading edge radiators in the "open" position, whereas at zero thrust the louvers were in the closed position. The downwash at zero thrust (ε_0) shown on the upper part of Fig. 10 and used as a datum for the downwash changes, has been estimated in the cases of these two models from tests

(a) without propellers, louvers closed,

(b) without propellers, louvers open,

(c) zero thrust, louvers closed.

Aeroplane A, the Sturgeon and Aeroplane B were also tested with flaps down. The flaps are shown in Figs. 2, 4 and 6 and the results are given in Fig. 11

4 Results and Discussion

4.1 Single propellers

Fig. 8 shows that the angles of downwash at full throttle on the Hornet model with both propellers right hand are similar to those with contra-rotating propellers. In the "handed" cases, however, there are very large effects from the rotation in the slipstream because most of the tailplane lies inboard of the thrust lines. At a thrust coefficient T_c = 0.3, propellers with tips going downwards in the middle cause about 5° more downwash, whilst with the tips going upwards in the middle, the downwash is reduced by about 5°.

Because of the large propeller diameter on the Hornet (relative to tail span and tail arm) there is no large or consistent difference in the velocity increments at the tailplane with the several modes of propeller rotation, (Fig. 9), in spite of the large changes in downwash.

4.2 Contra-rotating propellers - flaps up (Fig. 10)

For each model considered, the tailplane is above the wing chord (Table I) and is high relative to the centre of the slipstream at low incidence. As the incidence is increased, the downwash increases less rapidly and the tail moves closer to the trailing vortex sheet and more into the centre of the slipstream. In general, therefore, the increments of both downwash and velocity caused by propeller thrust are larger at high incidence than at low incidence. The only exceptions to this general rule are Aeroplane A and the Saunders-Roe 10/46 in respect to the velocity increment at the tailplane. For Aeroplane A the value of $d\varepsilon/d\alpha$ at zero thrust is high (0.65) and so the tailplane moves but little relative to the large slipstream circle, the result being that the velocity increment does not vary appreciably with incidence. In the case of the Saunders-Roe 10/46, because of the tailplane dihedral and the tail height, the tailplane is almost entirely above the slipstream over the small incidence range used so that the velocity increments are very small and there is no consistent variation with incidence.

The effect of the height of the tailplane, on the increments of downwash caused by propeller thrust, is large. This is shown by comparing Sections D and E of Fig.10 the tail being raised 0.22 × wing mean chord, or 0.31 × propeller diameter between the two cases. Unfortunately, there is insufficient data to give the velocity at the position of the raised tailplane*, but the effect of thrust would be very small owing to the tail being above the slipstream at any rate at low incidences.

4.3 Effect of lowering flaps (Fig, 11)

Lowering wing flaps causes a reduction in the velocity increment at the tailplane, presumably because the larger downwash at a given incidence deflects the slipstream further below the tailplane. In the case of Aeroplane B with flaps down the tailplane is almost clear of the slipstream band.

The changes of downwash ($\delta\varepsilon$) caused by thrust are, however, of similar magnitude to those with flaps up. A curious feature is that the values of $\delta\varepsilon$ on Aeroplane B show no variation with incidence when the flaps are lowered.

5 Conclusions

(a) Single propellers

In the one instance given of a twin-engined aeroplane with single propellers (Fig.8), unhanded propellers give roughly the same mean downwash at the tailplane as contra-propellers, while handed propellers give an additional $\pm 5^\circ$ at $T_c = 0.3$ according as the tips go down or up in the middle. This result depends on the geometry of the propellers and tailplane and cannot be generalised.

(b) Contra-propellers

Owing to the unsystematic nature of the data available, it is not possible at the present stage to generalise from the results. They give some indication of the range of magnitude of the effects involved and show the importance of tailplane height.

(c) General

It is felt unlikely that any useful generalisation can be based on the present data. Further attempts at a mathematical attack are desirable; any future experimental work should be of a systematic nature.

---

* The velocity between $T_c = 0$ and 0.2 is known sufficiently accurately for use in calculating the downwash, but velocity increments due to thrust are not available.

List of Symbols

α	- wing incidence (degrees)
ϵ_o	- mean downwash at tailplane at zero propeller thrust (degrees)
$\delta\epsilon$	- change of downwash due to propeller thrust
b	- fractional increment of velocity at tailplane due to propeller thrust
U	- velocity at tailplane at zero thrust
U(1+b)	- velocity at tailplane with thrust
T_c	- propeller thrust coefficient, thrust $\div \rho V^2 D^2$
ρ	- density of air
V	- tunnel or flight speed
D	- propeller diameter
R	- propeller radius

List of References

No.	Author	Title etc.
1	Bradfield	Wind Tunnel Data on the Effect of Slipstream on the Downwash and Velocity at the Tailplane. R & M 1468. June, 1932.
2	Anscombe, Winter, Morgan	Wind Tunnel Tests on the de Havilland F.12/43 with Various Modes of Propeller Rotation. Part I. Without Landing Flaps. A.R.C.7891. March, 1944.
3	Worrall, Pearce	Wind Tunnel Tests on a Twin-Engined Aircraft (Hornet) with Contra-rotating Propellers. A.R.C. 8589. February, 1945.
4	Anscombe, Morgan	Wind Tunnel Tests on the S.11/43 (Twin-Engined Aircraft with Contra-rotating Propellers). Part I. General Stability Tests. A.R.C. 8849. April, 1945.

Wt.2078.CP81.K3. Printed in Great Britain

Table I

Relevant Data

(All dimensions are model scale)

Detail \ Model	Aeroplane A	Hornet	Sturgeon	Aeroplane B	S.R.10/46
Wing standard mean chord (ft.)	1.626	1.606	1.447	0.966	0.919
Wing span (ft.)	8.80	9.00	9.23	9.58	9.17
Wing aspect ratio	5.4	5.6	6.4	9.9	10.0
Angle of wing to body datum	0.9°	1.1°	2.0°	3.5°	4.5°
Tail span (ft.)	3.30	3.30	3.08	3.125	2.73
Tail arm (from $\frac{1}{4}$ chord of wing) (ft.)	4.25	4.90	4.15	3.47	3.23
Tail height (above chord of wing centre-section) (ft.)	0.66*	0.43*	0.42	0.38 (orig. tail) 0.59 (raised tail)	0.41 at ℄) of tail ≁ 0.67 at tip)
No. of propellers	1	2	2	4	6
Rotation	Contra	Various	Contra	Contra	Contra
Propeller diameter (ft.)	2.50	2.40	1.54	0.667	0.667
No. of blades per propeller	8 (2x4)	4 (or 2x2)	6 (2x3)	4 (2x2)	6 (2x3)
Solidity at 0.7R	0.243	0.152	0.213	0.166	0.238
Angle of thrust line to wing chord	-0.9°	-1.1°	-2.0°	0°	0°
Spanwise distance of thrust line from ℄ of model (ft.)	0	1.43	1.06	0.80 (inner) 1.50 (outer)	0.71 (inner) 1.42 (middle) 2.13 (outer)

* Wing chord taken midway out across tailplane.

