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A flexible plate nozzle design for an operating Mach number range of 1.4 to 2.0

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THESIS

A FLEXIBLE PLATE NOZZLE DESIGN FOR AN OPERATING MACH NUMBER RANGE OF 1.4 TO 2.0

by

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A FLEXIBLE PLATE NOZZLE DESIGN FOR AN OPERATING MACH NUMBER RANGE OF 1.4 TO 2.0

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ABSTRACT

The design for a supersonic flexible plate nozzle is presented. The nozzle was required for a supersonic blow-down cascade wind tunnel facility at the Naval Postgraduate School's Gas Dynamics Laboratory. Overall dimensions were based on calculations of the required test section height and width which would give acceptable (2 minute) run times over an operating Mach number range from 1.4 to 2.0. A two-dimensional, constant-plate thickness, multiple-jack screw configuration was the concept used to effect the nozzle geometry changes. Mention is made of a multi-disciplinary design optimization routine which helped to rule out a single-jack, variable-plate thickness configuration. The aerodynamic and structural analysis used in the design process is presented in detail. Preliminary drawings of the nozzle mechanism are included.

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I. INTRODUCTION

A small transonic compressor cascade wind tunnel was designed and built at the Turbopropulsion Laboratory (TPL) at the Naval Postgraduate School, Monterey, California (Demo, 1978). The tunnel was used successfully to examine the shock structure at the tip of a transonic compressor rotor then being tested at the Laboratory. In recent years, the test section was modified to provide a simulation of the flow through blading of a Navy development fan. The goal was to obtain an acceptably two-dimensional and periodic simulation with only two blade passages so that the scale of the model was large enough to examine shock-boundary layer interaction, and its control using vortex generators. The development of the two passage simulation was reported (Shreeve et al, 1993) and recent measurements of the effects of vortex generators on the passage shock-boundary layer interaction were documented (Gamerdinger, 1995). In order to allow similar experimental studies to be conducted over a range of relative flow Mach numbers of interest in advanced fan designs, a variable Mach number apparatus with a larger test section was required. The design of the nozzle for the new apparatus, which would use the supply and exhaust piping of an existing 4x4 inch supersonic wind tunnel was the goal of the present work. The aim was to incorporate into the larger apparatus all the features proven successfully in the pilot experiment, but to provide them over a range of Mach number that could be varied continuously from 1.4 to 2. This range of Mach number was chosen based on the status of fan and compressor technology and would be of interest for many years.

Thus the focus of the present thesis was the design of a variable geometry nozzle and actuating mechanism for the new apparatus. For the test section area considered in the present design, Mach 2.0 was a limit set by the TPL blow down facility air receiver volume and pressure level, and the desired test duration. Because the blow down facility was an intermittent wind tunnel and the test durations relatively short, the nozzle mechanism was not required to change the test section Mach number during the course of a test. The mechanism was required to alter the nozzle shape during the intervening time between tests in which the air tanks were being repressurized. Based on the this length of time between tests, the nozzle mechanism was required to be able to provide a complete change in configuration from the Mach 1.4 to the Mach 2.0 shape within fifteen minutes.

A flexible-plate nozzle with screw jacks to alter the shape was the chosen concept for the design. This mechanism was chosen over a moveable-block concept because of the requirement to couple the nozzle with a cascade test section with boundary layer scoops on all four walls. An arrangement based on quick removal and installation of fixed-shape nozzle blocks was not chosen due to the expense involved in machining the many sets of nozzle blocks required to cover the desired Mach number range. The flexible plate nozzle design could potentially provide fast changes in geometry and a nearly continuous variation of test Mach number, at reasonable expense.

The present document records the design process followed and provides the details of the final design, which is shown in Figure 1 in a side view with the side plates removed. Chapter II discusses the constraints imposed by the existing blow-down facility, future test section design requirements and the initial sizing of the nozzle. Chapter III describes a flexible-plate nozzle design methodology developed at NASA Ames Research Facility (Melton, 1994), which was followed initially in the present project This design process involved a multi-disciplinary optimization of the flexible plate thickness variation. Chapter IV describes the design methodology used in the final design in which aerodynamic and structural solutions were derived separately. This design approach incorporated constant-thickness flexible plates with multiple screw jacks. Chapter V discusses features of the mechanism design, including the sealing problem, the jackscrew design, the jack mounting design and the support frame. Chapter VI presents conclusions and recommendations for further analysis and specifically a computational fluid dynamics analysis before commitment to manufacture is made. Finally, the appendices document the analytical and computational methods used in the design process.

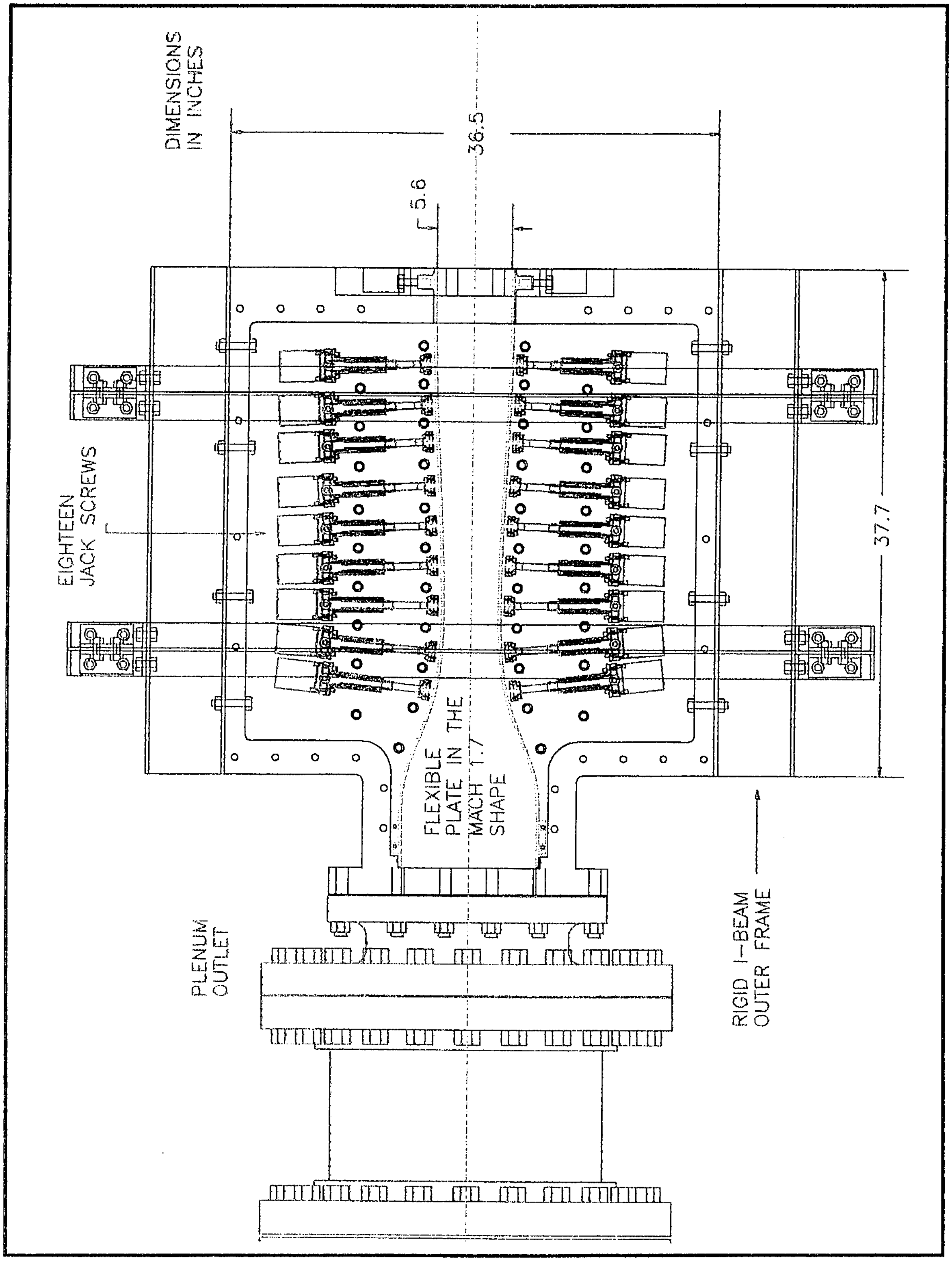


Figure 1. Two Dimensional Flexible Plate Nozzle

II. DESIGN REQUIREMENTS AND INITIAL SIZING

An initial sizing calculation was carried out to determine if the design requirements could be achieved. The calculations showed that the existing air supply system was capable of supporting Mach 2.0 operation for the test section of interest.

A. NOZZLE EXIT AREA

The sizing of the nozzle exit area was determined by the capabilities of the Gas Dynamics Laboratory (GPL) blow-down facility (Figure 2), the required stagnation pressure for Mach 2 operation and the desired test duration.

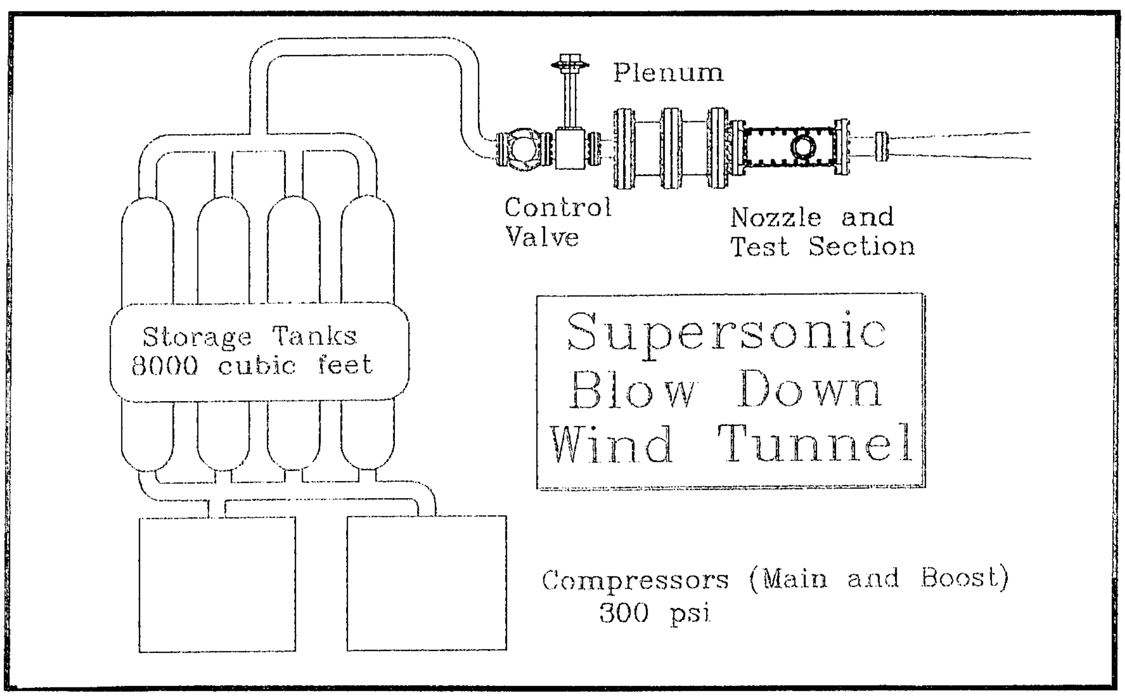


Figure 2. Blow Down Wind Tunnel Facility

The capacity of the storage tanks was 8000 cubic feet and the maximum pressure available through a combination of main and boost compressors was 300 pounds per square inch. The existing control valve was a Fisher Type 57-T. Data on the ability of this control valve to regulate air flow at low pressure differentials was not available. To maintain a particular Mach number in the test section, the plenum pressure had to be kept at a constant level. Therefore a series of tests was conducted to determine the lower limit in pressure differential across the control valve at which control of the plenum pressure was lost. The data taken from these tests were used to derive a coefficient of volumetric flow rate (Fisher, 1977), which in turn was used to determine the useful range in tank pressures available for testing.

Based on experience with the pilot transonic cascade facility, and the time needed for probe surveys, a nominal test duration of two minutes was chosen. The control-valve tests indicated that the time from when the control valve was first opened to when stable flow conditions were established, was approximately one minute. During this period the volumetric flow rate would be less than occurs during the steady test period. Consequently, the nozzle exit area was sized for a three minute steady flow at Mach 1.9, and this resulted in the selection of eighteen square inches. The derivation of the volumetric flow rate and the exit area calculation are given in Appendix A.

B. NOZZLE EXIT ASPECT RATIO

Factors constraining the test section geometry were examined to determine the dimensions of the nozzle exit. The aspect ratio of the test section is defined herein as the ratio of the vertical height to the horizontal width of a plane oriented perpendicular to the air flow (Figure 3).

Design specifications for current experimental high speed compressor blading were considered in selecting the aspect ratio. Though the trend in compressor blade stagger angles points toward angles in excess of seventy degrees, much lower angles (in the area of forty degrees) were found to be the limiting considerations in setting the test section width, given a number of desired blade passages. Three passages was the configuration chosen to provide improved flow periodicity compared to that attained in the pilot transonic facility. Using five passages, the generally accepted 'minimum' number for supersonic cascades, was ruled out due to the difficulty of resolving viscous effects with very small-scale blades. It was also desirable to design the larger supersonic test section to have improved two dimensionality compared to the pilot transonic test section.

The test section design envisioned here included the boundary layer scoop concept, proven so effective in the existing pilot transonic cascade (Shreeve et al, 1993). In addition to the test section area, the area occupied by the boundary layer at the nozzle exit had to be determined. This boundary layer area represented air flow which would be directed away from the test section by the boundary layer scoops but which had to be accounted for in determining the nozzle exit aspect

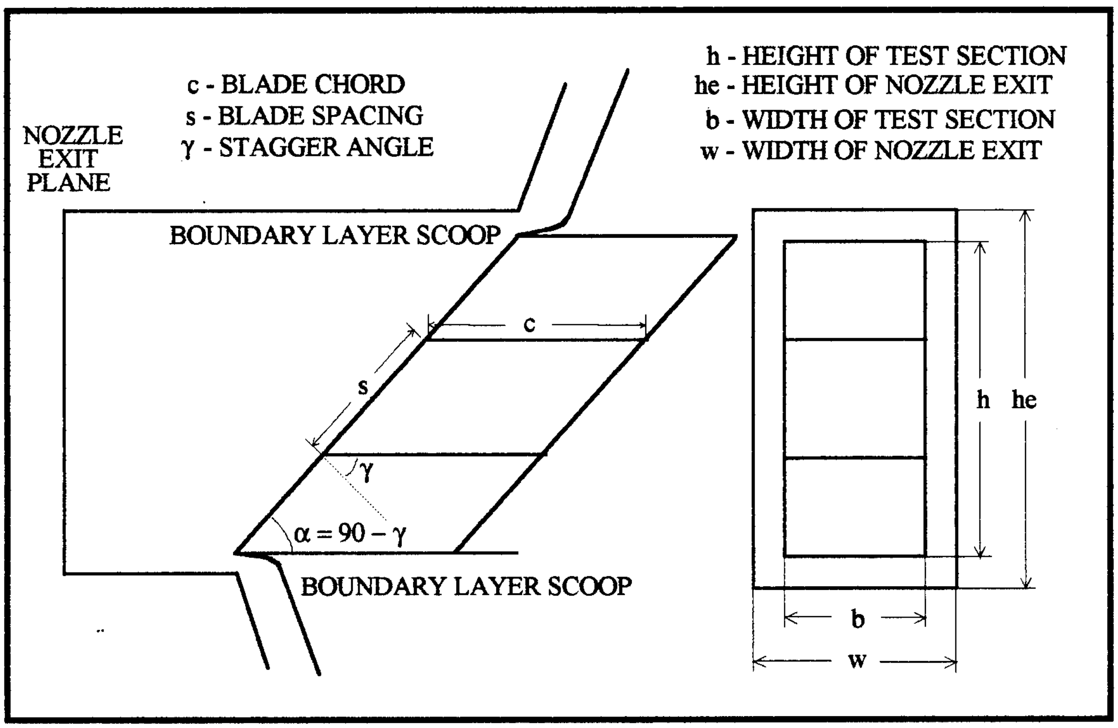


Figure 3. Test Section and Nozzle Exit Geometry

ratio. A boundary layer scoop depth of .25 inches was considered an acceptable loss from the test section area. By choosing this scoop depth, the nozzle length was limited to 25 inches. With these considerations, the exit area dimensions were determined as exit height, 5.6 inches and exit width 3.2 inches. A list of the parameters for the nozzle design is given in Table 1.

Maximum Exit Mach Number	2.0
Maximum Plenum (Supply) Pressure[psia]	115
Test Section Pressure[psia]	14.7
Nozzle Exit Height(he)[inches]	5.6
Nozzle Exit Width(w)[inches]	3.2
Test Section Height(h)[inches]	5.1
Test Section Width(b)[inches]	2.7
Nozzle Length (Throat to Exit)[inches]	25

Table 1. Nozzle Design Parameters

The nozzle exit aspect ratio determination is described in detail in Appendix A.

III. DESIGN CALCULATIONS USING AN AUTOMATED OPTIMIZATION ROUTINE

A multi-disciplinary design method developed by Melton of the NASA Ames Research Facility (Melton, 1994) was used to conduct the initial design study. The method was developed specifically for the redesign of a flexible plate nozzle used in the NASA Ames Unitary Wind Tunnel Facility. The nozzle controlled the Mach number of the transonic portion of the tunnel over the range 1.3 to 1.5. The redesign involved replacing a variable thickness flexible plate and single throat-jack nozzle configuration with an optimized, variable-thickness flexible plate and multiple-jack configuration.

The goal in the NASA design was to effect a desired aerodynamic shaping using a simple metal structure. There was no logical similarity between the aerodynamic shapes required to achieve good nozzle outflow conditions and the shape that would be taken by a metal plate under combined pressure and end point loads. If the pressure loads generated by the fluid flow were of the same order of magnitude as the forces required to deflect the plate, the aerodynamic and structural solutions directly affected one another. The optimization routine provided the ability to analyze the coupled aerodynamic and structural problems.

