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Date February 28, 1986

PREDICTION OF LIFT AND EXCESS THRUST COEFFICIENT FOR UPPER SURFACE BLOWN WINGS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

Knoxville, Tennessee

T. Patrick Lynch

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DEDICATION

To my wife, Betty, and my beloved father, Matthew Lynch

ACKNOWLEDGMENTS

The author wishes to greatly acknowledge his appreciation to his Major Professor and friend, Ralph Kimberlin, for his encouragement, assistance and for allowing the author a chance to fulfill a desire to explore the world of aviation in general. The sometimes lengthy conversations were invaluable in understanding the real life problems in flight research.

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Finally, a warm thanks to Madge Gibson for her advice and friendship in the days she spent preparing this thesis.

ABSTRACT

A prediction method was developed by Williams, Butler and Wood, (WBW) in 1961 which used linearized, inviscid flow theory for prediction of lift and excess thrust coefficient. The resulting work was developed into a prediction method for upper surface blown aircraft and tailored to The University of Tennessee Space Institute (UTSI) Ball-Bartoe Jetwing using the actual Jetwing physical dimensions for input. The data from the predictions were compared to data from full scale wind tunnel and flight tests. Additional comparisons were made to lift coefficient predictions from another prediction method. The Williams, Butler and Wood method is considered a simple and accurate preliminary design criteria which may be applied to other upper surface blown aircraft.

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LIST OF SYMBOLS

AR	Aspect ratio
C_D	Drag coefficient $= \frac{D}{1/2\ \rho V^2}$
C_{D_i}	Induced drag coefficient $C_{D_i} = \frac{C_L^2}{\pi AR+2C_J}$
C_{D_o}	Drag coefficient at zero lift without flap deflection or blowing
ΔC_{D_p}	Partial span drag coefficient
C_{EX}	Excess thrust coefficient
C_J'	Sectional blowing coefficient
C_J	Blowing coefficient
C_L	Lift coefficient $= \frac{L}{1/2\rho V^2 S}$
$C_{L_{max}}$	Maximum lift coefficient
$(C_L)_\infty$	Two dimensional lift coefficient
dV/dt	Flight path acceleration
$\frac{\partial C_L}{\partial \alpha}$	Partial derivative of the lift coefficient with respect to angle of attack
$\frac{\partial C_L}{\partial \theta}$	Partial derivative of the lift coefficient with respect to flap deflection
$F(AR, C_J)$	Correction factor due to finite aspect ratio wing
F_{EX}	Excess thrust
F_{GA}	Gross thrust available
F_{GR}	Gross thrust required for level flight
g	Acceleration due to gravity
K	Finite aspect ratio factor
L	Lift
r	Sectional thrust factor

S	Wing area
S'	Blown portion of wing area
W	Airplane weight
α	Angle of attack
θ	Flap deflection
γ	Aircraft angle of climb or flight path angle
σ	Value relating vorticity to downwash
τ	Ratio of maximum induced downwash to maximum total downwash
ν	Partial span blowing lift correction
λ	Partial span blowing lift correction

CHAPTER I

INTRODUCTION

The purpose of this thesis is to evaluate the validity of a method to predict the aerodynamic coefficients of a powered lift wing. The method evaluated was that developed by Williams, Butler, and Wood [1]. The most practical means of accomplishing this evaluation was by using the data produced by the prediction method, and then comparing these data with existing experimental and empirical data.

In writing this thesis three primary objectives were in mind:

1) To find a simple, reasonable, cost effective and efficient method for determining lift coefficient (C_L) and excess thrust coefficient (C_{EX}) for powered lift aircraft.
2) To use this method on the VAX 11/780 and develop a version small enough to be loaded on current "desktop" computers.
3) To compare this method in conjunction with existing aircraft data to determine its validity.

A preliminary design method was developed to predict values of C_L and C_{EX} for upper surface blown wings and flaps. If designers are able to predict reliable numbers for C_L and C_{EX}, many manhours and wind tunnel time can be saved; wind tunnel time and models are becoming more and more cost prohibitive.

Since an existing aircraft is to be used to illustrate the prediction method, it is necessary to explain briefly how the aircraft is constructed and explain a little of its history. The aircraft is called simply the "Jetwing".

The Ball-Bartoe Jetwing is a short take-off and landing, upper surface blown (STOL/USB) aircraft built in 1973 by the Ball-Bartoe Aircraft Company. The Jetwing was first flown in Mojave, California in July, 1977, by Mr. H. R. "Fish" Salmon. Wind tunnel tests were performed at NASA/Ames in their 40' x 80' tunnel on various configurations, and data recorded for lift, drag, and pitching moment [2].

The Jetwing is powered by a single engine (Pratt & Whitney JT15D-1 Turbofan) and all engine core exhaust and fan air is routed to slot nozzles located on the leading edge of the upper surface of the wing. As shown in Figure 1, the core exhaust is ducted over the inner portion of each wing and the fan by-pass air is ducted to the outer portion of each wing. A more complete description is given in UTSI Report 81-1 "A Flight Test Evaluation of the Ball-Bartoe Jetwing Propulsive Lift Concept," [3].

Other blown flap and blown wing aircraft exist in the United States and Britain, most notably the British Hunting H.126, the YC-14, and the quiet short-haul research aircraft (QSRA).

The H.126 uses eight thin nozzles in each wing plus two thruster nozzles behind the center of gravity to derive its thrust. Two roll jets, two yaw jets and two pitch jets located at the wing tips and tail section give the H.126 unusual handling characteristics in that all control surfaces were enhanced whether rolling, pitching, or yawing [4]. The wing and fuselage nozzles are used for propulsion while the pitch and yaw jets are used for control purposes. The roll jets are used for auto-stabilization [5]. A breakdown in percentage of mass flow portions for each use is given as follows:

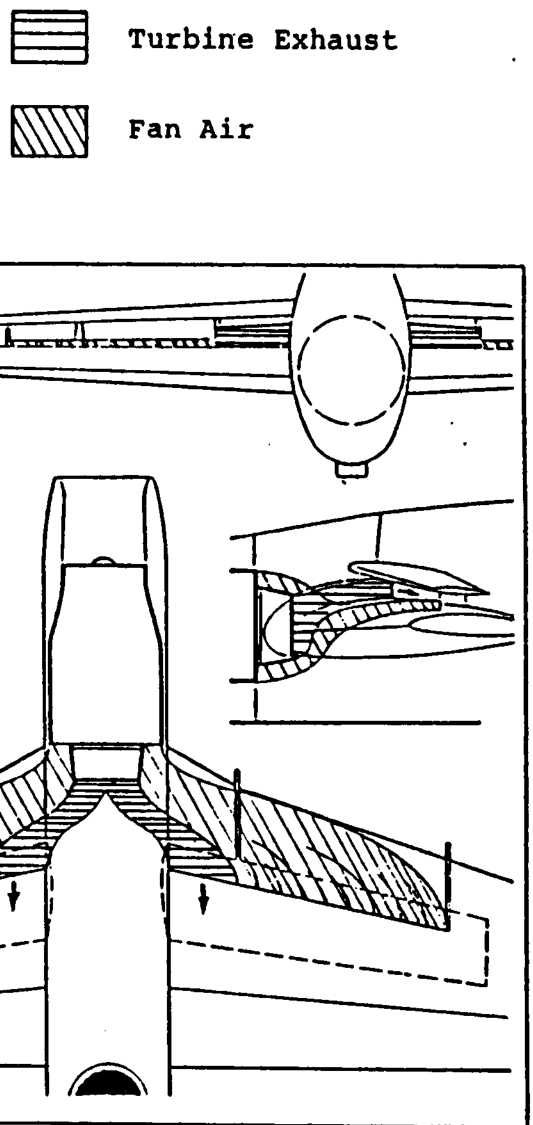

Figure 1. Jetwing Turbine and Fan Exhaust Arrangement.

Adapted from "Jetwing from Colorado," Air International, 14 (No. 2):69-71, Fine Scroll Limited, London, England, February 1978.

Jet-Flap (wing)	55%
Direct thrust	30%
Pitch	5%
Yaw	5%
Roll	5%

The major differences in the H.126 and Jetwing is the ducting arrangement and diverting of engine exhaust as the Jetwing directs all of its engine and fan exhaust over the wings. Other differences of primary importance are: aspect ratio, 4.48 for the Jetwing vs. 9.32 for the H.126, and the swept wing Jetwing versus the straight wing of the H.126.

The YC-14 uses two engines located forward and above the wing for its thrust. The slightly swept wing (4.9°) uses an outboard flap system and inboard flap system with the inboard flaps being the upper surface blown (USB) flaps. The YC-14 has an AR = 9.4 and uses a leading edge boundary layer control (BLC) system to augment the leading edge flap system. The BLC system uses blowing from direct engine bleed and allows a large reduction in wing area that is required for STOL missions [6]. The availability of data on the YC-14 is scarce since reports containing data or even good descriptions are still unpublished.

The quiet short-haul research aircraft (QSRA) was a modified deHavilland C-8A Buffalo and was converted to an aircraft that employed USB. The conversion was completed in April of 1978 when testing also started.

The QSRA uses four engines mounted on the inner unswept 50% portion of each wing. The outer portion of each wing has a 15° sweep and the entire wing has an aspect ratio of 9.0. The QSRA possesses a

BLC system for the wing leading edges and ailerons. This employs air which is bled from the fan and engine core [7]. The major purpose of the QSRA program was to prove its airworthiness and provide design and certification criteria for a quiet propulsion-lift, short-haul aircraft [8].

Of the three aircraft mentioned, the H.126, the YC-14 and the QSRA, the YC-14 and QSRA are the most similar in principle to the Jetwing (i.e. USB). The Jetwing's relatively small slotted USB arrangement is unique in that all of the jet exhaust is bypassed over the wing. It has relatively high lift coefficients (~ 6.5) in view of its low aspect ratio of 4.48.

This thesis deals with a simple, linearized system for estimating C_L and C_{EX}. These predictions for C_L and C_{EX} will be compared to the Jetwing wind tunnel and flight test data, as well as another prediction method for which data exists; the equivalent chord/flap theory (ECT) [9]. The ECT theory does not treat C_{EX} so only C_L can be compared with this prediction method.

For blowing coefficients greater than $C_J = 0.75$ and flap deflections greater than $\delta_f = 30°$, no flight test data exists. The Jetwing exhibits a rather severe tail stall problem beyond $C_J>0.75$ and $\delta_f>30°$. For $C_J>0.75$ and $\delta_f>30°$ only wind tunnel data and prediction methods are available and will be used.

The prediction method to be used was devised by Williams, Butler and Wood and will hereafter be referred to as the WBW method. A history and description of the WBW method is given in the following chapters.

CHAPTER II

BACKGROUND

The jet flap and jetwing concept as mentioned previously are not new concepts. In fact, a mathematical basis was formed first by Glauert [10] in 1927. Glauert [10] formulated theories using a hinged flap in a paper entitled "Theoretical Relationships for an Aerofoil with a Hinged Flap."

In 1931, not long after Glauert's treatment of the hinged flap, a report published by Millard Bamber [11] summarized his work with the following conclusions:

"1) The maximum lift of an airfoil may be greatly increased by removing the boundary layer or by accelerating it by jet action.

2) Within the limits of this investigation and at any angle of attack below maximum lift, the lift coefficient increases with the quantity of air flowing through the slot per unit time; i.e., with increases in slot opening or wing pressure.

3) The lift coefficient apparently continues to increase with the quantity of air flowing out through the slot; with the air flowing in through the slot, the lift coefficient apparently approaches as a maximum, the value obtained by theory for an inviscid fluid.

4) The drag coefficient of an airfoil, under the conditions of these tests, may be appreciably decreased.

5) Improved lateral control in stalled flight and greater speed ranges of airplanes appear possible by the use of this form of boundary layer control."

Millard Bamber was conducting experiments with slotted wings or blowing over the wing which gives the boundary layer additional kinetic energy and keeps the flow attached, thereby creating higher lift coefficients. The major points in Bamber's conclusions were that the blowing coefficient, C_J, (which was not used at that time) influenced the boundary layer by enhancing C_L and at the same time decreased the drag coefficient. In relation to the jetwing, the above five conclusions are also true.

In 1955, E. C. Maskell and S. B. Gates formulated the basic theoretical properties for a two-dimensional jet in inviscid flow [12]. D. A. Spence in 1956 solved the two-dimensional problem for a "pure" jet flap (jet ejected at the trailing edge) [13] and finally, for the hinged flap [14]. The solution for the two-dimensional hinged flap was extended to a finite aspect ratio wing assuming full span blowing of the wing in 1959 by Maskell and Spence [15].

After this work during the 1950's by Spence and Maskell, Williams, Butler and Wood published a report in 1961 entitled, "The Aerodynamics of Jet Flaps" [1], based primarily upon the work of Maskell and Spence. This work was used, along with semi-empirical evidence, in the formulation of the WBW method.

The WBW method was derived for thin jets, but the exact definition of thin jet was not given in the WBW report.

CHAPTER III

DESCRIPTION OF THE WBW METHOD

Primarily, the WBW prediction was established and developed at the Royal Aircraft Establishment (RAE) and National Physical Laboratory (NPL) by research work done in the late 1950's and early 1960's for the formulation of jet flap aerodynamics.

The WBW method used the linearized inviscid-flow theory as a convenient starting point [1]. This theory states that the lift for a two-dimensional thin flat plate with an incidence angle of α and a flap deflection of θ is described by:

$$(C_L)_\infty = \theta\left(\frac{\partial C_L}{\partial \theta}\right) + \alpha\left(\frac{\partial C_L}{\partial \alpha}\right) \tag{1}$$

with the sectional lift derivatives being equal when the flap/chord ratio (C_f/C) equals unity. The sectional derivative ($\partial C_L/\partial\theta$) is a function of the sectional blowing coefficient C_J', defined by WBW as being equal to the blowing coefficient times the ratio of the wing surface area to the blown wing surface area, or $C_J' = C_J\ (S/S')$.

Based upon semi-empirical evidence additional equations can be written:

$$C_L = F\left\{[1 + t/c][\lambda\theta \left(\frac{\partial C_L}{\partial \theta}\right)_\infty + \nu\alpha\left(\frac{\partial C_L}{\partial \alpha}\right)_\infty]\right\} - (t/c)\ C_J(\theta + \alpha) \tag{2}$$

where

$$\nu = \frac{S'\left(\frac{\partial C_L}{\partial \alpha}\right)_\infty + (S - S')\ \left(\frac{\partial C_L}{\partial \alpha}\right)_\infty \text{ at } C_J = 0}{S\left(\frac{\partial C_L}{\partial \alpha}\right)} \tag{3}$$

and

$$\lambda = S'/S \tag{4}$$

where S' is that portion of the total wing which uses USB,

and

$$F(AR,C_J) = \frac{AR + (\frac{2C_J}{\pi})}{AR + (2/\pi)(\frac{\partial C_L}{\partial \alpha})_\infty - 2(1 + \sigma)} , \tag{5}$$

where

$$\sigma = \frac{(1 - \tau)(C_J/\pi AR)}{\tau - (1 - \tau)(C_J/\pi AR)} \tag{6}$$

and

$$\tau = \frac{2(C_L)_\infty/(\theta + \alpha)}{\pi\ AR + 2\ (\frac{\partial C_L}{\partial \alpha}) - 2\pi(1 + \sigma)} . \tag{7}$$

The above equations for σ and τ are difficult to solve manually but can be easily calculated using numerical methods.

The term $(\partial C_L/\partial \alpha)_\infty$, at $C_J = 0$ in equation 3 represents $(\frac{\partial C_L}{\partial \alpha})$ taken from a 23015 airfoil plot which is the airfoil section type of the blown portion of the wing of the Jetwing aircraft. The term $(C_L)_\infty$ is simply the term shown in equation (1).

The two dimensional lift coefficient, C_L, for a thin, flat plate, is corrected for part span flaps and blowing and for the fuselage cut-out by ν and λ. The part span conversion factors λ and ν are multiplied by the respective derivatives to obtain corrections due to jet deflection θ and wing incidence α as shown in equation (2).

The effect of thickness to chord ratio (t/c) is corrected by addition of (1 + t/c).

The F-factor or aspect ratio (AR) conversion factor due to the lift increment of USB is shown in equation (5). The F-factor is dependent only on C_J, all other portions of its formula are either constant or are also dependent on C_J.

Cumulatively, the set of equations (1) - (7) are used in lift predictions for a blown flap aircraft.

The algebraic manipulations involved in calculating total C_L for blown flaps according to WBW method are shown in Appendix A.

Appendix B has been provided which includes a FORTRAN listing of the entire WBW prediction method and plotting routines.

Drag for a USB aircraft is a function of α and C_J. It is for this reason that conventional drag equations must be altered and the excess thrust term introduced. Maskell and Spence [14] developed an equation for the induced drag coefficient of a blown wing in 1959 given by,

$$C_{D_i} = \frac{C_L^2}{\pi AR + 2C_J} \, . \qquad (8)$$

If all of the mass flow is ejected over the wing, and knowing total drag;

$$C_D = C_{D_i} + C_{D_o} \qquad (9)$$

then

$$C_D = [C_L^2/(\pi AR + 2C_J)] + C_{D_o} \qquad (10)$$

where C_{D_o} = drag coefficient at zero lift and no flap deflection.

Since $C_L = f(C_J)$ and $C_D = f(C_J)$ then it is seen that C_J will occur in both sides of equation (10) and drag and thrust cannot be set equal. It is for this reason excess thrust must be introduced for USB aircraft since it does not contain terms other than thrust.

Another approach can be taken if the forces are summed for a USB aircraft in an accelerated climb.

Basically, if the forces are summed for a powered-lift aircraft (or any aircraft) during an accelerated climb, two equations are produced:

$$L = W \text{ Cos } \gamma \tag{11}$$

and

$$F_{GA} - D - W \text{ Sin}\gamma = w/g \frac{dv}{dt} \tag{12}$$

A linearized method to the excess thrust approach was taken by WBW and forces summed in coefficient form to produce the equation:

$$C_{EX} = rC_J - \frac{KC_L^2}{\pi AR + 2C_J} - C_{D_o} - \Delta C_{D_P}. \tag{13}$$

Simply stated, the gross thrust available is equal to the gross thrust required (F_{GR}) for level flight plus an amount of excess thrust which is used to accelerate the aircraft in a climbing attitude, namely excess thrust (F_{EX}). The thrust required for level flight, (F_{GR}), equals the drag;

$$F_{GR} = D \tag{14}$$

and

$$F_{GA} = F_{GR} + F_{EX}. \tag{15}$$

Therefore, from equations (12) and (14)

$$F_{EX} = W/g \frac{dV}{dt} + W \sin\gamma \tag{16}$$

and

$$C_{EX} = \frac{F_{EX}}{qS} \text{ (coefficient form).} \tag{17}$$

The factor K in equation (13) is the correction factor for a non-elliptical lift distribution. Since the effects of the blowing upon the lift distribution are unknown, this factor was assumed to be equal to unity.

