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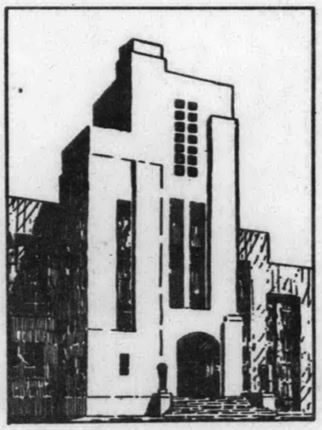
EFFECTS OF VARIOUS LINKAGE RATIOS ON THE FREE-STREAM HYDRODYNAMIC CHARACTERISTICS OF AN ALL-MOVABLE FLAPPED RUDDER

[redacted]

by

C.R. Olson



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NOTATION

L	Lift force
D	Drag force
$Q_{L.E.}$	Moment about leading edge of $\bar{c}$
ρ	Mass density
S	Projected area of rudder
U	Velocity
$\bar{c}$	Mean geometric chord of rudder
α	Rudder angle in degrees
δ	Flap angle relative to rudder-chord plane, measured perpendicular to flap hinge line in degrees
δ/α	Flap-linkage ratio
C_L	Lift coefficient $\left(\frac{L}{\rho/2\ SU^2}\right)$
C_D	Drag coefficient $\left(\frac{D}{\rho/2\ SU^2}\right)$
$C_{Q_{L.E.}}$	Moment coefficient about leading edge of mean geometric chord $\left(\frac{M}{\rho/2\ SU^2\bar{c}}\right)$

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ABSTRACT

The effects of various linkage ratios on the lift, drag, and torque characteristics of an all-movable-flapped rudder, having either a 20-per cent or 40-per cent flap, have been determined from free-stream tests, at low Reynolds number, for both ahead and astern conditions.

The results indicate that for the ahead condition the highest lift coefficient, is obtained with a 30-per cent flap using a 1.5 flap-linkage ratio. An increase in either the flap-chord or the flap-linkage ratio reduces the lift-drag ratio of the rudder and shifts the center of pressure rearward.

INTRODUCTION

The Bureau of Ships has been concerned recently with the design of all-movable-flapped rudders which have been proposed in an effort to improve the turning characteristics of surface ships and submarines. At the present time there is very little information, especially of a systematic nature, for low aspect ratio rudders of this type. The results of investigations conducted by the NACA and other agencies on low aspect ratio flapped wings are helpful in making estimates of the effectiveness of flapped rudder designs. Such data, which apply only to ahead conditions, can be found in References 1 through 6*.

The present investigation was made to determine the optimum combination of flap-linkage and flap-area ratio for a proposed submarine rudder. This was determined by conducting free-stream tests for a range of flap-linkage and flap-area ratios using a reflection-plane model of the rudder.

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*References are listed on page 9 of this report.

MODELS AND TEST APPARATUS

The lower rudder of Model 4538, representing a preliminary design of the SSN (SMALL), was used in these tests. The basic rudder, shown in Figure 1, is an all-movable (spade) type with a linkage-operated full-span flap. It has a NACA 0018 section, an effective aspect ratio (with reflection plane) of 2.40, a taper ratio of 0.82 and a balance area of 40 per cent.

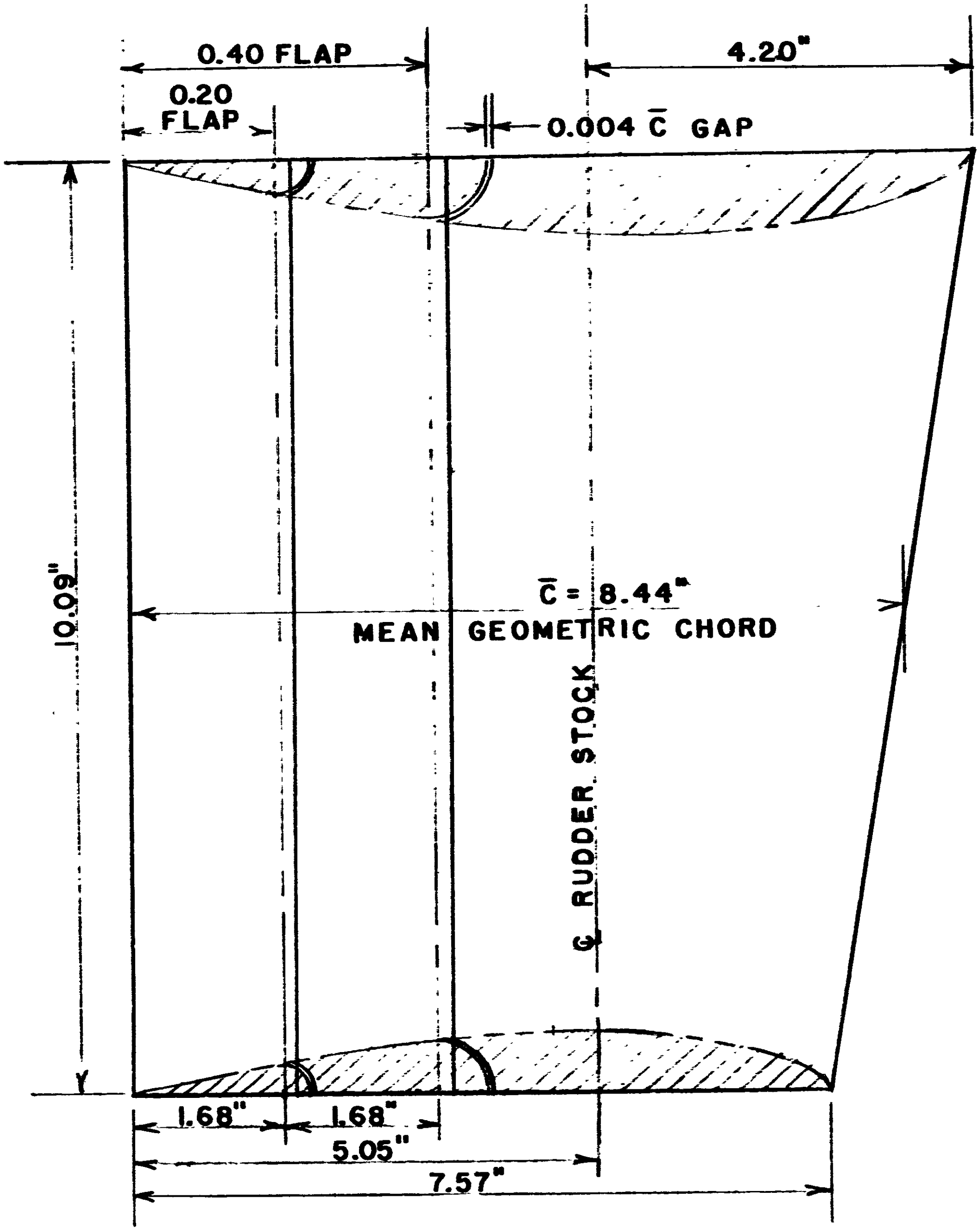
Although the original rudder was equipped with a 20-per cent flap; provision was also made for a 40-per cent flap. This involved a simple modification to the original rudder since both the flap trailing edge and hinge line were unswept. The flap-linkage mechanism provides for settings at fixed flap angles of 0, 5, 10, 20, and 30 degrees. With the flap locked at zero degrees the resulting configuration was equivalent to an all-movable rudder.

