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SUBJECT A SUMMARY OF HIGH SPEED WIND TUNNEL TEST RESULTS FOR THE AVRO CF-105, AND THEIR EFFECTS ON ESTIMATED PERFORMANCE.

PREPARED BY R. J. Templin and O.E. Michaelsen

ISSUED TO Internal

SUMMARY

This note compares some of the results of model tests on the CF-105, which were carried out in the Cornell transonic tunnel, in the 4 ft. wind tunnels at NACA, Langley, and in the 16 inch x 30 inch high speed tunnel at the NAE. These results are also comparedwith estimates which were previously made by Avro and NAE of various items which affect performance.

1.0 INTRODUCTION

Over a considerable period of time wind tunnel tests have been carried out on various models of the Avro CF-105 aircraft. In the same period separate estimates of performance have been made by Avro and by the NAE, and it has been only in the last few months that actual tunnel test results have become available throughout the range of Mach numbers from about 1.4 to 2.0. The most important, and, it is believed, the most reliable of these tests were carried out in the 4 ft. supersonic tunnels of the NACA at Langley, although at about the same time results were obtained from two very small models (a 1/50 scale half model and a 1/80 scale complete model) in the NAE 16 inch x 30 inch tunnel at Ottawa.

As a result of the NACA tests, it has been found necessary to revise downward the previous estimates of performance which had been released by the Company (for example Reference 1). The new performance estimate by the Company is summarized in Reference 2. In Reference 2 it is estimated that the steady turn load factor at a Mach number of 1.5 at 50,000 ft. altitude has been decreased from 1.88 to 1.57 as a result of these tests, although some improvement (to 1.65 g's) is expected by carrying out a proposal to use a small amount of upward aileron deflection at high altitudes in order to decrease trimming drag.

The last complete performance estimate which had been made by the NAE was sent to DRB towards the end of 1955, and in it an estimated load factor of 1.29 g's was quoted. In view of the very significant difference between this value, and that given by the Company (1.88 g's) it is not surprising that there was considerable discussion concerning the accuracy of the two estimates. It would now appear from Reference 2 that a more realistic figure lies between the two.

It may be of some interest to examine in more detail the way in which various estimated quantities differed from the measurements. The separate effects of the NACA results on manoeuvring performance have been itemized by Avro in Table I of Reference 2. In this table it appears that the degradation in performance can be attributed about equally to three factors: an increase in combat weight, in minimum drag, and in drag due to lift. A negligible effect is shown as being due to changes in trim drag. It must be pointed out that the relative size of these adjustments depends on the order in which they are worked out. For example, there would be an appreciable reduction in load factor due to increased trim drag if this increment had been tabulated first instead of last. Also, a new correction for thrust moment has been applied to the data.

It is felt that a more complete picture of the implications of the NACA results can be obtained by comparing them also with the previous NAE estimate of manoeuvring load factor. This is done below.

2.0 EFFECT OF NACA MEASUREMENTS ON NAE ESTIMATE OF LOAD FACTOR

The NAE estimate of manoeuvring load factor which was made more than a year ago was 1.29 g at M = 1.5 at 50,000 ft. This was calculated for a combat weight of 50,060 lb., with the aircraft centre of gravity at 28 percent of the mean aerodynamic chord. If this value is adjusted to the weight (51,050 lb.) and centre-of-gravity position (29.5%) used by Avro in Reference 2, it becomes 1.33 g.

Although the NACA results were mainly detrimental as compared with Avro estimates, there was one quantity whose value was much more favourable than either the Avro or NAE estimates had originally indicated. This is the pitching moment at zero lift (C_{m_0}). A favourable value of this quantity reduces the elevator angle required to trim and hence reduces trimming drag. If the interpolated NACA value of this quantity at M = 1.5 is inserted into the NAE estimates instead of the old NAE value, without other change in the method, the load factor rises from 1.33 to 1.47.

There is one more adjustment required to the old estimate, which previously had not been taken into account either by Avro or NAE. As mentioned in Reference 2, a correction for thrust momentum change and for vertical position of the centre of gravity from model to full scale is now being applied. The effect of this is calculated to add approximately 0.07 to the load factor, bringing the "adjusted" NAE estimate to 1.54, a value which is in close agreement with that given by Avro in Reference 2.

It should probably be mentioned at this point that a slightly lower value than this seems to be obtained directly from the Langley drag data. The pitching moments in the Langley tests were worked out about the 28 percent chord point, but if these are transferred to the actual aircraft C.G. position at 29½ percent, so that new trim points are determined, and the total trimmed drag is read directly off their graphs, a load factor of about 1.51 seems to result (after the correction for thrust moment is applied). No reason for the discrepancy between this value and the Avro value of 1.57 in Reference 2 has been discovered. The discrepancy is small enough, however, that perhaps it can be considered to be relatively unimportant.

The main implication is that of all the aerodynamic quantities previously estimated by NAE, a change in only one is required to bring the calculated performance into close agreement with that indicated by the tunnel tests. This does not necessarily mean that all other estimated quantities were correct, since some may have been pessimistic and others optimistic. As a matter of fact, however, a comparison of NAE estimates with NACA measurements, item by item, shows that the NAE estimates were either very accurate, or were slightly optimistic (except, of course, for C_{m_0}). This more detailed comparison is carried out in the following paragraphs.

3.0 COMPARISON OF ESTIMATED AND MEASURED VALUES OF AERODYNAMIC PARAMETERS

3.1 Minimum Drag

The minimum drag coefficient varies slightly over the supersonic range. At M = 1.5, the value now assumed by Avro as a result of the NACA tests is 0.0230. The NAE estimate was 0.0233, and the value most recently used by Avro in performance calculations was 0.020.

3.2 Drag Due to Lift

In Reference 2 it is pointed out by Avro that their estimate of drag due to lift was lower than the values obtained by the NACA. The definition of drag due to lift is simply the difference between the drag coefficient at any lift coefficient, and the minimum drag coefficient, with the elevators set at zero deflection in both cases.

Avro compare the NACA measurements with their estimated values of $C_{L_{C_{D_{min}}}}$, the lift coefficient for minimum drag, and e, the so-called efficiency factor which is related to the curvature of the parabolic drag polar. The actual value of drag due to lift at any lift coefficient is, of course, a function of both of these quantities and they can not be discussed separately. In fitting a parabola to the measured data it is quite possible to obtain different values of each of these two quantities without actually changing the drag coefficient appreciably over the interesting range of lift coefficients. As a matter of fact, in NAE attempts to do this for the Langley data, a somewhat more positive (i.e., more optimistic) value of $C_{L_{C_{D_{min}}}}$ is obtained than that shown in Ref. 2, but a lower value of e is obtained.