≁ Tail has 12° dihedral.

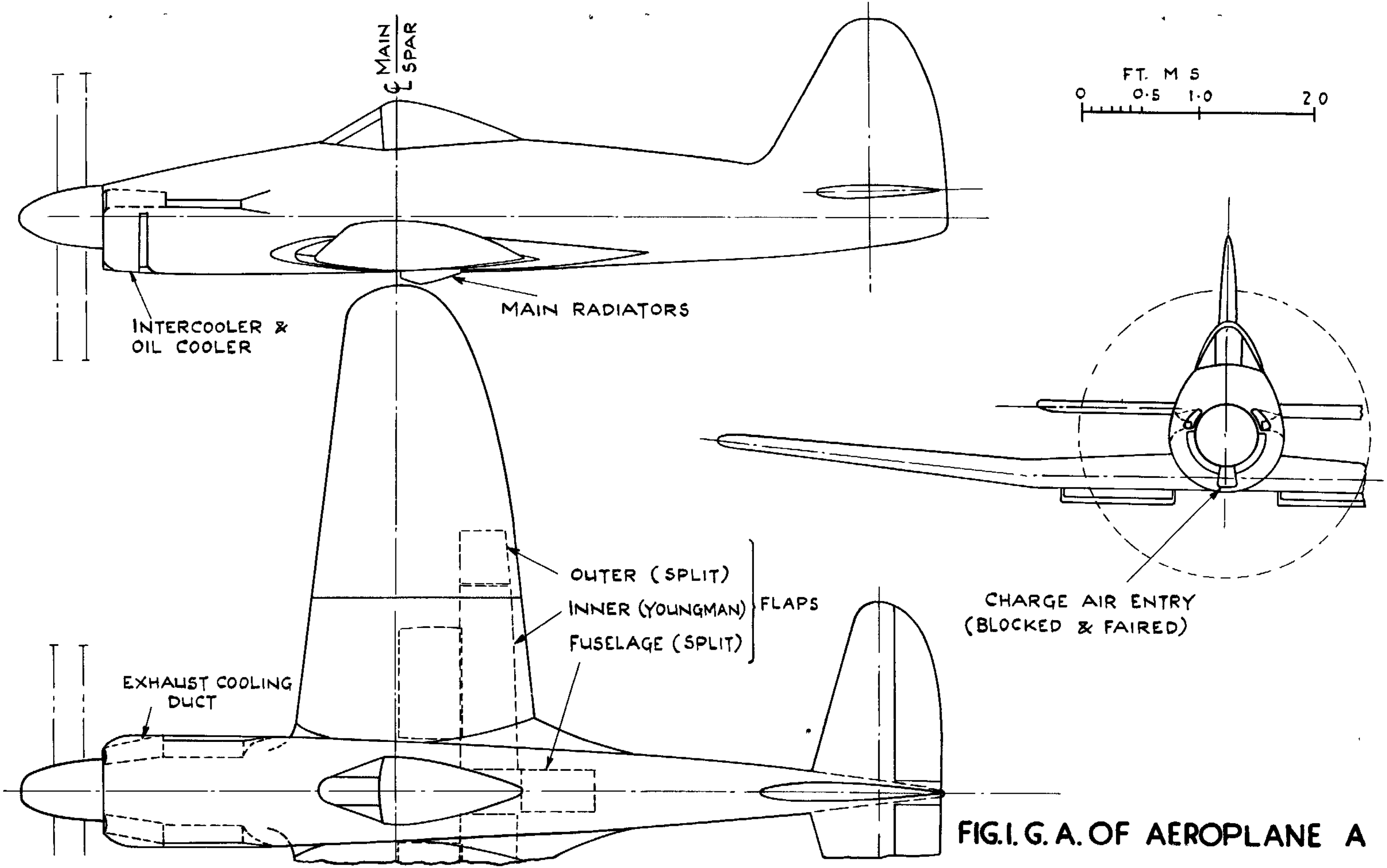

FIG.1. G.A. OF AEROPLANE A

FIG. 1.

