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Free-Flight Model Drag Measurements on a Transonic Fighter (Gloster Javelin)

by

G. H. Greenwood

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FREE-FLIGHT MODEL DRAG MEASUREMENTS ON A TRANSONIC FIGHTER (GLOSTER JAVELIN)

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SUMMARY

Zero-lift drag measurements were made on a series of wings proposed for a development of the Javelin. A comparison is made between the performance of the Mk.I wing ($\frac{t}{c} = 0.10$), the proposed wing ($\frac{t}{c} = 0.07$) and two wings having varying thickness:chord ratios and high rates of spanwise thickness taper near the root.

Models of the complete aircraft were also tested to investigate the reductions in drag obtained by a limited application of the area rule.

Replaces R.A.E. Tech. Note No. Aero 2594 - A.R.C. 20,997.

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1 INTRODUCTION

The Javelin was designed originally as a fighter for high-subsonic speeds and a wing thickness:chord ratio of 0.10 was considered suitable for the required performance. During the development of the aircraft a proposal was made to improve the performance at high subsonic Mach numbers and possibly to extend the speed range to supersonic Mach numbers by reducing the wing thickness. The original suggestion was for a constant-section wing with a thickness:chord ratio of 0.07 but various experimental results obtained on similar wings at the Royal Aircraft Establishment had shown that additional improvements could be achieved by varying the wing section and that these varying-section wings, since they allowed the $0.10 \frac{t}{c}$ to be retained at the root, were structurally more efficient than those of constant section and constant thickness:chord ratios.

The initial free-flight model experiments were therefore designed to compare the zero-lift drag values of the various section distributions suggested; these initial models consisted of wings with simplified engine nacelles mounted on a parallel-sided basic body.

While these experiments were under way, the implications of the sonic and supersonic area rules were being examined. As a result of this examination a second series of free-flight drag experiments was undertaken on complete models of the aircraft having various modifications indicated by the area rule. All these complete aircraft models had a varying thickness: chord ratio wing designed by the methods of Ref.1 (wing 3 in the following description).

2 DESIGN PRINCIPLES

The principles behind the modifications used here to improve the performance of the wings at high subsonic speeds are described in detail in Ref.1. Briefly, the aim is to counteract the effective loss in sweepback which occurs at the root of a swept wing by employing root sections having their maximum thickness further forward than the outboard sections. Additionally, use is made of the beneficial effects of spanwise thickness taper on supervelocities to incorporate sections at the root having higher thickness:chord ratios than those elsewhere on the wing[2,3].

Thus, compared with the constant $\frac{t}{c}$, RAE.101 section wing, the 'optimum' wing (wing 4 below) has thicker inboard sections with their maximum thickness further forward and thinner outboard sections changing to RAE.104 at the tip. Thus the maximum thickness line is more highly swept than on the wing with constant sections.

The various modifications investigated in this programme are illustrated in Figs.3 and 4; they are summarised below and in Table 1.

Wing 1 : The Mk.1 Javelin wing, $\frac{t}{c} = 0.10$, RAE.101 section throughout.

Wing 2 : The original suggestion for reducing wing-drag, $\frac{t}{c} = 0.07$, RAE.101 section throughout. Note that this and subsequent wings differ in planform from wing 1.

Wing 3 : The wing proposed for the Javelin development. This is designed according to Haines' concepts but some compromise to the 'optimum' design has been accepted to meet certain stowage problems in the aircraft.

Wing 4 : The 'optimum' design. Compared with wing 3 this has a thinner root section of $\frac{t}{c} = 0.10$ in place of 0.11 and a higher spanwise thickness taper near the root.

Additional details of the wings are given in Fig.1 and Table 1.

The design concepts underlying the area rule have been described at length elsewhere (e.g. Ref.4). The design of the development Javelin (using wing 3) had been fixed before the gains in overall drag reduction that could be achieved by area rule were fully appreciated and the application of the area rule to the second series of drag models was severely restricted to modifications which were practicable without radical alterations to the aircraft structure.

As is often found on delta wings which constitute a large part of the cross-sectional area, the overall sonic area distribution of the Javelin is reasonably smooth and symmetrical (Fig.15). The principal departure from a smooth curve arises from the cockpit canopy and the intakes; hence the initial fuselage modifications were designed to smooth out the fore part of the area distribution.

The resulting designs of the complete aircraft models are illustrated in Figs.10 to 13 and are summarised below and in Table.1.

Model A : The Javelin development (wing 3) having in place of a tailplane a body of revolution with the same sonic area distribution.

Model B : Model A with the addition of a fairing under the forebody and with the intakes swept back 40°. These modifications gave an improved sonic area distribution.

Model C : Area rule applied in the form of a fairing under the forebody and a slightly raised and 'idealised' cockpit canopy with the intakes swept back 65°. The aim of this design was to provide an improved supersonic ($M \simeq 1.3$) area distribution.

Model D : As for model B but with the addition of side fairings on the rear fuselage to improve the aft sonic area distribution.

3 EXPERIMENTAL TECHNIQUE AND DESCRIPTION OF THE MODELS

The general field technique was the standard one for free-flight model tests[6]. The models were launched from the ground and tracked throughout their flight by kinetheodolite cameras. Only the coasting part of the flight was used in the drag analysis.

3.1 First series models (wing-drag models)

In the construction of these models the rocket-motor provided a rigid member to which the wings were clamped and hence formed an integral part of the model structure. A smooth exterior was obtained by enclosing the motor within a cylindrical resin-bonded paper tube to which a perspex nose was added (Figs.1 and 2).

The flow over the wing roots was maintained as representative of the complete aircraft as possible by the fitting of wooden fairings geometrically similar to the aircraft fuselage and engine nacelles. Owing to the presence of the built-in rocket-motor it was not possible to permit air to flow through the engine intakes and so these were rounded-off by ellipsoidal fairings.

The scale of these wings was 1/10th full-size.

Longitudinal acceleration was telemetred from equipment contained within the perspex nose and an additional measurement of acceleration was made by means of radio reflection Doppler.

3.2 Second series models (complete aircraft)

These models were 1/15th scale aircraft with the various modifications already described. The intakes of the models permitted an entry flow comparable to that of the full-scale aircraft cruise condition. The entry area was directly scaled from the full-scale aircraft and the exit area was chosen to give an entry Mach number of approximately 0.80 for choked exit conditions, i.e. at flight speeds between $M = 1.0$ and 1.3. No duct-flow measurements were made because of space limitations; the duct internal drag was assumed to be the same for all models.

Telemetry equipment measuring longitudinal acceleration was housed in the forebody of the models.

The models were launched mounted pick-a-back fashion (Fig.14) on two 5" diameter rocket-motors from which the models separated when the rocket-motors ceased to burn.

The radio reflection Doppler method of measuring acceleration could not be used on these models because of the mixed echoes returning from the rocket-motors and the separated models.

4 RESULTS AND DISCUSSION

4.1 First series models (wing-drag models)

The results from these tests are presented in Fig.8; a further presentation on the basis of transonic similarity as suggested in Ref.5 is made in Fig.9.

The modifications proposed in Ref.1 to improve the high subsonic wing performance of the Javelin are presented therein as schemes I to V. Scheme I refers to the constant $\frac{t}{c} = 0.07$ wing which is wing 2 of the present tests. Schemes II and III refer to varying thickness:chord ratio wings which have been closely represented in wings 4 and 3 respectively in the present tests. Schemes IV and V were abandoned.

The differences between the wings proposed in schemes II and III and the actual wings tested are illustrated in Fig.5. These differences are in detail only and the design concepts are therefore thought to be valid.

It should be noted, however, that

(a) The design calculations of Ref.1 refer to conditions of $C_L = 0.2$, whereas the test C_L was zero, and

(b) Although body effects are considered in Ref.1, the assumed flow over the wing roots may well have been modified by the presence of the faired intakes on the models.

Thus the present tests cannot give a final assessment of the relative efficacy of the modifications.

In Ref.1 the performance predictions for schemes I, III and II are:- (C_L = 0.2)

Scheme	M_D	
I	0.93	(wing 2 of the present tests)
III	0.95 - 0.96	(wing 3 of the present tests)
II	0.965 - 0.97	(wing 4 of the present tests)

where M_D is defined as the free-stream Mach number at which C_D is 0.005 above the low speed value.

The test results (Fig.8) show that the drag-rise characteristics of these wings are qualitatively in agreement with the suggested trends but that there is not such a marked difference between the constant $\frac{t}{c}$ wing (M_D = 0.095+) and the others (M_D = 0.96) as Haines calculated. In this connection it should be remembered that the calculations were for C_L = 0.2 and for the wing alone, whereas the experimental drag values are for C_L = 0 and the complete test vehicle.

The marked decrease in drag at all Mach numbers of wings 2, 3 and 4 over the Mk.I Javelin ($\frac{t}{c}$ = 0.10) wing is clearly demonstrated.

Correlation by the transonic similarity rule is illustrated in Fig.9. The collapse of the results is sufficiently good to indicate that the refinements in design suggested in Ref.1 are having only a minor influence on the drag characteristics at transonic and supersonic speeds and that for all practical purposes the mean thickness* (other things being equal) is an adequate guide to the transonic performance of the particular configurations tested.

An attempt was made to correlate the measured reductions in drag-rise with calculated reductions using the sonic area rule. It was thought that drag reductions similar to those measured might have been achieved by applying the area rule to the wing-alone design, thus allowing a possibly greater freedom in volume disposition that that allowed by the more detailed

---

* Values of mean thickness:chord ratio were obtained using the relationship of Ref.3:-

$$\frac{\bar{t}}{c} = \left\{ \frac{1}{S} \int_0^s \left(\frac{t}{c}\right)^{5/3} . \, c \, . \, dy \right\}^{3/5}$$

where $\frac{\bar{t}}{c}$ = effective mean thickness:chord ratio

$\frac{t}{c}$ = local thickness:chord ratio

c = local chord at distance y from the wing centre-line

s = wing semispan

S = area of the half wing

subsonic theory, but confirmation of this point was made very difficult by the small differences in area distribution between the various wing-drag models.

For completeness, area distributions ($M = 1.0$) are shown in Figs.6 and 7.

4.2 Second series models (complete aircraft)

The results from these tests are presented in Fig.16. Sonic area distributions for all these models are presented in Fig.15.

The sonic area distribution of the unmodified development Javelin (model A, Fig.15) is clearly reasonable and the gains at sonic speed from a redistribution of area within the limited practicable scope were not expected to be great. This is confirmed by the measured transonic drag-rise (Fig.16), which indicates that the redistribution of area has had little or no effect on sonic drag although some improvement at $M \simeq 1.2$ is apparent, i.e. about 17% in wave drag*.

