SC 1004-A (3-55)

[redacted]

1994

[redacted]

Tech[redacted] Memo[redacted]

[redacted]

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 6-18-81 Authority: ☐ ADC ☒ ADD CCRP-RR Name:	Determination (Circle Numbers): 1. Classification Retained 2. Classification Changed to: U 3. Contains No DOE Classified Information 4. Coordinate With: 5. Contains UCAI? 6. Comments: un classified
2nd Review Date: 12-16-96 Authority: ADD Name: W Loeper	

SCTM-233-55-51

AN EMPIRICAL METHOD FOR PREDICTING THE ZERO LIFT TRANSONIC DRAG RISE OF LOW DRAG FIN-STABILIZED STORES AS A FUNCTION OF FINENESS RATIO AND MAXIMUM THICKNESS LOCATION

Arnold L. Ducoffe*

ABSTRACT

Data are presented on the variation of zero lift profile drag coefficient, above the drag rise Mach number, as a function of fineness ratio for fin-stabilized bodies of revolution of the Douglas Aircraft type. Also shown are the effects of maximum thickness position on the zero lift profile drag coefficient as a function of Mach number and fineness ratio.

C 1023

[redacted]

INVENTORIED DATE 3-22-69

DOWNGRADING OR DECLASSIFICATION STAMP	
CLASSIFICATION CHANGED TO: U Emelda Selph PERSON CHANGING MARKING & DATE R. T. [illegible] PERSON VERIFYING MARKING & DATE	AUTHORITY: CCRP-RR RECORD ID: 97SN147 DATED: 12/16/96

Case No. 409.04

October 19, 1955

* Associate Professor of Aeronautical Engineering, Georgia Institute of Technology and Consultant to Aerodynamics Department, Sandia Corporation.

UNCLASSIFIED

[redacted]

UNCLASSIFIED

DISTRIBUTION:
R. W. Henderson, 1200
L. A. Hopkins, Jr., 1300
G. E. Hansche, 5140
R. W. Shephard, 5120
J. P. Cody, 1320
W. J. Howard, 1330
C. H. DeSelm, 1210
W. A. Gardner, 1280
S. A. Moore, 1326
A. L. Ducoffe, Georgia Institute of Technology (2)
FC/AFSWP, Major L. A. Barnes
AFSWC, Col. L. V. Skinner (3)
Attn: Development Directorate
Attn: 4925th Test Group, Mr. Harry Gogan
Attn: COMMANDER, NASWF
Ira H. Abbott, NACA, Washington 25, D. C. (2)
W. T. Ryan, 2322, (2) to be forwarded to
Douglas Aircraft Co., Inc., El Segundo, California,
Attn: Mr. E. H. Heinemann for R. B. Smith
Chance Vought Aircraft, Incorporated, Grand Prairie, Texas
Attn: Mr. George E. Beers
R. K. Smeltzer, 1922-2
H. M. Willis, 1923 (6)

3 Cys. U. S. AEC. Div. of Tech. Inf. Extension, Oak Ridge, Tennessee.
4 Cys L. C. Guynes 3425

Org. 3413 (2)

TABLE OF CONTENTS

	Page
SUMMARY	3
INTRODUCTION	3
DISCUSSION	3
RESULTS	5
CONCLUSIONS	8
LIST OF SYMBOLS	9
REFERENCES	10
APPENDIX	12

SUMMARY

This paper presents an empirical method from which the zero lift transonic profile drag coefficient rise of fin-stabilized bodies of revolution (of the Douglas Aircraft type) may be predicted as a function of fineness ratio over the range $5 \leq L/D \leq 12.5$.

The data show that fineness ratio effects on the drag rise coefficient are small at the drag rise Mach number but become very important as the drag rise Mach number is exceeded. Over the transonic speed range the profile drag coefficient is found to decrease in essentially a parabolic manner with increasing fineness ratio.

An appendix is also included showing the effect of maximum thickness location on the zero lift profile drag coefficient.

INTRODUCTION

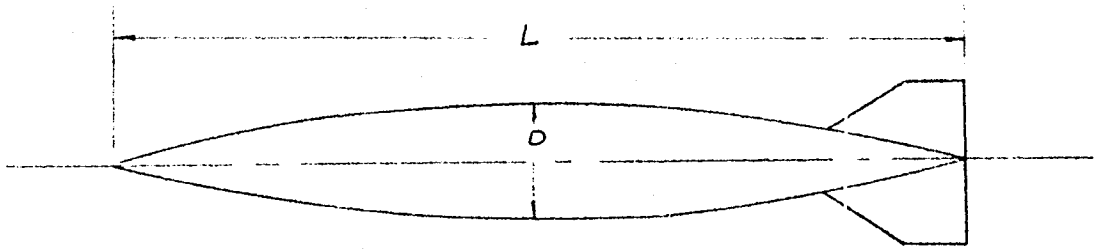
The design of stores or bombs for maximum aerodynamic efficiency in the transonic speed range is a very difficult problem because of the empirical manner in which the drag coefficient must be predicted. Since both the installed drag and the trajectory of a freely falling body are dependent on the drag coefficient, as well as other factors, a good qualitative estimate of the drag coefficient curve as a function of Mach number and lift coefficient is quite important. It is the purpose of this paper to analyse available experimental data in order that an empirical method can be devised for predicting the zero lift drag coefficient as a function of Mach number and fineness ratio in the transonic speed range. Data on low drag, fin-stabilized stores (such as the Douglas Aircraft store) will be used for this analysis. The range of Mach numbers over which the method will be applicable is, $0.85 \lesssim M \lesssim 1.2$ or 1.3.

DISCUSSION

The prediction of the transonic drag rise for fin-stabilized bodies of revolution is dependent on several factors, such as, nose slope, fin design, amount of body boattailing, location of the maximum thickness, and fineness ratio. For this analysis only low drag shapes (Figure 1) such as the Douglas Aircraft type store, will be considered. Since nose shape and fin design are fairly standard items for low drag store design at present no analysis on their effects will be presented. The amount of boattailing will be limited to base diameters of the order of 10% of the maximum store diameter. Thus the effect of boattailing (which will be small as stated above) can also be neglected in this study. The location of the maximum thickness will be assumed to be in the neighborhood of 30% of the store length. Additional data on

UNCLASSIFIED

FIG. 1



SCHEMATIC DRAWING OF A TYPICAL
LOW DRAG, FIN-STABILIZED BODY OF REVOLUTION

UNCLASSIFIED

the effect of maximum thickness location is presented as an appendix. The effect of fineness ratio (L/D) is the major topic of this paper and the analysis is concerned primarily with this parameter.

It will be assumed that the subsonic profile drag* coefficient at zero lift can be quantitatively predicted by available empirical methods in the Mach number range between zero and the drag rise Mach number. The drag rise Mach number (M_{DR}) is defined as the Mach number at which the slope $\left(dC_{D_\pi}/dC_L\right)_{C_L = 0}$ is equal to 0.10. C_{D_π} is the store drag coefficient based on frontal area ($\pi D^2/4$). For low drag fin-stabilized bodies of revolution the profile drag coefficient at $C_L = 0$ can be assumed to have a constant value in the vicinity of $C_{D_\pi} = 0.10$ for the Mach number range, $0 < M < M_{DR}$. The drag rise Mach number will usually lie in the Mach number range, $0.85 < M_{DR} < 0.97$, for free flight Reynolds.