The NASA optimization method also held the promise of generating a single throat jack configuration which, from a cost effectiveness standpoint, was appealing. The method was untried in the Mach number range of 1.4 to 2.0, but the excellent result achieved in NASA's 1.3 to 1.5 redesign instilled confidence in the methodology as a starting point for the NPS design.

A. OPTIMIZATION CODE

The optimization code was designed to provide a plate thickness distribution which, when placed under a combined load of the flow-field pressure and the throat jack, produced an exit flow condition which was acceptable to the designer. For the purpose of compressor cascade studies, the uniformity of the exit plane Mach distribution was of primary concern and was thus used as the nozzle optimization criterion. Known were the exit plane aspect ratio and Mach number range, which implied known nozzle area ratios and pressure ratios. The FORTRAN code developed by Melton and Erickson (Melton, 1994) iteratively determined the optimum thickness variation from a specified set of thickness variations. Nozzle length was set as constant within the optimization code, but was varied manually as part of the overall design optimization. Material properties for 17-7PH stainless steel were also defined within the code.

The optimization strategy used in the code is shown in Figure 4. Initially, a combination of thickness distributions was specified by the user. The code used the method of characteristics to compute flow-field solutions and a finite-element routine to compute structural deformation as a result of the throat deflection and flow field pressure loading. A constant thickness plate was assumed to begin the iteration. The boundary conditions simulated a plate which was fixed at the exit and deformed by a throat jack to achieve the required area ratio. A flow field solution was

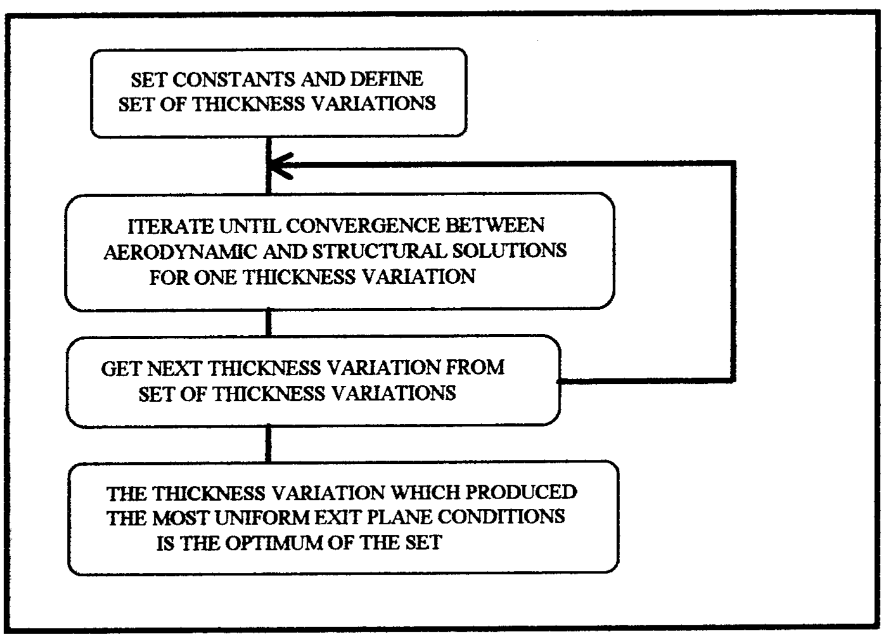


Figure 4. Flow Chart of the Automated Optimization Method

calculated based on this deformed shape. The first thickness distribution was chosen and the pressure loading from the flow field solution was applied along with the throat deflection boundary condition. The finite element routine was run on this updated flexible plate geometry and set of boundary conditions. From this structural solution a new shape was found which was used to compute a new flow field solution. This procedure was continued for one wall thickness distribution until the aerodynamic and structural solutions converged to within a specified tolerance. For this solution, the difference between the exit plane Mach distribution and the desired Mach number was stored in a vector, and the L2-norm was used to quantify the magnitude of the variation.

The next thickness distribution was taken from the set and the iteration process was repeated. The norm of the exit-plane Mach number variation for this converged solution was compared to the previous solution. If this exit plane Mach number variation was less than the previous one, the new thickness distribution was saved as the current optimum and the other value was discarded. This process was continued for the entire set of user-specified thickness distributions. The optimum thickness distribution of the defined set was that which resulted in the lowest exit-plane Mach number variation.

A nozzle shape was optimized for one on-design Mach number. Once the optimized shape was determined, the code was run again for the design plate thickness distribution at the required off-design Mach numbers. An exit-plane Mach number variation within .005 of the desired value was considered acceptable as it was two orders of magnitude less than the range of desired Mach numbers.

In the original code, boundary layer properties were taken from experimental data obtained in the existing NASA wind tunnel. An attempt was begun to incorporate a more general boundary layer subroutine into the code, but the amount of time necessary to complete the task proved to be excessive. Additionally, it was found that the time required per iteration as a result of adding an integral boundary layer routine would cause the overall optimization to more than double. The initial design studies were therefore conducted using an inviscid version of the code. Code operating details are given in Appendix B.

B. RESULTS OF ANALYSIS

The study conducted using Melton's optimization code indicated that a single jack, variable-plate thickness nozzle would not provide the desired uniformity in the exit plane Mach number over the range from 1.4 to 2.0. Two plate configurations were considered, a variable thickness distribution and a constant thickness distribution.

A study was conducted to determine the on-design Mach number and optimum thickness distribution that best satisfied the exit plane Mach number uniformity requirement. Figures 5, 6 and 7 show typical results of this study. For a design Mach number of 2.0 (Figure 5) the optimized thickness distribution produced an exit plane Mach distribution well within the desired tolerance.

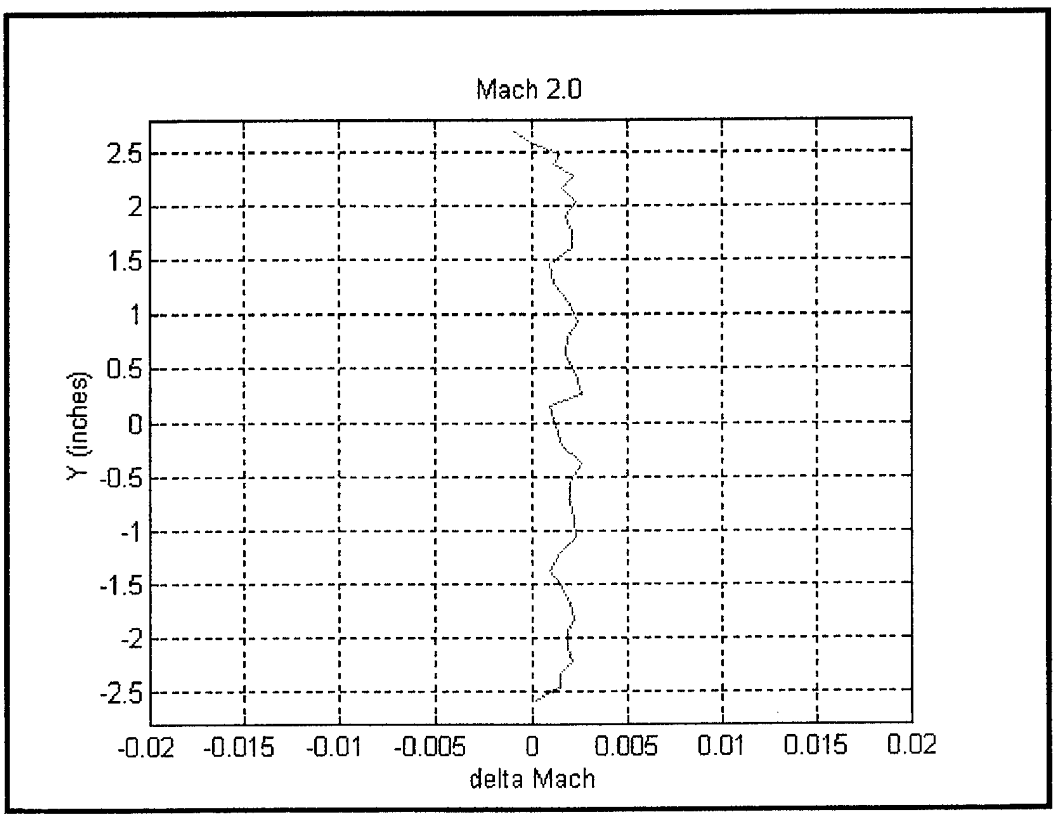


Figure 5. On-Design Exit Plane Mach Distribution (Variable Thickness)

The procedure followed was first to obtain the optimized solution which was acceptably uniform but not necessarily centered at the nominal Mach number. The entire distribution curve was then moved by changing the nozzle area ratio by slightly changing the throat jack setting. In Figure 5, the exit Mach number was uniformly .002 greater than the desired value. By adjusting the throat jack setting to achieve a larger area ratio, this curve could be moved to the left to achieve the desired M = 2.0 test condition.

The promising result shown on-design did not hold for the off-design conditions. From Figures 6 and 7 it can be seen that the off-design performance of the optimized M = 2.0 nozzle was unacceptable. It is noted however, that the degree of uniformity at the Mach numbers below 1.6 was much better that at all Mach numbers higher than 1.6.

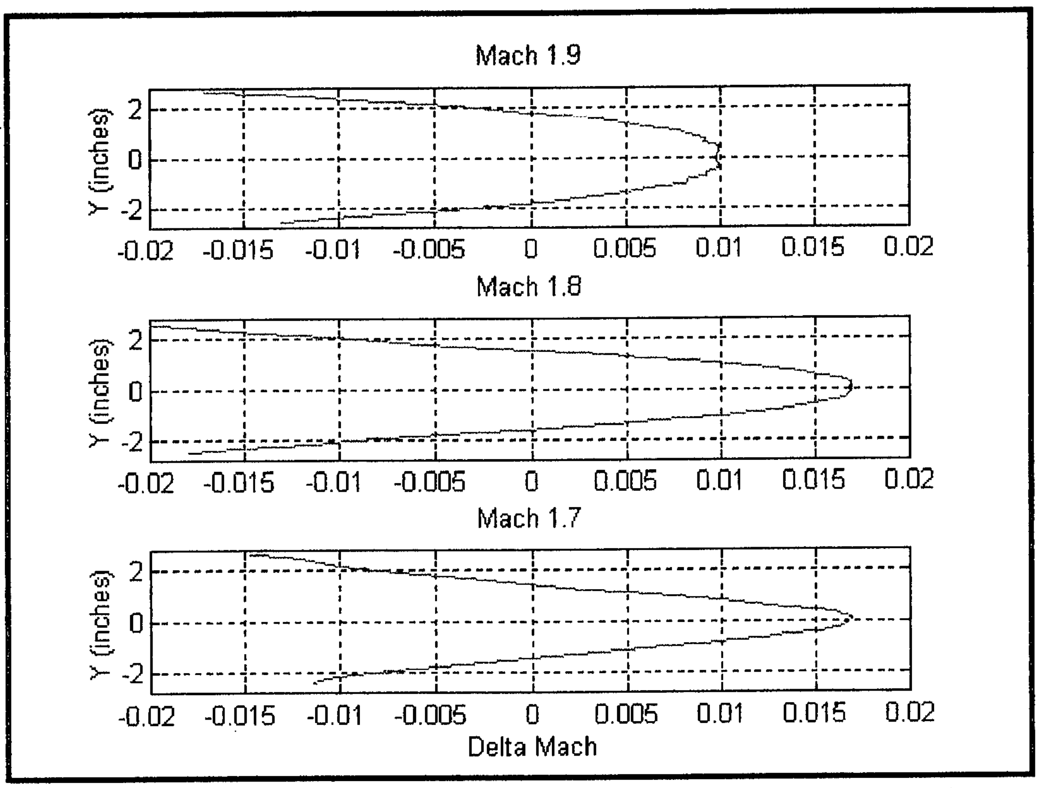


Figure 6. Off-Design Exit Plane Mach Distribution (Variable Thickness)

Further attempts showed that optimizing the thickness distribution for any Mach number between 1.7 and 2.0 produced off-design exit plane conditions which did not meet the targeted uniformity criteria.

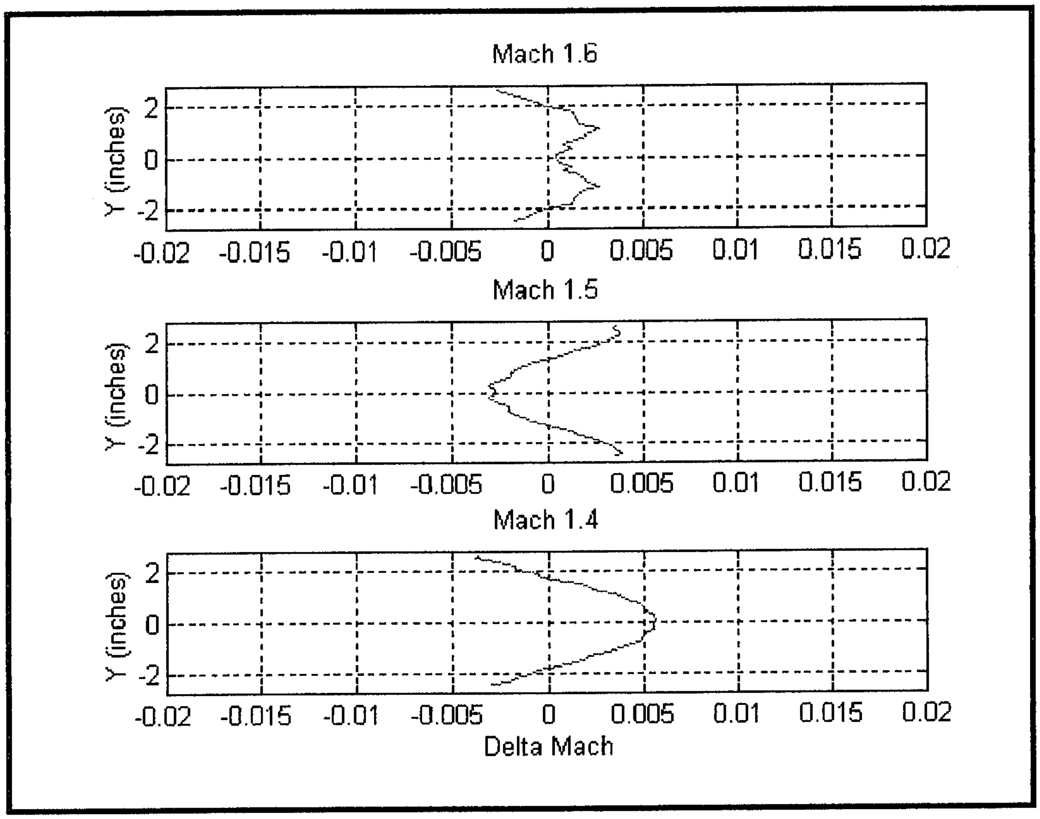


Figure 7. Off-Design Exit Plane Mach Distribution (Variable Thickness)

The uniformity shown at the lower Mach numbers was noted to be consistent with the success of the NASA redesign using this method.

A second study was conducted to determine the exit plane Mach number distributions that would result from deflected plates of uniform thickness. The procedure followed during the second study was to vary the plate thickness uniformly for a given Mach number until acceptable exit plane conditions were achieved. Figure 8 shows the constant thickness result for an on-design Mach number of 2.

A plate thickness of .132 inches was used to produce these results. The on-design uniform thickness was then run off-design. Figures 9 and 10 show the off-design performance of the uniform-plate thickness.

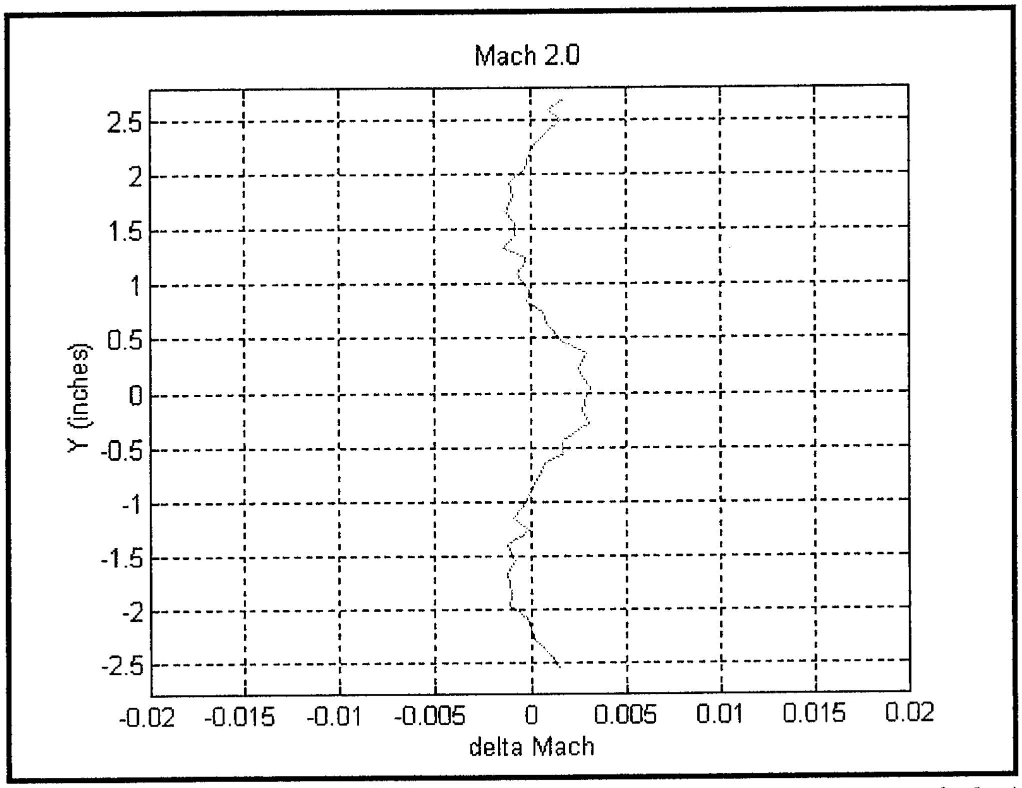


Figure 8. On-Design Exit Plane Mach Distribution (Uniform Thickness=.132 inches)

