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AN INTERACTIVE COMPUTATIONAL AERODYNAMICS ANALYSIS PROGRAM

THESIS

AFIT/GAE/AA/80D-9 (10) Enrique G. Hernandez
2nd Lieutenant USAF

(9) master's thesis

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AFIT/GAE/AA/80D-9

AN INTERACTIVE
COMPUTATIONAL AERODYNAMICS
ANALYSIS PROGRAM

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree

Master of Science

by

Enrique G. Hernandez, B.S.

2nd Lieutenant USAF

Graduate Aeronautical Engineering

December 1980

Approved for public release; distribution unlimited

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Enrique G. Hernandez

Contents

Abstract

This report details how existing aerodynamic analysis programs were combined and integrated into a fully interactive analysis program. The resulting program has several levels of user assistance, complete error protection, and protection against fatal terminations. The program was built around an aerodynamics analysis code which is capable of predicting the real fluid sectional characteristics of airfoils in flows with subcritical Mach numbers. In addition to the viscous flow solution, the program is also capable of several airfoil modification functions.

The program was developed as the basic building block upon which several other aerodynamics analysis codes will be added in the future.

AN INTERACTIVE TWO DIMENSIONAL
AERODYNAMICS ANALYSIS PROGRAM

I. Introduction

Computational aerodynamics is a rapidly growing field, characterized by problems that require extensive calculations. Many computer programs have been developed ranging from the solution of relatively simple two dimensional potential flows, to the numerical solution of the full Navier-Stokes equations.

In most cases the programs yield good results but suffer from poorly designed user interfaces which make the programs difficult to use. In some the required input is so complex that a very good program will be ignored by the user who does not have countless hours to spend learning how to use it. The unexperienced user will sometimes spend many hours trying to get even a simple case to run correctly.

This report demonstrates how already existing programs were modified and integrated into an interactive aerodynamics program that is both simple to use, and easy to update and maintain. The resulting computer program was developed as the basic building block upon which several other aerodynamic analysis codes will be added in the future.

Background and Problem Statement

Because of the complexity involved in the solution of aerodynamic flow problems, the resulting programs used to solve said problems are quite large and can not be run interactively. This increases the probability that a typing error will go undetected, resulting in an unsuccessful run.

Some of the most frustrating experiences which are inevitable when using computer programs are given below. Not all programs suffer from each of these problems, but it is rare to find a program which avoids them all.

1. The program suddenly terminates because of an incorrect value which causes an internal equation to become unsolvable. When termination occurs there is little or no information regarding where the error occurred.

2. Inherent with card deck inputs is the possibility of mistakenly typing in a comma in place of a period or vice-versa. In many cases an illegal character is typed and goes undetected until after it causes the program to end abruptly.

3. When a program is run using a card deck, a great deal of time is lost from the moment the program execution terminates to the time when the user

receives the output.

4. The program may run correctly producing good results and terminating normally. To make another run using the same input with minimal changes will require resubmital of the card deck or retyping of all the information for an interactive program. In either case there will be another long wait for the next set of results.

5. The desired results are finally obtained, but to perform another function on the same set of data may require use of yet another program.

6. The program may provide very good results but in very large amounts. This then presents the problem of data reduction.

7. The results of a successful run may be needed as inputs to yet another program. This may sometimes be the case with pressure, force, and moment distributions which must then be used as inputs to a graphics program.

8. When comparing the program results with experimental or other available data. Both sets of data will sometimes be required as input to a

separate plotting program. In either case, the end result is much more work for the user.

The continued typing of data or loss of valuable time when using card decks result in very poor use of most programs. In order to increase the efficient use of these programs, error protection and workload reduction must be provided for the user.

A serious drawback of many computational aerodynamics codes is that they are developed to solve a specific problem. However, computational areodynamics is a field advancing so fast that many programs are outdated soon after they are introduced. Most programmers are thus satisfied with a program if it yields desired results from the input data. Because of the time limitations and advancing technology, very few programmers try to perfect a program, and even fewer programmers try to make the program convenient to use.

Statement of Purpose

The purpose of this investigation is to develop an interactive computational aerodynamics analysis program using existing aerodynamics codes that will:

1. Be capable of solving viscous and inviscid two dimensional flow problems.

2. Require minimal effort by the user.

3. Be flexible enough to be useful to both the beginner and experienced user.

In order to achieve the stated purpose, five specific goals were developed. This Thesis project attempts to:

1. Integrate existing aerodynamics codes for the class of problems described above into one package with the benefits of a standard input format, and unified data structure which eliminates the retyping of input for each code.

2. Create new program functions in areas where currently available tools are inadequate or nonexistent.

3. Provide the capability of graphically comparing the program results with experimental or other available data.

4. Modify and further develop an existing user interface which gives the user complete control of the program and its data base with minimal effort from the user.

5. Structure the program so it is simple to maintain, modify, and extend in an effort to keep up with advancing technology.

Approach

The approach used for this investigation for the development and modification of the program will be one of modular, standardized top-down design. The basic idea consists of a five step process.

1. An overall picture is first developed of the program as a black box with the desired outputs determining the necessary inputs.

2. The black box is then subdivided into modules for which only the inputs and outputs are defined as necessary to meet the requirements of step 1.

3. Step 2 is then repeated consecutively on each module, until a level is reached where each module performs a single elementary function.

4. Each elementary module is developed and tested individually to verify that it provides the desired output for the given input.

5. As each elementary module is developed it is then combined and tested together with other modules thus forming a higher level module. This procedure is repeated until the initial black box is totally constructed.

The program is thus designed from the top down by first identifying what the required outputs will be, but it is built from the bottom up.

Constraints

The following constraints were placed on this project by the nature of the project, and the availability of resources.

1. The analysis codes to be integrated will be limited to those which solve the viscous and inviscid two dimensional flow problems. The running times of these codes must be less than 10 (CPU) seconds of computer time , in order to provide answers relatively quickly.

2. The goals must be sufficiently limited to allow accomplishment of the project in a nine month period.

3. Since most of the existing codes to be considered

are written in FORTRAN IV, the coding for the project will also be performed in this language.

4. The program will be constrained to operate in less than 65000 (octal) words of computer core memory. This limit is set by the CDC INTERCOM system which permits use of up to 65000 (octal) words of core memory.

5. The program results must be accurate and the same as those predicted by the original codes.

The computer program developed in this project was given the name ICAAP, which stands for Interactive Computational Aerodynamics Analysis Program, and will be so referenced in the rest of this report.

Design Philosophy

In the design and development of the computer program, the overriding philosophy will at all times be: "When a choice must be made, minimizing user time must take precedence over minimizing computer time". No effort will be spared to simplify the use of the computational codes which are to be integrated in this project.

Summary

An extensive search was conducted to find an efficient user interface as part of an existing computer program. Such an interface was found as part of a program called TOTAL (Ref 9). Several modifications were performed in an effort to tailor the interface for use in ICAAP. The modifications primarily involved changing the variables in the existing data base, definition of additional variables, definitions of additional mode switches for program control, and the replacement of existing program modules with those developed in this project.

The resulting interface has several levels of user prompting, error protection and abort protection. The interface makes ICAAP very easy to use while at the same time allowing users to customize program operation to their preference.

II. Description of the Program TOTAL

Introduction

To meet the first design goal of this project, integration of existing aerodynamic codes into one package, it became evident that the key to this problem would be the development of a very efficient interactive user interface. An extensive literature search was performed to find out if an interface which met this project's requirements had been previously developed as part of an existing aerodynamics analysis code. The result of the search was negative mainly due to the fact that most of the available aerodynamics codes were very large and not designed for interactive use.

Having failed to find the desired interface in the field of aerodynamics, the search was expanded to the field of interactive flight control system design. It was here that an excellent interface was found as part of an existing program called TOTAL developed by Larimer (Ref 9). This interface was selected for use with this project, and it became the basic building block of the computer program development. Because of the importance of the user interface, this entire section is devoted to describing its use and operation. The interface was selected for the following reasons.

1. The interface had the benefits of a standard input

format, unified data structure, complete user control of the program and data base, and it was simple to modify.

2. The original design goals of the program TOTAL were very much like those of this project.

3. The design approach and methodology used in TOTAL seemed very well suited for implementation in this project.

4. In the development of TOTAL, emphasis was placed in developing the program in such a way that new program modules could be easily added. Such emphasis made it relatively simple to replace existing program modules with others to be developed as part of this project.

5. Based on the author's extensive experience using TOTAL, the user interface was evaluated as excellent and very well suited for use in this project.

6. The author of TOTAL was available for consultation on the programming details and problems involved in the planned conversion.

Interactive User Interface

The key to the development of a computationally powerful and easy to use program is a very efficient user interface. Larimer (Ref 9:13,14) lists 12 different prerequisites which in his opinion are necessary for the development of such an interface. These prerequisites were found to be consistent with the goals of this project and are therefore repeated below.

1. Protection against premature program termination due to input errors.

2. Ability to recover from input errors without starting over.

3. Ability to selectively modify the value of any program variable at any time.

4. Ability to selectively display the value of any program variable at any time.

5. Ability to transfer the contents of any one variable to any other variable without manually retyping the data.

6. Ability to use the output of one program function

as the input to another without manually retyping the data.

7. Ability to provide help to the user at any time, especially when the input requested by the program is not understood.

8. Ability to selectively list the options available to the user whenever needed.

9. Ability to stop the program and restart it later without loosing any data.

10. Ability to abort a command without terminating the entire program.

11. Ability to assume different modes of operation to tailor the program's performance to the user's preferences.

12. Ability to control the flow of the program from function to function with complete freedom and as little effort as possible.

An interactive user interface such as the one described above can be divided into four principal parts. For the purpose of discussion, these parts will be referred to as program control, data base control, error protection, and user assistance. These parts of the interface as used in Ref 9 and their adaptation to this project will now be discussed.

Program Control

Entering a command or an option number are two widely used methods of providing program control. Both methods are used in TOTAL and are also used in this project. Commands are used when a program function is simple and frequently used. More complicated functions are provided as options for which the program will provide user assistance.

Functions which allow the user to select preferred modes of operation (i.e., whether or not the program is to repeat every input it recieves) are provided as mode control switches. These switches are logical variables which the user can turn "on" or "off" at any time. The use of switches is particularly useful because they enable the user to custom tailor program operation. The idea of the mode control switch, although extensively used in Ref 9, was expanded even further in this project.

Four output mode control switches were defined to give four separate forms of output with most options. Unlike TOTAL, the use of these mode switches effectively quadruples the number of ouput options available to the user while at the same time making the program easier to use. The manner in which the mode control switches are checked and executed is shown in Fig 1.

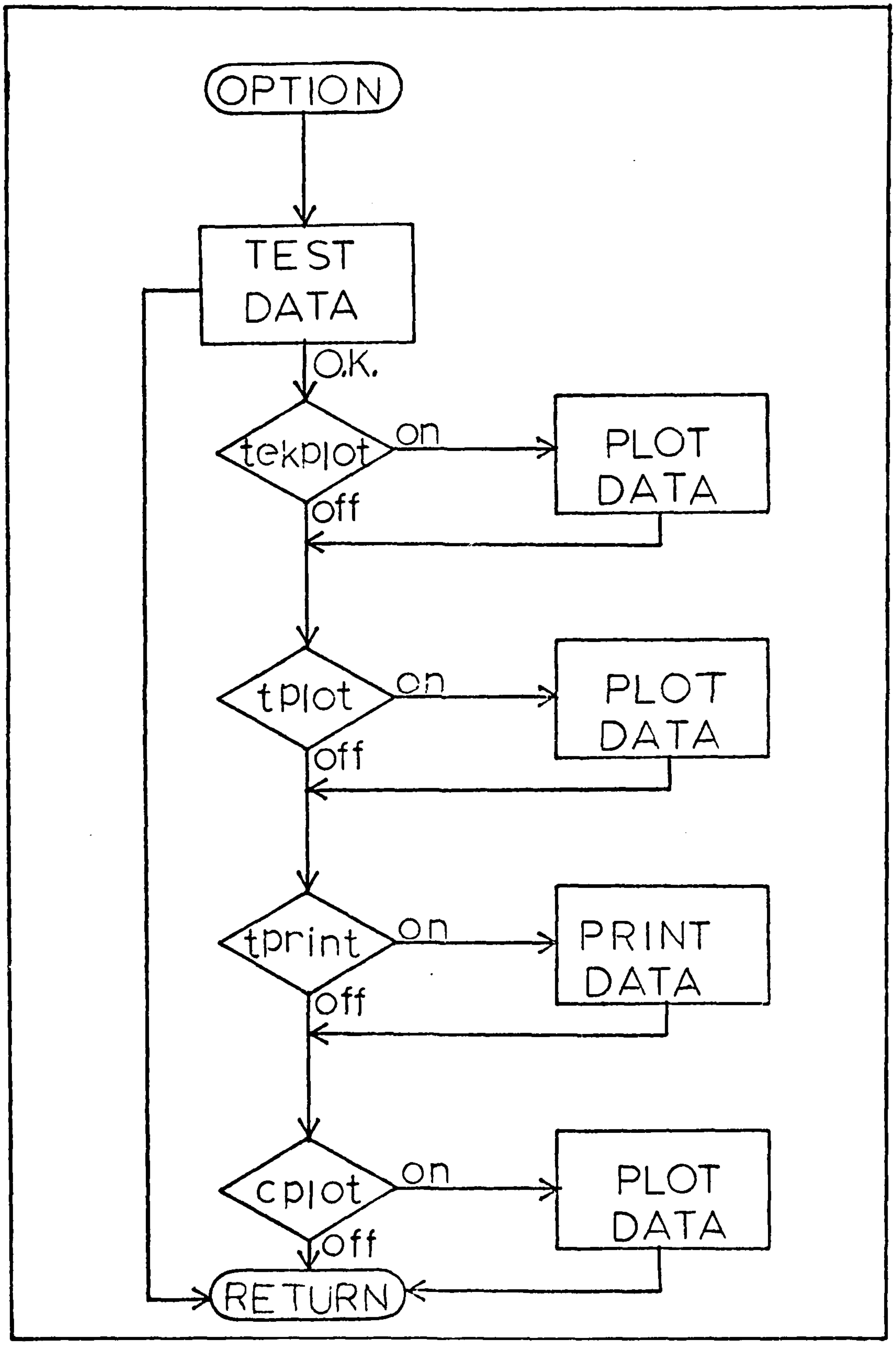

Figure 1. Mode Switch Execution Flow Chart

Data Base Control

Reference 9 defines data base control as: "The ability to list, modify, and transfer the contents of any variable used by the program." This idea is also used in this project although it was found that such control was only necessary for a few program variables. These variables are defined as Global program variables and their definitions and use are found in Section 4 of Appendix A.

Data base control is provided in Ref 9 and in this project as described in the following list.

1. To list the content of any variable location, the user only needs to type the name of the variable. If the variable is an array, then the user can list all the contents of the array by typing the array name. Single array locations can be listed by typing the array name followed by the location enclosed in parenthesis.

2. Variable modification is achieved by typing the variable's name (and subscripts if any) followed by an equal sign, followed by the new value, all in the same input string.

3. For scalar variables, transformation of information from one variable to another is accomplished in the

same manner described above.

4. Transfer of information from one array to another is performed in TOTAL by a command string of the form: "COPY,AVECTOR,BVECTOR" which instructs the program to copy the contents of "AVECTOR" into "BVECTOR". Use of this command was not found necessary in this project and was therefore not included. However, since COPY is a very powerful and useful command all the necessary provisions were made so that the command can be easily added if it is needed.

Error Protection and Recovery

Inadvertant input errors are the most commom type of errors in interactive computer programs. Ref 9 separates these errors into the following three categories.

1. Typing an illegal character.

2. Typing a number outside the range of acceptable values for a particular variable.

3. Typing a number which will cause an arithmetic operation to become insolvable.

All three types will usually result in abrupt program termination resulting in the total loss of all previously entered data. Use of the standard FORTRAN READ subroutine leaves little that can be done about typographical errors. As a solution to this problem, TOTAL uses a read subroutine which replaces the standard FORTRAN READ everywhere in the program. The subroutine reads data in alphanumeric format (standard FORTRAN format which accepts any character) and then uses a translation routine to convert the input to a useable format. Illegal characters detected are brought to the user's attention by an understandable message, and the user is given an immediate opportunity to make the needed corrections. Such an approach virtually eliminates the typographical error which is the most prominent cause of abnormal program termination. This approach was judged to be truly excellent and was therefore also incorporated in this project.

Errors which result from entering a number outside the acceptable range of values are easily prevented. Each variable is tested as it is entered to ensure that it is within the range of legal values. If the test fails, an error message is printed and the user is asked to retype the number.

Errors due to illegal arithmetic operations are much more difficult to prevent. Testing the argument of every single operation that can produce an error is of course the best way to prevent such errors. However, this is an unrealistic approach especially in a program as large as ICAAP. Such an approach is also unrealistic because of the excessive increase in computational times required to test all arithmetic operations with possibly illegal arguements. A more plausible approach is to extensively test the input variables as previously described and then test only the "critical" operations.

User Assistance

The user interface developed in Ref 9 has the unique capabilities of being able to "teach a new user how to operate the program, provide quick memory refreshing and prompting for the familiar user, and yet stay completely out of the way of the expert who has no need for help." The interface will at any time provide for the user a list of options available. The list is divided into groups according to function so that the user can get a short list for the group of interest.

The interface used in this project has several levels of prompting when the user is asked to enter data. With each prompt, there is a brief description of the data being requested. The experienced user can avoid getting the explanation by typing "SUPRESS" or "S" after the option number. Any time the user wants a more detailed explanation of a variable he can get it by entering "?" instead of the requested number.

Modifications Performed

In order to use the interactive user interface of TOTAL, several modifications were performed. Some of these modifications have already been briefly discussed in the previous pages. The modifications can be separated into the following groups:

1. Modifications to the data base.

2. Replacement of program modules.

3. Modifications to the user interface.

The modifications to the data base were simple. All variables which were used in the old data base and could not be used in the new one were replaced by new variables. These modifications drastically changed the vocabulary that the new program is able to understand. As previously discussed, the interface used in this project maintains the full data base control capabilities of the interface in TOTAL. The one exception is the COPY command which was not included although all the necessary preparations were made so that the command can later be added if it is needed.

Because of the structured programming approach used in both Ref 9 and this project, replacement of the program modules (overlays and subroutines) was fairly simple. The basic flow chart of the main overlay which is shown in Fig 2 remained the same. All overlays with the exception of READER, DECODER, HELP, TTYPLT, MISCELL, UPDATE, and HELP were replaced by those shown in the flow chart. Overlays HELP, UPDATE, and MISCELL were almost completely rewritten although the same names were used. Overlays DECODER and TTYPLT were also modified but to a smaller degree.

The modification performed were necessary because the mentioned overlays are those which form the user interface with the exception of TTYPLT which is an output overlay. A

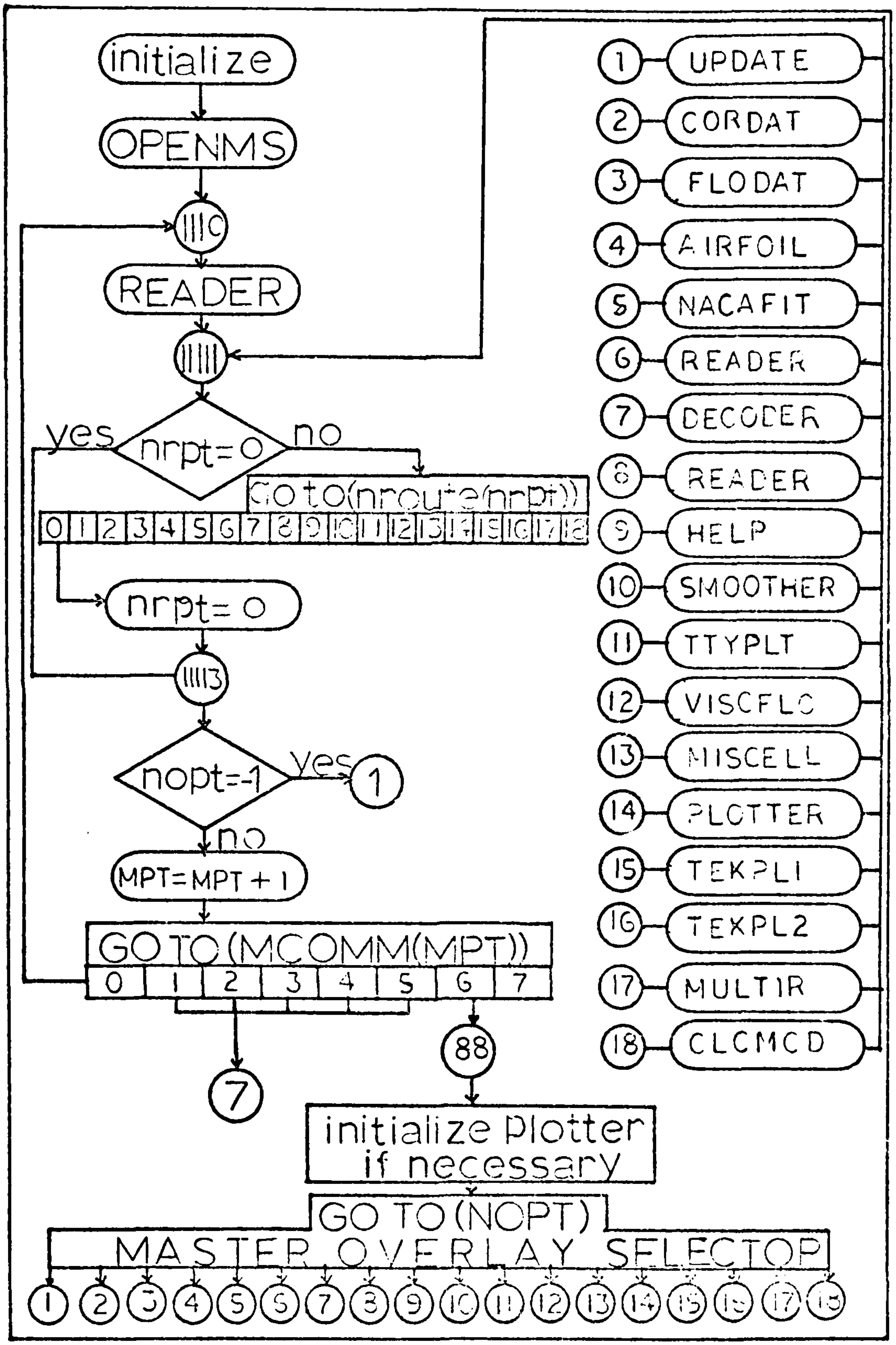

Figure 2. Flow Chart for ICAAF's MAIN overlay

discussion of each new overlay that was added is given in Appendix B.

Summary

This Section described how the user may control ICAAP's operation. This is acomplished by providing for the user: program control, data base control, error protection and recovery, and user assistance.

Very few modifications were performed on the program control interface. These modifications primarily involved the definition of four output mode switches, and the replacement of some existing switches with new ones. All new switches defined and used in this project and a discussion of their use is given in Section 4 of Appendix A.

III. Discussion of the Viscous Flow Program

Introduction

The solution code used for the two dimensional flow problem is based exclusively on the program developed by Gingrich and Bonner (Ref 4). With the exception of some modifications which were necessary to integrate the program into ICAAP, the solution code remains the same and yields the same results as the original.

The modifications performed changed the code format from a main program with several subroutines, to a primary overlay with three secondary overlays and four fewer subroutines. The new code makes extensive use of a random access file called MEMAUX to store the program results. Two other secondary overlays were also added to give the user the option of getting the boundary layer results for a user provided velocity distribution or one resulting from the inviscid solution using thin airfoil theory.

The new code was tested under several different conditions and found to give exactly the same results as the original. However several modifications were made which prevent the new code from aborting if turbulent boundary layer separation occurs. This problem often occured in the original code from Ref 4.

The viscous flow code of Ref 4 was selected for use in this project for the following reasons.

1. The code had been previously developed, tested, and

found to give good results for flows with subcritical Mach numbers.

2. The code was in active use at the US Air Force Aeronautical Systems Division, as an efficient aerodynamic analysis code.

3. It was suggested by Snyder (Ref 12) that a much more efficient and beneficial use of the code could be made if it was converted into an interactive code.

4. Extensive experience was obtained by the author in using the code as part of several classes at the Air Force Institute of Technology.

5. The solution time for a single case ranged from 3 to 8 CPU seconds for solution convergence. This range was well within the limits specified for this project.

Solution Techniques and Limitations

The report in Ref 4 describes a method for predicting real fluid sectional characteristics of single element airfoils at subsonic speeds. An iterative technique is applied between partial solutions to account for the effects of viscosity. The program uses the following solution techniques.

1. Airfoil incompressible conformal transformation theory of Theodorsen (Ref 15).

2. Nonlinear compressible airfoil corrections of Labrujere (Ref 8).

3. Laminar integral boundary layer method of Cohen-Reshotko (Ref 2,3).

4. Transition method of Schlichting-Ulrich and Granville (Ref 11,5).

5. Turbulent boundary layer method of Sasman-Cresci (Ref 10).

6. Circulation/Wake vorticity shedding criteria of Howarth-Spence (Ref 13).

7. Turbulent wake growth of Squire-Young (Ref 14).

A brief description of each technique is given in Sections 2.1 and 2.3 of Appendix A. A more detailed explanation of the use of these techniques can be found in Ref 4.

Modifications Performed

When using overlays or segmentation in a computer program, the information which is to be transmitted between segments or overlays must be passed through the use of COMMON statements. Any information which must be transmitted between primary overlays must be stored in COMMON in the main overlay. A similar restriction also applies when using segmentation.

The viscous flow code generates a very large amount of data for each flow solution. In order to provide flexibility in choosing how and when to examine the results, the ouput would normally have to be stored in COMMON in the main overlay. However, because of the 65000 (octal) word limit of this project, such an approach was found to be very inefficient and impractical. An alternative approach used in this project was to write all the output information into a random access file for retrieval at a later time. This method proved to be very efficient because the data did not use any core memory until the user specified an option which used the stored data. When such an option was selected, the necessary data was then read into the program and the option executed. In addition, since the data was written into a random access file, which allows any part of the data to be read back in any order, it was possible to eliminate lengthy waiting periods normally needed to rewind the file and skip over data which is not wanted when using sequential files. Although the use of the random access file did slightly increase the running times, the change was insignificant and could not be detected by the user.

One of the major modifications made involved the restructuring of the original code from a main program with several subroutines to a primary overlay with four secondary overlays and four less subroutines. The four subroutines that were eliminated were used to form the overlay BDLAYER which now acts as the boundary layer equation solver used in ICAAP. The flow chart for the resulting code is illustrated in Fig 3. The four labels in the flow chart do not represent the subroutines, instead they represent the four

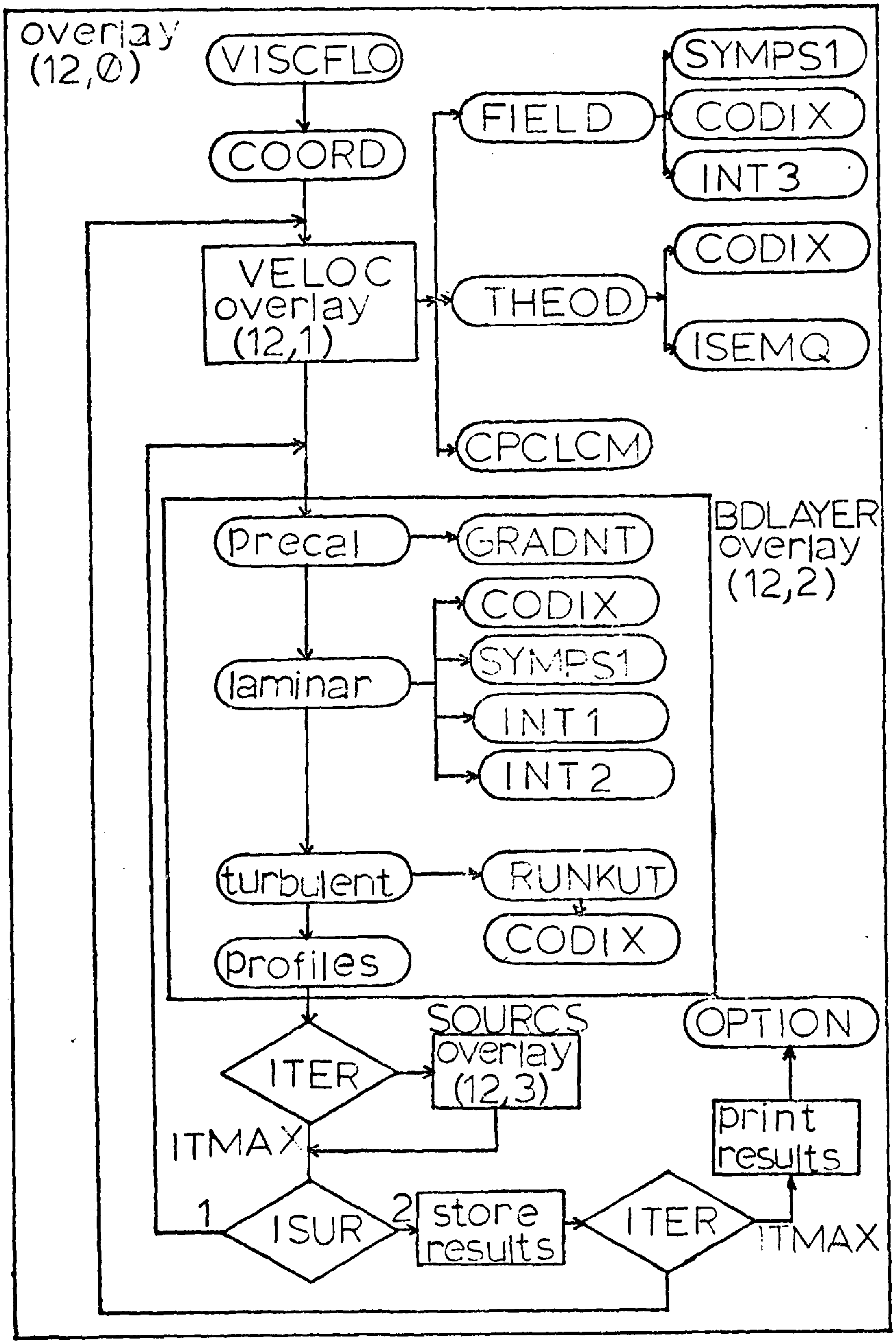

Figure 3. Flow Chart for VISCFLO overlay

completely distinct sections of the BDLAYER overlay.

The consolidation of the four subroutines into one overlay eliminated eight separate subroutine calls for each solution iteration. A savings of approximately 1 (CPU) second in computational times for each viscous-inviscid solution iteration was achieved by the described consolidation.

To minimize the amount of effort required from the user, the print indicators used by the original code and some additional new ones were made Global variables in ICAAP's data base. This modification gave the user the ability to change any of the solution input variables at any time without having to retype all the required inputs to execute the viscous flow solution. For example, the user may run the initial case by entering all the required variables, and then run several cases for different angles of attack by specifying the new angle and the option number for the viscous flow solution.

During the early stages of this project, it was found that the original code had a tendency to abruptly terminate if turbulent boundary layer separation occurred without giving the user any idea of what was happening. Such a termination in ICAAP would result in the complete loss of all the data previously generated.

A careful examination of the original code provided the following conditions which indicated that an abrupt termination was about to happen.

1. An incompressible form factor greater than 2.8 was calculated at one or more points in the boundary layer. This condition is indicative of turbulent boundary layer separation. In some cases this condition would occur at only a few points during the iteration process but the flow would reattach in the next iteration. However, the most frequent condition was one in which an incompressible form factor equal to or greater than 2.8 would be calculated at several stations. This condition would always result in divergence of the solution and a fatal termination.

2. A value of circulation which resulted in a lift coefficient greater than 3.5 or less than -3.5 would be calculated for one iteration. This was always indicative of the start of the solution divergence which would inevitably lead to a fatal termination.

To give the user some protection against such problems, a mode switch named NOFAIL ("on" by default) was introduced. With NOFAIL "on", ICAAP will test for the conditions described above and will return to the OPTION mode if either is detected. When this occurs, an informative message is printed describing for the user the condition which resulted in the abort of the option, and program control is returned to the user. A lift coefficient greater than 3.0 is unrealistic for single element airfoils, thus an overconservative value of 5.0 was choosen as the test for divergence and the abort of the option.

If the user is trying to calculate the maximum lift coefficient for an airfoil section, then he can turn NOFAIL "off". This will allow ICAAP to calculate form factors greater than 2.8 without aborting the option. However, the solution may also diverge and result in a total loss of the data if the solution diverges. To provide some safeguard against such a termination, another test was added. If ICAAP calculates a displacement, momentum thickness, or boundary layer thickness greater than 25% Chord, the viscous flow solution will also be aborted and program control returned to the user. If this condition occurs, it is indicative of severe turbulent boundary layer separation and the same informative message listed for the first condition previously discussed will also be printed.

Another modification performed was the manner in which the point of laminar to turbulent transition is set. In addition to the options available in the original code which allow the user to physically set the transition point or have the program calculate it, a third option was added. This option instructs ICAAP to set the point of transition at the point where instability is calculated, and was added on the recommendation of Snyder (Ref 12).

The last major modification involved the manner in which the data is entered into the program. A separate overlay called FLODAT was written to handle all the inputs to the viscous flow solution code. FLODAT requests all the necessary data, tests the inputs for illegal values, and gives the user an explanation (if it is requested) of the meaning of each variable and possible range of values. Overlay FLODAT will be discussed in more detail in Appendix B. Use of FLODAT represents a very large gain in efficiency over the original code which was restricted to a card deck input and the inherent errors that are associated with such an input form.

Summary

Several modifications were performed on the original viscous flow code of Ref 4. The modifications mainly involved the restructuring of the program with the use of overlays, and the storage of data using a random access file. Several tests for solution divergence were added, and the user was given control of whether they will be performed. The method of data input was completely changed from a card deck input to an interactive input with full user prompting, error protection and user assistance. Several test were performed which revealed that for the same inputs, ICAAP calculated exactly the same results as Ref 4.

IV. Discussion of the NACA Airfoil Coordinate Program

Introduction

The solution code used to determine the coordinate point distribution for NACA designated airfoils is based on a computer program developed by Kinsey and Bowers (Ref 7). Some modification were necessary to integrate the program into ICAAP. Except for these modifications, the solution code remains the same and yields exactly the same results as the original.

The modifications performed involved the development of a new primary overlay which makes use of some subroutines from the original code. The new code gives the user much more flexibility in selecting the number of coordinate points and point distribtuion.

Solution Techniques and Limitations

The code in Ref 7 consisted of two separate computer programs of which only one was used in this project. The program used in ICAAP uses the camber line and thickness distribution formulas as given in Ref 1 to determine the NACA designated airfoil coordinates. Airfoil coordinates for the 4 digit, 4 digit modified, 5 digit, 5 digit modified, 6-Series and 1-Series can be determined with some restrictions. These restrictions are discussed in Section 2.7 of Appendix A.

Modifications Performed

The original code had a point distribution with the airfoil coordinates concentrated at the leading and trailing edges. The code always provided a set number of points and the user had no way of changing it. The new code used in ICAAP provides much more flexibility in selecting the desired point distribution. There are two methods of obtaining the point distribution. The first uses the cosine spacing rule (see Section 2.7 of Appendix A) to give up to 200 points as specified by the user. This rule is well accepted in the field of aerodynamics because it provides a symetrical point distribution which is highly concentrated at the end points.

It was found that the 50 point maximum of the viscous flow code resulted in a point distribution from the cosine spacing rule which did not concentrate enough points at the leading and trailing edges. The second point distribution method was developed to solve this problem. This option will yield 49 points distributed in a way that is optimized for use by the viscous flow code. There are several other ways of achieving different point distributions which are discussed in Section 2.7 of Appendix A.

Another major modification performed changed the manner in which data is entered into the program. While the old code was restricted to card deck inputs, the new code requests from the user all the necessary variables. The new code will also provide an explanation of each variable and possible range of values. The output from the new code is stored in one dimensional Global arrays which are available for user inspection and modification at all times.

The last major modification changed the way in which swept airfoil sections were treated. The section of a sheared airfoil is defined by the NACA designation, parallel to the free stream regardless of the leading edge sweep. The defined section of a swept airfoil is always taken perpendicular to the leading edge. The original code calculated "corrected" coordinates parallel to free stream direction by multiplying the nondimensional y/c coordinates by the sine of the difference between 90 degrees and the sweepback angle. This procedure is incorrect and a better approach was used in ICAAP.

Since the airfoil coordinates are nondimensionalized by the chord length, there is no need to modify them in any way. For swept airfoils, the only needed correction is to multiply the given chord length by the cosine of the sweepback angle. The product will be a new "corrected" chord which is parallel to the free stream direction. The resulting dimensional coordinates will also be corrected. The correction is performed automatically by ICAAP prior to executing any of the flow solution options. If the chord length and sweepback angles are not changed, then the correction will be performed only once and will remain in effect until the chord or sweepback angle is changed.

Summary

The computer program for obtaining the coordinates of NACA designated airfoils in Ref 7 was modified as needed for integration into ICCAP. The modification involved the manner in which the point distribution is determined, the number of possible points, interactive input of program variables, use of an overlay structure, and the manner in which sweptback airfoils are handled. The new program was tested and found to give exactly the same results as the original code in Ref 7. The new code was also tested against the results in Ref 1 and found to give good results.

V. Results and Recommendations

The purpose of this project was to develop an interactive computational aerodynamics analysis program using existing analysis codes. The program was to be computationally powerful, simple to use, and capable of solving the compressible, incompressible, viscous, and inviscid flow about airfoil sections. This Section describes what was actually achieved and what further work remains to be done.

Three major achievements were produced as a result of this project. These achievements are the development of the computer program, a fully documented user's manual, and this report.

The Computer Program

The computer program developed in this project was named ICAAP which stands for Interactive Computational Aerodynamics Analysis Program. ICAAP is now in active use at the Air Force Aeronautical Systems Division. ICAAP will also be used in the future by the faculty and students of the Air Force Institute of Technology.

ICAAP is an interactive computational aerodynamics analysis program. It is composed of 100 options, several modes of operation, and a few special commands with which the user can exercise complete program control. The program is built around a two dimensional viscous flow solution code which predicts the real fluid characteristics of airfoil sections. ICAAP is complemented with several airfoil modification functions and a myriad of output functions. During program execution the user can select options, modify or list variables, and give commands.

The program allows the definition of macro routines using the basic program functions thus giving the user the ability to define new program functions. These routines and all other information stored in the program are saved in external storage files for use in subsequent runs. Several levels of user assistance are provided to help the user in executing the program. ICAAP was developed as the basic building block upon which other computer programs will be added in the future.

The User's Manual

The development of a detailed user's manual was given equal priority as the development of the program. Many excellent computer programs lie unused because the programmer never thought that someone else completely unfamiliar with the program might want to use it. Extensive use of examples was made throughout the manual to insure that every useful bit of information concerning the program was explained in a concise and logical manner. The user's manual is included in this report as Appendix A.

The Report

This report and the appendices provide a complete description of program development from its conception to the final product.

Recommendations for Future Development

ICAAP was developed as a building block upon which other analysis codes can be easily added. Therefore, the most important recommendation is that this program be maintained and expanded to integrate more analysis codes as they become available.

The expansion of the program can in general be divided into the addition of two dimensional and three dimensional analysis codes, and the addition of interacitve graphics capabilities. The following are six possible program modifications for two dimensional flow analysis.

1. Add a supersonic analysis code capable of predicting the shock and boundary layer interactions.

2. Add a transonic analysis code when an efficient one becomes available.

3. Add the capability of analyzing multi-element airfoils.

4. Add an airfoil design and optimization code. Such a code could use the existing code in ICAAP to create new airfoil sections by modifying the camberline and thickness distribution equations.

5. Replace the present method of predicting laminar to turbulent boundary layer transition when a better method becomes available.

6. Replace the present boundary layer analysis when a

better method becomes available.

7. The thin airfoil theory code developed in this project was included as teaching tool to be used at the Air Force Institute of Technology. The results predicted by this code are fairly accurate, but require longer runing times than the theory of Theodorsen, because of the slow convergence of the Fourier Series. A very simple simple but useful extension of ICAAP would be to replace the existing code with a faster and more accurate solution such as that proposed by Weber (Ref 16,17).

Since more and more three dimensional analysis codes are being constantly developed or improved, adding such a code to ICAAP would be a very logical extension. Such a code should be able to solve problems in the subsonic, transonic, or supersonic flow regimes. The major problems presented by such an addition are the extensive memory requirements, and long running times of three dimensional codes in general. These are not impossible obstacles, but they would represent quite a challenge.

The final recommendation is the addition of an interactive graphics capability. With interactive graphics the output may be displayed in various graphical forms. The user is given control of the program by the use of a light pen which he uses to enter data, select options and give commands. Such a capability would signify a quantum jump in the power and usefulness of ICAAP. Since the option numbers and command used in ICAAP are very well suited for display in a graphics menu format, such a modification would not require excessive rewriting of ICAAP's programs and subroutines.

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Appendix A

User's Manual for ICAAP

Contents

List of Figures

List of Tables

1.0 Introduction to ICAAP

ICAAP is an interactive computational aerodynamics analysis program. The user has 100 options, several modes of operation and a few special commands with which to exercise complete control over the program.

The program is built around a two-dimensional viscous flow solution code which predicts the real fluid characteristics of airfoil sections. However, ICAAP can also perform several airfoil modification functions and is complemented with a myriad of output functions. During program exectution, the user can select options, modify variables, list variables or give commands. This manual contains all the necessary information regarding the operation of this powerful and simple to use analysis tool.

In order to fully understand the operation of ICAAP, the user should first read through the entire manual paying special attention to Sections 1.1, 1.2, 1.3, and 1.4. After reading through the manual, the user needs only to read the Section which covers the options which will be used.

1.1 ICAAP'S INPUT MODES

ICAAP has three modes in which the user may enter information: OPTION, DATA, and CALCULATOR. With each mode there is a corresponding vocabulary of allowable inputs and characteristic prompts to the user.

OPTION mode

The OPTION mode is ICAAP's primary command mode and is characterized by the prompt:

OPTION>

When ICAAP is in this mode, the user may enter any command, select any option, modify variables and list data. This is the primary mode available to the user for program control.

Any number of commands or options may be typed on one line. If the last item on a line is followed by a comma , ICAAP will wait for another line of input before begining execution. CAUTION: The input items must be separated by a comma or a blank.

DATA mode

Once an option has been selected, if data is needed ICAAP will ask for it from the user. This is ICAAP's DATA mode and is characterized by a prompt of the form:

ENTER VAR1,VAR2 >>

The amount of explanation included with each prompt will depend on the position of the logical switch SUPRESS. If SUPRESS is "off", ICAAP will include with each prompt a detailed explanation of the data being requested. This mode is highly recommended when first learning how to use a particular option. If SUPRESS is "on", ICAAP will write only the names of the variables being requested. This mode allows for faster use of ICAAP as the user becomes more familiar with the use of each particular option.

When ICAAP requests input in the DATA mode, the user has a number of possible responses.

1. The user may enter the values of the required variables separated by blanks or commas. In this case ICAAP will accept and test the data for illegal inputs and proceed to execute the particular option if no input errors were detected.

2. The user may enter "?" to have ICAAP explain what information is being requested.

3. If one of the requested numbers needs to be calculated, the user may enter the CALCULATOR mode. When this mode is ended, ICAAP will repeat the prompt (and any numbers already entered) and wait for the remaining input.

4. If an item is to have the same value as the last time it was requested (or default value) the user may enter a "*" in place of the item to be left unchanged and continue with the rest of the input.

5. The user may list the current values of the requested variables by entering "L". Numbers will be listed in the order in which they were requested. The prompt (and any numbers entered before "L") will be repeated, and ICAAP will wait for the required input.

6. If one of the numbers requested is currently stored in a calculator register, the user may type X, Y, Z, T, or R1 through R20 in place of the number. This is especially useful when returning from the

CALCULATOR mode using the "C" option.

The user may access any global variable (see Section 4) in ICAAP's memory by entering "C" to go to the calculator, the variable's name to enter the value in the "X" register, "C" to return from the calculator, and "X" to tell ICAAP to use the value now stored in the "X" register.

7. The user may abort the option and return to the OPTION mode by entering "$".

The user may mix the above responses as needed while in the DATA mode. ICAAP will remain in the DATA mode until all the requested data has been entered.

CALCULATOR mode

The CALCULATOR mode may be entered at any time by entering "C". In this mode ICAAP operates like an HP-45 calculator (uses reverse polish notation) and this mode is characterized by a prompt of the form:

**

When this prompt is displayed the user may type a number, a key name (type "KEYS" for a list), or a "?" for a brief explanation of the calculator. The CALCULATOR mode is terminated by typing another "C". A complete description of ICAAP's calculator is given in Section 5 of this manual. ICAAP's calculator is simply a copy of the one in TOTAL and as a result, the discription in Section 5 is similar to that in Section 5 of Ref 3.

1.2 ICAAP's options

ICAAP is presently composed of 100 options which have been divided into groups of 10 depending on the general function of each option. The following list contains the main option groups.

```
 0-9--->Special Input Options.
10-19-->Solution of the Viscous Flow Problem.
20-29-->Theodorsen Transformation.
30-39-->Boundary Layer Information.
40-49-->Velocity and Pressure Distributions.
50-59-->Lift, Moment, and Drag Coefficients.
60-69-->Airfoil Description and Verification.
70-79-->Input/Ouput of Airfoil Coordinates.
80-89-->Smoothing and Airfoil Modification.
90-100->Miscellaneous Options.
```

In each case, the first option will provide a list of the next ten options. The complete details of each option and their use are given in Section 2 of this manual.

1.3 ICAAP's Variables

Many of ICAAP's variables may be directly listed or modified by the user while in the OPTION mode. Typing a variable's name will list the current value of that variable. Typing a variable name followed by an equal sign, followed by a number or another variable name will assign the value to the right of the equal sign to the variable on the left.

One dimensional arrays are referred to by subscripts. Typing YCRD(1) will list the value of the first location of YCRD. Typing YCRD will list all values currently stored in YCRD. A complete list of all variables available to the user may be found in Section 4 of this manual.

1.4 HELP

Help is available to the user at all times and may be requested by typing "?" in the DATA mode, or "HELP,option #" while in the OPTION mode.

2.0 Complete Description of Options

To fascilitate the use of ICAAP, the program has been divided into groups of options each of which is designed to perform related tasks. A break down of these groups and a discussion of each option are provided in this section.

With most options the user will have the choice of four different forms of output. Except where specified, the output mode must be selected prior to selecting the option to which it will apply. If the particular option has a fixed output mode (i.e., printed output only), as in the case of options 11 through 19, then selecting an output mode for such an option will be ignored. The output mode switch is automatically turned "off" after each option is executed.

The user selects the output mode while in the option mode by typing in the name of the output mode switch followed by the option number to which it will apply. The four output modes are described in depth in Section 4.3, however a short description of the output modes is given below.

TPRINT--->Printed data in a tabular format.

CPLOT---->CALCOMP plot of data written to file PLOT.

TPLOT---->Printer plot of output data.

TEKPLOT-->Tektronix plot of output data.

The mode switches specify what form of output will be required from the option, and more than one output mode (where applicable) can be specified for each option. For example, the command string

OPTION> TPRINT,61,TPLOT,CPLOT,63

causes the airfoil coordinates to be printed in a tabular format (option 61), and generates a Printer plot and CALCOMP plot of of the airfoil second derivative (option 63).

A key point to be remembered when selecting the output mode is that all mode switches are initially set "off", and stay that way until turned "on" by the user. After an option is executed using one of the output modes, ICAAP will turn the switch back to "off". With this procedure, ICAAP protects the user from inadvertently generating more than one form of output for a particular option.

ICAAP uses a unique implementation procedure to generate the four possible output formats as described by the flow chart in Fig 1. This procedure allows the user to generate one or any combination of the four possible output modes without having to execute the option again. The command string

OPTION> TPRINT,CPLOT,TPLOT,TEKPLOT,62

will generate all four output formats for the airfoil slope data. The use of the four output mode switches effectively quadruples the number of options available to the user while at the same time significantly reducing execution time.

There are some special options where all four of the possible output modes are not available. These options and the reasons for using a particular form of output will be described in the following section along with all other options.

CAUTION: The plots and tables at the end of this manual are provided as examples only of what the outputs for each option will look like. The printed and plotted data may not agree in each example, although in actual execution all printed and plotted data for a particular option will be the same. In addition, the experimental data plotted with the CL, CM, CD, CP, and V/VO curves do not represent an actual comparison of the results predicted by ICAAP against experimental data. Here again, the plots are intended to represent only what the actual program outputs will look like.

2.1 Special Input Options

Option 0: This option provides a quick list of options 0 through 9.

Option 1: This option rewinds the local file MEMORY and reads in all the information necessary to restart ICAAP. With the use of option 1, the user can temporarily end ICAAP to work on something else, then later restart the program using option 1 to recover the data stored in MEMORY. This procedure saves the user from having to re-enter a set of data each time that ICAAP is executed.

Options 2 through 9 are strictly input options and as such have no output mode associated with them. Any output mode which is selected will be ignored and turned "off" by ICAAP. After the data has been been entered with these options it is saved in the Random Access file MEMAUX for future use.

It is very important to note that the data is written into MEMAUX after all points have been entered by the user. If a mistake is made while entering points, continue entering points and then execute the particular option again using "*" in place of the good values and replacing the bad ones. This procedure is necessary because the data is stored in MEMAUX after all data has been entered. The limitation is imposed by the use of a Random Access file to save core memory.

If the user aborts the option using a "$" before all points are entered, all the data entered will be lost and will have to be entered again. Since once entered there will be no need to modify the data, the vectors into which they are stored are not Global variables and can not be directly accessed by the user. However, options 40 through 59 have been provided for the user to selectively print or plot the data entered with options 2 through 9.

Option 2: The purpose of this option is to allow the user to enter a lift coefficient CL vs angle of attack ALPHA distribution. ICAAP will first request that the user enter the number of points to be entered (limited to 30) and will then request the coordinate points (ALPHA,CL) one point at a time. There are no output modes available with this option, and any selected will be ignored and turned "off" by ICAAP.

Option 3: The purpose of this option is to enter a moment coefficient CM vs ALPHA distribution. This option works exactly as option 2 but the requested coordinate points are in the form (ALPHA,CM).

Option 4: The purpose of this option is to enter a lift coefficient CL vs drag coefficient CD distribution. This option works exactly as option 2 but the requested coordinate points are in the form (CD,CL).

Option 5: The purpose of this option is to enter a pressure coefficient distribution (CP). This option works exactly as option 2 but the requested coordinate points are in the form (X/CHORD,Y/CHORD,CP).

Option 6: The purpose of this option is to enter a nondimensional velocity distribution (V/V0). This option works exactly as option 2 but the requested coordinates are in the form (X/CHORD,Y/CHORD,V/VO).

Option 7: This is a spare option.

Option 8: This is a spare option.

Option 9: This is a spare option.

2.2 Solution of the Two Dimensional Flow Problem.

The program used by ICAAP for the solution of the two-dimensional viscous flow around an airfoil section is a modification of the one developed in Ref 1. The modifications performed primarily involved reconfigurating the original code with the use of Overlays so that the program could fit into ICAAP's memory requirements. Additional modifications were necessary to store the information needed for several of ICAAP's options into a Random Access file called MEMAUX. Based on the recommendation of DR James Snyder (Ref 5), another modification was made which allows the user to command ICAAP to internally set the point of transition at the point where instability is calculated. This is automatically performed by ICAAP when the user sets the values of NTRANU and NTRANL to 888 prior to executing options 11 through 19.

The variable NOFAIL (default is "on") was also defined. The purpose of NOFAIL is to stop program execution if ICAAP calculates a value of circulation which would result in a lift coefficient greater than 5.0. This value of 5.0 was chosen based on experience gained from several runs in which conditions of separation were purposely entered to determine program stability. It was found that if the selected value of circulation resulted in a CL>3.50 ,the program would likely abort. The value 5.0 was chosen as an overly conservative check for conditions that would lead to program termination. If NOFAIL is "on" ICAAP will also stop execution of options 11 through 19 and return to the OPTION mode if a value greater than 2.8 is calculated for the incompressible form factor. Reference 1 uses 2.8 as the limiting value after which the boundary layer is considered to be in a state of turbulent separation. This maximum value is also the accuracy limit of the turbulent boundary layer analysis included in ICAAP.

With the exception of the above mentioned modifications, the viscous flow analysis code used by ICAAP is basically the same as that in Ref 1, and both codes will predict identical results for the same given conditions. Reference 1 contains a detailed description of the theory, equations, and program limitations of the original code. This reference also contains a detailed comparison of the program results and experimental data.

The user who desires a complete program description for the viscous flow code should consult Ref 1. The following pages are a brief summary of the program, included here to give the user some idea of the methodology and program limitations.

The report describes a method for predicting real fluid sectional characteristics of single element airfoils at subsonic speeds. An iterative technique is applied between partial solutions which represent the viscous and inviscid flows to account for the effects of viscosity. The program developed uses the following solution techniques (Ref 1:43-47).

1. Airfoil incompressible conformal transformation theory of Theodorsen.

2. Non-linear compressible airfoil corrections of Labrujere.

3. Laminar integral boundary layer method of Cohen-Reshotko.

4. Transition method of Schlichting-Ulrich-Granville.

5. Turbulent integral boundary layer method of Sasman-Cresci.

6. Circulation/Wake vorticty shedding criteria of Howarth-Spence.

7. Turbulent wake growth of Squire-Young.

CONFORMAL TRANSFORMATION THEORY (Ref 1:3-6)

The conformal transformation theory states that the fluid motion about a two dimensional airfoil with circulation in a uniform stream, can be calculated from the known flow about a circular cylinder centered at the origin. The solution to a specific problem is a two step process. The airfoil is first transformed into a shape very close to a circle in an intermeditae plane using the Jowkowski transformation (Ref 1:3). The resulting contour is then transformed to a circle in the complex plane centered at the origin using a series summation (Ref 1:4). Once the transformation is complete, the inviscid flow around the cylinder is calculated by establishing the value of the circulation. The circulation is determined from the Kutta condition which is satisfied by requiring a stagnation point at the physical trailing edge. With the circulation so established (Ref 1:5), the resulting flow field is transformed back into the flow field around the airfoil section. For more details on the Theodorsen trasnformation, see Section 2.3 of this manual.

COMPRESSIBLE AIRFOIL CORRECTIONS (Ref 1:6-7)

A uniformly valid theoretical solution of compressible flow requires the use of a nonlinear equation of motion. This approach was considered to be beyond the scope of Ref 1. Instead, an approximate analysis proposed by Labrujere, et al based on local corrections to compressible small disturbance theory was selected (Ref 1:6). The technique recognizes the fundamental nonlinear behavior of the compressible flow in the vicinity of the leading edge region approaching the sonic condition.

VISCOUS SOLUTION (Ref 1:8)

The viscous flow analysis defines the attached flow real fluid characteristics within the boundary layer. This means that that the wall shear layer and wake development are determined from a prescribed external pressure distribution. The adiabatic wall condition is recognized as good for subcritical flows (Ref 1:8) and is used in the program since the surface temperature information is seldom available.

LAMINAR BOUNDARY LAYER (Ref 1:8-15)

The Cohen-Reshotko method is used to solve the laminar boundary layer equations. This is an integral method which involves the momentum integral equation for compressible laminar cases with arbitrary pressure gradients and heat transfer. This method does not have restrictions on compressibility, pressure gradient, heat transfer, Prandtl number or type of free stream velocity distribution (Ref 4:3) which are present in other methods.

<u>TRANSITION METHOD (Ref 1:15-18)</u>

To achieve a reasonably accurate prediction of skin friction and profile drag on the airfoil, it is essential to have an accurate prediction of where the boundary layer remains completely turbulent with time (Ref 1:15). Mach number, heat transfer, mass transfer, Reynolds number, pressure distribution, wall roughness and free stream turbulence are all factors which affect the location of the transition point. Unfortunately, the established theoretical criteria can not predict the location of the transition point, but can establish the point beyond which transition occurs.

The method in Ref 1 for transition on a smooth wall is based on stability theory in conjunction with an empirical correlation relating the end of the transition region to the theoretical instability point. The stability analysis of Schlichting and Ulrich is used to predict where the laminar boundary layer first becomes unstable. The distance between the point of transition and the start of completely turbulent flow is predicted using the empirical correlation of Granville (Ref 1:16).