Data for predicting the profile drag coefficient at zero lift for Mach numbers in the transonic speed range was obtained from flight test data, wind tunnel data, and drop test data on the Mk 7. In order to eliminate small discrepancies in the subsonic zero lift profile drag coefficient because of Reynold's number, shape, fin design, etc., the data is presented in the form of $C_{D_\pi} - C_{D_{\pi_{DR}}}$ as a function of $M - M_{DR}$ and fineness ratio. Figure 2 schematically shows the manner in which the quantities $C_{D_\pi} - C_{D_{\pi_{DR}}}$ and $M - M_{DR}$ are measured.

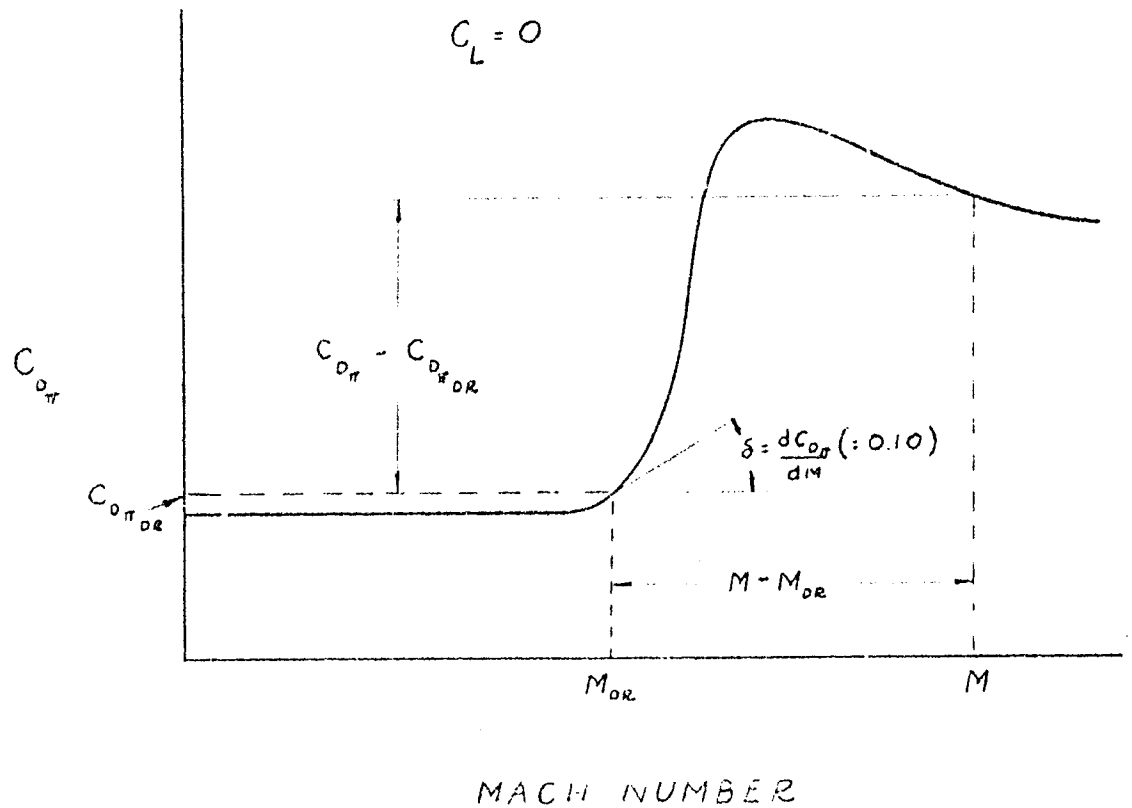
RESULTS

The results of this analysis are presented in Figures 3 and 4 wherein the incremental variations in zero lift profile drag coefficient above the drag rise Mach number is presented as a function of the incremental Mach number (above the drag rise Mach number) and fineness ratio. Data showing the effect of maximum thickness location is found in Figures 5-1 in the appendix.

The data in Figure 3 indicate that the zero lift incremental store drag coefficient is reduced with increasing fineness ratio ($5 \leq L/D \leq 12.5$) in the transonic Mach number range. Although sufficient data are not available for fineness ratios above 12.5, indications (from scattered data not presented herein) are that little is to be gained in drag reduction for the transonic speed range if L/D = 12.5 is exceeded. The data are seen to form a fairly well-defined family of curves, thus allowing reliable interpolations and extrapolations for values of L/D not shown. Also shown in the trends of Figure 3 is the fact that fineness ratio effects are

* Profile drag is herein defined as total drag less skin friction drag.

[redacted]



TYPICAL PLOT OF PROFILE DRAG COEFFICIENT AS A FUNCTION OF MACH NUMBER

[redacted]

