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VOLUME I

MARK IV SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM MODIFICATIONS AND COMPUTER GRAPHICS

AD

VOLUME I - SURFACE STREAMLINE TRACING

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TECHNICAL REPORT AFWAL-TR-80-3117, VOLUME I

FINAL REPORT FOR MAY 1978 - DECEMBER 1980

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This technical report has been reviewed and is approved for publication.

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Modifications were made to two areas of the Mark IV Supersonic Arbitrary-Body program. First, the previous streamline method was replaced with one capable of tracing continuous surface streamlines. The method includes a means of locating the origins of the streamlines. Changes were also made to the viscous methods in the Mark IV code. The integral boundary layer methods, which must be applied along inviscid streamlines, were modified to ensure their compatibility with the new streamline method. Several discrepancies were observed in the previous coding of the integral methods, and the problems were corrected.

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PREFACE

This report was prepared for the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under contract number F33615-78-C-3001. The contract was initiated under project number 2404, task number 240407 and work unit number 24040718. The work was performed by the Aeronautical Systems Technology Division, Science Applications, Inc. (SAI) in Irvine, California as part of the Hypersonic Aeromechanics Technology (HAT) program. The HAT program was initiated in May 1978 and completed in December 1980. Mr. R. D. Neumann (AFWAL/FIMG) was the Air Force Project Engineer. Mr. L. A. Cassel was the SAI Program Manager for the period May 1978 to December 1979, Mr. S. Taylor for the period January 1980 to September 1980 and Mr. M. L. Lopez assumed the responsibilities in September 1980. Mr. S. Taylor also served as Principal Investigator for the HAT program's Aerodynamics Task. This report was submitted for publication in January 1981.

The author gratefully acknowledges the contributions of Mr. D. Shereda of the Air Force Wright Aeronautical Laboratories (FIMG) whose guidance was instrumental in the successful completion of the task. The author also wishes to thank Mr. T. Duncan, Mr. M. L. Lopez, Mrs. K. Mamelli and Mrs. C. Davis for their assistance in completing this report.

This report is documented in two volumes. Volume I describes modifications made to the Mark IV Supersonic-Hypersonic Arbitrary-Body computer program, and Volume II documents two computer graphics codes used to validate Mark IV geometries.

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INTRODUCTION

This report describes new developments related to the Mark IV Supersonic-Hypersonic Arbitrary-Body Program (Reference 1), a FORTRAN computer code employing design methods for computing the aerodynamic characteristics of complex configurations. The effort is documented in two volumes. Volume I describes improvements made to the Mark IV program itself, and Volume II documents two computer graphics codes used to validate Mark IV geometries. Contained in Volume II (Reference 2) is a detailed description of TEKPIC, a new interactive graphics code that allows the user to examine many orientations of a given vehicle in a minimal amount of time. However, the TEKPIC program uses only an approximate method for displaying the visible lines of the geometry. A second graphics code, HIDDEN, requiring significantly more central processor (CP) time and core memory than TEKPIC, but capable of removing hidden lines, is used to complement the TEKPIC program.

The primary objective of the work documented in Volume I was to incorporate into the Mark IV program a method for tracing inviscid surface streamlines over arbitrary geometries. The Newtonian streamline method, which provides the flow direction at any point on the surface given only the freestream velocity (vector) and the local surface outward normal, is employed in the modified Mark IV program.

Although the basis of the streamline method is simple, many difficult problems arise when attempting to generalize the approach to arbitrary geometries.

Normally, the inviscid flow properties (including the direction cosines of the surface velocity) are known only at specific points on the surface. Since streamlines do not generally pass through these points, a method must be available for interpolating between the points. The interpolation procedure becomes quite complex for arbitrary configurations. Another problem encountered is that of locating the origins for the streamlines. Streamlines may emanate from blunted stagnation regions in which the surface outward normal is aligned with freestream velocity, or they may originate from the leading edges of wings, canards, nacelles, etc. in which the surface outward normal is not aligned with the freestream velocity. Given only the orientation of the outward normal with respect to the freestream vector, a consistent method can be developed for locating stagnation region origins but not the latter origins.

An initial attempt to develop a general-body streamline method was made by the authors of the Mark IV program. A surface spline technique (Reference 3) was applied to certain user-specified regions of the geometry as a means of interpolating for the surface flow properties. (The term region, as used in the original Mark IV program, is defined as a collection of geometry Panels; see Reference 1, Volume I for a complete definition of Panels, Sections, and Elements.) The surface fitting method has the disadvantage that it is not a parametric spline. That is, the surface fit of a given flow quantity within a region requires an appropriate choice of two of the three independent variables to ensure that the dependent variable is not multivalued. Each region must therefore be fit independently of other regions, and positional continuity between spline regions is not guaranteed. This poses a problem when attempting to trace streamlines from region to region. The latest release of the Mark IV program contained no means of tracing streamlines across region boundaries. Therefore, running lengths along the streamlines could not be accurately predicted, and no method could be implemented for locating streamline origins.

Although the surface spline used in the Mark IV program has several disadvantages, the incorporation of other more sophisticated spline methods would be beyond the scope of the present effort. Furthermore, the use of other spline methods would require significant modification of the geometry input procedure which was not to be altered. However, in the new streamline method, improvements were made to the manner in which the nonparametric spline method was used. Rather than surface fitting quantities over large regions of the geometry, which may lead to erroneous interpolations, the surface spline is applied only to each geometry Panel. Not only does this approach improve the accuracy of the interpolations, but it greatly simplifies the tracing of streamlines from one spline region (Panel) to another. (The term region, as used in the remainder of this report is synonymous with the surface of <u>one</u> Panel.)

The new streamline method also has the ability to locate the origins of the streamlines. This is accomplished by distributing starting points along the aftmost boundaries of the geometry, and tracing the streamlines forward, against the flow direction, until the appropriate origins are located. After all streamlines are computed, the distribution is examined to ensure that it is sufficiently distributed over the geometry for subsequent boundary layer calculations. If some surface areas are void of streamlines, new starting points are strategically positioned and more streamlines are traced.

The user may wish to know surface property information (including viscous related parameters) only at specific points on the body. An option has therefore been included which allows starting points to be input by the user. If starting points are input, the user must request whether the integration is to be performed with or against the direction of flow. If the streamlines are integrated in the direction of flow, it is assumed that the starting point is also an origin.

The primary purpose of calculating inviscid surface streamlines is to provide paths along which boundary layer methods may be applied. A secondary objective of the effort described in this report was to ensure that the integral boundary layer methods employed in the original version of the Mark IV program were compatible with the new streamline method. The integral methods (References 4 and 5) were originally coded in a separate computer program by McNally (Reference 6) who was mainly concerned with boundary layers in shock-free flowfields. In the coding of the equations, isentropic conditions were assumed to exist along all streamlines extending from the freestream to the geometry surface. Therefore, the McNally coding required modification for use in the Mark IV program. However, several discrepancies were discovered in the Mark IV coding of the integral methods. Many of the boundary layer edge quantities appearing in the integral equations were still based on freestream conditions instead of local conditions, e.g. p_o, ρ_o. Therefore, an additional objective of the effort described in this report was to correct the coding of the integral methods.

One constraint placed upon all modifications to the Mark IV program was that the overall operation of the program was not to be affected. Only those parts of the program directly involved with either the streamline tracing or the integral boundary layer methods were changed. No modifications were made to the geometry package, the inviscid aerodynamics methods, the shielding analysis, or the special routines. As a consequence, unless streamline or viscous calculations are desired, the user follows the input data formats exactly as they are described in Volume I of the original Mark IV documentation.

The streamline method and the viscous analyses are accessed from the AERO executive routine in the same manner as described in the original documentation. Section II of the present report describes the input data required to use the new streamline method and the modified viscous methods option. The information in this section is intended to completely replace the input data instructions for both the Surface Streamline Option (pp. 92-98 in Volume I of Reference 1) and the Viscous Program Option (pp. 114-128). However, the format of the Mark III Program (Reference 7) Skin Friction Element Data Cards used in the Mark IV program, has not been altered. The only other data formats changed in the Mark IV program were those associated with the Surface Data Transfer Option, used only when streamline calculations are desired.

A detailed description of the theory and the algorithms used in the new streamline method is given in Section III of this report. A relatively brief description of the integral boundary layer equations used in the Mark IV code is also presented in Section III. The theory and the coding of the integral methods are well-documented in McNally's report (Reference 6). Section IV of this report contains general information for those wishing to modify either the streamline method or the viscous methods.

The modified Mark IV program is operational on the CDC CYBER 750 computer maintained by the ASD Computer Center, Wright-Patterson AFB, Ohio.

SECTION II

USER'S GUIDE

The user's guide presented here is intended to serve only as a supplement to the original user's manual of the Mark IV program (Reference 1, Volume I). Only those changes that affect either the input data formats or the operation of the original version of the code are documented in the present report. Unless the user is interested in tracing streamlines or in computing viscous effects, the user may rely solely on the original user's manual.

The general organization of the modified Mark IV program, shown in Figure 1, is identical to that of the original version of the code. In the normal operation of the program the geometry package is called first to generate and save on local storage unit 4 the quadrilateral element data. The geometry data on unit 4 (a random access or mass storage unit) includes the four corner points, the three components of the outward normals, the areas, and the centroids of all elements comprising the vehicle geometry.

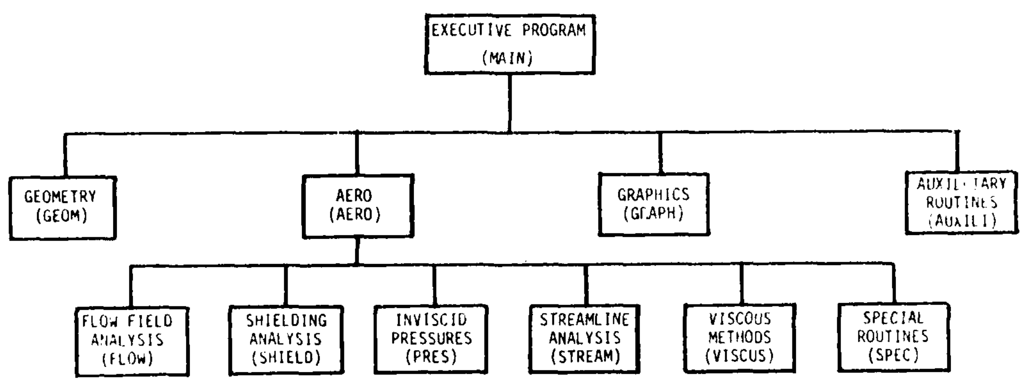


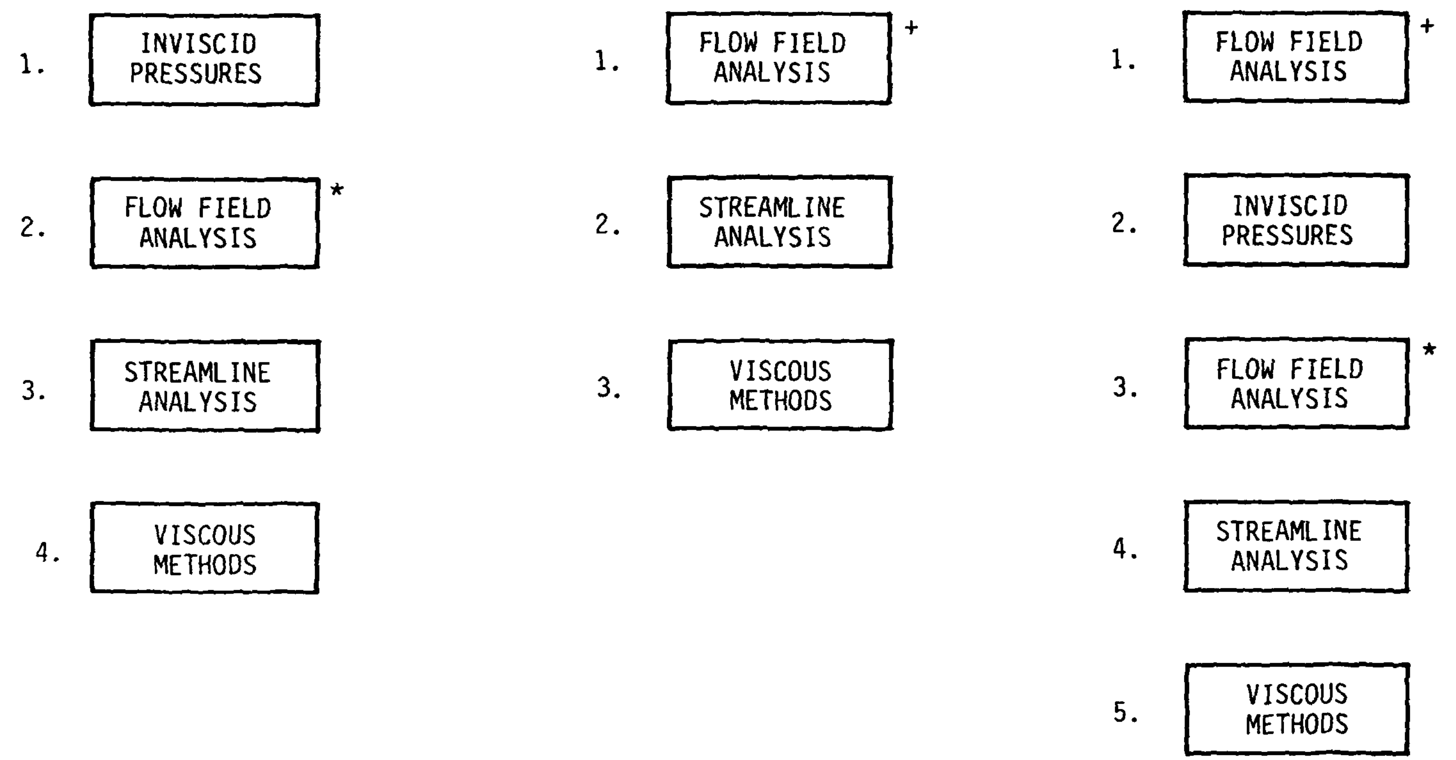
Figure 1. Functional Organization of Mark IV Program

Once the geometry data have been saved on unit 4 the user may proceed with the aerodynamic calculations. The aerodynamics program, AERO, consists of six separate components, and each component is responsible for performing a certain analysis. The AERO program requires the user to specify a sequence of integers identifying the particular analyses to be employed and the order in which they are to be used. Technically, the analyses may be called in any sequence, and each analysis may be called any number of times. In practice, however, some analyses depend on results generated by other options in AERO. For example, the Special Routines option, responsible for summing the forces and moments of the various vehicle components, requires that the Inviscid Pressures analysis be performed first.

Prior to accessing the Streamline option it is necessary that a specific sequence of calls be made to other AERO options. The calculation of surface streamlines requires the prior computation of surface flow data. Two methods may be used to generate the surface data. The data may be hand-loaded using the Surface Data Transfer sub-option of the Flow Field Analysis option, or the data may be generated using the Inviscid Pressures option. The hand-loaded data are stored on unit 10, a random access unit containing all flowfield information generated by the Flow Field Analysis option. The formats of the surface data on unit 10 are compatible with the Streamline option, but the data generated by the Inviscid Pressures option are stored on unit 4 in formats not compatible with the Streamline option. Therefore, if the surface data are generated by the Inviscid Pressure option, the data must be transferred from unit 4 to unit 10 before the Streamline option may be called. The data transfer is accomplished by the Surface Data Transfer sub-option of the Flow Field Analysis option, the same option used to hand-load surface data. The surface data on unit 10 may consist of a combination of data generated by the Inviscid Pressures option and hand-loaded data. Once all the surface data are stored on unit 10, the Streamline option may be accessed.

The utilization of the Viscous Methods option also requires that other analyses be performed first. The Viscous Methods option contains two approaches for computing boundary layer effects. The first method is the Mark III Element Skin Friction method which requires that the Inviscid Pressures option be called previously. Although the Mark III Element Skin Friction analysis is fairly crude, it is the only method in the Mark IV program capable of estimating the contribution of skin friction to the total vehicle forces and moments. The second approach available in the Viscous Methods option applies boundary layer methods along the inviscid streamlines generated previously in the Streamline option. Although the approach is more sophisticated than the Mark III Element Skin Friction method, it is not capable of predicting the contribution of skin friction to the total vehicle forces and moments. The latter method should be used only when detailed boundary layer information is desired (momentum thickness, displacement thickness, etc.), or when heat transfer predictions at specific points on the body are required.

Shown in Figure 2 are the three possible user-specified sequences of AERO calls to the various options that may be used to generate streamlines and to subsequently make integral boundary layer calculations along the streamlines. The particular sequence of calls used is specified on the Aero Flag Card described on p. 69 in Reference 1, Volume I and are read by the AERO program. Following the Aero Flag Card are the Flight Condition Card, the Reference Dimension Card, and the α-β Cards which are also read by the AERO program. The remainder of the data to be prepared depend upon the specific AERO options selected. For example, if the first option is the Inviscid Pressure option, the user would turn to the Pressure Calculation Program Input Data on p. 101 in Reference 1, Volume I. After all data for the Pressure Calculation Program are prepared, the data formats for the second option are located in the user's manual, and so on. However, if the option selected is the Streamline Analysis option, the Viscous Methods option, or the Flow Field option in which surface data are to be hand-loaded or transferred from unit 4 to unit 10, the user must refer to the following descriptions of the data preparation. For optimal use of the Streamline and Viscous options it is suggested that the user become familiar with the theory of the methods presented in Section III.



a. Surface properties for all Panels calculated by program

b. Surface properties for all Panels hand loaded

c. Surface properties for some Panels hand loaded, properties for remaining Panels calculated by program

*Surface data transferred from unit 4 to unit 10.

+Surface data hand loaded directly to unit 10.

Figure 2. Possible AERO Option Calls for Streamline/Viscous Calculations

1. SURFACE DATA TRANSFER OPTION

The data formats given for the Surface Data Transfer option in Reference 1, Volume I (pp. 89-91) may not be used with the modified Mark IV program. Instead, the user should refer to the data formats presented here.

This option is one of several in the Flow Field Analysis program, and is used to transfer surface data to unit 10 from either the input unit (hand-loaded data) or unit 4 (data generated previously by the Inviscid Pressures option). The data are placed on unit 10 in formats acceptable by the streamline option. The Surface Data Transfer option is exercised only if IDTYP(1) = 2 on the Region Directory Table Card, Reference 1, Volume I (pp. 76) read by program FLOW, the executive program for the Flow Field Analysis option. This option may also be used to read and print out surface data previously stored on unit 10 if IRW = 1 on the Region Directory Table Card.

As described in Reference 1, all flow field data generated or read by the Flow Field Analysis option are stored on unit 10, the flow field unit. Each of the analyses in the Flow Field Analysis option, including the surface data transfer, may be applied to any user-specified collection of geometry Panels. For a given angle of attack and set of freestream conditions, the results of each flow field analysis are stored in a "flow region." The region number, IREG, associated with a particular analysis is identified by the user on the Region Directory Table Card. Surface data transferred from unit 10 must be stored in flow region 1 (IREG = 1), and hand-loaded surface data must be placed in flow region 2 (IREG = 2). If streamline calculations are desired, the surface data in regions 1 and 2, taken collectively, must uniquely define the surface flow quantities over the surface of the entire vehicle.

When transferring surface data to unit 10, the information is further divided into "subregions." A subregion is simply defined as the collection of surface flow properties over one geometry Panel. In the original version of the Mark IV program, the surface properties associated with several Panels could be grouped together into one subregion. However, since the surface properties associated with each subregion are fit with a surface spline (for interpolation purposes) in the Streamline option, erroneous interpolations may result if a subregion contains the properties of more than one Panel. Therefore, the number of subregions to be loaded, NSREG, as specified by the user on the Flow Field Control Card below, simply corresponds to the number of Panels whose surface property data will be placed on unit 10. Only one Flow Field Control Card is read for each call to the Surface Data Transfer option.

Flow Field Control Card (3I2)

This card is input only if IDTYP (1) = 2 and IRW = 0.

Column	Code	Routine Format	Explanation
1-2	NSREG	FFSURF I2	Total number of subregions (geometry panels) to be loaded from unit 4 to unit 10 or hand loaded (assumed at least = 1).
3-4	KTRNSF	FFSURF I2	Type of surface data transfer. = 0 Data will be read from unit 4 and placed on unit 10. (Next card read will be the Surface Data Panel Selection card). ≠ 0 Data will be hand loaded and stored on unit 10. (Next cards read will be the Hand Loaded Surface Property Data cards).
5-6	IPRINT	FFSURF I2	Print flag. = 0 Do not print surface data. = 1 Print.

Hand-Loaded Surface Property Data Cards

These cards are used to hand load surface property data directly to the flow field unit 10 and are used only if KTRNSF ≠ 0, otherwise skip this section and go to Surface Data Panel Selection Cards, pp. 12. The first card identifies the gometry Panel with which the data are to be associated and specifies the number of data points (sets of Surface Data Coordinate and Surface Data Property Cards) to be read. The number of sets of Surface Data Panel

Hand-Loaded Surface Property Data Cards (Continued)

Identification, Surface Data Coordinate, and Surface Data Property Cards must equal NSREG on the Flow Field Control Card.

Surface Data Panel Identification Cards (2I5)

Column	Code	Routine Format	Explanation
1-5	IPANL(I)	FFSURF I5	Panel number on unit 4 with which the data are to be associated.
6-10	NPTS	FFSURF I5	The number of data points to be read for this subregion.

Surface Data Coordinate Card (6F10.0)

1-10	DATA(1)	FFSURF F10.0	X-coordinate of the surface data point.
11-20	DATA(2)	FFSURF F10.0	Y-coordinate of the surface data point.
21-30	DATA(3)	FFSURF F10.0	Z-coordinate of the surface data point.
31-60	DATA(4-6)	FFSURF 3F10.0	(not used).

Surface Data Property Card (6F10.0)

1-10	DATA(7)	FFSURF F10.0	Surface Mach number.
11-20	DATA(8)	FFSURF F10.0	X-direction cosine component of the surface velocity vector.
21-30	DATA(9)	FFSURF F10.0	Y-direction cosine component of the surface velocity vector.
31-40	DATA(10)	FFSURF F10.0	Z-direction cosine component of the surface velocity vector.
41-50	DATA(11)	FFSURF F10.0	P/P_∞.
51-60	DATA(12)	FFSURF F10.0	T/T_∞.

Surface Data Panel Selection Cards (10I5)

These cards are used when surface data are to be transferred from unit 4 to unit 10 by the routine FFSURF. The cards are input only if KTRNSF = 0 on the Flow Field Control Card. In subsequent streamline calculations the surface flow properties of each Panel's element centroids will be fit with the surface spline for interpolation purposes.

Column	Code	Routine Format	Explanation
1-5	IPANEL(I+1)	FFSURF I5	Panel numbers of the surface data on unit 4 to be transferred to the flow field storage unit 10. Panel numbers correspond to the order in which the Panels were read by the geometry routines.
6-10	IPANEL(I+2)	FFSURF I5	
11-15	IPANEL(I+3)	FFSURF I5	
16-20	IPANEL(I+4)	FFSURF I5	
21-25	IPANEL(I+5)	FFSURF I5	NOTE:
26-30	IPANEL(I+6)	FFSURF I5	$I = \begin{cases} 0 & \text{for } 1 \leq NSREG \leq 10 \\ 0,10 & \text{for } 10 < NSREG \leq 20 \\ 0,10,20 & \text{for } 20 < NSREG \leq 30 \\ 0,10,20,30 & \text{for } 30 < NSREG \leq 40 \\ 0,10,20,30,40 & \text{for } 40 < NSREG \leq 50 \end{cases}$
31-35	IPANEL(I+7)	FFSURF I5	
36-40	IPANEL(I+8)	FFSURF I5	
41-45	IPANEL(I+9)	FFSURF I5	
46-50	IPANEL(I+10)	FFSURF	Example: for NSREG = 13, only 2 panel Selection Cards are required.

2. SURFACE STREAMLINE OPTION

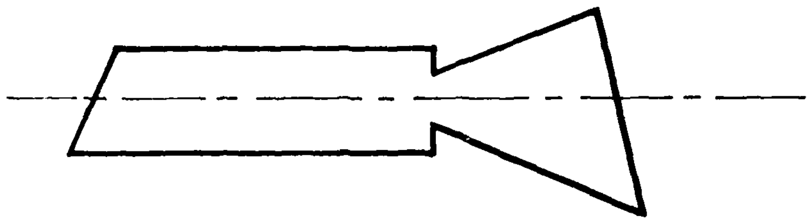
The new streamline method in the Mark IV program requires a different data format than that described on pp. 92-98 in Reference 1. The information presented here is intended to completely replace the old Surface Streamline option.

The Surface Streamline option is called from the AERO executive program as described previously. The streamline method requires that the surface velocity direction cosines at all the Element centroids be defined a priori. Therefore, surface property information (M_∞, p/p_∞, T/T_∞, and the surface velocity direction cosines) for the entire vehicle must be available on unit 10 prior to accessing the Surface Streamline option. If the Inviscid Pressure option is used to generate surface data, the direction cosines of the surface velocity at each Element centroid are calculated using Newtonian theory (see Section III - Theory). If the data are hand-loaded using the Surface Data Transfer option, "exact" streamlines may be traced if the surface velocity direction cosines are exact. The hand-loaded data points do not necessarily have to correspond with the Element centroids.

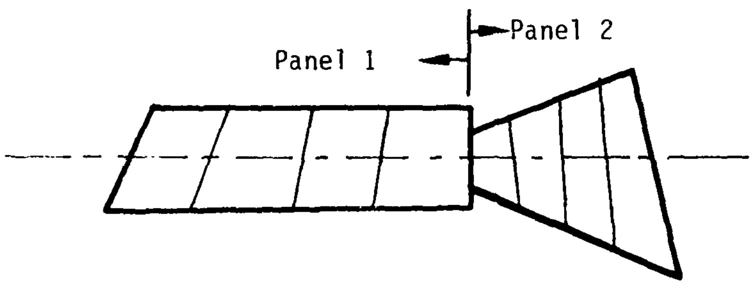
One of the major problems associated with tracing streamlines over arbitrary Mark IV geometries is that of interpolating between the Element centroids for the surface flow properties. Since streamlines generally do not pass through the Element centroids, a means must be available for estimating the inviscid flow properties at any point on the surface. The Mark IV program employs the surface spline technique presented by Harder and Desmaris in Reference 3. The method generally cannot be applied to the entire vehicle surface since it is required that the quantity to be fit (e.g. p/p_∞) be well-behaved within the boundaries of the spline. Therefore, the surface flow field must be divided into separate regions in which the surface properties do not exhibit rapid changes within each region. In the new streamline method, the surface properties corresponding to each geometry Panel are surface fit. For a geometry consisting of N Panels, a total of N independent spline fits are required. for each flow quantity. The six flow quantities that are fit include p/p_∞, T/T_∞, M, and the three components of the unit surface velocity.

As defined in the Surface Data Transfer option, the flow properties associated with a Panel are termed a subregion. The use of Panel boundaries for sub-dividing the surface flow field into well-behaved subregions is a logical approach since the inviscid properties, calculated using the local slope methods in the Mark IV program, do not exhibit radical behavior over a Panel unless the Panel itself contains rapid changes in character. Although it is difficult to concisely define a "well-behaved" flow property or geometry Panel, two rules of thumb may be used when preparing the geometry. First, a Panel should not contain rapid changes in curvature. For example, the longitudinal curvature of a spherically-blunted cone changes discontinuously from a nonzero value on the nosecap to a zero value at the sphere-cone juncture. The geometry should therefore be described by two Panels - the nosecap and conical frustum. Secondly, each Panel should contain only one geometry Section. Although the Mark IV geometry package permits the user to group several Sections into one Panel, no need exists for more than one Section within a Panel unless either the general shape or the boundaries of a surface change discontinuously. The curvature of the flat surface illustrated in Figure 3 is certainly well-behaved, but the slope of the boundaries changes discontinuously. The surface spline as used in the new streamline method requires that each subregion, or Panel, consist of three or four boundaries whose slopes are continuous. Furthermore, since the spline is two-dimensional, each Panel must contain at least three Elements whose centroids are not colinear (i.e., not a function of one spatial variable).

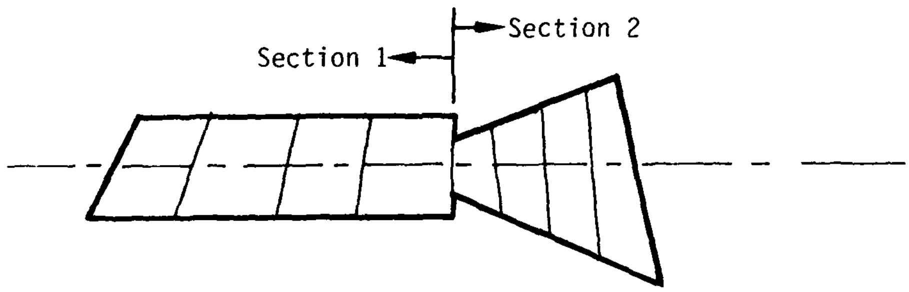
In the new streamline method two options are available for initializing the streamline computation. First, the user may specify the points on the vehicle surface from which the streamlines are to be traced. Such points are termed starting points which may or may not correspond to true streamline origins. Since the user usually does not know the locations of the streamline origins a priori, an option has been included which allows the streamline equations to be integrated against the flow direction until a true origin is located by the streamline method. Running lengths saved along the streamline are then automatically reordered. For any given point on the body, therefore, this approach permits the calculation



a. Original surface



b. Correct means of grouping
Elements: 2 Panels, 1 Section each



c. Incorrect means of grouping
Elements: 1 Panel, 2 Sections

Figure 3. Restriction on Geometry Preparation

of the surface flow history prior to the point specified. If the user indicates that the equations are to be integrated in the direction of flow, the starting point is assumed to coincide with a true origin.

The second option included in the new streamline method for initializing the streamline calculation allows the user to request that starting points be automatically distributed by the program. If this option is selected, starting points are distributed along the aft-most boundaries of the geometry and the streamlines are traced forward, against the flow direction, until the appropriate origins are located. After all running lengths are reordered, the method has the capability to determine whether the initial streamlines are sufficiently distributed for subsequent skin friction calculations and integration. If the streamlines are not sufficiently distributed, new starting points are strategically distributed over the geometry surface and additional streamlines are computed. (Although the Viscous Methods option in the modified Mark IV program is capable of applying boundary layer methods along the surface streamlines, the present version of the code does not contain a method for assessing the contribution of viscous shear along the streamlines to total vehicle forces and moments. Instead, the user must resort to the Mark III Skin Friction Method included in the Viscous Methods option).

Two criteria are used in the new streamline method for locating the origin of each streamline. The first criterion is simple: if the dot product of the freestream velocity and the local surface velocity is less than some small arbitrary value, an origin has been located. However, streamlines may originate from the leading edges of swept wings, nacelles, etc. in which the above criterion is useless. Therefore, as part of the input data preparation for the Surface Streamline option, the user must indicate whether each Panel contains a leading edge boundary, a trailing edge boundary, or all interior boundaries. A given Panel contains a leading edge boundary if no other Panels lie forward of and adjacent to the Panel. Trailing edge boundaries and interior boundaries are defined similarly. Provision has also been made for Panels that contain both leading and trailing edge boundaries.

In order to gain familiarity with the new streamline method, it is suggested that the user begin with a simple geometry such as a cone, a flat plate, or only a few Panels of the vehicle of interest. After the preliminary streamline calculation, other Panels may be easily added.

The preparation of the input data for the Surface Streamline option is particularly simple. The data consists of four sets of cards:

(1) Surface Property Access Card - indicates where the surface property data are to be found on unit 10. This card is read only once per entry into the Streamline option.

(2) Streamline Data Card - contains general streamline information including flags that indicate which options are to be used. This card is also read only once per entry into the Streamline option.

(3) Panel Description Cards - each card contains information regarding the general shape of a Panel. The number of these cards must equal the number of Panels on unit 4. The order in which the cards are input must coincide with the order in which the Panel information was stored on unit 4.

(4) Streamline Starting Point Cards - indicate the points from which the streamline calculations are to begin. These cards follow the Panel Description Cards, and are used only if the starting points are to be input by the user, as specified on the Streamline Data Card.

A detailed description of the formats for each set of cards is presented in the following pages.

Surface Property Access Card (4I2)

Column	Code	Routine Format	Explanation
1-2	NDSET	STREAM I2	Data set number where surface properties will be found on unit 10.
3-4	IABSET	STREAM I2	α-β set number where surface properties will be found on unit 10.
5-6	IREGON(1)	STREAM I2	Flow region number where surface properties will be found on unit 10 if data were transferred from unit 4. = 1 If data were transferred from unit 4 to unit 10. = 0 If not.
7-8	IREGON(2)	STREAM I2	Flow region number where surface properties will be found on unit 10 if data were hand loaded. = 2 If data were hand load. = 0 If not. NOTE: The surface flow property information of the two regions taken collectively must uniquely define the surface properties of the entire vehicle.

Streamline Data Card (5I2, 10X, 2F10.0)

Column	Code	Routine Format	Explanation
1-2	NSTR	STREAM I2	Total number of streamlines to be traced if ISTART ≠ 2. If ISTART = 2, NSTR is the number of streamlines per aft Panel (KBNDRY = 2 or 3 on the Panel Description card pp. 20) to be traced. No maximum allowable value is established for this parameter.
3-4	IPRINT	STREAM	Print coordinates and corresponding flow properties of each streamline. = 0 Do not print. = 1 Print.

Streamline Data Card (Continued)

Column	Code	Routine Format	Explanation
5-6	ISTORE	STREAM I2	Save information along each streamline on units 50 and 51 (see Section IV-New Local Storage Units). = 0 Do not save. = 1 Save.
7-8	ISTART	STREAM I2	Streamline starting condition flag. = 0 Start streamline calculation at the centroid of the given Element number of the specified Panel number. (See Streamline Starting Point Cards, pp. 21). = 1 Start streamline calculations at the given X, Y, Z locations. (See Streamline Starting Point cards, pp. 21). = 2 Appropriate starting points will be distributed by the code.
9-10	MORSTR	STREAM I2	Additional streamlines flag. Used only if ISTART = 2. = 0 No additional streamlines. = 1 Locate appropriate additional starting points to ensure that a sufficient streamline distribution exists for viscous force computations and integration.
21-30	DIRECT	STREAM F10.0	Specifies the direction of the streamline integration. = 1 Integrate in the direction of the flow. = -1 Integrate against the flow direction. The streamlines will be traced until a true origin is reached. The running lengths of the streamlines will be re-ordered so that the maximum running lengths occur at the starting points and a zero running length corresponds to the true origins. If ISTART = 2, DIRECT is automatically set to -1.