The higher subsonic drag levels of models A and D (Fig.16) may well be due in part to the unswept intakes of model A and the larger effective base area of model D because of the rear fuselage fairings. It is clear that the performance of model D has been affected adversely by the application of additional cross-sectional area without regard to its effect on non-wave drag. Model B is the same configuration as model D but without the rear fairings; a comparison of the drag rise of these two models (Fig.16) indicates that were it not for the large viscous effects of the rear fairings which undoubtedly are present at all Mach numbers, the performance of model D would have been considerably improved.

5 CONCLUSIONS

5.1 Wing design

In an attempt to ease the stowage and structural problems associated with reducing the thickness:chord ratio of the Javelin wing, various wing designs having a common planform and differing spanwise thickness:chord ratio distributions were suggested. The zero-lift drag measurements of the present investigation indicate that:-

(a) Compared with the wing of constant thickness:chord ratio a wing having better stowage and structural characteristics can be achieved without transonic drag penalty if its mean $\frac{t}{c}$ ratio is the same as that of the wing with constant $\frac{t}{c}$.

(b) However, rather less benefit in drag rise Mach number was obtained from the section modifications than detailed estimates had suggested. This may be due in part to the difference in lift coefficient between measurement ($C_L = 0$) and design ($C_L = 0.2$).

5.2 Area-rule modifications

Minor modifications to the aircraft fuselage to try and improve the area distribution of the complete aircraft produced little effect at sonic speed but did reduce the wave drag at $M = 1.2$ by about 17%.

---

* But note that although the improvements are small the 'area-rule' model has achieved its performance with an appreciable increase in the volume of the fuselage forebody.

LIST OF SYMBOLS

A = Aspect ratio

C = local wing chord

C_{D_0} = total drag coefficient at zero lift

C_L = lift coefficient

ℓ = relevant length (Figs.6 and 7)

M = free-stream Mach number

M_D = Mach number at which drag coefficient is 0.005 above low speed value

R_E = Reynolds number

S = cross-sectional area

S.M.C. = standard mean chord

$\frac{t}{c}$ = maximum thickness:chord ratio

$\frac{\bar{t}}{c}$ = effective mean maximum thickness:chord ratio

x = relevant distance (Figs.6 and 7)

γ = ratio of specific heats (1.4)

ΔC_{D_0} = drag-rise coefficient = C_{D_0} (total) - C_{D_0} (low speed)

η = fraction of wing semispan

Λ_{LE} = sweepback of wing leading edge

$\Lambda_{\frac{c}{4}}$ = sweepback of wing quarter-chord line

λ = taper ratio, ratio of tip chord to root chord.

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2	Newby, K.W.	The effects of taper on the supervelocities on three-dimensional wings at zero incidence. A.R.C. R & M 3032. June, 1955.
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5	Spreiter, J.R.	On the application of transonic similarity rules to wings of finite span. N.A.C.A. Report No.1153. 1953.
6	Hamilton, J.A., Hufton, P.A.	Free flight techniques for high speed aerodynamic research. Royal Aeronautical Society Journal. March, 1956.

TABLE 1

Summary of models

Wing-drag models

Model	Description	λ	$\frac{t}{c}$	Λ_{LE}	Section	A (Gross)
1	Mk.I Javelin wing	0.10	0.10	47.6°	RAE.101	2.98
2	Original suggestion for reducing wing drag	0.196	0.07	48.0°	RAE.101	2.95
3	Proposed Javelin development	0.196	0.11 0.065 0.050	48.0°	Section II (Ref.1) RAE.102 RAE.104	2.95
4	'Optimum' wing of Ref.1	0.196	0.10 0.07 0.065 0.050	48.0°	Section II (Ref.1) RAE.100 RAE.101 RAE.104	2.95

Complete aircraft models

Model	Description
A	Javelin development aircraft using wing 3. Tailplane replaced by a body of revolution of equal sonic area distribution. No area rule.
B	As model A but with improved sonic area distribution forward of main spar datum. Intakes swept 40°.
C	Aircraft with area distribution designed for improved performance at $M \simeq 1.3$. Intakes swept 65°.
D	As model B but with side fairings on rear fuselage to further improve sonic area distribution.

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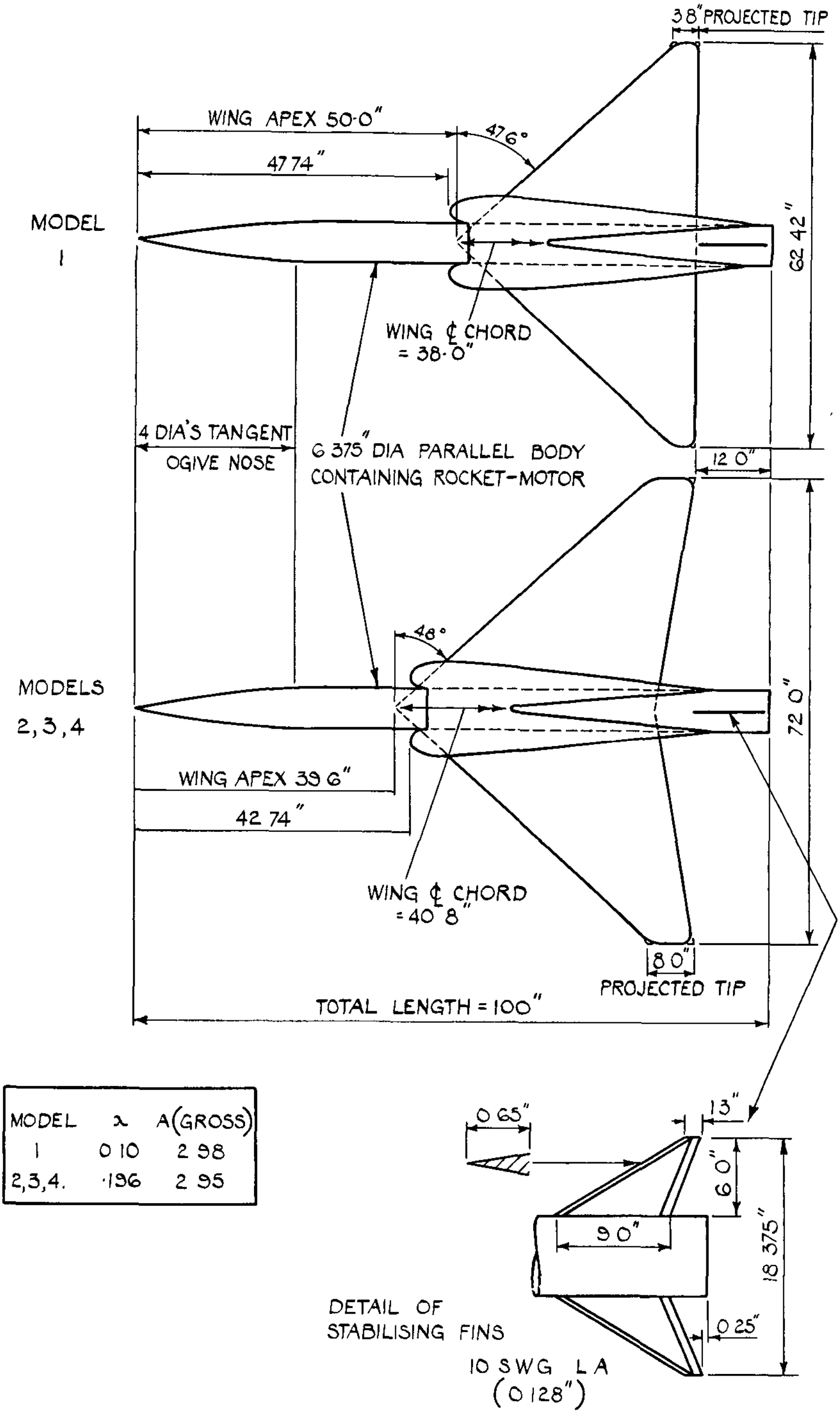
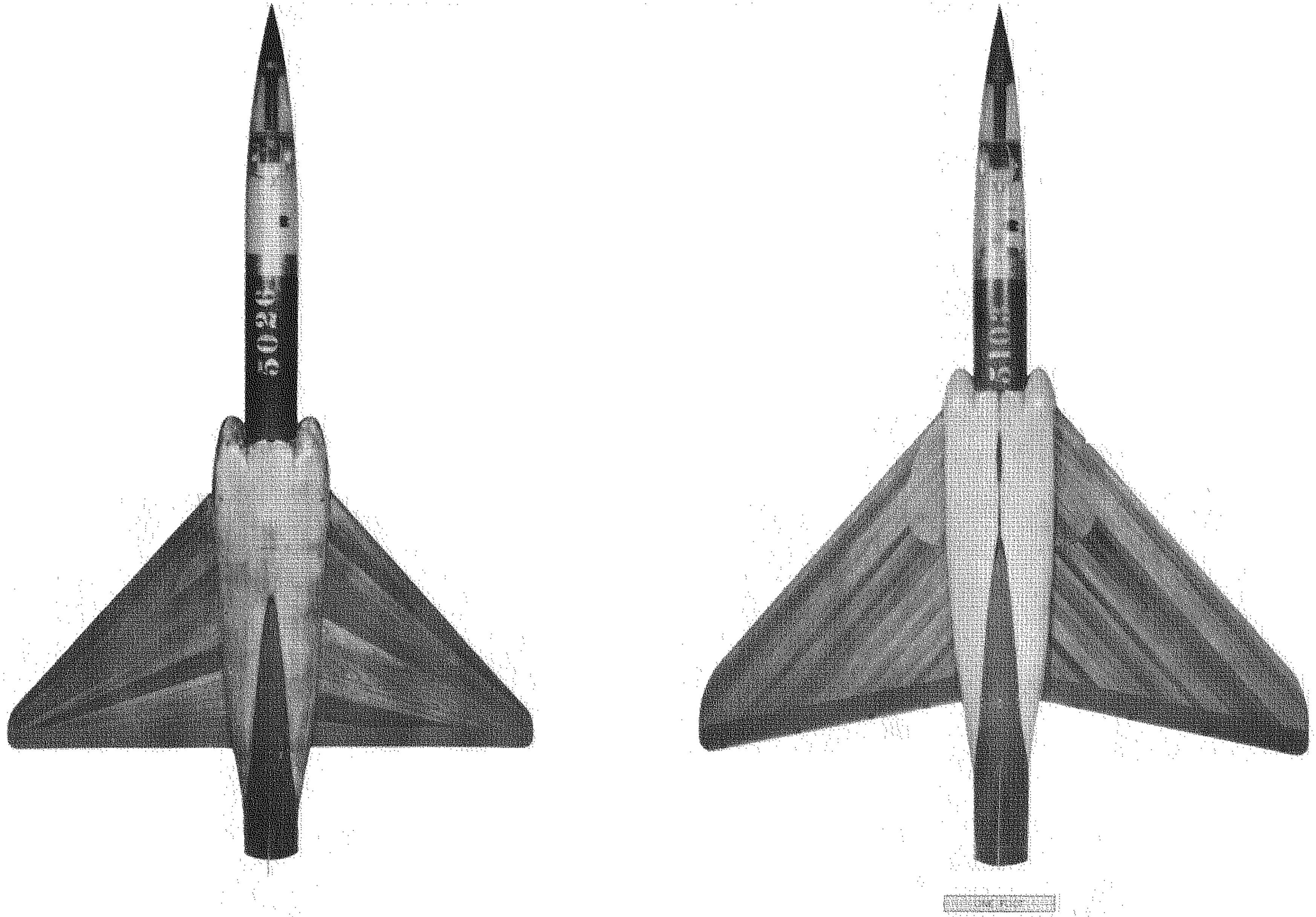


