File pl Mr. J. Lukasiewicz

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SUBJECT ESTIMATED LIFT AND DRAG CHARACTERISTICS OF FOUR WINGS AT SUPERSONIC SPEEDS.

PREPARED BY R. J. Templin

ISSUED TO Internal

S U M M A R Y

Empirical methods of estimating the lift and drag characteristics of untwisted and uncambered wings at supersonic speeds have been developed in the Aerodynamics Laboratory. These methods are applied in the present note to the estimation of the characteristics of four wings at present undergoing force tests in the 10-inch supersonic tunnel.

ESTIMATED LIFT AND DRAG CHARACTERISTICS OF FOUR WINGS AT SUPERSONIC SPEEDS

1. INTRODUCTION

At the present time a series of half-wing models is being tested over a range of supersonic speeds in the 10-inch tunnel of the Aerodynamics Section, to determine, if possible, means of increasing the maximum lift-drag ratio of wings suitable for supersonic fighters. The first of these wings (referred to in the following as Wing A) was chosen for its geometric simplicity and also because it closely resembled the wing configuration on a proposed Canadian supersonic fighter. It is of delta plan form with 60° leading edge sweep, having a three-percent thick aerofoil section at all spanwise stations. The other three wings so far constructed for tests are modifications of Wing A, which it was hoped at the time would lead towards higher values of the supersonic maximum lift-drag ratio.

In parallel with this work, and at the request of the NAE Technical Advisory Panel, a collection of aerodynamic data for swept wings was begun in the Laboratory. An analysis of the experimental data so far gathered has led to a method of estimating the lift and drag characteristics of arbitrary wing configurations, and the present tunnel tests provide an opportunity of testing the method.

This note will not describe in detail the empirical basis for the method, but will be concerned only with the results as applied to the present series of wings.

2. WING SERIES

Figure 1 lists the pertinent geometric characteristics of the four wings which have so far been constructed for tests. Although not shown in this diagram, the wing tips were actually cut off slightly because of the vanishing thickness at the tips. However, the empirical method of estimating the aerodynamic characteristics does not require a knowledge of aspect ratio or of taper ratio explicitly, and these quantities have no effect on the estimated values of C_{D0}, dC_D/dC_L^2, or $(L/D)_{max}$. This will be discussed later.

3. ESTIMATED LIFT AND DRAG CHARACTERISTICS

3.1 Minimum Drag Coefficient

It is assumed that the minimum drag coefficient of thin plane wings at supersonic speeds consists of two parts:

$$C_{D0} = C_{Df} + C_{Dw}$$

where C_{Df} is the skin friction drag coefficient and C_{Dw} is the wave drag or thickness drag coefficient at zero lift.

The mean Reynolds number of the tunnel tests is approximately one million and it is estimated from the data of Reference 1 that the appropriate skin friction coefficient is

$$C_f = 0.003$$

and thus $$C_{Df} = 2 \times C_f = 0.006$$

There is some uncertainty in this value, however, since it assumes fully turbulent flow over the wing surfaces. The mean Reynolds number is such that some laminar flow would be expected if the wings were unswept, but it is possible that the high degree of sweep prevents this. If possible, flow visualization tests should be carried out at low incidences on at least one of the wings.

The zero lift wave drag coefficient, C_{Dw}, has been estimated in the following way. It was found in the analysis mentioned above that C_{Dw} is given empirically by the relation,

$$C_{Dw} = \left(\frac{t}{c}\right)^2 (\cot \Lambda)\, f_1(m) \qquad (1)$$

where $f_1(m)$ = an empirical function of m
$m = \beta \cot \Lambda$
$\beta = \sqrt{M^2 - 1}$
Λ = leading edge sweep
t/c = wing thickness-chord ratio.

The empirical function $f_1(m)$ is plotted in Figure 2, and the estimated values of C_{D0} for the four wings are shown in Figure 3.

3.2 Drag Due to Lift

The estimation of drag due to lift is based on the data contained in Reference 2. Since the publication of Reference 2, further analysis has been carried out on the available experimental results and it has been found that to a reasonably close degree of approximation, the drag due to lift is given empirically by the relation,

$$\frac{dC_D}{dC_L^2} = (\tan\Lambda)\, f_2(m) \qquad (2)$$

where $f_2(m)$ is an empirical function of m, shown in Figure 2.