Streamline Data Card (Continued)

Column	Code	Routine Format	Explanation
31-40	XNOSE	STREAM F10.0	The axial location, X, of the forward-most point on the vehicle.

Panel Description Cards (2I2)

The number of these cards must equal the total number of subregions (geometry Panels) in regions IREGON(1) and IREGON(2). The order in which these cards are read must correspond to the order in which the Panels were read by the geometry routines, e.g. the 3rd Panel Description Card must apply to Panel number 3.

Column	Code	Routine Format	Explanation
1-2	KSHAPE(I)	STREAM I2	Surface spline flag. = 0 The Ith Panel is not a body of revolution. = 1 The Ith Panel is best described in cylindrical coordinates. The spline will use the functional form $R = f(A,\phi)$. KSHAPE(I) should be set to 1 only if the circumferential angles of all cross-sections are 180°. If the Panel is a true body of revolution (360°), the Panel must be divided into two Panels.
3-4	KBNDRY(I)	STREAM I2	Panel boundary flag. = 0 The Ith Panel is an interior Panel. Adjacent Panels lie on all four sides (an adjacent Panel may include the plane of symmetry). = 1 The Ith Panel is a leading edge Panel. No Panels are adjacent to the forward most boundary of this Panel. = 2 The Ith Panel is a trailing edge Panel. No Panels are adjacent to the aft most boundary of this Panel.

Panel Description Cards (Continued)

Column	Code	Routine Format	Explanation
3-4	KBNDRY(I)	STREAM I2	= 3 The Ith Panel contains both leading and trailing edges.

Streamline Starting Point Cards (2I3, 4X, 3F10.0)

These cards are used only if ISTART = 0 or 1, see pp. 19. The number of these cards must equal NSTR, the number of streamlines to be traced.

1-3	LPANEL	STREAM I3	The Panel number on unit 4 for the start of the streamline. Used if ISTART = 0 or 1.
4-6	L	STREAM I3	Element number in Panel LPANEL for the start of the streamline. Used only if ISTART = 0.
11-20	XS	STREAM F10.0	X-coordinate of the streamline starting point. Used only if ISTART = 1.
21-30	YS	STREAM F10.0	Y-coordinate of the streamline starting point. Used only if ISTART = 1.
31-40	ZS	STREAM F10.0	Z-coordinate of the streamline starting point. Used only if ISTART = 1.

3. VISCOUS PROGRAM OPTION

The Viscous Program option, called from the AERO executive program as shown in Figure 1, is used for all viscous calculations. Two sub-options are available in the Viscous option for estimating the effects of the boundary layer. One sub-option is used when detailed boundary layer information is required at specific points on the body, and another is used to estimate the contribution of skin friction to total vehicle forces and moments. The following user-oriented descriptions of both sub-options are intended to completely replace the documentation given on pp. 114-128 in Reference 1, Volume I.

The first sub-option applies boundary layer methods along inviscid surface streamlines generated previously by the Surface Streamline option. Selection of this sub-option requires that the streamline data be available on unit 50 (see ISTORE on the Streamline Data Card described in the Surface Streamline option, pp. 19). Although Mark III Skin Friction methods (flat plate methods) may be used along the streamlines, the primary purpose of the current sub-option is to provide the user with a means for estimating detailed boundary layer properties along the streamlines. Integral boundary layer methods (References 4 & 5) are employed to provide such information as momentum thickness, displacement thickness, and velocity profiles as well as skin friction and heat transfer.

If the user requires the contribution of skin friction to total vehicle forces and moments, the second sub-option must be used. This sub-option is known as the Mark III Skin Friction method, and employs flat plate methods to each of the Elements in the geometry and therefore does not provide variable properties along the streamlines. Since running lengths to each of the Elements must be input, the user normally prepares a simplified geometry model. Prior to accessing the Mark III Skin Friction method it is necessary that inviscid surface property data, generated by the Inviscid Pressures option of the AERO program, be available.

Modifications to the Viscous Program option were necessary to ensure that the integral boundary layer methods, which must be applied along inviscid surface streamlines, are compatible with the new streamline method. Corrections were also made to the equations used in the integral methods as described in Section III - Theory. However, only minor changes were made to the overall input data procedure for the Viscous Program option. Although modifications were made to the initial data cards used by both sub-options, no changes were made to the format of the Mark III Skin Friction Element Data Cards.

Viscous Method Card (I2, 8X, 15A4)

Column	Code	Routine Format	Explanation
1-2	ISFMTH	VISCUS I2	Viscous method flag. = 0 Apply viscous methods along inviscid surface streamlines. Wall temperature, if it is not input, will be calculated by the Mark III skin friction methods. The Boundary Layer Method Control Card, pp. 24, will be expected next. The Mark III Skin Friction cards will not be input. = 1 Calculate skin friction coefficients using the Mark III program methods. The Mark III Skin Friction Coefficients Basic Flag Card, pp. 30, will be expected next.
11-70	TITLE	VISCUS 15A4	Title to be printed on the skin friction output pages.

INPUT DATA FOR VISCOUS CALCULATIONS ALONG STREAMLINES

Viscous calculations along streamlines may be made only when ISFMTH = 0 on the Viscous Method Card. If ISFMTH = 1, skip to the Mark III Skin Friction Coefficient Basic Flap Card, pp. 30. One of two methods may be selected for computing viscous effects along the surface streamlines. The more commonly used option employs integral boundary layer methods which are applicable to arbitrary pressure gradients. The second option consists of the same methods used by the Mark III Skin Friction program. Such methods are strictly applicable only to zero pressure gradient flows.

Boundary Layer Method Control Card (I2, 2I1, I2, I1, 3X, 4F10.0)

Column	Code	Routine Format	Explanation
1-2	ISTRML	INTEG I2	Streamline number for this set of viscous calculations. N Boundary Layer Method Control cards for N streamlines. No maximum value is assigned to this parameter.
3	LASTSL	INTEG I1	Last streamline flag. = 0 This is not the last Boundary Layer Method Control Card. If ISFM = 0, another Boundary Layer Method Control Card is expected after the Integral Method Flag Card, pp. 27-29. If ISFM = 1, another Boundary Layer Method Control Card will be expected next. = 1 This is the last Boundary Layer Method Control Card. The program will return to the AERO routine after viscous calculations are made along this streamline.
4	ISFM	INTEG I1	Boundary Layer Method Card for this streamline. = 0 Use integral boundary layer method. = 1 Use one of the Mark III Skin Friction methods. Method will be selected by using the IWT flag below.

Boundary Layer Method Control Card (Continued)

Column	Code	Routine Format	Explanation
5-6	IWT	INTEG I2	Wall temperature method flag. This flag controls the selection of the method to be used in calculating the wall temperature in routine TEMP. This flag is used for both ISFM = 0 and = 1. When ISFM = 1 it also controls the skin friction coefficient calculation procedure selection. In the discussions below the methods to be used for laminar and turbulent flow are separated by a slash (i.e., Laminar/Turbulent).
			= 0 Use Reference Temperature/Spalding-Chi methods to calculate temperature.
			= 1 Use adiabatic wall temperature and Reference Temperature/Spalding-Chi methods.
			= 2 Use input wall temperature and Reference Temperature/Spalding Chi methods. Wall temperature is input in CC 11-20 and CC 21-30.
			= 3 Use Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods.
			= 4 Use adiabatic wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods.
			= 5 Use input wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods. Wall temperature is input in CC 11-20 and CC 21-30.
			= 6 Use Reference Temperature/Reference Temperature methods.
			= 7 Use input wall temperature and Reference Temperature/Reference Temperature methods. Wall temperature is input in in CC 11-20 and CC 21-30.
			= 8 Use Reference Enthalpy/Reference Enthalpy methods.

Boundary Layer Method Control Card (Continued)

Column	Code	Routine Format	Explanation
5-6	IWT	(Continued)	= 9 Use input wall temperature and Reference Enthalpy/Reference Enthalpy methods. Wall temperature is input in CC 11-20 and CC 21-30.
7	IPRINT	INTEG I1	Iteration and local skin friction print flag for use in routine TEMP. = 0 Do not print. = 1 Print iteration results for wall temperature and the final local skin-friction data in routine TEMP. = 2 Print the final local skin-friction data from routine TEMP but do not print the iteration results. This is the recommended option for most applications.
11-20	SURFI6	INTEG F10.0	Input wall temperature for laminar calculations, °R. This input is used when IWT = 2, 5, 7, or 9.
21-30	SURFI7	INTEG F10.0	Input wall temperature for turbulent calculations, °R. This input is used when IWT = 2, 5, 7, or 9.
31-40	RETRAN*	INTEG F10.0	Transition Reynolds number X 10^{-6}. Turbulent boundary layer calculations begin when the local edge Reynolds number attains this value. If ISFM = 0 and RETRAN = 0, the initial displacement thickness (DTURB) and the initial momentum thickness (TTURB), specified on the Integral Method Flag Card below, must both be non-zero.
41-50	STRAN*	INTEG	Transition running length, ft. Turbulent boundary layer calculations begin when the running length along the streamline attains this value. If ISFM = 0 and STRAN = 0., the initial displacement thickness (DTURB) and the initial momentum thickness (TTURB), specified on the Integral Method Flag Card below, must both be non-zero.

*Transition occurs when either RETRAN or STRAN is exceeded.

Integral Method Flag Card (11I2, 8X, 5F10.0)

This card is input only when ISFM = 0.

Column	Code	Routine Format	Explanation
1-2	NVP	INTEG I2	Number of points desired in the velocity profile at each station. (Usually input = 20). No maximum value is assigned to this parameter.
3-4	KSMTH	INTEG I2	Number of times distribution of surface velocity is to be smoothed prior to computation of surface gradients (=0,1,2,3, etc.). No maximum value is assigned to this parameter.
5-6	KSPLN	INTEG I2	Integer indicating manner in which surface gradients are to be calculated. = 0 Weighted-difference technique (preferred). = 1 Spline curve-fit technique.
7-8	KLE	INTEG I2	Flag indicating the type of initial condition existing at the first streamline point. = 0 Stagnation point or initial values given. = 1 Sharp leading edge.
9-10	KATCH	INTEG I2	Flag indicating whether laminar boundary layer separation (if encountered) should reattach as a turbulent boundary layer. = 0 Stop calculations if separation encountered. = 1 Reattach. The input variable CTHET (below) must be non-zero.
11-12	KPRE	INTEG I2	Preliminary calculation print flag. = 0 Output suppressed. = 1 Output printed.
13-14	KGRAD	INTEG I2	Print flag for surface velocity and Mach number gradients. = 0 Output suppressed. = 1 Output printed.

Integral Method Flag Card (Continued)

Column	Code	Routine Format	Explanation
15-16	KSDE	INTEG I2	Flag for printing direct results of the integration of the laminar and turbulent boundary layer equations. (Usually input = 0). = 0 Output suppressed. = 1 Output printed.
17-18	KLAM	INTEG I2	Flag for printing results of laminar instability and transition calculations. = 0 Output suppressed. = 1 Output printed.
19-20	KMAIN	INTEG I2	Flag for printing principal boundary layer information (C_f, Nu, δ^*, θ, etc.). Usually input = 1. = 0 Output suppressed. = 1 Output printed.
21-22	KPROF	INTEG I2	Flag for printing velocity profiles. = 0 Output suppressed. = 1 Output printed.
31-40	CTHET	INTEG F10.0	Ratio of momentum thickness after reattachment to momentum thickness at laminar separation. This parameter used when KATCH = 1 if separation occurs.
41-50	DLAM	INTEG F10.0	Initial displacement thickness (ft.), if any, of the laminar boundary layer. If DLAM is zero, initial laminar displacement thickness will be calculated by the program according to the value of the KLE flag specified above.
51-60	TLAM	INTEG F10.0	Initial momentum thickness (ft.), if any, of the laminar boundary layer. If TLAM is zero, initial laminar momentum thickness will be calculated by the program according to the value of the KLE flag specified above.

Integral Method Flag Card (Continued)

Column	Code	Routine Format	Explanation
61-70	DTURB	INTEG F10.0	Initial displacement thickness (ft.), if any, of the turbulent boundary layer. If the boundary layer is turbulent at the first streamline point (RETRAN = 0. or STRAN = 0.), DTURB must be non-zero. If transition occurs downstream of the first streamline point, DTURB may be set to zero and the laminar value at the transition point is used.
71-80	TTURB	INTEG F10.0	Initial momentum thickness (ft.) if any, of the turbulent boundary layer. If the boundary layer is turbulent at the first streamline point, TTURB must be non-zero. If transition occurs downstream of the first streamline point, TTURB may be set to zero and the laminar value at the transition point is used.

NOTE: If LASTSL = 0, another Boundary Layer Method Control Card will be expected after the above card. If LASTSL = 1, the program will return to AERO.

MARK III SKIN FRICTION METHOD

Mark III Skin Friction Basic Flag Card (I2, 2I1)

Column	Code	Routine Format	Explanation
1-2	NCOMP	VISCUS I2	Total number of vehicle Components to be analyzed. Each Component may consist of one or more vehicle panels. The grouping of Panels to form Components is controlled by the Geometry Data Source Card below.
3	IFSAVE	VISCUS I1	Force data save flag. = 0 Set up a new force data save file (unit 9). Save skin friction force data for future summation. = 1 Save skin friction force data on unit 9 for future summation. Use old unit 9 file and just add the new force data onto the file. = 2 Do not place the force data on the force data file unit.
4	IPRINT	VISCUS I1	Skin friction print flag. = 0 Do not print. = 1 Print detailed skin friction intermediate results.

Geometry Data Source Card (20I2, 1X, I3)

Column	Code	Routine Format	Explanation
1-2 etc. 39-40	IPANL(1) IPANL(20)	VISCUS 20I2	The identification numbers for all of the Panels on the Quadrilateral Element Storage unit (4) that are to be grouped to form this vehicle component.
41-44	NS	VISCUS I3	Number of skin friction elements to be analyzed. This number must be equal to the number of elements on the Quadrilateral Element save unit (4) for this vehicle Component and must not be greater than 100. The number of Skin Friction Element Data Cards must be = NS. This input is used for the Mark III skin friction option only.

Mark III Skin Friction Element Data Cards
(I2, 8I1, 2F9.0, 3F6.0, 2F6.0, F4.0, 8X, I2)

One Skin Friction Element Data Card must be loaded for each element stored on the Quadrilateral Element Storage unit (4) for each vehicle Component. The format of these cards is exactly the same as the Type 11 cards used on the Mark III program (Mode 1 skin friction method). However, some of the parameters on the old Type 11 card are not actually used by this new version of the program.

Column	Code	Routine Format	Explanation
1-2	IS(I,1)	SKINFR I2	Skin friction element number.
3	IS(I,2)	M3SF I1	Viscous-Inviscid interaction effect flag. = 0 Use tangent-wedge in interaction correction. = 1 Use tangent-cone in interaction correction.
4	IS(I,3)	SKINFR I1	Calculate induced pressures due to boundary layer displacement effects. Skin friction is not calculated. = 0 No = 1 Yes
5	IS(I,4)	SKINFR I1	Skin-friction summation flag. = 0 Use turbulent skin friction data in calculating forces. (Note: The program will make a switch to laminar summation at very low Reynolds number, where turbulent results are not meaningful). = 1 Use laminar skin friction data in calculating forces.
6	IS(I,5)	SKINFR I1	(Not used in this program).

Mark III Skin Friction Element Data Cards (Continued)

Column	Code	Routine Format	Explanation
7	IS(I,6)	SKINFR I1	Wall-temperature and skin-friction method Flag. The program always calculates both laminar and turbulent skin-friction results. The result to be added to the pressure calculations is indicated by the flag in CC 5. In the discussions below the methods to be used for laminar and turbulent flow are separated by a slash (i.e., Laminar/Turbulent). (Integer) = 0 Calculate wall temperature and skin friction using Reference Temperature/Spalding-Chi methods. = 1 Use adiabatic wall temperature and Reference Temperature/Spalding-Chi methods. = 2 Use input wall temperature and Reference Temperature/Spalding-Chi methods. T_w input in CC 47-52 and 53-58. = 3 Calculate wall temperature and skin friction using Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods. = 4 Use adiabatic wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods. = 5 Use input wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods. T_w input in CC 47-52 and 53-58. = 6 Calculate wall temperature and skin friction using Reference Temperature/Reference Temperature methods. = 7 Use input wall temperature and Reference Temperature/Reference Temperature methods. T_w input in CC 47-52 and 53-58.

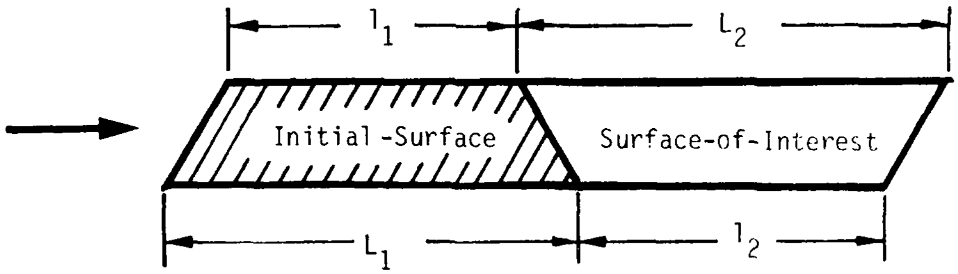
Mark III Skin Friction Element Data Cards (Continued)

Column	Code	Routine Format	Element
7	IS(I,6)	(Continued)	= 8 Calculate wall temperature and skin friction using Reference Enthalpy/Reference Enthalpy methods.
			= 9 Use input wall temperature and Reference Enthalpy/Reference Enthalpy methods. T_w input in CC 47-52 and 53-58.
8	IS(I,7)	SKINFR I1	Flag to control printing of skin-friction data for each skin-friction surface element.
			= 0 Do not print.
			= 1 Print skin-friction data. This is recommended option for most applications.
9	IS(I,8)	SKINFR I1	Print flag for flow characteristics before and after the shock or expansion.
			= 0 Do not print.
			= 1 Print flow characteristics.
10	IS(I,9)	SKINFR I1	Iteration and local skin friction print flag.
			= 0 Do not print.
			= 1 Print iteration results for wall temperature and the final local skin-friction data.
			= 2 Print the final local skin-friction data but not the iteration results. This is the recommended option for most applications.
11-19	SURF(I,1)	SKINFR F9.0	Skin friction element surface wetted area in same units as S_{ref}. If input as 0.0 then the program will use the surface area as calculated from the input geometry unit for each element. The input wetted area must correspond to the input skin-friction geometry

Mark III Skin Friction Element Data Cards (Continued)

Column	Code	Routine Format	Explanation
11-19	SURF(I,1)(Continued)		(i.e., if the Symmetry flag is 0, left side of the vehicle input, then the input wetted area should be only for the left side).

The four input quantities in CC 20 through 46 furnish to the program the planform shape of the skin-friction surface being analyzed ("Surface-of-Interest"), and the shape of the initial-surface (to account for the fact that the flow has traversed some other part of the shape before reaching the surface of interest). This information is not obtained from the input skin-friction geometry data input on the Type 3 cards. The input skin-friction geometry data are used only to establish the position and orientation of the centroid and the area of each skin-friction surface. The diagram below illustrates the input parameters required on the Skin Friction Element Data Cards.



20-28	SURF(I,2)	SKINFR F9.0	The longest length of the surface-of-interest (L_2 in the diagram above). Feet
29-34	SURF(I,3)	SKINFR F6.0	The longest length of the initial-surface (L_1 in the diagram above). Feet.

Mark III Skin Friction Element Data Cards (Continued)

Column	Code	Routine Format	Explanation
35-40	SURF(I,4)	SKINFR F6.0	The taper ratio of the initial-surface (ℓ_1/L_1). This taper ratio is defined as the ratio of the shortest chord length to the longest chord length. If both the initial-surface longest-length and the longest length of the surface-of-interest are on the same edge of the shape, then the taper ratio of the initial-surface is input as a positive number. If these lengths are on opposite sides of the shape such as in the diagram on the previous page then the initial surface taper ratio is input as a negative number. With these ground rules the absolute value of the taper ratio will never be greater than 1.0.
41-46	SURF(I,5)	SKINFR F6.0	The taper ratio of the surface-of-interest (ℓ_2/L_2). This taper ratio is defined as the ratio of the shortest chord length. This taper ratio is always positive and never greater than 1.0.
47-52	SURF(I,6)	SKINFR F6.0	Input wall temperature for laminar calculations, °R. This input is used when CC 7 = 2, 5, 7, or 9.
53-58	SURF(I,7)	SKINFR F6.0	Input wall temperature for turbulent calculations, °R. This input is used when CC 7 = 2, 5, 7, or 9.
59-62	SURF(I,8)	SKINFR F4.0	(Not used in present program)
71-72	TYPE	SKINFR I2	Card Type number. Not used in present program.

4. SAMPLE CASES

The following three sample cases are provided to guide the user in preparing input data for the Streamline Option and the Viscous Option. Both input and output data are included for an ogive-cylinder, a blunted bicone, and the forebody of the X-24C. The entire input data deck is provided for each case, but the output includes only the results of the streamline and viscous calculations. Comments are provided where necessary.

CASE 1: OGIVE-CYLINDER GEOMETRY

This case generates streamlines using the program-specified starting point option (ISTART = 2). Three starting points are distributed automatically by the program along the aft-most panels of the geometry (the cylinder in this case), and the streamlines are integrated forward toward the nose. The "additional" streamline option is also used (MØRSTR = 1) which ensures that the streamlines are sufficiently distributed over all surfaces of the geometry. It should be noted that integral boundary layer calculations cannot be made if ISTART = 2 since the starting solution logic is not built into the program.

In the following output, streamline numbers 1 through 3 comprise the initial streamline distribution. Streamline numbers 4 through 10 were calculated by the "additional" streamline option.

CASE 1: INPUT

```
SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

12                                                                  01
 80000003 SPHERICALLY BLUNTED OGIVE CYLINDER
   1002          00                  PANEL NO.1 ID CARD
SPHERE                               ELLIPSE GENERATION             10      1     104
0.          0.     180.    90.          0.         0.      0.       0       1     105
-.02        0.     180.    9.06         .06        0.      0.       0       1     105
-.06        0.     180.    9.03         .06        0.      0.       0       1     105
-.0639      0.     180.    9.09326      .09326     0.      0.       4       1     105
   2002          00                  PANEL NO.2 ID CARD
OGIVE                                ELLIPSE GENERATION             10      1     204
-.0639      0.     180.    9.09326      .09326     0.      0.       0       1     205
-1.         0.     180.    9.44657      .44657     0.      0.       0       1     205
-2.         0.     180.    9.80525      .80525     0.      0.       0       1     205
-4.         0.     180.    91.4652      1.4652     0.      0.       0       1     205
-6.         0.     180.    92.0505      2.0505     0.      0.       0       1     205
-8.         0.     180.    92.5636      2.5636     0.      0.       0       1     205
-10.        0.     180.    93.0061      3.0061     0.      0.       0       1     205
-12.        0.     180.    93.3797      3.3797     0.      0.       0       1     205
-14.        0.     180.    93.6836      3.6836     0.      0.       0       1     205
-16.        0.     180.    93.9242      3.9242     0.      0.       0       1     205
-18.        0.     180.    94.0962      4.0962     0.      0.       0       1     205
-20.        0.     180.    94.2862      4.2862     0.      0.       0       1     205
-22.325     0.     180.    94.25        4.25       0.      0.       4       1     205
   3102          00                  PANEL NO.3 ID CARD
CYLINDER                             ELLIPSE GENERATION             10      1     304
-22.325     0.     180.    94.25        4.25       0.      0.       0       1     305
-35.        0.     180.    94.25        4.25       0.      0.       0       1     305
-47.5       0.     180.    94.25        4.25       0.      0.       4       1     305
 SPHERICALLY BLUNTED OGIVE CYLINDER
316                                  AERO PROGRAM INPUT
5.95        -2000.      24.0[illegible]   1[illegible].75   0.1
1.          1.          1.          0.         0.          1.
12.0        0.0         0.0         0.         0.0         0.0         0.0
 12                                  [illegible] COEFFICIENTS
 1 2 3                  000          COMPONENT ORG. CARD
 1 1001     1.80        1.0          1.0        1.0         0.0         0.0
0                                    [illegible]
10 1 5.95                            DATA [illegible]
10 1 12.  0.0                        [illegible]
10 1200                                [illegible]
 3 0 0                                                 SURFACE DATA TRANSFER
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    1    2    3                                   PANEL SELECTION
 1 1 1                                            LOCATE SURF. DATA ON UNIT 10
3 1 1 2 1           -1.       0.                  STREAMLINE FLAGS
 1 1                                              PANEL SHAPE INFO
 1 0                                              PANEL SHAPE INFO
 1 2                                              PANEL SHAPE INFO
```

CASE 1: OUTPUT

STREAMLINE NO. 1

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1975E-01	[illegible]	-.5125E-01	.8296E+00	.4034E+02	.7103E+01	1
.2509E-02	-.2161E-01	[illegible]	-.5553E-01	.5690E+00	.3938E+02	.7020E+01	1
.1349E-01	-.2744E-01	[illegible]	-.6434E-01	.1065E+01	.3468E+02	.6587E+01	1
.2401E-01	-.3457E-01	.4771E-06	-.7552E-01	.1313E+01	.2990E+02	.5997E+01	1
.3453E-01	-.4315E-01	.4770E-06	-.7997E-01	.1649E+01	.2525E+02	.5235E+01	1
.4505E-01	-.5207E-01	.3658E-06	-.6550E-01	.2062E+01	.2045E+02	.4368E+01	1
.1045E+01	-.9881E+00	.9156E-06	-.4359E+00	.2707E+01	.1383E+02	.3277E+01	2
.1220E+01	-.1153E+01	[illegible]	-.4914E+00	.2721E+01	.1372E+02	.3257E+01	2
.3500E+01	-.3311E+01	[illegible]	-.1205E+01	.2906E+01	.1225E+02	.3004E+01	2
.5706E+01	-.5423E+01	[illegible]	-.1635E+01	.3098E+01	.1086E+02	.2768E+01	2
.8003E+01	-.7645E+01	.1277E+00	-.2415E+01	.3306E+01	.9489E+01	.2536E+01	2
.1028E+02	-.9865E+01	.1937E+00	-.2987E+01	.3522E+01	.8215E+01	.2321E+01	2
.1254E+02	-.1229E+02	.2652E+00	-.3315E+01	.3747E+01	.7040E+01	.2122E+01	2
.1479E+02	-.1431E+02	.3415E+00	-.3639E+01	.3981E+01	.5962E+01	.1938E+01	2
.1703E+02	-.1654E+02	.4165E+00	-.3881E+01	.4232E+01	.4981E+01	.1770E+01	2
.1926E+02	-.1876E+02	.4755E+00	-.4043E+01	.4471E+01	.4102E+01	.1617E+01	2
.2149E+02	-.2099E+02	.5496E+00	-.4119E+01	.4724E+01	.3325E+01	.1479E+01	2
.2503E+02	-.2453E+02	.6517E+00	-.4130E+01	.4894E+01	.2872E+01	.1396E+01	3
.2754E+02	-.2704E+02	.7704E+00	-.4114E+01	.4895E+01	.2861E+01	.1395E+01	3
.3005E+02	-.2955E+02	[illegible]	-.4094E+01	.4900E+01	.2827E+01	.1390E+01	3
.3256E+02	-.3205E+02	[illegible]	-.4064E+01	.4930E+01	.2759E+01	.1379E+01	3
.3507E+02	-.3455E+02	.1154E+01	-.4023E+01	.4902E+01	.2685E+01	.1364E+01	3
.3757E+02	-.3705E+02	[illegible]	-.3970E+01	.4965E+01	.2638E+01	.1355E+01	3
.4006E+02	-.3954E+02	[illegible]	-.3905E+01	.4969E+01	.2622E+01	.1352E+01	3
.4256E+02	-.4202E+02	[illegible]	-.3828E+01	.5004E+01	.2593E+01	.1345E+01	3
.4505E+02	-.4451E+02	.1803E+01	-.3739E+01	.5055E+01	.2498E+01	.1322E+01	3
.4755E+02	-.4700E+02	[illegible]	-.3644E+01	.5099E+01	.2433E+01	.1304E+01	3
.4875E+02	-.4750E+02	[illegible]	-.3625E+01	.5105E+01	.2425E+01	.1301E+01	3

S	streamline arc length
(X,Y,Z)	Cartesian coordinates of streamline
M	local Mach number
P/PINF	local pressure/P_∞
T/TINF	local temperature/T_∞
PANEL	Panel number associated with a streamline point

STREAMLINE NO. 2

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1975E-01	.5652E-06	-.5124E-01	.9295E+00	.4934E+02	.7103E+01	1
.1138E-01	-.2690E-01	.5694E-05	-.6223E-01	.1623E+01	.3564E+02	.6682E+01	1
.2191E-01	-.3330E-01	.5454E-06	-.7194E-01	.1261E+01	.3884E+02	.6131E+01	1
.3243E-01	-.4144E-01	.5471E-06	-.7632E-01	.1576E+01	.2618E+02	.5398E+01	1
.4295E-01	-.5024E-01	.5494E-06	-.8434E-01	.1972E+01	.2144E+02	.4546E+01	1
.1337E+01	-.1263E+01	.5591E-01	-.5287E+00	.2751E+01	.1349E+02	.3214E+01	2
.3638E+01	-.3434E+01	.1642E+00	-.1243E+01	.2954E+01	.1191E+02	.2944E+01	2
.5918E+01	-.5625E+01	.5544E+00	-.1675E+01	.3169E+01	.1038E+02	.2686E+01	2
.8198E+01	-.7922E+01	.5578E+00	-.2400E+01	.3369E+01	.8975E+01	.2451E+01	2
.1045E+02	-.1002E+02	.6312E+00	-.2641E+01	.3620E+01	.7677E+01	.2232E+01	2
.1269E+02	-.1222E+02	.1096E+01	-.3177E+01	.3861E+01	.6484E+01	.2029E+01	2
.1492E+02	-.1442E+02	.1745E+01	-.3417E+01	.4114E+01	.5395E+01	.1843E+01	2
.1714E+02	-.1652E+02	.1773E+01	-.3562E+01	.4377E+01	.4411E+01	.1673E+01	2
.1935E+02	-.1871E+02	.1891E+01	-.3615E+01	.4649E+01	.3536E+01	.1518E+01	2
.2155E+02	-.2106E+02	[illegible]126E+01	-.3572E+01	.4929E+01	.2773E+01	.1379E+01	2
.2389E+02	.2313E+02	[illegible]41E+01	-.3469E+01	.5149E+01	.2324E+01	.1282E+01	3
.2639E+02	-.2580E+02	[illegible]47E+01	-.3321E+01	.5184E+01	.2221E+01	.1266E+01	3
.2884E+02	-.2825E+02	.2737E+01	-.3123E+01	.5237E+01	.2080E+01	.1246E+01	3
.3129E+02	-.3067E+02	.3046E+01	-.2869E+01	.5346E+01	.1874E+01	.1203E+01	3
.3371E+02	-.3306E+02	.3311E+01	-.2561E+01	.5458E+01	.1692E+01	.1161E+01	3
.3613E+02	-.3543E+02	.3560E+01	-.2201E+01	.5555E+01	.1534E+01	.1127E+01	3
.3853E+02	-.3779E+02	.3731E+01	-.1795E+01	.5658E+01	.1367E+01	.1092E+01	3
.4092E+02	-.4013E+02	.3962E+01	-.1350E+01	.5774E+01	.1197E+01	.1054E+01	3
.4331E+02	-.4240E+02	.4090E+01	-.8899E+00	.5822E+01	.1155E+01	.1039E+01	3
.4572E+02	-.4464E+02	.4162E+01	-.4446E+00	.5765E+01	.1231E+01	.1050E+01	3
.4815E+02	-.4724E+02	.4185E+01	-.4073E-01	.5755E+01	.1320E+01	.1066E+01	3
.6841E+02	-.4756E+02	.4205E+01	-.5230E-13	.5730E+01	.1329E+01	.1068E+01	3

STREAMLINE NO. 3

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1947E-01	.1945E-02	-.5075E-01	.6294E+00	.4843E+02	.7103E+01	1
.9371E-02	-.2543E-01	.3426E-02	-.5469E-01	.9655E+00	.3658E+02	.6766E+01	1
.1989E-01	-.3145E-01	.4760E-02	-.7604E-01	.1226E+01	.3171E+02	.6255E+01	1
.3042E-01	-.3944E-01	.5775E-02	-.7741E-01	.1565E+01	.2702E+02	.5553E+01	1
.4096E-01	-.4811E-01	.5932E-02	-.6288E-01	.1868E+01	.2234E+02	.4718E+01	1
.1374E+00	-.1377E+00	.1221E-01	-.1384E+00	.2667E+01	.1418E+02	.3336E+01	2
.9768E+00	-.9337E+00	[illegible]	-.5980E+00	.2774E+01	.1335E+02	.3183E+01	2
.2828E+01	-.2666E+01	[illegible]	-.9256E+00	.2990E+01	.1164E+02	.2899E+01	2
.4801E+01	-.4536E+01	[illegible]	-.1527E+01	.3249E+01	.9850E+01	.2596E+01	2
.6838E+01	-.6477E+01	[illegible]	-.1575E+01	.3555E+01	.8826E+01	.2290E+01	2
.8913E+01	-.8465E+01	.2023E+01	-.1665E+01	.3896E+01	.6332E+01	.2003E+01	2
.1101E+02	-.1049E+02	.2340E+01	-.1687E+01	.4262E+01	.4826E+01	.1744E+01	2
.1313E+02	-.1253E+02	.3775E+01	-.1424E+01	.4645E+01	.3549E+01	.1526E+01	2
.1525E+02	-.1459E+02	.3519E+01	-.1138E+01	.5034E+01	.2519E+01	.1332E+01	2
.1738E+02	-.1667E+02	.3744E+01	-.7755E+00	.5413E+01	.1747E+01	.1176E+01	2
.1952E+02	-.1875E+02	.4050E+01	-.3014E+00	.5742E+01	.1245E+01	.1064E+01	2
.2166E+02	-.2084E+02	.4355E+01	.2069E-01	.5932E+01	.1021E+01	.1005E+01	2
.2383E+02	-.2257E+02	.4156E+01	.4925E+00	.5788E+01	.1242E+01	.1058E+01	3
.2625E+02	-.2536E+02	[illegible]	.9936E+00	.5865E+01	.1096E+01	.1019E+01	3
.2866E+02	-.2773E+02	.3970E+01	.1325E+01	.5940E+01	.1017E+01	.1003E+01	3
.3106E+02	-.3002E+02	.3796E+01	.1753E+01	.5971E+01	.9681E+00	.9940E+00	3
.3347E+02	-.3244E+02	.3562E+01	.2165E+01	.5994E+01	.9321E+00	.9871E+00	3
.3588E+02	-.3482E+02	.3335E+01	.2529E+01	.6000E+01	.9245E+00	.9855E+00	3
.3831E+02	-.3721E+02	.3071E+01	.2643E+01	.5966E+01	.9430E+00	.9868E+00	3
.4075E+02	-.3962E+02	.2594E+01	.3107E+01	.5965E+01	.9774E+00	.9955E+00	3
.4321E+02	-.4206E+02	.2547E+01	.3321E+01	.5944E+01	.1009E+01	.1002E+01	3
.4569E+02	-.4452E+02	.2219E+01	.3484E+01	.5928E+01	.1033E+01	.1006E+01	3
.4817E+02	-.4702E+02	.2124E+01	.3605E+01	.5914E+01	.1055E+01	.1011E+01	3
.4868E+02	-.4750E+02	[illegible]	.3625E+01	.5910E+01	.1059E+01	.1012E+01	3