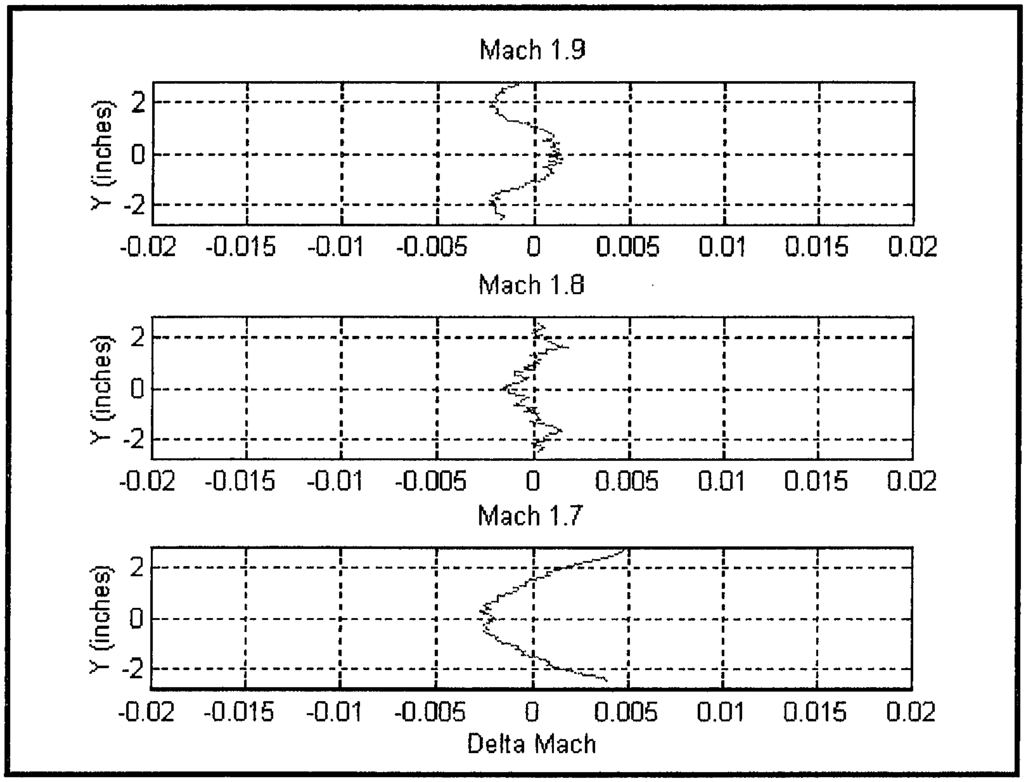


Figure 9. Off-Design Exit Plane Mach Distribution (Uniform Thickness=.132 inches)

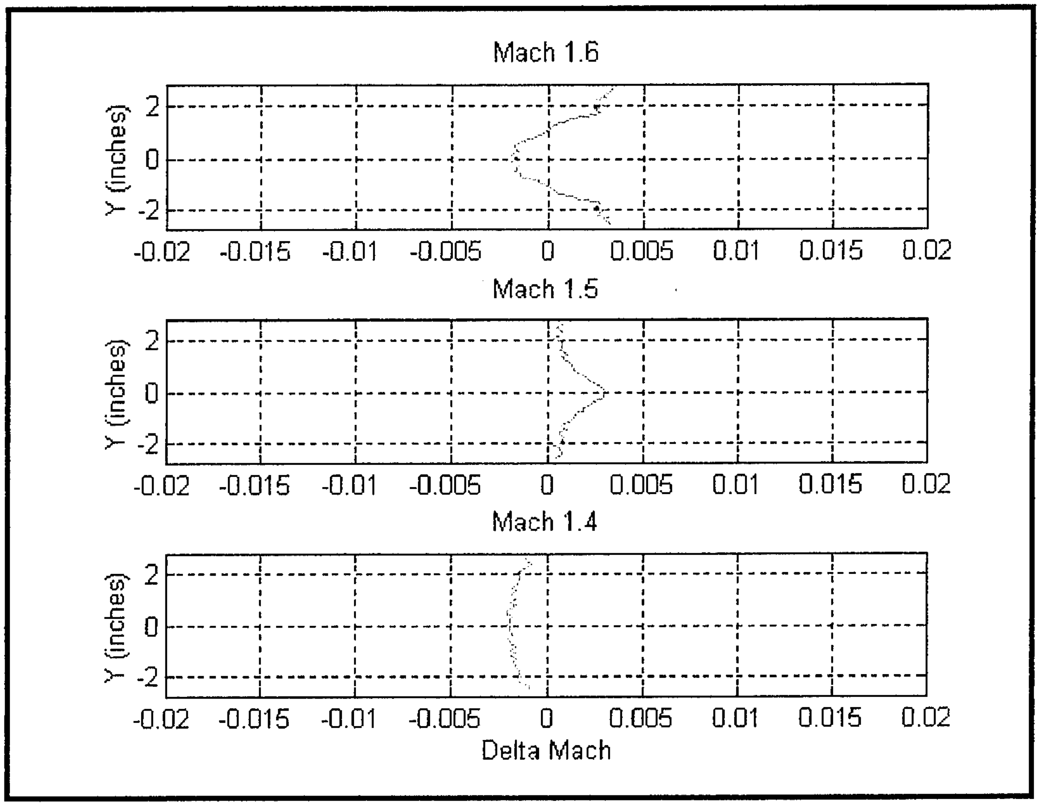


Figure 10. Off-Design Exit Plane Mach Distribution (Uniform Thickness=.132 inches)

The off-design performance for the uniform thickness plate was seen to be acceptable, but the thickness of .132 inches presented a problem in sealing the plate. The minimum practical O-ring diameter was considered to be .07 inches which required a gland width of .11 inches. A plate thickness of .25 inches was considered to be necessary to accommodate the O-ring gland.

A uniform plate thickness of .25 inches was analyzed to determine the nozzle exit flow uniformity. The results are shown in Figures 11 and 12. It can be seen that a plate of this increased thickness would require additional jacks to adjust the shape to achieve the desired uniformity at the exit plane. The .25 inch plate did however produce better exit plane Mach number uniformity than the variable thickness optimized solution. The results indicated that, for the Mach number range under consideration, a constant thickness plate was a better configuration than the optimized variable thickness plate.

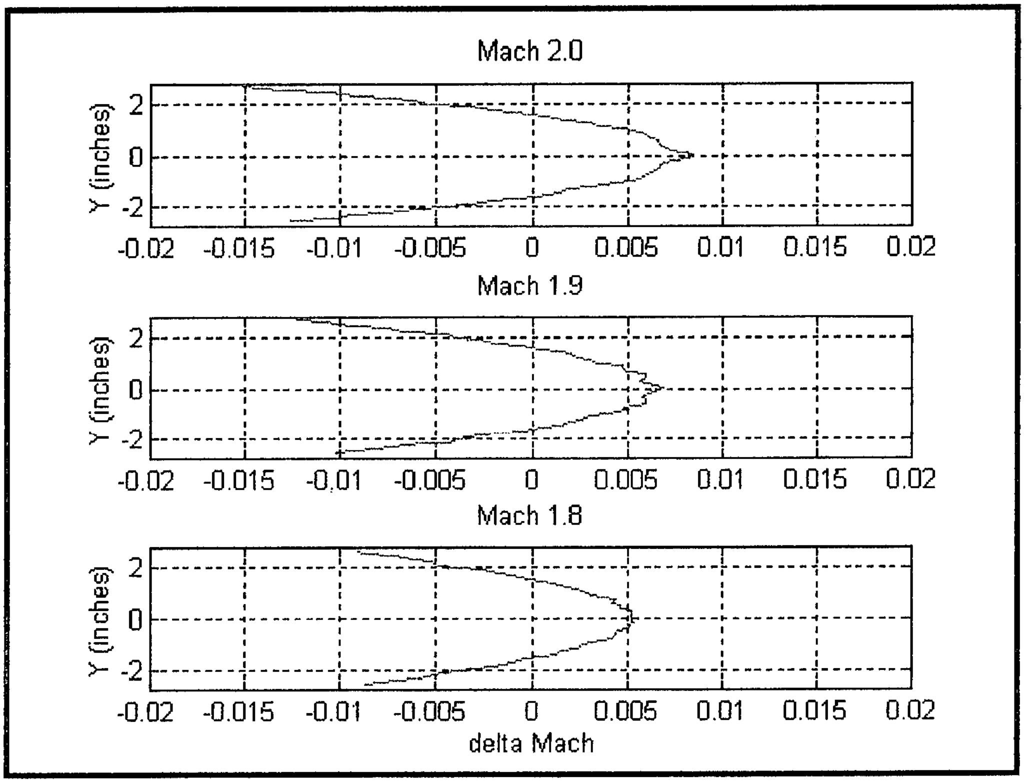


Figure 11. Exit Plane Mach Distribution (Uniform Thickness=.25 inches)

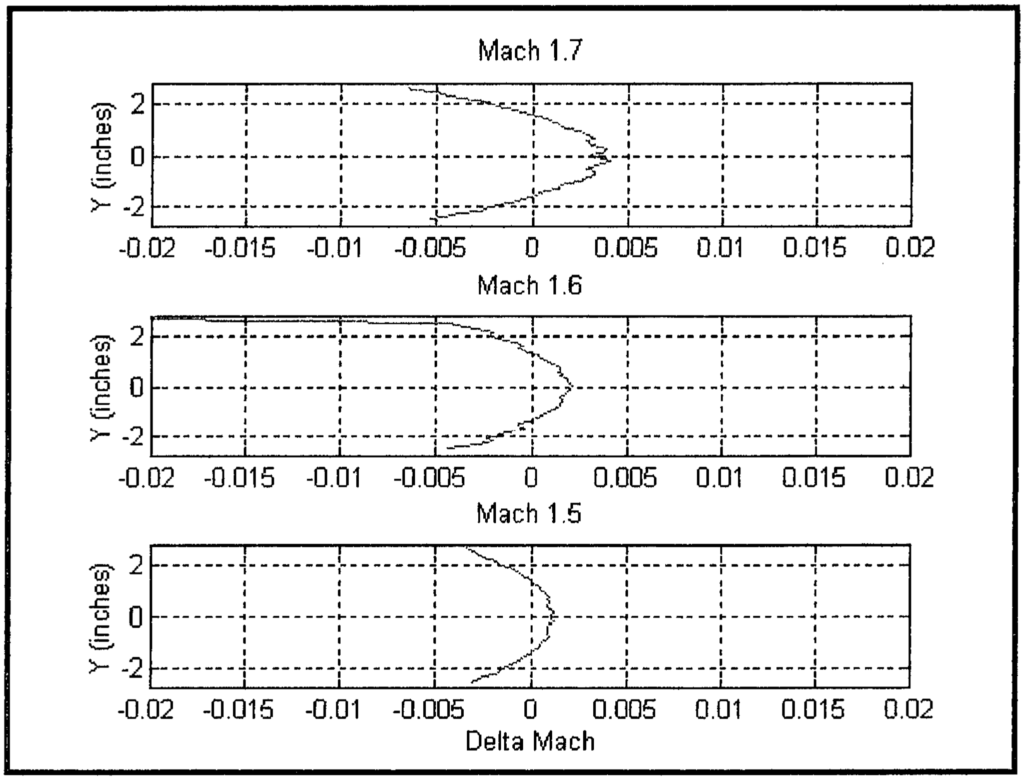


Figure 12. Exit Plane Mach Distribution (Uniform Thickness=.25 inches)

IV. DESIGN USING SEPARATE AERODYNAMIC AND STRUCTURAL ANALYSES

A. DESIGN STRATEGY

Since the optimization code had shown that a constant thickness plate gave better flow uniformity throughout the design Mach number range than plates of varying thickness, a logical approach was to begin with a constant thickness plate. The plate would be formed precisely to the shape required for one particular (design) Mach number, and a number of jacks, distributed along the plate, would be used to produce the precise wall shapes required at all other Mach numbers.

The goal then was to determine whether a series of on-design aerodynamic shapes could be achieved using a .25 inch thick steel plate. The design process therefore involved discrete aerodynamic and structural phases. The aerodynamic phase involved the generation of a nearly continuous family of wall contours to provide uniform flow at Mach numbers from 1.4 to 2.0, and which accounted for boundary layer growth. The structural phase involved determining the jack forces and jack distribution necessary to achieve the aerodynamic shapes, and finding a practical method of implementing what was required.

B. AERODYNAMIC SHAPE GENERATION

The nozzle shape was separated into supersonic and subsonic portions. The shape of the supersonic section was determined for an inviscid perfect gas using the method of characteristics. An integral boundary layer method was used to compute the displacement thickness. The boundary layer growth for a two-dimensional nozzle effectively decreased the area ratio for a given nozzle geometry. In the present design, the exit dimensions were fixed and therefore, to account for the exit area lost to displacement thickness, the throat area was decreased. Boundary layer growth along the side plates was accounted for by further decreasing the throat height. A modified version of a method of characteristics and integral boundary layer code developed at the Naval Ordnance

Laboratory (Sievwright, 1995) was used to generate supersonic nozzle shapes over the Mach number range, 1.4 to 2, at increments of .01.

A constant radius of curvature at the throat was specified and used for all of the shapes. The shapes had common axial lengths and exit half heights, but different contour lengths. In order to construct a constant-length plate mechanism which could create these shapes, the length along the curves had to be constant, and the axial length had to be variable. Polynomial fits of the coordinates provided by the code were used to modify the shapes so that they represented a series of constant length curves. The resulting configuration was a plate fixed at the exit plane and free to move vertically and horizontally at the throat.

The method of characteristics required the solution to start at some finite distance downstream of the throat. The user specified a radius of curvature and the code generated throat half heights (based on the exit half height). These parameters defined the throat geometry. Implicit in the analysis was a zero slope at the throat. When the viscous effects were accounted for by adding displacement thickness, the slope at the first point in the method of characteristics solution was changed. As a result, the polynomial fit, which corrected the method of characteristics solution to the throat geometry, had a non-zero slope at the throat. To correct this problem, a separate transition polynomial, which maintained the geometry of the throat, was derived to join the throat to the first point of the method of characteristics solution. This transition polynomial is illustrated in Figure 13, and is described in detail in Appendix C.

The subsonic section shape was considered to be less critical. At the throat it was necessary to ensure continuity in curvature and the nozzle inlet dimensions were dictated by the existing plenum exit dimensions. The subsonic shape also had to be monotonic. These conditions were met by parameterized exponential functions (Verhoff, 1995). Figure 14 shows the range of nozzle shapes which resulted. The Y value represents the vertical distance from the nozzle centerline and the X value represents the longitudinal dimension of the nozzle. The value X = 0 is at the throat of the Mach 2 shape. The aerodynamic analysis is given in detail in Appendix C.

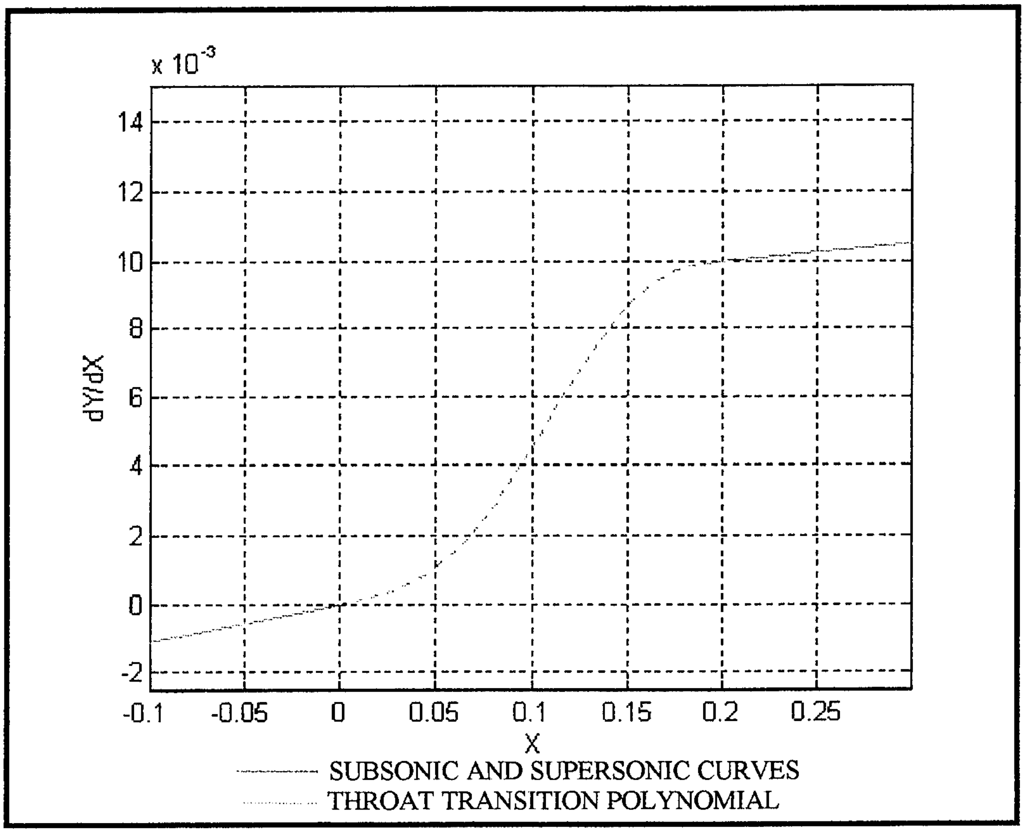


Figure 13. Slope of Throat Transition Polynomial (Mach 2.0 Shape)

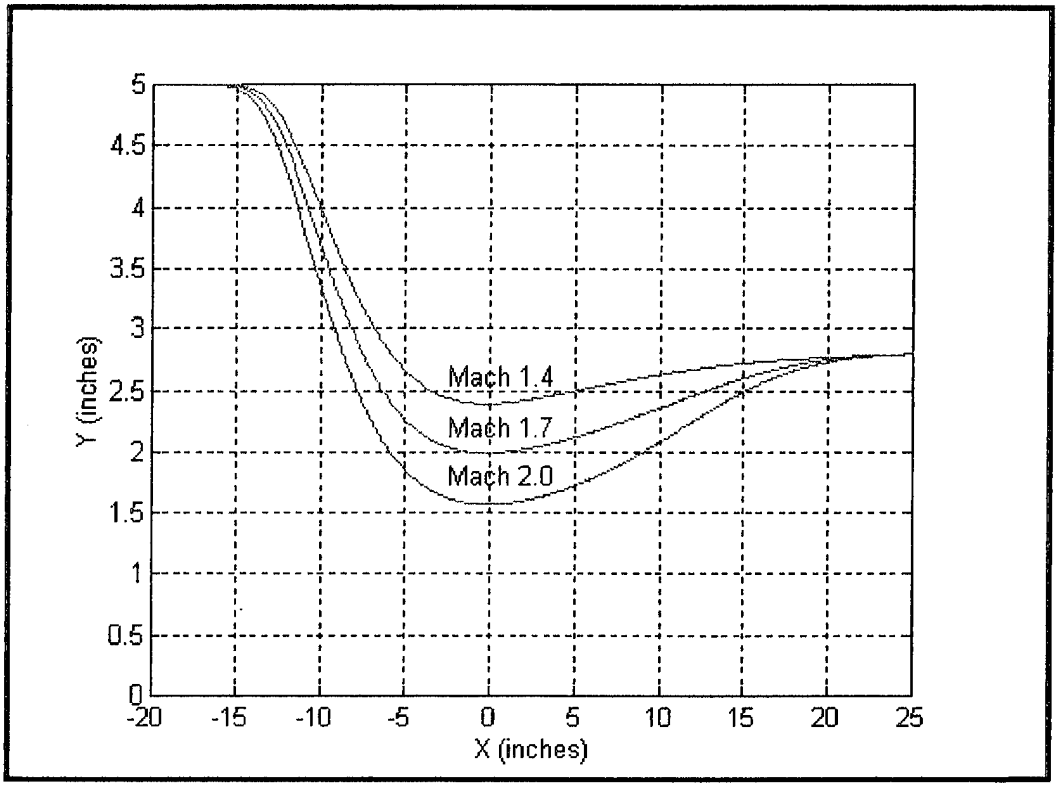


Figure 14. Range of Nozzle Shapes

C. STRUCTURAL ANALYSIS

The structural analysis was concentrated on resolving three issues. The first issue was whether a practical arrangement of jacks could be found which could achieve the aerodynamic shapes. The second issue was to design a physical attachment mechanism between the jack and the flexible plate. The third issue was it determine the effect of the pressure loading on the structure. The structural analysis was conducted using I-DEAS Master Series™ (Lawry, 1994).