The estimated values of $\frac{dC_D}{dC_L^2}$ for the four wings are shown in Figure 4.

3.3 Maximum Lift-Drag Ratio

Having estimated the values of C_{D0} and $\frac{dC_D}{dC_L^2}$ for the four wings, it is a simple matter to calculate also for their maximum lift-drag ratios from the relation

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2\sqrt{C_{D0}\frac{dC_D}{dC_L^2}}}$$

The results of this calculation are shown in Figure 5.

4. DISCUSSION AND CONCLUSION

Examination of equations (1) and (2) shows that the empirical method used here to estimate the lift and drag characteristics of arbitrary wings does not require explicit knowledge of aspect ratio or taper ratio. The significant variables are Mach number, leading edge sweep and thickness-chord ratio. It follows that when aspect ratio and taper ratio are varied by, for example, successively cutting off the tip of a delta wing, no change in the quantities

C_{DO}, dC_D/dC_L^2 and $(L/D)_{max}$ is predicted. It would be of considerable interest to check this in the present experiments. Also it will be noted that the method predicts no difference in these parameters between wings C and D.

The friction drag coefficient was assumed to be 0.006, which is approximately correct for a fully turbulent boundary layer at a Reynolds number of about 10^6. As was pointed out previously, however, there may be extensive areas of laminar flow on an aerofoil model at this Reynolds number, which may drop the local value of skin friction coefficient to as low as 0.001 (0.002 for two surfaces). For this reason it would be of interest to measure the transition position on one of the models, at least, over the low incidence range, and at several values of the Mach number.