STREAMLINE NO. 4

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1045E-01	[illegible]	-.5070E-01	.9201E+00	.4057E+02	.7122E+01	1
.6109E-02	[illegible]	[illegible]	-.5536E-01	.9193E+00	.3816E+02	.6912E+01	1
.1677E-01	-.2970E-01	[illegible]	-.6702E-01	.1124E+01	.3338E+02	.6450E+01	1
.2729E-01	[illegible]	[illegible]	-.7542E-01	.1398E+01	.2864E+02	.5809E+01	1
.3782E-01	-.4536E-01	[illegible]	[illegible]	.1749E+01	.2399E+02	.5012E+01	1
.4834E-01	-.5443E-01	[illegible]	[illegible]	.2186E+01	.1911E+02	.4132E+01	1
.1811E+01	[illegible]	[illegible]	[illegible]	.2817E+01	.1296E+02	.3124E+01	2
.4034E+01	-.3817E+01	[illegible]	-.1537E+01	.3025E+01	.1136E+02	.2855E+01	2
.6267E+01	-.5955E+01	[illegible]	-.1692E+01	.3252E+01	.9829E+01	.2594E+01	2
.8492E+01	[illegible]	.1024E+01	-.2328E+01	.3469E+01	.8394E+01	.2353E+01	2
.1071E+02	-.1026E+02	.1422E+01	-.2647E+01	.3744E+01	.7050E+01	.2125E+01	2
.1291E+02	-.1242E+02	[illegible]	[illegible]	.4017E+01	.5800E+01	.1912E+01	2
.1511E+02	-.1457E+02	[illegible]	-.2947E+01	.4309E+01	.4654E+01	.1714E+01	2
.1730E+02	-.1673E+02	[illegible]	[illegible]	.4619E+01	.3629E+01	.1534E+01	2
.1948E+02	[illegible]	.2947E+01	-.2825E+01	.4940E+01	.2744E+01	.1374E+01	2
.2165E+02	[illegible]	.3232E+01	-.2617E+01	.5266E+01	.2019E+01	.1234E+01	2
.2411E+02	[illegible]	[illegible]	-.2341E+01	.5422E+01	.1809E+01	.1175E+01	3
.2655E+02	[illegible]	[illegible]	-.2030E+01	.5541E+01	.1576E+01	.1132E+01	3
.2897E+02	-.2825E+02	[illegible]	-.1646E+01	.5695E+01	.1310E+01	.1079E+01	3
.3136E+02	[illegible]	[illegible]	-.1198E+01	.5796E+01	.1165E+01	.1046E+01	3
.3374E+02	[illegible]	[illegible]	-.7076E+00	.5856E+01	.1090E+01	.1026E+01	3
.3611E+02	-.3523E+02	[illegible]	[illegible]	.5910E+01	.1018E+01	.1012E+01	3
.3848E+02	[illegible]	[illegible]	[illegible]	.5961E+01	.9608E+00	.9967E+00	3
.4086E+02	[illegible]	[illegible]	[illegible]	.5977E+01	.9596E+00	.9922E+00	3
.4325E+02	-.4221E+02	[illegible]	.1297E+01	.5940E+01	.1017E+01	.1003E+01	3
.4567E+02	-.4459E+02	[illegible]	.1702E+01	.5903E+01	.1073E+01	.1014E+01	3
.4311E+02	-.4700E+02	[illegible]	.2034E+01	.5863E+01	.1133E+01	.1026E+01	3
.4861E+02	-.4750E+02	[illegible]	[illegible]	.5855E+01	.1146E+01	.1029E+01	3

etc.

STREAMLINE NO. 10

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1713E-01	.2355E-01	-.4024E-01	.8299E+00	.4091E+02	.7102E+01	1
.1424E-02	[illegible]	.2476E-01	-.4077E-01	.8540E+00	.4038E+02	.7052E+01	1
.1387E-01	[illegible]	.3560E-01	-.4561E-01	.1096E+01	.3699E+02	.6515E+01	1
.2444E-01	[illegible]	.4467E-01	-.5268E-01	.1359E+01	.2966E+02	.5901E+01	1
.3494E-01	[illegible]	.5142E-01	-.5744E-01	.1693E+01	.2446E+02	.5137E+01	1
.4549E-01	[illegible]	[illegible]	-.6022E-01	.2079E+01	.1992E+02	.4334E+01	1
.5601E-01	-.5547E-01	.6172E-01	-.6256E-01	.2557E+01	.1533E+02	.3502E+01	1
.2402E+00	-.2244E+00	.1378E+00	-.6077E-01	.3250E+01	.9837E+01	.2596E+01	2
.4328E+00	-.3949E+00	.2194E+00	-.6980E-01	.3501E+01	.8331E+01	.2341E+01	2
[illegible]	-.7714E+00	.3534E+00	[illegible]	.3942E+01	.6122E+01	.1967E+01	2
.1494E+01	[illegible]	.5437E+00	.1735E+00	.4431E+01	.4229E+01	.1640E+01	2
.2594E+01	[illegible]	.7617E+00	.5167E+00	.4967E+01	.2826E+01	.1389E+01	2
.4255E+01	[illegible]	.9672E+00	.1042E+01	.5323E+01	.1907E+01	.1212E+01	2
.6294E+01	[illegible]	[illegible]	.1647E+01	.5649E+01	.1366E+01	.1094E+01	2
.8478E+01	[illegible]	.1176E+01	.2226E+01	.5864E+01	.1094E+01	.1026E+01	2
.1070E+02	[illegible]	.1200E+01	.2736E+01	.5948E+01	.1005E+01	.1001E+01	2
.1294E+02	[illegible]	.1156E+01	.3167E+01	.5948E+01	.1006E+01	.1001E+01	2
.1517E+02	[illegible]	.1147E+01	.3515E+01	.5946E+01	.1008E+01	.1001E+01	2
.1740E+02	[illegible]	[illegible]	.3780E+01	.5947E+01	.1007E+01	.1001E+01	2
.1962E+02	[illegible]	[illegible]	[illegible]	.5946E+01	.1009E+01	.1001E+01	2
.2185E+02	[illegible]	[illegible]	.4061E+01	.5947E+01	.1007E+01	.1001E+01	2
.2296E+02	[illegible]	[illegible]	.4129E+01	.5984E+01	.9240E+00	.9899E+00	2

*** AERODYNAMIC ANALYSIS IS COMPLETE

CASE 2: SPHERICALLY BLUNTED BICONE

The user-specified starting point option (ISTART = 1) is used to generate seven streamlines on a $10.5^o/7^o$ bicone at 10^o angle of attack. A TEKPIC plot of the streamlines is shown in Figure 4 , which follows the last output page for this case. Two integral boundary layer calculations are made along each streamline. In the first calculation the boundary layer is specified to be fully turbulent, and in the second calculation the boundary layer transitions from laminar to turbulent flow at S = 1.0 ft. The viscous solutions are presented herein along only one representative streamline (No. 4) because of the large quantity of output data generated. Solutions along other streamlines are identical in format.

The viscous methods assume that all lengths are in feet. The transition point is controlled by the STRAN parameter, and RETRAN is set to an arbitrary large number. Note that if the boundary layer is fully turbulent the initial displacement thickness, δ^*, and momentum thickness, θ, must be specified.

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
 0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

12
08        3                     SPHERICALLY BLUNTED BICONE
NOSE  2
SPHERE                          ELLIPSE GENERATION            11      NOSE04
0.0       0.0       180.    9 0.       0.                             NOSE05
-.0008    0.        180.    9 .0083    .0083                          NOSE05
-.0017    0.        180.    9 .012     .012                           NOSE05
-.0033    0.        180.    9 .0163    .0163                          NOSE05
-.005     0.        180.    9 .0198    .0198                          NOSE05
-.007     0.        180.    9 .0226    .0226                          NOSE05
-.0083    0.        180.    9 .025     .025                           NOSE05
-.0125    0.        180.    9 .03      .03                            NOSE05
-.017     0.        180.    9 .033     .033                           NOSE05
-.025     0.        180.    9 .038     .038                           NOSE05
-.0341    0.        180.    9 .041     .041                   4       NOSE05
FCON  2
FORECONE                                                      11      FCON04
-.0341    0.        180.    9 .041     .041                           FCON05
-.0833    0.        180.    9 .05      .05                            FCON05
-.25      0.        180.    9 .081     .081                           FCON05
-.417     0.        180.    9 .112     .112                           FCON05
-.583     0.        180.    9 .143     .143                           FCON05
-.75      0.        180.    9 .174     .174                           FCON05
-.917     0.        180.    9 .205     .205                   4       FCON05
ACON1 2
AFTCONE                                                       11      ACON04
-.917     0.        180.    9 .205     .205                           ACON05
-1.083    0.        180.    9 .225     .225                           ACON05
-1.25     0.        180.    9 .246     .246                           ACON05
-1.417    0.        180.    9 .266     .266                           ACON05
-1.583    0.        180.    9 .286     .286                           ACON05
-1.75     0.        180.    9 .307     .307                           ACON05
-1.938    0.        180.    9 .3299    .3299                  4       ACON05
SPHERICALLY BLUNTED BICONE
3164                            AERO INPUT PROGRAM
8.0       -2600.    12.53     98.00      1
.34212    1.9375    1.9375
10.
03
01
0101  1   1.83      1.0
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
0           1           2           3           4           5           6           7           8
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

02                2
03                2
0                              MASTER DIRECTORY
10 1 8.0                       DATA DIRECTORY
10 1 10.  0.                   A-B DIRECTORY
10 12 0                        REGION DIRECTORY
03,0 1                         FF CONTROL
   1    2    3                                          PANEL SELECTION
 1 1 1 0                                              SURF. PROP. ACCESS
 7 1 1 1           -1.                                STREAMLINE DATA
 1 1                                                  PANEL DESCRIPTION
 1 0                                                  PANEL DESCRIPTION
 1 2                                                  PANEL DESCRIPTION
  3  6    -1.9375   0.         -.3299
  3  6    -1.9375   .165       -.2857
  3  6    -1.9375   .2857      -.165
  3  6    -1.9375   .3299      0.
  3  6    -1.9375   .2857      .165
  3  0    -1.9375   .165       .2857
  3  6    -1.9375   0.         .3299
0                                INTEGRAL B-L METHOD
 100 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 200 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 300 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 400 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 500 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 600 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 700 52   600.      600.
20 0 0.0 1 1.0 1.0 1.0          2.                                 .00001    .000005
 100 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 200 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 300 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 400 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 500 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 600 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
 710 52   600.      600.        100.        1.0
20 0 0.0 1 1.0 1.0 1.0          2.
```

CASE 2: OUTPUT

STREAMLINE NO. 1

S	X	Y	Z	M	P/PINF	1/TINF	PANEL
0.	-.1244E-02	0.	-.8045E-02	.6929E+00	.8183E+02	.1259E+02	1
.4284E-02	-.3220E-02	0.	-.1459E-01	.7013E+00	.7819E+02	.1250E+02	1
.1004E-01	-.6621E-02	0.	-.2136E-01	.8432E+00	.7077E+02	.1208E+02	1
.1567E-01	-.1001E-01	0.	-.2624E-01	.1037E+01	.6366E+02	.1130E+02	1
.2000E-01	-.1370E-01	0.	-.2907E-01	.1736E+01	.4571E+02	.8012E+01	1
.2553E-01	-.1789E-01	0.	-.3307E-01	.2114E+01	.3768E+02	.7228E+01	1
.3045E-01	-.2216E-01	0.	-.3548E-01	.2235E+01	.3571E+02	.6902E+01	1
.3538E-01	-.2661E-01	0.	-.3753E-01	.2794E+01	.2700E+02	.5387E+01	1
.7232E-01	-.6281E-01	0.	-.4556E-01	.4403E+01	.1118E+02	.2829E+01	2
.1544E+00	-.1436E+00	0.	-.6030E-01	.4390E+01	.1126E+02	.2842E+01	2
.2365E+00	-.2243E+00	0.	-.7505E-01	.4386E+01	.1129E+02	.2847E+01	2
.3186E+00	-.3051E+00	0.	-.8982E-01	.4368E+01	.1126E+02	.2845E+01	2
.4007E+00	-.3858E+00	0.	-.1046E+00	.4385E+01	.1130E+02	.2848E+01	2
.4828E+00	-.4666E+00	0.	-.1194E+00	.4380E+01	.1135E+02	.2853E+01	2
.5648E+00	-.5473E+00	0.	-.1342E+00	.4380E+01	.1133E+02	.2855E+01	2
.6469E+00	-.6280E+00	0.	-.1490E+00	.4365E+01	.1130E+02	.2848E+01	2
.7290E+00	-.7088E+00	0.	-.1638E+00	.4365E+01	.1129E+02	.2848E+01	2
.8111E+00	-.7895E+00	0.	-.1786E+00	.4363E+01	.1130E+02	.2850E+01	2
.8932E+00	-.8703E+00	0.	-.1933E+00	.4386E+01	.1127E+02	.2847E+01	2
.9835E+00	-.9595E+00	0.	-.2068E+00	.5001E+01	.8049E+01	.2299E+01	3
.1066E+01	-.1041E+01	0.	-.2167E+00	.4969E+01	.8193E+01	.2324E+01	3
.1148E+01	-.1123E+01	0.	-.2266E+00	.4946E+01	.8300E+01	.2342E+01	3
.1230E+01	-.1204E+01	0.	-.2365E+00	.4950E+01	.8287E+01	.2339E+01	3
.1312E+01	-.1285E+01	0.	-.2463E+00	.4976E+01	.8172E+01	.2319E+01	3
.1394E+01	-.1367E+01	0.	-.2561E+00	.4995E+01	.8083E+01	.2304E+01	3
.1476E+01	-.1449E+01	0.	-.2657E+00	.4994E+01	.8089E+01	.2305E+01	3
.1558E+01	-.1530E+01	0.	-.2755E+00	.4978E+01	.8163E+01	.2317E+01	3
.1640E+01	-.1612E+01	0.	-.2853E+00	.4954E+01	.8269E+01	.2336E+01	3
.1722E+01	-.1693E+01	0.	-.2952E+00	.4943E+01	.8310E+01	.2344E+01	3
.1804E+01	-.1774E+01	0.	-.3052E+00	.4951E+01	.8270E+01	.2338E+01	3
.1886E+01	-.1856E+01	0.	-.3151E+00	.4976E+01	.8101E+01	.2319E+01	3
.1969E+01	-.1938E+01	0.	-.3250E+00	.5001E+01	.8050E+01	.2299E+01	3

STREAMLINE NO. 2

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.1357E-02	.1876E-05	-.8519E-02	.6936E+00	.8168E+02	.1259E+02	1
.3741E-02	-.3435E-02	.3011E-03	-.1529E-01	.7038E+00	.7775E+02	.1250E+02	1
.9683E-02	-.6828E-02	.6687E-03	-.2180E-01	.8436E+00	.7076E+02	.1205E+02	1
.1546E-01	-.1021E-01	.9497E-03	-.2657E-01	.1034E+01	.6364E+02	.1129E+02	1
.2040E-01	-.1391E-01	.1079E-02	-.3019E-01	.1798E+01	.4433E+02	.8383E+01	1
.2532E-01	-.1809E-01	.1191E-02	-.3321E-01	.2137E+01	.3750E+02	.7225E+01	1
.3025E-01	-.2235E-01	.1297E-02	-.3556E-01	.2245E+01	.3556E+02	.6873E+01	1
.3517E-01	-.2679E-01	.1418E-02	-.3756E-01	.2827E+01	.2655E+02	.5310E+01	1
.1321E+00	-.1720E+00	.3651E-02	-.5624E-01	.4426E+01	.1106E+02	.2806E+01	2
.2216E+00	-.2101E+00	.6350E-02	-.7216E-01	.4431E+01	.1104E+02	.2801E+01	2
.3112E+00	-.2981E+00	.9760E-02	-.8800E-01	.4445E+01	.1097E+02	.2767E+01	2
.4007E+00	-.3862E+00	.1385E-01	-.1038E+00	.4452E+01	.1092E+02	.2780E+01	2
.4903E+00	-.4743E+00	.1861E-01	-.1194E+00	.4457E+01	.1090E+02	.2775E+01	2
.5799E+00	-.5623E+00	.2400E-01	-.1349E+00	.4468E+01	.1083E+02	.2764E+01	2
.6695E+00	-.6504E+00	.3004E-01	-.1502E+00	.4469E+01	.1072E+02	.2743E+01	2
.7591E+00	-.7385E+00	.3670E-01	-.1652E+00	.4495E+01	.1067E+02	.2778E+01	2
.8488E+00	-.8266E+00	.4399E-01	-.1871E+00	.4511E+01	.1060E+02	.2772E+01	2
.9623E+00	-.9384E+00	.5374E-01	-.1971E+00	.5174E+01	.7347E+01	.2172E+01	3
.1065E+01	-.1040E+01	.6190E-01	-.2075E+00	.5126E+01	.7524E+01	.2200E+01	3
.1168E+01	-.1142E+01	.7084E-01	-.2177E+00	.5108E+01	.7605E+01	.2219E+01	3
.1270E+01	-.1244E+01	.8039E-01	-.2275E+00	.5147E+01	.7442E+01	.2191E+01	3
.1373E+01	-.1346E+01	.9056E-01	-.2368E+00	.5207E+01	.7211E+01	.2152E+01	3
.1476E+01	-.1447E+01	.1013E+00	-.2455E+00	.5225E+01	.7116E+01	.2130E+01	3
.1578E+01	-.1549E+01	.1128E+00	-.2578E+00	.5215E+01	.7160E+01	.2143E+01	3
.1681E+01	-.1651E+01	.1249E+00	-.2618E+00	.5198E+01	.7230E+01	.2155E+01	3
.1784E+01	-.1752E+01	.1376E+00	-.2693E+00	.5224E+01	.7112E+01	.2137E+01	3
.1887E+01	-.1854E+01	.1512E+00	-.2762E+00	.5285E+01	.6881E+01	.2095E+01	3
.1971E+01	-.1938E+01	.1625E+00	-.2814E+00	.5360E+01	.6507E+01	.2033E+01	3

STREAMLINE NO. 3

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.2689E-02	.6704E-03	-.1360E-01	.7049E+00	.7959E+02	.1255E+02	1
.5335E-02	-.5364E-02	.1452E-02	-.1950E-01	.8430E+00	.7071E+02	.1208E+02	1
.1159E-01	-.8779E-02	.2154E-02	-.2479E-01	.8417E+00	.7085E+02	.1209E+02	1
.1676E-01	-.1221E-01	.2667E-02	-.2870E-01	.1459E+01	.5101E+02	.9680E+01	1
.2169E-01	-.1623E-01	.3052E-02	-.3190E-01	.2125E+01	.3775E+02	.7252E+01	1
.2661E-01	-.2045E-01	.3401E-02	-.3449E-01	.2152E+01	.3714E+02	.7165E+01	1
.3154E-01	-.2475E-01	.3716E-02	-.3645E-01	.2503E+01	.3140E+02	.6125E+01	1
.3646E-01	-.2931E-01	.4066E-02	-.3860E-01	.3354E+01	.1977E+02	.4247E+01	1
.1376E+00	-.1287E+00	.8964E-02	-.5667E-01	.4471E+01	.1082E+02	.2761E+01	2
.2265E+00	-.2161E+00	.1466E-01	-.7205E-01	.4487E+01	.1073E+02	.2740E+01	2
.3154E+00	-.3034E+00	.2177E-01	-.8682E-01	.4513E+01	.1058E+02	.2720E+01	2
.4043E+00	-.3909E+00	.3016E-01	-.1011E+00	.4531E+01	.1048E+02	.2703E+01	2
.4934E+00	-.4783E+00	.3984E-01	-.1149E+00	.4547E+01	.1038E+02	.2687E+01	2
.5825E+00	-.5657E+00	.5074E-01	-.1279E+00	.4576E+01	.1022E+02	.2660E+01	2
.6716E+00	-.6532E+00	.6280E-01	-.1402E+00	.4608E+01	.1005E+02	.2630E+01	2
.7607E+00	-.7406E+00	.7595E-01	-.1517E+00	.4636E+01	.9879E+01	.2604E+01	2
.8500E+00	-.8281E+00	.9022E-01	-.1622E+00	.4665E+01	.9730E+01	.2578E+01	2
.9713E+00	-.9472E+00	.1098E+00	-.1735E+00	.5598E+01	.6471E+01	.2021E+01	3
.1073E+01	-.1048E+01	.1250E+00	-.1781E+00	.5373E+01	.6526E+01	.2040E+01	3
.1176E+01	-.1149E+01	.1411E+00	-.1814E+00	.5464E+01	.6415E+01	.2017E+01	3
.1278E+01	-.1250E+01	.1578E+00	-.1835E+00	.5491E+01	.6103E+01	.1965E+01	3
.1380E+01	-.1351E+01	.1750E+00	-.1843E+00	.5592E+01	.5745E+01	.1902E+01	3
.1483E+01	-.1451E+01	.1926E+00	-.1836E+00	.5669E+01	.5487E+01	.1858E+01	3
.1585E+01	-.1552E+01	.2106E+00	-.1816E+00	.5712E+01	.5348E+01	.1834E+01	3
.1687E+01	-.1653E+01	.2290E+00	-.1785E+00	.5752E+01	.5218E+01	.1812E+01	3
.1790E+01	-.1754E+01	.2477E+00	-.1739E+00	.5839E+01	.4937E+01	.1765E+01	3
.1893E+01	-.1855E+01	.2664E+00	-.1680E+00	.5965E+01	.4581E+01	.1760E+01	3
.1977E+01	-.1938E+01	.2814E+00	-.1625E+00	.6075E+01	.4357E+01	.1647E+01	3

STREAMLINE NO. 4

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.3679E-02	.1928E-02	-.1641E-01	.7114E+00	.7775E+02	.1253E+02	1
.3362E-02	-.5337E-02	.2588E-02	-.1954E-01	.8659E+00	.6969E+02	.1200E+02	1
.9789E-02	-.8754E-02	.3784E-02	-.2469E-01	.8086E+00	.7205E+02	.1220E+02	1
.1515E-01	-.1216E-01	.4694E-02	-.2849E-01	.1461E+01	.5133E+02	.9673E+01	1
.2008E-01	-.1616E-01	.5402E-02	-.3158E-01	.2169E+01	.3689E+02	.7109E+01	1
.2501E-01	-.2036E-01	.6036E-02	-.3411E-01	.2158E+01	.3702E+02	.7145E+01	1
.2993E-01	-.2462E-01	.6586E-02	-.3597E-01	.2487E+01	.3107E+02	.6168E+01	1
.3486E-01	-.2915E-01	.7184E-02	-.3796E-01	.3339E+01	.2000E+02	.4273E+01	1
.6049E-01	-.5426E-01	.9100E-02	-.4304E-01	.4517E+01	.1056E+02	.2716E+01	2
.1478E+00	-.1400E+00	.1664E-01	-.5728E-01	.4532E+01	.1047E+02	.2702E+01	2
.2351E+00	-.2258E+00	.2631E-01	-.7057E-01	.4569E+01	.1026E+02	.2667E+01	2
.3226E+00	-.3117E+00	.3799E-01	-.8271E-01	.4614E+01	.1001E+02	.2624E+01	2
.4102E+00	-.3976E+00	.5151E-01	-.9351E-01	.4664E+01	.9735E+01	.2579E+01	2
.4980E+00	-.4835E+00	.6668E-01	-.1028E+00	.4716E+01	.9467E+01	.2533E+01	2
.5859E+00	-.5695E+00	.8329E-01	-.1104E+00	.4792E+01	.9080E+01	.2467E+01	2
.6741E+00	-.6557E+00	.1011E+00	-.1163E+00	.4870E+01	.8692E+01	.2402E+01	2
.7624E+00	-.7419E+00	.1199E+00	-.1203E+00	.4949E+01	.8302E+01	.2339E+01	2
.8509E+00	-.8282E+00	.1395E+00	-.1225E+00	.5042E+01	.7891E+01	.2268E+01	2
.9818E+00	-.9561E+00	.1668E+00	-.1216E+00	.5890E+01	.4829E+01	.1738E+01	3
.1083E+01	-.1056E+01	.1851E+00	-.1160E+00	.5948E+01	.4611E+01	.1709E+01	3
.1185E+01	-.1155E+01	.2034E+00	-.1085E+00	.6048E+01	.4337E+01	.1659E+01	3
.1286E+01	-.1255E+01	.2214E+00	-.9930E-01	.6201E+01	.3937E+01	.1568E+01	3
.1388E+01	-.1355E+01	.2388E+00	-.8845E-01	.6370E+01	.3514E+01	.1514E+01	3
.1490E+01	-.1454E+01	.2554E+00	-.7602E-01	.6502E+01	.3213E+01	.1460E+01	3
.1592E+01	-.1554E+01	.2713E+00	-.6226E-01	.6597E+01	.3011E+01	.1422E+01	3
.1695E+01	-.1655E+01	.2867E+00	-.4733E-01	.6691E+01	.2812E+01	.1380E+01	3
.1797E+01	-.1755E+01	.3011E+00	-.3121E-01	.6832E+01	.2531E+01	.1335E+01	3
.1900E+01	-.1855E+01	.3146E+00	-.1412E-01	.6971E+01	.2295E+01	.1286E+01	3
.1984E+01	-.1938E+01	.3250E+00	-.4061E-14	.7022E+01	.2290E+01	.1271E+01	3

STREAMLINE NO. 3

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.4099E-02	.3798E-02	-.1737E-01	.7297E+00	.7629E+02	.1247E+02	1
.6576E-02	-.7470E-02	.5740E-02	-.2253E-01	.7932E+00	.7299E+02	.1226E+02	1
.1281E-01	-.1081E-01	.7569E-02	-.2656E-01	.1154E+01	.5932E+02	.1090E+02	1
.1774E-01	-.1455E-01	.8833E-02	-.2963E-01	.2044E+01	.3914E+02	.7517E+01	1
.2266E-01	-.1871E-01	.9974E-02	-.3222E-01	.2224E+01	.3579E+02	.6938E+01	1
.2759E-01	-.2290E-01	.1094E-01	-.3413E-01	.2305E+01	.3457E+02	.6691E+01	1
.3251E-01	-.2729E-01	.1186E-01	-.3576E-01	.2965E+01	.2476E+02	.5002E+01	1
.8632E-01	-.7998E-01	.1894E-01	-.4485E-01	.4608E+01	.1004E+02	.2631E+01	2
.1695E+00	-.1615E+[illegible]	.3160E-01	-.5515E-01	.4675E+01	.9677E+01	.2569E+01	2
.2531E+00	-.2433E+[illegible]	.4680E-01	-.6304E-01	.4788E+01	.9100E+01	.2471E+01	2
.3373E+00	-.3256E+00	.6399E-01	-.6828E-01	.4916E+01	.8470E+01	.2360E+01	2
.4221E+00	-.4083E+00	.8263E-01	-.7067E-01	.5058E+01	.7824E+01	.2250E+01	2
.5076E+00	-.4915E+00	.1022E+00	-.7021E-01	.5210E+01	.7180E+01	.2147E+01	2
.5937E+00	-.5752E+00	.1222E+00	-.67[illegible]E-01	.5373E+01	.6544E+01	.2037E+01	2
.6804E+00	-.6594E+00	.1421E+00	-.6125E-01	.5540E+01	.5926E+01	.1933E+01	2
.7677E+00	-.7440E+[illegible]	.1618E+00	-.5303E-01	.5709E+01	.5342E+01	.1830E+01	2
.8554E+00	-.8290E+[illegible]	.1809E+00	-.4264E-01	.5877E+01	.4830E+01	.1745E+01	2
.9874E+00	-.9574E+00	.2051E+00	-.2429E-01	.6839E+01	.2562E+01	.1333E+01	3
.1088E+01	-.1056E+01	.2184E+00	-.7692E-02	.6992E+01	.2245E+01	.1281E+01	3
.1189E+01	-.1155E+01	.2303E+00	.1015E-01	.7113E+01	.2053E+01	.1241E+01	3
.1291E+01	-.1254E+01	.2409E+00	.2871E-01	.7286E+01	.1801E+01	.1188E+01	3
.1392E+01	-.1353E+01	.2500E+00	.4783E-01	.7461E+01	.1559E+01	.1137E+01	3
.1494E+01	-.1453E+01	.2576E+00	.6734E-01	.7576E+01	.1417E+01	.1106E+01	3
.1597E+01	-.1553E+01	.2643E+00	.8707E-01	.7645E+01	.1342E+01	.1088E+01	3
.1699E+01	-.1654E+01	.27[illegible]	.1069E+00	.7706E+01	.1273E+01	.1072E+01	3
.1802E+01	-.1754E+01	.2748E+00	.1259E+00	.7798E+01	.1167E+01	.1046E+01	3
.1904E+01	-.1855E+01	.2737	.1467E+00	.7649E+01	.1130E+01	.1030E+01	3
.1989E+01	-.1938E+01	.2[illegible]	.1625E+00	.7781E+01	.1236E+01	.1053E+01	3

STREAMLINE NO. 6

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.4056E-02	.8118E-02	-.1568E-01	.7487E+00	.7536E+02	.1241E+02	1
.2077E-02	-.5332E-02	.9695E-02	-.1731E-01	.9169E+00	.6732E+02	.1181E+02	1
.9236E-02	-.8684E-02	.1358E-01	-.2090E-01	.8478E+00	.7097E+02	.1207E+02	1
.1472E-01	-.1204E-01	.1667E-01	-.2349E-01	.1574E+01	.4872E+02	.9227E+01	1
.1964E-01	-.1640E-01	.1906E-01	-.2564E-01	.2351E+01	.3390E+02	.6012E+01	1
.2457E-01	-.2017E-01	.2116E-01	-.2730E-01	.2343E+01	.3361E+02	.6578E+01	1
.2950E-01	-.2438E-01	.2289E-01	-.2839E-01	.2619E+01	.2906E+02	.5818E+01	1
.3442E-01	-.2885E-01	.2471E-01	-.2953E-01	.3503E+01	.1844E+02	.5995E+01	1
.4673E-01	-.4077E-01	.2777E-01	-.3089E-01	.4934E+01	.8403E+01	.2351E+01	2
.1172E+00	-.1095E+00	.4335E-01	-.3230E-01	.5169E+01	.7336E+01	.2173E+01	2
.1904E+00	-.1807E+00	.6028E-01	-.2938E-01	.5456E+01	.6226E+01	.1984E+01	2
.2608E+00	-.2547E+00	.7743E-01	-.2238E-01	.5770E+01	.5171E+01	.1802E+01	2
.3459E+00	-.3313E+00	.9392E-01	-.1175E-01	.6090E+01	.4227E+01	.1640E+01	2
.4274E+00	-.4103E+00	.1091E+00	.1851E-02	.6380E+01	.3494E+01	.1510E+01	2
.5110E+00	-.4913E+00	.1227E+00	.1767E-01	.6032E+01	.2934E+01	.1409E+01	2
.5963E+00	-.5739E+00	.1345E+00	.3502E-01	.6652E+01	.2508E+01	.1326E+01	2
.6828E+00	-.6578E+00	.1450E+00	.5338E-01	.7051E+01	.2155E+01	.1261E+01	2
.7702E+00	-.7427E+00	.1538E+00	.7241E-01	.7232E+01	.1857E+01	.1204E+01	2
.8583E+00	-.8283E+00	.1614E+00	.9183E-01	.7354E+01	.1693E+01	.1168E+01	2
.9789E+00	-.9459E+00	.1657E+00	.1168E+00	.7906E+01	.1093E+01	.1022E+01	3
.1080E+01	-.1046E+01	.1700E+00	.1353E+00	.7995E+01	.9965E+00	.1001E+01	3
.1182E+01	-.1146E+01	.1705E+00	.1535E+00	.8003E+01	.9957E+00	.9993E+00	3
.1284E+01	-.1246E+01	.1705E+00	.1713E+00	.8007E+01	.9929E+00	.9983E+00	3
.1387E+01	-.1347E+01	.1699E+00	.1885E+00	.8017E+01	.9859E+00	.9906E+00	3
.1489E+01	-.1448E+01	.1689E+00	.2051E+00	.8018E+01	.9840E+00	.9957E+00	3
.1592E+01	-.1550E+01	.1677E+00	.2214E+00	.8012E+01	.9901E+00	.9972E+00	3
.1694E+01	-.1651E+01	.1665E+00	.2376E+00	.8009E+01	.9923E+00	.9980E+00	3
.1797E+01	-.1753E+01	.1651E+00	.2534E+00	.8016E+01	.9864E+00	.9963E+00	3
.1900E+01	-.1854E+01	.1637E+00	.2690E+00	.8001E+01	.9989E+00	.9998E+00	3
.1984E+01	-.1938E+01	.1625E+00	.2814E+00	.7982E+01	.1016E+01	.1004E+01	3

STREAMLINE NO. 7

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.6085E-03	.1101E-11	.5207E-02	.7614E+00	.7641E+02	.1237E+02	1
.1375E-01	-.3788E-02	.7525E-12	.1598E-01	.1340E+01	.5642E+02	.1015E+02	1
.2077E-01	-.7156E-02	.7556E-12	.2222E-01	.1754E+01	.4629E+02	.8542E+01	1
.2686E-01	-.1053E-01	.7413E-12	.2685E-01	.2387E+01	.3410E+02	.6450E+01	1
.3182E-01	-.1412E-01	.7412E-12	.3033E-01	.3002E+01	.1745E+02	.3748E+01	1
.3674E-01	-.1818E-01	.7423E-12	.3326E-01	.4265E+01	.1200E+02	.2975E+01	1
.4167E-01	-.2233E-01	.7332E-12	.3556E-01	.4548E+01	.1103E+02	.2687E+01	1
.4659E-01	-.2669E-01	.7249E-12	.3757E-01	.5660E+01	.6538E+01	.1803E+01	1
.8353E-01	-.6281E-01	.7333E-12	.4556E-01	.8059E+01	.9102E+00	.9865E+00	2
.1656E+00	-.1430E+00	.7290E-12	.6030E-01	.8045E+01	.9345E+00	.9897E+00	2
.2477E+00	-.2243E+00	.7218E-12	.7505E-01	.8043E+01	.9365E+00	.9900E+00	2
.3298E+00	-.3051E+00	.7107E-12	.8982E-01	.8040E+01	.9417E+00	.9907E+00	2
.4119E+00	-.3858E+00	.7014E-12	.1046E+00	.8040E+01	.9429E+00	.9907E+00	2
.4940E+00	-.4666E+00	.6869E-12	.1194E+00	.8039E+01	.9447E+00	.9911E+00	2
.5761E+00	-.5473E+00	.6768E-12	.1342E+00	.8039E+01	.9441E+00	.9911E+00	2
.6581E+00	-.6280E+00	.6561E-12	.1490E+00	.8041E+01	.9408E+00	.9905E+00	2
.7402E+00	-.7088E+00	.6443E-12	.1638E+00	.8048E+01	.9324E+00	.9889E+00	2
.8223E+00	-.7895E+00	.6237E-12	.1786E+00	.8055E+01	.9214E+00	.9873E+00	2
.9044E+00	-.8703E+00	.5900E-12	.1933E+00	.8064E+01	.8909E+00	.9854E+00	2
.9947E+00	-.9595E+00	.5665E-12	.2068E+00	.8050E+01	.9191E+00	.9885E+00	3
.1077E+01	-.1041E+01	.5412E-12	.2167E+00	.8029E+01	.9549E+00	.9932E+00	3
.1159E+01	-.1123E+01	.5170E-12	.2266E+00	.8025E+01	.9622E+00	.9943E+00	3
.1241E+01	-.1204E+01	.4805E-12	.2365E+00	.8024E+01	.9634E+00	.9945E+00	3
.1323E+01	-.1285E+01	.4472E-12	.2463E+00	.8023E+01	.9652E+00	.9948E+00	3
.1405E+01	-.1367E+01	.4067E-12	.2561E+00	.8022E+01	.9606E+00	.9949E+00	3
.1487E+01	-.1449E+01	.3654E-12	.2657E+00	.8022E+01	.9667E+00	.9949E+00	3
.1569E+01	-.1530E+01	.3201E-12	.2755E+00	.8022E+01	.9660E+00	.9949E+00	3
.1651E+01	-.1612E+01	.2660E-12	.2853E+00	.8023E+01	.9643E+00	.9947E+00	3
.1733E+01	-.1693E+01	.2088E-12	.2952E+00	.8024E+01	.9629E+00	.9944E+00	3
.1816E+01	-.1774E+01	.1507E-12	.3057E+00	.8027E+01	.9590E+00	.9938E+00	3
.1898E+01	-.1856E+01	.7951E-13	.3151E+00	.8038E+01	.9392E+00	.9912E+00	3
.1980E+01	-.1938E+01	.8121E-14	.3250E+00	.8065E+01	.8917E+00	.9851E+00	3

INITIAL CONDITION FOR FULLY TURBULENT CALCULATION (STREAMLINE NO. 4)

INPUT DATA

```
STREAMLINE NO. 4
LASTSL =.0      ISFM = 0      IWT =  5      IPRINT = 2
UNF16 =       600.     SURFIT =       600.     RETRAN =          0.     STRAN =          0.

