U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 61-107

A SUMMARY ANALYSIS OF AN STOL TRANSPORT

Task 9R38-11-009-02
Contract DA 44-177-TC-356
Job Order No. 6
August 1961

prepared by :

UNIVERSITY OF WICHITA
Wichita, Kansas

DISCLAIMER NOTICE

* * *

ASTIA AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from

Armed Services Technical Information Agency
Arlington Hall Station
Arlington 12, Virginia

* * *

This report has been released to the Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C., for sale to the general public.

The findings and recommendations contained in this report are those of the contractor and do not necessarily reflect the views of the Chief of Transportation or the Department of the Army.

* * *

ACKNOWLEDGEMENT

Acknowledgement is due to Dean Kenneth Razak for his counsel and encouragement in the preparation of this thesis, and to the University of Wichita Department of Engineering Research for making available wind tunnel data for the analysis.

Wichita, Kansas

June, 1961 **William H. Wentz, Jr.**

Task 9R38-11-009-02
Contract DA 44-177-TC-356
August 1961

A SUMMARY ANALYSIS OF AN STOL TRANSPORT

By

Kenneth Razak

and

A. J. Craig

UWER Report No. 365

Prepared by
University of Wichita
Department of Engineering Research
Wichita, Kansas

for
U.S. Army Transportation Research Command
Fort Eustis, Virginia

HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

FOREWORD

The theoretically optimum parameters for a short take-off and landing (STOL) transport described herein are based upon conclusions reached by the University of Wichita in its STOL and boundary layer control aircraft research over the past few years. Basically, the aim of this report is to define design parameters of an STOL transport capable of consistent landing performance in accord with the best performance of the aircraft (independent of pilot individuality).

The U. S. Army Transportation Research Command is in general agreement with the approach and methodology of this analysis.

It is expected that the data provided herein would be valuable in subsequent design and development of an STOL transport if such an aircraft is required.

FOR THE COMMANDER:

APPROVED BY:

George I. Schuck
GEORGE I. SCHUCK
Project Engineer

Raphael F. Garofalo
RAPHAEL F. GAROFALO, CWO-4, USA
Assistant Adjutant

CONTENTS

A SUMMARY ANALYSIS OF AN STOL TRANSPORT

By

Kenneth Razak and A. J. Craig

SUMMARY

A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not hertofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane.

Salient features of the airplane are:

1. An integrated thrust/lift propulsion system from either a single or multiple engines.
2. A combined system for both increasing the maximum lift coefficient and controlling the lift/drag ratio of the wing.
3. A wing loading sufficiently high, 35 pounds per square foot, for a cruise speed of 370 knots.

The landing distance of this airplane is 1170 feet and the take-off distance is 1380 feet, both over a 50-foot obstacle at ICAO standard sea level conditions.

A method of analysis is described which involves the use of trailing edge flaps deflected to 100 degree and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

INTRODUCTION

Extensive experimentation (Reference 6 and 7) in wind tunnels and in full scale flight tests has demonstrated that an extended range of aerodynamic parameters is available to the airplane designer through the use of blowing boundary layer control (BLC). These tests show (1) a maximum lift coefficient of 4.5 to 5.0 can be achieved with a single slotted flapped airfoil and (2) at these values of C_L, the drag coefficient can be varied from .8 to 1.6 at essentially constant lift coefficient by varying flap deflection from 70 to 100 degrees.

The higher lift coefficients can be used to reduce landing speeds or to provide the same landing speed at increased wing loadings. This has been done on the Lockheed C-130 which has been modified to become the BLC-130, with the results as given in Reference 2. Here the incorporation of BLC provided landing ground rolls of consistently one-third the value for the vehicle without BLC; moreover, the improved performance was accomplished without complex pilot techniques or problems in handling characteristics.

The flight test landings of the BLC-130 were made to an open field rather than over an obstacle and flight verification of the benefits of variable drag in making steep approaches was not obtained. However, in STOL operation, the problem of achieving consistency in minimum-distance landings has been shown to depend primarily upon control of the flight path to the barrier (References 3 and 4), and the wind tunnel results presented in Reference 6 demonstrate that the use of flap deflection above 60 degrees can provide the required path control. Furthermore, this method of path control can be accomplished with the aircraft descending at a constant pitch attitude, thus relieving the pilot of the necessity to rotate the aircraft prior to contacting the ground (References 4 and 5). No aircraft has been designed as yet to take advantage of the above factors.

This report is a highly condensed description of the concept and procedures of selection of parameters and design and, in conjunction with the references, can be used to actually lay out a preliminary design of this new type of fixed wing airplane.

DESIGN CONCEPTS

No attempt will be made in this summary analysis to depict an actual airplane in terms of three views, inboard profiles, and other design drawings. Instead, the set of physical features and aerodynamic parameters which are unique in the proposed airplane will be described and the salient items of performance will be determined.

Power Plant

The development of power plants over the past several years has been such that the main problem of the BLC airplane, i.e., the availability of an engine, has been solved. An engine for a BLC airplane must be able to pump sufficient air to satisfy the highest BLC demand and preferably should be usable for propulsion during cruise.

An example of such an engine is the Bristol-Siddeley 53/5 as described in Reference 1. This power plant provides separate "cold" and "hot" airflows which may be deflected in selected directions so as to provide either lift or thrust or modulated in between pure lift or thrust. In an STOL application, the cold air discharge is ideally suited to provide BLC air since it can supply the sufficiently large mass flows at a pressure ratio of approximately 2:1, while the hot airflow can be used for primary propulsion. For cruising flight, the cold air can be used to assist in propulsion.

Aerodynamic Configuration

Ground cargo loading requirements for an STOL transport will probably dictate a high wing arrangement such as the C-130. The combination lift-thrust engine or engines would be located so that the cold air would flow laterally in the wings while the hot air would discharge through a rearward pointing tail pipe. The engines thus would be located near the center of gravity on the top of the fuselage.

Wind tunnel data have shown that large pitching moments, i.e., -.8 to -1.4 accompany flap deflections of 60 degrees to 100 degrees on a BLC wing when the moments are referred to the quarter-chord station longitudinally and on the chord line vertically. This would necessitate either variable location of the center of gravity or large balancing forces. Since a canard configuration provides a vertical force in the direction of wing lift rather than opposed as in the conventional tail location, a higher trimmed airplane lift coefficient is realized with the canard. The stability problems of a canard surface could be eliminated by allowing it to "free float" in cruise or high speed, becoming effective only to trim out the extra increment of negative C_m.

Questions with regard to stability and control characteristics, particularly in flight at high lift coefficients during landing approaches over an obstacle, can be answered only by specific wind tunnel testing of the particular design. It should be noted, however, that no serious problems were encountered by Lockheed in the flight tests of the BLC-130 during simulated steep approaches at altitude, during stalls, or during simulated failure of the BLC system in an approach.

Selection of a Wing Loading

Most of the items of performance of an aircraft depend upon wing loading and selection of a particular value is the first task in designing a BLC vehicle. The conflicting requirements of high load carrying ability and high cruise speed versus short take-off distances and low approach speeds are best satisfied by the application of BLC when the wing loading is chosen in the range of 30 to 40 pounds per square foot. The upper limit is bounded by choking airflow in the BLC nozzles or maximum allowable rate of sink in a landing approach over a barrier.

In the majority of wind tunnel testing on BLC models, data were obtained on the aerodynamic parameters at a constant value of either quantity or momentum coefficient. In an actual airplane, a constant flow quantity is maintained, resulting in variable quantity and momentum coefficients as the airspeed varies. The method used for this design is to establish a flow quantity adequate to insure attached flow throughout the flight regime and hold this flow quantity constant.

For a wing loading of 35 pounds per square foot, a maximum lift coefficient of 4.8 can be realized with 90 degree flap deflection and a C_Q of 0.040. To be conservative in assuring attached flow, assume a condition of $C_L = 4.0$ and level flight. For a wing loading of 35 pounds per square foot, a flow quantity of 3,400 feet cubic per second or a weight flow of 270 pounds per second of sea level air is required for an airplane of 35,000 pounds gross weight. This flow quantity in addition to 8,000 pounds of exhaust thrust is currently available in either a single or multiple by-pass engines. Proper selection of BLC blowing slot geometry will produce exit velocities below sonic speed and careful duct design from the engine to the wing will prevent choking conditions anywhere in the BLC system.

Summary Specifications

With a wing loading of 35 pounds per square foot and a wing area of 1,000 square feet as set by the combination of aerodynamic and powerplant requirements and capabilities, the following specifications for the airplane may be written:

W/S = 35 pounds per square foot

S = 1,000 square feet

W = 35,000 pounds

C_{Do} = .020

BLC airflow = 270 pounds per second

Configuration = similar to C-130 except jet propelled

Empty Weight = 21,400 pounds, (estimated)

Flap deflections, δ_f = up to 100 degrees

PERFORMANCE

Take-off Distance

The take-off performance of the airplane is computed as follows:

BLC airflow = 270 pounds per second

Jet thrust = 8,000 pounds

C_L at lift-off = 4.0

C_D at lift-off = .6

Flap deflection = 60 degrees

Initial acceleration $= \left(\frac{8,000}{35,000}\right) g =$ 7.35 feet per second squared

Acceleration at lift-off $= \left(\frac{8,000}{35,000} - \frac{D}{L}\right) g =$ 2.5 feet per second squared

Velocity at lift-off $= \sqrt{\frac{35}{4.0 \times .001189}} =$ 86 feet per second

Ground roll $= \frac{1}{2} at^2 = \frac{V^2}{2a} = \frac{86^2}{9.85} =$ 750 feet

Rate of climb (@ $C_L = 4.0$) $= \frac{8,000-(D/L)L}{W} V$

$= \frac{2,750}{35,000} \times 86 =$ 6.75 feet per second or 405 feet per minute

Distance to climb to 50 feet $= \frac{50}{6.75} \quad 86 \cos(\text{Sin}^{-1}\frac{6.75}{86})$

$=$ 630 feet

Total take-off distance = 1,380 feet

Landing Performance

With the engine supplying BLC air but no thrust (i.e., thrust diverted laterally) and with flap deflections being controlled by the pilot between 70 degrees and 100 degrees, a mean descent path angle of 12.5 degrees is achieved. The change of the flap deflection controls the descent angle between 9 degrees and 16 degrees at constant airspeed and flare is accomplished by applying full thrust just before touch down. The approach is made at constant attitude while the flare is made at constant angle of attack.

$$\text{Air path} = \frac{50}{\tan\gamma} = \frac{50}{\tan 12.5^{\circ}} = 225 \text{ feet}$$

$$\text{Flare length} = \frac{R\gamma}{z} = \left[\frac{V^2 \text{ appr}}{g}\right] = \left[\frac{1}{n-1}\right] \gamma$$

$$\text{where } n = C_{L\max}/C_{L\text{appr}}$$

and flare length = 110 feet

This distance is based upon a load factor which varies with time as airplane accelerates at constant angle of attack and has been computed for three seconds duration.

The ground roll is computed on the basis of a touchdown speed of 108 feet per second to which the airplane is accelerated from an approach speed of 86 feet per second in order to flare. A deceleration of 7 feet per second squared is assumed during the ground roll since the turning off of the BLC air will quickly put the entire weight of the airplane on the wheels.

The ground roll is then $\frac{V^2}{2a} = \frac{108}{2\text{x}7} = 835$ feet

Total landing distance = 225 + 110 + 835 = 1,170 feet.

Cruise Performance

At 20,000 feet ISA, engine data shows gross thrust to be 9,280 pounds assuming a C_D of 0.020,

$$\text{gross thrust} - \text{momentum drag} = q\ S\ C_D$$

$$9{,}280 - (\text{mass flow})\ V = \rho/2\ (1{,}000)\ (0.020)\ V^2$$

$$9{,}280 - 217\ V/g = .000633\ (\ 20\ )\ V^2$$

$V = 625$ feet per second $= 425$ miles per hour or 370 knots

Manufacturers data for the engine gives fuel flow to be 4,750 pounds per hour at this altitude and 95 per cent fan r.p.m.

This presumes the cold and the hot air flow is used as thrust in cruise. Should the cold air flow be used to simply blow over an undeflected flap in cruise, a measure of the efficiency of such a technique could be wind tunnel determined to compare to the mechanically more complex method of diverting BLC air by some nozzle arrangement during the cruise condition.

The net engine thrust required to propel an aircraft from which air is issuing from a slot over the flap can be determined from the following relationship:

$$T_n = \left(C_{Do} + \frac{C_L{}^2}{\pi AR}\right) \frac{W}{C_L} - \rho_s Q \left\{ \sqrt{\frac{\eta_r w/s}{\rho a/2\ C_L} + \frac{p_f}{\frac{\rho_a a}{2}} - \frac{2\Delta p_\ell}{a}} - \sqrt{\frac{w/s}{\rho a/2\ C_L}} \right\}$$

where

T_n = Net engine thrust, pounds

C_{Do} = Airplane parasite drag coefficient

C_L = Airplane flight lift coefficient $= \dfrac{L}{\rho a/2\ SV^2}$

AR = Airplane Aspect ratio

W = Airplane gross weight, pounds

S = Airplane wing area, square feet

ρ_a = Atmospheric air density, slugs per cubic foot

ρ_s = Density of air issuing from blowing slot

Q = Volume flow of air at atmospheric pressure, cubic foot

η_r = Ram recovery at air intake, per cent

p_f = Pressure of air discharged from fan engine, pounds per square foot, gage

Δp_ℓ = Pressure drop in ducts between fan discharge and blowing slot, pounds per square foot

V = Flight velocity, feet per second

This equation can be solved for the net thrust required at any altitude and the result compared with the thrust available from the engine. In either case, i.e., pumping over the flap or using the entire engine flow for propulsion, the top speed will be over 400 miles per hour.

Rate of Descent

The sink rate which would accompany a wing loading of 35 pounds per square foot with a blowing air quantity flow of 270 pounds per second can be secured from the data presented in Reference 6, pages 51 to 54 and from Reference 8. These data show a range of descent path angles from -9 degrees to -16 degrees. A value of -12.5 degrees is secured at a lift coefficient of 4.0 with a rate of sink of 18.6 feet per second. This rate of sink produces an elapsed time from the barrier of only three seconds which is a near minimum as shown in Reference 3.

OPERATING CHARACTERISTICS

Many proposed STOL machines have offered performance in excess of that listed above, particularly with regard to shorter takeoff and landing distances. The salient feature of this particular STOL machine, i.e., a BLC machine, is that the landing distance as given above can be realized with consistency.

Stated directly, the field length requirements for this aircraft may be based upon the distances given above without allowances for variation of pilot performance (Reference 3). This consistency is achieved by a set of operating characteristics, including a controlled L/D ratio at constant lift, not possible with conventional machines.

From the standpoint of the pilot, the ability to control drag independent of lift in the landing over a barrier is the most important feature of this airplane. By this means the flight path may be made either steeper or flatter while maintaining a constant speed along the path, permitting precise placement of the flight path in space without increasing ground speed, hence, without increasing landing distance.

Another important feature is the ability to make the entire approach and flare at a constant pitch attitude, thus relieving the pilot of the necessity of rotating the airplane prior to contacting the ground with all the associated problems of rotational dynamics, transient response to elevator action, etc.

Details of stability and control would require wind tunnel data on the specific configuration, but the success in flight operation of the Lockheed-BLC-130 would suggest no insurmountable difficulties. In the process of wind tunnel testing, a set of stability derivatives and aerodynamic parameters could be determined while operating the model at constant pumping quantity, the method to be used in flight.

CONCLUSIONS

Sufficient data exist and a procedure has been announced for the design of a STOL transport with a speed ratio (ratio of top to landing speed) of about 7 to 1 and with which landing distances equal to the best performance of the airplane can be consistently achieved.

An airplane with the characteristics presented in this report would effectively supplement large and small helicopters. An operations analysis would determine the exact value in a military logistic or tactical situation. Should the operations analysis give favorable conclusions, the aerodynamic data necessary for the preliminary design is available in the references as listed.

REFERENCES

1. Bristol Siddeley Engines Limited, B.E. 53/5 Lift Thrust Engine, Filton Bristol, England, December 1959.

2. Butz, J.S., Jr., "Lockheed Applies BLC to Large Aircraft," Aviation Week, June 20, 1960, pp. 181, 183, 185.

3. Craig, A.J., "Achieving Consistency in Maximum Performance STOL Landings," University of Wichita Engineering Report No. 351, TREC Technical Report 61-41, Contract DA 44-177-TC-356, School of Engineering, University of Wichita, Wichita, Kansas, January 1961.

4. Craig, A.J., "A constant Attitude Landing System for STOL Aircraft," Master's Thesis, June 1960.

5. Lockheed BLC-130 unpublished data.

6. Stalter, James L., and Wattson, Robert K., "Circulation Control Research Wind Tunnel Tests of a Powered, Blowing-Type, Circulation Control Research Airplane Model," University of Wichita Engineering Report No. 187-1 through -5, Contract No. NONR 201(01), School of Engineering, University of Wichita, Wichita, Kansas.

   187-1 - Investigation of the Basic Aerodynamic Characteristics of a Circulation Control Research Model, James L. Stalter, December 1956.

   187-2 - Effects of Power on the Aerodynamic Characteristics of a Circulation Control Research Model, James L. Stalter and Robert K. Wattson, Jr., March 1957.

   187-3 - Effects of a Blowing-Type Circulation Control System on Control Surface Characteristics, James L. Stalker, May 1957.

   187-4 - Effects of Wing Circulation Control and Power on Flow Characteristics in the Region of the Tail Surfaces, James L. Stalter, April 1957.

187-5 - Flow Visualization Studies with Power and Wing Circulation Control, James L. Stalter and Robert K. Wattson, Jr., February 1957.

7. Stalter, James L., and Wattson, Robert K., "Experimental Investigation of a Means of Obtaining Independent Control of Lift and Drag in Landing Approach," University of Wichita Engineering Report No. 315-5, Contract No. DA 44-177-TC-356, School of Engineering, University of Wichita, Wichita, Kansas, April 1959.

8. Wentz, William H. Jr., "The Topology of the Aerodynamic Parameters of an Airplane with a Jet-Augmented Flap," Master's Thesis, University of Wichita, June 1961.

APPENDIX

The following was written as a master's thesis by William H. Wentz, Jr., and is presented as an appendix in its original form.

THE TOPOLOGY OF THE AERODYNAMIC PARAMETERS OF AN AIRPLANE WITH A JET-AUGMENTED FLAP

BY

WILLIAM H. WENTZ, JR.

A THESIS
SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF AERONAUTICAL ENGINEERING

THE UNIVERSITY OF WICHITA
WICHITA, KANSAS
JUNE, 1961

TABLE OF CONTENTS

LIST OF SYMBOLS

AR	Aspect ratio, $(\text{Span})^2/S$
C_L	Lift coefficient, L/qS
C_D	Drag coefficient, D/qS
C_{D_i}	Induced drag due to lift, $C_L{}^2/\pi\,AR$
C_M	Pitching moment coefficient about 20% chord, $M/qS\overline{C}$
C_μ	Blowing air momentum coefficient, J/qS
$\overline{C}$	Mean aerodynamic chord, ft
D	Drag force, lb
g	Gravitational acceleration, 32.2 ft/sec^2
J	Blowing air momentum, $\dot{m}V_j$, lb
L	Lift force, lb
$\dot{m}$	Blowing air mass flow, slugs/sec
M	Pitching moment about 20% chord, ft-lb
q	Free stream dynamic pressure, $1/2\,\rho V^2$, lb/ft^2
S	Wing area, ft^2
T	Thrust force, lb
V	True airspeed, knots
V_j	Jet velocity, ft/sec
V_{sink}	Vertical sinking speed, ft/sec
W	Airplane weight, lb

α	Angle of attack, degrees
γ	Flight path angle relative to horizon, degrees
δ_{flap}	Flap deflection, degrees
θ	Airplane attitude relative to horizon, degrees
ρ	Free stream air density, slugs/ft^3

THE TOPOLOGY OF THE AERODYNAMIC PARAMETERS OF AN AIRPLANE WITH A JET-AUGMENTED FLAP

INTRODUCTION

In the past several years, much research has been accomplished to investigate various devices intended to produce high lift coefficients. The jet-augmented flap has been the object of particularly intensive study as a high-lift device. The traditional method of low-speed wind tunnel testing such devices is to hold dynamic pressure (q) constant, and obtain data by changing angle of attack and flap deflection for a series of blowing air quantities. The data thus obtained are reduced to conventional lift, drag, and moment coefficient form. The blowing air quantity or momentum is also reduced to coefficient form. It is not practical or desirable, however, to fly an airplane with blowing air <u>quantity coefficient</u> or <u>momentum coefficient</u> constant as speed changes. It is much simpler (and therefore more desirable) to fly with constant blowing air <u>quantity</u> or <u>momentum</u>.

The primary purpose of this investigation is to provide a means of predicting from wind tunnel data the lift, drag, and pitching moment of an airplane with varying speed while (1) airplane weight and (2) blowing momentum are held constant. This, then, is an investigation of the topology of the aerodynamic parameters of such an airplane. Data from reference 1 [1] are presented to illustrate the method.

The University of Wichita Department of Engineering Research (ref. 1) has investigated the use of the jet augmented flap as a means of controlling airplane landing approach angle and speed. Reference 1 presents results for a particular configuration which show that the flap is effective in this capacity for several constant <u>blowing quantity coefficients</u> (C_q's). A secondary purpose of the present investigation is to compute the approach performance for an airplane similar to the model of reference 1 with constant <u>blowing momentum</u> (or quantity).

---

[1] References will be found in the List of References on page 26.