The rudder was mounted with the root chord adjacent to a flat plate (reflection plane) which in turn was rigidly attached to the towing carriage, as shown in Figure 2. The rudder stock was attached to a 3-component strain-gage balance which measured the lift, drag and torque acting on the rudder. A small clearance, about 1/8 inch, was maintained between the rudder and the reflection plane.

TEST PROCEDURE

The tests were conducted at towing carriage speeds of 4 knots for the ahead direction and 3 knots for the astern direction. This corresponded to Reynolds numbers based on the mean geometric chord of 0.70 feet, of approximately 0.4×10^6 and 0.3×10^6, respectively. These low velocities were used to avoid distortion or damage to the wooden rudder and its fittings.

Tests were conducted for both 20-per cent and 40-per cent flaps. For each fixed flap angle setting, the rudder angle was varied at 5-degree increments up to 35 degrees while the towing carriage was operating at test speed. The flap-linkage ratios resulting from these combinations are given in Table 1. The nominal linkage ratios as used in the report are given in Table 2.



Section	NACA 0018	Total Area in Sq. In.	85.0
Taper Ratio	0.82	0.20 Flap Area in Sq. In.	17.0
Geometric Aspect Ratio	1.20	0.40 Flap Area in Sq. In.	34.0
Effective Aspect Ratio	2.40	Balance Area in Sq. In.	34.0

Figure 1 — Characteristics of All-movable Flapped Rudder

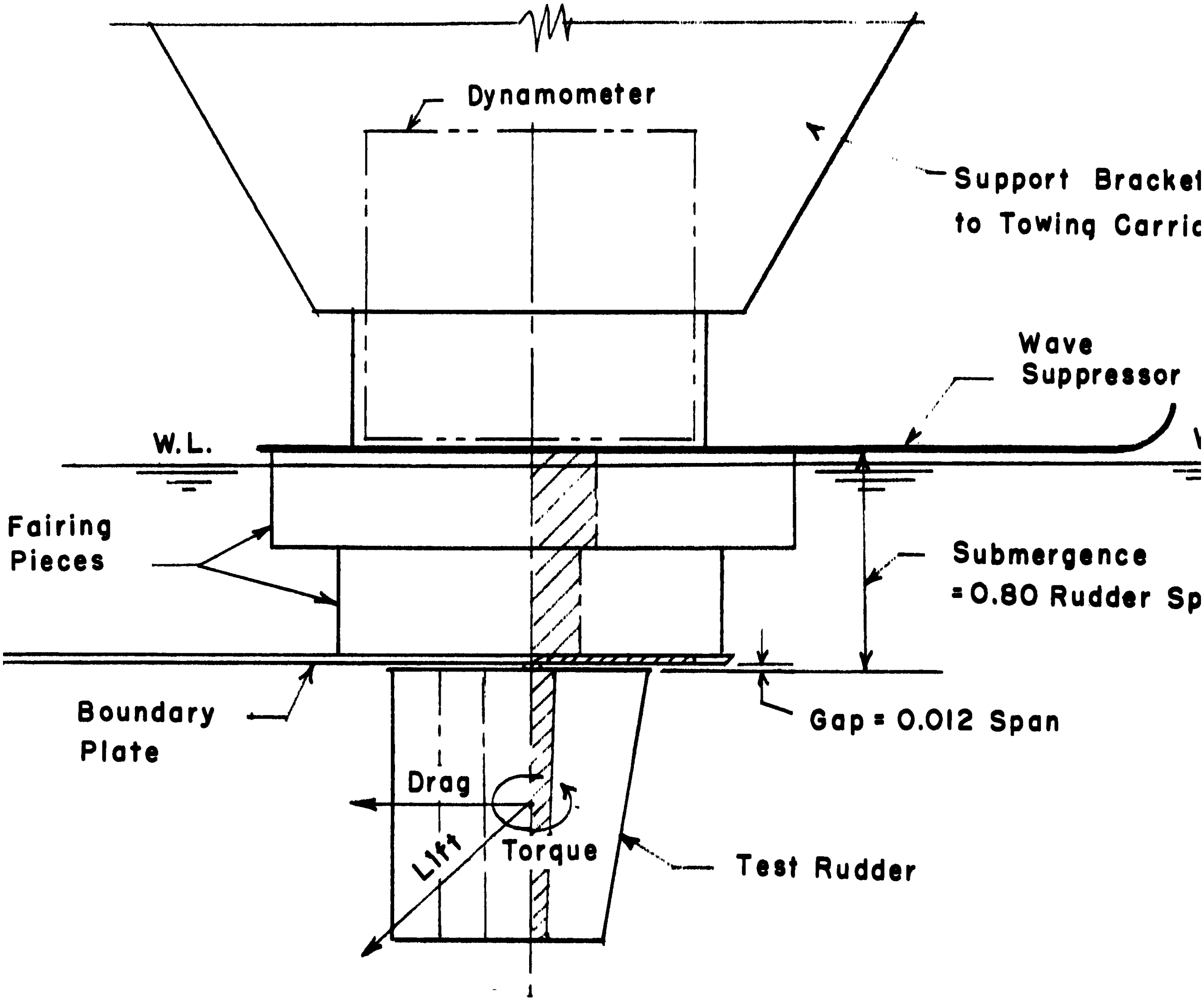


Figure 2 — Sketch of Rudder Towing Apparatus

TABLE 1

TAB LINKAGE RATIOS TESTED

Tab Angle	Rudder Angle in degrees						
	5	10	15	20	25	30	35
0	0	0	0	0	0	0	0
5	1	1/2	1/3	1/4	1/5	1/6	1/7
10	2	1	2/3	1/2	2/5	1/3	2/7
20	4	2	4/3	1	4/5	2/3	4/7
30	6	3	2	1 1/2	6/5	1	6/7

TABLE 2

NOMINAL TAB LINKAGE RATIO

Rudder Angle in degrees				
5	10	15	20	25
0	0	0	0	0
1/2	1/2	1/2	1/2	1/2
1	1	1	1	1
1 1/2	1 1/2	1 1/2	1 1/2	
2	2	2		
2 1/2	2 1/2			
3	3			

DISCUSSION OF RESULTS

The effects of variation in flap-linkage ratio on the lift, drag, torque, and effective center of pressure coefficients for the 20-per cent and 40-per cent flap rudders are presented in Figures 3 through 8 and in the Appendix. These results are presented as a function of the nominal linkage ratio and were obtained from cross-plots of the basic data. Data were obtained for rudder angles up to 35 degrees. The data for rudder angles above 25 degrees are questionable because of early stalling due to the low test Reynolds numbers and have been deleted. However, the lift coefficient versus rudder angle curve, below stall, does not appear to vary in the Reynolds number range between 0.6×10^6 and 3.5×10^6 (5). Therefore, it is reasonable to assume that the lift coefficient curve for rudder angles of less than 25 degrees is valid at full-scale Reynolds numbers.

It should be noted that data given in this report are for free stream and are not directly applicable to a rudder operating on a ship since the effects of hull interference and boundary layer on the hydrodynamic characteristics of the rudder are not included.