The sectional thrust factor (r) is a correction factor for the losses associated with physical parameters. These parameters include: interferences in the slot nozzle, slot width, high skin friction of the flap surface, and flap interfaces [1]. For no losses, the r factor would be unity. However, due to loses, r is not expected to be greater than 0.96. An r-factor = 0.83 is suggested by WBW for the initial configurations treated by this thesis, but an r=1 was used for the calculations and plots in Figures 2-11 since the WBW paper states, "Unfortunately, although the drag increment associated with part-span effects can be significant..., there is as yet no sound theoretical basis for its prediction." The term "Delta F" in the plots refers to flap deflection (θ).

The WBW paper suggests values for r and K, but no direct correlation was made between flap deflection and these values. Since the K factor affects the C_L^2 term in the equation, any change in K only

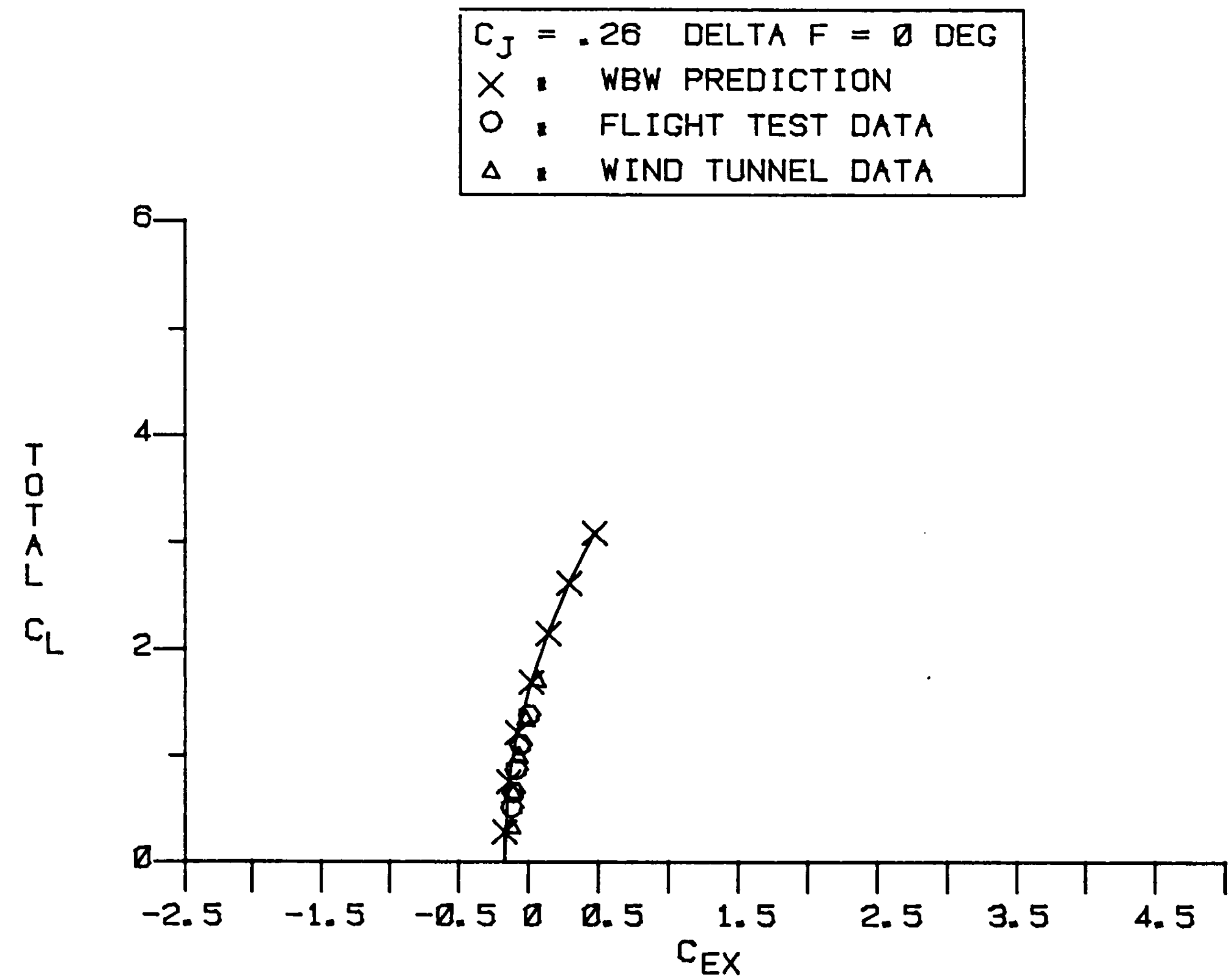

Figure 2. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.26 and Flap Deflection of 0°.

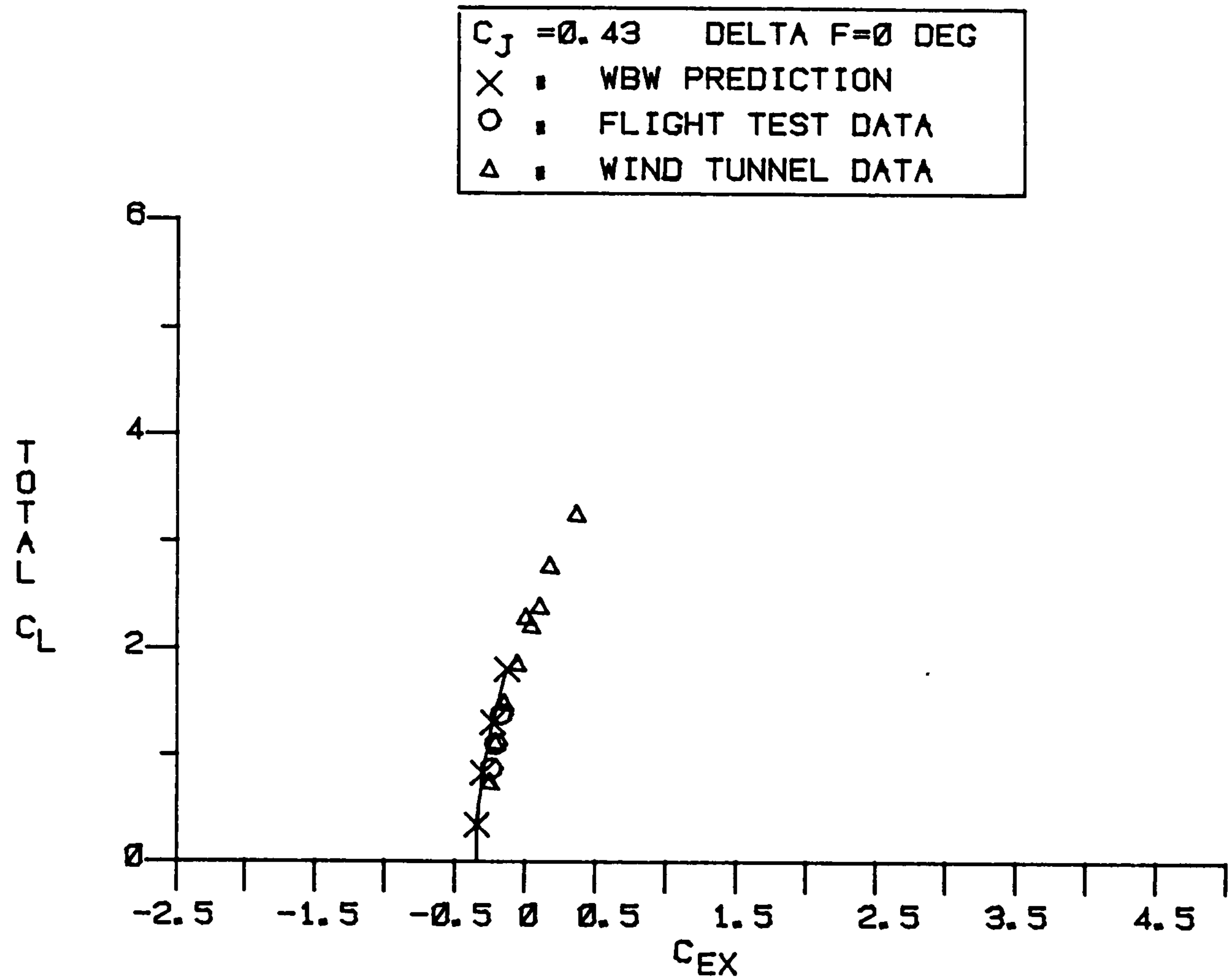

Figure 3. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.43 and Flap Deflection of 0°.

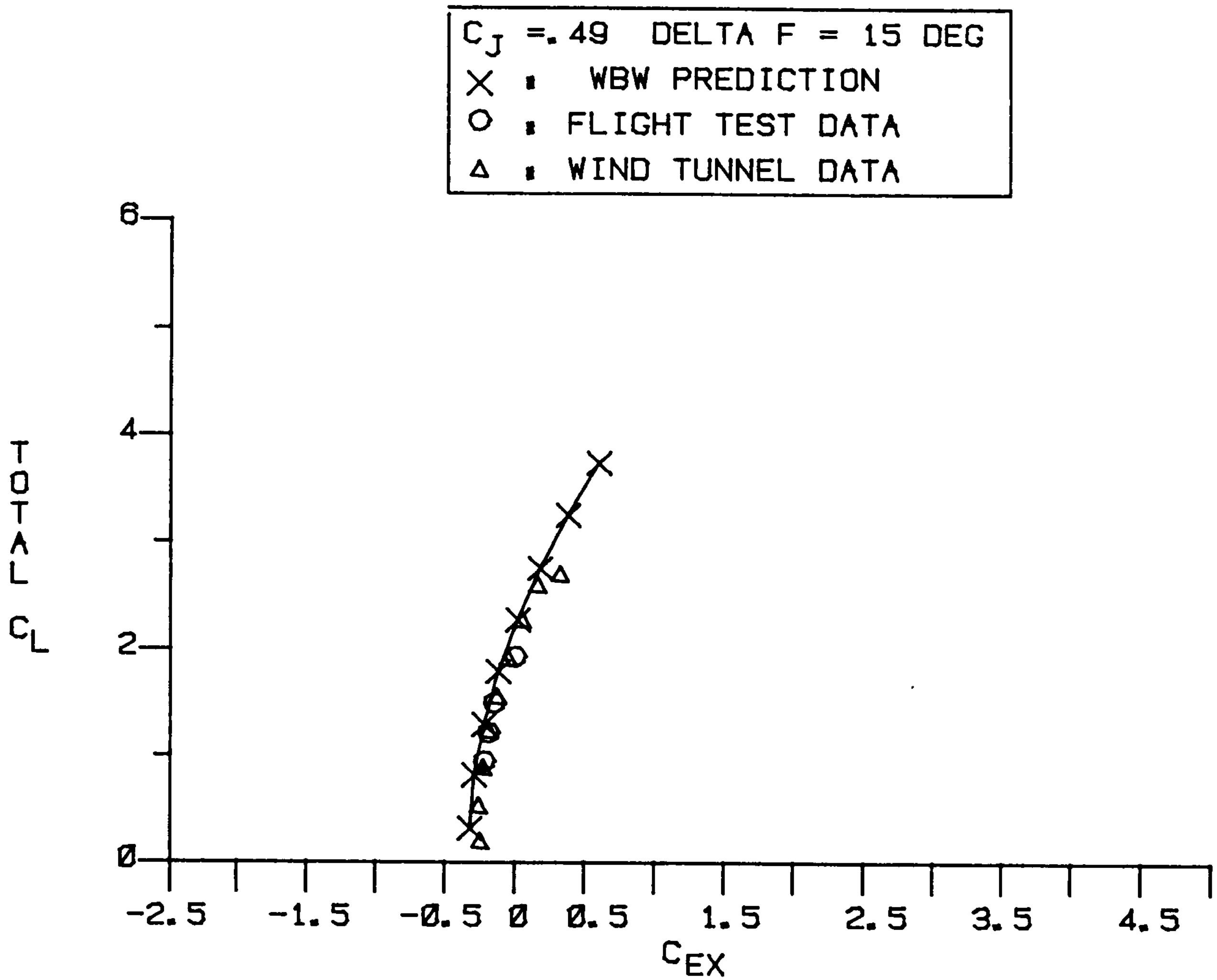

Figure 4. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.49 and Flap Deflection of 15°.

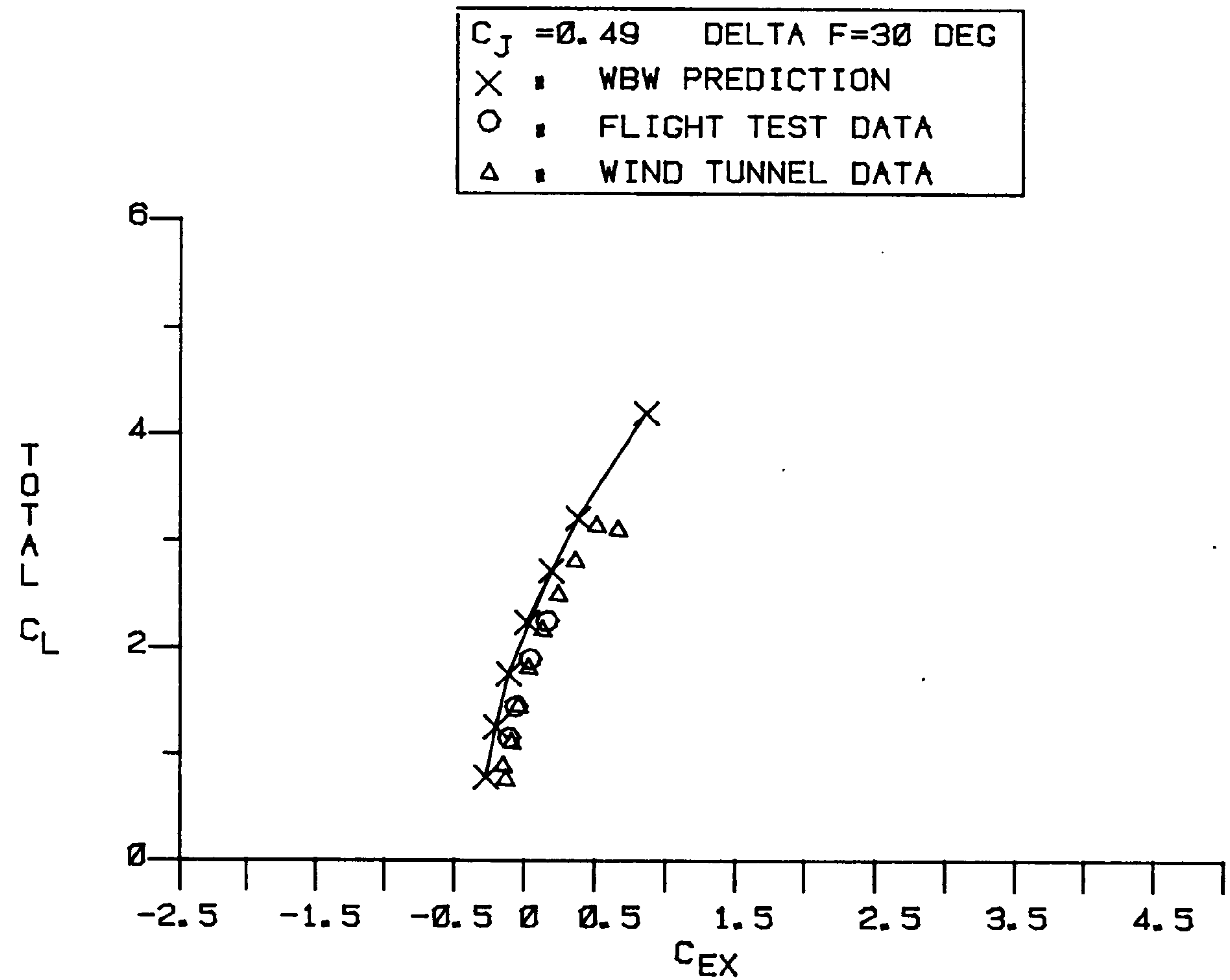

Figure 5. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.49 and Flap Deflection of 30°.

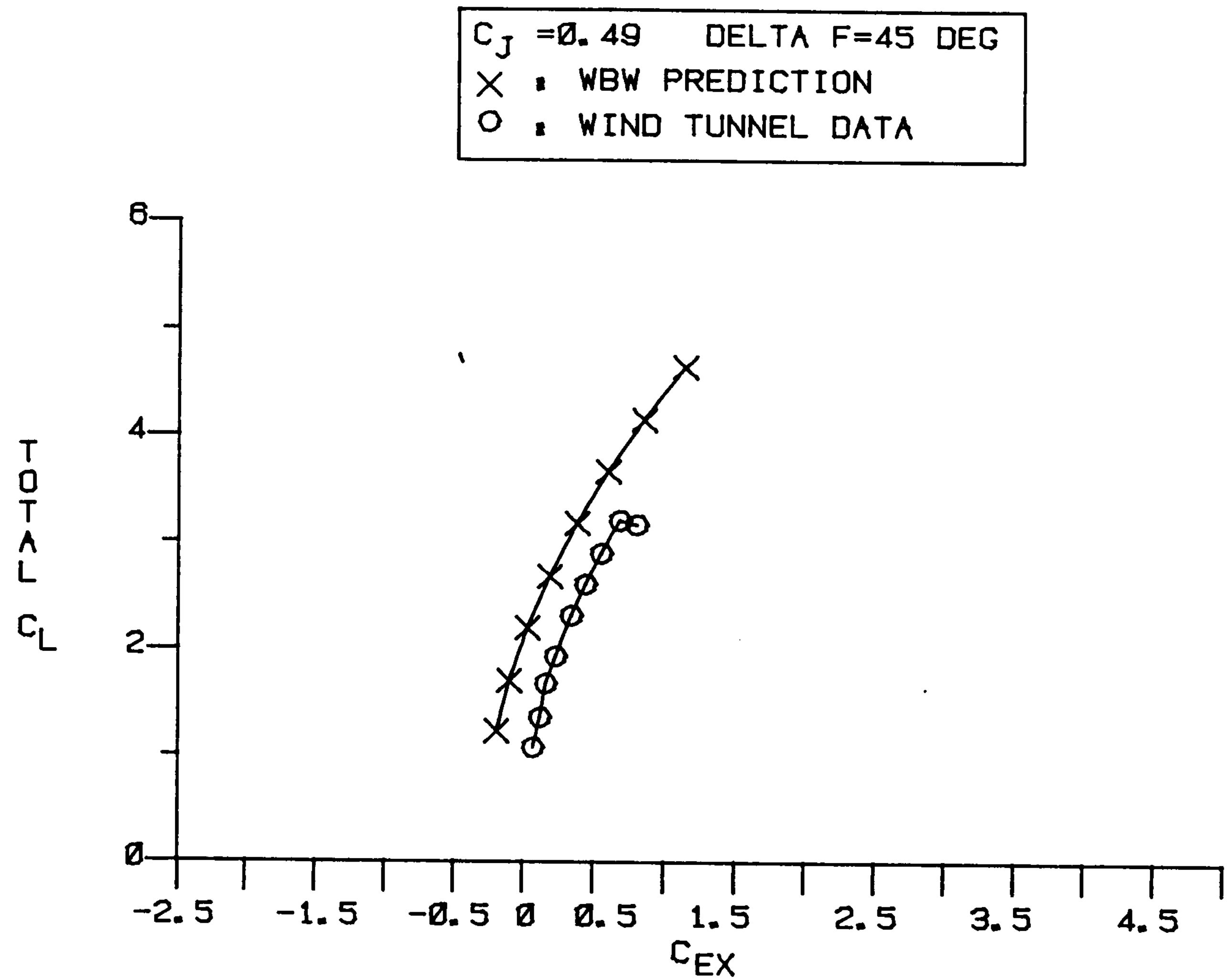

Figure 6. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.49 and Flap Deflection of 45°.