EFFECTS OF TRAILING EDGE BLOWING OVER HIGHLY DEFLECTED FLAPS

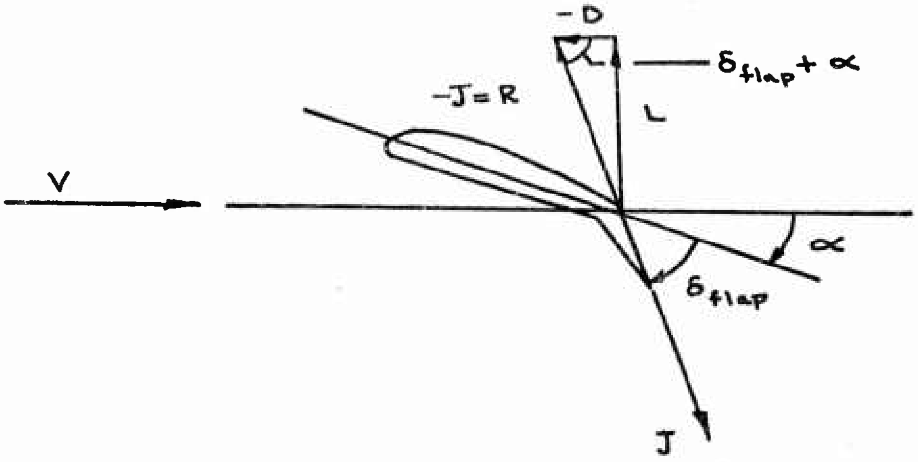
Several benefits are derived from blowing a jet of air over a highly deflected flap. First, blowing with any aft-facing nozzle on an airfoil induces a suction upstream from the nozzle, thus providing a favorable pressure gradient. The boundary layer is thinned by this pressure gradient and (for low amounts of blowing) the total drag is reduced even though the skin friction drag is increased.

A related and extremely important effect of the favorable pressure gradient is the delay of separation. This delay results in increased lift coefficient. If separation can be prevented, potential flow lift coefficients (see ref. 2) are approached. Therefore, as blowing is increased over a highly deflected flap the separation point moves aft and the lift coefficient increases rapidly, with a corresponding increase in induced drag.

As blowing is increased beyond that required for complete flow attachment, the lift coefficient continues to increase due to the component of the jet momentum in the lift direction. (This component is present with any amount of blowing.) Similarly, the component of jet momentum in the thrust direction results in a change in measured drag force. (All data presented in this paper are based upon measured forces. No corrections for momentum components have been made.) For infinite blowing,

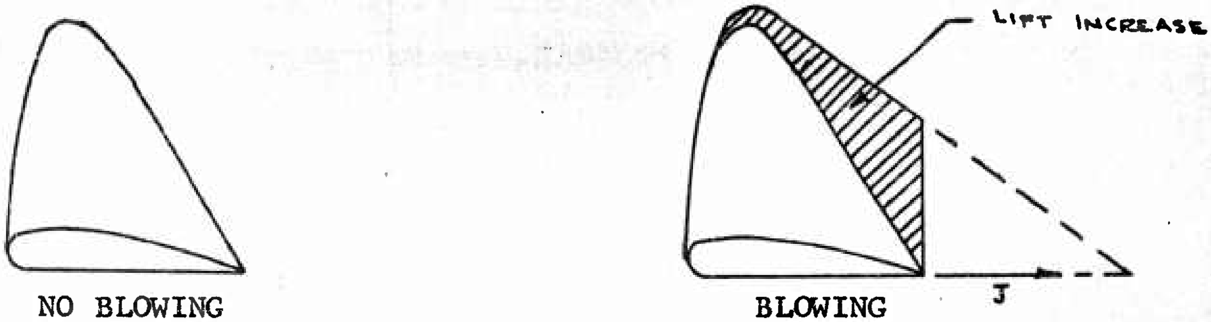
$$dC_L / dC_D = \tan^{-1}(\delta_{flap} + \alpha)$$

(See sketch below.)



H. B. Helmbold (ref. 3) has shown that the introduction of a trailing edge jet into the flow field will increase the circulation lift of an airfoil. Since a continuous jet film or sheet can support a pressure difference, the pressure on the upper surface at the trailing edge need not be equal to the pressure on the lower surface at the trailing edge. This "super-circulation" may grossly increase the lift as shown below.

LIFT DISTRIBUTIONS



NO BLOWING BLOWING

This may be likened to adding a trailing-edge extension and computing lift coefficients based upon the original wing area. This latter concept is the basis of D. A. Spence's (ref. 4) hinged flap analogy to the jet flap.

It is interesting to note that since the jet sheet has greater momentum than the surrounding air, it will not be deflected as readily as the surrounding air. Therefore, at the same lift coefficient, a wing with a trailing-edge jet will afford greater resistance to vortex roll-up, resulting in less induced drag. Span efficiency factors greater than 100% have been measured (ref. 5) with a pure jet-flap (no mechanical flap). However, the wing with a highly deflected jet-augmented mechanical flap will have a pressure force increase in the drag direction due to this same effect. (Rotate the "lift" increase shown in the sketch above 90° for a 90° flap deflection, for example.) This latter case will yield a lower span efficiency factor. Reference 7 shows data for a two-dimensional jet-augmented flap with drag coefficients as high as .30 due to this pressure force in the drag direction.

DESCRIPTION OF THE WIND TUNNEL MODEL

The half-model used in reference 1 was a configuration considered typical of probable STOL transport type airplanes. The semispan wing was tapered in both planform and thickness. The airfoil section at the root was the NACA 23018 and at the tip was the NACA 23012. The wing was equipped with a 25% chord single slotted flap along 75% of the wing span. The outboard 25% of the wing was equipped with a 30% chord aileron which could be drooped along with the flap to a maximum deflection of 30°. A slot in the wing trailing edge served as a nozzle for blowing air over the flap and aileron. The slot was tapered to provide a constant .006 slot to chord ratio. All the data presented in this paper are based upon fullspan (flap and aileron) blowing. The fuselage was half of a body of revolution of a modified NACA 0015 airfoil section. The model was tested without tail and without engine nacelles. Photos, sketches, and a more detailed description of the hardware are contained in reference 1.

LIFT, DRAG, AND PITCHING MOMENT ANALYSIS

B. S. Stratford, in 1956, performed certain experiments with jet flaps in which the density of the blowing gas was varied by a factor of three. His work (ref. 6) demonstrated that the blowing coefficient which determines the circulation round an airfoil is the momentum coefficient ($C_\mu = J/qS$). Consequently, C_μ is used throughout this paper as the pertinent blowing parameter.

It is not practical to hold C_μ constant as speed changes, since this would require complicated throttling of the blowing system. It is more realistic to consider constant blowing momentum. Consider then an airplane with constant lift (equals weight in level flight) and constant blowing momentum (J). The following are conventional definitions:

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$$

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$$

$$C_M = \frac{M}{\frac{1}{2}\rho V^2 S \bar{c}}$$

$$C_\mu = \frac{J}{\frac{1}{2}\rho V^2 S}$$

With L and J constant,

$$J/L = \text{constant} = \frac{C_\mu \frac{1}{2}\rho V^2 S}{C_L \frac{1}{2}\rho V^2 S}$$

Since L and J occur simultaneously,

$$J/L = C_\mu / C_L$$

for any speed in level flight. The problem then is to obtain data at constant C_μ / C_L. Conventional wind tunnel data are currently presented in the following form:

$$C_L = (\delta_{flap}, \alpha, C_\mu \text{ or } C_q)$$
$$C_D = (\delta_{flap}, C_L, C_\mu \text{ or } C_q)$$
$$C_M = (\delta_{flap}, C_L, C_\mu \text{ or } C_q)$$

The desired forms may be obtained as follows:

(a) plot C_L vs C_μ with α constant

(b) construct constant C_μ / C_L lines

(c) plot C_L vs α from the intersections obtained in (b).

On the C_L vs C_μ plane, constant C_μ / C_L's are represented by straight lines through the origin. (See figures 1 through 5.)

These straight lines, then, represent operating lines along which an airplane will fly with constant weight in level flight and constant blowing. Note at this point that as C_L increases, C_μ increases. This means that the lift curve slope ($dC_L/d\alpha$) with constant C_μ / C_L will be greater than that shown by a constant C_μ line in the C_L vs α plane.

Drag and moment coefficient data are treated in a similar fashion. First the drag or moment coefficient is plotted against C_L with constant α (C_μ variable). Then, using the C_L vs α combinations previously determined which result in constant C_μ / C_L, it is possible to obtain C_D and C_M vs C_L at constant C_μ / C_L. (See figures 17 through 28.)

RESULTS OF THE LIFT, DRAG, AND MOMENT ANALYSIS

LIFT

The C_L vs C_μ data (figures 1 through 5) demonstrate clearly the region of flow attachment at low C_μ. In this region C_L increases about 10 times as fast as C_μ. This means that every pound of additional blowing momentum yields 10 pounds of lift. The curves then demonstrate a sharp change in slope as the flap becomes completely attached. The final slope becomes equal to the reaction component of momentum. (One additional pound of thrust with 90° flap yields about one additional pound of lift.) For the range of C_μ tested (up to 1.2), no really significant "supercirculation" was observed.

The C_L vs α data at constant C_μ / C_L (figures 6 through 10) show the following characteristics when compared to the constant C_μ case:

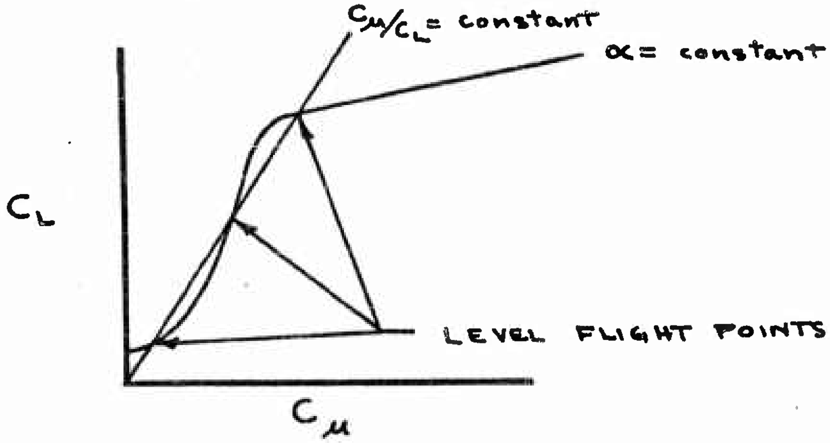
(1) The stall angle of attack at high lift is not appreciably changed.

(2) In the region of fully attached flow, the C_L vs α curve is essentially linear but with a greater slope than with constant C_μ. For example, comparison with constant C_μ curves of reference 1 shows an increase in $dC_L/d\alpha$ from .075 per degree

to .085 per degree for the 100° flap deflection.

(3) At low angles of attack, (flow not completely attached) the C_L curve has a sharp drop as α is diminished. This makes flight at these angles untenable.

Item (3) above requires further discussion. The peculiar shape of the C_L vs C_μ curves results in multiple intersections with constant C_μ/C_L lines at low C_μ/C_L and low α.



Since the constant C_μ/C_L line represents an airplane in level flight, the lower intersections represent higher speeds at which the airplane can fly at the same angle of attack. At these higher speeds, however, the forward velocity has blown the jet sheet aft, causing the flap to partially separate. The loss of lift is illustrated by a drop in the C_L vs α curves (figures 7, 8, 9, and 10) at lower angles of attack. Because of the large excursions of lift it is desirable not to fly in this region. This imposes definite limits upon C_μ/C_L and α. Values of C_μ/C_L less than 1/10 or α less than -8° are not considered in the approach analysis of the configuration considered in this paper. In some instances it is seen that C_μ/C_L must be greater than 1/10 to avoid this phenomenon.

The C_L vs δ_{flap} data (figures 11 through 16) illustrate the effectiveness of high flap deflections as a means of changing drag without changing lift. Particularly in the range of flap deflections from 80 to 100 degrees, there is very little change in lift. The drop in C_L due to flap separation at low C_μ/C_L is seen here also.

DRAG

The lift-drag polars (figures 17 through 23) at constant α illustrate clearly the first three effects of blowing discussed previously (page 6). The constant C_μ/C_L polars are essentially parallel extensions of the no blowing ($C_\mu/C_L = 0$) polar. No gross change from the constant C_μ case is shown.

MOMENT

The C_L vs C_M data (figures 24 through 28) at constant α illustrate the powerful effect of blowing to move the center of lift aft. This also illustrates the difficulty of changing blowing to control approach. (One possible method of balancing the airplane while the blowing quantity is changed would be to bleed air out an auxiliary jet for balance.) The constant C_μ / C_L data show a much smaller change in C_M as C_L or flap deflection changed. Thus the trim changes required at constant blowing would be relatively small. Change in downwash at the tail with flap deflection would be a prime consideration in locating the horizontal tail. If the downwash or moment change were large, the elevator would have to be geared in some manner to the flap.

LANDING APPROACH ANALYSIS

Airplanes capable of short field landings must be able to fly steep descent angles at low speeds. This implies high drag/lift at high lift coefficients. These criteria are fulfilled by the jet-augmented flap with flap deflections greater than 70°. (See figures 17 through 23.) The purpose of reference 1 was to evaluate flap deflections of 70 to 110 degrees with blowing circulation control as a means of obtaining and controlling steep descents. The results illustrated that flap deflection could be used as a means of changing descent angle by changing drag without greatly changing lift.

One purpose of the present study is to determine the effectiveness of the flap in this capacity if blowing momentum is not changed. Two simple paths are considered:

(1) Constant airspeed

(2) Constant attitude

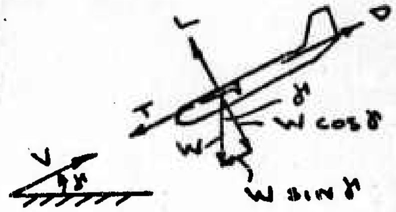
both at constant blowing, i.e.

$$J = \text{constant}$$

$$W = \text{constant}$$

$$J/W = (C_\mu / C_L)_{\text{level}} = \text{constant}$$

In a steady approach with zero thrust



$$L = W \cos \gamma$$

$$D = W \sin \gamma \qquad (\text{SINCE } T = 0)$$

$$\tan \gamma = \frac{D}{L} = \frac{C_D}{C_L}$$

$$C_L = \frac{L}{qS} = \frac{W \cos \gamma}{qS}$$

$$C_\mu = \frac{J}{qS}$$

$$C_\mu / C_L = (J/W)\, 1/\cos \gamma$$

For constant airspeed, the method of computation is as follows:

CONSTANT AIRSPEED APPROACH

(1) Select δ_{flap}, V, J/W, and W/S

(2) Assume γ

(3) Compute $C_\mu / C_L = (J/W)\, 1/\cos \gamma$

(4) Compute $C_L = W \cos \gamma / qS$

(5) Look up $C_D = f(\delta_{flap}, C_\mu/C_L, C_L)$ (figures 17 through 23)

(6) Compute $\gamma = \tan^{-1}(C_D/C_L)$

(7) Iterate until γ converges

(8) Compute $V_{SINK} = V(\sin \gamma)$

For constant attitude the method of computation is as follows:

CONSTANT ATTITUDE APPROACH

(1) Select δ_{flap}, θ, J/W, and W/S

(2) Assume γ

(3) Compute $C_\mu / C_L = (J/W)\,1/\cos\gamma$

(4) Compute $\alpha = \gamma - \theta$

(5) Look up $C_L = f(\delta_{flap}, C_\mu/C_L, \alpha)$ (figures 6 through 10)

(6) Look up $C_D = f(\delta_{flap}, C_\mu/C_L, C_L)$ (figures 17 through 23)

(7) Compute $\gamma = \tan^{-1}(C_D/C_L)$

(8) Iterate until γ converges

(9) Compute $V = \sqrt{W \cos\gamma / \frac{1}{2}\rho S}$

(10) Compute $V_{sink} = V(\sin\gamma)$

For the purposes of this paper a hypothetical airplane was studied, geometrically similar to the model of reference 1, with a wing area of 1,000 sq ft and a gross weight of 35,000 lb. Using the methods described above, approach angles and speeds were computed for blowing momentum to weight ratios of 1/10, 1/8, 1/7, and 1/5. Results of these computations are shown on figures 29 through 32. These data show that the flap is an effective approach angle control for angles from 7 to 19 degrees, with sinking speeds from 10 to 25 ft per second, and landing speeds of 43 to 55 knots.

For J/W less than 1/5, the airplane D/L ratio decreases in the range from 100 to 110 degree flap deflections. This is because of the high blowing requirement to maintain flow attachment with 110 degree flap deflections. The primary effect of increasing J/W however, is to reduce airplane speed, and therefore to reduce sinking speed.

These data are bounded on the high approach angle side by the stall boundary, and on the low angle by $\alpha = -8^\circ$ or $\theta = -18^\circ$, whichever occurs first. The -18° limit on θ is believed to be a practical one from the standpoint of landing gear geometry. The -8° limit on α is the limit of the data available. Because of the sudden decrease in C_L at low α mentioned previously (page 15), it is not practical to extrapolate beyond the data.

A physical description of the use of flap deflection at constant attitude as an approach control is in order here. Consider the airplane with 7,000 lb of blowing momentum (figure 32) at an attitutde of -14° and with flaps at 110°. The descent angle is 18.4°, the sinking speed is 23 ft per second, and the airplane velocity is 43 knots. Now if it is desired to flatten the approach to 6°, the flap deflection is changed to 70°. Since the drag is now less, the airplane will accelerate to a speed of 55 knots, thereby giving the extra lift needed to slow the descent to 10 ft per second. Oddly enough, this system basically utilizes a drag change to produce a lift change.

Since the drag cannot be made zero (without considerable longitudinal blowing) the only way to reduce the sinking speed to zero is to add thrust from the main engines. The descent might be further reduced by reducing the flap deflection below 70°. An attempt was made to construct lift-drag polars from a very meager amount of 60° flap data from references 1 and 2. This attempt was not successful, however. Therefore, one recommendation of this paper is that data with lower flap deflections be obtained to determine better the useful limits of flap deflections as an approach control.

One interesting thing is noted about the constant attitude approach. If the airplane is at the stalling speed at maximum descent angle, reducing the flap deflection (and descent angle) gives a margin from the stall boundary. Because of this it is possible to execute a conventional flare after reducing flaps to 70°. This conventional flare serves to rotate the airplane into touchdown attitude, and to reduce the sink rate to zero. The necessity of executing such a flare is really determined by the capability of the landing gear system.

RESULTS OF THE APPROACH ANALYSIS

The approach analysis shows that the jet-augmented flap with constant blowing is an effective tool for controlling descent angle within the range of flap deflections tested.

Increasing the blowing momentum to airplane weight ratio (J/W) increases the effective range of flap deflections, and hence the range of approach angles possible. It should be noted that descent angles obtained are functions only of J/W and are not affected by wing loading (W/S). Therefore the approach angles shown are applicable to any wing loading with the same J/W.

Changing W/S affects the airspeed for a given C_L because of the relationship between C_L, W/S and V. (V is proportional to the square root of W/S.) Sink speeds are affected by the same factor. Approach speeds and sink rates at other wing loadings are given by:

$$V = V_{W/S=35} \sqrt{\frac{W/S}{35}}$$

Analysis of the dynamics of the airplane is beyond the scope of this paper. Flying a constant airspeed approach requires changing pitch attitude as flight path angle is changed. Flying a constant attitude approach requires changing of speed as flight path angle is changed. These require, respectively, pitch and longitudinal accelerations. An important step then, in the evaluation of the proposed approach control system would be the use of a flight simulator. This would permit study of the foregoing pitch and longitudinal accelerations as well as the effects of pilot reaction time. All of these are extremely important when one realizes that the time from 50 feet to ground contact is between 2 and 5 seconds for the range of sinking speeds considered here.

CONCLUSIONS

1. C_μ/C_L is a useful parameter for analyzing jet-augmented flap performance.
2. The lift curve slope ($dC_L/d\alpha$) is .085 per degree with constant C_μ/C_L compared to .075 per degree with constant C_μ in the region of attached flow.
3. With constant blowing it is possible to change approach angle from 19 to 7 degrees by changing flap deflection without changing attitude. Sink rate for a 35 lb/ft^2 wing loading is correspondingly changed from 23 to 10 ft/sec.
4. Additional data with smaller flap deflections would be required to determine the lower flap deflection useful limit for controlling approach angle.
5. The airplane dynamics of this problem should be studied by use of a flight simulator in order to determine the speed and attitude corrections possible within the time available to the pilot.

REFERENCES

1. Stalter, J. L., and Wattson, Robert K. Jr., *Experimental Investigation of a Means of Obtaining Independent Control of Lift and Drag in Landing Approach*, University of Wichita, Department of Engineering Research Report 315-5, April 1959.
2. Hoy, J. A., and Eggington, W. J., *An Exact Theory of a Thin Aerofoil with Large Flap Deflection*, Journal of the Royal Aeronautical Society, November 1956, pp. 753-757.
3. Helmbold, H. B., *On the Lift of a Blowing Wing in a Parallel Stream*, University of Wichita Engineering Study No. 135, April 1954.
4. Spence, D. A., *Lift on a Thin Airfoil with a Jet-Augmented Flap*, Aeronautical Quarterly, August 1958, pp. 287-299.
5. Lockwood, V. E., Turner, Thomas R., and Riebe, John M., *Wind-Tunnel Investigation of Jet-Augmented Flaps on a Rectangular Wing to High Momentum Coefficients*, NACA TN 3865, December 1956.
6. Stratford, B. S., *Early Thoughts on the Jet Flap*, Aeronautical Quarterly, February 1956, pp. 45-59.
7. Wallace, Richard E., and Stalter, J. L., *Systematic Two-Dimensional Tests of an NACA 23015 Airfoil Section with a Single-Slotted Flap and Circulation Control*, University of Wichita Aerodynamic Report No. 120, 1954.