The Mach 1.7 shape was chosen as the on-design (undeformed) shape for the structural analysis. The jacks were mounted so that they were locally perpendicular to the flexible plate. The other shapes in the Mach number range were produced by deflecting the plate from the Mach 1.7 shape. By choosing the mid-range Mach number, the maximum deflection required at the throat was .42 inches. Jack force requirements and the jack distribution were determined by the amount of force required to effect the curvature change between the Mach 1.7 shape and the extremes of the Mach number range. The extremes in curvature variation were represented by the difference between the Mach 1.7 shape and the Mach 1.4 and Mach 2 shapes (Figure 15). The shapes represented by the these differences were applied to a model which consisted of flat plate with the proposed distribution of jack attachments. The Mach 2 shape required greater deflection from the Mach 1.7 shape, and was thus used as the shape to be achieved by using a combination of jacks.

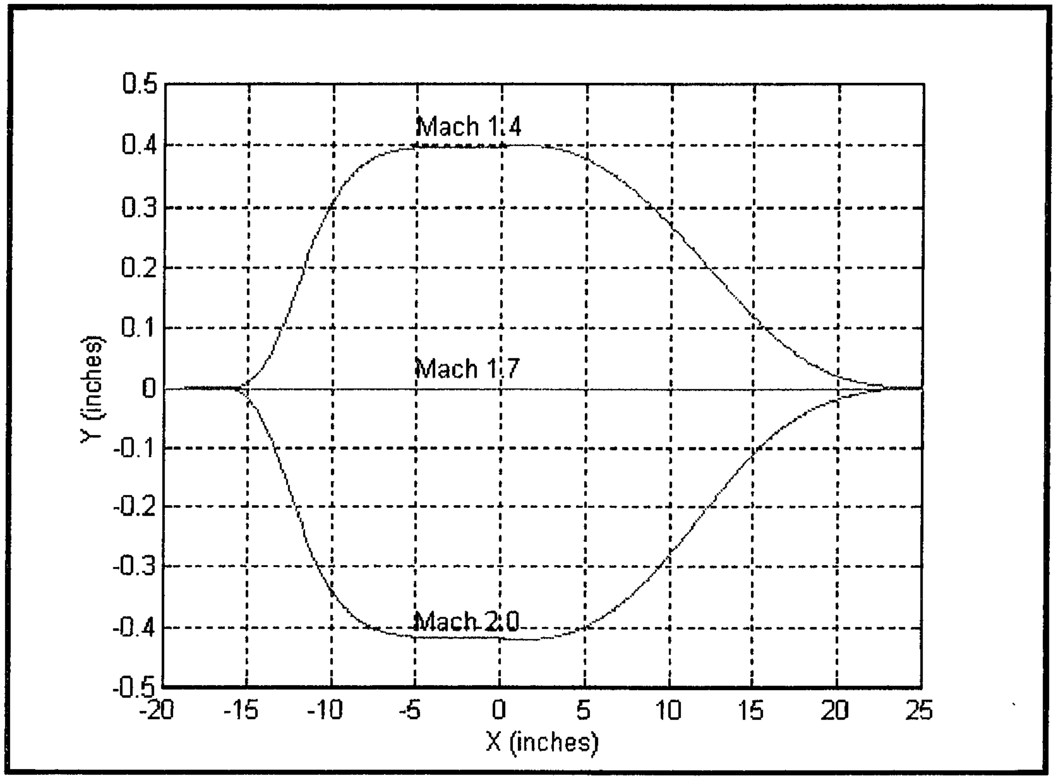


Figure 15. Extreme Curvature Variation from the Mach 1.7 Shape

Two primary factors defined the structural design problem; the jack and the flexible plate. The amount of force an individual jack could exert was limited by its size. The more force a jack was capable of producing, the greater the ability to control the curvature of the plate. The larger size requirement for a stronger jack, however, required greater spacing between jacks, resulting in less control over the curvature. Additionally, the forces imposed on the flexible plate were not allowed to cause yielding or result in a fatigue life of less than 100,000 cycles (Bannantine et al., 1990).

Nine jack mounting points were located at approximately three inch intervals from seven inches to 24.5 inches upstream of the exit. The results of the finite element analysis are shown in Figure 16.

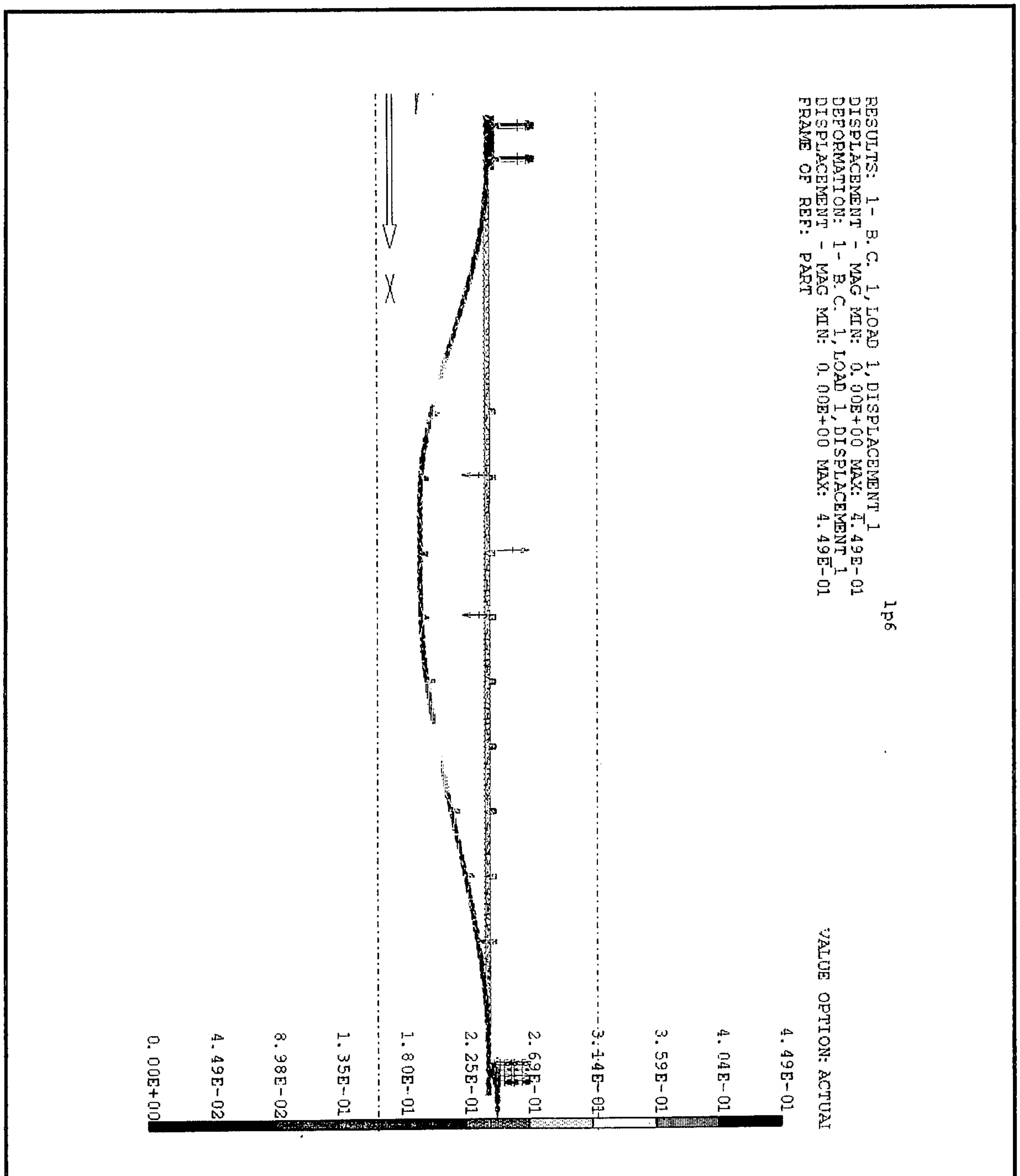


Figure 16. Finite Element Solution for Approximation of the Mach 2 Curvature Variation

To achieve the downward deflection, a 225 pound and a 140 pound load was applied at points 3.5 inches upstream of the throat and three inches downstream of the throat respectively. To produce the curvature required for the Mach 2 shape, a 275 pound load was applied in the upward direction at the throat.

The analysis of the jack mounting fixture involved the simplified model shown in Figure 17.

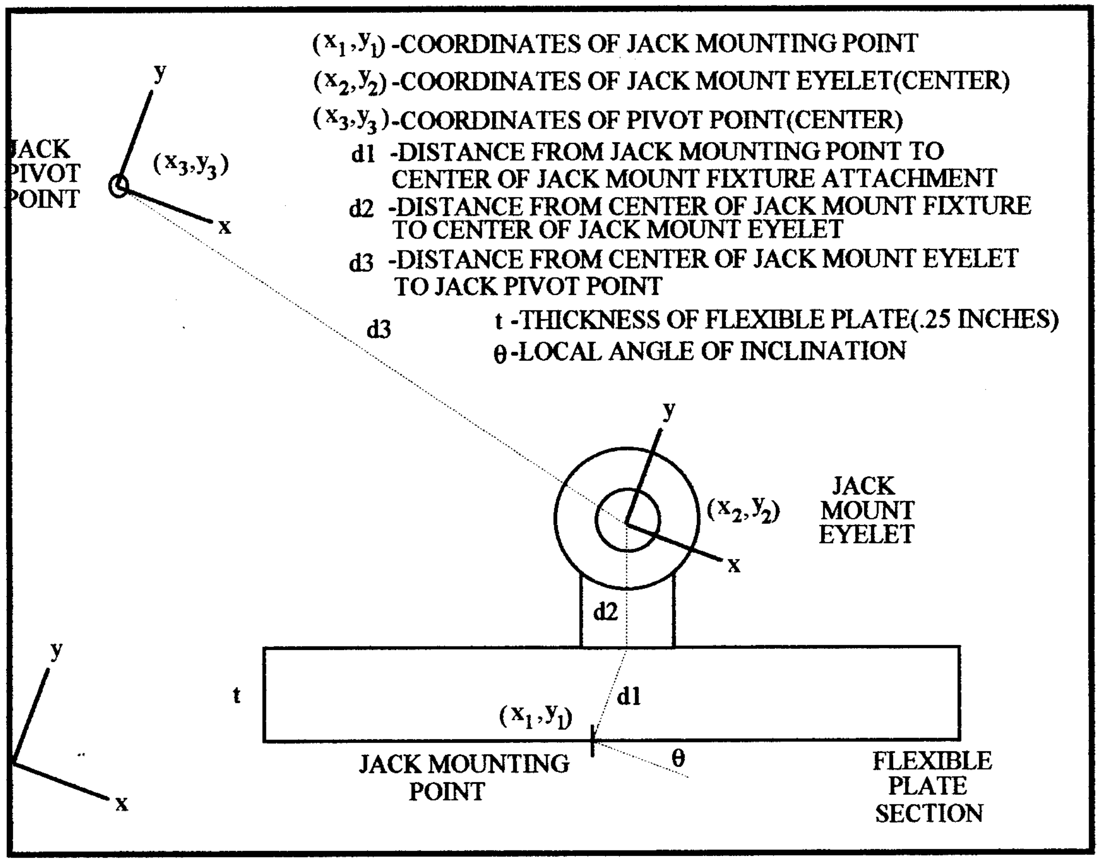


Figure 17. Jack Mount Geometry

The fixture used to attach the jack to the flexible plate had to be large enough to meet the same yield and fatigue requirements as the plate. The size could not be so large, however that the increased stiffness of the flexible plate made the aerodynamic shape unattainable. The distance of the jack mount pivot point from the center of the flexible plate multiplied by the off-design jack force produced a moment at the plate-jack mount point. A 250 pound force was applied at an maximum off-design angle of 4.5 degrees. The resulting stress concentration at the interface between the jack mount fixture and the flexible plate was less than 10000 psi. Additionally, the maximum deflection of the flexible plate between two jack mount points was approximately .00004 inches. This deflection was two orders of magnitude less than the expected machining tolerance of .001 inches.

The structure was designed to minimize the effects of the aerodynamic pressure loading. The internal pressure loading decreased non-linearly from the entrance to the exit of the nozzle. The loads imposed by pressure differential caused a displacement between the jack mount points and a moment about each jack mount point. A structural model was constructed, and is shown in Figure 18, to determine the effects of the pressure loading.

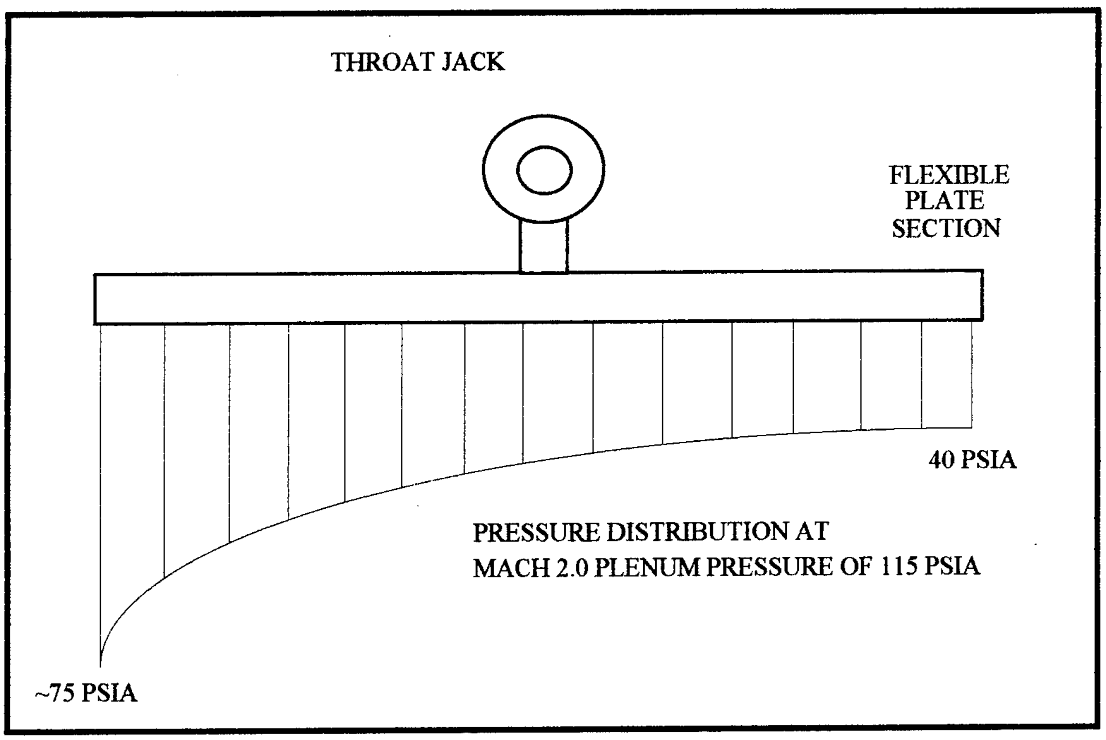


Figure 18. Pressure Loading on Flexible Plate at Mach 2.0

The largest pressure loads were found to occur in the subsonic section of the nozzle where structural deformation would not adversely affect the supersonic flow. The primary area of interest was the section of plate to either side of the throat jack, because of the sensitivity of the nozzle exit flow Mach number to the throat contour. Along the length of this 6.5 inch section the pressure dropped from approximately 75 psia to 40 psia for a Mach 2.0 exit condition and plenum pressure of 115 psia. The maximum deflection of the plate section between the throat jack and the first jack downstream of the throat was approximately .0002 inches. This amount of deflection was an order of magnitude less than the expected machining tolerance and was therefore considered to be acceptable. The cost of reducing this deflection was an increase in plate thickness or the addition of another jack. These options were considered to be unacceptable.

The graphical outputs of the finite element analysis conducted on the proposed structure are given in Appendix D.

