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The Effect of Fuselage Modifications on the Zero-Lift Transonic Drag of a Fighter Aircraft (Hunter F.Mk.1) as Measured by Free-Flight Model Tests

by

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THE EFFECT OF FUSELAGE MODIFICATIONS ON THE ZERO-LIFT TRANSONIC DRAG OF A FIGHTER AIRCRAFT (HUNTER F. MK.I) AS MEASURED BY FREE-FLIGHT MODEL TESTS

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SUMMARY

Free-flight model tests have been conducted on three 1/10th scale models of the Hawker Hunter F. Mk.1 aircraft to investigate the effect of body shaping on zero-lift transonic drag. The models were: (a) unmodified aircraft (b) the aircraft modified by a rear fuselage fairing only, based upon a restricted application of the design method of Küchemann and (c) the aircraft modified by a complete fairing according to the sonic area rule.

Appreciable reductions (20 - 40%) in sonic drag were produced by both modifications, the greater being due to sonic area rule.

The gains attributable to the Küchemann modification have been confirmed by full-scale aircraft tests but there are differences between the absolute values of drag as measured by the full-scale tests and the model tests.

LIST OF CONTENTS

TABLE

LIST OF ILLUSTRATIONS

1 INTRODUCTION

In the course of an early examination of the effects of the sonic area-rule a proposal was made to test its effect on the drag, stability and control of an existing aircraft having a basically "poor" area distribution.

The aircraft chosen for the test was the Hunter F. Mk.1 and the proposal was to improve the area distribution of this aircraft by adding fairings to the existing fuselage. In practice, however, it was found impossible to fit the fairings in the appropriate regions and the idea of full-scale aircraft tests embodying the area-rule modifications was abandoned.

A second course open to effect drag reductions on this aircraft was to apply the principles of shock-wave control expounded by Küchemann and Hartley[1]. A preliminary study was made demonstrating that the pressure distribution in the wing root was such that shocks in that region were likely to appear relatively early and to move rearwards relatively quickly, leading to a premature and rapid drag rise. Thus some improvement in the wing-body junction pressure distribution appeared possible by suitably shaping the fuselage so as to induce velocities which restore full isobar sweep and delay the rearward passage of the shocks. Such a shaping of the fuselage was found to be impracticable on the full-scale Hunter and a compromise was effected in the form of a partial, rear-fuselage fairing designed to induce more positive pressures in the subsonic pressure distribution of the wing-body junction near the trailing edge. This could be expected to delay the rearward movement of the shocks but it could not effectively improve the velocities and isobar sweep near the crest of the wing. It was recognised that the effectiveness of this compromise method would fall considerably short of that which could have been achieved by an unrestricted application of the Küchemann design method. The fact that the rear fairing itself would initiate shocks and possibly separated flow and hence impose a drag penalty was not overlooked.

The test made on the full-scale aircraft fitted with the rear fairing is described in Ref. 3; a previous test made on an unmodified production Hunter and used to assess the gains in performance of the modified version is described in Ref. 4.

Owing to the impracticability of testing the effect of area-rule on the full-scale aircraft, free-flight model experiments were initiated in which the zero-lift drag of a model of the unmodified production Hunter could be compared with the drag of two models modified by a rear fairing and area-rule respectively. The area-rule model included also a front fairing in addition to a rear fairing; and the modified body shape was such that its pressure field could be expected not only to retard the rearward movement of the shocks, once they had appeared, but also to favourably affect the flow conditions near the crest of the wing so as to delay the appearance of shocks. Thus improvements in both the critical Mach number and the transonic drag rise were expected.

The tests on these models are the subject of this note.

2 DESIGN OF THE MODELS

The models tested were:

(a) Unmodified Hunter Mk.1 aircraft (Model 1, Figs. 1 and 5)

(b) Hunter with rear fairing (Model 2, Figs. 1 and 6)

(c) Hunter with area-rule applied (Model 3, Figs. 2 and 7

Model 1 was flown successfully but the tailplane of model 2 broke off in flight. There was evidence, however, that the breakage occurred fairly cleanly from the fuselage and the effect of its loss could be reasonably assessed. At this stage the manufacture of model 3 was nearly complete and it was found that little could be done to improve the tailplane strength without interfering with the internal ducting. It was decided, therefore, to remove the tailplane of model 3 before flight to avoid the risk of a failure whose effect might have been less easy to assess than that of model 2.

For the purpose of direct drag comparison between all the models and between the models and full-scale aircraft an estimate of the drag of the tailplane has been added to the results from models 2 and 3.

Apart from the fuselage modifications on 2 and 3 the models were all 1/10th scale Hunter Mk. 1 aircraft; but in order that they should fly at zero lift the 1.5 degrees positive wing-setting angle of the full-scale aircraft was reduced to zero and the tailplane, where fitted, was lowered to lie in the same plane as the wing.

The intake geometry of the full-scale aircraft was preserved and all the models had internal ducts designed to give an entry Mach number of 0.82 with the exit choked.

Area distributions (M = 1.0) of all the models are shown in Fig. 8 and a comparison of fuselage contours in Fig. 3.

2.1 Unmodified Hunter Mk.1 aircraft (Model 1)

Apart from the wing-setting angle and tailplane position this was a directly scaled-down Hunter Mk.1 aircraft.

2.2 Aircraft with rear fairing (Model 2)

The design of this model was based on the full-scale aircraft of Ref. 3.

2.3 Aircraft with area-rule (Model 3)

The design procedure for this model was to take the area distribution of the basic aircraft and to build it up where necessary to accord with an improved distribution suggested by the sonic area-rule. (Fig.8). The necessary additional cross-sectional area was confined entirely to the fuselage and was applied in such a manner that the flow into the intakes was kept substantially the same as on the other models. In general, as little interference as possible was made to the basic Hunter configuration and no attempt was made to extend the fuselage to accommodate the full "optimum" sonic area-rule distribution.

3 MODEL CONSTRUCTION

All the models were made basically of teak. The ducts, for most of their length in the fuselage, were thin-gauge, light-alloy tubes terminating at the exit in a mild-steel open ferrule which formed the extreme fuselage external contour. The teak wings had Tufnol trailing edges and were reinforced internally with metal plates to give added root bending strength. The tailplane, where fitted, was of Tufnol, glued into the fuselage as was the fin which carried a faired-in copper telemetry aerial. The forward part of the fuselage was hollowed out to accommodate the telemetry components and self-destruction unit. The models were surface-finished with Phenoglaze polish and all control gaps were faired-in.

4 METHOD OF TEST

Each model was mounted on a twin 5-inches diameter solid-fuel rocket assembly (Fig. 4) which boosted it to the required test velocity. At approximately maximum velocity ($M \simeq 1.2$), the rockets having ceased to burn, the models separated from the rocket assembly and flew on alone in coasting flight. During the free-flight period the model decelerated under its own drag force and the response of a longitudinal accelerometer was radio-telemetered from the model to the ground station and recorded.

From this record of the model's deceleration and from a knowledge of its trajectory and velocity gained from kine-theodolite observations and radio Doppler reflection the drag was computed. Details of the analytical methods used to obtain drag coefficients from free-flight model tests are contained in Ref. 5.