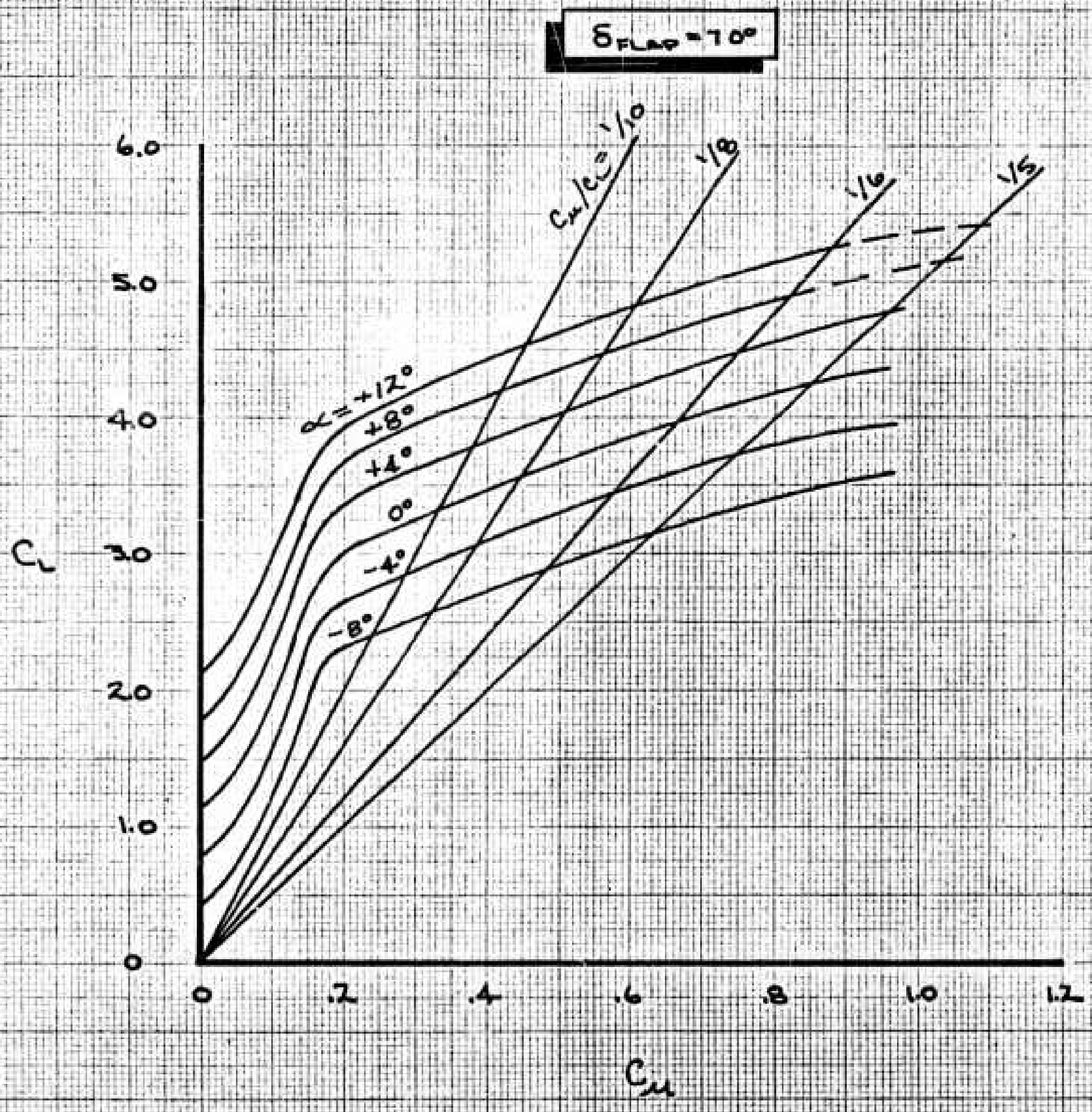

δFLAP = 70°
Cμ/CL = 1/10
1/8
1/6
1/5
α = +12°
+8°
+4°
0°
-4°
-8°
CL
6.0
5.0
4.0
3.0
2.0
1.0
0
0
.2
.4
.6
.8
1.0
1.2
Cμ

Figure 1

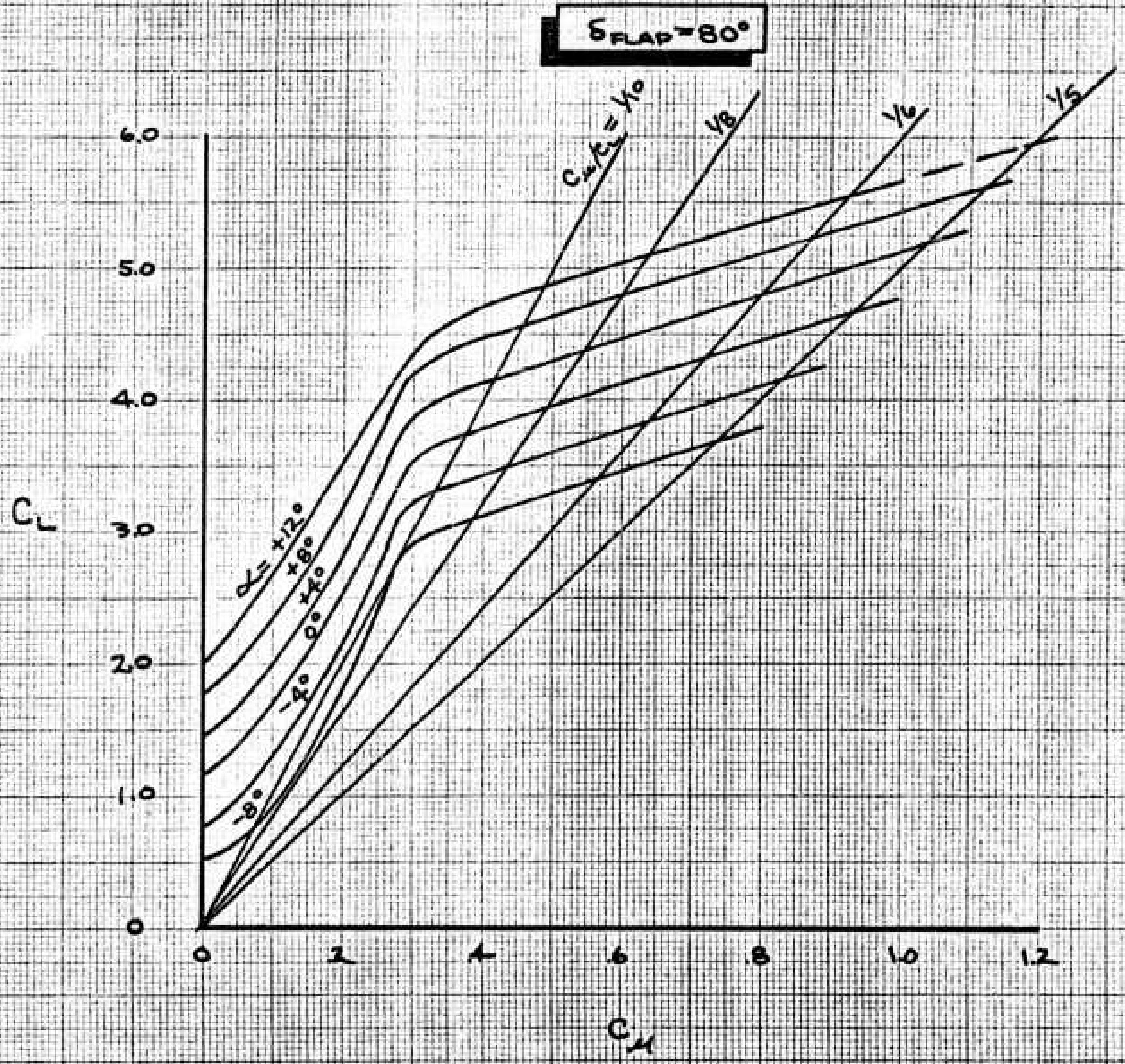

δFLAP = 80°
Cμ/CL = 1/10
1/8
1/6
1/5
α = +12°
+8°
+4°
0°
-4°
-8°
CL
6.0
5.0
4.0
3.0
2.0
1.0
0
0
.2
.4
.6
.8
1.0
1.2
Cμ

Figure 2

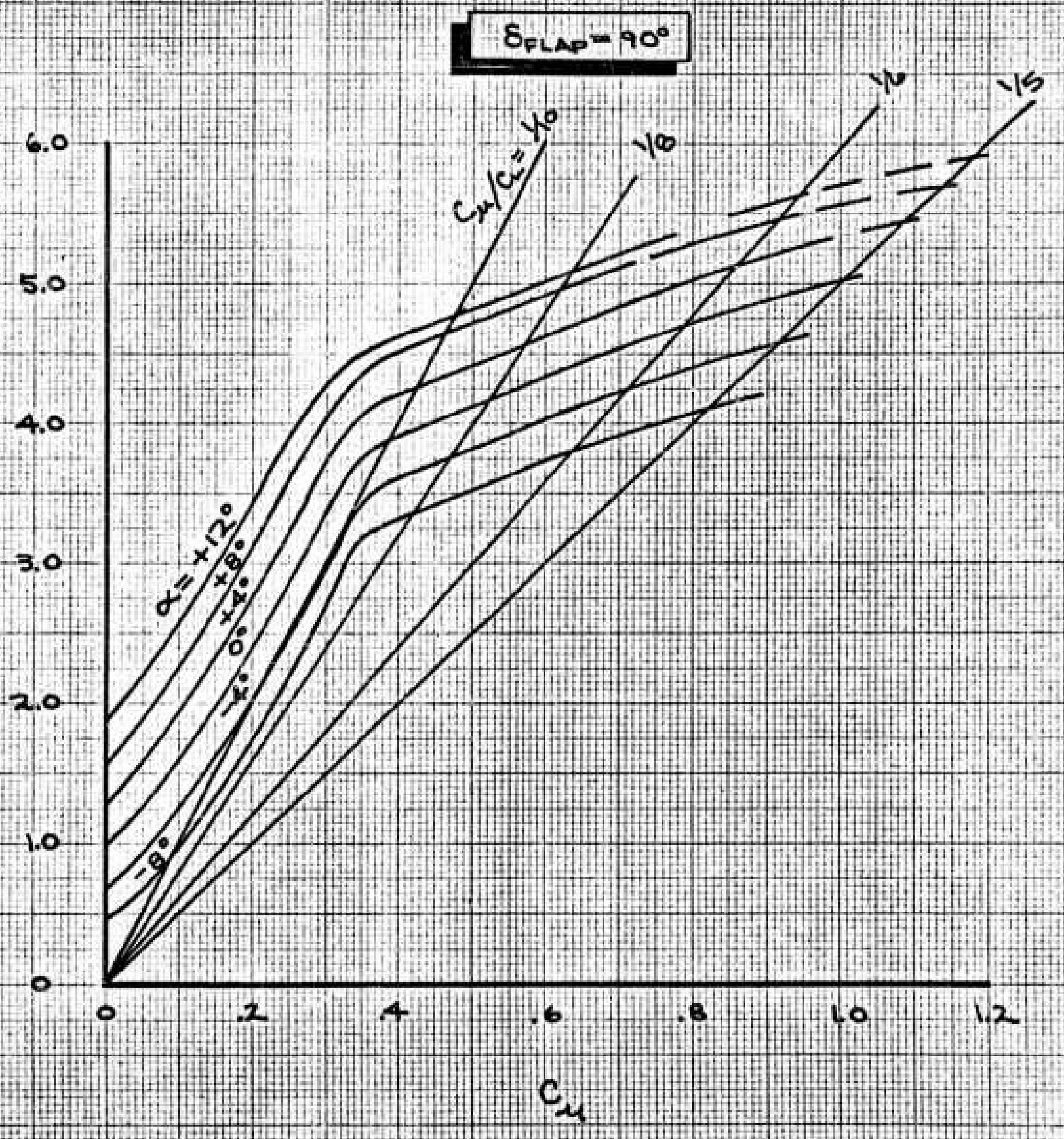

δFLAP = 90°
C_L
C_μ
$C_\mu/C_L = 1/10$
1/8
1/6
1/5
α = +12°
+8°
+4°
0°
-4°
-8°
0
1.0
2.0
3.0
4.0
5.0
6.0
0
.2
.4
.6
.8
1.0
1.2

Figure 3

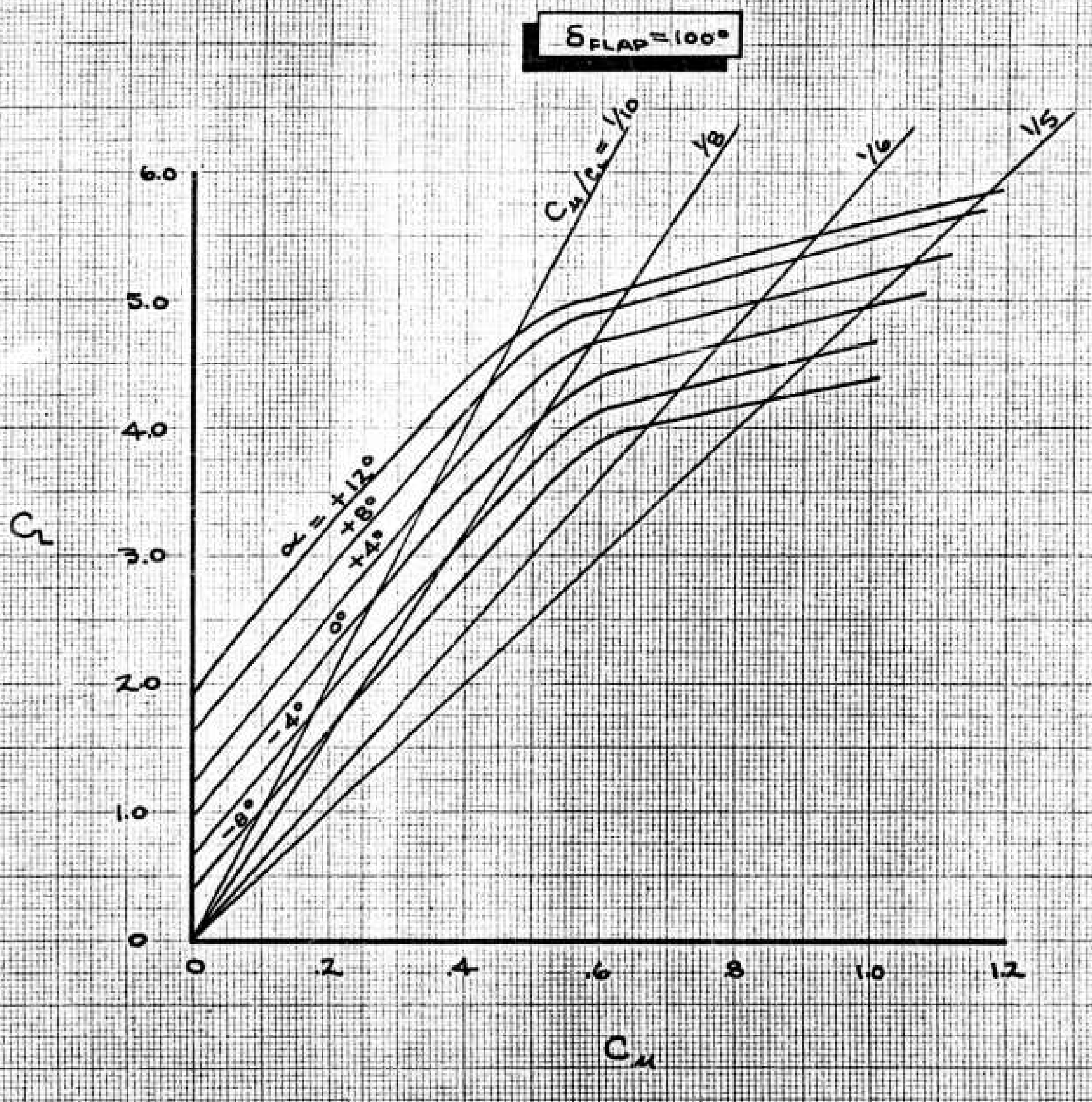
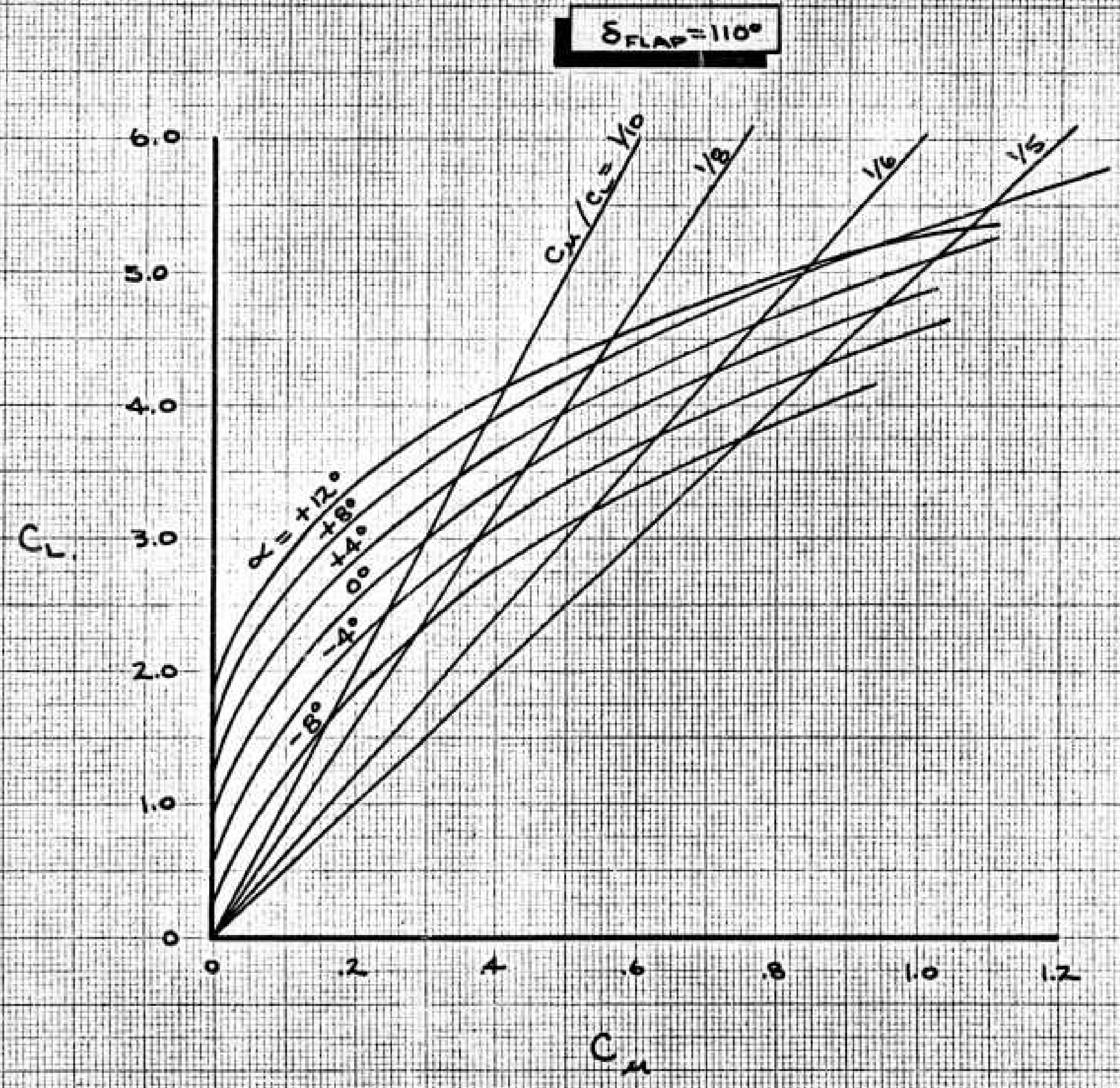

δ_FLAP = 100°
$C_\mu/C_L = 1/10$
1/8
1/6
1/5
α = +12°
+8°
+4°
0°
-4°
-8°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
0
.2
.4
.6
.8
1.0
1.2
C_μ

Figure 4



δFLAP=110°
6.0
5.0
4.0
3.0
2.0
1.0
0
CL
0
.2
.4
.6
.8
1.0
1.2
Cμ
Cμ/CL = 1/10
1/8
1/6
1/5
α = +12°
+8°
+4°
0°
-4°
-8°

Figure 5

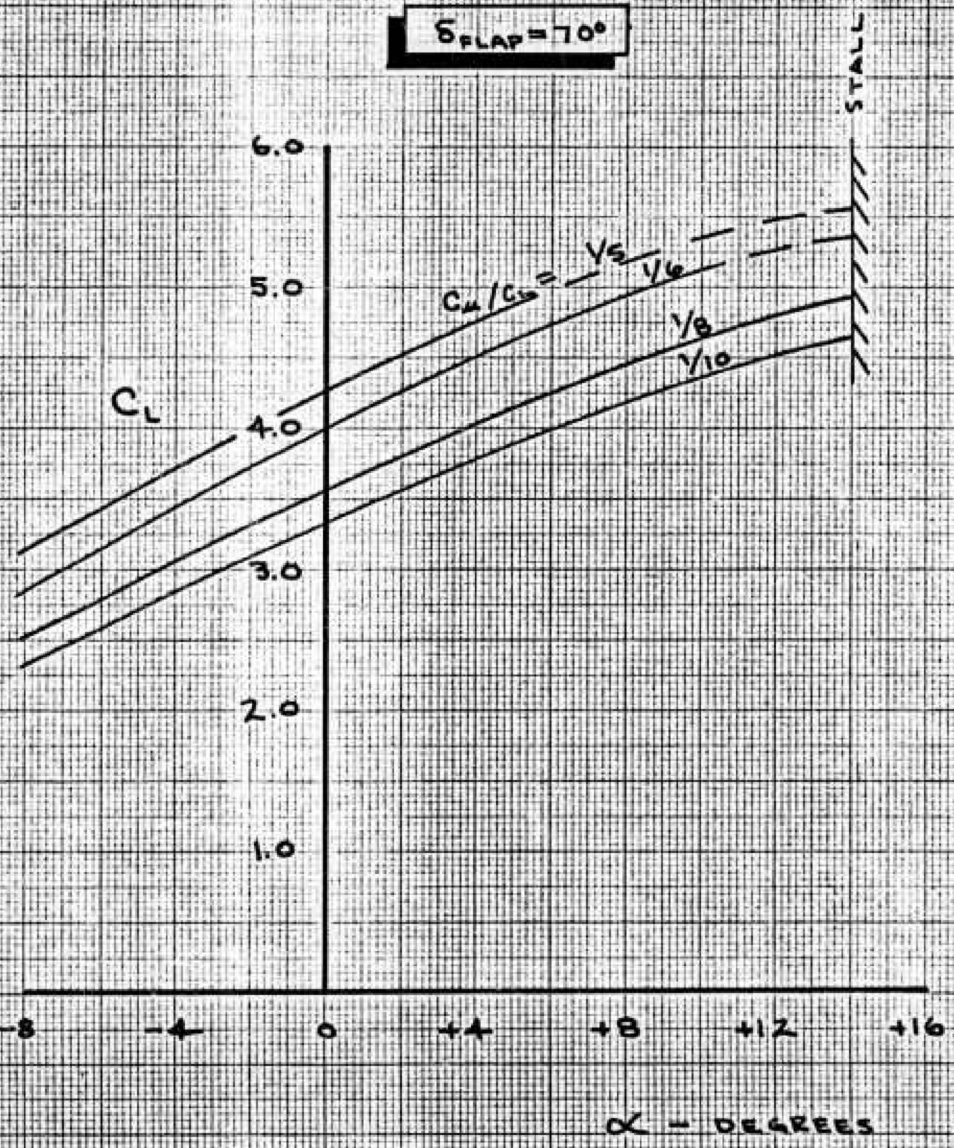

$\delta_{FLAP} = 70°$
STALL
6.0
5.0
4.0
3.0
2.0
1.0
C_L
$C_\mu / C_D = 1/5$
1/6
1/8
1/10
-8
-4
0
+4
+8
+12
+16
α – DEGREES