UNCLASSIFIED

UNCLASSIFIED

FIG 2

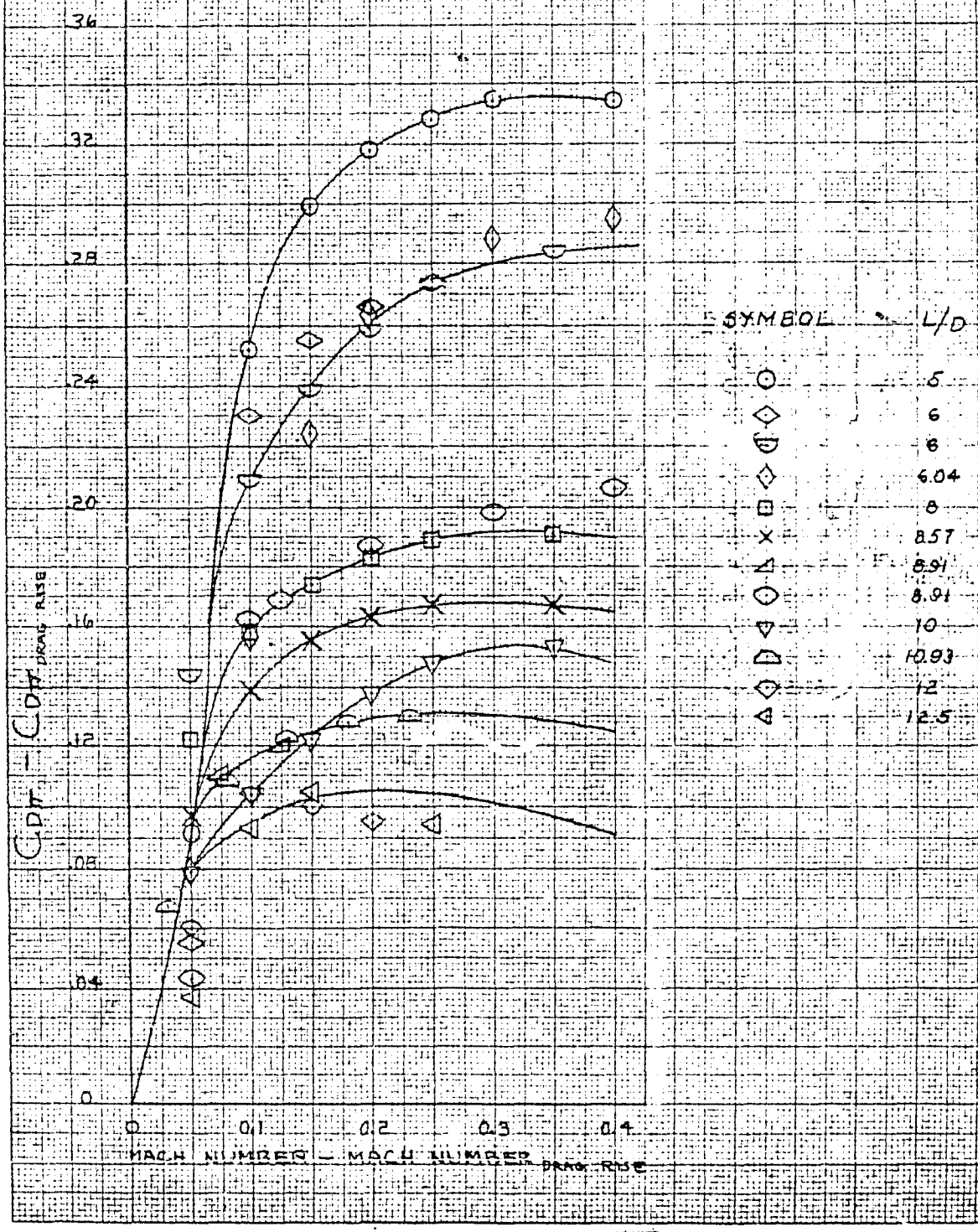
2000

UNCLASSIFIED

[redacted]

FIG. 3 2001

ZERO LIFT TRANSONIC DRAG RISE FOR LOW DRAG FIN-STABILIZED BODIES OF REVOLUTION AS A FUNCTION OF FINENESS RATIO



[redacted]

UNCLASSIFIED

quite small near the drag rise Mach number $M_{DR} < M < M_{DR} + 0.05$ but get increasingly larger as the Mach number is increased up to approximately $M_{DR} + 0.05 < M < M_{DR} + 0.30$. Figure 4 represents a faired crossplot of Figure 3 and is presented because of its applicability for design purposes.

The effect of maximum thickness location, shown in Figures 5-11 in the appendix, is seen to be a very important parameter, from the viewpoint of drag, in determining optimum or near optimum shapes. The effect of maximum thickness location with L/D as a parameter is shown in Figures 5-7 and the effect of L/D with thickness location as a parameter is presented in Figures 8-11. No analysis of this data is presented because the maximum thickness location for fin-stabilized stores is dictated not only by drag but also by stability considerations. The data have been presented for use in the design of stores whose maximum thickness position might differ radically from that of the Douglas Aircraft type.

CONCLUSIONS

The curves showing the effect of fineness ratio on fin-stabilized bodies of revolution are applicable for stores which approximately satisfy the following conditions:

a) tangent-ogive nose shape approximately two to three calibers in length

b) maximum thickness location in the neighborhood of 30% of the store length

c) boattail diameters less than 10% of the store maximum diameter

d) standard or present-day low drag body fin designs

In the transonic speed range fineness ratios of the order of 12.5 appear to be optimum from the standpoint of zero lift profile drag coefficient. The effect of fineness ratio becomes more and more pronounced as the drag rise Mach number is exceeded up to a value of the free-stream Mach number equal to $M_{DR} + 0.3$. Above this latter value of the free-stream Mach number the effect of fineness appears to diminish slightly.

The data presented should give a good approximation to the zero lift transonic drag coefficient variation for free flight Reynolds numbers.

The effect of maximum thickness location for minimum store drag is found to be a function of the value of the transonic Mach number and fineness ratio. However, when considering optimum maximum thickness positions from the viewpoint of drag the question of store stability must also be considered.

LIST OF SYMBOLS

D	store diameter
K	location of store maximum thickness in %L
L	store length
L/D	store fineness ratio
M	Mach number
M_{DR}	drag rise Mach number i.e., Mach number where $\left(\frac{d\,C_{D_\pi}}{d\,M}\right)_{C_L = 0} = 0.10$
C_{D_π}	store zero lift profile drag coefficient based on store frontal area $\left(\frac{\pi D^2}{4}\right)$
$C_{D_{\pi_{DR}}}$	store zero lift profile drag coefficient at the drag rise Mach number
C_L	lift coefficient
π	3.1416

LIST OF REFERENCES

1. Hart, R. G. and Katz, E. R., Flight Investigations at High-Subsonic, Transonic, and Supersonic Speeds to Determine Zero-Lift Drag of Fin-Stabilized Bodies of Revolution Having Fineness Ratios of 12.5, 8.91, and 6.04 and Varying Positions of Maximum Diameter, NACA RM L 9 I 30, November 1949.

2. Stevens, Joseph E. and Purser, Paul, Flight Measurements of the Transonic Drag of Several Isolated External Stores and Nacelles, NACA RM L 54 L 07, March 1955.

3. Hart, Roger G., Flight Investigations at Mach Numbers from 0.8 to 1.5 to Determine the Effects of Nose Bluntness on the Total Drag of Two Fin-Stabilized Bodies of Revolution, NACA RM L 50 I 08 a, October 1950.