5 RESULTS FROM THE MODEL TESTS

The drag coefficients obtained from the model tests are presented in Figs. 9 and 10.

The results from models 2 and 3 include an estimate of the tailplane drag. The skin-friction drag values for this estimate assumed leading-edge transition and zero heat transfer, and the wave-drag values were obtained from Ref. 7. No attempt was made to include fuselage/tailplane interference effects.

The salient feature of the drag curves is the marked decrease in the magnitude of the drag rise brought about by the fuselage modifications. The subsonic drag levels of all the models show no significant differences and are within the known experimental uncertainty of the free-flight model technique.

5.1 Aircraft with rear fairing (Model 2)

The results from this model show a reduction in C_{Do} at $M = 1.0$ of about 0.007 compared with the unmodified aircraft model (Fig. 10). This reduction is seen to diminish with increasing Mach number and disappears at approximately $M = 1.14$. No delay in the drag-rise Mach number is apparent compared with the unmodified design.

5.2 Aircraft with area-rule (Model 3)

The reduction in total drag rise and the delay of the drag-rise Mach number is very marked for this model.

A reduction in C_{Do} at $M = 1.0$ of about 0.014 has been achieved and the drag-rise Mach number is delayed by approximately 0.04 (Fig. 10). The drag reduction is seen to decrease progressively between $M = 1.0$ and $M = 1.1$ and disappears (by extrapolation) before $M = 1.2$.

6 COMPARISON OF FULL-SCALE WITH MODEL RESULTS

A direct comparison of the measured total drag from the full-scale aircraft tests of Ref. 3 and 4 (corrected to $C_L = 0$) is made with the model results in Fig. 12.

In this comparison of measured drag no account is taken of the differences in surface finish, surface irregularities, Reynolds number and other known differences between full-scale and model; thus the comparison is valid only as a qualitative indication that the order of drag reduction due to the fuselage modification is confirmed by the model tests.

The agreement in subsonic drag levels between full-scale and the relevant models is good, but above the drag-rise Mach number there is a marked disagreement in measured drag.

7 DISCUSSION

The results from the tests confirm that considerable reductions in transonic drag can be achieved by suitable additions to the fuselage of what is basically a subsonic design. Even the partial application of the Küchemann design method produces a drag reduction at sonic speed of about 20 per cent, and the area-rule about 40 per cent. Altogether, the results confirm the physical arguments underlying the design of the modifications.

To appreciate the drag reductions obtained, one might consider the reductions in wing thickness, which would be needed to achieve the same results. Using the similarity rules as suggested by Ref. 8, it can be shown that the thickness/chord ratio of the wing of the unmodified production aircraft would have to be reduced from its existing value of 0.085 to about 0.07 to produce a drag reduction comparable to that due to the rear fairing only and to about 0.06 to produce a reduction comparable to that due to the complete fairing of the area-rule.

In these tests the two body shapes had limitations imposed upon them by the need to conform to an existing basic configuration. In each example the resultant body shape had features which could conceivably be related to the design concepts of the other e.g. the rear fairing of model 2 fulfils the requirements of area-rule in improving the rearward area distribution and conversely the body contours of the area-rule model could conceivably induce a favourable pressure distribution in the wing-body junction with resultant delay in the rearward movement of the shocks. In fact, the two methods are only two aspects of the same physical phenomenon.

The drag discrepancy between full-scale aircraft and model of the present tests cannot be explained fully in terms of Reynolds number difference, but it is known that there are drag components (e.g. intake spillage, duct internal drag, jet interference etc.,) which are at variance between the models and full-scale and it is to these differences and to the marked differences in surface finish that the drag discrepancy is attributed.

8 CONCLUSIONS

(a) The application of a rear fairing to the fuselage of the Hunter reduced the sonic wave drag by about 20 per cent, but made no measurable difference in the drag-divergence Mach number.

(b) The gains due to the rear fairing are in satisfactory agreement with those obtained by full-scale drag measurements on a similarly modified aircraft but there are differences in the absolute drag values obtained from the two techniques. In particular, the rear fairing did improve the drag-divergence Mach number in the full-scale tests.

(c) The application of the sonic area-rule to the Hunter fuselage reduced the sonic wave drag by about 40 per cent, and increased the drag-divergence Mach number by 0.04.

LIST OF REFERENCES

Ref. No.	Author(s)	Title, etc.
1	Küchemann, D., Hartley, D.E.	The design of swept wings and wing-body combinations to have low drag at transonic speeds. A.R.C. 17871. April, 1955.
3	Andrews, D.R., Dee, F.W., Waters, D.	Flight measurements of the drag of an aircraft fitted with a rear fuselage fairing designed to reduce the transonic drag. A.R.C. 19219. C.P.459 November, 1956.
4	Andrews, D.R., Nethaway, J.E.	Flight measurements of the drag of a swept wing aircraft (Hunter F. Mk.1) at Mach numbers up to 1.2, together with some measurements of lift curve slope. A.R.C. 17947. June, 1955.
5	Lawrence, T.F.C., Swan, J., Warren, C.H.E.	Development of a transonic research technique using ground-launched rocket-boosted models. Part II. Drag measurements. A.R.C. 14167. March, 1951.
7	Bishop, R.A., Cane, E.G.	Charts of the theoretical wave drag of wings at zero-lift. C.P. No. 313. June, 1956.
8	Spreiter, J.R.	On the application of transonic similarity rules to wings of finite span. N.A.C.A. Report 1153. 1953.

TABLE 1

Details of models

Wing

Area (Gross)	3.4 sq ft
Area (Nett) (unmodified model)	2.85 sq ft
Span	3.37 ft
Aspect ratio (on gross wing)	3.34
Taper ratio (on gross wing)	0.41
Angle of sweepback at L.E.	44°
Angle of sweepback at $\frac{1}{4}$ chord	40°
Wing setting to fuselage datum	0°
Section	'Hawker' symmetrical
Max thickness/chord ratio	0.085
Position of max thickness	0.375 chord

Tailplane

Area (Gross)	0.54 sq ft
Area (Nett)	0.36 sq ft
Span	1.18 ft
Aspect ratio (on gross tailplane)	2.58
Taper ratio (on gross tailplane)	0.55
Angle of sweepback at L.E.	45°
Angle of sweepback at $\frac{1}{4}$ chord	41.5°
Tailplane setting to fuselage datum	0°
Section	'Hawker' symmetrical
Max thickness/chord ratio	0.080
Position of max thickness	0.34 chord