Curves of neutral stability for the incompressible laminar boundary layer were determined by Schlichting and Ulrich as a function of K, the velocity profile shape factor. From the curves of neutral stability, the minimum theoretical critical Reynolds number RCRIT is determined as a function of shape factor. The incompressible analysis is extended to adiabatic compressible flow (Ref 1:17) and the equivalent incompressible shape factor KI and mometum thickness Reynolds number RTHI are calculated.

KI and RTHI are determined as a function of x from the solution of the laminar boundary layer. The point of instability is located when RTHI=RCRIT. The mean shape factor KBAR is computed and the quantity DIF=RTRAN-RINST is determined as a function of KBAR. DIFF is the difference between the momentum thickness Reynolds numbers at the points of transition and instability. The increment DIFF is then added to the local momentum thickness Reynolds number at the point of instability RINST, to obtain a local transition momentum thickness Reynolds number RTRAN. Transition is then predicted when RTHI=RTRAN.

Transition may be accomplished in three ways: (a) naturally, using the criteria specified above; (b) at a point specified by the user; (c) at the point of instability when so specified by the user.

Separation is predicted in laminar flow when the skin friction coefficient becomes negative. In turbulent flow, separation is predicted when the icompressible form factor FORMI (or HI) becomes greater than 2.8.

It should be noted that the values of the momentum thickness Reynolds number are calculated based on the local momentum thickness as the characteristic length.

TURBULENT BOUNDARY LAYER (Ref 1:18-23)

The Sasman-Cresci method is used for the solution of the turbulent boundary layer. The method expresses the turbulent boundary layer in terms of the momentum and moment of momentum integral equations for compressible turbulent cases with arbitrary pressure gradients and heat transfer. The resulting system is then solved simultaneously to provide the boundary layer parameters.

WAKE GROWTH AND EFFECTS (Ref 1:23-26)

The viscous flow calculations are extended downstream of the trailing edge to evaluate the effect of a turbulent wake inviscid stream line displacement on the sectional characteristics. The wake flow is described using mean quantities, with the compressible wall shear stress term deleted from the compressible boundary layer momentum equation.

The effect of the wake is established from the displacement thickness distributions above and below the stream line originating at the trailing edge. For downstream distances greater than half CHORD, the wake is considered symetric and the integral displacement thickness is assumed to reach an asymptotic value. Near the trailing edge, the displacement thickness above and below the wake centerline are approximated using a third order polynomial.

VISCID-INVISCID INTERACTION (Ref 1:27-30)

The displacement effect of the boundary layer and wake is represented according to Spence by an asymetric source distribution: "The Kutta condition is applied at the edge of the upper and lower surface boundary layers at the trailing edge to establish the circualtion of the real flow. The velocities at these points are determined from separate contributions of the potential flow (of reduced circulation) and the source distribution."

This method is advantageous because the airfoil shape remains constant between iterations, and the potential solution is modified as a function of the circulation only. The displacement effect of the wake and boundary layer are represented by an asymetric source distribution with linear strength dQ/ds (s is the arc length along the assumed trailing edge streamline) distributed on the airfoil surface and the trailing edge stream line. The displacement flux Q is given by Q=Ue*DELSR were Ue is the velocity at the edge of the boundary layer and DELSR is the displacement thickness.

On the airfoil surface, Q is established from the viscous flow analysis. Q is determined for each "component" (i.e., upper and lower) of the wake by an approximating polynomial. The manner in which this is done is analogous to the displacement thickness approximation.

SOLUTION CONVERGENCE (Ref 1:31)

"The convergence of the iterative process depends on the relative effect of the viscous parameters, and the extent to which they may be accounted for in the solution." The present analysis does not account for separated regions and may fail to converge if separation occurs.

For attached flow, Ref 1 indicates that the solution will always converge at a rate determined by the particular solution. In general convergence may be assumed after:

$$|(VU-VL)|/VO < 0.005$$

where VU and VL are the upper and lower trailing edge velocities, and VO is the free stream velocity.

"If separation is indicated on only one surface the solution will usually converge, but the validity will depend upon the extent of the separated region. If separation is indicated on only one surface or oscillates between the upper and lower surfaces, the solution will not necessarily converge."

DISCUSSION OF PROGRAM RESULTS (Ref 1:39)

1. "The Spence iterative approach adequately predicts the effects of viscosity on lift for unseparated flow." A computational time savings of approximately a factor of five is achieved for the potential solution, since it does not need to be recalculated for each iteration.

2. "For compressible flow use of conformal mapping techniques for the inviscid solution eliminates uncertainties in the pressure distribution associated with the chord line singularity methods

of previous studies."

3. "The nonlinear compressibility corrections may be applied with confidence in subcritical flows for moderately low lift coefficients."

4. "For attached flow, the total drag coefficient may be calculated accurately for Reynolds numbers representative of model and full scale conditions."

5. "Comparisons with the results of methods that solve the differential form of the boundary layer equations indicate that with respect to drag calculations, comparable accuracy is obtained with the present integral methods." Computation times were found to be one or two orders of magnitude less than for the differential methods.

6. "The variation of section drag with Mach number can be predicted with the present method." Subcritical drag increases can thus be determined up to the point approaching drag divergence.

INPUT VARIABLES FOR THE VISCOUS FLOW SOLUTION

ALPHA	angle of attack in degrees.
CHORD	airfoil chord length in feet, also referenced as c or C.
IBLYR	boundary layer print indicator: 0. suppress all printed data (default), 1. print all data.
ICPV	pressure and velocity print indicator: 0. suppress all printed data (default), 1. print pressure and velocity data.
INTVL	number of intervals into which the circle will be broken into to evaluate the potential flow solution. The accuracy and also the running times will increase as INTVL increases up to the limit of 100. INTVL should be even and and usually equal to NCRD.
ITMAX	number of viscous-inviscid iterations (default ITMAX=3), with 3 being usually enough for convergence, and 15 the maximum number.
KCOMP	compressibility indicator: 0. incompressible flow (default), 1. compressible flow.
KPRNI	viscous-inviscid iteration print indicator: 0. print first and last iteration (default), 1. print all iterations, 2. print last iteration only.
KPRNO	Theodorsen mapping print indicator: 0. suppress all print out (default), 1. print mapping information.
KTHEO	Theodorsen transformation mode indicator: 0. initial case (default), 1. use previous transformation, 2. use previous incompressible transformation.
NITER	number of mapping solution iterations, normally 3 to 8 (default NITER=3).
NFTERMS	number of terms in Fourier Series for the thin airfoil theory solution. NFTERMS=50 by default, and NFTERMS=100 is the maximum allowed.

NTRANL — coordinate point on the airfoil lower surface where the user commands ICAAP to set transition. If NTRANL=0 (default) ICAAP will calculate the point of transition. If NTRANL=-88, ICAAP will set transition at the point where instability occurs. The numbering starts with point 1 at the leading edge and proceeds clockwise around the airfoil back to the last point which is also the leading edge.

NTRANU — same as NTRANL but for the upper surface.

MACH — free stream Mach number (default MACH=0). The Mach number is limited to the range of 0. to 1.

PTZ — airflow total pressure in pounds per square foot (default PTZ=2116.8 psf).

RLE — airfoil leading edge radius divided by the chord (default RLE=0.0).

RTE — airfoil trailing edge radius divided by the chord (default RTE=0.0).

TTZ — airflow total temperature in degrees Rankine (default TTZ=516.688 R).

XCRD — x/c coordinate input vector.

XMREF — x/c coordinate of the moment reference point (default XMREF=.25). This variable is also referenced as X/REFC in the output.

YCRD — y/c coordinate input vector.

YMREF — y/c coordinate of the moment reference point (default YMREF=0.0). This variable is also referenced as Z/REFC in the output.

VUVL — absolute value of the difference between the upper and lower trailing edge velocities divided by the free stream velocity. This variable set a .005 by default sets the iteration convergence criterion.

When selecting KTHEO other than 0 after the initial solution, it is important to adhere to the following guide lines as given in Ref 1.

KTHEO=1	for KCOMP=0, any input change is allowed, for KCOMP=1, any input change is allowed except ALPHA and MACH.
KTHEO=2	for KCOMP=1.0 any input change is allowed except ALPHA.

OUTPUT FOR THE VISCOUS FLOW SOLUTION

THEODORSEN TRANSFORMATION

A DR/DRP	absolute value of the derivative of RHO with respect to RHOP.
A DR/DZ	absolute value of the derivative of RHO with respect to ZETA.
A DRP/DZ	absolute value of the derivative of RHOP with respect to ZETA.
A DW/DR	absolute value of the derivative of the complex potential W, with respect to RHO.
ALPHA	angle of attack.
BETA	SQRT(1-MACH**2) is a compressibility factor.
EP	intermediate value of EPS calculated during each transformation iteration.
EPS	EPS=PHI-THETA= polar angle difference in the circle plane.
DEPS/DPH	derivative of EP with respect to PH.
DEPS/DPHI	derivative of EPS with respect to PHI.
DPSI/DPHI	derivative of PSI with respect to PHI.
IP RHO	value of RHO in the intermediate transformation plane.
IP RHOP	value of RHOP in the intermediate transformation plane.
IP ZETA	value of ZETA in the intermediate transformation plane.
MACH	Mach number.
PH	intermediate value of PHI calculated during each transformation iteration.
PHI	polar angle in the circle plane.
PS	intermediate value of PSI calcualted during each transformation iteration.

PSI	natural log of the contour polar radius in the circle plane.
R	contour polar radius in the intermediate transformation plane.
RHO	complex variable in the circle plane.
RHOP	complex variable in the intermediate transformation plane.
RP RHO	RHO in the airfoil plane.
RP RHOP	RHOP in the airfoil plane.
RP ZETA	ZETA in the airfoil plane.
THETA	polar angle in the intermediate plane.
X/C	nondimensional X airfoil coordinate.
Z/C	nondimensional Z or Y airfoil coordinate.
ZETA	complex variable in the airfoil plane.
W	complex potential in the airfoil plane.

BOUNDARY LAYER VARIABLES

ALPHA	angle of attack.
C=CHORD	chord length in feet.
CL	lift coefficient.
CM	moment coefficient.
CDT	total drag coefficient.
CF	skin friction coefficient.
CP	pressure coefficient.
CX	X component of the normal force coefficient.
CZ	Y or Z component of the normal force coefficient.
DELSR/C	displacement thickness divided by CHORD.

DIFF	difference between the momentum thickness Reynolds numbers at transition and instability.
DELTA/C	boundary layer thickness divided by CHORD.
DMDS	derivative of ME with respect to S.
DTH	ratio of transformed DELTA over transformed THET.
D/QOC	drag divided by the free stream dynamic pressure, and the chord.
H=FORM	compressible form factor.
HI=FORMI	incompressible form factor.
GAMMA/VO	ratio of circulation to free stream velocity.
KBAR	mean shape factor.
KI	incompressible shape factor.
MACH	Mach number.
ME	Mach number at the edge of the boundary layer.
N	normal stream line coordinate.
RINST	momentum thickness Reynolds number at the point of instability where the local momentum thickness is used as the characteristic length in the calculated value.
RCRIT	critical momentum thickness Reynolds number where the local momentum thickness is used as the characteristic length in the calculated value.
RTRAN	momentum thickness Reynolds number at the point of transition where the local momentum thickness is used as the characteristic length in the calculated value.
RWTH	wake momentum thickness Reynolds number where the local momentum thickness is used as the characteristic length in the calculated value.
S	tangential stream line coordinate.

SHEAR	shear parameter.
SINST	arc length at point of instability.
SSEP	arc length at point of separation.
STRAN	arc length at point of transition.
THET/C	momentum thickness divided by the CHORD.
TAUW/QO	free stream skin friction coefficient.
V/VO	local velocity divided by the free stream velocity.
VF/VO	velocity in the wake divided by the free stream velocity.
VN/VO	normal component of the wake velocity divided by the free stream velocity.
VS/VO	tangential component of the wake velocity divided by the free stream velocity.
(VU-VL)/VO	difference between the upper and lower trailing edge velocities divided by the free stream velocity. This parameter is used to judge solution convergence which is assumed after (VU-VL)/VO<0.005.
XFIELD/C	X coordinate in the wake divided by CHORD.
XSTAG/C	X coordinate of the stagnation point divided by CHORD.
ZFIELD/C	Z coordinate in the wake divided by CHORD.
ZSTAG/C	Z or Y coordinate of the stagnation point divided by CHORD.

EXECUTION OF OPTIONS.

Once the user is satisfied with the accuracy and smoothness of the airfoil coordinate data, the next probable step will be to use options 11 through 19 to solve the two-dimensional flow problem. The ouput from these options is limited to printed data. Selecting any output mode (including TPRINT) will be ignored and the switch turned off by ICAAP after execution. The user will be given several options to select which part of the output will be printed, by selecting values of different print indicators. The data necessary to execute other options is saved in a random access file called MEMAUX, and retrieved when needed.

Because of the large amount of printed data generated by these options, all the output is written into the file ANSWER. The user can thus run a particular case or set of cases, stop ICAAP, route ANSWER to the high speed line printer, and restart ICAAP using option 1 to recover the necessary data from MEMORY. The only outputs which will come to the user's terminal are the section force and moment coefficients, chord, Reynolds number, Prandtl number, free stream velocity, stagnation pressure and temperature, and the quantity (VU-VL)/VO which is used to judge solution convergence between iterations.

In the first iteration, the velocity and pressure distributions used to calculate CL, CM, CX, and CZ are those from the potential flow solution around a circle. If the user only desires the inviscid results, then ITMAX=1 should be selected. After the first iteration, the effects of viscosity are taken into consideration and the resulting velocity and pressure distributions no longer correspond to potential flow. The user should note that since the first iteration is the potential flow solution, the boundary layer does not yet exist and therefore (VU-VL)/VO=0.0 for this iteration. The format of this output is represented in Fig 2.

CAUTION: The point distribution used with this set of options is CRUCIAL to the accuracy of the results. Section 2.8 of this manual covers the ways which the coordinate points can be entered, and Section 2.9 covers some of the ways in which the distribution can be modified. Because of the high gradients in the leading and trailing edge regions, the coordinate points should be highly concentrated there.

Option 10: This option provides a quick list of options 10 through 19.

Option 11: This option solves the two-dimensional airfoil problem using a viscous flow analysis code as described in Ref 1.

When the user selects this option, ICAAP first checks that the airfoil coordinates have been previously entered and are stored in the input vectors *XCRD* and *YCRD*. If the coordinates are available, ICAAP will then proceed to prompt from the user the necessary input variables. A brief explanation of the possible values for each requested variable is included as part of each prompt unless the

SUPPRESS switch was turned "on" prior to executing this option. If this switch is "on", the prompt will be limited to only the name of the required variable. If a more detailed discription is desired the user needs only to type a "?" in place of the requested variable. In the option mode, the user may also type HELP,11 to get help from ICAAP in executing this option.

Option 12: In many cases, the user will input the necessary data, execute option 11 and then will want to run another case with a minimal number of changes. Since it would be very inconvenient to re-enter all the data, option 12 has been provided to solve this problem. This option operates exactly as option 11, but it uses all the existing information and thus requires no inputs. If the user previously obtained a solution and wishes to run another case at a different Mach number, it can be done with the following command string.

OPTION> <u>MACH=.15,12</u>

This command string modifies the Mach number and then solves the newly defined flow problem using the viscous flow code, and all other previously defined variables.

If this option is executed prior to using option 11, ICAAP will execute this option using the default or currently available values for the required variables.

Option 13: The purpose of this option is to give the user the ability to make a first approximation at the effects of viscosity on an inviscid velocity field around an airfoil section which has been previously generated by another computer program. This option is very much like option 11 in that most of the required inputs are the same. Variables such as KTHEO, KPRNO, NITER, ITMAX, RLE, RTE, INTVL, which are associated with the Theodorsen transformation and viscous-inviscid iterations will not be requested.

Prior to executing this option, the user must enter the nondimensional velocity distribution V/VO and the airfoil coordinates using option 6. When option 13 is selected, the coordinates entered with option will be stored into the input vectors XCRD and YCRD and will then be available for user modification. Such modification is not recommended if option 13 is to be tried again, because the velocity distribution will no longer correspond to the modified coordinate point distribution.

In all other ways, this option works like option 11, and is executed by a similar command string.

Option 14: The purpose of this option is to provide a practical way of solving the viscous flow problem for several different cases where only the angle of attack ALPHA changes. The information generated by this option, is also that which is needed to execute options 51 through 59.

The required inputs for this option are exactly the same as those for option 11 plus the variables DALPHA, and LCOUNT. DALPHA is the incremental change in angle of attack for each run, and LCOUNT is the total number of runs which is limited to 30. The two additional variables are requested after all the initial run inputs have been requested as in option 11.

Once these variables have been entered, ICAAP will proceed to solve the first case (i.e., LCOUNT=1) using the value of ALPHA as the angle of attack. In the next case, ALPHA=ALPHA+DALPHA and LCOUNT=2. After the first case, ICAAP will use the initial Theodorsen transformation to reduce the computational requirements. The results from each iteration are written at the user's terminal as in option 11, with the rest of the data written into the file ANSWER.

Option 15: This is a spare option.

Option 16: In many cases the user may wish to compare some previously obtained airfoil sectional characteristics with those calculated by ICAAP. To do so, the Reynolds number of both flows must be the same if the principle of flow similarity is to hold. ICAAP calculates REYC based on the given values of PTZ, TTZ, CHORD, and MACH for a particular flow problem. Since ICAAP uses a special curve fit for the kinematic viscosity of the air, the user has little control over the computed value of REYC.

This option is thus provided to allow the user to calculate REYC without solving the viscous flow problem. This option also allows the user to fi. ı the required CHORD to achieve a desired value of REYC. Two options are provided as given below.

1. The value of REYC is calculated based on the values of PTZ, TTZ, MACH, and CHORD given by the user.

2. The value of CHORD is determined based on the values of PTZ, TTZ, MACH, and REYC.

When this option is selected, ICAAP will first ask the user to select the required output variable according to the list given above. Once the selection is made, ICAAP will request the remaining four inputs also as described in the previous list.

Option 17: The purpose of this option is to give the user the ability to make a first approximation for the effects of viscosity of an inviscid velocity field calculated using a Thin Airfoil Theory solution. This theory is used to calculate the velocity field. The pressure coeeficient distribution is calculated using the compressibility correction of Ref 1.

The Prandtl-Glauert compressibility correction is used for the lift and moment coefficients which are determined from the coefficients of the Fourier Series instead of from the integration of the pressure distribution.

With the exception of the manner in which the velocity distribution is generated, this option works like option 13. All the required inputs and resulting outputs will also be the same. Like option 13, this option will calculate the resulting boundary layer factors and give a one iteration approximation at the effects of viscosity.

This option was provided primarily as a teaching tool to better understand the Thin Airfoil Theory solution. The singular velocity at the leading edge has been replaced by a linear approximation using the velocities at points immediately before and after the leading edge, to determine the velocity at this point. The velocity distribution has also been improved by dividing the calculated velocity by Riegel's correction factor (Ref 7). The mathematical statement of this factor is given by:

CORRF=SQRT(1.0+(dy/dx)**2)

where DZ/DX is the airfoil slope at each coordinate point.

Option 18: The purpose of this option is to provide a convenient way to obtain angle of attack sweeps using the Thin Airfoil solution. This option works as option 14, but uses a different flow soltion code and performs only one viscous-inviscid iteration. All the required inputs and resulting output, is the same for both options.

Option 19: This is a spare option.

2.3 Theodorsen Transformation.

This set of options is provided as an aid in evaluating the results from the Theodorsen transformation as used in options 11 through 19. In order to do this, it is first necessary to discribe the theory behind the transformation as reported in Ref 6, and implemented in Ref 1.

According to Theodorsen, it is possible to transform the potential field around any closed contour, into the potential field around a circle. "The first step is to transform the airfoil into a curve which ordinarily does not differ greatly from a circle by the transformation

$$\zeta = z' + \frac{a^2}{z'}$$

where ζ is a complex quantity defining points in the plane describing the flow around the airfoil and z' is another complex quantity defining points in the plane describing the flow around the almost circular curve." The parameter a, is a geometrical scale factor with dimensions of length. Notice that at great distances from the origin $z' \to \zeta$ and thus both flows are similar at infinity. In particular, α is identical in both flows with α defined as the direction of the flow at infinity relative to some fixed reference in the body.

The potential function of the flow past a circle is given (Ref 6:5) by

$$W(Z) = -V\left(Z + \frac{a^2 e^{2\psi_0}}{Z}\right) - \frac{i\Gamma}{2\pi}\log\frac{Z}{a e^{\psi_0}}$$

and the velocity is defined by

$$\frac{dW}{dZ}(Z) = -V\left(1-\frac{a^2 e^{2\psi_0}}{Z^2}\right) - \frac{i\Gamma}{2\pi Z}$$

where W is the complex velocity potential, ψ_0 is a small constant quantity, Γ is the circulation, V is the free stream velocity, and z is a complex quantity defining points in the circle plane.

By applying the Kutta condition which requires that dW/dz vanish at the physical trailing edge, the circulation is uniquely defined (Ref 6:5) by

$$\Gamma = 4\pi V a e^{\psi_0} \sin(\alpha + \epsilon_T)$$

where ϵ_T is defined as the angle of zero lift.

The flow around the circle can now be transformed into the flow around any contour. If the flow at infinity is not altered, then the force on the body at the origin will remain at a fixed value of $L=\rho V \Gamma$ where ρ is the air density. The flow in the z plane is then transformed into the z′ plane (Ref 6:5) by the general transformation

$$Z' = Z e^{\sum_n (A_n + i B_n) \frac{1}{Z^n}}$$

which leaves the flow at infinity unaltered, and where the constants are determined by boundary conditions.

The velocity in the plane is then defined by

$$\frac{dW}{d\zeta} = \frac{dW}{dZ} \cdot \frac{dZ}{dZ'} \cdot \frac{dZ'}{d\zeta}$$

using the chain rule of differentiation.

With the theory behind the transformation now explained, some of the variables will now be redefined to be consistent with those in Ref 1. These variables will be defined by their program names (in capital letters) and will be so referenced henceforth.

THETA $=\Theta$	is the contour polar angle in the intermediate plane.
ZETA $=\zeta$	x+iy=complex variable in the airfoil plane.
W	complex potential in the airfoil plane.
PSI	ln(R) where R is the contour polar radius in the circle plane.
EPS $=\epsilon$	PHI-THETA=contour polar angle difference.
PHI $=\phi$	is the polar angle in the circle plane.
DWDZ	dW/dz=u+iv is the complex velocity potential.
GAMMA $=\Gamma$	is the value of circulation.
RHO $=\rho=Z$	is the complex variable in the circle plane.
RHOP $=\rho'=Z'$	is the complex variable in the intermediate plane.
A $=a$	is the geometrical scaling constant with units of length.
DEPS/DPHI	derivative of EPS with respect to PHI.
DPSI/DPHI	derivative of PSI with respect to PHI.

The graphical representation of these variables as used in Ref 1 can be found in Fig 65. Since only R(Θ) is known initially, the resulting set of integrals are solved by successive approximations where PHI=THETA in the first pass. The results of these iterations are written into the file

ANSWER if the user so desires, and are also available for review with the following set of options.

Since the user can ask for up to 8 transformation iterations (3 is usually sufficient) and there are 5 data vectors of up to 101 data points associated with each iteration, it was considered impractical to print out this information at the user's terminal. For this reason TPRINT is not available with these options. As indicated above, the data will be written into ANSWER when *KPRNO*=1. TPLOT is not presently available although it will be in the future.

Option 20: This option provides a quick list of options 20 through 29.

Option 21: The purpose of this option is to selectively output the PSI vs PHI distribution for each transformation iteration. There are no inputs required with this option, and the command string

OPTION> <u>CPLOT,TEKPLOT,21</u>

generates the outputs represented in Fig 3 and Fig 4.

Option 22: The purpose of this option is to selectively output the EPS vs PHI distribution for each transformation iteration. There are no inputs required for this option, and the command string

OPTION> <u>CPLOT,TEKPLOT,22</u>

generates the outputs represented in Fig 5 and Fig 6.

Option 23: The purpose of this option is to selectively output the DPSI/DPHI vs PHI distribution for each transformation iteration. There are no inputs required for this option, and the command string

OPTION> <u>CPLOT,TEKPLOT,23</u>

generates the outputs represented in Fig 7 and Fig 8.

Option 24: The purpose of this option is to selectively output the DEPS/DPHI vs PHI distribution for each transformation iteration. There are no inputs required with this option, and the command string

OPTION> <u>CPLOT,TEKPLOT,24</u>

generates the outputs represented in Fig 9 and Fig 10.

Option 25: This is a spare option.

Option 26: This is a spare option.

Option 27: This is a spare option.

Option 28: This is a spare option.

Option 29: This is a spare option.

2.4 Boundary Layer Information

This set of options is provided for the user to selectively examine the boundary layer information generated by the solution of the viscous flow problem using options 11 through 19. As discussed in Section 2.2 of this manual, the user may specify what part of the boundary layer information is to be written into the file ANSWER. However, in order to better evaluate the results, it is most desirable to have the ability of selectively plotting or printing a particular set of results. This is provided for the user by the use of the TPRINT, CPLOT, and TEKPLOT output modes with each option. TPLOT is not available for these options because of the poor resolution of the line printer.

There is no input required for this set of options with the exception that the information to be examined must already exist as a result of executing options 11 through 19. This information is stored in a Random Acess file called MEMAUX for future use. Unlike other data (i.e., XCRD and YCRD vectors) the information stored in MEMAUX is not available to the user except through the use of this set of options.

There are four global variables available to the user with these options that allow a great deal of flexibility in selecting the appearance of the plots. These variables are CFMAX, DELSTRM, CPMAX, VMAX and are simply scaling variables used to truncate the data for plotting. When drawing plots

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2 OF 3
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for these options, ICAAP checks to make sure that the absolute value of the data does not exceed the scaling variable. Any variable that exceeds the existing maximum is truncated to the value of the scaling variable. ICAAP then proceeds to select the best scaling possible for the resulting data. This procedure allows the user to ignore points which are very much greater than the rest of the data (i.e., the pressure coefficient becomes very large at the leading edge) and examine the remaining points using a more representative scaling.

For this set of options, the airfoil is not divided into upper and lower surfaces by the chord line from the leading to the trailing edge. Instead the upper surface consists of all points from the stagnation point clockwise to the trailing edge. The lower surface consists of all points from the stagnation point counterclockwise to the trailing edge.

Option 30: This option provides a quick list of options 31 through 39.

Option 31: This option is used to examine the skin friction coefficient CF at each coordinate point. The variable CFMAX is used to control the maximum allowable value of CF for plotting. CFMAX is set at 0.012 by default but may be modified at any time by the user while in OPTION mode. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,31</u>

generates the outputs represented in Table 1, Fig 11 and Fig 12.

Option 32: This option is used to examine the displacement thickness DELSR at each coordinate point. The variable DELSTRM is used to determine the maximum allowable value of DELSR to be used for plotting. DELSTRM is set equal to 0.02 by default but may be modified by the user at any time while in the OPTION mode. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,32</u>

generates the outputs represented in Table 2, Fig 13 and Fig 14.

Option 33: This option is used to examine the momentum thickness THETA at each coordinate point. The variable DELSTRM is also used here as in option 32. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,33</u>

generates the outputs represented in Table 3, Fig 15 and Fig 16.

Option 34: This option is used to examine the compressible form factor FORM (or H) at each coordinate point. The form factor is defined as the ratio of the displacement thickness to the momentum thickness. The boundary layer is considered to be in a state of turbulent separation at points were the incompressible form factor

FORMI (or HI) is greater than 2.8 as discussed in option 35. Because of this limitation, the maximum scaling value is set at 3.5 but unlike CFMAX and DELSTRM, the user can nct modify this value. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,34

generates the outputs represented in Table 4, Fig 17 and Fig 18.

Option 35: This option is used to examine the incompressible form factor FORMI (or HI) at each coordinate point. This factor is used to predict were turbulent boundary layer separation occurs. In Ref 1, the authors define the turbulent boundary separation as locations were FORMI is greater than 2.8, which is also the limit of computational accuracy for the turbulent boundary layer analysis included in ICAAP. As in option 34, the maximum scaling value is set at 3.5 and is not available for user modification. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,35

generates the outputs represented in Table 5, Fig 19 and Fig 20.

Option 36: This option is used to examine the Mach number ME at the edge of the boundary layer. The maximum scaling value is set at 2.0 and is not available for user modication. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,36

generates the outputs represented in Table 6, Fig 21 and Fig 22.

This option is of special importance in judging the accuracy and validity of the calculated results. The viscous flow code used by ICAAP will accurately predict the airfoil sectional characteristics up to the point where MACH=1.0 in the boundary layer. For MACH>1.0 shocks will begin to form and the results from ICAAP will loose accuracy very quickly. The user should then use this option to judge wether or not to accept the calculated results as valid for a particular set of conditions.

Option 37: This option is used to examine the boundary layer thickness DELTA at each coordinate point. The variable DELSTRM is used as in option 32 to determine the maximum allowable value of DELTA to be used for plotting. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,37

will generate the outputs represented in Table 7, Fig 23 and Fig 24.

Option 38: This is a spare option.

Option 39: This is a spare option.

2.5 Velocity and Pressure Distribution

The pressure and velocity distribution calculated by ICAAP while executing options 11 through 19 will be written into the file ANSWER if the user so specifies while entering the required data. However, since tabular data is often difficult to interpret, it is very convenient to have the ability of selectively plotting or printing this data. In some cases the user may wish to plot the data calculated by ICAAP against another set such as experimental data. For this situation it is very advantageous to be able to plot both sets of data separately or combined on the same graph for comparison. It is to meeting the above mentioned needs that this section has been devoted. TPLOT is not available with these options because of the poor resolution of the line printer. If an ouput mode is not selected with these options, the option will be aborted by ICAAP. If TPLOT is selected for any of these options, it will be ignored and turned "off" after execution.

Option 40: This option provides a quick list of options 40 through 49.

Option 41: The purpose of this option is to selectively ouput the pressure coefficient CP distribution calculated by ICAAP using options 11 through 19. The maximum allowable value of CP to be used for plotting is set by the Global variable CPMAX. CPMAX is set at -3.0 by default, but can be modified at any time by the user while in the option mode.

There are no inputs required for this option, with the exception of the output mode. The data used is the latest available data which is stored in the XCRD and CP vectors. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,41

generates the ouputs represented in Table 8, Fig 25, and Fig 26.

Option 42: The purpose of this option is to selectively output a pressure coefficient distribution entered by the user using option 5. The data source is the only difference between this option and option 41. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,42

will also generate the outputs represented in Table 8, Fig 25 and Fig 26. Use of this option with option 5 enables the user to examine a velocity distribution from any source, wihtout having to write a computer program to do the printing and plotting.

Option 43: The purpose of this option is to compare a user provided CP distribution awainst one calculated by ICAAP. This option is very useful in determining the accuracy of ICAAP's solution against experimental or other data for various conditions. There are no inputs required for this option, with the exeception of the output mode. ICAAP will use the latest data available resulting from the execution of options 11 through 19, and that entered by the user with option 5 and stored in the file MEMAUX. The command string

OPTION> <u>CPLOT,TEKPLOT,43</u>

will generate the ouputs represented in Fig 27 and Fig 28. Since TPRINT is available with options 41 and 42, it is not available with this option.

Option 44: The purpose of this option is to selectively ouput the nondimensional velocity V/V0 distribution calculated by ICAAP using options 11 through 19. The maximum allowable value of V/V0 to be used for plotting is set by the Global variable VMAX. VMAX is set at 3.0 by default, but can be modified at any time by the user while in the option mode. V is the local value of the velocity and V0 is the free stream velocity.

There are no inputs required for this option, with the exception of the output mode. The data used is the latest available data which is stored in the XCRD and V vectors. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,44</u>

generates the ouputs represented in Table 9, Fig 29, and Fig 30.

Option 45: The purpose of this option is to selectively output a nondimensional velocity distribution entered by the user using option 6. With the exeception of the data source, this option works like option 44. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,45</u>

will also generate the outputs represented in Table 9, Fig 29 and Fig 30. Use of this option with option 6 enables the user to examine a velocity distribution from any source, without having to write a computer program to do the printing and plotting.

Option 46: The purpose of this option is to compare a user provided V/V0 distribution against one calculated by ICAAP. This option is very useful in determining the accuracy of ICAAP's solution against experimental or other data for various conditions. There are no inputs required for this option, with the exeception of the output mode. ICAAP will use the latest data available resulting from the execution of options 11 through 19, and that entered by the user with option 6 and stored in the file MEMAUX. The command string

OPTION> <u>CPLOT,TEKPLOT,46</u>

will generate the ouputs represented in Fig 31 and Fig 32. Since TPRINT is available with options 44 and 45, it is not available with this option.

Option 47: This is a spare option.

Option 48: This is a spare option.

Option 49: This is a spare option.

2.6 Lift, Moment and Drag Coefficients

When dealing with the problem of flow around airfoils, the eventually desired results are values for the lift, drag and moment coefficients for the airfoil under various conditions. The values of these coefficients at various angles of attack ALPHA are extremely important in determining the performance of the airfoil section. These so called ALPHA sweeps are also very important in approximating the resulting coefficients on three dimensional wings using a particular airfoil section. Because of their importance, this section is dedicated to selectively outputing ALPHA sweeps calculated by ICAAP with option 14, and also those provided by the user for comparison.

The moment coefficient is determined about a point selected by the user with the use of the variables XMREF and YMREF.

TPLOT is not available with these options because of the poor resolution of the line printer. If TPLOT is selected for any of these options, it will be ignored and turned "off" by ICAAP. If an output mode is not selected with these options, the option will be aborted.

Option 50: This option provides a quick list of options 50 through 59.

Option 51: The purpose of this option is to selectively output a lift coefficient CL vs ALPHA distribtution as calculated by option 14. There are no inputs required with this option, with the exception of the output mode. In addition, the data must have been previously generated by option 14. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,51

generates the outputs represented in Table 10, Fig 33 and Fig 34.

Option 52: The purpose of this option is to selectively output a CL vs ALPHA distribution previously supplied by the user using option 2. This option works like option 51, except for the source of the data. This option is provided so that the user may examine a CL vs ALPHA distribution from any source, without the need of writing a computer program to print or plot such an often used set of data. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,52

will also generate the ouputs represented in Table 10, Fig 33 and Fig 34.

Option 53: The pupose of this option is to selectively plot a user provided CL vs ALPHA distribution, against one calculated by ICAAP's option 14. The only requirement for executing this option, is that both the calculated and user supplied data must exist prior to executing this option. The command string

OPTION> <u>CPLOT,TEKPLOT,53</u>

generates the outputs represented in Fig 35 and Fig 36. Since TPRINT is available with options 51 and 52, it is not available with this option.

Option 54: The purpose of this option is to selectively output a moment coefficient CM vs ALPHA distribtution as calculated by option 14. There are no inputs required with this option, with the exception of the output mode. In addition, the data must have been previously generated by option 14. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,54</u>

generates the outputs represented in Table 11, Fig 37 and Fig 38.

Option 55: The purpose of this option is to selectively output a CM vs ALPHA distribution previously supplied by the user using option 3. Except for the source of the data, this option operates exactly as option 54. This option is provided so that the user may examine a CM vs ALPHA distribution from any source, without the need of writing a computer program to print or plot such an often used set of data. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,55</u>

will also generate the ouputs represented in Table 11, Fig 37 and Fig 38.

Option 56: The pupose of this option is to selectively plot a user provided CM vs ALPHA distribution, against one calculated by ICAAP's option 14. The only requirement for executing this option, is that both the calculated and user supplied data must exist prior to executing this option. The command string

OPTION> <u>CPLOT,TEKPLOT,56</u>

generates the outputs represented in Fig 39 and Fig 40. Since TPRINT is available with options 54 and 55, it is not available with this option.

Option 57: The purpose of this option is to selectively output a lift coefficient CL vs drag coefficient CD distribtution as calculated by option 14. There are no inputs required with this option, with the exception of the output mode. In addition, the data must have been previously generated by option 14. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,57</u>

generates the outputs represented in Table 12, Fig 41 and Fig 42.

Option 58: The purpose of this option is to selectively output a CL vs CD distribution previously supplied by the user using option 4. Except for the source of the data, execution of this option is the same as option 57. This option is provided so that the user may examine a CL vs CD distribution from any source, without the need of writing a computer program to print or plot such an often used set of data. The command string

OPTION> <u>TPRINT,CPLOT,TEKPLOT,58</u>

will also generate the ouputs represented in Table 12, Fig 41 and Fig 42.

Option 59: The pupose of this option is to selectively plot a user provided CL vs CD distribution, against one calculated by ICAAP's option 14. The only requirement for executing this option, is that both the calculated and user supplied data must exist prior to executing this option. The command string

OPTION> <u>CPLOT,TEKPLOT,59</u>

generates the outputs represented in Fig 43 and Fig 44. Since TPRINT is available with options 57 and 58, it is not available with this option.

2.7 Airfoil Discription and Verification.

For this set of options, all forms of output are available with each option, except where a particular form was found to be impractical. Examples of this are options 61 and 65 where the printer can not provide the necessary resolution between points and TPLOT is therefore not available with these options.

When options 61 through 69 are specified, ICAAP fits a cubic spline to the input coordinates stored in vectors XCRD and YCRD, and calculates the necessary derivatives. This approach protects the user from accidentally trying to plot a set of data corresponding to a previous input coordinate set. Before fitting the spline, ICAAP checks to see if the required data has been previously entered in the proper format (trailing edge is point 1 and the numbering increases clockwise around the airfoil back to the trailing edge which is also the last point). If no output mode is selected, ICAAP simply aborts the option.

Option 60: This option provides a quick list of options 60 through 69.

Option 61: This option plots or tabulates the nondimensional airfoil coordinates X/CHORD and Y/CHORD. No input is required from the user, but the coordinate points must have been previously entered (see start of this section). The scaling of the airfoil plot allows for airfoils which are up to 60 percent CHORD in thickness.

Since most airfoils are less than 20 percent thick, the scaling provided in ICAAP is more than adequate.

There may be some cases where the input airfoil is very thin (3 percent or less) resulting in poor resolution of the airfoil plot. In such cases the user may wish to use the switch FATPLOT as in the following command string.

OPTION> FATPLOT,CPLOT,61

This command string turns "on" the switch FATPLOT which is a logical switch set to "off" by default. When turned "on", FATPLOT cuts the y axis scale in half for options 61 and 65. This distorts the actual shape of the airfoil by cutting the plot aspect ratio in half, but it will still provide a good idea of the actual airfoil shape for very thin airfoils. Once FATPLOT is "on", it remains "on" and must be turned "off" by the user. The resulting plot from the above command string can be found in Fig 63. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,61

generates three forms of output which are represented in Table 13, Fig 45 and Fig 46. The output mode TPLOT is not available with this option because of the poor resolution of a line printer in plotting the coordinate points.

Option 62: This option plots or tabulates the values of the airfoil slope dy/dx at each coordinate point. As in option 61, the only requirement for execution is that the airfoil coordinates must have been previously entered into the input vectors XCRD and YCRD.

Since the slope will be very large near the leading edge, the values are truncated for plotting to the value of SLOPEM (default=.30). The variable SLOPEM is a global variable which is the maximum value of the slope data to be plotted. The value can be changed by the user at any time while in the option mode by using the command string

OPTION> <u>SLOPEM=.40</u>

The values of the slope are calculated with the chain rule of differentiation (see any calculus book). The slope of x and y with respect to arc length s are first calculated by fitting a cubic spline to the coordinates, and then used to calculate the slope according to:

$$dy/dx=(dy/ds)/(dx/ds)$$

Use of this option involves a command string such as:

OPTION> <u>TPRINT,CPLOT,TEKPLOT,TPLOT,62</u>

which generates four separate forms of output for this option as demonstrated in Table 14, Fig 48, Fig 49 and Fig 50.

Option 63: This option plots or tabulates the values of the airfoil slope rate of change at each coordinate point. As in option 62, the only requirement for execution is that the airfoil coordinates must have been previously stored in the input vectors XCRD and YCRD.

Since the second derivative will be very large near the leading edge, the values are also truncated to a maximum value for plotting given by YTPRIM (default=3.0). The variable YTPRIM is a global variable which can be modified by the user at any time while in option mode (see option 61).

The values of the second derivative are also calculated using the chain rule of differentiation (see option 61). The second derivatives of x and y with respect to arc length s are calculated first and then used to calculate the values of slope rate of change at every point.

Use of this option involves a command string such as:

OPTION> <u>TPRINT,CPLOT,TEKPLOT,TPLOT,63</u>

which generates the four forms of output represented in Table 15, Fig 51, Fig 52 and Fig 53.

Option 64: This option plots or tabulates the values of the airfoil curvature at each point. The only requirement for execution is that as in option 63, the airfoil coordinates must have been previously entered into the input vectors XCRD and YCRD.

Use of this option involves a command string such as:

OPTION> <u>TPRINT,CPLOT,TEKPLOT,64</u>

which generates the two output formats which are represented in Table 16, Fig 55 and Fig 56. Note that because of the resulting complexity of the plot in Fig 55, and the poor resolution of the line printer, the TPLOT output mode is not available with this option. As in previous options, selecting TPLOT for this option will be ignored by ICAAP, and the mode switch turned "off".

Option 65: This option plots or tabulates the airfoil coordinate points, slope, slope rate of change, and curvature. If a plot is generated, it is a composite plot containing the four plots normally generated by options 61 through 64. The command string

OPTION> <u>CPLOT,65</u>

will generate the composite plot found in Fig 56. If the TPRINT mode is selected, the output from this option will be the four tables normally generated by options 61 through 64.

The principal purpose of this option is to give the user a quick idea of how smooth or "noisy" the input coordinate data is without having to execute four separate options. Since the airfoil plot is only 1/4 of its normal size, the FATPLOT switch (see option 61) may also be used with this option. As in options 61 and 64, the TPLOT and TEKPLOT modes are not available for this option.

Option 66: This is a spare option.

Option 67: In many cases, the coordinate point data may represent an airfoil with an open trailing edge. Since the airfoil section used by ICAAP must be closed, this option is provided as a means of closing the trailing edge of an open airfoil section.

The approach taken in this option is to modify the upper and lower airfoil surfaces from a point specified by the user, back towards the trailing edge. The new surfaces are found with the use of an approximating polynomial of an order specified by the user.

NLOW (default=10) identifies the number of points from the lower trailing edge clockwise, from where the approximation will begin back toward the lower trailing edge which is point 1.

NUP (default=10) identifies the number of points from the upper trailing edge counter clockwise, from which the approximation will begin back toward the upper trailing edge which is also counted as point 1.

POWER (default=3.5) identifies the power of the approximating polynomial to be used. Figure 57 explains the results from this option.

The default values used in this option were selected based on experience gained using this option and on the recommendation of Snyder (Ref 5). Different combinations of the given variables will give different results and it is left up to the user to judge how accurate the results are. The reason for this is that there are infinitely many combinations which can be used to achieve similar results.

If the user desires to use all the default values, then this option can be executed by simply using:

OPTION> 67

If the user wants to use his values for any of the variables, then this can be simply accomplished with the command string

OPTION> <u>NUP=5,NLOW=2,POWER=3.0,67</u>

Note that since the function of this option is only to modify the coordinate points there is no need to specify any output mode. If an output mode is specified, it will be ignored and turned "off" by ICAAP.

Option 68: This option provides a very smooth plot of the airfoil section which does not include plot axis or symbols. A cubic spline is used to interpolate additional points in addition to those given as input. As in option 65, the only input required for this option are the coordinate points which must be stored in the input vectors XCRD and YCRD.

The size of the airfoil section will be that of the chord length CHORD interpreted as inches at the time of execution. Therefore if CHORD=10.0, the airfoil section will be 10.0 inches long plus an extra inch for the plot margins. The vertical margin dimension is determined by:

YBOX=6.0/9.0*(CHORD+1.0)

With the use of the above formula, the user may get a plot of the airfoil section (as would be needed for a template) which does not include any margins by selecting a big enough CHORD such that YBOX>9.0 inches. Note that since the plot size is determined by the variable CHORD, the use of a scale factor FACT is redundant and ignored by this option. For example, the command string

OPTION> CHORD=8,CPLOT,68

generates a CALCOMP plot of the section which is 9.0 inches long and 6.0 inches high as demonstrated in Fig 58. The user may also modify the distance between the points to be interpolated by redifining the variable GAIN (default is 0.05). GAIN is a global variable which may be modified at any time by the user while in the option mode. The optimum value of GAIN will be determined by the smallest distance between points which can be distinguished by the plotter being used.

Since the only purpose of this option is to provide a very smooth airfoil plot, all other forms of output will be ignored by ICAAP.

Option 69: This is a spare option.

2.8 Input and Output of Airfoil Coordinate Points

This set of options is used to input or output the airfoil coordinate points. The coordinate points as referenced and used everywhere in ICAAP are assumed to be nondimensional fractions of the chord length in the form: X/CHORD and Y/CHORD.

The X and Y coordinate points are stored in two one-dimensional arrays (vectors) named XCRD and YCRD respectively. These vectors are global variables and are available for user inspection or modification at all times.

Option 70: This option provides a quick list of options 70 through 79.

Option 71: This option is used to input the airfoil coordinates from the keyboard. ICAAP will expect the point distribution to be in one of two formats. The first assumes the leading edge to be the first and last point to be entered. The numbering sequence starts with 1 at the leading edge and increases clockwise around the airfoil back to the leading edge which is the last point NCRD. The second format assumes the numbering sequence to start with 1 at the trailing edge and increase clockwise around the airfoil back to the trailing edge which is also counted as the last point NCRD.

When execution of this option begins, ICAAP will scan the input data to find the maximum chord length and then nondimensionalize the data by dividing it by the maximum chord length. If the entered data is at an angle (i.e., the leading and trailing edge y/c coordinates are not equal) ICAAP will determine the angle of twist using the following formula.

TWISTD=ArcSin((YTE-YLE)/CHORD)

TWISTD is the angle of twist in degrees, YTE and YLE are the trailing and leading edge y/c coordinates, and CHORD is the maximum calculated chord length.

If the value of TWISTD is not zero, then the input data will be rotated TWISTD degrees, with the new and old data tabulated as in Table 21.

ICAAP will first request the number of points to be entered, NCRD, and will then request the points to be entered one at a time. After all points have been entered, ICAAP will store the point distribution in the second format described above and will test for a closed airfoil by checking that YCRD(1)=YCRD(NCRD). If an open airfoil is detected, ICAAP will print an error message and suggest to the reader the use of option 67 to close the trailing edge to a point.

There is no output from this option except for points which are echoed as they are entered if the switch ECHO is "on", and the new rotated coordinates if TWISTD is not zero. Selecting any output format for this option will be ignored by ICAAP and the mode switch turned "off" after execution.

Option 72: This is a spare option.

Option 73: Execution of this option, is like that of option 71. The only difference is that the coordinate points are read in free format from a user supplied file called CRDPTS. This file must be attached prior to initializing ICAAP in order to use this option to read in the data from a permanent file as in option 71, with the data separated by a "," or a blank. ICAAP will expect to first read the number of coordinate points followed by the points one pair at a time. If the switch ECHO is "on", ICAAP will print each point as it is read in. All output modes selected for this option are ignored and turned "off" after execution.

Option 74: This option works opposite to option 73. The purpose of this option is to save the coordinate points stored in vectors XCRD and YCRD on file CRDPTS in a format suitable for use with option 73 at a later time. One possible use for this option is to modify a coordinate point distribution as desired, then use option 74 followed by a temporary termination of ICAAP. The user is then free to copy and catalog the local file CRDPTS as a permanent file for future use.

When this option is selected, the existing file CRDPTS is returned and the the data is written to a newly opened file. This procedure is necessary to avoid trying to overwrite on a permanent file. All output modes selected for this option are ignored and turned "off" by ICAAP after execution.

Option 75: This is a spare option.

Option 76: Since many of today's aerodynamic flow problems involve in one way or another the use of the NACA designated airfoils, it is very convenient to have a simple means of obtaining the coordinate point distribution for such airfoils. This is exactly the purpose of option 76 using part of a program (ref. 2) developed at the U.S. Air Force Flight Dynamics Laboratory.

Unlike the original program, the one used by ICAAP calculates only the airfoil coordinate points, using the cosine spacing rule to distribute the points. This is a widely accepted rule in the field of aerodynamics because it concentrates the point distribution at the leading and trailing edge where a smooth airfoil definition is most critical. The mathematical statement of this rule is given below where NP is the maximum number of points, N is the current point number and PI is the constant 3.141592654.

X/CHORD(N)=(1.0-COS(N*PI/NP))/2.

The following is a summary of the program capabilities and limitations as discussed in appendix I of Ref 2. The program has the capability of providing up to 200 coordinate points for NACA airfoils with some given restrictions.

1. (4-Digit)----------: no restrictions.

2. (4-Digit Modified)-: position of maximum thickness must be 0.2, 0.3, 0.4, 0.5, or 0.6 CHORD as indicated in the designation by the second integer in the suffix.

3. (5-Digit)----------: no restrictions.

4. (5-Digit Modified)-: same as 4-Digit Modified.

5. (1-Series)---------: position of minimum pressure must be 0.6, 0.8, or 0.9 CHORD as indicated by the second integer in the designation.

6. (6-Series)---------: position of minimum pressure must be 0.3, 0.4, 0.5, or 0.6 CHORD as indicated by the second integer of the designation.

There is an additional restriction with the 6-Series sections. These sections where derived with the use of conformal transformations to match a given pressure distribution. The procedure involved the use of intuetive choices for certain functions which are not documented. Without knowledge of these functions, it is not possible to use exact mathematical expressions for the camber line and thickness distributions of these sections. Kinsey and Bowers use an approximate method, adopted in ICAAP, based on the 4 and 5-Digit Series which gives the section coordinates accurate to within .35%chord (Ref 2:**). The leading edge radius predicted by the approximate method is not as accurate. To correct this problem, ICAAP fits a cubic spline to the section coordinates and then estimates a new leading edge radius. The calculated value is accurate to within 10.0% of the actual value.

The first input that will be required from the user is the selection of the NACA series type by selecting the value of NACA from the table given below.

The second input required by ICAAP is the actual NACA designation with a maximum of eight digits. The designations are entered according to one of the following examples, where a "-" indicates a blank. The A in the designations is replaced by a 1.

NACA Series	NACA Designation	NACA	Input to ICAAP
4-Digit	0012	1	[0012]
4-Digit Modified	2406-32	2	[2406 32]
5-Digit	23118	3	[23118]
5-Digit Modified	43006-65	4	[43006 65]
1-Series	16-212	5	[16 212]
6-Series	65,2A212a=.6	6	[65212126]
6-Series	64A212	6	[64 1212]
6-Series	63,2-212	6	[632 212]
6-Series	64-005	6	[64 005]

The difference between coordinates of the designations is negligible. Fractional inputs in hundreths of percent chord are allowed for 4-Digit, 5-Digit and 1-Series airfoils. The fractional part of the thickness value is placed immediately to the right of the NACA designation. A 4-Digit symetrical airfoil with a maximum thickness of 12.25% chord is entered as [001225].

CAUTION: ICAAP does not use its standard READS subroutine to read in the series designation. The user must take special care to type 8 integers or less for the designation. The user should also avoid using the special control characters ($, ?, L) normally available because an error condition will result when trying to read them.

The next input required for this option are the sweep indicator (ISWEEP) and the sweepback angle (PHE) in degrees. ISWEEP=1-->indicates an airfoil with no sweep (default). ISWEEP=2-->indicates an airfoil sweptback PHE degrees.

A sheared airfoil has the section coordinates defined by the NACA designation parallel to the stream flow regardless of leading edge sweep. The defined section of swept airfoils is always taken perpendicular to the leading edge. Since the airfoil coordinates are nondimensional, it is only necessary to compute a corrected chord length for swept airfoils. This operation is performed by ICAAP prior to execution of options 11 through 19.

It is important to note that ICAAP does not calculate the three dimensional velocity distributions on swept or sheared airfoils. The velocity distribution is calculated for a transformed airfoil section which has been rotated PHE degrees.

The last input required by this option is the desired number of airfoil coordinate points which must be 200 or less. If the selected number is even, the actual number that will be calculated is one less. If the requested number of points is odd then the number calculated will be the same.

The output for this option consists of the airfoil coordinates which will be stored in XCRD and YCRD and the leading and trailing edge radius nondimensionalized by the chord. If an output mode other than TPRINT is selected for this option, it will be ignored and turned "off" after execution.

Option 77: The purpose of this option is to provide an alternative point distribution to that given by the cosine spacing rule in option 76. This option is specially designed to generate 49 coordinate points for NACA designated airfoils, with the highest point concentration at the leading and trailing edges. The following table indicates where the x/c coordinates will be for the upper and lower y/c values.

1.0000	0.4000	0.0200	0.0600	0.5600
0.9800	0.3500	0.0100	0.0800	0.6400
0.9400	0.3000	0.0050	0.1000	0.7200
0.9000	0.2500	0.0010	0.1500	0.8000
0.8500	0.2000	0.0000	0.2000	0.8500
0.8000	0.1500	0.0010	0.2500	0.9000
0.7200	0.1000	0.0050	0.3000	0.9400
0.6400	0.0800	0.0100	0.3500	0.9800
0.5600	0.0600	0.0200	0.4000	1.0000
0.4800	0.0400	0.0400	0.4800	

Use of this option is highly recommended when using NACA designated sections in options 11, 12, 13, 14, and 15. The point distribution provided by this option is superior to that of option 76 with only 49 coordinate points. This option works like option 76 with the exception of the distribution, and the number of points.

Option 78: This is a spare option.

Option 79: This is a spare option.

2.9 Smoothing and Coordinate Point Mofication.

The problem of airfoil coordinate point smoothing can be broken up into two distinct parts. The first is the smoothing of data points whose relative values vary little from point to point. This is a difficult and complex problem which is beyond the scope of ICAAP at the present time. This problem will be treated indepth in future versions of ICAAP. The second smoothing problem is that in which one or more points are vastly different from the surrounding points. This problem is usually the result of a typing error (i.e., a misplaced decimal point). This is a much more common problem than the first and it is to solving this problem that this section is dedicated.

As in options 60 through 69, ICAAP will work on the data stored in the XCRD and YCRD vectors. Besides these two vectors, there are three other global variables (NFIRST, NLAST, and NSEGPT) which can be used to modify the operation of options 80 through 89. These variables are defined and discussed in the following pages.

Option 80: This option provides a quick list of options 80 throufh 89.

Option 81: This option is used to plot a user specified segment of the coordinates (i.e., the leading and trailing edge regions) in an attempt to identify points which are in error. The global variable NSEGPT (default is 5) controls the maximum number of points within the segment of interest. The default value was chosen to optimize the scaling used in the resulting plots. However, the user may at any time reset NSEGPT to any value between 1 and the number of points available. For example, the command string

OPTION> NSEGPT=10

resets the variable to 10 and it will remain that way until the user changes it.

Upon requesting option 81, ICAAP will ask the user to enter the value of the first (NFIRST) and last (NLAST) points which define the segment of interest. These are also global variables which may be modified at the user's discretion. The numbering sequence used is the same as that discussed in Section 2.8 of this manual for options 71 through 79. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,81

will generate three forms of output which are represented in Table 17, Fig 59 and Fig 60. If no output mode is specified for this option, ICAAP will simply return to the OPTION mode.

Option 82: The purpose of this option is to allow the user to replace one or more coordinate points which are believed to be in error, one at a time. Two separate modes are provided for achieving the replacement. The first allows the user to enter the new (X/C,Y/C) coordinates for the point in question. In the second mode the user only needs to identify the point in question, and ICAAP will use a cubic spline to interpolate a new ordinate value (Y/C) at the same abcissa (X/C). The interpolation is achieved by temporarily deleting the point in question, fitting a cubic spline to the new point distribution, and then using the calculated derivatives to obtain the new ordinate value. This technique has been found to give very good results except at the leading and trailing edge points where the derivatives are very large and rapidly changing.

Unlike the other coordinate points, the leading and trailing edge points are interpolated by using a weighted average approach. This approach involves using the derivatives from the points just before and immediately after the point in question to calculate two (usually different) estimates for the new ordinate. The estimates are then multiplied by a weighting factor and then the average of the two products is taken as the new ordinate value. The weighting factor is a function of the arc length between the points such that the further away a point is from the point in question (leading or trailing edge), the smaller its influence will be on the final average value.