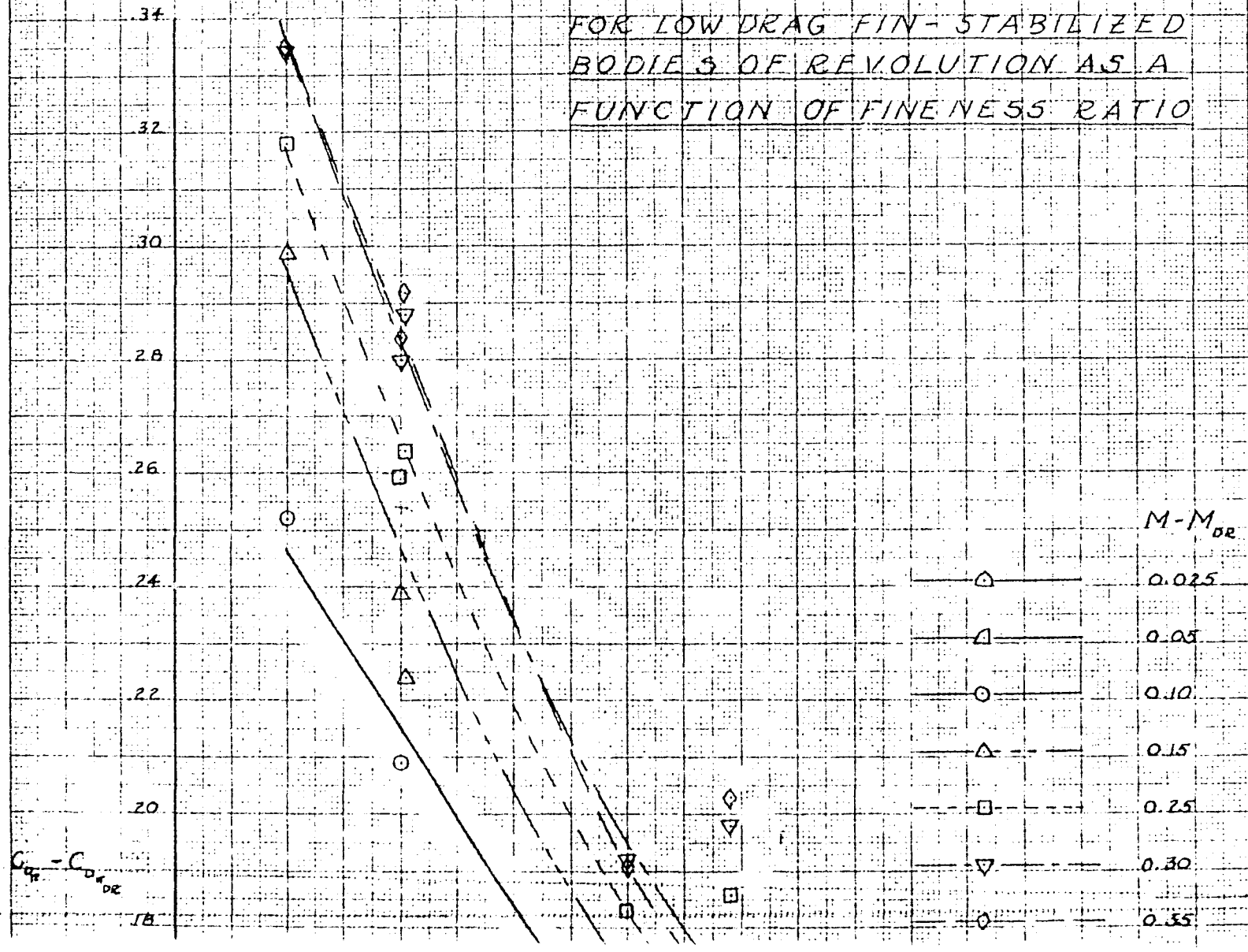
4. Thompson, J. R. and Kurbjun, M. C., Drag Measurements at Transonic Speeds of Two Bodies of Fineness Ratio 9 with Different Locations of Maximum Body Diameter, NACA RM L 8 A 28 b, July 1954.

K&E 10 X 10 TO THE CM. 359-14LG
KEUFFEL & ESSER CO. MADE IN U.S.A.

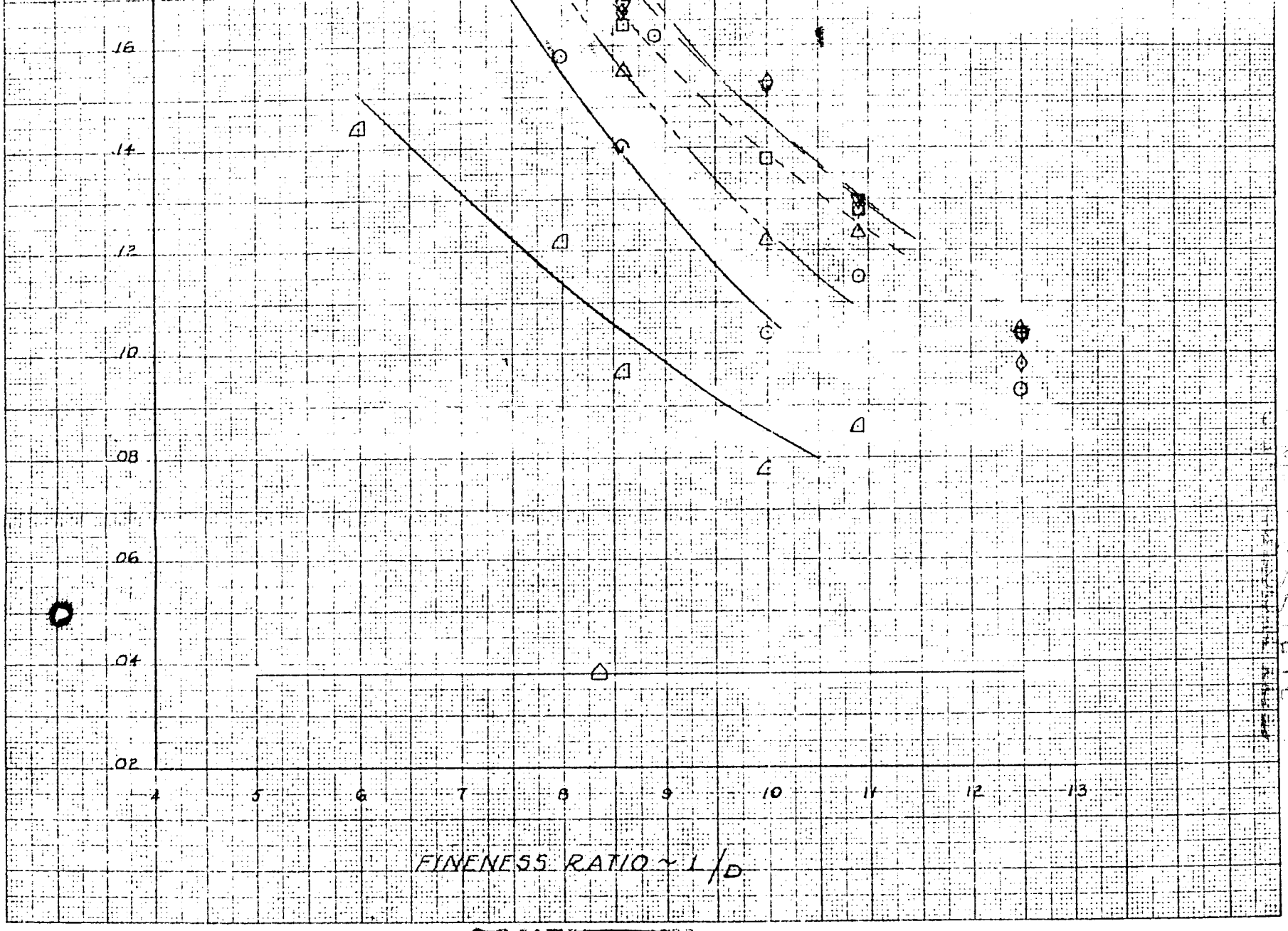
[redacted]

FIG. 4

ZERO LIFT TRANSONIC DRAG RISE FOR LOW DRAG FIN-STABILIZED BODIES OF REVOLUTION AS A FUNCTION OF FINENESS RATIO



UNCLASSIFIED



[redacted]