Fin

Area (Nett)	0.35 sq ft
Angle of sweepback at L.E.	53°

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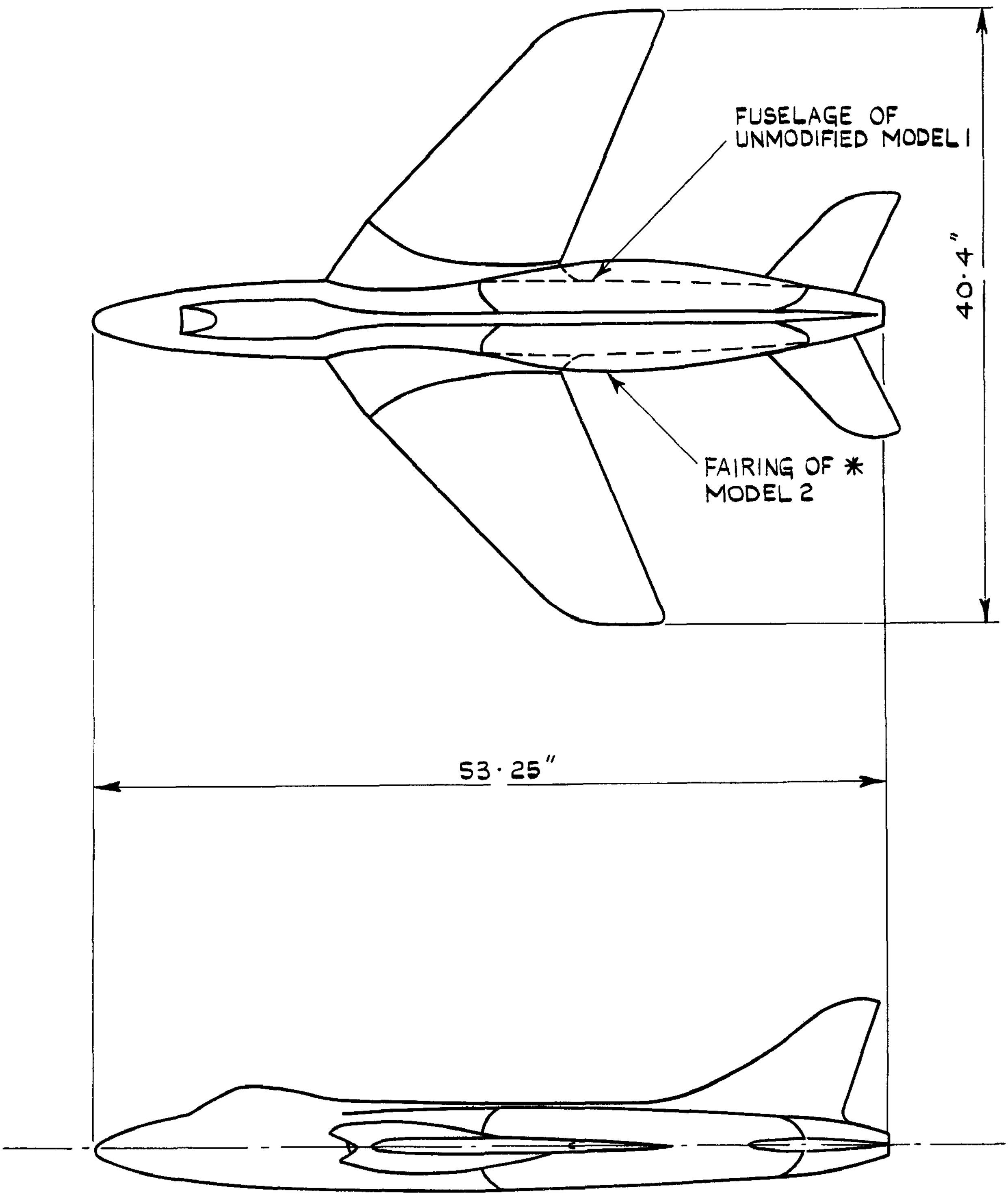

* MODEL 2 TAILPLANE FAILED IN FLIGHT

FIG. 1. GENERAL ARRANGEMENT OF MODELS 1 & 2 SHOWING FAIRING.

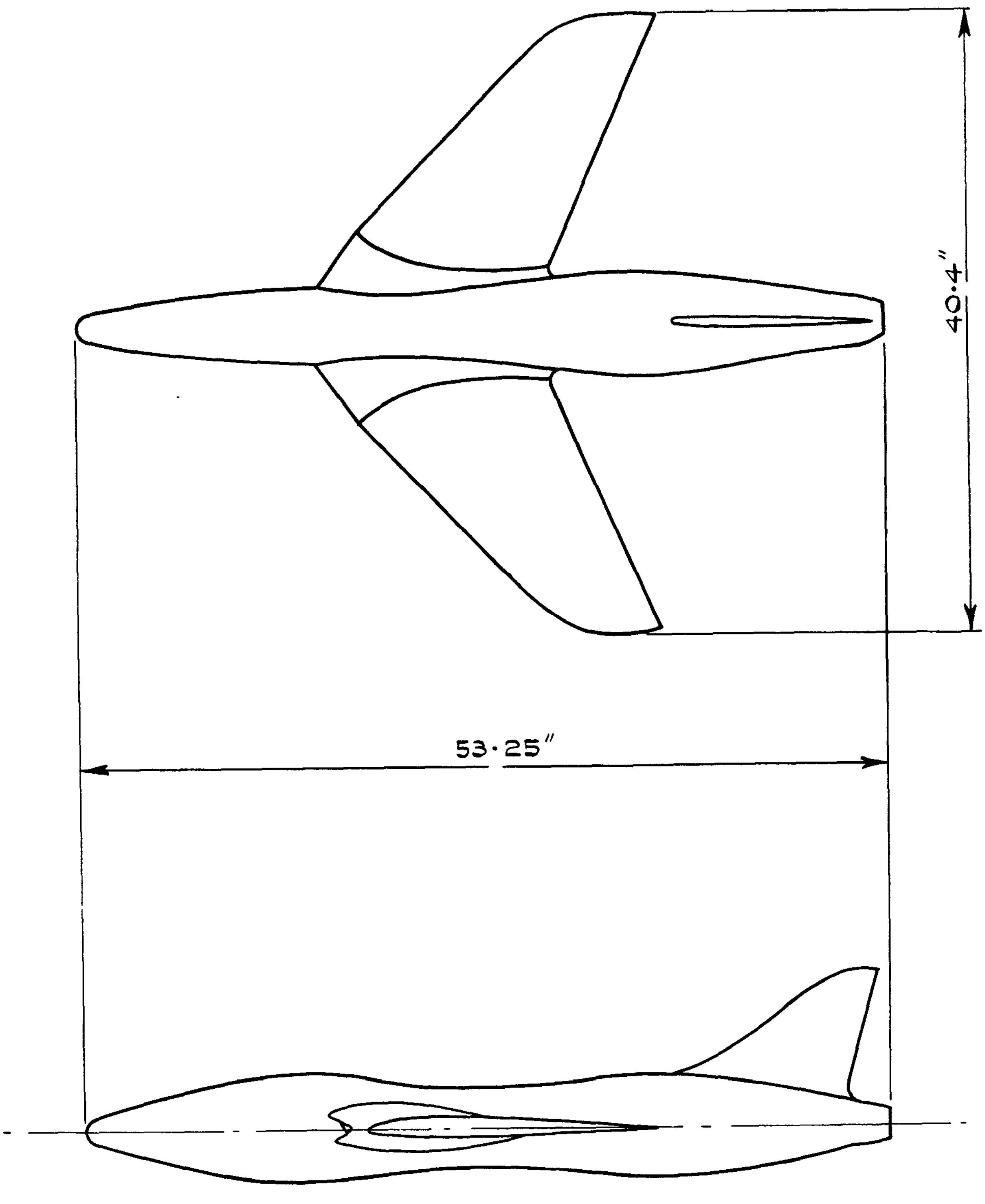

FIG. 2. GENERAL ARRANGEMENT OF MODEL 3
(AREA RULE)