Option 83: The purpose of this option is to provide the slope of the airfoil surface for a segment of interest. This option performs like option 81 and has the same limitations. The only difference between the two options is that option 83 outputs the airfoil surface slope. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,83

generates the outputs represented in Table 18, Fig 61 and Fig 62.

Option 84: The purpose of this option is to provide the slope rate for a segment of interest. This option operates exactly as options 81, and 83 except that the slope rate of change is provided as output. The command string

OPTION> TPRINT,CPLOT,TEKPLOT,84

generates the outputs represented in Table 19, Fig 63 and Fig 64.

Option 85: This is a spare option.

Option 86: The purpose of this option is to tabulate the values of the airfoil coordinates, slope, and slope rate of change for a segment of interest. The ouput from this option is printed data only, as demonstrated in Table 20. This table was generated by the command string

OPTION> NSEGPT=40,86

Since only printed output is available with this option, all other output modes selected with this option will be ignored and turned "off" after execution.

Option 87: The purpose of this option is to delete one or more coordinate points from an existing distribution. This option is of special importance when the user wants to change the form of the airfoil coordinate point distribution.

The user may ask for a point distribution of up to 200 points using option 76, and then use this option to delete groups of points near the middle of the airfoil section until the desired number of points is achieved. This procedure will result in a point distribution which is highly concentrated at the leading and trailing edge regions where a smooth airfoil definition is the most critical.

When this option is selected, ICAAP will ask the user to enter the number of points to be deleted and the number of the first point to be deleted. If the TPRINT mode is selected, ICAAP will print out the new point distribution. All other modes of output will be ignored and truned "off" after execution.

Option 88: The purpose of this option is to insert one or more points into an existing coordinate point distribution. As with option 87, this option can be used to achieve a point distribution which is higly concentrated at the leading and trailing edge regions.

When this option is selected, ICAAP will ask the user to enter the number of points to be inserted and the number of the point in the present distribution after which the new points will inserted. ICAAP will then ask the user to enter the points one at a time. If TPRINT is selected for this option, ICAAP will print out the new coordinate distribution. Since printed output is the only output mode available, selecting any other output mode will be ignored and the mode switch turned "off" after execution.

Option 89: The purpose of this option is to add airfoil coordinate points at user specified x/c locations. When the user enters the desired x/c value, ICAAP will use a cubic spline to calculate the corresponding y/c value.

The only requirement for execution of this option is that the airfoil coordinates must have been previously entered. When this option is selected, ICAAP will first ask the user to select on which surface (upper or lower) the new y/c value will be calculated. After the surface is selected, ICAAP will then ask for the x/c value at which the point is to be located.

The output from this option consists only of the (x/c,y/c) coordinates of the added point. If any output mode is selected with this option it will be ignored and turned "off" after the option is executed.

2.10 Miscellaneous Options

This set of options are dedicated to performing various functions which are of special interest, but are not related to the other option groups.

Option 90: This option provides a quick list of options 90 through 99.

Option 91: When the user types STOP to end ICAAP, the existing file MEMORY is returned and all data (including the contents of MEMAUX) is automatically written into a new file MEMORY. This option allows the user to store this data without having to stop the program. Periodic use of this option is recommended to prevent the loss of all data in the event of an uncontrolled program termination.

Option 92: This option erases the screen on the Tektronix terminals.

Option 93: This option provides the current switch settings of all switches in ICAAP. When the user types HELP,93 ICAAP will provide a complete description of each switch and how to use them.

Option 94: This option provides a hard copy of the screen contents for Tektronix terminals.

Option 95: This option provides a summary of the latest new features added to ICAAP.

Option 96: This option provides a list of all special commands that are allowed in the OPTION mode. This list can also be generated by typing COMMANDS. Section 3 of this manual contains a complete description of these commands.

Option 97: The purpose of this option is to provide for the user a quick reference list of all of ICAAP's Global variables. This list can also be generated by typing VARIABLES. Section 4 of this manual contains a complete description of these variables, and also how to list and modify them.

Option 98: The purpose of this option is to list the ten main option groups of ICAAP. This list can also be generated by typing OPTIONS.

Option 99: This option provides a brief introduction on the use of ICAAP. The same introduction is also obtained by typing HELP.

3.0 Special Commands

ICAAP has several special commands whose purpose is to enhance the user's control of the program. In the following list, the commands are in capital letters, items in parenthesis are optional parameters, and those in small letters refer to general command types. The minimum allowable abbreviation for each command is given by the underlined letters. Note that as discussed in Section 1.1, commands may only be entered in the OPTION mode.

STOP,(SUP)	end ICAAP (suppress messages).
HELP,(option number)	get help from ICAAP on (specified option number).
Switchname,(ON or OFF)	turn switch (on or off). If the switch name is typed alone, it is equivalent to typing Switchname,ON.
CALCULATOR	delayed entry into the CALCULATOR mode.
CREATE,keyname,string	define a macro using the given keyname to execute the specified command string.
PAGE	skip to the top of a new page in file ANSWER.
COMMENT,(string)	write string in file ANSWER.
RETURN,file	return the specified local file.
ROUTE,file	route file to the plotter or printer. The user will also be asked to give the terminal identification TID, the disposition code DC, the user identification FID, and the computer system ST.

STOP,(SUP)

This command stores all the data necessary to restart ICAAP into the file MEMORY. The command also notifies the user of any files that have been created during execution, and terminates ICAAP. All messages will be suppressed if the user enters STOP,S.

HELP,(option number)

The user can get help from ICAAP to execute any option by typing HELP followed by the option number. The command string

OPTION> HELP,72

will give the user a brief explanation of how to execute option 72. The discussion given by the HELP command is brief but enough to refresh the user's memory on the details of that option. More detailed explanations are given for each option in Section 2 of this manual.

Switchname,(ON or OFF)

The purpose of this command is to allow the user to set ICAAP's control switches. With the use of this command and the control switches, the user can custom taylor ICAAP's operation to fit individual needs and preferences. Option 93 in Section 2.10 has a complete description of ICAAP's control switches.

CALCULATOR

The purpose of this command is to allow a delayed entry into the CALCULATOR mode. When the user enters a C, the CALCULATOR mode will begin immediately after the carriage return key is pressed. Entering this mode in such a manner will preceed all othe commands in the input string. The command string

OPTION> <u>ECHO,OFF,73,C,11,S</u>

will be executed in the order

C,ECHO,OFF,73,11,s

to allow the user to jump directly into the CALCULATOR mode at any time. To enter the calculator in the sequence specified, the user must use a longer abbreviation such as CALC instead of C.

<u>CREATE,keyname,command string</u>

The CREATE command is provided so that the user can difine a macro command made up of any combination of commands, option numbers, variable names and other macros. The net result of this command is the ability to <u>program</u> ICAAP to perform for example lengthy command strings.

There are three possible macro names (key names) allowed in this mode: AKEY, BKEY and CKEY. "Each key can be made of up to 50 instructions to do anything allowed in the OPTION mode. These instructions are then executed like a subprogram any time the key name is typed" (Ref 3:A-70).

For example, if the user wants a macro that will read in the airfoil coordinates from file CRDPTS, generate a Tektronix plot of the airfoil, and solve the viscous flow problem, he could enter

OPTION> CREATE,AKEY,73,TEKPLOT,63,11

and press the carriage return. The commands would then be executed when he entered AKEY.

Another command string such as

OPTION> CREATE,BKEY,CALC,ALPHA=X,12,BKEY

will allow the user to run consecutive solutions of the viscous flow problem using option 12. ICAAP will pause in the CALCULATOR mode to give the user a chance to enter the angle of attack into the X register. After the user enters C to leave the CALCULATOR mode,

is executed. The final command in the string BKEY makes BKEY call itself and the sequence is repeated, stopping in the CALCULATOR mode for the next value of ALPHA. This process is repeated endlessly until the user enters a $ to abort the loop. CAUTION, if a pause is not included somewhere in the loop to request some input, the user will not have a chance to end the loop, and will have to totally abort ICAAP with a %A.

Each macro key can have up to 50 commands, and since one macro can call another, the user has the capability of creating a program up to 150 steps long. The macros are stored in sequential files which the user can catalog and retrieve at a later date.

4.0 ICAAP's Variables

ICAAP's data base is divided into two main types of variables. Local variables are defined as those used by one or more overlays but not available for user modification. Global variables are those used by one or more overlays, and available at all times for user inspection and modification. ICAAP's Global variables are subdivided into scalar constants and one dimensional arrays (vectors). Each variable may be listed by simply typing its name, and may be assigned or modified as described in the following sections.

4.1 Scalar Variables

The user may modify the values of the scalar variables by setting the variable equal to a number or another Global variable. For example, the variable CHORD may be typically listed or modified in the following ways.

CHORD	value of CHORD is listed.
CHORD=5.6	CHORD is set equal to 5.6.
CHORD=ALPHA	CHORD is set to the value of ALPHA.
CHORD=XCRD(1)	CHORD is set to the value of the first location in the vector XCRD.
CHORD=X	CHORD is set to the value of the X register

A complete list of ICAAP'S Global variables can be found at the end of this section.

4.2 One Dimensional Variables (Vectors)

Although ICAAP uses a variety of vectors, they are all in one way or another dependent on the input vectors XCRD and YCRD. These two vectors contain the x/c and y/c airfoil coordinates where c is the airfoil chord length. All other vectors will in general contain data (i.e., CP and V/VO) which was calculated using XCRD and YCRD. The data in these other arrays can be examined by one or more of ICAAP's options, but there is no point in modifying them without also changing the input vectors. However, it is most desirable to be able to change the values in XCRD and YCRD at any time, such as changing a YCRD value which is found to be inaccurate. The following list indicates some of the possible ways in which ICAAP's vectors can be modified.

XCRD	all the contents of XCRD are listed.
XCRD(3)	the contents of XCRD(3) are listed.
XCRD(5)=.25	the contents of the fifth location in XCRD are set equal to .25.
XCRD(1)=X	the first location in XCRD is set equal to the contents of the X register.
XCRD(1)=REGISTER(1)	the first location in XCRD is set equal to the contents of the first location in REGISTER.

4.3 Ouput Modes

During the development stages of ICAAP, it was determined that having four separate options to output a particular set of data (i.e., printed, Printer plot Calcomp plot, Tektronix plot) as done in Ref 3 would be redundant. A more efficient procedure designed for ICAAP is to have one option execute one or any combination of the four forms of outputs depending on the setting of four output mode switches which are set by the user. These switches and their definitions are given below.

CPLOT	when this switch is "on", a Calcomp plot will be generated for the data in question, and written to the file PLOT.
TEKPLOT	when this switch is "on", a Tektronix plot will be generated for the data in question similar to that generated by CPLOT. To use this switch, the user must be at a Tektronix terminal.
TPLOT	when this switch is "on", a Printer plot of the data in question will be generated at the user's terminal.
TPRINT	when this switch is "on", the data in question will be printed at the user's terminal in a tabular manner.

In each case, if the option has a variable output format, the mode switch must be typed (this turns it "on") immediately prior to the option to which it will apply. All four mode switches are initially "off", and are turned "off" after an option is executed. If a mode is specified for an option which does not have a variable output format, the switch will be ignored and turned "off" after the option is executed. This procedure was found necessary to prevent inadvertent generation of plots or printed data by an output mode switch which is left "on". For example, the command string

OPTION> CPLOT,TEKPLOT,TPLOT,TPRINT,62,TEKPLOT,63

generates the output modes represented in Fig 48, Fig 49, Fig 50, Table 14, and Fig 52.

GLOBAL SCALAR VARIABLES

ALPHA	angle of attack in degrees.
CDT	total section drag coefficient (list only).
CFMAX	maximum value to which the skin friction coefficient will be truncated for plotting.
CHORD	airfoil chord length in feet.
CL	section lift coefficient (list only).
CM	section moment coefficient (list only).
CPMAX	maximum value to which the pressure coefficient will be truncated for plotting.
DELSTRM	maximum value to which the displacement thickness will be truncated for plotting.
DGAMOU	change in circulation between viscid and inviscid iterations. This variable should normally be used at its default value, unless the solution for given conditions should fail to converge.
FACTOR	scale factor for Calcomp Plots.
GAIN	plotting increment between points in option 68.
IBLYR	boundary layer print indicator.
ICPV	pressure and velocity print indicator.
INTVL	number of solution intervals around the circle in the Theodorsen transformation.

ITMAX	number of viscous-inviscid iterations.
KPLT	plotting symbol indicator.
KPRNI	viscous-inviscid solution print indicator.
KPRNO	Theodorsen transformation print indicator.
KTHEO	Theodorsen transformation mode indicator.
MACH	Mach number.
NCRD	number of airfoil coordinate points (list only).
NITER	number of Theodorsen transformation iterations.
NFIRST	first point defining an airfoil segment.
NFTERMS	number of terms to be used in the Fourier Series Summations of options 17 and 18.
NLAST	last point defining an airfoil segment.
NLOW	coordinate point on airfoil lower surface defining the start of the approximating polynomial in option 67.
NPTS	plotting point increment (i.e., plot every 2nd point).
NSEGPT	maximum number of points in airfoil segment.
NTRANL	lower surface laminar-turbulent transition point indicator.
NTRANU	upper surface laminar-turbulent transition point indicator.
NUP	coordinate point on upper surface defining the starting point of the approximating polynomial in option 67.
POWER	power of approximating polynomial in option 67.
PTZ	total pressure in pounds per square foot.
REYC	Reynolds number (list only).
RLE	airfoil leading edge radius divided by the chord length.

RTE	airfoil trailing edge radius divided by the chord length.
SLOPEM	maximum value to which the airfoil slope will be tuncated for plotting.
T	calculator stack register.
TTZ	total temperature in degrees Kelvin.
TWISTD	transformed airfoil relative angle of twist in degrees for option 72.
VMAX	maximum value to which the velocity V/VO will be truncated for plotting.
X	calculator display register.
XMREF	nondimensional X/C airfoil moment reference point.
Y	calculator stack register.
YMREF	nondimensional Y/C or Z/C airfoil moment reference point.
YTPRIM	maximum value to which the airfoil second derivative will be truncated for plotting.
VUVL	absolute value of the difference between the upper and lower trailing edge velocities divided by the free stream velocity. This variable set at 0.005 by default sets the iteration convergence criterion.
Z	calculator stack register.

GLOBAL VECTORS

DATA	data array containing the inputs necessary for execution of options 11, 12, 13, 14, and 15.
REGISTER	calculator memory registers.
XCRD	nondimensional X/CHORD airfoil coordinate vector.
YCRD	nondimensional Y/CHORD airfoil coordinate vector.

5.0 ICAAP's Scientific Calculator

The calculator used by ICAAP operates in the same way as that in TOTAL (Ref 3: Section 5). The calculator is modeled after an HP-45 hand calculator which uses reverse polish notation. It has a stack of four registers X, Y, Z, and T where X is the display register, and twenty registers stored in the Global vector REGISTER. The user may enter or leave the CALCULATOR mode at any time by typing a C. This mode is represented by the prompt **. A listing of the calculator keys may be obtained at any time by typing "KEYS" as shown below.

** KEYS

ROLL	CHS	LOG	MEMORY
EXCHANGE	SIN	ALOG	STORE
CLX	COS	POLAR	RECALL
CLEAR	ASIN	FIX	DTOR
RECIPROCAL	TAN	RECTANG	LASTX
SQUARE	ACOS	SCI	RTOD
SQROOT	ATAN	LIST	DEGREES
YTOX	LN	STACK	RADIANS
PI	EXP	FASTSTACK	KEYS

These keys are defined later in this section.

"To enter a number into the X register, the user simply types it. Numbers are entered automatically when followed by a blank, comma, or carriage return. Typing any of the variable names listed in Section 4 automatically enters the variable's value into the X register."

Entering 1.0, 2.0, 3.0, and 4.0 can be done as follows.

```
** 1,2,3,4,STACK
T=                1.000000
Z=                2.000000
Y=                3.000000
X=                4.000000
```

The 1 is initially entered in the X register until it is moved into Y by the 2. The 3 moves the 2 and 1 up another register. The 4 is the last number entered which leaves the contents of the four stack registers as demonstrated above by the STACK command.

"Once numbers have been entered, all operations occur between X and Y. For example typing a "+" would add the contents of X to Y, and leave the result in X. The contents of Z then drop into Y and T drops into Z. The contents of register T are unaffected. Similar results are obtained by typing "-", "*", or "/", where "/" divides Y by X and "-" substracts X from Y."

To evaluate the equation

(3.14*2.78+8.62*98.6)/6.02

the user would enter

```
** 3.14,2.78,*,8.62,98.6,*,+,6.02,/
```

with the answer being printed after the following sequence of events is performed.

1. 3.14 is entered in the X register.
2. 2.78 is entered in the X register and 3.14 is moved into Y.

3. X and Y are multiplied, leaving the result 8.73 in X.

4. 8.62 is entered into X moving 8.73 into Y.

5. 98.6 is entered into X moving 8.62 into Y, and 8.73 into Z.

6. X and Y are multiplied leaving the result 849.93 in X and dropping 8.73 back into Y.

7. X and Y are added leaving the result 858.66 in X.

8. 6.02 is entered into X moving 858.66 into Y.

9. Y is divided by X leaving the result 142.63 in X.

10. the value in the X register is printed as the answer.

Further explanations on the use of stack operations are beyond the scope of this manual. The user should refer to the user's manual of any Hewlett-Packard calculator for a more detailed explanation of the stack operations.

In the following descriptions, old refers to the key status before it is executed, and new refers to the status afterwards. The minimum allowed abbreviation for each key is given by the underlined letters.

ACOS	sets new X equal to Arccos(old X).
ALOG	sets new X equal to 10 raised to the old X power.
ASIN	sets new X equal to Arcsin(old X).
ATAN	sets new X equal to Arctan(old X).
CLEAR	clear stack (sets X, Y, Z, and T to 0.0).
CHS	change sign of X.
CLX	clear X (sets X equal to 0.0).

COS	sets new X equal to Cos(old X).
DEGREES	puts calculator in degree mode.
DTOR	converts old X in degrees to new X in radians.
EXCHANGE	moves old X into new Y, and old Y into new X.
EXP	sets new X equal to exp(old X).
FASTSTACK	prints contents of X, Y, Z, and T registers horizontally.
FIX	when followed by any number from 0 to 14, will set all future calculator displays to that many decimal places.
KEYS	list all the calculator keys.
LASTX	recalls the value of X prior to the last operation.
LIST	prints contents of X register. This key is very useful in displaying intermediate results in a long string of calculator commands.
LN	sets new X equal to the natural log(old X).
LOG	sets new X equal to the common log(old X).
MEMORY	prints contents of all 20 memory registers.
PI	enters 3.14159265358979 into new X, old X into new Y, old Y into new Z, and old Z into new T.
POLAR	converts X and Y in rectangular coordinates to polar, where X is the magnitude and Y is the angle.
RADIANS	puts calculator in radian mode.
RECALL	this command must be followed by a number from 1 to 20. This command stores the contents of the specified register into the new X.
RECL	this is another form of RECALL.
RECIPROCAL	sets new X equal to reciprocal of old X.

RECTANG	converts X magnitude and Y angle into X and Y rectangular coordinates.
ROLL	moves old Y into new X, old Z into new Y, old T into new Z, and old X into new T.
RTOD	converts old X in radians to new X in degrees.
SCI	when followed by a number form 0 to 14, will set all numbers displayed thereafter in scientific notation with the specified number of decimal places.
SIN	sets new X equal to Sin(old X).
SQROOT	sets new X equal to the square root of old X.
SQUARE	sets new X equal to old X squared.
STACK	prints contents of X, Y, Z, and T registers vertically.
STORE	must be followed by a number from 1 to 20. The contents of X are stored in the specified memory register.
TAN	sets new X equal to Tan(old X).
YTOX	sets new X equal to old Y to the old X power, moves old Z into new Y, and old T into new Z.

The calculator may be entered at any time, even in the middle of an option while entering data. See Section 1.1 for further details on the CALCULATOR mode.

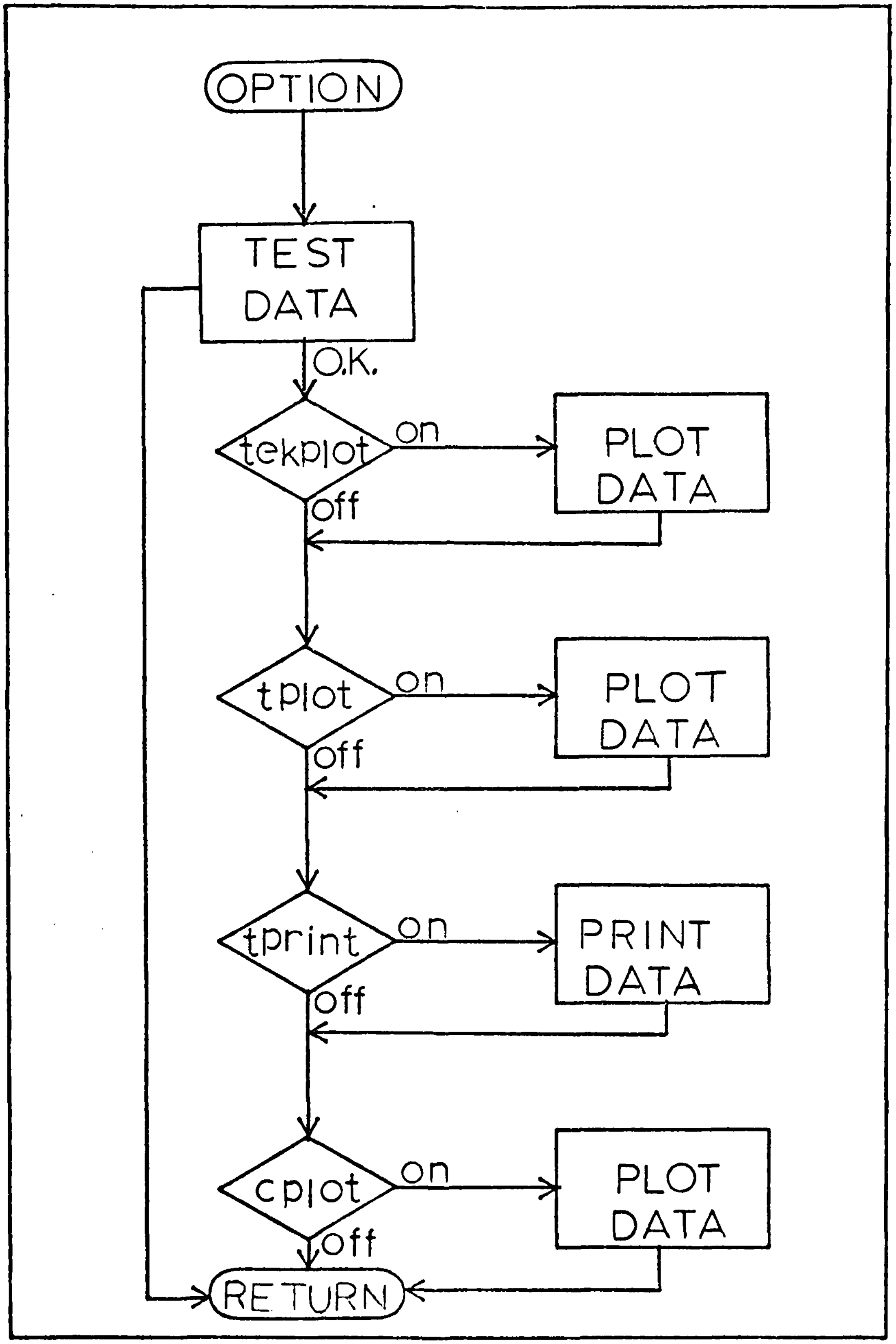


Figure 1. Options Execution Flow Chart.

```
CHORD  =      4.3628   FT

MACH   =       .3000

VO     =   331.9585   FT/SEC

PTO    =  2116.8000   PSF

TTO    =   518.6880   DEG R

PR     =       .7093

REC    =    9.0000E+06


MACH =     .3000   ALPHA =    2.0000   REC =     9.0000E+06

MOMENT REFERENCE POINT   XREF/C =  .2500      ZREF/C = 0.0000

ITER       CL          CM          CDT         CDF       (VU-VL)/VO

  1      .44193     -.05112      .00546      .00457     0.0000000

  2      .38711     -.03972      .00527      .00455      .0647807

  3      .38594     -.03944      .00527      .00455      .0025331
UPPER SURFACE

INSTABILITY OCCURS AT STATION   5
TRANSITION  OCCURS AT STATION   6

LOWER SURFACE

INSTABILITY OCCURS AT STATION   9
TRANSITION  OCCURS AT STATION  19


RUN TOOK  2.082 CPU SECONDS
```

Figure 2. Output from Viscous Flow Solution.

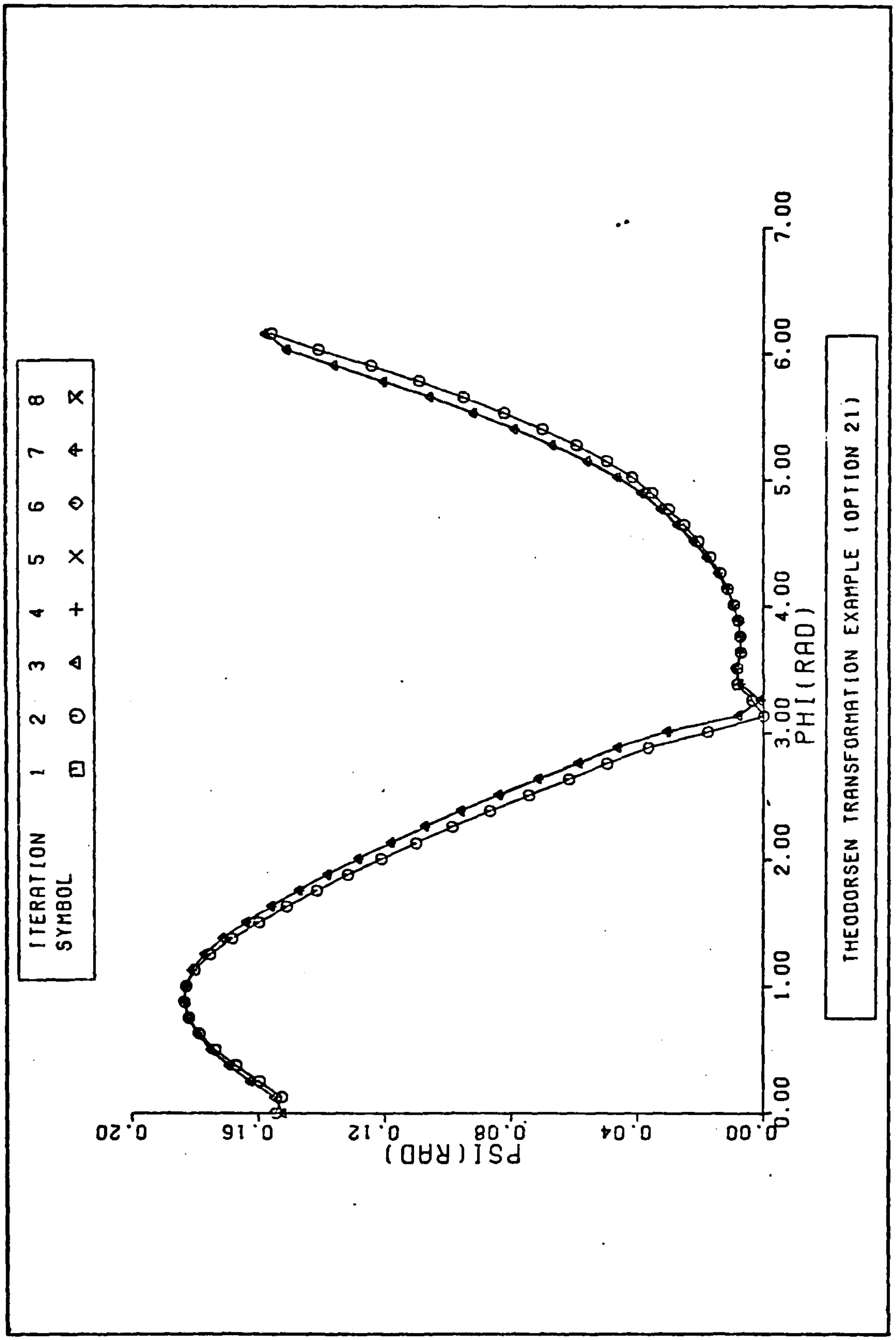


Figure 3. PSI vs PHI (CPLOT).

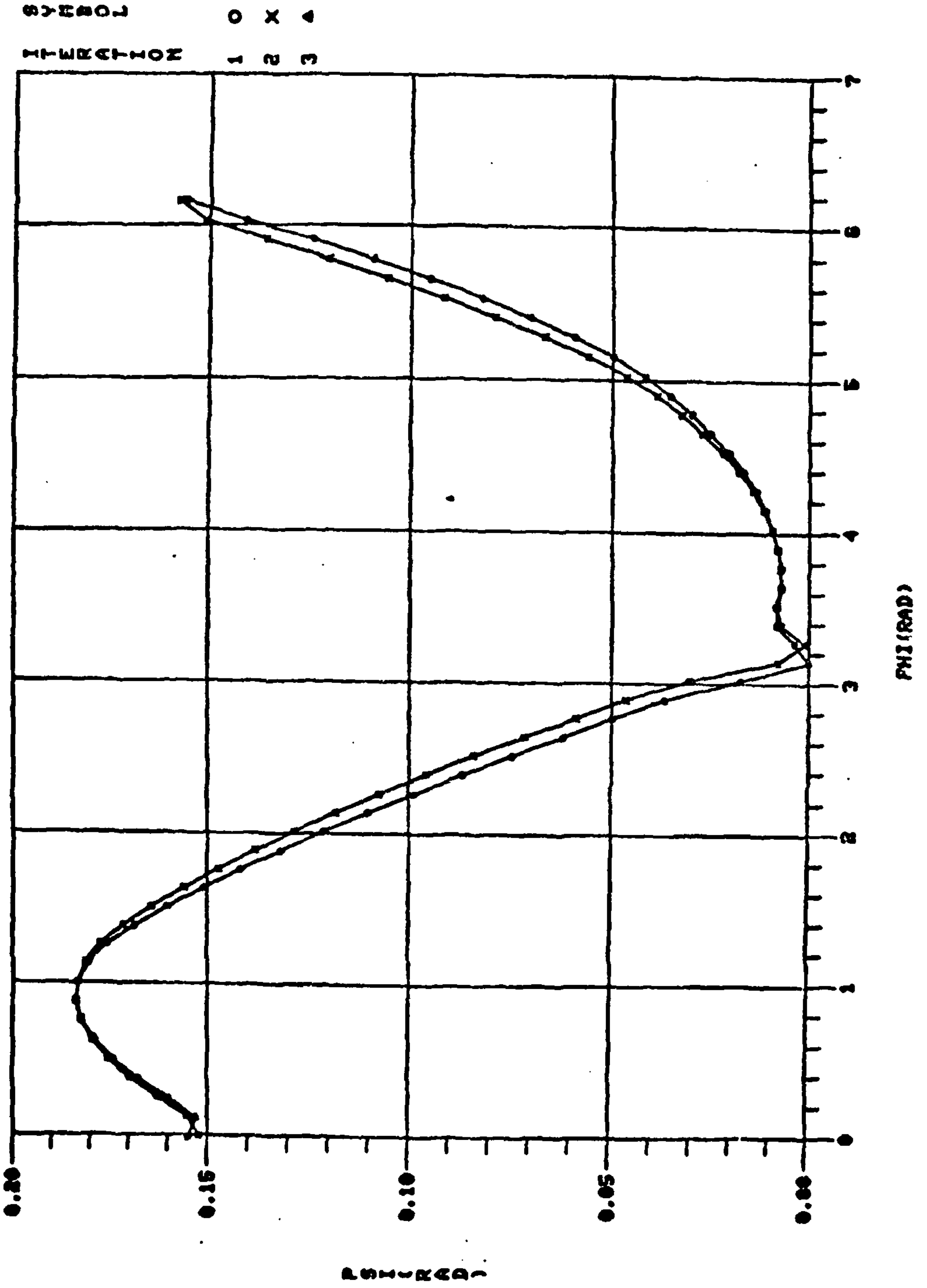


Figure 4. PSI vs PHI (TEKPLOT).

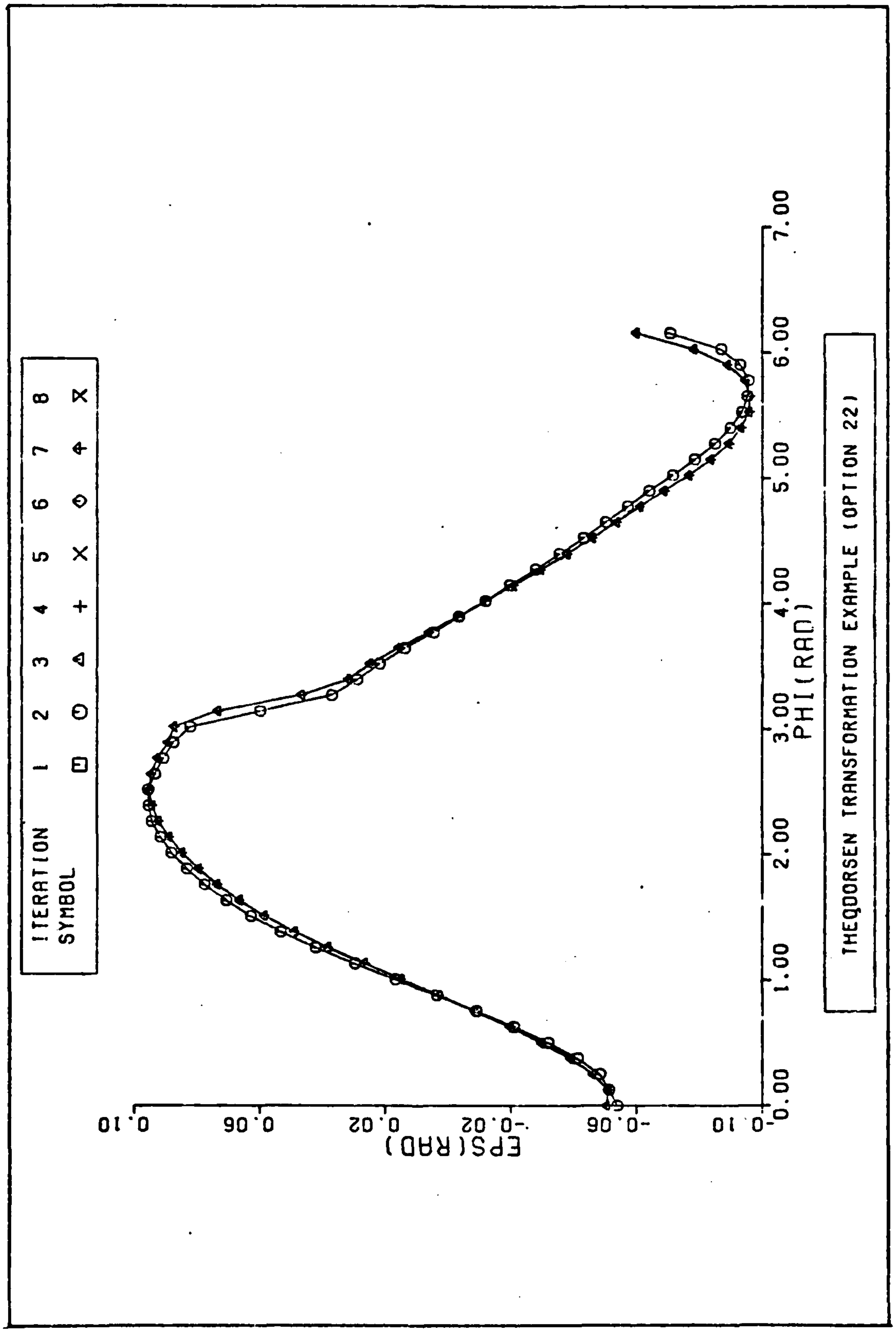


Figure 5. EPS vs PHI (CPLOT).

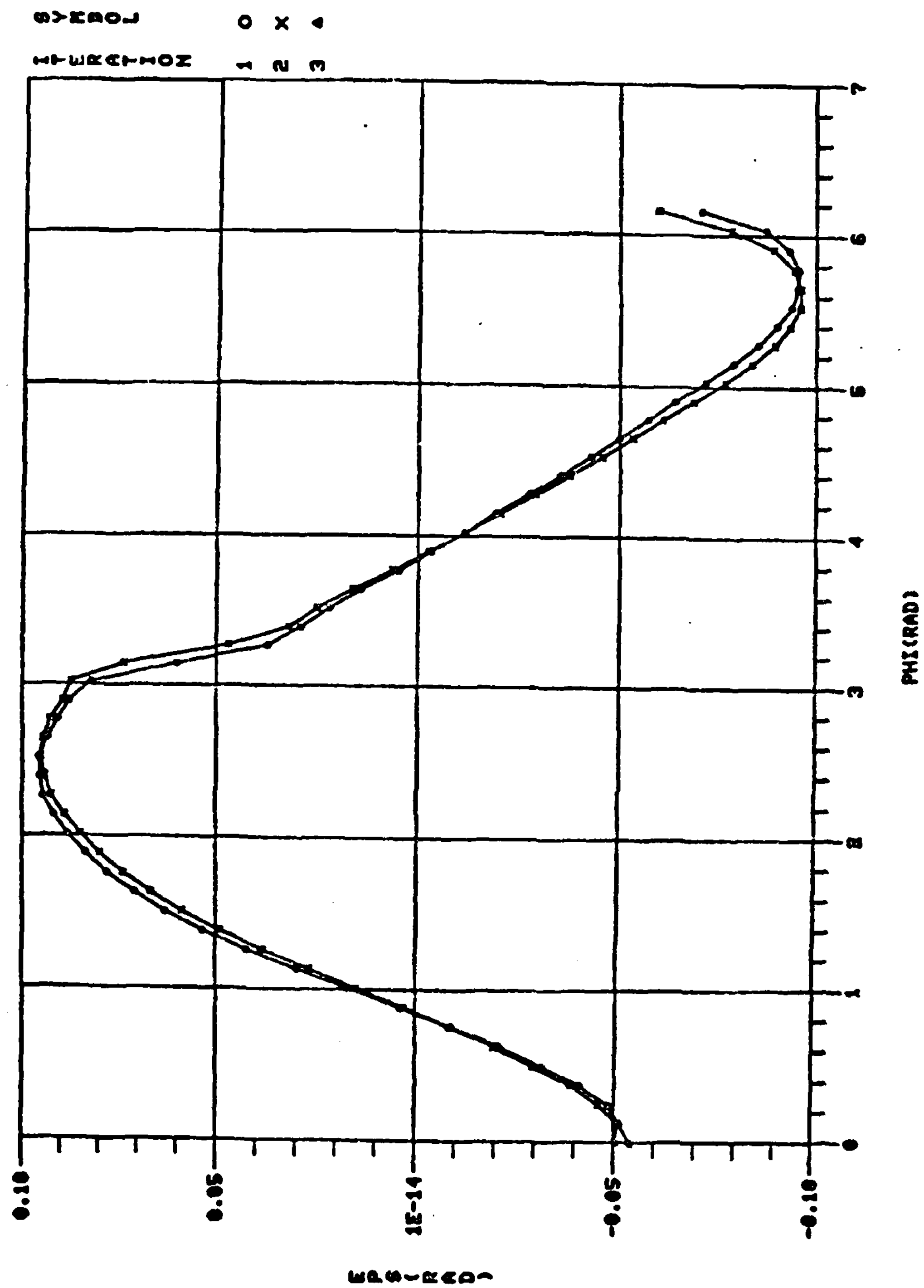


Figure 6. EPS vs PHI (TEKPLOT).

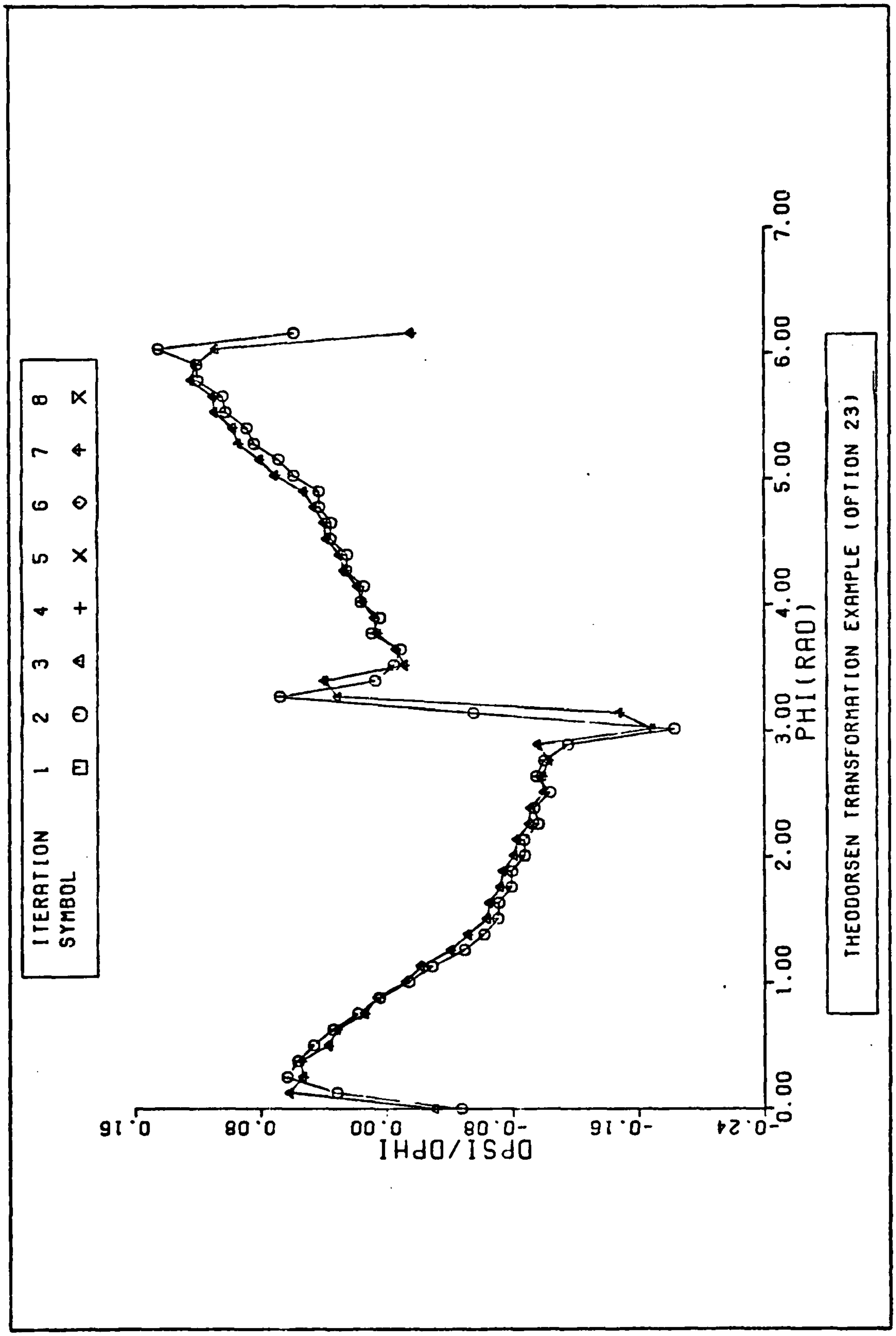


Figure 7. DPSI/DPHI vs PHI (CPLOT).

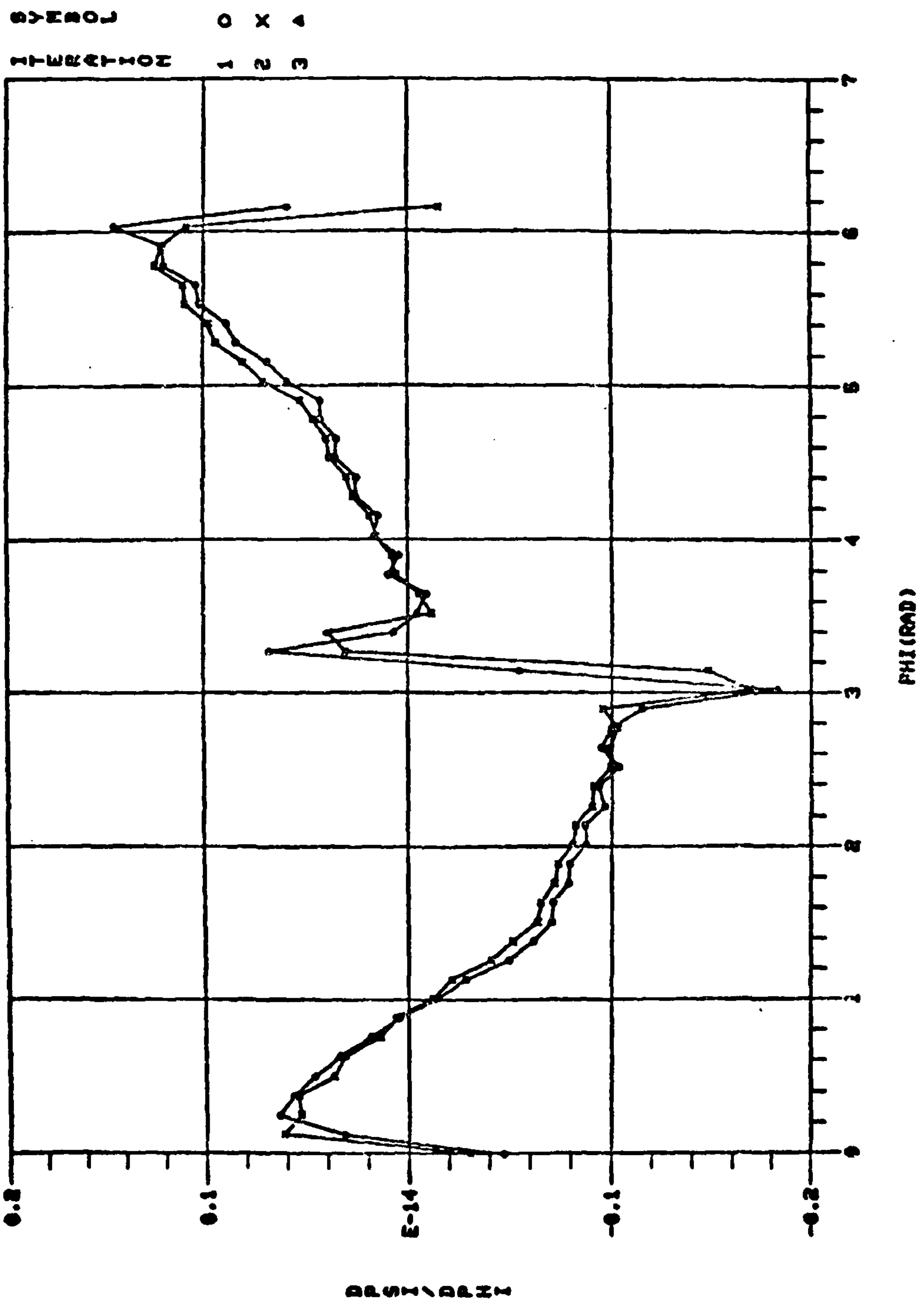


Figure 8. DPSI/DPHI vs PHI (TEKPLOT).

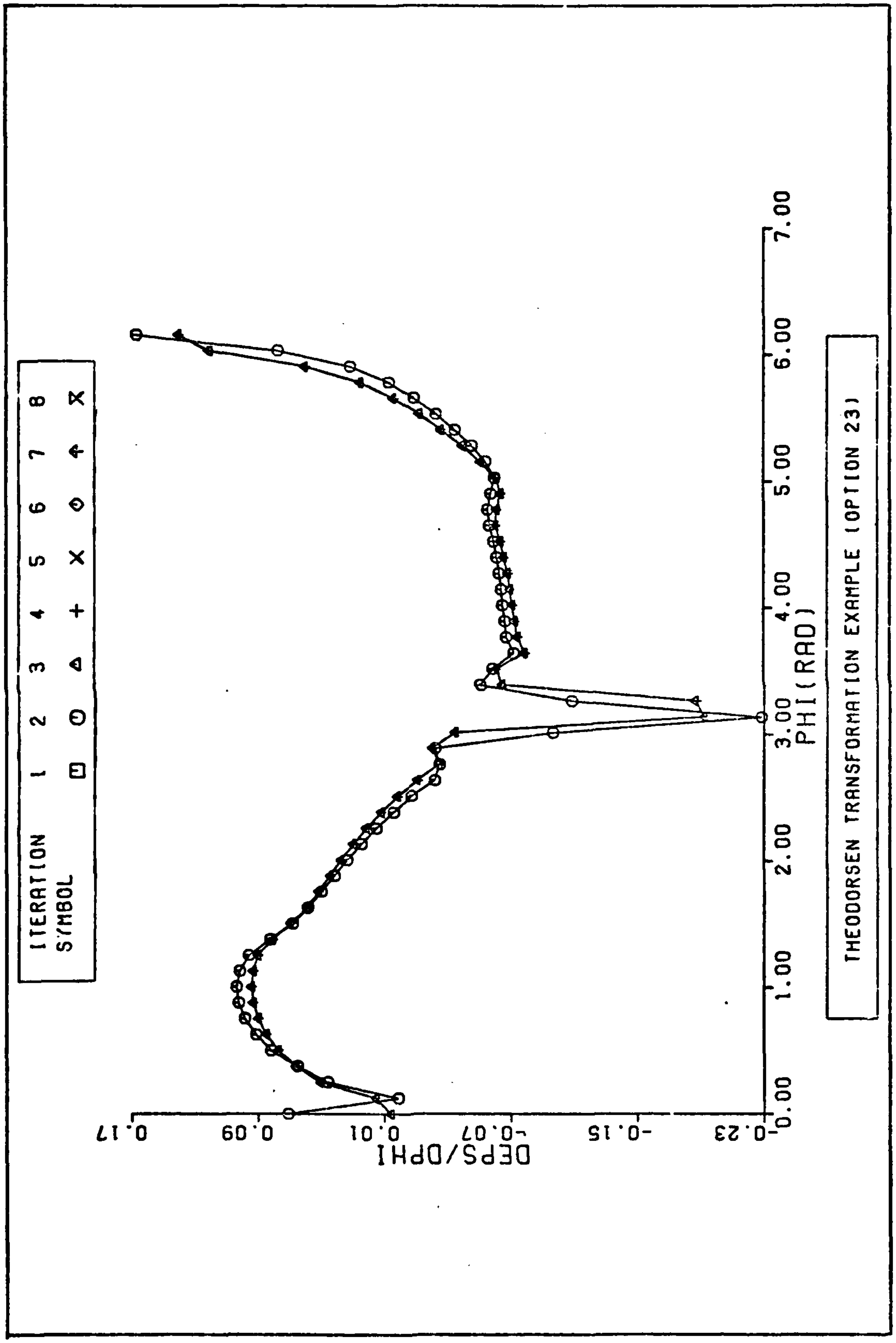


Figure 9. DEPS/DPHI vs PHI (CPLOT).

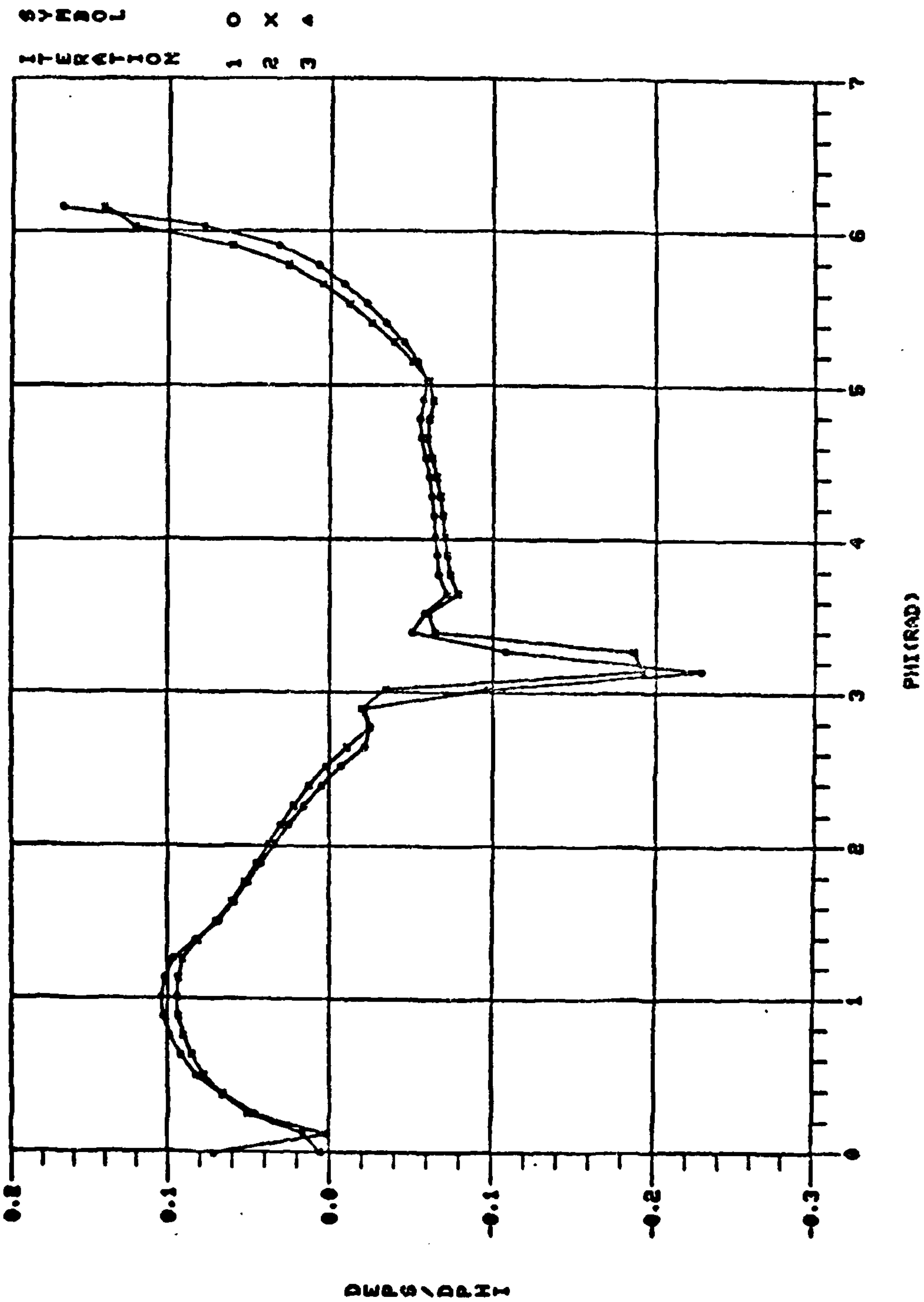


Figure 10. DEPS/DPHI vs PHI (TEKPLOT).