MODEL	λ	A(GROSS)
1	0 10	2 98
2,3,4.	·196	2 95

FIG.1. G.A. OF WING-DRAG MODELS



MODEL 1

MODELS 2,3 & 4

FIG.2. WING-DRAG MODELS

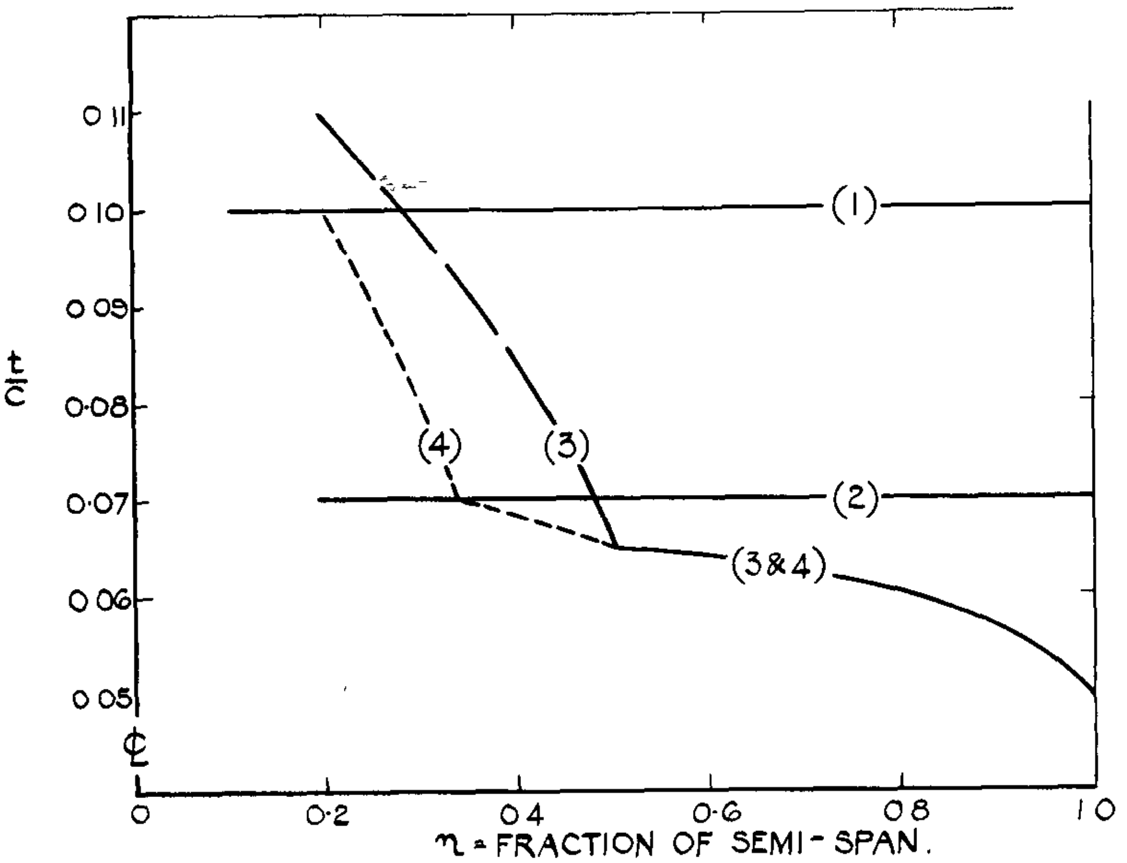


FIG.3. SPANWISE DISTRIBUTION OF $\frac{t}{c}$, WING-DRAG MODELS.

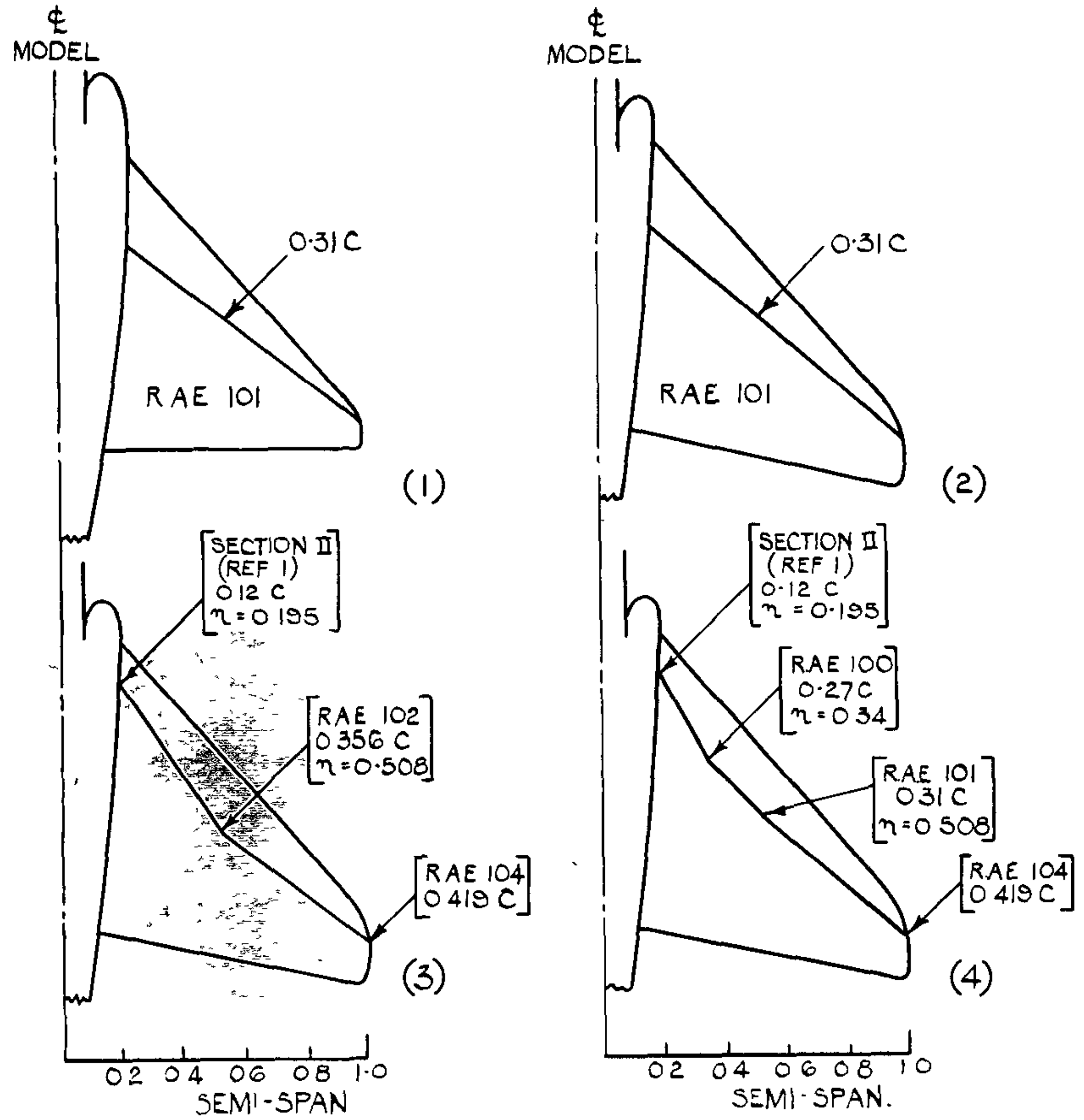
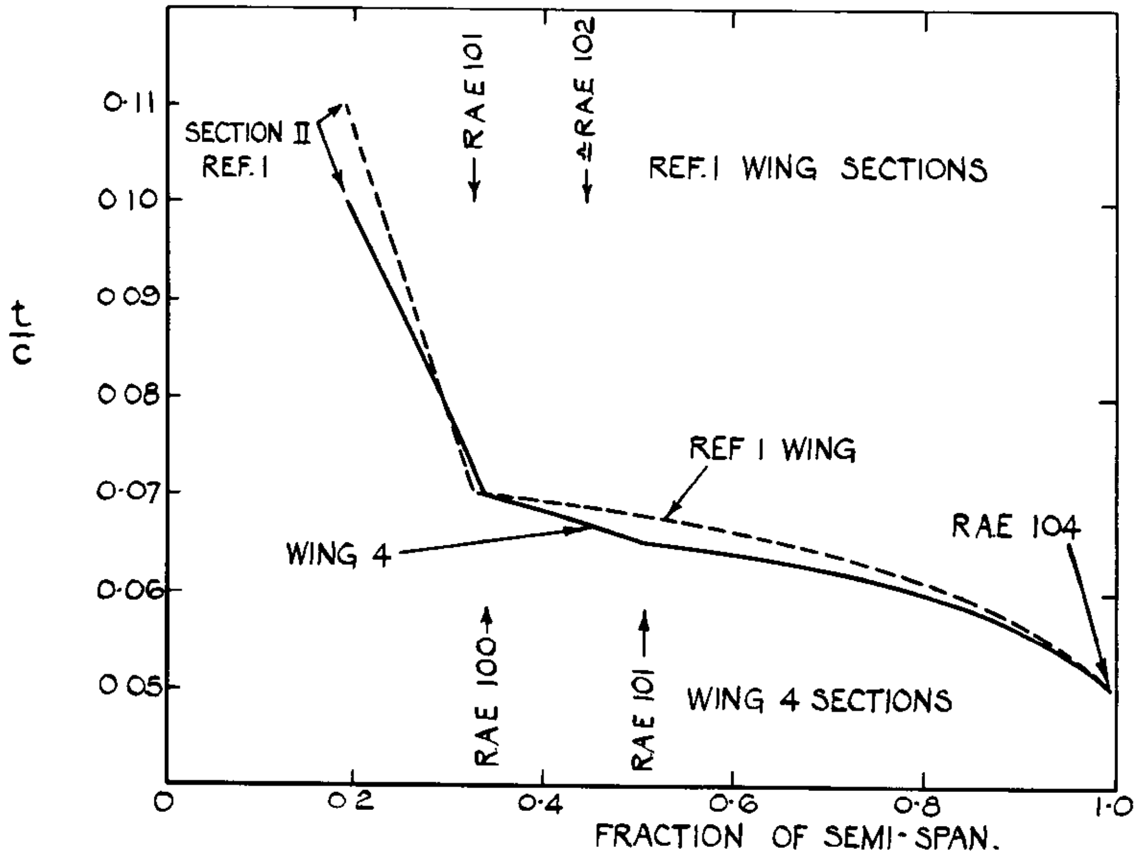
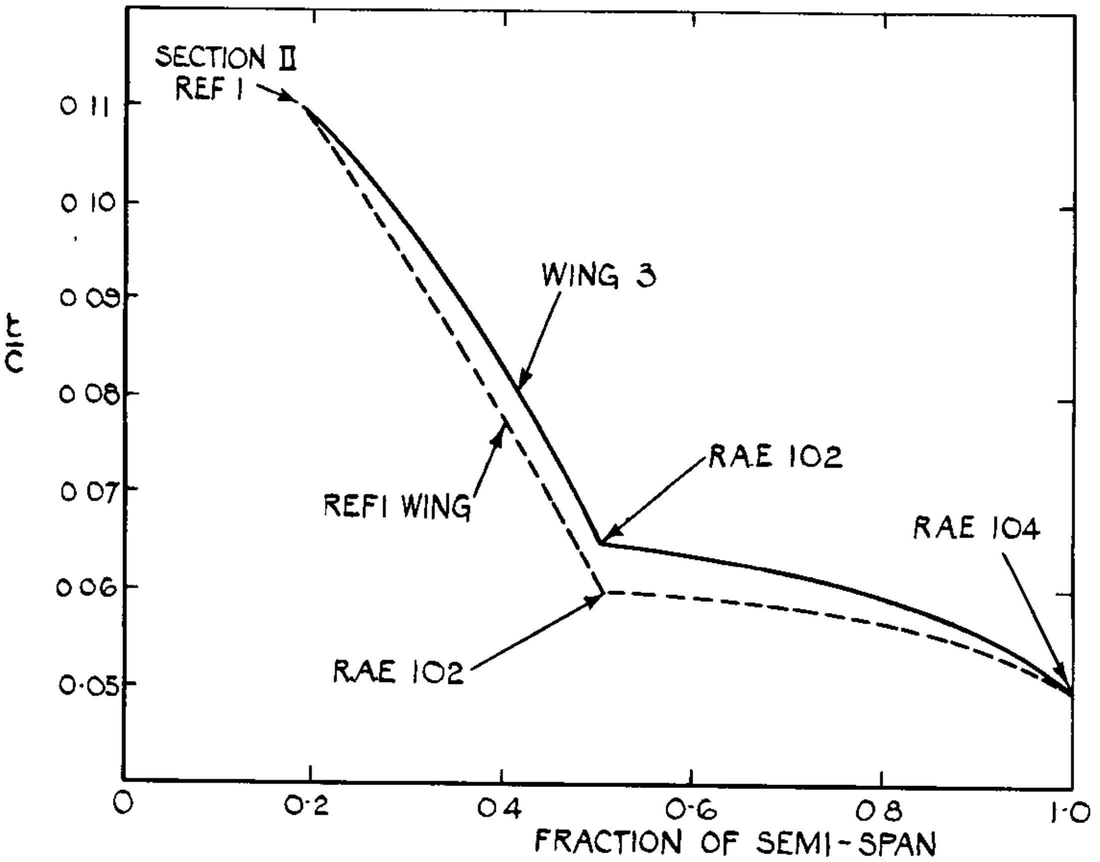