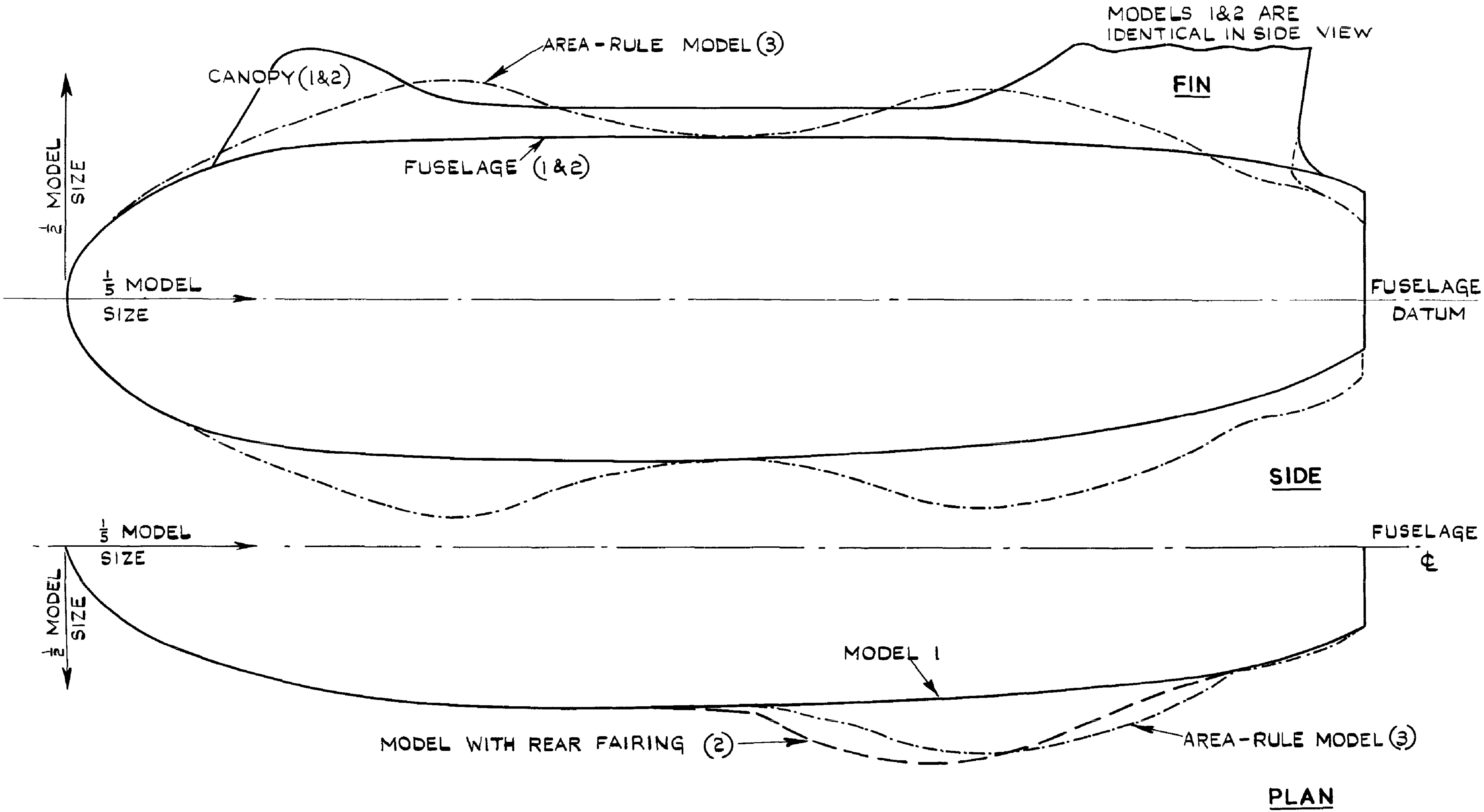

FIG. 3. COMPARISON OF FUSELAGE CONTOURS (MODELS 1, 2 & 3).