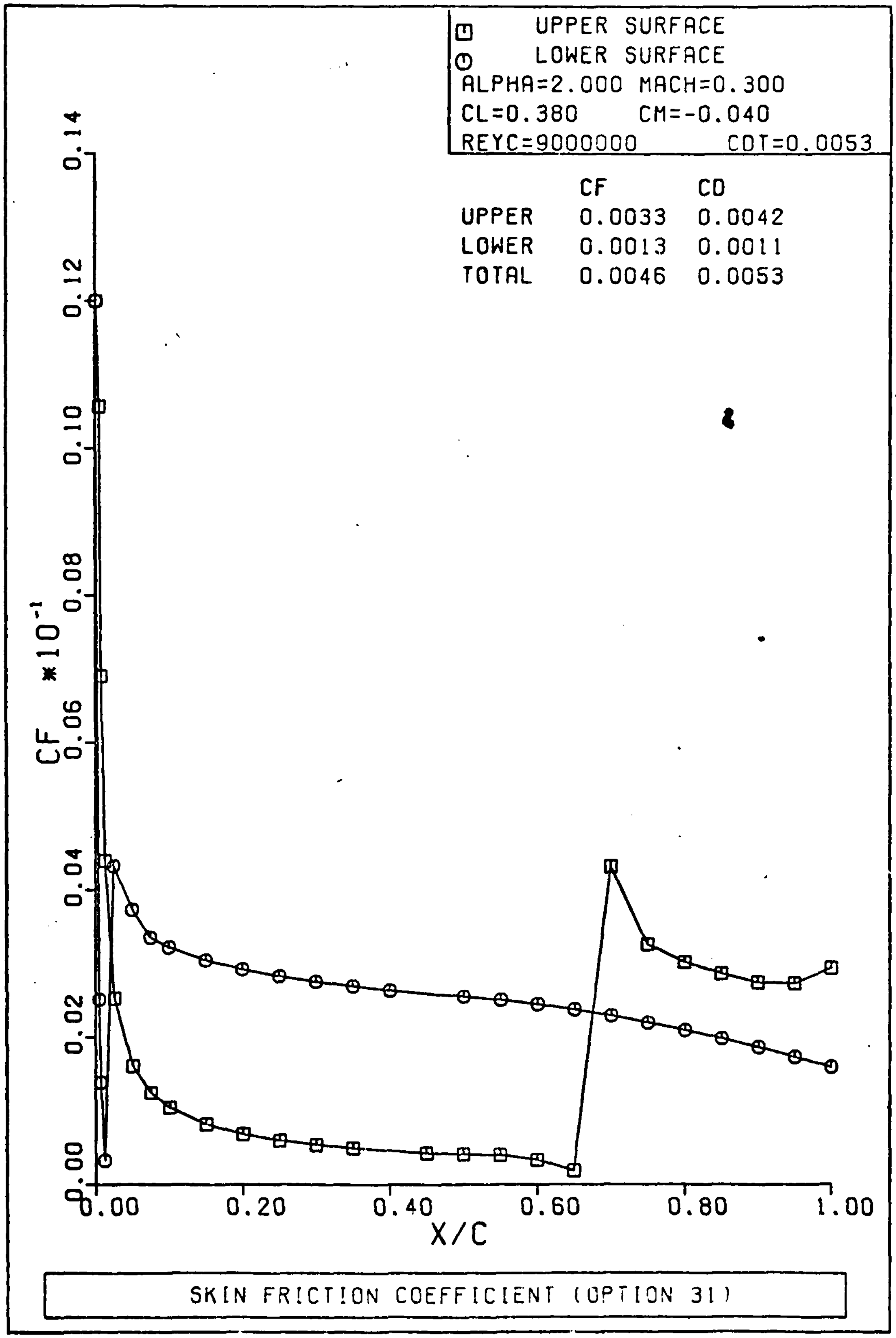


Figure 11. Skin Friction Coefficient (CPLOT).

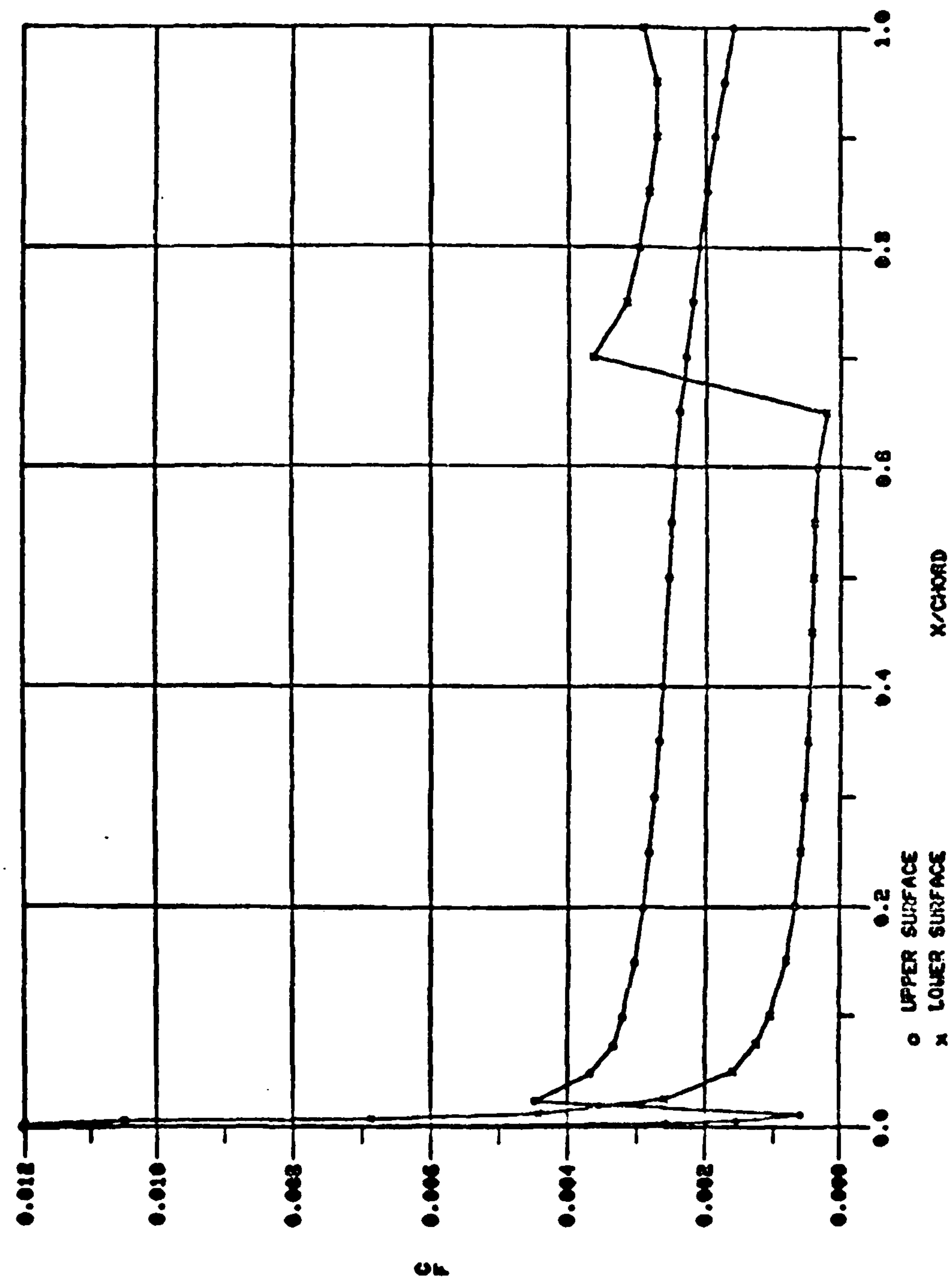


Figure 12. Skin Friction Coefficient (TEKPLOT).

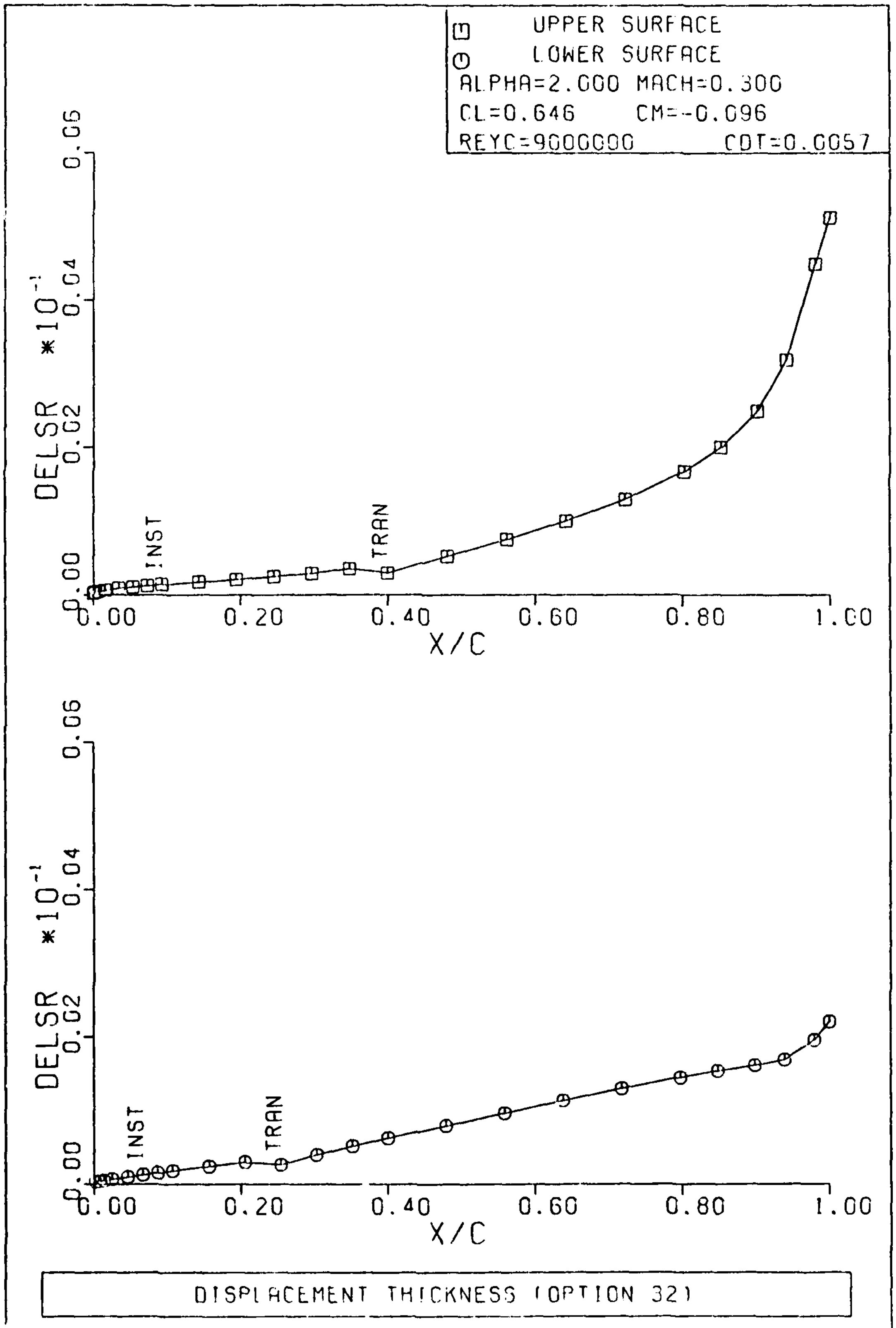


Figure 13. Displacement Thickness (CPLOT).

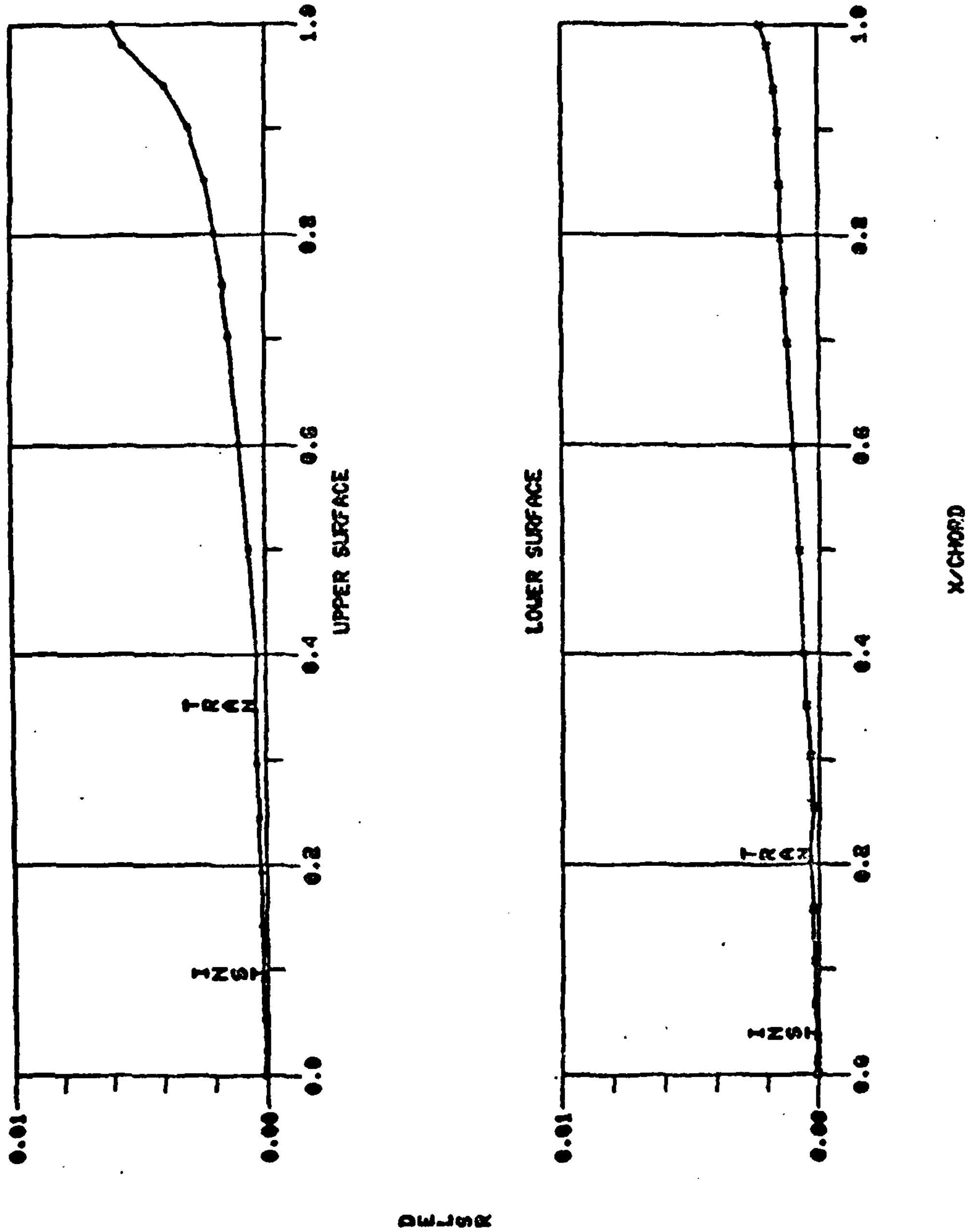


Figure 14. Displacement Thickness (TEKPLOT).

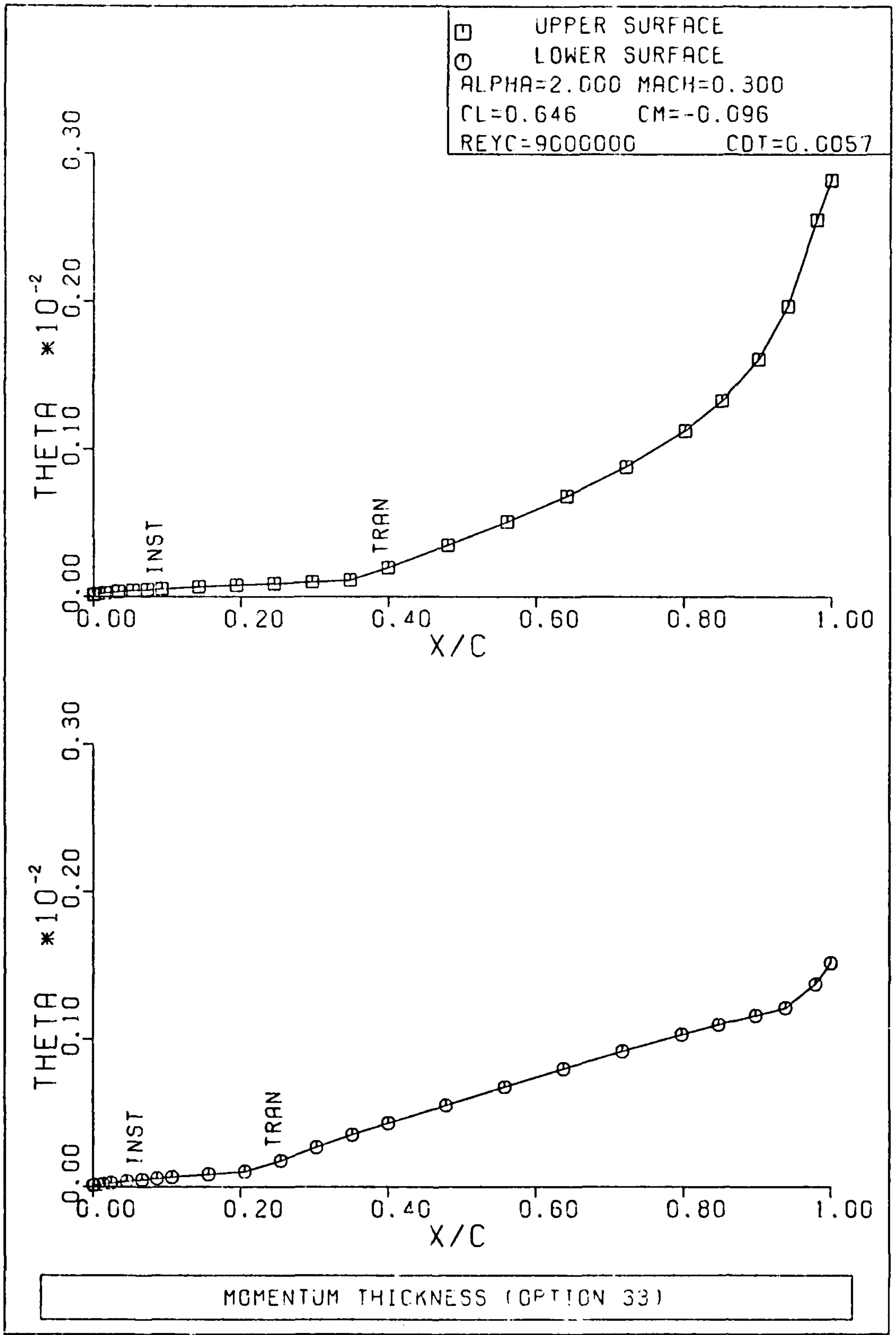


Figure 15. Momentum Thickness (CPLOT).

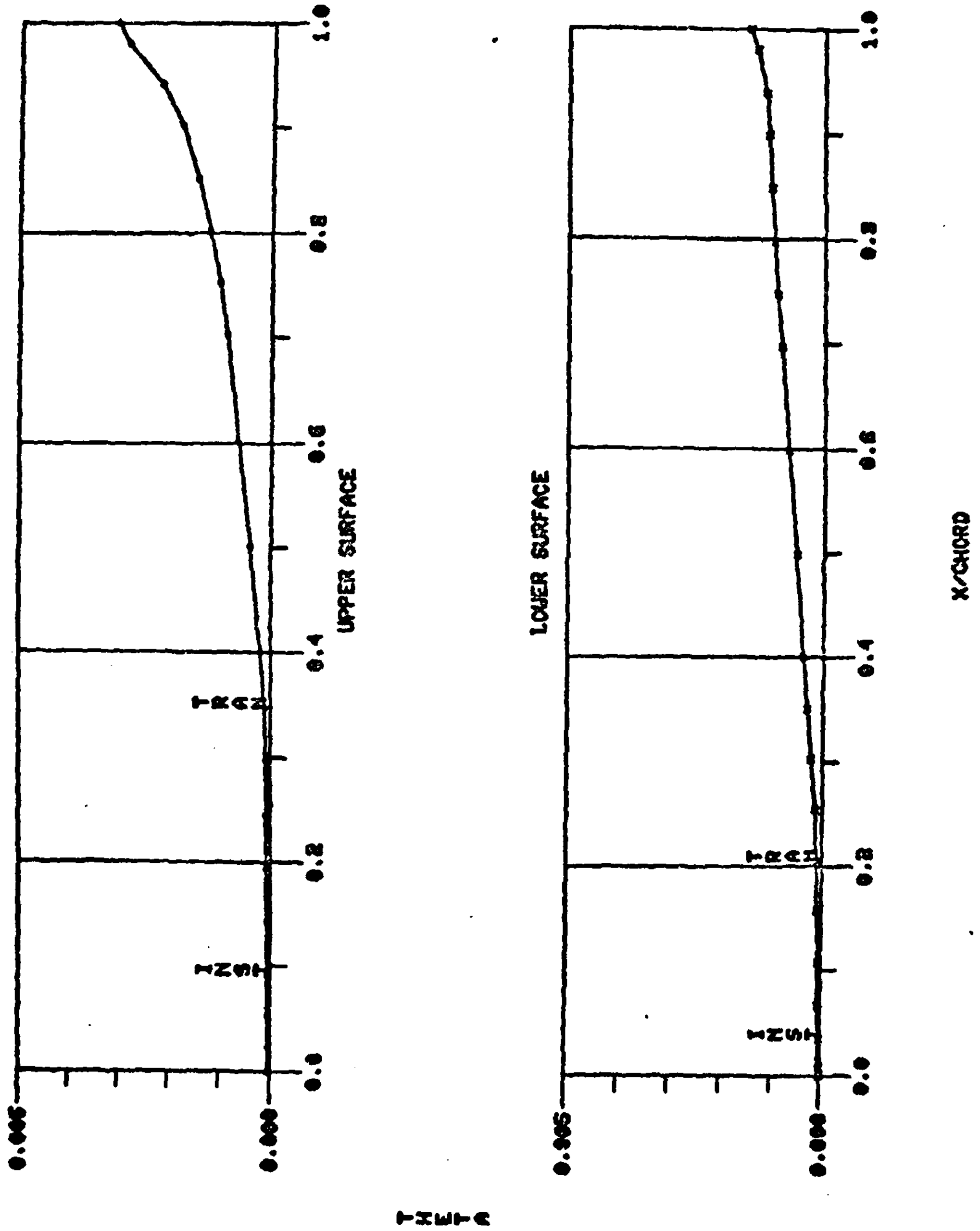


Figure 16. Momentum Thickness (TEKPLOT).

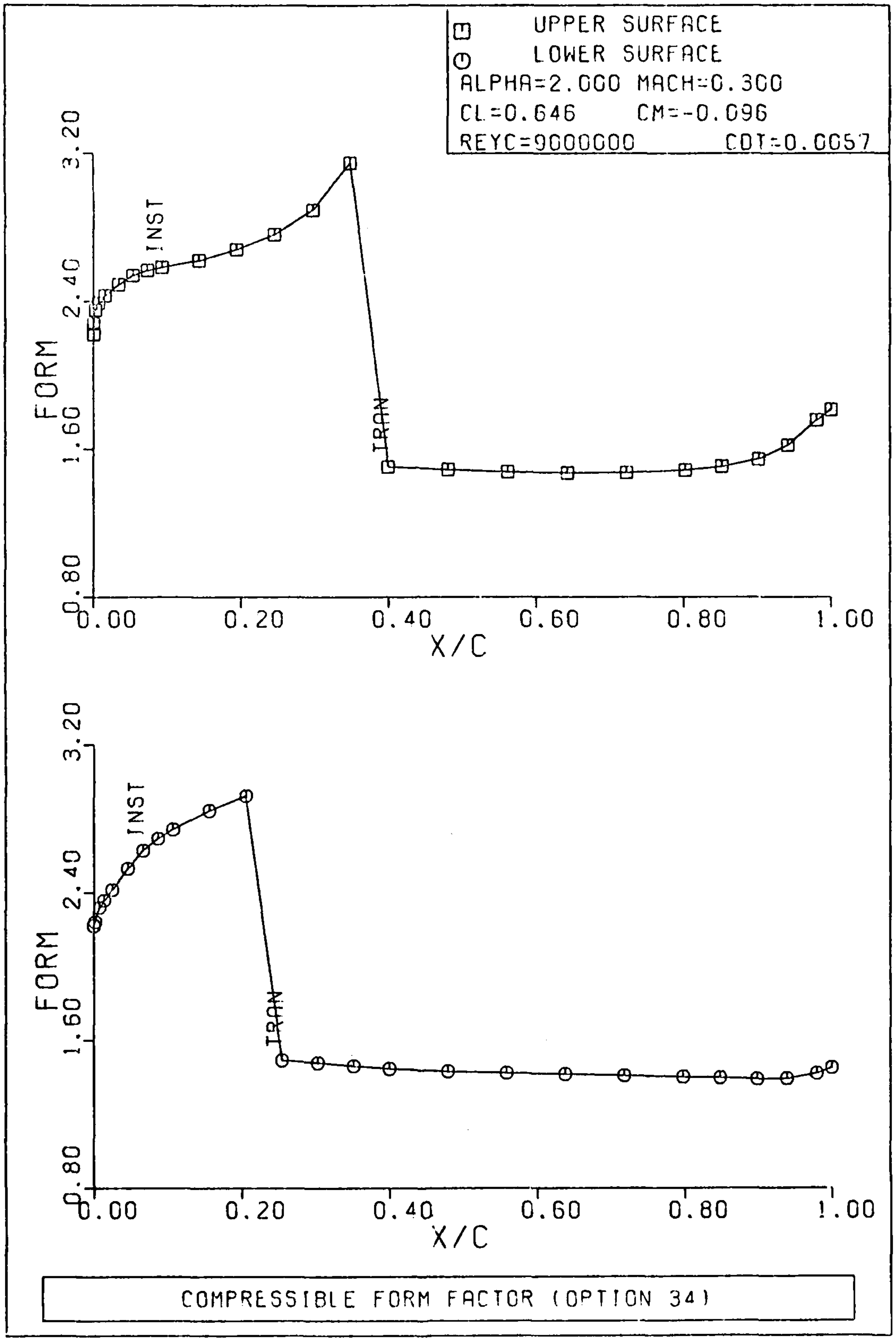


Figure 17. Compressible Form Factor (CPLOT).

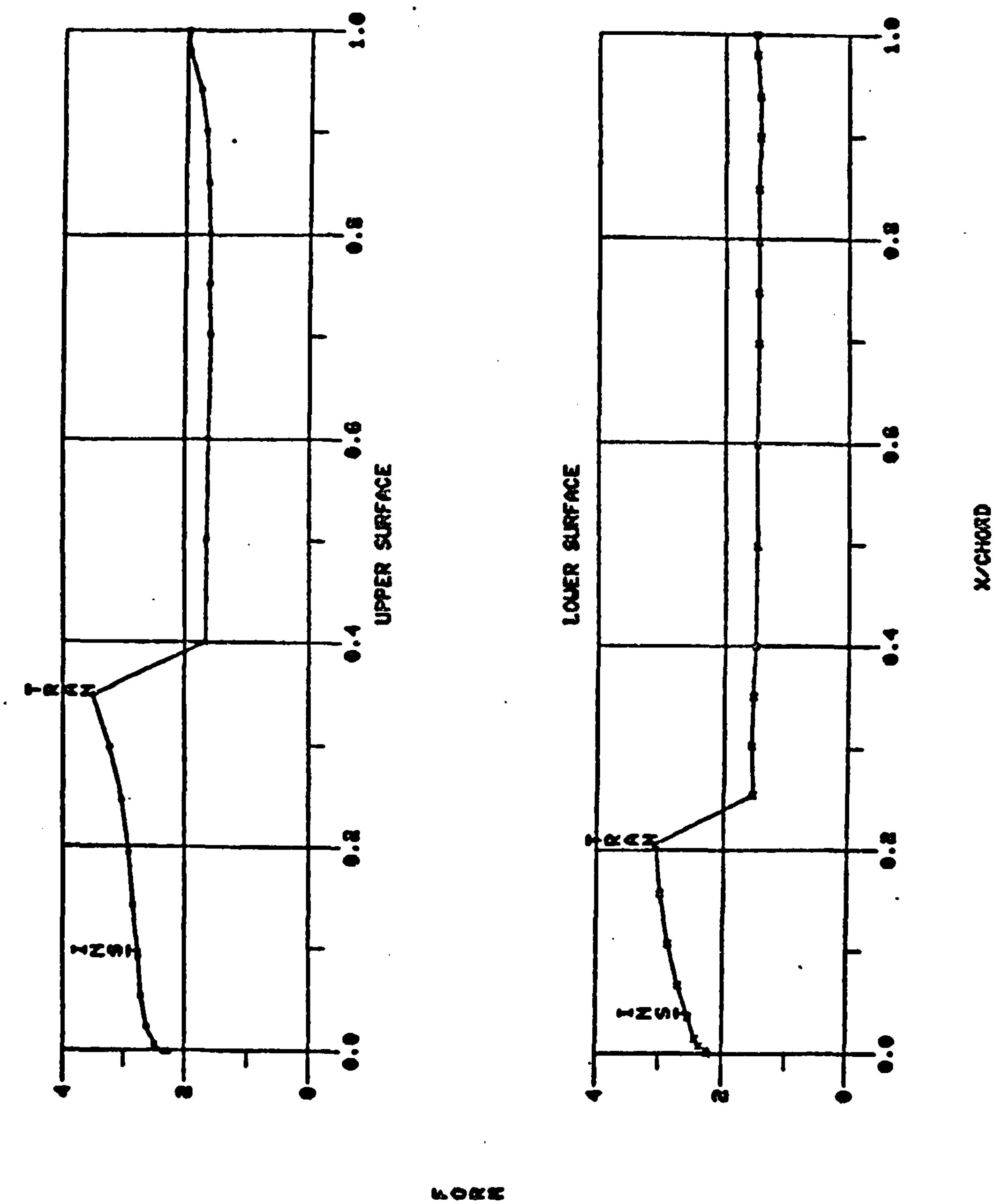


Figure 18. Compressible Form Factor (TEKPLOT).

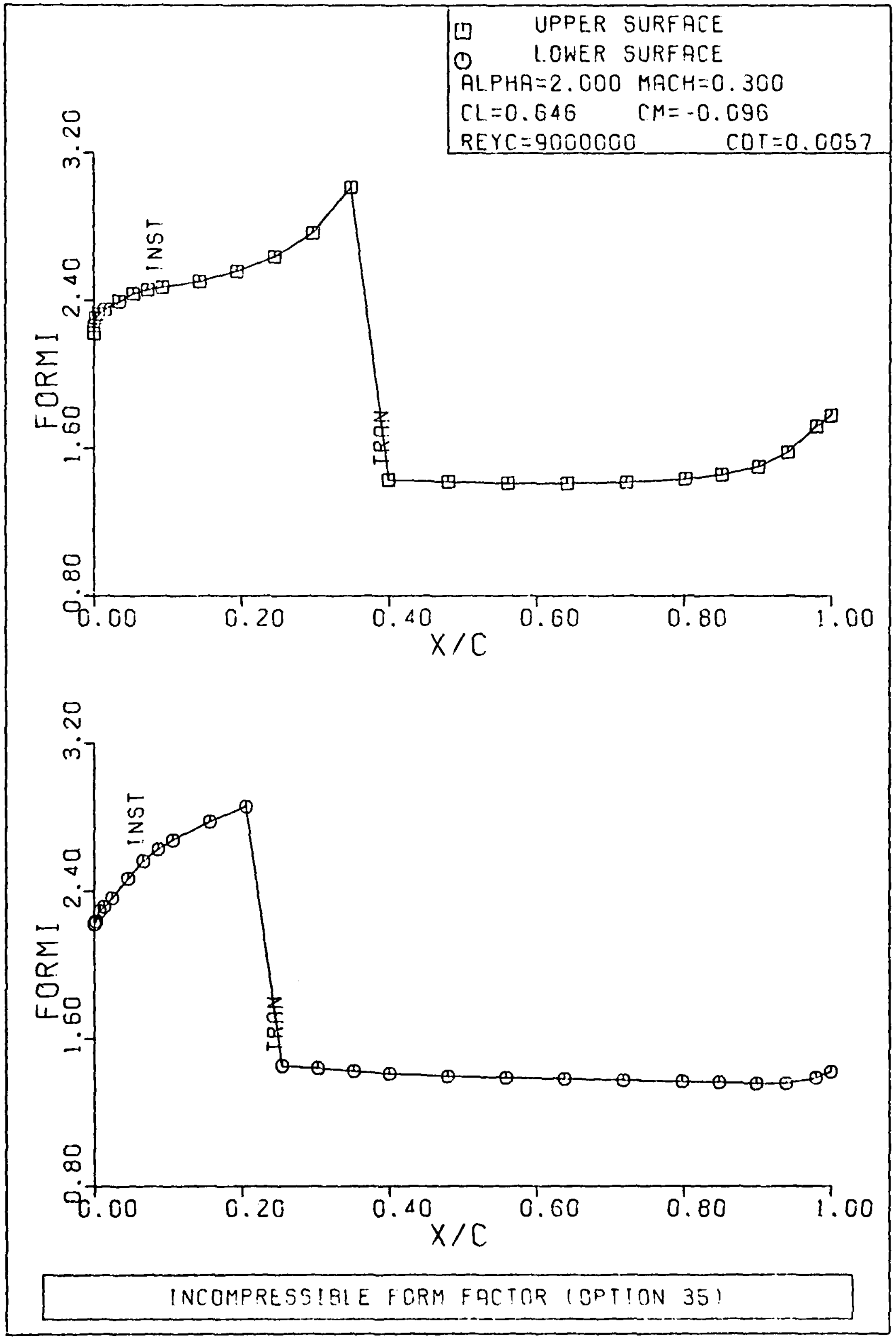


Figure 19. Incompressible Form Factor (CPLOT).

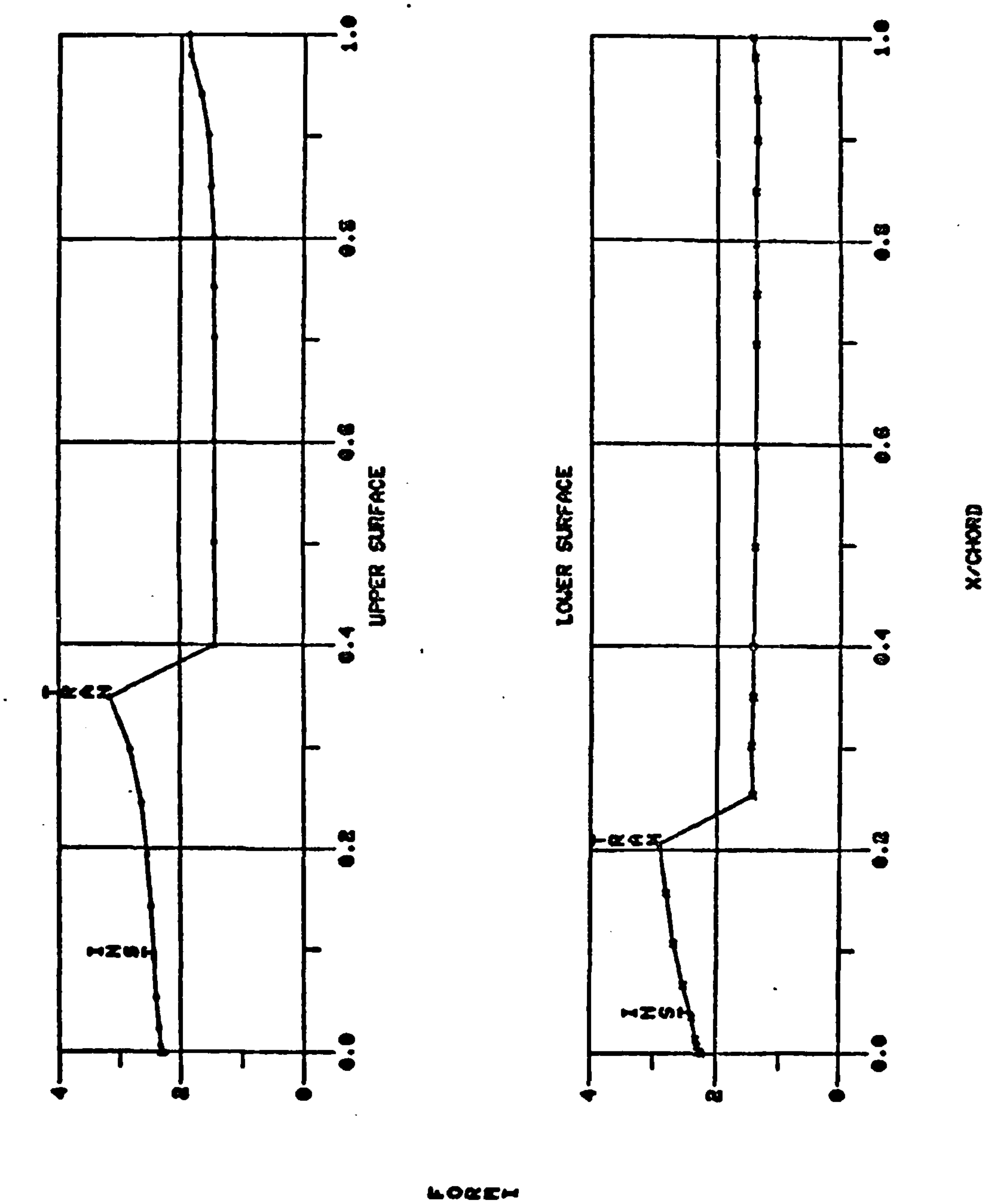


Figure 20. Incompressible Form Factor (TEKPLOT).

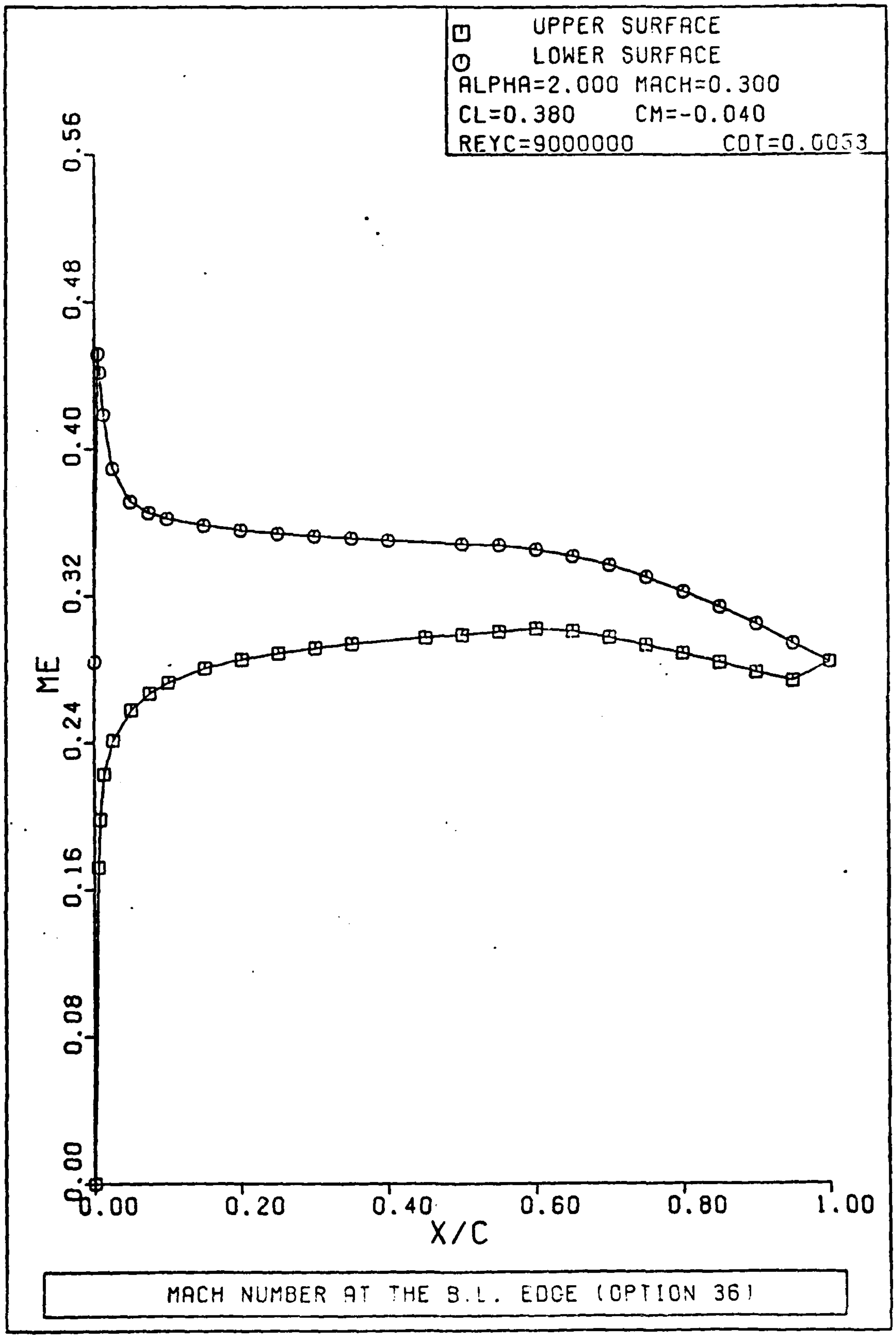


Figure 21. MACH at Edge of Boundary Layer (CPLOT).

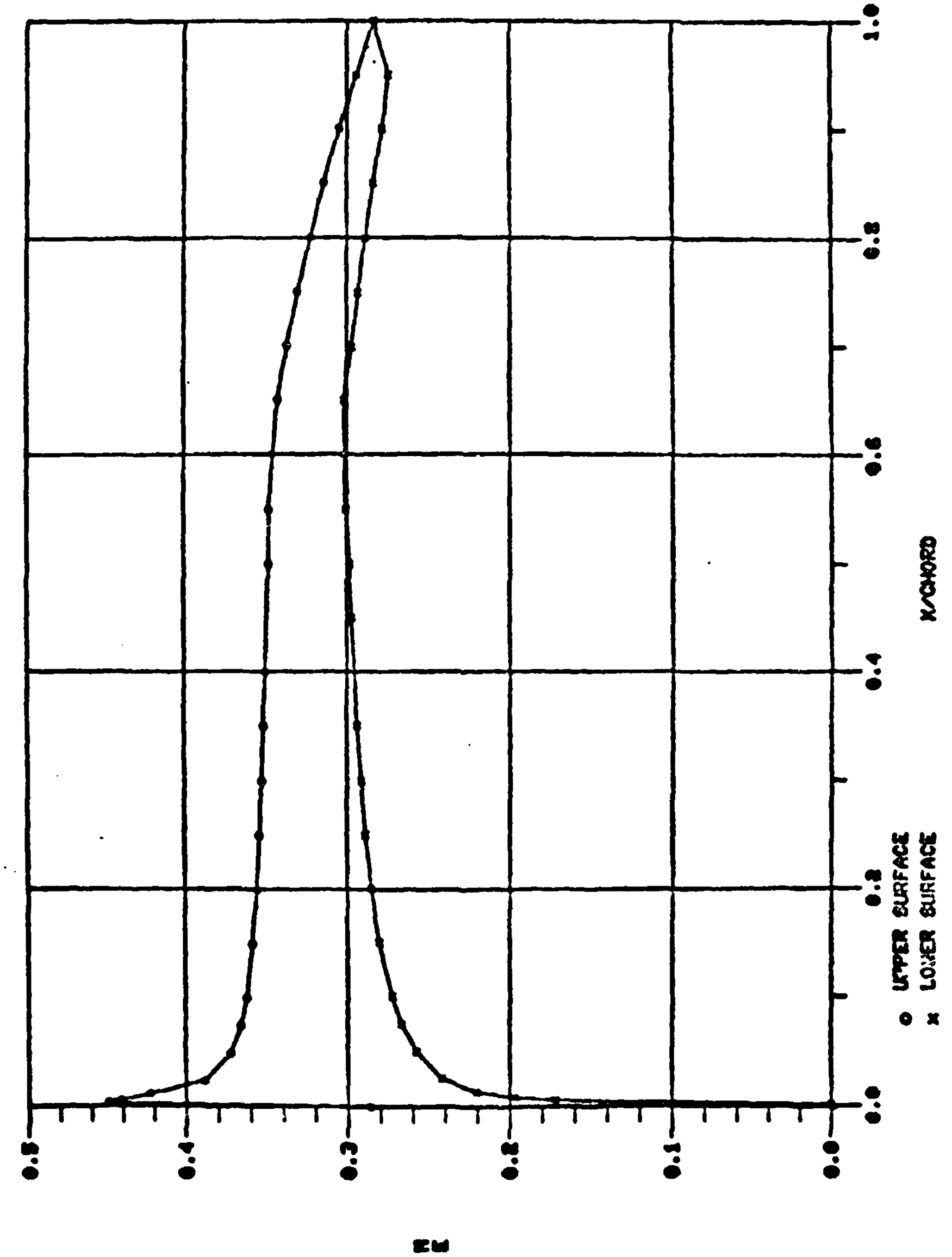


Figure 22. MACH at Edge of Boundary Layer (TEKPLOT).

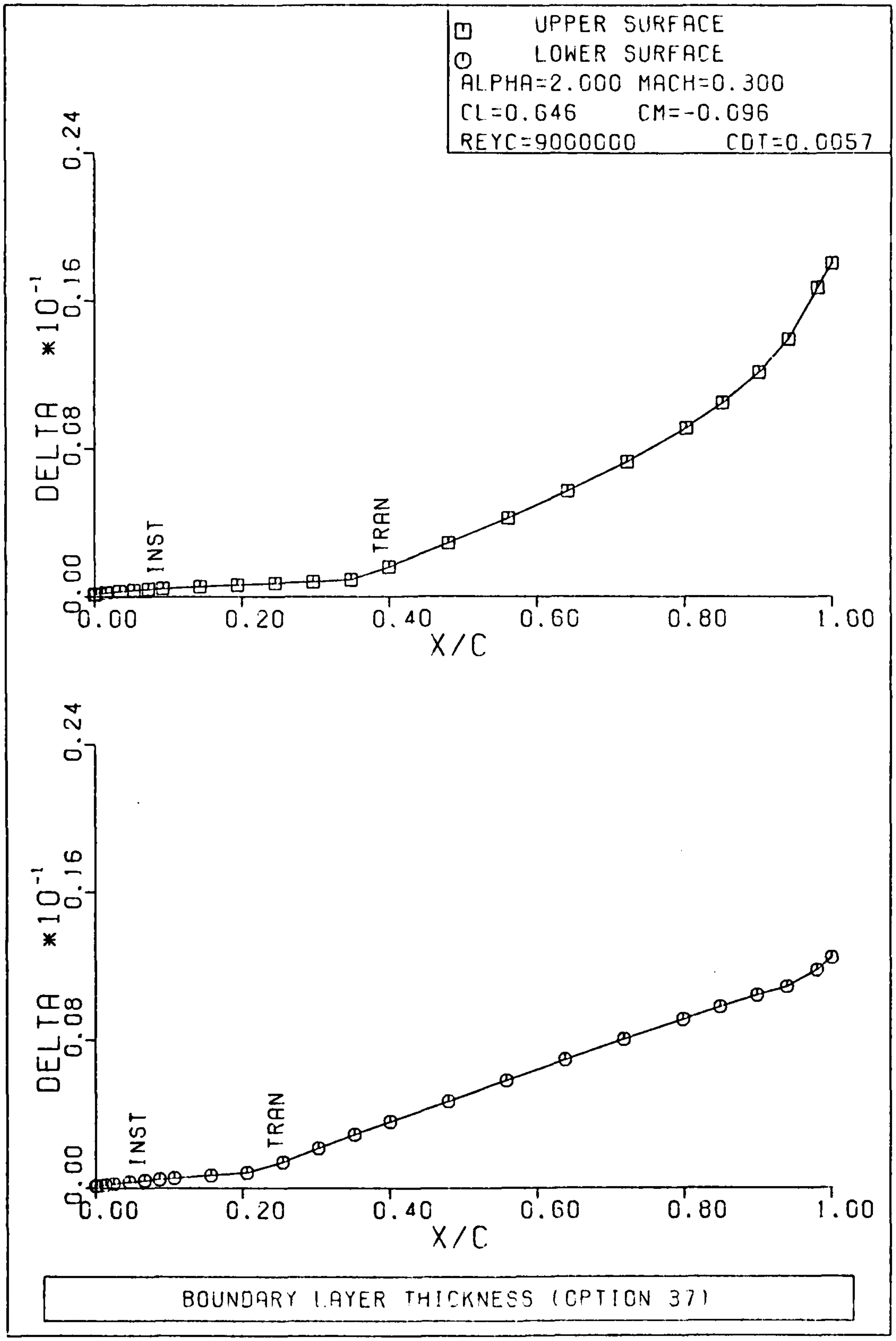


Figure 23. Boundary Layer Thickness (CPLOT).

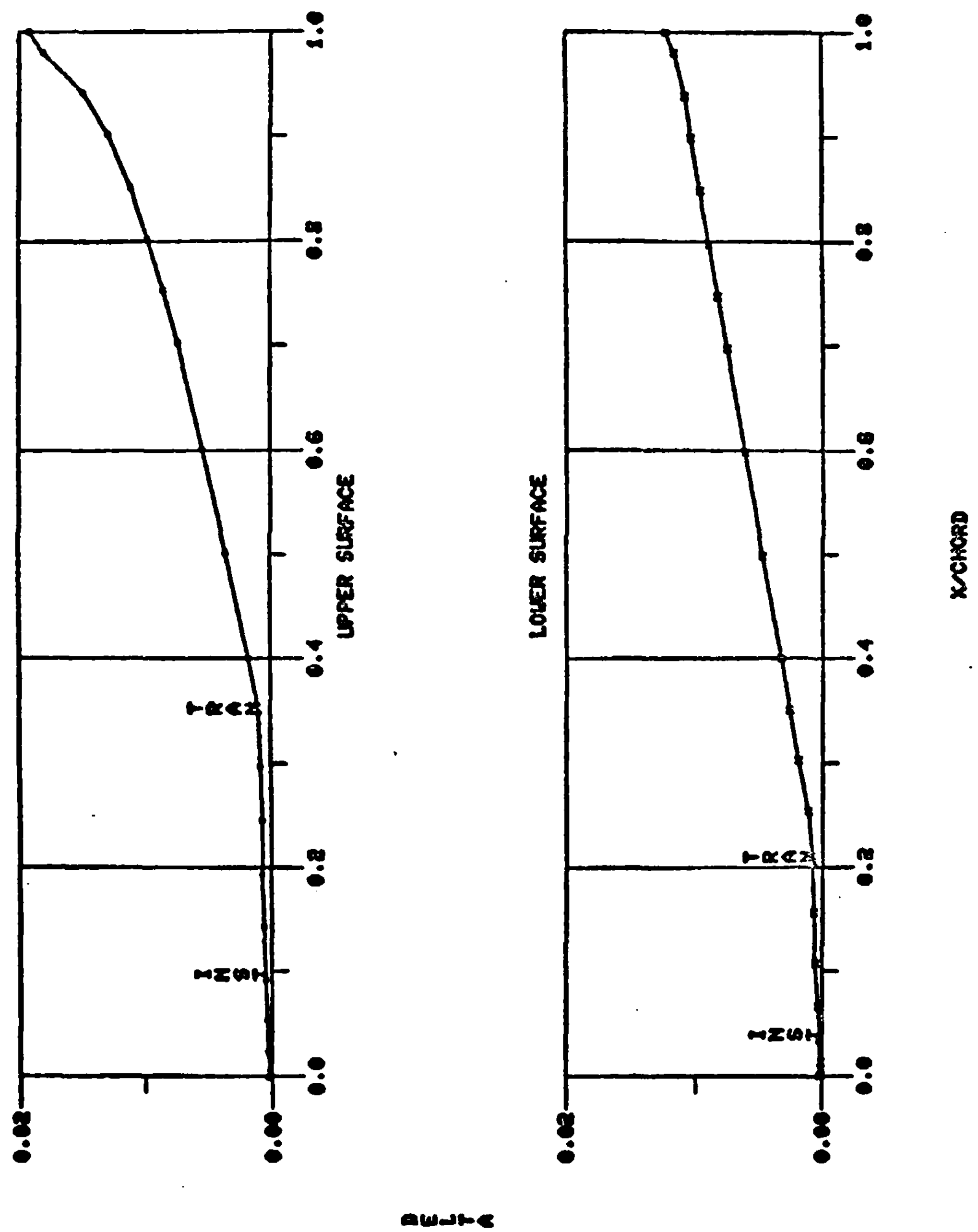


Figure 24. Boundary Layer Thickness (TEKPLOT).

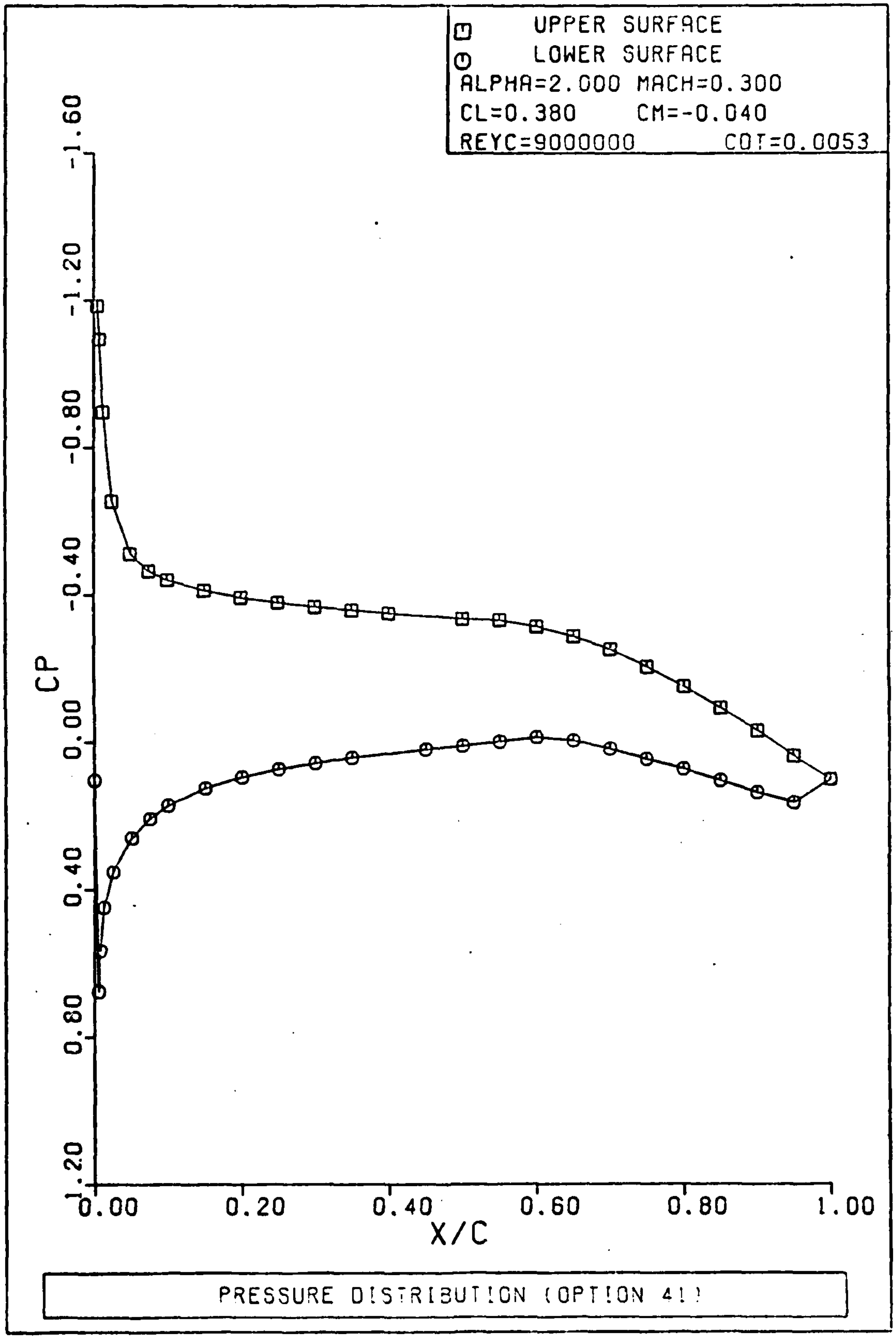


Figure 25. Pressure Coefficient Distribution (CPLOT).