V. MECHANICAL DESIGN

The mechanical layout of the nozzle design is shown in Figure 1 and was accomplished using AutoCad®(Omura, 1993). The flexible plate was designed to be made of stainless steel and formed so that it took the shape required for Mach 1.7. The plate was restrained fully at the nozzle exit. A slip joint was used to enable the nozzle entrance to translate in the direction parallel to the nozzle centerline and to ensure zero slope at the entrance. Eighteen jack screws arranged along the upper and lower nozzle plates, were designed to force the plates to the shapes required for all other Mach numbers. An aluminum frame provided a structural base for steel side plates and a means of attachment to the plenum and test section. A large I-beam outer frame provided the structural rigidity to support the jack loads. The list of coordinates describing the Mach 1.7 shape and engineering drawings of the nozzle components are provided in Appendix E.

A seal was provided between the flexible plate edges and the side walls. The seal consisted of a .07 inch O-ring inserted in a groove machined along the .25 inch edges. Tube-shaped spacers were used to ensure that .002 inches of clearance was maintained between the flexible plate edges and the side walls. A .139 inch O-ring was used to seal the gap between the flexible plate and the frame upstream of the slip joint.(Parker, 1981)

The jack screw used in the nozzle mechanism was unique to this design. The accuracy requirements for positioning the flexible plate (.001 inches) precluded the use of pneumatic or hydraulic actuators. A system incorporating eighteen stepper motors and a controller interfaced with the cascade Data Acquisition System computer was to be used. The controlling software would be designed to schedule the jack screw lengths necessary to achieve the required shape for a given Mach number. The system would be a multi-channel equivalent of the system developed by Myre for traversing probes (Myre, 1993). The jack screw design was based on the use of a 2.25 inch by 2.25 inch square stepper motor rated at 150 ounce inches of torque, mounted to drive a threaded shaft. The selected nominal thread size was 3/8 - 32 of the American National extra fine thread series (Morse, 1968). As the shaft was rotated, the force necessary to deflect the plate was applied to a telescoping tube with the same internal thread dimensions. The jack length program required the coordinates of the center of the jack-mount eyelet and the jack pivot point. The coordinates of the center of the jack-mount eyelet for any given Mach number was determined using the aerodynamic analysis routine presented in Appendix D. The jack pivot points were determined using AutoCad, by positioning the jack screw perpendicular to the flexible plate, establishing the pivot point location and reading the relative coordinates provided by the software. The jack-length program is given in Appendix D. The jacks were mounted on bolts inserted through one half-inch steel side plates

The inner frame was made of aluminum for ease of machining. The primary purpose of the inner frame was to hold the three sets of steel side plates in place. Two sets of side plates served as the structural foundation for the jack pivot points. One set of plates was used to seal the nozzle. The aluminum inner frame also provided the means of attaching the nozzle mechanism to the plenum and the test section. At the inlet end of the nozzle, the inner frame mated with the existing plenum outlet plate. The aluminum frame was mounted to an outer frame consisting of ten 6x12 inch wide flange I-beams (Bauld, 1986).

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The present study provided the necessary information to construct a two-dimensional flexible-plate nozzle for an operating Mach number range of 1.4 to 2.0, designed to be incorporated in the supersonic wind tunnel at the Naval Postgraduate School's Gas Dynamics Laboratory. Three phases were involved. The first was to examine the ability of the blow-down facility to provide the necessary run times in tests using a suitable scaled compressor cascade test section. The second was a design study using a multi-disciplinary optimization routine. This study assessed the feasibility of using a single jack and a flexible plate with varying thickness to achieve acceptable exit Mach number uniformity over the range required for cascade model tests. The third phase addressed the nozzle design using independent aerodynamic and structural solutions.

The initial sizing study showed that the supersonic blow-down facility was capable of providing the necessary air flow for a test section with a cross sectional area large enough to accommodate cascade models of interest. The system was calculated to provide steady test conditions at $M = 1.9$ for three minutes with a nozzle exit area of 18 square inches.

The design study using the optimization code showed that a single jack, variable plate-thickness configuration was not able to produce exit flow uniformity that was within desired limits over the design Mach number range. The study also showed however, that a constant thickness plate was capable of producing an acceptable exit plane Mach variation. The specific uniform thickness which gave this promising result was .132 inches, which was considered too thin to seal effectively. A plate thickness of .25 inches, which could be sealed with an O-ring of 1/16 inches, was thought to be necessary. Analysis of the .25 inch plate showed that the performance, while unacceptable, was far better over the full Mach number range than the optimized variable thickness configuration. The .25 inch plate was thus considered a logical starting point for a multiple jack design study. The general conclusion was that the optimized single-jack arrangement could give good results at lower supersonic Mach numbers (for which it was developed), but that the changes in shape required at Mach numbers approaching 2 were too large to be approximated well using a single jack and thickness distribution optimized at one Mach number

In the third phase, the aim of the multiple jack, constant plate-thickness design study was to determine if specific aerodynamically determined optimum shapes could be achieved using a reasonable number of jacks arranged along a .25 inch stainless steel plate. An aerodynamic analysis was performed to determine the nozzle shapes capable of producing Mach numbers from 1.4 to 2. Finite-element models were used to determine the jack distribution and jack forces necessary to achieve the off-design nozzle shapes, based on the plate being unstressed with the contour required at the design Mach number = 1.7. Additional structural analysis was carried out to determine a durable means of attaching the jack to the plate without greatly increasing the stiffness of the plate. These studies showed that it was possible to achieve the required aerodynamic shapes with the mechanism described. The analysis also showed that the stress concentrations associated with the jack mounting fixture were well below the endurance limit.

The following elements in the process are seen to be key to completing the present design:

-successfully deriving on-design contours which had a common throat radius of curvature, and common surface length

-finding an accurate analytical approximation for the family of contours from the subsonic approach region to the supersonic exit plane

-using an unstressed, machined shape at a Mach number near the middle of the required range

-using integrally machined bosses for jack attachment

-using deflected flat-plate modeling to find off-design stresses.

B. RECOMMENDATIONS

The analysis conducted showed that a nozzle mechanism could be built which was capable of producing the required aerodynamic shapes. Two areas of structural analysis are recommended for further study. The first is to examine the effects of thermal gradients, which must develop during the course of wind tunnel tests, on the flexible plate. The second is to examine the out-of-plane bending or 'saddling' that should occur due to Poisson's effect along the seven inch section of plate stretching from the last jack to the nozzle exit.

The goal of the third phase was to produce a mechanism which produced on-design shapes at all Mach numbers over the required range. In fact, the only perfect on-design shape is for M = 1.7, the unstressed condition of the flexible plate. The exit plane Mach variation for all the shapes other than the Mach 1.7 shape (which was machined to provide a perfect result) was not calculated. The application of a viscous CFD code to the off-design shapes produced by the elastically deformed plate, is therefore recommended to determine the off-design exit-plane Mach number distributions.

Finally, a detailed cost analysis is required before a commitment can be made to the proposed design.

APPENDIX A. NOZZLE EXIT AREA AND ASPECT RATIO DETERMINATION

A. NOZZLE EXIT AREA DETERMINATION

The nozzle exit area determination was based on the ideal gas law and the mass flow relationships. The following nomenclature was used in the development of the nozzle exit area relationship:

a - Local sound velocity(ft/s)

A - Nozzle exit area(ft^2)

A^* - Throat area(ft^2)

c_p - Specific heat at constant pressure(Btu/lbm-^oR)

C_v - Control valve volumetric flow rate coefficient

g_c - Acceleration due to gravity(ft/s^2)

G - Gas specific gravity

m - Mass(slugs)

m_1 - Mass of air in tanks at beginning of test(slugs)

m_2 - Mass of air in tanks at end of test(slugs)

$\overset{o}{m}$ - Mass flow rate(slugs/s)

M - Mach number

p - static pressure (lbf/ft^2)

p_1 - Pressure in tanks at beginning of test(lbf/ft^2)

p_t - Plenum stagnation pressure(lbf/ft^2)

p_t^* - Stagnation pressure at throat (sonic) condition(lbf/ft^2)

Δp - Pressure differential across control valve when the valve loses its ability to control the plenum pressure(lbf/ft^2)

Q_{scfh} - Volumetric flow rate in standard cubic feet per hour(ft^3/hr)

R - Gas constant(ft-lbf/lbm-^oR)

t - Run time(sec)

T - Static temperature(^oR)

T_1 - Temperature in tanks at beginning of test(^oR)

T2 - Temperature in tanks at end of test(^oR)

T_t - Stagnation temperature(^oR)

T_t^* - Stagnation pressure throat(^oR)

v - Flow velocity(ft/s)

V - Tank volume(ft^3)

γ - Ratio of specific heats

ρ - density($slugs/ft^3$)

ρ_{st} - Standard atmospheric density($slugs/ft^3$)

Using the ideal gas assumption and the mass flow rate relation, an expression for the nozzle exit area was found as follows:

using $$p = \rho RT \tag{1}$$

and $$\overset{o}{m} = \rho A v \tag{2}$$

it can be shown that

$$A = \frac{\sqrt{\frac{\gamma - 1}{2\gamma}}\,\overset{o}{m}\,v_t}{\sqrt{\gamma}\,pM\left(1 + \frac{\gamma - 1}{2}M^2\right)^{1/2}} \tag{3}$$

where,

$$v_t = \sqrt{2c_pT_t} \tag{4}$$

The mass of air in the storage tanks at the beginning and the end of the test was used to determine the mass flow rate as follows:

$$m_1 = \rho_1 V = \frac{p_1}{RT_1} V \tag{5}$$

and

$$m_2 = \frac{(p_t + \Delta p)V}{RT_2} \tag{6}$$

so that

$$\overset{o}{m} = \frac{m_1 - m_2}{t} \tag{7}$$

The volumetric flow rate in standard cubic feet per hour was given by

$$Q_{scfh} = \frac{\overset{o}{m}(3600)}{\rho_{st}} \tag{8}$$

and was related to the volumetric flow rate coefficient of the control valve (Fisher, 1977) using

$$C_v = \frac{Q_{scfh}}{60}\sqrt{\frac{G}{p_t \Delta p}} \tag{9}$$

Equations (5) through (9) were combined to yield a quadratic equation in $\sqrt{\Delta p}$, with solutions given by

$$\sqrt{\Delta p} = \frac{-C_v \pm \sqrt{C_v^{\,2} - 4\left(\frac{V(60)\sqrt{G}}{\sqrt{p_t}RtT_2\rho_{st}}\right)\left[\frac{V(60)\sqrt{G}}{\sqrt{p_t}Rt\rho_{st}}\left(\frac{p_t}{T_2} - \frac{p_1}{T_1}\right)\right]}}{2\left(\frac{V(60)\sqrt{G}}{\sqrt{p_t}RtT_2\rho_{st}}\right)} \tag{10}$$

C_V was determined experimentally using the supersonic tunnel at a Mach number of 1.4. A^* was known for the nozzle, average values for p_t^* and T_t^* were taken in three tests. The tests involved running the tunnel until the control valve could no longer control the plenum pressure. The following 'choked' mass flow relationship was used to compute $\overset{o}{m}$,

$$\overset{o}{m} = \frac{p_t^* A^*}{\sqrt{T_t^*}} g_c \sqrt{\frac{\gamma}{R g_c}} \left[\frac{\gamma+1}{2}\right]^{\frac{-(\gamma+1)}{2(\gamma-1)}} \tag{11}$$

and C_V was found from equation (9) and equation (10). The tests results were:

$$p_t^* = 44.7212 \frac{lb}{in^2} \qquad A^* = 14.3507 in^2 \qquad T_t^* = 508.17^\circ R$$

$$\overset{o}{m} = .47059 \frac{slug}{s} \qquad Q_{scfh} = 712437.65 \frac{ft^3}{hr} \quad C_v = 1.6576$$

A spread sheet was used to find exit areas for a range of Mach numbers, run times and initial tank pressures. The results are given in Tables 2, 3 and 4.

Mach #	RunTime(min)	P1(psi)	Area(in^2)
1.8	3	260	17.38721912
1.8	3	270	18.07997832
1.8	3	280	18.75730801
1.8	3	290	19.4201954
1.8	3	300	20.06952674
1.8	2.5	260	18.65062775
1.8	2.5	270	19.36192545
1.8	2.5	280	20.05655125
1.8	2.5	290	20.73562524
1.8	2.5	300	21.40014744
1.8	2	260	20.04168194
1.8	2	270	20.76930749
1.8	2	280	21.47911511
1.8	2	290	22.17235298
1.8	2	300	22.85013004

Table 2. Nozzle Exit Areas

Mach #	RunTime(min)	P1(psi)	Area(in^2)
1.9	3	260	15.85116582
1.9	3	270	16.55758881
1.9	3	280	17.24769901
1.9	3	290	17.92257689
1.9	3	300	18.58318867
1.9	2.5	260	17.12754154
1.9	2.5	270	17.85704739
1.9	2.5	280	18.56862914
1.9	2.5	290	19.26354644
1.9	2.5	300	19.94291799
1.9	2	260	18.55170355
1.9	2	270	19.30187784
1.9	2	280	20.0326015
1.9	2	290	20.74531332
1.9	2	300	21.44128302

Table 3. Nozzle Exit Areas

Mach #	RunTime(min)	P1(psi)	Area(in^2)
2	3	260	14.15579788
2	3	270	14.88156796
2	3	280	15.5898198
2	3	290	16.28176385
2	3	300	16.95847725
2	2.5	260	15.42726067
2	2.5	270	16.18234737
2	2.5	280	16.91776377
2	2.5	290	17.63497146
2	2.5	300	18.3352595
2	2	260	16.86958312
2	2	270	17.65149433
2	2	280	18.411624
2	2	290	19.15169694
2	2	300	19.8732217

Table 4. Nozzle Exit Areas

B. NOZZLE EXIT ASPECT RATIO DETERMINATION

The nomenclature used in the nozzle exit aspect ratio calculations is shown in Figure 19.

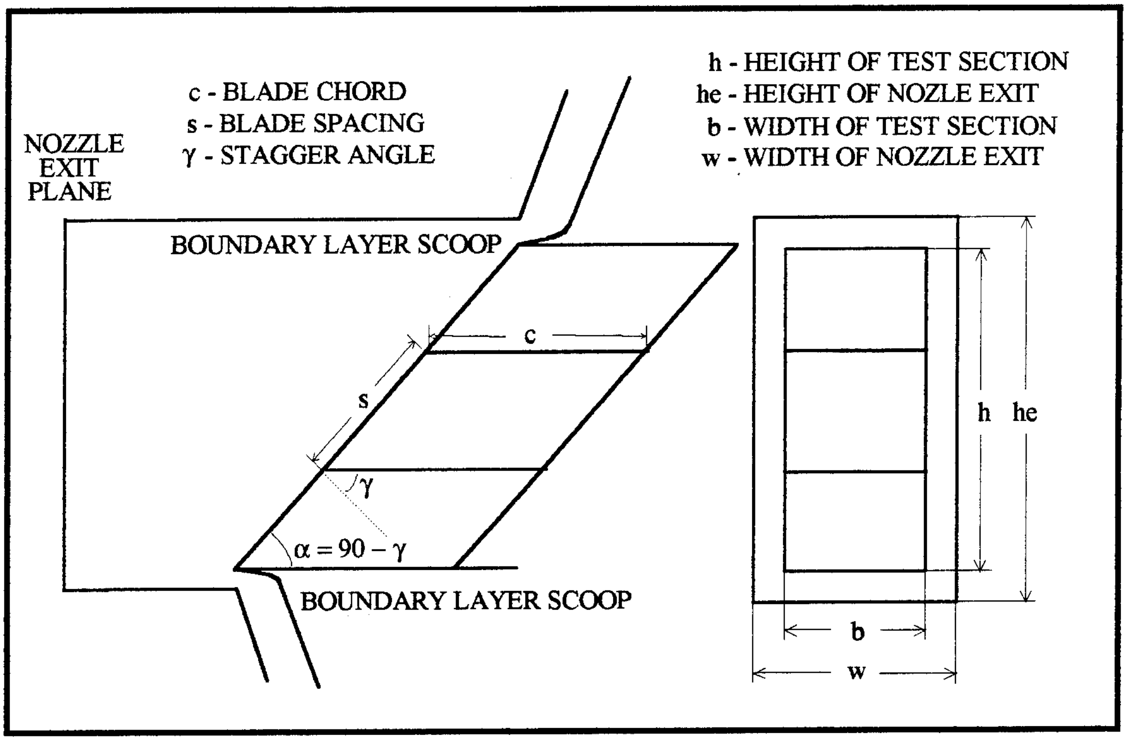


Figure 19. Test Section and Nozzle Exit Geometry

The height of the test section for a three blade passage configuration was given by

$$h = 3\sin\alpha \tag{12}$$

The angle, α was based on the stagger angle for the cascade to be tested. The test section width was

$$b = \frac{b}{c}\frac{c}{s}s \tag{13}$$

where, $\frac{b}{c}$ would determine the degree of two dimensionality and $\frac{c}{s}$ was the solidity of the cascade to be tested. The test section area was given by

$$A_{ts} = hb = 3s^2\frac{b}{c}\frac{c}{s}\sin\alpha \tag{14}$$

and the boundary layer scoop area was

$$A_s = 2bd + 2hd = 2d(b+h) \quad (15)$$

where d was the depth of scoop determined by the boundary layer thickness. The nozzle exit dimensions were determined using the following relationships:

$$w = b+2d \quad (16)$$

$$h_e = h + 2d \quad (17)$$

The following MATLAB program was used to find the test section aspect ratio:

```
%Program testsec.m
%Calculates test section parameters.
%Specified parameters:
%    Farea - Nozzle exit area
%    sol   - Blading solidity (c/s)
%    twoD  - Factor of two dimensionality (b/c)
%    staggerangle - exactly that
%    b,h   - Starting values for test section width
%            and height respectively. From these
%            values, a shooting iteration is conducted
%            until convergence is achieved.
%    d     - Boundary layer thickness at nozzle exit
%
%Output values:
%    s - Blade spacing
%    c - Blade chord
%    b - Test section width (converged solution)
%    h - Test section height (converged solution)


Farea = 18;
sol = 1.97;
twoD = .6;
staggerangle = 40;
alpha = (90 - staggerangle)*pi/180;
b = 4;          %test section width
h = 5;          %test section height
d = .25

c=0;s=0;m=0;
maxit = 7;
out = zeros(maxit,4);

out(1,:) = [s c b h];
for m = 1:maxit,
        s = sqrt(   (Farea-(2*d*(h+b+(2*d))))/(3*sin(alpha)*twoD*sol)  );
        c = sol*s;
        b = twoD*c;
        h = (Farea-(2*d*(h+b+(2*d))))/b;
```

```
        out(m+1,:) = [s c b h];
end
out
```

For the values assumed in the program, the result was a nozzle exit height of 5.6 inches and a nozzle exit width of 3.2 inches.