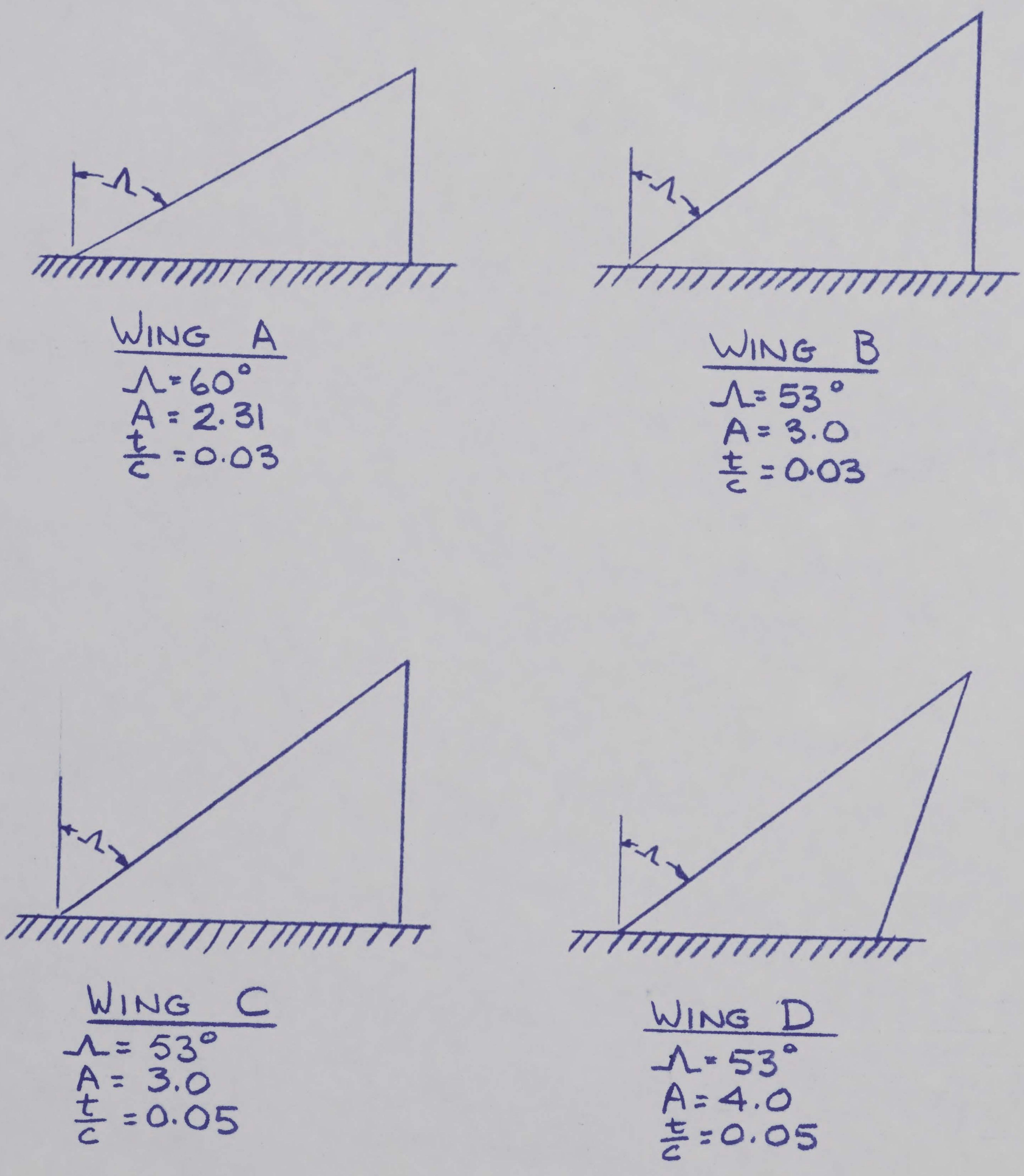
5. REFERENCES

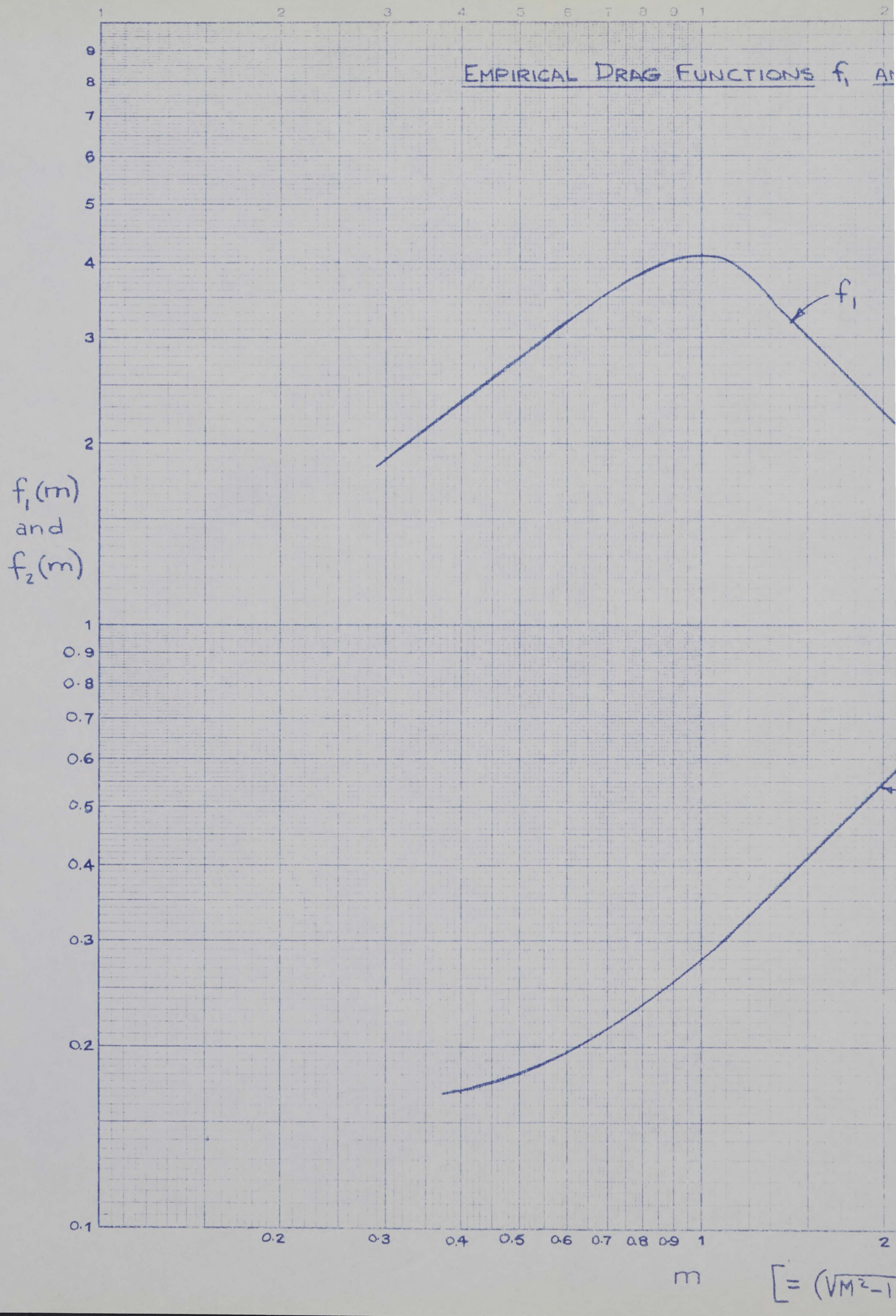
1. Satish Dhawan - Direct Measurements of Skin Friction - NACA TN 2567 January 1952.