In order to sidestep this issue and to directly compare measurements of drag due to lift with previous estimates, Figures

1, 2, 3 and 4 have been prepared. Usually the quantities plotted in this way are the drag coefficient versus the square of the lift coefficient. For aeroplanes which have a symmetrical parabolic drag polar this will produce a straight line. However, for the CF-105, due to the effect of wing camber and of the otherwise asymmetric configuration, the drag polars are displaced towards positive lift coefficients and a straight line would not result. The situation is restored by plotting instead the quantity $\sqrt{C_D - C_{D_{min}}}$ versus lift coefficient. A reasonable straight line still results, which intersects the C_L axis at the value of C_L for minimum C_D. In these figures, the results of NACA and NAE measurements are compared with previous estimates by Avro and the NAE.

It appears that the NAE estimates of drag due to lift were accurate (when compared with NACA measurements). The NAE measurements were in general somewhat more pessimistic than the estimate.

3.3 Trim Drag

The trim drag of the aircraft can be conveniently defined as the difference between the total drag coefficient in trimmed flight, and the drag coefficient at the same lift coefficient with the elevators set at zero deflection. This quantity has, in the past, been the one which generated most discussion because of the rather large differences between NAE and Avro estimates. It can be said to be a function of two main parameters: the drag increment due to a given elevator deflection, and the elevator angle required to trim. Previous estimates differed from one another only with respect to the latter quantity; there had been general agreement on the drag increment due to any given elevator angle, whereas the estimates of elevator angle required was the subject of discussion.

In Figure 7 of Reference 2, the drag increment for a given elevator angle is plotted by Avro, and it is stated that a single curve represents both the Avro estimate and the Langley data at a Mach number of 1.5. This curve has been reproduced also in Figure 5 of the present note. Actually it will be found that in Figure 5, the NACA data seems to give a slightly different curve to that plotted by Avro, and in fact that it agrees more closely with the NAE estimate. However, the drag coefficient scale used in this graph is an expanded one, and since the maximum difference between any of the curves is not more than about 0.001 in C_D, the differences are hardly significant. The NACA graphs can scarcely be read to greater precision.

The elevator angle required to trim the aircraft was the quantity which differed greatly between Avro and NAE estimates. It can be shown that the elevator angle is given by the expression

$$\delta_e = \frac{-C_{m_0} - \frac{dC_m}{dC_L} C_L}{C_{m_\delta}}$$

where C_{m_0} is the zero lift pitching moment coefficient.

$\frac{dC_m}{dC_L}$ is the static margin of the aircraft.

C_{m_δ} is the elevator effectiveness parameter at constant lift coefficient.

The static margin is a function of the aerodynamic centre position and the centre of gravity position. Thus the estimation of elevator angle required to trim at a given lift coefficient depends on the estimation of three aerodynamic quantities, C_{m_δ}, C_{m_o} and aerodynamic centre position. The differences in previous estimates were chiefly due to a difference in the estimated value of C_{m_δ} although the NAE estimates were more pessimistic for the other two quantities as well.

As a result of the NACA tests it now appears that the Avro estimate of elevator angle to trim (and hence of trim drag) was accurate at load factors of about 1.5 at a Mach number of 1.5 at 50,000 ft., because optimism in the estimation of C_{m_δ} is now counteracted by a favourable value of C_{m_o}, and also by the application of a new correction for thrust moment, which is favourable.

In order to obtain a complete picture of all of these effects, the three aerodynamic quantities mentioned above are plotted in Figures 6, 7 and 8.

3.3.1 C_{m_o}

Values of C_{m_o} according to the two estimates are compared in Figure 6 with the measurements made at Cornell and at NACA and NAE. It will be noticed immediately that the NACA measurements stand somewhat apart from the other data. The results from Cornell and from the two models tested at NAE appear to be consistent with one another. The estimates made by Avro and by NAE differ somewhat from one another, but were both extrapolations based on the Cornell data as an end point. They differ in shape from the supersonic tunnel measurements but cross over the curves obtained in the NAE tunnel.

Because of the large scale model used in the Langley tests, it is reasonable to expect that they are the more reliable, but the question should probably be kept open to some extent because of the large effect of C_{m_0} on manoeuvrability. The difference between the old value assumed by NAE, and that now given by the NACA produces a difference of roughly 0.15 g in thrust limited load factor at M = 1.5 at 50,000 ft. It is difficult to account for the measured differences, but two or three possibilities suggest themselves. Slight flow curvature in a wind tunnel at the model location produces the same effects as wing camber, and hence can change C_{m_0}. This effect can be checked and corrected by testing the model in the upright and inverted positions, but as far as is known, this was not done in any of the tunnels. It is intended to do such a test using the 1/80 scale model at the NAE as soon as time permits. It is interesting to note, however, that both models in the NAE tunnel produced the same curve. It will also be noted in Figure 6 that a value of C_{m_0} was obtained by the NACA with the intakes faired, which is in close agreement with the estimates and with other measurements at a Mach number of 1.41. This may suggest that in the other tests the intakes were not running full. However, it is understood that the model used in the Cornell tests was almost identical with that in the NACA tests, and furthermore, although the NAE models were much smaller, the test Reynolds number was not greatly different. It is intended to carry out a further check test at the NAE with similarly faired intakes to determine whether in this case also there is a resulting decrease in C_{m_0}. Another possibility which may account for differences is that a moment transfer calculation may have been carried out with the wrong sign in one or more of the tunnel tests. This has been thoroughly checked in the NAE case, but is not so easily done for the NACA results. It is only a remote possibility, because such simple mistakes are not often made.

There is a possibility that further checks on the correct value of C_{m_0} may be obtained from the free flight rocket model firings, since they are carried out at nearly zero lift. It is not known whether this has already been done by the Company.

3.3.2 Aerodynamic centre position

In Figure 7, the aerodynamic centre position is plotted against Mach number. With the exception of the 1/50 scale half model tests, the measured results appear to agree more closely with the NAE estimate than with the Avro estimate, at least in the medium supersonic range. Since the aerodynamic centre seems to be some 2 percent further aft than that estimated by the Company at a Mach number of 1.5, their estimates of elevator angle to trim would be slightly optimistic as a result.

3.3.3 C_{m_δ} at constant C_L (Elevator effectiveness)

In Figure 8, C_{m_δ} is plotted against Mach number.

This was the quantity which had generated the most lengthy discussions, since it appeared to be the one which differed appreciably in the two sets of estimates. The NAE method of estimation was an extrapolation method which therefore depended on the accuracy of the Cornell data. It is understood that the Avro curve was originally also obtained by an extrapolation method, but later was supported by the introduction of a new and somewhat more elaborate procedure which was thoroughly discussed by Avro in Reference 3. It now appears that this method was in error since at Mach numbers in the neighbourhood of 1.5, the Langley data (and also that obtained in the NAE tunnel) falls approximately 20 percent below the Avro estimate, and also seems to fall slightly below the NAE estimate. The discrepancy increases with increasing Mach number.

Fortunately at low load factors (in the neighbourhood of 1.5) at 50,000 ft., and at M = 1.5, the new value of C_{m_δ} is counteracted by the new and favourable value of C_{m_0} obtained by the NACA. At higher load factors, however, the elevator angles required to trim will now be considerably larger than those originally estimated, and although the RCAF specification does not refer to unsteady manoeuvres, they are of considerable importance in interception manoeuvres. The maximum load factor as limited either by maximum elevator angle or maximum available hinge moment will now be considerably reduced.