APPENDIX B. OPTIMIZATION CODE

The nozzle optimization code was written by Melton and Erickson of the NASA Ames Research Facility. Melton modified the code for use in the present design, provided all the information necessary to run it on NPS computers and was the point of contact at NASA Ames. The program was a working code and required some knowledge of the FORTRAN 77 programming language. The code was run on the NPS CRAY EL-98 which increased the per iteration CPU time approximately five times over NASA's CRAY C-90.

The optimization code was used interactively and as a batch process. Because of the limit on interactive CPU time, more than approximately twenty iterations required operation in batch mode. For the present design study, the optimization process required many iterations and was run as a batch job. The off-design performance assessment at each Mach number required one iteration and was performed interactively.

The program was written to read a command line specified input file. When the program was run interactively the following command specified the input file and ran the code:

nozopt < input_file

Because the program was a working code, the arbitrary program name **nozopt.f** was used for the version at NPS. The original name was **mocfem.f**.

In order to run the code as a batch process, a batch file had to be written. The following file is example of this batch file:

```
# QSUB -q prem        # regular queue(reg,prem)
# QSUB -o r1.batch    # name the output file
# QSUB -eo            # direct errors to the output file
# QSUB -lT 200000     # Set the CPU time limit(total time)
# QSUB -lt 200000     # Set the CPU time limit(individual job time)
# QSUB -lM 10Mw       # Set the CPU memory limit
# QSUB -eo            # Standard output direction
# QSUB -me
#
#--- Set shell variables
```

```
11   set RUN  = r1                 #input should be copied to match
12   set SCR  = $TMPDIR
13   set nozl = nozopt
14   #
15   cd $SCR
16   #
17   #--- Copy the required files to the scratch directory
18   cp /d1/tgemmert/${RUN}.in  .
19   #cp /d1/tgemmert/input16  .
20   cp /d1/tgemmert/${nozl}  .
21   #
22   Assign:
23   #
24   #env FILENV=.ass${RUN} assign -a ${RUN}_ctrmach   fort.3
25   #env FILENV=.ass${RUN} assign -a ${RUN}_strdist   fort.4
26   #env FILENV=.ass${RUN} assign -a ${RUN}_deflect   fort.8
27   #env FILENV=.ass${RUN} assign -a ${RUN}_walldef   fort.13
28   #env FILENV=.ass${RUN} assign -a ${RUN}_presdist  fort.14
29   #env FILENV=.ass${RUN} assign -a ${RUN}_wallmach  fort.15
30   #env FILENV=.ass${RUN} assign -a ${RUN}_thickdist fort.16
31   #env FILENV=.ass${RUN} assign -a ${RUN}_ctrlm     fort.12
32   #
33   env FILENV=.ass${RUN} $nozl < ${RUN}.in > ${RUN}.prt
34   #
35   #--- Copy the output files back to the main directory
36   cp   ${RUN}_ctrmach     /d1/tgemmert/r1
37   cp   ${RUN}_strdist     /d1/tgemmert/r1
38   cp   ${RUN}_deflect     /d1/tgemmert/r1
39   cp   ${RUN}_walldef     /d1/tgemmert/r1
40   cp   ${RUN}_presdist    /d1/tgemmert/r1
41   cp   ${RUN}_wallmach    /d1/tgemmert/r1
42   cp   ${RUN}_thickdist   /d1/tgemmert/r1
43   cp   ${RUN}_ctrlm       /d1/tgemmert/r1
44   cp   ${RUN}.prt         /d1/tgemmert/r1
```

The line numbers were added to aid in reference. The '#' symbol indicates comment lines except in lines 1-8. The per iteration time was approximated as 50 seconds and when multiplied by the number of iterations, determined the total CPU time required for an optimization run. This CPU time was specified in lines 4 and 5. The CPU memory requirements were conservatively estimated as 10 megawords. A common input file name and output directory name was set in line 11. The program name was specified in line 13. Lines 18 and 20 copy the input file and the executable code to the scratch directory. Lines 24 through 31 were commented out, but remain as an example of how to manipulate the default **fort.*** output files. Line 33 specified the file in which screen output was to be saved. Lines 36 through 41 copied the output files from the scratch directory to the output directory. The name of this file was **runner.nqs** and it was submitted to **sirius** (the NPS CRAY EL-98) by typing the following at the UNIX command line:

qsub runner.nqs

The input file for the optimization code is listed here:

```
10 Number of design variables
 1 Number of design iterations
 # of      Starting   Starting   Reduction
variations   value      radius      factor
     1        0.0        0.0        0.7  x-station
     1        0.25       0.0        0.7    thickness
     1        5.0        0.0        0.7  x-station
     1        0.25       0.0        0.7    thickness
     1       10.0        0.0        0.7  x-station
     1        0.25       0.0        0.7    thickness
     1       15.0        0.0        0.7  x-station
     1        0.25       0.0        0.7    thickness
     1       25.0        0.0        0.7  last x-station
     1        0.25       0.0        0.7    thickness

 1    Number of design conditions
2.0   Design Mach number
50    Number of points from N to S wall
1.0  x-location of upstream characteristic starting line
16563.38  Stagnation pressure (psf)
2116.8  Plenum pressure (psf)
 1.0  North nozzle jack setting
 1.0  South nozzle jack setting
 0.0   Throat displacement thickness 0.63575
 0.0   Displacement thickness growth coefficient 0.00875
 0.0   Foreshortening distance (positive) (.30651)
 0.0 Upstream rotation angle (degrees) N
 0.0 Upstream rotation angle (degrees) S
 0.0 Downstream rotation angle (degrees) N
 0.0 Downstream rotation angle (degrees) S
 3.2 Width of flexwall (inches)
 2.8 Half height of nozzle exit or vert dist from centerline to exit
25.0 Length (horizontally) from throat to exit
```

For the present design study, five points were chosen along the flexible plates as points of specified thickness. The program generated the remaining wall thickness values by spline fitting the five thickness values. It was possible to optimize the thickness distribution for a constant longitudinal value along the wall or this 'x-station' could be varied. The design variables referred to in line 1 were the thickness and x-station values specified in lines 5 through 14. The number of design variables was twice the number of stations along the wall. The program was set for multiple iterations in line 2. The point about which the thickness optimization was carried out was specified in the 'starting value' column of lines 5, 7, 9, 11 and 13. The starting thickness value was specified in the 'starting value' column of lines 6, 8, 10, 12 and 14. A search radius was specified in the 'starting radius' column. The starting radius specified the range of values around the starting values which the program searched during the optimization. This distance to either side of the starting value was divided into equal lengths by the value specified in the '# of variations' column. The value specified in the 'reduction factor' column was used to reduce the search radius on subsequent iterations. This input file was set up for an interactive, single iteration run. Lines 16 and lines 24 through 30 were not changes in this version of the program. Lines 17 through 23 and lines 31 through 33 require the user to specify appropriate values for a nozzle of interest.

The program output consisted of; exit plane Mach distribution, flexible plate stress distribution, plate shape with respect to the exit, the plate shape with respect to the nozzle centerline, the flow field pressure distribution, the Mach number at the plate surface, the plate thickness distribution, the centerline Mach distribution and the restraining forces at the exit and throat. A MATLAB™ script file was used to display the output. This file is shown below:

```
%program plotnoz.m

load r1_ctrmach;
load r1_strdist;
load r1_deflect;
load r1_walldef;
load r1_presdist;
load r1_wallmach;
load r1_thickdist;
load r1_ctrlm;

subplot(4,2,1);plot(r1_ctrmach(:,2),r1_ctrmach(:,1));grid;
axis([-.01,.01,-2.8,2.8]);
title('Exit Plane Mach Distribution');
```

```
ylabel('Y');
xlabel('Del Mach');

subplot(4,2,2);plot(r1_strdist(:,1),r1_strdist(:,2));grid;
title('Stress Distribution');
ylabel('Stress');
xlabel('X');

subplot(4,2,3);plot(r1_deflect(:,1),r1_deflect(:,2));grid;
title('Wall Deflection (from base)');
ylabel('Y');
xlabel('X');

subplot(4,2,4);plot(r1_walldef(:,1),r1_walldef(:,2),r1_walldef(:,1),r1_walldef(:,3),'y');grid;
title('Wall Shape wrt Centerline');
ylabel('Y');
xlabel('X');

subplot(4,2,5);plot(r1_presdist(:,1),r1_presdist(:,2));grid;
title('Pressure Distribution');
ylabel('Pressure');
xlabel('X');

subplot(4,2,6);plot(r1_wallmach(:,1),r1_wallmach(:,2));grid;
title('Wall Mach Number Distribution');
ylabel('M');
xlabel('X');

subplot(4,2,7);plot(r1_thickdist(:,1),r1_thickdist(:,2));grid;
title('Wall Thickness Distribution');
ylabel('T');
xlabel('X');

subplot(4,2,8);plot(r1_ctrlm(:,1),r1_ctrlm(:,2));grid;
title('Centerline Mach Distribution');
ylabel('M');
xlabel('X');
```

An abbreviated flow chart for the nozzle optimization code is depicted in Figure 20.

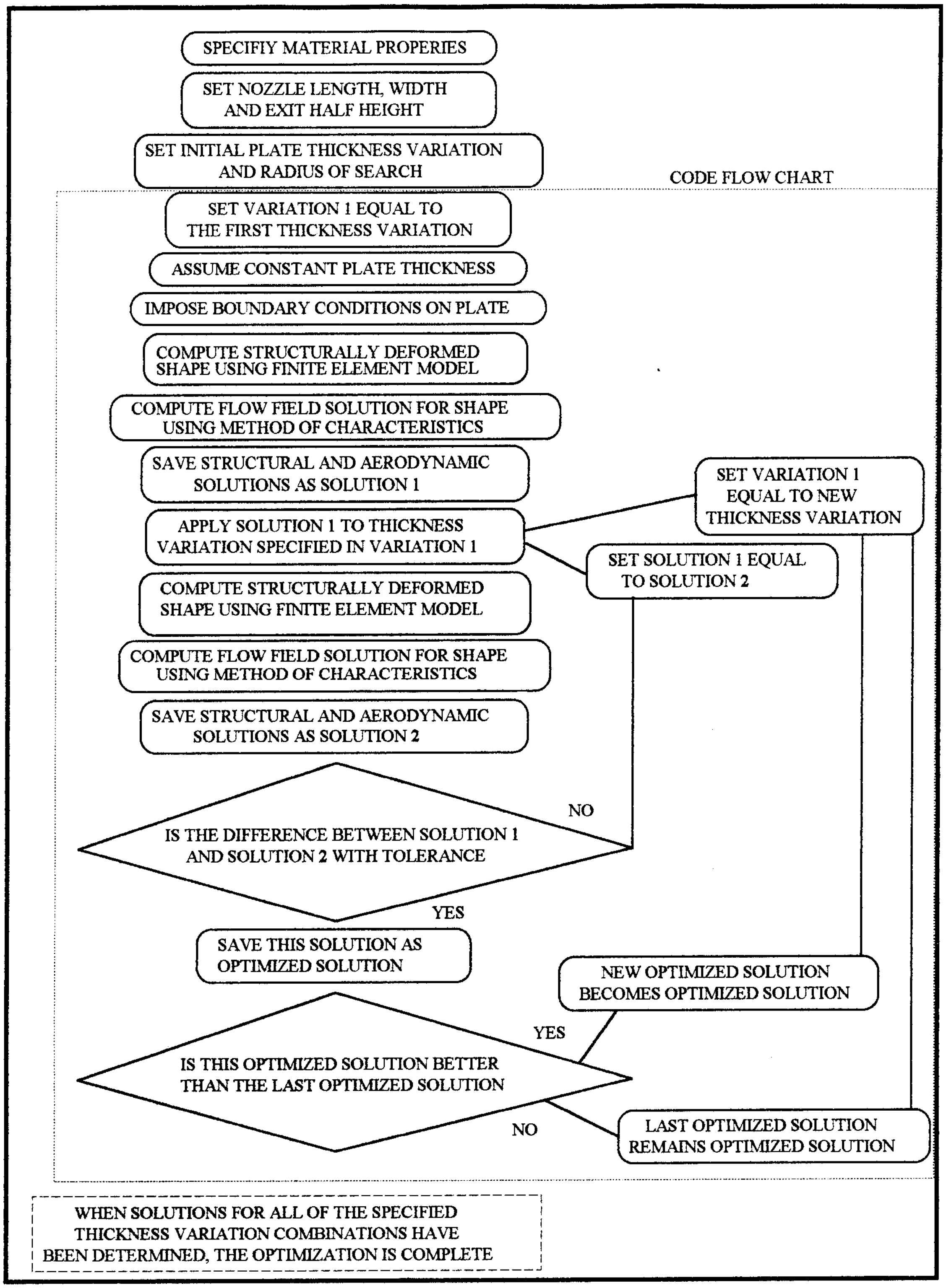


Figure 20. Flow Chart of Optimization Method

APPENDIX C. AERODYNAMIC SHAPE DEVELOPMENT

A. SUPERSONIC SHAPE

The supersonic shape was generated using a modified version of a program written at the Naval Ordnance Laboratory (Sievwright, 1995). The program was modified from the Sievwright version to facilitate the fast iteration required to generate the 61 shapes covering the Mach number range 1.4 to 2. The code read input values from a command-line specified input file. The method of characteristics was used to determine the inviscid contours. An integral boundary layer solution was then found for the inviscid solution. The displacement thickness was added to the dimensions of the inviscid nozzle shape. To find the shape which provided the desired area ratio, the specified initial exit half height was decreased until the desired exit half height was reached by the code generated solution. The input file is listed here:

```
2  INDSR - TYPE OF NOZZLE, 1-SHORT, 2-REGULAR, 3-EXPONENTIAL
1  INDYTH - THROAT OR EXIT HEIGHT TO BE READ IN YTHEX 1-YEXIT, 2-YTH
1  INDXTE - INDICATE XT OR XEXIT TO BE READ IN XEXXT, 1-XEXIT, 2-XT
2  INDOUT - INDICATE OUTPUT, 1-STEP BY STEP, 2- WALL POINTS ONLY
1.4 GAMMA - RATIO OF SPECIFIC HEATS (1.4)
2.0 ***SMT - TEST SECTION MACH NUMBER
25. XEXXT - EXIT LENGTH OR BEGINNING OF TEST RHOMBUS (INCHES)
2.66006 ***YTHEX - HALF HEIGHT OF NOZZLE THROAT OR EXIT DEPENDING ON
        INDYTH (INCHES)
95. RCT - RADIUS OF CURVATURE AT THROAT (INCHES)
.5 DELMUL - MULT. FACTOR FOR X INCREMENT (1.0-150 PTS, 0.5-400 PTS)
2  INDMO-BLAYER MODE: 1. LAMINAR, 2. TURBULENT, 3. LAM-TRANS-TURB
1  INDTW-WALL TEMP 1. CONST=TWALL, 2. ADIA WALL TEMP,3. TEMP DIST
        INPUT BY USER
1  INDTR-TRANS IND(IF INDMO=3)1.TRANS AT RETHETA VALUE GIVEN IN TRCON,
        2.TRANS AT X GIVEN IN TRCON
2  INDWC- IND BLAYER CALC 1. CENTERLINE ONLY, 2. WALL ONLY, 3. BOTH
0  TRCON-TRANSITION CONSTANT EQUAL TO RETHETA (REYNOLDS NUMBER      BASED
ON THE MOMENTUM THICKNESS OF THE BOUNDARY LAYER) OR    XTRANS
(HORIZONTAL DISTANCE RELATIVE TO THE THROAT) DEPENDING  ON INDTR
.00001  THZERO-THETA (MOMENTUM THICKNESS) AT THROAT IN    FEET(USUALLY=1.0E-
5)
114.9868  ***PO-STAGNATION PRESSURE IN LBS/IN2
520.    TO-SUPPLY TEMP IN DEGREES R
520.    TWALL-WALL TEMP IN DEGREES R IF INDTW=1
0.0     XTEND-EXTENSION LENGTH OF NOZZLE WALL PAST EXIT AS DEFINED
```

BY THE ISENTROPIC CORE(INCHES) (ASSUMES UNIFORM DUCT FLOW)