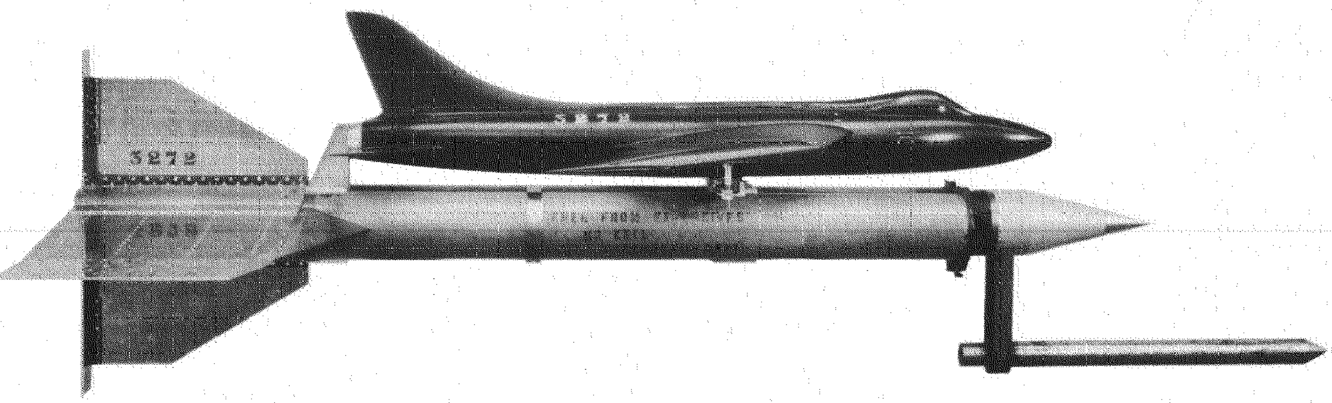

FIG.4. MODEL BOOSTING ARRANGEMENT

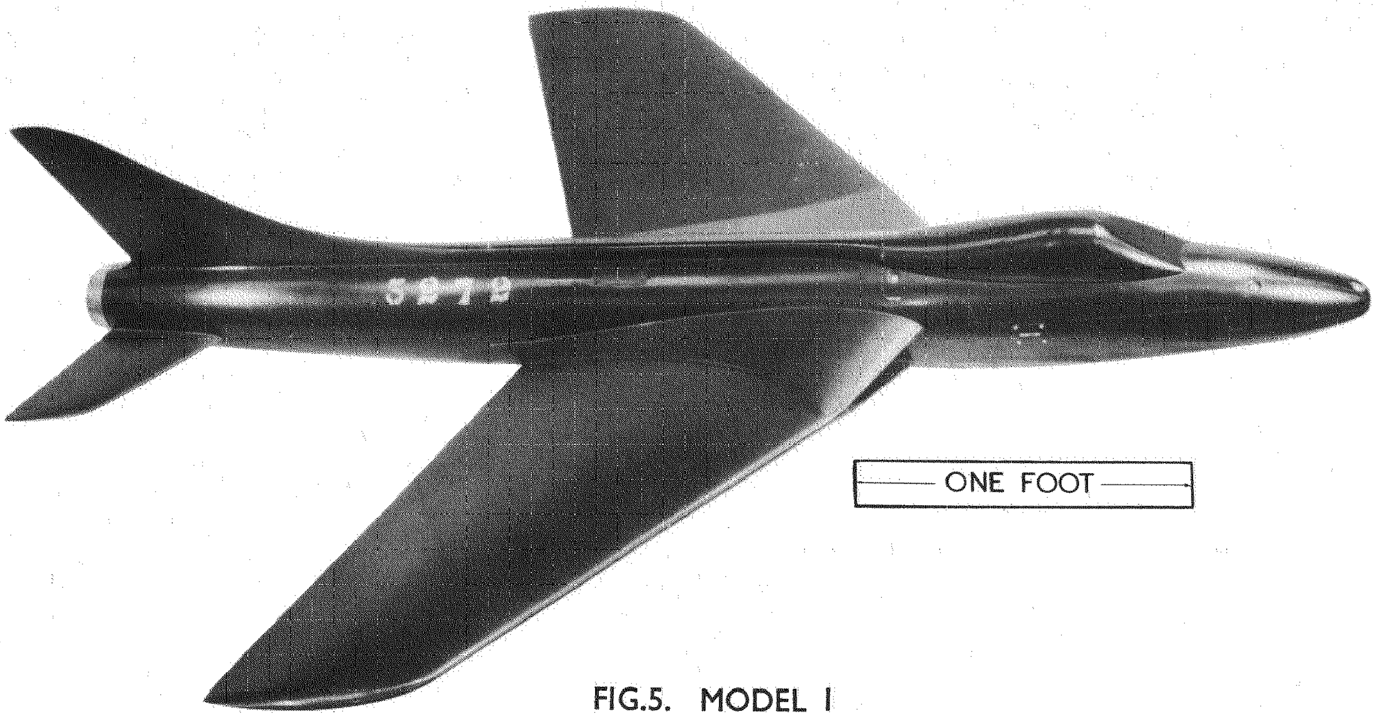

FIG.5. MODEL I

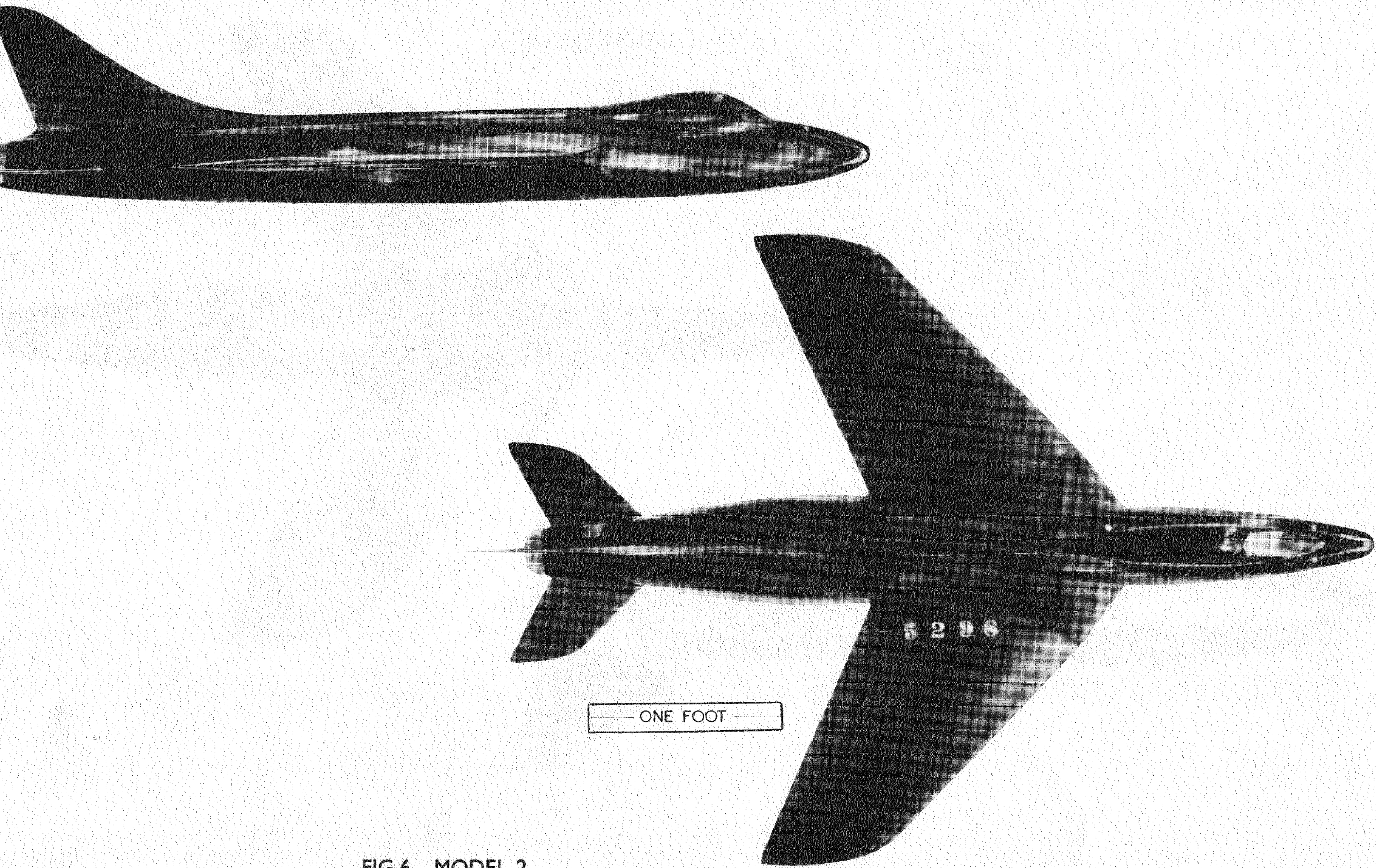