Figure 6

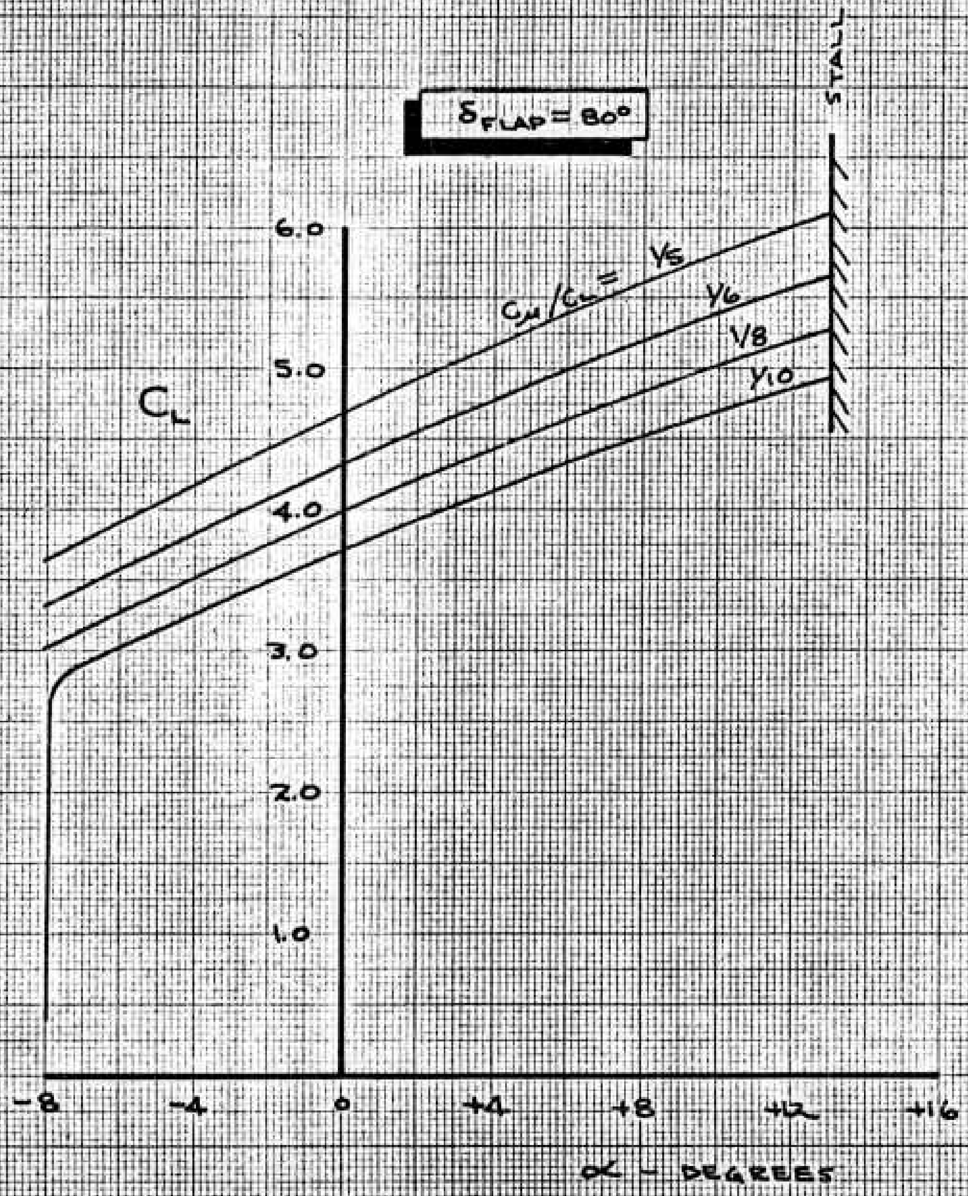

δ_FLAP = 80°
STALL
C_μ/C_u = 1/5
1/6
1/8
1/10
C_L
6.0
5.0
4.0
3.0
2.0
1.0
-8
-4
0
+4
+8
+12
+16
α - DEGREES

Figure 7

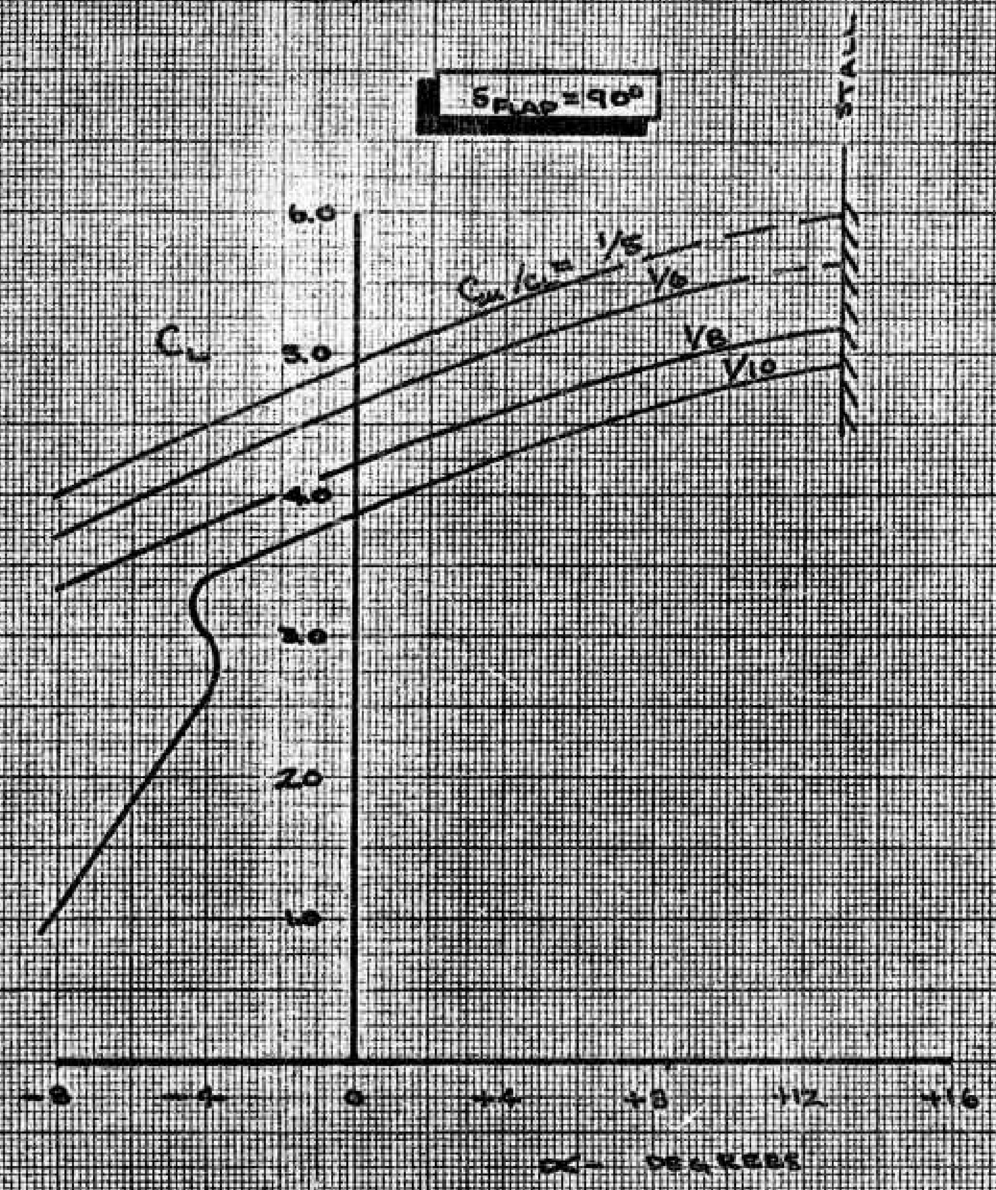

$\delta_{FLAP} = 90°$
STALL
$C_\mu / C_L = 1/5$
1/6
1/8
1/10
C_L
6.0
5.0
4.0
3.0
2.0
1.0
-8
-4
0
+4
+8
+12
+16
α - DEGREES

Figure 8

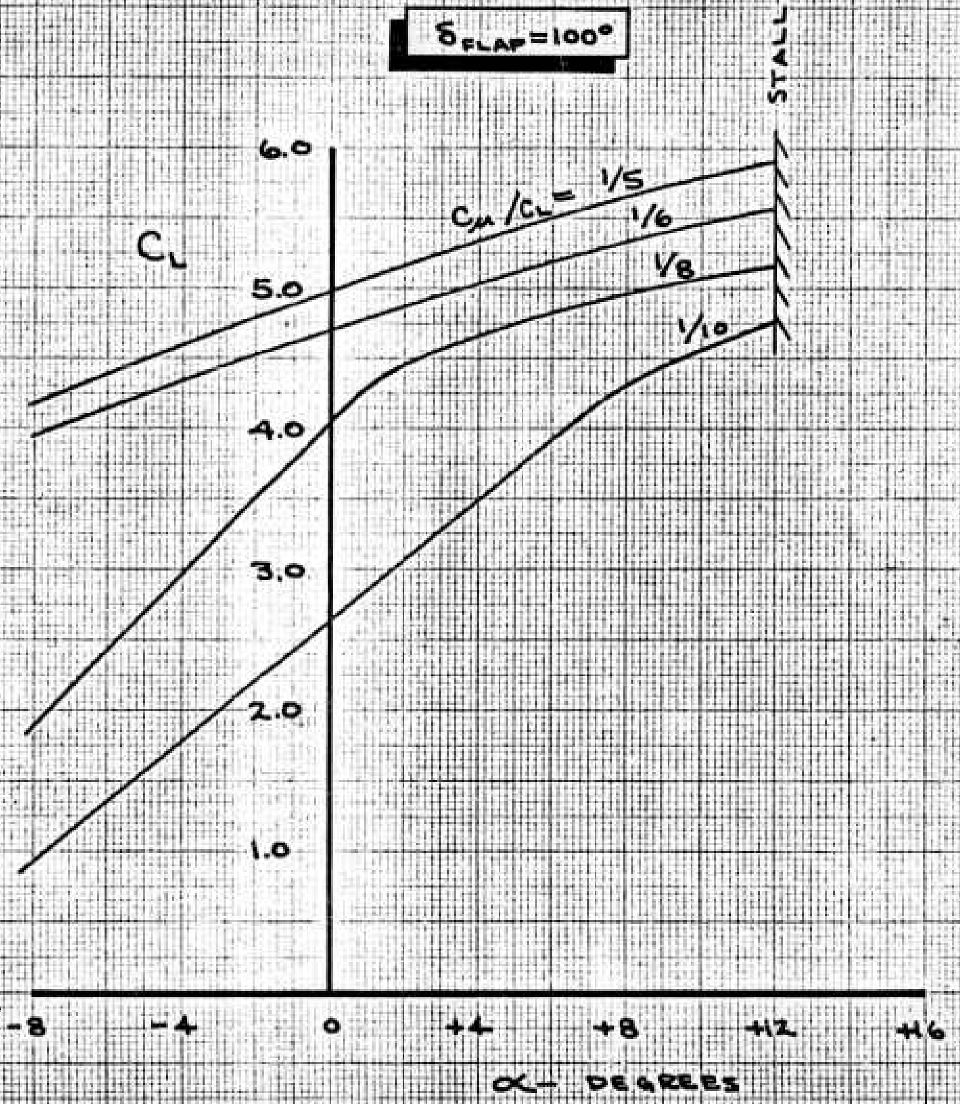

$\delta_{FLAP} = 100°$
STALL
6.0
5.0
4.0
3.0
2.0
1.0
C_L
$C_\mu / C_L = 1/5$
1/6
1/8
1/10
-8
-4
0
+4
+8
+12
+16
α – DEGREES

Figure 9

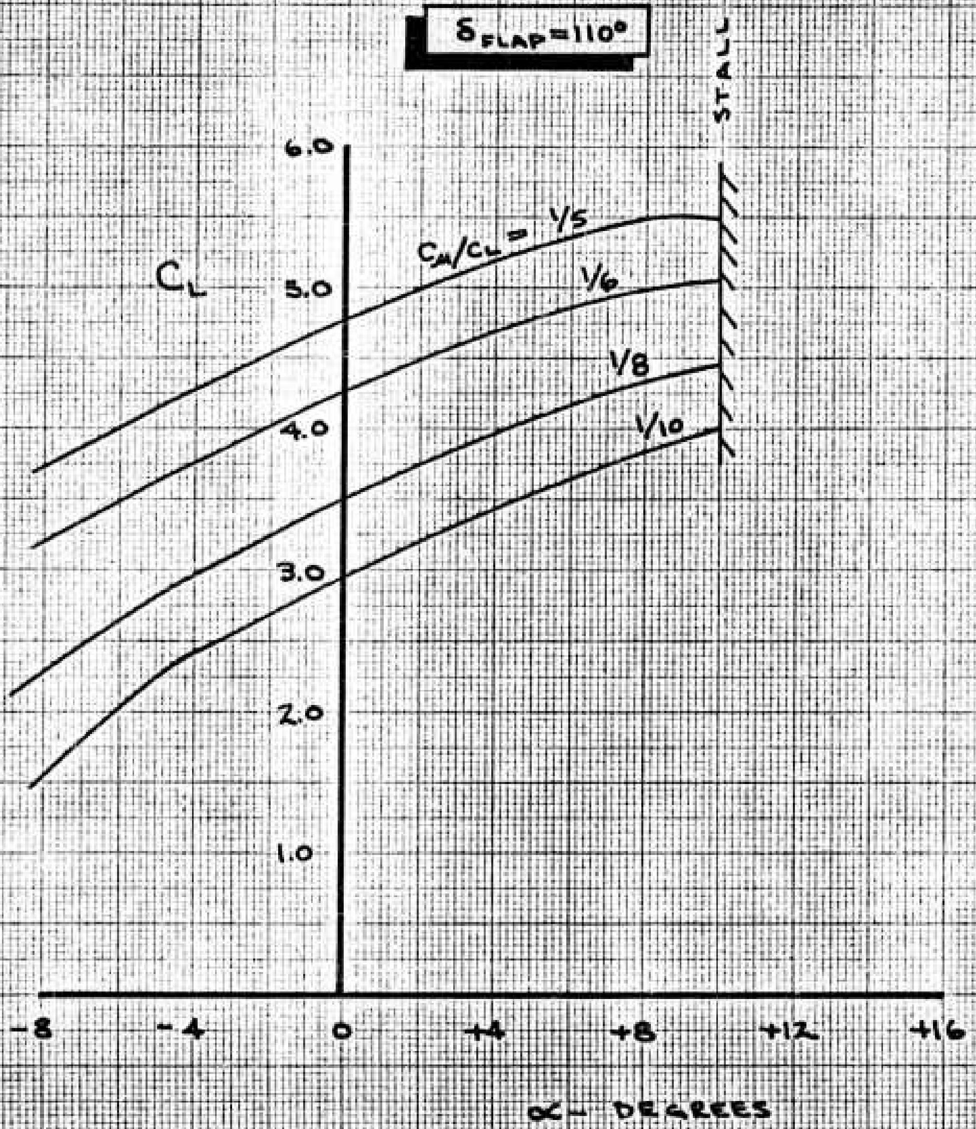

δ FLAP = 110°
STALL
CL
6.0
5.0
4.0
3.0
2.0
1.0
CM/CL = 1/5
1/6
1/8
1/10
-8
-4
0
+4
+8
+12
+16
α – DEGREES

Figure 10

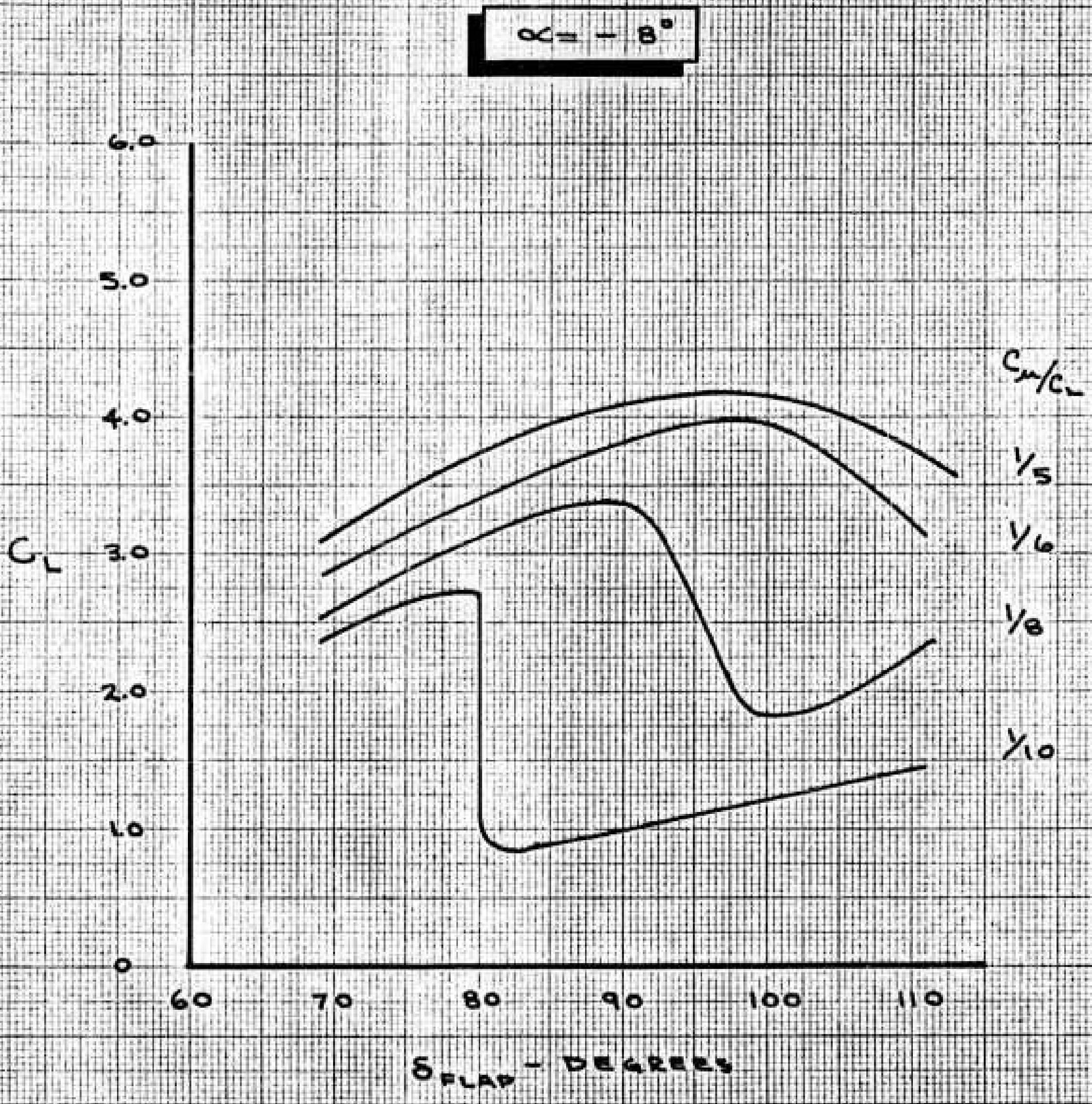

α = - 8°
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
60
70
80
90
100
110
δ_{FLAP} - DEGREES
C_μ / C_L
1/5
1/6
1/8
1/10