FIG.4. LINES OF MAXIMUM THICKNESS, WING-DRAG MODELS.



(a) COMPARISON BETWEEN WING 4 AND SCHEME II OF REF. 1.



(b) COMPARISON BETWEEN WING 3 AND SCHEME III OF REF. 1.

FIG. 5. (a & b) COMPARISON OF PROPOSED WINGS (REF. 1) AND TEST WINGS.

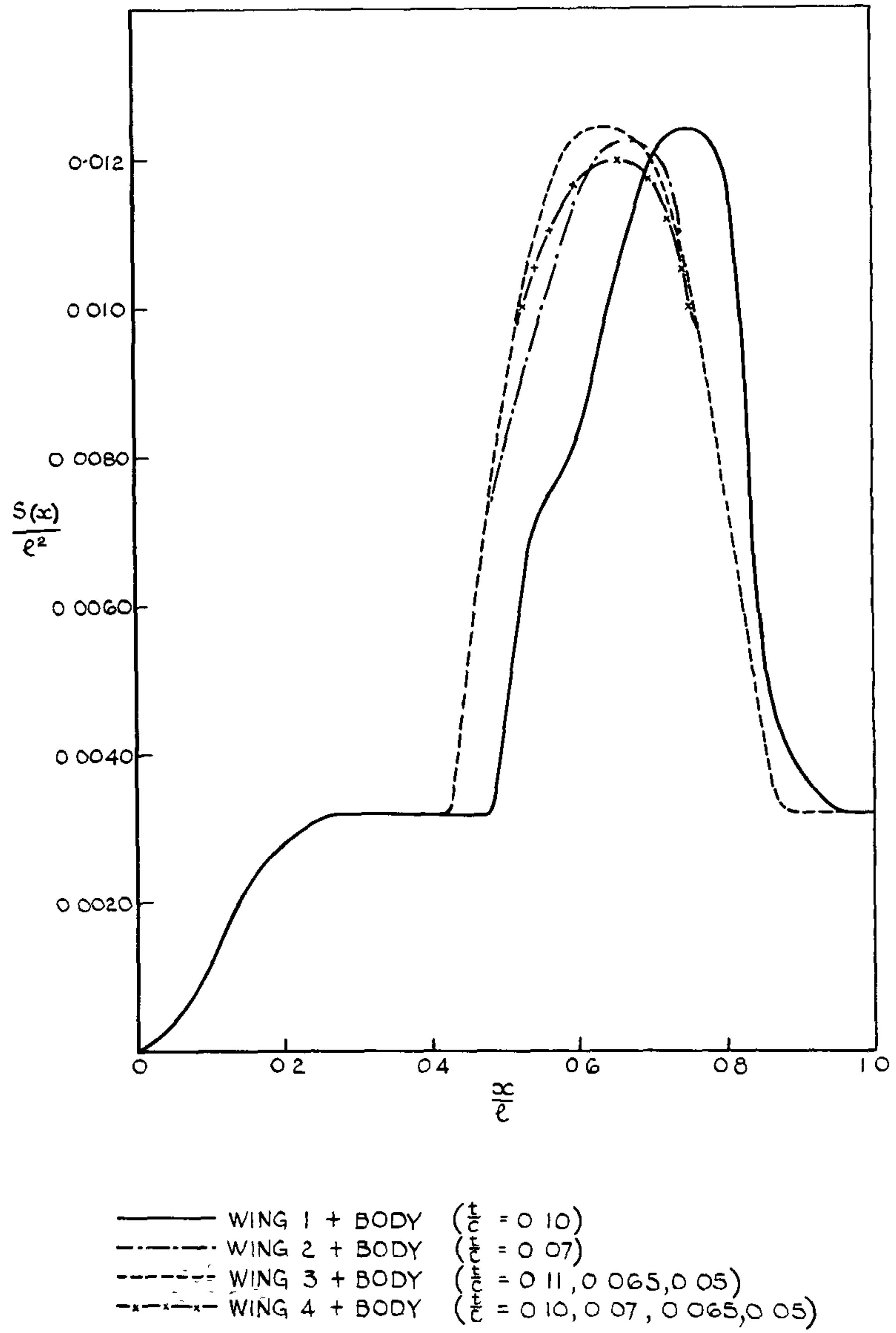


FIG.6. AREA DISTRIBUTIONS OF WING-DRAG MODELS: WING + BODY. (M=1·0).