UNCLASSIFIED

APPENDIX

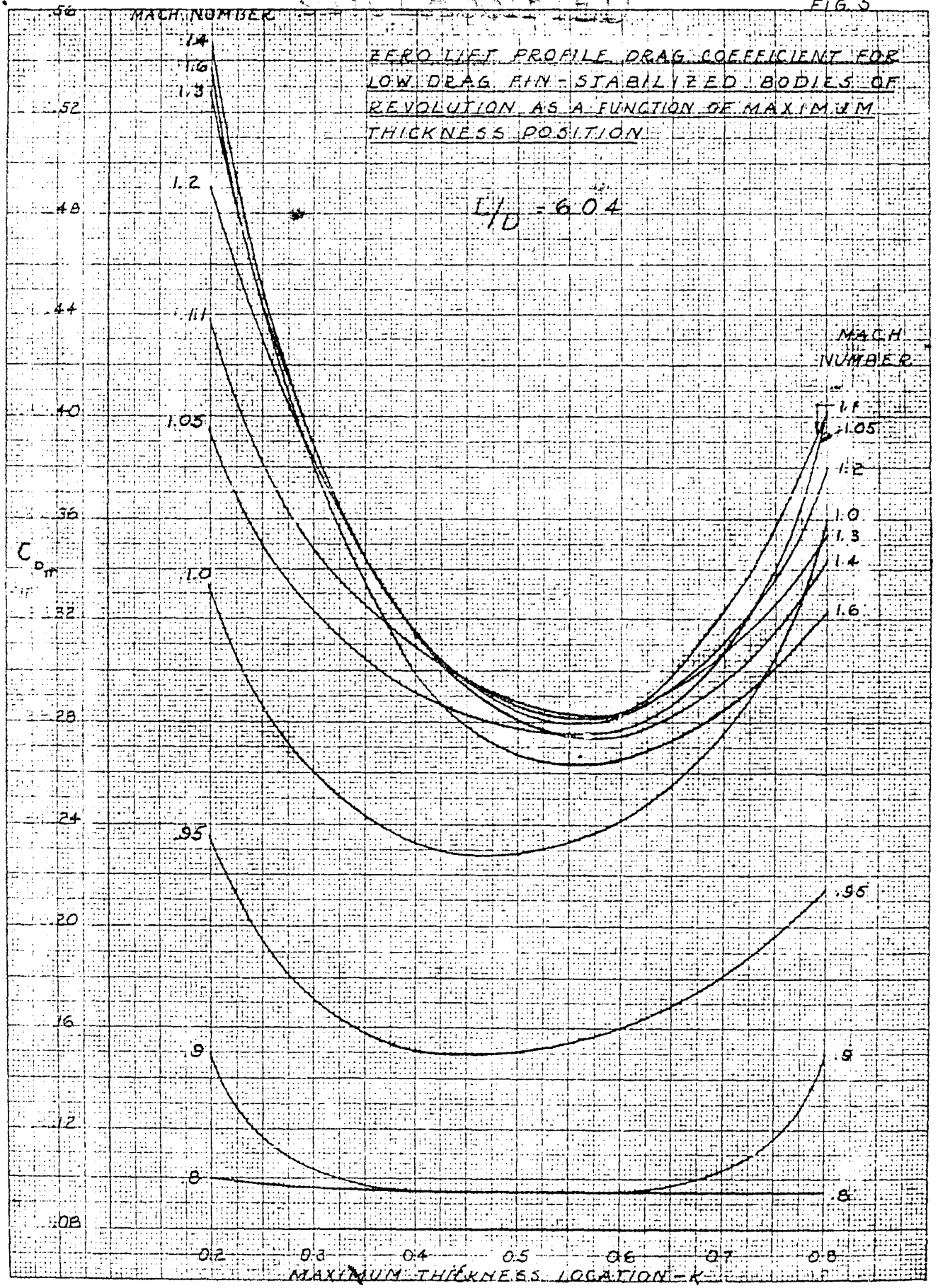
The effect of maximum thickness location, K, in per cent of store length (measured from the nose of the store) is presented in Figures 5-11. The data in Figures 5-7 show the effect of maximum thickness location on store profile drag coefficient, C_{D_π} for values of fineness ratio of 6.04, 8.91, and 12.5, respectively. Figures 8-11 show the variation of C_{D_π} with fineness ratio with maximum thickness locations of 0.2, 0.4, 0.6, and 0.8, respectively.

[redacted]

UNCLASSIFIED

2007

FIG. 3



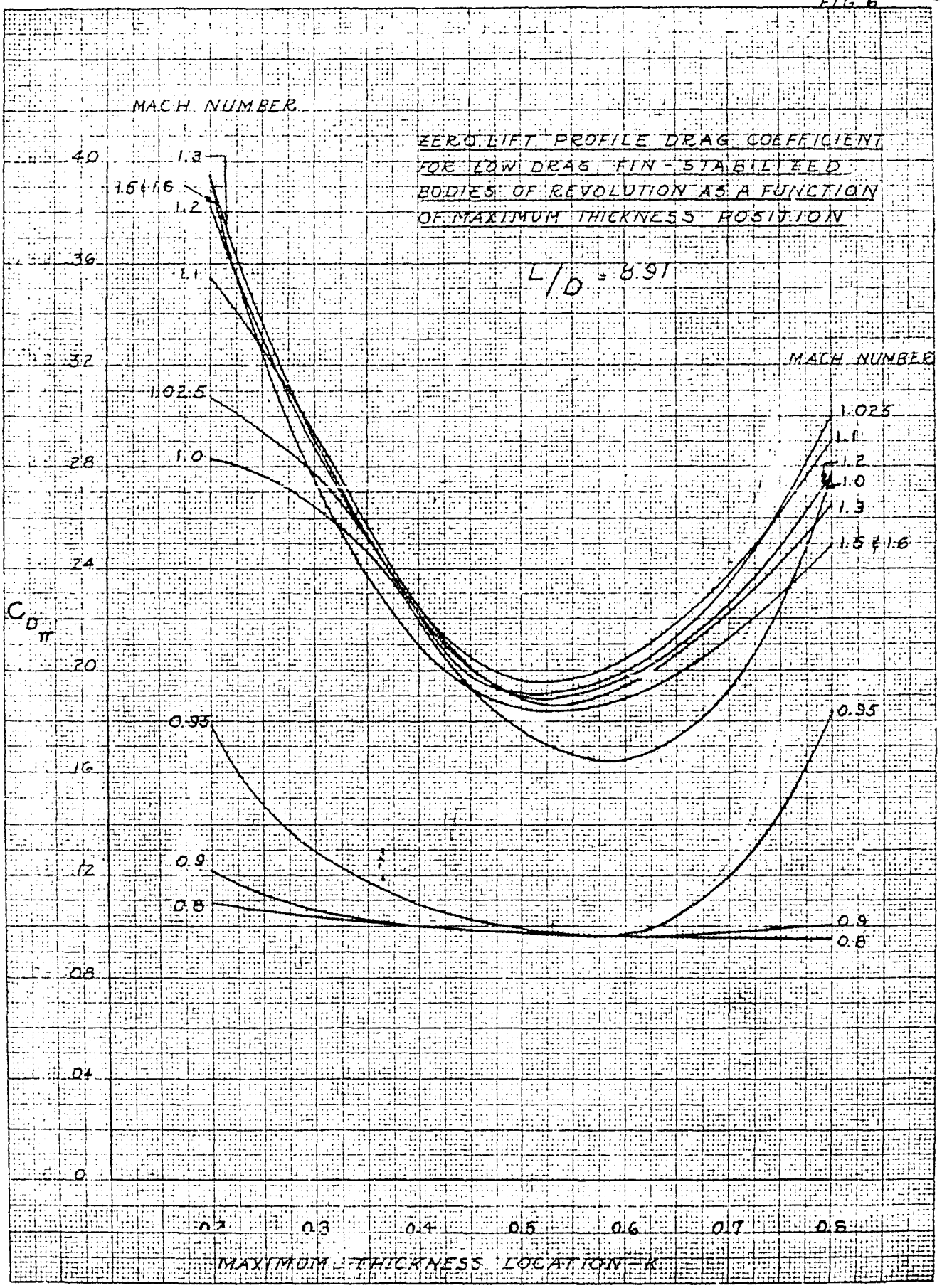
[redacted]