0.0 DL-INCREMENT IN X FROM ISENTROPIC EXIT TO EXTENSION LENGTH IN (INCHES)

3.2 B-WIDTH OF NOZZLE

1.4 GAMMA-RATIO OF SPECIFIC HEATS

0.76 OMEGA-EXPONENT IN VISCOSITY-TEMP RELATION (AIR=0.76)

28.97 WATE-MOLECULAR WT OF GAS (AIR=29)

0.24 CP-SPEC HEAT OF GAS IN BTU/LB-DEG R(AIR=0.24)) OR LEAVE BLANK AND LET PROGRAM PICK VALUES

0.72 PR-PRANDTL NUMBER (AIR=0.72)

The modified version of the method of characteristics, viscous boundary layer code was called **mocvbl.f** and is listed below:

```
      include "mocsub.f"
      include "vblsub.f"

      PROGRAM mocvbl
C  driver code for method of characteristics and viscous
C  boundary layer subroutines
C        1         2         3         4         5         6         7
C23456789012345678901234567890123456789012345678901234567890123456789012

      call mocsub
      call vblsub
      end

      SUBROUTINE SETXEQ(XW,NO,XL,SML,NEND)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION XW(600),XL(600),SML(600),SMM(600)
      DO 70 J=1,600
      JT=J
      IF (XL(J).GE.XW(NO) ) GO TO  71
   70 CONTINUE
   71 K=JT
      KEND=NEND-3
      DO 40 I=NO,NEND
    5 IF(XW(I).LE.XL(K)) GO TO 10
      K=K+1
      GO TO 5
   10 IF(K.LE.KEND) GO TO 20
      GO TO 30
   20 CALL LAGINT(XL(K-2),SML(K-2),5,XW(I),SMM(I),DYO)
      GO TO 40
   30 CALL LAGINT(XL(K-4),SML(K-4),5,XW(I),SMM(I),DYO)
   40 CONTINUE
      DO 60 J=NO,NEND
      XL(J)=XW(J)
      SML(J)=SMM(J)
```

```
 60 CONTINUE
   RETURN
    END
   SUBROUTINE LAGINT(X,Y,NPTS,XX,YY,DYY)
   IMPLICIT DOUBLE PRECISION (A-H,O-Z)
   DIMENSION X(1),Y(1)
   YY=0.
   DYY=0.
   DO 40 I=1,NPTS
   C1=1.
   C2=1.
   DO 10 J=1,NPTS
   IF (J .EQ. I) GO TO 10
   C1=C1*(XX-X(J))
   C2=C2*(X(I)-X(J))
 10 CONTINUE
   SUM=0.
   DO 30 J=1,NPTS
   IF (J .EQ. I) GO TO 30
   C3=1.
   DO 20 K=1,NPTS
   IF (K .EQ. I .OR. K .EQ. J) GO TO 20
   C3=C3*(XX-X(K))
 20 CONTINUE
   SUM=SUM+C3
 30 CONTINUE
   C=Y(I)/C2
   YY=YY+C*C1
   DYY=DYY+C*SUM
 40 CONTINUE
   RETURN
    END


   subroutine mocsub
**********************************************************************
* Modified by: LT Douglas L. Seivwright                    *
* March 1994                                               *
* BY TERRY EMMERT 15 DEC 1994                              *
*                                                          *
* INDSR - INDICATE TYPE OF NOZZLE, 1-SHORT, 2-REGULAR, 3-EXPONENTIAL *
* INDYTH - INDICATE THROAT OR EXIT HEIGHT TO BE READ IN YTHEX      *
*        1-YEXIT, 2-YTH                                    *
* INDXTE - INDICATE XT OR XEXIT TO BE READ IN XEXXT, 1-XEXIT, 2-XT *
* INDOUT - INDICATE OUTPUT, 1-STEP BY STEP, 2- WALL POINTS ONLY    *
*                                                          *
*                                                          *
* GAMMA - RATIO OF SPECIFIC HEATS (1.4)                    *
* SMT - TEST SECTION MACH NUMBER                           *
* XEXXT - EXIT LENGTH OR BEGINNING OF TEST RHOMBUS (INCHES)        *
* YTHEX - THE HALF HEIGHT OF NOZZLE THROAT OR EXIT DEPENDING ON    *
* INDYTH (INCHES)                                          *
```

```
* RCT - RADIUS OF CURVATURE AT THROAT (INCHES)              *
* DELMUL - MULT. FACTOR FOR X INCREMENT (1.0-150 PTS, 0.5-400 PTS)   *
*                                    *
**********************************************************************


      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      INTEGER ERROR

      DIMENSION Y(2,400),X(2,400),A(2,400),SM(2,400),ETA(2,400),
     1T(2,400),THE(2,400),XL(600),XW(600),YW(600),SML(600),
     2SMW(600),THEW(600),XCOR(600),FMT(10),R(600),SMLR(400),
     3SMWR(400),XLXEX(400),XLYEX(400),YWYEX(400),XLXT(400)

      CHARACTER*8,FMT

      CHARACTER*20,TYPE1,TYPE2,TYPE3,HGT1,HGT2,LGTH1,LGTH2,
     1OUTPT1,OUTPT2

      CHARACTER*1,TYPNOZ,TYPHGT,TYPLTH,TYPOUT,INSRP

      COMMON Y(2,400),X(2,400),A(2,400),SM(2,400),ETA(2,400),T(2,400),
     1THE(2,400),XL(600),XW(600),YW(600),SML(600),SMW(600),THEW(600),
     2XCOR(600),FMT(10),R(600)

      COMMON SMLR(400),SMWR(400),XLXEX(400),XLYEX(400),YWYEX(400),
     1XLXT(400)


C
C   OUTPT1 IS THE MAIN OUTPUT FILE FOR char6.f WHICH DISPLAYS THE
C   ISENTROPIC CORE DATA OF THE NOZZLE.  OUTPT2 IS THE DATA FROM
C   THE OUTPT1 FILE THAT IS USED FOR THE VISCOUS CALCULATIONS IN
C   nbl6.f
C

C     OPEN(UNIT=16,FILE='outpt1',STATUS='UNKNOWN')
      OPEN(UNIT=17,FILE='outpt2',STATUS='UNKNOWN')


C
C   DO NOT REMOVE THESE ASSIGNMENT STATEMENTS.  THESE VARIBLES WERE
C   USED IN THE ORIGINAL PROGRAM FORMAT WHICH DETERMINED THE OUTPUT
C   MEDIUM FOR THE DATA, i.e., MAGNETIC TAPE OR PUNCH CARDS.  THE
C   MEANS FOR THIS NO LONGER EXISTS, HOWEVER PORTIONS OF THE PROGRAM
C   STILL REFER TO THESE VARIBLES IN ORDER TO EXECUTE BUT EFFECT THE
C   OUTPUT IN A BENIGN MANNER
C
```

```
      INDCAL=0
      INDTAP=0
      INDCRD=0

C     FMT = M2

C     INDSR=2
C     INDYTH=1
C     INDXTE=1
C     INDOUT=2
C     GAMMA=1.4
C     SMT = 2.0
C     XEXXT = 25.
C     YTHEX = 2.8
C     RCT = 20.
C     DELMUL = .5

      read(*,*) INDSR
      read(*,*) INDYTH
      read(*,*) INDXTE
      read(*,*) INDOUT
      read(*,*) GAMMA
      read(*,*) SMT
      read(*,*) XEXXT
      read(*,*) YTHEX
      read(*,*) RCT
      read(*,*) DELMUL

C     WRITE(16,40)
C  40 FORMAT(1X,15X,'U.S. NAVAL ORDANCE LABORATORY, WHITE OAK, MARYLAND'
C    1,//,5X,'COMPUTER PROGRAM FOR THE DESIGN OF TWO-DIMENSIONAL'
C    2'SUPERSONIC NOZZLES',//,34X,'PART I',//,20X,'THE ISENTROPIC'
C    3'CORE OF THE NOZZLE',/////)
C     WRITE(16,406)(FMT(I),I=1,10)
C 406 FORMAT(20X,10A8////)
C     WRITE(16,41)  INDSR,INDYTH,INDXTE,INDOUT,INDCAL,INDTAP,INDCRD,
C    1GAMMA,SMT,XEXXT,YTHEX,RCT,DELMUL
C  41 FORMAT(          20X,'INPUT DATA',//,20X,'CARD NO. 1',
C    1       5X,'INDSR =',I12,/,34X,'INDYTH =',I12,/,
C    734X,'INDXTE =',I12,/,34X,'INDOUT =',I12,/,34X,'INDCAL =',I12/,
C    834X,'INDTAP =',I12,/,34X,'INDCRD =',I12//
C    520X,'CARD NO. 2', 5X,'GAMMA =',E12.5,/,37X,'SMT =',E12.5,/,35X,
C    6'XEXXT =',E12.5,/,35X,'YTHEX =',E12.5,/,37X,'RCT =',E12.5,/,
C    934X,'DELMUL =',E12.5)
      EPSC=0.001
      LOLITA=25
      GA=GAMMA+1.
```

```
      GB=GAMMA-1.
      GC=2.*GB
      GD=GA/GC
      GE=GA/GB
      GG=2./GB
      GI=GA/2.
      WU=SQRT(GE)
      TERM=(GA/(2.0+GB*SMT**2))**GD
      ETAW=SMT*TERM
      TANA=1./SQRT(SMT**2-1.)
      IF(INDYTH.EQ.1) GO TO 50
      YEXIT=YTHEX/ETAW
      YTH=YTHEX
      GO TO 60
   50 YEXIT=YTHEX
      YTH=YTHEX*ETAW
   60 IF(INDXTE.EQ.1) GO TO 65
      XT=XEXXT
      XEXIT=XT+YEXIT*SQRT(SMT*SMT-1.0)
      GO TO 70
   65 XEXIT=XEXXT
      XT=XEXIT-YEXIT*SQRT(SMT*SMT-1.0)
   70 DO 80 I=1,600
      XW(I)=0.0
      SMW(I)=1.00000
      YW(I)=ETAW
   80 CONTINUE
      GO TO (100,85,98),INDSR
   85 B=XT/2.0/(SMT-1.0)*SQRT(GA/RCT/YTH)-2.0
      IF(B.GT.-2..AND.B.LT.1.0) GO TO 95
C     WRITE (16,90) B
C  90 FORMAT(1X,///,19X,'** CUBIC CENTERLINE MACH NO. DISTRIBUTION',/,
C    123X,'IS NOT APPROPRIATE FOR INPUT GIVEN, B =',E12.6)
      WRITE(*,1200)
 1200 FORMAT(1X,'***CUBIC CENTERLINE MACH NO. DISTRIBUTION IS NOT'
     1' APPROPRIATE FOR INPUT',/,1X,'GIVEN')
      GO TO 98
   95 CALL REG(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA,XEXIT
     1,ETAW,DELMUL)
      GO TO 110
   98 CALL XPO(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA,XEXIT
     1,ETAW,DELMUL)
      GO TO 110
  100 CALL SHO(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA,XEXIT
     1,ETAW,DELMUL)
  110 ASSIGN 740 TO MU
      KAPPA=2
      NEN=NEND-1
      Y(2,1)=0.0
      THE(2,1)=0.0
      T(2,1)=0.0
      ETA(2,1)=0.0
```

```
C     WRITE(16,111)
C 111 FORMAT(1X,///,10X,'CHARACTERISTICS MANIPULATION  '
C    1'(* INTERPOLATED WALL VALUES)',//,5X,'N',4X,'K',6X,'X(INCHES)'
C    2,5X,'Y(INCHES)',7X,'MACH NO.',5X,'STREAM ANGLE',/)
      DO 900 N=1,NEN
      N1=N
      IF(LASTN.LE.N) GO TO 370
      SM(2,1)=SML(N)
      X(2,1)=XL(N)
      A(2,1)=1./SQRT(SML(N)**2-1.)
      IF(N.GT.1) GO TO 470
      KO=1
      GO TO 850
  370 X(2,KAPPA)=XL(N)
      Y(2,KAPPA)=(XL(N)-XT)*TANA
      SM(2,KAPPA)=SMT
      A(2,KAPPA)=TANA
      T(2,KAPPA)=0.0
      THE(2,KAPPA)=0.0
      ETA(2,KAPPA)=ETAW*Y(2,KAPPA)
  470 IF(LASTN.GT.N) GO TO 490
      KAPPA=KAPPA+1
  490 DO 700 K=KAPPA,N
      KO=K
      THEL=THE(1,K-1)-WU*ATAN(1./(WU*A(1,K-1)))+ATAN(1./A(1,K-1))
      THER=THE(2,K-1)+WU*ATAN(1./(WU*A(2,K-1)))-ATAN(1./A(2,K-1))
      THE(2,K)=(THEL+THER)/2.
      T(2,K)=SIN(THE(2,K))/COS(THE(2,K))
      CALL ACOM(A(1,K-1),A(2,K-1),WU,THEL,THER,EPSC,LOLITA,A(2,K))
      TAB=(T(2,K-1)+T(2,K))/2.
      AAB=(A(2,K-1)+A(2,K))/2.
      TAA=(T(1,K-1)+T(2,K))/2.
      AAA=(A(1,K-1)+A(2,K))/2.
      SM(2,K)=SQRT(A(2,K)**2+1.)/A(2,K)
      SMAB=(SM(2,K-1)+SM(2,K))/2.
      CAT=(TAB-AAB)/(1.+TAB*AAB)
      DAT=(TAA+AAA)/(1.-TAA*AAA)
      X(2,K)=(Y(1,K-1)-Y(2,K-1)+CAT*X(2,K-1)-DAT*X(1,K-1))/(CAT-DAT)
      Y(2,K)=Y(2,K-1)+CAT*(X(2,K)-X(2,K-1))
      CALL ATE(GA,GD,SMAB,GB,THE(2,K),ETA(2,K-1),X(2,K),X(2,K-1),Y(2,K),
     1Y(2,K-1),SM(2,K-1),SM(2,K),ETA(2,K))
      KIP=K-KAPPA+2
      IF (INDOUT.EQ.2) GO TO 650
      XX=X(2,K)*YEXIT
      YY=Y(2,K)*YEXIT
      THD=THE(2,K)*57.3
C     WRITE (16,491) N,K,XX,YY,SM(2,5),THD
C 491 FORMAT(1X,2I5,4E15.6)
  650 IF(ETA(2,K).GT.ETAW) GO TO 720
  700 CONTINUE
      GO TO 850
  720 CALL WINTER (ETAW,X(2,K),X(2,K-1),X(2,K-2),ETA(2,K),ETA(2,K-1),ETA
```

```
  1(2,K-2),XW(N),K)
   GO TO MU,(740,760)
 740 ASSIGN 760 TO MU
   NO=N1
 760 CALL WINTER(ETAW,Y(2,K),Y(2,K-1),Y(2,K-2),ETA(2,K),ETA(2,K-1),ETA(
  12,K-2),YW(N),K)
   CALL WINTER(ETAW,SM(2,K),SM(2,K-1),SM(2,K-2),ETA(2,K),ETA(2,K-1),E
  1TA(2,K-2),SMW(N),K)
   CALL WINTER (ETAW,THE(2,K),THE(2,K-1),THE(2,K-2),ETA(2,K),ETA(2,K-
  11),ETA(2,K-2),THEW(N),K)
   XX=XW(N)*YEXIT
   YY=YW(N)*YEXIT
   THD=THEW(N)*57.3
C    WRITE (16,492) N,K,XX,YY,SMW(N),THD
C 492 FORMAT(1X,1H*,2I5,4E15.6)
 850 DO 900 IOTA=1,KO
   X(1,IOTA)=X(2,IOTA)
   Y(1,IOTA)=Y(2,IOTA)
   A(1,IOTA)=A(2,IOTA)
   T(1,IOTA)=T(2,IOTA)
   SM(1,IOTA)=SM(2,IOTA)
   THE(1,IOTA)=THE(2,IOTA)
   ETA(1,IOTA)=ETA(2,IOTA)
 900 CONTINUE
   XW(NEND)=XL(NEND)
   YW(NEND)=1.
   SMW(NEND)=SMT
   THEW(NEND)=0.0
   CALL SETXEQ(XW,NO,XL,SML,NEND)
 960 JO=NEND-NO
   DO 990 J=1,JO
   NJ=NO+J
   SML(J )=SML(NJ)
   SMW(J )=SMW(NJ)
   XL(J )=XL(NJ)*YEXIT
   XW(J )=XW(NJ)*YEXIT
   YW(J )=YW(NJ)*YEXIT
   THEW(J )=THEW(NJ)*57.3
 990 CONTINUE
   XEXIT=XEXIT*YEXIT
   XT=XT*YEXIT
   J11=JO-1
   DO 991 J4=2,J11
   DS=SQRT((XW(J4+1)-XW(J4-1))**2+(YW(J4+1)-YW(J4-1))**2)
   DTHE=THEW(J4+1)-THEW(J4-1)
   IF(DTHE.EQ.0.0) DTHE=1.E-6
   R(J4)=DS/DTHE*57.3
 991 CONTINUE
   R(1)=0.0
   R(JO)=0.0
C    WRITE(16,493)
C 493 FORMAT(1X,///,30X,'FINAL OUTPUT TO PART I, ISENTROPIC CORE CONTOUR
```

```
C    1',//,5X,'I',4X,'X(INCHES)',6X,'Y(INCHES)',5X,'CL MACH NO.',4X,
C    2'WALL MACH NO.',3X,'WALL ANGLE',2X,'RAD OF CURV (IN)   ',/)
C     WRITE(16,494)(I,XL(I),YW(I),SML(I),SMW(I),THEW(I),R(I),I=1,JO)
C  494 FORMAT(1X,I5,6E15.6)
      CONT=0.0
C     WRITE(17,142) (FMT(J),J=1,10)
C  142 FORMAT(10A8)
      WRITE(17,140)JO,YTH,YEXIT,XT,XEXIT
  140 FORMAT(I5,4E20.7)
      WRITE(17,141)(XL(J),YW(J) ,SMW(J),CONT,SML(J),J=1,JO)
  141 FORMAT(5E20.7)
      END FILE 17
      REWIND 17
C     CLOSE(16)
      CLOSE(17)
C     WRITE(*,1100)
C 1100 FORMAT(1X,///,'OUTPUT ISENTROPIC DATA FOR NOZZLE CONTOUR'
C    1,' STORED IN FILENAME outpt1'
C    2,///,'DATA FROM THIS FILE TO BE USED IN THE VISCOUS'
C    3,' PROGRAM nbl6.f IS STORED',/,'IN FILENAME outpt2')
      return
      END


      SUBROUTINE REG(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA
     1,XEXIT,ETAW,DELMUL)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION XL(600),SML(600),XCOR(600)
      SKIFG(X)=SMT-(SMT-1.0)*(1.0-B*X/XT)*(1.0-X/XT)*(1.0-X/XT)
C     WRITE(16,10) SMT,YTH,YEXIT,XEXIT,XT
C  10 FORMAT(1X,////,19X,'NOZZLE PARAMETERS (LENGTHS IN INCHES)'
C    1,//,5X,'MACH NO.',5X,'YTH',10X,'YEXIT',7X,'XEXIT',8X,'XT'
C    2,/,1X,5E13.5,/)
C     WRITE(16,20) RCT,B
C  20 FORMAT(1X,27X,'RCT',10X,'B',/,22X,2E13.5,///,10X,
C    1'CENTERLINE MACH NUMBER DISTRIBUTION USING CUBIC EQUATION',
C    2//,20X,'N',7X,'X',15X,'MACH NO.',/)
      XT=XT/YEXIT
      XEXIT=XEXIT/YEXIT
      XB=0.0
      DO 50 I5=1,600
      XB=XB+0.00001
      SMB=SKIFG(XB)
      IF(SMB.GE.1.0001) GO TO 60
   50 CONTINUE
   60 XL(1)=XB
      SML(1)=SMB
      XCOR(1)=XB*YEXIT
      DELX=0.0001
      DO 88 I=2,600
      IT=I
```

```
      IF(I.LE.20) GO TO 80
      DELX=LOG(100.*(XL(I-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
   80 XL(I)=XL(I-1)+DELX
      XCOR(I)=XL(I)*YEXIT
      SML(I)=SKIFG(XL(I))
      IF(XL(I).GE.XT) GO TO 85
   88 CONTINUE
   85 LASTN=IT
      SML(I)=SMT