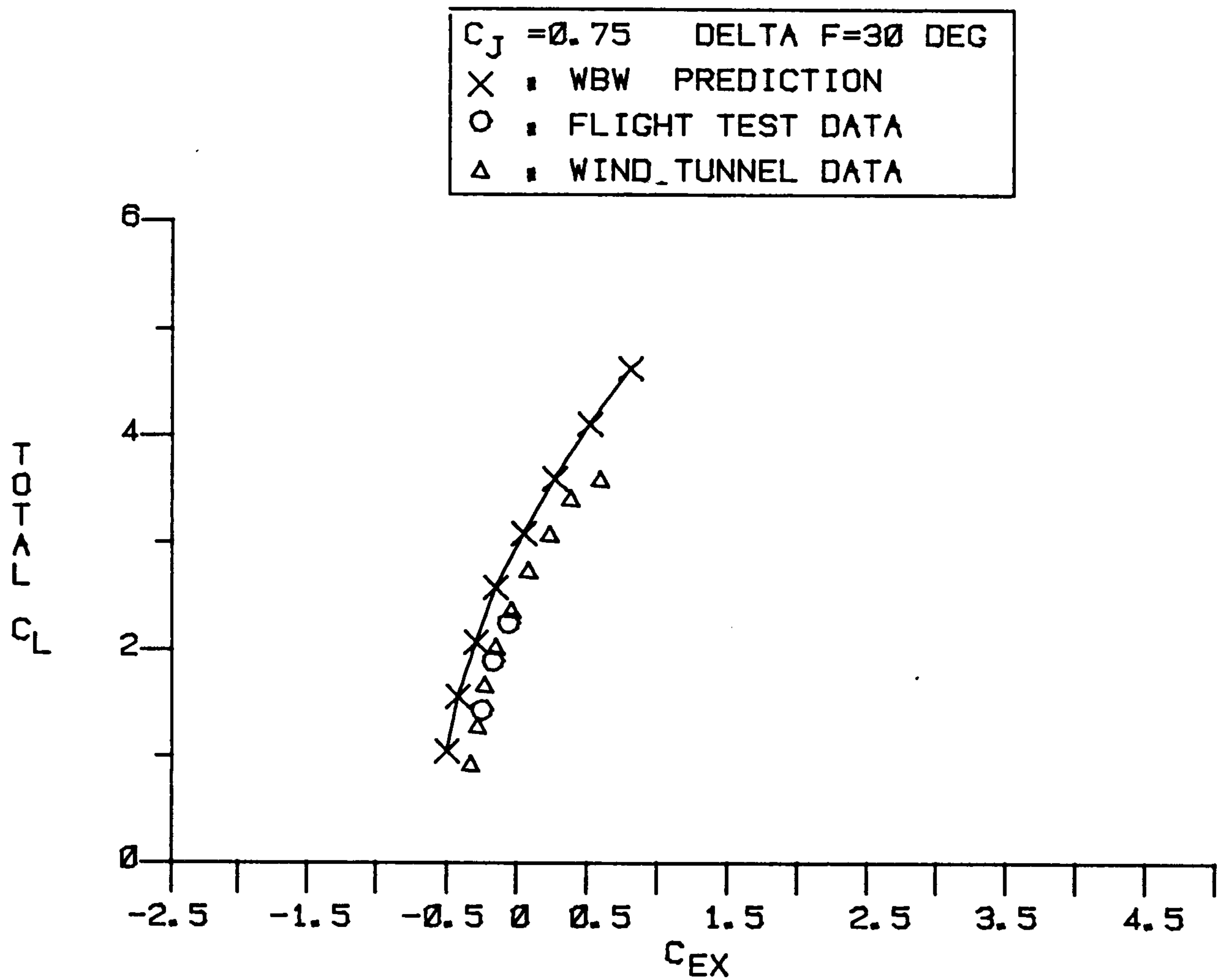

Figure 7. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.75 and Flap Deflection of 30°.

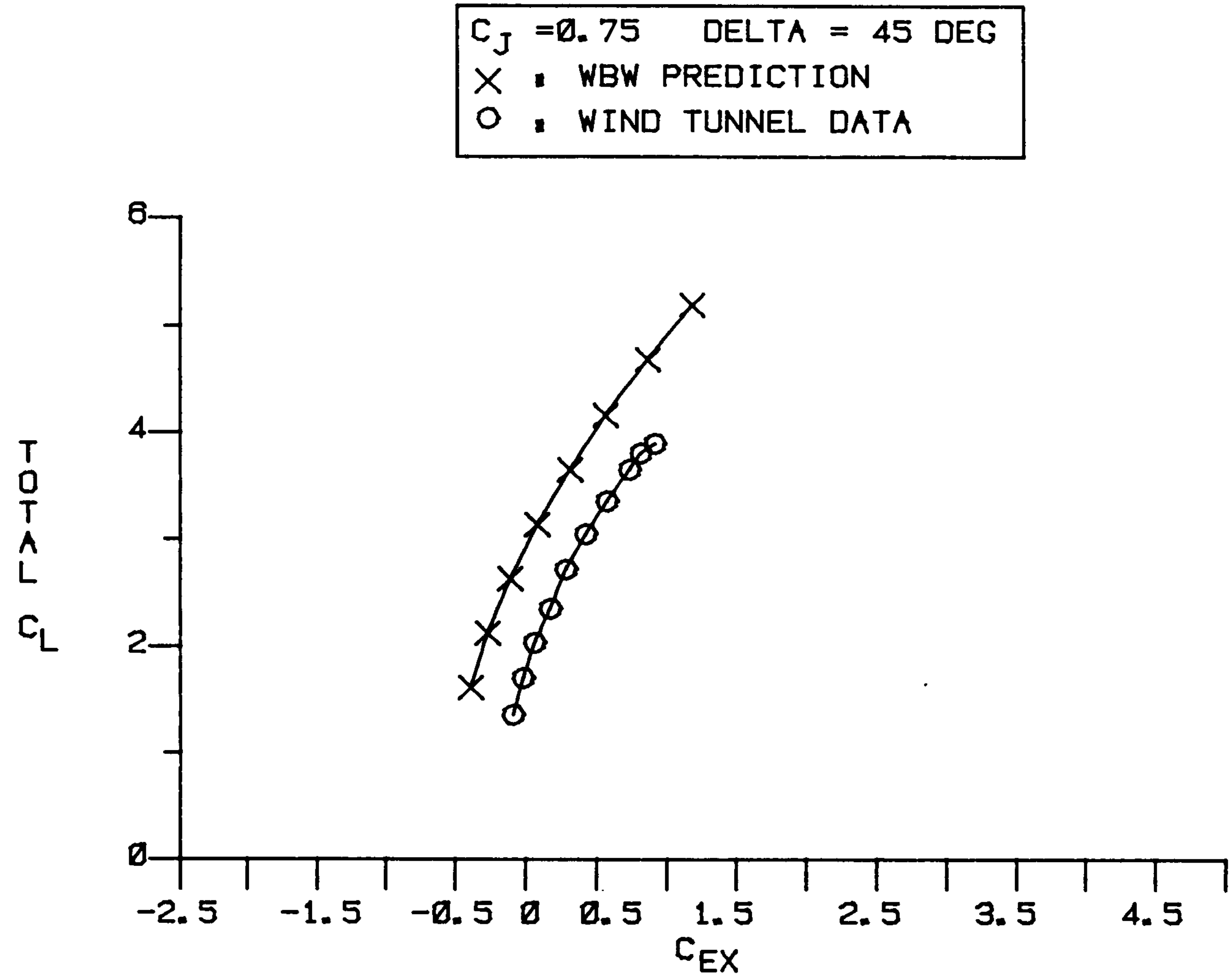

Figure 8. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 0.75 and Flap Deflection of 45°.

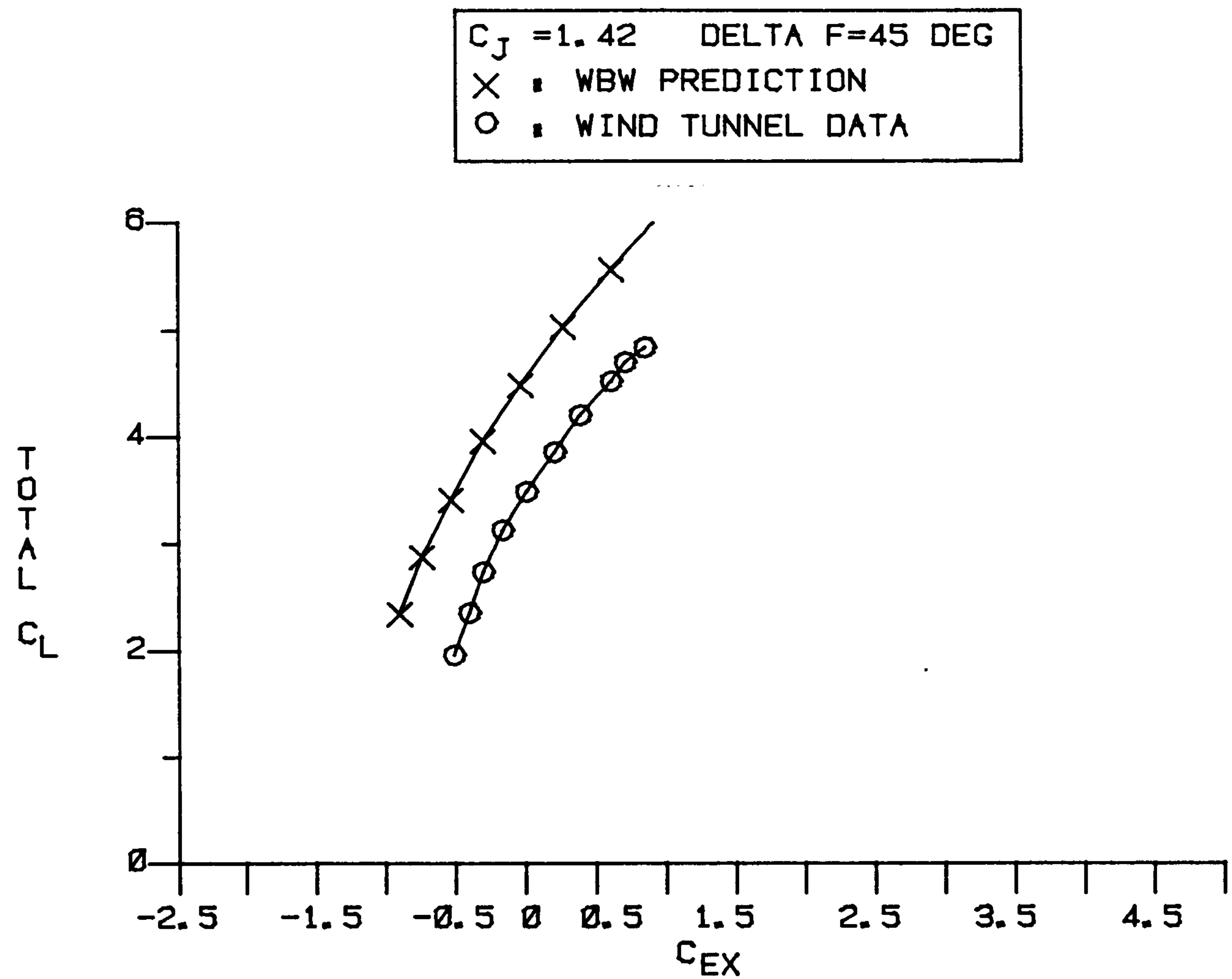

Figure 9. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 1.42 and Flap Deflection of 45°.

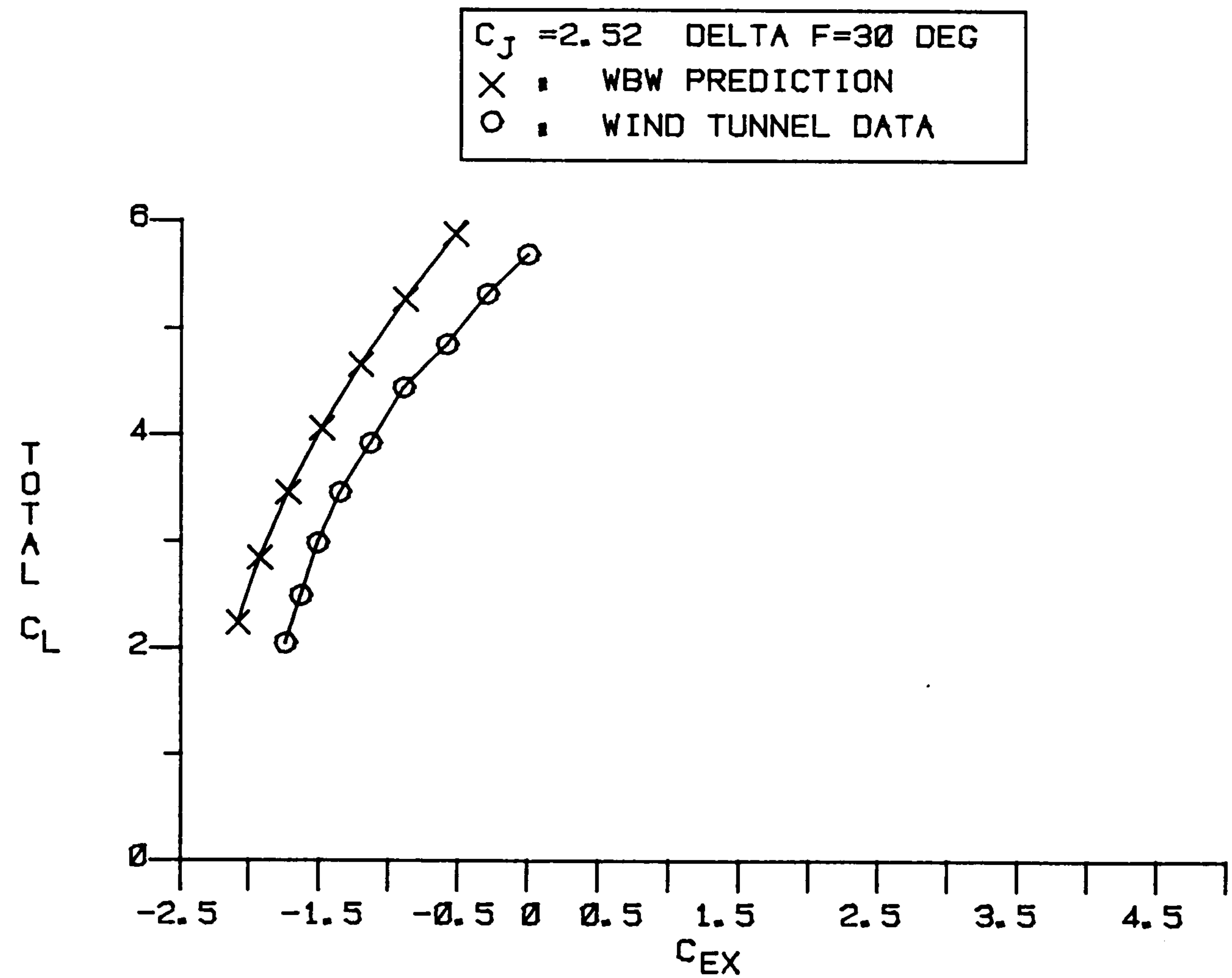

Figure 10. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 2.52 and Flap Deflection of 30°.