INTEGRAL METHOD CONTROL DATA
NVP= 20   NTURB=  2   KPVM=  0   KSMTH=  0   KSPLN=  0   KLE=  0   KATCH=  1   KPRE=  1
KGRAD=  0   KSDE=  1   KLAM=  0   KMAIN=  1   KPROF=  0
CIMET=   2.00000   DLAM=   0.00010   TLAM=   0.00000   DTURB=   .00001   TTURB=   .00001

BASIC PARAMETERS
   PSZ  =     12.53000   TSZ  =      98.00000   UZ   =   3882.35686   ASZ  =    485.29461   ATZ  =   1802.78965
   RHSZ =   .74485E-04   RHTZ =    .52695E-01   MUSZ =   .79673E-07   MUTZ =   .73390E-06   NUSZ =   .10696E-02
   NUTZ =   .13927E-04   CP   =    6007.93000   TC   =       .00001
```

Note: The last character "Z" in each of the basic parameters refers to freestream conditions.

PSZ	static pressure (psf)
TSZ	static temperature (°R)
UZ	freestream velocity (ft/sec)
ASZ	static sound speed (ft/sec)
ATZ	total sound speed (ft/sec)
RHSZ	static density (slugs/ft^3)
RHTZ	total density (slugs/ft^3)
MUSZ	dynamic viscosity, μ, static conditions (lb_F-sec/ft^2)
MUTZ	dynamic viscosity, μ_o, total conditions (lb_F-sec/ft^2)
NUSZ	kinematic viscosity, ν, static conditions (ft^2/sec)
NUTZ	kinematic viscosity, ν_o, total conditions (ft^2/sec)
CP	specific heat at constant pressure (ft-lb_F/slug-°R)
TC	thermal conductivity (ft-lb_F/ft-sec-°R)

EXPLANATION OF PRELIMINARY CALCULATIONS

The Preliminary Calculations output provides the local conditions at each point of the given streamline. Only those variable names that require an explanation are given below. For example, PRESS obviously refers to the static pressure. Units for all variables are always given in the lb_F-slug-ft-sec-°R system.

POPTZ	local static pressure/freestream stagnation pressure
VOVCR	local velocity/speed of sound at Mach 1
SOL	local running length/total arc length
TWAL	wall temperature
TAWL	adiabatic wall temperature for laminar flow
TAWT	adiabatic wall temperature for turbulent flow
TBAR	Eckert reference temperature
RW	Reynolds number at the wall (UE*S/NUW)
SW	enthalpy function at the wall, $-1 + h_w/(h_o)_{edge}$
SUTHL	proportionality constant in the locally linear viscosity relation
RHSW	density at the wall
RHSE	edge density
HEADW	local dynamic pressure based on wall density
HEADE	local dynamic pressure based on edge density
NUW	kinematic viscosity at the wall
MUBAR	dynamic viscosity based on Eckert reference temperature

PRELIMINARY CALCULATIONS

STATION	PRES	UE	MF	POPTZ	VOVCR
1	974.20324	1222.11811	.711384	.713592	.742607
2	873.19276	1455.70265	.865901	.613217	.884542
3	902.82890	137 .92950	.808648	.650389	.853030
4	643.16803	2204.43706	1.460520	.288348	1.339502
5	462.28797	2807.03772	2.169452	.098101	1.705605
6	463.86604	2799.41929	2.158065	.099864	1.701030
7	396.82511	2997.83766	2.487302	.059696	1.821603
8	250.53992	3349.49952	3.339130	.016512	2.035280
9	132.29010	3612.73129	4.517028	.003383	2.195236
10	131.22997	3615.00530	4.531530	.003322	2.196618
11	128.60535	3620.77727	4.568848	.003172	2.200125
12	125.43307	3627.63911	4.614194	.003000	2.204295
13	121.98548	3635.04965	4.664413	.002821	2.208798
14	118.62176	3642.39796	4.715548	.002651	2.213263
15	113.76889	3653.03756	4.792077	.002417	2.219726
16	108.91396	3663.51087	4.870470	.002201	2.226092
17	104.02004	3673.63550	4.949345	.002006	2.232244
18	98.88011	3685.00726	5.041837	.001800	2.239154
19	60.51259	3768.71459	5.889998	.000709	2.290018
20	57.77022	3773.33420	5.948054	.000668	2.292825
21	54.34815	3781.02800	6.048172	.000603	2.297500
22	49.33401	3792.14179	6.200965	.000517	2.304253
23	44.03249	3803.62532	6.370091	.000437	2.311231
24	40.26091	3812.02008	6.501800	.000385	2.316332
25	37.72880	3817.79247	6.596712	.000351	2.319839
26	35.23790	3823.33750	6.691483	.000321	2.323209
27	31.71279	3831.20061	6.832392	.000282	2.327987
28	28.75399	3838.49316	6.970513	.000248	2.332418
29	28.69436	3841.10991	7.021956	.000237	2.334008

STATION	X	Y	S	SOL
1	-.00368	.00193	0.00000	0.00000
2	-.00534	.00259	.00336	.00169
3	-.00875	.00378	.00979	.00493
4	-.01216	.00469	.01515	.00764
5	-.01616	.00540	.02008	.01012
6	-.02036	.00604	.02501	.01260
7	-.02462	.00659	.02993	.01508
8	-.02915	.00718	.03486	.01757
9	-.05426	.00910	.06049	.03049
10	-.14005	.01664	.14777	.07447
11	-.22585	.02631	.23513	.11851
12	-.31169	.03799	.32261	.16260
13	-.39757	.05151	.41022	.20675
14	-.48352	.06668	.49800	.25099
15	-.56955	.08329	.58595	.29532
16	-.65567	.10109	.67410	.33974
17	-.74188	.11988	.76242	.38426
18	-.82818	.13947	.85095	.42887
19	-.95605	.16682	.98175	.49480
20	-1.05559	.18514	1.08309	.54588
21	-1.15514	.20344	1.18461	.59704
22	-1.25482	.22141	1.28632	.64830
23	-1.35459	.23878	1.38816	.69963
24	-1.45445	.25537	1.49015	.75103
25	-1.55444	.27134	1.59233	.80253
26	-1.65454	.28667	1.69470	.85413
27	-1.75475	.30113	1.79724	.90581
28	-1.85507	.31463	1.89990	.95755
29	-1.93750	.32497	1.98414	1.00000

STATION	AE	TSE	TWAL	TAWL	TAWT	TBAR
1	1717.945	1228.19[illegible]	600.000	1328.793	1336.117	937.814
2	1681.141	1176.044	600.000	1319.057	1329.405	921.761
3	1695.335	1195.986	600.000	1322.774	1331.967	927.909
4	1599.351	947.973	600.000	1278.146	1301.244	851.706
5	1293.892	696.645	600.000	1239.449	1274.753	775.506
6	1297.189	700.20[illegible]	600.000	1239.920	1275.074	776.572
7	1295.257	604.469	600.000	1228.302	1267.193	748.034
8	1003.105	498.705	600.000	1213.947	1257.652	693.921
9	799.803	266.183	600.000	1213.685	1257.834	651.255
10	797.745	264.815	600.000	1213.743	1257.877	650.881
11	792.492	261.34[illegible]	600.000	1213.894	1257.990	649.933
12	786.191	257.20	600.000	1214.084	1258.131	648.805
13	779.315	252.721	600.000	1214.302	1258.292	647.586
14	772.423	248.271	600.000	1214.531	1258.460	646.377
15	762.308	241.811	600.000	1214.887	1258.721	644.626
16	752.188	235.434	600.000	1215.265	1258.996	642.901
17	742.247	229.251	600.000	1215.658	1259.281	641.232
18	730.886	222.287	600.000	1216.131	1259.625	639.357
19	639.850	170.361	600.000	1220.728	1262.903	625.540
20	634.381	167.462	600.000	1221.043	1263.125	624.777
21	625.152	162.625	600.000	1221.582	1263.506	623.506
22	611.541	155.620	600.000	1222.394	1264.079	621.671
23	597.107	148.361	600.000	1223.275	1264.700	619.775
24	586.302	143.04[illegible]	600.000	1223.947	1265.173	618.389
25	578.742	139.375	600.000	1224.423	1265.507	617.437
26	571.374	135.849	600.000	1224.891	1265.835	616.521
27	560.741	130.840	600.000	1225.573	1266.313	615.224
28	550.676	126.185	600.000	1226.224	1266.770	614.021
29	547.014	124.512	600.000	1226.462	1266.937	613.590

STATION	RW	SW	SUTHL	HHSW	HHST	HEADW	HEADE	NUW	NUBAR
1	0.0	-.6	1.294	.9459E-03	.4621E-03	.7064E+03	.3451E+03	.4453E-03	.6581E-06
2	9850.6	-.6	1.294	.8478E-03	.4325E-03	.6983E+03	.4583E+03	.4968E-03	.6471E-06
3	27928.7	-.6	1.294	.8766E-03	.4398E-03	.8238E+03	.4133E+03	.4805E-03	.6514E-06
4	49531.3	-.6	1.294	.6245E-03	.3952E-03	.1517E+04	.9604E+03	.6745E-03	.5979E-06
5	60066.3	-.6	1.294	.4489E-03	.3866E-03	.1768E+04	.1523E+04	.9384E-03	.5444E-06
6	74851.1	-.6	1.294	.4504E-03	.3659E-03	.17[illegible]5E+04	.1512E+04	.9352E-03	.5452E-06
7	82078.0	-.6	1.294	.3853E-03	.3824E-03	.1771E+04	.1719E+04	.1093E-02	.5251E-06
8	67427.4	-.6	1.294	.2433E-03	.3486E-03	.1365E+04	.1955E+04	.1731E-02	.4871E-06
9	66645.2	-.6	1.294	.1284E-03	.2895E-03	.8382E+03	.1839E+04	.3279E-02	.4572E-06
10	161591.6	-.6	1.294	.1274E-03	.2887E-03	.8326E+03	.1880E+04	.3306E-02	.4569E-06
11	252396.3	-.6	1.294	.1249E-03	.2867E-03	.8185E+03	.1879E+04	.3373E-02	.4563E-06
12	338395.7	-.6	1.294	.1218E-03	.2841E-03	.8013E+03	.1869E+04	.3458E-02	.4555E-06
13	419319.3	-.6	1.294	.1184E-03	.2812E-03	.7625E+03	.1858E+04	.3556E-02	.4546E-06
14	496002.2	-.6	1.294	.1152E-03	.2783E-03	.7640E+03	.1846E+04	.3657E-02	.4538E-06
15	561362.1	-.6	1.294	.1105E-03	.2741E-03	.7370E+03	.1829E+04	.3813E-02	.4525E-06
16	620023.4	-.6	1.294	.1057E-03	.2695E-03	.7096E+03	.1809E+04	.3983E-02	.4513E-06
17	671605.5	-.6	1.294	.1010E-03	.2643E-03	.6815E+03	.1784E+04	.4176E-02	.4501E-06
18	714749.9	-.6	1.294	.9601E-04	.2591E-03	.6518E+03	.1759E+04	.4367E-02	.4488E-06
19	516114.7	-.6	1.294	.5875E-04	.2069E-03	.4172E+03	.1470E+04	.7169E-02	.4391E-06
20	544250.8	-.6	1.294	.5609E-04	.2010E-03	.3993E+03	.1471E+04	.7509E-02	.4386E-06
21	561145.9	-.6	1.294	.5277E-04	.1947E-03	.3772E+03	.1392E+04	.7962E-02	.4377E-06
22	554734.7	-.6	1.294	.4790E-04	.1847E-03	.3444E+03	.1328E+04	.8793E-02	.4364E-06
23	535940.6	-.6	1.294	.4275E-04	.1729E-03	.3093E+03	.1251E+04	.9852E-02	.4351E-06
24	527199.3	-.6	1.294	.3909E-04	.1640E-03	.2840E+03	.1191E+04	.1077E-01	.4341E-06
25	528716.8	-.6	1.294	.3663E-04	.1577E-03	.2670E+03	.1149E+04	.1150E-01	.4334E-06
26	526322.1	-.6	1.294	.3421E-04	.1511E-03	.2501E+03	.1104E+04	.1231E-01	.4328E-06
27	503362.7	-.6	1.294	.3079E-04	.1412E-03	.2260E+03	.1036E+04	.1368E-01	.4319E-06
28	483380.8	-.6	1.294	.2792E-04	.1327E-03	.2057E+03	.9780E+03	.1509E-01	.4310E-06
29	504115.0	-.6	1.294	.2766E-04	.1343E-03	.2055E+03	.9904E+03	.1512E-01	.4307E-06

TURBULENT DIFFERENTIAL EQUATIONS - SOLUTION FOR F AND FORMI

S	F	FORMI	S	F	FORMI	S	F	FORMI	S	F	FORMI
0.00000	5.5	3.9136	.01984	160.5	1.4727	.03968	281.7	1.3000	.05952	366.1	1.3000
.07937	591.5	1.3000	.09921	775.8	1.3000	.11905	971.2	1.3000	.13889	1169.9	1.3000
.15873	1373.0	1.3000	.17857	1575.6	1.3000	.19841	1775.1	1.3000	.21825	1973.1	1.3000
.23810	2168.7	1.3000	.25794	2362.2	1.3000	.27778	2553.6	1.3000	.29762	2742.8	1.3000
.31746	2929.8	1.3000	.33730	3114.6	1.3000	.35714	3297.2	1.3000	.37699	3477.8	1.3000
.39683	3656.1	1.3000	.41667	3832.4	1.3000	.43651	4005.8	1.3000	.45635	4176.3	1.3000
.47619	4343.7	1.3000	.49603	4508.1	1.3000	.51588	4669.0	1.3000	.53572	4826.0	1.3000
.55556	4979.1	1.3000	.57540	5128.2	1.3000	.59524	5273.4	1.3000	.61508	5415.8	1.3000
.63492	5555.7	1.3000	.65476	5693.0	1.3000	.67461	5827.8	1.3000	.69445	5959.8	1.3000
.71429	6088.5	1.3000	.73413	6214.0	1.3000	.75397	6336.3	1.3000	.77381	6454.0	1.3000
.79365	6561.0	1.3000	.81350	6656.3	1.3000	.83334	6740.1	1.3000	.85318	6812.7	1.3000
.87302	6877.4	1.3000	.89286	6938.9	1.3000	.91270	6996.5	1.3000	.93254	7050.0	1.3000
.95238	7099.4	1.3000	.97223	7144.5	1.3000	.99207	7186.2	1.3000	1.01191	7230.9	1.3000
1.03175	7279.4	1.3000	1.05159	7339.8	1.3000	1.07143	7388.1	1.3000	1.09127	7447.5	1.3000
1.11112	7502.9	1.3000	1.13096	7552.6	1.3000	1.15080	7596.7	1.3000	1.17064	7655.2	1.3000
1.19048	7668.2	1.3000	1.21032	7695.9	1.3000	1.23016	7718.5	1.3000	1.25001	7736.1	1.3000
1.26985	7748.8	1.3000	1.28969	7756.7	1.3000	1.30953	7762.7	1.3000	1.32937	7768.6	1.3000
1.34921	7774.2	1.3000	1.36905	7779.6	1.3000	1.38889	7784.6	1.3000	1.40874	7791.1	1.3000
1.42858	7799.9	1.3000	1.44842	7811.1	1.3000	1.46826	7824.7	1.3000	1.48810	7840.5	1.3000
1.50794	7858.1	1.3000	1.52778	7876.4	1.3000	1.54763	7895.5	1.3000	1.56747	7915.3	1.3000
1.58731	7935.9	1.3000	1.60715	7956.2	1.3000	1.62699	7974.1	1.3000	1.64683	7989.3	1.3000
1.66667	8002.0	1.3000	1.68652	8012.1	1.3000	1.70636	8019.5	1.3000	1.72620	8023.9	1.3000
1.74604	8025.2	1.3000	1.76588	8023.5	1.3000	1.78572	8018.7	1.3000	1.80556	8011.6	1.3000
1.82540	8007.0	1.3000	1.84525	8005.9	1.3000	1.86509	8008.4	1.3000	1.88493	8014.3	1.3000
1.90477	8023.8	1.3000	1.92461	8038.3	1.3000	1.94445	8058.5	1.3000	1.96429	8086.5	1.3000
1.98414	8116.2	1.3000	1.98414	8116.2	1.3000						

S — local running length

F — first dependent variable in turbulent boundary layer equations (related to momentum thickness)

FORMI — second dependent variable, the incompressible form factor

(S, F, FORMI: See Section III - Theory)

PRINCIPAL BOUNDARY LAYER INFORMATION

INSTABILITY DOES NOT OCCUR

TRANSITION DOES NOT OCCUR

SEPARATION DOES NOT OCCUR

LAMINAR BOUNDARY LAYER DOES NOT OCCUR

TURBULENT BOUNDARY LAYER - STATIONS 1 TO 29

STATION	X	S	DELSR	THET	DELTA	FORM	FORMI
1	-.003679	0.000000	.000010	.000005	.000017	2.0000	3.[illegible]136
2	-.005337	.003362	.000034	.000018	.000061	1.9161	3.5[illegible]01
3	-.008754	.009789	.000058	.000039	.000120	1.4730	2.7094
4	-.012155	.015155	.000063	.000038	.000183	1.6097	2.0693
5	-.016162	.020080	.000078	.000037	.000411	2.0965	1.6706
6	-.020358	.025005	.000088	.000043	.000498	2.0445	1.6270
7	-.024618	.029931	.000112	.000045	.000695	2.4710	1.3649
8	-.029155	.034856	.000193	.000049	.001324	3.9268	1.3420
9	-.054263	.060492	.000522	.000078	.004000	6.6558	1.3000
10	-.140047	.147765	.001312	.000196	.010061	6.6955	1.3000
11	-.225848	.235135	.002033	.000299	.015586	6.7982	1.3000
12	-.311686	.322614	.002707	.000391	.020750	6.9243	1.3000
13	-.397573	.410224	.003358	.000475	.025761	7.0654	1.3000
14	-.483521	.497997	.003985	.000553	.030549	7.2106	1.3000
15	-.569546	.585950	.004644	.000625	.035606	7.4311	1.3000
16	-.655675	.674096	.005305	.000693	.040675	7.6606	1.3000
17	-.741884	.762423	.005978	.000757	.045835	7.8954	1.3000
18	-.828185	.850946	.006618	.000809	.050775	8.1756	1.3000
19	-.956053	.981753	.011347	.001032	.086905	10.9916	1.3000
20	-1.055587	1.083090	.012228	.001092	.093748	11.2605	1.3000
21	-1.155145	1.184612	.013332	.001153	.102211	11.5658	1.3000
22	-1.254817	1.286321	.014849	.001224	.113845	12.1351	1.3000
23	-1.354586	1.388163	.016706	.001307	.128077	12.7819	1.3000
24	-1.454454	1.490153	.018393	.001363	.141014	13.2979	1.3000
25	-1.554438	1.592329	.019834	.001450	.152058	13.6763	1.3000
26	-1.654545	1.694704	.021404	.001522	.164097	14.0597	1.3000
27	-1.754750	1.797242	.023801	.001626	.182470	14.6399	1.3000
28	-1.855074	1.899900	.026288	.001727	.201543	15.2206	1.3000
29	-1.937500	1.984135	.026595	.001723	.203896	15.4390	1.3000

DELSR displacement thickness, δ^*

THET momentum thickness, θ

DELTA boundary layer thickness, δ

FORM compressible form factor

FORMI incompressible form factor

STATION	CFE	TAUW	RTH	DTDY	NUSS	HTRAN	CRN
1	.00046	.16726	13.7	0.00	0.00	0.0000	3.342
2	.00062	.28380	52.2	310894.19	1.43	1129.7430	4.257
3	.00176	.72832	112.2	850644.97	11.38	3091.1165	4.327
4	.00382	3.66853	123.1	2528639.13	54.65	9188.6963	3.462
5	.00701	10.67712	111.8	5459757.66	167.48	19839.9424	2.592
6	.00726	10.97923	128.5	5634159.03	208.69	20473.6909	2.604
7	.00668	11.47822	124.4	5379592.94	241.32	19547.9091	2.272
8	.00509	9.94899	95.3	4000314.19	212.02	14536.5433	1.618
9	.00329	6.21578	80.4	2245172.37	206.46	8158.6205	1.062
10	.00256	4.63468	214.3	1744755.36	391.89	6340.1799	1.057
11	.00226	4.25509	321.0	1532131.09	547.51	5567.5351	1.044
12	.00208	3.88975	410.0	1396637.63	664.73	5075.6990	1.028
13	.00195	3.61756	485.7	1295352.86	807.22	4707.1185	1.012
14	.00184	3.40419	550.4	1215480.28	919.27	4416.8735	.995
15	.00175	3.19444	598.8	1135902.95	1010.42	4127.7014	.970
16	.00166	3.00942	637.0	1065803.21	1090.23	3872.9694	.946
17	.00159	2.63979	667.0	1001627.46	1158.56	3640.4911	.923
18	.00153	2.68584	679.9	943408.97	1217.06	3428.2070	.896
19	.00118	1.72796	542.7	588215.71	871.14	2137.4879	.697
20	.00115	1.64283	548.6	558267.85	911.86	2028.7345	.685
21	.00111	1.54292	546.0	523198.04	934.11	1901.2234	.666
22	.00106	1.40903	527.7	475555.35	921.15	1728.0970	.639
23	.00101	1.26706	504.6	425865.17	869.38	1547.5303	.610
24	.00098	1.16374	489.3	389956.01	873.60	1417.0418	.580
25	.00095	1.09220	481.5	365225.75	873.86	1327.1757	.575
26	.00093	1.02216	472.8	341126.07	868.24	1239.6011	.561
27	.00089	.92513	455.3	307679.75	830.44	1118.7889	.541
28	.00086	.84307	439.4	279842.77	797.39	1016.9068	.523
29	.00085	.84081	437.6	278835.30	829.53	1013.2458	.516

CFE skin friction coefficient based on local edge conditions

TAUW wall shearing force (CFE*HEADE)

RTH Reynolds number based on momentum thickness

DTDY temperature gradient at the wall

NUSS local Nusselt number

HTRAN heat transfer rate ($ft\text{-}lb_F/ft^2\text{-}sec$)

CRN Reynolds analogy parameter, CFW*RW/NUSS

INITIAL CONDITIONS FOR LAMINAR-TO-TURBULENT CALCULATION (STREAMLINE 4)

INPUT DATA

```
STREAMLINE NO. 4
LASTSL = 0     ISFM = 0      INT = 5      IPRINT = 2
DRFID =       600.     SURFIZ =       600.     RETRAN =       100.     STRAN =        1.

INTEGRAL METHOD CONTROL DATA
NTT= 20   NTURB= 2   KFVM=        KSMTH= 0   KSPLN= 0   KLF= 0   KATCH= 1   KPRE= 1
KGRAD= 0   KSDE= 1   KLAM= 0   KMAIN= 1   KPROF= 0
CIMF1=  2.00000   DLAM=   0.00000   TLAM=   0.00000   DTURB=   0.00000   TTURB=   0.00000