3.3.4 Elevator angle to trim

In Figure 6 of Reference 2, the elevator angles required to trim the aircraft are plotted against load factor at M = 1.5 at 50,000 ft. This figure is reproduced as Figure 9 in the present note, with a new curve added for comparison. The new curve is the original NAE estimate (corrected to 29½ percent C.G. position and to the new aircraft combat weight). It will be seen that while the NAE curve is parallel to that now given by the Langley tests, it differs from it by approximately four degrees of elevator angle. This difference is accounted for mainly by the new value of C_{m_0}, although one degree is due to the new thrust and drag moment correction.

Figure 9 illustrates further that the load factor as limited by available elevator deflection (30 degrees) must be considerably reduced and will be in the neighbourhood of 3 g's at combat speed and altitude.

3.4 Total Trimmed Drag

Figure 10 has been prepared to summarize the total drag and load factor situation at a Mach number of 1.5. Total drag coefficient is plotted against lift coefficient, and an auxiliary scale has been added so that load factor can be read off directly. Actually the load factor scale would be different for other aircraft combat weights, and that shown was calculated for 51,050 lb., given by Avro in Reference 2.

The combat thrust at 50,000 ft. has been reduced to coefficient form and plotted in Figure 10 so that the thrust limited load factor can be read directly. It will be noticed that the curve labelled Avro, May 1956, gives a load factor of 1.79, rather than 1.88. The reason for the difference is merely that the load factor scale applies to the new increased combat weight. It should also be pointed out that in this graph no correction is applied for thrust moment, in order to provide a comparison of aerodynamic data. It appears that the Langley results lie approximately one-third of the distance between the old NAE estimate (after adjustment to the new weight and to 29½ percent C.G. position) and the old Avro estimate (after adjustment to the new weight). The curve labelled "Langley Tests" is as read directly from the NACA graphs, followed by an interpolation to 1.5 Mach number.

4.0 MAXIMUM LOAD FACTOR AS LIMITED BY ELEVATORS

It has already been pointed out that although the previous Avro estimates of elevator angle to trim were accurate at a load factor of about 1.5 g's at a Mach number of 1.5 at 50,000 ft., they are considerably optimistic at higher load factors. It is quite likely that under combat conditions the use of tighter manoeuvres would often be resorted to in order to reduce the turning radius and to decelerate. At a load factor of 1.57 at M = 1.5, the turning radius is more than 10 miles.

At 50,000 ft. altitude the limitation on maximum load factor is the elevator angle available to trim. The maximum elevator deflection is 30 degrees, but at Mach numbers approaching 2, this angle may not be achievable because of hinge moment limitations. Figure 11 has been prepared to show the estimated limitations based on the Langley tests. These estimates are superimposed for comparison on a figure taken from the Avro brochure dated September 1954 (Reference 4). The estimates shown have not been corrected for thrust moment and so are slightly low. They will serve, however, to show the order of the limitations, and the amount by which these have decreased from earlier estimates.

It should also be pointed out that the favourable effect of deflecting ailerons upward has not been taken into account in this calculation, and since this is estimated by Avro to reduce the elevator angle by about 2 degrees, there would be a further small increase in these limitations (approximately 0.2 g's).

Figure 11 indicates that the maximum load factor as limited by elevator deflection may be decreased from about 5 g's to about 3 g's at a Mach number of 1.5 at 50,000 ft.

The importance of the limiting load factor is difficult to assess but studies such as that at present in progress at CARDE may answer the question.

5.0 REDUCTION OF TRIM DRAG BY MEANS OF AILERON DEFLECTION

In Reference 2 the suggestion is made that trim drag can be reduced, and performance improved, by using aileron deflection to assist in longitudinal trim at high altitudes.

The NAE has made no independent estimate of the effectiveness of the ailerons for this purpose, mainly because it was believed that the aeroelasticity of the wing would have to be taken into account in making an accurate estimate, and no aeroelastic data is available. The pitching moment with one aileron deflected downward was measured in the NACA tests at a Mach number of 1.41, and it appears to be close to one-half of that due to deflecting elevators the same amount. Thus for the rigid aeroplane it might be expected that a given upward deflection of the ailerons (both in the same sense) would result in a reduction of elevator angle equal to about one-half of this amount. In Figure 9, the elevator angle to trim is shown as given by Avro in Reference 2 with the ailerons deflected upwards by 4 degrees. It will be seen that the aileron deflection is estimated to result in a 2 degree reduction in elevator angle. It is understood that the estimate has been corrected for aeroelastic effects, and it follows that these must be small.

Reference 2 does not make it clear whether the drag of the deflected ailerons has been added in calculating load factor. No estimate of this additional drag has been made by the NAE, although this could be done by using a method similar to that developed by Morris at Avro for calculating elevator drag.

6.0 EFFECT OF NEW DRAG DATA ON COMBAT WEIGHT

The combat weight is defined as being the weight of the aircraft with missiles unfired, but with only one-half of the fuel required for the high speed combat mission. Since the fuel required is a function of the aircraft drag throughout the mission, the combat weight must be recalculated whenever the drag estimates are revised. In the present case, the NAE has not attempted to do this because it is a somewhat lengthy calculation to carry out accurately.

In Reference 2 the Company state that of the total increase of 2350 lb. in combat weight, only 250 lb. is due to an increase in combat fuel. This is surprisingly low in view of the rather large revision in drag estimates. It is also stated in Reference 2, however, that some numerical errors in previous calculations have been corrected and it may be that the apparently small increase in fuel weight is a reflection of this fact.

7.0 CONCLUSION

As a result of an assessment by the NAE of the NACA wind tunnel results for the CF-105, and of a comparison with other data and with previous estimates, the following conclusions have been reached.

1. In approximate agreement with the figure given in Reference 2, it is concluded that the NACA results indicate a revised steady load factor between 1.5 and 1.6 should be achievable for an aircraft weight of 51,050 lb. at a Mach number of 1.5 at

50,000 ft. (if no account is taken of the favourable effect of deflecting ailerons upward). This value is to be compared with that given by Avro (1.88 g) in Reference 1, and the value estimated by NAE (1.29 g) towards the end of 1955. The increase in load factor due to upward deflection of the ailerons has not been estimated, but probably would not differ greatly from the increase given in Reference 2 (approximately 0.8 g).

2. The previous value of the load factor calculated by Avro appears to have been too high due to optimistic estimates of almost all of the aerodynamic parameters involved. Although Reference 2 indicates that previous estimates of trim drag were accurate, this is true only at the low load factor now achieved.

3. The previous NAE estimate appears to have been too low mainly due to a pessimistic estimate of the pitching moment at zero lift, which, in the NACA measurements, is twice as large as the NAE estimate at a Mach number of 1.5 and about 70 percent larger than the Avro estimate. There may still be some doubt as to the accuracy of the NACA result, but it should be possible to obtain checks from other sources.