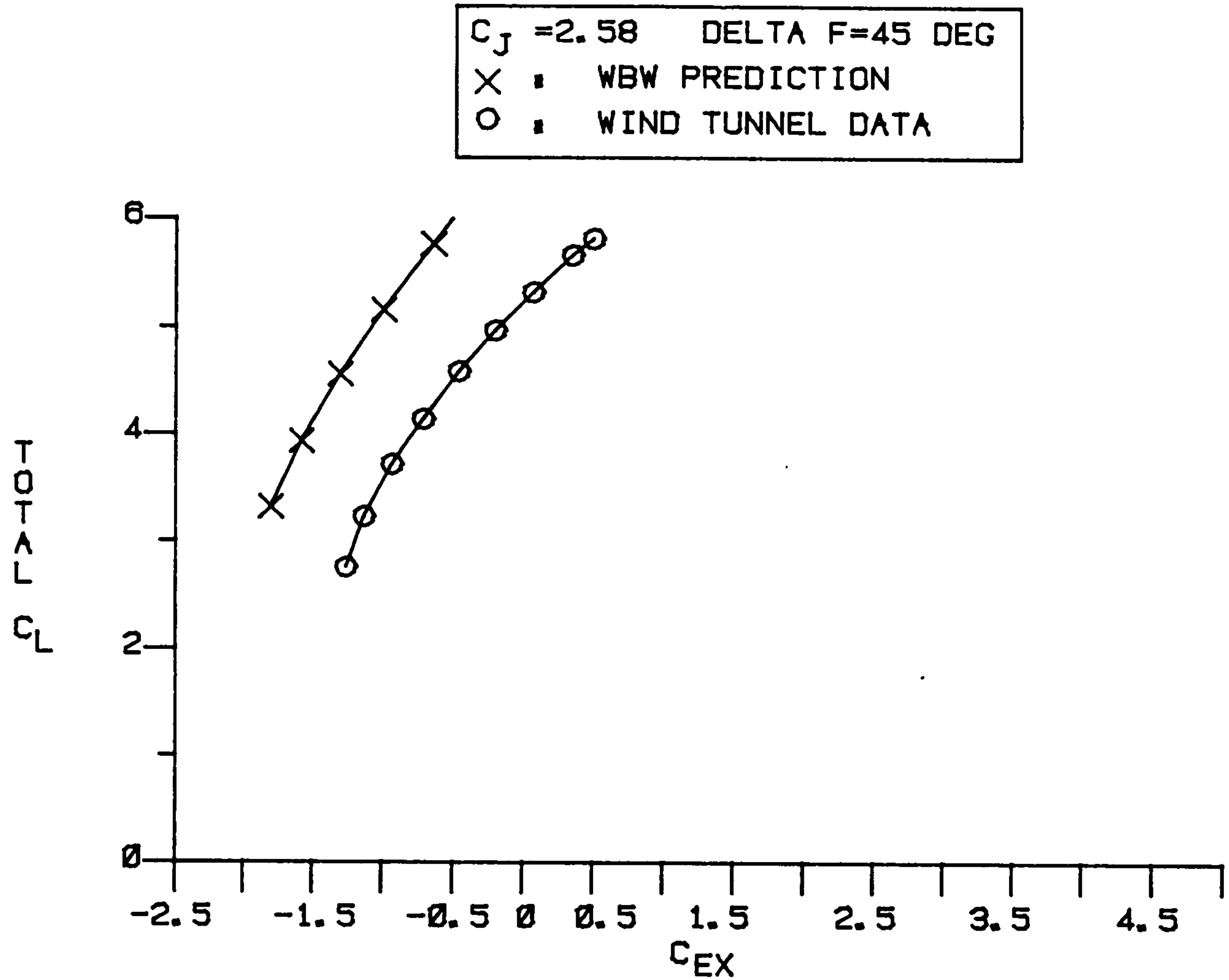

Figure 11. Lift Coefficient vs. Excess Thrust Coefficient for C_J = 2.58 and Flap Deflection of 45°.

affects the shape of the drag curve, especially at the higher C_L values. In examining the C_L equation,

$$C_L = F\{[1 + \frac{t}{c}][\lambda\theta(\frac{\partial C_L}{\partial \theta})_\infty + \nu\alpha\ (\frac{\partial C_L}{\partial \alpha})_\infty]\} - \frac{t}{c}\ C_J(\theta+\alpha), \tag{18}$$

it can be seen that for each flap deflection there exists a correction in the lift equation which directly modifies the C_L prediction (i.e., there exists one C_L vs. α curve for each C_J that is linear).

In the excess thrust equation,

$$C_{EX} = rC_J - \frac{KC_L^2}{(\pi AR + 2C_J)} - C_{D_o} - \Delta C_{D_P}, \tag{19}$$

there is no direct correction for flap deflection. It is not a linear function since C_L is squared in the excess thrust equation. The only significant effect on the C_L vs. C_{EX} plot is the rC_J portion of the equation. The WBW paper did suggest that one portion of r was a loss due to the turning of the jet sheet from the flap surface (i.e. separation from the flap surface).

CHAPTER IV

DISCUSSION

The purpose of this thesis was to evaluate the validity and then develop a reliable method for predicting lift and drag for USB wings and compare them with Jetwing data. By using the work of WBW and using physical parameters particular to the Jetwing, it was possible to arrive at a set of equations that work for the Jetwing.

Computer Methodology

The WBW prediction method is easily applied to the set of coupled equations given as a function of sigma (σ) and tau (τ). Coupled equations are difficult to solve since each variable is dependent on the other and the equations cannot be separated into one equation having only one of the variables in it.

$$\sigma = \frac{(1 - \tau)(C_J/\pi AR)}{\tau - (1 - \tau)(C_J/\pi AR)} \qquad (20)$$

and

$$\tau = \frac{2(C_L)_\infty/(\theta + \alpha)}{\pi\ AR + 2\ (\frac{\partial C_L}{\partial \alpha}) - 2\pi(1 + \sigma)}. \qquad (21)$$

These otherwise exhaustible equations can be solved quite easily using computer optimization techniques. One such method developed by Sheela and Ramamoorthy [16] called Sequential Weight Increasing Factor Technique (SWIFT) was used in the computer program to solve for σ and consequently for F and finally for the lift on a jet flapped wing, C_L.

Williams, Butler, and Wood Results and Discussion

Using the steps outlined in Appendix A, one can arrive at values of C_L for the Jetwing. The results are shown in Figures 12-19.

One would expect adequate approximations using the WBW method since all of the assumptions have been made using linearized, inviscid flow theory. For a conventional airplane; that is, $C_J = 0$, for a given flight configuration and Reynolds number, there exists only one C_L for a given α. For the Jetwing, or powered-lift airplane, there is one C_L vs. α curve for each C_J. This fact complicates calculation of C_L and C_D. It is noted here that for USB, $C_D = f(\alpha, C_J)$, so that again conventional methods must be altered.

In calculating C_L vs. α plots for the Jetwing using the WBW method, it is readily seen that the method does not account for separated flow. The plot only lends itself to Jetwing C_L vs. α plots for values of α below where separation occurs. Ideally, with the equations in Appendix A, one could never stall if the blowing coefficient was high enough. There are, of course, limitations such as engine output and structural capability.

The wind tunnel data for the Jetwing was taken at the flap trailing edge, which, in our case, was fortunate since this includes losses due to shear and normal forces. The value for C_J in the WBW method then can be used directly, with no corrections applied.

In the calculation of C_{EX}, the r-factor not only seems to be related to flap deflection, but in the case of the Jetwing, seems to

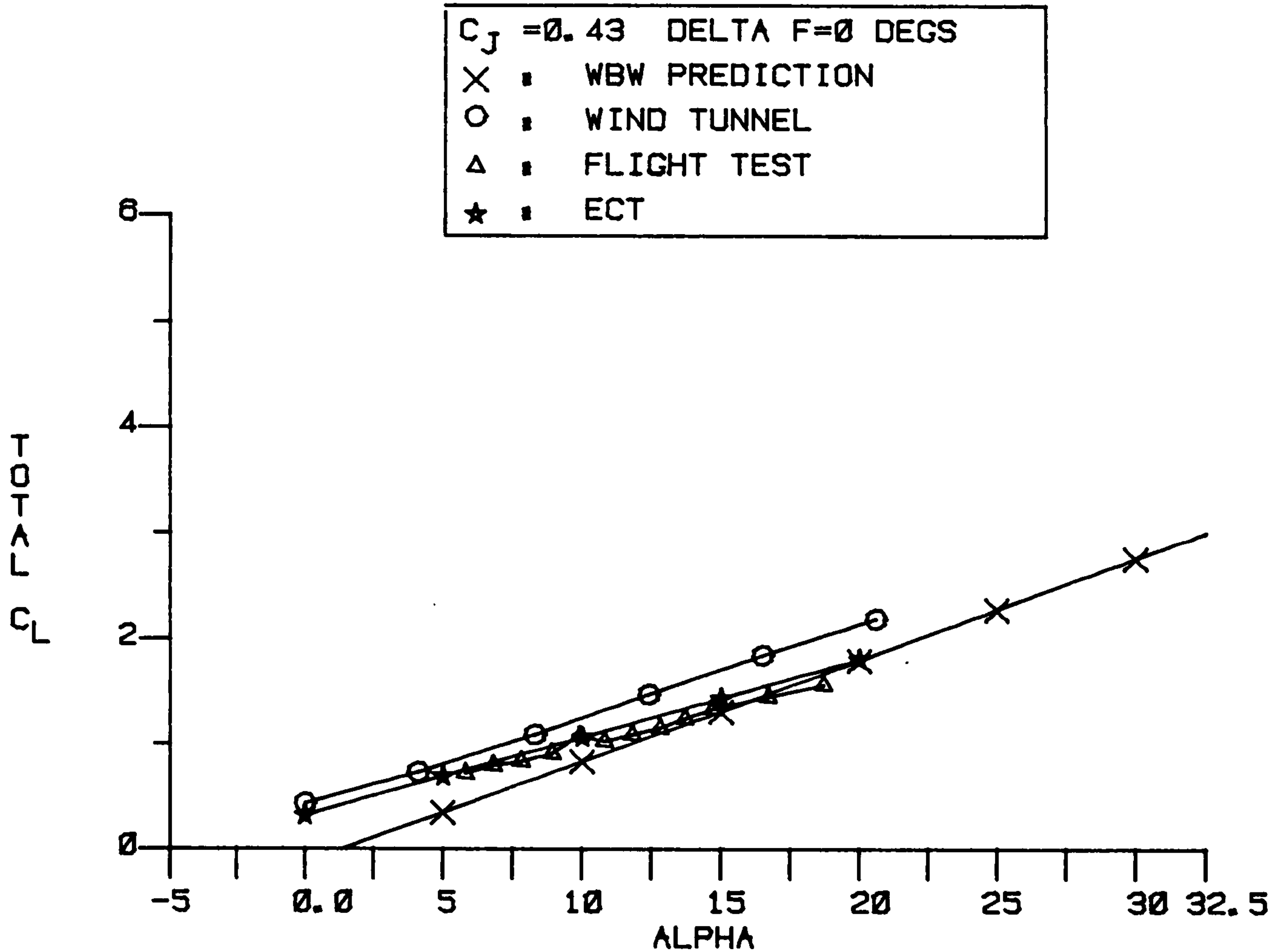

Figure 12. Lift Coefficient vs. Angle of Attack for C_J = 0.43 and Flap Deflection of 0°.

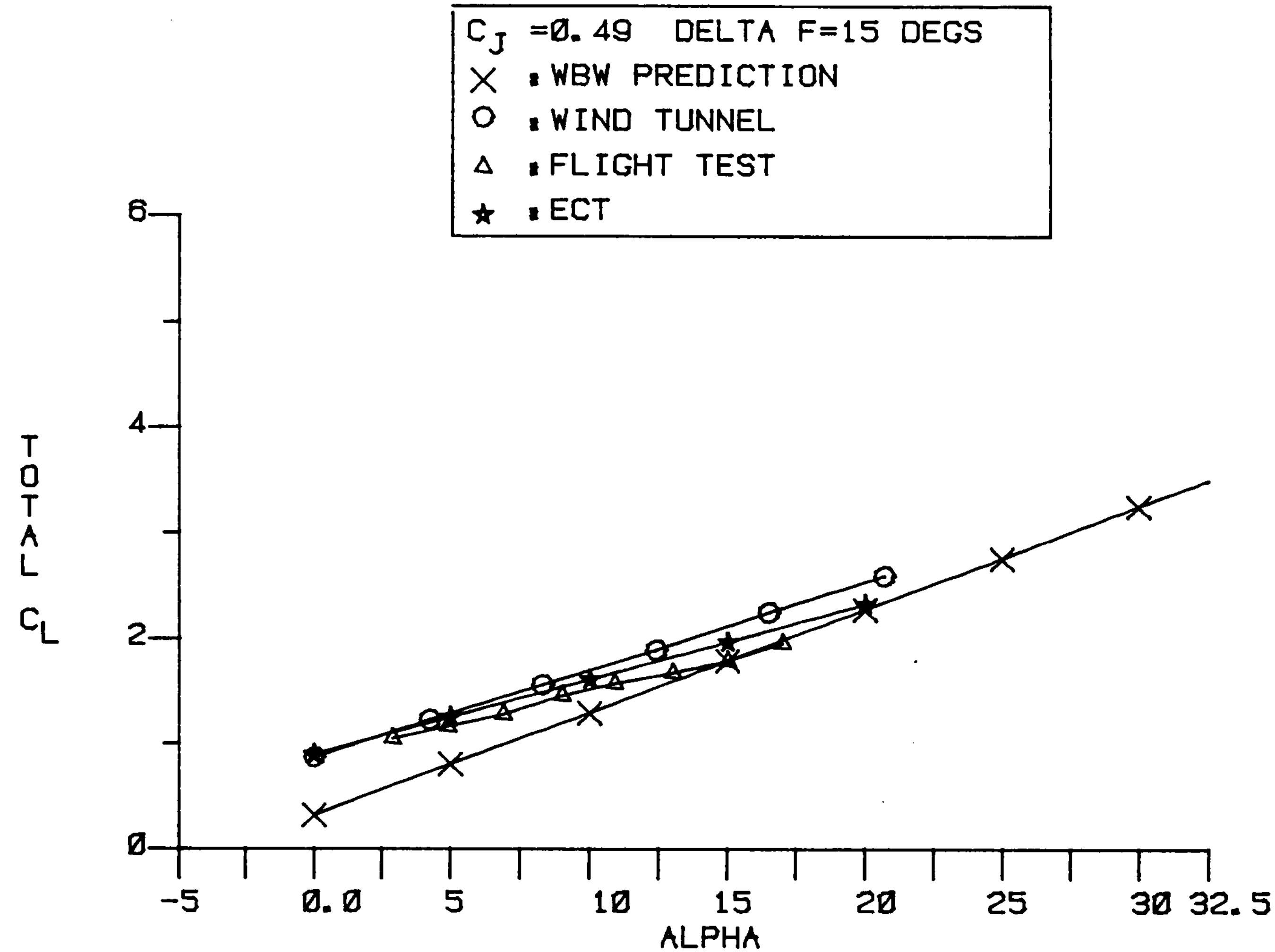

Figure 13. Lift Coefficient vs. Angle of Attack for C_J = 0.49 and Flap Deflection of 15°.

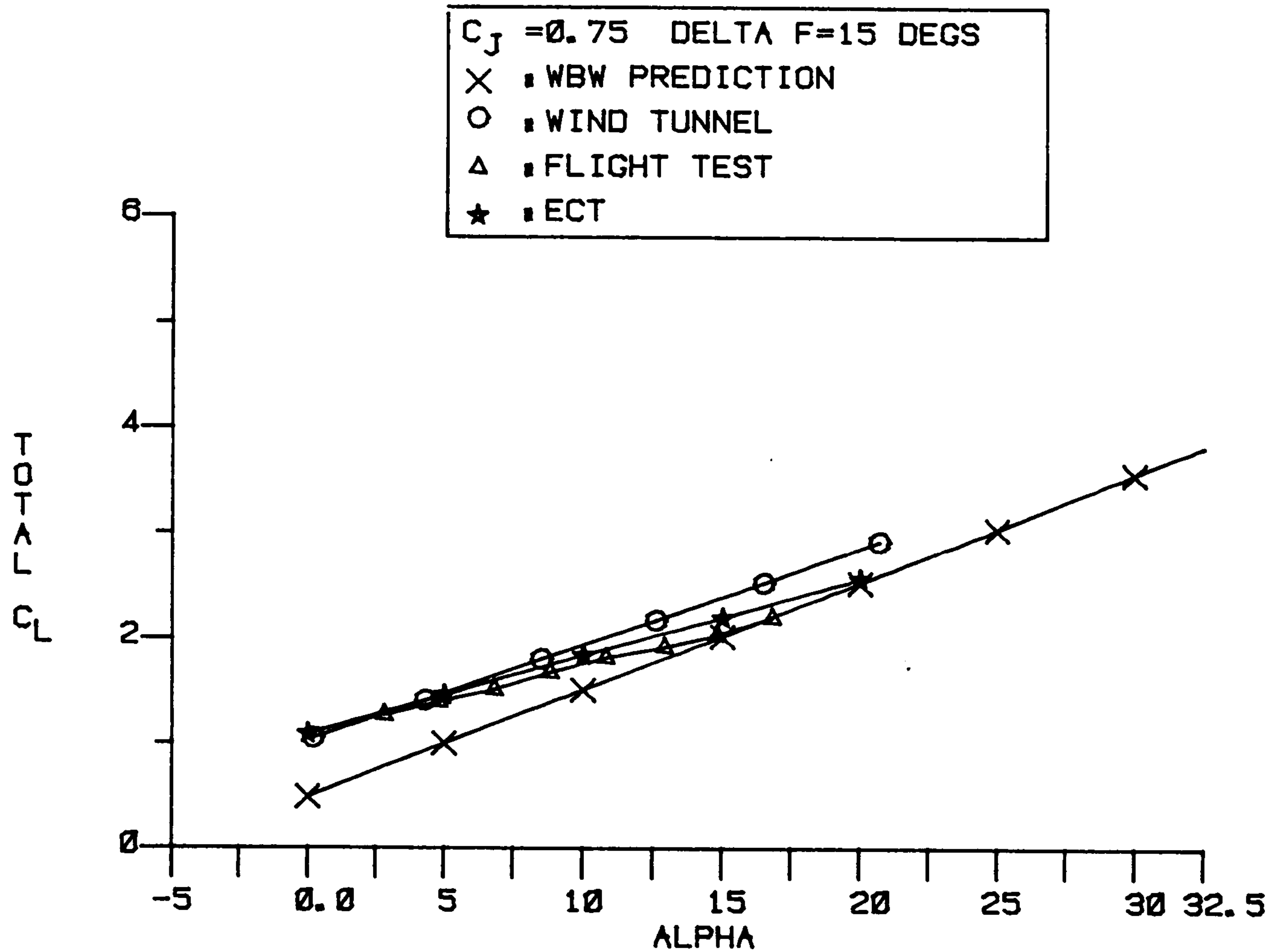

Figure 14. Lift Coefficient vs. Angle of Attack for C_J = 0.75 and Flap Deflection of 15°.