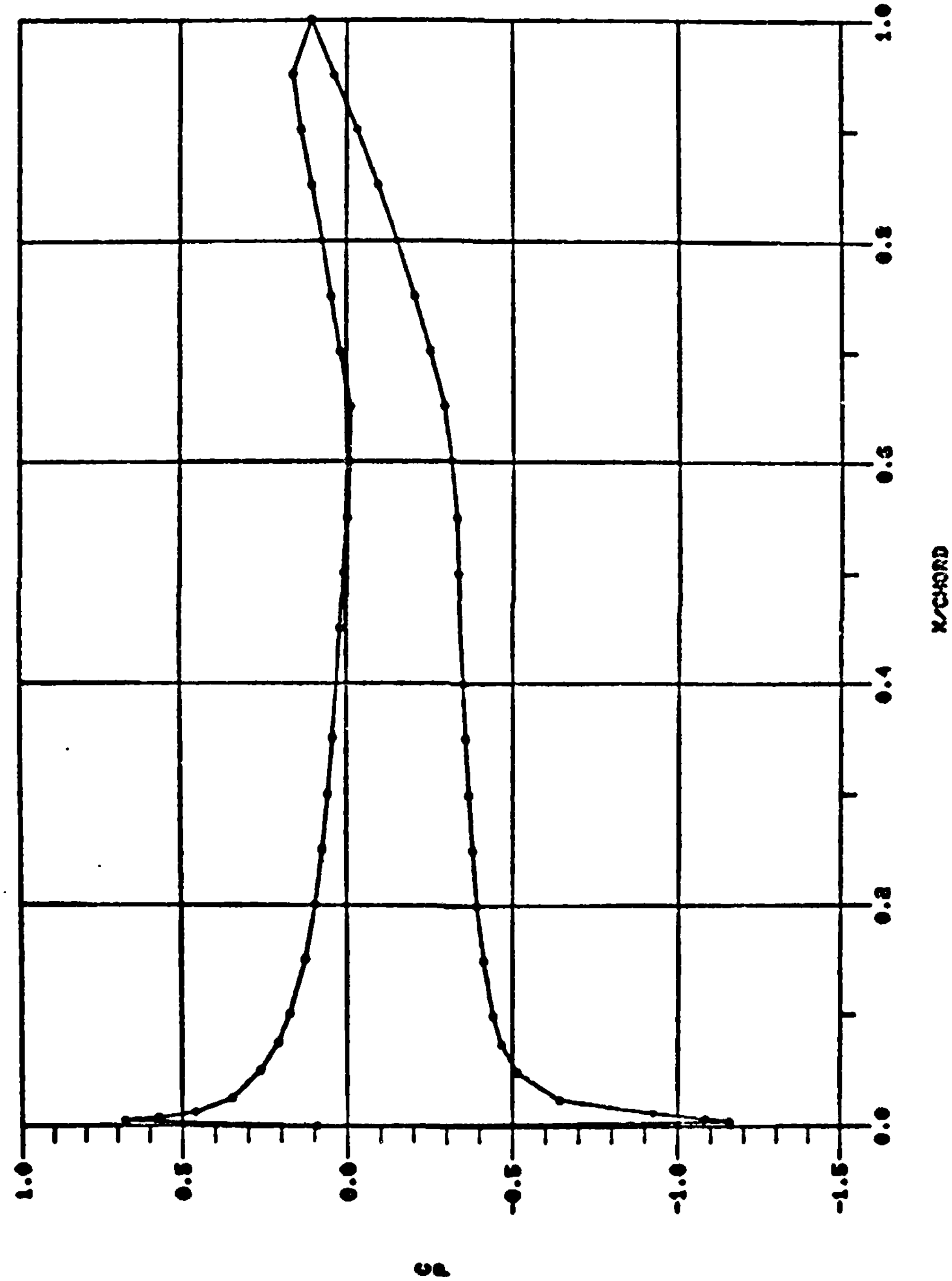


Figure 26. Pressure Coefficient Distribution (TEMPLOT).

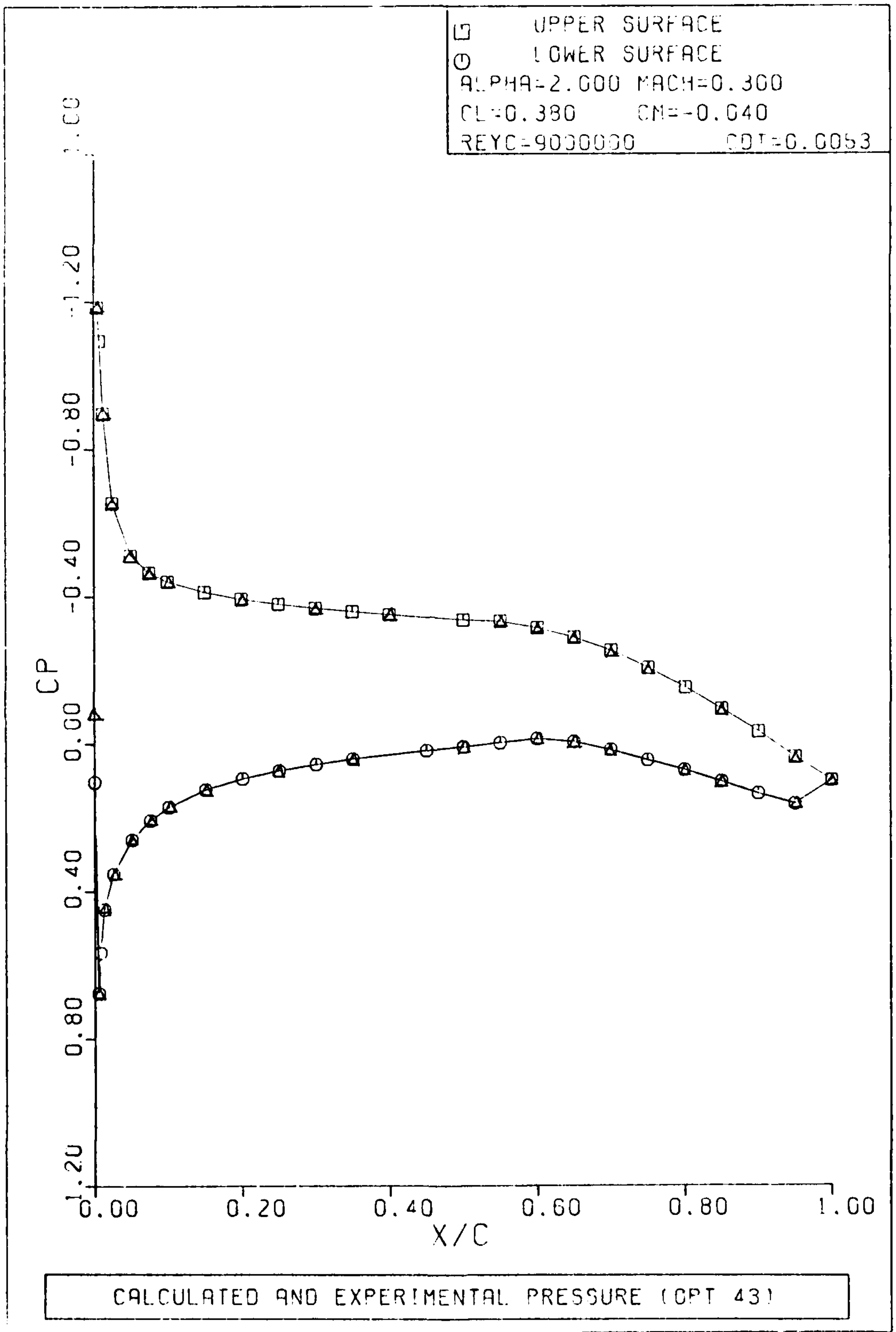


Figure 27. Calculated and Experimental Pressure Distribution (CPLOT).

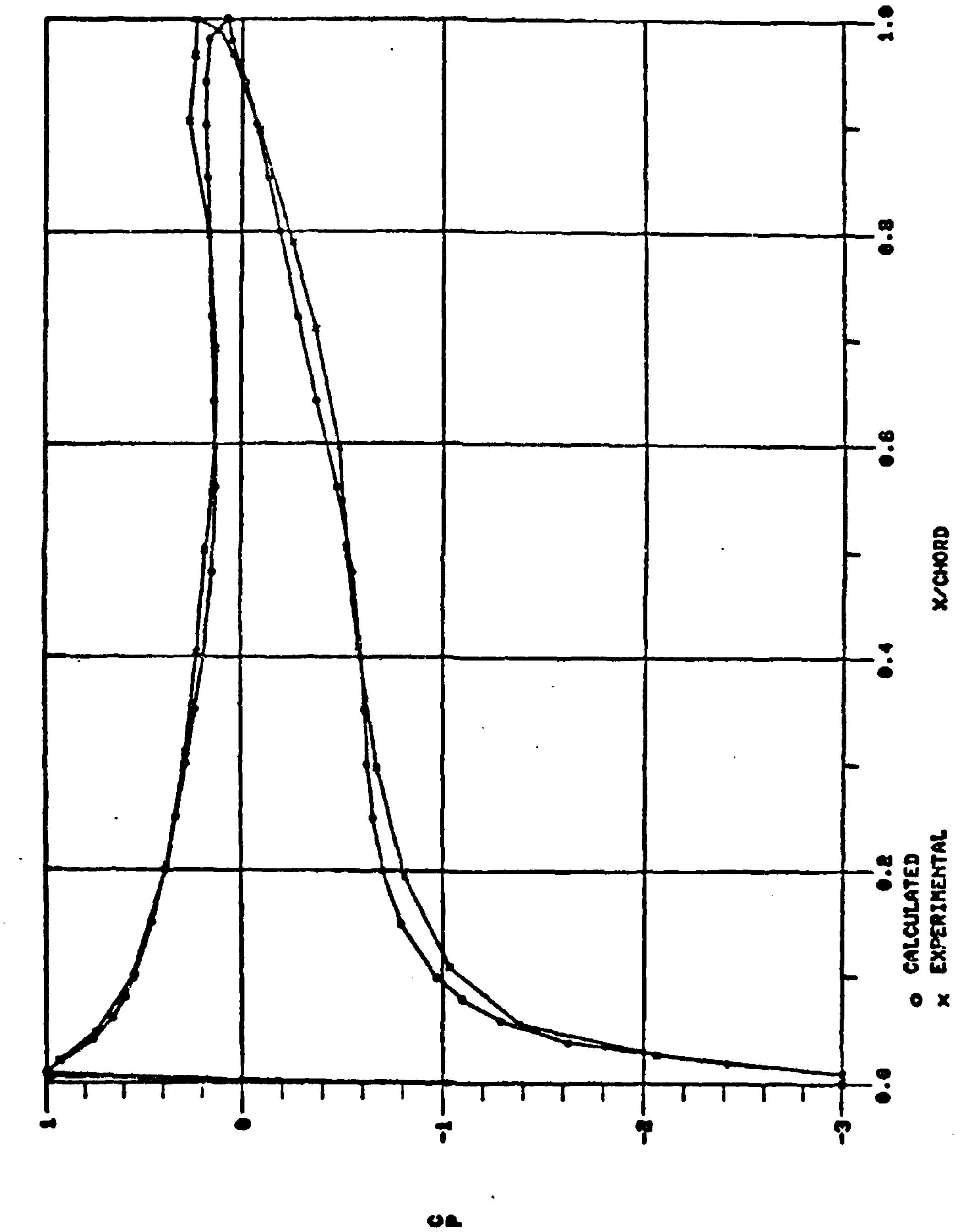
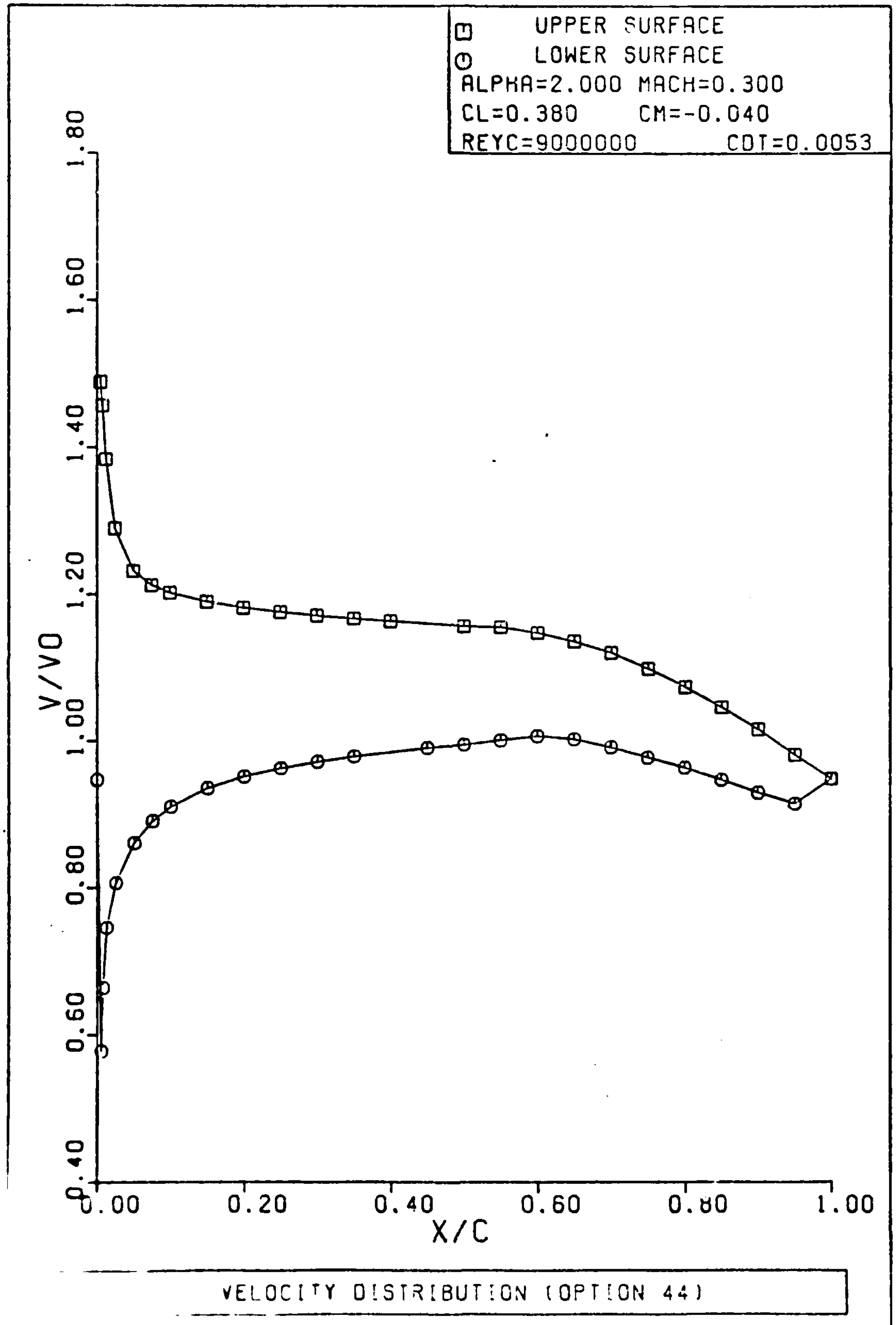


Figure 28. Calculated and Experimental Pressure Distribution (TEKPLOT).



.9. Nondimensional Velocity (CPLOT).

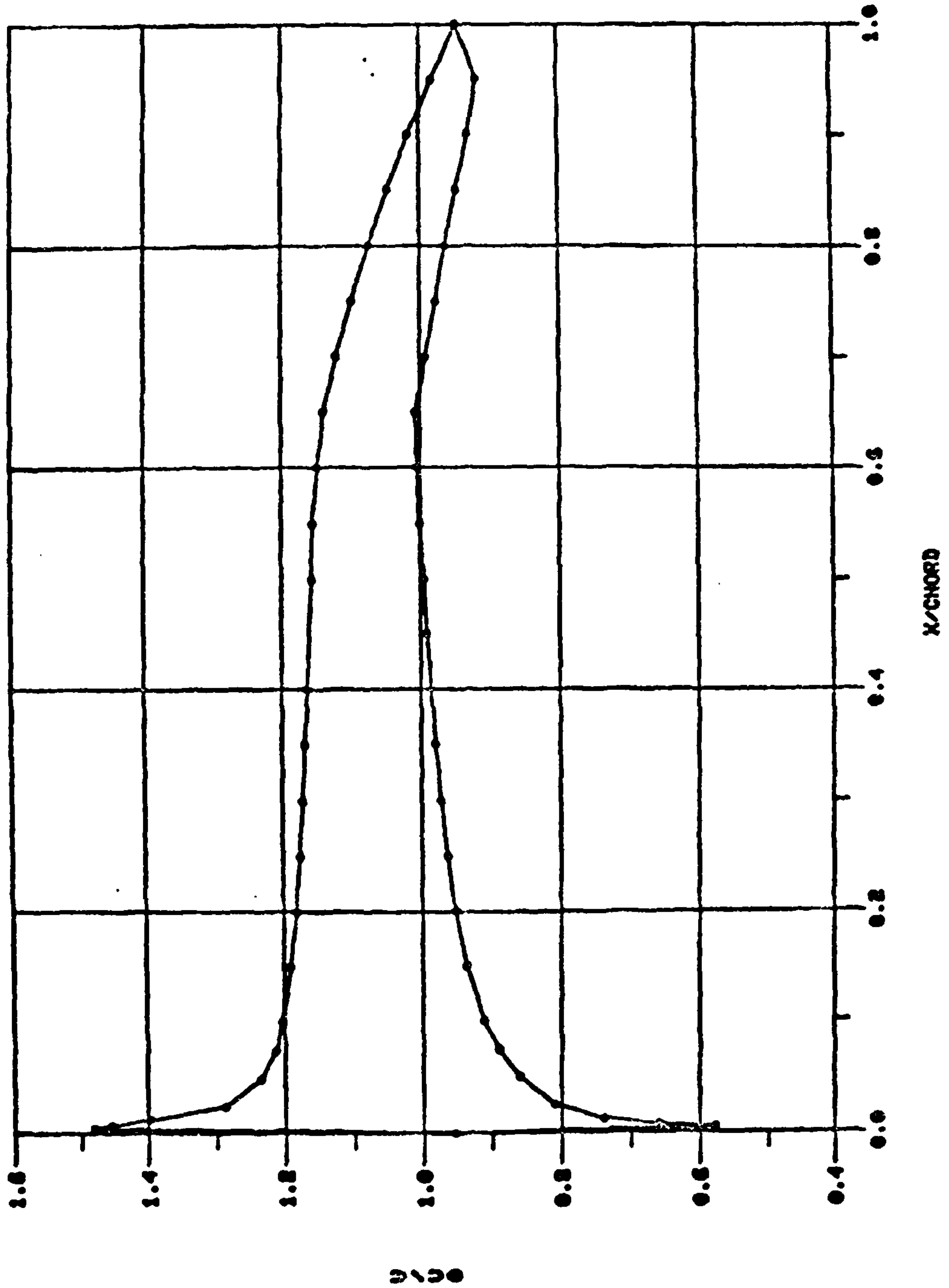


Figure 30. Nondimensional Velocity (TEKPLOT).

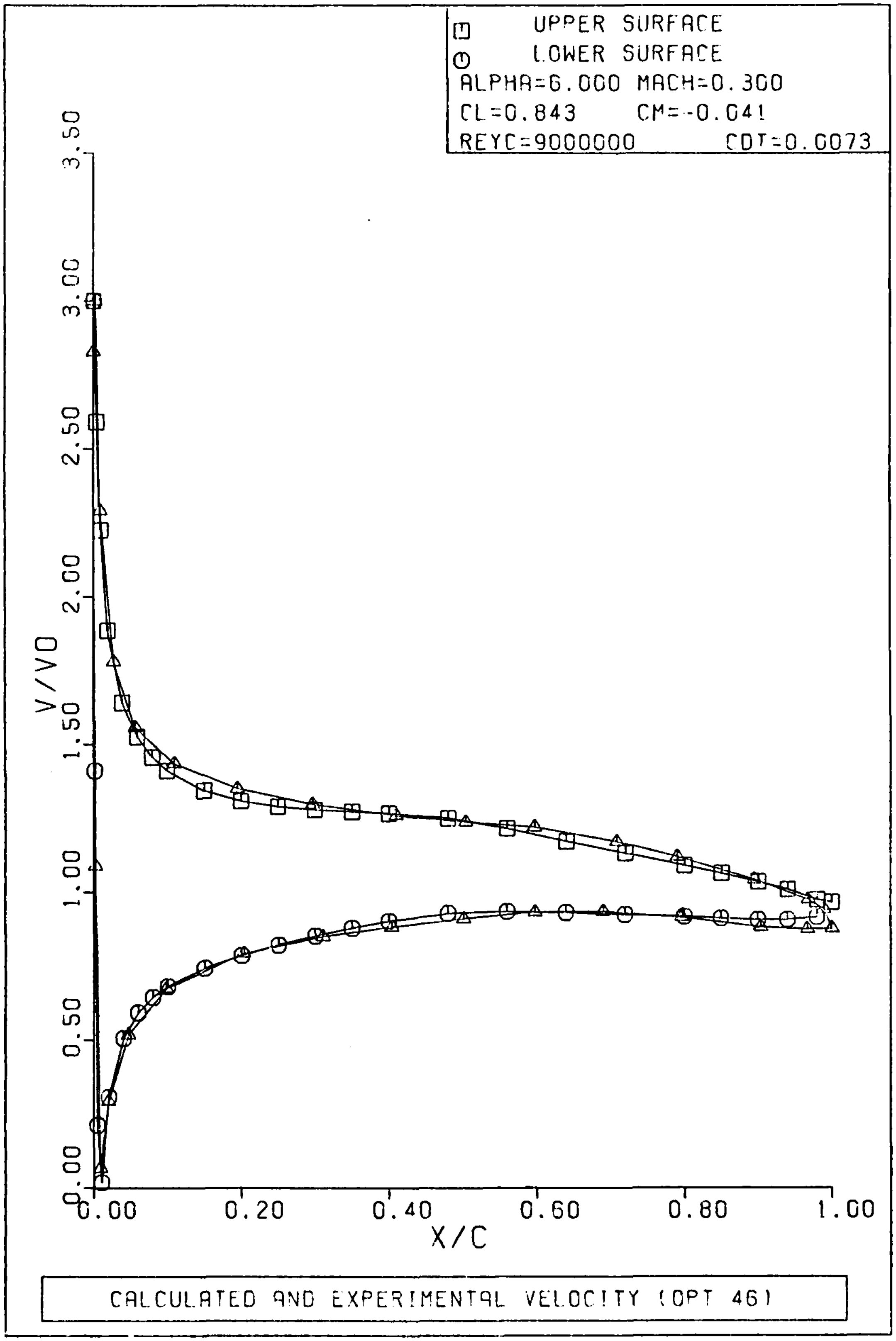


Figure 31. Calculated and Experimental Nondimensional Velocity (CPLOT).

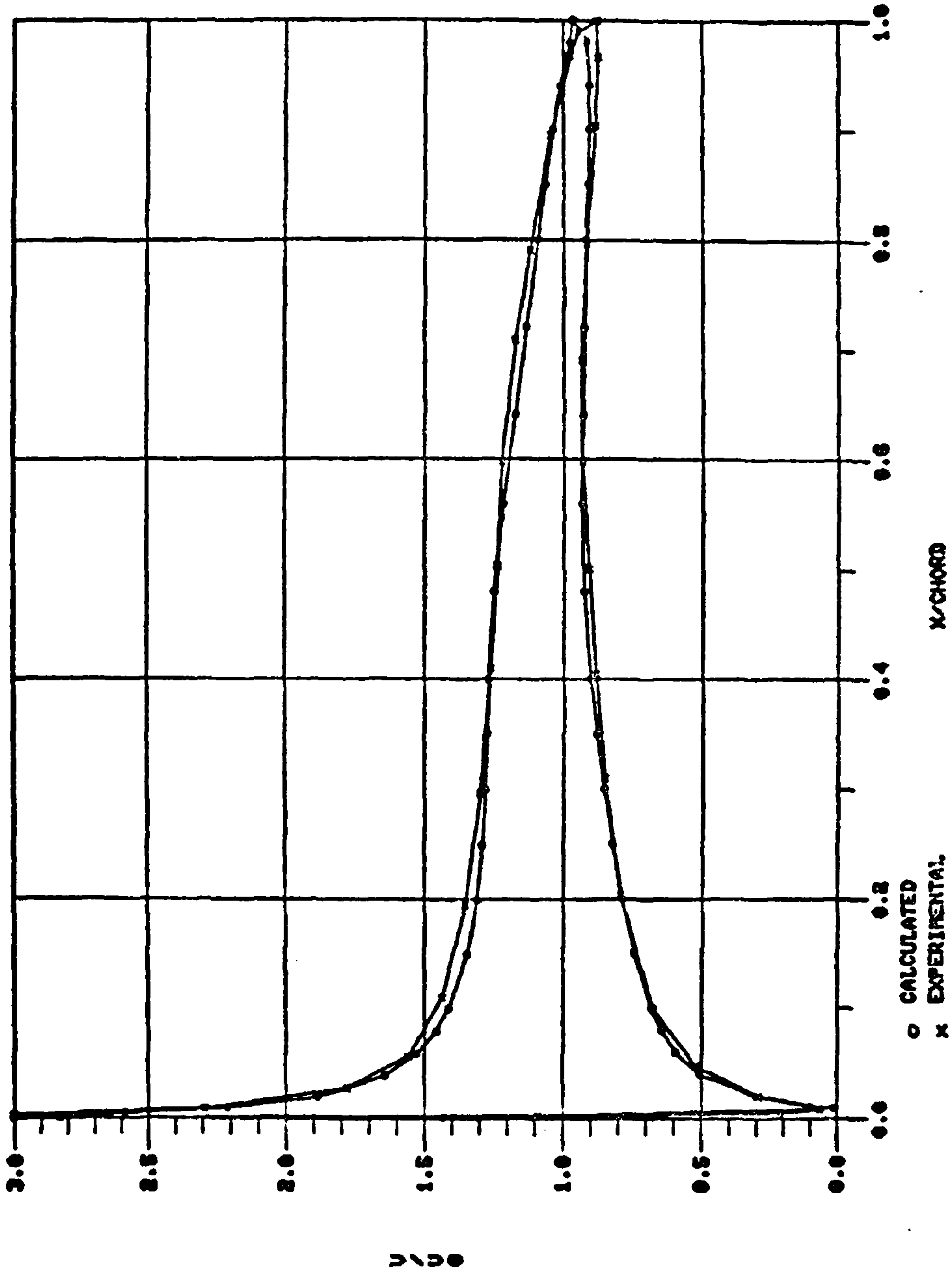


Figure 32. Calculated and Experimental Nondimensional Velocity (TEKPLOT).

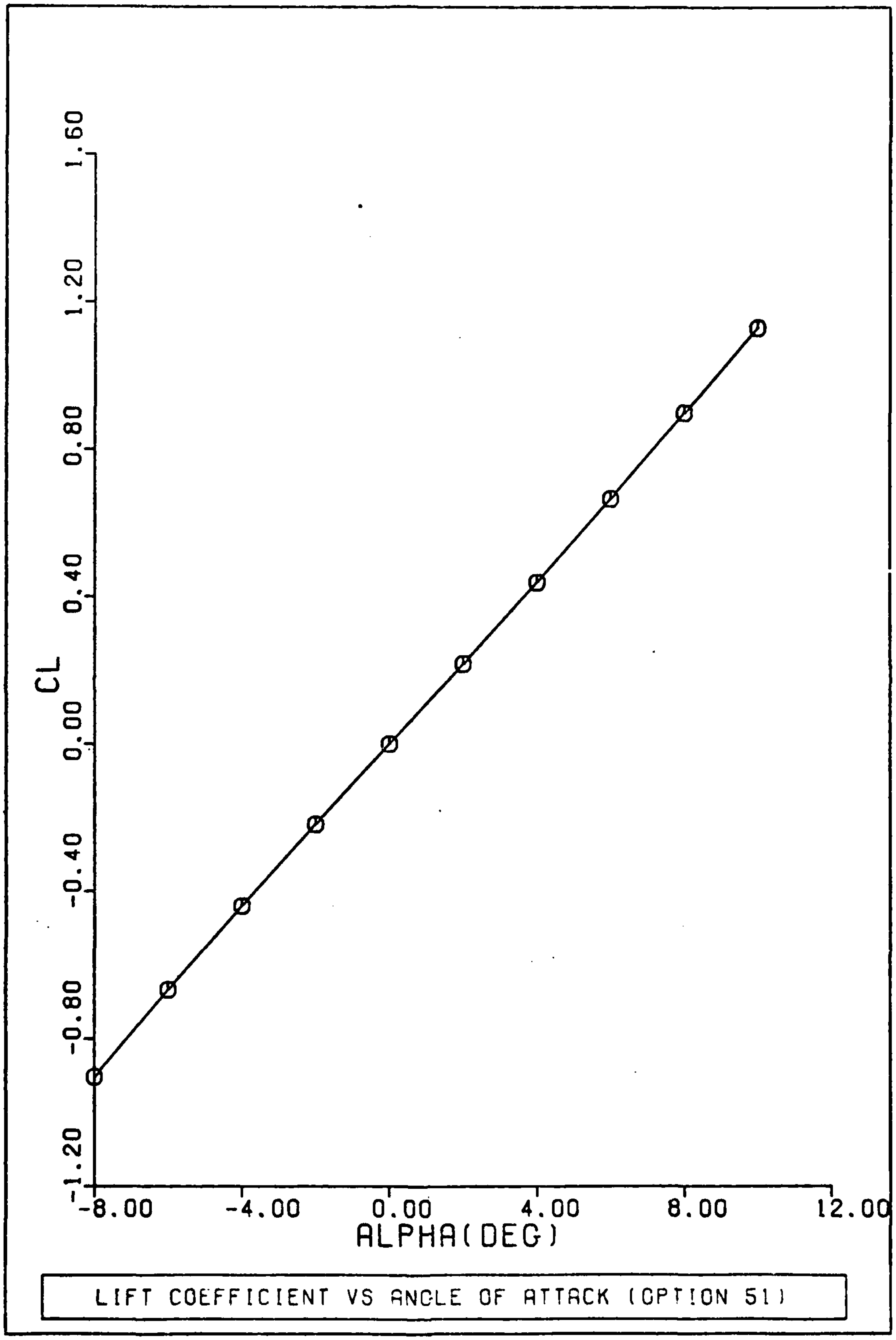


Figure 33. Lift Coefficient vs Angle of Attack (CPLOT).

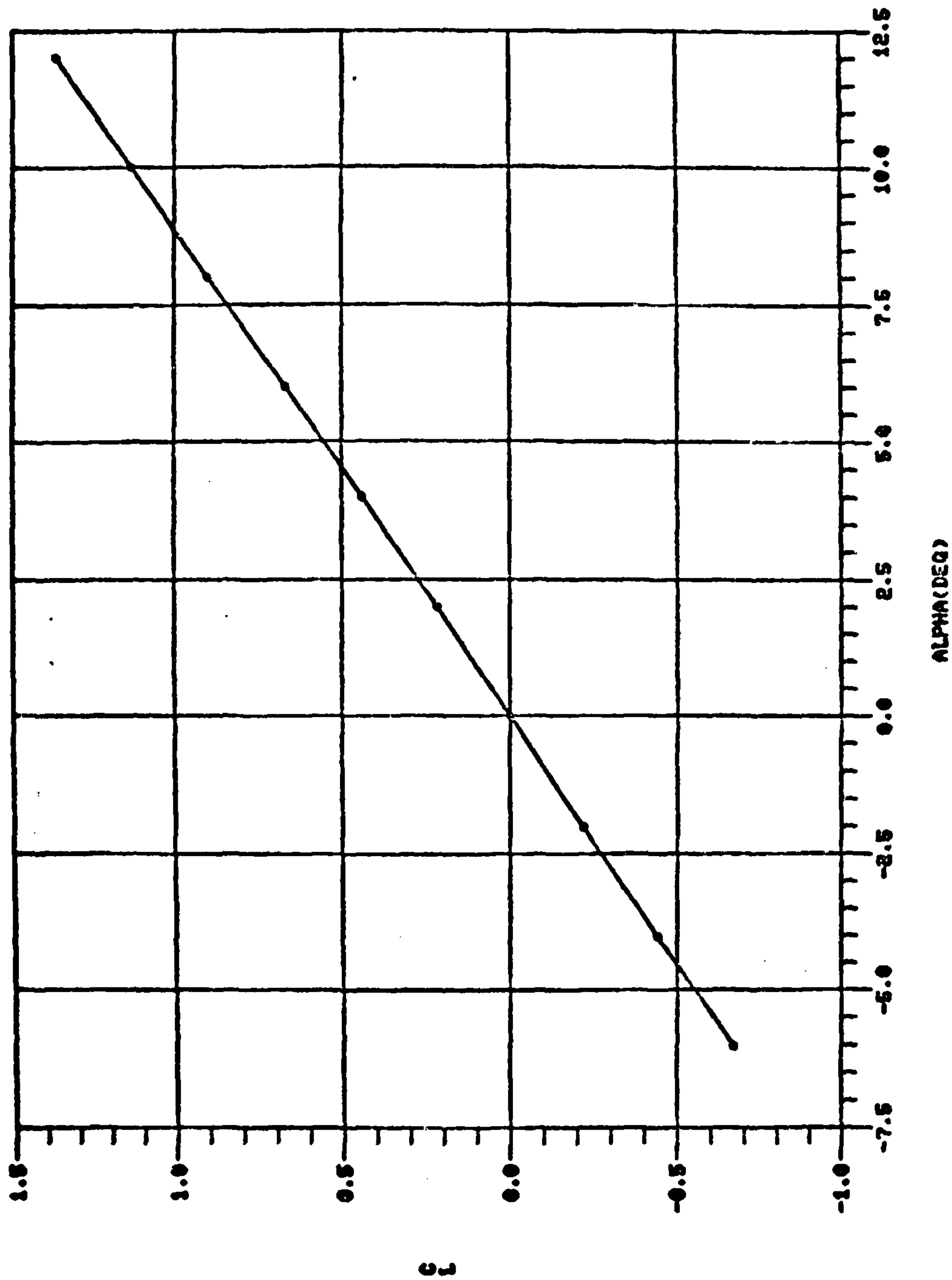


Figure 34. Lift Coefficient vs Angle of Attack (TEKPLOT).

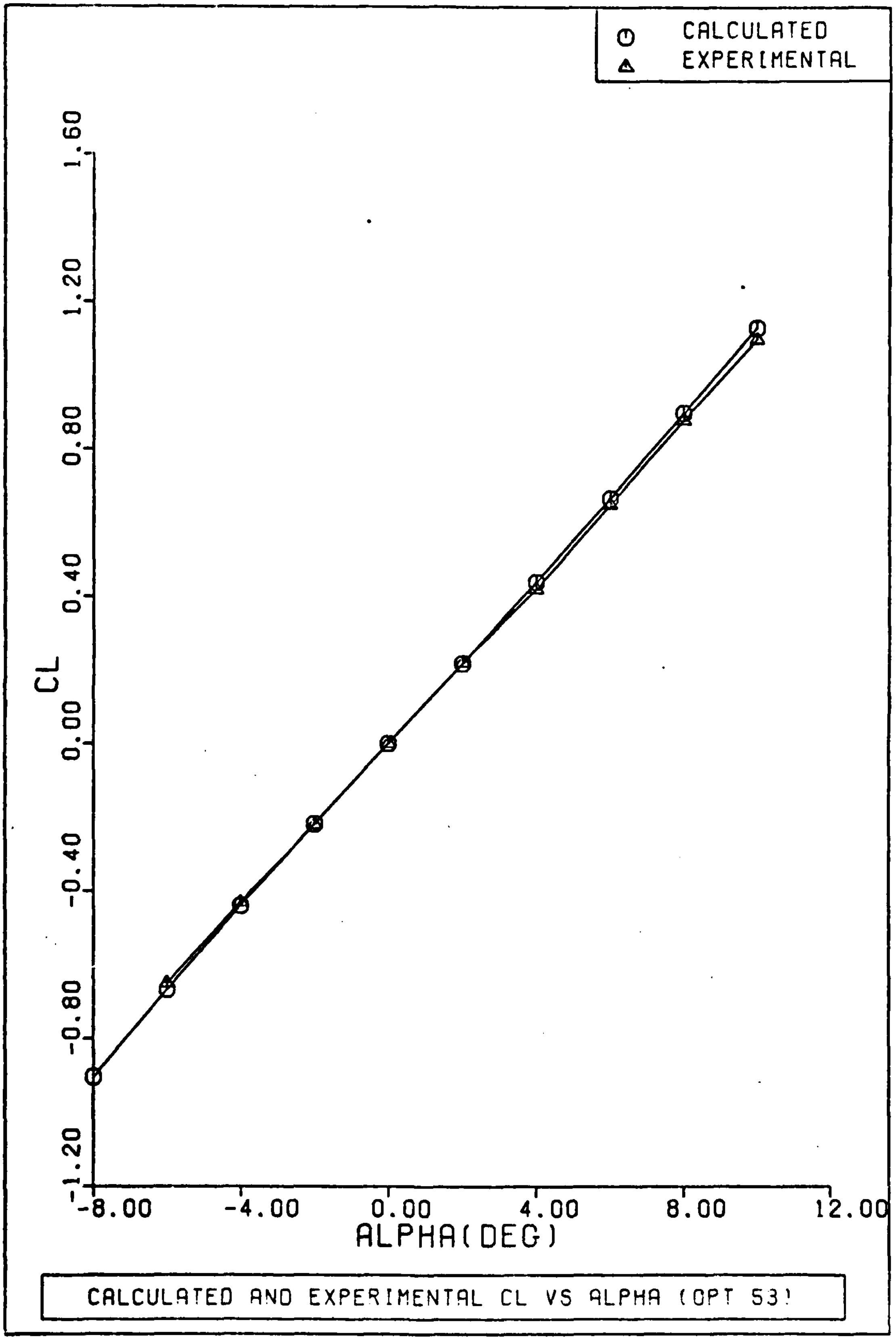


Figure 35. Calculated and Experimental Lift Coefficient vs Angle of Attack (CPLOT).

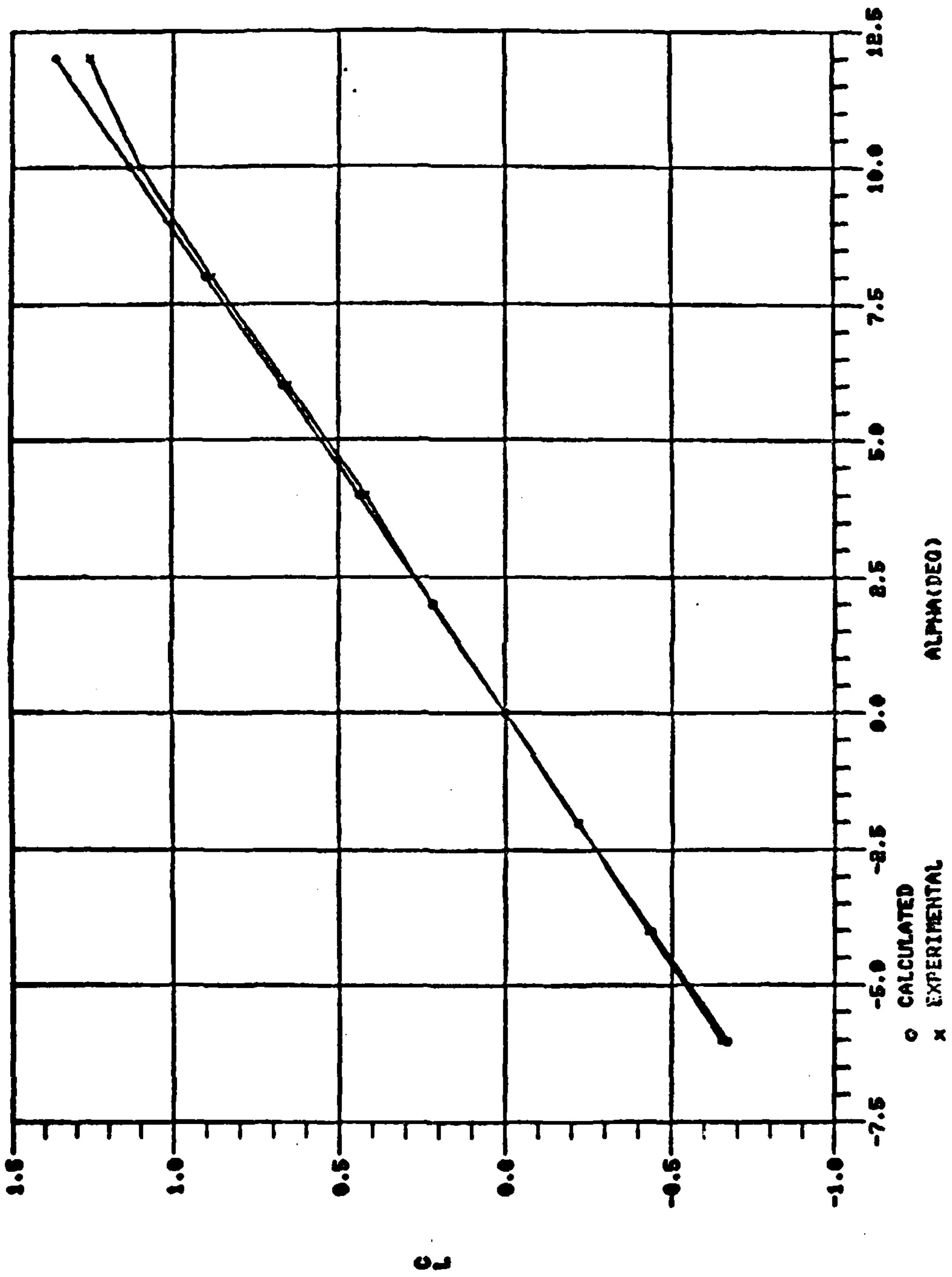


Figure 36. Calculated and Experimental Lift Coefficient vs Angle of Attack (TEKPLOT).

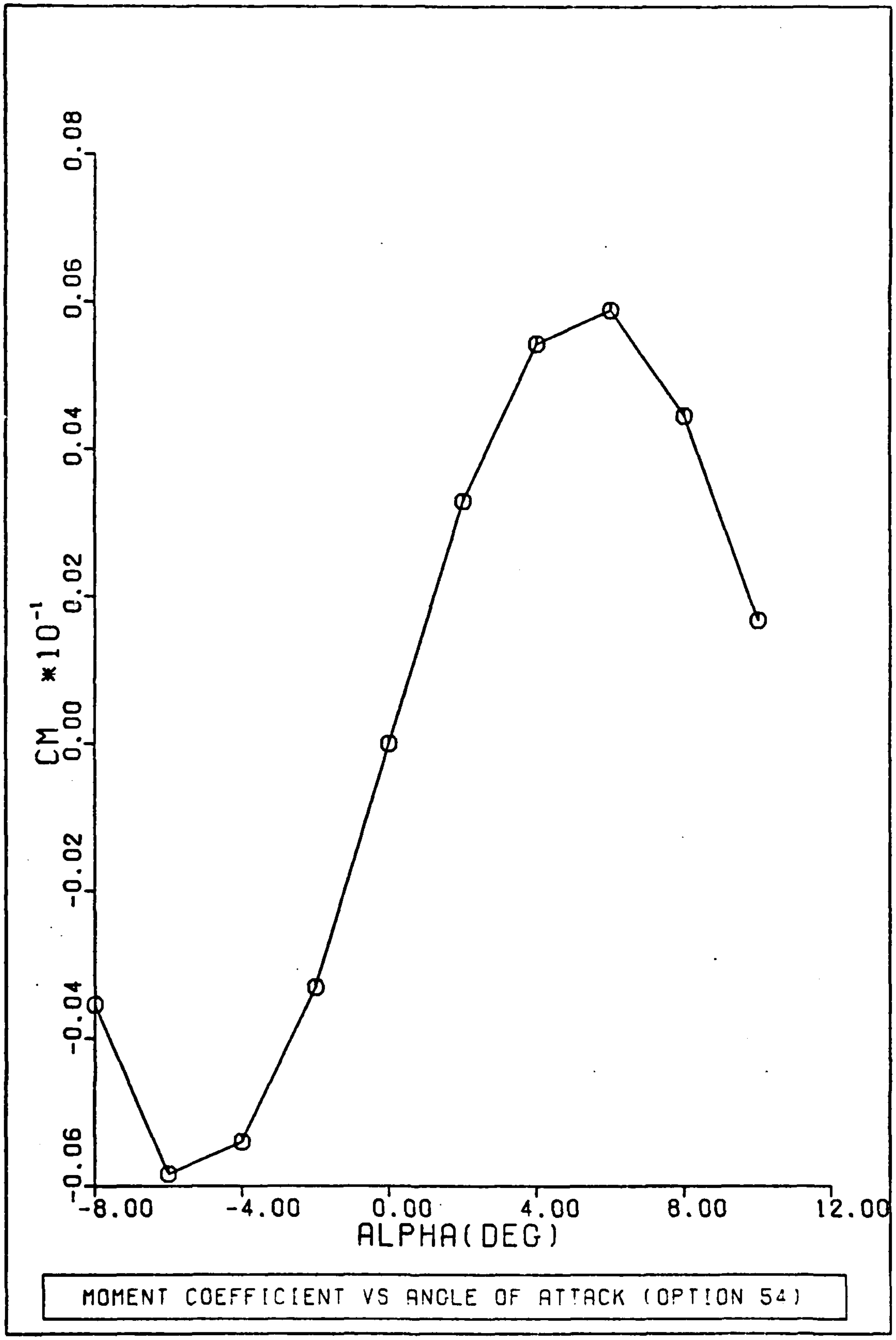


Figure 37. Moment Coefficient vs Angle of Attack (CPLOT).

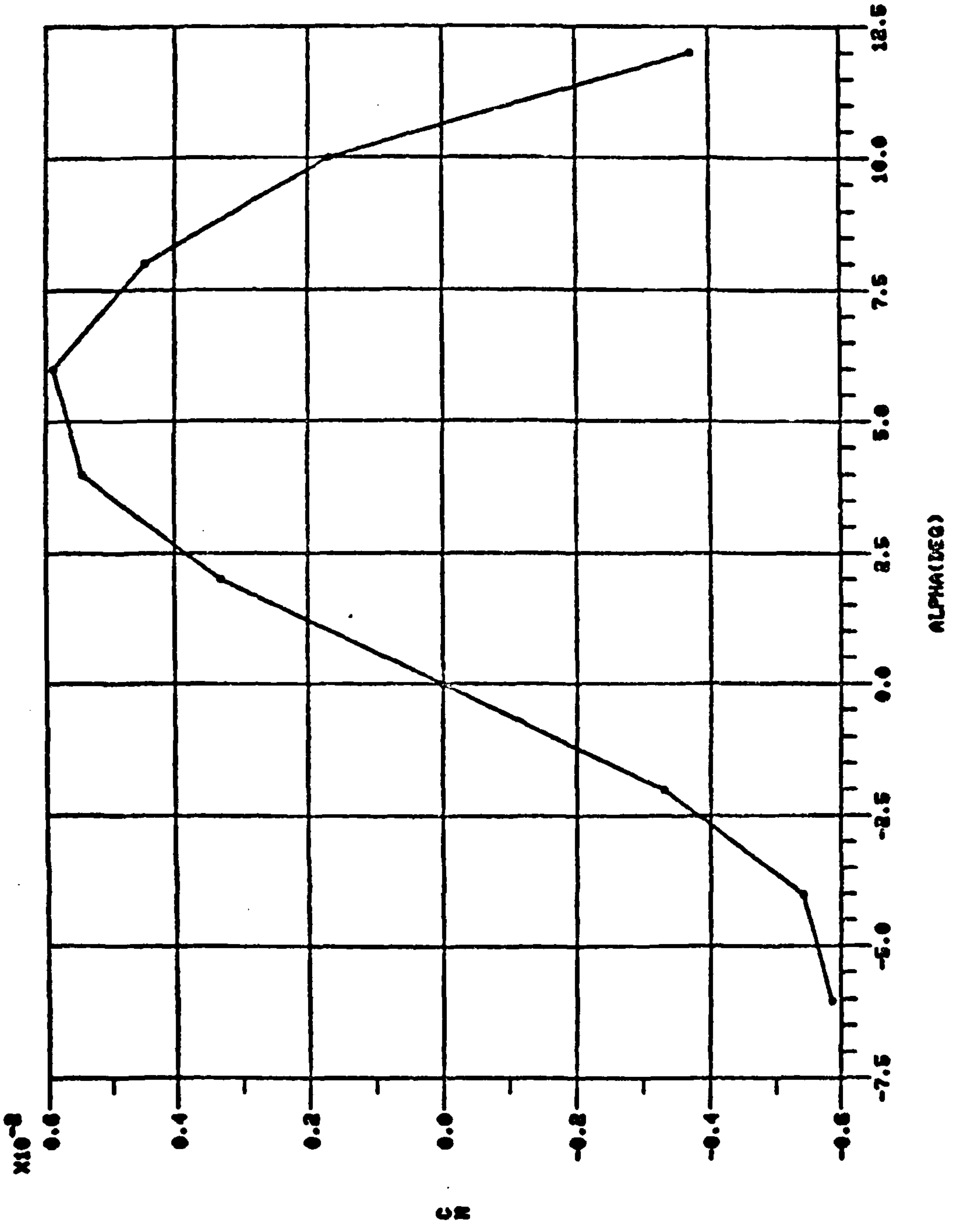


Figure 38. Moment Coefficient vs Angle of Attack (TEKPLOT).

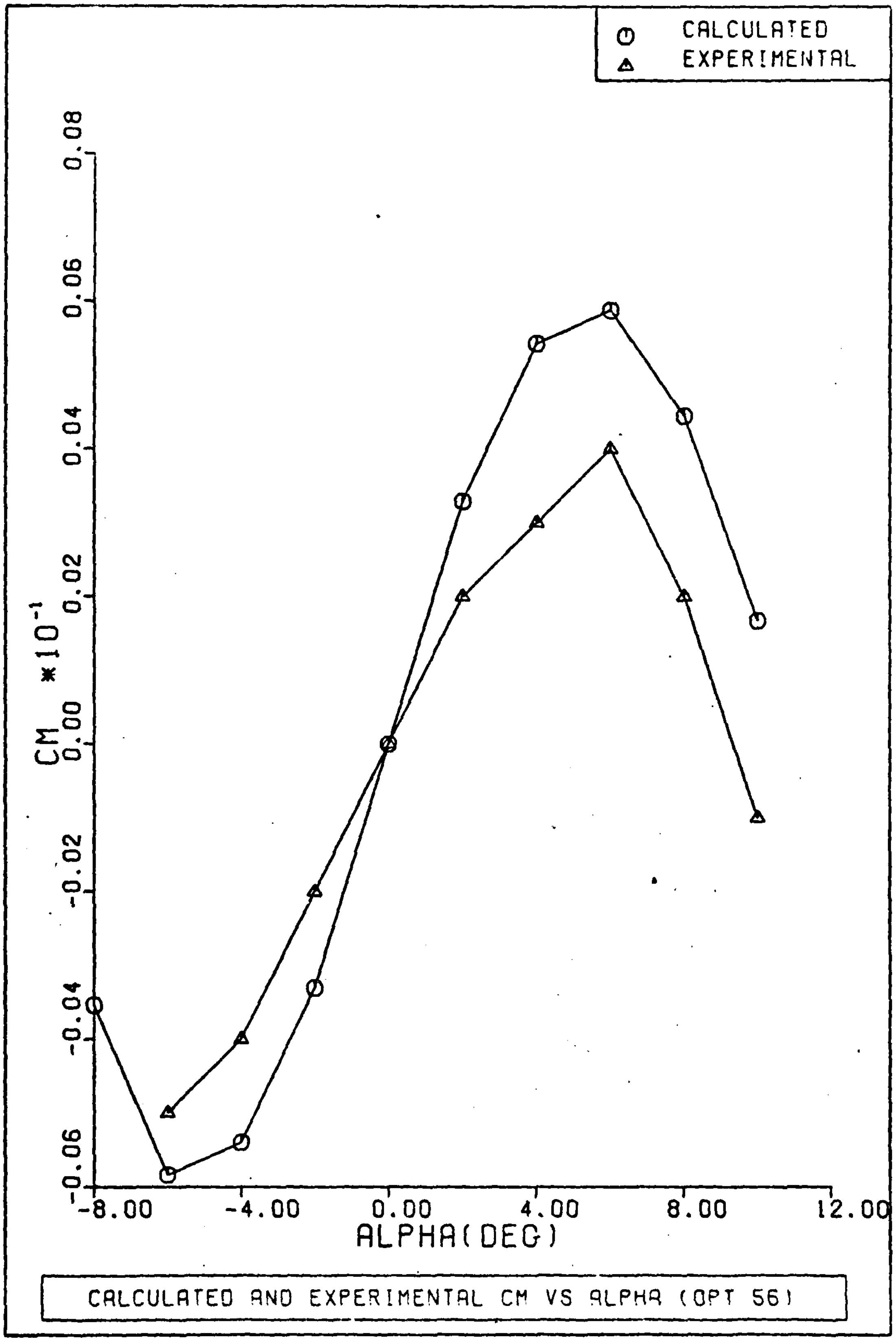


Figure 39. Calculated and Experimental Moment Coefficient vs Angle of Attack (CPLOT).

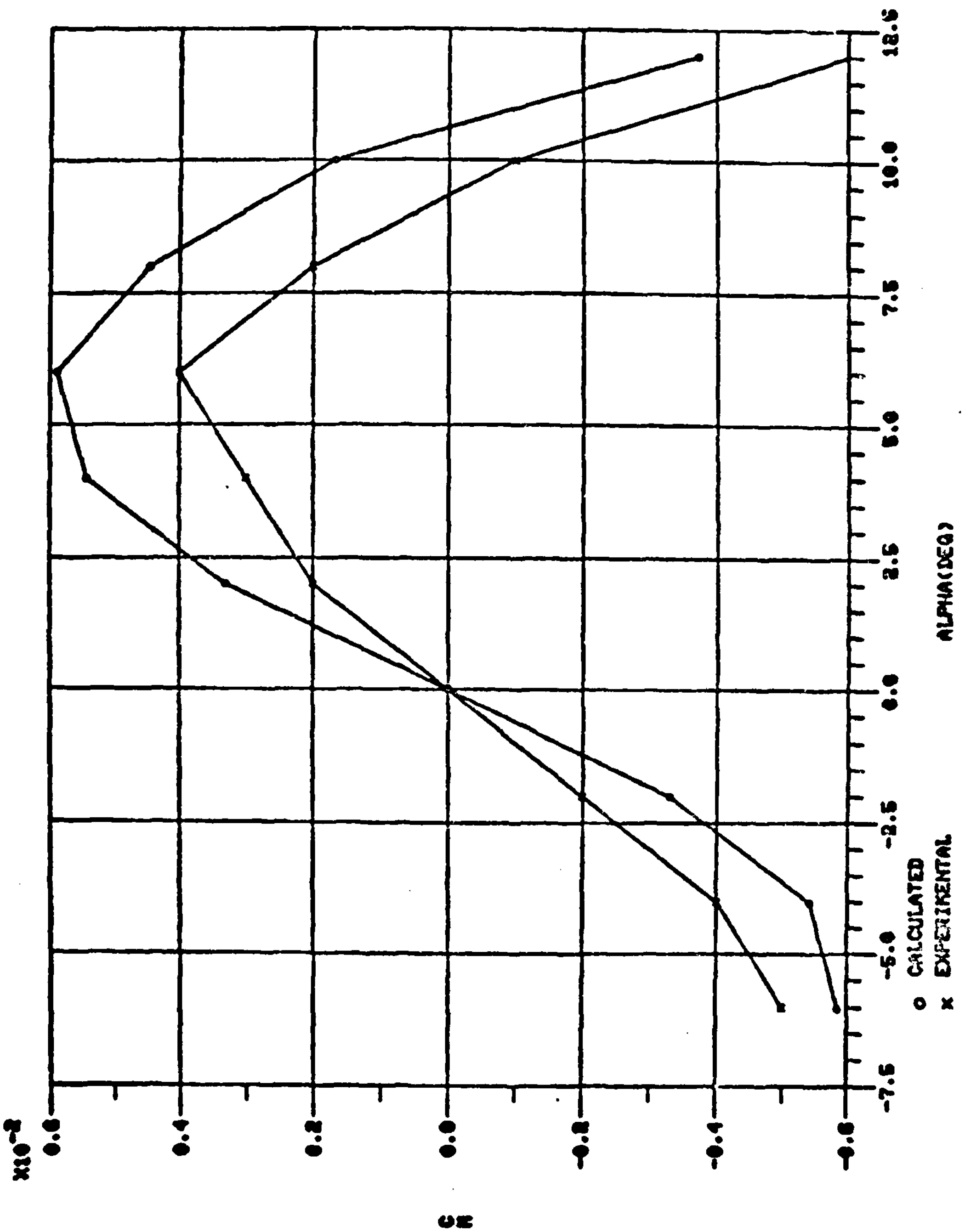


Figure 40. Calculated and Experimental Moment Coefficient vs Angle of Attack (TEKPLOT).