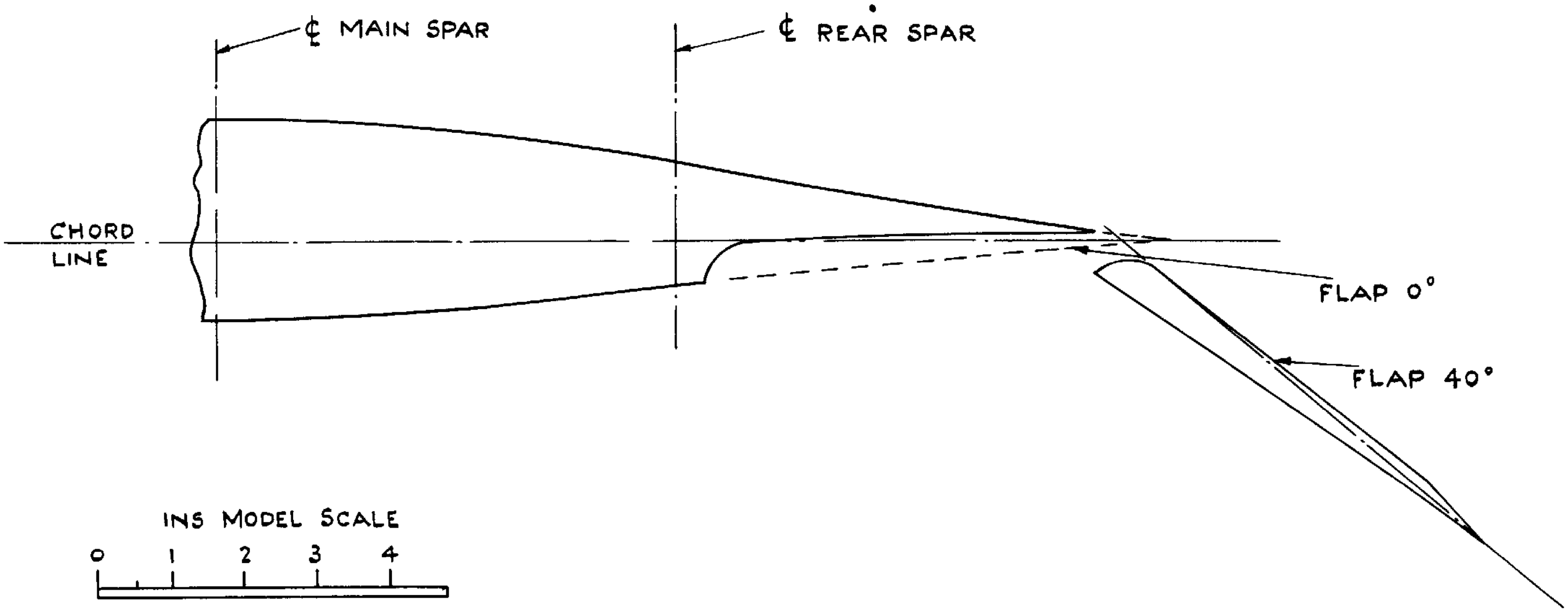

FIG. 2 TYPICAL SECTION SHOWING YOUNGMAN FLAPS
AEROPLANE A

FIG. 2