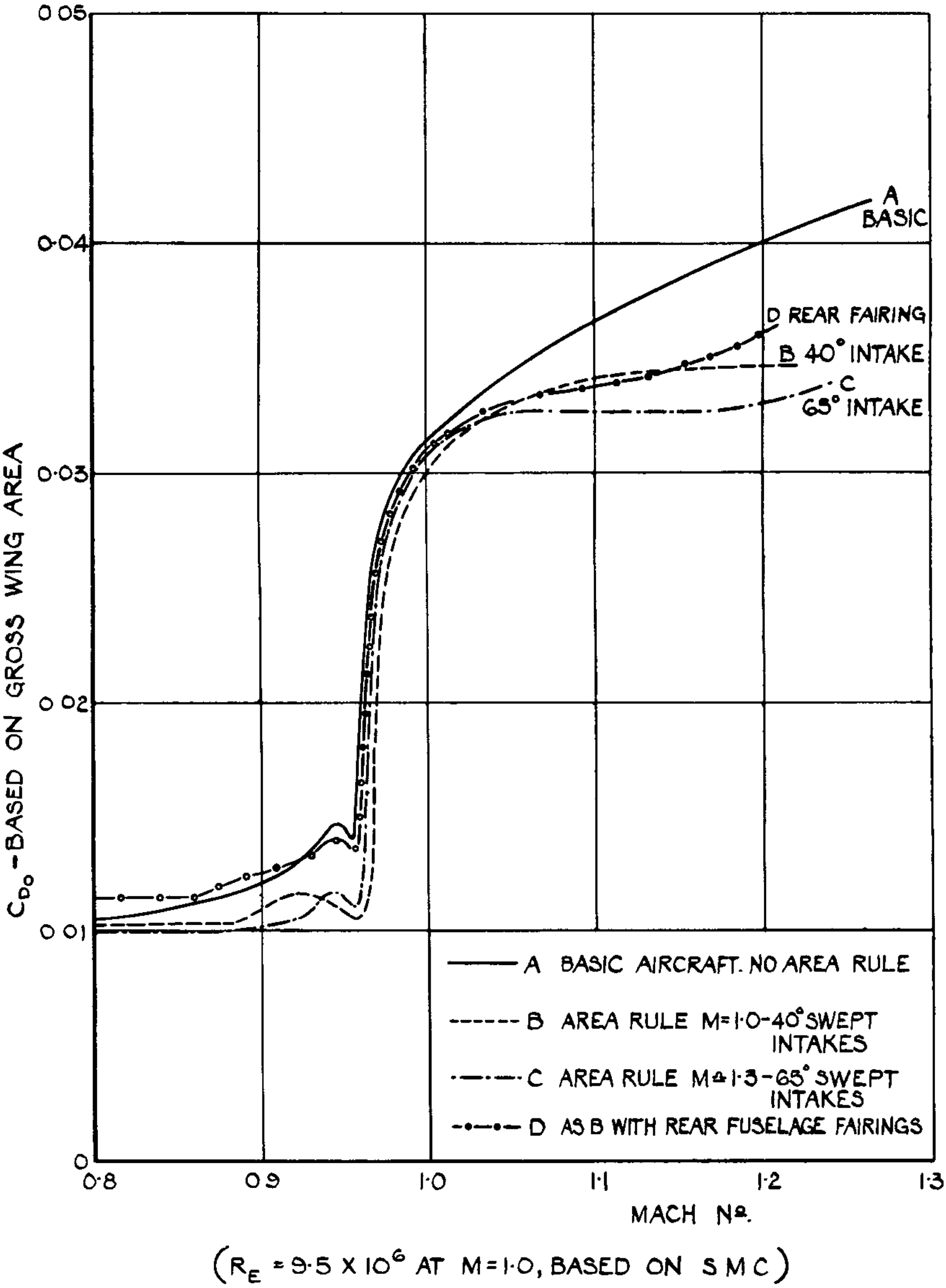


FIG.16. ZERO-LIFT DRAG OF COMPLETE MODELS

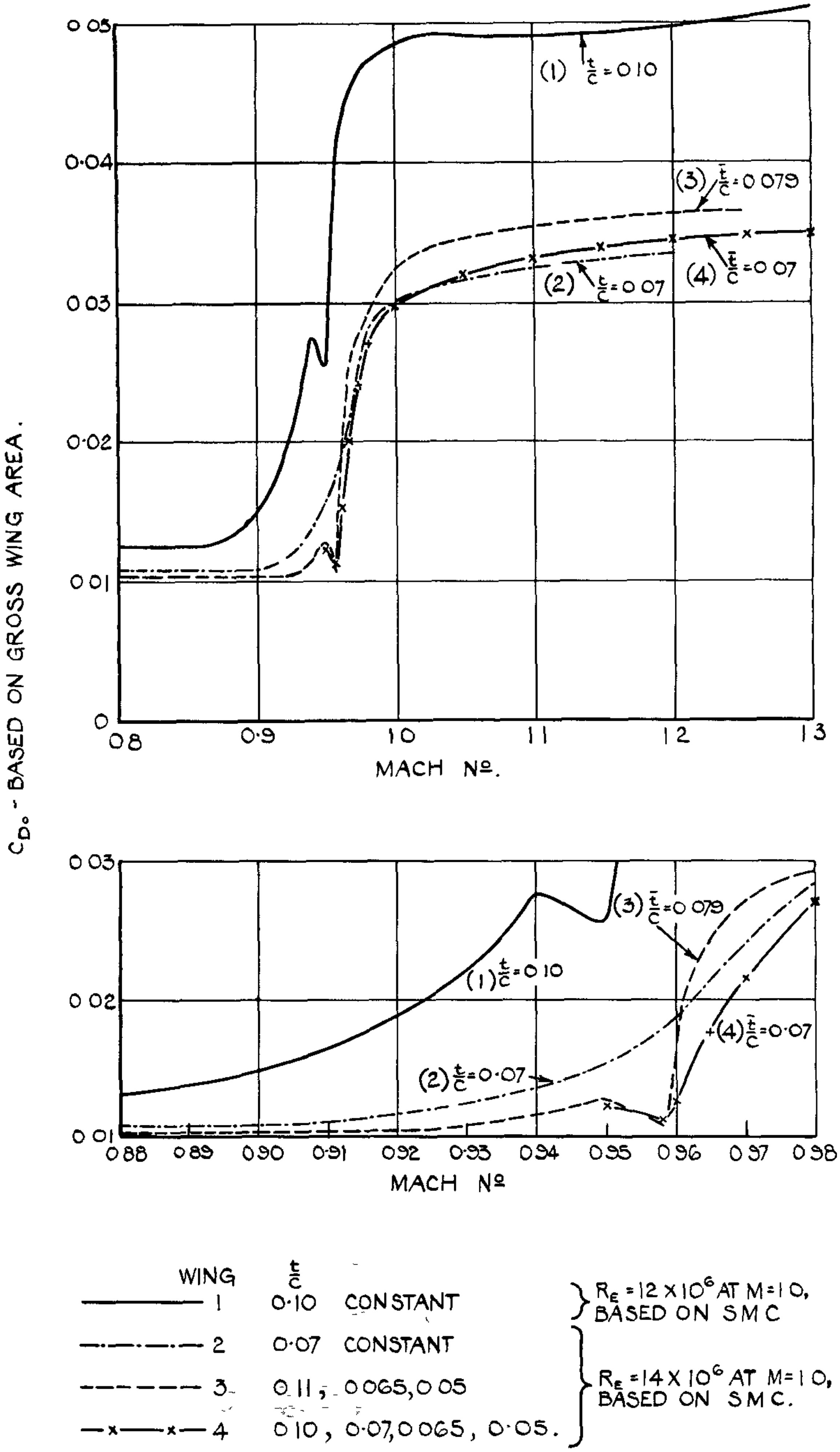


FIG. 8. ZERO-LIFT DRAG — WING-DRAG MODELS.

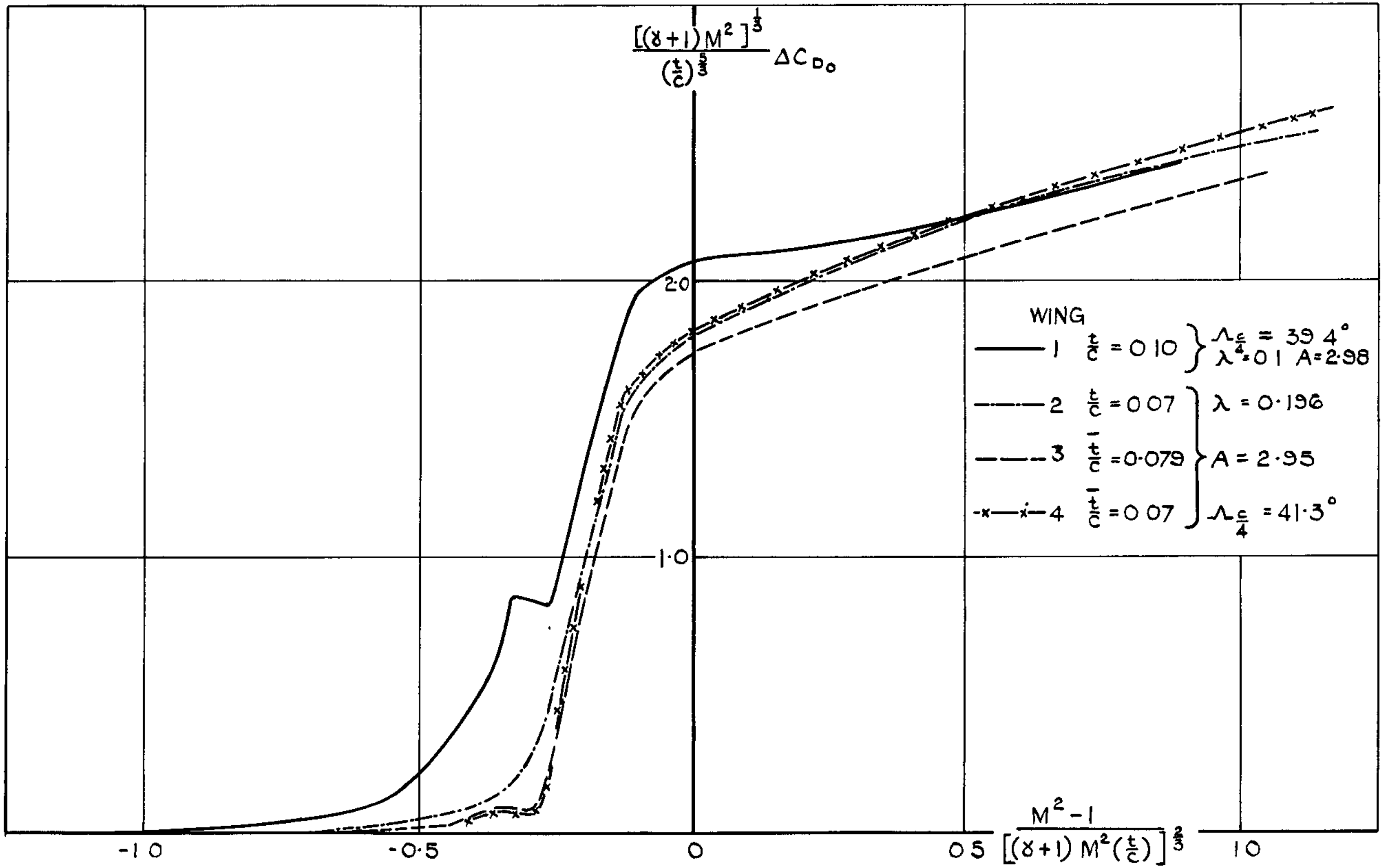
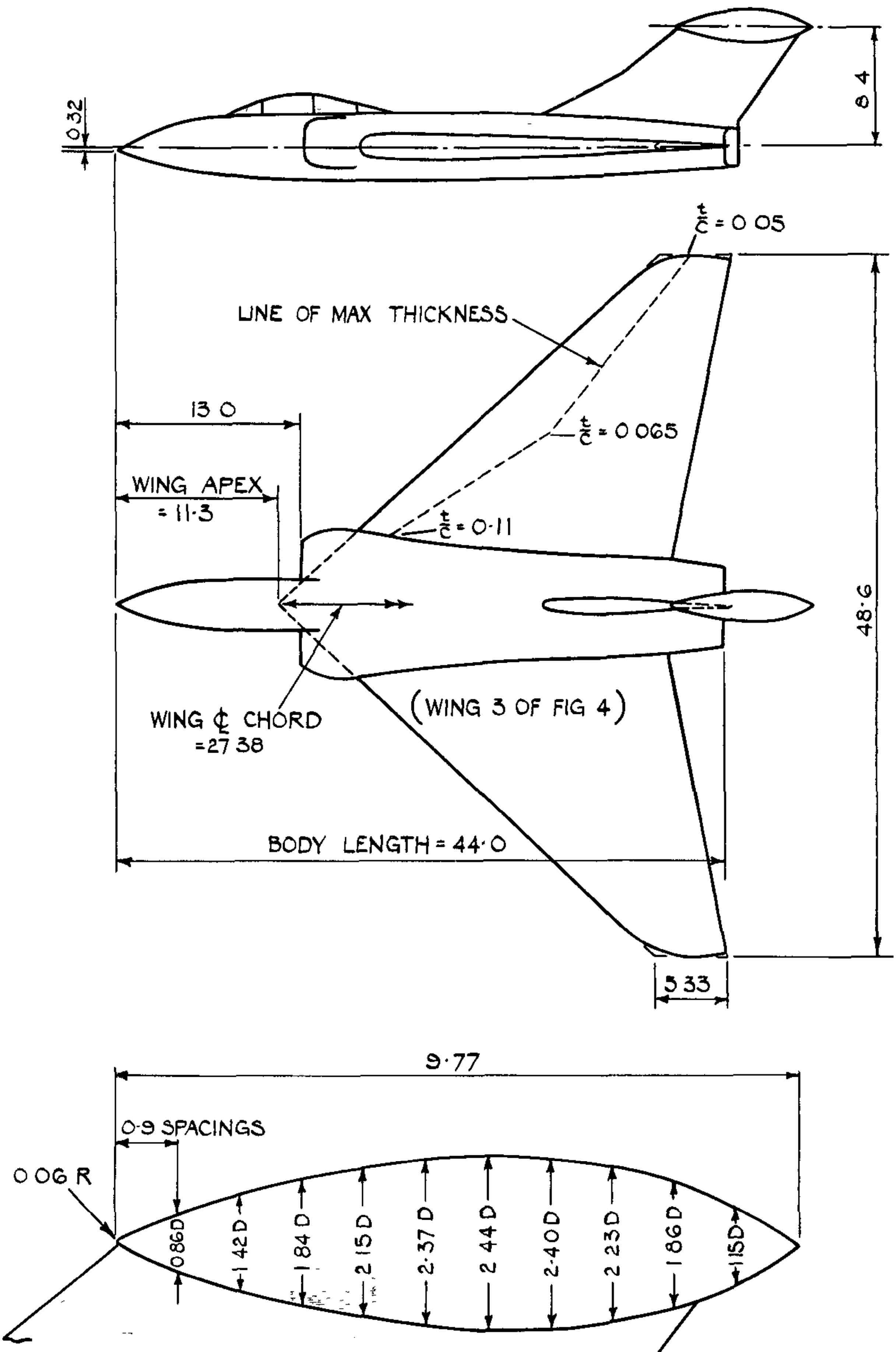