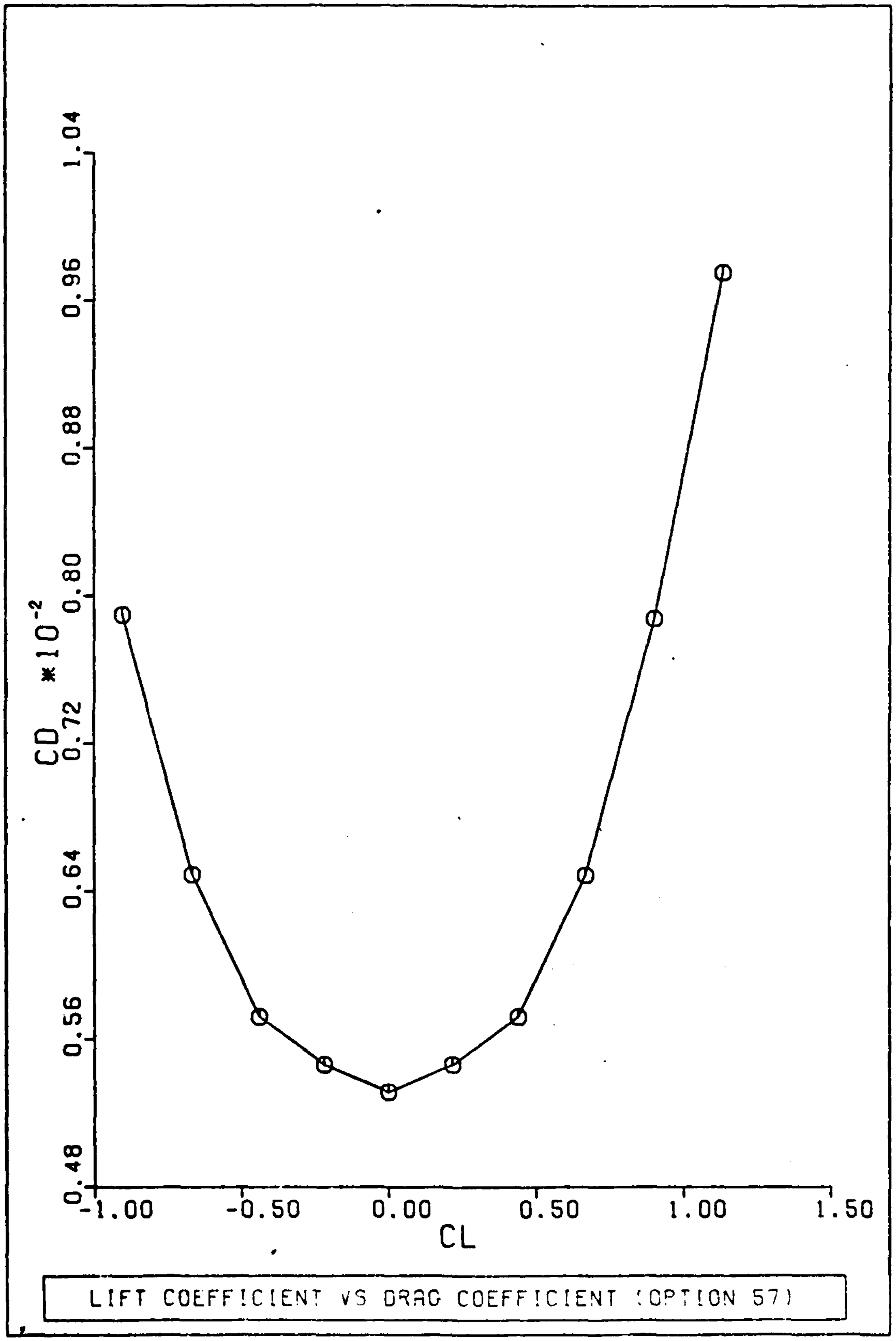


Figure 41. Lift vs Drag coefficient (CPLOT).

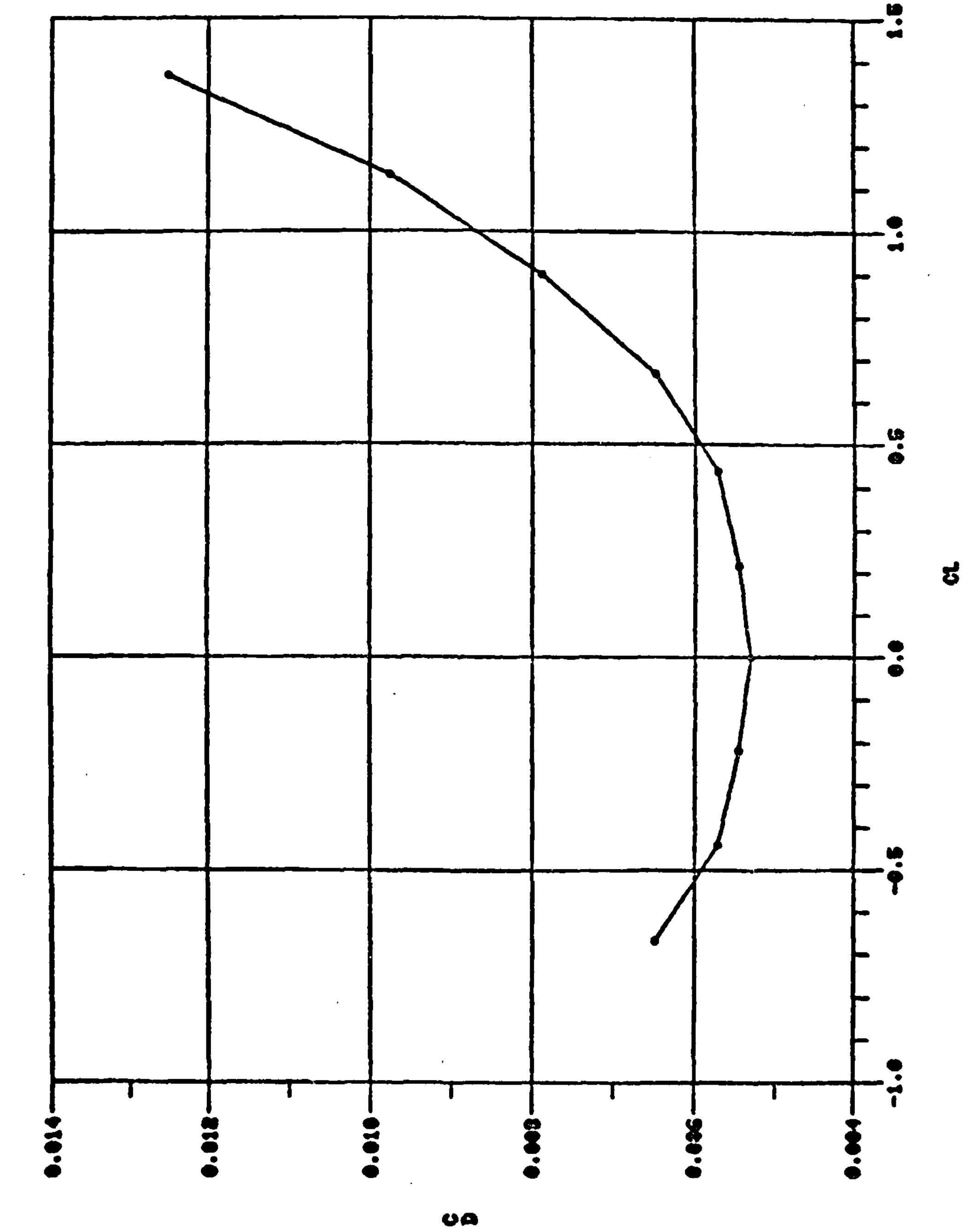


Figure 42. Lift vs Drag coefficient (TEKPLOT).

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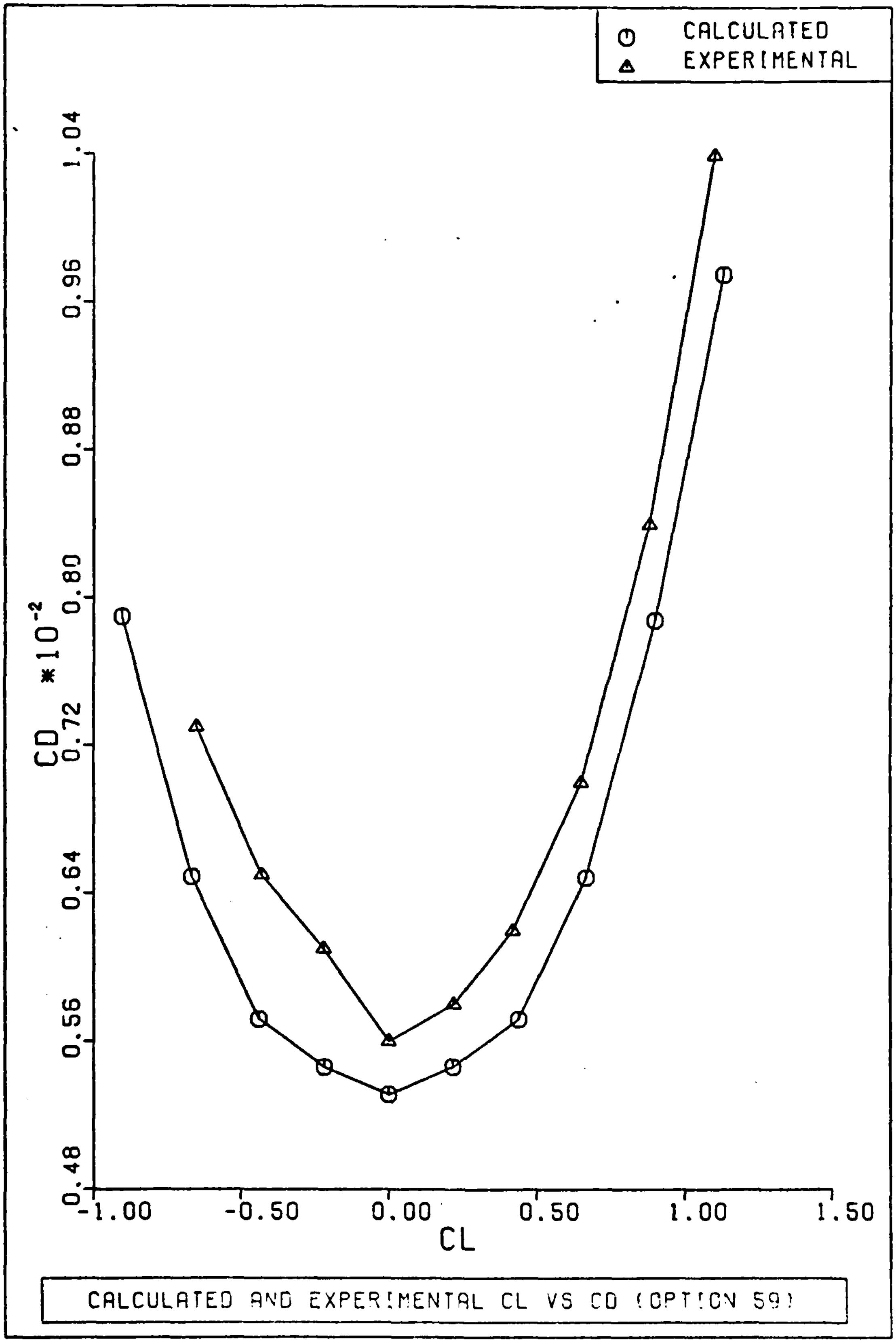

Figure 43. Calculated and Experimental Lift vs Drag Coefficient (CPLOT).

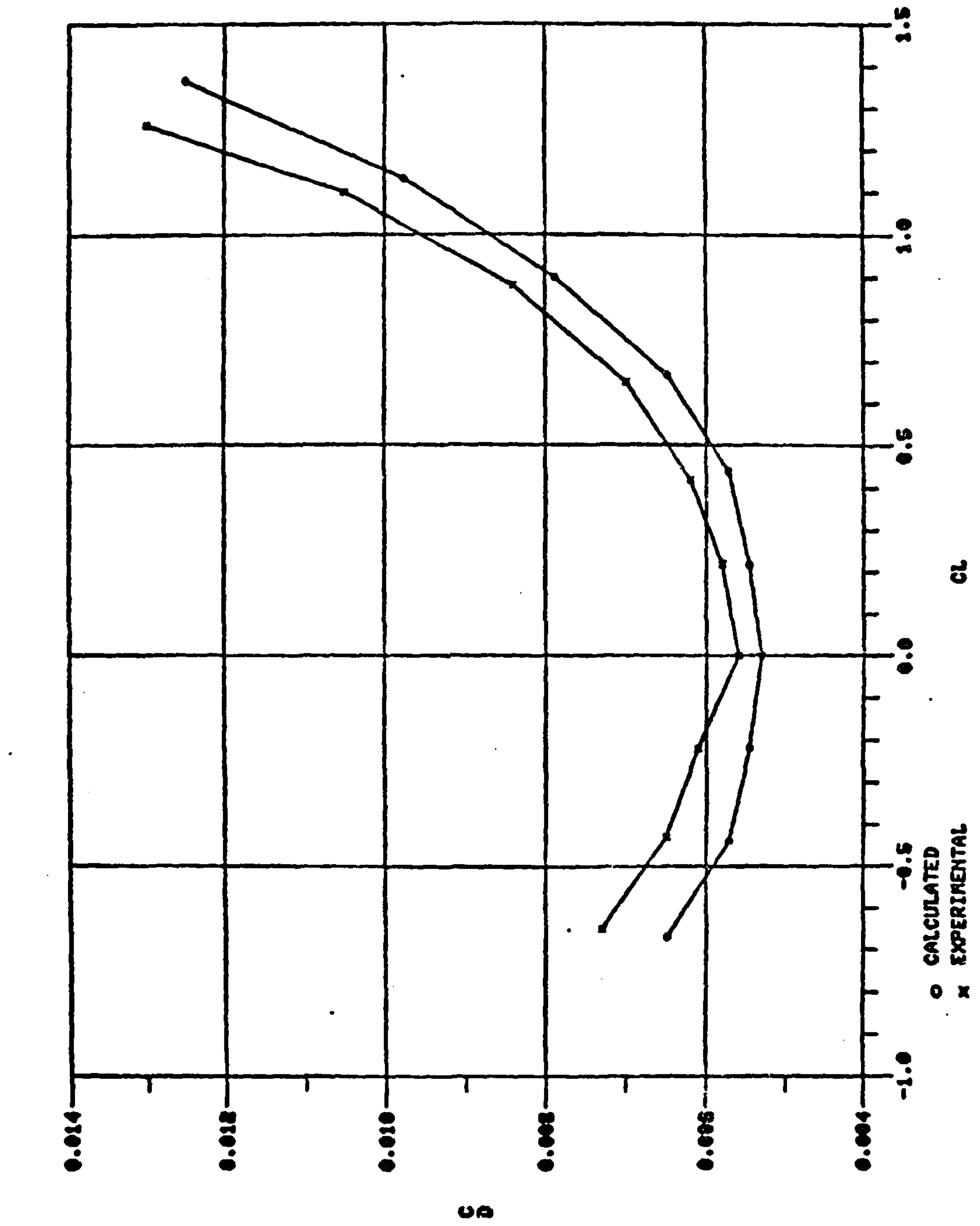

Figure 44. Calculated and Experimental Lift vs Drag Coefficient (TEKPLOT).

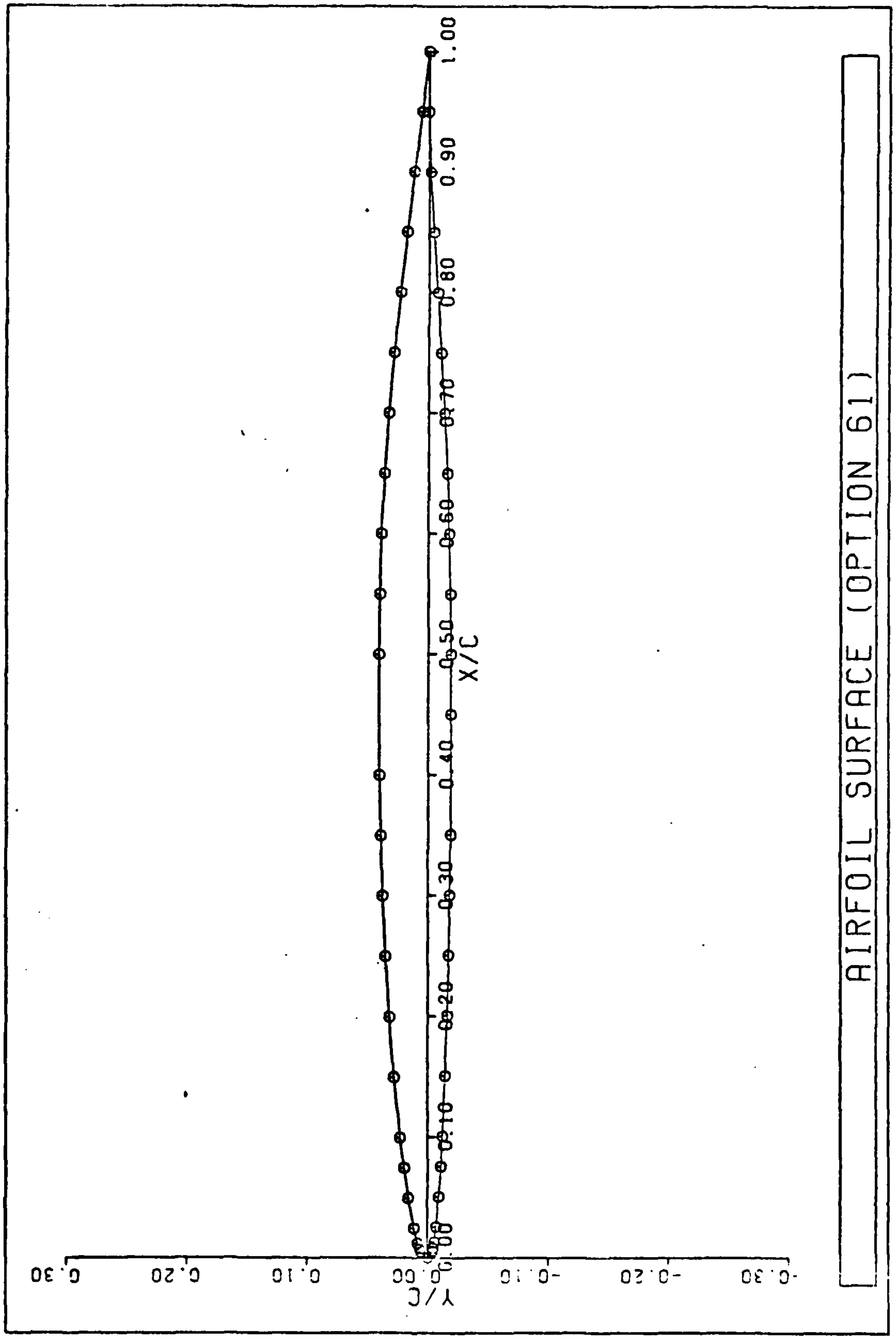

Figure 45. Airfoil Surface (CPLOT).

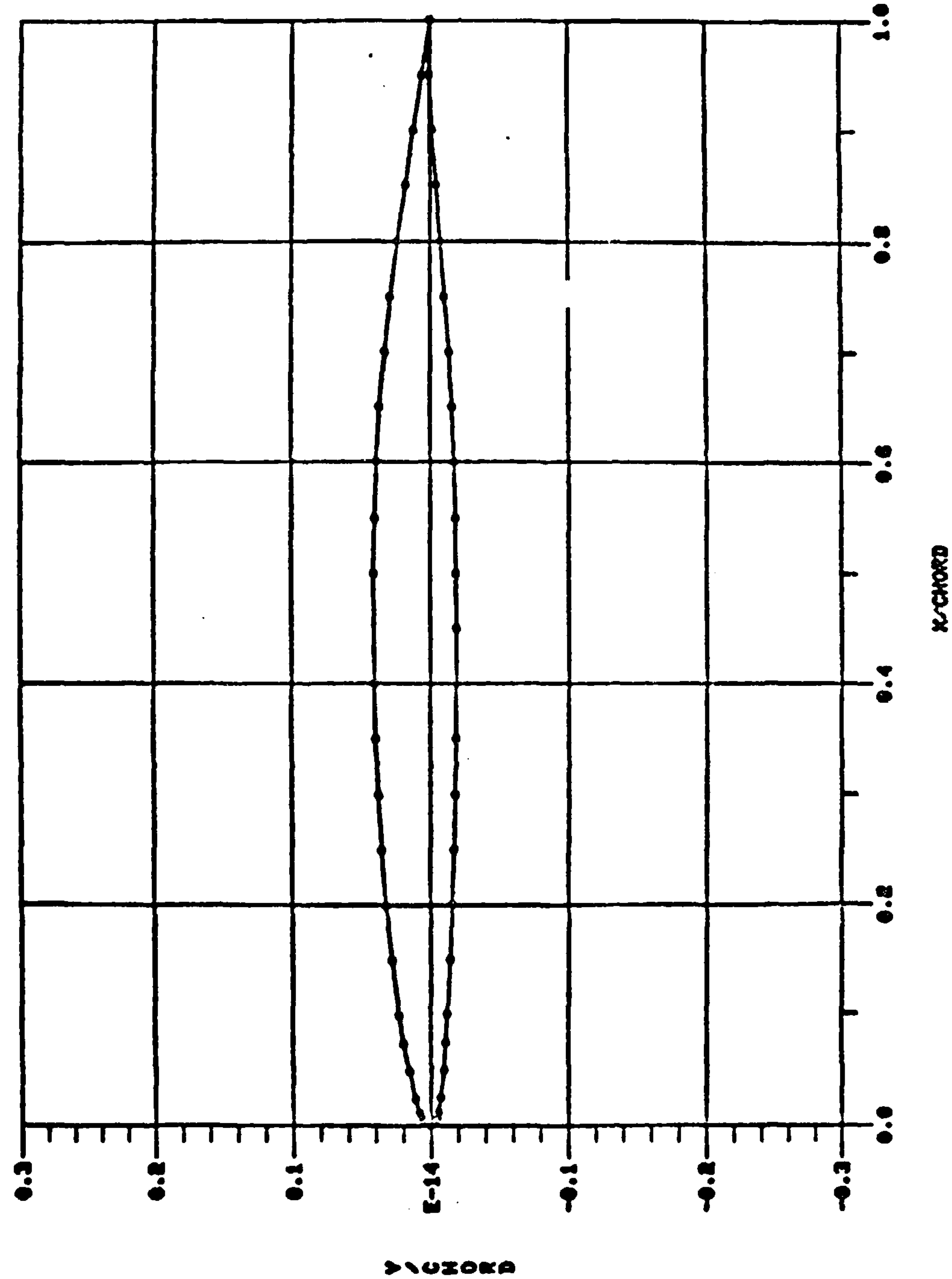

Figure 46. Airfoil Surface (TEKPLOT).

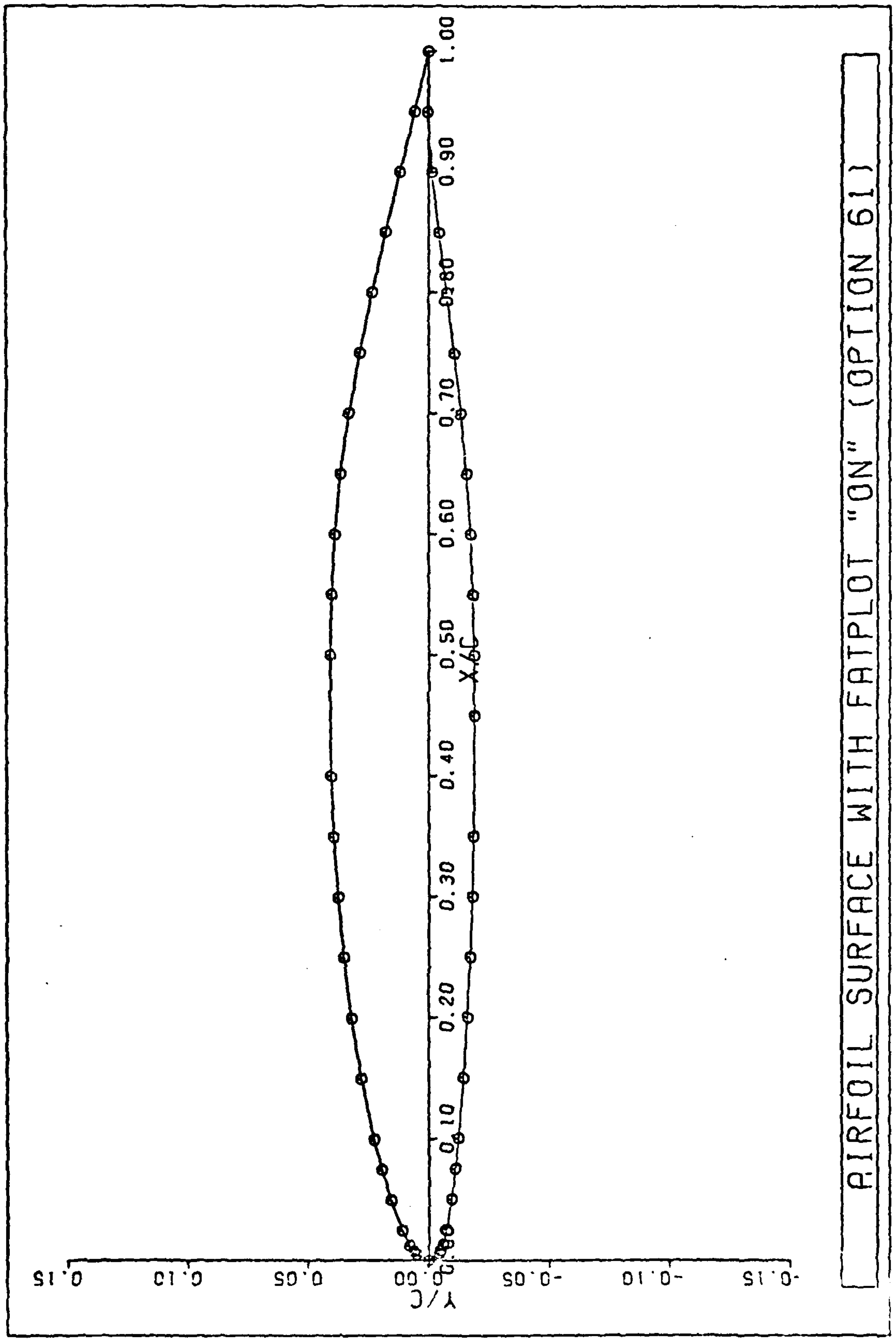

Figure 47. Airfoil Surface with FATPLOT "on" (CPLOT).

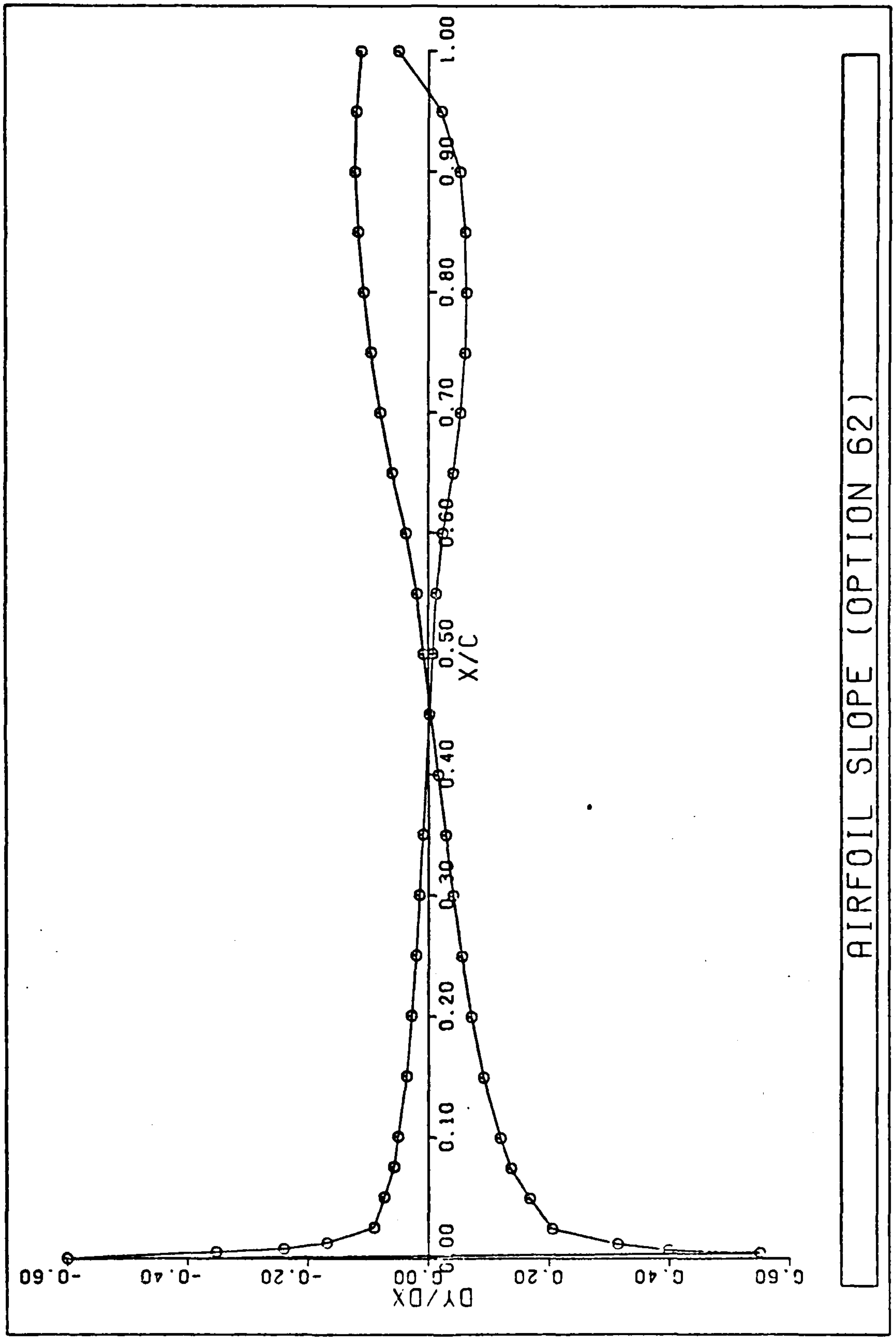

Figure 48. Airfoil Slope (CPLOT).

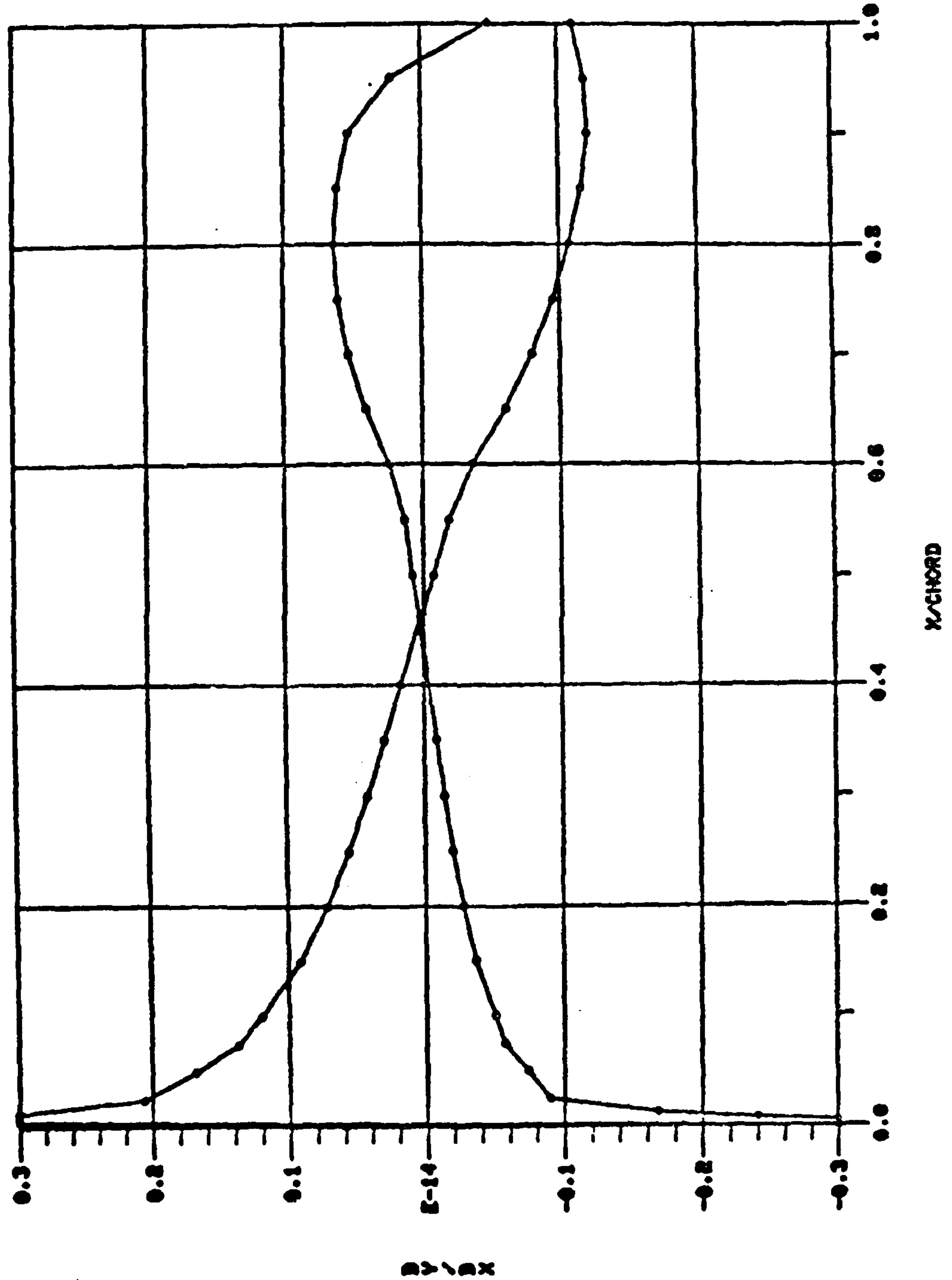

Figure 49. Airfoil Slope (TEKPLOT).

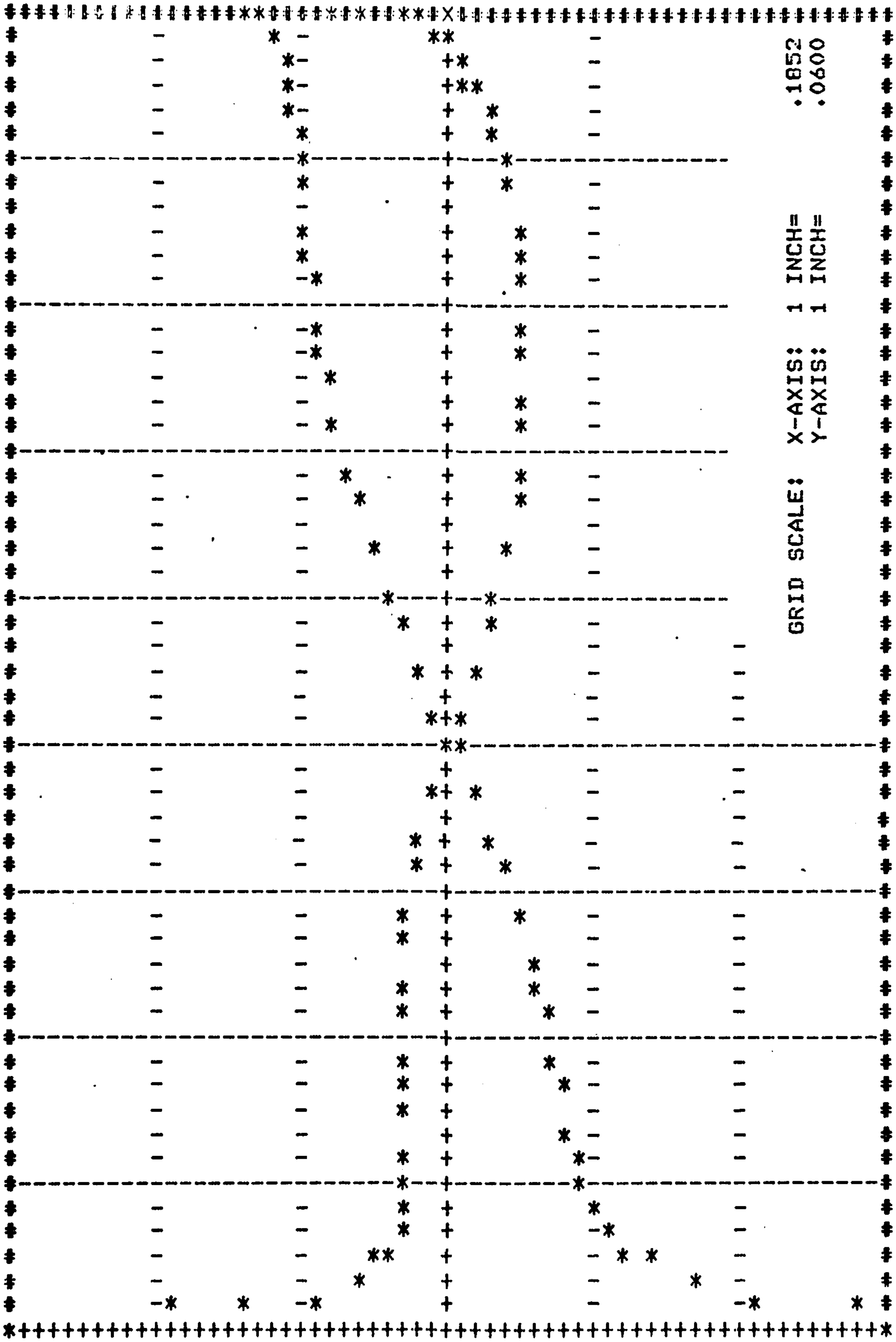

Figure 50. Airfoil Slope (TPLOT).

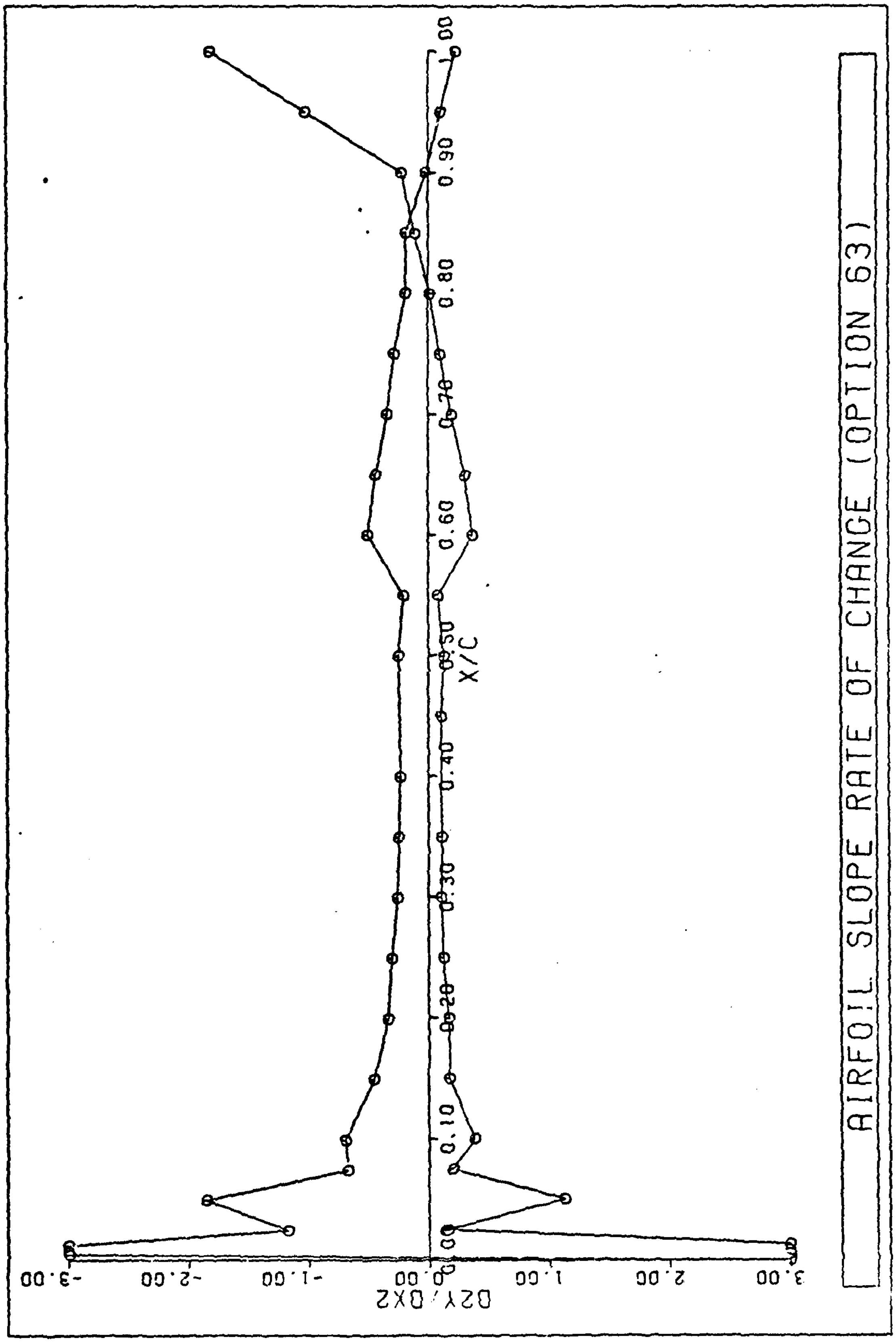

Figure 51. Airfoil Slope Rate of Change (CPLOT).

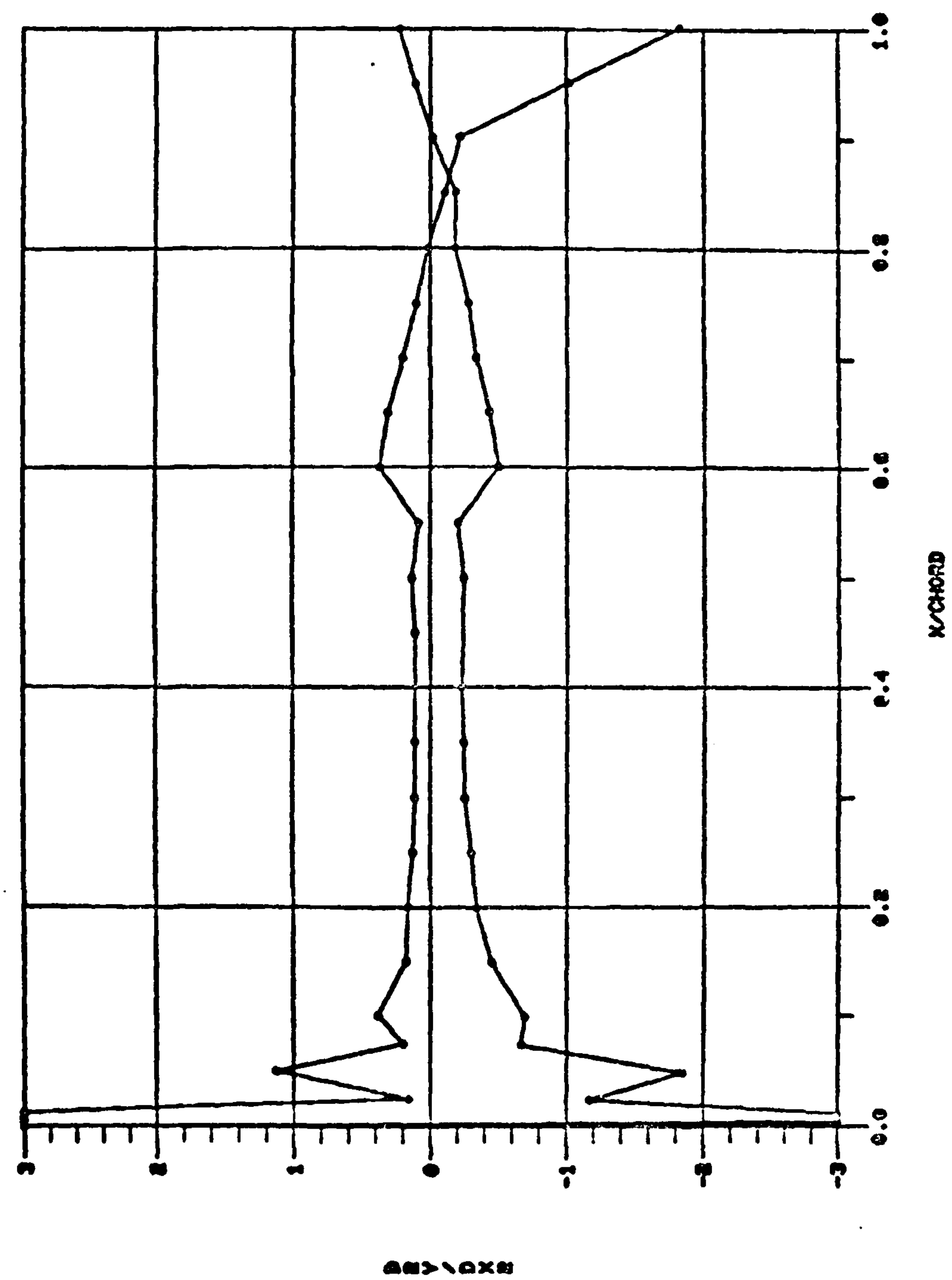

Figure 52. Airfoil Slope Rate of Change (TEKPLOT).

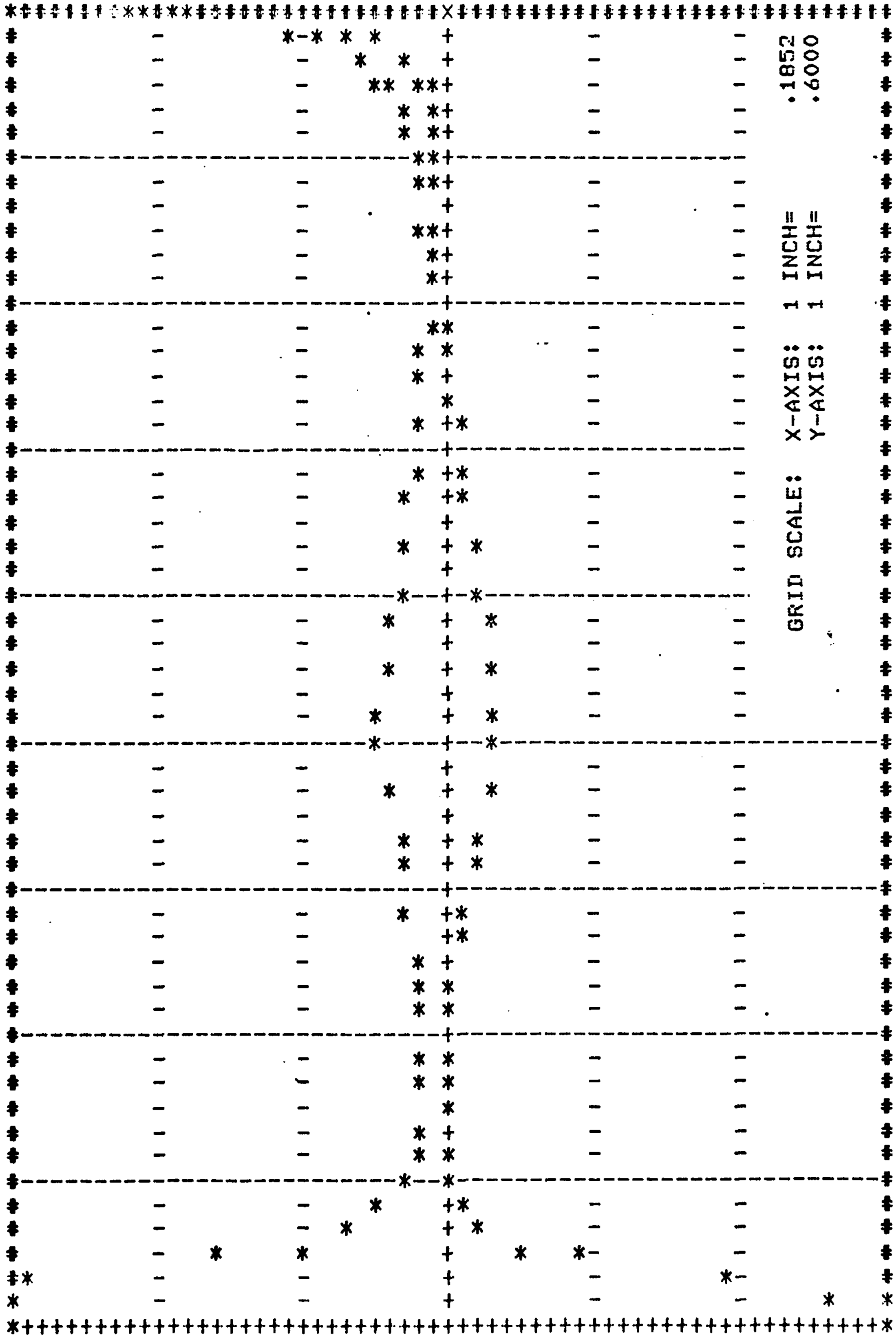

Figure 53. Airfoil Slope Rate of Change (TPLOT).

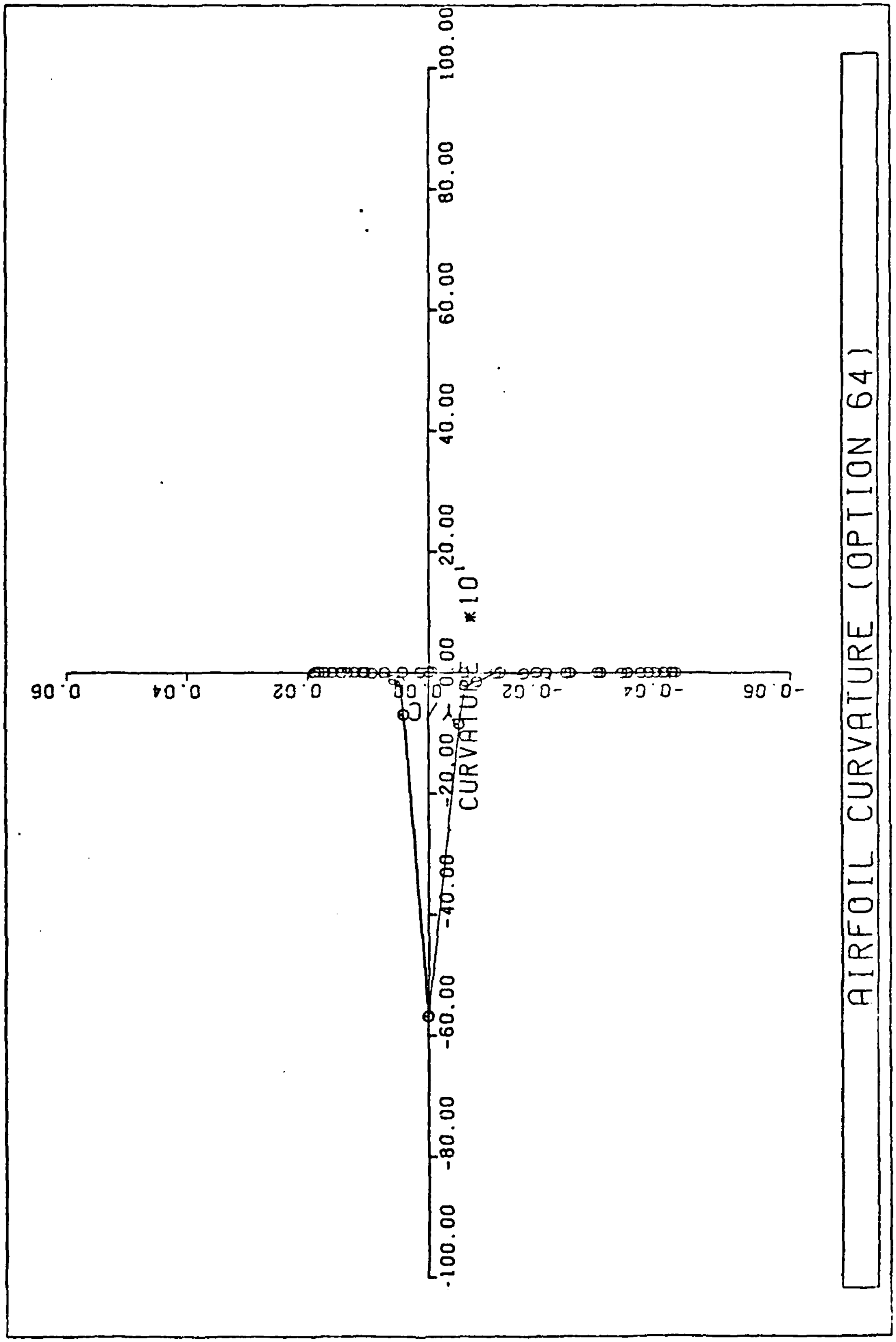

Figure 54. Airfoil Curvature (CPLOT).

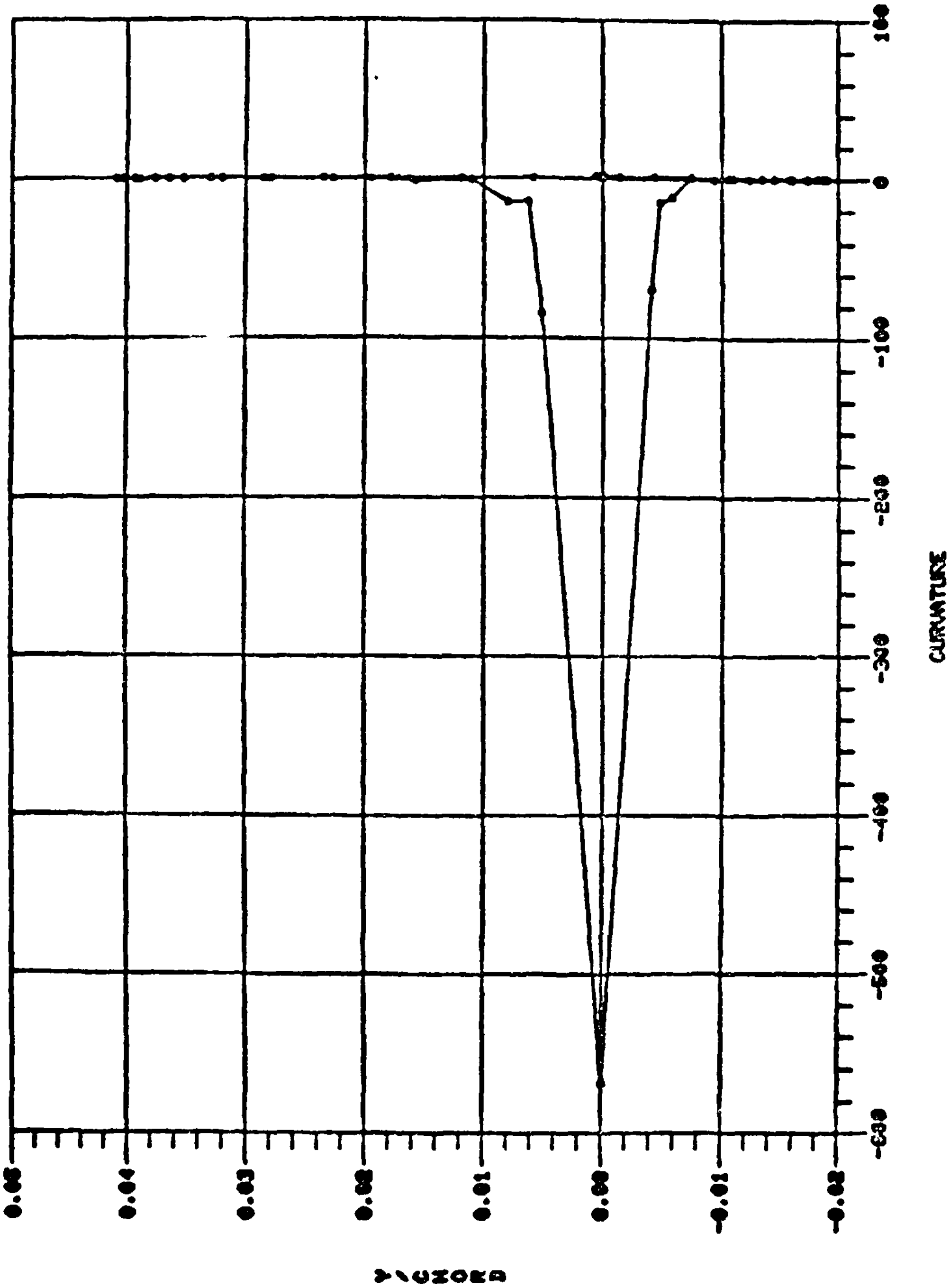

Figure 55. Airfoil Curvature (TEKPLOT).