2. R.J. Templin - A Collection and Analysis of Experimental Data on the Drag Due to Lift of Finite Wings at Supersonic Speed. NAE Laboratory Memorandum AE-10t, January 1953.

FIG. 1

MODEL HALF-WINGS

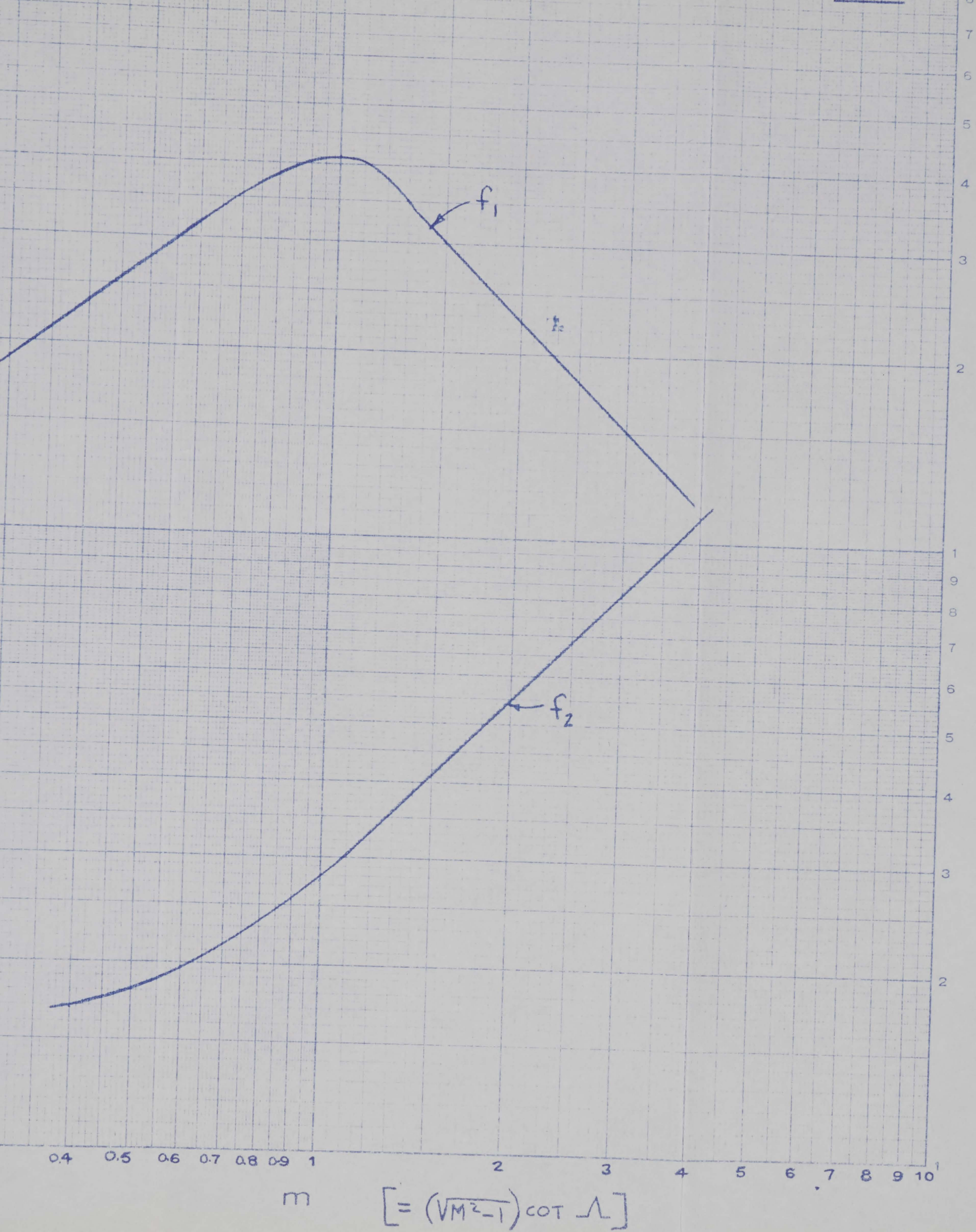




EMPIRICAL DRAG FUNCTIONS f1
f1
f1(m) and f2(m)
m

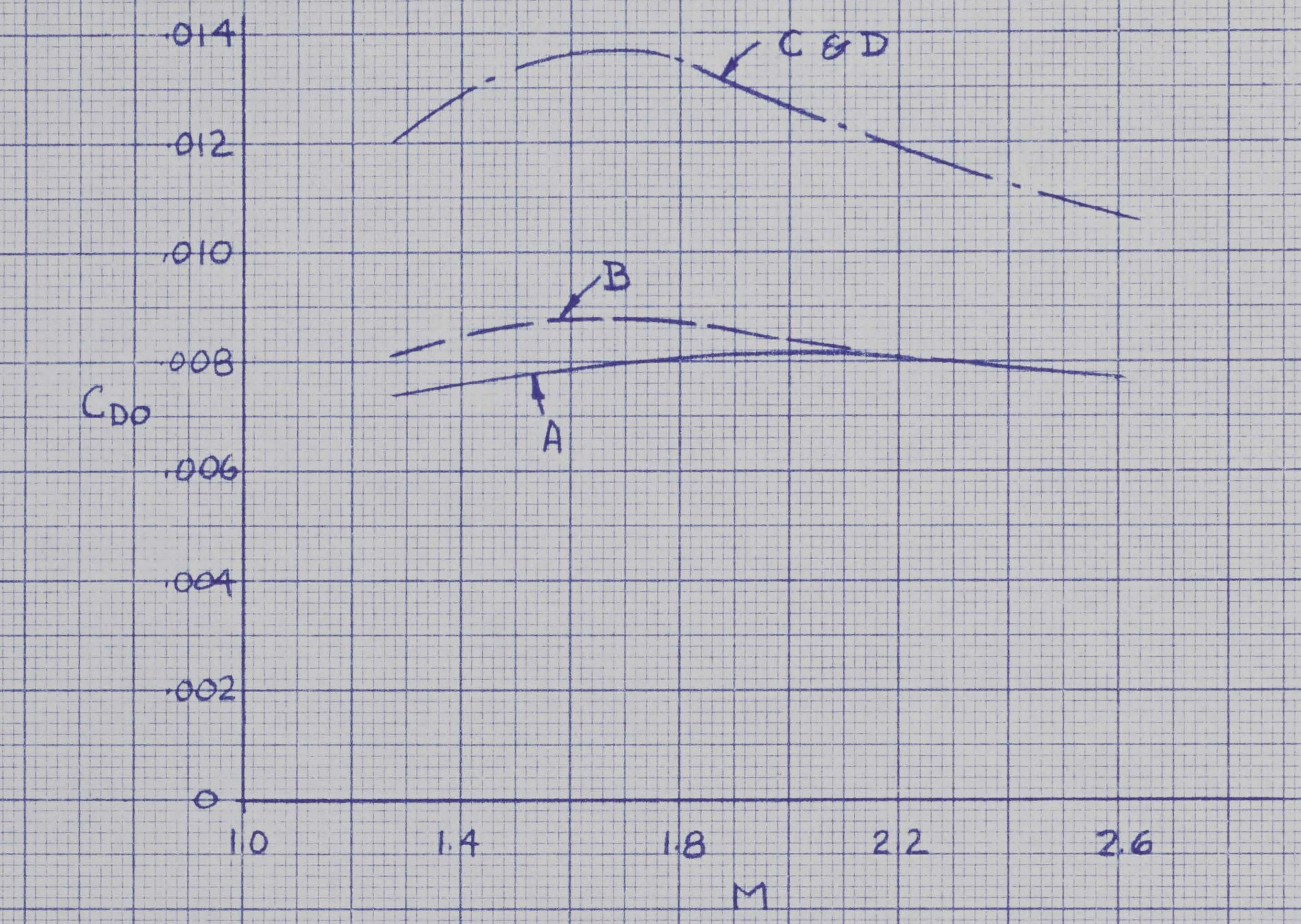