Figure 11

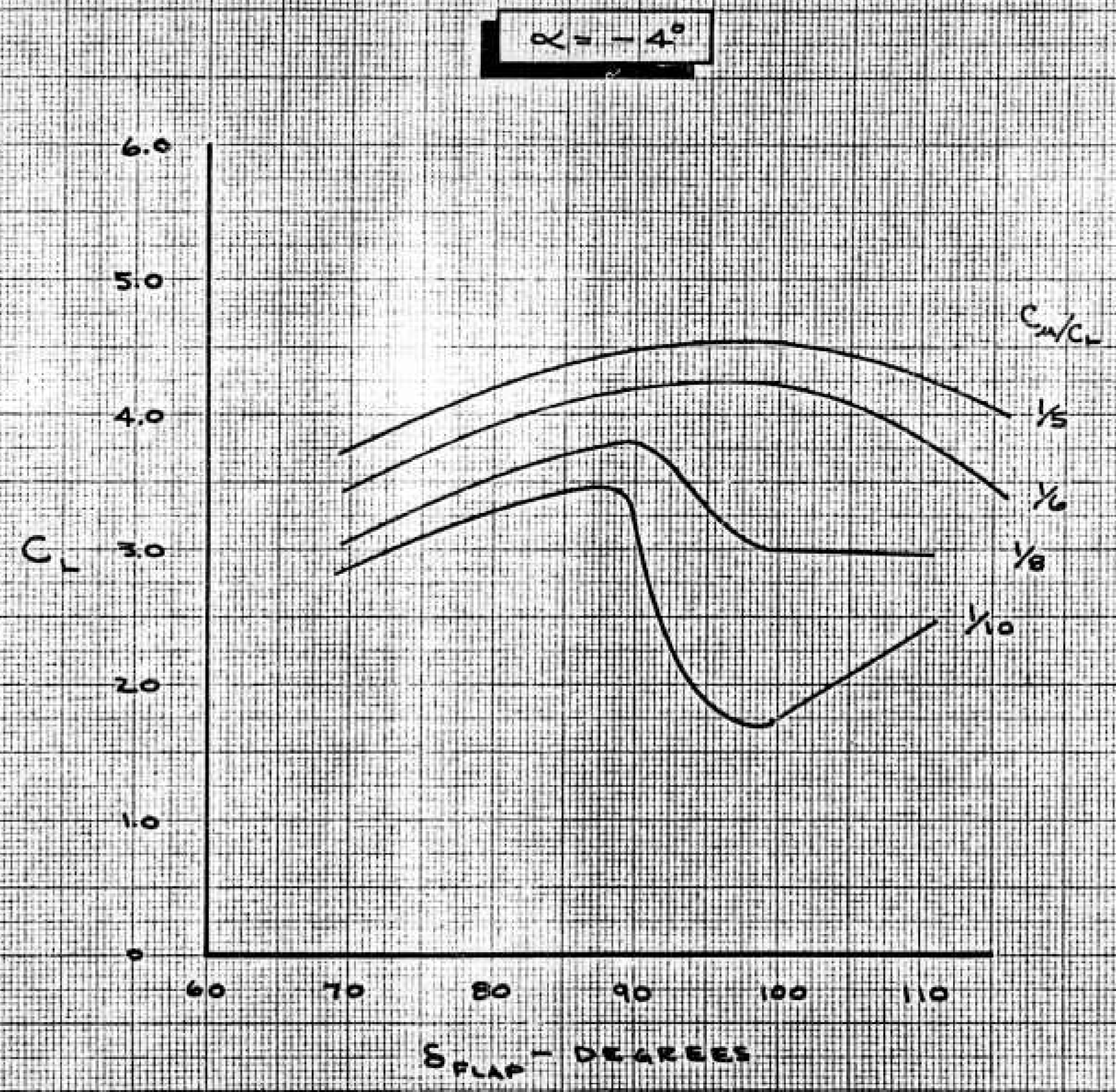

α = −4°
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
60
70
80
90
100
110
δ_FLAP − DEGREES
C_M/C_L
1/5
1/6
1/8
1/10

Figure 12

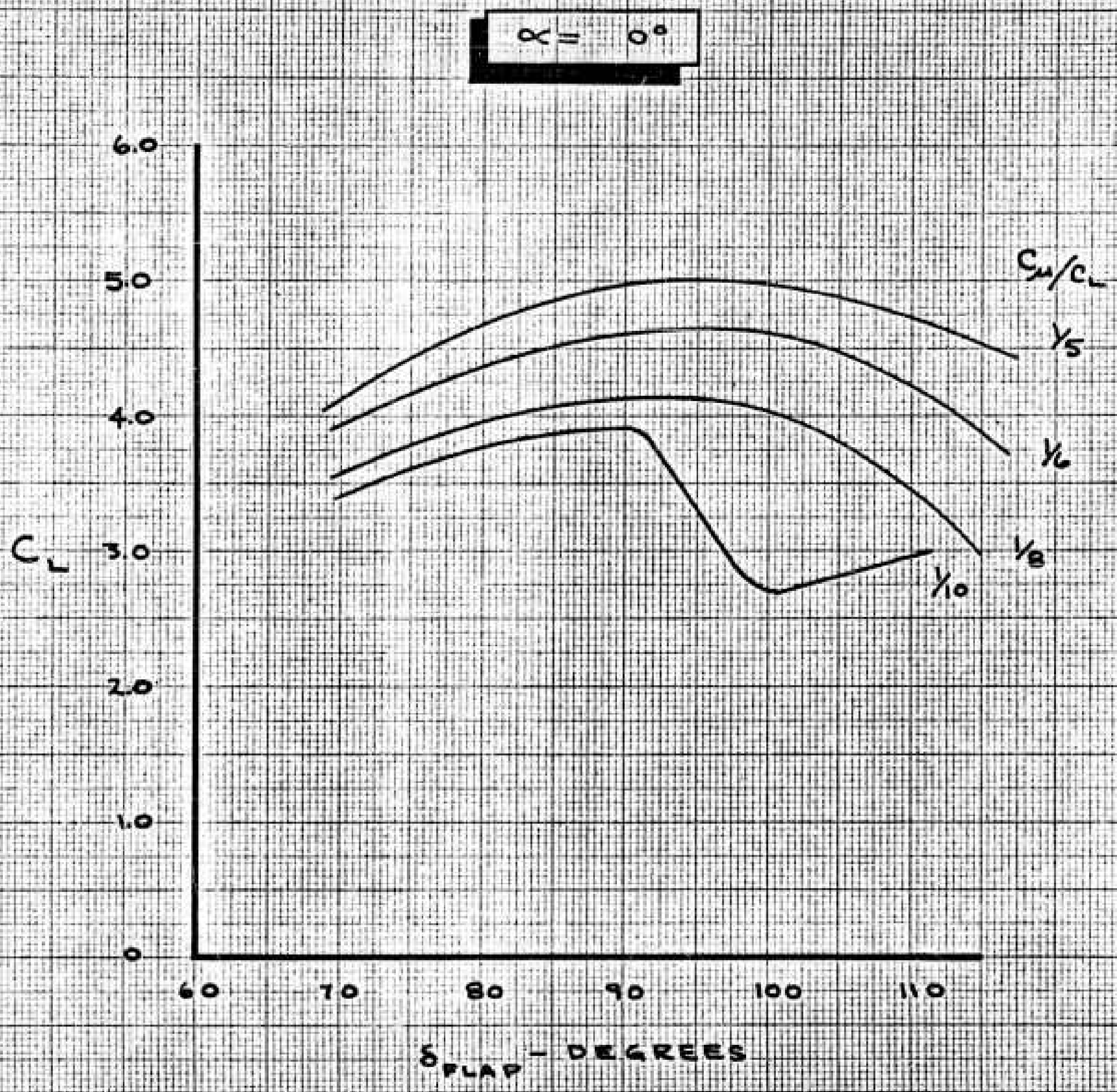

α = 0°
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
Cμ/CL
1/5
1/6
1/8
1/10
60
70
80
90
100
110
δ FLAP – DEGREES

Figure 13

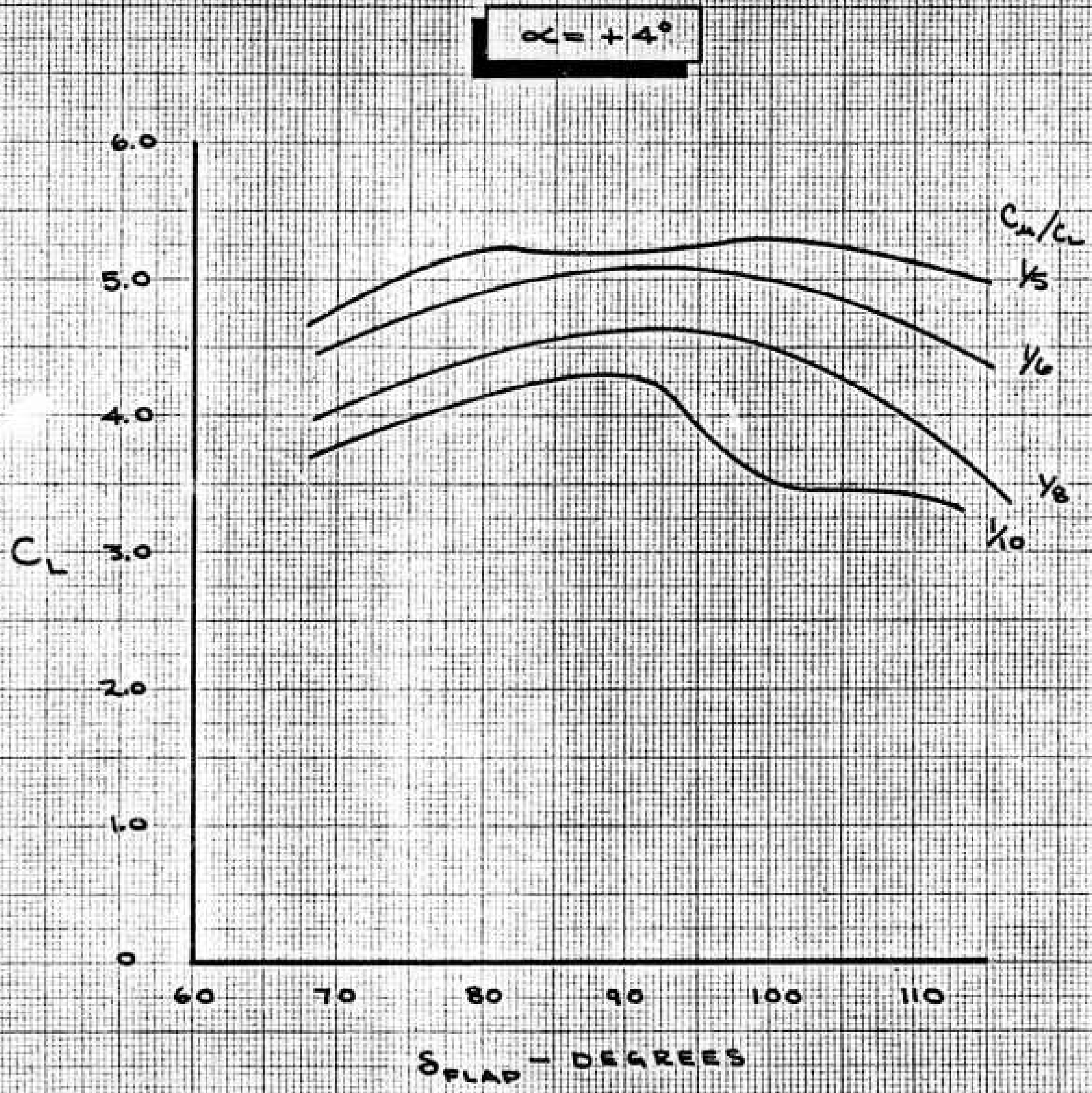

α = +4°
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
60
70
80
90
100
110
δ_FLAP – DEGREES
Cμ/CL
1/5
1/6
1/8
1/10

Figure 14

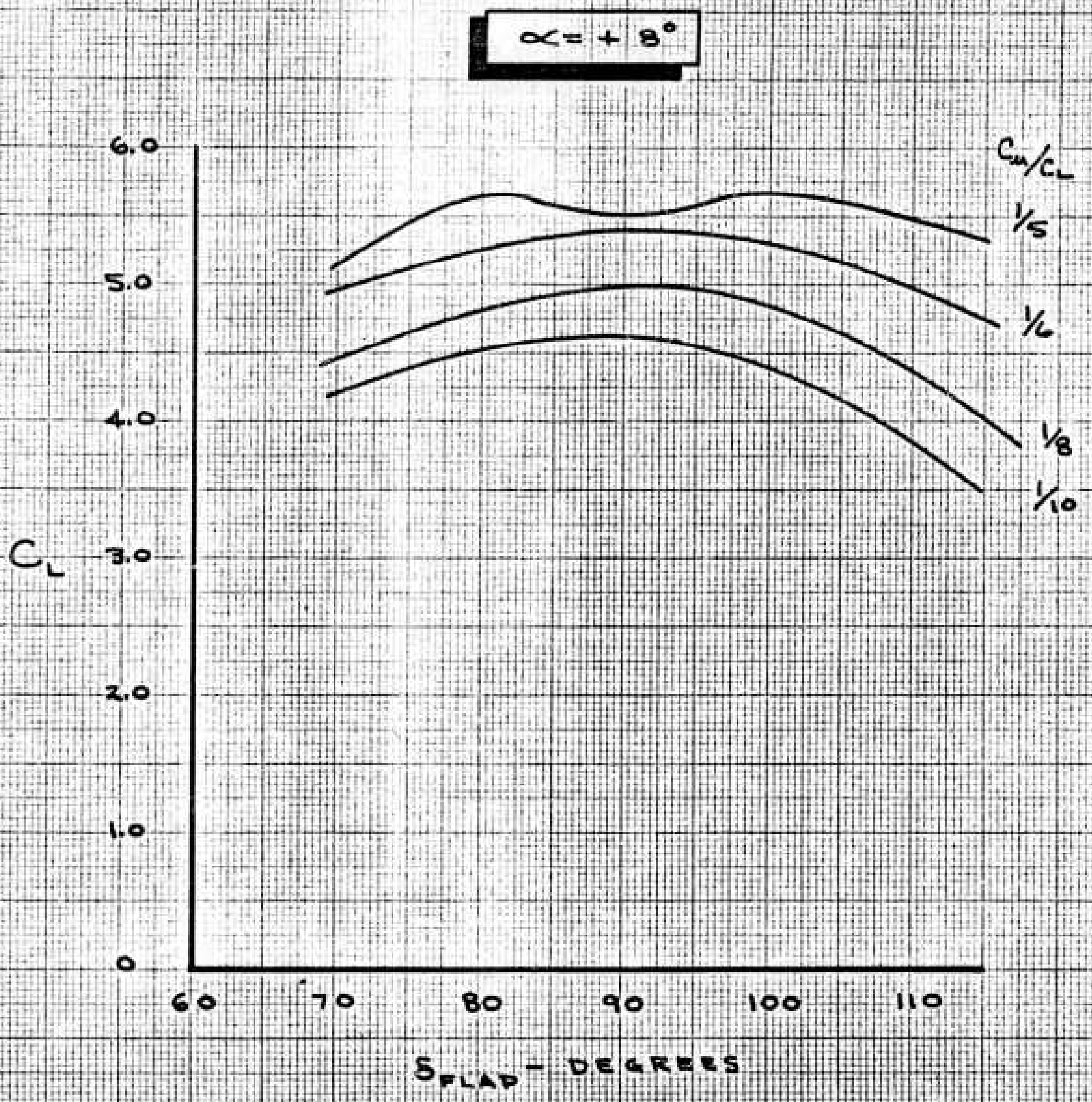

α = + 8°
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
C_μ/C_L
1/5
1/6
1/8
1/10
60
70
80
90
100
110
δ_{FLAP} – DEGREES

Figure 15

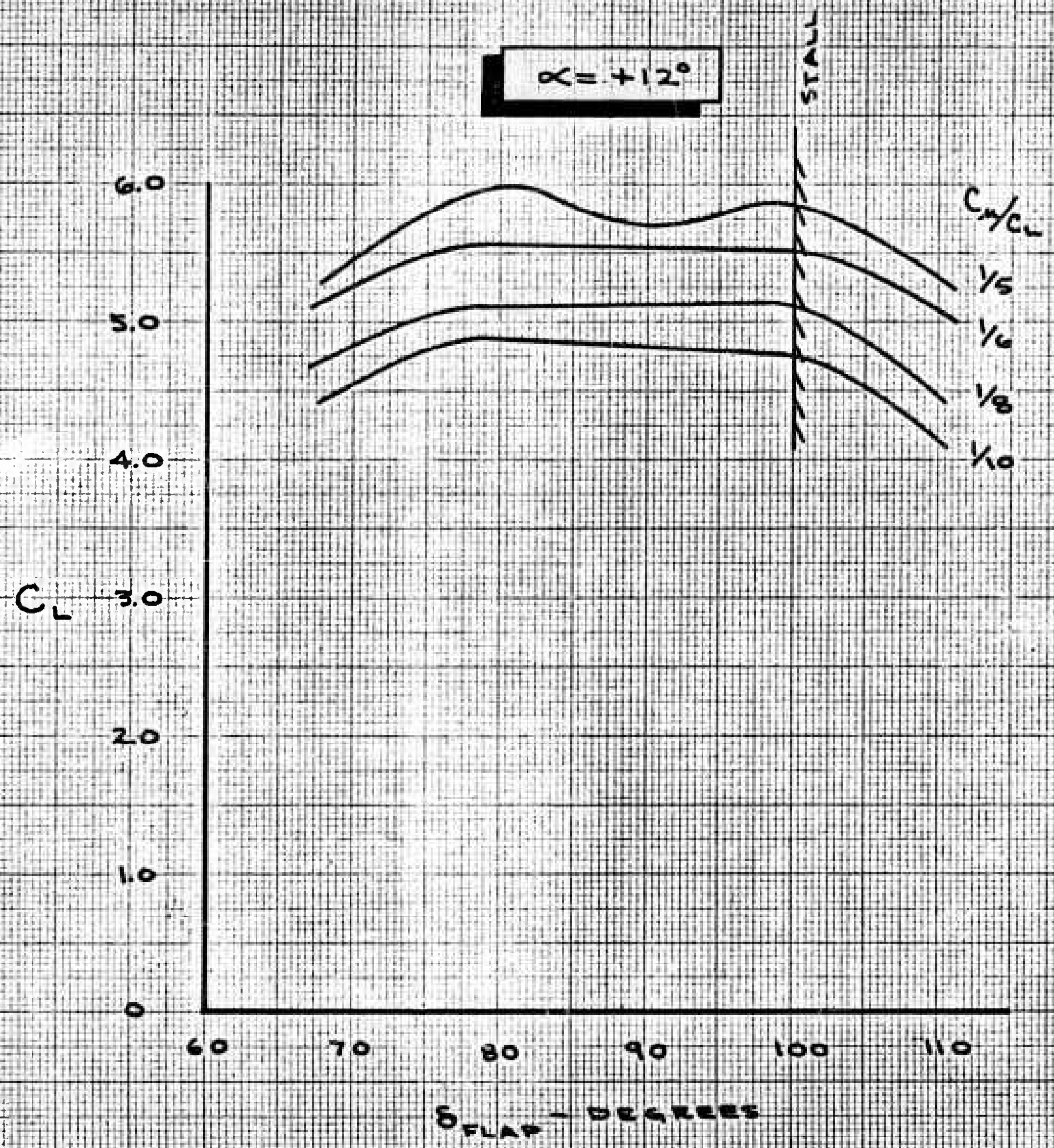

α = +12°
STALL
6.0
5.0
4.0
3.0
2.0
1.0
0
C_L
C_μ/C_L
1/5
1/6
1/8
1/10
60
70
80
90
100
110
δ_{FLAP} – DEGREES

Figure 16

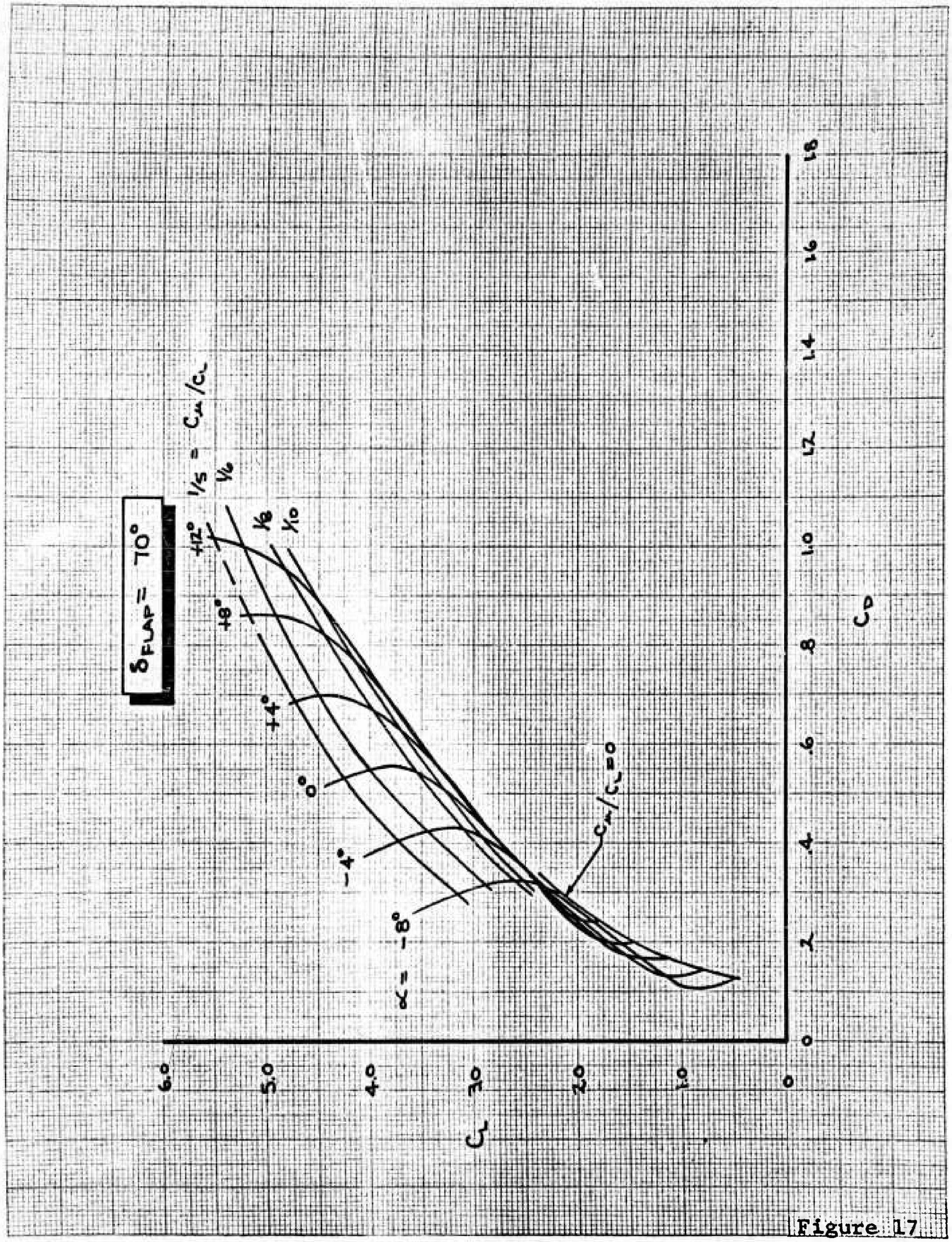

δFLAP = 70°
1/5 = Cμ/CL
1/6
1/8
1/10
+12°
+8°
+4°
0°
-4°
α = -8°
Cμ/CL = 0
CD
CL
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
0
1.0
2.0
3.0
4.0
5.0
6.0