BASIC PARAMETERS
   PSZ  =    12.03000   TSZ  =     98.00000   UZ   =  3882.35686   ASZ  =   485.29461   ATZ  =  3832.78965
   RMSZ =  .74485E-04   RHTZ =  .52695E-01   MUSZ =  .79673E-07   MUTZ =  .73390E-06   NUSZ =  .10696E-02
   MUTZ =  .13927E-04   CP   =   6007.93000   TC   =      .00061
```

PRELIMINARY CALCULATIONS

STATION	PRES	UE	MF	POFTZ	VOVCR
1	974.20324	1222.11811	.711384	.713592	.742607
2	873.19276	1455.70265	.865901	.613217	.864542
3	902.82890	137[illegible].92950	.808648	.650369	.833036
4	663.16803	2204.43706	1.460520	.288348	1.339562
5	462.28707	2807.03772	2.169452	.098101	1.705665
6	463.86604	2799.41929	2.158065	.099866	1.701036
7	396.82511	2997.83766	2.487302	.059696	1.821663
8	250.53992	3349.49952	3.339130	.010512	2.035286
9	132.29010	3612.73129	4.517028	.003383	2.195256
10	131.22997	3615.00539	4.531530	.003322	2.196618
11	128.60535	362[illegible].77727	4.568848	.003172	2.200125
12	125.43307	3627.63911	4.614194	.003000	2.204295
13	121.98548	3635.04965	4.664413	.002821	2.208798
14	118.62176	3642.39796	4.715548	.002651	2.213263
15	113.76889	3653.03756	4.792077	.002417	2.219728
16	108.91396	3663.51087	4.870470	.002201	2.226092
17	104.02004	3673.63550	4.949345	.002106	2.232244
18	98.88011	3685.00726	5.041837	.001800	2.239154
19	60.51259	3708.71459	5.889996	.000700	2.290010
20	57.77022	3773.33420	5.948054	.000664	2.292825
21	54.34815	3781.02800	6.048172	.000603	2.297510
22	49.33401	3792.14179	6.200965	.000517	2.304253
23	44.03249	38[illegible]3.62532	6.370091	.000437	2.311231
24	40.26091	3812.02008	6.501800	.000385	2.316332
25	37.72880	3817.79247	6.596712	.000351	2.319859
26	35.23790	3823.33750	6.691483	.000321	2.323209
27	31.71279	3831.20161	6.832392	.000282	2.327987
28	28.75399	3836.49316	6.970513	.000245	2.332416
29	28.69436	3841.10991	7.021954	.000237	2.334008

STATION	X	Y	S	SOL
1	-.00368	.00197	0.00000	0.00000
2	-.00534	.00[illegible]59	.00136	.00169
3	-.00875	.00378	.00979	.00493
4	-.01216	.00469	.01515	.00764
5	-.01616	.00540	.02008	.01012
6	-.02036	.00604	.02501	.01260
7	-.02462	.00659	.02993	.01508
8	-.02915	.00718	.03496	.01757
9	-.05426	.00910	.06049	.03049
10	-.14005	.01604	.14777	.07447
11	-.22585	.02631	.23513	.11851
12	-.31169	.03799	.32261	.16260
13	-.39757	.05151	.41022	.20675
14	-.48352	.06668	.49800	.25099
15	-.56955	.08329	.58595	.29532
16	-.65567	.10109	.67410	.33974
17	-.74188	.11988	.76242	.38426
18	-.82818	.13947	.85095	.42887
19	-.95605	.16682	.98175	.49480
20	-1.05559	.18574	1.08309	.54588
21	-1.15514	.20344	1.18461	.59704
22	-1.25482	.22141	1.28672	.64830
23	-1.35459	.23878	1.38816	.69963
24	-1.45445	.25537	1.49015	.75103
25	-1.55444	.27134	1.59233	.80253
26	-1.65454	.28667	1.69470	.85413
27	-1.75475	.30113	1.79724	.90581
28	-1.85507	.31463	1.89990	.95755
29	-1.93750	.32497	1.98414	1.00000

STATION	AE	TSE	TWAL	TAWL	TAWT	TBAR
1	1717.945	1228.100	600.000	1328.793	1330.117	937.814
2	1681.141	1176.044	600.000	1319.057	1329.405	921.761
3	1695.335	1195.986	600.000	1322.774	1331.967	927.909
4	1509.351	947.973	600.000	1278.146	1301.244	851.706
5	1293.892	696.665	600.000	1239.449	1274.755	775.500
6	1297.189	700.200	600.000	1239.920	1275.074	776.572
7	1205.257	604.469	600.000	1228.302	1267.193	748.034
8	1003.105	418.705	600.000	1213.947	1257.652	693.921
9	799.803	266.183	600.000	1213.645	1257.934	651.255
10	797.745	264.815	600.000	1213.743	1257.877	650.881
11	792.492	261.340	600.000	1213.894	1257.990	649.933
12	786.191	257.200	600.000	1214.084	1258.131	648.805
13	779.315	252.721	600.000	1214.302	1258.292	647.586
14	772.423	248.271	600.000	1214.531	1258.460	646.377
15	762.308	241.811	600.000	1214.887	1258.721	644.620
16	752.188	235.434	600.000	1215.265	1258.996	642.901
17	742.247	229.251	600.000	1215.658	1259.281	641.232
18	730.886	222.287	600.000	1216.131	1259.623	639.357
19	639.850	170.361	600.000	1220.728	1262.905	625.540
20	634.381	167.462	600.000	1221.043	1263.125	624.777
21	625.152	162.625	600.000	1221.582	1263.506	623.506
22	611.541	155.620	600.000	1222.394	1264.079	621.671
23	597.107	148.361	600.000	1223.275	1264.700	619.775
24	586.302	143.04	600.000	1223.947	1265.173	618.389
25	578.742	139.375	600.000	1224.423	1265.507	617.437
26	571.374	135.849	600.000	1224.891	1265.835	616.521
27	560.741	130.840	600.000	1225.573	1266.313	615.224
28	550.676	126.185	600.000	1226.224	1266.770	614.021
29	547.016	124.512	600.000	1226.462	1266.937	613.590

TION	RW	SW	SUTHL	RHSW	RHSE	HEADW	HEADL	NUW	MUBAR
1	0.0	-.6	1.294	.9459E-03	.4621E-03	.7064E+03	.3451E+03	.4453E-03	.6583E-06
2	9850.6	-.6	1.294	.8478E-03	.4325E-03	.8983E+03	.4583E+03	.4968E-03	.6471E-06
3	27928.7	-.6	1.294	.8766E-03	.4398E-03	.8238E+03	.4133E+03	.6805E-03	.6514E-06
4	49531.3	-.6	1.294	.6245E-03	.3952E-03	.1517E+04	.9604E+03	.6745E-03	.5979E-06
5	60060.3	-.6	1.294	.4489E-03	.3866E-03	.1768E+04	.1523E+04	.9384E-03	.5444E-06
6	74851.1	-.6	1.294	.4504E-03	.3859E-03	.1765E+04	.1512E+04	.9352E-03	.5452E-06
7	82078.0	-.6	1.294	.3853E-03	.3824E-03	.1731E+04	.1719E+04	.1093E-02	.5251E-06
8	67427.4	-.6	1.294	.2433E-03	.3486E-03	.1365E+04	.1953E+04	.1731E-02	.4871E-06
9	66645.2	-.6	1.294	.1264E-03	.2895E-03	.8382E+03	.1889E+04	.3279E-02	.4572E-06
10	161591.6	-.6	1.294	.1274E-03	.2887E-03	.8326E+03	.1886E+04	.3306E-02	.4569E-06
11	252390.3	-.6	1.294	.1249E-03	.2867E-03	.8185E+03	.1879E+04	.3373E-02	.4563E-06
12	338395.7	-.6	1.294	.1218E-03	.2841E-03	.8013E+03	.1869E+04	.3458E-02	.4555E-06
13	419319.3	-.6	1.294	.1184E-03	.2812E-03	.7825E+03	.1858E+04	.3556E-02	.4546E-06
14	496082.2	-.6	1.294	.1152E-03	.2783E-03	.7640E+03	.1846E+04	.3657E-02	.4538E-06
15	561362.1	-.6	1.294	.1105E-03	.2741E-03	.7370E+03	.1829E+04	.3813E-02	.4525E-06
16	620923.4	-.6	1.294	.1057E-03	.2695E-03	.7096E+03	.1809E+04	.3983E-02	.4513E-06
17	671605.5	-.6	1.294	.1010E-03	.2643E-03	.6815E+03	.1784E+04	.4170E-02	.4501E-06
18	714749.9	-.6	1.294	.9601E-04	.2591E-03	.6518E+03	.1759E+04	.4387E-02	.4488E-06
19	516114.7	-.6	1.294	.5875E-04	.2069E-03	.4172E+03	.1470E+04	.7169E-02	.4391E-06
~~20~~	~~564250.8~~	~~-.6~~	~~1.294~~	~~.5649E-04~~	~~.2010E-03~~	~~.3993E+03~~	~~.1431E+04~~	.7509E-02	.4386E-06
21	561145.9	-.6	1.294	.5277E-04	.1947E-03	.3772E+03	.1392E+04	.7982E-02	.4377E-06
22	554734.7	-.6	1.294	.4790E-04	.1847E-03	.3444E+03	.1326E+04	.8793E-02	.4364E-06
23	535940.6	-.6	1.294	.4275E-04	.1729E-03	.3093E+03	.1251E+04	.9852E-02	.4351E-06
24	527199.3	-.6	1.294	.3909E-04	.1640E-03	.2840E+03	.1191E+04	.1077E-01	.4341E-06
25	528716.8	-.6	1.294	.3663E-04	.1577E-03	.2670E+03	.1149E+04	.1150E-01	.4334E-06
26	526322.1	-.6	1.294	.3421E-04	.1511E-03	.2501E+03	.1104E+04	.1231E-01	.4328E-06
27	503362.7	-.6	1.294	.3079E-04	.1412E-03	.2260E+03	.1036E+04	.1368E-01	.4319E-06
28	483386.8	-.6	1.294	.2792E-04	.1327E-03	.2057E+03	.9780E+03	.1509E-01	.4310E-06
29	544115.0	-.6	1.294	.2766E-04	.1343E-03	.2055E+03	.9904E+03	.1512E-01	.4307E-06

RESULTS FROM INTEGRATION OF LAMINAR B.L. DIFFERENTIAL EQUATION

S (FT)	S/L	ME	PW/D(S/L)	TO/TE	SW	CORR'N NO.	CLAM2M
0.	0.	.71138E+00	.91196E+02	.11012E+01	-.55634E+00	-.12797E+00	-.95422E-03
.19841E-01	.10000E-01	.21351E+01	.13103E+02	.19079E+01	-.55634E+00	-.41016E-01	-.23623E-03
.39683E-01	.20000E-01	.35609E+01	.19307E+03	.34678E+01	-.55634E+00	-.27918E+00	-.99523E-05
.59524E-01	.30000E-01	.44725E+01	.15390E+02	.49731E+01	-.55634E+00	-.68792E-01	-.73082E-05
.79365E-01	.40000E-01	.45202E+01	.53560E+01	.50864E+01	-.55634E+00	-.29689E-01	-.63375E-05
.99207E-01	.50000E-01	.45235E+01	.39704E+01	.50973E+01	-.55634E+00	-.25145E-01	-.94181E-05
.11905E+00	.60000E-01	.45268E+01	.25848E+01	.50983E+01	-.55634E+00	-.18450E-01	-.10565E-04
.13889E+00	.70000E-01	.45301E+01	.11992E+01	.51043E+01	-.55634E+00	-.96099E-02	-.11806E-04
.15873E+00	.80000E-01	.45362E+01	.62417E+00	.51154E+01	-.55634E+00	-.56176E-02	-.13144E-04
.17857E+00	.90000E-01	.45447E+01	.70524E+00	.51397E+01	-.55634E+00	-.70681E-02	-.14465E-04
.19841E+00	.10000E+00	.45532E+01	.78631E+00	.51461E+01	-.55634E+00	-.86820E-02	-.15744E-04
.21825E+00	.11000E+00	.45616E+01	.86737E+00	.51616E+01	-.55634E+00	-.10458E-01	-.16986E-04
.23810E+00	.12000E+00	.45704E+01	.94128E+00	.51777E+01	-.55634E+00	-.12303E-01	-.18187E-04
.25794E+00	.13000E+00	.45807E+01	.97478E+00	.51963E+01	-.55634E+00	-.13747E-01	-.19351E-04
.27778E+00	.14000E+00	.45910E+01	.10075E+01	.52151E+01	-.55634E+00	-.15260E-01	-.20477E-04
.29762E+00	.15000E+00	.46012E+01	.10406E+01	.52341E+01	-.55634E+00	-.16843E-01	-.21567E-04
.31746E+00	.16000E+00	.46115E+01	.10737E+01	.52532E+01	-.55634E+00	-.18495E-01	-.22620E-04
.33730E+00	.17000E+00	.46226E+01	.10930E+01	.52736E+01	-.55634E+00	-.19983E-01	-.23638E-04
.35714E+00	.18000E+00	.46340E+01	.11076E+01	.52945E+01	-.55634E+00	-.21429E-01	-.24621E-04
.37699E+00	.19000E+00	.46454E+01	.11222E+01	.53156E+01	-.55634E+00	-.22916E-01	-.25571E-04
.39683E+00	.20000E+00	.46567E+01	.11368E+01	.53369E+01	-.55634E+00	-.24427E-01	-.26488E-04
.41667E+00	.21000E+00	.46682E+01	.11668E+01	.53583E+01	-.55634E+00	-.26327E-01	-.27372E-04
.43651E+00	.22000E+00	.46797E+01	.12289E+01	.53797E+01	-.55634E+00	-.29045E-01	-.28216E-04
.45635E+00	.23000E+00	.46913E+01	.12911E+01	.54013E+01	-.55634E+00	-.31888E-01	-.29018E-04
.47619E+00	.24000E+00	.47028E+01	.13532E+01	.54231E+01	-.55634E+00	-.34856E-01	-.29778E-04
.49603E+00	.25000E+00	.47144E+01	.14154E+01	.54451E+01	-.55634E+00	-.37944E-01	-.30496E-04
.51588E+00	.26000E+00	.47311E+01	.14874E+01	.54762E+01	-.55634E+00	-.41694E-01	-.31169E-04
.53572E+00	.27000E+00	.47484E+01	.15604E+01	.55087E+01	-.55634E+00	-.45683E-01	-.31791E-04
.55556E+00	.28000E+00	.47656E+01	.16335E+01	.55416E+01	-.55634E+00	-.49855E-01	-.32364E-04
.57540E+00	.29000E+00	.47829E+01	.17065E+01	.55749E+01	-.55634E+00	-.54209E-01	-.32885E-04
.59524E+00	.30000E+00	.48003E+01	.17476E+01	.56086E+01	-.55634E+00	-.57688E-01	-.33362E-04
.61508E+00	.31000E+00	.48180E+01	.17529E+01	.56420E+01	-.55634E+00	-.60060E-01	-.33806E-04
.63492E+00	.32000E+00	.48356E+01	.17581E+01	.56762E+01	-.55634E+00	-.62445E-01	-.34222E-04
.65476E+00	.33000E+00	.48533E+01	.17632E+01	.57104E+01	-.55634E+00	-.64888E-01	-.34610E-04
.67461E+00	.34000E+00	.48709E+01	.17691E+01	.57452E+01	-.55634E+00	-.67402E-01	-.34972E-04
.69445E+00	.35000E+00	.48886E+01	.18024E+01	.57793E+01	-.55634E+00	-.70985E-01	-.35305E-04
.71429E+00	.36000E+00	.49064E+01	.18357E+01	.58138E+01	-.55634E+00	-.74673E-01	-.35606E-04
.73413E+00	.37000E+00	.49241E+01	.18691E+01	.58487E+01	-.55634E+00	-.78466E-01	-.35878E-04
.75397E+00	.38000E+00	.49418E+01	.19024E+01	.58840E+01	-.55634E+00	-.82366E-01	-.36120E-04
.77381E+00	.39000E+00	.49612E+01	.21170E+01	.59226E+01	-.55634E+00	-.94596E-01	-.36323E-04
.79365E+00	.40000E+00	.49820E+01	.24661E+01	.59631E+01	-.55634E+00	-.11360E+00	-.36434E-04
.81350E+00	.41000E+00	.50027E+01	.28152E+01	.60044E+01	-.55634E+00	-.13337E+00	-.36448E-04
.83334E+00	.42000E+00	.50234E+01	.31643E+01	.60463E+01	-.55634E+00	-.15384E+00	-.36376E-04
.85318E+00	.43000E+00	.50563E+01	.34582E+01	.61084E+01	-.55634E+00	-.17442E+00	-.36228E-04
.87302E+00	.44000E+00	.51850E+01	.33767E+01	.63337E+01	-.55634E+00	-.19231E+00	-.36030E-04
.89286E+00	.45000E+00	.53136E+01	.31753E+01	.65763E+01	-.55634E+00	-.21268E+00	-.35811E-04
.91270E+00	.46000E+00	.54423E+01	.30339E+01	.68382E+01	-.55634E+00	-.23002E+00	-.35579E-04
.93254E+00	.47000E+00	.55709E+01	.28924E+01	.71218E+01	-.55634E+00	-.26295E+00	-.35339E-04
.95238E+00	.48000E+00	.56996E+01	.27510E+01	.74300E+01	-.55634E+00	-.29424E+00	-.35096E-04
.97223E+00	.49000E+00	.58282E+01	.26095E+01	.77660E+01	-.55634E+00	-.32000E+00	-.33712E-04
.99207E+00	.50000E+00	.58959E+01	.24362E+01	.79572E+01	-.55634E+00	-.30785E+00	-.31599E-04
.10119E+01	.51000E+00	.59073E+01	.22334E+01	.79788E+01	-.55634E+00	-.28460E+00	-.31420E-04
[illegible]	.52000E+00	.59186E+01	.20306E+01	.80056E+01	-.55634E+00	-.26079E+00	-.31266E-04
.10516E+01	.53000E+00	.59300E+01	.18279E+01	.80328E+01	-.55634E+00	-.23696E+00	-.31136E-04
.10714E+01	.54000E+00	.59414E+01	.16251E+01	.80598E+01	-.55634E+00	-.21283E+00	-.31096E-04

.10913E+01	.55000E+00	.59561E+01	.15784E+01	.80947E+01	-.55634E+00	-.20976E+00	-.30954E-04
.11119E+01	.56000E+00	.59757E+01	.17540E+01	.81408E+01	-.55634E+00	-.23770E+00	-.30857E-04
.11310E+01	.57000E+00	.59953E+01	.19295E+01	.81874E+01	-.55634E+00	-.26649E+00	-.30730E-04
.11508E+01	.58000E+00	.60148E+01	.21051E+01	.82345E+01	-.55634E+00	-.29611E+00	-.30593E-04
.11706E+01	.59000E+00	.60344E+01	.22807E+01	.82872E+01	-.55634E+00	-.32000E+00	-.29819E-04
.11905E+01	.60000E+00	.60570E+01	.24464E+01	.83368E+01	-.55634E+00	-.32000E+00	-.27079E-04
.12103E+01	.61000E+00	.60866E+01	.25883E+01	.84076E+01	-.55634E+00	-.32000E+00	-.24742E-04
.12302E+01	.62000E+00	.61166E+01	.27303E+01	.84797E+01	-.55634E+00	-.32000E+00	-.22669E-04
.12500E+01	.63000E+00	.61464E+01	.28723E+01	.85529E+01	-.55634E+00	-.32000E+00	-.20819E-04
.12698E+01	.64000E+00	.61762E+01	.30142E+01	.86275E+01	-.55634E+00	-.32000E+00	-.19162E-04
.12897E+01	.65000E+00	.62066E+01	.31244E+01	.87038E+01	-.55634E+00	-.32000E+00	-.17840E-04
.13095E+01	.66000E+00	.62395E+01	.30787E+01	.87838E+01	-.55634E+00	-.32000E+00	-.17461E-04
.13294E+01	.67000E+00	.62725E+01	.30330E+01	.88652E+01	-.55634E+00	-.32000E+00	-.17082E-04
.13492E+01	.68000E+00	.63054E+01	.29873E+01	.89482E+01	-.55634E+00	-.32000E+00	-.16709E-04
.13691E+01	.69000E+00	.63384E+01	.29416E+01	.90327E+01	-.55634E+00	-.32000E+00	-.16342E-04
.13889E+01	.70000E+00	.63710E+01	.28924E+01	.91180E+01	-.55634E+00	-.31969E+00	-.15991E-04
.14087E+01	.71000E+00	.63967E+01	.27510E+01	.91829E+01	-.55634E+00	-.31063E+00	-.15885E-04
.14286E+01	.72000E+00	.64223E+01	.26096E+01	.92470E+01	-.55634E+00	-.30123E+00	-.15788E-04
.14484E+01	.73000E+00	.64479E+01	.24682E+01	.93129E+01	-.55634E+00	-.29140E+00	-.15696E-04
.14683E+01	.74000E+00	.64735E+01	.23268E+01	.93798E+01	-.55634E+00	-.28126E+00	-.15616E-04
.14881E+01	.75000E+00	.64991E+01	.21854E+01	.94476E+01	-.55634E+00	-.27066E+00	-.15542E-04
.15079E+01	.76000E+00	.65183E+01	.21132E+01	.94971E+01	-.55634E+00	-.26600E+00	-.15473E-04
.15278E+01	.77000E+00	.65368E+01	.20490E+01	.95448E+01	-.55634E+00	-.26203E+00	-.15408E-04
.15476E+01	.78000E+00	.65552E+01	.19847E+01	.95929E+01	-.55634E+00	-.25793E+00	-.15340E-04
.15675E+01	.79000E+00	.65736E+01	.19204E+01	.96416E+01	-.55634E+00	-.25371E+00	-.15286E-04
.15873E+01	.80000E+00	.65920E+01	.18562E+01	.96908E+01	-.55634E+00	-.24935E+00	-.15232E-04
.16071E+01	.81000E+00	.66104E+01	.18967E+01	.97399E+01	-.55634E+00	-.25898E+00	-.15177E-04
.16270E+01	.82000E+00	.66288E+01	.19728E+01	.97872E+01	-.55634E+00	-.27360E+00	-.15118E-04
.16468E+01	.83000E+00	.66472E+01	.20489E+01	.98358E+01	-.55634E+00	-.28869E+00	-.15055E-04
.16667E+01	.84000E+00	.66655E+01	.21249E+01	.98849E+01	-.55634E+00	-.30405E+00	-.14987E-04
.16865E+01	.85000E+00	.66839E+01	.22010E+01	.99346E+01	-.55634E+00	-.31976E+00	-.14914E-04
.17064E+01	.86000E+00	.67075E+01	.22853E+01	.99971E+01	-.55634E+00	-.32000E+00	-.14019E-04
.17262E+01	.87000E+00	.67348E+01	.23754E+01	.10069E+02	-.55634E+00	-.32000E+00	-.13105E-04
.17460E+01	.88000E+00	.67620E+01	.24654E+01	.10142E+02	-.55634E+00	-.32000E+00	-.12266E-04
.17659E+01	.89000E+00	.67893E+01	.25555E+01	.10217E+02	-.55634E+00	-.32000E+00	-.11493E-04
.17857E+01	.90000E+00	.68166E+01	.26456E+01	.10292E+02	-.55634E+00	-.32000E+00	-.10780E-04
.18056E+01	.91000E+00	.68436E+01	.26205E+01	.10366E+02	-.55634E+00	-.31367E+00	-.10366E-04
.18254E+01	.92000E+00	.68703E+01	.24360E+01	.10438E+02	-.55634E+00	-.29814E+00	-.10319E-04
.18452E+01	.93000E+00	.68970E+01	.22514E+01	.10511E+02	-.55634E+00	-.28197E+00	-.10260E-04
.18651E+01	.94000E+00	.69237E+01	.20669E+01	.10585E+02	-.55634E+00	-.26510E+00	-.10216E-04
.18849E+01	.95000E+00	.69504E+01	.18823E+01	.10660E+02	-.55634E+00	-.24744E+00	-.10179E-04
.19048E+01	.96000E+00	.69735E+01	.16816E+01	.10726E+02	-.55634E+00	-.22584E+00	-.10147E-04
.19246E+01	.97000E+00	.69856E+01	.14313E+01	.10759E+02	-.55634E+00	-.19419E+00	-.10124E-04
.19445E+01	.98000E+00	.69977E+01	.11810E+01	.10791E+02	-.55634E+00	-.16202E+00	-.10109E-04
.19643E+01	.99000E+00	.70098E+01	.93063E+00	.10827E+02	-.55634E+00	-.12922E+00	-.10104E-04
.19841E+01	.10000E+01	.70220E+01	.68030E+00	.10862E+02	-.55634E+00	-.95705E-01	-.10108E-04

DM/D(S/L) Mach number gradient in the nondimensionalized arc length, S/L, where $0 \leq S/L \leq 1$

TO/TE ratio of total temperature to local static temperature

SW enthalpy function at the wall

CORR'N NO. pressure gradient parameter, n (see theory)

CTAB2N dependent variable (see theory)

TURBULENT DIFFERENTIAL EQUATIONS - SOLUTION FOR F AND FORMI

S	F	FORMI	S	F	FORMI	S	F	FORMI	S	F	FORMI
1.08309	6488.0	2.1174	1.10293	6497.7	1.5076	1.12277	6529.5	1.4239	1.14261	6569.6	1.3530
1.16246	6612.9	1.3097	1.18239	6655.5	1.3000	1.20214	6693.4	1.3000	1.22198	6720.6	1.3000
1.24182	6755.0	1.3000	1.26166	6778.6	1.3000	1.28150	6798.0	1.3000	1.30135	6813.8	1.3000
1.32119	6829.1	1.3000	1.34103	6843.8	1.3000	1.36087	6858.0	1.3000	1.38071	6871.8	1.3000
1.40055	6885.5	1.3000	1.42039	6901.0	1.3000	1.44023	6918.4	1.3000	1.46008	6937.7	1.3000
1.47992	6958.9	1.3000	1.49976	6981.8	1.3000	1.51960	7005.4	1.3000	1.53944	7029.5	1.3000
1.55928	7054.2	1.3000	1.57912	7079.4	1.3000	1.59897	7105.0	1.3000	1.61881	7126.7	1.3000
1.63865	7150.0	1.3000	1.65849	7168.9	1.3000	1.67833	7185.3	1.3000	1.69817	7199.3	1.3000
1.71801	7210.6	1.3000	1.73786	7218.9	1.3000	1.75770	7224.2	1.3000	1.77754	7220.7	1.3000
1.79738	7226.4	1.3000	1.81722	7276.3	1.3000	1.83706	7229.2	1.3000	1.85690	7235.3	1.3000
1.87674	7244.3	1.3000	1.89659	7256.4	1.3000	1.91643	7272.2	1.3000	1.93627	[illegible]	1.3000
1.95611	7379.2	1.3000	1.97595	7359.5	1.3000	1.98414	7364.9	1.3000			

PRINCIPAL BOUNDARY LAYER INFORMATION

INSTABILITY DOES NOT OCCUR

TRANSITION OCCURS AT STATION 20

SEPARATION DOES NOT OCCUR

LAMINAR BOUNDARY LAYER - STATIONS 1 TO 19

TURBULENT BOUNDARY LAYER - STATIONS 20 TO 29

STATION	X	S	DELSR	THET	DELTA	FORM	FORMI
1	-.003679	0.000000	.000148	.000055	.000393	.8735	1.6202
2	-.005337	.003362	.000056	.000057	.000411	.9064	1.0951
3	-.008754	.009789	.000044	.000047	.000328	.9297	1.6418
4	-.012155	.015155	.000099	.000061	.000457	1.0[illegible]60	2.0187
5	-.016162	.020080	.000227	.000080	.000680	2.8286	2.3796
6	-.020358	.025005	.000198	.000069	.000610	2.8590	2.4369
7	-.024618	.029931	.000272	.000074	.000732	3.6503	2.6377
8	-.029155	.034856	.000664	.000109	.001364	6.1126	2.9492
9	-.054263	.060492	.000891	.000089	.001417	10.0514	2.8890
10	-.140047	.147765	.001156	.000116	.001829	9.9418	2.8063
11	-.225848	.235135	.001453	.000144	.002289	10.1046	2.8136
12	-.311686	.322614	.001727	.000168	.002703	10.3697	2.8246
13	-.397573	.410224	.001990	.000189	.003095	10.5374	2.8357
14	-.483521	.497997	.002245	.000208	.003469	10.7894	2.854[illegible]
15	-.569546	.585950	.002554	.000229	.003914	11.1699	2.8799
16	-.655675	.674096	.002865	.000248	.004354	11.5458	2.8974
17	-.741884	.762423	.003195	.000267	.004822	11.9609	2.9261
18	-.828185	.850946	.003609	.000285	.005449	12.0678	3.0367
19	-.956053	.981753	.008474	.000482	.011855	17.5668	3.2372
20	-1.055587	1.083090	.013872	.000982	.038699	14.1294	2.1174
21	-1.155145	1.184612	.011947	.001032	.091549	11.5658	1.3000
22	-1.254817	1.286321	.013390	.001103	.102656	12.1351	1.3000
23	-1.354586	1.388163	.015150	.001185	.116148	12.7819	1.3000
24	-1.454454	1.490153	.016761	.001260	.128501	13.2979	1.3000
25	-1.554438	1.592329	.018151	.001327	.139154	13.6763	1.3000
26	-1.654545	1.694704	.019661	.001398	.150737	14.0597	1.3000
27	-1.754750	1.797242	.021935	.001498	.168171	14.6399	1.3000
28	-1.855074	1.899900	.024297	.001596	.186278	15.2204	1.3000
29	-1.937500	1.984135	.024634	.001596	.188861	15.4396	1.3000

STATION	CFE	TAUW	RTH	UTDY	NUSS	HIRAN	CRN
1	0.00000	0.00000	150.9	0.00	0.00	0.0000	3.342
2	.01430	6.55152	167.8	4220125.08	19.73	15335.3031	3.211
3	.01749	7.22898	133.6	5399768.09	73.13	19621.9493	2.955
4	.00697	6.09080	199.4	3171835.34	70.68	11525.9751	2.728
5	.00298	4.53686	239.9	1720188.43	54.02	6250.9074	2.547
6	.00401	6.06430	207.6	1883690.37	73.61	6845.0490	3.119
7	.00345	5.93647	204.2	1454174.26	69.27	5284.2517	3.644
8	.00190	3.71943	214.1	698707.72	39.67	2539.2173	4.207
9	.00114	2.14798	97.6	573973.17	56.58	2085.7320	2.781
10	.00071	1.34568	127.1	467699.32	112.60	1699.5494	2.137
11	.00058	1.09462	154.4	371214.86	142.18	1348.9392	2.188
12	.00051	.95281	175.7	311212.66	163.50	1130.9003	2.269
13	.00046	.85327	193.1	269051.46	179.67	977.6927	2.348
14	.00043	.79533	207.2	236447.91	191.61	859.2163	2.487
15	.00041	.74392	219.0	205480.72	195.81	746.6862	2.673
16	.00038	.68862	226.2	182256.97	199.68	662.2946	2.785
17	.00037	.65434	235.3	161746.15	200.30	587.7613	2.978
18	.00041	.71877	239.3	141495.59	195.42	514.1738	3.734
19	.00038	.55898	253.6	75665.77	119.67	274.9581	5.362
20	.00033	.47181	493.3	160337.71	261.88	582.0433	.685
21	.00114	1.59017	489.1	538871.95	962.09	1958.1801	.666
22	.00109	1.44863	475.9	488921.77	947.04	1776.0686	.639
23	.00104	1.30069	457.6	437168.70	917.99	1588.6056	.610
24	.00100	1.19308	445.9	399786.51	895.62	1452.7644	.589
25	.00097	1.11846	440.7	374007.89	894.87	1359.0887	.575
26	.00095	1.04568	434.3	348977.07	888.23	1268.1305	.561
27	.00091	.94559	419.6	314688.57	848.81	1143.5312	.541
28	.00088	.86105	406.7	285811.01	814.39	1038.5944	.523
29	.00087	.85825	405.4	284017.10	846.74	1034.2560	.516

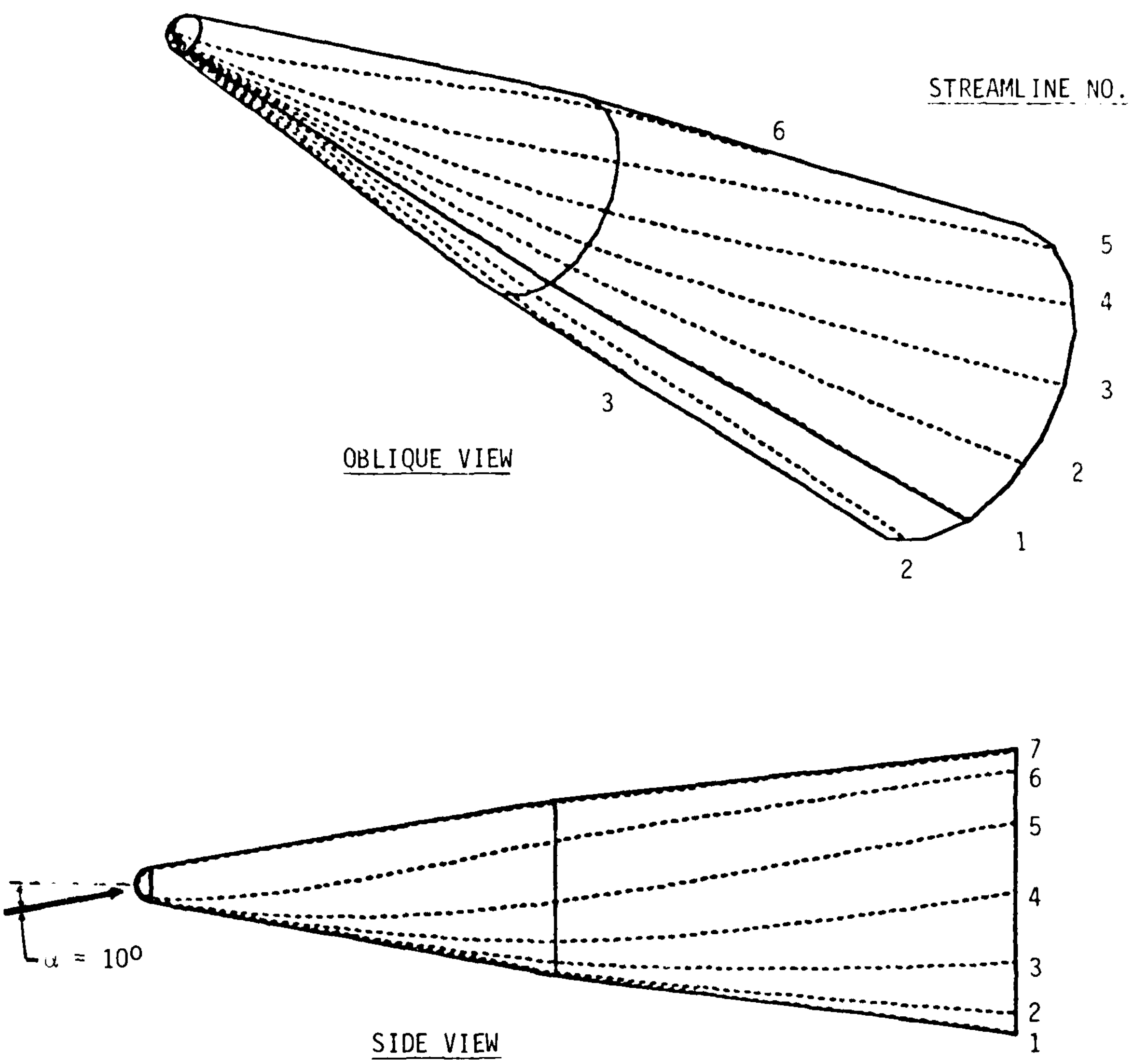


Figure 4 . Streamline Distribution for Case 2 Bicone at $\alpha = 10^{o}$

CASE 3: X-24C FOREBODY

This case traces streamlines over the forebody of the X-24C using the program-specified starting point option (ISTART = 2). "Additional" streamlines are not calculated. A plot of the streamlines is shown in Figure (5) which follows the last output page. This plot was generated by program TEKPIC, an interactive computer graphics code (Reference 2) used to display Mark IV geometries and streamlines. The reader should pay particular attention to the preparation of the X-24C geometry - no Panels contain rapid changes in curvature. Shown in the plot are the boundaries of each of the panels; the individual Elements are not drawn.

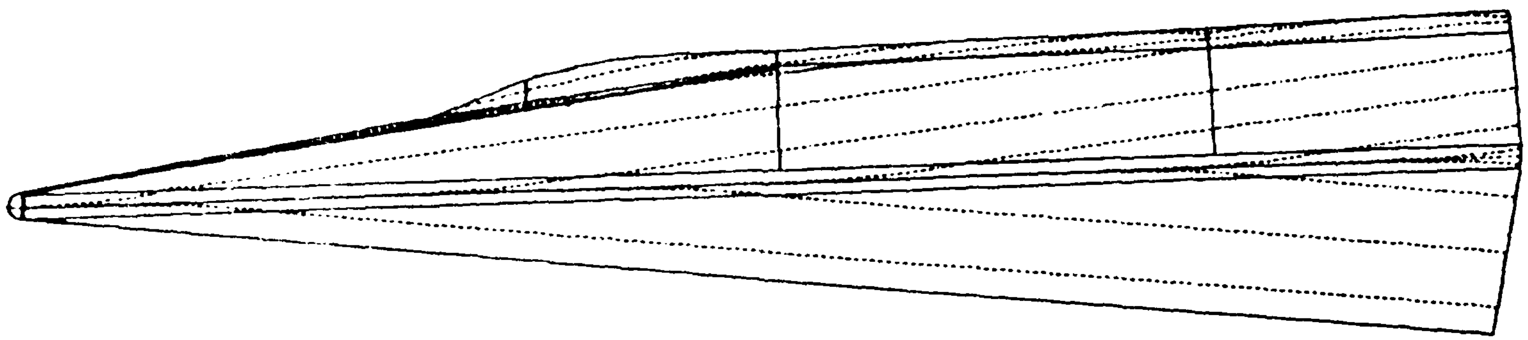


Figure 5. Streamline Distribution for X-24C Forebody (α = 5°)

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

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0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

12
 80000020              4240-341              -
NCAP  2          1                           PANEL ID CARD
NOSECAP                                      ELLIPSE GNRTN          10      NOSE 4
-13.403    0.      180.   11 0.              0.          17.68  0.      0       NOSE 5
-13.601    0.      180.   11 1.243           1.298       17.66  0.      0            5
-14.177    0.      180.   11 2.355           2.477       17.66  0.      0            5
-15.078    0.      180.   11 3.255           3.423       17.66  0.      0            5
-16.222    0.      180.   11 3.327           4.074       17.66  0.      0            5
-17.605    0.      180.   11 3.979           4.347       17.66  0.      4            5
FRC1  2          1                           PANEL ID CARD
FOREBODY CROWN (1ST PIECE)                   ELLIPSE GNRTN          10      FRC1 4
-17.605    116.7 180.    3  3.579             3.579      18.537 0.      0       FRC1 5
-80.0      116.7 180.    3 11.170            11.176      25.535 0.      0            5
-122.5     116.7 180.    3 16.341            16.341      30.302 0.      4            5
LE    2          1                           PANEL ID CARD
LEADING EDGE                                 ELLIPSE GNRTN          10      LEDG 4
-17.605    0.      116.7   5  4.0             4.0        17.318  0.142 0    LEDG 5
-80.       0.      116.7   5  4.0             4.0        13.708 13.974 0         5
-122.5     0.      115.7   5  4.0             4.0        11.249 23.396 0         5
-139.0     0.      116.7   5  4.0             4.0        10.294 27.054 0         5
-158.0     0.      116.7   5  4.0             4.0         9.195 31.266 0         5
-188.0     0.      116.7   5  4.0             4.0         7.459 37.917 0         5
-228.0     0.      116.7   5  4.0             4.0         5.145 46.784 0         5
-348.0     0.      116.7   5  4.0             4.0        -1.798 73.387 0         5
-432.0     0.      116.7   5  4.0             4.0        -6.659 92.009 4         5
FBFS  1          1                           PANEL ID CARD
 1     FOREBODY FLAT SIDE                    ELEMENT DATA
-17.605     3.716     19.115     2-17.605     3.543     19.459          FBFS 3
-17.605     3.368     19.807      -17.605     3.198     20.144               3
-80.0      17.549     15.505     1-80.0      15.026     20.521               3
-80.0      12.598     25.543      -80.0       9.961     30.552               3
-122.5     26.971     13.847     1-122.5     22.047     21.245               3
-122.5     18.721     27.449      -122.5     14.601     37.641               3
-139.0     30.679     12.091     1-139.0     25.604     21.526               3
-139.0     21.136     30.966      -139.0     16.395     40.396               3
-158.0     34.841     10.992     1-158.0     29.300     21.850               3
-158.0     23.917     32.712      -158.0     18.460     43.560               3
-188.0     41.492      9.256     1-188.0     34.848     22.361               3
-188.0     28.398     35.470      -188.0     21.721     47.566               3
-228.0     50.360      6.942     1-228.0     42.263     23.042               3
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

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0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

-228.0    34.163    39.147    -228.0    26.070    55.238    3         3
RTMP  1         1                    PANEL ID CARD
 1    BOTTOM RAMP                    ELEMENT DATA
-17.605   0.        13.318   2-17.605   8.047     13.318         RAMP 3
-17.605   0.995     13.318    -17.605   0.142     13.318              3
-80.0     0.        9.708    1-80.0     4.058     9.708               3
-80.0     9.316     9.708     -80.0     13.974    9.708               3
-122.5    0.        7.249    1-122.5    7.799     7.249               3
-122.5    15.507    7.249     -122.5    23.396    7.249               3
-139.0    0.        6.294    1-139.0    9.016     6.294               3
-139.0    18.036    6.294     -139.0    27.054    6.294               3
-158.0    0.        5.195    1-158.0    10.422    5.195               3
-158.0    20.844    5.195     -158.0    31.266    5.195               3
-188.0    0.        3.459    1-188.0    12.639    3.459               3
-188.0    25.278    3.459     -188.0    37.917    3.459               3
-228.0    0.        1.145    1-228.0    15.595    1.145               3
-228.0    31.180    1.145     -228.0    46.764    1.145               3
-348.0    0.        -5.798   1-348.0    24.462    -5.798              3
-348.0    48.925    -5.798    -348.0    73.367    -5.798              3
-432.0    0.        -10.659  1-432.0    30.670    -10.659             3
-432.0    61.339    -10.659   -432.0    92.009    -10.659   3         3
FBC2  1         1                    PANEL ID CARD
 1    FOREBODY CROWN (2ND PIECE)     ELEMENT DATA
-122.5    14.681    37.641   2-122.5    10.977    42.407         FBC2 3
-122.5    5.887     45.547    -122.5    0.        46.643              3
-139.0    16.395    40.396   1-139.0    13.312    44.445              3
-139.0    9.103     47.784    -139.0    4.447     48.942              3
-158.0    18.468    43.565   1-158.0    16.0      46.758              3
-158.0    13.0      49.561    -158.0    9.053     51.688    3         3
FBC3  1         1                    PANEL ID CARD
 1    FOREBODY CROWN (3RD PIECE)     ELEMENT DATA
-158.0    18.468    43.566   2-158.0    16.0      46.758         FBC3 3
-158.0    13.0      49.597    -158.0    9.053     51.688              3
-188.0    21.711    48.763   1-188.0    20.208    50.771              3
-188.0    18.375    52.479    -188.0    16.344    53.835              3
-228.0    26.065    55.645   1-228.0    25.000    56.874              3
-228.0    25.536    56.445    -228.0    25.273    56.723    3         3
CNP1  1         1                    PANEL ID CARD
 1    CANOPY (1ST PIECE)             ELEMENT DATA
-122.5    0.        46.643   2-122.5    0.        46.643         CNP1 3
-122.5    0.        46.643    -122.5    0.        46.643              3
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

-122.5    0.        46.643     -122.5    0.        46.643              3
-122.5    0.        46.643     -122.5    0.        46.643              3
-122.5    0.        46.643     -122.5    0.        46.643              3
-139.     4.447     48.942    1-139.     4.00      50.03               3
-139.     3.60      50.93      -139.     3.25      51.81               3
-139.     2.91      52.6       -139.     2.56      53.25               3
-139.     2.00      53.75      -139.     1.50      54.10               3
-139.     0.75      54.40      -139.     0.        54.50               3
-158.     9.653     51.60     1-158.     8.50      53.90               3
-158.     7.40      56.08      -158.     6.35      58.17               3
-158.     5.33      60.20      -158.     4.56      61.40               3
-158.     3.66      62.40      -158.     2.75      63.13               3
-158.     1.37      63.75      -158.     0.        64.00     5         3
CNP2  1          1                 PANEL ID CARD
 1    CANOPY (2ND PIECE)           ELEMENT DATA
-158.      9.653    51.60     2-158.      8.50     53.90          CNP2 3
-158.      7.40     56.08      -158.      6.35     58.17               3
-158.      5.33     60.20      -158.      4.56     61.4                3
-158.      3.66     62.40      -158.      2.75     63.13               3
-158.      1.37     63.75      -158.      0.       64.00               3
-173.     13.00     52.72     1-173.     12.62     55.17               3
-173.     11.04     57.62      -173.     10.37     60.97               3
-173.      9.09     62.52      -173.      7.86     64.70               3
-173.      6.25     66.25      -173.      4.56     67.37               3
-173.      2.34     68.20      -173.      0.       66.40               3
-188.     16.344    53.938    1-188.     15.65     55.75               3
-188.     14.92     57.67      -188.     14.21     59.58               3
-188.     13.50     61.50      -188.     11.50     64.60               3
-188.      9.60     67.23      -188.      6.73     69.23               3
-188.      3.47     70.47      -188.      0.       76.90               3
-206.     20.36     55.18     1-206.     19.93     56.33               3
-206.     19.50     57.49      -206.     [illegible] 55.63             3
-206.     18.65     59.78      -206.     15.55     55.91               3
-206.     13.10     67.76      -206.      9.10     76.01               3
-206.      4.71     71.74      -206.      0.       72.20               3
-228.     25.271    56.827    1-228.     25.271    56.825              3
-228.     25.271    56.873     -228.     25.271    56.875              3
-228.     25.271    56.9.3     -228.     21.271    62.952              3
-228.     17.487    66.610     -228.     12.[illegible] 69.695         3
-228.      6.288    71.71[illegible] -228. 0.      72.46[illegible] 5  3
FLT1  1          1                 PANEL ID CARD
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 1    FLAT TOP (1ST PIECE)          ELEMENT DATA
-228.        0.     72.4     2-228.      0.      72.4               FLT1 3
-228.        0.     72.4      -228.      0.      72.4                    3
-300.     9.997     72.4     1-300.   6.664      72.4                    3
-300.     3.332     72.4      -300.      0.      72.4                    3
-348.    16.661     72.4     1-348.  11.107      72.4                    3
-348.     5.554     72.4      -348.      0.      72.4         3          3
FLT2  1         1                   PANEL ID CARD
 1    FLAT TOP (2ND PIECE)          ELEMENT DATA
-348.    16.661     72.4     2-348.  11.107      72.4               FLT2 3
-348.     5.554     72.4      -348.      0.      72.4                    3
-390.    23.748     72.4     1-390.  15.832      72.4                    3
-390.     7.916     72.4      -390.      0.      72.4                    3
-432.    30.835     72.4     1-432.  20.557      72.4                    3
-432.    10.278     72.4      -432.      0.      72.4         3          3
ALC1  1         1                   PANEL ID CARD
 1    AFT-CANOPY CROWN (1ST PIECE) ELEMENT DATA
-228.    25.271   56.923     2-228.  21.071    62.052               AFC1 3
-228.    17.407   66.410      -228.  12.098    69.863                    3
-228.     6.200   71.712      -228.      0.      72.4                    3
-300.    40.876   53.366     1-300.  36.722    59.756                    3
-300.    31.268   65.986      -300.  24.779    69.079                    3
-300.    17.572   71.559      -300.   9.997      72.4                    3
-348.    51.279   51.051     1-348.  46.022    56.225                    3
-348.    40.507   64.194      -348.  33.233    66.677                    3
-348.    25.154   71.458      -348.  16.661      72.4         3          3
ACC2  1         1                   PANEL ID CARD
 1    AFT-CANOPY CROWN (2ND PIECE) ELEMENT DATA
-348.    51.279   51.061     2-348.  46.622    58.225               AFC2 3
-348.    40.507   64.194      -348.  33.233    66.677                    3
-348.    25.154   71.458      -348.  16.661    72.400                    3
-390.    59.818   58.166     1-390.  54.765    57.630                    3
-390.    48.594   63.850      -390.  41.615    65.521                    3
-390.    32.597   71.416      -390.  23.748    72.400                    3
-432.    68.357   49.271     1-432.  63.308    57.936                    3
-432.    56.681   63.505      -432.  46.7?7    66.365                    3
-432.    40.040   71.37?      -432.  30.835    72.400         3          3
MFLS  1         1                   PANEL ID CARD
 1    MID FLAT SIDE                 ELEMENT DATA
-228.    50.369    5.942     2-228.  42.263    25.042               MDFS 3
-228.    34.163   32.147      -228.  ?.272     50.?25                    3
```