LIFT CHARACTERISTICS

Figure 3(a) shows that, for the ahead condition, the lift coefficient increases with an increase in flap-linkage ratio. The amount of this increase is greater for the 40-per cent flap than for the 20-per cent flap at all rudder angles below 25 degrees The optimum flap-area ratio for the present rudder was found to be approximately 30 per cent as shown in Figure 4.

The aforementioned trends may be interpreted in terms of the effects of the lift developed by a rudder on the tactical diameter of a given vessel. The increase in lift of a rudder does not decrease the tactical diameter in direct proportion. For example, the lift coefficient of a rudder having a 20-per cent flap and a linkage ratio of 1.0 is 45 per cent higher than a comparable all-movable rudder. However, the tactical diameter of the submarine model using such a flapped rudder is only 12 per cent less than that with the all-movable rudder (7). Assuming that this ratio of percentage increase in rudder lift to percentage decrease in tactical diameter is typical, i.e., approximately 4:1, it is not necessary to obtain precise values of maximum lift coefficients for this purpose.

It may be noted that a lift increase equal to that of a flapped rudder could be obtained by increasing the area of an all-movable rudder by about 50 per cent. The drag for this enlarged rudder would be roughly 20-per cent less than for the various flap arrangements. These results lead to the speculation that flapped rudders may be of more advantage than plain all-movable rudders mainly when space limitations prevent adjustment of rudder area. This deduction is based on the larger rudder angles only since the drag penalty of the flap rudder does not apply at the small angles.

For the astern condition, the results shown in Figures 3(b) and 5 indicate a decrease in lift coefficient over most of the rudder angle range with an increase in either flap-linkage or flap-area ratio. However, there is less loss in lift for the 20-per cent than for the 40-per cent flap rudder.

DRAG CHARACTERISTICS

The drag coefficient of the flapped rudder in the ahead condition increases at all rudder angles with an increase in flap-linkage ratio, as shown in Figure 6(a). This increase is greater for the 40-per cent than for the 20-per cent flapped rudder. In general, the increase in drag with an increase in flap-linkage ratio or flap area, is greater than the corresponding increase in lift. This corresponds to a reduction in the lift-drag ratios.

For the astern condition, Figure 6(b), the drag increases with an increase in flap-linkage ratio but not as sharply as for the ahead condition. The drag values for the 40-per cent flapped rudder break down at increasingly smaller angles as the flap-linkage ratio increases. This breakdown prevents any consistent comparison between the 20-and 40-per cent flapped rudders but in any case the differences are small.

TORQUE AND EFFECTIVE CENTER OF PRESSURE CHARACTERISTICS

For the ahead condition, the torque coefficient increases with an increase in either flap-linkage or flap-area ratio, as shown in Figure 7(a). However, the converse is true for the astern condition as shown in Figure 7(b). These trends are similar to those exhibited by the lift coefficient.

The effective center of pressures for both the ahead and astern conditions which are shown in Figures 8(a) and 8(b), were derived from the torque and lift coefficient data. For the ahead condition, there is a large rearward shift in effective-center of pressure with an increase in flap-linkage ratio but only a small change with an increase in flap-area ratio.

For astern motion, however, the effective center of pressure tends to move forward rapidly with an increase in linkage ratio, and for some cases is located beyond the leading edge of the mean geometric chord. For simplification of the effective center of pressure calculations for the astern condition a nominal chord for the rudder was used. This nominal chord is defined as the straight line connecting the forward edge of the rudder with the extreme edge of the flap in its deflected position.

CONCLUSIONS

A free-stream investigation made to determine the optimum combination of flap-linkage and flap-area ratio for an all-movable flapped rudder indicates the following conclusions:

1. The highest lift coefficient is obtained with a 30-per cent flap and a flap-linkage ratio of 1.5. The lift coefficient for this configuration is about 50 per cent higher than an all-movable rudder of equal area.

2. An increase in either flap-linkage or flap-area ratio results in a reduction of the rudder lift-drag ratio. Consequently, flapped rudders are recommended mainly when space limitations prevent adjustment of rudder area to produce the required lift.

3. Increases in both flap-area and flap-linkage ratio tend to shift the center of pressure of the rudder rearward.

4. For the astern condition, an increase in either flap-area or flap-linkage ratio reduces the lift of the rudder.

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3. NACA TN 2288 - "Estimation of Low-Speed Lift and Hinge-Moment Parameters for Full-Span Trailing-Edge Flaps on Lifting Surfaces with and without Sweepback", by Jules B. Dods, Jr., dtd April 1952

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7. TMB CONFIDENTIAL Report C-703 of April 1955 - "Surfaced Turni Maneuvering, and Rudder Torque Tests on Model 4538 Representi the SSN (SMALL) SS578", by C. R. Olson and F. D. Bradley