FIG.9. CORRELATION OF WING-DRAG MODEL RESULTS (TRANSONIC SIMILARITY RULE REF. 5) .



DETAIL OF EMPENNAGE FAIRING

ALL DIMENSIONS IN INCHES

FIG. 10. G.A. OF UNMODIFIED AIRCRAFT, MODEL A.

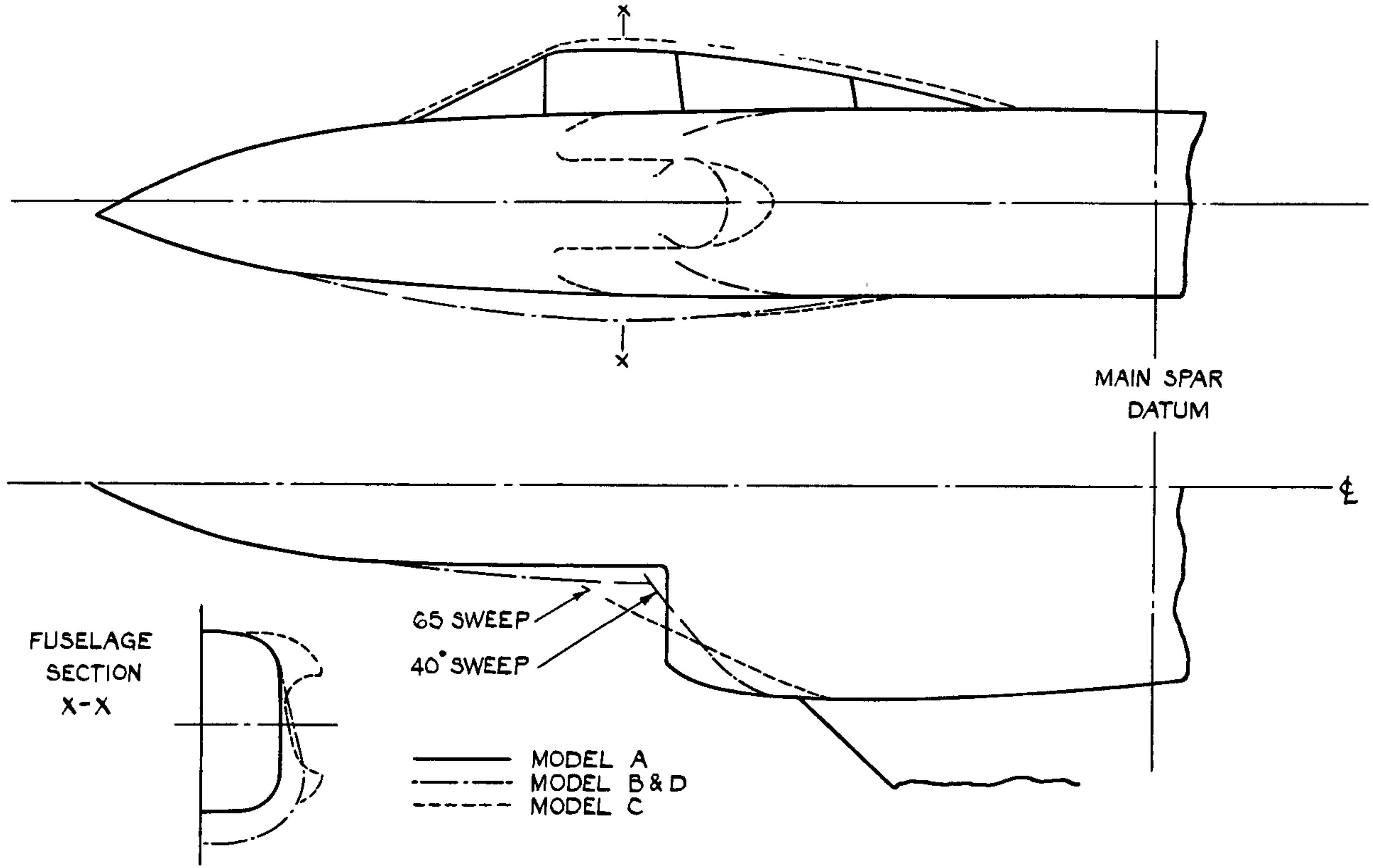


FIG.11. AREA-RULE MODIFICATIONS, F'WD OF AIRCRAFT MAIN SPAR.
(COMPLETE MODELS).