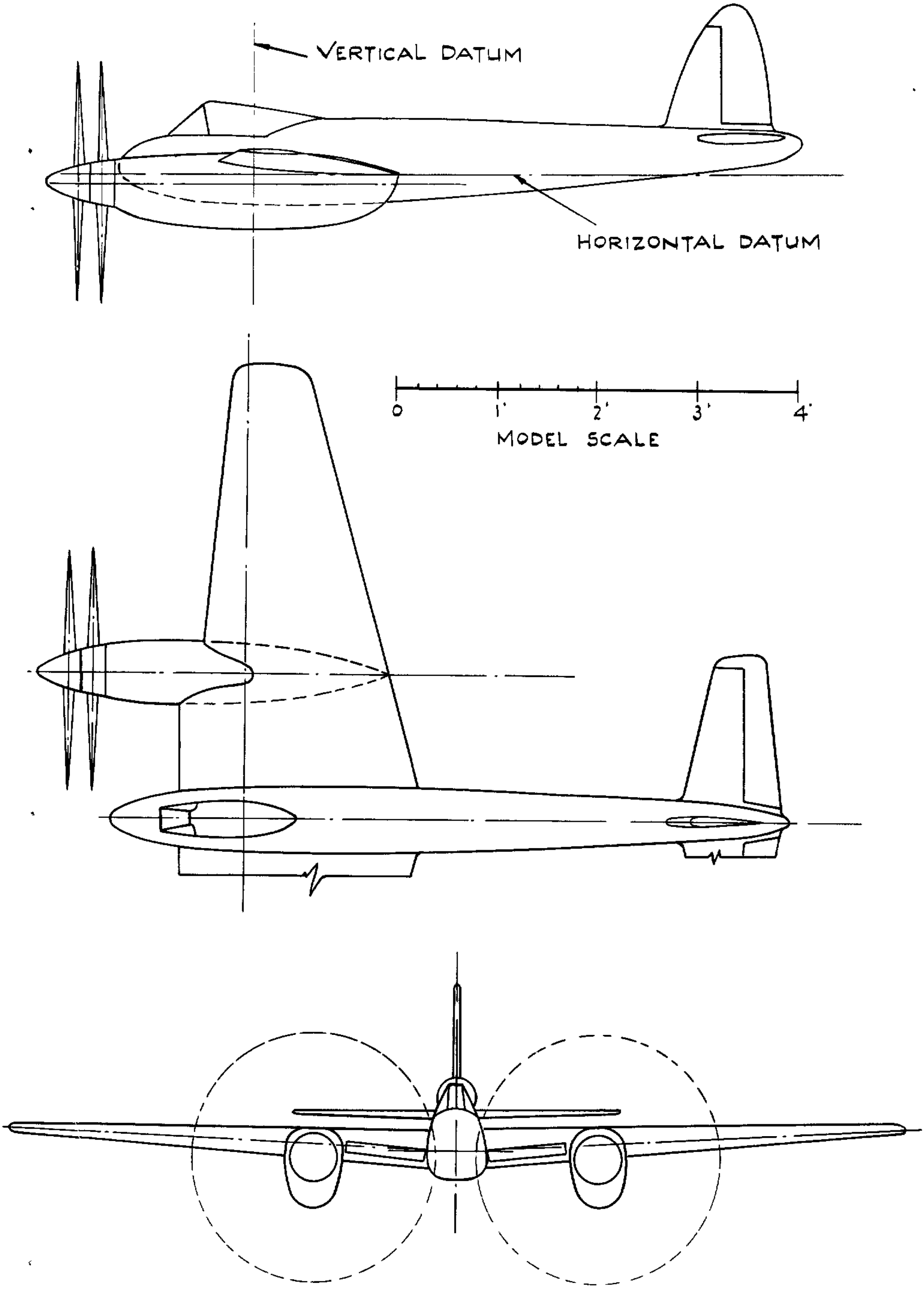

FIG. 3 G.A OF HORNET MODEL

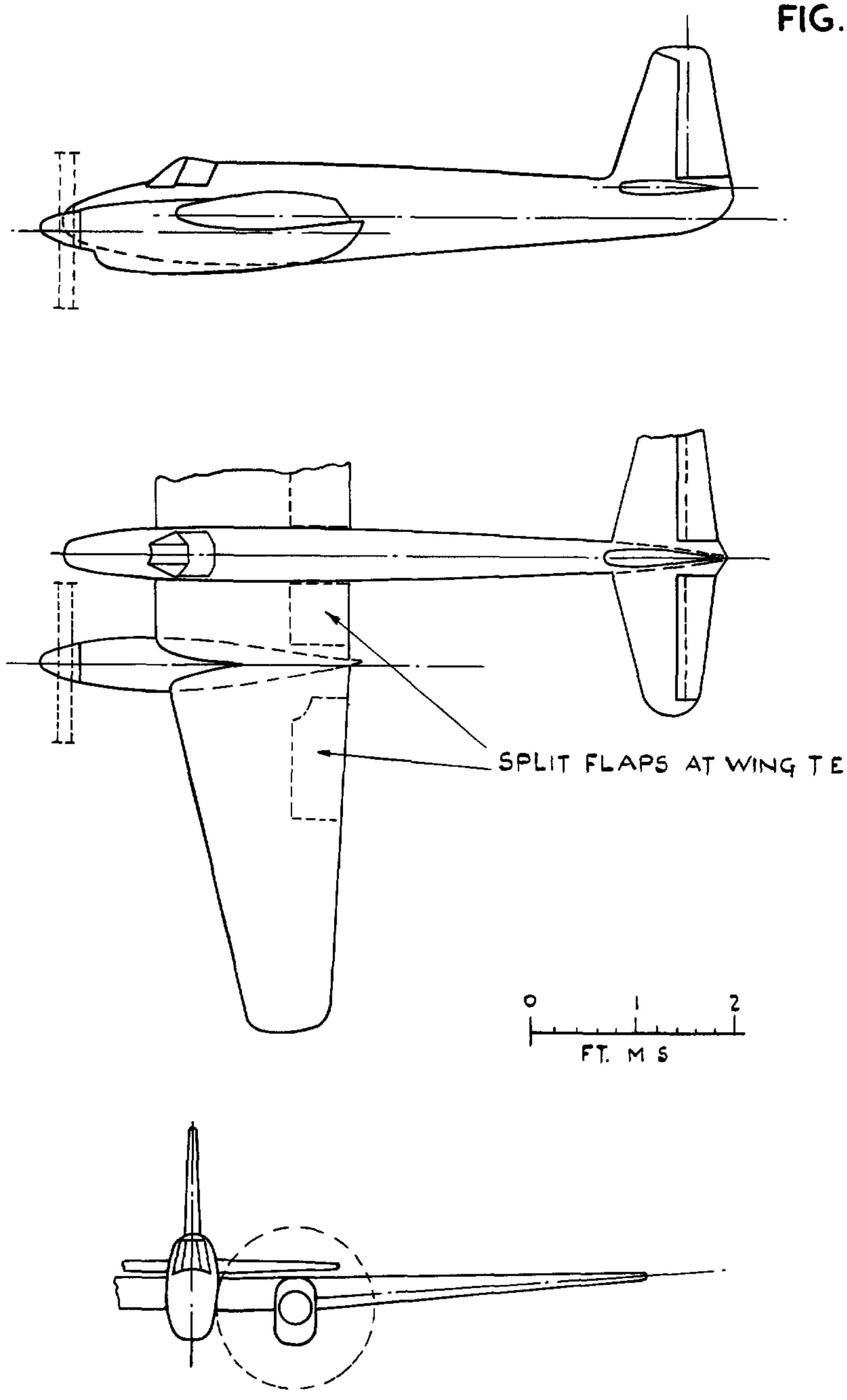

FIG. 4 G.A. OF STURGEON MODEL.