Figure 17

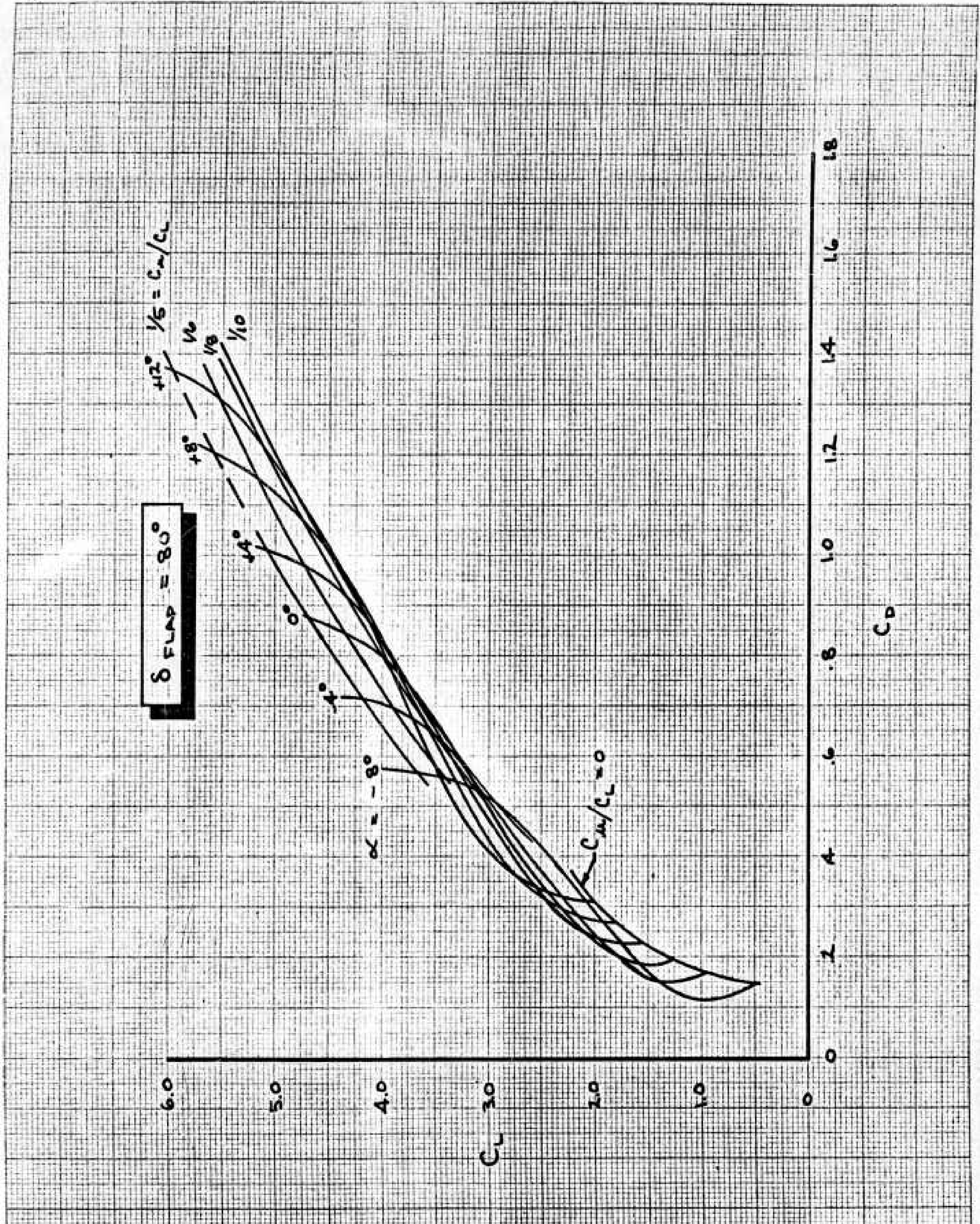

δ FLAP = 80°
α = −8°
−4°
0°
+4°
+8°
+12°
1/5 = Cμ/CL
1/6
1/8
1/10
Cμ/CL = 0
CL
6.0
5.0
4.0
3.0
2.0
1.0
0
CD
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure 18

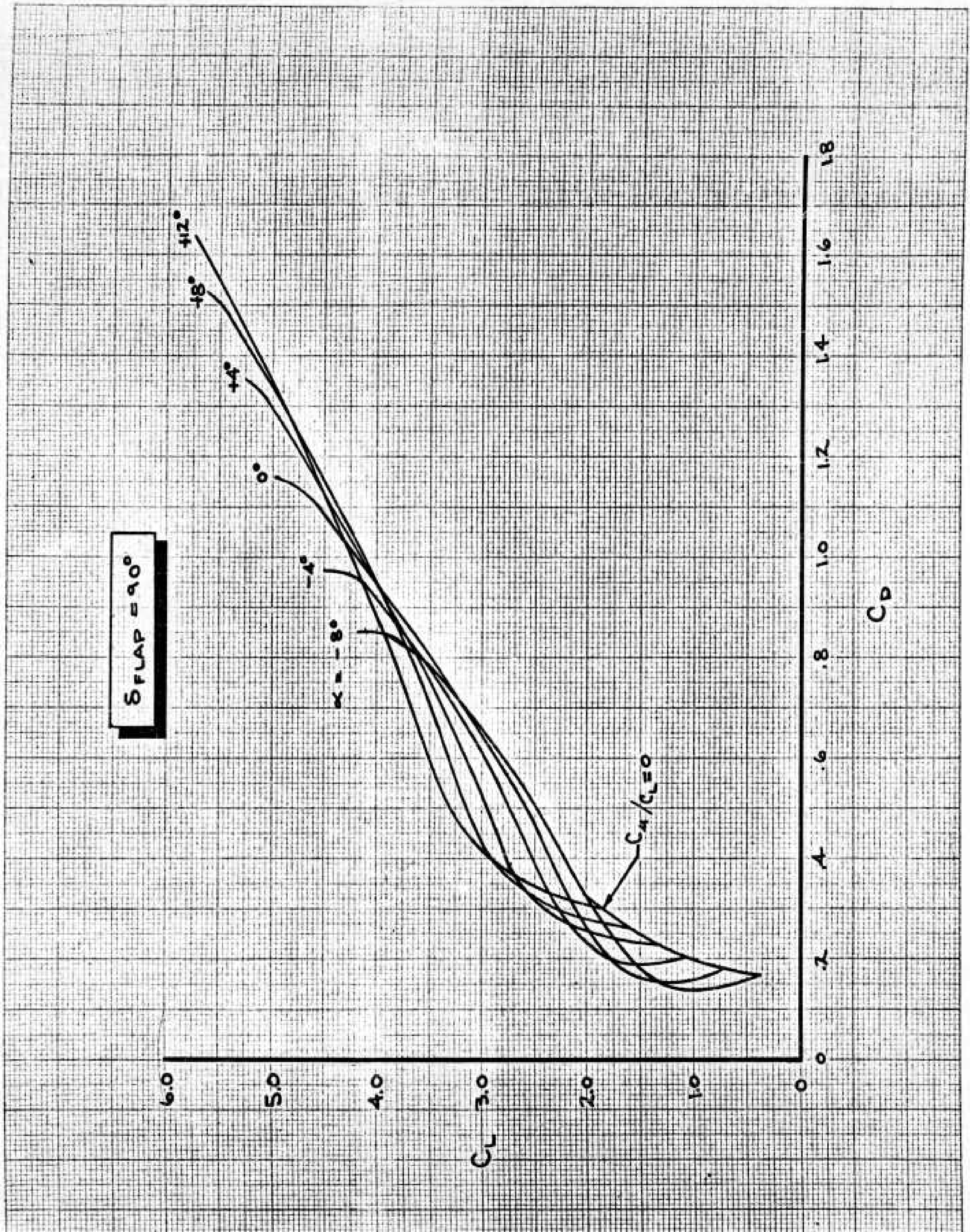

δFLAP = 90°
+12°
+8°
+4°
0°
-4°
α = -8°
CM/CL=0
CL
6.0
5.0
4.0
3.0
2.0
1.0
0
CD
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure 19

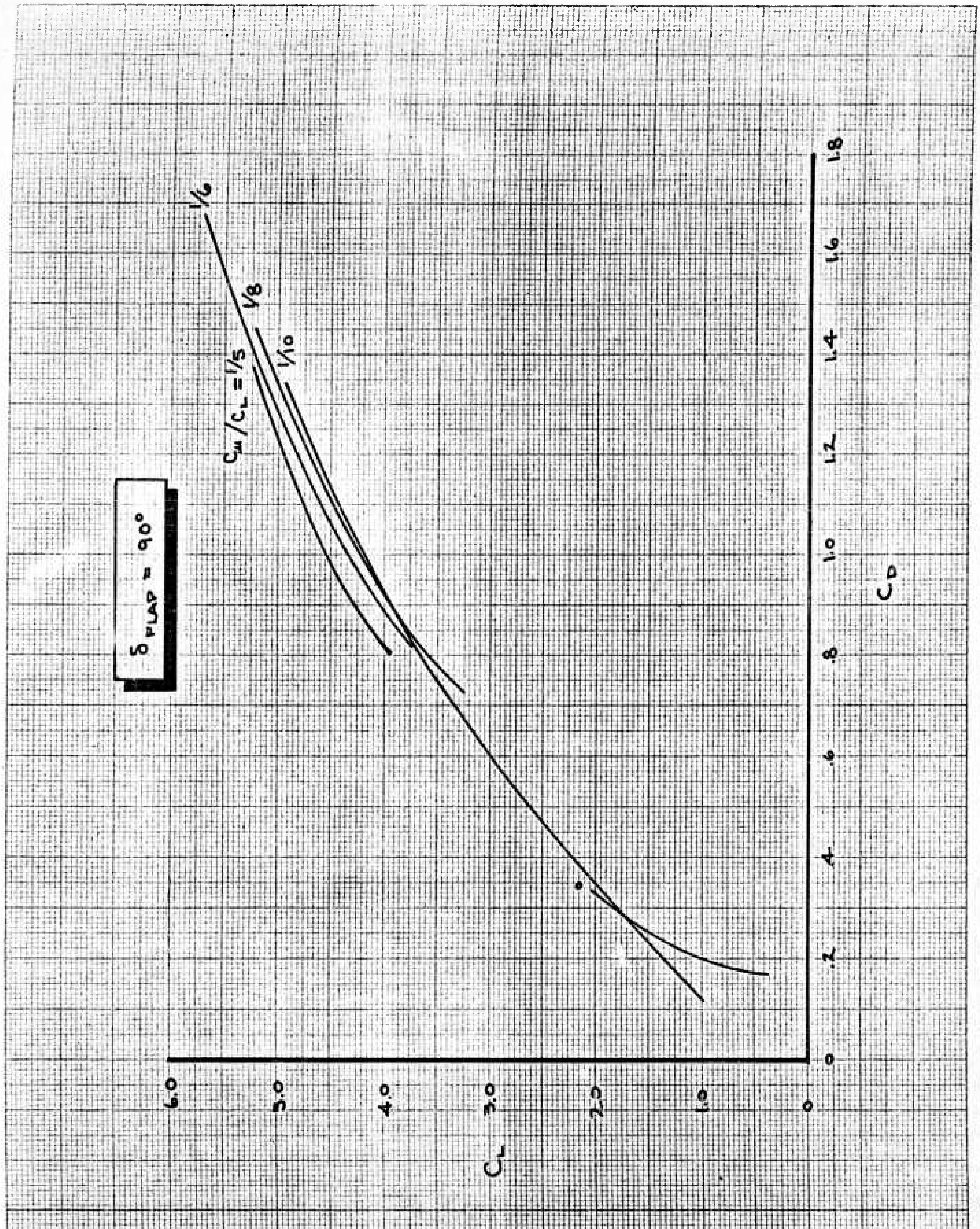

δ FLAP = 90°
C_μ/C_L = 1/5
1/6
1/8
1/10
C_L
C_D
6.0
5.0
4.0
3.0
2.0
1.0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure 20

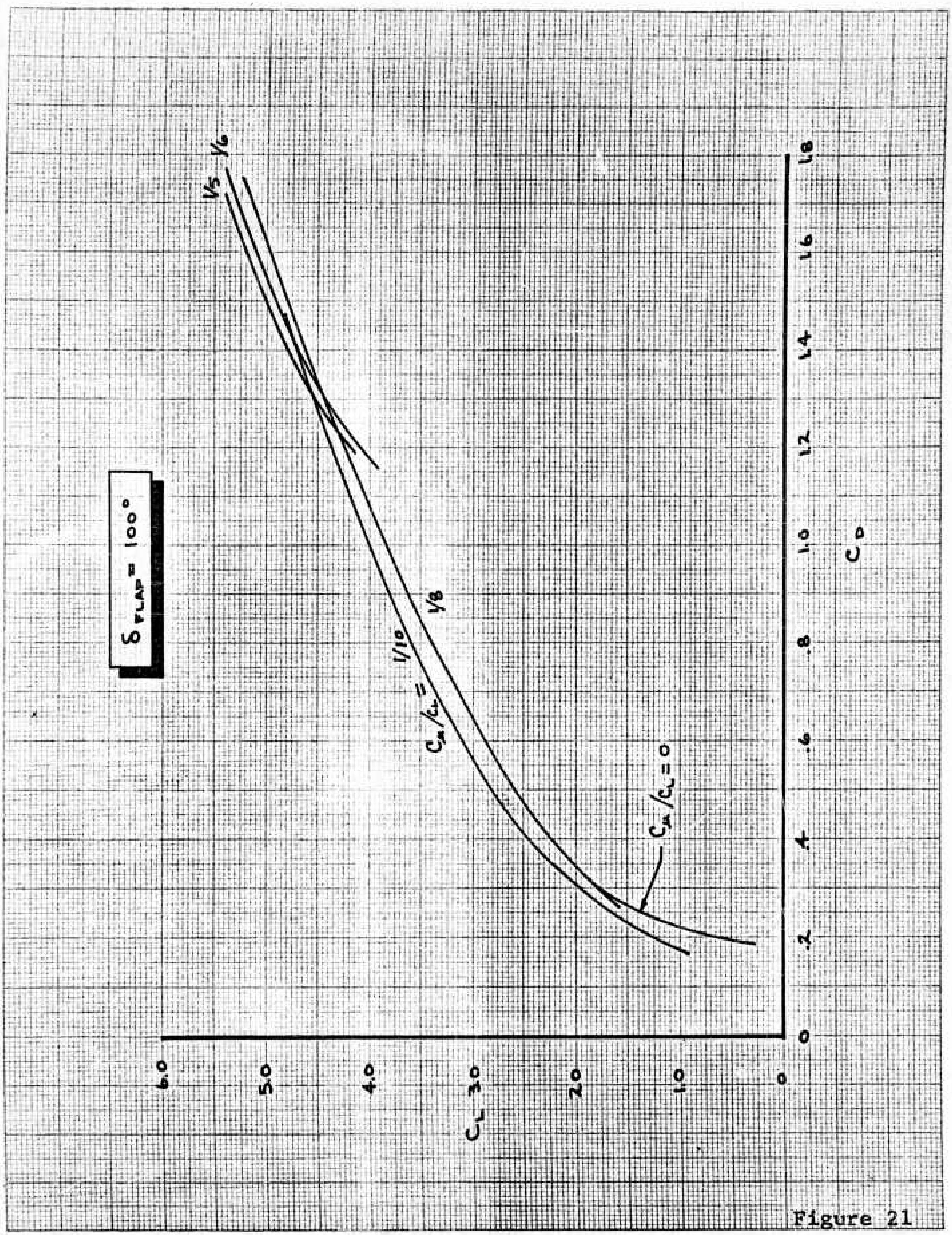

$\delta_{FLAP} = 100°$
$C_\mu / C_L =$
1/10
1/8
1/6
1/5
$C_\mu / C_L = 0$
C_L
0
1.0
2.0
3.0
4.0
5.0
6.0
C_D
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure 21

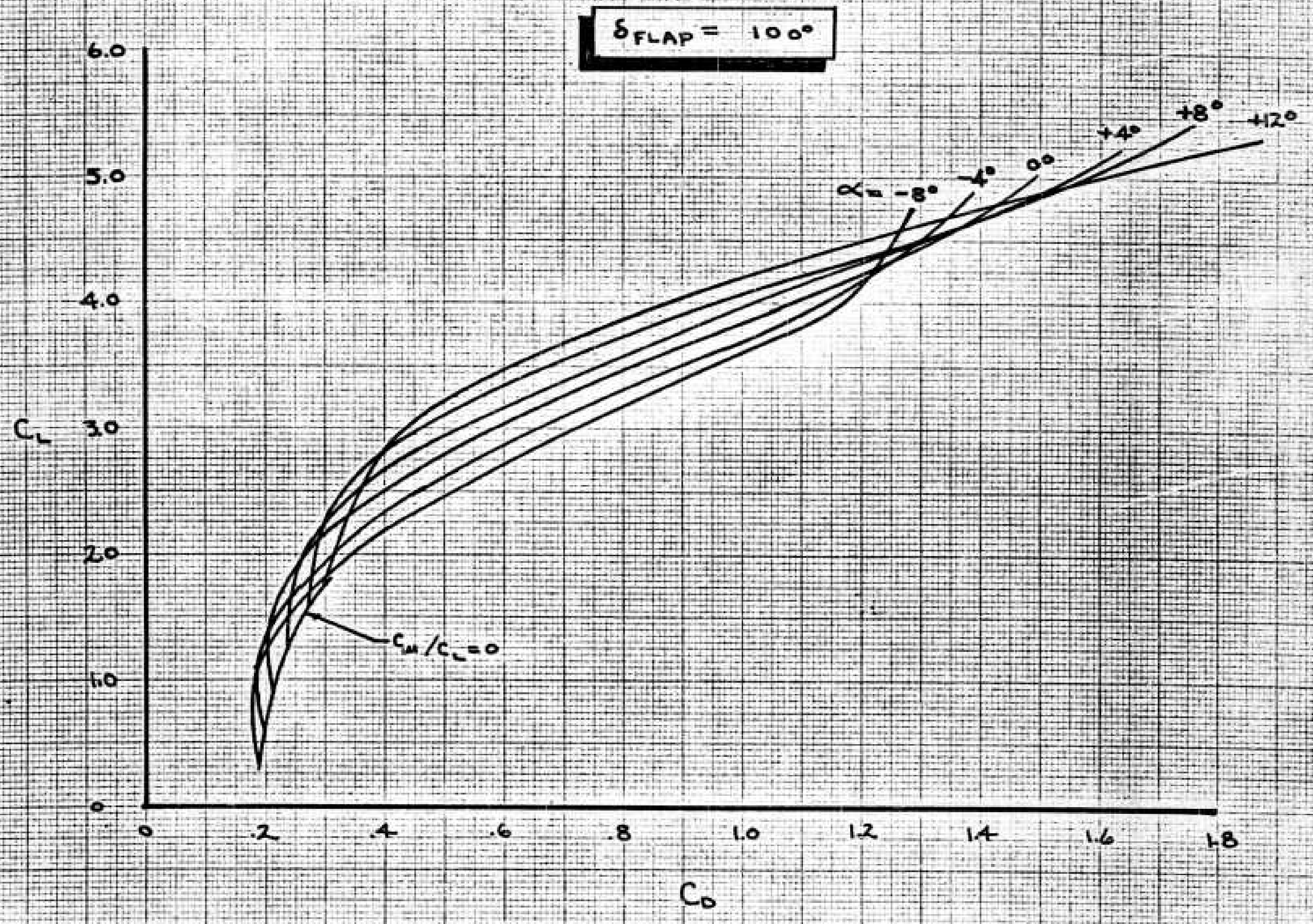

δ_FLAP = 100°
α = -8°
-4°
0°
+4°
+8°
+12°
C_M/C_L = 0
C_L
0
1.0
2.0
3.0
4.0
5.0
6.0
C_D
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

Figure 22

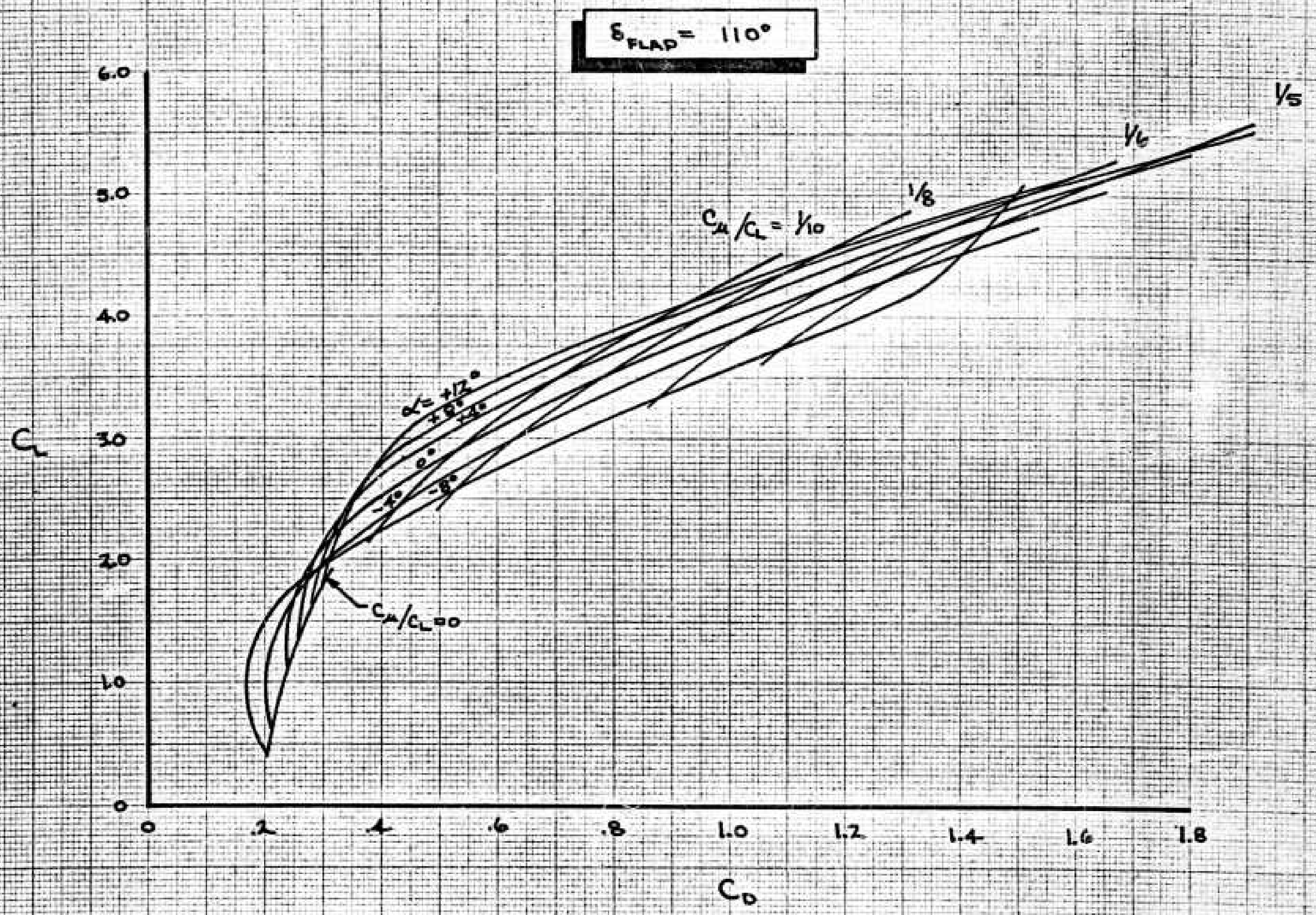

$\delta_{FLAP} = 110°$
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_D
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
$C_\mu / C_L = 1/10$
1/8
1/6
1/5
$\alpha = +12°$
+8°
+4°
0°
-4°
-8°
$C_\mu / C_L = 0$