EMPIRICAL DRAG FUNCTIONS f_1 AND f_2

FIG 2



ESTIMATED MINIMUM DRAG COEFFICIENT

FIG 3



ESTIMATED DRAG DUE TO LIFT

FIG 4

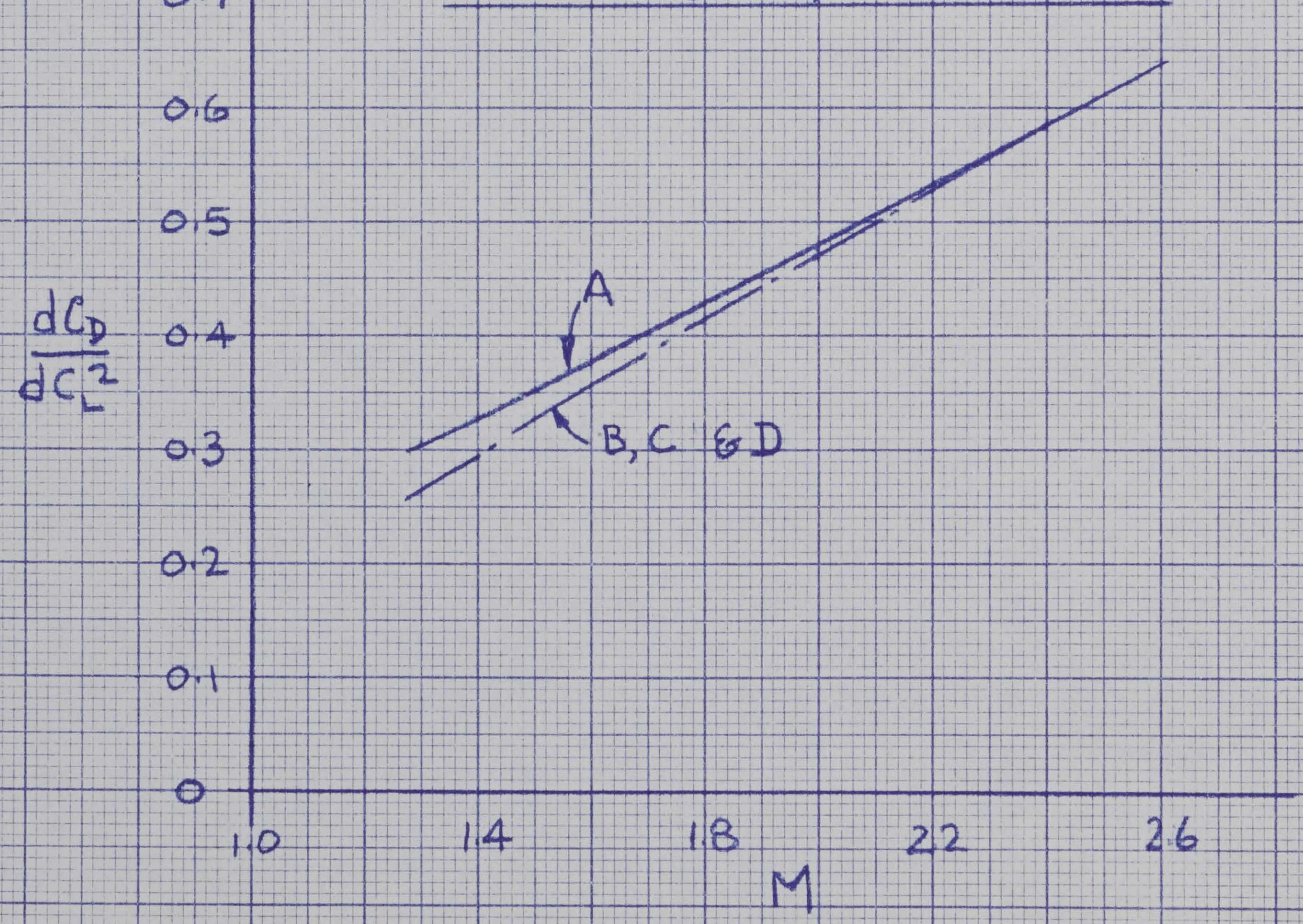