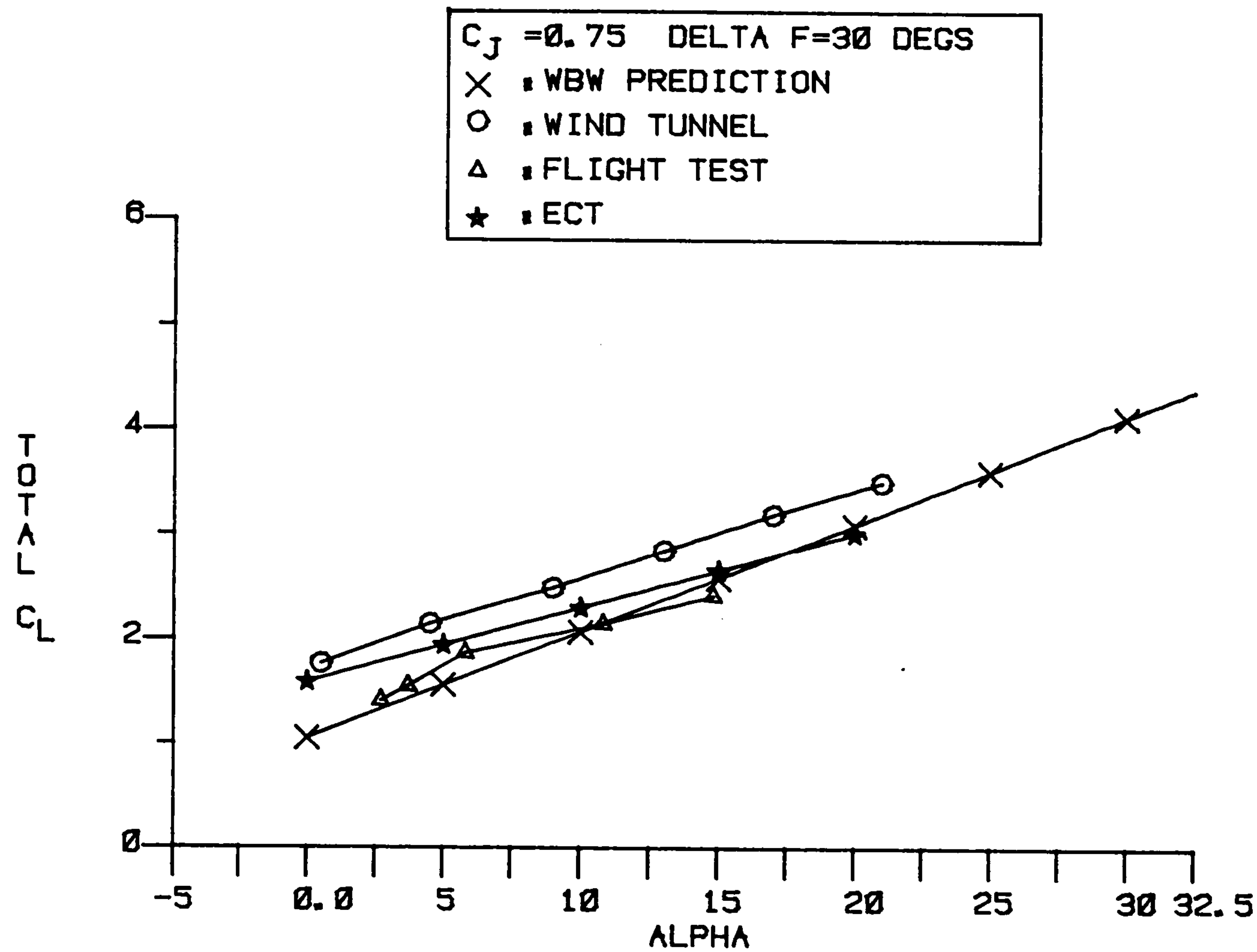

Figure 15. Lift Coefficient vs. Angle of Attack for C_J = 0.75 and Flap Deflection of 30°.

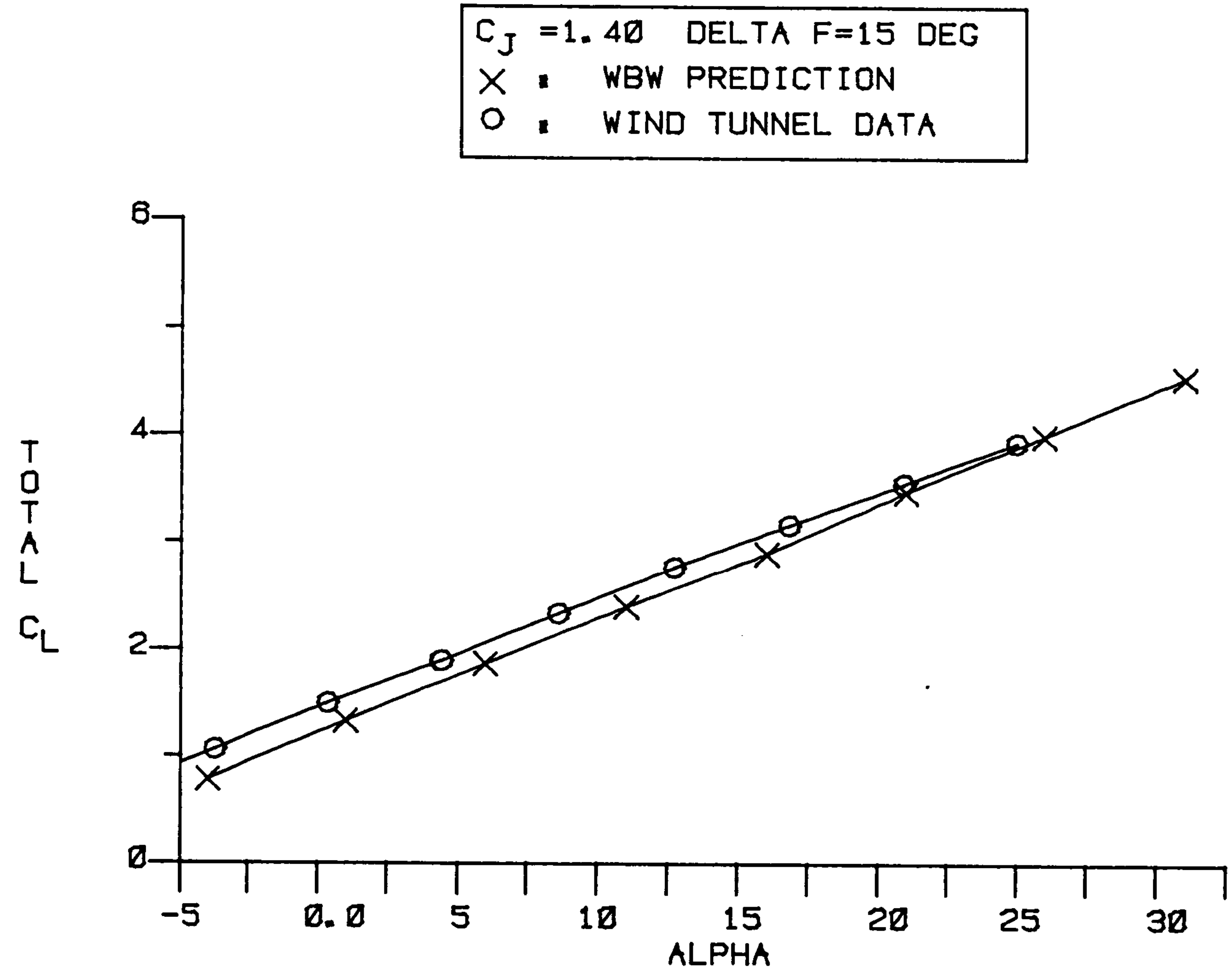

Figure 16. Lift Coefficient vs. Angle of Attack for C_J = 1.40 and Flap Deflection of 15°.

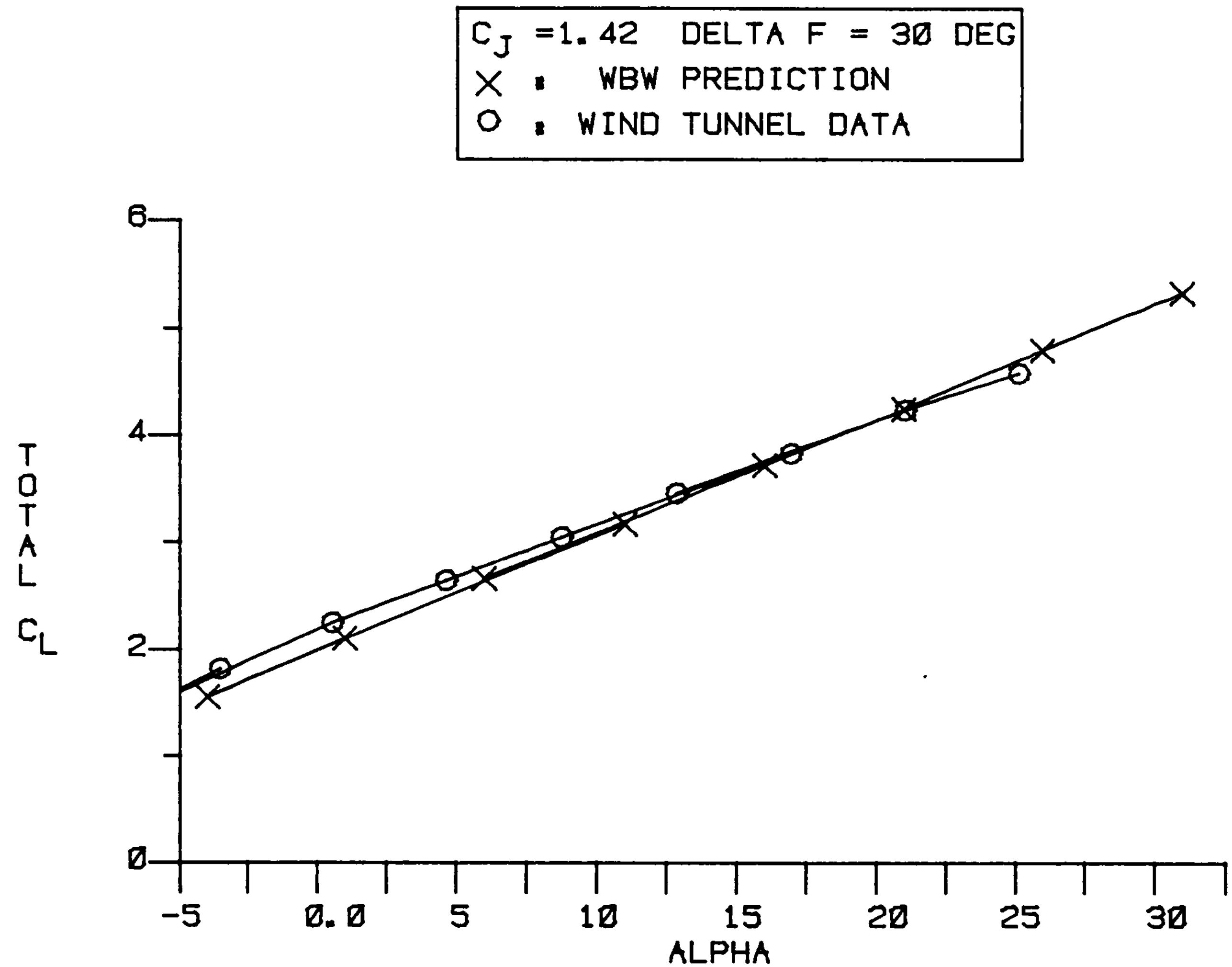

Figure 17. Lift Coefficient vs. Angle of Attack for C_J = 1.42 and Flap Deflection of 30°.

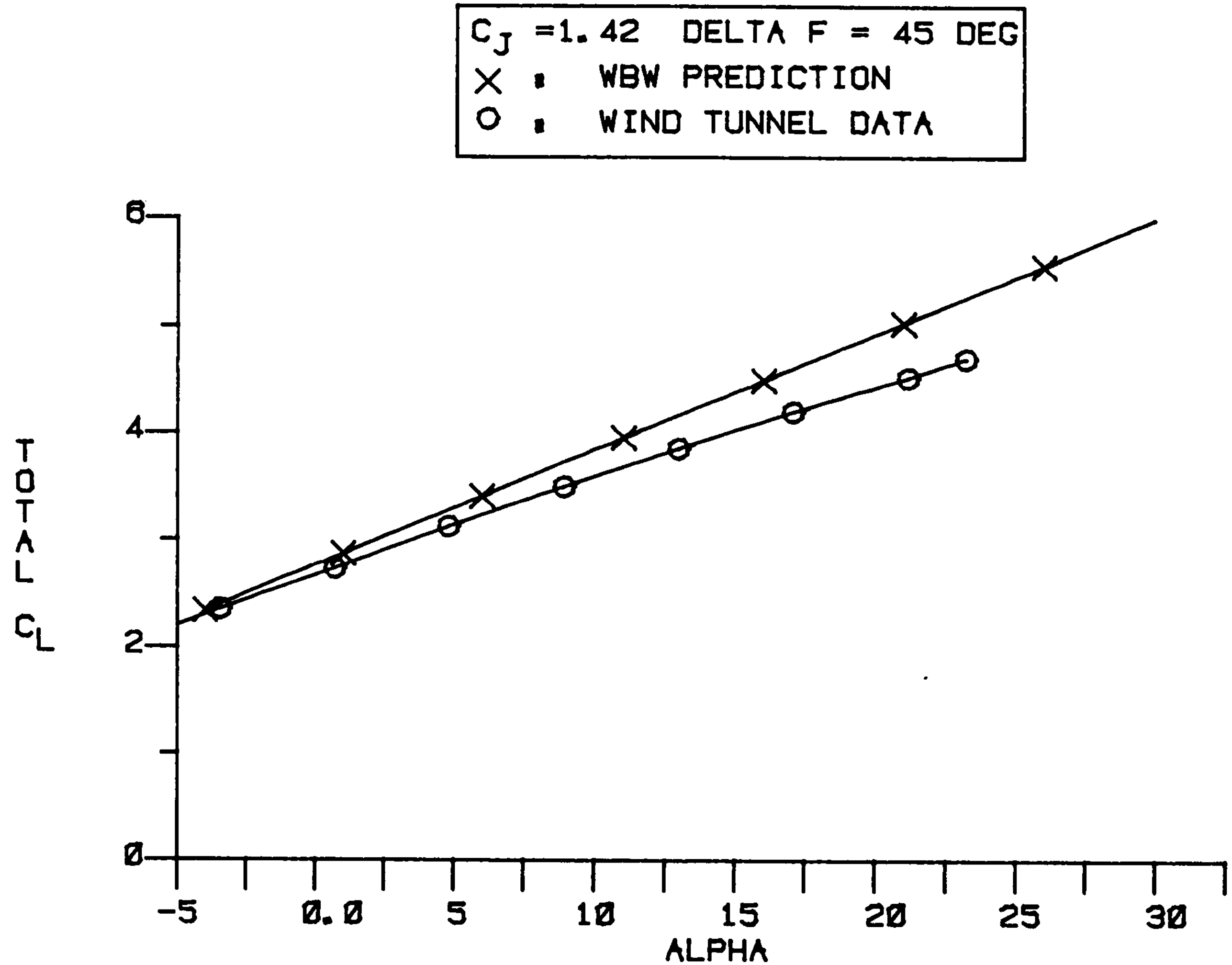

Figure 18. Lift Coefficient vs. Angle of Attack for C_J = 1.42 and Flap Deflection of 45°.

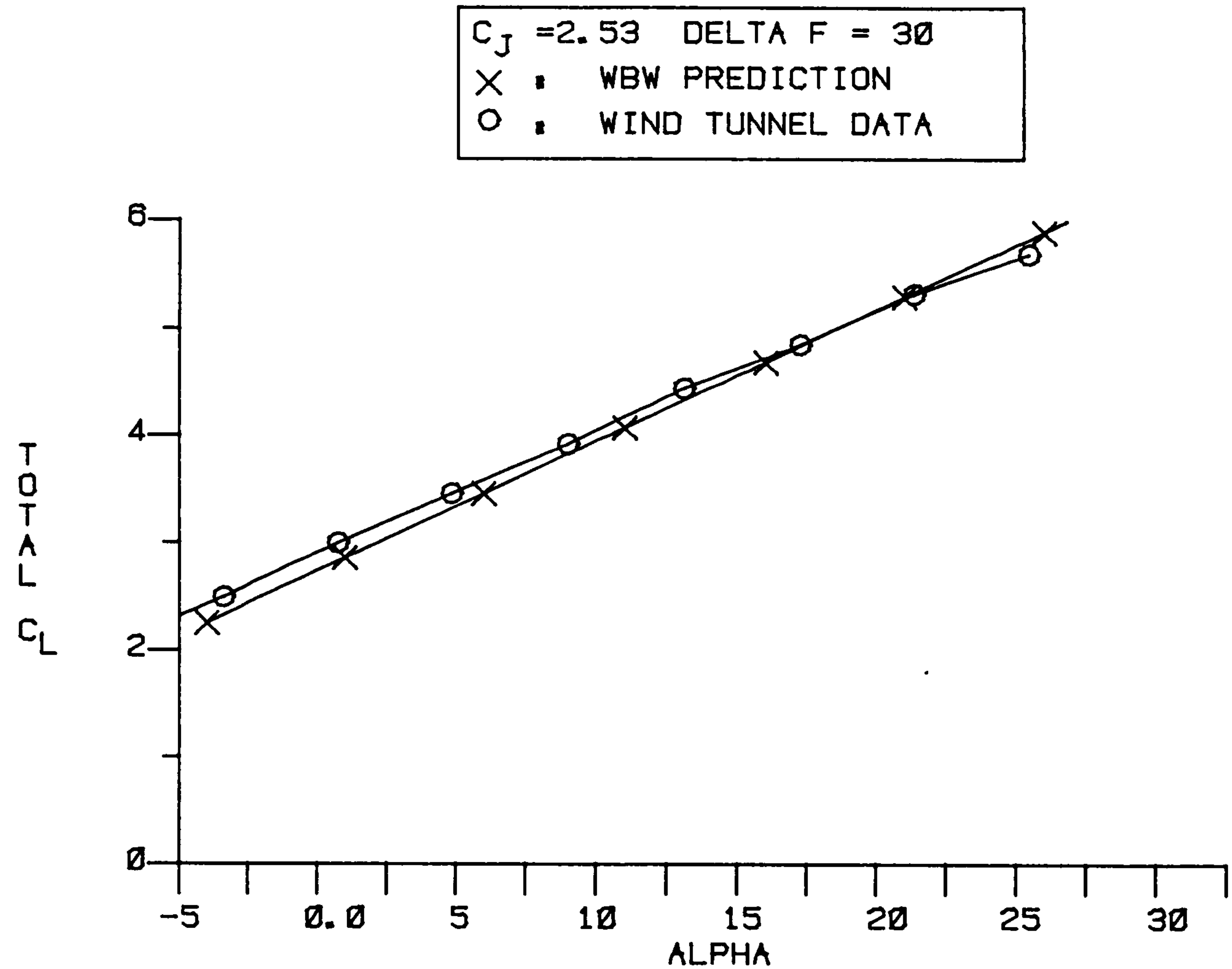

Figure 19. Lift Coefficient vs. Angle of Attack for C_J = 2.53 and Flap Deflection of 30°.

be a function of flap deflection. A good assumption is that at a given C_J and no flap deflection r can be given a unity value since C_J was taken in the wind tunnel at the flap trailing edge. As the flap is deflected there are momentum losses due to separation, boundary layer growth and scrubbing drag.