FIG.6. MODEL 2

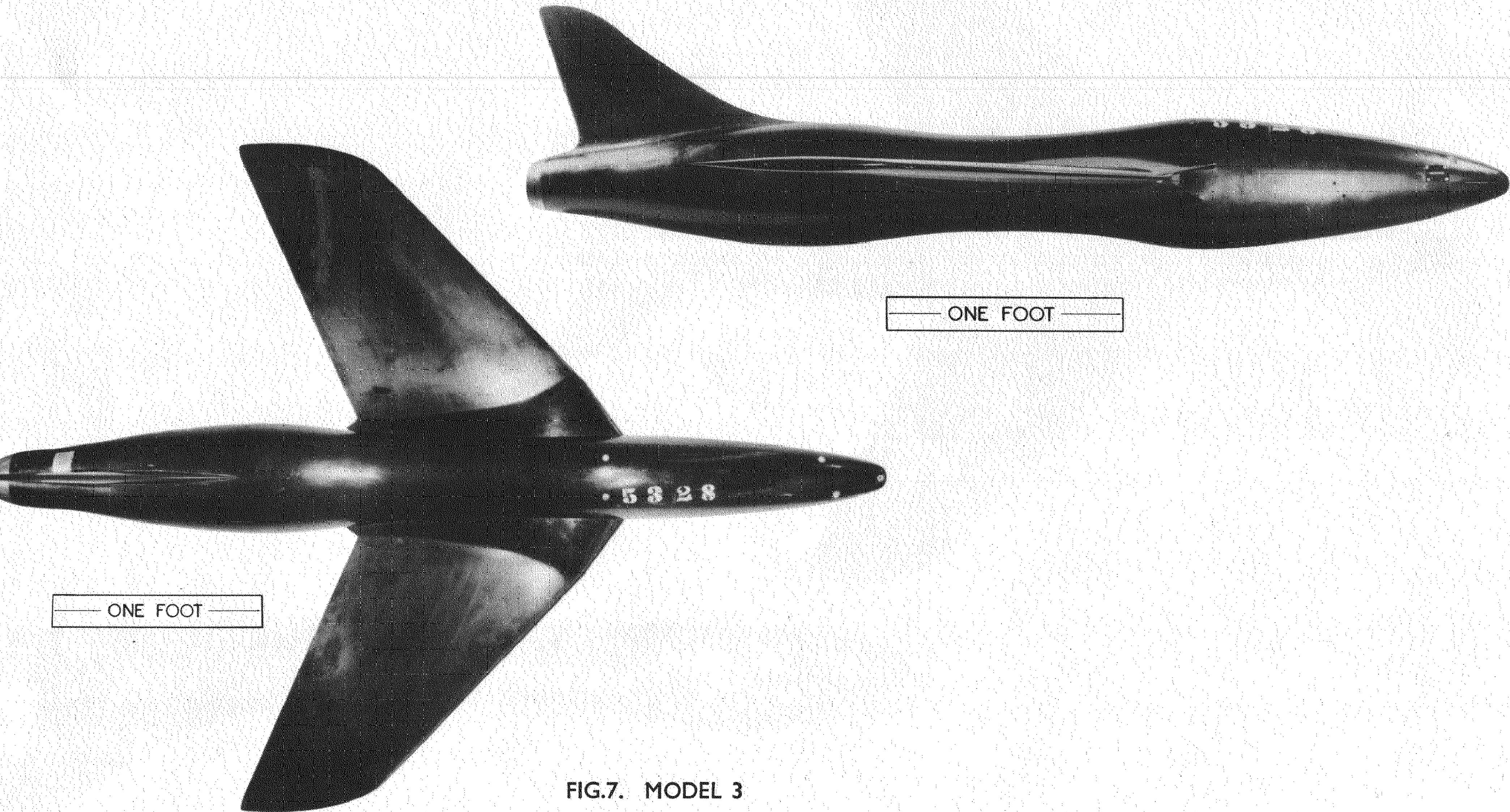

FIG.7. MODEL 3

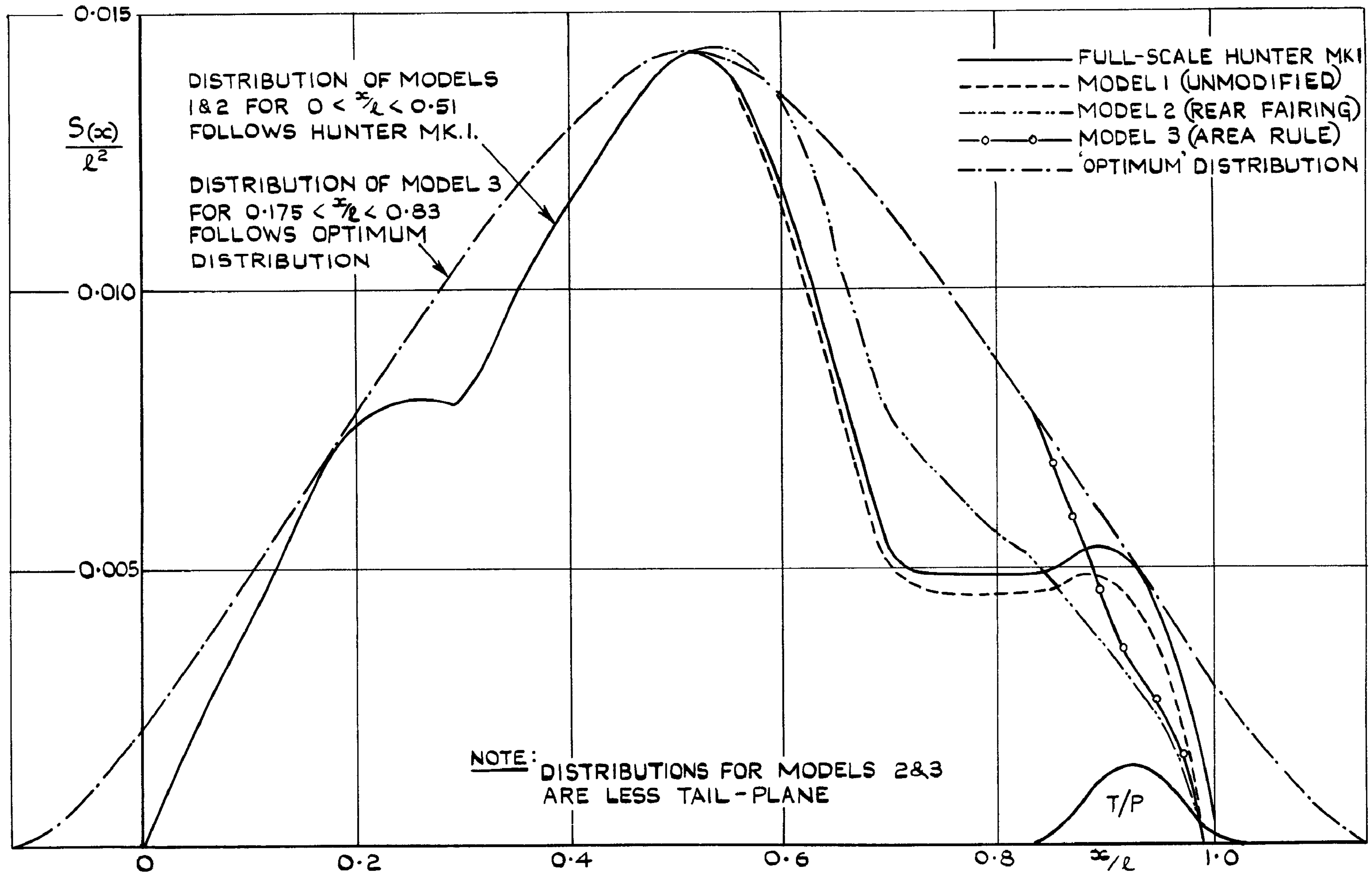

FIG 8. AREA DISTRIBUTIONS FOR M = 1·0.