UNCLASSIFIED

[redacted]

2008

FIG. 6

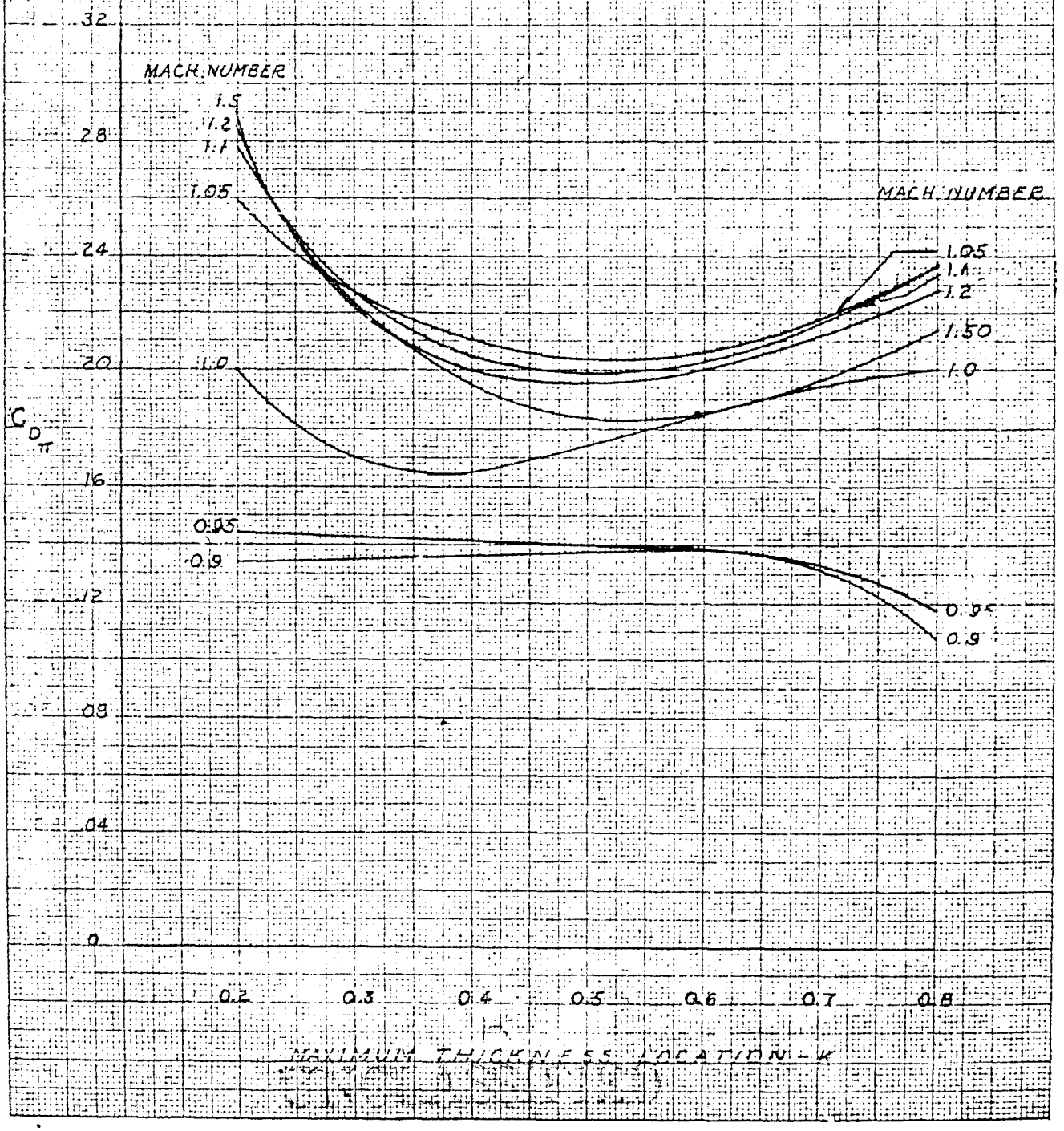


[redacted]

FIG. 7

ZERO LIFT PROFILE DRAG COEFFICIENT FOR LOW DRAG FIN-STABILIZED BODIES OF REVOLUTION AS A FUNCTION OF MAXIMUM THICKNESS POSITION