If r = 1 at zero flap deflection, then as the flap is deflected the thrust factor then becomes the horizontal component of the thrust, or $r = \cos\theta$. In looking at the wind tunnel data as compared to the WBW data at higher flap deflections it was increasingly evident that $C_{EX} = f(\theta)$. An example of using r as unity was shown in Figures 12-19. Using a correction for ram drag in Figures 20, 21 and 22 illustrates that correcting for ram drag alone does not enhance the WBW prediction except at small flap deflections. If $r = \cos\theta$ is used to modify the C_{EX} equation, it is clearly seen in Figures 23, 24 and 25 that the modified prediction is a good one.

In reading the papers of Gates, Maskell and Spence [7,8,9] it is readily seen that the simple vector approximation does not explain the physics of the problem. The author considers this a worthwhile endeavor but beyond the scope of this thesis. The r-factor in the simple identity is that portion of unity which can be used in the C_{EX} equation. Figures 23, 24 and 25 reflect the applied assumption for r. These figures show good agreement between the wind tunnel data and the prediction method as modified by $r = \cos\theta$.

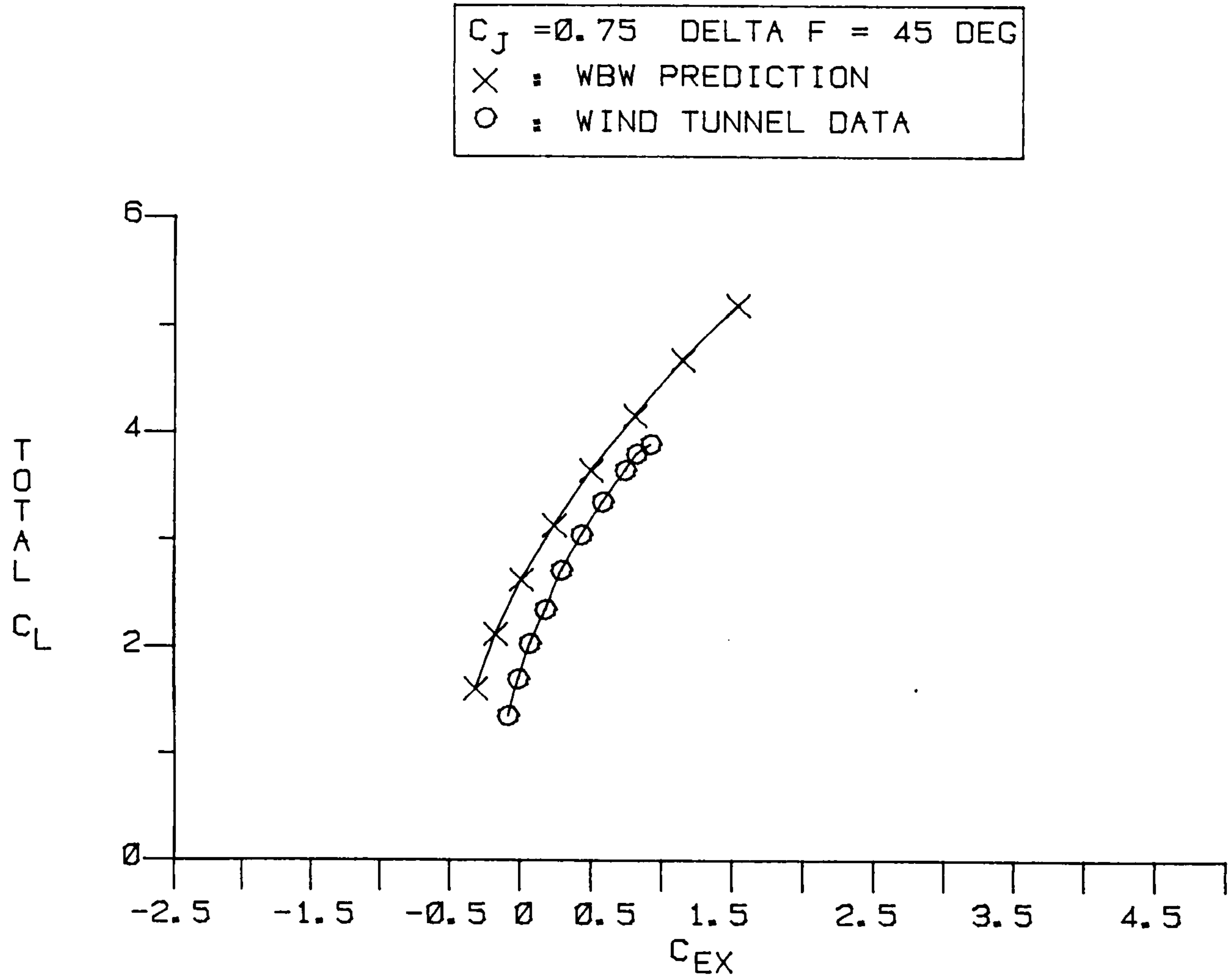

Figure 20. Typical Plot of C_L vs. C_{EX} for a Low Blowing Coefficient and High Angle of Attack With Ram Drag Correction Only.

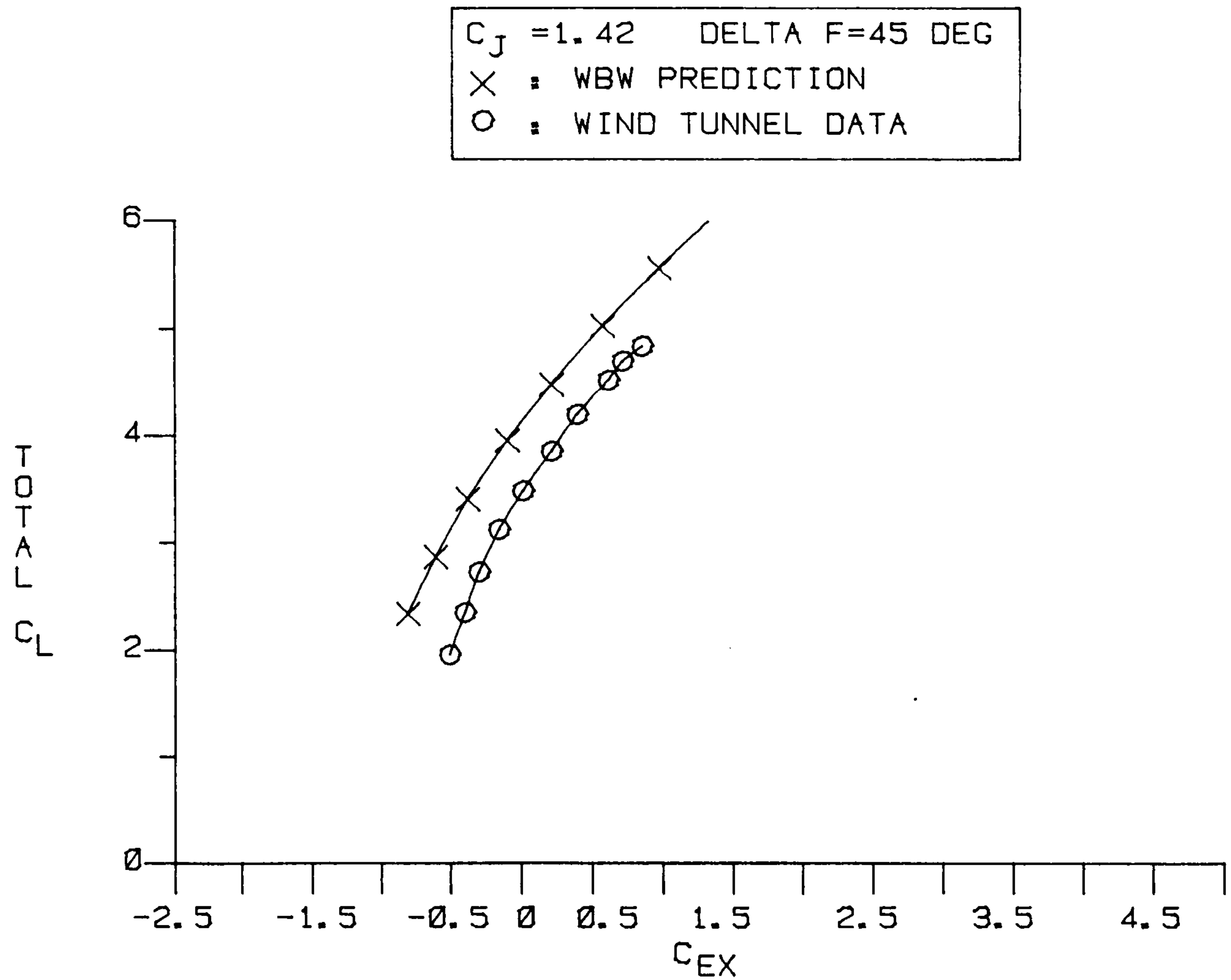

Figure 21. Typical Plot of C_L vs. C_{EX} for a Middle Range Blowing Coefficient and High Angle of Attack With Ram Drag Correction Only.

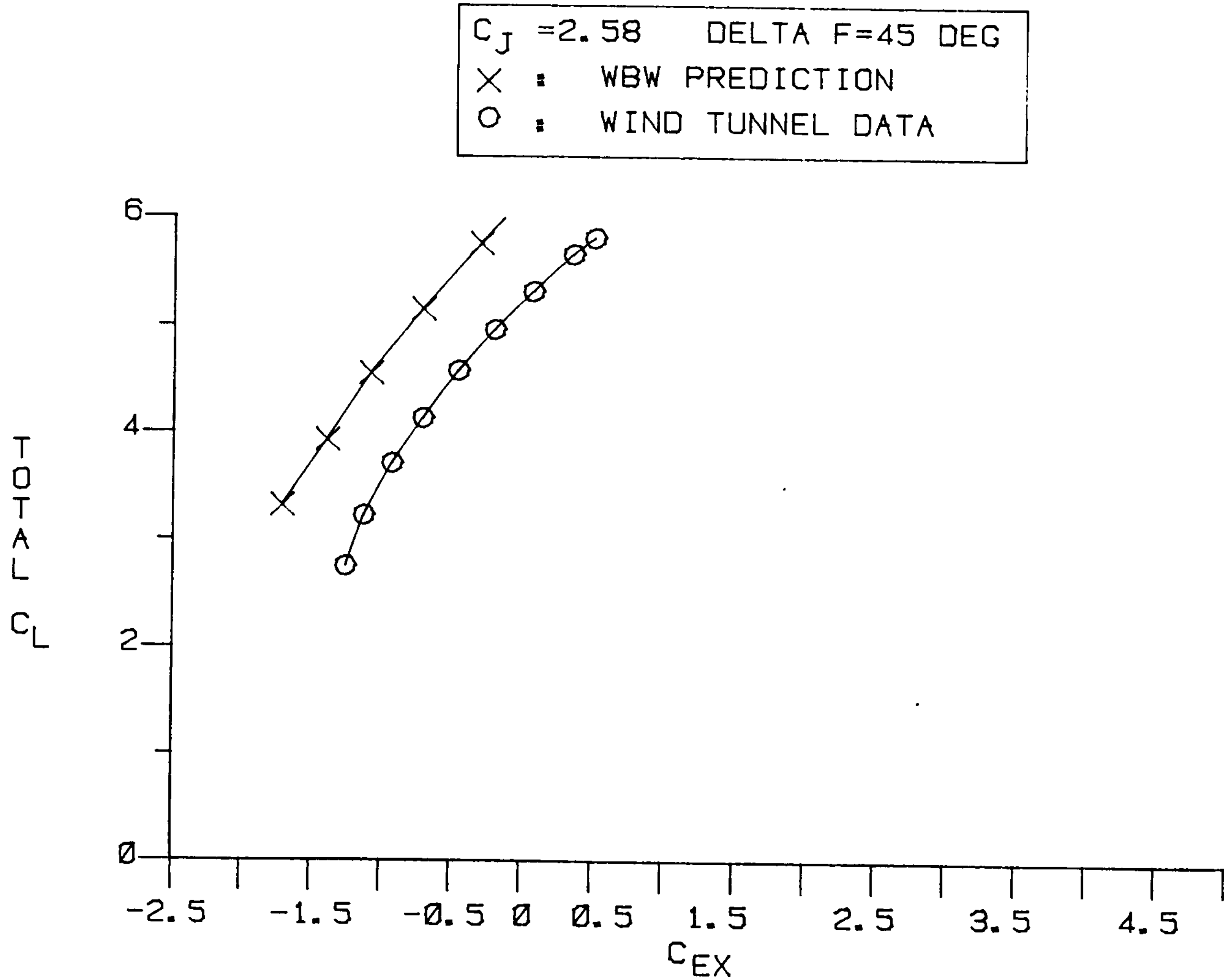

Figure 22. Typical Plot of C_L vs. C_{EX} for a High Blowing Coefficient and a High Angle of Attack With Ram Drag Correction Only.

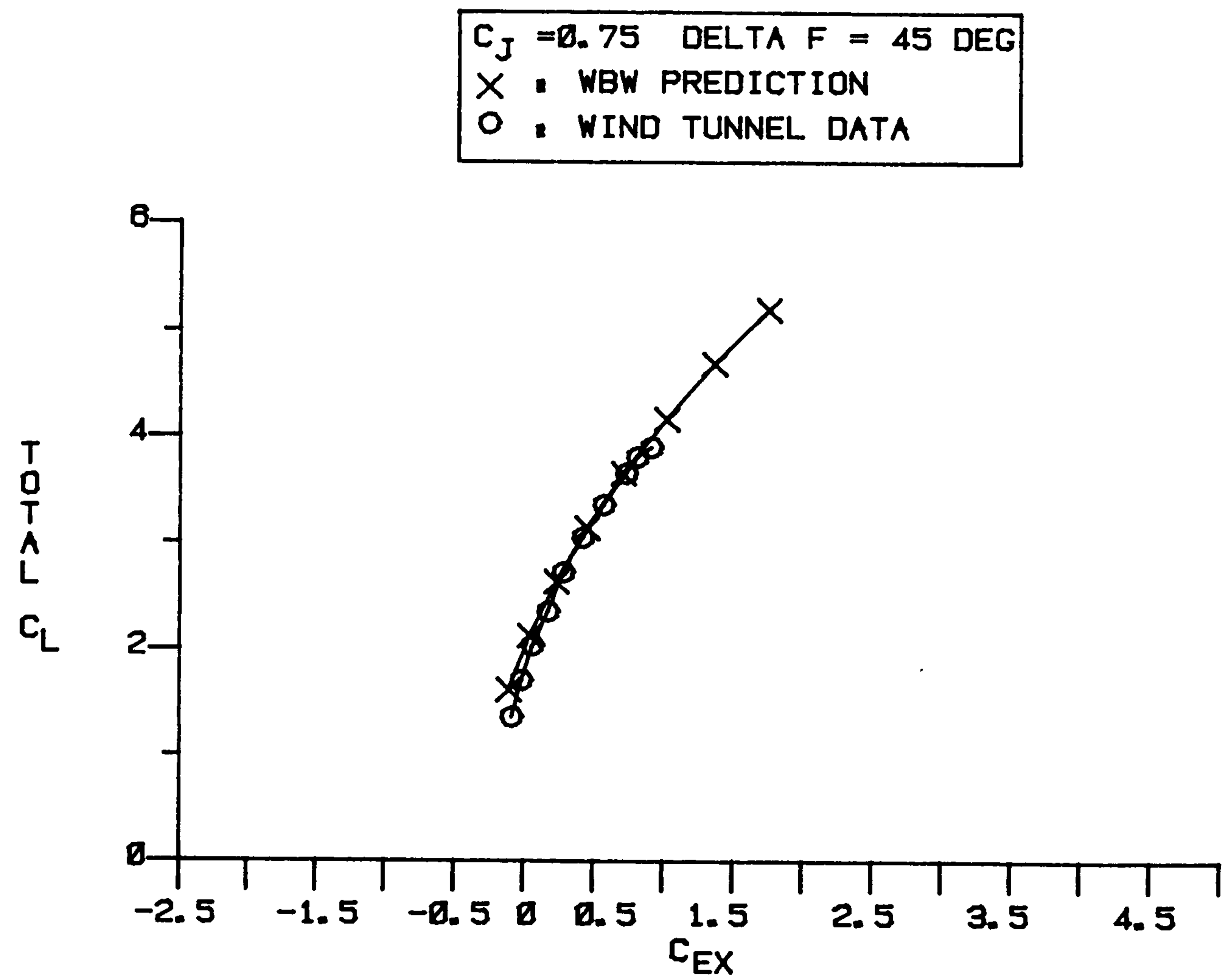

Figure 23. C_L vs. C_{EX} with r = Cos 45° and C_J = 0.75.