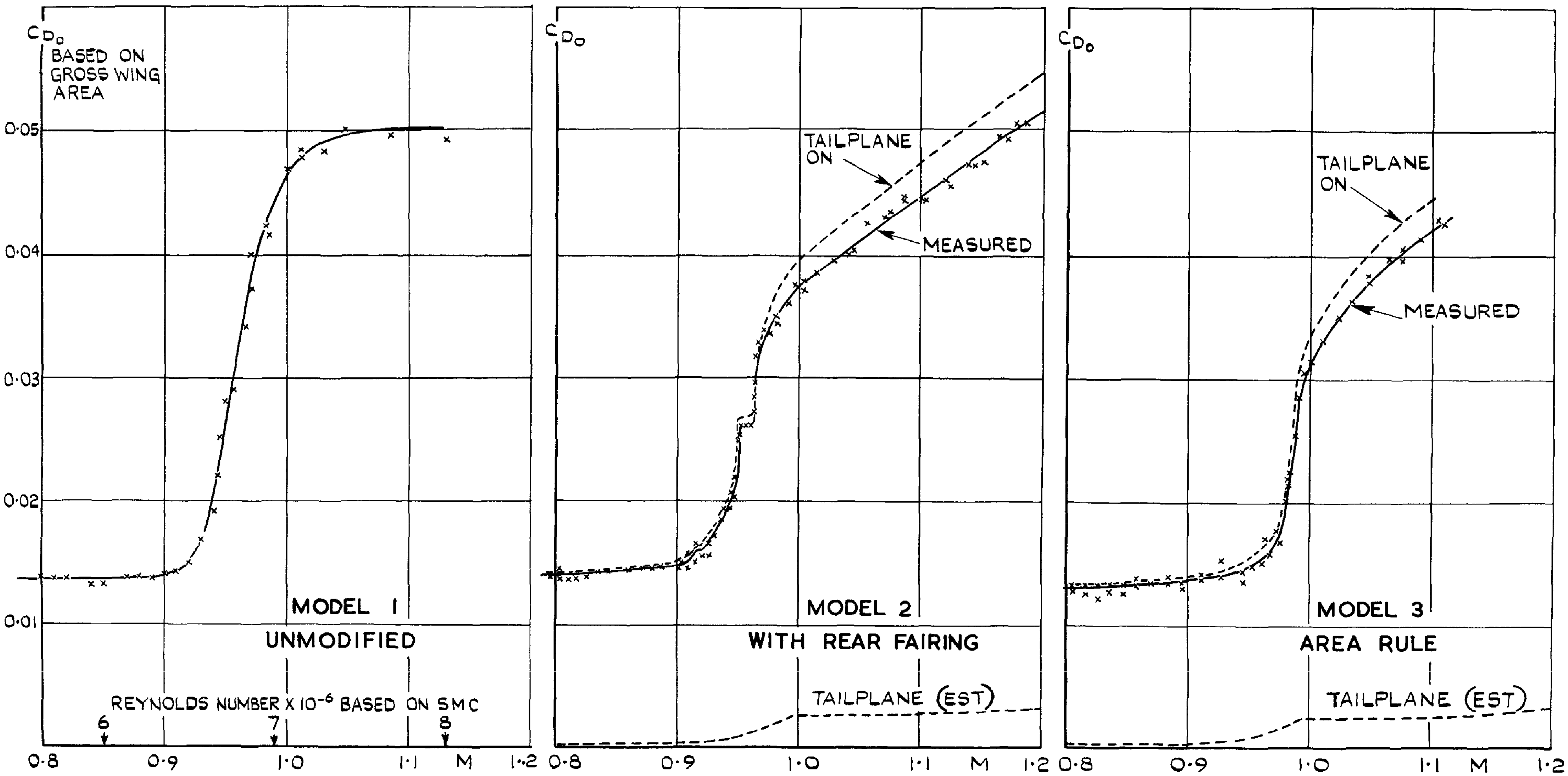

FIG. 9. ZERO-LIFT DRAG OF MODELS.

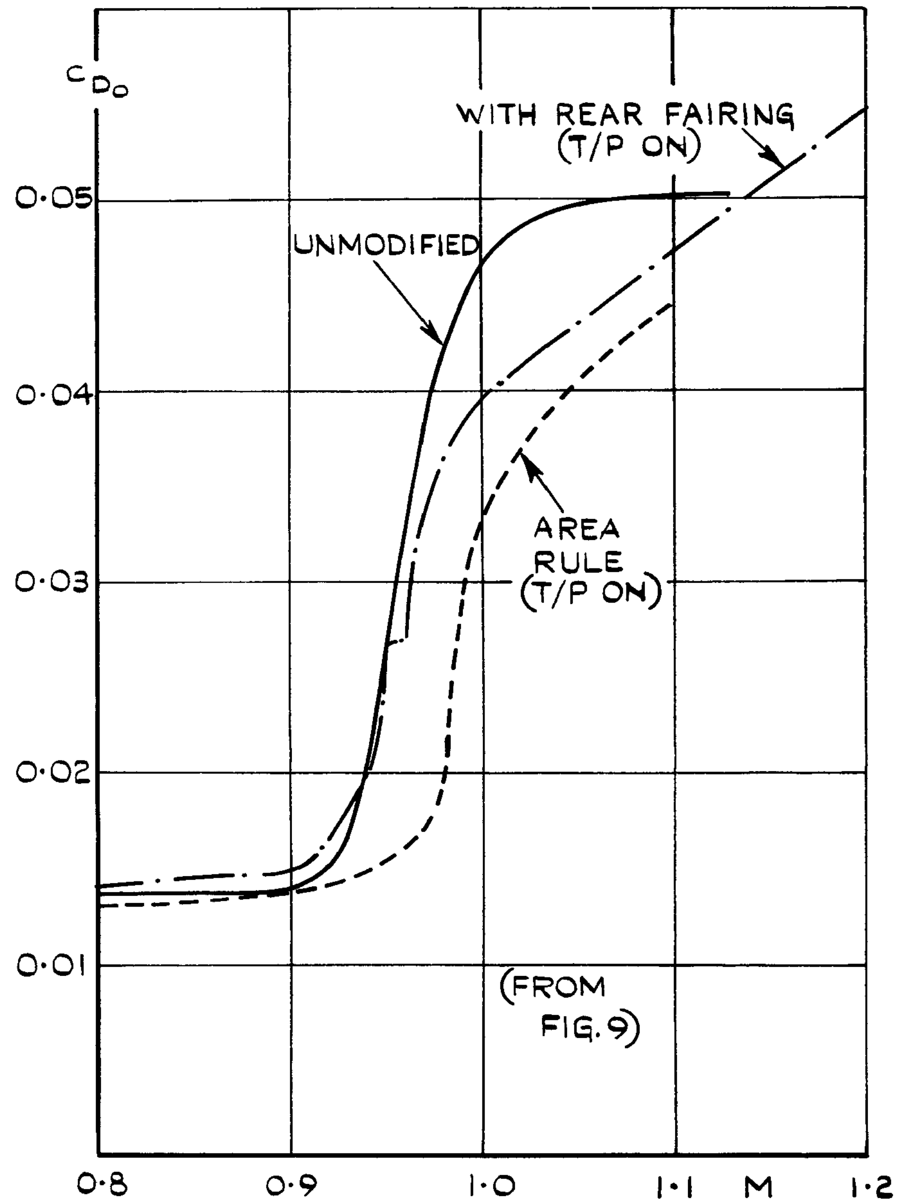

FIG.10. DRAG COMPARISON OF MODELS.