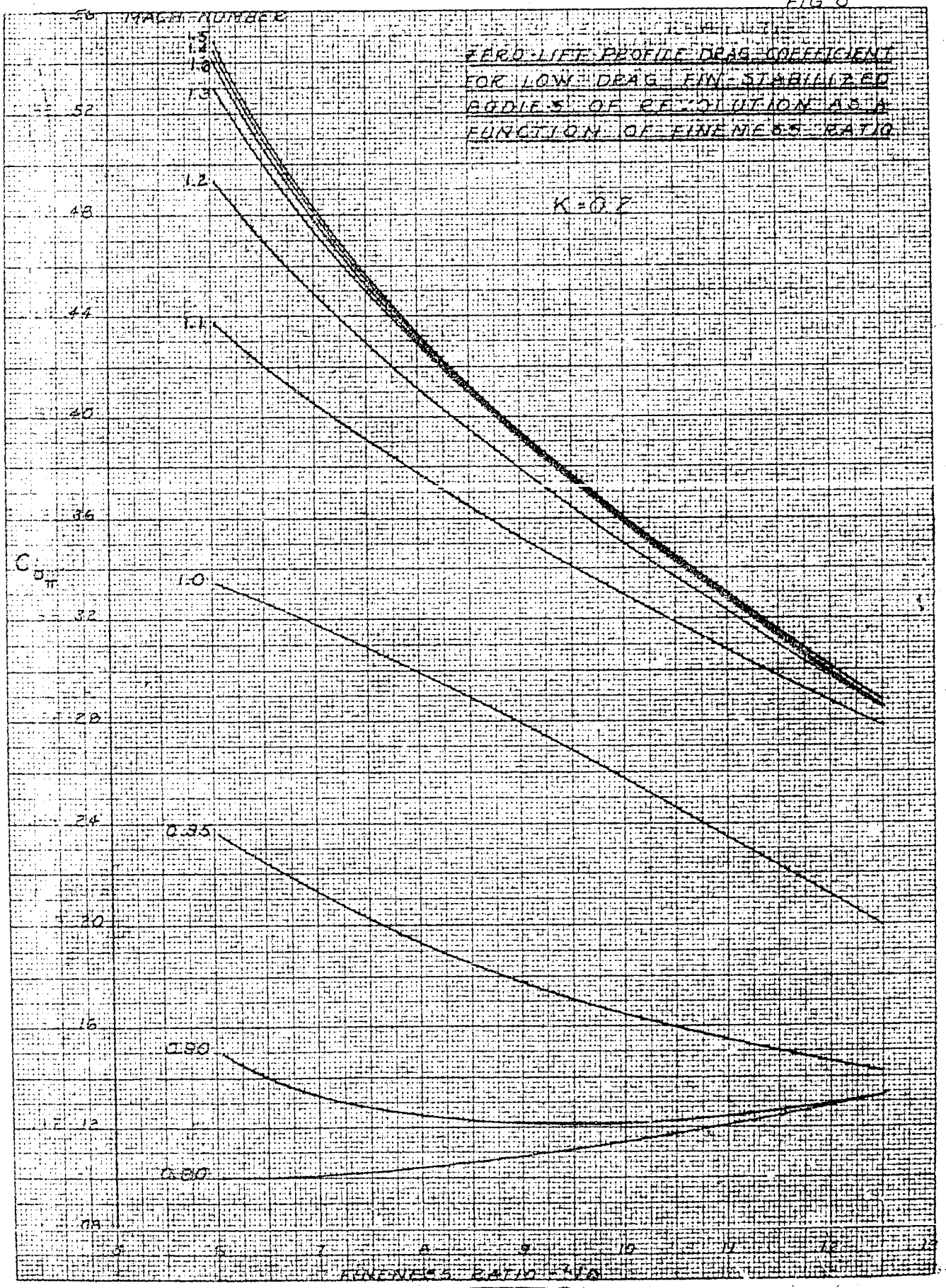
$L/D = 12.5$



[redacted]

2010

FIG 8



[redacted]