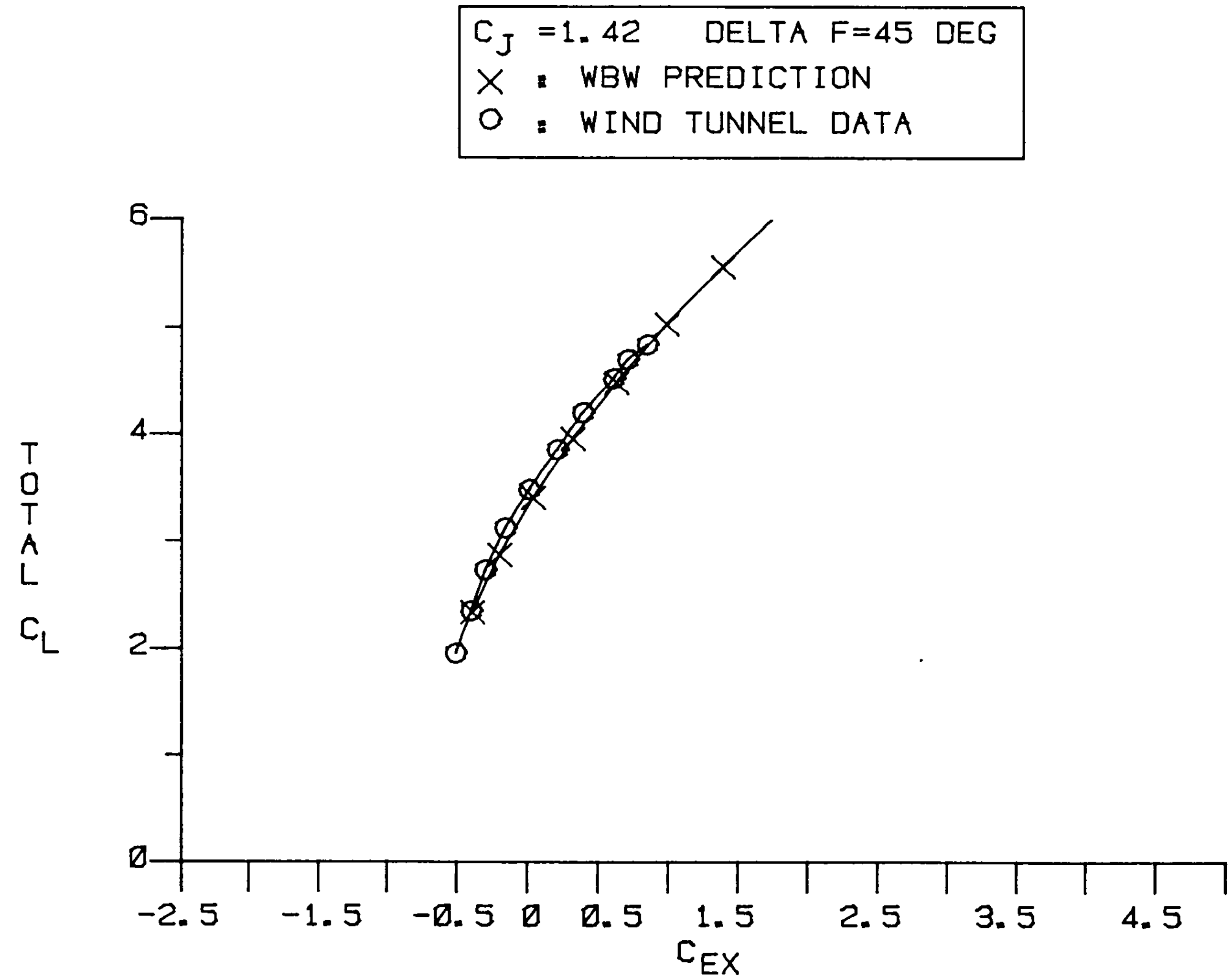

Figure 24. C_L vs. C_{EX} with r = Cos 45° and C_J = 1.42.

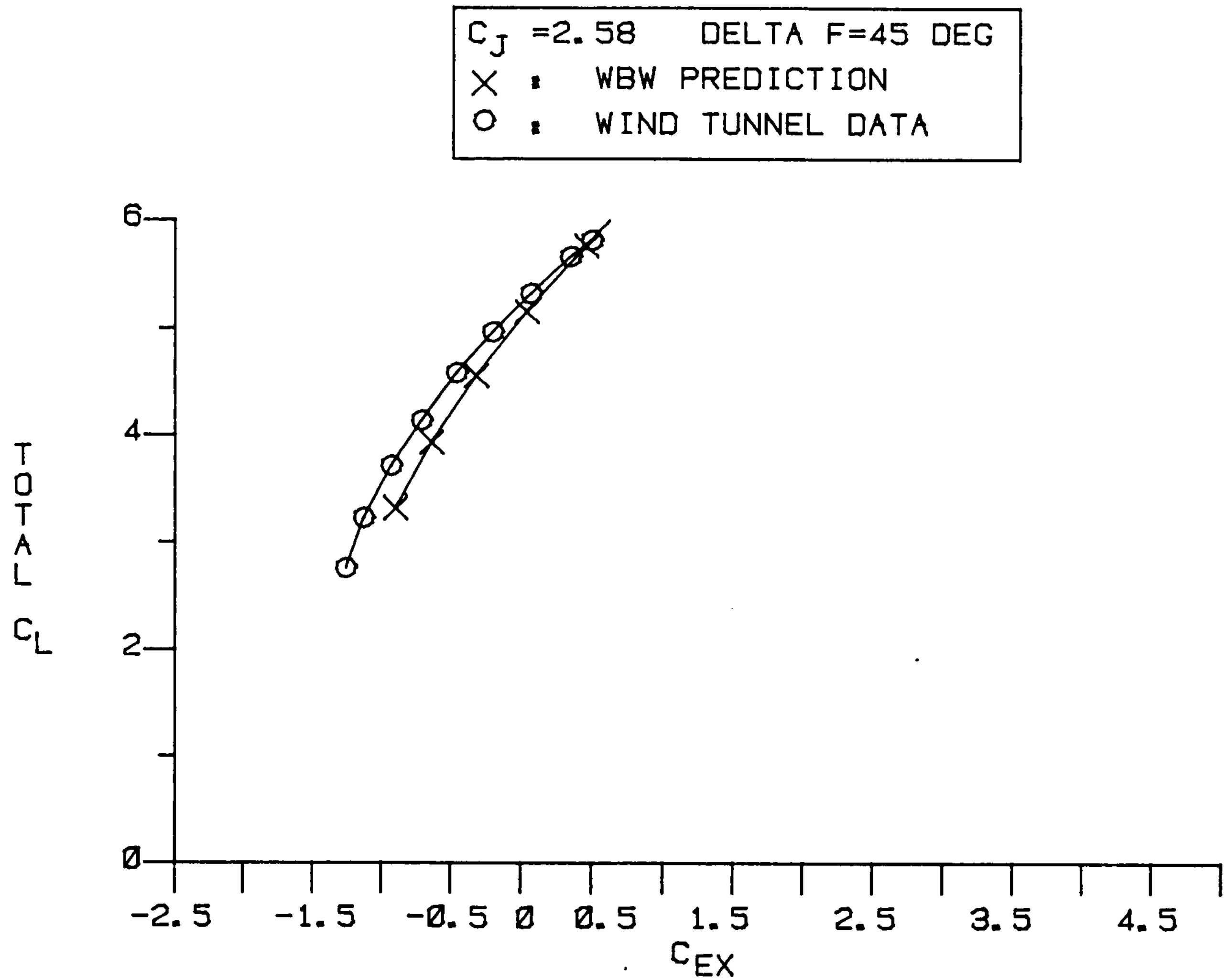

Figure 25. C_L vs. C_{EX} with r = Cos 45° and C_J = 2.58.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The plots for C_L vs. α developed using the WBW method show good agreement with wind tunnel data, flight test data and equivalent flap theory for the Jetwing aircraft.
2. The unmodified WBW method tends to over-predict the C_L vs. C_{EX} plot for wind tunnel and flight test data, primarily due to the lack of flap deflection and ram drag term.
3. The shape of the C_L vs. C_{EX} curve is affected by the K-factor. Using $K < 1$ tends to "straighten" out the WBW prediction, especially with higher blowing coefficients (C_J) and flap deflections (θ).
4. Spence's and Maskell's work, which was the basis of the WBW method, is sound theoretically in relation to the Jetwing comparisons.
5. The thrust factor (r) is a direct correction for C_{EX} (in relation to the Jetwing) for a three dimensional finite aspect ratio approximation, and a first approximation of its value appears to be the cosine of the flap deflection angle.

Recommendations

1. The WBW method should be applied to other aircraft (e.g., the H.126, YC-14 or QSRA) for additional substantiation.

2. The ram drag term is quantifiable and should be included in the WBW formulation for any future use.

3. The r-factor and K-factor should be investigated if the WBW method is used beyond the preliminary design stage.

4. The Jetwing tail stall problem must be corrected in order to allow higher blowing coefficients and flap deflections and consequently investigations of this type.

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LIST OF REFERENCES

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APPENDIXES

APPENDIX A

ALGEBRAIC STEPS FOR WBW PREDICTION METHOD

The equations seen below are the steps algebraically taken to arrive at C_L for finite AR wing using the Williams, Butler and Wood prediction method.

(1) Calculate C_J'

$$C_J' = C_J(S/S')$$

$$S = 105\ ft^2$$

$$S' = 77\ ft^2$$

(2) Calculate $\partial C_L/\partial\theta$ and $\partial C_L/\partial\alpha$

$$\partial C_L/\partial\theta = [4\pi C_J'(1 + 0.151\ C_J'^{1/2} + 0.139C_J')]^{1/2}$$

$$\partial C_L/\partial\alpha = 2\pi(1 + 0.151\ C_J'^{1/2} + 0.219C_J')$$

(3) Calculate F, factor for finite AR wing.

$$F = \frac{AR + (2C_J/\pi)}{AR + 2 + 0.604\ (C_J^{1/2}) + 0.876C_J} \quad \text{for } C_J<1$$

(4) Calculate λ and ν, lift increment corrections due to part-span flaps and fuselage cut-out.

$$\lambda = S'/S$$

$$\nu = \frac{S'(\partial C_L/\partial\alpha) + (S - S')(\partial C_L/\partial\alpha)}{\Sigma[\partial C_L/\partial\alpha)}$$

at $C_J = 0$; $(\partial C_L/\partial\alpha) = 5.79$ for Jetwing from 23015 C_L vs. α airfoil plot.

(5) Substitute appropriate quantities

$$C_L = F[(1 + t/c)\{\lambda\theta(\partial C_L/\partial\theta) + \nu\alpha(\partial C_L/\partial\alpha)\}] - (t/c)C_J(\theta + \alpha)$$

$$\text{use } F = \frac{AR + 2C_J/\pi}{AR + 2/\pi(\partial C_L/\partial\alpha) - 2(1 + \sigma)}$$

where

$$\sigma = \frac{(1 - \tau)(C_J/\pi AR)}{\tau - (1 - \tau)(C_J/\pi AR)}$$

and

$$\tau = \frac{2(C_L)_{2D}/(\theta + \alpha)}{\pi AR + 2(\partial C_L/\partial\alpha) - 2\pi(1 + \sigma)}$$

also

$$(C_L)_{2D} = \theta(\delta C_L/\delta\theta) + \alpha(\delta C_L/\delta\alpha).$$

For each C_J there are nine (9) different values of sigma (σ), consequently there are nine (9) different values of F, which contain corrections related to conversions of 2-DC_L into 3-DC_L. F is a function of only AR and C_J. This can be done for constant values of C_J varying only α.

APPENDIX B

USE AND LISTING OF FORTRAN PROGRAMS

Use of FORTRAN Program

The FORTRAN code listed is for calculation of total C_L and C_{EX} for WBW method. In this code called JETWING.FOR, are also the subroutines for σ and τ. JETWING.FOR prints to an output file called JET.OUT which contains all of the calculated parameters in Appendix A, and the necessary data for plotting C_L vs α and C_L vs. C_{EX}. When running JETWING.FOR on the VAX 11/780, for which it was written, one simply types RUN JETWING and hits return and then enters a blowing coefficient such as 2.5 and the solutions are printed to the output file JET.OUT.

This information is then entered into a data file called PLOT4.DAT with α or C_{EX} first, a space, and then the respective C_L. If only one curve per plot is desired use PLOT4.FOR and when the computer asks "How Many Points in Second Plot", just enter zero and continue, etc. The resulting plot will have only one curve.

The data and labeling must be entered in the manner shown in the FORTRAN plotting routine.

FORTRAN Program for WBW Prediction Method

```
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/AA/CMUX,A,THETAX,ALPHAX,DCLAX,CLX,PI
      DIMENSION R(14),X(14),ALPHA(10),THETA(10),CD0(5)
      DATA (CD0(I),I=1,4)/0.085D0,0.16D0,0.18D0,0.20D0/
      CALL ASSIGN(6,'DISK$DSK1:JET.OUT')
   10 FORMAT(/2X,130('*'))
   20 FORMAT(/5X,'CMU',6X,'ALPHA',5X,'THETA',5X,'DCLBYDA',15X,'CL',15X
     1,'ZETA',15X,'SIGMA',7X,'F',7X,'TOTAL CL',2X,'CFEX',/)
   30 FORMAT(2X,F4.2,7X,F6.2,4X,F6.2,2X,F10.6,12X,F8.4,9X,F9.5,10X,F9
     1.5,2X,F8.4,2X,F8.4,2X,F6.3)
   40 FORMAT(2X,130('-'))
      PI=3.1415927D0
      A=4.48D0
      S=105.6D0
      TBYC=0.18D0
      S1=77.D0
      EPS=1.0E-10
      R(1)=0.D0
      ACCEPT *,CMU
      WRITE(6,10)
      WRITE(6,20)
      WRITE(6,10)
      CMU1=CMU*S/S1
      DCLDTX=(4.D0*PI*CMU1*(1.D0+0.151D0*CMU1**0.5+0.139D0*CMU1))**0.5
      DCLAX=2.D0*PI*(1.D0+0.151D0*CMU1**0.5+0.219D0*CMU1)
      DO 100 J=1,8
      WRITE(6,40)
      ALPHA(J)=(J-2)*5.D0+1.D0
      DO 100 K=1,4
      ALPHAX=ALPHA(J)*PI/180.D0
      THETA(K)=(K-1)*15.D0+9.D0
      THETAX=THETA(K)*PI/180.D0
      CLX=THETAX*DCLDTX+ALPHAX*DCLAX
      CMUX=CMU
      IF(CMUX.LE.1.D0) GO TO 50
      CALL SWIFT(R,FMN,X,EPS)
      SIGMA=((1.D0-X(1))*CMU/(PI*A))/(X(1)-(1.D0-X(1))*CMU/(PI*A))
      F=(A+2.D0*CMUX/PI)/(A+2.D0*DCLAX/PI-2.D0*(1.D0+SIGMA))
      GO TO 60
   50 F=(A+2.D0*CMUX/PI)/(A+2.D0+0.604D0*DSQRT(CMUX)+0.876D0*CMUX)
   60 ANU=(S1*DCLAX+5.72958D0*(S-S1))/(S*DCLAX)
      ALAMDA=S1/S
      CL=F*(1.D0+TBYC)*(ALAMDA*THETAX*DCLDTX+ANU*ALPHAX*DCLAX)-TBYC*CMUX
     1*(THETAX+ALPHAX)
      CFEX=-CMUX+CD0(K)+CL**2/(PI*A+2.D0*CMUX)
      THETAX=THETAX*180.D0/PI
      ALPHAX=ALPHAX*180.D0/PI
      WRITE(6,30) CMUX,ALPHAX,THETAX,DCLAX,CLX,X(1),SIGMA,F,CL,CFEX
  100 CONTINUE
      WRITE(6,10)
      STOP
      END
      SUBROUTINE SWIFT(R,FMN,X,EPS)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION C(15),FN(15),R(14),X(14),P(15,15),F(15),PB(14),PS(14),PT
     1S(14),AA(15)
      COMMON/ELA/YI,FI,WAIT
      COMMON/GG/N,NX,K
      NOR=0
      N=1
```

```
      NX=N+1
      A=1.DØ
      B=Ø.5DØ
      G=2.ØDØ
      NFE=Ø
      K=Ø
      STEP=Ø.5DØ
      WAIT=1.ØDØ
  3ØØ FORMAT(8F1Ø.5)
   6Ø FORMAT(2X,'FUN VALUE',E2Ø.1Ø,/,(7(2X,F15.6)))
      CR=YI
      FNR=FI
      CALL START(P,R,STEP)
      DO 2 I=1,NX
      DO 3 J=1,N
    3 X(J)=P(I,J)
      CALL FUN(Z,X)
C     WRITE(6,6Ø) Z,(X(J),J=1,N)
      C(I)=YI
      FN(I)=FI
    2 F(I)=Z
      NFE=NFE+NX
      FMNO=1.ØE+3Ø
   5Ø CALL ZMAX(F,FMX,MX)
      CALL ZMIN(F,FMN,MN)
      DO 2ØØ J=1,N
      PB(J)=Ø.ØDØ
      DO 1ØØ I=1,NX
  1ØØ PB(J)=PB(J)+P(I,J)
      PB(J)=PB(J)-P(MX,J)
  2ØØ PB(J)=PB(J)/N
      DO 4 J=1,N
    4 PS(J)=(1+A)*PB(J)-A*(P(MX,J))
      CALL FUN(FPS,PS)
      NFE=NFE+1
      CPS=YI
      FNPS=FI
      IF(FPS.LT.FMN) GO TO 2Ø
      GO TO 7
   2Ø DO 6 J=1,N
    6 PTS(J)=G*PS(J)+(1-G)*PB(J)
      CALL FUN(FPTS,PTS)
      FNPTS=FI
      CPTS=YI
      NFE=NFE+1
      IF(FPTS.LT.FPS) GO TO 9
      GO TO 3Ø
    9 DO 8 J=1,N
    8 P(MX,J)=PTS(J)
      F(MX)=FPTS
      C(MX)=CPTS
      FN(MX)=FNPTS
      GO TO 17
   3Ø DO 1Ø J=1,N
   1Ø P(MX,J)=PS(J)
      F(MX)=FPS
      C(MX)=CPS
      FN(MX)=FNPS
      GO TO 17
    7 DO 5 I=1,NX
      IF(I.EQ.MX) GO TO 5
      IF(FPS.LE.F(I)) GO TO 3Ø
    5 CONTINUE
      IF(FPS.GT.FMX) GO TO 55
      DO 14 J=1,N
   14 P(MX,J)=PS(J)
   55 DO 13 J=1,N
   13 PTS(J)=B*P(MX,J)+(1-B)*PB(J)
```

```
      SUBROUTINE ZMAX(F,FMX,MX)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION F(15)
      COMMON/GG/N,NX,K
      FMX=F(1)
      MX=1
      DO 151 I=2,NX
      IF(F(I).LE.FMX) GO TO 151
      FMX=F(I)
      MX=I
  151 CONTINUE
      RETURN
      END
      SUBROUTINE ZMIN(F,FMN,MN)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION F(15)
      COMMON/GG/N,NX,K
      FMN=F(1)
      MN=1
      DO 153 I=2,NX
      IF(F(I).GE.FMN) GO TO 153
      FMN=F(I)
      MN=I
  153 CONTINUE
      RETURN
      END
      SUBROUTINE START(P,R,STEP)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION R(14),P(15,14)
      COMMON/GG/N,NX,K
      STEP1=(STEP/(N*SQRT(2.DØ)))*(SQRT(N+1.DØ)+N-1.DØ)
      STEP2=(STEP/(N*SQRT(2.DØ)))*(SQRT(N+1.DØ)-1.DØ)
      DO 5Ø1 J=1,N
  5Ø1 P(1,J)=Ø.ØDØ
      DO 5Ø2 I=2,NX
      DO 5Ø2 J=1,N
      P(I,J)=STEP2
      L=I-1
      P(I,L)=STEP1
  5Ø2 CONTINUE
      DO 5Ø3 I=1,NX
      DO 5Ø3 J=1,N
  5Ø3 P(I,J)=R(J)+P(I,J)
      RETURN
      END
      SUBROUTINE FUN(Z,ZX)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/AA/CMU,A,THETA,ALPHA,DCLA,CL,PI
      COMMON/ELA/YI,FI,WAIT
      COMMON/GG/NN,NX,KXX
      DIMENSION ZX(14),GC(1Ø)
   1Ø FORMAT(/5X,'X(1)=',F1Ø.6,/5X,'FUN=',F1Ø.6,/)
      IF(CMU.EQ.Ø.DØ) GO TO 5Ø
      P=1.DØ+((1.DØ-ZX(1))*CMU/(PI*A))/(ZX(1)-(1.DØ-ZX(1))*CMU/(PI*A))
      GO TO 51
   5Ø P=1.DØ
   51 F=ZX(1)*(PI*A+2.DØ*DCLA-2.DØ*PI*P)-2.DØ*CL/(THETA+ALPHA)
C     NIC=4
      YI=Ø.DØ
C     DO 1ØØ I=1,NIC
C     IF(GC(I).GE.Ø.DØ) GO TO 1ØØ
C     YI=YI-GC(I)
C 1ØØ CONTINUE
      FI=ABS(F)
      Z=FI+YI/WAIT
C     IF(KXX.EQ.1) WRITE(6,1Ø) ZX(1),Z
      RETURN
      END
```

```
      CALL FUN(FPTS,PTS)
      NFE=NFE+1
      CPTS=YI
      FNPTS=FI
      IF(FPTS.GT.FMX) GO TO 15
      DO 16 J=1,N
   16 P(MX,J)=PTS(J)
      F(MX)=FPTS
      C(MX)=CPTS
      FN(MX)=FNPTS
      GO TO 17
   15 DO 4Ø I=1,NX
      DO 4Ø J=1,N
   4Ø P(I,J)=(P(I,J)+P(MN,J))*Ø.5DØ
      DO 2Ø1 I=1,NX
      DO 2Ø2 J=1,N
  2Ø2 X(J)=P(I,J)
      CALL FUN(Z,X)
      FN(I)=FI
      C(I)=YI
  2Ø1 F(I)=Z
      NFE=NFE+NX
   17 CONTINUE
      CALL ZMIN(F,FMN,MN)
C     WRITE (6,25ØØ) NFE
C     WRITE (6,6Ø)FMN,(P(MN,J),J=1,N),C(MN)
      DO 2Ø5 J=1,N
      PB(J)=Ø.Ø
      DO 2Ø4 I=1,NX
  2Ø4 PB(J)=PB(J)+P(I,J)
  2Ø5 PB(J)=PB(J)/NX
      DIFF=FMNO-FMN
      DIFF=ABS(DIFF)
      FMNO=FMN
      IF(DIFF.EQ.Ø.ØDØ) GO TO 69
      NOR=Ø
      IF(DIFF.GT.EPS) GO TO 41
      GO TO 42
   69 NOR=NOR+1
      IF(NOR.GT.3Ø) GO TO 42
   41 BB=Ø.ØDØ
      DO 12 I=1,NX
      AA(I)=Ø.ØDØ
      DO 11 J=1,N
   11 AA(I)=AA(I)+(P(I,J)-PB(J))**2
      BB=BB+AA(I)
   12 CONTINUE
      THETA=SQRT(BB)/NX
      IF(THETA.GT.WAIT) GO TO 5Ø
      WAIT=THETA
      DO 21Ø I=1,NX
  21Ø F(I)=FN(I)+C(I)/WAIT
      GO TO 5Ø
   42 CONTINUE
   54 FORMAT(5X,'OPTIMAL SOLUTION')
 25ØØ FORMAT(2X,'NO. OF FUNCTION EVALUATIONS',I3)
      DO 58 J=1,N
   58 X(J)=P(MN,J)
      K=1
C     WRITE (6,54)
      CALL FUN(Z,X)
      RETURN
      END
```