4. A detailed comparison of NAE estimates with measured values of other aerodynamic parameters shows remarkable agreement in all cases.

5. A comparison of total trimmed drag at a Mach number of 1.5 indicates that the NACA data lies considerably closer to the previous NAE estimate than to the Avro estimate. (See Figure 10).

6. The favourable value of pitching moment at zero lift, which was found in the NACA tests, counteracts, at low lift

coefficients, the optimistic estimate of elevator effectiveness which had been made previously by Avro. At higher lift coefficients, however, this effect begins to fade out, with the result that the elevator angles to trim at high load factors are now considerably increased, and the maximum load factor as limited by available elevator deflection must be reduced below that previously given by the Company. The effect of this on combat effectiveness can probably be assessed in studies at present being carried out by DRB at CARDE.

8.0 REFERENCES

1. CF-105 Monthly Performance Report No. 8, May, 1956.
2. Effect of NACA Wind Tunnel and Free Flight Tests on the Estimated Performance of the CF-105, Avro Report dated October 1956.
3. Note on Elevator Power and Pitching Moment at Zero Lift of CF-105, Avro Report P/Stability/97, Jan. 1956.
4. Twin Engine Supersonic All-Weather Fighter CF-105, Avro Canada Brochure dated 23 September 1954.

RJT/FM

FIGURE 1

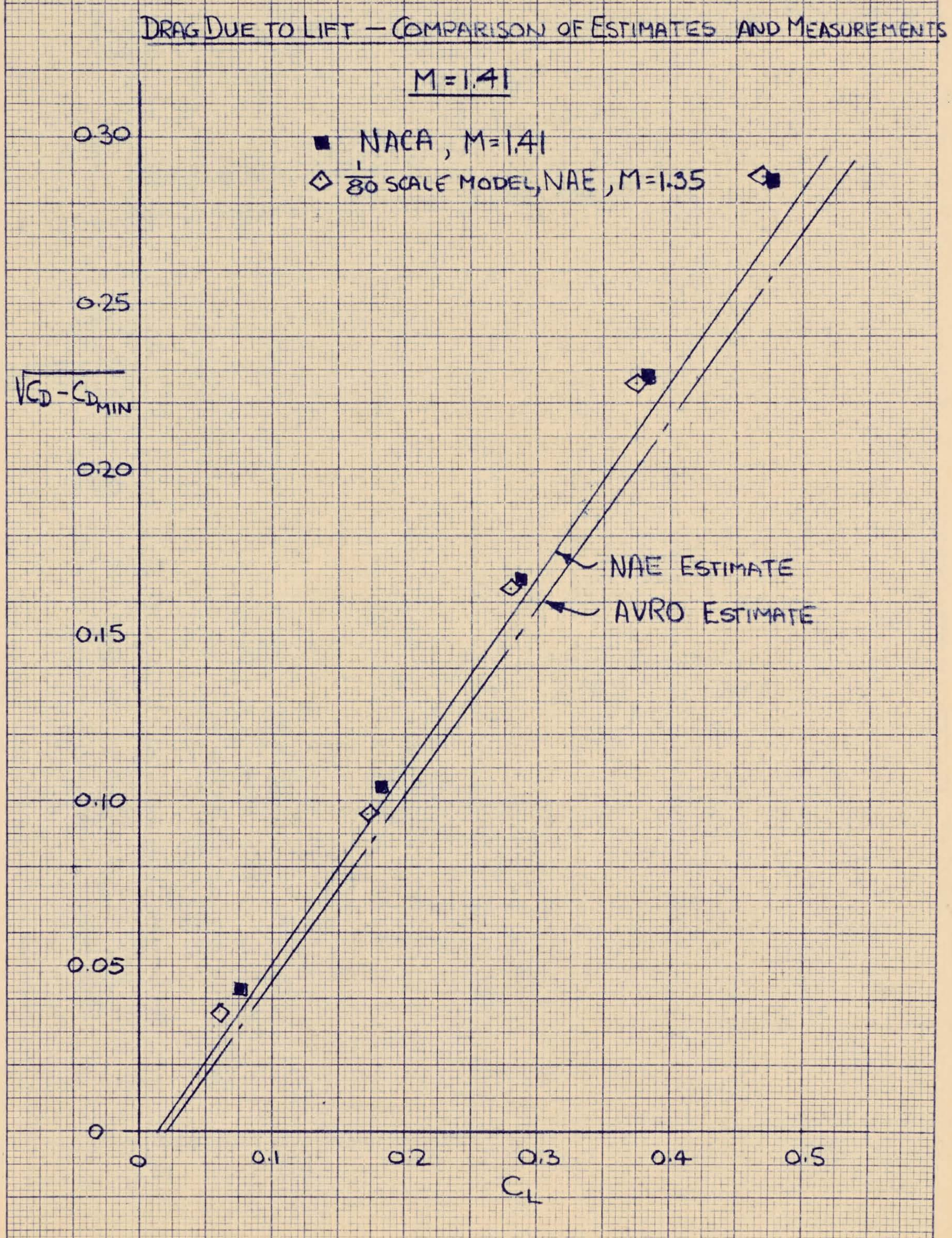
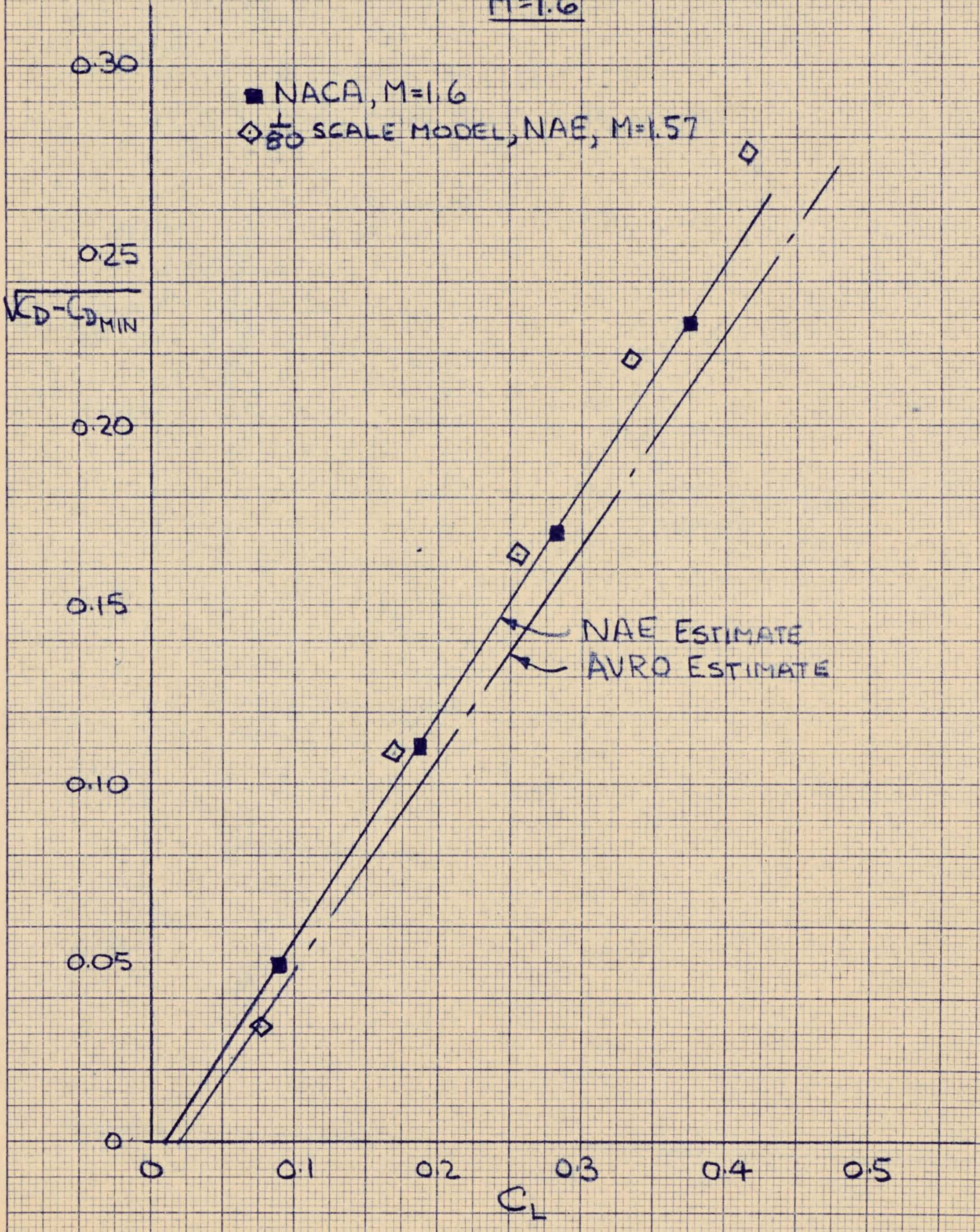