Figure 23

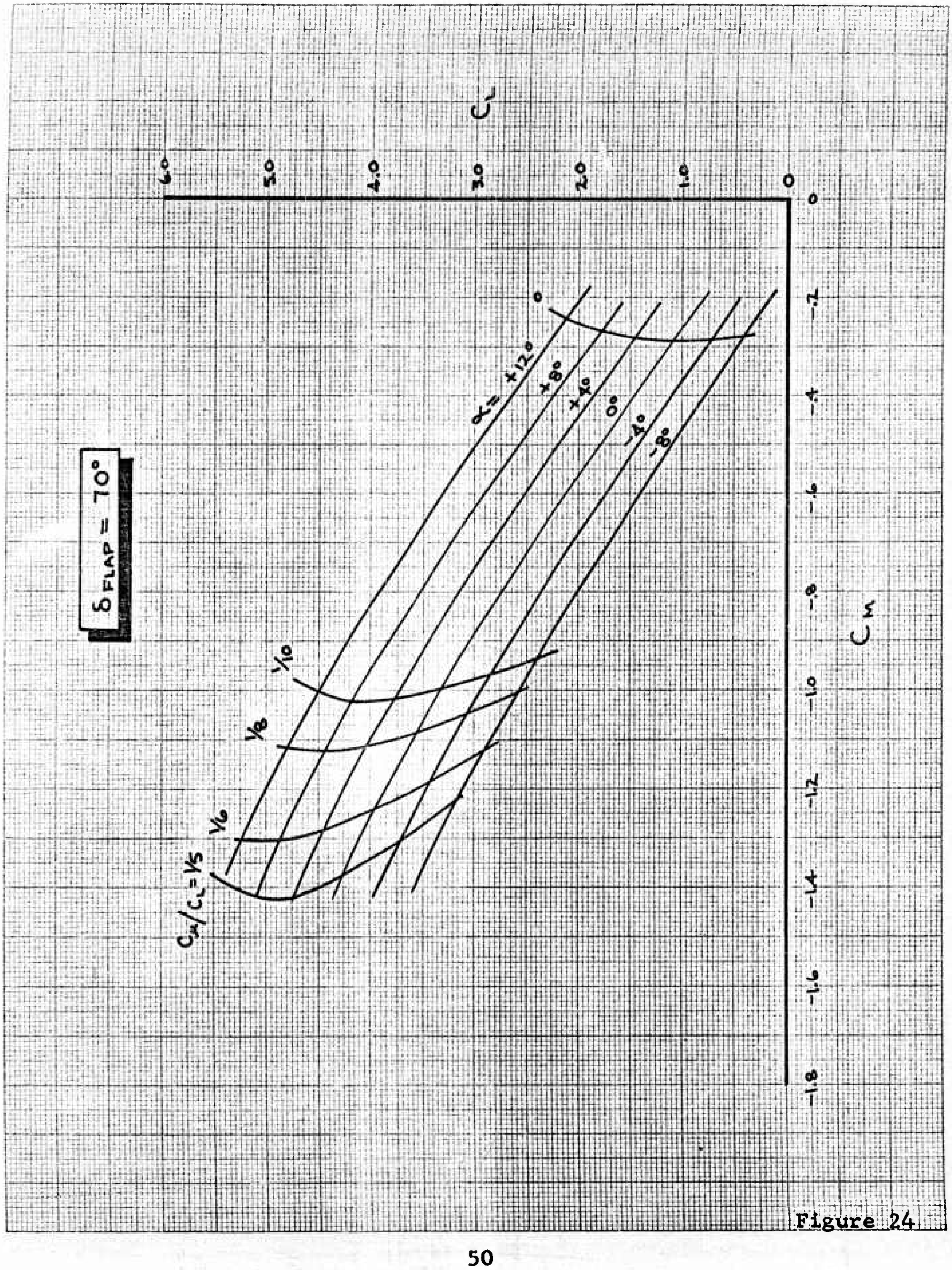
δ FLAP = 70°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_M
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
-1.8
α = +12°
+8°
+4°
0°
-4°
-8°
Cμ/CL = 1/5
1/6
1/8
1/10
0

Figure 24

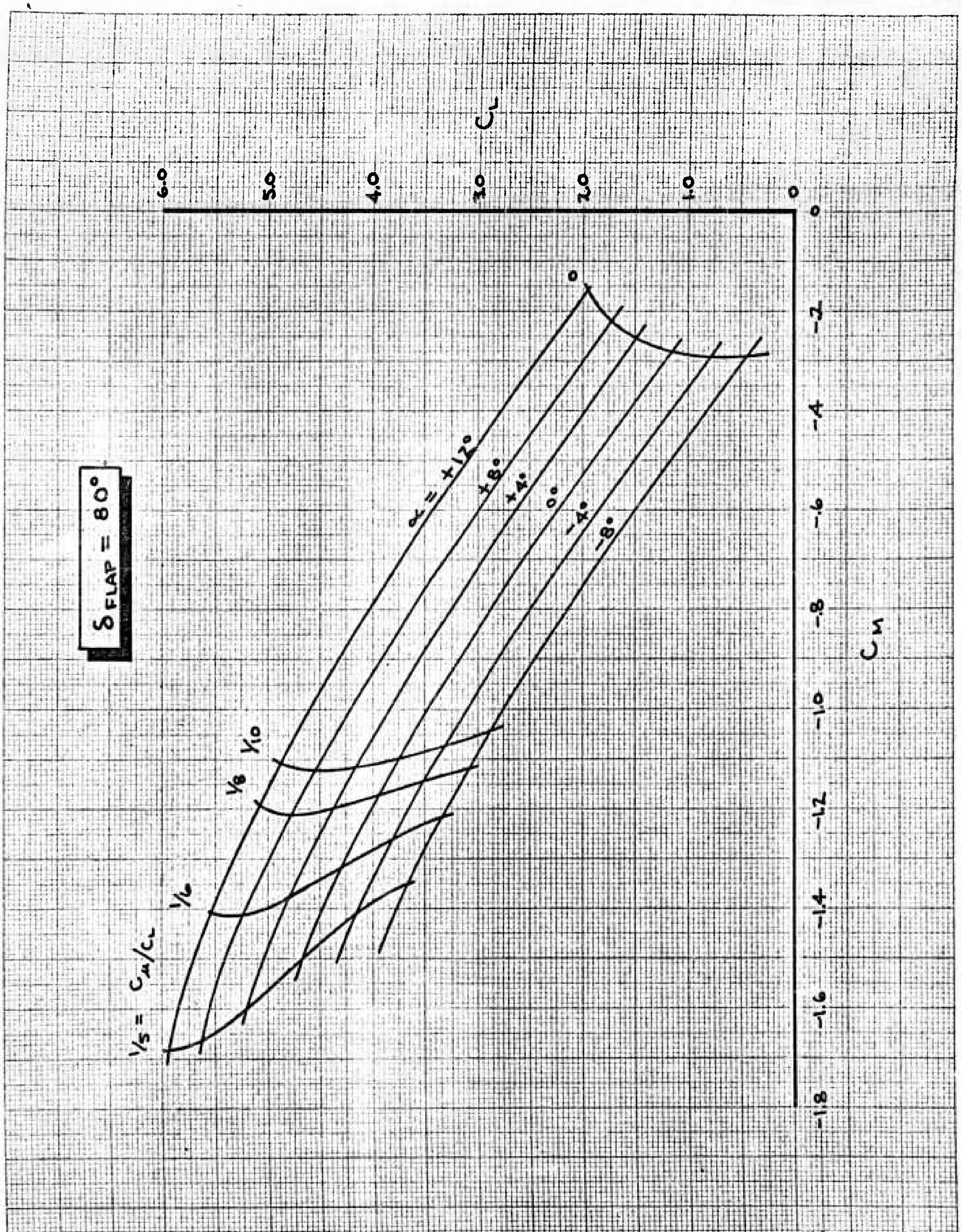

δ FLAP = 80°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_M
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
-1.8
α = +12°
+8°
+4°
0°
-4°
-8°
1/5 = C_μ/C_L
1/6
1/8
1/10
0

Figure 25

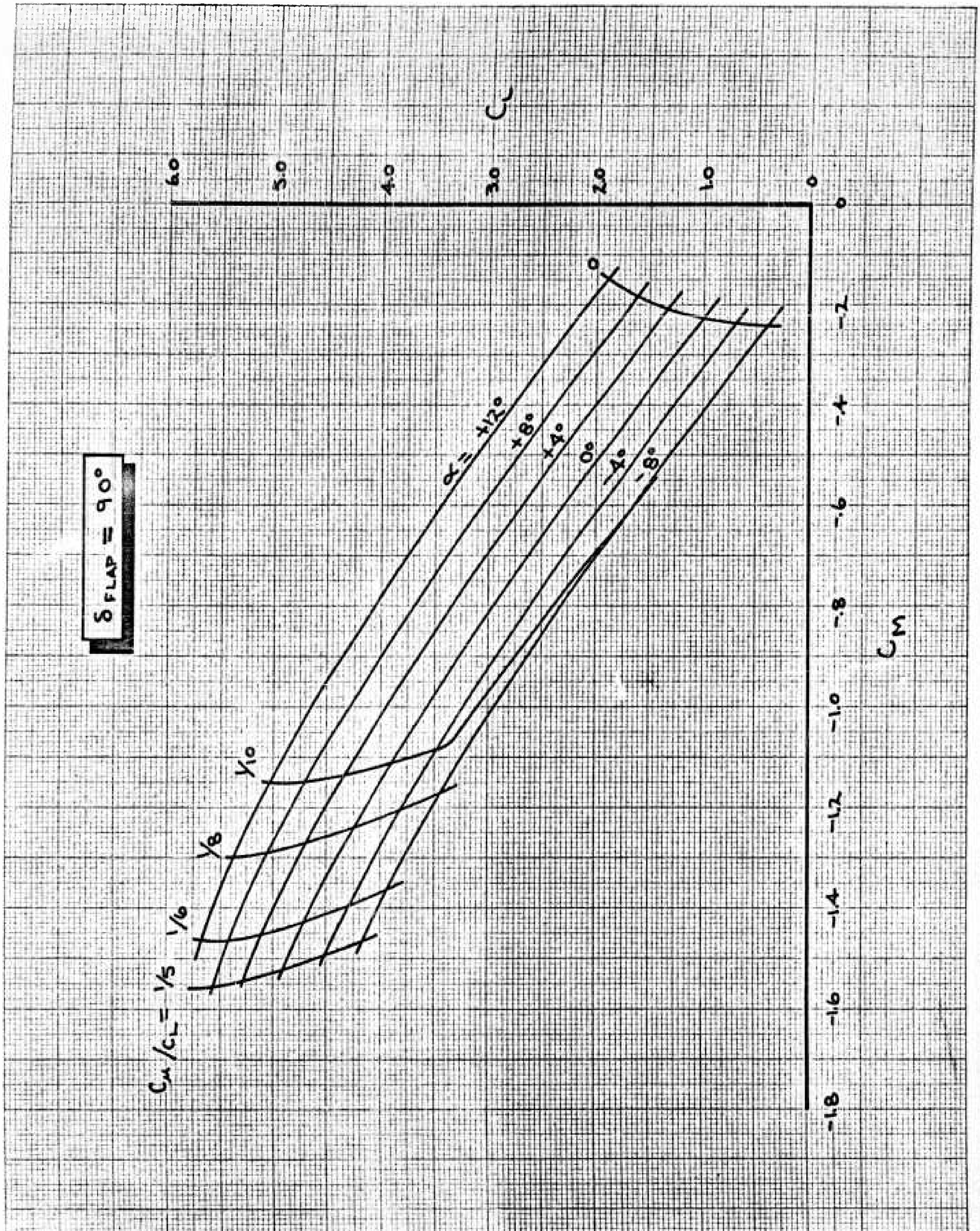

δ FLAP = 90°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_M
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
-1.8
α = +12°
+8°
+4°
0°
-4°
-8°
C_μ/C_L = 1/5
1/6
1/8
1/10
0

Figure 26

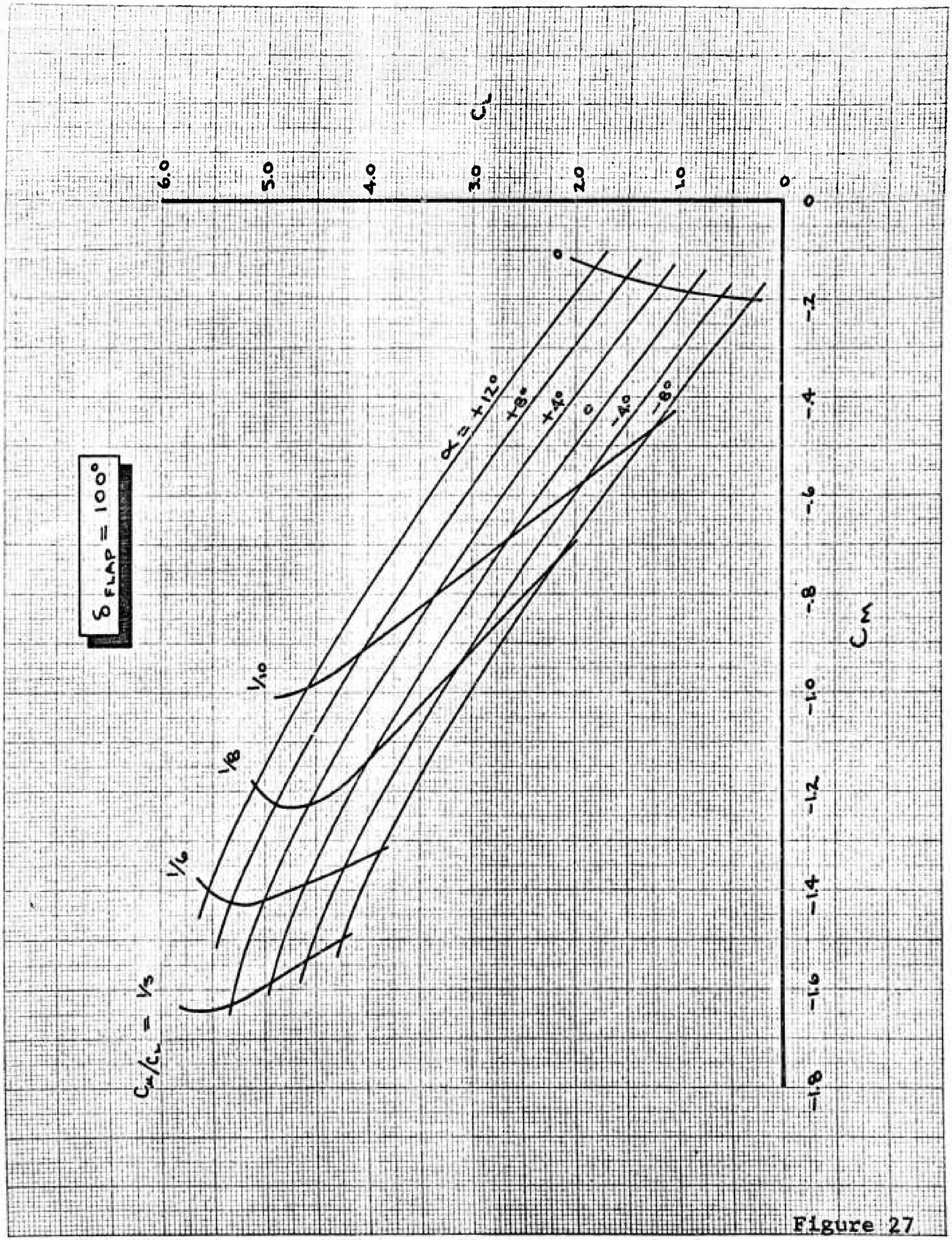

δ FLAP = 100°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_M
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
-1.8
α = +12°
+8°
+4°
0
-4°
-8°
Cμ/C_L = 1/5
1/6
1/8
1/10
0

Figure 27

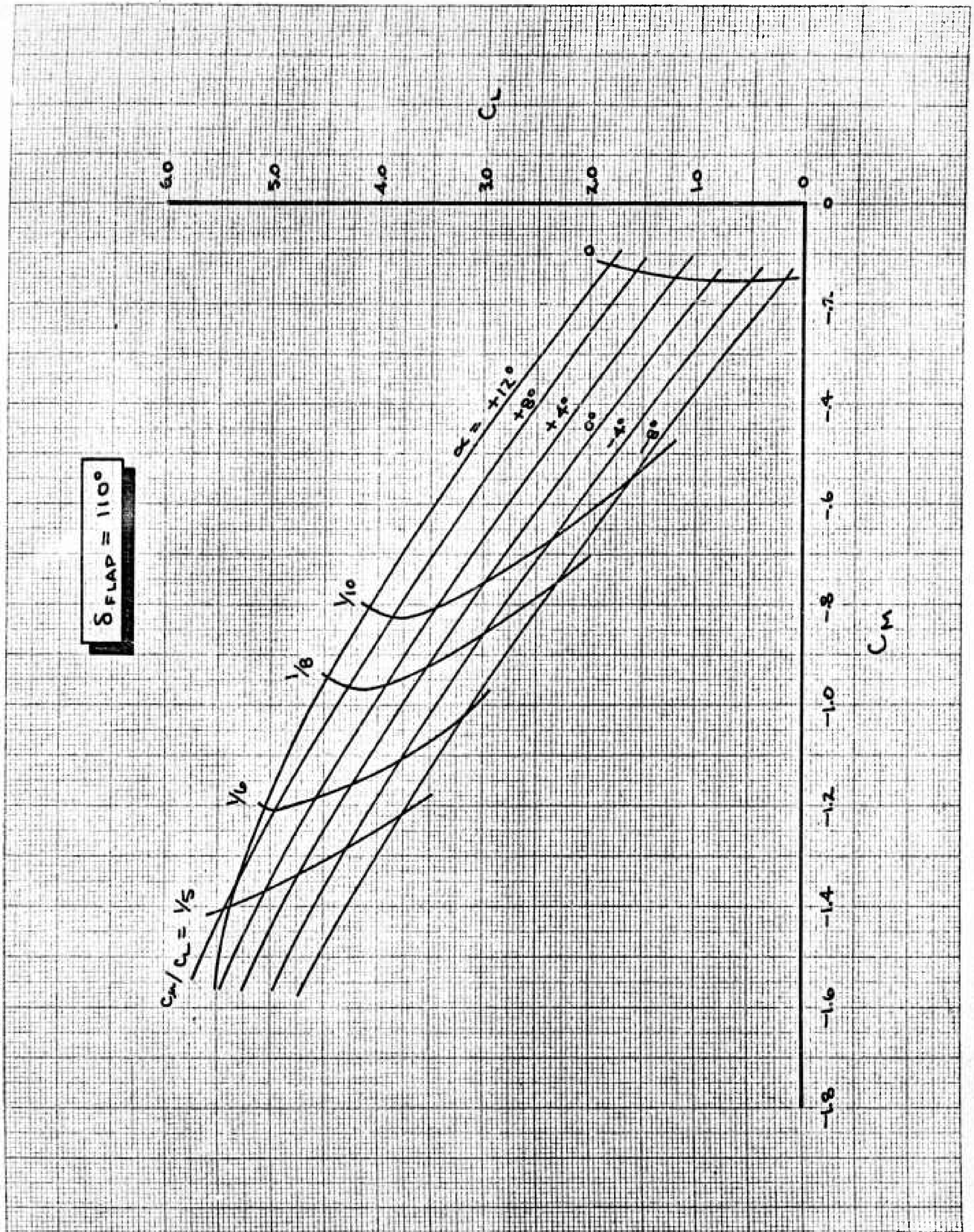

δ FLAP = 110°
C_L
6.0
5.0
4.0
3.0
2.0
1.0
0
C_M
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
-1.8
α = +12°
+8°
+4°
0°
-4°
-8°
C_M/C_L = 1/5
1/6
1/8
1/10
0