SUPERSONIC-HYPERSONIC ARBITRARY X-24C PROGRAM INPUT DATA

```
0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

-300.      66.323     2.776     1-360.       37.757     19.430              3
-300.      49.573    36.082      -330.   -   40.077     53.360              3
-348.      76.965    -0.011     1-349.       66.443     17.020              3
-348.      59.842    34.040      -343.       51.208     51.061     3        3
AFLS1 1           1                   PANEL ID CARD
 1    AFT FLAT SIDE                   ELEMENT DATA
-348.      76.965    -6.901     2-345.       69.405     17.020          AFFS 3
-348.      59.842    34.049      -348.       51.238     51.061              3
-390.      84.272    -2.431     1-390.       72.454     15.101              3
-390.      68.636    32.634      -397.       59.018     50.106              3
-432.      95.583    -4.961     1-432.       66.368     13.113              3
-432.      77.432    31.227      -432.       68.337     45.271     3        3
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
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 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
 .003958    .003958    .003958
           X-24C STREAMLINES
316
7.18       -2000.     [illegible]   10.[illegible]   [illegible]
1.         1.         1.        [illegible]   [illegible]    0.
0.         0.         0.        0.           0.          0.         0.
 22                             [illegible] CALC [illegible]
 1 2 3 4 5 6 7 8 910100
 1 1001    1.50       1.        1.           1.          [illegible]  3.0
1112131415            200
0                               MASTER DIRECTORY
10 1 7.16                       DATA DIRECTORY
10 1 0.    0.                   [illegible] DIRECTORY
10 1200                         [illegible] DIRECTORY
15 0 0
```