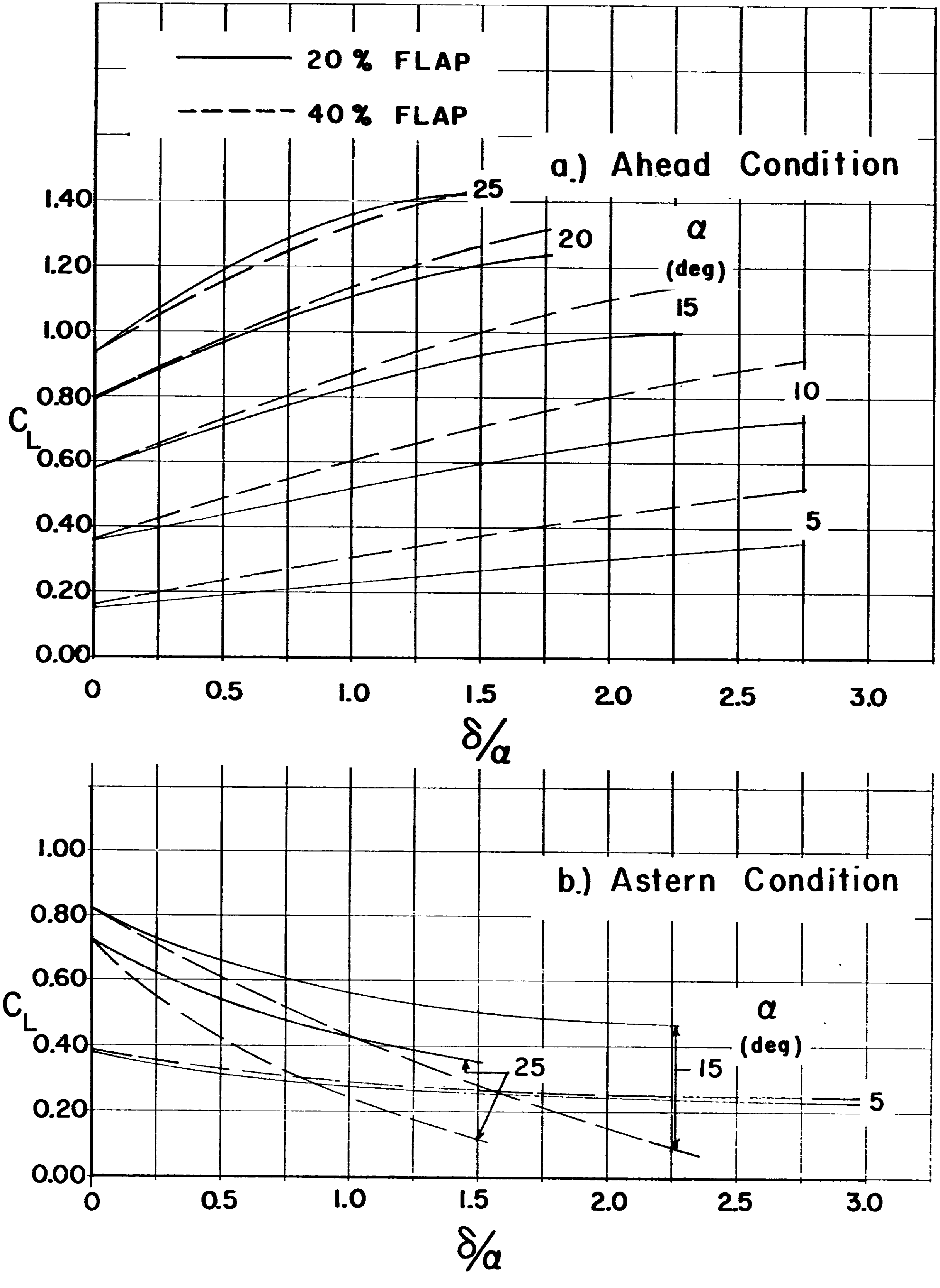

Figure 3 – Lift Coefficient Curves

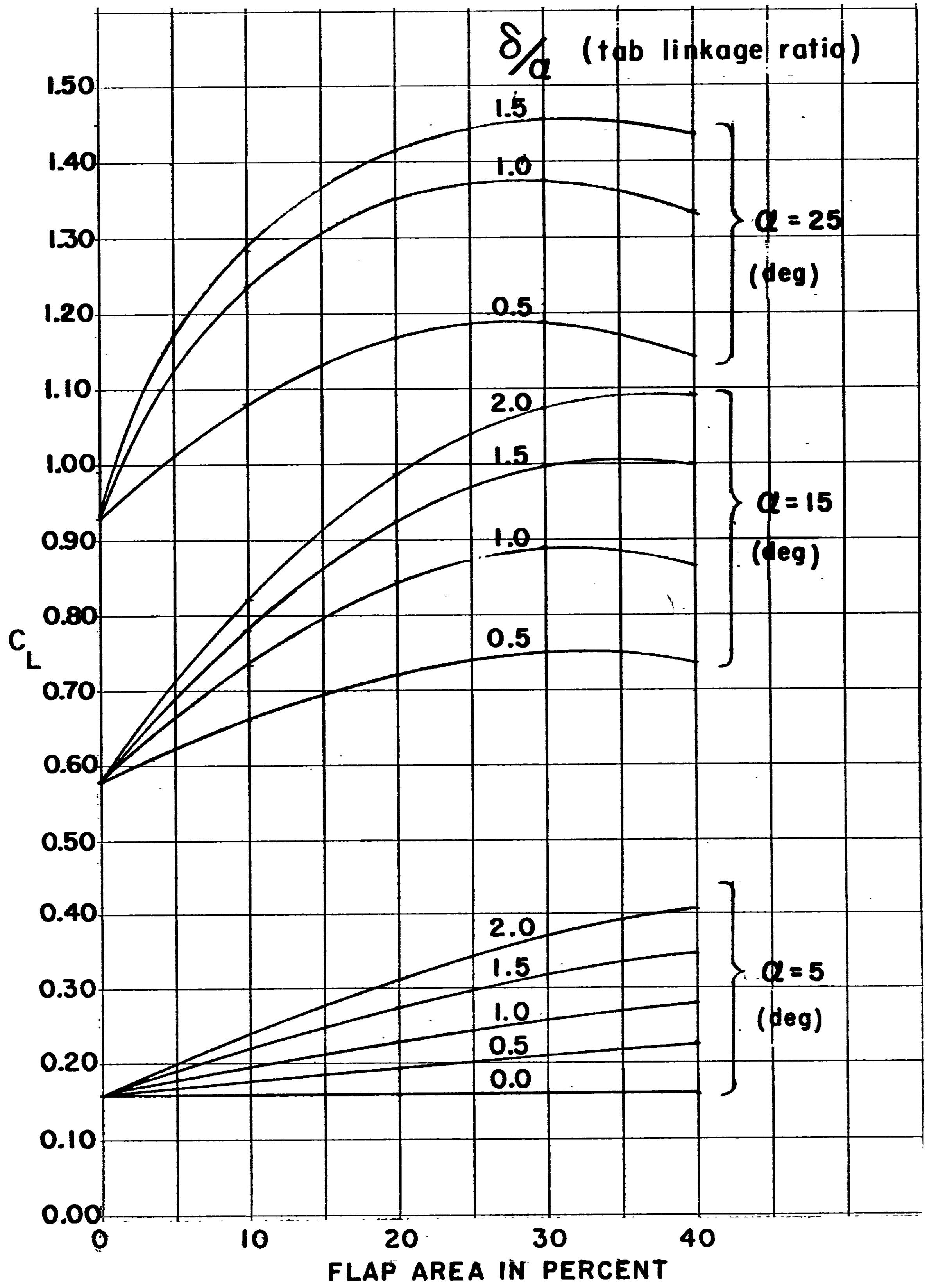

Figure 4 – Effect of Flap Area on the Lift Coefficients For the Ahead Condition