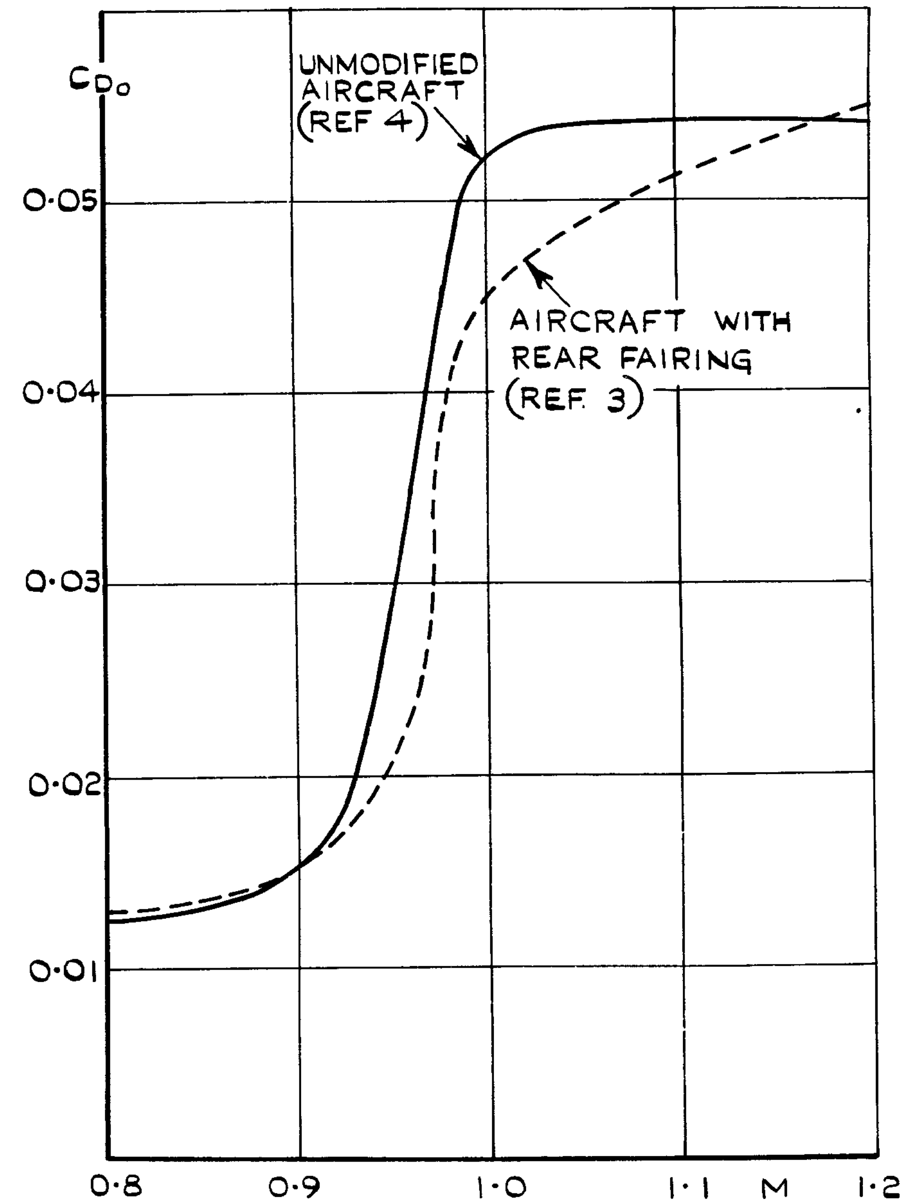

FIG.11. DRAG OF FULL-SCALE AIRCRAFT.

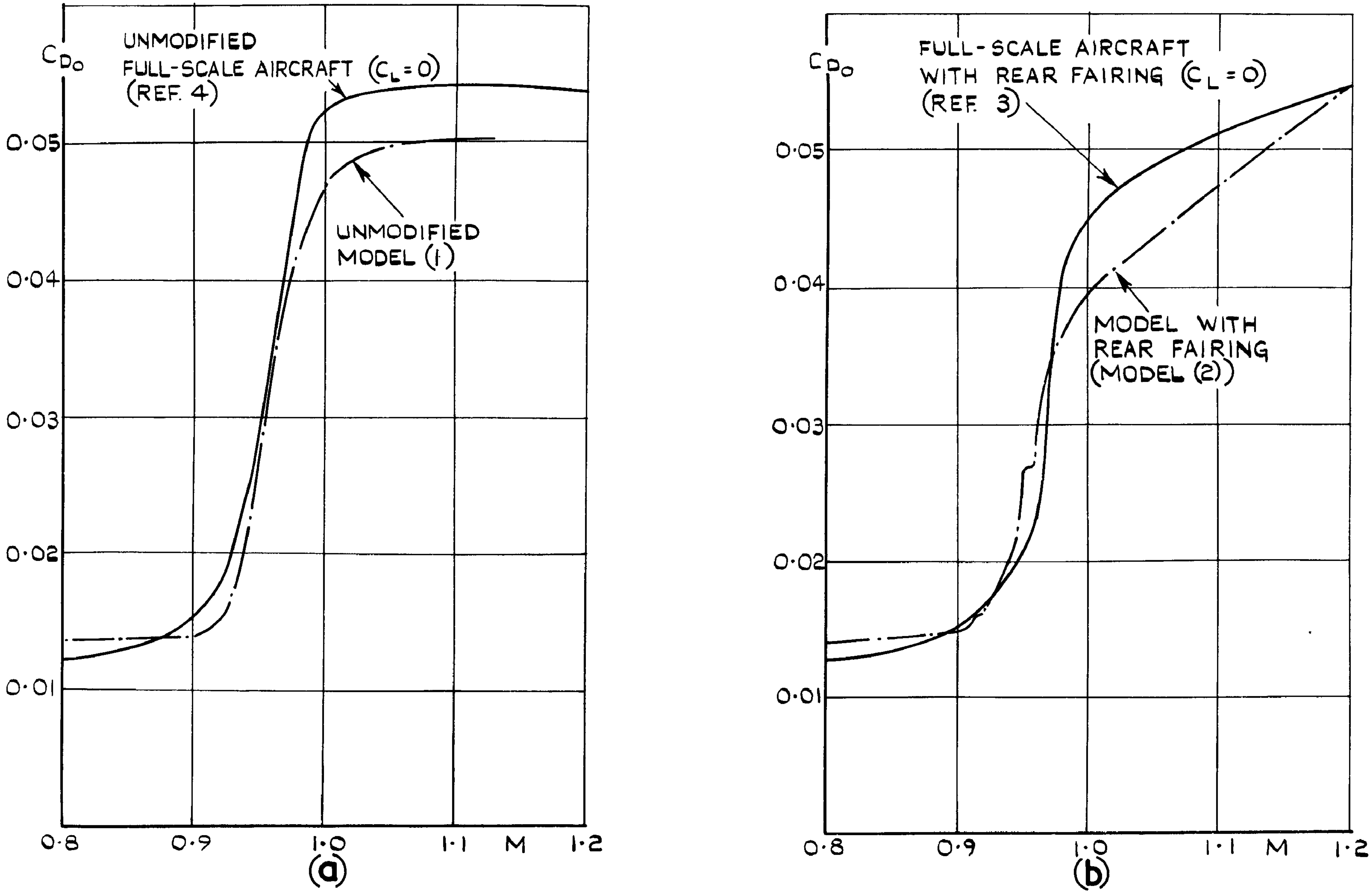

FIG. 12. (a & b) COMPARISON BETWEEN MODEL & FULL-SCALE DRAG.

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