Figure 28

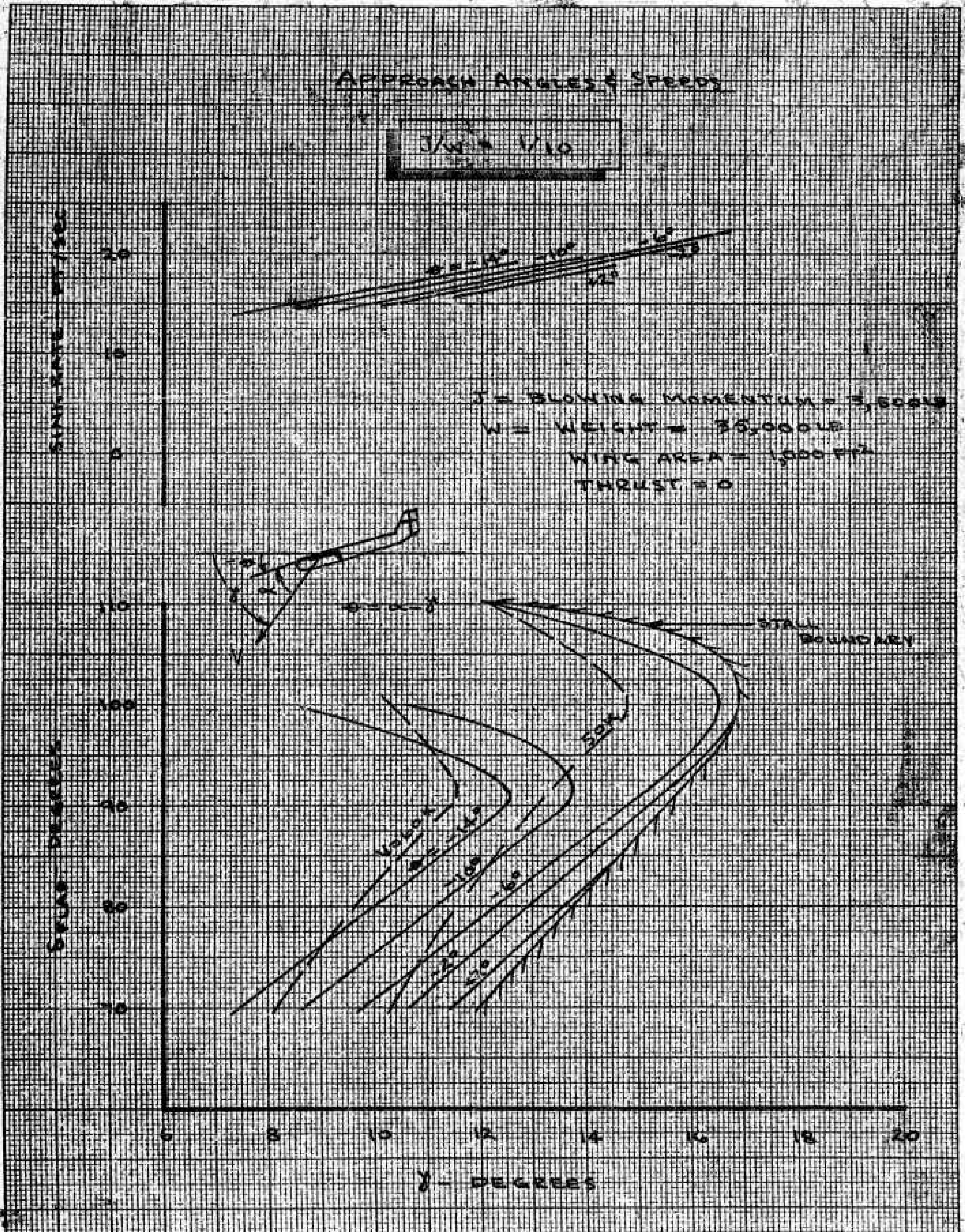

APPROACH ANGLES & SPEEDS
J/W = 1/10
SINK RATE – FT/SEC
20
10
0
θ = –14°
–10°
–6°
–2°
+2°
J = BLOWING MOMENTUM = 3,500 LB
W = WEIGHT = 35,000 LB
WING AREA = 1,000 FT²
THRUST = 0
–θ
γ
α
V
θ = α – γ
STALL BOUNDARY
110
100
90
80
70
50K
V50K
θ = –14°
–10°
–6°
–2°
+2°
SPEED DEGREES
6
8
10
12
14
16
18
20
γ – DEGREES

Figure 29

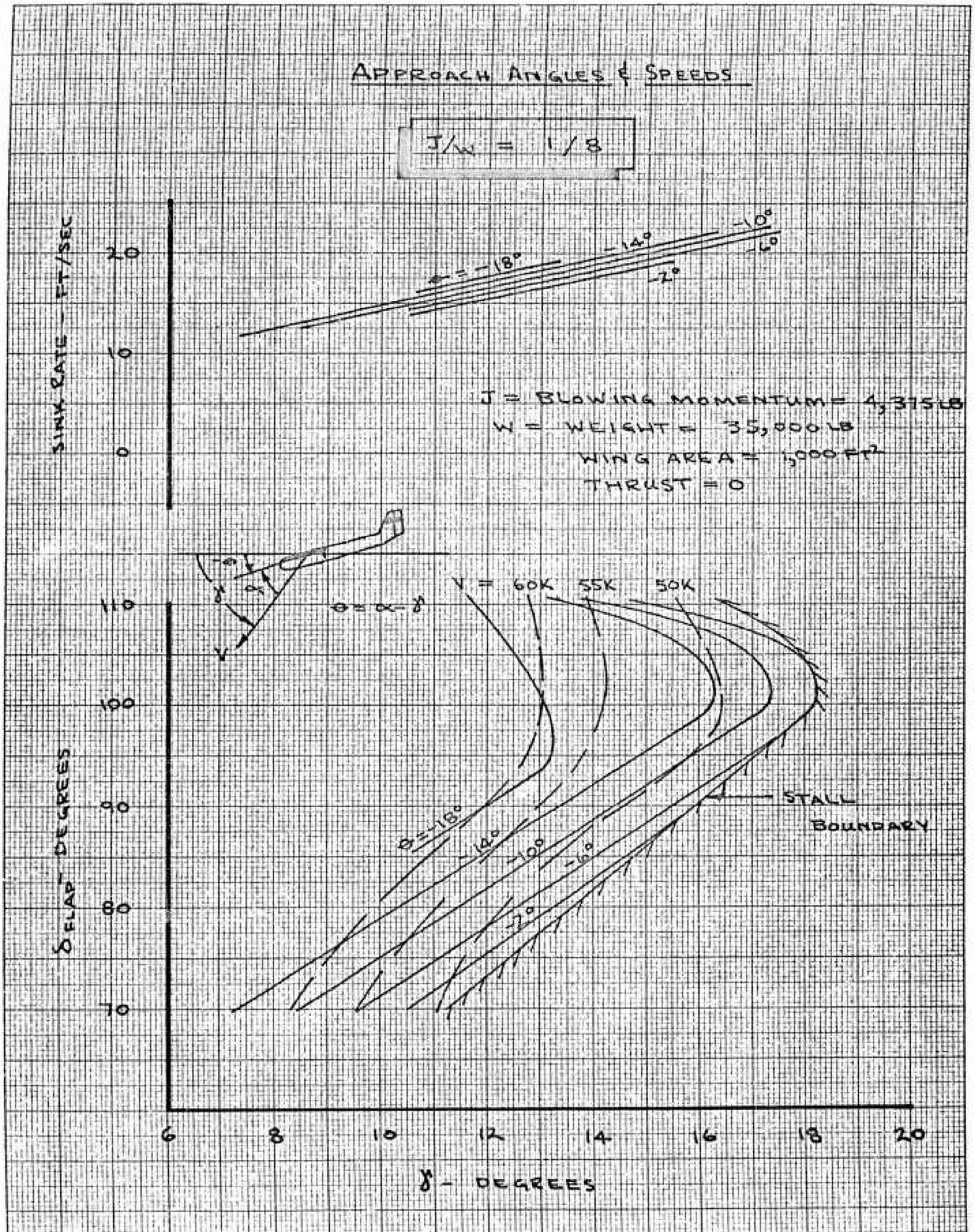

APPROACH ANGLES & SPEEDS
J/W = 1/8
SINK RATE – FT/SEC
20
10
0
−18°
−14°
−10°
−6°
−2°
J = BLOWING MOMENTUM = 4,375 LB
W = WEIGHT = 35,000 LB
WING AREA = 1,000 FT²
THRUST = 0
θ
γ
α
V
θ = α − γ
V = 60K
55K
50K
θ = −18°
−14°
−10°
−6°
−2°
STALL BOUNDARY
δFLAP – DEGREES
110
100
90
80
70
6
8
10
12
14
16
18
20
γ – DEGREES

Figure 30

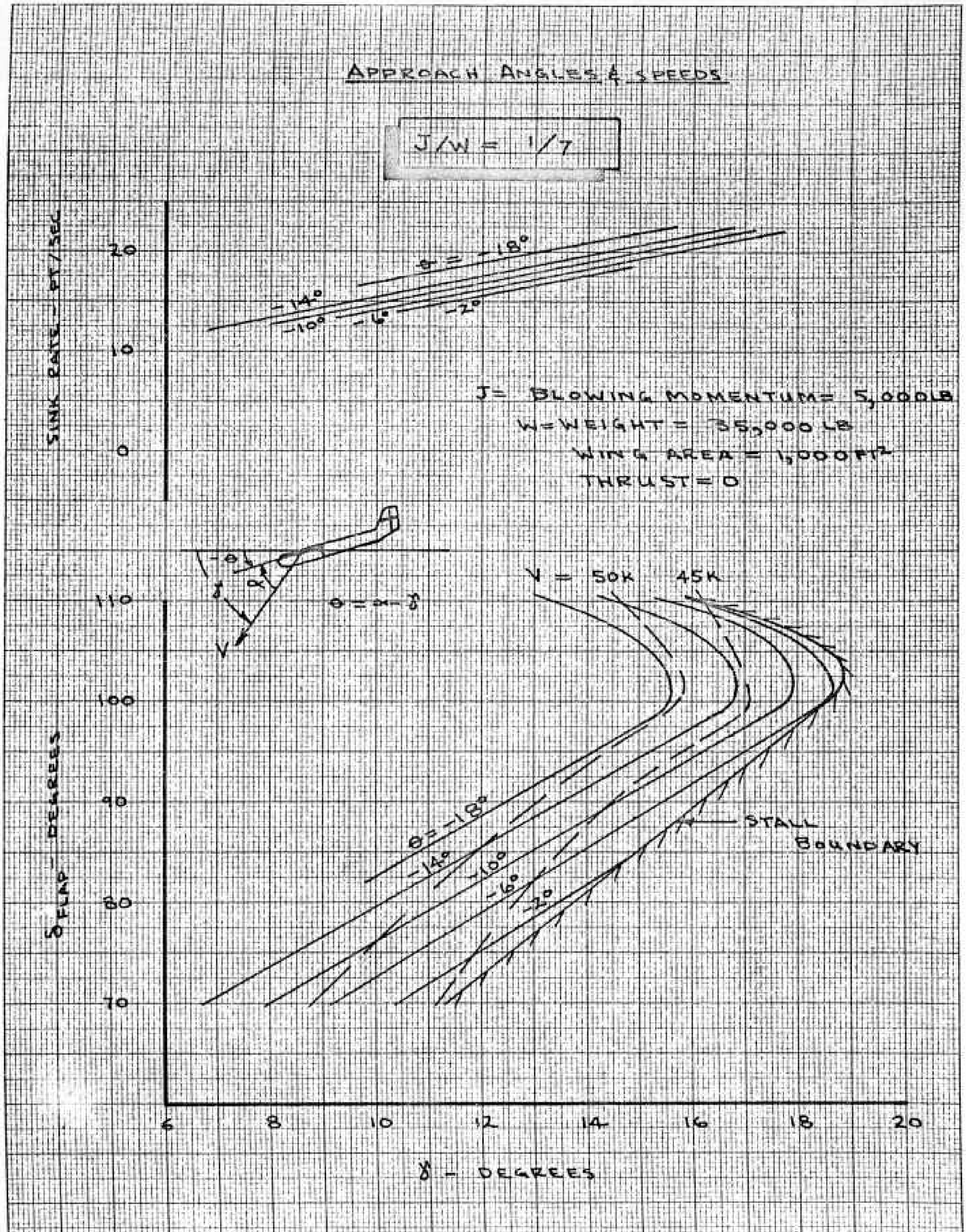

APPROACH ANGLES & SPEEDS
J/W = 1/7
SINK RATE – FT/SEC
20
10
0
θ = −18°
−14°
−10°
−6°
−2°
J= BLOWING MOMENTUM= 5,000LB
W=WEIGHT = 35,000 LB
WING AREA = 1,000FT²
THRUST=0
−θ
α
γ
V
θ = α − γ
V = 50K
45K
δ FLAP – DEGREES
110
100
90
80
70
θ=−18°
−14°
−10°
−6°
−2°
STALL BOUNDARY
6
8
10
12
14
16
18
20
γ – DEGREES

Figure 31

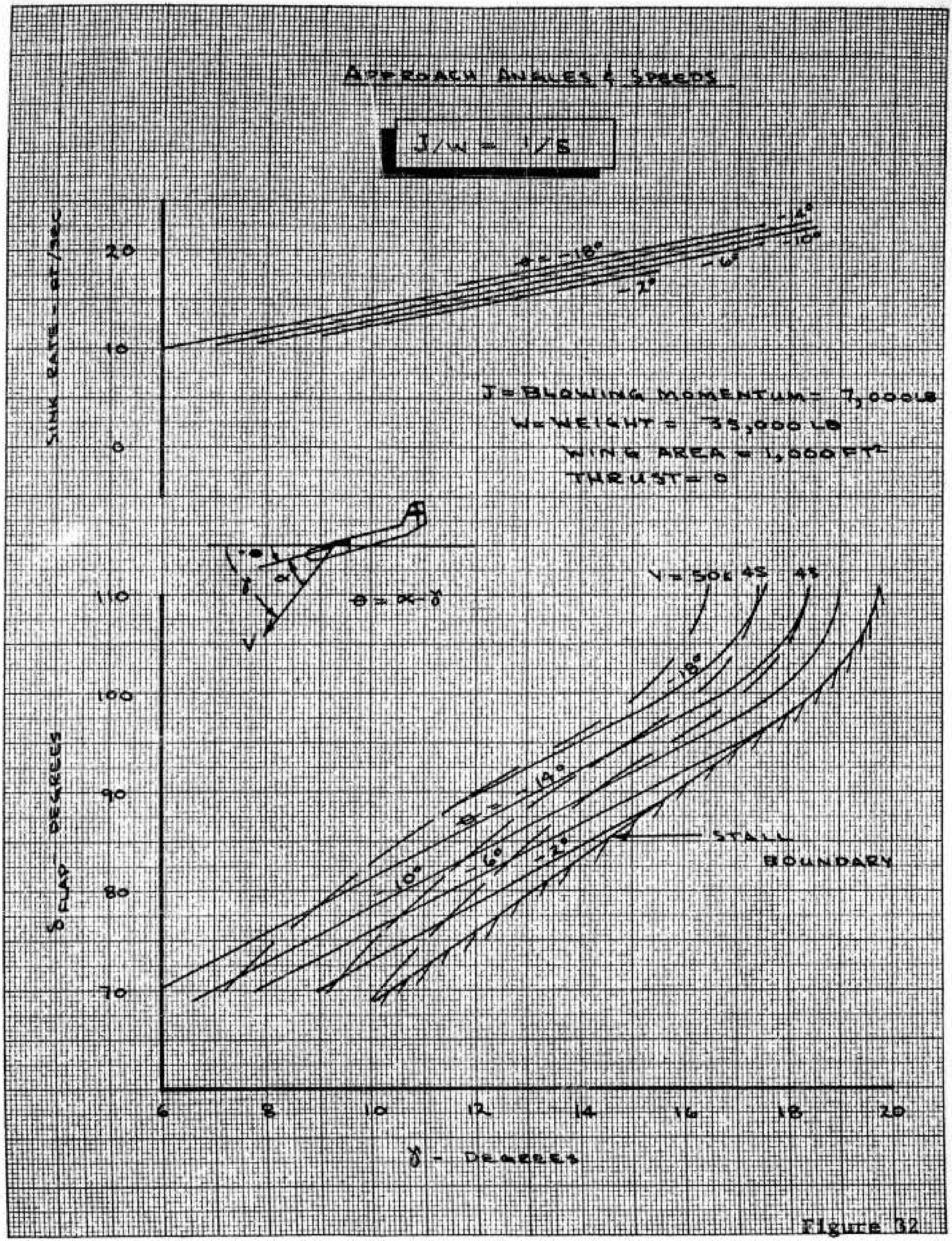

APPROACH ANGLES & SPEEDS
J/W = 1/5
SINK RATE - FT/SEC
20
10
0
θ = -18°
-14°
-10°
-6°
-2°
J = BLOWING MOMENTUM = 7,000 LB
W = WEIGHT = 35,000 LB
WING AREA = 1,000 FT²
THRUST = 0
θ
α
γ
V
θ = α - γ
V = 50K 45 43
-18°
θ = -14°
-10°
-6°
-2°
STALL BOUNDARY
δ FLAP - DEGREES
110
100
90
80
70
6
8
10
12
14
16
18
20
γ - DEGREES

Figure 32

DISTRIBUTION

USCONARC	(2)
First US Army	(1)
Second US Army	(1)
Third US Army	(1)
Fourth US Army	(1)
Fifth US Army	(1)
Sixth US Army	(2)
USA Infantry Center	(1)
USA Command & General Staff College	(1)
Army War College	(1)
USA Arctic Test Board	(1)
USA Cold Weather and Mountain School	(1)
USA Aviation School	(2)
USA Armor Board	(1)
USA Aviation Board	(2)
USA Aviation Test Office	(1)
Deputy Chief of Staff for Logistics, DA	(4)
Deputy Chief of Staff for Military Operations, DA	(1)
ORO, Johns Hopkins University	(1)
ARO, OCRD	(1)
Office of Chief of R&D, DA	(1)
ARO, Durham	(1)
USA Liaison Officer, Naval Air Test Center	(2)
USA Chemical Corps Board	(1)
USA Ordnance Missile Command	(1)
USA Ordnance Board	(1)
USA Quartermaster Board	(2)
USA QM Research and Engineering Command	(1)
USA QM Field Evaluation Agency	(2)
USA Signal Board	(1)
Chief of Transportation, DA	(6)
USA Transportation Combat Development Group	(1)
USA Transportation Board	(2)
USA Transportation Materiel Command	(20)
USA Transportation Training Command	(1)
USA Transportation School	(3)
USA Transportation Research Command	(32)
USATRECOM Liaison Officer, USA Engineer Waterways Experiment Station	(1)
USATRECOM Liaison Office, Wright-Patterson AFB	(1)
USATRECOM Liaison Officer, USA R&D Liaison Group (9851 DU)	(1)

TC Liaison Officer, USAERDL	(1)
USATRECOM Liaison Officer, Detroit Arsenal	(1)
USA Transportation Terminal Command, Atlantic	(1)
USA Transportation Terminal Command, Pacific	(3)
USA TC Liaison Officer, Airborne and Electronics Board	(1)
USA Europe (Rear)/Communications Zone	(2)
Hq USATDS	(1)
US Army, Pacific	(1)
US Army, Alaska	(3)
Eighth US Army	(2)
US Army Transportation Agency, Japan	(1)
US Army, Ryukyu Islands/IX Corps	(1)
US Army, Hawaii	(3)
US Army, Caribbean	(2)
Allied Land Forces Southeastern Europe	(2)
Air Research & Development Command	(1)
APGC(PGTRI), Eglin AFB	(1)
WADD(WWAD-Library)	(1)
Air University Library	(1)
Hq USAF (AFDFD)	(1)
Air Force Systems Command	(3)
Chief of Naval Research	(1)
Bureau of Naval Weapons	(7)
Asst. Chief for Research & Development (OW), Navy	(1)
US Naval Postgraduate School	(1)
David Taylor Model Basin	(1)
Hq, US Marine Corps	(1)
Marine Corps Schools	(3)
MC Liaison Officer, USA Transportation School	(1)
US Coast Guard	(1)
National Aviation Facilities Experimental Center	(10)
NASA, Washington, D. C.	(6)
George C. Marshall Space Flight Center, NASA	(4)
Langley Research Center, NASA	(3)
Ames Research Center, NASA	(1)
Lewis Research Center, NASA	(1)
US Government Printing Office	(1)
Library of Congress	(2)
US Army Standardization Group, U.K.	(1)
US Army Standardization Group, Canada	(1)
Canadian Army Liaison Officer, USA Transportation School	(3)
British Joint Services Mission (Army Staff)	(3)
Armed Services Technical Information Agency	(10)

Institute of Aeronautical Sciences	(1)
Human Resources Research Office	(1)
Boeing Airplane Company, Seattle	(1)
Northrop Corporation, (NORAIR Division)	(1)
University of Wichita	(10)
Boeing Company, Wichita	(1)
Lockheed Aircraft Corporation (Georgia Division)	(1)
Douglas Aircraft Corporation (El Segundo Division)	(1)
Ryan Aeronautical Company	(1)
Grumman Aircraft Engineering Corporation	(1)
North American Aviation, Inc.	(1)
Convair, a Division of General Dynamics Corporation	(1)

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

University of Wichita, Department of
Engineering Research, Wichita, Kansas.
A SUMMARY ANALYSIS OF AN STOL TRANSPORT,
Kenneth Razak and A.J. Craig

Report TREC 61-107, August 1961, Report
14 pp, Appendix 58 pp, (Contract DA
44-177-TC-356) DA Proj. 9R38-11-009-02,
Unclassified Report.

SUMMARY - A preliminary analysis has been made of an STOL transport of 35,000 pounds gross weight equipped with features that produce a total performance not heretofore achieved in a single airplane. The prime goal of the analysis was to secure an airplane in which a pilot could consistently achieve landings such that the landing field length is the same as the best performance of the airplane. The landing distance of this airplane is 1,170 feet and the take-off distance is 1,380 feet, both over a 50 foot obstacle at ICAO standard sea level conditions. A method of analysis is described which involves the use of trailing edge flaps deflected to 100° and the use of thrust to flare the airplane. The control of the airplane L/D ratio makes it possible to achieve consistently the above landing distances.

UNCLASSIFIED

1. Aircraft - flying qualities
2. Contract DA 44-177-TC-356
   Job Order No. 6

UNCLASSIFIED

UNCLASSIFIED