FIG. 9

ZERO LIFT PROFILE DRAG COEFFICIENT FOR LOW DRAG FIN-STABILIZED BODIES OF REVOLUTION AS A FUNCTION OF FINENESS RATIO

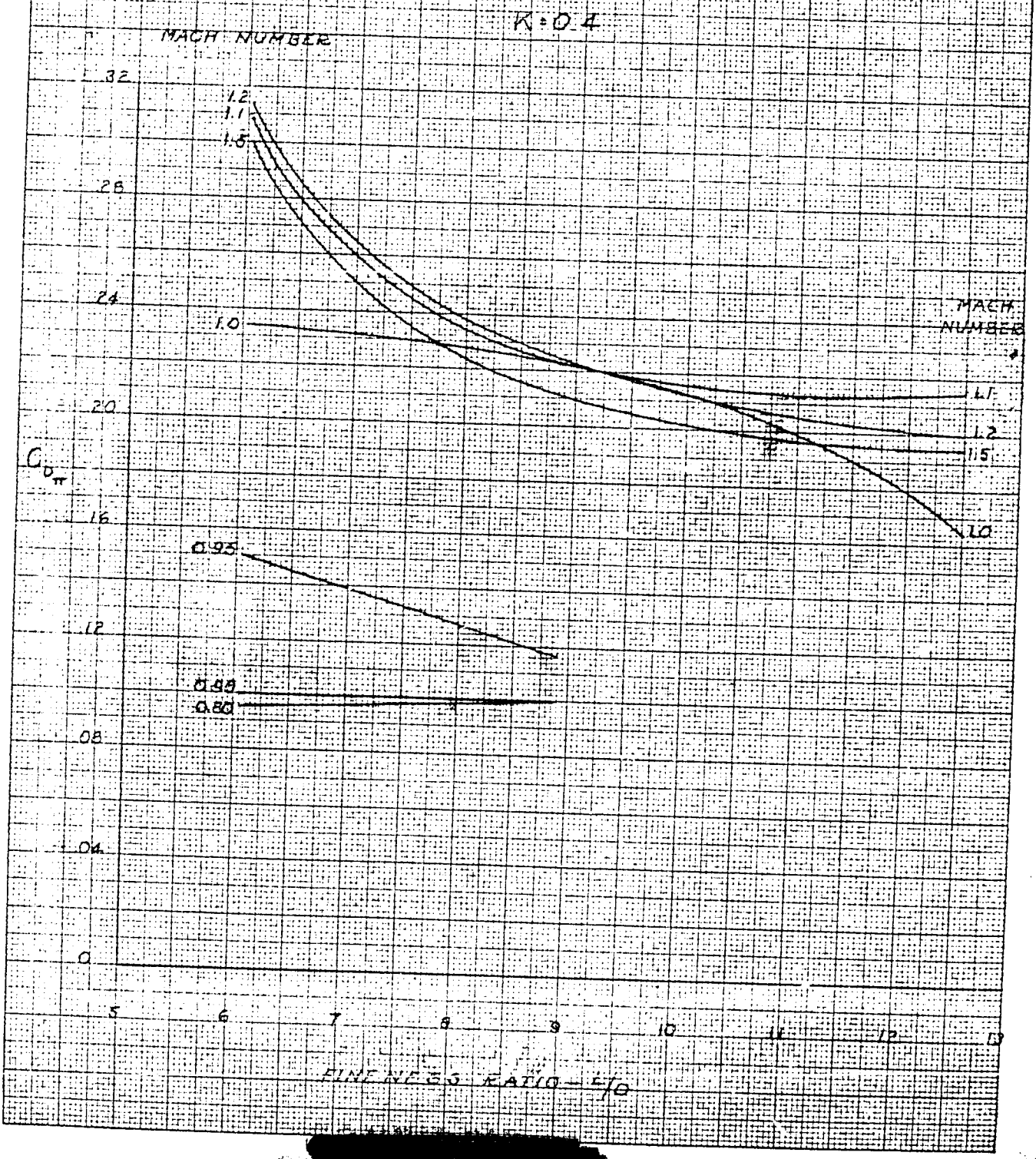


FIG 10

ZERO LIFT PROFILE DRAG COEFFICIENT FOR LOW DRAG FIN-STABILIZED BODIES OF REVOLUTION AS A FUNCTION OF FINENESS RATIO

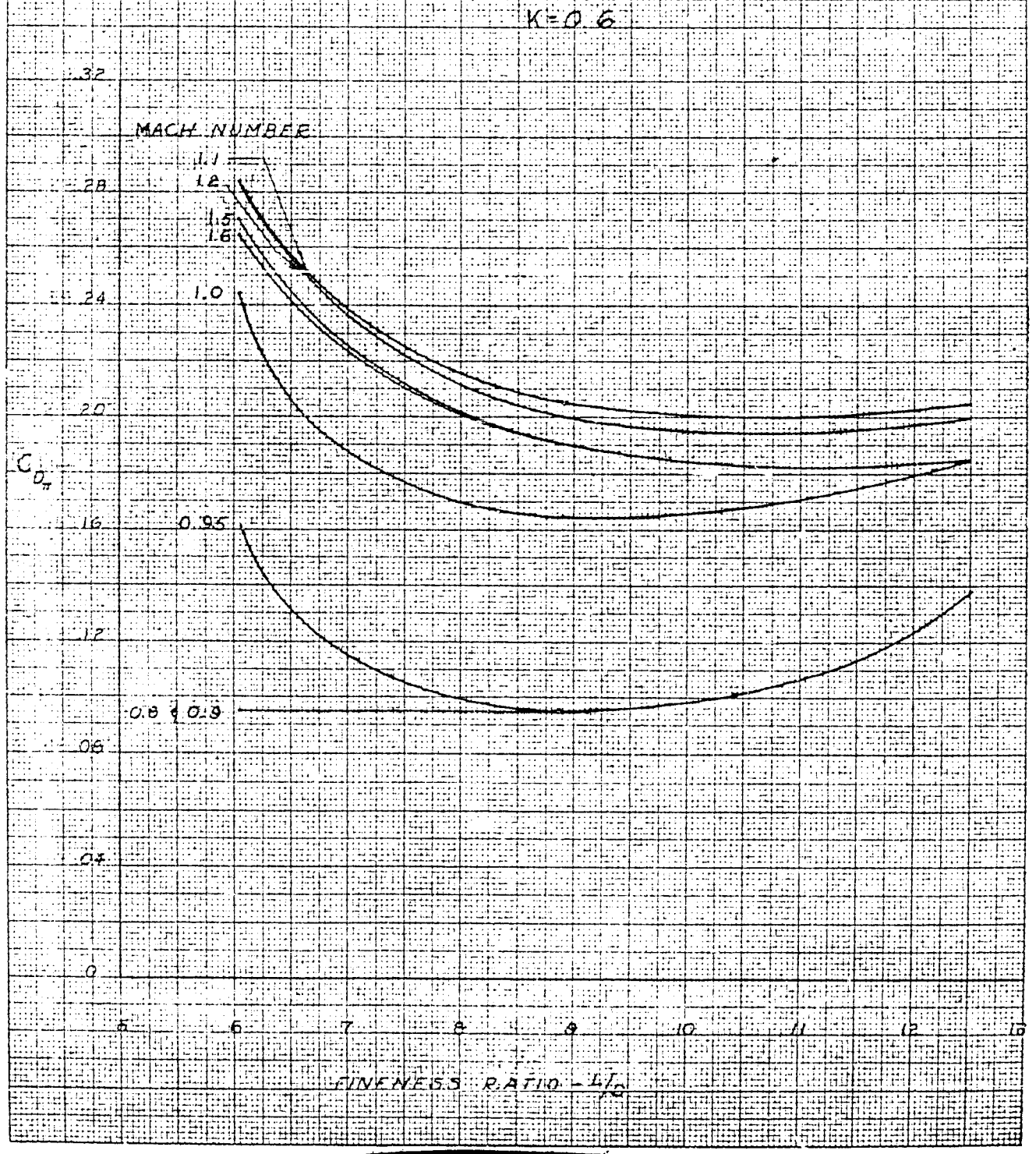
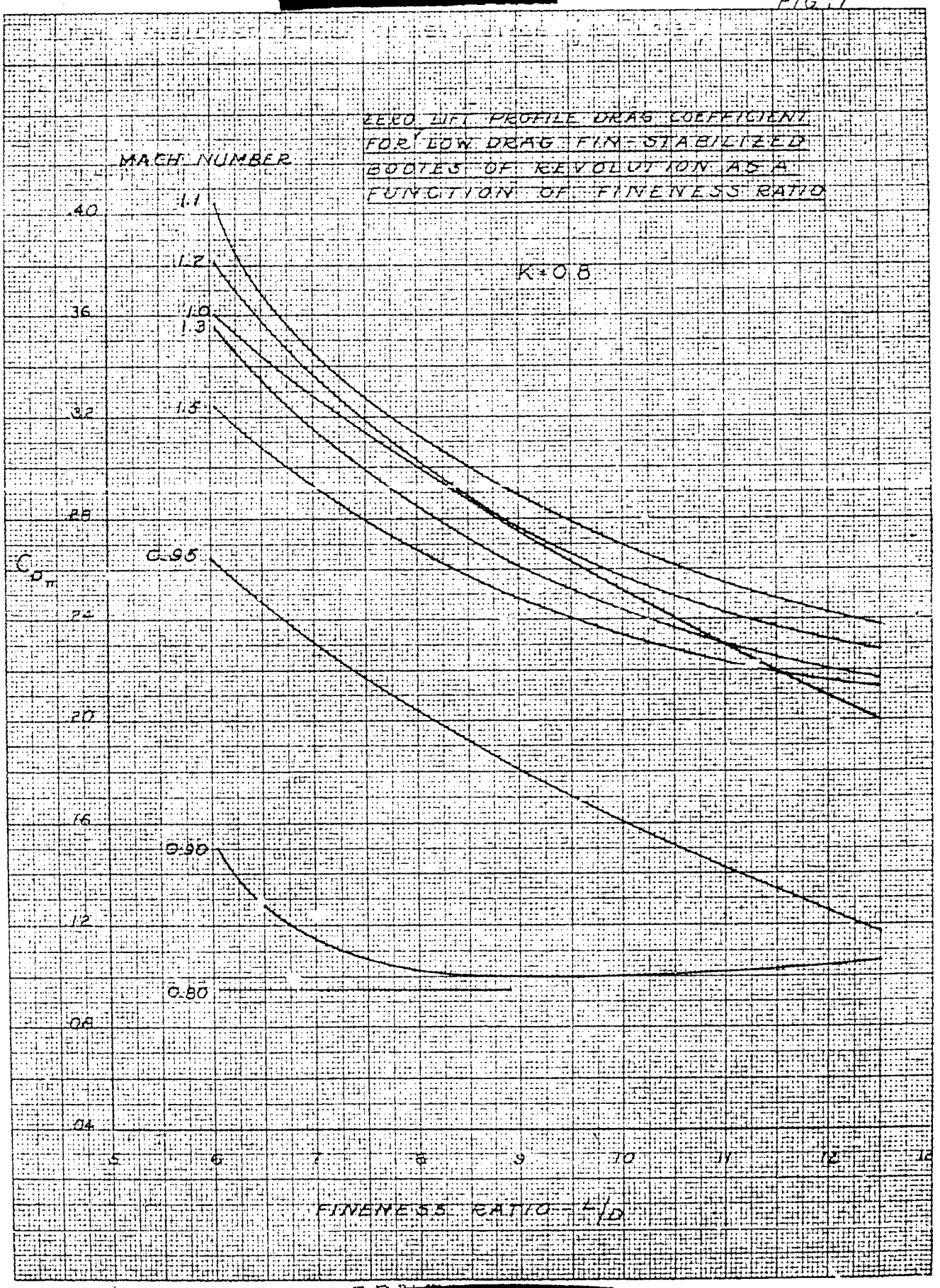


FIG 11



KEUFFEL & ESSER CO.
Millimeter, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.