DRAG DUE TO LIFT — COMPARISON OF ESTIMATES AND MEASUREMENTS
M = 1.41
NACA, M = 1.41
1/80 SCALE MODEL, NAE, M = 1.35
NAE ESTIMATE
AVRO ESTIMATE
0.30
0.25
0.20
0.15
0.10
0.05
0
0
0.1
0.2
0.3
0.4
0.5
$\sqrt{C_D - C_{D_{MIN}}}$
C_L

FIGURE 2

DRAG DUE TO LIFT – COMPARISON OF ESTIMATES AND MEASUREMENTS

M=1.6



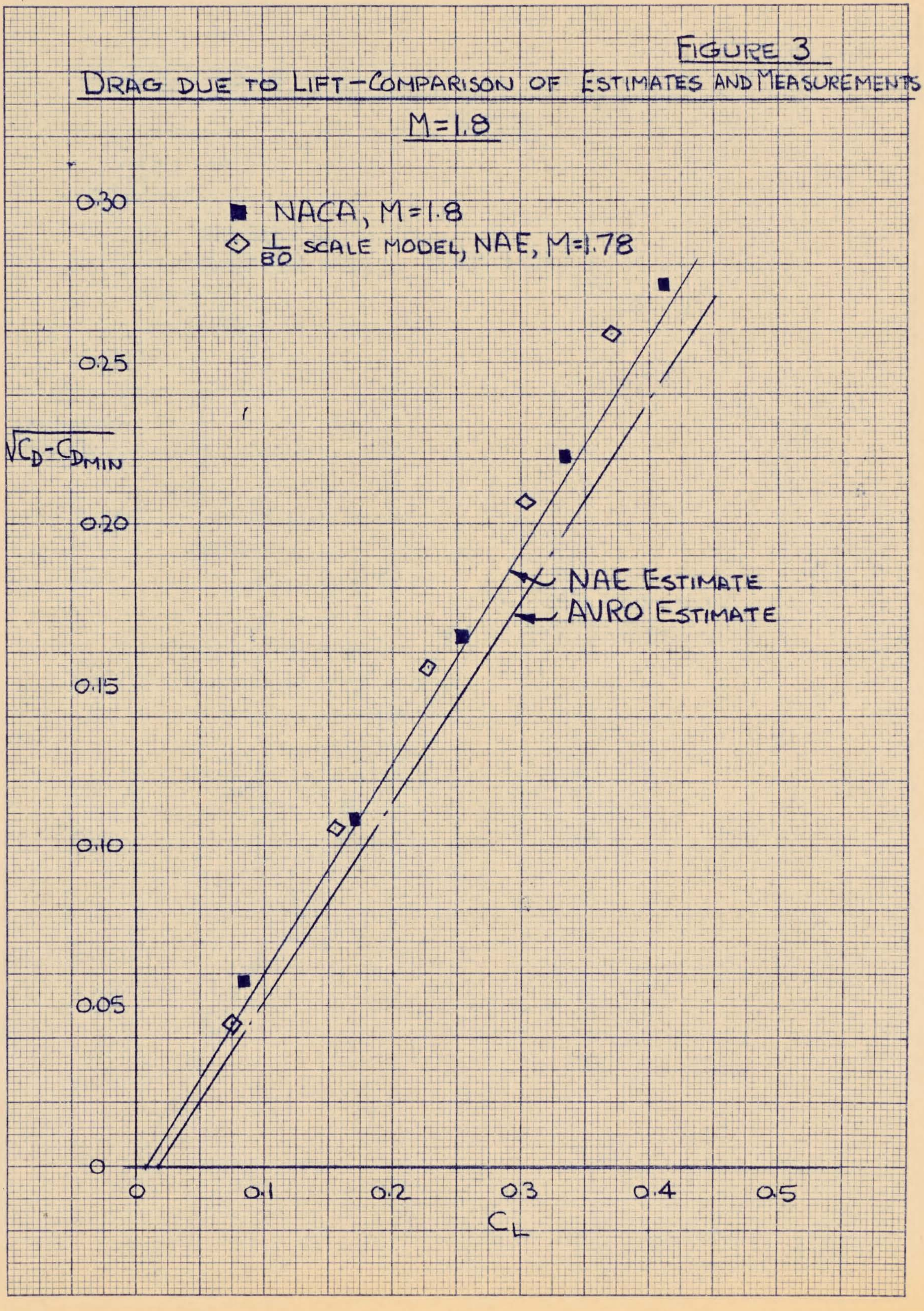


FIGURE 3
DRAG DUE TO LIFT—COMPARISON OF ESTIMATES AND MEASUREMENTS
M=1.8
NACA, M=1.8
1/80 SCALE MODEL, NAE, M=1.78
NAE ESTIMATE
AVRO ESTIMATE
$\sqrt{C_D - C_{D_{MIN}}}$
0.30
0.25
0.20
0.15
0.10
0.05
0
0
0.1
0.2
0.3
0.4
0.5
C_L