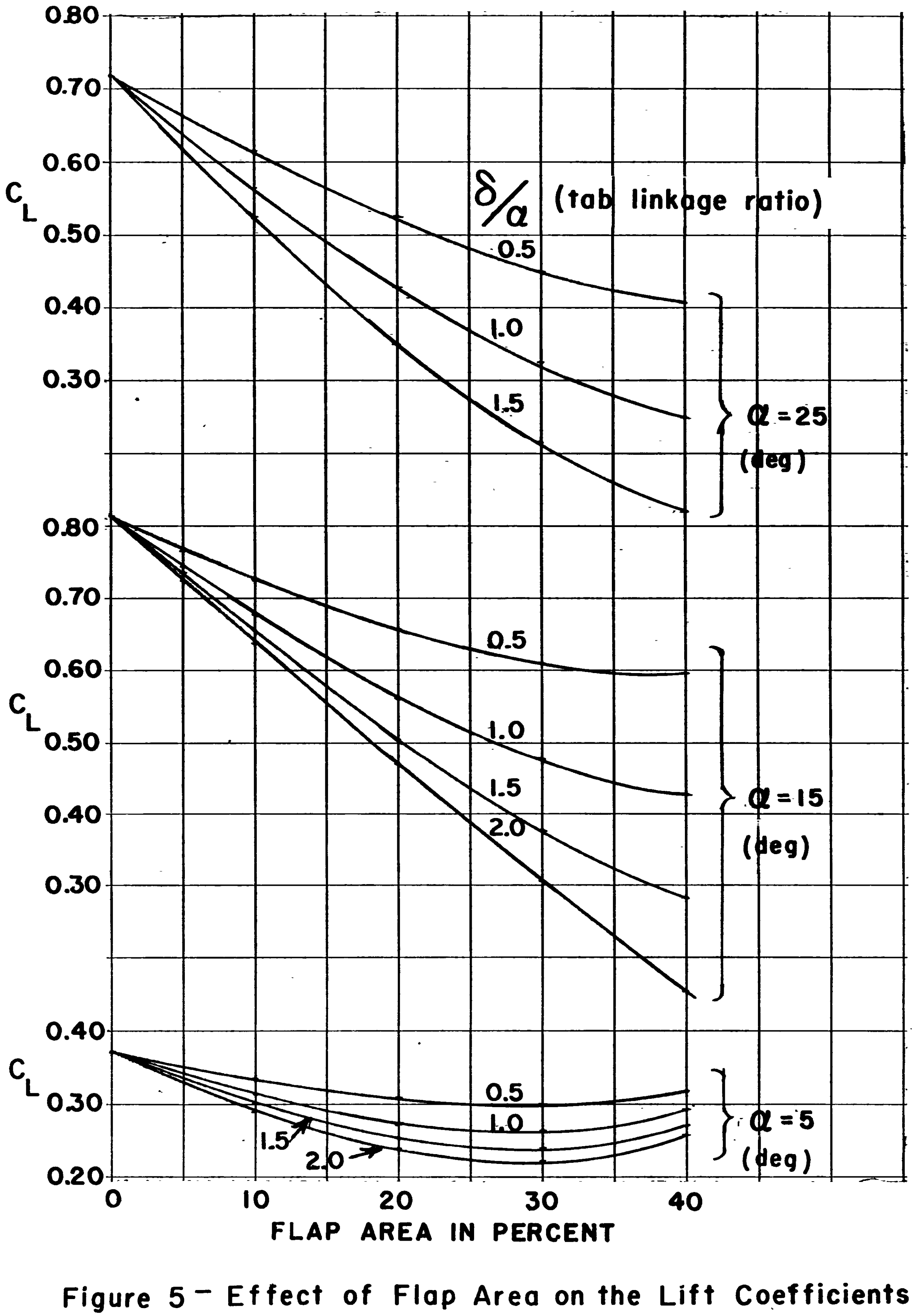

Figure 5 – Effect of Flap Area on the Lift Coefficients for the Astern Condition

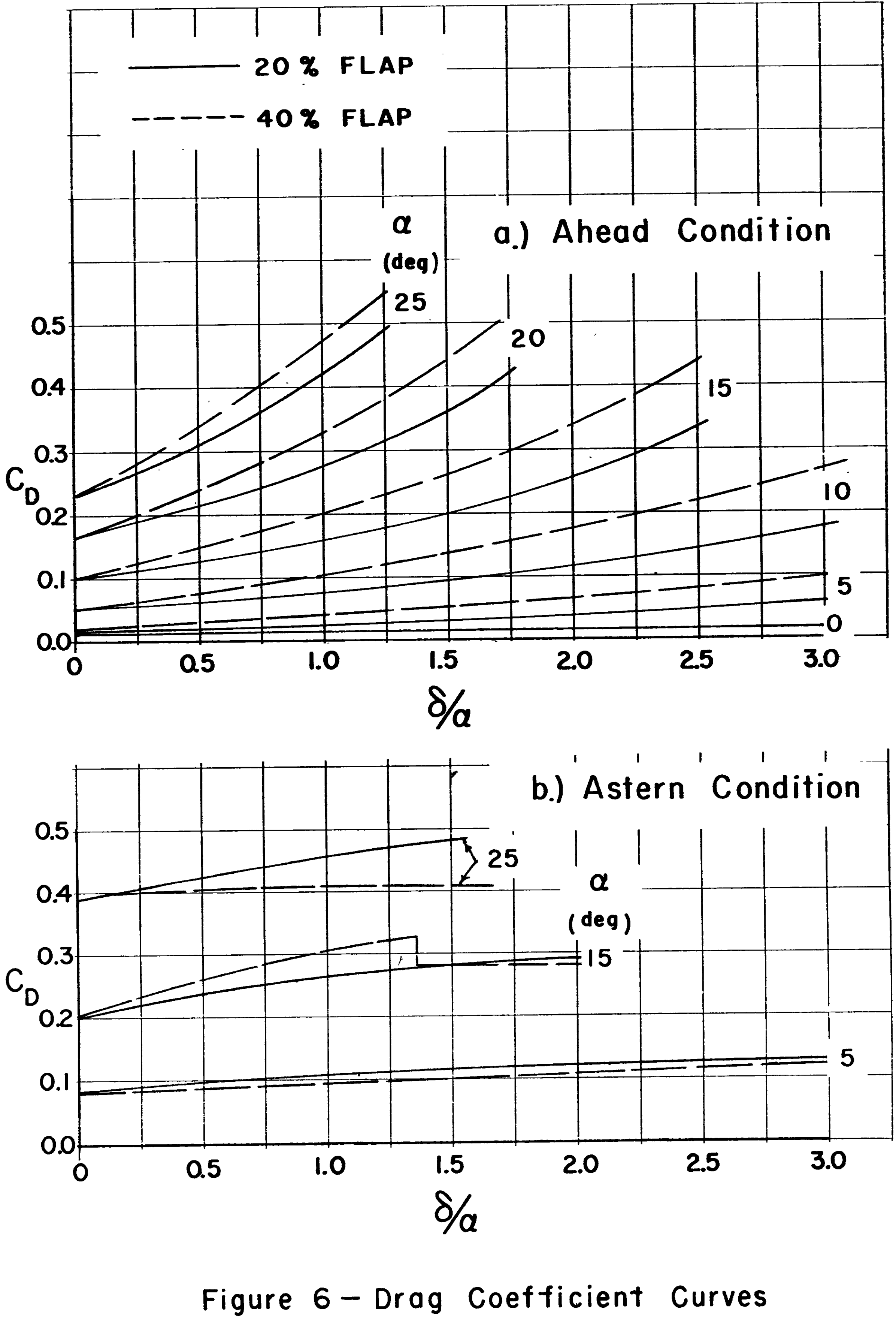

Figure 6 – Drag Coefficient Curves

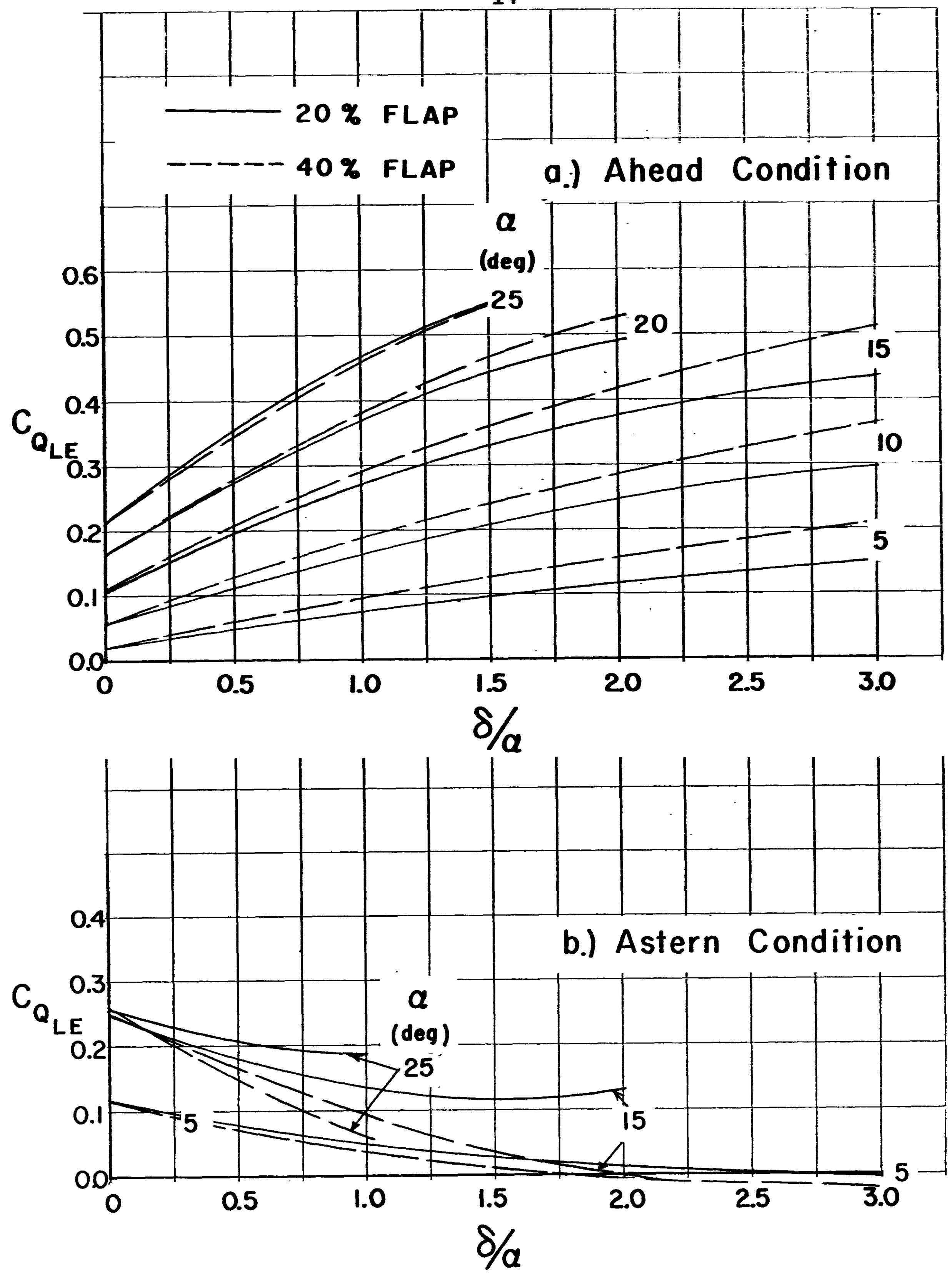