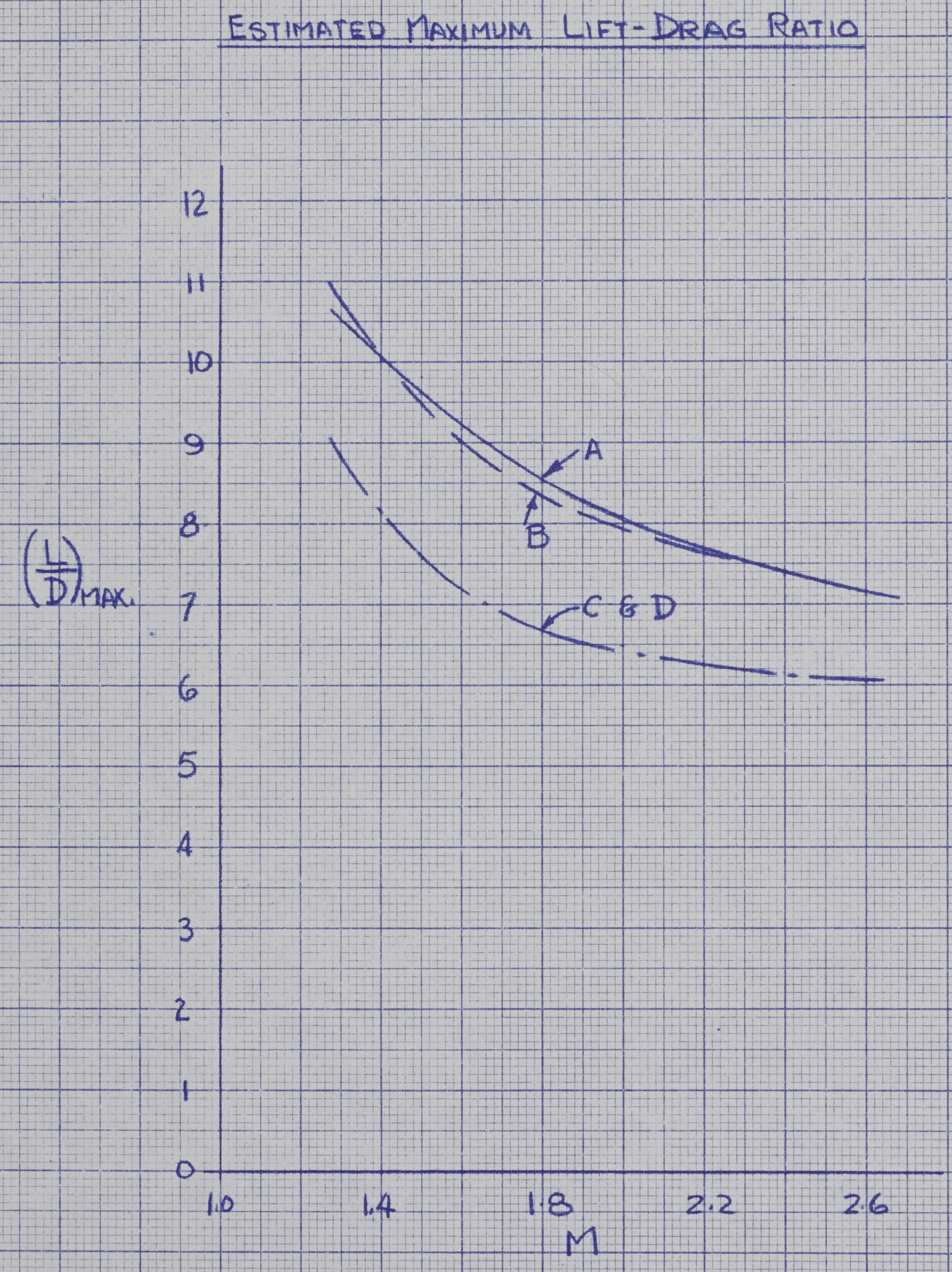


FIG 5


ESTIMATED MAXIMUM LIFT-DRAG RATIO
(L/D)MAX.
12
11
10
9
8
7
6
5
4
3
2
1
0
1.0
1.4
1.8
2.2
2.6
M
A
B
C & D