FIGURE 4

DRAG DUE TO LIFT - COMPARISON OF ESTIMATES AND MEASUREMENTS

M=2.0

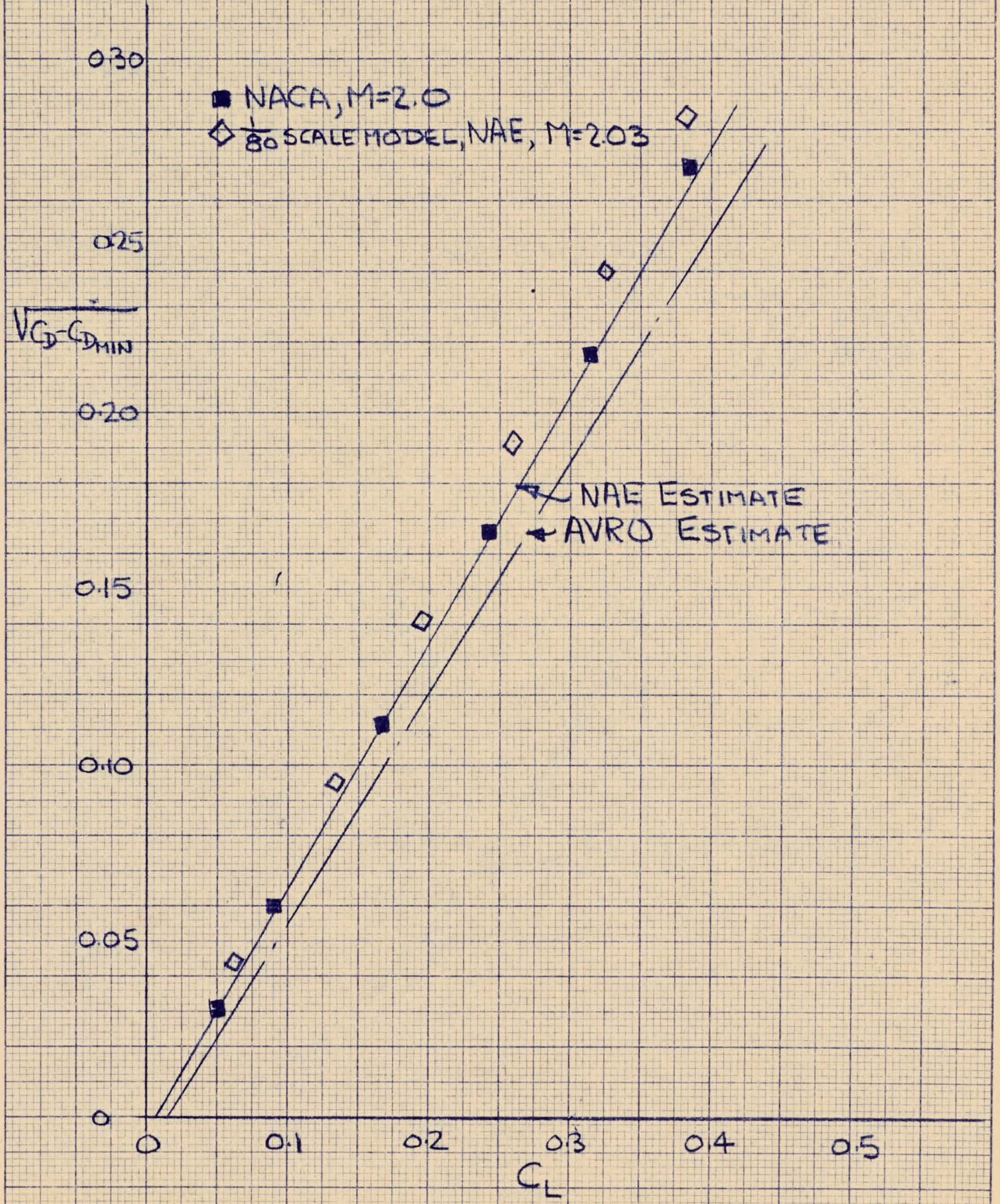
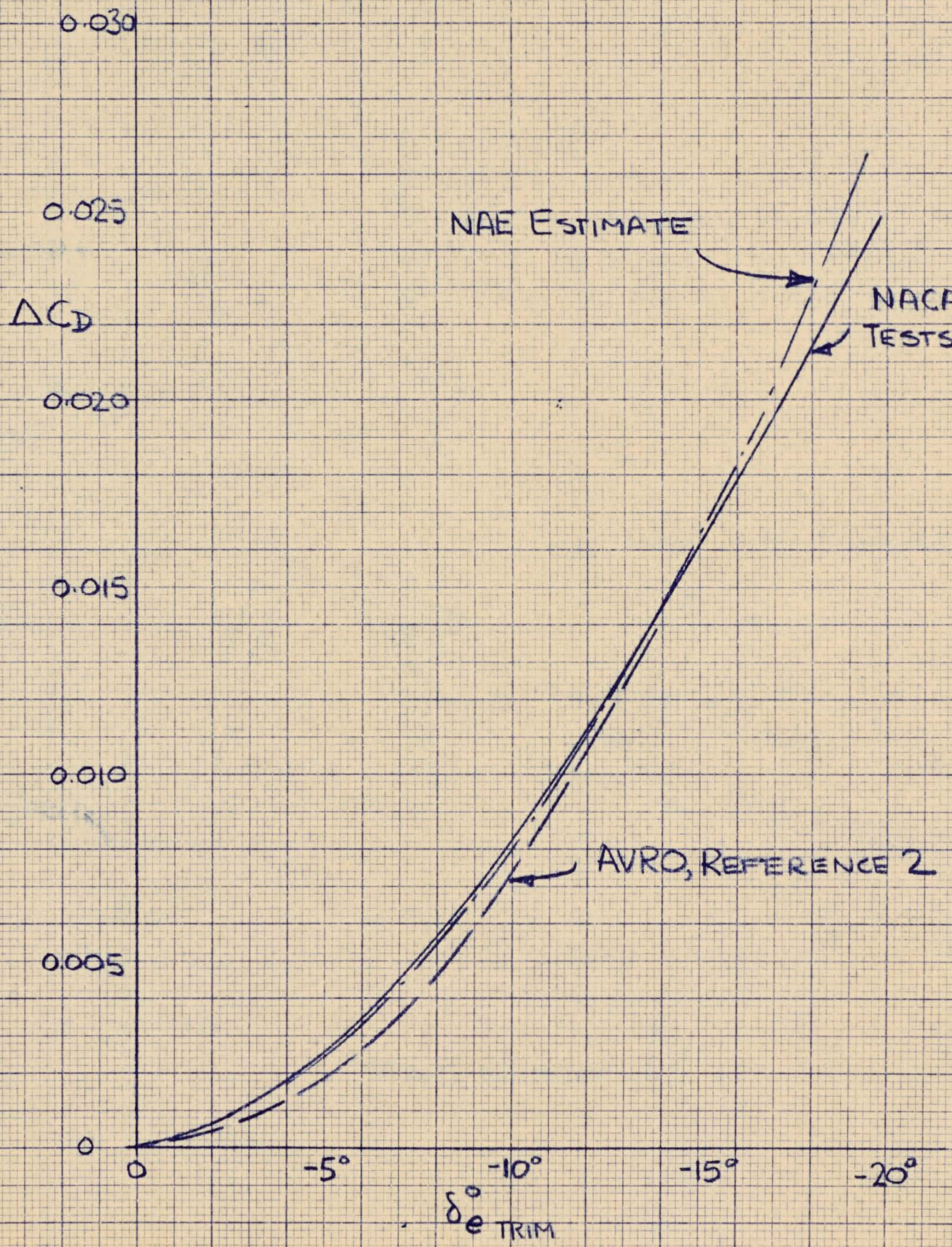