FIG. 5

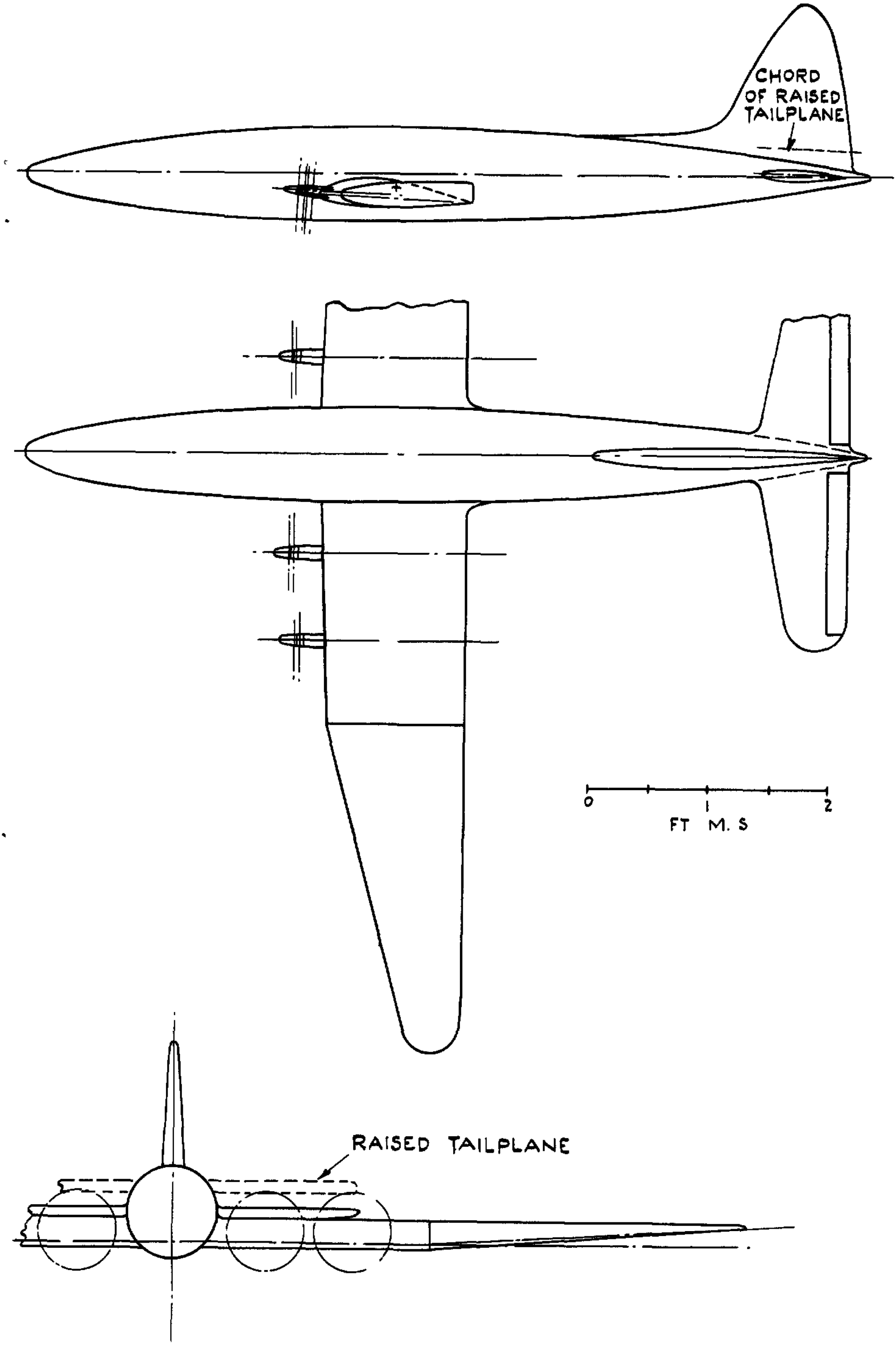

FIG. 5 G.A OF AEROPLANE B.

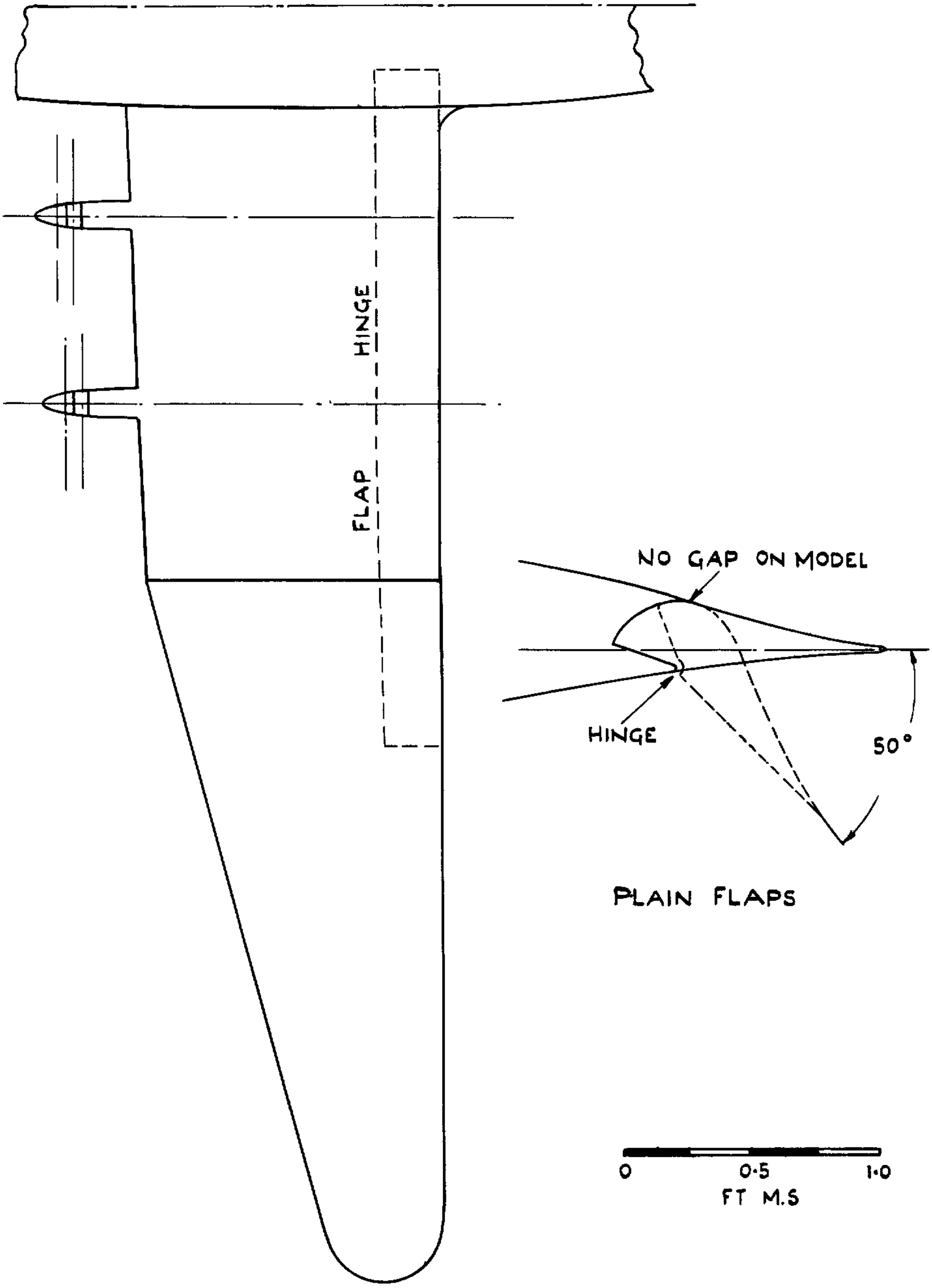

FIG. 6. DETAILS OF PLAIN FLAPS
AEROPLANE B.