FORTRAN Plotting Routine for Lift Coefficient vs. Angle of Attack

```
      DIMENSION XDATA1(25),YDATA1(25),XDATA2(25),YDATA2(25),
     $XDATA3(25),YDATA3(25),XDATA4(25),YDATA4(25),ATITLE(6)
      CHARACTER* 8Ø TITLE,ATITLE
      INTEGER STRING(8Ø)
      OPEN(UNIT=1,NAME='PLOT4.DAT',TYPE='OLD')

      CALL INITT(24ØØ)
      CALL BINITT

      TYPE*,'HOW MANY DATA POINTS FOR THE FIRST CURVE ?'
      ACCEPT*,IP
      TYPE*,' '
      TYPE*,'HOW MANY DATA POINTS FOR THE SECOND CURVE ?'
      ACCEPT*,JP
      TYPE*,' '
      TYPE*,'HOW MANY DATA POINTS FOR THE THIRD CURVE ?'
      ACCEPT*,KP
      TYPE*,' '
      TYPE*,'HOW MANY DATA POINTS FOR THE FOURTH CURVE ?'
      ACCEPT*,LP

      DO I = 1,IP
        READ(1,*)XDATA1(I),YDATA1(I)
      END DO

      DO J = 1,JP
        READ(1,*)XDATA2(J),YDATA2(J)
      END DO

      DO K = 1,KP
        READ(1,*)XDATA3(K),YDATA3(K)
      END DO

      DO L = 1,LP
        READ(1,*)XDATA4(L),YDATA4(L)
      END DO

      READ(1,5Ø) ATITLE(1)
      READ(1,5Ø) ATITLE(2)
      READ(1,5Ø) ATITLE(3)
      READ(1,5Ø) ATITLE(4)
      READ(1,5Ø,END=5) ATITLE(5)
 5Ø   FORMAT(A8Ø)

  5   CONTINUE
      CALL PLOTKK
      CALL TEKON
      CALL INITT(24ØØ)
      CALL BINITT
      CALL SLIMY(13Ø,6ØØ)
      CALL XFRM(2)
      CALL XLAB(Ø)
      CALL YFRM(2)
      CALL XTICS(15)
      CALL XMFRM(1)
      CALL NPTS(IP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL DLIMX(-2.5Ø,2.5Ø) ! THIS SETS THE X LIMITS
      CALL DLIMY(Ø.Ø, 5.ØØØØ)! THIS SETS THE Y LIMITS
      CALL SYMBL(2)
      CALL CHECK(XDATA1,YDATA1)
      CALL DSPLAY(XDATA1,YDATA1)
```

```
      CALL SYMBL(1)!
      CALL NPTS(JP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL CPLOT(XDATA2,YDATA2)

      CALL SYMBL(3)!
      CALL NPTS(KP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL CPLOT(XDATA3,YDATA3)

      CALL SYMBL(5)
      CALL NPTS(LP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL CPLOT(XDATA4,YDATA4)
***********************************************************************
****************** THIS SECTION PRINTS THE TITLES FOR THE PLOT ********
***********************************************************************

      CALL MOVABS(351,755)
      CALL DRWABS(785,755)
      CALL DRWABS(785,585)
      CALL DRWABS(351,585)
      CALL DRWABS(351,75Ø)

C      TITLE ='C  = Ø.75  Delta F = 21 Deg.'
      TITLE = ATITLE(1)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(36Ø,727)
      CALL HLABEL(3Ø,STRING)

      TITLE ='J'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(375,717)
      CALL HLABEL(1,STRING)

      CALL MOVABS(373,7ØØ)
      CALL SYMOUT(2,1.Ø)
C      TITLE =': W. B. W. PREDITION'
      TITLE = ATITLE(2)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,694)
      CALL HLABEL(2Ø,STRING)

      CALL MOVABS(373,673)
      CALL SYMOUT(1,1.Ø)
C      TITLE =': FLIGHT TEST DATA'
      TITLE = ATITLE(3)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,661)
      CALL HLABEL(2Ø,STRING)

      CALL MOVABS(373,636)
      CALL SYMOUT(3,1.Ø)
C      TITLE =': JET FLIGHT TEST DATA'
      TITLE = ATITLE(4)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,628)
      CALL HLABEL(23,STRING)

      CALL MOVABS(373,6Ø1)
      CALL SYMOUT(5,1.Ø)
C      TITLE =': JET WING EQUIVALENT CORD TH.
      TITLE = ATITLE(5)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,595)
      CALL HLABEL(3Ø,STRING)

      TITLE = 'TOTAL'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(33,44Ø)
      CALL VLABEL(5,STRING)
```

```
      TITLE = 'C'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(33,29Ø)
      CALL HLABEL(1,STRING)

      TITLE = 'L'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(48,28Ø)
      CALL HLABEL(1,STRING)

      TITLE = 'ALPHA'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(5ØØ,55)
      CALL HLABEL(5,STRING)

C      TITLE = 'C  VS. ALPHA FOR W.B.W. AND NASA AMES FLIGHT TEST DATA'
C      CALL CONVERT(TITLE,STRING)
C      CALL MOVABS(15Ø,2Ø)
C      CALL HLABEL(55,STRING)

C      TITLE = 'L'
C      CALL CONVERT(TITLE,STRING)
C      CALL MOVABS(165,13)
C      CALL HLABEL(1,STRING)

      TITLE = '-5      Ø.Ø'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(135,81)
      CALL HLABEL(12,STRING)

      TITLE = '5       1Ø'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(345,81)
      CALL HLABEL(12,STRING)

      TITLE = '15      2Ø'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(538,81)
      CALL HLABEL(12,STRING)

      TITLE = '25      3Ø'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(738,81)
      CALL HLABEL(12,STRING)

      TITLE = '32.5'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(885,81)
      CALL HLABEL(4,STRING)


C      CALL SCURSR(ICHAR,IX,IY)
C       CALL PNTABS(IX,IY)
C       WRITE(6,5ØØØ)IX,IY
C 5ØØØ  FORMAT(1X,'1X =',I3,'  1Y =',I3)
C       CALL SCURSR(ICHAR,IX,IY)
C       WRITE(6,5ØØØ)IX,IY
C 5ØØ1  FORMAT(1X,'2X =',I3,'  2Y =',I3)
**********************************************************************
**********************************************************************

      CLOSE(UNIT=1)
      CALL TINPUT(I)  ! THIS MAKES THE PROGRAM PAUSE UNTIL A RETURN
      CALL FINITT(Ø,Ø)   ! THIS CALL CLEARS THE MEMORY OF THE HP PLOTER.
  5ØØ END
***********************************************************************
*      SUBROUTINE TO CHANGE TITLE CHARACTERS INTO ASCII CODE          *
***********************************************************************
```

```
      SUBROUTINE CONVERT(TITLE,STRING)
      CHARACTER*8Ø TITLE
      INTEGER STRING(8Ø)
       DO I = 1,8Ø
        STRING(I) = ICHAR(TITLE(I:I))
        END DO
      RETURN
      END
************************************************************************
```

FORTRAN Plotting Routine for C_L vs C_{EX}

```
      DIMENSION XDATA1(25),YDATA1(25),XDATA2(25),YDATA2(25),
     $XDATA3(25),YDATA3(25),ATITLE(6)
      CHARACTER* 8Ø TITLE,ATITLE
      INTEGER STRING(8Ø)
      OPEN(UNIT=1,NAME='PLOT3.DAT',TYPE='OLD')

      CALL INITT(24ØØ)
      CALL BINITT

      TYPE*,'HOW MANY DATA POINTS FOR THE FIRST CURVE ?'
      ACCEPT*,JP
      TYPE*,' '
      TYPE*,'HOW MANY DATA POINTS FOR THE SECOND CURVE ?'
      ACCEPT*,IP
      TYPE*,' '
      TYPE*,'HOW MANY DATA POINTS FOR THE THIRD CURVE ?'
      ACCEPT*,KP

      DO I = 1,JP
        READ(1,*)XDATA1(I),YDATA1(I)
      END DO

      DO J = 1,IP
        READ(1,*)XDATA2(J),YDATA2(J)
      END DO

      DO J = 1,KP
        READ(1,*)XDATA3(J),YDATA3(J)
      END DO

      READ(1,5Ø) ATITLE(1)
      READ(1,5Ø) ATITLE(2)
      READ(1,5Ø) ATITLE(3)
      READ(1,5Ø,END=5) ATITLE(4)
   5Ø FORMAT(A8Ø)

    5 CONTINUE
      CALL PLOTKK
      CALL TEKON
      CALL INITT(24ØØ)
      CALL BINITT
      CALL SLIMY(13Ø,6ØØ)
      CALL XFRM(2)
      CALL XLAB(Ø)
      CALL YFRM(2)
      CALL XTICS(15)
      CALL XMFRM(1)
      CALL NPTS(JP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL DLIMX(-2.5Ø, 2.5) ! THIS SETS THE X LIMITS
      CALL DLIMY(Ø.Ø, 5.ØØØØ)! THIS SETS THE Y LIMITS
      CALL SYMBL(2)
      CALL CHECK(XDATA1,YDATA1)
      CALL DSPLAY(XDATA1,YDATA1)

      CALL SYMBL(1)!
      CALL LINE(-1)
      CALL NPTS(IP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL CPLOT(XDATA2,YDATA2)
      CALL LINE(-1)
```

```
      CALL SYMBL(3)!
      CALL NPTS(KP) ! THIS SET THE NUMBER OF DATA POINTS
      CALL CPLOT(XDATA3,YDATA3)

*****************************************************************************
****************** THIS SECTION PRINTS THE TITLES FOR THE PLOT *********
*****************************************************************************

      CALL MOVABS(351,755)
      CALL DRWABS(755,755)
      CALL DRWABS(755,62Ø)
      CALL DRWABS(351,62Ø)
      CALL DRWABS(351,75Ø)

C      TITLE ='C  = Ø.75  Delta F = 21 Deg.'
      TITLE = ATITLE(1)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(36Ø,727)
      CALL HLABEL(3Ø,STRING)

      TITLE ='J'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(375,717)
      CALL HLABEL(1,STRING)

      CALL MOVABS(373,7ØØ)
      CALL SYMOUT(2,1.Ø)
C      TITLE =': W. B. W. PREDITION'
      TITLE = ATITLE(2)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,694)
      CALL HLABEL(2Ø,STRING)

      CALL MOVABS(373,673)
      CALL SYMOUT(1,1.Ø)
C      TITLE =': FLIGHT TEST DATA'
      TITLE = ATITLE(3)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,661)
      CALL HLABEL(2Ø,STRING)

      CALL MOVABS(373,636)
      CALL SYMOUT(3,1.Ø)
C      TITLE =': JET FLIGHT TEST DATA'
      TITLE = ATITLE(4)
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(4Ø5,628)
      CALL HLABEL(23,STRING)

      TITLE = 'TOTAL'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(33,44Ø)
      CALL VLABEL(5,STRING)

      TITLE = 'C'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(33,29Ø)
      CALL HLABEL(1,STRING)

      TITLE = 'L'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(48,28Ø)
      CALL HLABEL(1,STRING)

      TITLE = 'C'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(5Ø5,55)
      CALL HLABEL(5,STRING)
```

```
      TITLE = 'EX'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(522,46)
      CALL HLABEL(5,STRING)

C       TITLE = 'C  VS. ALPHA FOR W.B.W. AND NASA AMES FLIGHT TEST DATA'
C       CALL CONVERT(TITLE,STRING)
C       CALL MOVABS(15Ø,2Ø)
C       CALL HLABEL(55,STRING)

C       TITLE = 'L'
C       CALL CONVERT(TITLE,STRING)
C       CALL MOVABS(165,13)
C       CALL HLABEL(1,STRING)

      TITLE = '-2.5   -1.5'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(117,81)
      CALL HLABEL(12,STRING)

      TITLE = '-Ø.5    Ø.5'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(317,81)
      CALL HLABEL(12,STRING)

      TITLE = ' Ø '
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(38Ø,81)
      CALL HLABEL(12,STRING)

      TITLE = ' 1.5    2.5'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(517,81)
      CALL HLABEL(12,STRING)

      TITLE = '3.5    4.5'
      CALL CONVERT(TITLE,STRING)
      CALL MOVABS(728,81)
      CALL HLABEL(12,STRING)

C     TITLE = 'Ø.4'
C     CALL CONVERT(TITLE,STRING)
C     CALL MOVABS(883,81)
C     CALL HLABEL(4,STRING)


C      CALL SCURSR(ICHAR,IX,IY)
C        CALL PNTABS(IX,IY)
C        WRITE(6,5ØØØ)IX,IY
C 5ØØØ   FORMAT(1X,'1X =',I3,'  1Y =',I3)
C        CALL SCURSR(ICHAR,IX,IY)
C        WRITE(6,5ØØØ)IX,IY
C 5ØØ1   FORMAT(1X,'2X =',I3,'  2Y =',I3)
************************************************************************
************************************************************************

      CLOSE(UNIT=1)
      CALL TINPUT(I)  ! THIS MAKES THE PROGRAM PAUSE UNTIL A RETURN
      CALL FINITT(Ø,Ø)   ! THIS CALL CLEARS THE MEMORY OF THE HP PLOTER.
  5ØØ END
************************************************************************
*       SUBROUTINE TO CHANGE TITLE CHARACTERS INTO ASCII CODE          *
************************************************************************
```

```
      SUBROUTINE CONVERT(TITLE,STRING)
      CHARACTER*8Ø TITLE
      INTEGER STRING(8Ø)
       DO I = 1,8Ø
        STRING(I) = ICHAR(TITLE(I:I))
        END DO
      RETURN
      END
************************************************************************
```

VITA

T. Patrick Lynch is a native Tennessean, born in Chattanooga and raised in Music City, USA, Nashville, Tennessee. He received his high school education at Father Ryan High School, Nashville, Tennessee and was graduated in 1967. Following high school, he attended The University of Tennessee in Knoxville, Tennessee, where he received a Bachelor of Science degree in Engineering Physics. He moved to Tullahoma, Tennessee in 1978 and worked for the Arnold Engineering Development Center and entered the Masters program at The University of Tennessee Space Institute.

He is married to the former Betty Wiggins of Nashville, Tennessee, and has three children, Kendall 7, Greer 4, and Michael 2.