FIGURE 5

DRAG INCREMENT TO TRIM VERSUS ELEVATOR ANGLE

M = 1.5



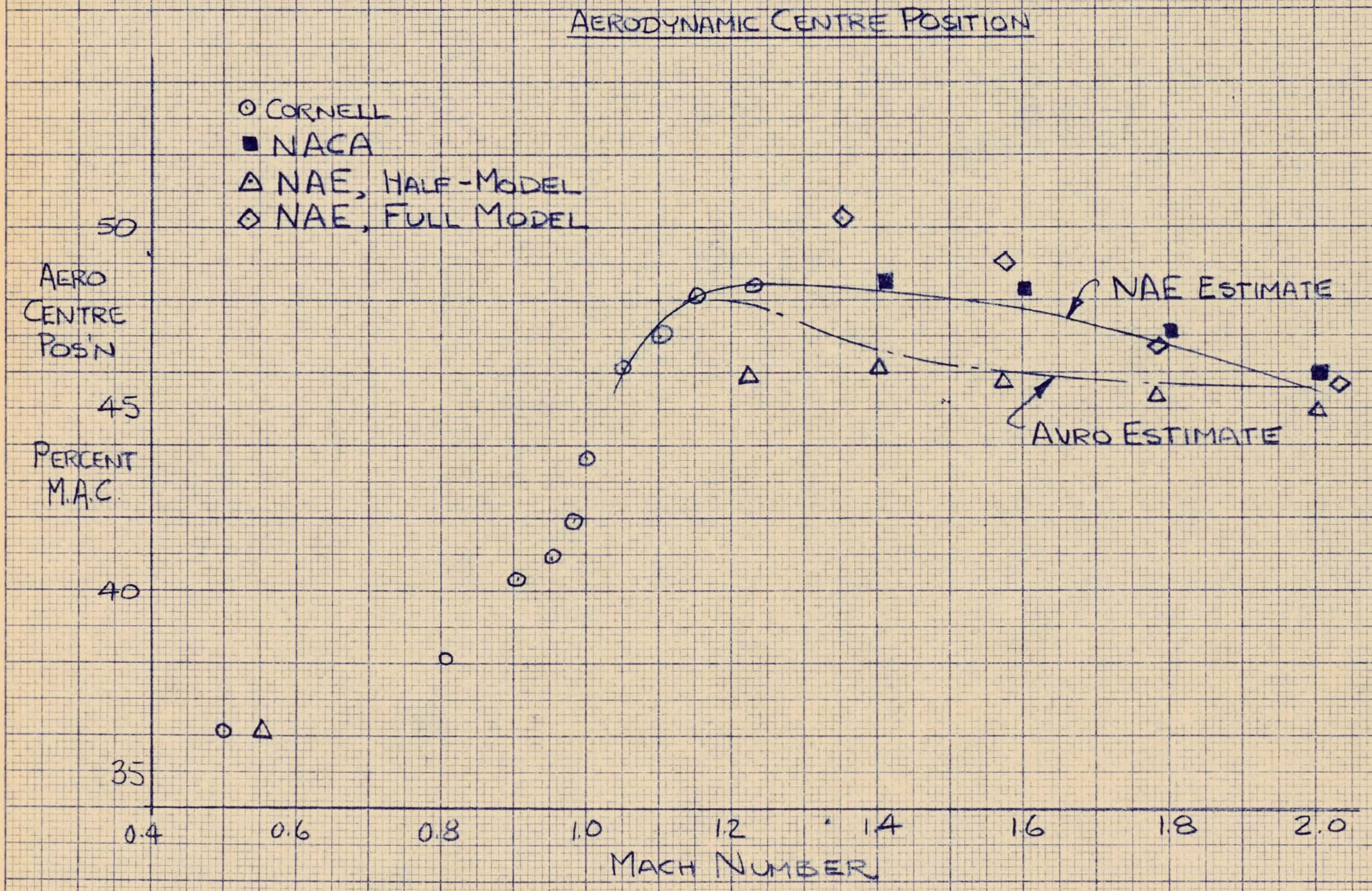

AERODYNAMIC CENTRE POSITION
CORNELL
NACA
NAE, HALF-MODEL
NAE, FULL MODEL
AERO CENTRE POS'N PERCENT M.A.C.
50
45
40
35
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
MACH NUMBER
NAE ESTIMATE
AVRO ESTIMATE