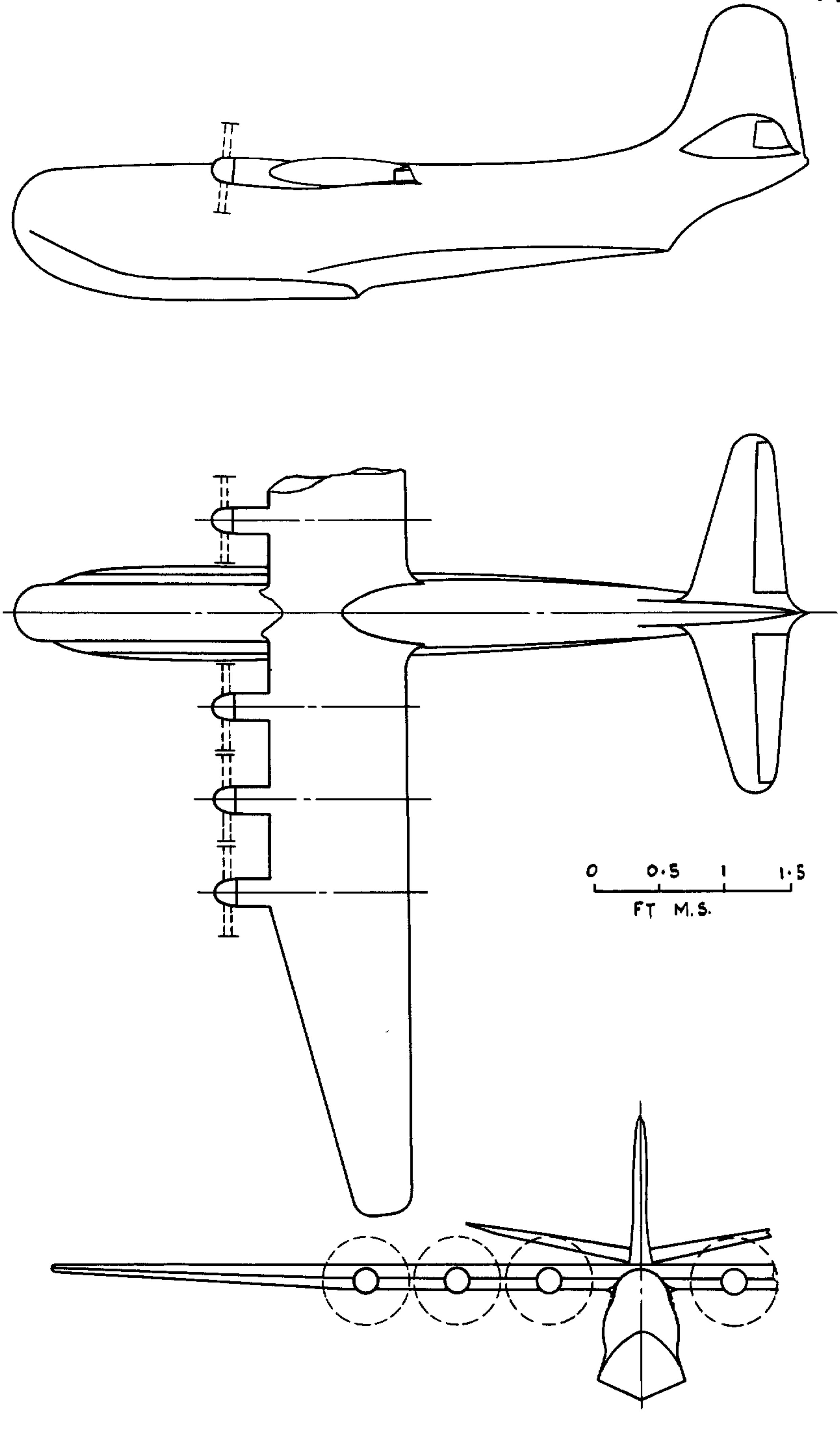

FIG. 7. G.A. OF S.R. 10/46 MODEL.

FIG. 8.

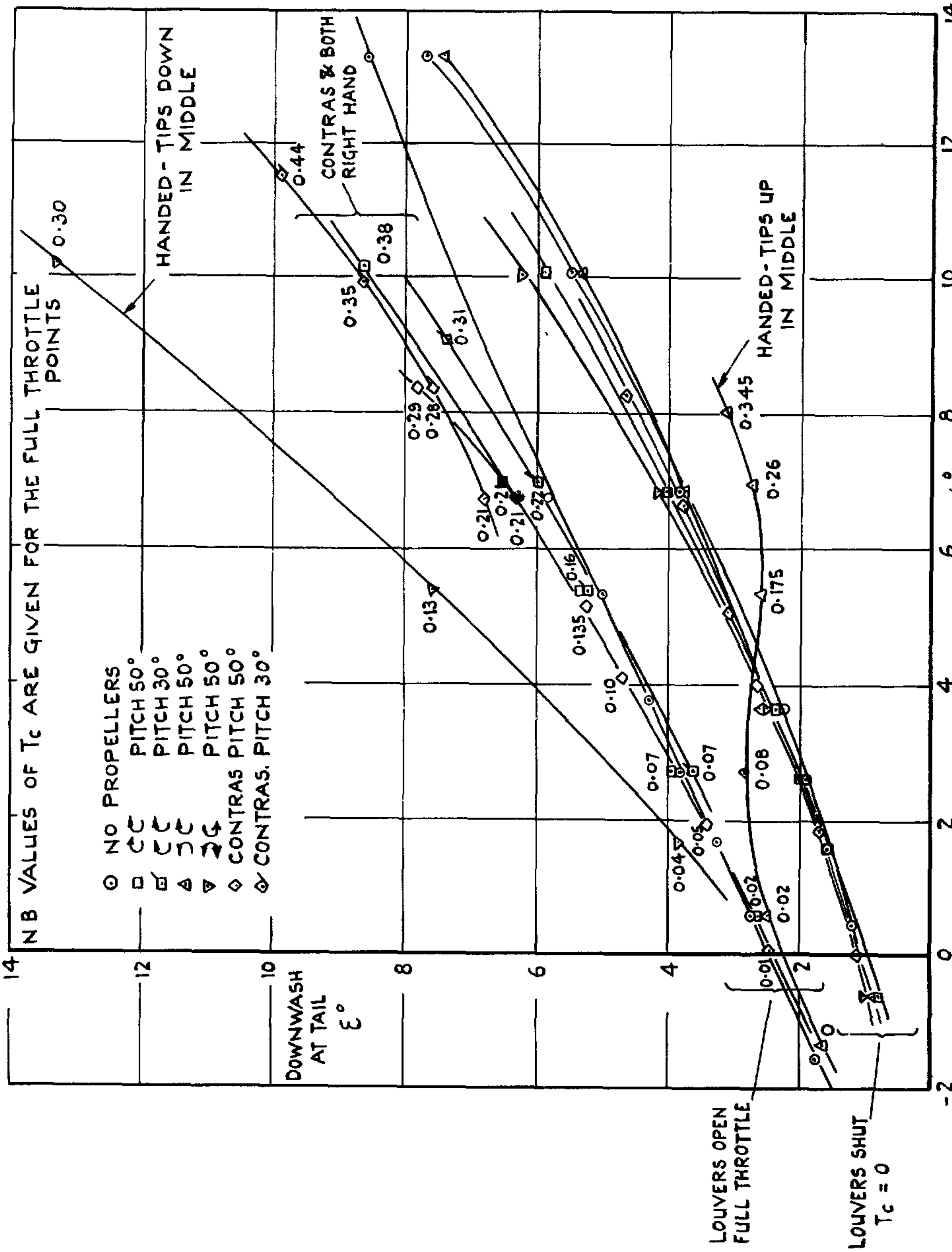

FIG. 8. EFFECT OF VARIOUS MODES OF PROPELLER ROTATION ON DOWNWASH AT TAIL FOR $T_c = 0$ AND FULL THROTTLE.