Figure 7— Torque Coefficient Curves

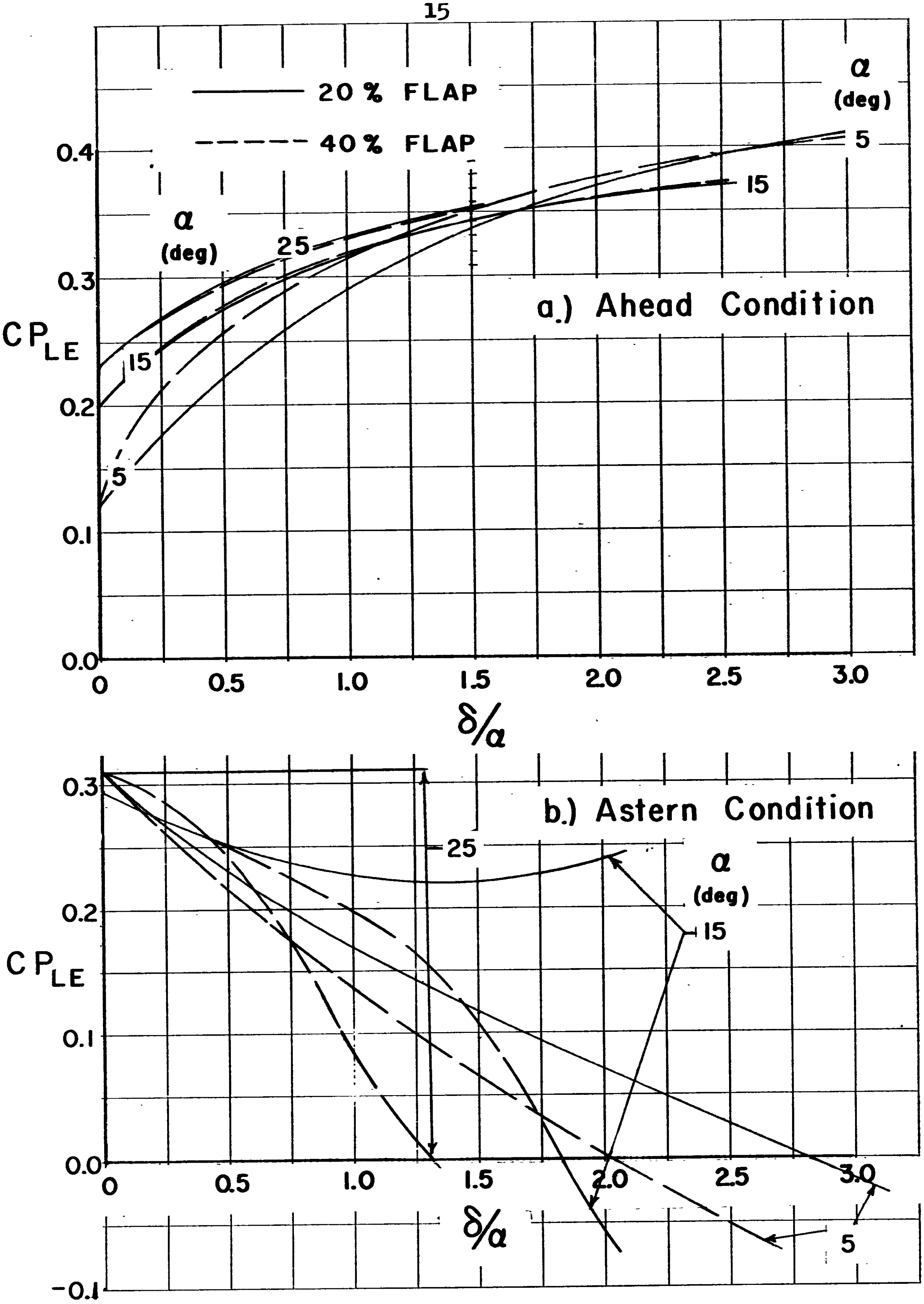

Figure 8 — Center of Pressure Curves

APPENDIX

The faired test data are given as a function of rudder angle in the following figures:

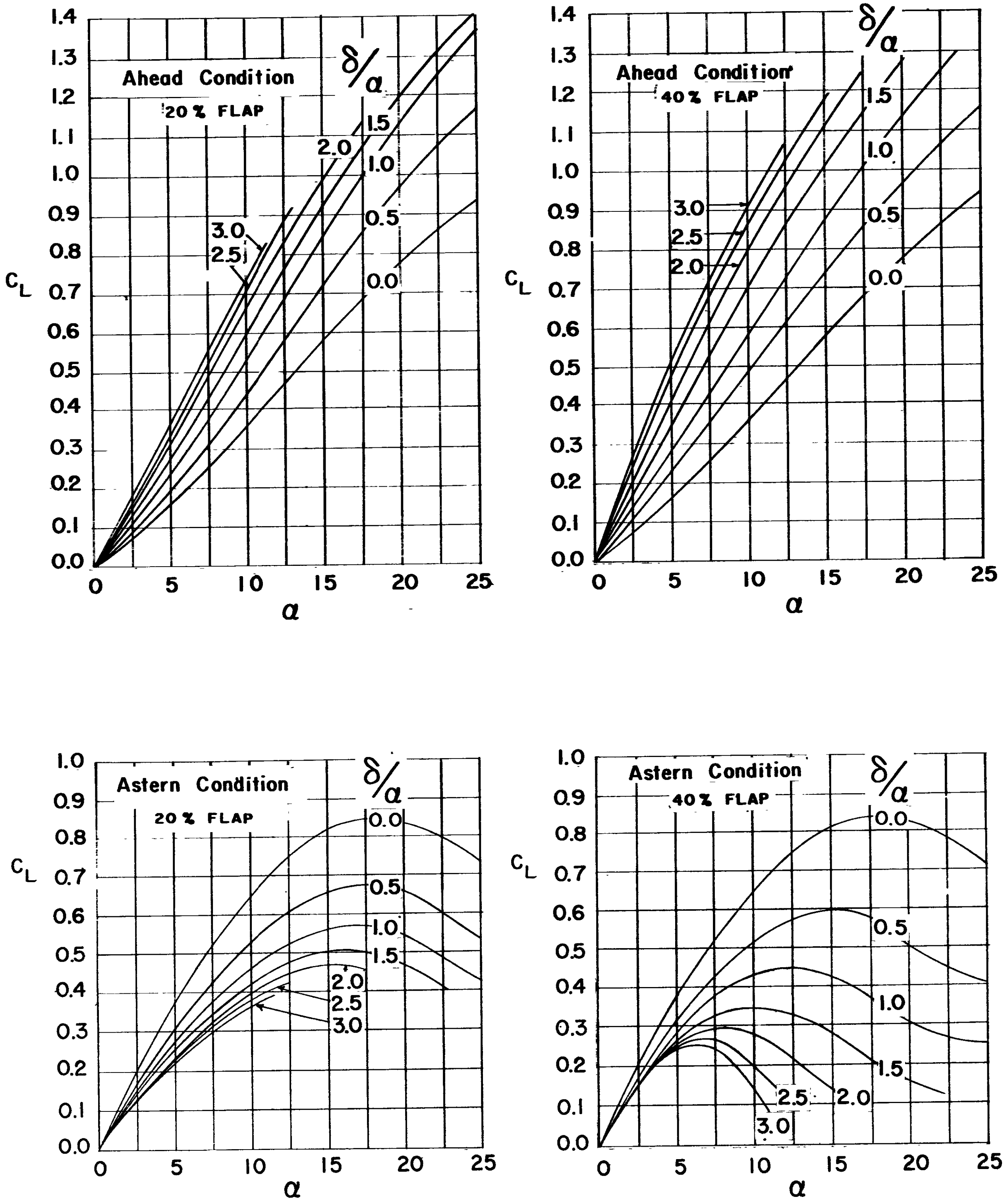

Figure 9 - Lift Coefficient Curves

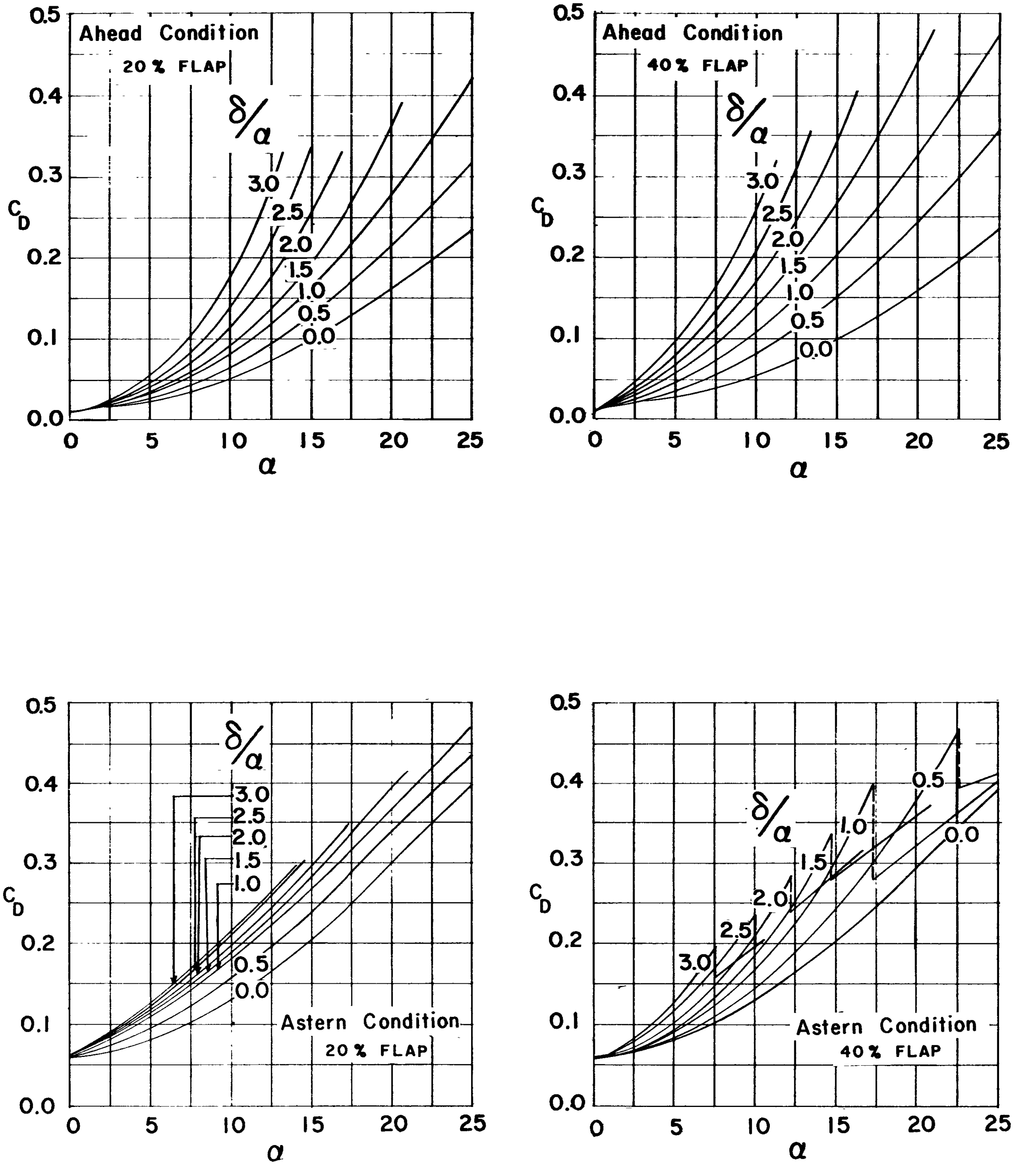

Figure 10 – Drag Coefficient Curves

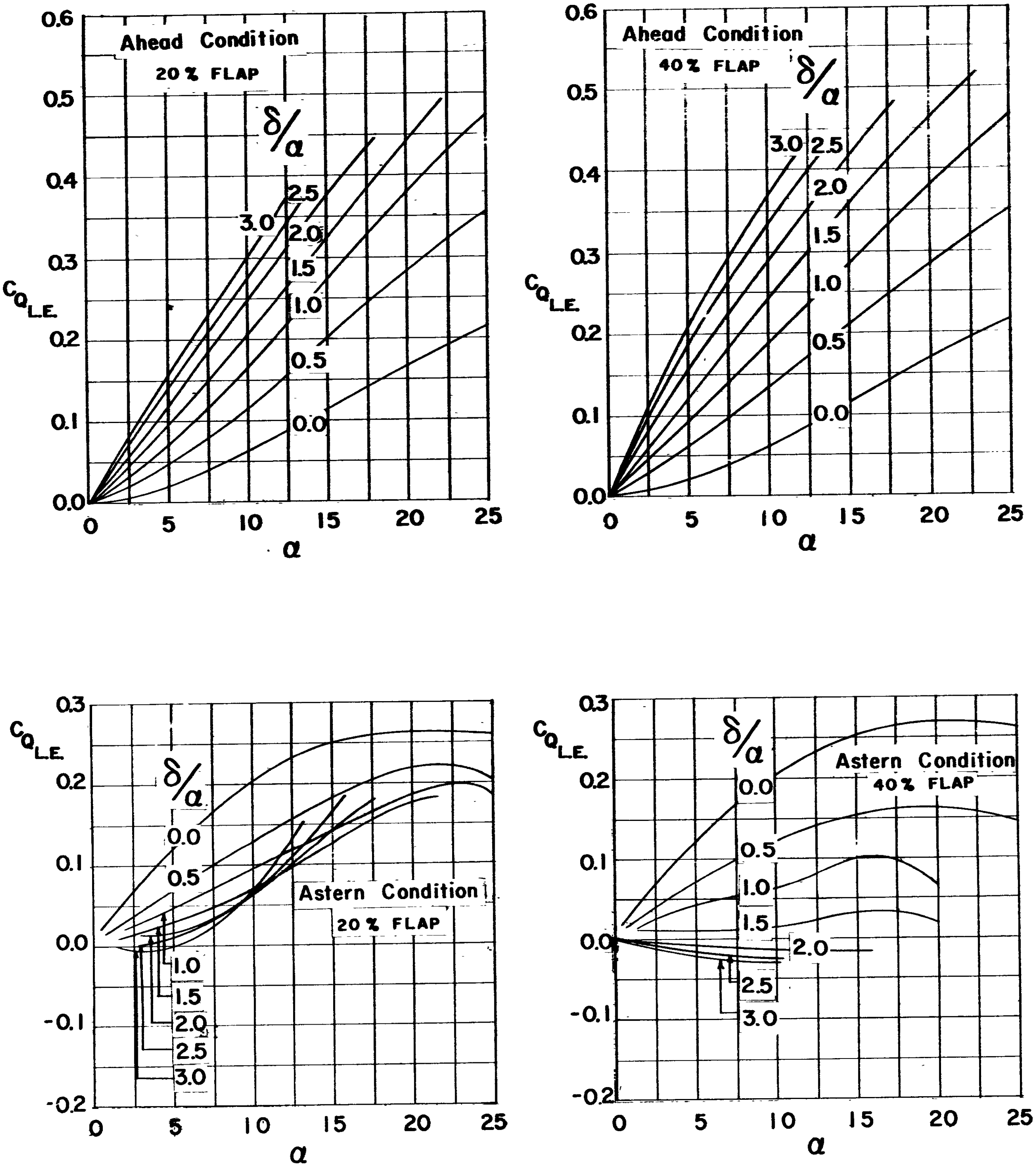