SUPERSONIC-HYPERSONIC ARBITRARY-BODY PROGRAM INPUT DATA

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    1    2    3    4    5    6         6    9   10
   11   12   13   14   15
 1 1 1
 3 1 1 2 0            -1.0          -.033
 1 1
 0 0
 1 2
 0 0
 0 2
 0 0
 0 0
 0 0
 0 0
 0 0
 0 2
 0 0
 0 2
 0 0
 0 2
```

STREAMLINE NO. 1

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.5296E-01	[illegible]	.6924E-01	.7103E+00	.6634E+02	.1027E+02	1
.3194E-02	-.5317E-01	.1743E-02	.6910E-01	.7210E+00	.6664E+02	.1025E+02	1
.1109E-01	-.5445E-01	.5166E-02	.6779E-01	.5596E+00	.5575E+02	.9354E+01	1
.1437E-01	-.5625E-01	[illegible]	.6579E-01	.1322E+01	.4378E+02	.6381E+01	1
.1689E-01	-.5792E-01	[illegible]	.6627E-01	.1912E+01	.3335E+02	.6532E+01	1
.1911E-01	-.5960E-01	[illegible]	.6575E-01	.2511E+01	.2427E+02	.5092E+01	1
.2129E-01	-.6142E-01	[illegible]	.6545E-01	.3223E+01	.1619E+02	.3575E+01	1
.2348E-01	-.6740E-01	[illegible]	.6525E-01	.4164E+01	.9922E+01	.2531E+01	1
.2566E-01	-.6549E-01	[illegible]	.6511E-01	.5378E+01	.5100E+01	.1667E+01	1
.7385E-01	-.1125E+00	[illegible]	.6217E-01	.5433E+01	.4219E+01	.1639E+01	3
.2421E+00	-.2765E+00	[illegible]	.5270E-01	.5402E+01	.4291E+01	.1651E+01	3
.4104E+00	-.4405E+00	.7771E-01	.4321E-01	.5465E+01	.4289E+01	.1651E+01	3
.5786E+00	-.6044E+00	[illegible]	.3372E-01	.5419E+01	.4286E+01	.1650E+01	3
.7469E+00	-.7696E+00	[illegible]	.2423E-01	.5410E+01	.4254E+01	.1650E+01	3
.9152E+00	-.9326E+00	[illegible]	.1474E-01	.5413E+01	.4275E+01	.1648E+01	3
.1083E+01	-.1097E+01	[illegible]	.5252E-02	.5411E+01	.4281E+01	.1650E+01	3
.1252E+01	-.1261E+01	[illegible]	-.4246E-02	.5409E+01	.4289E+01	.1651E+01	3
.1419E+01	-.1424E+01	[illegible]	-.1378E-01	.5405E+01	.4299E+01	.1653E+01	3
.1550E+01	-.1552E+01	.5436E+00	-.2251E-01	.5425E+01	.4242E+01	.1643E+01	3
.1611E+01	-.1611E+01	.5561E+00	-.2784E-01	.5468E+01	.4063E+01	.1610E+01	3
.1646E+01	-.1645E+01	[illegible]	-.3168E-01	.5565E+01	.3769E+01	.1562E+01	3
.1671E+01	-.1669E+01	[illegible]	-.3495E-01	.5726E+01	.3419E+01	.1496E+01	3
.1693E+01	-.1691E+01	[illegible]	-.3799E-01	.5944E+01	.2924E+01	.1402E+01	3
.1711E+01	-.1709E+01	[illegible]	-.4449E-01	.6217E+01	.2360E+01	.1296E+01	3

STREAMLINE NO. 2

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.5303E-01	.1610E-02	.6919E-01	.7190E+00	.6684E+02	.1925E+02	1
.3114E-02	-.5323E-01	.2137E-02	.6904E-01	.7199E+00	.6684E+02	.1925E+02	1
.1038E-01	-.5474E-01	.6899E-02	.6772E-01	.8609E+00	.5500E+02	.9791E+01	1
.1358E-01	-.5637E-01	.2902E-02	.6675E-01	.1355E+01	.4312E+02	.8272E+01	1
.1608E-01	[illegible]	.1056E-01	.6024E-01	.1948E+01	.3278E+02	.6430E+01	1
.1829E-01	-.5970E-01	.1183E-01	.6583E-01	.2549E+01	.2375E+02	.4919E+01	1
.2047E-01	-.6154E-01	.1390E-01	.6547E-01	.3272E+01	.1575E+02	.3601E+01	1
.2265E-01	-.6352E-01	.1570E-01	.6524E-01	.4229E+01	.9608E+01	.2471E+01	1
.2484E-01	-.6562E-01	.1624E-01	.6510E-01	.5461E+01	.4827E+01	.1624E+01	1
.1535E+00	-.1931E+00	.4246E-01	.5764E-01	.5415E+01	.4270E+01	.1648E+01	3
.3219E+00	-.3551E+00	.7577E-01	.4816E-01	.5408E+01	.4291E+01	.1652E+01	3
.4900E+00	-.5141E+00	.1151E+00	.3066E-01	.5409E+01	.4267E+01	.1651E+01	3
.6583E+00	-.6837E+00	.1535E+00	.2917E-01	.5410E+01	.4285E+01	.1650E+01	3
.8266E+00	-.8472E+00	.1579E+00	.1968E-01	.5412E+01	.4281E+01	.1649E+01	3
.9949E+00	-.1011E+01	.2242E+00	.1019E-01	.5414E+01	.4275E+01	.1648E+01	3
.1163E+01	-.1175E+01	.2580E+00	.7089E-03	.5409E+01	.4286E+01	.1651E+01	3
.1331E+01	-.1339E+01	.2969E+00	-.6795E-02	.5407E+01	.4293E+01	.1652E+01	3
.1498E+01	-.1502E+01	.3559E+00	-.1844E-01	.5406E+01	.4288E+01	.1651E+01	3
.1629E+01	-.1630E+01	.3713E+00	-.2719E-01	.5444E+01	.4188E+01	.1633E+01	3
.1692E+01	-.1691E+01	.3739E+00	-.3257E-01	.5512E+01	.4000E+01	.1598E+01	3
.1710E+01	-.1706E+01	.3774E+00	-.3449E-01	.5556E+01	.3884E+01	.1578E+01	3

STREAMLINE NO. 5

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.5303E-01	[illegible]	.6919E-01	.7168E+00	.6684E+02	.1025E+02	1
.9838E-02	-.5427E-01	.48[illegible]E-02	.6912E-01	.7663E+00	.5680E+02	.1008E+02	1
.1275E-01	-.5585E-01	[illegible]E-02	.6697E-01	.1193E+01	.4653E+02	.8805E+01	1
.1539E-01	-.5753E-01	.1014E-01	.6637E-01	.1767E+01	.3574E+02	.6964E+01	1
.1765E-01	-.5917E-01	.1167E-01	.6595E-01	.2362E+01	.2638E+02	.5346E+01	1
.1993E-01	-.6057E-01	.126[illegible]E-01	.6556E-01	.3033E+01	.1801E+02	.3983E+01	1
.2201E-01	-.62[illegible]1E-01	[illegible]E-01	.6529E-01	.3913E+01	.1125E+02	.2784E+01	1
.2420E-01	-.64[illegible]8E-01	.14[illegible]E-01	.6514E-01	.5055E+01	.6209E+01	.1851E+01	1
.9875E-01	-.1377E+00	[illegible]E-01	.6072E-01	.5426E+01	.4238E+01	.1642E+01	3
.2678E+00	-.3017E+00	[illegible]E-01	.5125E-01	.5407E+01	.4292E+01	.1652E+01	3
.4353E+00	-.4657E+00	.10[illegible]E+00	.4175E-01	.5409E+01	.4288E+01	.1651E+01	3
.6035E+00	-.6295E+00	.1397E+00	.3226E-01	.5410E+01	.4286E+01	.1650E+01	3
.7718E+00	-.7930E+00	.1769E+00	.2277E-01	.5411E+01	.4285E+01	.1650E+01	3
.9401E+00	-.957[illegible]E+00	.2124E+00	.1328E-01	.5414E+01	.4275E+01	.1648E+01	3
.1108E+01	-.1122E+01	.2468E+00	.3798E-02	.5411E+01	.4263E+01	.1650E+01	3
.1277E+01	-.12[illegible]E+01	[illegible]E+00	-.5679E-02	.5408E+01	.4290E+01	.1651E+01	3
.1445E+01	-.1450E+01	.3214E+00	-.1511E-01	.5407E+01	.4293E+01	.1652E+01	3
.1602E+01	-.1483E+01	.3550E+00	-.2326E-01	.5435E+01	.4211E+01	.1637E+01	3
.1692E+01	-.1691E+01	.3759E+00	-.2595E-01	.5525E+01	.3960E+01	.1592E+01	3
.1711E+01	-.1709E+01	.3790E+00	-.2099E-01	.5562E+01	.3858E+01	.1574E+01	3

etc.

STREAMLINE NO. 15

S	X	Y	Z	M	P/PINF	T/TINF	PANEL
0.	-.5304E-01	.1622E-02	.6918E-01	.7207E+00	.6684E+02	.1025E+02	1
.8373E-02	-.5413E-01	.4570E-02	.6625E-01	.7559E+00	.5990E+02	.1016E+02	1
.1230E-01	-.5574E-01	.6877E-02	.6784E-01	.1148E+01	.4756E+02	.6952E+01	1
.1498E-01	.5736E-01	[illegible]	.6641E-01	.1713E+01	.3663E+02	.7127E+01	1
.1726E-01	-.5903E-01	.1135E-01	.6598E-01	.2309E+01	.2716E+02	.5474E+01	1
.1945E-01	-.6060E-01	.1255E-01	.6557E-01	.2967E+01	.1870E+02	.4097E+01	1
.2163E-01	-.6273E-01	.1352E-01	.6531E-01	.3625E+01	.1177E+02	.2881E+01	1
.2381E-01	-.6479E-01	[illegible]	.6515E-01	.4943E+01	.6617E+01	.1921E+01	1
.4791E-01	[illegible]	[illegible]	.6356E-01	.5440E+01	.4199E+01	.1635E+01	3
.2161E+00	-.2523E+00	[illegible]	.5411E-01	.5409E+01	.4288E+01	.1651E+01	3
.3643E+00	-.4162E+00	[illegible]	.4470E-01	.5409E+01	.4288E+01	.1651E+01	3
.5418E+00	-.5658E+00	[illegible]	.3659E-01	.5419E+01	.4257E+01	.1645E+01	3
.6309E+00	[illegible]	.1463E+00	.3367E-01	.5493E+01	.4050E+01	.1608E+01	3
.6807E+00	-.7052E+00	.1569E+00	.3440E-01	.5641E+01	.3644E+01	.1536E+01	3
.7158E+00	-.7357E+00	.1634E+00	.3581E-01	.5767E+01	.3251E+01	.1469E+01	3
.8578E+00	.9114E+00	[illegible]	.3659E-01	.5959E+01	.2865E+01	.1396E+01	14
.9008E+00	-.9534E+00	[illegible]	.4309E-01	.5958E+01	.2865E+01	.1396E+01	14
.9438E+00	-.9962E+00	[illegible]	.4961E-01	.5958E+01	.2865E+01	.1396E+01	14
.9861E+00	[illegible]	[illegible]	.5613E-01	.5958E+01	.2866E+01	.1396E+01	14
.1029E+01	[illegible]	[illegible]	.6266E-01	.5958E+01	.2867E+01	.1397E+01	14
.1072E+01	-.1124E+01	[illegible]	.6919E-01	.5957E+01	.2867E+01	.1397E+01	14
.1116E+01	-.1166E+01	[illegible]	.7573E-01	.5957E+01	.2868E+01	.1397E+01	14
.1159E+01	[illegible]	[illegible]	[illegible]	.5957E+01	.2869E+01	.1397E+01	14
.1202E+01	-.1251E+01	[illegible]	.8887E-01	.5956E+01	.2870E+01	.1397E+01	14
.1245E+01	-.1294E+01	[illegible]	.9539E-01	.5956E+01	.2870E+01	.1397E+01	14
.1289E+01	-.1337E+01	[illegible]	.1020E+00	.5956E+01	.2870E+01	.1397E+01	14
.1347E+01	-.1394E+01	[illegible]	.1108E+00	.5958E+01	.2866E+01	.1396E+01	15
.1379E+01	-.1426E+01	[illegible]	.1156E+00	.5958E+01	.2866E+01	.1397E+01	15
.1411E+01	-.1457E+01	[illegible]	.1205E+00	.5958E+01	.2867E+01	.1397E+01	15
.1443E+01	[illegible]	[illegible]	.1254E+00	.5958E+01	.2867E+01	.1397E+01	15
.1476E+01	[illegible]	[illegible]	.1303E+00	.5957E+01	.2867E+01	.1397E+01	15
.1508E+01	[illegible]	[illegible]	.1352E+00	.5957E+01	.2867E+01	.1397E+01	15
.1540E+01	[illegible]	[illegible]	.1401E+00	.5957E+01	.2867E+01	.1397E+01	15
.1573E+01	[illegible]	[illegible]	.1450E+00	.5957E+01	.2867E+01	.1397E+01	15
.1605E+01	[illegible]	[illegible]	[illegible]	.5957E+01	.2866E+01	.1397E+01	15
.1639E+01	[illegible]	[illegible]	[illegible]	.5957E+01	.2866E+01	.1397E+01	15
.1667E+01	[illegible]	[illegible]	[illegible]	.5957E+01	.2868E+01	.1397E+01	15

*** AERODYNAMIC ANALYSIS IS COMPLETE

SECTION III

THEORY

Discussed in this section are the modifications made to the version of the Mark IV program released in November 1973 (Reference 1). The two primary changes made to the program involve surface streamline tracing and the application of integral boundary layer methods along the surface streamlines.

The original version of the Mark IV program contains both a Newtonian streamline tracing method and a means for calculating detailed boundary layer properties along the streamlines. Due to the nature of the surface spline used in the streamline method to interpolate for the surface properties, the surface flow field must be divided into regions in which the flow properties are "well-behaved," i.e., the properties do not exhibit sudden changes within a region. However, no means exists in the original version of the Mark IV program for tracing streamlines from region to region. Therefore, the arc lengths along the streamlines, necessary for subsequent boundary layer calculations, are correct only for those streamlines whose corresponding region contains a true origin.

Other difficulties with the old streamline method are concerned with the location of the streamline origins. The user must supply the program with the origin for each streamline, but streamline origins are not usually known a priori. Furthermore, if the skin friction distribution is to be integrated to obtain the contribution of viscous shear to vehicle forces and moments, the starting points for the streamlines must be strategically placed to ensure that the resultant streamlines are sufficiently distributed over the geometry surface. Since streamline divergence is particularly evident on three-dimensional bodies, small changes in the placement of starting points normally result in large variations of the final streamline distributions, and the user cannot be expected to make a proper selection of the starting points. (Starting points used in this context are not necessarily true origins. Since the surface velocity field contains singularities at stagnation points, streamline calculations often begin some small distance ε from the true origin.)

The old streamline method has been replaced by one capable of tracing continuous surface streamlines. In addition, streamline origins may be located automatically by the program. However, an option has been provided to allow the user to specify starting points if so desired. Logic has also been included which identifies those surfaces of the geometry that are not sufficiently covered by the initial streamlines. If more streamlines are required, additional starting points are strategically placed and more streamlines are traced.

The primary purpose of tracing surface streamlines is to provide paths for subsequent boundary layer calculations. The particular methods used in the Mark IV code are integral methods (References 4 & 5) originally coded by McNally (Reference 6) in a project unrelated to the Mark IV program. Since the integral methods rely on streamline information, the replacement of the old streamline method required minor modifications to the FORTRAN coding of the boundary layer methods.

However, the results of some simple flat plate calculations revealed several discrepancies related to modifications made to McNally's FORTRAN program by the authors of the Mark IV program. As mentioned in Volume II of Reference 1, modifications to the McNally program were necessary to remove the assumption of isentropic flow used implicitly in the coding of the integral methods. However, the isentropic assumption was not properly removed, and steps were taken in the current effort to correct the problems. In addition, the integral equation used in the laminar boundary layer method (equation 32 of Reference 4) was replaced by the original form of the equation, a nonlinear, ordinary differential equation (equation 27 of Reference 4). Given in the "Integral Boundary Layer Methods" sub-section of this report are brief descriptions of the integral methods used in the Mark IV program for the laminar and turbulent boundary layers. Changes made to the methods and to the FORTRAN coding of the methods are also discussed.

1. Streamline Tracing

Although several methods are available for tracing inviscid surface streamlines (References 8 & 9), the one approach which is consistent with the engineering design methods of the Mark IV program is the Newtonian method, also known as the Steepest Descent method. The Newtonian model assumes that a stream of particles impinging on a surface retains its tangential component of momentum. Thus, the velocity at any point on the surface is assumed to lie in the plane formed by the freestream velocity and the local outward normal,

$$\overline{V}_S = \hat{n} \times (V_\infty \times \hat{n}) \tag{1}$$

where $\hat{n}$ is the unit outward normal and V_∞ is the freestream velocity. Since the surface velocity is simply the time rate of change of the position vector, $\bar{r}$, the Newtonian streamline equation may be written

$$\frac{d\bar{r}}{dt} = \hat{n} \times (V_\infty \times \hat{n}) \tag{2}$$

Using the definition of the magnitude of the surface velocity, $V_S = dS/dt$, where S is the streamline arc length, the vector streamline equation becomes

$$\frac{d\bar{r}}{dS} = \hat{V}_S \tag{3}$$

where $\hat{V}_S$ is the unit surface velocity calculated from Equation 1 .

The vector Equation 3 is a system of three ordinary differential equations, but it is necessary to solve only two of the equations. Since the streamlines must lie on the geometry surface at all times, one coordinate of the streamline position is related to the other two by the function describing the surface, $X_1 = f(X_2, X_3)$, where $\bar{r} = X_1\hat{i} + X_2\hat{j} + X_3\hat{k}$.

One of the most difficult problems related to arbitrary-body streamline tracing is that of interpolating for the inviscid flow properties. Although the unit surface velocity is of interest for Newtonian streamline calculations, such edge conditions as static pressure and temperature are required for subsequent boundary layer calculations. In the Mark IV program the inviscid properties are calculated only at the Element centroids. A surface interpolation method must therefore be available to estimate the flow properties, including the unit surface velocity, between the centroids.

The Mark IV program employs the surface interpolation method presented by Harder and Desmaris in Reference 3. This method is not a parametric spline, i.e., an appropriate choice of the two independent variables is required to avoid multiple-values of the dependent variable. For example, attempts to surface fit a body of revolution in a Cartesian coordinate system would result in multiple-values of the dependent variable, regardless of whether the X-, Y-, or Z- coordinate is chosen as the dependent variable. It would be more appropriate to fit a body of revolution in cylindrical coordinates, $R = R(A,\phi)$, where A is an axial distance and ϕ is a meridonal angle. In the new streamline method, the surface spline for each Panel assumes one of three functional forms: $Z = Z(X,Y)$, $Y = Y(X,Z)$, or $R = R(A,\phi)$. Parametric splines, however, do not require the appropriate selection of the two independent variables.

The Harder and Desmaris surface spline, as used in the Mark IV program, has the advantage that the known coordinates used in generating the spline need not be ordered in a rectangular array, but has the disadvantage that it does not guarantee continuity of the fit between geometry panels. The spline must be applied to each geometry Panel, independently of all other Panels, and the quantity to be fit for each Panel (pressure, temperature, one appropriate geometry coordinate, etc.) must be well-behaved. Although it is difficult to succinctly define "well-behaved" in this context, experience has shown that the shape of the surface within the boundaries of a Panel must not contain rapid changes in curvature. Since local-slope pressure methods are used in the Mark IV program, the inviscid surface properties are generally well-behaved within a Panel's boundaries if the shape of the Panel is well-behaved.

The nonparametric form of the Mark IV surface spline and the lack of continuity of the surface fits between Panels seriously complicate the development of an arbitrary-body streamline method. To facilitate the streamline tracing a pseudo parametization of the surface spline is introduced. As shown in Figure 6, this parametization maps the 2-D domain associated with each Panel to a unit square, known as the u-v plane. A true parametric spline maps all three coordinates to the u-v plane. One advantage of working in the u-v plane is that the streamline integration is considerably simplified. After each integration step, a check must be made to determine if the streamline has crossed the boundaries of the current Panel. If the streamline integration is performed in the u-v plane, the check involves a simple test of the values of the independent variables, u and v: a streamline exceeds the boundaries of a given Panel if u or v is greater than 1 or less than 0. A similar check in Cartesian or cylindrical coordinates is far more complicated. Once a streamline exceeds the boundaries of a given Panel, the surface spline of the adjacent Panel must be used to continue the interpolation of the unit surface velocity required by the streamline equations.

Once the appropriate functional form of a particular Panel is determined, $Y = Y(X,Z)$ or $Z = Z(X,Y)$ or $R = R(A,\phi)$, a bilinear mapping is used to transform the domain of the Panel's spline to the unit square,

$$X_1(u,v) = X_{11}(1-u)(1-v) + X_{12}(1-u)v + X_{13}uv + X_{14}u(1-v) \tag{4a}$$

$$X_2(u,v) = X_{21}(1-u)(1-v) + X_{22}(1-u)v + X_{23}uv + X_{24}u(1-v) \tag{4b}$$

where, as shown in Figure 7, X_{iu} is the i^{th} coordinate of the j^{th} corner point of the Panel's boundary, and X_i is the i_{th} coordinate of any point in the domain. Thus, the point $(u,v) = (0,0)$ on the unit square corresponds to the point $(X_1,X_2) = (X_{11},X_{21})$ from Equation 4 . Depending upon the appropriate functional form of the Panel, the coordinate pair (X_1,X_2) represents (X,Z), (X,Y) or (A,ϕ).

Once the appropriate domain of each Panel is mapped to the unit u-v square, the inviscid surface properties and the third geometry coordinate

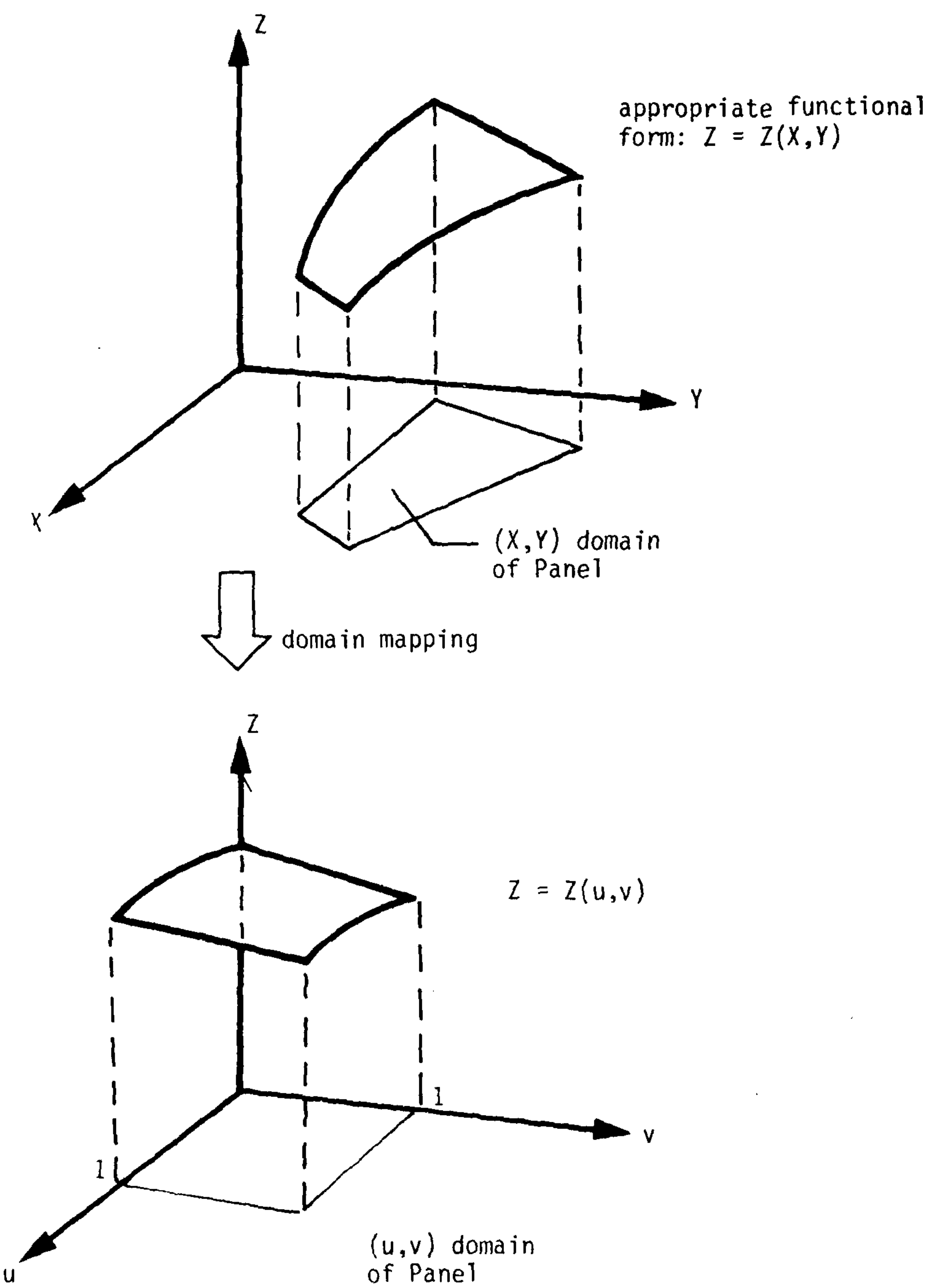

Figure 6. Surface Spline Domain Transformation

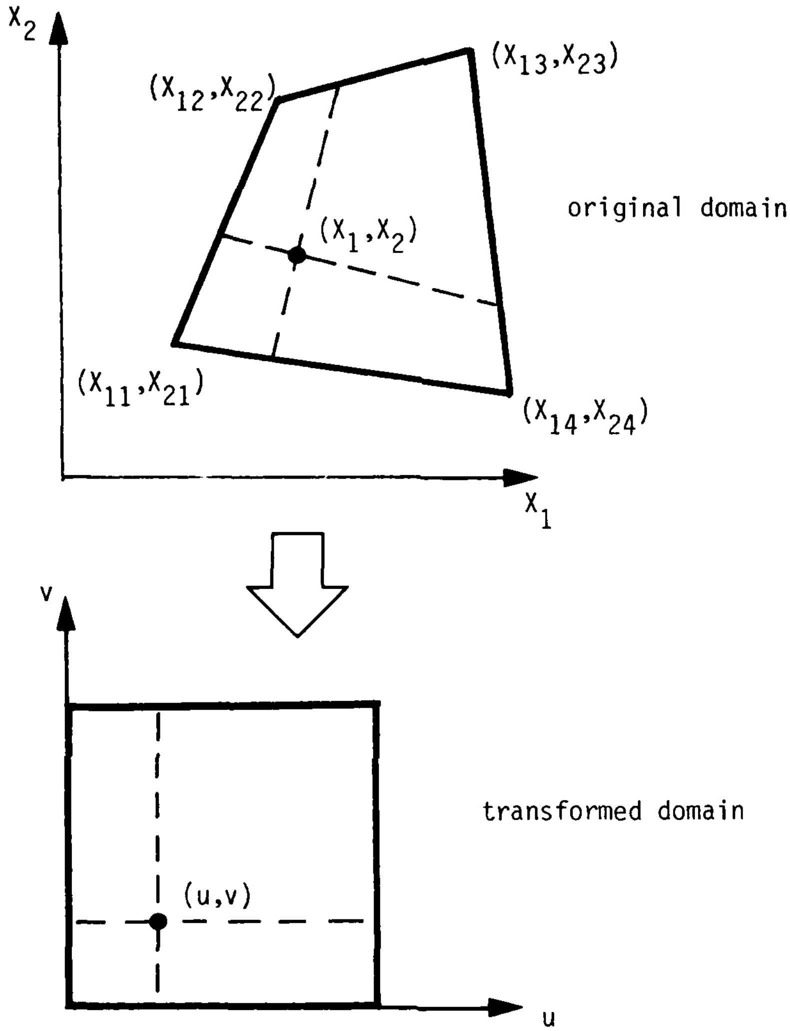

Figure 7. Bilinear Mapping of Each Panel's Domain

of the centroids of each Panel are surface fit with u and v as the independent variables, i.e. p = p(u,v), T = T(u,v), $V_X = V_X(u,v)$, etc. One spline fit is required for each surface property of each Panel. The surface fits are calculated for all Panels prior to the streamline calculations, and the spline coefficients are stored on a random access unit for later use.

If the streamlines are to be integrated in the u-v plane, the streamline equations must reflect the change of coordinates. Choosing two of the components of the vector Equation 3 , the transformation to the u-v plane yields

$$\frac{du}{ds} = \frac{\begin{vmatrix} C_1 & C_2 \\ \frac{\partial X_1}{\partial v} & \frac{\partial X_2}{\partial v} \end{vmatrix}}{D} \tag{5a}$$

$$\frac{dv}{ds} = - \frac{\begin{vmatrix} C_1 & C_2 \\ \frac{\partial X_1}{\partial u} & \frac{\partial X_2}{\partial u} \end{vmatrix}}{D} \tag{5b}$$

where,

$$D = \begin{vmatrix} \frac{\partial X_1}{\partial u} & \frac{\partial X_2}{\partial u} \\ \frac{\partial X_1}{\partial v} & \frac{\partial X_2}{\partial v} \end{vmatrix}$$

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and,

$$(C_1,C_2) = \begin{cases} (\hat{V}_X,\hat{V}_Y) & \text{, if } (X_1,X_2) = (X,Y) \\ (\hat{V}_X,\hat{V}_Z) & \text{, if } (X_1,X_2) = (X,Z) \\ (\hat{V}_A,\hat{V}_\phi/R), & \text{if } (X_1,X_2) = (A,\phi) \end{cases}$$

All partial derivatives may be evaluated from Equations 4a and b which describe the bilinear mapping.

Given a starting point, the Panel associated with that point is identified, and the corresponding spline coefficients are retrieved from the random access unit. The starting point is transformed to the u-v plane, and the spline coefficients are used to interpolate for the surface properties at the starting point. A quartic Runge-Kutta integration of the streamline equations, 5a and b, is used to trace the streamlines across the u-v plane of the given Panel. At each step of the integration, u and v are mapped back to the Mark IV Cartesian coordinate system, and the (X,Y,Z) coordinates of the streamline are saved every N integration steps.

If u or v is greater than 1 or less than 0 the streamline has exceeded the boundaries of the current Panel, and a search must be made for the adjacent Panel. Since the Panels need not be input by the user in any specific order, and since more than one Panel may be adjacent to one boundary of a Panel, a brute force search is performed to locate the proper adjacent Panel. Before searching for the adjacent Panel, the streamline is integrated an arbitrarily small distance ε past the boundary of the last Panel. The Cartesian coordinates of the last streamline point are then mapped to the u-v planes of all remaining Panels. If the transformed point does not lie within the unit u-v boundaries of a given Panel, that Panel cannot be the desired adjacent Panel. However, if the transformed point does lie within a Panel's u-v boundaries, that Panel may or may not be the desired adjacent Panel. As shown in Figure 8, the domains of two Panels may overlap. To ascertain which Panel is the one of interest, the distance, d, between the streamline point and the surface of each of the two

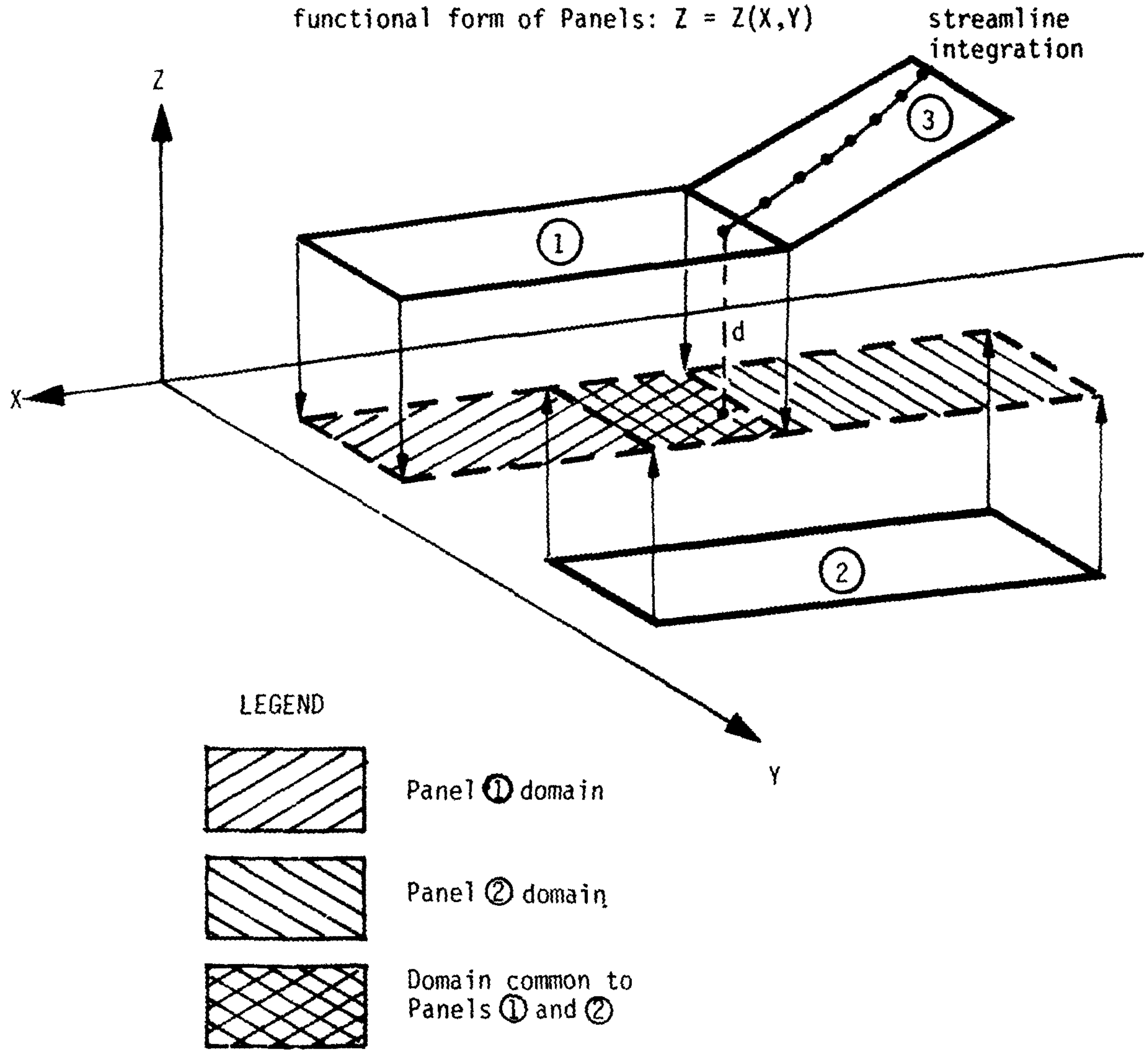


Figure 8. Overlapping Spline Domains

Panels is computed. The Panel nearest the streamline point is assumed to be the desired adjacent Panel. Once the correct adjacent Panel is located the streamline integration continues.

Integration of the streamline equations may be performed along or against the flow direction. Since the true origins of the streamlines are not known a priori, an option has been provided in the new streamline method which allows the starting points for the streamlines to be automatically distributed along the aft-most boundaries of the vehicle. The streamlines are then traced against the flow direction until the true origins are located. Since streamlines may originate from stagnation regions or from sharp leading edges, two criteria are used to determine when a streamline has reached its true origin: (1) the streamline encounters a stagnation region, $\hat{V}_S \cdot \hat{V}_\infty < \varepsilon$, or (2) the streamline reaches a leading edge (a Panel boundary that is not adjacent to any upstream Panel).

Starting points may also be input by the user. If the direction of integration is specified by the user to be against the surface flow, the procedure followed when starting points are program-specified is employed. If the streamlines are traced in the direction of flow, the starting points are assumed to be true origins, and the integration continues until a trailing edge or a stagnation region is encountered. A trailing edge is any Panel boundary that is not adjacent to any downstream Panel.

A technique has also been included in the new streamline method which strategically distributes additional starting points, based on the initial streamline distribution, to ensure that the streamlines are sufficiently distributed for future skin friction calculations and integration. As the streamlines in the initial distribution are integrated across Panel boundaries, the intersections of the streamlines with the Panel boundaries are saved. In this manner, the streamlines' entrance and exit points to all Panels are known. A particularly simple algorithm may be developed if the points are saved in the u-v plane. As shown in Figure 9, straight lines are constructed in the u-v plane between the entrance and exit points of each Panel. If any of the areas bounded by the straight line segments and a Panel's boundaries is greater than some

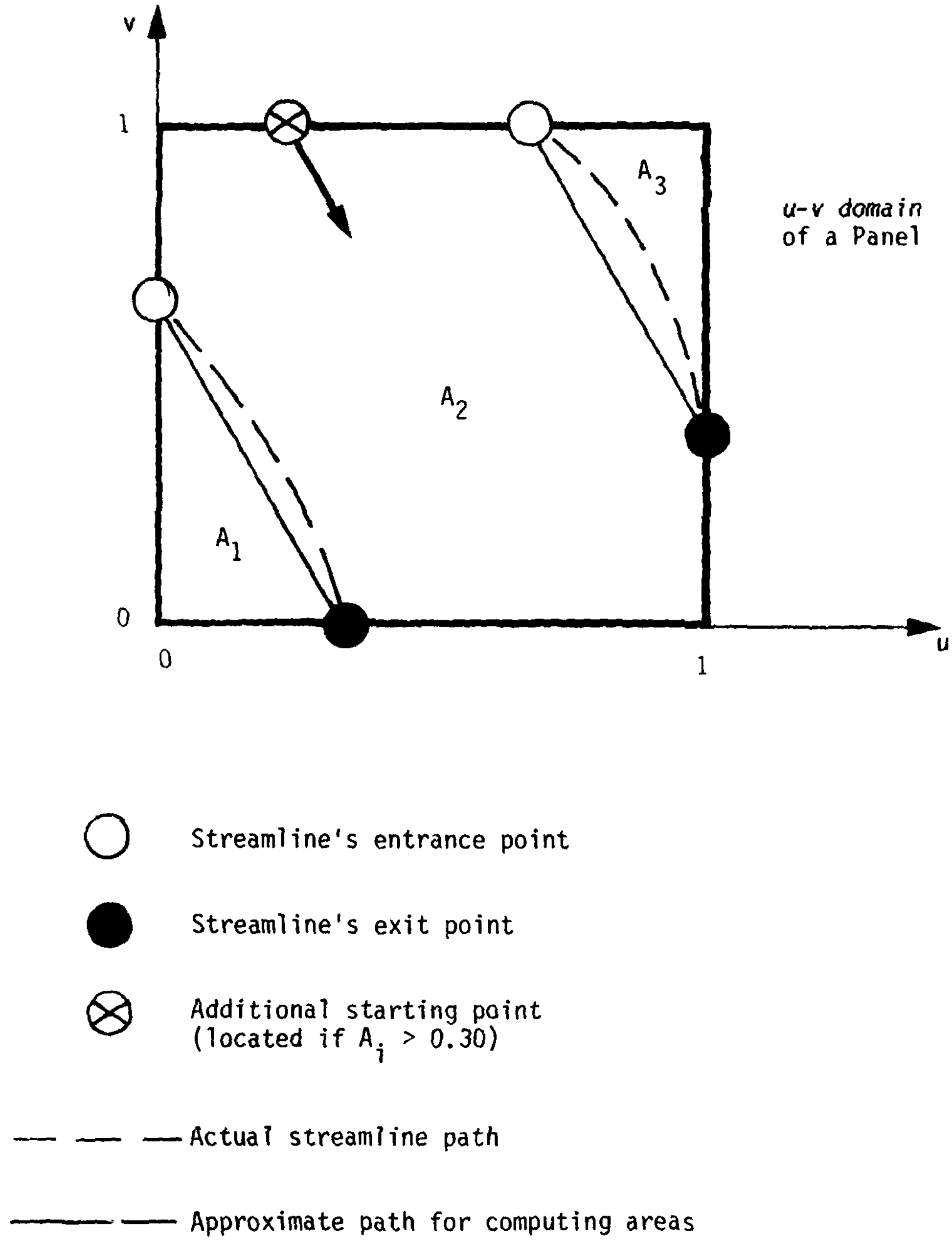


Figure 9. Algorithm Used to Ensure Sufficient Streamline Distribution

arbitrary value (.30 used presently), appropriate additional starting points are distributed.

The algorithm is applied to all Panels of the geometry starting with the aft-most Panels. In this manner the number of additional streamline computations is kept to a minimum since the additional streamlines from the aft Panels tend to fill-in the distribution over the upstream Panels. If an upstream Panel requires additional streamlines, the integrations are performed only in the forward direction, toward the streamline origins. Additional streamlines are never traced in the aft direction.

Validation of the FORTRAN coding of the Newtonian streamline equations was straightforward. A cylindrical geometry at angle of attack was used in the validation since the outward normal at any point may be expressed analytically. Simple hand calculations of the unit surface velocity at points along the streamlines were in excellent agreement with the corresponding streamline directions.

Comparisons of the Newtonian method (Steepest Descent) with more sophisticated inviscid streamline methods have been made by other investigators (Reference 9 is one among many). No such detailed comparisons were part of the present effort.

Shown in Figure 5 is the streamline distribution over the X-24C forebody at 5 degrees angle of attack. The streamlines were generated using the program-specified starting point option in the new Mark IV streamline method. The plot was produced by the TEKtronix PICtures (TEKPIC) program (Reference 2), an interactive tektronix picture drawing code developed as part of the present effort.

2. Integral Boundary Layer Methods

Given the inviscid condition long the three-dimensional streamlines, boundary layer methods may be employed to predict such quantities as skin friction and heat transfer. The boundary layer methods chosen by the original authors of the Mark IV program include the method due to Cohen and Reshotko (Reference 4) for the laminar boundary layer, and the method presented by Sasman and Cresci (Reference 5) for the turbulent boundary layer. Both methods are integral approaches applicable to two-dimensional, compressible flows with arbitrary pressure gradients and heat transfer. The Schlichting-Ulrich method (Reference 10) is used to predict the point of neutral stability of the laminar boundary layer, and the distance between the point of instability and the transition point is predicted using the empirical curve presented by Granville (Reference 11).

Each of the methods were incorporated into a FORTRAN computer code by McNally (Reference 6), and later modified for use in the Mark IV program. During the current effort, initial modifications were made to the peripheral coding (COMMON blocks, random access read/writes, etc.) to insure that the integral methods received the proper inviscid edge conditions from the new streamline method. However, the results of subsequent flat plate calculation using the integral methods, as coded in the Mark IV program, were in disagreement with accepted simplified theories (Eckert's reference enthalpy and Van Driest II). As described below, the errors were due primarily to the fact that several of the variables appearing in the equations were based on freestream conditions rather than local conditions. In addition to correcting such errors, the current effort involved the replacement of Cohen and Reshotko's linearized equations with the nonlinear form of their equations.

Only a brief description of the integral methods is presented here. The derivations of the laminar and turbulent boundary layer method may be found in References 4 and 5, respectively. Detailed descriptions of the various curve fits used in the program (e.g., thermal conductivity, $k = k[T]$), the integration schemes, and the FORTRAN coding of the methods are given in Reference 6.

a. Laminar Boundary Layer Method

Cohen and Reshotko's approximate method is based on an approach first introduced by Thwaites. The standard Stewartson-Illingsworth transformation is first applied to Prandtl's compressible boundary layer equations, and the transformed equations are then integrated with respect to the coordinate normal to the surface to yield a set of nonlinear, first order differential equations--the integral equations. These equations are then expressed in terms of three dimensionless parameters related to wall shear, surface heat transfer, and the pressure gradient. The momentum equation becomes,

$$-U_e \frac{d}{dX}\left(\frac{n}{U_{e_X}}\right) = 2[n(H_{tr} + 2) + \ell] \tag{6}$$

where,

$$U_e = a_o u_e/a_e = a_o M_e$$

$$X = \int_o^x \lambda \frac{a_e}{a_o} \frac{p_e}{p_o}\, dx$$

$$\lambda = \left(\frac{T_o + k_{su}}{T_w + k_{su}}\right) \sqrt{\frac{T_w}{T_o}} \quad ; \; k_{su} = 198.6°R \text{ (air)}$$

$$n \equiv -\frac{U_{e_X}}{\nu_o} \theta_{tr}^2 = -\frac{u_{e_x} \theta^2}{\nu_w} \left(\frac{T_w}{T_e}\right)^2 \left(\frac{T_o}{T_e}\right)$$

$$H_{tr} = \frac{\delta^*_{tr}}{\theta_{tr}}$$, form factor for $M_e << 1$.

$$\theta_{tr} \equiv \int_o^\Delta \frac{U}{U_e}\left(1 - \frac{U}{U_e}\right) dY$$

$$\delta^*_{tr} \equiv \int_o^\Delta \left(1 - \frac{U}{U_e} + S\right) dY$$

$$Y = \frac{a_e}{a_o} \int_0^y \frac{\rho}{\rho_o} \, dy$$

$$\ell \equiv \frac{\theta_{tr}}{U_e} \left(\frac{\partial U}{\partial Y} \right)_w = \frac{\theta}{u_e} \frac{T_w}{T_e} \left(\frac{\partial u}{\partial y} \right)_w$$

$$r \equiv \frac{\theta_{tr}^3}{U_e} \left(\frac{\partial^3 U}{\partial Y^3} \right)_w = n\theta \frac{T_w}{T_o} \frac{\partial}{\partial y} \left(\frac{T}{T_e} \right)_w, \text{ [used in energy equation]}$$

A similar procedure may be followed for the energy equation, but the following assumption negates the need for the energy equation. Analogous to Thwaites approach, universal functions were sought for the shear parameter, ℓ, and the heat transfer parameter, r, in terms of the pressure gradient parameter, n, and the wall enthalpy function, $S_w \equiv \frac{h_w}{h_o} - 1$. Such relationships were extracted from similar solutions (Falkner-Skan type flows) to the compressible, laminar boundary layer equations (Reference 12). Therefore, the fundamental equation to be solved is

$$-U_e \frac{d}{dX} \left(\frac{n}{U_{e_X}} \right) = N(n, S_w) \tag{7}$$

where $N(S_w, n)$ is given from similar solutions. Given n along a streamline, the parameters ℓ and r may be determined from the curve fits $\ell = \ell(n, S_w)$ and $r = r(n, S_w)$ obtained from the similar solutions. Finally, the momentum thickness, the skin friction, and the heat transfer may be calculated from the definitions of n, ℓ, and r, respectively.

Cohen and Reshotko simplified Equation 7 by noting that the function $N(n, S_w)$ is approximately linear in n for fixed values of S_w,

$$N = A + Bn \tag{8}$$

Equation 7 may then be solved to yield,

$$n = -AU_e^{-B} \, U_{e_X} \int_0^X U_e^{B-1} \, dX \tag{9}$$

or, in terms of physical quantities,

$$n = -\frac{A}{u_e}\frac{du_e}{dx}\left(\frac{T_o}{T_e}\right)^{(K+1)} M_e^{(1-B)} \int_o^x \left(\frac{T_o}{T_e}\right)^{-K} M_e^{(B-1)}\, dx \qquad (10)$$

where

$K = (3\gamma - 1)/(2\gamma - 2)$.

The latter equation was coded into McNally's FORTRAN boundary layer program which was later modified for use in the Mark IV program. In Volume II of Reference 1 it was stated that the isentropic assumption used implicitly throughout the boundary layer equations required a major modification of McNally's coding. This modification primarily consisted of replacing (T_o/T_e), wherever it appeared in the equations, by $(p_o/p_e)^{(\gamma-1)/\gamma}$. It is not clear why this thermodynamic relation was used. The isentropic edge assumption, mentioned by McNally in Reference 6, applies to the manner in which the edge conditions are calculated. Since McNally was concerned only with the boundary layers of shock-free flowfields, such quantities as the kinematic viscosity, $\nu_0 = \mu_0/\rho_0$, appearing in the definition of the pressure gradient parameter n, were based on freestream conditions. However, since the Mark IV program was designed for supersonic-hypersonic flows, the entropy changes instantaneously across the bow shock, and continues to vary along each surface streamline (edge temperature in the Mark IV code is calculated by assuming tangent-wedge conditions to exist locally). Therefore, by using local conditions instead of freestream conditions, the "isentropic assumption" is removed.

The other modification made to the Mark IV integral methods involved the laminar boundary layer equation itself. As may be observed from the plot of $N(n,S_w)$ versus n with S_w as the parameter in Figure 4 of Reference 4, N is linear in n only for values of S_w very near zero, i.e., for approximately adiabatic walls. To circumvent this problem, McNally allowed the constants A and B to vary with the pressure gradient parameter n. However, the mathematical validity of fixing coefficients in a differential equation, solving the equation, and subsequently allowing the coefficients to vary is questionable. Therefore, the linearized equation was replaced with the original nonlinear relation, Equation 7 . Transforming this equation back to physical quantities there results

$$\frac{d}{dx}\left[\frac{n}{\left(\frac{T_o}{T_e}\right)^K \frac{dM_e}{dx}}\right] = - \frac{N(n,S_w)}{M_e\left(\frac{T_o}{T_e}\right)^K} . \tag{11}$$

Equation 11 can easily be solved using the quartic Runge-Kutta numerical integration technique. The initial value of n depends on whether the streamline originates at a stagnation region or at a sharp leading edge. Curve fits of n_{SP} versus S_w obtained from similar solutions are used for stagnation regions. If the streamline originates at a sharp leading edge, n = 0.

b. Turbulent Boundary Layer Method

The method due to Sasman and Cresci employs the momentum integral and the moment-of-momentum integral equations for arbitrary pressure gradients. A Mager-Type transformation is then used to simplify the equations. Rather than solve the energy equation simultaneously with the momentum and moment-of-momentum equations, Sasman and Cresci assumed the Crocco relation to hold for flows with heat transfer and pressure gradient. In addition, the Ludwieg-Tillman skin friction relation for incompressible turbulent flow (Reference 13) was used to relate the incompressible skin friction coefficient, C_f', to the transformed adiabatic form factor, H_i, and the momentum thickness, θ. The corresponding relation for compressible flow was obtained by referencing the parameters in the Ludweig-Tillman skin friction relation to the Eckert reference enthalpy. Finally, the normalized boundary layer shear distribution,

$$\int_0^1 \frac{\tau}{\tau_w}\, d\eta,$$

appearing in the moment-of-momentum integral equation, was related to the transformed form factor and the incompressible skin friction coefficient using the results of Libby, et. al.(Reference 14). The resulting turbulent boundary layer equations, in terms of physical quantities, become

$$\frac{df}{dx} = 1.268\left\{-\frac{f}{M_e}\frac{dM_e}{dx}\left[1 + (S_w + 1)H_i + A\right]\right\} \tag{12a}$$

and,

$$\frac{dH_i}{dx} = -\frac{1}{2M_e}\frac{dM_e}{dx}\left[H_i(H_i + 1)^2(H_i - 1)\right]\left[1 + S_w\frac{H_i^2 + 4H_i - 1}{(H_i + 1)(H_i + 3)}\right] +$$

$$\frac{A(H_i^2 - 1)}{f}\left[H_i - \frac{0.011(H_i + 1)(H_i - 1)^2}{H_i^2}\frac{2}{C_f}\frac{T_o}{\bar{T}}\right] \tag{12b}$$

where,

$$f = (M_e a_o \Theta/\nu_o)^{1.268}$$

$$H \equiv \frac{\delta^*}{\theta} \approx (1 + S_w)H_i\left[1 + \frac{\gamma - 1}{2}M_e^2\right] + \frac{\gamma - 1}{2}M_e^2$$

$$\Theta = \theta\left(\frac{T_o}{T_e}\right)^3$$

$$A = 0.123\,e^{-1.561H_i}\left(\frac{M_e a_o}{\nu_o}\right)\left(\frac{T_e}{\bar{T}}\right)\left(\frac{T_e}{T_o}\right)^3\left(\frac{\mu}{\mu_o}\right)^{0.268}$$

$$\frac{C_f}{2} = 0.123e^{-1.561H_i}\left(\frac{u_e\theta}{\bar{\nu}}\right)^{-0.268}\left(\frac{T_e}{\bar{T}}\right)^{1.268}$$

$$\frac{\bar{T}}{T_o} = 0.5\frac{T_w}{T_o} + 0.22Pr^{1/3} + (0.5 - 0.22Pr^{1/3})\frac{T_e}{T_o}$$

As with the nonlinear laminar boundary layer equation, the quartic Runge-Kutta integration scheme is used to solve the system of Equations 12a and 12b . Unlike the laminar boundary layer method, the heat transfer coefficient is not given by Sasman and Cresci's method. Instead, Reynold's analogy is used to relate the Stanton number, St, to the skin friction coefficient,

$$St = \frac{q_w}{\rho_e \mu_e C_p (T_r - T_w)} = \frac{C_f}{2} Pr^{-2/3} \tag{13}$$

During the current effort, no modifications were made to the form of the turbulent boundary layer equations. However, the Mark IV authors again replaced T_o/T_e, wherever it appeared in the equations, by $(p_o/p_e)^{(\gamma-1)/\gamma}$ and used the freestream value of p_o instead of the local value. The kinematic viscosity, ν_o, was also based on freestream conditions. All such problems were corrected.

c. Comparisons and Discussion

Comparisons of the laminar and turbulent integral boundary layer methods used in the Mark IV program were made with other simplified methods and with experimental data. The comparisons were made to validate the FORTRAN coding of the methods, but not to ascertain the validity of the methods themselves. However, one obvious deficiency of the equations, as coded in the Mark IV program, is that they were derived from the two-dimensional boundary layer equations. For arbitrary geometries, it would be more appropriate to use the axisymmetric form of the equations which accounts, in part, for the spreading of the streamlines. To arrive at the axisymmetric form of the equations one must begin with the axisymmetric continuity equation,

$$\frac{\partial(\rho u R)}{\partial x} + \frac{\partial(\rho v R)}{\partial y} = 0 \tag{14}$$

instead of the two-dimensional form,

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \qquad (15)$$

used in the derivation of Equations 11 , 12a , and 12b . The variable R is the local radius of the axisymmetric body. For a two-dimensional body, $R \to \infty$ and $dR/dx = 0$, and Equation 14 reduces to the two-dimensional form.

Utilizing Equation 14 instead of 15 in Sasman and Cresci's analysis, it may be shown that Equations 12a and 12b may be expressed in axisymmetric form by adding the term $(- f/R)(dR/dx)$ to the right-hand side of Equation 12a . For arbitrary three-dimensional bodies, however, the inclusion of this term requires the proper choice of the radius R. One possible approach is to approximate (ℓ/R) by the surface curvature normal to the local streamline direction. The rate of change of this transverse curvature along the streamline is also required. In this manner the problem of determining the effect of streamline spreading on skin friction and heat transfer is reduced to a geometrical problem.

In general, the effect of streamline spreading is to increase the skin friction and heat transfer coefficients. For example, the laminar heat transfer coefficient on a cone is a factor of $\sqrt{3}$ higher than that on a flat plate, for identical inviscid edge conditions and wall temperature. Since the laminar and turbulent integral methods used in the Mark IV program were derived using the two-dimensional continuity equation, the user should be aware that the methods will under-predict the heat transfer on axisymmetric or three-dimensional geometries.

The FORTRAN coding of the integral methods was checked out by first using a flat plate geometry. For a zero pressure gradient it may easily be shown that Cohen and Reshotko's prediction of the skin friction coefficient reduces to

$$C_f \equiv \frac{\tau_w}{\frac{1}{2}\rho_e u_e^2} = \frac{0.664}{\sqrt{Re_x}} \sqrt{\frac{\rho_w \mu_w}{\rho_e \mu_e}} . \tag{16}$$

The Mark IV skin friction output was in exact agreement with hand calculations using Equation 16 . Code predictions of heat transfer rate were compared with hand calculations using Equation 16 and Reynold's analogy

$$q = \left(\frac{C_f}{2} Pr^{-2/3}\right) \rho_e u_e C_p \ (T_r - T_w) \tag{17}$$

where the recovery temperature, T_r, was based on a recovery factor of $r = Pr^{1/2}$. The code's prediction of q agrees well with the simple Reynold's analogy as shown in Figure 10.

Comparisons of the Mark IV code's turbulent skin friction predictions for a flat plate were made with calculations using van Driest's method (Reference 15). In Figure 11, the two are shown to be in excellent agreement for $T_w/T_o = 1$ (approximately an adiabatic wall), but for nonadiabatic walls Sasman and Cresci's method seems to predict significantly higher values of C_f than does van Driest's method. However, the Mark IV code output matches calculations presented by Sasman and Cresci in Reference 5.

The coding of the Mark IV integral methods was also checked out for nonzero pressure gradients using a spherical geometry. Laminar heating rates at the stagnation point were calculated by the Mark IV program, and were compared with calculations using the Fay-Riddel method (Reference 16). Although the stagnation point heating rate predicted by the Mark IV code actually corresponds to a cylindrical stagnation point, the difference between cylindrical and spherical stagnation point heating should only be approximately 10%. However, factors of 2 and 3 were observed between the Fay-Riddel and the Mark IV predictions, depending on the freestream conditions used. A thorough examination of the Mark IV calculations revealed that the error was primarily due to the inability of the Mark IV code to accurately predict the stagnation point velocity gradient which strongly influences the heating rate. Consistent with the Fay-Riddel calculation, the normal velocity gradient computation (local tangent wedge) was replaced by the relation

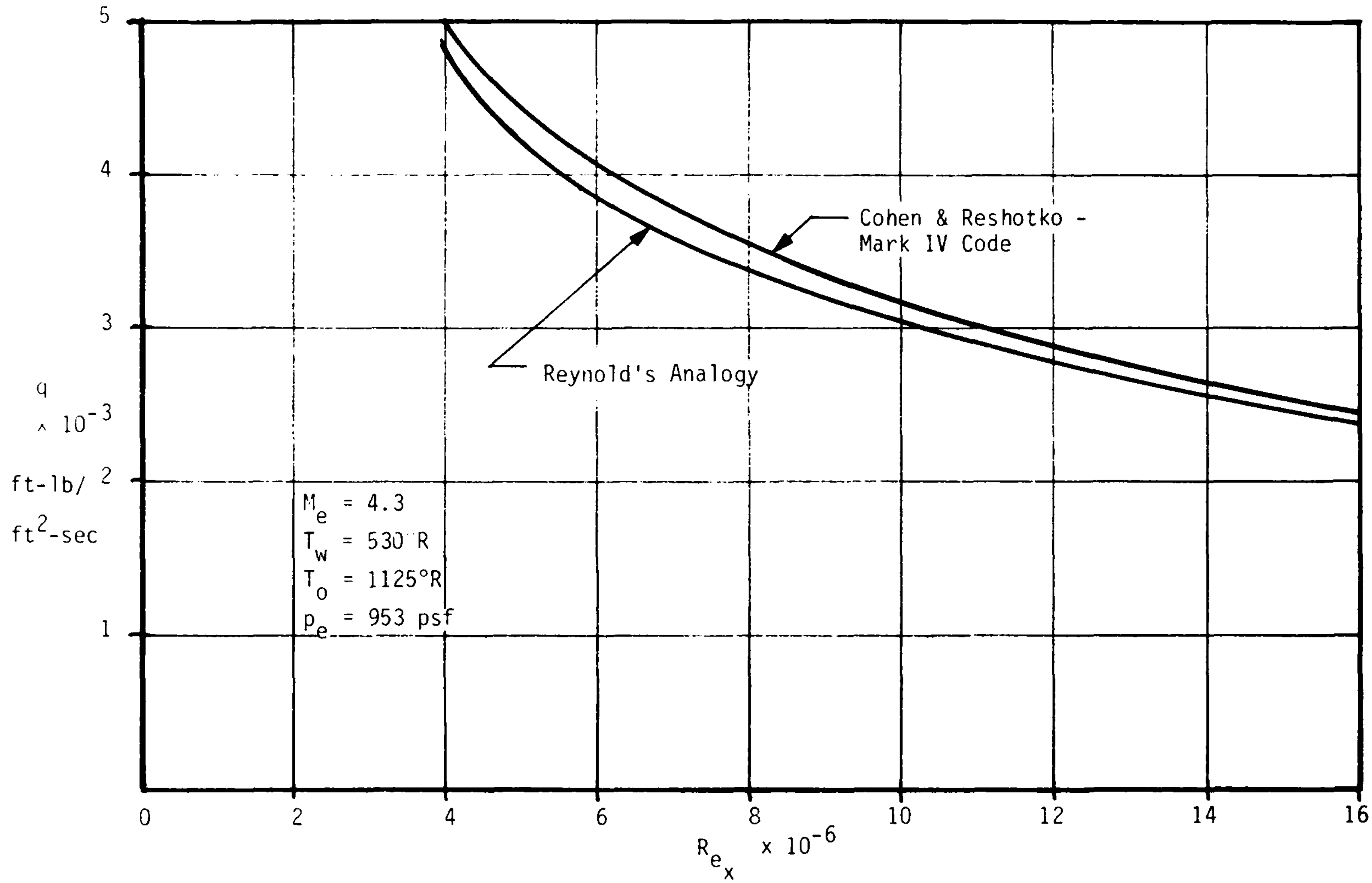


Figure 10. Heat Transfer on a Flat Plate - Laminar Boundary Layer

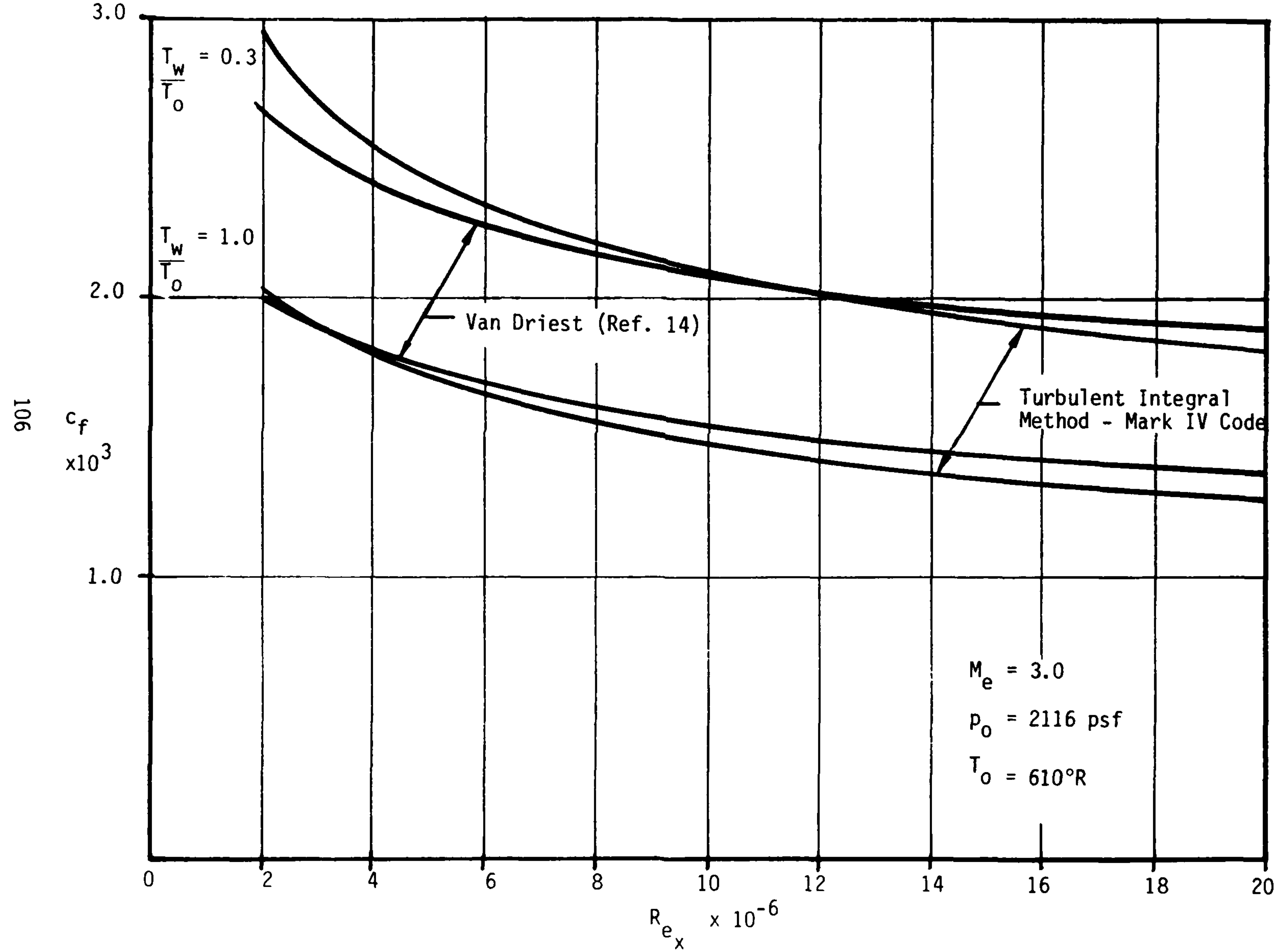


Figure 11. Skin Friction Variation on a Flat Plate

$$\frac{du}{dx} = \frac{1}{R}\left[\frac{2(p_{SP} - p_{\infty})}{\rho_{SP}}\right]^{1/2} \tag{18}$$

where R is the radius at the stagnation point and p_{SP} and ρ_{SP} are the total pressure and density, respectively behind the normal shock. As shown in Figure 12, this approach yields a vast improvement in the stagnation point heat transfer prediction. However, due to funding and time limitations this procedure was not made a permanent part of the Mark IV program.

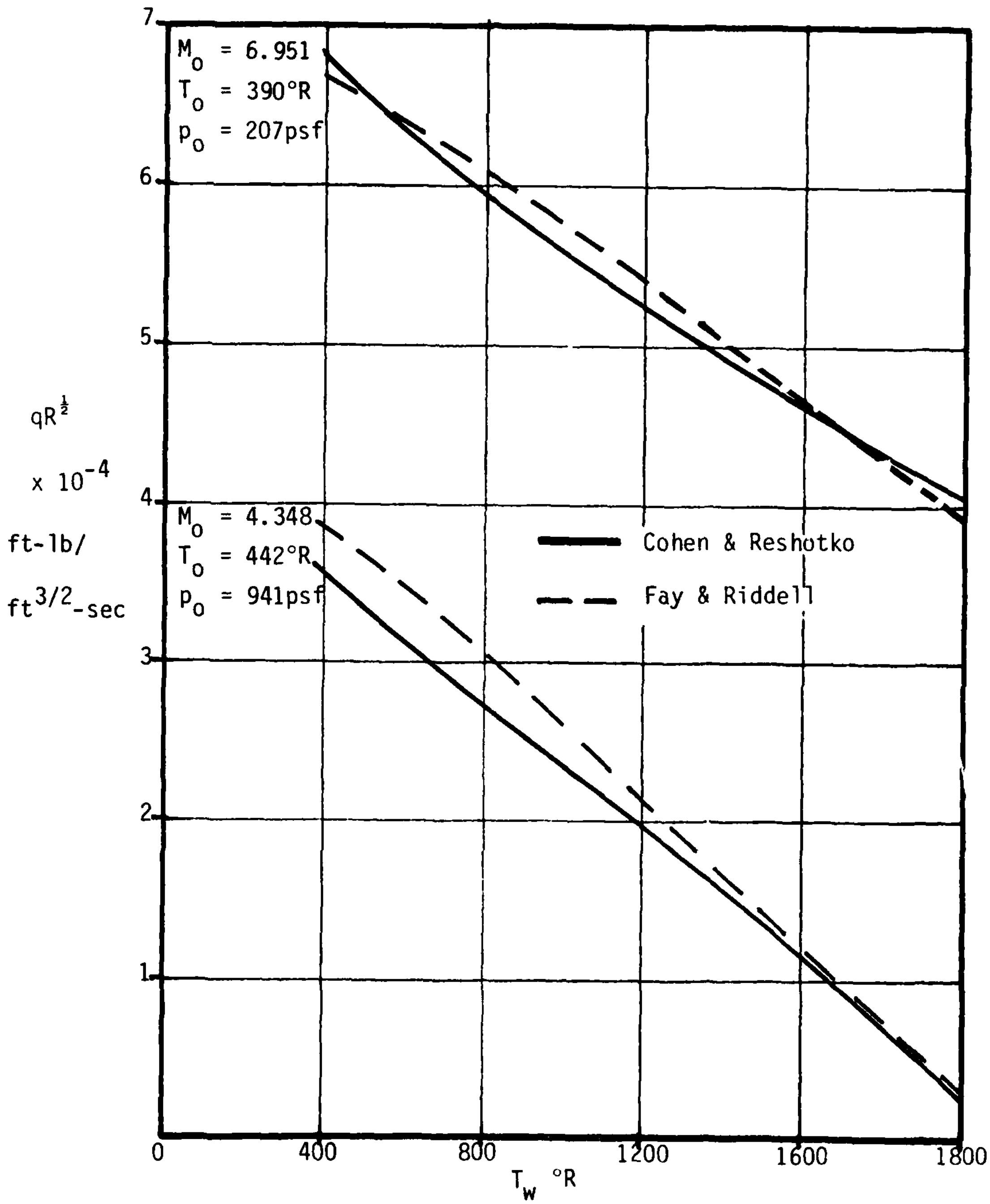


Figure 12. Stagnation Point Heat Transfer

SECTION IV

INFORMATION FOR THE PROGRAMMER

As discussed in Section II the general organization of the modified Mark IV program is identical to that of the original version (Reference 1). However, some major changes were made to certain components of the program including the overlay, which contains the viscous methods, and the overlay which traces surface streamlines. Outlined in Subsection 1, Program Structure, are the organizational changes made to each of the two overlays.

In Subsection 2, New Local Storage, detailed descriptions of two new random access units are given. Unit 50 contains surface spline information for each of the geometry Panels and surface property data (P/P_∞, T/T_∞, etc.) along each of the streamlines. Unit 51 is used to store the coordinates of the streamlines for later use by the interactive picture drawing program TEKPIC (Reference 2).

1. Program Structure

The algorithms developed during the present effort to trace continuous surface streamlines required that the subroutines comprising overlay (MARK 4,2,6) in the original version of the Mark IV program be replaced. Shown in Figure 13 is a flow diagram of the new streamline overlay. The names of three of the subroutines in the original Mark IV program (STREAM, SFNTRP, and VALUE) have been retained in the new streamline overlay since these subroutines perform functions which are analogous to those required in the original program. However, the actual FORTRAN coding of the new routines bears no resemblence to the original coding. Two additional subroutines (RNGKTA and TRACE) are included in the new streamline analysis. Given in Table 1 are descriptions of all subroutines in the new streamline overlay.

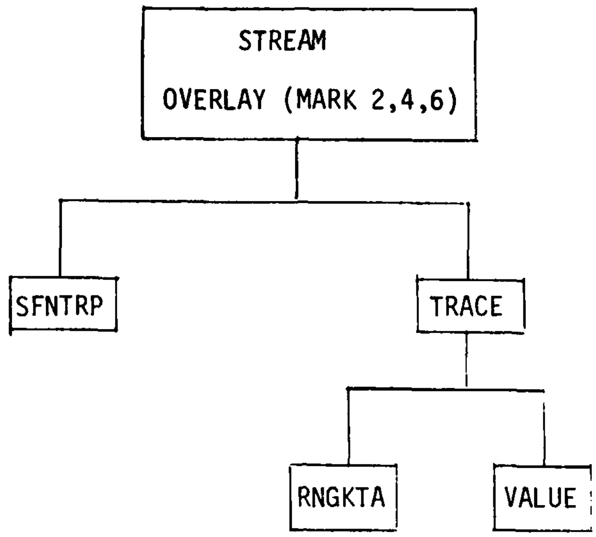


Figure 13. Structure of Streamline Overlay

Table 1. Overlay (MARK 4,2,6) Subroutine Descriptions

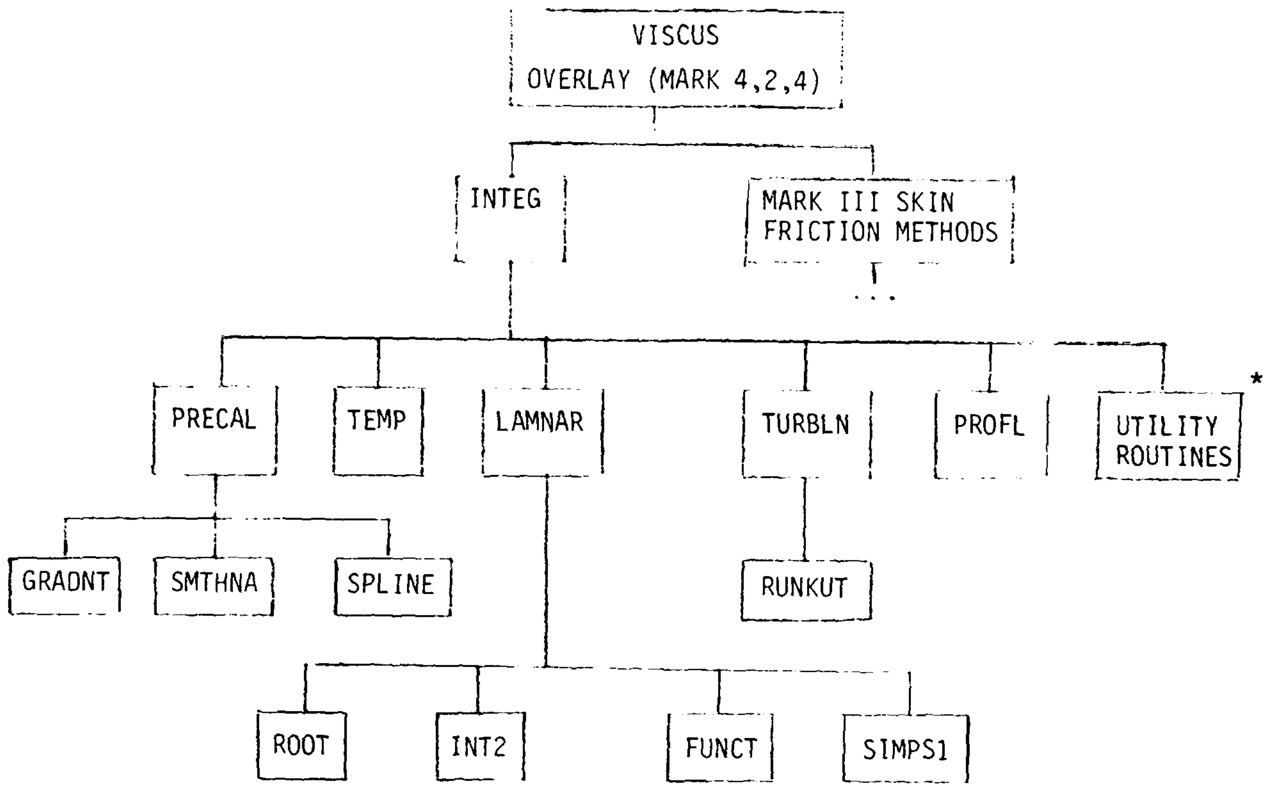
SUBROUTINE	DESCRIPTION
RNGKTA	Subroutine responsible for integrating the streamline equations (see Section III - Theory, Equations 5a and 5b) employs a quartic Runge-Kutta Integration scheme. Called from subroutine TRACE.
SFNTRP	Prior to the streamline calculations this subroutine maps the two appropriate independent variables [(X,Y), (X,Z), or (A,ϕ)] to the unit u-v plane. The surface flow properties (P/P_∞, T/T_∞, M, surface velocity direction cosines, and the dependent geometry coordinate) of each Panel are then fit with the surface spline. SFNTRP is called from STREAM one time for each Panel of the vehicle. After each call, STREAM places the spline information on Unit 50 for later use.
STREAM	Main program for the streamline analysis. Responsible for initializing the appropriate variables, reading user-prepared streamline data (flap, etc.), reading surface flow properties from Unit 10, coordinating the surface spline calculations, and coordinating the actual streamline tracing. Routine STREAM also contains the algorithm used to trace "additional" streamlines.
TRACE	This subroutine is called one time from the main routine, STREAM, for each streamline. Given the starting point for a streamline, this subroutine traces it until a true origin is reached (DIRECT = -1 on the Streamline Data Card, Section II - User's Guide), or until a trailing edge is encountered (DIRECT = 1). If DIRECT = -1, the running lengths along the streamlines are reordered so that S = 0 corresponds to the true origin. TRACE also retains on Unit 50 the surface properties along the streamlines which are subsequently used by the Viscous Methods option.
VALUE	Given the spline coefficients and the bilinear mapping coefficients for a particular Panel, this subroutine returns the interpolated values of the surface flow properties at a given point. The coordinates of the point may be given in the Cartesian system used by the Mark IV program, or they may be given in (u,v) coordinates. If the coordinates are specified with respect to the Mark IV system, subroutine VALUE also provides the corresponding (u,v) coordinates of the point, and vice versa. Subroutine VALUE also indicates whether or not the given point lies within the boundaries of the given Panel.

The Viscous Methods option, overlay (MARK 4,2,4), employs two approaches for viscous related computations: (1) "flat plate" techniques applied to a simplified geometry model (Mark III Skin Friction Method), and (2) boundary layer calculations made along the inviscid streamlines generated by the Streamline Analysis. Outlined in Figure 14 is the interrelationship of those subroutines used to compute viscous effects along the surface streamlines. Since neither the structure nor the overall operation of the Mark III Skin Friction method was modified, those subroutines associated with tne Mark III approach are not shown.

With one exception all subroutines called by INTEG are associated only with the integral boundary layer methods which are applied along the surface streamlines. Subroutine TEMP, however, employs flat plate skin friction methods which may be used along the streamlines in place of the integral methods (see ISFM flag on the Boundary Layer Method Control Card, Section II - User's Guide). Subroutines CFINPT, SFNTR3, VALU3, and INT1 used in the original version of the Mark IV program are not required in the modified version and were removed. Otherwise, the subroutine organization of the Viscous Methods overlay remains unchanged from the original structure.

The two subroutines most affected by the modification of the Viscous Methods overlay are INTEG and LAMNAR. Surface flow properties along the streamlines are accessed from Unit 50 by subroutine INTEG. (Unit 10 contained the streamline data in the original version of the program.) The organization of Unit 50 is discussed in Subsection 2, New Local Storage Units. The laminar integral boundary layer equation used previously in LAMNAR was replaced with a more general equation, as discussed in Section III - Theory. This ordinary differential equation is solved in subroutine LAMNAR using the quartic Runge-Kutta method.

Other changes to the Viscous Methods overlay were minor and do not affect the general flow of the program. Such modifications included a restructure of the labeled COMMON blocks and the correction of several local property calculations (discussed in Section III).



*Utility routines include CURVFT and LGRNGE which are called from more than 1 subroutine.

Figure 14. Structure of Viscous Methods Overlay

Given in Table 2 are brief descriptions of the functions performed by the subroutines listed in Figure 14.

Table 2. Description of Modified Subroutines in Overlay (MARK 4,2,4)

Subroutine	Description
CURVFT	Evaluates a polynomial f(x,y) at a specified point (x,y) given the coefficients of the polynomial.
FUNCT	Contains an expression for the displacement thickness δ^* in terms of the correlation number n. Subroutine FUNCT is used in LAMNAR when the initial correlation number must be determined from a user-specified displacement thickness (see also ROOT).
GRADNT	Computes the gradient of a tabulated function using finite difference techniques.
INTEG	Subroutine responsible for coordinating boundary layer calculations along streamlines. Initializes variables, reads user-prepared data and options, accesses the surface property data along the streamlines from Unit 50, and calls the various boundary layer analyses in a logical order.
INT2	Yields a dimensionless shape factor based on momentum thickness $[(\theta^2/\nu_w)\ du_e/dx]$. Subroutine INT2 is used in LAMNAR to help locate the transition point.
LAMNAR	Solves the laminar boundary layer equation (see Section III -Theory, Equation 11), checks for laminar instability and transition to turbulent flow, and computes the initial values for the turbulent boundary layer analysis.
LGRNGE	Interpolates a given tabulated function using Lagrange's four-point method.
PRECAL	Performs preliminary calculations for the integral boundary layer methods, including the smoothing of data along the streamlines, if necessary, and the computation of all gradients required by the boundary layer equations.
PROFIL	Computes the velocity profiles for the laminar (Pohlhausen quartic) and turbulent (power law) boundary layers. PROFIL also prints the boundary layer parameters computed in subroutines LAMNAR and TURBLN.

Table 2 (Cont'd.) Description of Modified Subroutines in Overlay (MARK 4,2,4)

Subroutine	Description
ROOT	Locates the root of a given function f(x) within a specified interval.
RUNKUT	Solves the coupled differential equations for the turbulent boundary layer using a fixed-step quartic Runge-Kutta method.
SIMPS1	Integrates a given function f(x) over a specified interval using Simpson's rule.
SMTHNA	Routine used to smooth tabulated data.
SPLINE	Computes the first and second derivatives of a function of one variable using a cubic spline technique.
TEMP	Primarily responsible for calculating an equilibrium wall temperature for the Mark III Skin Friction method. Subroutine TEMP may also be used to calculate skin friction coefficients along the inviscid surface streamlines.
TURBLN	Coordinates the integration of the turbulent boundary layer equations and subsequently calculates other boundary parameters of interest (momentum thickness, displacement thickness, etc.)
VISCUS	Main routine for the Viscous Methods overlay. Coordinates the Mark III Skin Friction calculation, but does not coordinate viscous calculations along streamlines (see INTEG).

For a more detailed description of the subroutines see Reference 6.

2. New Local Storage Units

The tracing of continuous surface streamlines over arbitrary vehicle configurations requires that a surface interpolation method be available for estimating geometrical and surface flow properties at points other than the Elements' centroids. As discussed in Section II, Subsection 2 (Surface Streamline Tracing), inviscid analyses in the Mark IV program calculate surface flow properties only at the Elements' centroids, and the data are subsequently placed on random access Unit 10 for use by the streamline analysis. The interpolation method of Harder and Desmaris (Reference 3) is then used to surface fit the following quantities as a function of two appropriate geometrical variables: P/P_∞, T/T_∞, M, $\tilde{V}_1$, $\tilde{V}_2$, $\tilde{V}_3$, and X_3, where $\tilde{V}_i$ is the i^{th} component of the unit surface velocity vector and X_3 is the coordinate not used as an independent variable in the surface fit.

Due to the nature of the interpolation method, each of the seven variables are surface fit Panel-by-Panel. Thus, in order to provide a complete description of one particular variable's surface distribution (e.g., p/p_∞), a total of N surface fits are required corresponding to the N Panels of the vehicle. Therefore, a total of 7 X N surface fits are needed to describe the surface distribution of all seven variables over the entire vehicle.

The surface fitting procedure, described in Section III - Subsection 1 (Streamline Tracing) and in References 1 and 3, is performed in overlay (MARK 4,2,6), which contains the streamline analysis, prior to the actual tracing of the streamlines. For each Panel of the geometry the coordinates of the Elements' centroids and the corresponding flow variables are read from Unit 10, fit with the surface spline, and the resulting spline coefficients are saved on random access Unit 50 for later use. The streamline calculation begins when the spline coefficients of the last Panel are computed and saved. As the streamlines are integrated from one Panel to another, a new set of spline coefficients are read from Unit 50 and are used to interpolate for the values of the flow variables at any point on the surface of the Panel. Due to the size of the arrays required to hold the spline coefficients of each Panel, only the coefficients associated with one Panel may be placed in memory at any one time.

Two types of data are placed on random access Unit 50. Data related to the surface splines are stored on the first half on Unit 50, and streamline data are placed on the second half of the unit. As shown in Table 3, two records are allocated to each Panel for storing the spline coefficients and related variables. The Panel information is placed on Unit 50 in the same order that the Panel Identification Cards are read by program GEOM, the Mark IV geometry program (see Reference 1, Vol. I, p. 18). That is, records 1 and 2 correspond to Panel 1, records 3 and 4 to Panel 2, etc.

Table 3. Structure of Random Access Unit 50 (See Table 4 for definitions of all variables)

Record	Contents
1	Ten integer variables related to the surface splines of Panel 1. (See first 10 elements of COMMON block SURFIT below and Table 4).
2	Real variables related to the surface splines of Panel 1. (See remainder of COMMON block SURFIT below and Table 4).
3	Same integer variables as those in record 1, but as applied to Panel 2.
4	Same real variables as those in record 2, but as applied to Panel 2.
•	
•	
•	
2*NP-1 (NP = # Panels)	Same integer variables as those in record 1, but as applied to Panel NP.
2*NP	Same real variables as those in record 2, but as applied to Panel NP.

Table 3 (Cont'd.) Structure of Random Access Unit 50 (See Table 4 for definitions of all variables)

Record	Contents	
2*NP+1	ISFLAG(10)	Streamline 1
2*NP+2	SSTRM(150)	Streamline 1
2*NP+3	XSTRM(150)	Streamline 1
2*NP+4	YSTRM(150)	Streamline 1
2*NP+5	ZSTRM(150)	Streamline 1
2*NP+6	EMSTRM(150)	Streamline 1
2*NP+7	PSTRM(150)	Streamline 1
2*NP+8	TSTRM(150)	Streamline 1
2*NP+9	CFSTRM(150)	Streamline 1
2*NP+10	IPSTRM(150)	Streamline 1
• • •		
2*NP+1 +10*(NS-1)	ISFLAG(10)	Streamline NS
• • •		
2*NP+1 +10*(NS-1) +9	IPSTRM(150)	Streamline NS

The spline-related data are retrieved from Unit 50 after having first placed the FORTRAN names in a single labeled COMMON block:

```
      COMMON/SURFIT/N1,N2,N3,IU,IW,ID,IORN,ISYM,ICL,IDUM(1),
     1  CPT(4,3),ORGN(3),ROT(3,3),PSIO,THETO,PHIO,UD(500),WD(500),
     2  ULE,WLE,FLOWC(7),FLOWD(500,7),AU,AW,BX,CX,DX,BY,CY,DY,DUM(56)
```

The data for Panel number IPANEL are read from Unit 50 using the following statements:

```
IREC = 2*IPANEL -1
CALL READMS (50, N1, 10, IREC)
IREC = IREC + 1
CALL READMS (50, CPT (1,1), 4600, IREC)
```

The spline data for Panel number IPANEL are then available to all subroutines in the streamline tracing overlay through the labeled COMMON block.

Following the last record containing spline information are the streamline data. Ten records are allocated to each streamline with each record containing the values of a particular flow quantity (e.g., T/T_∞) along that streamline.

Listed below in Table 4 are brief descriptions of the variables stored on Unit 50.

Table 4. Dictionary for Unit 50 Data (listed in relative order of appearance)

I. Spline-related Data

Variable Name	Description
N1	Number of centroids in the Panel.
N2	Number of data points used to generate the surface spline (usually, N2 = N1).
N3	Number of spline coefficients used to surface fit a particular quantity. N3 = N2 + 3, and is the same for each of the seven variables that are surface fit.

Table 4 (Cont'd.) Dictionary for Unit 50 Data (listed in relative order of appearance)

Variable Name	Description
IU	Identifies the first independent variable used in the surface fit. Corresponds to the x-coordinate if the functional form of the Panel is either Y = F(X,Z) or Z = F(X,Y). IU corresponds to the axial component A if the Panel's functional form is R = F(A,Ø), where R is a radius and Ø is a circumferential angle. IU = 1 always.
IW	Identifies the second independent variable used in the surface fit. IW = 2 if either of the functional forms Z = F(X,Y) or R = F(A,Ø) is used. If the form Y = F(X,Z) is used, IW = 3.
ID	Identifies the coordinate not used as an independent variable in the fit. This third coordinate is fit with the surface spline in the same manner that the six flow variables are fit.
IORN	Flag indicating whether element data for this Panel were input by cross-section or in streamwise strips. (See Panel Identification Card description, Reference 1, Volume I, p. 18).
ISYM	Indicates whether or not the vehicle has a plane of symmetry. ISYM = 0 if a plane of symmetry exists. Otherwise, ISYM = 1.
ICL	Has the value 1 if ISYM = 0 and the vehicle is oriented such that the sideslip angle is zero. Otherwise, ICL = 0.
IDUM(1)	Not used.
CPT(4,3)	Array containing the coordinates of a Panel's four corner points.
ORGN(3)	Coordinates of the origin used when the Panel is fit in a cylindrical coordinate system, R = F(A,Ø). If the appropriate functional form of the Panel is Y = F(X,Z) or Z = F(X,Y) then ORGN(1), (2), (3) = 0.

Table 4 (Cont'd.) Dictionary for Unit 50 Data (listed in relative order of appearance)

Variable Name	Description
ROT(3,3)	Matrix used to transform the Mark IV coordinate system to one in which the x-axis is aligned with the axial coordinate A in a cylindrical coordinate system. If the Panel's functional form is not R = F(A,Ø) then ROT(3,3) is the identity matrix.
PSIO,THETO	Yaw, pitch and roll angles, respectively, used to form the matrix ROT(3,3).
UD(500), WD(500)	The u- and v-coordinates of the centroids of the Panel (see Section III - Theory).
ULE,WLE	Variables used to describe the orientation of the Panel relative to the x-axis of the Mark IV coordinate system. Used only when the Panel's functional form is R = F(A,Ø). If the dot product of the unit vectors along the cylindrical axis A and the Mark IV, x-axis is less than .707 (45°), then ULE = 0, WLE = -10. Otherwise, ULE = -10., WLE = 0.
FLOWC(7)	Array containing the average value of each of the seven variables that are surface fit.
FLOWD(500,7)	Array containing the spline coefficients of each of the seven spline-fit variables.
AU,AW,BX,CX, DX,BY,CY,DY	Certain additive and multiplicative combinations of the four sides of a Panel. Used in the interpolation process.
DUM(56)	Not used.
II. Streamline Data	
ISFLAG(10)	Array of integer flags. ISFLAG(1) is the number of points saved along a given streamline. Remainder of array is not used.
SSTRM(150)	Running lengths along a streamline.
XSTRM(150) YSTRM(150) ZSTRM(150)	The x=, y-, and z-coordinates, respectively, of the points along a streamline.

Table 4 (Cont'd.) Dictionary for Unit 50 Data (listed in relative order of appearance)

Variable Name	Description
EMSTRM(150)	Local Mach number along the streamline.
PSTRM(150)	P/P_∞ along the streamline.
TSTRM(150)	T/T_∞ along the streamline.
CFSTRM(150)	Not used.
IPSTRM(150)	Panel numbers along the streamlines.

The organization of Unit 50 does not permit the saving of multiple cases. Only the streamline data associated with one set of freestream conditions (Mach number, angle of attack, etc.) may be saved at any one time. Therefore, if boundary layer calculations are to be made along the streamlines, the viscous analysis must immediately follow the streamline calculations.

A second random access device, Unit 51, was added to the Mark IV program to provide a communication link with program TEKPIC, an interactive computer graphics program designed specifically for displaying Mark IV geometries and surface streamlines. If the user-specified variable ISTORE is set equal to 1 on the Streamline Data Card (see Section II - Surface Streamline Option), then the coordinates of points along the streamlines are automatically saved on Unit 51. These streamline data are used only by program TEKPIC and do not affect any calculations made in the Mark IV program.

Provisions are made on Unit 51 for storing multiple cases. A maximum of 5 streamline distributions may be stored, each corresponding to a particular set of freestream conditions, and all bookkeeping is handled internally. If the streamline coordinates are to be used subsequently by the TEKPIC program, the contents of Unit 51 must be saved on a permanent file device following the execution of the Mark IV program. Furthermore, it is not necessary that all 5 streamline cases be placed on Unit 51 at once (one execution of the Mark IV program). If, after having saved 1, 2, 3, or 4 streamline distributions on one file of a permanent file device, it is permissible to attach that permanent file device at a later time as Unit 51 and to use the Mark IV program to generate new streamline distributions. The new streamline distributions are automatically appended to the streamlines already existing on the file. However, the streamline data must not be used with program TEKPIC until all desired streamline distributions have been placed on Unit 1.

The structure of Unit 51 is fully documented in Reference 2 for those interested in using program TEKPIC.

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