FLAPS 0°

HORNET.

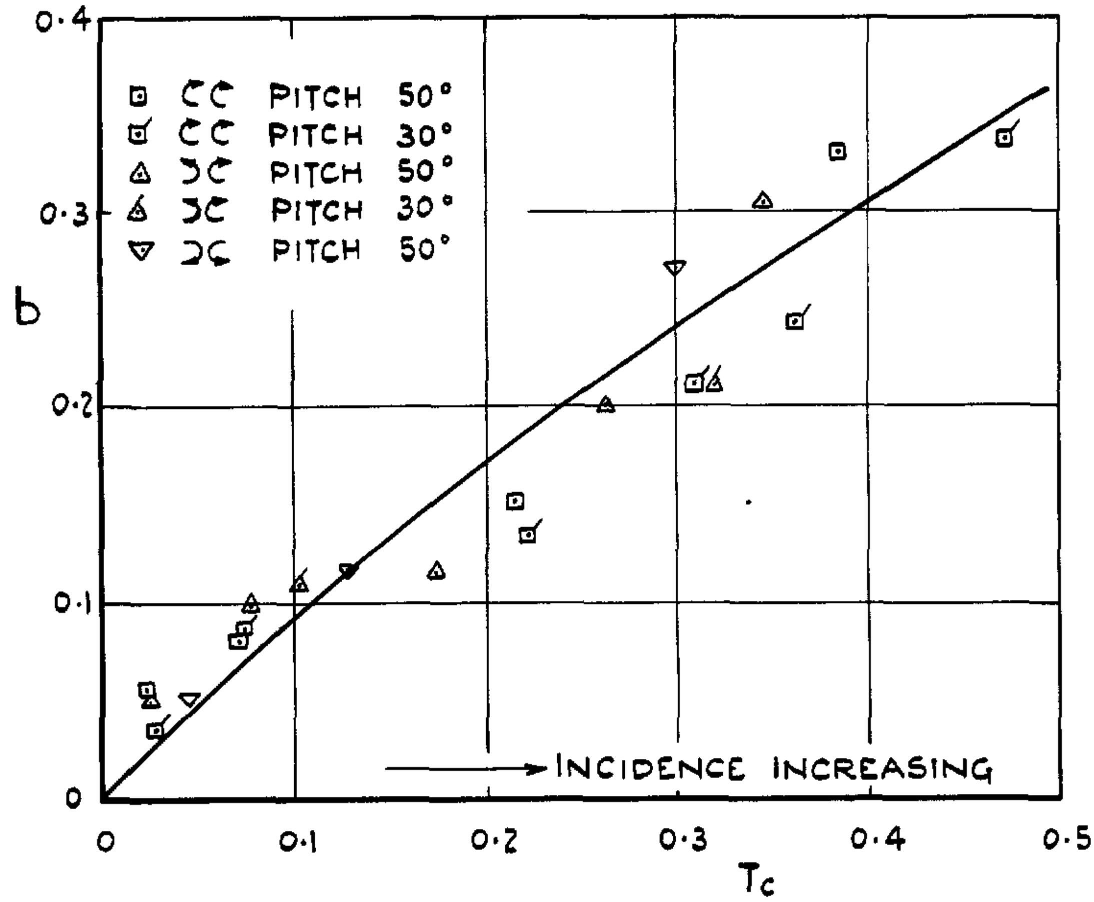

FIG. 9. EFFECT OF VARIOUS MODES OF PROPELLER ROTATION ON VELOCITY AT TAILPLANE.— FLAPS 0°.

HORNET.