Figure 11 – Moment Coefficient Curves

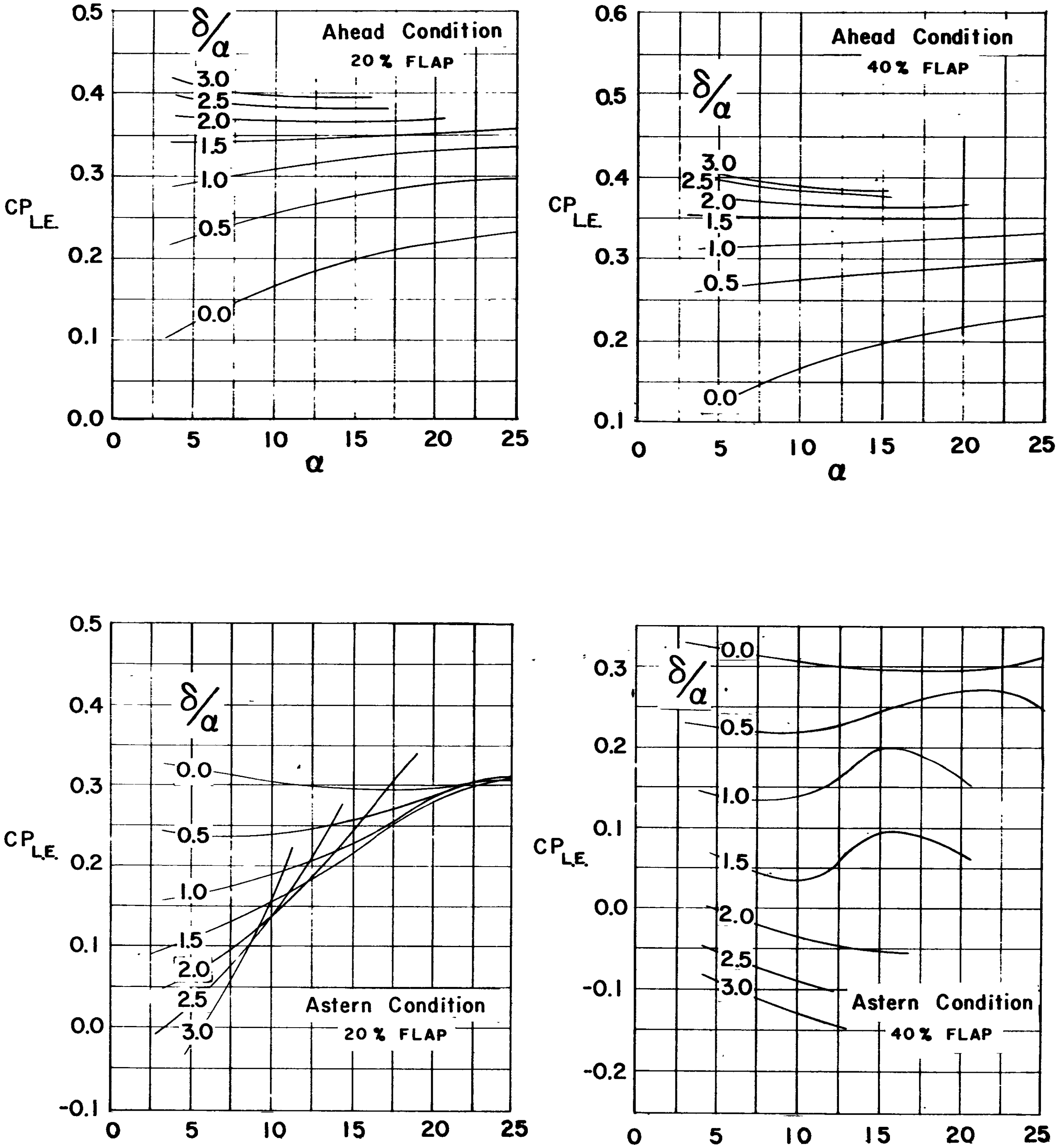

Figure 12 – Center of Pressure Curves

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