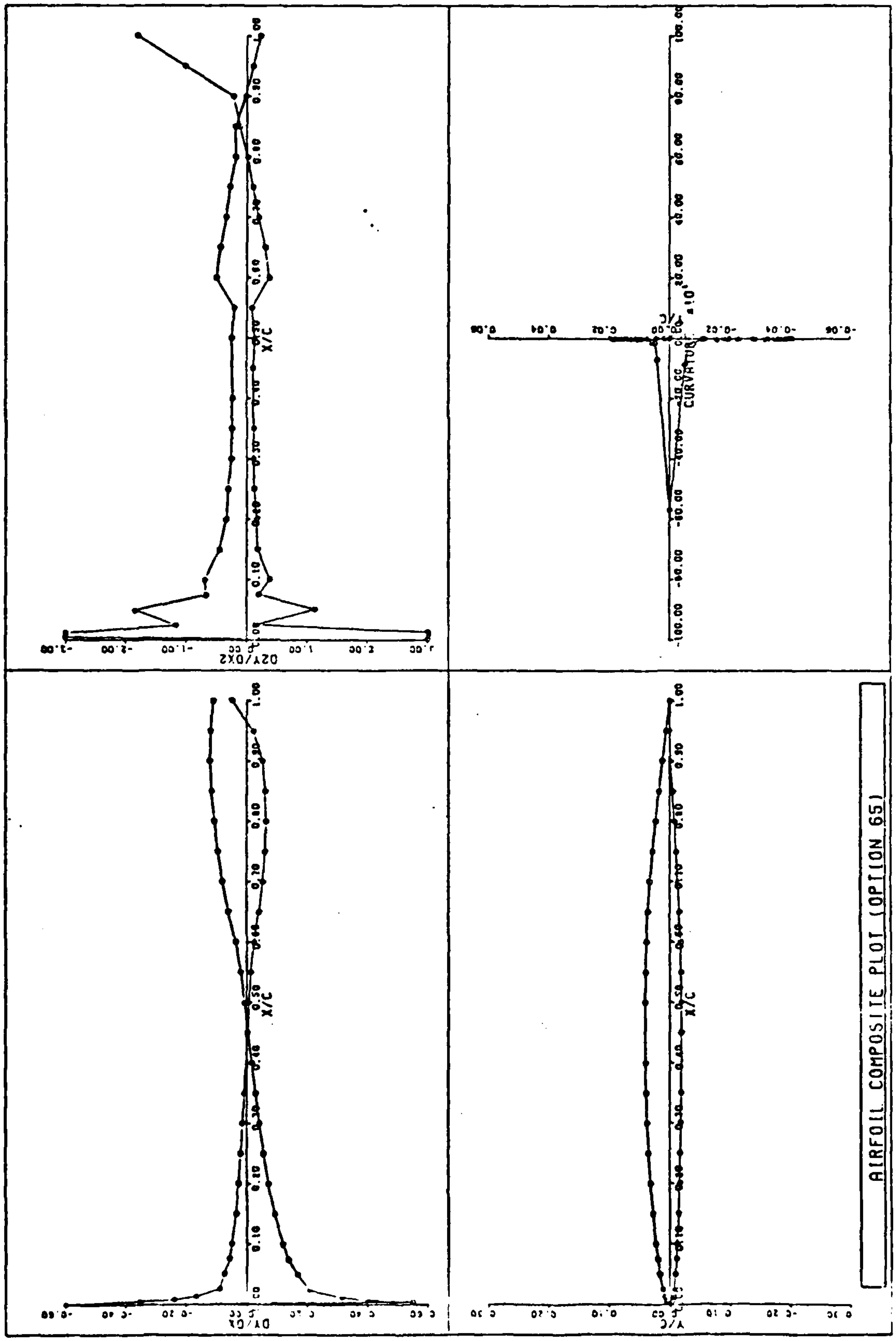

Figure 56. Composite Airfoil Plot (CPLOT).

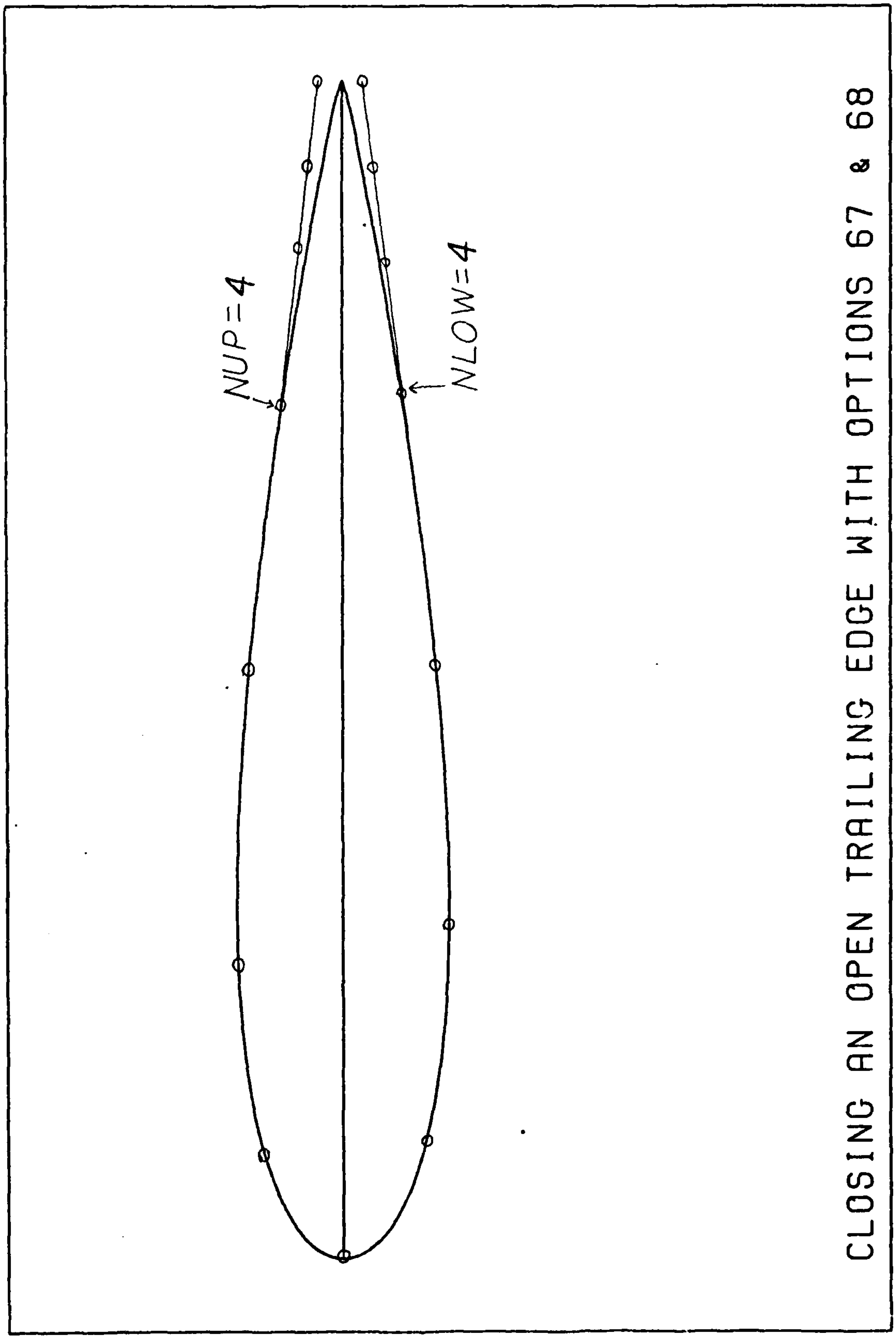

Figure 57. Thick Trailing Edge Faired to a Point.

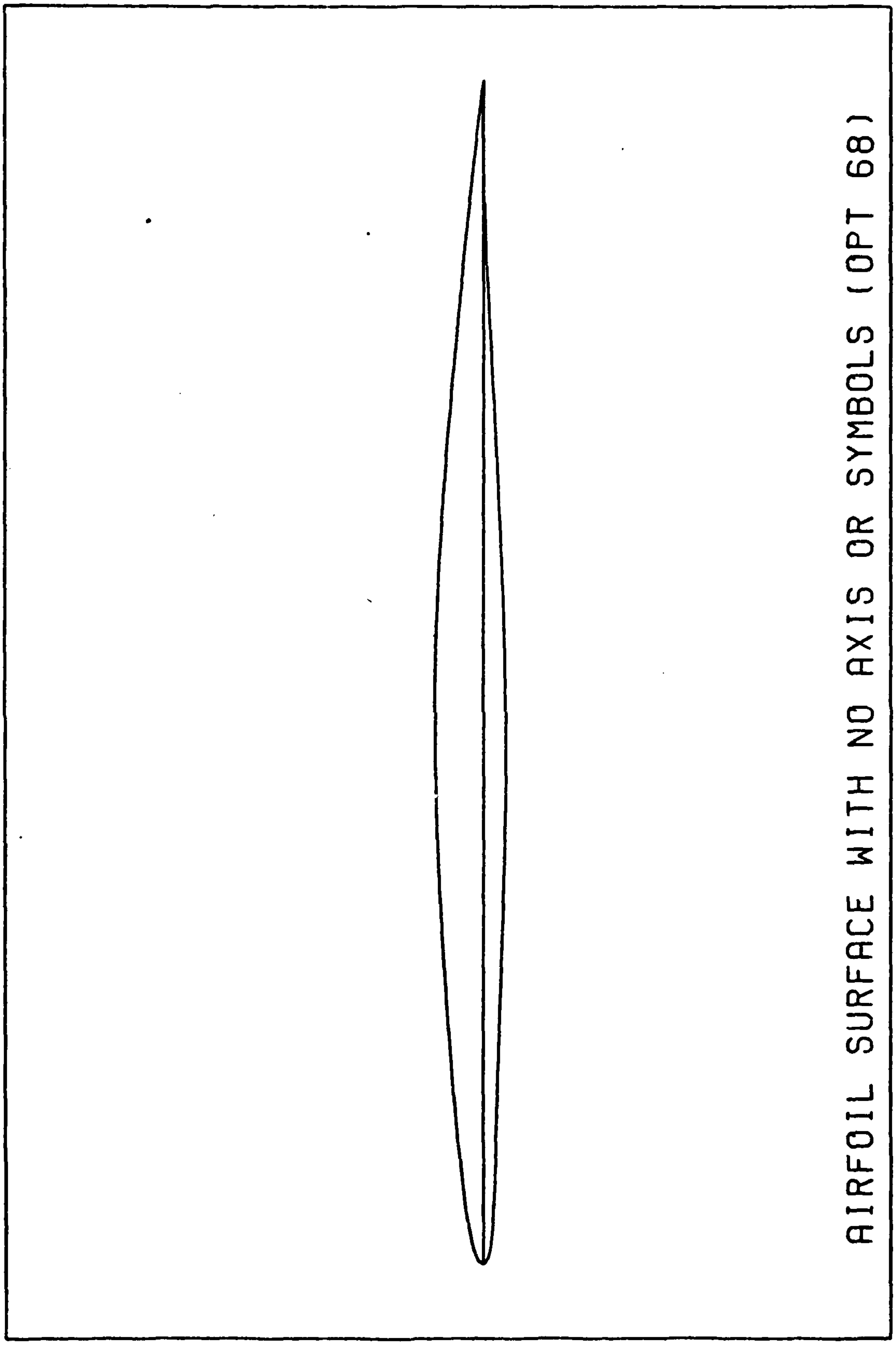

Figure 58. Very Smooth Airfoil Plot (CPLOT).

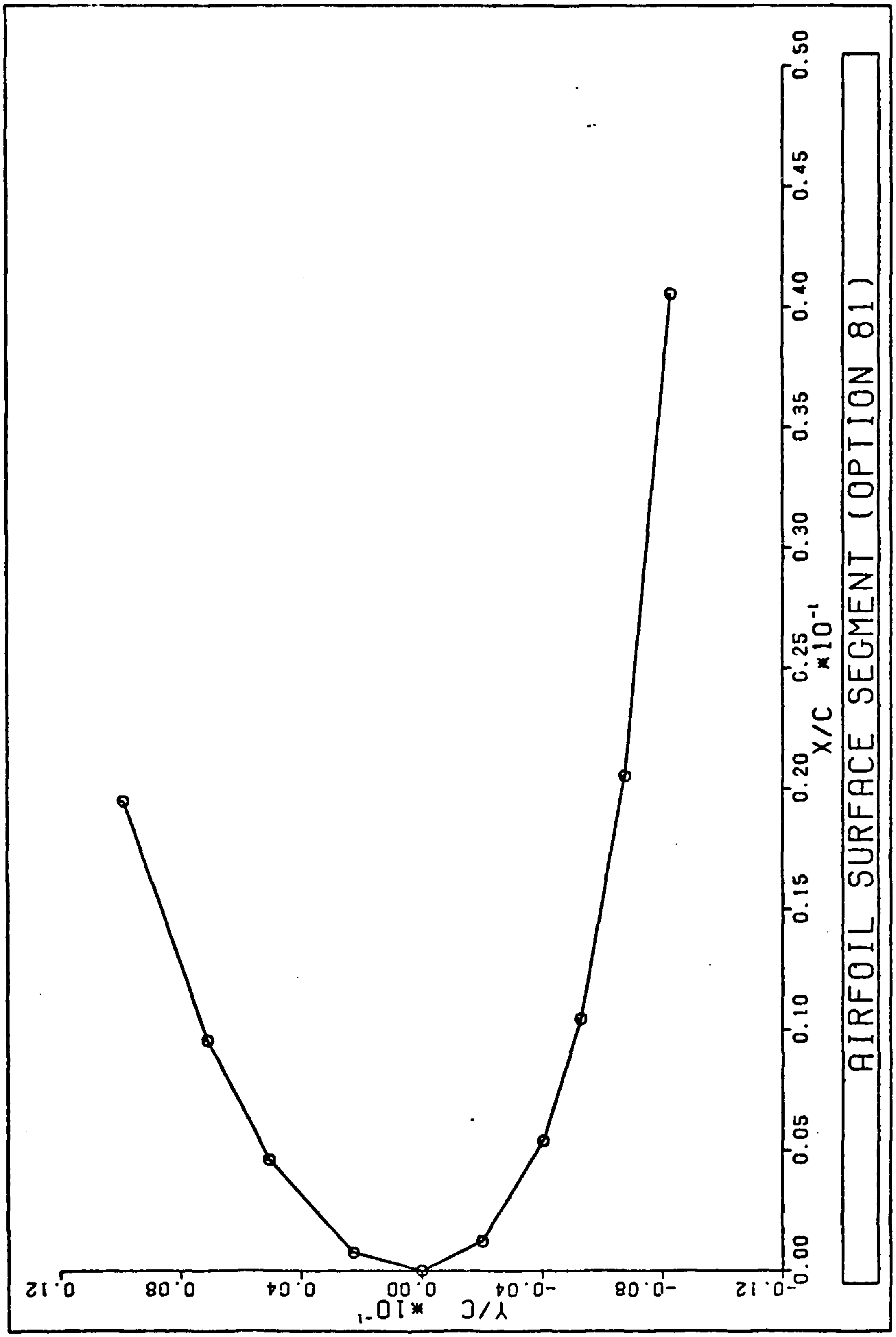

Figure 59. Airfoil Surface (CPLOT).

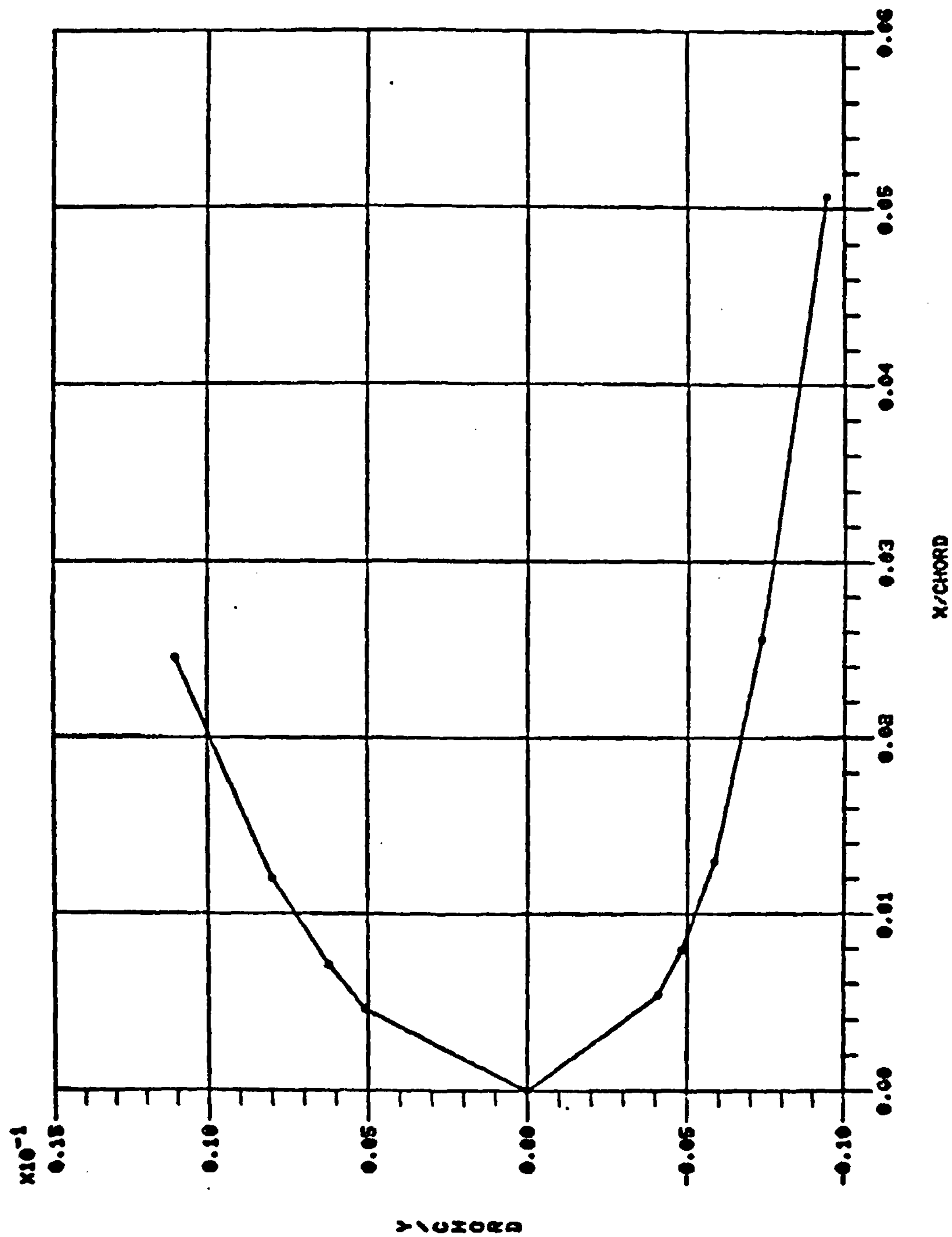

Figure 60. Airfoil Surface (TEKPLOT).

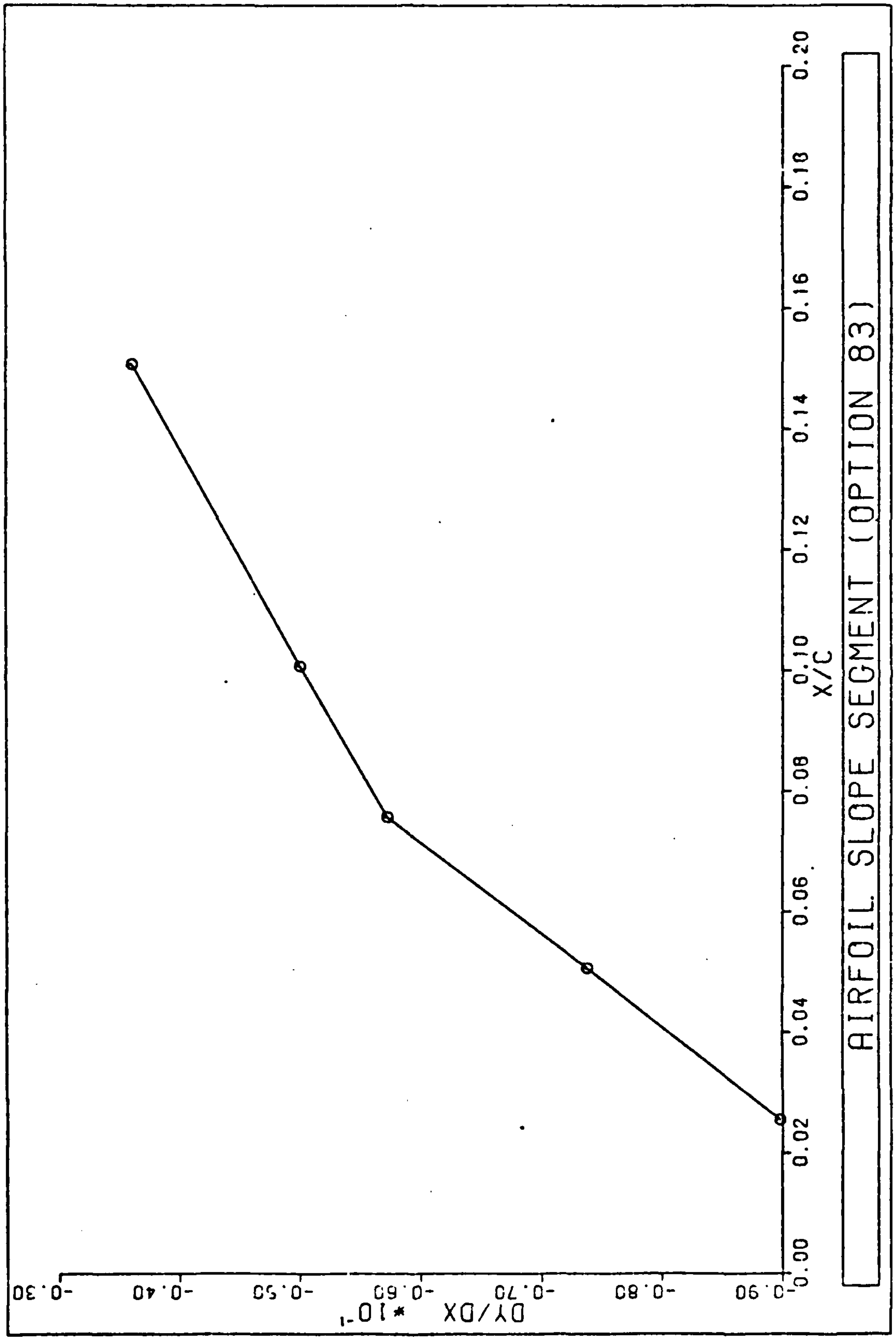

Figure 61. Airfoil Slope (CPLOT).

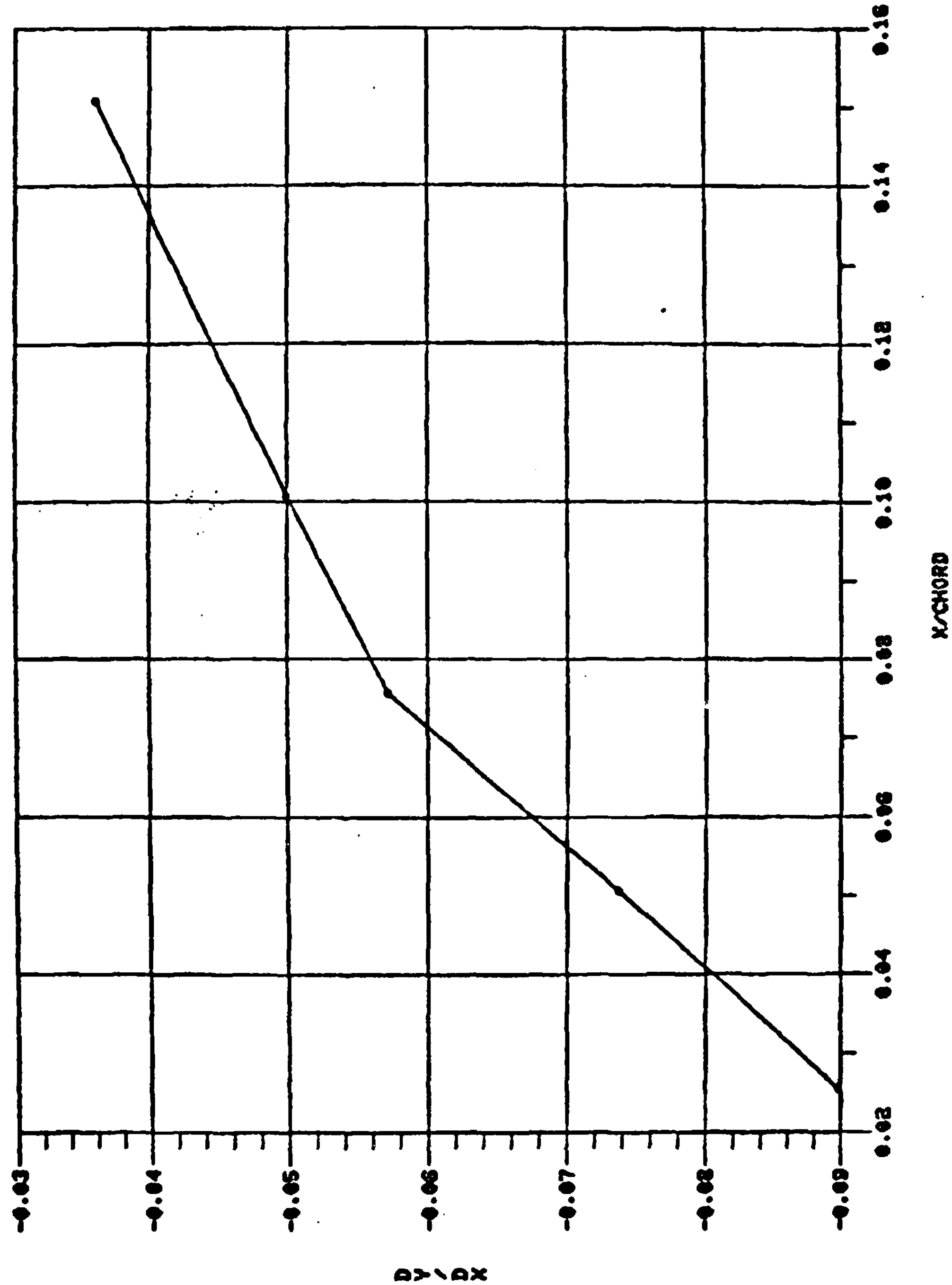

Figure 62. Airfoil Slope (TEKPLOT).

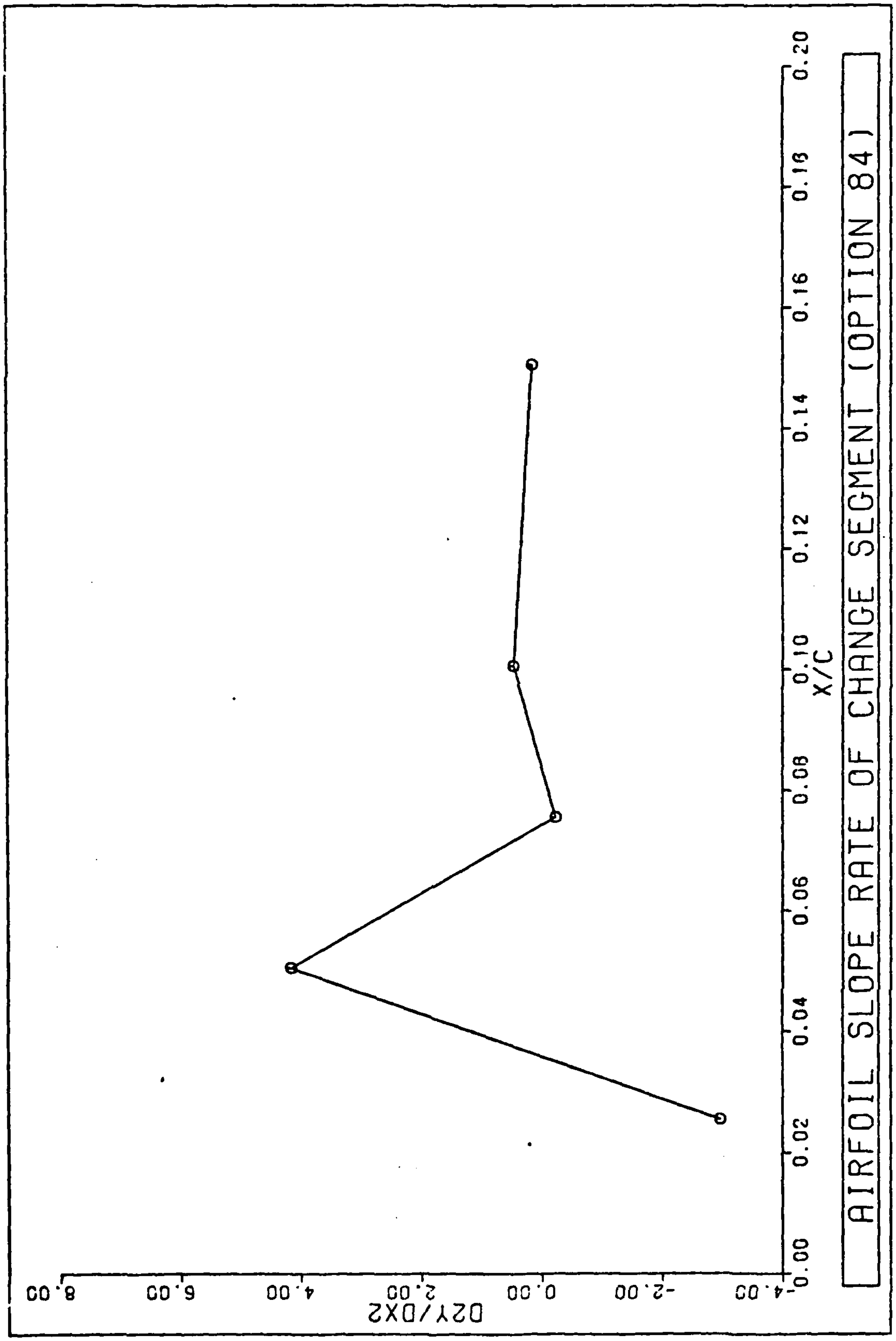

Figure 63. Airfoil Slope Rate of Change (CPLOT).

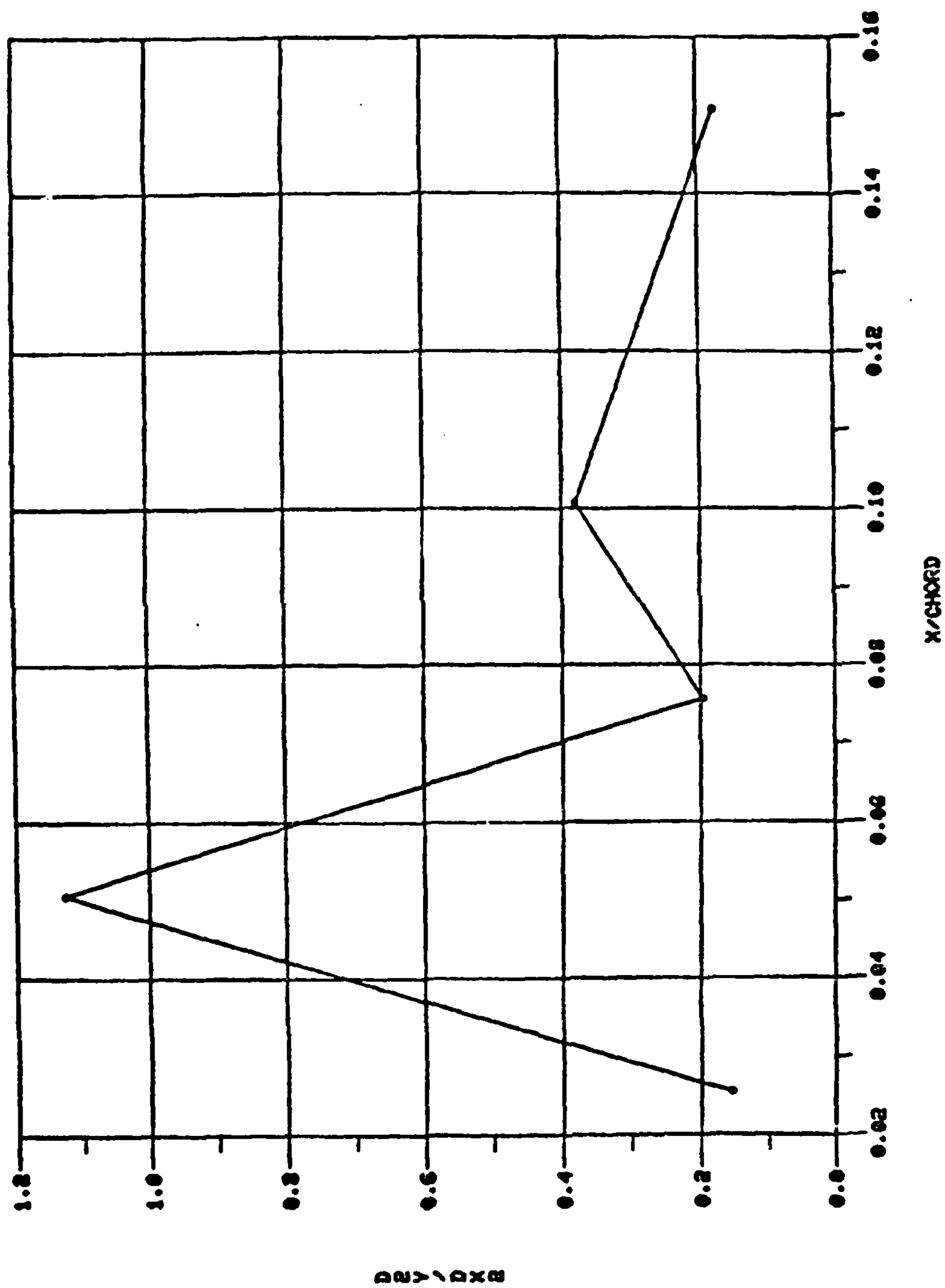

Figure 64. Airfoil Slope Rate of Change (TEKPLOT).

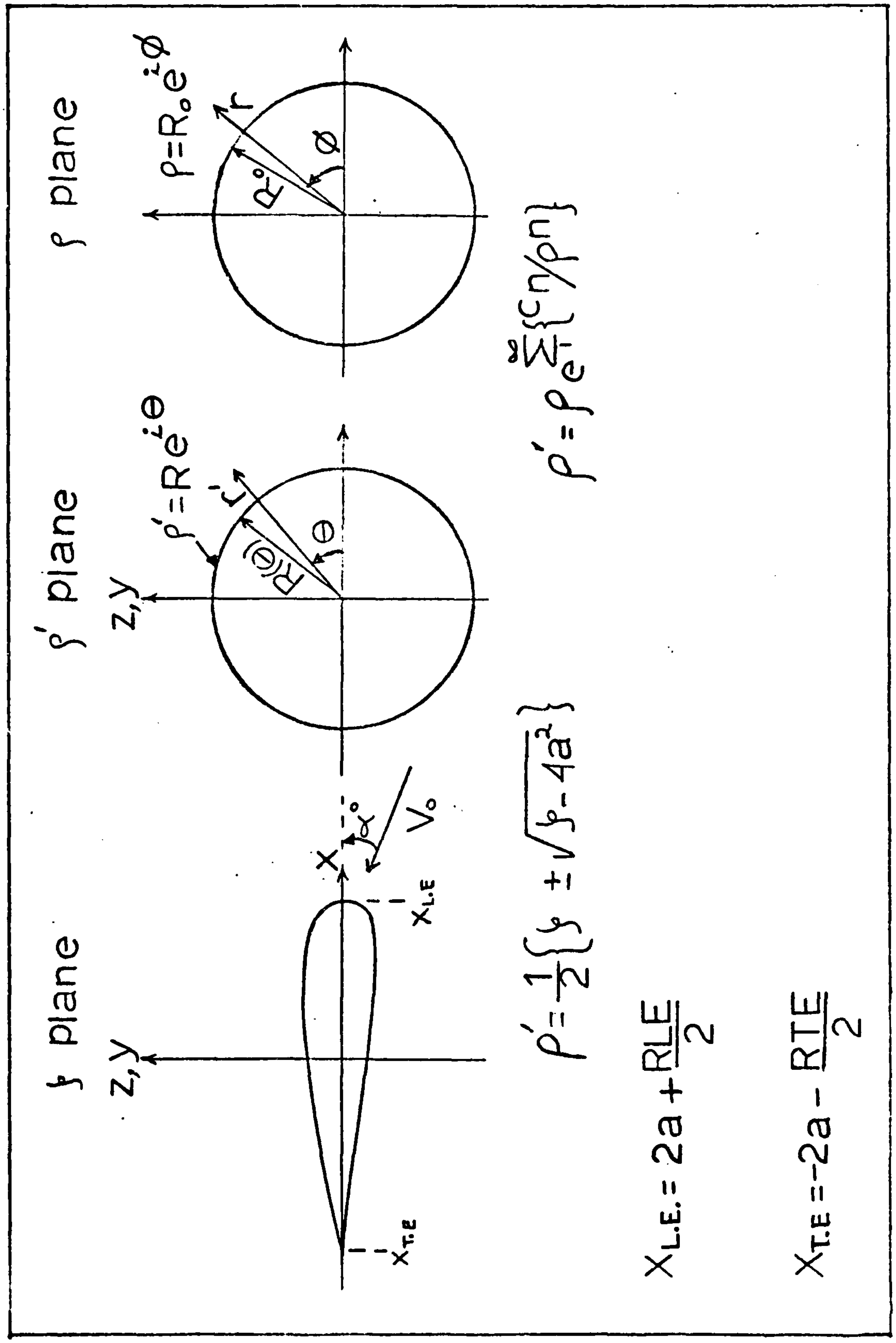

Figure 65. Theodorsen Transformation Planes.

NO.	X/CHORD	Y/CHORD	CF
1	.8499326541E-03	-.1709373220E-02	.1000000000E+03
2	0.	0.	.1505130598E-01
3	.4510000000E-02	.5090000000E-02	.2452527847E-02
4	.7070000000E-02	.6220000000E-02	.1291998457E-02
5	.1202000000E-01	.7950000000E-02	.4419123203E-03
6	.2447000000E-01	.1132000000E-01	.4511101652E-02
7	.4341000000E-01	.1572000000E-01	.3581587150E-02
8	.7439000000E-01	.1947000000E-01	.3336864173E-02
9	.9939000000E-01	.2268000000E-01	.3209097727E-02
10	.1494200000E+00	.2791000000E-01	.3035588399E-02
11	.1994700000E+00	.3196000000E-01	.2914477225E-02
12	.2495400000E+00	.3513000000E-01	.2822778785E-02
13	.2996200000E+00	.3754000000E-01	.2747825572E-02
14	.3497100000E+00	.3929000000E-01	.2584983297E-02
15	.3998100000E+00	.4042000000E-01	.2630753462E-02
16	.5000000000E+00	.4088000000E-01	.2540061203E-02
17	.5500900000E+00	.4020000000E-01	.2498691510E-02
18	.6001800000E+00	.3886000000E-01	.2449856844E-02
19	.6502500000E+00	.3641000000E-01	.2381156829E-02
20	.7003100000E+00	.3288000000E-01	.2292173829E-02
21	.7503400000E+00	.2848000000E-01	.2192650931E-02
22	.8003400000E+00	.2339000000E-01	.2090504320E-02
23	.8503100000E+00	.1780000000E-01	.1982437618E-02
24	.9002300000E+00	.1182000000E-01	.1860113581E-02
25	.9501200000E+00	.5780000000E-02	.1724740708E-02
26	.1000000000E+01	0.	.1590610732E-02
27	.8499326541E-03	-.1709373220E-02	.1000000000E+03
28	.5390000000E-02	-.4090000000E-02	.1052181578E-01
29	.7930000000E-02	-.4820000000E-02	.5894810427E-02
30	.1298000000E-01	-.5840000000E-02	.4401089983E-02
31	.2553000000E-01	-.7300000000E-02	.2521170465E-02
32	.5059000000E-01	-.9400000000E-02	.1507913484E-02
33	.7561000000E-01	-.1093000000E-01	.1244574775E-02
34	.1006100000E+00	-.1234000000E-01	.1049215259E-02
35	.1505800000E+00	-.1445000000E-01	.8149657848E-03
36	.2005300000E+00	-.1604000000E-01	.6833229273E-03
37	.2504500000E+00	-.1723000000E-01	.5966222013E-03
38	.3003800000E+00	-.1810000000E-01	.5371787317E-03
39	.3502900000E+00	-.1859000000E-01	.4926611514E-03
40	.4501000000E+00	-.1905000000E-01	.4273821103E-03
41	.5000000000E+00	-.1882000000E-01	.4048236941E-03
42	.5499100000E+00	-.1830000000E-01	.4021546332E-03
43	.5998200000E+00	-.1744000000E-01	.3511178445E-03
44	.6497400000E+00	-.1581000000E-01	.1889947888E-03
45	.6995900000E+00	-.1344000000E-01	.3648795080E-02
46	.7496500000E+00	-.1058000000E-01	.3152314963E-02
47	.7996500000E+00	-.7470000000E-02	.2968073389E-02
48	.8496300000E+00	-.4340000000E-02	.2825542627E-02
49	.8997700000E+00	-.1480000000E-02	.2703713497E-02
50	.9498800000E+00	.5400000000E-03	.2596126127E-02
51	.1000000000E+01	0.	.2915522443E-02

Table 1. Skin Friction Coefficient.

NO.	X/CHORD	Y/CHORD	DELSR
1	.3499326541E-03	-.1703373220E-02	.7750491384E-05
2	0.	0.	.1111463531E-04
3	.4510000000E-02	.5090000000E-02	.3519822923E-04
4	.7070000000E-02	.6220000000E-02	.5134753760E-04
5	.1202000000E-01	.7980000000E-02	.7763458995E-04
6	.2447000000E-01	.1102000000E-01	.7930346160E-04
7	.4341000000E-01	.1572000000E-01	.1787295493E-03
8	.7439000000E-01	.1947000000E-01	.2582085673E-03
9	.9939000000E-01	.2268000000E-01	.3258064338E-03
10	.1494200000E+00	.2791000000E-01	.4516396515E-03
11	.1994700000E+00	.3196000000E-01	.5673578000E-03
12	.2495400000E+00	.3513000000E-01	.6777378743E-03
13	.2996200000E+00	.3754000000E-01	.78447321[illegible]5E-03
14	.3497100000E+00	.3929000000E-01	.8878743941E-03
15	.3998100000E+00	.4042000000E-01	.9889170368E-03
16	.5000000000E+00	.4038000000E-01	.1186080965E-02
17	.5500900000E+00	.4020000000E-01	.1294428275E-02
18	.6001300000E+00	.3886000000E-01	.1392597813E-02
19	.6502500000E+00	.3641000000E-01	.1527045843E-02
20	.7003100000E+00	.3288000000E-01	.1701595559E-02
21	.7503400000E+00	.2848000000E-01	.1914391701E-02
22	.8003400000E+00	.2339000000E-01	.2165115040E-02
23	.8503100000E+00	.1780000000E-01	.2464821254E-02
24	.9002300000E+00	.1182000000E-01	.2843774070E-02
25	.9501200000E+00	.5780000000E-02	.3325995089E-02
25	.1000000000E+01	0.	.3896671035E-02
27	.3499326541E-03	-.1709373220E-02	.1578479123E-04
28	.5390000000E-02	-.4090000000E-02	.2513153773E-04
29	.7330000000E-02	-.4820000000E-02	.3374544081E-04
30	.1298000000E-01	-.5840000000E-02	.4552937983E-04
31	.2553000000E-01	-.7300000000E-02	.7330918741E-04
32	.5059000000E-01	-.9400000000E-02	.1068393024E-03
33	.7561000000E-01	-.1099000000E-01	.132487[illegible]45E-03
34	.1006100000E+00	-.1234000000E-01	.1532873665E-03
35	.1505800000E+00	-.1445000000E-01	.1902155875E-03
36	.2005300000E+00	-.1604000000E-01	.2214737555E-03
37	.2504600000E+00	-.1723000000E-01	.2493975050E-03
38	.3003800000E+00	-.1810000000E-01	.2742038263E-03
39	.3502900000E+00	-.1869000000E-01	.2966857563E-03
40	.4501900000E+00	-.1905000000E-01	.3376359905E-03
41	.5000000000E+00	-.1882000000E-01	.3556109643E-03
42	.5499100000E+00	-.1833000000E-01	.3666995721E-03
43	.5998200000E+00	-.1744000000E-01	.3888555222E-03
44	.6497400000E+00	-.1581000000E-01	.4704465323E-03
45	.6995300000E+00	-.1344000000E-01	.3050975796E-03
46	.7496500000E+00	-.1058000000E-01	.4528034323E-03
47	.7996500000E+00	-.7470000000E-02	.5883197404E-03
48	.8496300000E+00	-.4340000000E-02	.7301689983E-03
49	.8997700000E+00	-.1480000000E-02	.8820525548E-03
50	.9498800000E+00	.5400000000E-03	.994686[illegible]E-03
51	.1000000000E+01	0.	.9428443718E-03

Table 2. Displacement Thickness.

NO.	X/CHORD	Y/CHORD	THETA
1	.3499326541E-03	-.1709373220E-02	.3489113134E-05
2	0.	0.	.4651753878E-05
3	.4510000000E-02	.5090000000E-02	.1294614853E-04
4	.7070000000E-02	.6220000000E-02	.1704987402E-04
5	.1202000000E-01	.7980000000E-02	.2412159469E-04
6	.2447000000E-01	.1102000000E-01	.5193355315E-04
7	.4941000000E-01	.1572000000E-01	.1177456058E-03
8	.7439000000E-01	.1947000000E-01	.1700250732E-03
9	.9939000000E-01	.2268000000E-01	.2169405767E-03
10	.1494200000E+00	.2791000000E-01	.3046634991E-03
11	.1994700000E+00	.3196000000E-01	.3875569955E-03
12	.2495400000E+00	.3513000000E-01	.4665799345E-03
13	.2995200000E+00	.3754000000E-01	.5433769432E-03
14	.3497100000E+00	.3929000000E-01	.6181076874E-03
15	.3998100000E+00	.4042000000E-01	.6913921834E-03
16	.5000000000E+00	.4088000000E-01	.8349387033E-03
17	.5500900000E+00	.4020000000E-01	.9063938613E-03
18	.5001800000E+00	.3886000000E-01	.9834745801E-03
19	.5502500000E+00	.3641000000E-01	.1075765130E-02
20	.7003100000E+00	.3288000000E-01	.1191924907E-02
21	.7503400000E+00	.2846000000E-01	.1330495635E-02
22	.8003400000E+00	.2339000000E-01	.1491253725E-02
23	.8503100000E+00	.1780000000E-01	.1579155315E-02
24	.9002300000E+00	.1182000000E-01	.1909053563E-02
25	.9501200000E+00	.5780000000E-02	.2191052202E-02
26	.1000000000E+01	0.	.2513917941E-02
27	.3499326541E-03	-.1709373220E-02	.7106073567E-05
28	.5390000000E-02	-.4090000000E-02	.1064011330E-04
29	.7930000000E-02	-.4820000000E-02	.1428692723E-04
30	.1298000000E-01	-.5840000000E-02	.1945730534E-04
31	.2553000000E-01	-.7300000000E-02	.3004505996E-04
32	.5059000000E-01	-.9400000000E-02	.4337822806E-04
33	.7561000000E-01	-.1099000000E-01	.5338515403E-04
34	.1006100000E+00	-.1234000000E-01	.6156580940E-04
35	.1505300000E+00	-.1445000000E-01	.7575163152E-04
35	.2005300000E+00	-.1604000000E-01	.8770515455E-04
37	.2504500000E+00	-.1723000000E-01	.9835798785E-04
38	.3003800000E+00	-.1810000000E-01	.1079755373E-03
39	.3502900000E+00	-.1869000000E-01	.1167322715E-03
40	.4501000000E+00	-.1935000000E-01	.1325890091E-03
41	.5000000000E+00	-.1882000000E-01	.1397709255E-03
42	.5499100000E+00	-.1830000000E-01	.1464722723E-03
43	.5998200000E+00	-.1744000000E-01	.1515875503E-03
44	.5497400000E+00	-.1531000000E-01	.1597583467E-03
45	.5995300000E+00	-.1344000000E-01	.2124591227E-03
46	.7496500000E+00	-.1058000000E-01	.3085324485E-03
47	.7996500000E+00	-.7470000000E-02	.4024602523E-03
48	.8495900000E+00	-.4340000000E-02	.5010395069E-03
49	.8997700000E+00	-.1480000000E-02	.6563371524E-03
50	.9498300000E+00	.5400000000E-03	.5931312[illegible]E-03
51	.1000000000E+01	0.	.6816180552E-03

Table 3. Momentum Thickness.

NO.	X/CHORD	Y/CHORD	FORM
1	.8499326541E-03	-.1709373220E-02	.2221398853E+01
2	0.	0.	.2389342342E+01
3	.4510000000E-02	.5090000000E-02	.2796051545E+01
4	.7070000000E-02	.6220000000E-02	.3011630[illegible]35E+01
5	.1202000000E-01	.7980000000E-02	.3218459190E+01
6	.2447000000E-01	.1102000000E-01	.1526870533E+01
7	.4941000000E-01	.1572000000E-01	.1517917534E+01
8	.7439000000E-01	.1947000000E-01	.1518646958E+01
9	.9939000000E-01	.2268000000E-01	.1501822705E+01
10	.1494200000E+00	.2791000000E-01	.1479114719E+01
11	.1994700000E+00	.3196000000E-01	.1463933638E+01
12	.2495400000E+00	.3513000000E-01	.1452565233E+01
13	.2995200000E+00	.3754000000E-01	.1443698848E+01
14	.3497100000E+00	.3923000000E-01	.1436439703E+01
15	.3998100000E+00	.4042000000E-01	.1430327193E+01
16	.5000000000E+00	.4088000000E-01	.1420550532E+01
17	.5500900000E+00	.4020000000E-01	.1417075214E+01
18	.6001800000E+00	.3886000000E-01	.1415987453E+01
19	.6502600000E+00	.3641000000E-01	.1419497434E+01
20	.7003100000E+00	.3288000000E-01	.1427603827E+01
21	.7503400000E+00	.2848000000E-01	.1438856155E+01
22	.8003400000E+00	.2339000000E-01	.1451875367E+01
23	.8503100000E+00	.1780000000E-01	.1467884875E+01
24	.9002300000E+00	.1182000000E-01	.1489625504E+01
25	.9501200000E+00	.5780000000E-02	.1517989889E+01
26	.1000000000E+01	0.	.1550039074E+01
27	.8499326541E-03	-.1709373220E-02	.2221398853E+01
28	.5390000000E-02	-.4090000000E-02	.2361970883E+01
29	.7930000000E-02	-.4820000000E-02	.2362123174E+01
30	.1298000000E-01	-.5846000000E-02	.2391393548E+01
31	.2553000000E-01	-.7300000000E-02	.2439974075E+01
32	.5059000000E-01	-.9400000000E-02	.2462982173E+01
33	.7561000000E-01	-.1099000000E-01	.2481723653E+01
34	.1005100000E+00	-.1234000000E-01	.2489813225E+01
35	.1505300000E+00	-.1445000000E-01	.2511642111E+01
36	.2005300000E+00	-.1604000000E-01	.2525207836E+01
37	.2504600000E+00	-.1723000000E-01	.2535610076E+01
38	.3003800000E+00	-.1812000000E-01	.2539469783E+01
39	.3502300000E+00	-.1859000000E-01	.2541591559E+01
40	.4501000000E+00	-.1905000000E-01	.2546495512E+01
41	.5000000000E+00	-.1882000000E-01	.2544241319E+01
42	.5499100000E+00	-.1830000000E-01	.2553545001E+01
43	.5998200000E+00	-.1744000000E-01	.2565227291E+01
44	.6497400000E+00	-.1581000000E-01	.2944539865E+01
45	.6996300000E+00	-.1344000000E-01	.1436057642E+01
46	.7496500000E+00	-.1058000000E-01	.1467603927E+01
47	.7996500000E+00	-.7470000000E-02	.1461878305E+01
48	.8496900000E+00	-.4340000000E-02	.1457334413E+01
49	.8997700000E+00	-.1480000000E-02	.1454811[illegible]E+01
50	.9498300000E+00	.5400000000E-03	.14350[illegible]E+01
51	.1000000000E+01	0.	.1383244421E+01

Table 4. Compressible Form Factor.

NO.	X/CHORD	Y/CHORD	FORMI
1	.8499326541E-03	-.1709373220E-02	.2221379853E+01
2	0.	0.	.2338521473E+01
3	.4510000000E-02	.5090000000E-02	.2553543705E+01
4	.7070000000E-02	.6220000000E-02	.2868320195E+01
5	.1202000000E-01	.7980000000E-02	.3080759734E+01
6	.2447000000E-01	.1102000000E-01	.1456619343E+01
7	.4341000000E-01	.1572000000E-01	.1453239865E+01
8	.7439000000E-01	.1947000000E-01	.1456046473E+01
9	.9939000000E-01	.2268000000E-01	.1440632440E+01
10	.1494200000E+00	.2791000000E-01	.1419748304E+01
11	.1994700000E+00	.3196000000E-01	.1405797074E+01
12	.2495400000E+00	.3513000000E-01	.1395254453E+01
13	.2996200000E+00	.3754000000E-01	.1387037225E+01
14	.3497100000E+00	.3923000000E-01	.1380395813E+01
15	.3998100000E+00	.4042000000E-01	.1374778925E+01
16	.5000000000E+00	.4088000000E-01	.1365872387E+01
17	.5500900000E+00	.4029000000E-01	.1362753571E+01
18	.6001800000E+00	.3885000000E-01	.1362185095E+01
19	.6502600000E+00	.3641000000E-01	.1366557999E+01
20	.7003100000E+00	.3288000000E-01	.1376148507E+01
21	.7503400000E+00	.2848000000E-01	.1389145343E+01
22	.8003400000E+00	.2339000000E-01	.1404120301E+01
23	.8503100000E+00	.1780000000E-01	.1422183403E+01
24	.9002300000E+00	.1182000000E-01	.1446135534E+01
25	.9501200000E+00	.5780000000E-02	.1476975354E+01
26	.1000000000E+01	0.	.1511252252E+01
27	.8499326541E-03	-.1709373220E-02	.2221379853E+01
28	.5390000000E-02	-.4090000000E-02	.2343040494E+01
29	.7330000000E-02	-.4820000000E-02	.2337196955E+01
30	.1298000000E-01	-.5840000000E-02	.2359565275E+01
31	.2553000000E-01	-.7300000000E-02	.2402222340E+01
32	.5059000000E-01	-.9400000000E-02	.2419591583E+01
33	.7561000000E-01	-.1099000000E-01	.2435098430E+01
34	.1006100000E+00	-.1234000000E-01	.2440889345E+01
35	.1505800000E+00	-.1445000000E-01	.2459105417E+01
36	.2005300000E+00	-.1634000000E-01	.2471241820E+01
37	.2504500000E+00	-.1723000000E-01	.2480194005E+01
38	.3003800000E+00	-.1810000000E-01	.2482980240E+01
39	.3502900000E+00	-.1869000000E-01	.2484276495E+01
40	.4501300000E+00	-.1905000000E-01	.2487686641E+01
41	.5000000000E+00	-.1882000000E-01	.2484904784E+01
42	.5499100000E+00	-.1830000000E-01	.2444375701E+01
43	.5998200000E+00	-.1744000000E-01	.2524043182E+01
44	.6497400000E+00	-.1581000000E-01	.2876702195E+01
45	.6996900000E+00	-.1344000000E-01	.1395549587E+01
46	.7496500000E+00	-.1058000000E-01	.1427715730E+01
47	.7996500000E+00	-.7470000000E-02	.1423119993E+01
48	.8496900000E+00	-.4345000000E-02	.1420917934E+01
49	.8997700000E+00	-.1480000000E-02	.1418993165E+01
50	.9498800000E+00	.5400000000E-03	.1400714137E+01
51	.1000000000E+01	0.	.1347137007E+01

Table 5. Incompressible Form Factor.