FIG.10

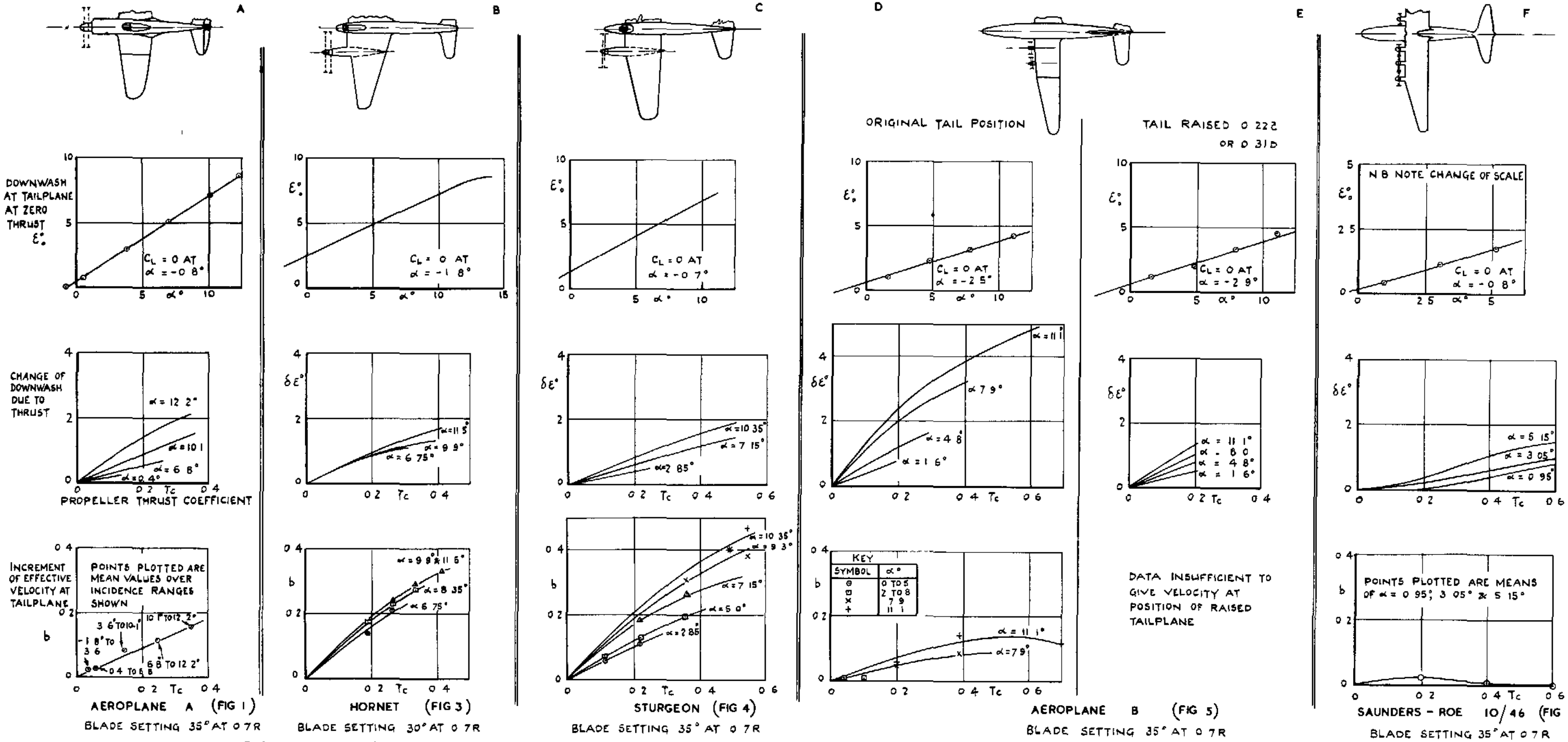

FIG 10 EFFECT OF PROPELLER THRUST ON DOWNWASH AND VELOCITY AT TAILPLANE — FLAPS UP (CONTRA-ROTATING PROPELLERS)

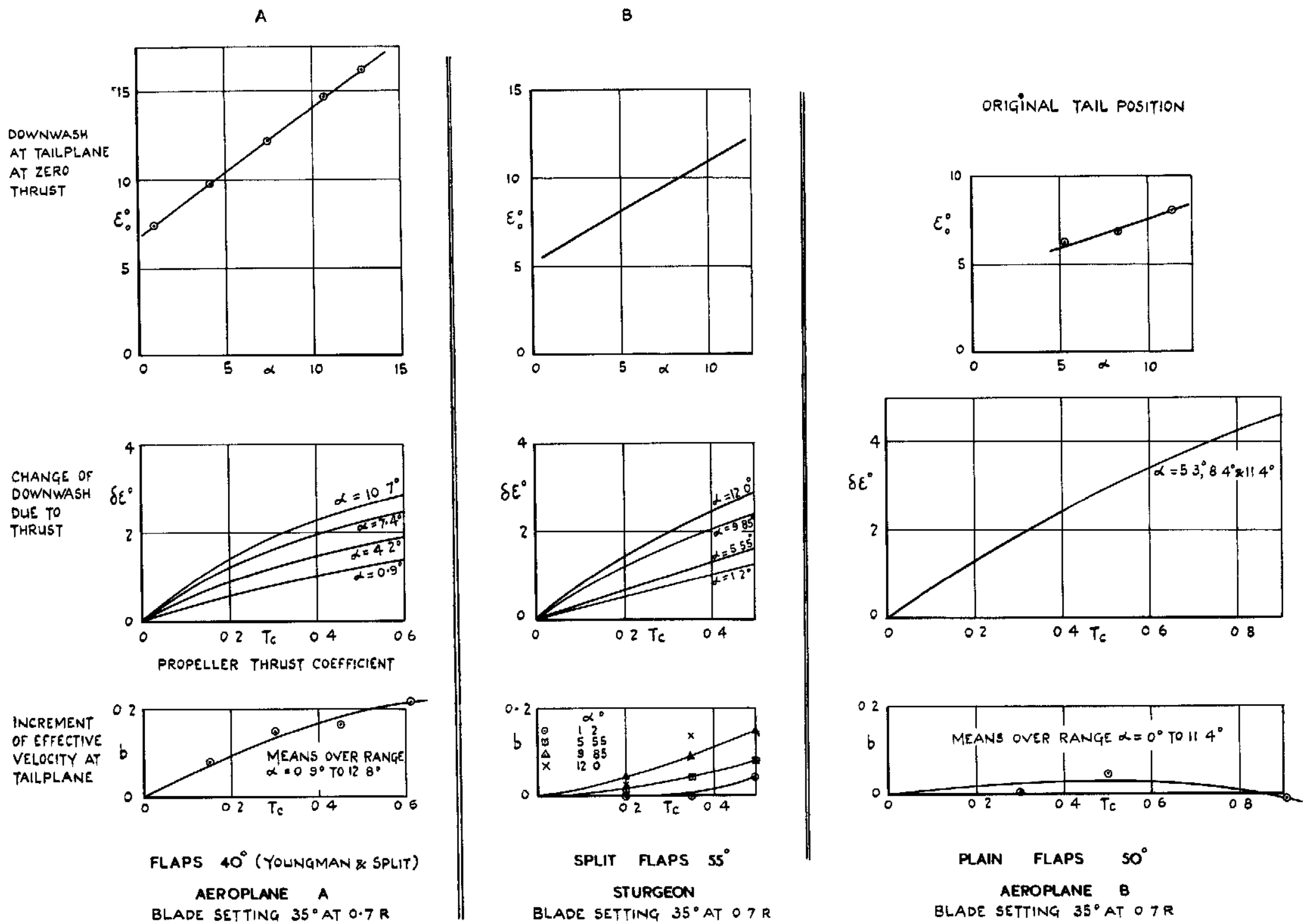

FIG.11. EFFECT OF PROPELLER THRUST ON DOWNWASH & VELOCITY AT TAILPLANE —— FLAPS DOWN. (CONTRA-ROTATING PROPELLERS)

FIG. 11

C.P. No. 21
10925
A.R.C. Technical Report

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased from:
York House, Kingsway, LONDON, W.C.2, 429 Oxford Street, LONDON, W 1,
P.O. Box 569, LONDON, S.E.1,
13a Castle Street, EDINBURGH, 2. | 1 St Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 | 1 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 | 80 Chichester Street, BELFAST,
or from any Bookseller

1950

Price 1s. 6d. net

S.O. Code No. 23 - 9006 - 21