FIGURE 7

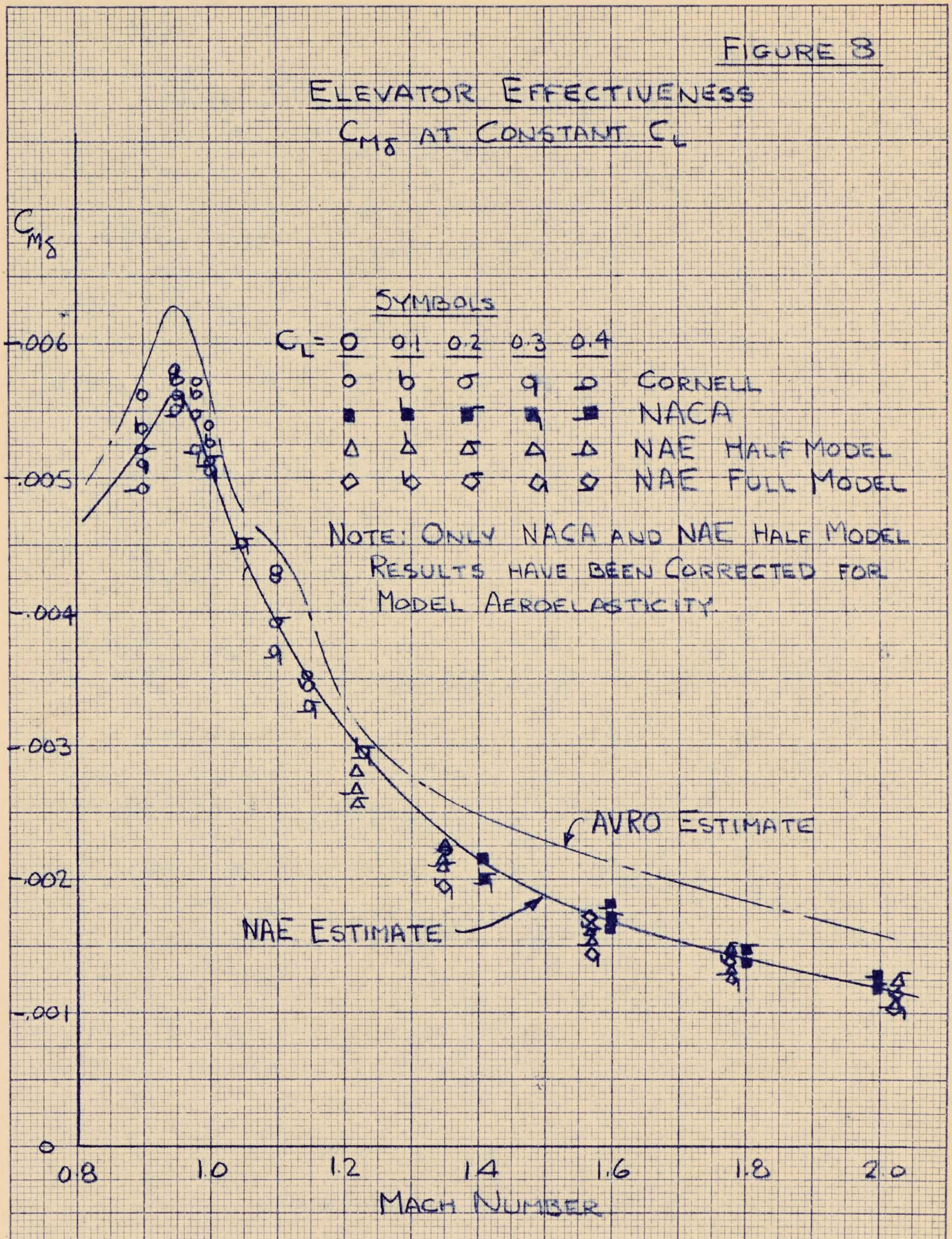


FIGURE 8
ELEVATOR EFFECTIVENESS
C_{M_δ} AT CONSTANT C_L
C_{M_δ}
SYMBOLS
C_L = 0 0.1 0.2 0.3 0.4
CORNELL
NACA
NAE HALF MODEL
NAE FULL MODEL
NOTE: ONLY NACA AND NAE HALF MODEL RESULTS HAVE BEEN CORRECTED FOR MODEL AEROELASTICITY.
AVRO ESTIMATE
NAE ESTIMATE
-.006
-.005
-.004
-.003
-.002
-.001
0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
MACH NUMBER

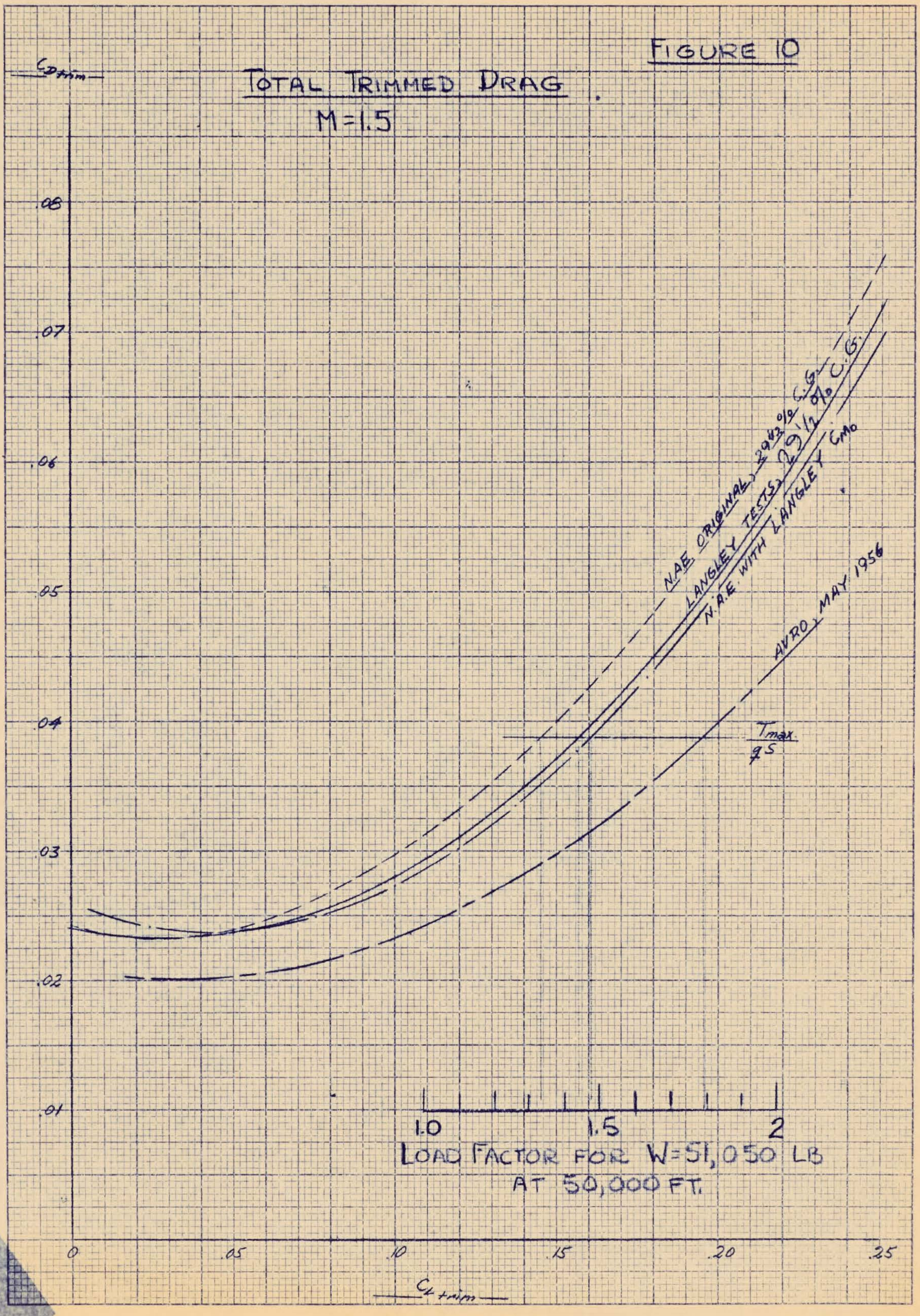


FIGURE 10
TOTAL TRIMMED DRAG
M=1.5
$C_{D_{trim}}$
.08
.07
.06
.05
.04
.03
.02
.01
0
.05
.10
.15
.20
.25
$C_{L_{trim}}$
NAE ORIGINAL, 29 2/3 % C.G.
LANGLEY TESTS, 29 1/2 % C.G.
N.A.E. WITH LANGLEY C_{M_0}
AVRO, MAY 1956
$\frac{T_{max}}{qS}$
1.0
1.5
2
LOAD FACTOR FOR W=51,050 LB
AT 50,000 FT.

FIGURE 11

PERFORMANCE FLIGHT ENVELOPE AT 50,000 FT