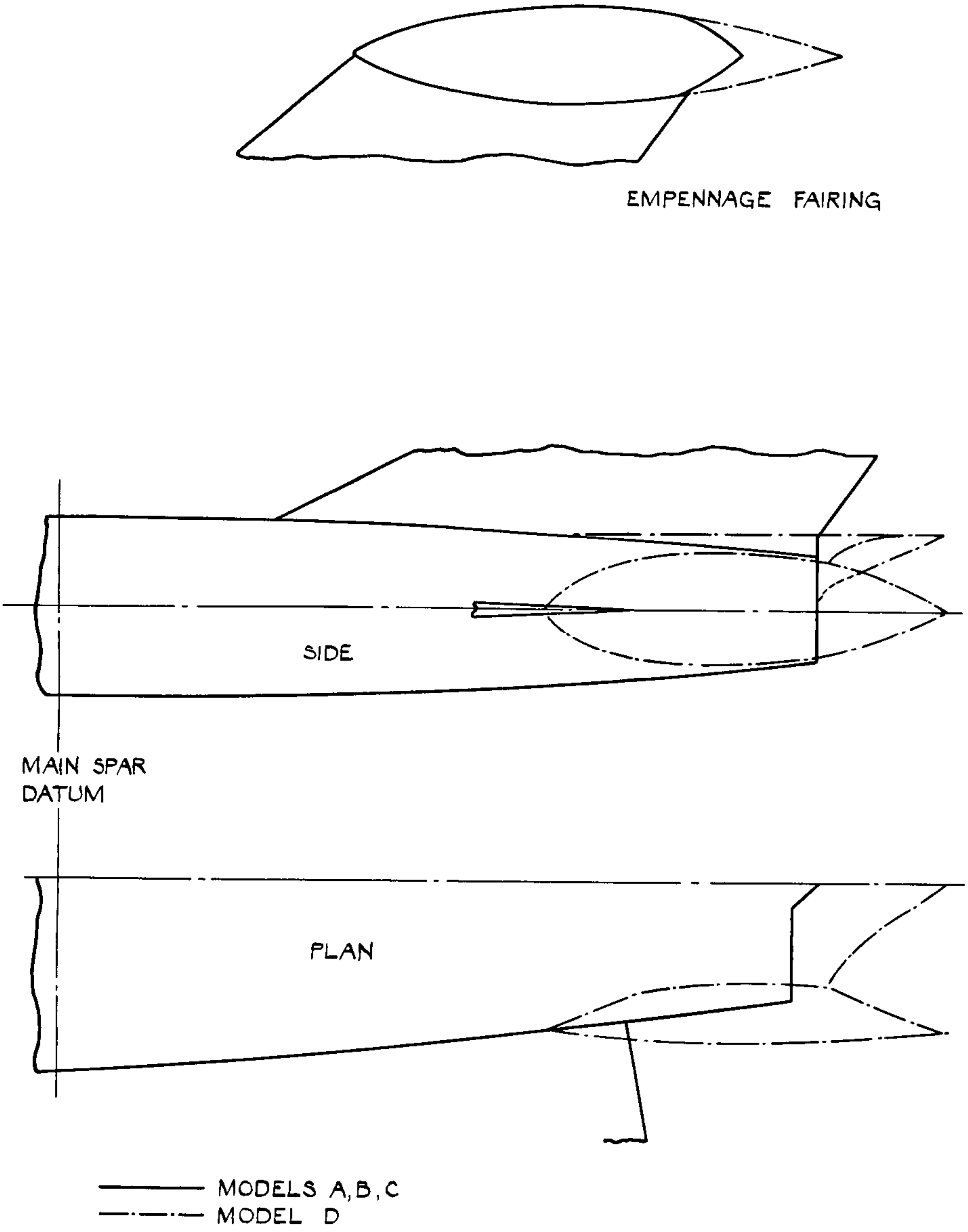
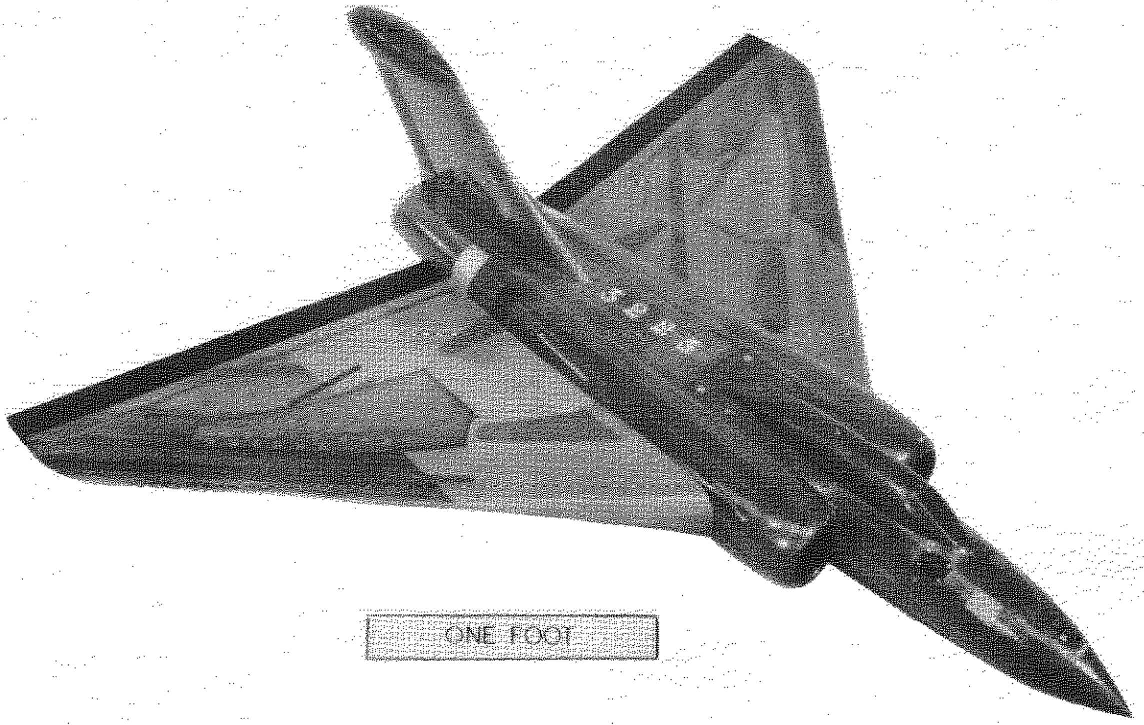
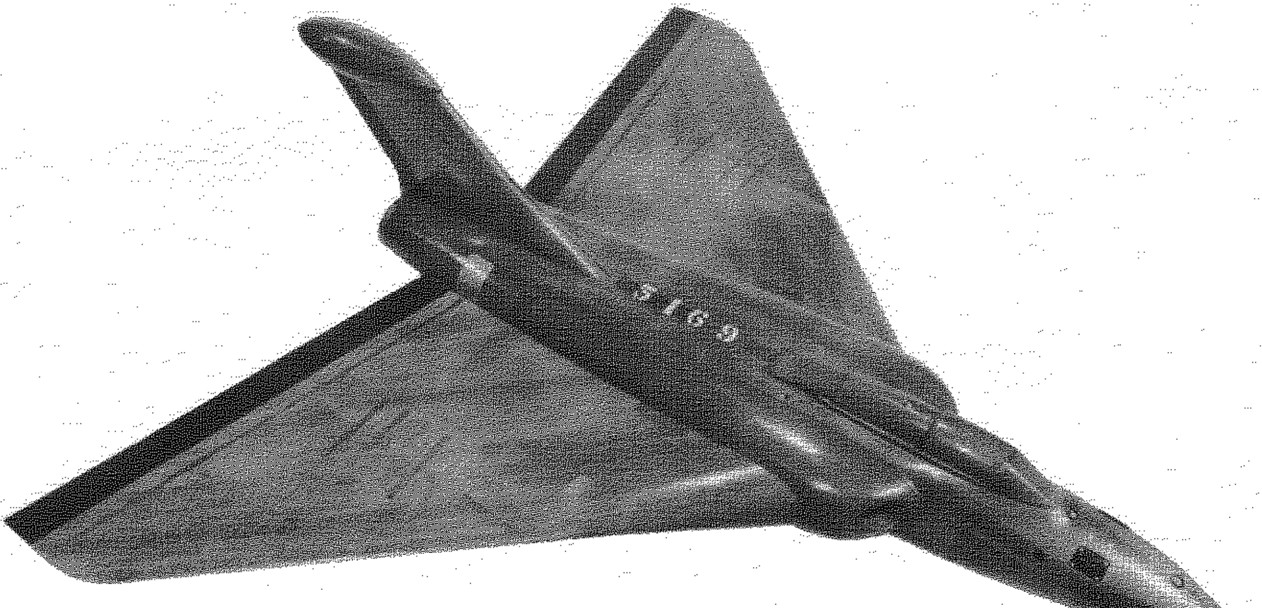


FIG.12. AREA-RULE MODIFICATIONS AFT OF AIRCRAFT MAIN SPAR (COMPLETE MODELS)

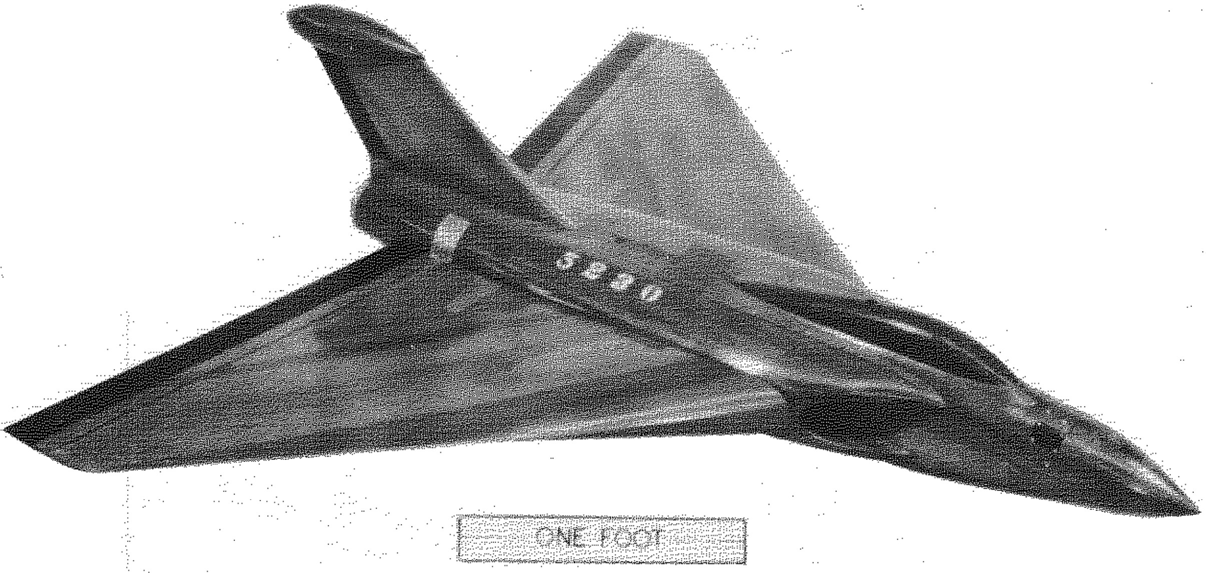


MODEL 'A'

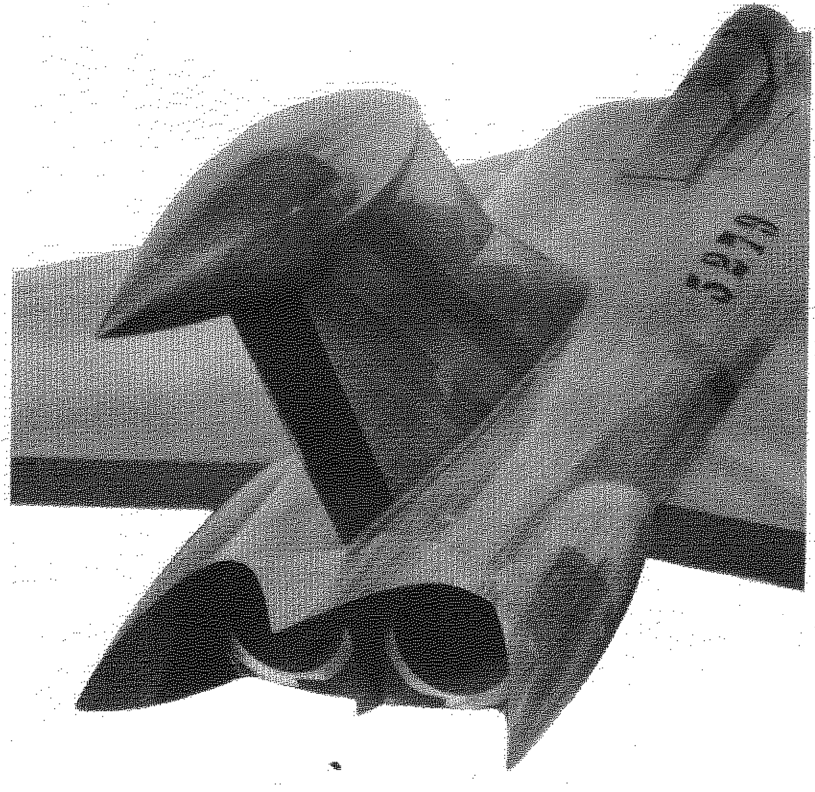


MODEL 'B'

FIG. 13a. COMPLETE MODELS



MODEL 'C'



MODEL 'D,' SHOWING REAR FUSELAGE FAIRING
(Forward part of model is as Model 'B')