NO.	X/CHORD	Y/CHORD	ME
1	.8499326541E-03	-.1709373220E-02	0.
2	0.	0.	.2826484516E+00
3	.4510000000E-02	.5090000000E-02	.4514926975E+00
4	.7070000000E-02	.6220000000E-02	.4394130762E+00
5	.1202000000E-01	.7980000000E-02	.4189333224E+00
6	.2447000000E-01	.1102000000E-01	.3867431941E+00
7	.4941000000E-01	.1572000000E-01	.3713525493E+00
8	.7439000000E-01	.1947000000E-01	.3651227193E+00
9	.9939000000E-01	.2258000000E-01	.3621768072E+00
10	.1494200000E+00	.2791000000E-01	.3583462973E+00
11	.1994700000E+00	.3196000000E-01	.3556905775E+00
12	.2495400000E+00	.3513000000E-01	.3539678765E+00
13	.2996200000E+00	.3754000000E-01	.3524032283E+00
14	.3497100000E+00	.3929000000E-01	.3511753313E+00
15	.3998100000E+00	.4042000000E-01	.3500594622E+00
16	.5000000000E+00	.4088000000E-01	.3430157191E+00
17	.5500900000E+00	.4020000000E-01	.3470881075E+00
18	.6001800000E+00	.3886000000E-01	.3454690359E+00
19	.6502500000E+00	.3641000000E-01	.3423554475E+00
20	.7003100000E+00	.3288000000E-01	.3368248323E+00
21	.7503400000E+00	.2848000000E-01	.3301045697E+00
22	.8003400000E+00	.2339000000E-01	.3224925783E+00
23	.8503100000E+00	.1780000000E-01	.3142451943E+00
24	.9002300000E+00	.1182000000E-01	.3047897937E+00
25	.9501200000E+00	.5780000000E-02	.2942327283E+00
26	.1000000000E+01	0.	.2840824913E+00
27	.8499326541E-03	-.1709373220E-02	0.
28	.5300000000E-02	-.4090000000E-02	.1723830163E+00
29	.7930000000E-02	-.4820000000E-02	.1980128144E+00
30	.1298000000E-01	-.5840000000E-02	.2229093055E+00
31	.2553000000E-01	-.7300000000E-02	.2412045973E+00
32	.5059000000E-01	-.9400000000E-02	.2579021573E+00
33	.7561000000E-01	-.1099000000E-01	.2667099913E+00
34	.1006100000E+00	-.1234000000E-01	.2729637005E+00
35	.1505800000E+00	-.1445000000E-01	.2804659185E+00
36	.2005300000E+00	-.1634000000E-01	.2853683278E+00
37	.2504600000E+00	-.1723000000E-01	.2887872973E+00
38	.3003800000E+00	-.1810000000E-01	.2914477355E+00
39	.3502900000E+00	-.1869000000E-01	.2936956825E+00
40	.4501900000E+00	-.1905000000E-01	.2971515241E+00
41	.5000000000E+00	-.1882000000E-01	.2986153894E+00
42	.5499100000E+00	-.1830000000E-01	.3000282365E+00
43	.5998200000E+00	-.1744000000E-01	.3023614043E+00
44	.6497400000E+00	-.1581000000E-01	.3020047595E+00
45	.6996300000E+00	-.1344000000E-01	.2975687595E+00
46	.7495500000E+00	-.1058000000E-01	.2932255793E+00
47	.7996500000E+00	-.7470000000E-02	.2890718935E+00
48	.8496300000E+00	-.4340000000E-02	.2840914003E+00
49	.8997700000E+00	-.1480000000E-02	.2783733011E+00
50	.9498900000E+00	.5400000000E-03	.2737139[illegible]E+00
51	.1000000000E+01	0.	.2840824913E+00

Table 6. MACH at the Edge of the Boundary Layer.

NO.	X/CHORD	Y/CHORD	DELTA
1	.8499326541E-03	-.1709373220E-02	.3147951525E-04
2	0.	0.	.3939485187E-04
3	.4510000000E-02	.5090000000E-02	.1053730970E-03
4	.7070000000E-02	.6220000000E-02	.1386645981E-03
5	.1282000000E-01	.7980000000E-02	.1984036203E-03
6	.2447000000E-01	.1102000000E-01	.4106723201E-03
7	.4341000000E-01	.1572000000E-01	.9338073053E-03
8	.7439000000E-01	.1947000000E-01	.1343976259E-02
9	.9939000000E-01	.2268000000E-01	.1744355431E-02
10	.1494200000E+00	.2791000000E-01	.2511648983E-02
11	.1994700000E+00	.3196000000E-01	.3252574255E-02
12	.2495400000E+00	.3513000000E-01	.3971807229E-02
13	.2996200000E+00	.3754000000E-01	.4678671361E-02
14	.3497100000E+00	.3923000000E-01	.5373902929E-02
15	.3998100000E+00	.4042000000E-01	.6061321179E-02
16	.5000000000E+00	.4085000000E-01	.7420055284E-02
17	.5500900000E+00	.4023000000E-01	.8094512701E-02
18	.5001800000E+00	.3885000000E-01	.8790322095E-02
19	.5502500000E+00	.3641000000E-01	.9548125443E-02
20	.7003100000E+00	.3288000000E-01	.1042305361E-01
21	.7503400000E+00	.2848000000E-01	.1141342259E-01
22	.8003400000E+00	.2333000000E-01	.1252787035E-01
23	.8503100000E+00	.1780000000E-01	.1377782621E-01
24	.9002300000E+00	.1182000000E-01	.1521978179E-01
25	.9501200000E+00	.5780000000E-02	.1569537588E-01
26	.1000000000E+01	0.	.1875885121E-01
27	.8499326541E-03	-.1709373220E-02	.6411243532E-04
28	.5390000000E-02	-.4090000000E-02	.8962752114E-04
29	.7930000000E-02	-.4820000000E-02	.1206725936E-03
30	.1298000000E-01	-.5840000000E-02	.1532603515E-03
31	.2553000000E-01	-.7300000000E-02	.2493163672E-03
32	.5059000000E-01	-.9400000000E-02	.3587455624E-03
33	.7561000000E-01	-.1093000000E-01	.4402229984E-03
34	.1006100000E+00	-.1234000000E-01	.5072345443E-03
35	.1505800000E+00	-.1445000000E-01	.6222088961E-03
36	.2005300000E+00	-.1634000000E-01	.7190643127E-03
37	.2504600000E+00	-.1723000000E-01	.8053734653E-03
38	.3003900000E+00	-.1810000000E-01	.8838533075E-03
39	.3502900000E+00	-.1869000000E-01	.9554547723E-03
40	.4501000000E+00	-.1905000000E-01	.1084852646E-02
41	.5000000000E+00	-.1882000000E-01	.1144175692E-02
42	.5499100000E+00	-.1830000000E-01	.1207447462E-02
43	.5998200000E+00	-.1744000000E-01	.1237723381E-02
44	.5497400000E+00	-.1581000000E-01	.1287677093E-02
45	.5996900000E+00	-.1344000000E-01	.1804193047E-02
46	.7496500000E+00	-.1058000000E-01	.2512563584E-02
47	.7996500000E+00	-.7470000000E-02	.3295585941E-02
48	.8496300000E+00	-.4340000000E-02	.4117988262E-02
49	.8997700000E+00	-.1480000000E-02	.4988693774E-02
50	.9498800000E+00	.5400000000E-03	.5840421978E-02
51	.1000000000E+01	0.	.6233503673E-02

Table 7. Boundary Layer Thickness.

NO.	X/CHORD	Y/CHORD	CP
1	.1000000000E+01	0.	.1018934181E+00
2	.9498800000E+00	.5400000000E-03	.1557036192E+00
3	.8997700000E+00	-.1430000000E-02	.1372820255E+00
4	.8495300000E+00	-.4340000000E-02	.1018377157E+00
5	.7996500000E+00	-.7470000000E-02	.7046276561E-01
6	.7496500000E+00	-.1058000000E-01	.4394073354E-01
7	.5996300000E+00	-.1344000000E-01	.1586735255E-01
8	.6497400000E+00	-.1581000000E-01	-.1316558900E-01
9	.5998200000E+00	-.1744000000E-01	-.1551544669E-01
10	.5499100000E+00	-.1830000000E-01	-.1849231172E-03
11	.5000000000E+00	-.1882000000E-01	.9043383119E-02
12	.4501000000E+00	-.1905000000E-01	.1857882531E-01
13	.3502900000E+00	-.1869000000E-01	.4091952591E-01
14	.3003800000E+00	-.1810000000E-01	.5533232922E-01
15	.2504500000E+00	-.1723000000E-01	.7226815505E-01
16	.2005300000E+00	-.1604000000E-01	.9383833177E-01
17	.1505800000E+00	-.1445000000E-01	.1243825125E+00
18	.1006100000E+00	-.1234000000E-01	.1702410836E+00
19	.7561000000E-01	-.1099000000E-01	.2076961681E+00
20	.5059000000E-01	-.9400000000E-02	.2590307008E+00
21	.2553000000E-01	-.7330000000E-02	.3522495019E+00
22	.1298000000E-01	-.5840000000E-02	.4479377374E+00
23	.7930000000E-02	-.4820000000E-02	.5570423733E+00
24	.5390000000E-02	-.4090000000E-02	.6759017877E+00
25	0.	0.	.1108408140E+00
25	.4510000000E-02	.5090000000E-02	-.1182528480E+01
27	.7070000000E-02	.6220000000E-02	-.1075697574E+01
28	.1202000000E-01	.7980000000E-02	-.8990414407E+00
29	.2447000000E-01	.1102000000E-01	-.6334305053E+00
30	.4941000000E-01	.1572000000E-01	-.5119581987E+00
31	.7439000000E-01	.1947000000E-01	-.4638454795E+00
32	.9939000000E-01	.2268000000E-01	-.4413194029E+00
33	.1494200000E+00	.2791000000E-01	-.4122326403E+00
34	.1994700000E+00	.3196000000E-01	-.3922080013E+00
35	.2495400000E+00	.3513000000E-01	-.3792792387E+00
36	.2996200000E+00	.3754000000E-01	-.3675798509E+00
37	.3497100000E+00	.3929000000E-01	-.3584341512E+00
38	.3998100000E+00	.4042000000E-01	-.3501374547E+00
39	.5000000000E+00	.4088000000E-01	-.3349968062E+00
40	.5500900000E+00	.4020000000E-01	-.3281472395E+00
41	.5001800000E+00	.3886000000E-01	-.3162201045E+00
42	.5502600000E+00	.3641000000E-01	-.2934207713E+00
43	.7003100000E+00	.3288000000E-01	-.2533279345E+00
44	.7503400000E+00	.2848000000E-01	-.2053159723E+00
45	.8003400000E+00	.2339000000E-01	-.1518895323E+00
46	.8503100000E+00	.1780000000E-01	-.9513533137E-01
47	.9002300000E+00	.1182000000E-01	-.3157728595E-01
48	.9501200000E+00	.5780000000E-02	.3746233955E-01
49	.1000000000E+01	0.	.1018934181E+00

Table 8. Pressure Coefficient Distribution.

NO.	X/CHORD	Y/CHORD	V/V0
1	.1000000000E+01	0.	.9478073438E+00
2	.3498800000E+00	.5400000000E-03	.9137343812E+00
3	.3997700000E+00	-.1480000000E-02	.9290532450E+00
4	.5495900000E+00	-.4340000000E-02	.9478368933E+00
5	.7996500000E+00	-.7470000000E-02	.9541828993E+00
6	.7495500000E+00	-.1058000000E-01	.9778050115E+00
7	.5996900000E+00	-.1344000000E-01	.9920374534E+00
8	.5497400000E+00	-.1581000000E-01	.1006563278E+01
9	.5998200000E+00	-.1744000000E-01	.1007730552E+01
10	.5499100000E+00	-.1830000000E-01	.1000092453E+01
11	.5000300000E+00	-.1882000000E-01	.9954683600E+00
12	.4501000000E+00	-.1935000000E-01	.9906779524E+00
13	.3502900000E+00	-.1863000000E-01	.9793457474E+00
14	.3003300000E+00	-.1810000000E-01	.9719755252E+00
15	.2504500000E+00	-.1723000000E-01	.9532492100E+00
16	.2005300000E+00	-.1604000000E-01	.9520289221E+00
17	.1505800000E+00	-.1445000000E-01	.9359234500E+00
18	.1005100000E+00	-.1234000000E-01	.9112657251E+00
19	.7561000000E-01	-.1099000000E-01	.8906555095E+00
20	.5059000000E-01	-.9400000000E-02	.8616641200E+00
21	.2553000000E-01	-.7300000000E-02	.8065403363E+00
22	.1298000000E-01	-.5840000000E-02	.7459923034E+00
23	.7930000000E-02	-.4820000000E-02	.6533607085E+00
24	.5390000000E-02	-.4090000000E-02	.5780433184E+00
25	0.	0.	.9430985708E+00
26	.4510000000E-02	.5090000000E-02	.1488422284E+01
27	.7070000000E-02	.6220000000E-02	.1450099977E+01
28	.1202000000E-01	.7980000000E-02	.1384860955E+01
29	.2447000000E-01	.1102000000E-01	.1281655839E+01
30	.4941000000E-01	.1572000000E-01	.1232057873E+01
31	.7439000000E-01	.1947000000E-01	.1211927757E+01
32	.9939000000E-01	.2268000000E-01	.1202402815E+01
33	.1494200000E+00	.2791000000E-01	.1190035865E+01
34	.1994700000E+00	.3196000000E-01	.1181475441E+01
35	.2495400000E+00	.3513000000E-01	.1175823477E+01
36	.2995200000E+00	.3754000000E-01	.1170752241E+01
37	.3497100000E+00	.3923000000E-01	.1166774493E+01
38	.3998100000E+00	.4042000000E-01	.1153152537E+01
39	.5000000000E+00	.4088000000E-01	.1156526141E+01
40	.5500900000E+00	.4023000000E-01	.1153512885E+01
41	.5001800000E+00	.3886000000E-01	.1148257793E+01
42	.5502600000E+00	.3641000000E-01	.1138147024E+01
43	.7003100000E+00	.3288000000E-01	.1120171943E+01
44	.7503400000E+00	.2848000000E-01	.1098393931E+01
45	.8003400000E+00	.2339000000E-01	.1073500123E+01
46	.3503100000E+00	.1780000000E-01	.1046584793E+01
47	.9002300000E+00	.1182000000E-01	.1015675983E+01
48	.3501200000E+00	.5780000000E-02	.9811051079E+00
49	.1000000000E+01	0.	.9478075438E+00

Table 9. Nondimensional Velocity Distribution.

NO	CL	ALPHA	CL	ALPHA
1	-.101428E+01	-.800000E+01	-.744063E+00	-.600000E+01
3	-.487890E+00	-.400000E+01	-.243041E+00	-.200000E+01
5	-.477197E-09	0.	.243333E+00	.200000E+01
7	.489180E+00	.400000E+01	.746942E+00	.600000E+01
9	.101970E+01	.800000E+01	.126592E+01	.100000E+02
11	.149106E+01	.120000E+02		

Table 10. Lift Coefficient vs Angle of Attack

NO	CM	ALPHA	CM	ALPHA
1	-.487936E-02	-.800000E+01	-.721707E-02	-.600000E+01
3	-.610772E-02	-.400000E+01	-.312255E-02	-.200000E+01
5	.369690E-10	0.	.306065E-02	.200000E+01
7	.583232E-02	.400000E+01	.659314E-02	.600000E+01
9	.366663E-02	.800000E+01	.175877E-02	.100000E+02
11	-.112028E-02	.120000E+02		

Table 11. Moment Coefficient vs Angle of Attack

NO	CL	CD	CL	CD
1	-.101428E+01	.785223E-02	-.744063E+00	.652128E-02
3	-.487890E+00	.584254E-02	-.243041E+00	.520325E-02
5	-.477197E-09	.505857E-02	.243333E+00	.520411E-02
7	.489180E+00	.585263E-02	.746942E+00	.655454E-02
9	.101970E+01	.794267E-02	.126592E+01	.954390E-02
11	.149106E+01	.108431E-01		

Table 12. Lift vs Drag Coefficient.

AIRFOIL COORDINATE POINT DATA. NCRD= 49

	X/CHORD	Y/CHORD	X/CHORD	Y/CHORD
1	1.00000000	0.00000000	.94988000	.00054000
3	.89977000	-.00148000	.84969000	-.00434000
5	.79965000	-.00747000	.74966000	-.01058000
7	.69959000	-.01344000	.64974000	-.01581000
9	.59982000	-.01744000	.54991000	-.01830000
11	.50003000	-.01882000	.45010000	-.01905000
13	.35023000	-.01869000	.30038000	-.01810000
15	.25046000	-.01723000	.20053000	-.01604000
17	.15058000	-.01445000	.10061000	-.01234000
19	.07561000	-.01099000	.05059000	-.00940000
21	.02553000	-.00730000	.01298000	-.00564000
23	.00793000	-.00482000	.00539000	-.00409000
25	0.00000000	0.00000000	.00461000	.00509000
27	.00707000	.00622000	.01202000	.00798000
29	.02447000	.01102000	.04941000	.01572000
31	.07439000	.01947000	.09939000	.02268000
33	.14942000	.02791000	.19947000	.03196000
35	.24954000	.03513000	.29962000	.03754000
37	.34971000	.03929000	.39981000	.04042000
39	.50003000	.04088000	.55009000	.04020000
41	.60013000	.03886000	.65026000	.03641000
43	.70031000	.03288000	.75034000	.02848000
45	.80034000	.02339000	.85031000	.01780000
47	.90023000	.01182000	.95012000	.00578000
49	1.00000000	0.00000000		

Table 13. Airfoil Coordinate Points.

NO.	X/CHORD	Y/CHORD	DY/DX
1	.1000000000E+01	0.	-.4964722822E-01
2	.9498800000E+00	.5400000000E-03	.2143932505E-01
3	.8997700000E+00	-.1480000000E-02	.5250350900E-01
4	.8495300000E+00	-.4340000000E-02	.5081526225E-01
5	.7996500000E+00	-.7470000000E-02	.6325271458E-01
6	.7495500000E+00	-.1058000000E-01	.6046151953E-01
7	.6996300000E+00	-.1344000000E-01	.5320314797E-01
8	.6497400000E+00	-.1581000000E-01	.4076955143E-01
9	.5998200000E+00	-.1744000000E-01	.2401175114E-01
10	.5499100000E+00	-.1830000000E-01	.1282993284E-01
11	.5000000000E+00	-.1882000000E-01	.7519117707E-02
12	.4501000000E+00	-.1905000000E-01	.1776758520E-02
13	.3502300000E+00	-.1869000000E-01	-.2063712573E-02
14	.3003800000E+00	-.1810000000E-01	-.1457097883E-01
15	.2504500000E+00	-.1723000000E-01	-.2039935207E-01
16	.2005300000E+00	-.1604000000E-01	-.2761437561E-01
17	.1505800000E+00	-.1445000000E-01	-.3513509881E-01
18	.1006100000E+00	-.1234000000E-01	-.5001626553E-01
19	.7561000000E-01	-.1099000000E-01	-.5721770944E-01
20	.5059000000E-01	-.9400000000E-02	-.7375625589E-01
21	.2553000000E-01	-.7300000000E-02	-.8979521732E-01
22	.1298000000E-01	-.5840000000E-02	-.1581321584E+00
23	.7330000000E-02	-.4820000000E-02	-.2402876805E+00
24	.5390000000E-02	-.4090000000E-02	-.3528342090E+00
25	0.	0.	-.9764553219E+01
26	.4510000000E-02	.5090000000E-02	.5504395945E+00
27	.7070000000E-02	.6220000000E-02	.3387951823E+00
28	.1202000000E-01	.7980000000E-02	.3142975010E+00
29	.2447000000E-01	.1102000000E-01	.2058511914E+00
30	.4941000000E-01	.1572000000E-01	.1582504483E+00
31	.7439000000E-01	.1947000000E-01	.1368805244E+00
32	.9939000000E-01	.2268000000E-01	.1198309337E+00
33	.1494200000E+00	.2791000000E-01	.9125975577E-01
34	.1994700000E+00	.3195000000E-01	.7151577271E-01
35	.2495400000E+00	.3513000000E-01	.5537503442E-01
36	.2995200000E+00	.3754000000E-01	.4128862737E-01
37	.3497100000E+00	.3929000000E-01	.2365272293E-01
38	.3998100000E+00	.4042000000E-01	.1557785857E-01
39	.5000000000E+00	.4038000000E-01	-.7572968183E-02
40	.5500900000E+00	.4020000000E-01	-.1910889775E-01
41	.6001900000E+00	.3886000000E-01	-.3687736757E-01
42	.6502500000E+00	.3641000000E-01	-.5040134870E-01
43	.7003100000E+00	.3283000000E-01	-.7987483503E-01
44	.7503400000E+00	.2848000000E-01	-.9553315182E-01
45	.8003400000E+00	.2339000000E-01	-.1072371965E+00
46	.8503100000E+00	.1780000000E-01	-.1165245194E+00
47	.9002300000E+00	.1192000000E-01	-.1216431252E+00
48	.9501200000E+00	.5780000000E-02	-.1194794910E+00
49	.1000000000E+01	0.	-.1112731805E+00

Table 14. Airfoil Slope Distribution.

NO.	X/CHORD	Y/CHORD	D2Y/DX2
1	.1000000000E+01	0.	-.1816873353E+01
2	.9498300000E+00	.5400000000E-03	-.1019533375E+01
3	.8997700000E+00	-.1480000000E-02	-.2197047978E+00
4	.8496300000E+00	-.4340000000E-02	-.1120842097E+00
5	.7996500000E+00	-.7470000000E-02	.1466785333E-01
6	.7496500000E+00	-.1058000000E-01	.3695581653E-01
7	.6996300000E+00	-.1344000000E-01	.1934918717E+00
8	.6497400000E+00	-.1531000000E-01	.3042625551E+00
9	.5998200000E+00	-.1744000000E-01	.3571454934E+00
10	.5499100000E+00	-.1830000000E-01	.3105289983E-01
11	.5000000000E+00	-.1882000000E-01	.1277515594E+00
12	.4501300000E+00	-.1905000000E-01	.1064147995E+00
13	.3502300000E+00	-.1869000000E-01	.1108175390E+00
14	.3003300000E+00	-.1810000000E-01	.1098720101E+00
15	.2504600000E+00	-.1723000000E-01	.1236415402E+00
16	.2005300000E+00	-.1604000000E-01	.1553993394E+00
17	.1505800000E+00	-.1445000000E-01	.1757672261E+00
18	.1006100000E+00	-.1234000000E-01	.3799858974E+00
19	.7561000000E-01	-.1099000000E-01	.1961222512E+00
20	.5059000000E-01	-.9400000000E-02	.1125278292E+01
21	.2553000000E-01	-.7300000000E-02	.1548627540E+00
22	.1298000000E-01	-.5840000000E-02	.1221874001E+02
23	.7330000000E-02	-.4820000000E-02	.1772838583E+02
24	.5390000000E-02	-.4090000000E-02	.5972125118E+02
25	0.	0.	.5406312746E+05
26	.4510000000E-02	.5090000000E-02	-.9120683234E+02
27	.7070000000E-02	.6220000000E-02	-.1934738223E+02
28	.1202000000E-01	.7980000000E-02	-.1552837025E+02
29	.2447000000E-01	.1102000000E-01	-.1171345183E+01
30	.4941000000E-01	.1572000000E-01	-.1846712940E+01
31	.7439000000E-01	.1947000000E-01	-.5714922045E+00
32	.9939000000E-01	.2268000000E-01	-.6927430939E+00
33	.1494200000E+00	.2791000000E-01	-.4538790086E+00
34	.1994700000E+00	.3196000000E-01	-.3384832992E+00
35	.2495400000E+00	.3513000000E-01	-.3053495337E+00
36	.2996200000E+00	.3754000000E-01	-.2563012195E+00
37	.3497100000E+00	.3923000000E-01	-.2482695543E+00
38	.3998100000E+00	.4042000000E-01	-.2337918795E+00
39	.5000000000E+00	.4086000000E-01	-.2504214663E+00
40	.5500900000E+00	.4020000000E-01	-.2061898831E+00
41	.6001900000E+00	.3886000000E-01	-.5035984392E+00
42	.6502500000E+00	.3641000000E-01	-.4359331901E+00
43	.7003100000E+00	.3288000000E-01	-.3421032327E+00
44	.7503400000E+00	.2848000000E-01	-.2837684233E+00
45	.8003400000E+00	.2339000000E-01	-.1842154393E+00
46	.8503100000E+00	.1780000000E-01	-.1875155343E+00
47	.9002300000E+00	.1182000000E-01	-.1738834259E-01
48	.9501200000E+00	.5730000000E-02	.1040735461E+00
49	.1000000000E+01	0.	.2247742855E+00

Table 15. Airfoil Slope Rate of Change Distribution.

NO.	X/CHORD	CURVATURE	RADIUS
1	.1000000000E+01	.1818150927E+01	.5500093447E+00
2	.9498800000E+00	.1018320778E+01	.9820083343E+00
3	.8997700000E+00	.2188742479E+00	.4568633513E+01
4	.8495300000E+00	.1114550571E+00	.8972145849E+01
5	.7995500000E+00	-.1458052164E-01	-.6858413141E+02
6	.7495500000E+00	-.9642539241E-01	-.1037050172E+02
7	.6995300000E+00	-.1926758673E+00	-.5190063572E+01
8	.6497400000E+00	-.3035132879E+00	-.3294715093E+01
9	.5998200000E+00	-.3668281562E+00	-.2726072094E+01
10	.5499100000E+00	-.8103536407E-01	-.1234029132E+02
11	.5000000000E+00	-.1277335278E+00	-.7828430375E+01
12	.4501000000E+00	-.1064157654E+00	-.9397103863E+01
13	.3502900000E+00	-.1108047027E+00	-.9024687715E+01
14	.3003800000E+00	-.1098373973E+00	-.9104367225E+01
15	.2504600000E+00	-.1235650041E+00	-.8092975293E+01
16	.2005300000E+00	-.1652131343E+00	-.6052787537E+01
17	.1505800000E+00	-.1754213369E+00	-.5700560819E+01
18	.1006100000E+00	-.3786390670E+00	-.2541037565E+01
19	.7561000000E-01	-.1950530165E+00	-.5126811253E+01
20	.5059000000E-01	-.1118731044E+01	-.8938293457E+00
21	.2553000000E-01	-.1519888495E+00	-.6579433025E+01
22	.1298000000E-01	-.1209859404E+02	-.8265354855E-01
23	.7330000000E-02	-.1538515041E+02	-.6499773959E-01
24	.5390000000E-02	-.6965110534E+02	-.1435727395E-01
25	0.	-.5687038112E+03	-.1758384558E-02
26	.5190000000E-02	-.8459882746E+02	-.1182049483E-01
27	.7070000000E-02	-.1471386249E+02	-.6796312023E-01
28	.1202000000E-01	-.1478753659E+02	-.6762475833E-01
29	.2447000000E-01	-.1093419362E+01	-.9145617659E+00
30	.4941000000E-01	-.1774432118E+01	-.5535695835E+00
31	.7439000000E-01	-.6528318771E+00	-.1531787945E+01
32	.9939000000E-01	-.6781953483E+00	-.1474591414E+01
33	.1494200000E+00	-.4453304224E+00	-.2245523660E+01
34	.1994700000E+00	-.3359170837E+00	-.2976925105E+01
35	.2495400000E+00	-.3049532919E+00	-.3279190724E+01
36	.2998200000E+00	-.2555544039E+00	-.3911530553E+01
37	.3497100000E+00	-.2479571372E+00	-.4032955095E+01
38	.3998100000E+00	-.2337078540E+00	-.4278845358E+01
39	.5000000000E+00	-.2504040864E+00	-.3993545051E+01
40	.5500300000E+00	-.2060883261E+00	-.4852288429E+01
41	.6001800000E+00	-.5025800363E+00	-.1989732834E+01
42	.6502500000E+00	-.4335895643E+00	-.2306328573E+01
43	.7003100000E+00	-.3388684243E+00	-.2950997873E+01
44	.7503400000E+00	-.2799326899E+00	-.3572287325E+01
45	.8003400000E+00	-.1810877215E+00	-.5522185557E+01
46	.8503100000E+00	-.1837597839E+00	-.5441887113E+01
47	.9002300000E+00	-.1700959242E-01	-.5879035635E+02
48	.9501200000E+00	.1018830075E+00	.9815179423E+01
49	.1000000000E+01	.2205789302E+00	.4531470213E+01

Table 16. Airfoil Curvature and Radius.

	X/CHORD	Y/CHORD	X/CHORD	Y/CHORD
20	.04055448	-.00828950	.02051449	-.00674586
22	.01045271	-.00529893	.00538288	-.00404379
24	.00123455	-.00200792	0.00000000	0.00000000
26	.00076545	.00225961	.00461712	.00504581
28	.00954729	.00708151	.01948551	.00986655

Table 17. Airfoil Surface Segment

NO.	X/CHORD	Y/CHORD	DY/DX
20	.4055448281E-01	-.8289501083E-02	-.5630938444E-01
21	.2051448886E-01	-.6745863797E-02	-.1057877697E+00
22	.1045271339E-01	-.5298925909E-02	-.2021886711E+00
23	.5382879583E-02	-.4043794982E-02	-.2981715170E+00
24	.1234553224E-02	-.2007918421E-02	-.9064036653E+00
25	0.	0.	-.8504706911E+01
26	.7654467755E-03	.2259614381E-02	.1385590123E+01
27	.4617120417E-02	.5045805619E-02	.4728114683E+00
28	.9547286611E-02	.7081511617E-02	.3565183166E+00
29	.1948551114E-01	.9866548332E-02	.2303178494E+00

Table 18. Airfoil Slope Segment

NO.	X/CHORD	Y/CHORD	D2Y/DX2
20	.4055448281E-01	-.8289501083E-02	.1268898901E+01
21	.2051448886E-01	-.6745863797E-02	.3676971653E+01
22	.1045271339E-01	-.5298925909E-02	.1588907890E+02
23	.5382879583E-02	-.4043794982E-02	.2207148212E+02
24	.1234553224E-02	-.2007918421E-02	.3846094470E+03
25	0.	0.	.3264853783E+06
26	.7654467755E-03	.2259614381E-02	-.8729194588E+03
27	.4617120417E-02	.5045805619E-02	-.2560432182E+02
28	.9547286611E-02	.7081511617E-02	-.2134831789E+02
29	.1948551114E-01	.9866548332E-02	-.5223992967E+01

Table 19. Airfoil Slope Rate of Change Segment.

	X/CHORD	Y/CHORD	DY/DX	D2Y/DX2
5	.799660E+00	-.747000E-02	.632527E-01	.146679E-01
6	.749660E+00	-.105800E-01	.604615E-01	.969558E-01
7	.699590E+00	-.134400E-01	.532031E-01	.193492E+00
8	.649740E+00	-.158100E-01	.407695E-01	.304263E+00
9	.599820E+00	-.174400E-01	.240118E-01	.367145E+00
10	.549910E+00	-.183000E-01	.128299E-01	.810529E-01
11	.500000E+00	-.188200E-01	.761912E-02	.127752E+00
12	.450100E+00	-.190500E-01	.177677E-02	.106415E+00
13	.350290E+00	-.186900E-01	-.906371E-02	.110818E+00
14	.300380E+00	-.181000E-01	-.145710E-01	.109872E+00
15	.250460E+00	-.172300E-01	-.203994E-01	.123642E+00
16	.200530E+00	-.160400E-01	-.276149E-01	.155400E+00
17	.150580E+00	-.144500E-01	-.361351E-01	.175752E+00
18	.100610E+00	-.123400E-01	-.500153E-01	.379985E+00
19	.755100E-01	-.109900E-01	-.572177E-01	.196122E+00
20	.505900E-01	-.940000E-02	-.737563E-01	.112528E+01
21	.255300E-01	-.730000E-02	-.697952E-01	.154853E+00
22	.129800E-01	-.584000E-02	-.168182E+00	.122187E+02
23	.793000E-02	-.482000E-02	-.240281E+00	.177284E+02
24	.539000E-02	-.409000E-02	-.352834E+00	.597213E+02
25	0.	0.	-.976457E+01	.540631E+06
26	.461000E-02	.509000E-02	.550440E+00	-.912058E+02
27	.707000E-02	.622000E-02	.398795E+00	-.190474E+02
28	.120200E-01	.798000E-02	.314298E+00	-.155294E+02
29	.244700E-01	.110200E-01	.205851E+00	-.117135E+01
30	.494100E-01	.157200E-01	.168250E+00	-.184871E+01
31	.743900E-01	.194700E-01	.136881E+00	-.671492E+00
32	.993900E-01	.226800E-01	.119831E+00	-.692743E+00
33	.149420E+00	.279100E-01	.912598E-01	-.450870E+00
34	.199470E+00	.319600E-01	.715158E-01	-.338433E+00
35	.249540E+00	.351300E-01	.553751E-01	-.306350E+00
36	.299620E+00	.375400E-01	.412885E-01	-.256301E+00
37	.349710E+00	.392900E-01	.286527E-01	-.248251E+00
38	.399810E+00	.404200E-01	.165773E-01	-.233792E+00
39	.500000E+00	.408800E-01	-.767297E-02	-.230421E+00
40	.550090E+00	.402000E-01	-.191089E-01	-.205159E+00
41	.600180E+00	.388600E-01	-.368774E-01	-.503598E+00
42	.650269E+00	.364100E-01	-.604013E-01	-.435933E+00
43	.700310E+00	.328800E-01	-.798749E-01	-.342103E+00
44	.750340E+00	.284800E-01	-.955332E-01	-.283768E+00
45	.800340E+00	.233900E-01	-.107237E+00	-.184216E+00

Table 20. Airfoil Segment Properties.

CHORD= 14.3866 TWISTD= 46.2684

XI	YI	XOUT	YOUT
.994522E+01	.103956E+02	.100000E+01	0.
.944620E+01	.987934E+01	.950093E+00	.258050E-03
.894996E+01	.934053E+01	.899186E+00	-.707247E-03
.845489E+01	.879460E+01	.847978E+00	-.207396E-02
.796060E+01	.824680E+01	.796714E+00	-.356969E-02
.746659E+01	.769949E+01	.745487E+00	-.505586E-02
.697262E+01	.715471E+01	.694389E+00	-.642257E-02
.647833E+01	.661447E+01	.643504E+00	-.755512E-02
.598357E+01	.608109E+01	.592942E+00	-.833405E-02
.548810E+01	.555463E+01	.542692E+00	-.874502E-02
.499228E+01	.503119E+01	.492577E+00	-.899351E-02
.449626E+01	.451041E+01	.442587E+00	-.910342E-02
.350325E+01	.347601E+01	.342919E+00	-.893139E-02
.300626E+01	.296239E+01	.293241E+00	-.864944E-02
.250889E+01	.245115E+01	.243664E+00	-.823370E-02
.201108E+01	.194263E+01	.194204E+00	-.766503E-02
.151266E+01	.143745E+01	.144881E+00	-.690522E-02
.101349E+01	.936657E+00	.957430E-01	-.589691E-02
.763446E+00	.688720E+00	.712755E-01	-.525179E-02
.512954E+00	.442698E+00	.468826E-01	-.449198E-02
.261532E+00	.200775E+00	.226508E-01	-.348845E-02
.135193E+00	.832355E-01	.106767E-01	-.279076E-02
.839039E-01	.397675E-01	.602896E-02	-.230333E-02
.578799E-01	.198251E-01	.377688E-02	-.195449E-02
0.	0.	0.	0.
.405270E-01	.929834E-01	.661753E-02	.243236E-02
.638110E-01	.128560E+00	.952320E-02	.297235E-02
.111200E+00	.195599E+00	.151674E-01	.381340E-02
.231840E+00	.351936E+00	.288164E-01	.526613E-02
.474961E+00	.652809E+00	.556101E-01	.751211E-02
.719473E+00	.945688E+00	.820691E-01	.930413E-02
.964748E+00	.123399E+01	.108335E+00	.108381E-01
.145684E+01	.180038E+01	.160428E+00	.133373E-01
.195037E+01	.235654E+01	.212075E+00	.152727E-01
.244501E+01	.290511E+01	.263395E+00	.167876E-01
.294055E+01	.344705E+01	.314426E+00	.179392E-01
.343687E+01	.398326E+01	.365206E+00	.187755E-01
.393395E+01	.451408E+01	.415752E+00	.193155E-01
.492988E+01	.555969E+01	.516123E+00	.195353E-01
.542875E+01	.607438E+01	.565945E+00	.192104E-01
.592830E+01	.658323E+01	.615507E+00	.185700E-01
.642892E+01	.708216E+01	.664620E+00	.173992E-01
.693037E+01	.757121E+01	.713278E+00	.157124E-01
.743253E+01	.805234E+01	.761573E+00	.136097E-01
.793511E+01	.852706E+01	.809565E+00	.111774E-01
.843791E+01	.899705E+01	.857330E+00	.850608E-02
.894063E+01	.946305E+01	.904892E+00	.564842E-02
.944311E+01	.992822E+01	.952400E+00	[illegible]
.994522E+01	.103956E+02	.100000E+01	0.

Table 21. Transformed Airfoil Coordinate Points.

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3. Larimer, S.J. "An Interactive Computer Aided Design Program For Digital and Continuous Control System Analysis and Synthesis." AFIT Master's Thesis. Wright-Patterson AFB, Ohio: Air Force Institute of Technology, 1978.

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OPTION >HELP

ICAAP IS AN INTERACTIVE COMPUTATIONAL AERODYNAMICS
ANALYSIS PROGRAM DESIGNED TO SOLVE THE TWO DIMENSIONAL,
SUBSONIC, COMPRESSIBLE AND VISCID FLOW PROBLEM ABOUT
AIRFOILS, AND ALSO PERFORM VARIOUS AIRFOIL MODIFICATION
AND ANALYSIS FUNCTIONS
IT CONTAINS 100 OPTIONS DIVIDED INTO GROUPS OF 10
ACCORDING TO GENERAL APPLICATION.

OPTIONS ENDING IN 0 LIST THE NEXT 10 OPTIONS,
FOR EXAMPLE, OPTION 30 LISTS OPTIONS 30 THRU 39.

THE FOLLOWING ARE THE MAIN OPTION GROUPS:
*  0-9   SPECIAL INPUT OPTIONS
* 11-19  SOLUTION OF THE VISCOUS FLOW PROBLEM
* 21-29  THEODORSEN TRANSFORMATION INFORMATION
* 31-39  BOUNDARY LAYER INFORMATION
* 41-49  PRESSURE AND VELOCITY DISTRIBUTIONS
* 51-59  LIFT, MOMENT AND DRAG COEFFICIENTS
* 61-69  AIRFOIL DESCRIPTION AND VERIFICATION
* 71-79  INPUT OF AIRFOIL COORDINATES
* 81-89  SMOOTHING AND AIRFOIL MODIFICATION
* 91-99  MISCELLANEOUS OPTIONS

SELECT OPTION 90 FOR A LIST OF OPTIONS OF PARTICULAR
INTEREST IN GETTING STARTED.

WHEN INPUT IS REQESTED BY ICAAP, THE USER MAY:
  ENTER THE REQUESTED INFORMATION, OR:
  TYPE  ?  FOR EXPLANATION OF INPUT NEEDED,
  TYPE  L  FOR LIST OF CURRENT VARIABLE VALUES,
  TYPE  *  TO LEAVE INPUT ITEM UNCHANGED,
  TYPE  C  TO USE CALCULATOR BEFORE OR DURING INPUT,
  TYPE  $  TO ABORT THE OPTION,
  TYPE  X  (OR Y,Z,T, OR R1 THRU R20) TO TELL ICAAP
           TO GET REQUESTED INFO FROM CORRESPONDING
           CALCULATOR REGISTER.

  TO END ICAAP TYPE  STOP.

OPTION >0,10,20,30,40,50,60,70,80,90

( 0-9 ) SPECIAL INPUT OPTIONS
*  0    LIST OPTIONS
*  1    RECOVER ALL DATA FROM FILE MEMORY
*  2    ENTER CL VS ALPHA DISTRIBUTION
*  3    ENTER CM VS ALPHA DISTRIBUTION
*  4    ENTER CL VS CD    DISTRIBUTION
*  5    ENTER PRESSURE (CP) DISTRIBUTION
*  6    ENTER VELOCITY (V/V0) DISTRIBUTION
* 7-9   SPARE OPTIONS
```

```
(10-19) SOLUTION OF THE VISCOUS FLOW PROBLEM
* 10    LIST OPTIONS
* 11    INITIAL VISCOUS FLOW SOLUTION USING THEODORSEN
*       TRANSFORMATION AND COMPLETE USER PROMPTS
* 12    VISCOUS FLOW SOLUTION USING PREVIOUSLY ENTERED
*       DATA AND NO USER PROMPTS
* 13    VISCOUS FLOW SOLUTION USING A USER PROVIDED
*       V/VO VELOCITY DISTRIBUTION
* 14    CONTINOUS FLOW SOLUTION FOR CHANGING ALPHA
* 15    CONTINOUS FLOW SOLUTION FOR CHANGING MACH
* 16    1. REYC FOR GIVEN: PTZ,TTZ,CHORD,MACH
*       2. CHORD FOR GIVEN: PTZ,TTZ,REYC,MACH
* 17    THIN AIRFOIL THEORY VISCID APPROXIMATION
* 18    CONTINUOUS FLOW SOLUTION FOR CHANGING ALPHA
        USING THIN AIRFOIL THEORY APPROXIMATION
* 19    SPARE OPTION

(20-29) THEODORSEN TRANSFORMATION
* 20    LIST OPTIONS
* 21    PSI VS PHI DISTRIBUTION
* 22    EPS VS PHI DISTRIBUTION
* 23    DPSI/DPHI VS PHI DISTRIBUTION
* 24    DEPS/DPHI VS PHI DISTRIBUTION
* 25-29 SPARE OPTIONS

(30-39)  BOUNDARY LAYER INFORMATION
FOUR POSSIBLE OUTPUT MODES ARE AVAILABLE BY SPECIFYING
ONE OR MORE OF THE FOLLOWING MODE SWITCHES
TPRINT---->PRINTED OUTPUT IN TABULAR FORM
TPLOT----->SKETCH DATA AT THE USER'S TERMINAL
CPLOT----->CALCOMPLOT PLOT OF DATA
TEKPLOT--->TEKTRONIX PLOT OF DATA(TEKTRONIX TERM. ONLY)
* 30    LIST OPTIONS
* 31    SKIN FRICTION COEFFICIENT DISTRIBUTION
* 32    DISPLACEMENT THICKNESS DISTRIBUTION
* 33    MOMENTUM THICKNESS DISTRIBUTION
* 34    COMPRESSIBLE FORM FACTOR DISTRIBUTION
* 35    INCOMPRESSIBLE FORM FACTOR DISTRIBUTION
* 36    MACH NUMBER AT BOUNDARY LAYER EDGE
* 37    BOUNDARY LAYER THICKNESS DISTRIBUTION
* 38-39 SPARE OPTIONS

(40-49)  VELOCITY AND PRESSURE DISTRIBUTIONS
FOUR POSSIBLE OUTPUT MODES ARE AVAILABLE BY SPECIFYING
ONE OR MORE OF THE FOLLOWING MODE SWITCHES
TPRINT---->PRINTED OUTPUT IN TABULAR FORM
TPLOT----->SKETCH DATA AT THE USER'S TERMINAL
CPLOT----->CALCOMPLOT PLOT OF DATA
TEKPLOT--->TEKTRONIX PLOT OF DATA(TEKTRONIX TERM. ONLY)
* 40    LIST OPTIONS
* 41    CALCULATED CP DISTRIBUTION
* 42    USER SUPPLIED CP DISTRIBUTION
* 43    CALCULATED AND USER SUPPLIED CP
```

```
*        DISTRIBUTION
* 44     CALCULATED V/VO DISTRIBUTION
* 45     USER SUPPLIED V/VO DISTRIBUTION
* 46     CALCULATED AND USER SUPPLIED V/VO
*        DISTRIBUTION
* 47-49 SPARE OPTIONS

(50-59)  LIFT,MOMENT AND DRAG COEFFICIENTS
FOUR POSSIBLE OUTPUT MODES ARE AVAILABLE BY SPECIFYING
ONE OR MORE OF THE FOLLOWING MODE SWITCHES
TPRINT---->PRINTED OUTPUT IN TABULAR FORM
TPLOT----->SKETCH DATA AT THE USER'S TERMINAL
CPLOT----->CALCOMPLOT PLOT OF DATA
TEKPLOT--->TEKTRONIX PLOT OF DATA(TEKTRONIX TERM. ONLY)
* 50     LIST OPTIONS
* 51     CALCULATED CL VS ALPHA DISTRIBUTION
* 52     USER SUPPLIED CL VS ALPHA DISTRIBUTION
* 53     USER SUPPLIED AND CALCULATED CL VS
*        ALPHA DISTRIBUTION
* 54     CALCULATED CM VS ALPHA DISTRIBUTION
* 55     USER SUPPLIED CM VS ALPHA DISTRIBUTION
* 56     USER SUPPLIED AND CALCULATED CM VS
*        ALPHA DISTRIBUTION
* 57     CALCULATED CL VS CD DISTRIBUTION
* 58     USER SUPPLIED CL VS CD DISTRIBUTION
* 59     USER SUPPLIED AND CALCULATED CL VS
*        CD DISTRIBUTION

(60-69) AIRFOIL DISCRIPTION AND PROPERTIES
FOUR POSSIBLE OUTPUT MODES ARE AVAILABLE BY SPECIFYING
ONE OR MORE OF THE FOLLOWING MODE SWITCHES
TPRINT---->PRINTED OUTPUT IN TABULAR FORM
TPLOT----->SKETCH DATA AT THE USER'S TERMINAL
CPLOT----->CALCOMPLOT PLOT OF DATA
TEKPLOT--->TEKTRONIX PLOT OF DATA(TEKTRONIX TERM. ONLY)
* 60     LIST OPTIONS
* 61     AIRFOIL SURFACE DESCRIPTION
* 62     AIRFOIL SURFACE SLOPE
* 63     AIRFOIL SURFACE SECOND DERIVATIVE
* 64     AIRFOIL CURVATURE AND RADIUS
* 65     COMPOSITE AIRFOIL PLOT
* 66     SPARE OPTION
* 67     OPEN TRAILING EDGE CLOSED TO A POINT
* 68     AIRFOIL SURFACE PLOT WITH NO SYMBOLS
*        OR AXIS
* 69     SPARE OPTION

(70-79) INPUT/OUTPUT OF AIRFOIL COORDINATE DATA
* 70     LIST OPTIONS
* 71     ENTER COORDINATE POINTS FROM THE KEYBOARD
* 72     SPARE OPTION
* 73     READ COORDINATE POINTS FROM FILE CRDPTS
* 74     STORE COORDINATE POINTS INTO FILE CRDPTS
* 75     SPARE OPTION
```

```
* 76    COORDINATE POINTS FOR NACA DESIGNATED AIRFOILS
* 77    COORDINATE POINTS FOR NACA DESIGNATED AIRFOILS
*       WITH POINT DISTRIBUTION (49) SPECIALIZED FOR
*       USE WITH OPTIONS 11, 12, 13, 14, 15
* 78-79 SPARE OPTIONS

(80-89) AIRFOIL SMOOTHING AND MODIFICATION
FOUR POSSIBLE OUTPUT MODES ARE AVAILABLE BY SPECIFYING
ONE OR MORE OF THE FOLLOWING MODE SWITCHES
TPRINT---->PRINTED OUTPUT IN TABULAR FORM
TPLOT----->SKETCH DATA AT THE USER'S TERMINAL
CPLOT----->CALCOMPLOT PLOT OF DATA
TEKPLOT--->TEKTRONIX PLOT OF DATA(TEKTRONIX TERM. ONLY)
* 80    LIST OPTIONS
* 81    AIRFOIL SURFACE SEGMENT
* 82    INTERPOLATE NEW Y/C POINT AT OLD X/C VALUE
* 83    AIRFOIL SLOPE SEGMENT
* 84    AIRFOIL SECOND DERIVATIVE SEGMENT
* 85    SPARE OPTION
* 86    TABULATE (X/C,Y/C), DY/DX, AND D2YDX2 FOR
*       AIRFOIL SEGMENT OF INTEREST
* 87    DELETE (X/C,Y/C) COORDINATE POINTS
* 88    INSERT (X/C,Y/C) COORDINATE POINTS
* 89    INTERPOLATE Y/C VALUE FOR X/C INPUT

(90-99) OPTIONS OF PARTICULAR INTEREST
* 90    LIST OPTIONS
* 91    REWIND AND UPDATE MEMORY FILE WITH CURRENT DATA
* 92    ERASE SCREEN (TEKTRONIX GRAPHICS TERMINALS ONLY)
* 93    LIST CURRENT SWITCH SETTINGS (ECHO,ANSWER,ETC)
* 94    HARD COPY (TEK TERMINAL WITH HARD COPY UNIT ONLY)
* 95    PRINT NEW FEATURES BULLETIN
* 96    LIST SPECIAL COMMANDS ALLOWED IN OPTION MODE
* 97    LIST VARIABLE NAME DIRECTORY
* 98    LIST MAIN OPTIONS OF ICAAP
* 99    GIVE INTRODUCTION TO ICAAP

OPTION >
```

Appendix B

Discussion of ICAAP's Overlays

Introduction

ICAAP is composed of 1 main overlay, 18 primary overlays and 5 secondary overlays. The primary overlays were developed to perform the data base control, program control, user assistance,input, output, and problem solution functions performed by ICAAP. This Appendix contains a brief description of each overlay in ICAAP.

UPDATE

UPDATE is one of ICAAP's smallest overlays designed for data base control. Update stores all the data necessary to restart ICAAP into a sequential file called MEMORY. This function is normally done when the user ends ICAAP, or periodically at the user's command. This overlay also reads from MEMORY the data necessary to restart ICAAP.

CORDAT

CORDAT is an input overlay developed in this project to handle all the details associated with the input of the airfoil coordinates, pressure and velocity distributions. CORDAT is also used to read in lift and moment coefficient vs angle of attack distributions, and lift vs drag distributions as supplied by the user.

FLODAT

FLODAT is an input overlay developed in this project to handle the user prompting, and error protection of all input variables for overlay VISCFLO.

AIRFOIL

AIRFOIL is an output overlay developed in this project. It handles the four possible output modes for options associated with the verification of the airfoil and its physical properties. Some of the possible outputs are the airfoil surface and slope distributions.

NACAFIT

This is a problem solution overlay which is the result of the modifications made to the program from Ref 7. NACAFIT provides the coordinate point distributions for NACA designated airfoils.

READER

READER is the overlay in ICAAP responsible for all the interactive functions. All data entered by the user is recieved by READER, translated, checked for errors, and coded into a set of numerical commands which ICAAP can execute. READER is also responsible for performing all the calculator functions.

Overlay READER was transplanted in its complete form from the program TOTAL and only minor modifications were performed. The modifications only changed the vocabulary of variables and commands which READER is capable of understanding.

DECODER

DECODER is responsible for decoding the machine instructions set up by READER and executing the resulting commands. Since all instructions can not be performed by DECODER, many times DECODER will simply set up a command sequence which will call the proper overlays into memory to perform the required instructions.

HELP

HELP is a user assistance overlay designed to provide several levels of user assistance. HELP provides aid in executing an option, and also provides explanations when the user enters a "?" instead of the requested variable.

SMOOTHER

This is an output and problem solution overlay developed in this project to handle the interpolation, insertion, smoothing and deletion of airfoil coordinate points. SMOOTHER also handles the four possible output modes for options that examine the properties of an airfoil segment.

TTYPLT

TTYPLT is an output overlay designed to perform the printer plots for the different options. TTYPLT is an adaptation of a similar overlay in the porgram TOTAL.

VISCFLO

VISCFLO is a problem solution overlay developed in this project to solve the viscous, compressible, two dimensional flow about airfoils. This overlay is the result of the adaptations and modifications performed on the main program in Ref 4. VISCFLO uses 5 secondary overlays which actually solve the flow problem while it acts as the solution and job flow controller.

VELOC

VELOC is a secondary overlay used by VISCFLO to determine the inviscid velocity and pressure distributions about airfoils of arbitrary shape. This overlay is the result of the modifications and adaptations made to the subroutine by the same name in Ref 4.

BDLAYER

BDLAYER is a secondary overlay used by VISCFLO to compute the boundary layer characteristics for the velocity and pressure field determined by VELOC. BDLAYER is the result of the modifications and integration of subroutines PROFIL, LAMNAR, TURBLN, and PRECAL from Ref 4.

SOURCS

SOURCS is a secondary overlay used by VISCFLO to compute the airfoil wake characteristics and add a source distribution on the surface of the airfoil. The source distribution is used to effectively model the displacement effects of the boundary layer computed by BDLAYER.

VELOC2

VELOC2 is a secondary overlay developed in this project to calculate the pressure distribution for a user supplied velocity distribution. It uses the same compressibility correction factors as VELOC. This overlay also handles all the necessary calculations needed by VISCFLO in order to determine to a first approximation (only one viscous-inviscid iteration) the effects of viscosity on the inviscid velocity distribution.

TAFT

TAFT is a secondary overlay developed in this project to compute the airfoil inviscid flow properties using thin airfoil theory as described in Karamachetti (Ref 6). Like VELOC2, this overlay sets up all the necessary calculations needed by VISCFLO to obtain a first approximation of the effects of viscosity.

MISCELL

MISCELL is a primary overlay used by ICAAP to handle miscellaneous program control and user assitance functions.

PLOTTER

PLOTTER is an output overlay developed in this project and used by ICAAP to provide for the user the four possible output formats for options that work on the data from the flow solutions. This data includes the pressure, velocity and Mach number distributions, and the boundary layer information.

TEKPL1

TEKPL1 is an output overlay developed in this project and used by PLOTTER to perform the Tektronix plots of the pressure, velocity Mach number, and boundary layer data.

TEKPL2

TEKPL2 is an output overlay developed in this project and used by PLOTTER and CLCMCD to perform the Tektronix plots for the lift, moment and drag coefficient distributions. This overlay also handle the plots for the Theodorsen transformation data.

MULTIR

MULTIR is a program control overlay developed in this project. It is responsible for all the inputs, bookeeping and commands needed to provide Mach number and angle of attack sweeps. MULTIR provides an easy way to run several viscous flow solutions while only changing the Mach number or angle of attack. This overlay is also responsible for the storage of the resulting data which will later be used by CLCMCD.

CLCMCD

CLCMCD is an output overlay developed in this project. It is developed in this project to handle all operations to provide all possible forms of outputs for the options that work on the lift, moment, and drag coefficient distributions calculated by VISCFLO or entered by the user.

NOTICE

NOTICE is a program control overlay whode only purpose is to print the latest features added to ICAAP. Although in its present form ICAAP does not have any new features, this overlay was provided to make documenting new program capabilities easier.

VITA

Enrique G. Hernandez was born on 23 September 1957 in Oriente, Cuba. He graduated from Miami Sr High School in 1974, and with High Honors from the George T. Baker Aviation School where he recieved the FAA Powerplants Licence. In 1979 he recieved a Bachelor of Science in Aerospace Engineering Degree from the University of Florida. Upon graduation, he was commissioned Second Lieutenant in the USAF as an Honor Graduate and Distinguished Graduate of the Air Force ROTC program. After graduation he entered active duty at the Air Force Institute of Technology in 1979.

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Interactive Aerodynamics Analysis
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Airfoil Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report details how existing aerodynamics analysis programs were combined and integrated into a fully interactive analysis program. The resulting program has several levels of user assistance, complete error protection, and protection against fatal terminations. The program was built around an aerodynamics analysis code which is capable of predicting the real fluid characteristics of of airfoils in flows with subcritical Mach numbers. In addition to the viscous flow solution, the program is also capable of several airfoil modification

functions. The program was developed as the basic building block upon which several other aerodynamics analysis codes will be added in the future.

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3