FIG.13b. COMPLETE MODELS

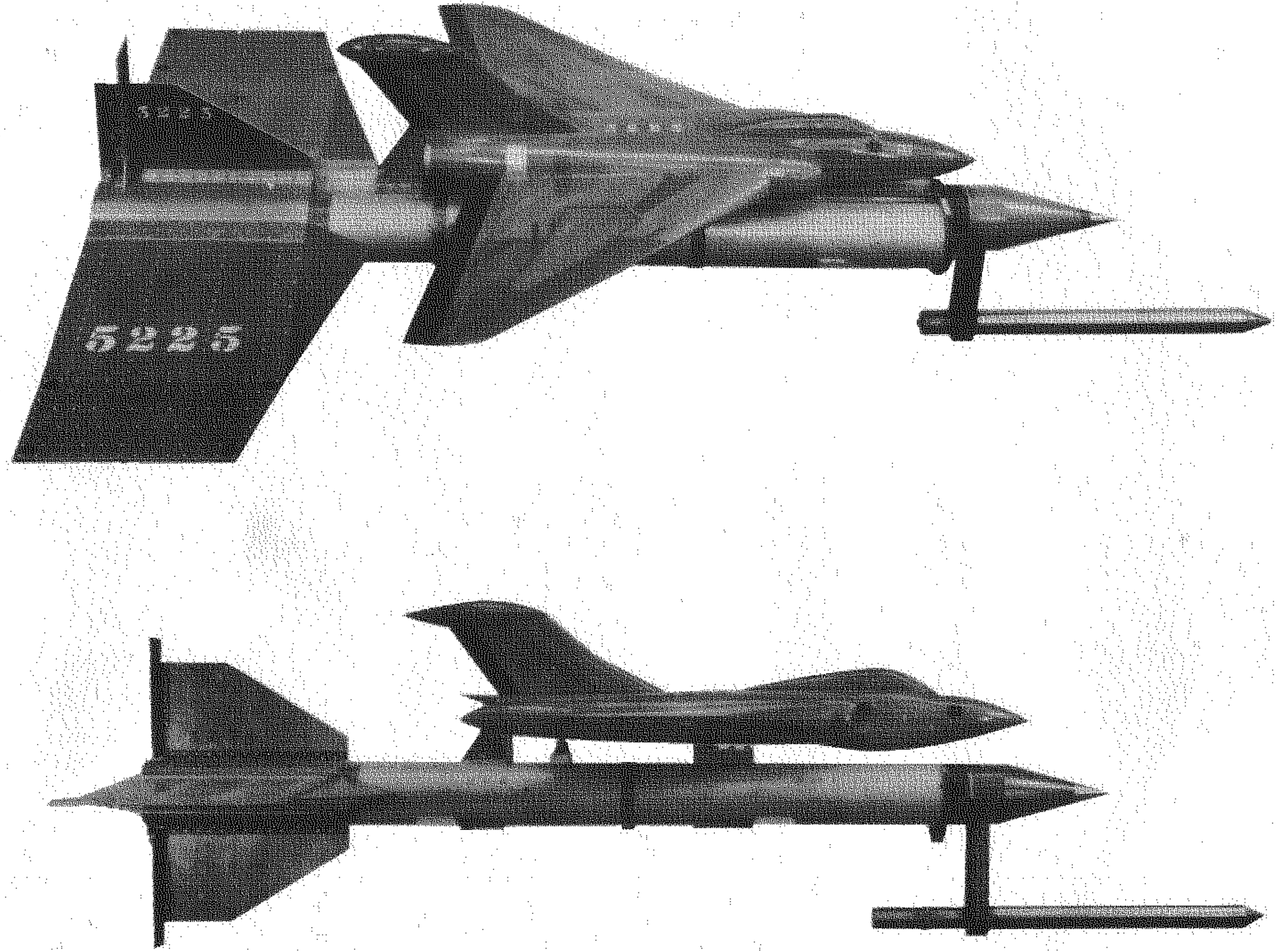


FIG.14. BOOSTING METHOD-COMPLETE MODELS

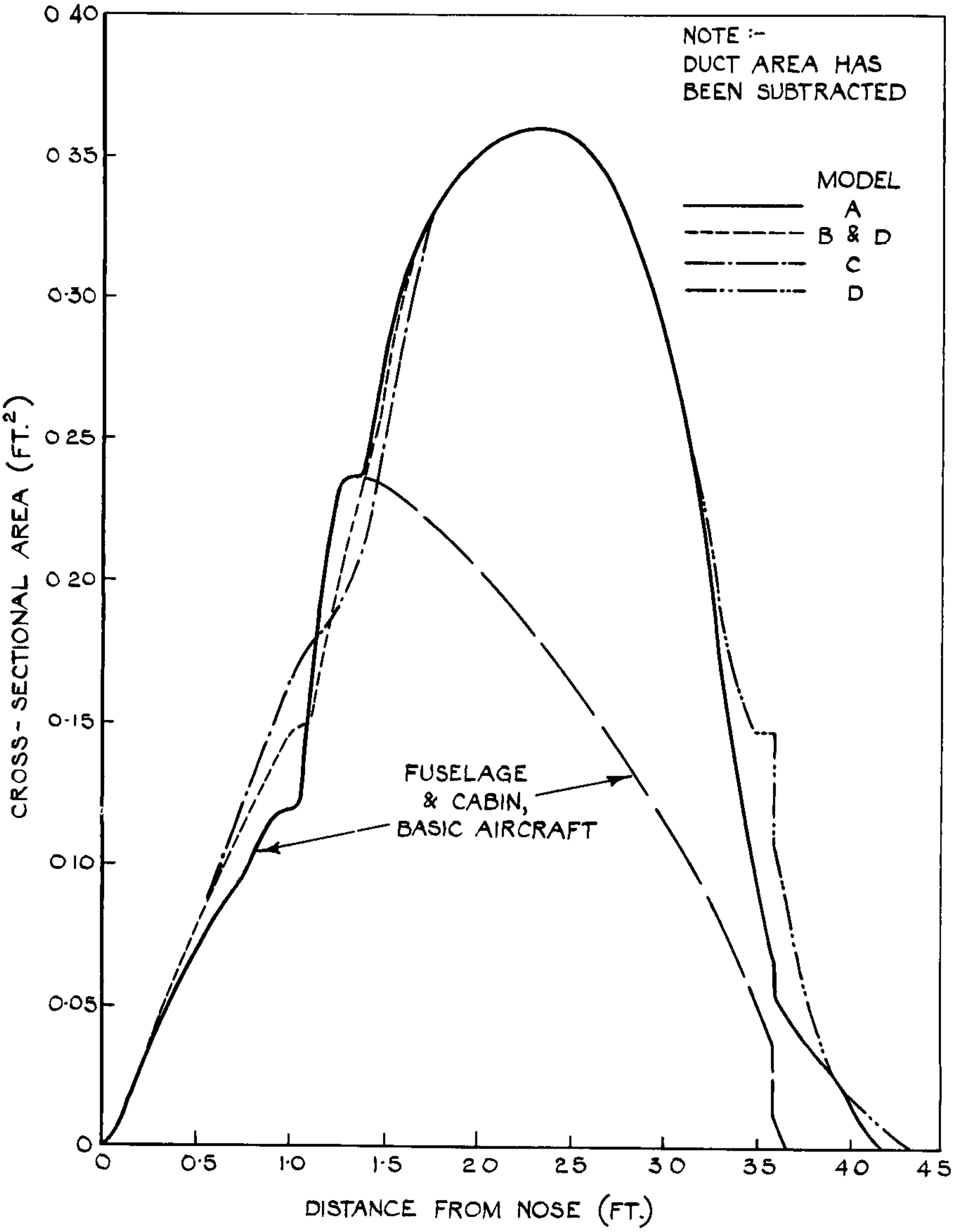


FIG.15. AREA DISTRIBUTIONS OF COMPLETE MODELS (M = 1·0).

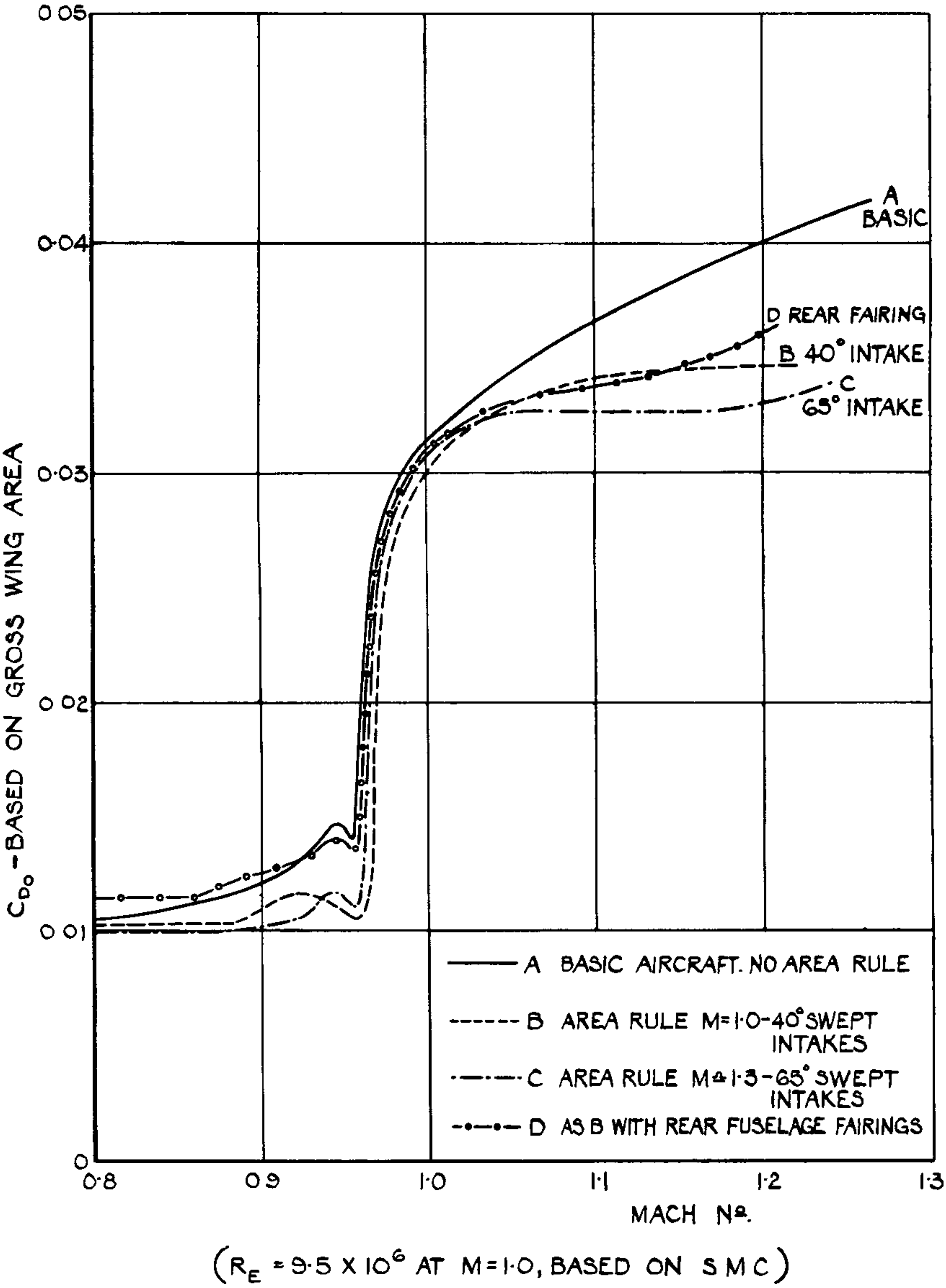


FIG.16. ZERO-LIFT DRAG OF COMPLETE MODELS

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FREE-FLIGHT MODEL DRAG MEASUREMENTS ON A TRANSONIC
FIGHTER (GLOSTER JAVELIN). Greenwood, G.H. Nov.1958.

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