      XL(I)=XT
      XCOR(I)=XL(I)*YEXIT
      N1=LASTN+1
      DO 90 J=N1,600
      JTM=J
      DELX=LOG(100.*(XL(J-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
      XL(J)=XL(J-1)+DELX
      XCOR(J)=XL(J)*YEXIT
      SML(J)=SMT
      IF(XL(J). GE. XEXIT) GO TO 95
   90 CONTINUE
   95 NEND=JTM
      XL(NEND)=XEXIT
      XCOR(NEND)=XL(NEND)*YEXIT
      SML(NEND)=SMT
C     WRITE(16,100)(K,XCOR(K),SML(K),K=1,NEND)
C 100 FORMAT(16X,I5,E15.6,2X,E15.6)
      RETURN
       END
      SUBROUTINE SHO(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA
     1,XEXIT,ETAW,DELMUL)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION XL(600),SML(600),XCOR(600)
      SKIFG(X)=((((C6*X+C5)*X+C4)*X+C3)*X+C2)*X+C1
      C1=1.0
      C2=0.023652
      C3=0.80082
      C4=-0.44309
      C5=0.09893
      C6=-0.78644E-2
      ASSIGN 81 TO NU
      XB=0.0
      DO 50 I5=1,600
      XB=XB+0.00001
      XC=XB/ETAW
      SMB=SKIFG(XC)
      IF(SMB.GE.1.0001) GO TO 60
   50 CONTINUE
   60 XL(1)=XB
      SML(1)=SMB
      XCOR(1)=XB*YEXIT
```

```
      XEXIT=3.0
      DELX=0.0001
      DO 88 I=2,600
      IT=I
      IF(I.LE.20) GO TO 80
      DELX=LOG(100.*(XL(I-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
   80 XL(I)=XL(I-1)+DELX
      GO TO NU,(81,83)
   81 XCC=XL(I)/ETAW
      IF(XCC.LE.1.60174) GO TO 82
      C1=1.4554
      C2=0.74251
      C3=0.17251
      C4=-0.037244
      C5=0.62572E-2
      C6=-0.34138E-3
      ASSIGN 83 TO NU
      GO TO 83
   82 XCOR(I)=XL(I)*YEXIT
      XC=XL(I)/ETAW
      SML(I)=SKIFG(XC)
      GO TO 86
   83 XCOR(I)=XL(I)*YEXIT
      XC=LOG(XL(I)/ETAW)
      SML(I)=SKIFG(XC)
   86 IF(SML(I).GE.SMT) GO TO 85
   88 CONTINUE
   85 LASTN=IT
      SML(I)=SMT
      XT=XL(I)
      XCOR(I)=XT*YEXIT
      XEXIT=XT+SQRT(SMT**2-1.)
      N1=LASTN+1
      DO 90 J=N1,600
      JTM=J
      DELX=LOG(100.*(XL(J-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
      XL(J)=XL(J-1)+DELX
      XCOR(J)=XL(J)*YEXIT
      SML(J)=SMT
      IF(XL(J). GE. XEXIT) GO TO 95
   90 CONTINUE
   95 NEND=JTM
      XL(NEND)=XEXIT
      XCOR(NEND)=XL(NEND)*YEXIT
      SML(NEND)=SMT
C      WRITE(16,98) SMT,YTH,YEXIT,XCOR(NEND),XCOR(LASTN)
C   98 FORMAT(1X,////,19X,'NOZZLE PARAMETERS (LENGTHS IN INCHES)'
C     1,//,5X,'MACH NO.',5X,'YTH',10X,'YEXIT',7X,'XEXIT',8X,
C     2'XT',/,1X,5E13.5,
C     3///,10X,'CENTERLINE MACH NUMBER DISTRIBUTION FOR A SHORT NOZZLE',
```

```
C    4//,20X,'N',7X,'X',10X,'MACH NO.',/)
C     WRITE(16,100)(K,XCOR(K),SML(K),K=1,NEND)
C  100 FORMAT(16X,I5,2E15.6)
      RETURN
       END
      SUBROUTINE XPO(XL,SML,XCOR,SMT,YTH,YEXIT,XT,RCT,B,LASTN,NEND,GAMMA
     1,XEXIT,ETAW,DELMUL)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION XL(600),SML(600),XCOR(600)
      SKIFG(X)=TM2*(1.-(EXP(C2*(1.-X/XT)*(1.-X/XT))-1.)/TM1)+1.
      DMDX=0.5*SQRT((GAMMA+1.)/RCT/YTH)
      T=DMDX*XT/(SMT-1.)
      ITER=0
      G1=0.001
      T1=2.0
      E1=1.-2./T
      G2=T/2.0
   30 EP=EXP(G2)
      T2=2.*G2*EP/(EP-1.)
      E2=1.-T2/T
      IF(ABS(E2).LE.0.0001) GO TO 45
      B1 =(G2-G1)/(E2-E1)
      ITER=ITER+1
      IF(ITER.GT.50) GO TO 35
      G1=G2
      E1=E2
      G2=G1-B1*E1
      IF(G2.EQ.0.00) G2=0.0001
      GO TO 30
C  35 WRITE(16,40) ITER
C  40 FORMAT(1X,20X,'ITERATION IN SUB XPO EQUALS',I5)
   35  return
   45 C2=G2
C     WRITE(16,47) SMT,YTH,YEXIT,XEXIT,XT
C  47 FORMAT(1X,////,19X,'NOZZLE PARAMETERS (LENGTHS IN INCHES)'
C    1,//,9X,'MACH NO.',7X,'YTH',10X,'YEXIT',7X,'XEXIT',8X,'XT'
C    2,/,5X,5E13.5,/)
C     WRITE(16,48) RCT,DMDX,C2
C  48 FORMAT(1X,23X,'RCT',8X,'DMT',8X,'C2',/,18X,3E13.5,///,7X,
C    1'CENTERLINE MACH NUMBER DISTRIBUTION USING EXPONENTIAL'
C    2'EQUATION',//,23X,'N',7X,'X',10X,'MACH NO.',/)
      TM1=EXP(C2)-1.0
      TM2=SMT-1.0
      XT=XT/YEXIT
      XEXIT=XEXIT/YEXIT
      XB=0.0
      DO 50 I5=1,600
      XB=XB+0.00001
      SMB=SKIFG(XB)
      IF(SMB.GE.1.0001) GO TO 60
   50 CONTINUE
   60 XL(1)=XB
```

```
      SML(1)=SMB
      XCOR(1)=XB*YEXIT
      DELX=0.0001
      DO 88 I=2,600
      IT=I
      IF(I.LE.20) GO TO 80
      DELX=LOG(100.*(XL(I-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
   80 XL(I)=XL(I-1)+DELX
      XCOR(I)=XL(I)*YEXIT
      SML(I)=SKIFG(XL(I))
      IF(XL(I).GE.XT) GO TO 85
   88 CONTINUE
   85 LASTN=IT
      SML(I)=SMT
      XL(I)=XT
      XCOR(I)=XL(I)*YEXIT
      N1=LASTN+1
      DO 90 J=N1,600
      JTM=J
      DELX=LOG(100.*(XL(J-1)/XEXIT)+1.)/460.*XEXIT
      DELX=DELX*DELMUL
      XL(J)=XL(J-1)+DELX
      XCOR(J)=XL(J)*YEXIT
      SML(J)=SMT
      IF(XL(J). GE. XEXIT) GO TO 95
   90 CONTINUE
   95 NEND=JTM
      XL(NEND)=XEXIT
      XCOR(NEND)=XL(NEND)*YEXIT
      SML(NEND)=SMT
C     WRITE(16,100)(K,XCOR(K),SML(K),K=1,NEND)
C 100 FORMAT(18X,I5,2E15.6)
      RETURN
       END
      SUBROUTINE ACOM(P,Q,W,S,R,EPSC,LOLITA,AC)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
 1005 DIMENSION ANOT(100),AP(100)
 1030 ANOT(1)=(P+Q)/2.
 1040 AP(1)=W*ATAN(1./(W*ANOT(1)))-ATAN(1./ANOT(1))+(S-R)/2.
 1050 ANOT(2)=ANOT(1)+.1
 1060 AP(2)=W*ATAN(1./(W*ANOT(2)))-ATAN(1./ANOT(2))+(S-R)/2.
 1070 DO 1110 KOUNT=3,LOLITA
 1080 ANOT(KOUNT)=ANOT(KOUNT-1)-AP(KOUNT-1)*(ANOT(KOUNT-1)-ANOT(KOUNT-2)
     1)/(AP(KOUNT-1)-AP(KOUNT-2))
 1090 AP(KOUNT)=W*ATAN(1./(W*ANOT(KOUNT)))-ATAN(1./ANOT(KOUNT))+(S-R)/2.
 1095 JULES=KOUNT
 1100 IF(ABS((ANOT(KOUNT)-ANOT(KOUNT-1))/ANOT(KOUNT))-EPSC)1145,1145,111
     10
 1110 CONTINUE
 1145 AC=ANOT(JULES)
      IF(JULES.LT.LOLITA) GO TO 1150
```

```
C     WRITE (16,1146)
C 1146 FORMAT(20X,'KOUNT')
 1150 RETURN
      END
      SUBROUTINE WINTER (EXM,R,S,T,XI,XJ,XK,TERP,K)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIFF(XI,XJ)=XI-XJ
      DIVAYF(R,S,XI,XJ)=DIFF(R,S)/DIFF(XI,XJ)
      DIVBYF(R,S,T,XI,XJ,XK)=DIVAYF(DIVAYF(R,S,XI,XJ),DIVAYF(S,T,XJ,XK),
     1XI,XK)
      IF (K .EQ. 2) GO TO 10
      TERP=R+DIFF(EXM,XI)*(DIVAYF(R,S,XI,XJ)+DIFF(EXM,XJ)*DIVBYF(R,S,T,X
     1I,XJ,XK))
      GO TO 15
   10 TERP=(EXM-XJ)*R/(XI-XJ)+(EXM-XI)*S/(XJ-XI)
   15 RETURN
      END
      SUBROUTINE ATE(GA,GD,SMAB,GB,THETA,ETA1,X2,X1,Y2,Y1,SM1,SM2,ETA2)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      PQF(FM)=FM*(GA/(2.+GB*FM**2))**GD
      X2X1=X2-X1
      Y2Y1=Y2-Y1
      SNA=.5*(1./SM1+1./SM2)
      ETA2=ETA1+.5*(PQF(SM1)+PQF(SM2))*SNA*SQRT(X2X1*X2X1+Y2Y1*Y2Y1)
      RETURN
      END


      subroutine vblsub
*************************************************************************
*  Modified by: LT Douglas L. Seivwright                    *
*  March 1994                                               *
*                                                           *
*                                                           *
*  PROGRAM INPUTS:                                          *
*                                                           *
*                                                           *
*                                                           *
*  INDMO-BOUNDARY LAYER MODE: 1. STRICTLY LAMINAR, 2. STRICTLY       *
*     TURBULENT, 3. LAM-TRANS-TURB                          *
*  INDTW-WALL TEMP INDICATION: 1. CONSTANT=TWALL, 2. ADIA WALL TEMP, *
*     3. TEMPERATURE DISTRIBUTION INPUT BY USER             *
*  INDTR-TRANSITION INDICATION(IF INDMO=3): 1. TRANS AT RETHETA VALUE *
*     GIVEN IN TRCON, 2. TRANS AT X GIVEN IN TRCON          *
*  INDWC- INDICATE BOUNDARY LAYER CALCULATION:              *
*      1. CALCULATE CENTERLINE ONLY, 2. CALCULATE WALL ONLY,    *
*      3. CALCULATE BOTH                                    *
*                                                           *
*                                                           *
*  TRCON-TRANSITION CONSTANT EQUAL TO RETHETA (REYNOLDS NUMBER BASED *
*     ON THE MOMENTUM THICKNESS OF THE BOUNDARY LAYER) OR XTRANS *
*     (HORIZONTAL DISTANCE RELATIVE TO THE THROAT) DEPENDING    *
```

```
*      ON INDTR                                            *
*  THZERO-THETA (MOMENTUM THICKNESS) AT THROAT IN FEET              *
*       (USUALLY= 1.0E-5)                                  *
*     PO-STAGNATION PRESSURE IN LBS/IN2                    *
*     TO-SUPPLY TEMP IN DEGREES R                          *
*   TWALL-WALL TEMP IN DEGREES R IF INDTW=1                *
*   XTEND-EXTENSION LENGTH OF NOZZLE WALL PAST EXIT AS DEFINED      *
*       BY THE ISENTROPIC CORE(INCHES) (ASSUMES UNIFORM DUCT FLOW) *
*     DL-INCREMENT IN X FROM ISENTROPIC EXIT TO EXTENSION LENGTH   *
*       IN (INCHES)                                        *
*     B-WIDTH OF NOZZLE                                    *
*                                                          *
*                                                          *
*   GAMMA-RATIO OF SPECIFIC HEATS                          *
*   OMEGA-EXPONENT IN VISCOSITY-TEMP RELATION (AIR=0.76)          *
*    WATE-MOLECULAR WT OF GAS (AIR=29)                     *
*     CP-SPECIFIC HEAT OF GAS IN BTU/LB-DEG R  (AIR=0.24)) OR LEAVE *
*       BLANK AND LET PROGRAM PICK VALUES                  *
*     PR-PRANDTL NUMBER (AIR=0.72)                         *
*                                                          *
*                                                          *
*  ** IFINDTW=3:                                           *
*    NUM-NUMBER OF WALL TEMP INPUT CARDS (THREE OR MORE POINTS      *
*       ARE REQUIRED OR PROGRAM WILL TERMINATE DATA OUTPUT PRIOR    *
*       TO COMPLETING RUN)                                 *
*    XXX-DISTANCE FROM THROAT IN INCHES                    *
*    TWW-WALL TEMPS. (DEGREES R) CORRESPONDING TO X=XXX            *
*                                                          *
*                                                          *
************************************************************************

C      1      2      3      4      5      6      7
C2345678901234567890123456789012345678901234567890123456789012345678901 2

      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
     1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),YSAV(1000),
     2DELTAS(1000),YS(1000),DELY(1000),YYY(1000),YC2DLY(1000),
     >blayer(1000),momth(1000),dispth(1000)

      CHARACTER*8, FMT
      REAL B
      COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
     1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
     2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
     3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
     4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
     5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
     6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
     7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG,B,DELIN,
     >THEIN,DELSIN
```

```
OPEN(UNIT=17,FILE='outpt2',STATUS='UNKNOWN')
OPEN(UNIT=26,FILE='outpt3',STATUS='UNKNOWN')
open(unit=20,file='visdata',status='unknown')
HALF A(1) = .01357623
HALF A(2) = .031126762
HALF A(3) = .047579256
HALF A(4) = .062314485
HALF A(5) = .074797995
HALF A(6) = .084578260
HALF A(7) = .091301710
HALF A(8) = .094725305
HALF A(9) = HALFA(8)
HALFA(10) = HALFA(7)
HALFA(11) = HALFA(6)
HALFA(12) = HALFA(5)
HALFA(13) = HALFA(4)
HALFA(14) = HALFA(3)
HALFA(15) = HALFA(2)
HALFA(16) = HALFA(1)
XI(1) = .005299535
XI(2) = .02771249
XI(3) = .0671844
XI(4) = .1222978
XI(5) = .19106188
XI(6) = .27099161
XI(7) = .35919822
XI(8) = .45249374
XI(9) = .54750626
XI(10) = .64080178
XI(11) = .72900839
XI(12) = .80893812
XI(13) = .8777022
XI(14) = .9328156
XI(15) = .97228751
XI(16) = .99470046
XILN(1) = -5.2401361
XILN(2) = -3.5858719
XILN(3) = -2.7003143
XILN(4) = -2.1012962
XILN(5) = -1.6551579
XILN(6) = -1.3056674
XILN(7) = -1.0238809
XILN(8) = -0.79298127
XILN(9) = -0.60238131
XILN(10) = -.44503503
XILN(11) = -.31606998
XILN(12) = -.21203278
XILN(13) = -.13044784
XILN(14) = -.069547711
XILN(15) = -.028103680
XILN(16) = -.0053135801
```

```
C
C  INTRODUCTION TO PROGRAM
C

     LAP = 0.0
     XINC=0.0
     INDCF=1
     INDPRG=2
     INDINP=2
     ITMES=0
   9 ITMES=ITMES+1
  10 CALL RESTOR
     QSUM=0.0
     DHL=0.0


     CALL IN
     IF(LAP.EQ.2) go to 699


     CP1=CP
     CALL DATA
     PRSQR = SQRT (PR)
     PR2MI6 = PR**(-.16666667)
     PRQBRT = PR**(.33333333)
     GO TO (100,110,100),INDMO
 100 L=1
     GO TO 130
 110 L=5
 130 THETA = THZERO
 417 GMUO=(.01298256/(TO+216.))*SQRT ((TO/672.)**3)
     GM1O2=(GAMMA-1.)/2.
     GO1MG=GAMMA/(1.-GAMMA)

     DO 300 N=MIN,MAX

     TETO=1./(1.+((GAMMA-1.)/2.)*(EME(N)**2))
     TE=TETO*TO
     IF (CP1.EQ.0.0) CP=(0.2405-1.186E-05*TE+20.1E-09*TE*TE)
    $ *32.175
 419 AE=SQRT (49764.*GAMMA*TE/WATE)
     UE=EME(N)*AE
     GMUE=2.14E-8*TE**1.5/(TE+180.)
     GMUE=2.27E-08*TE**1.5/(TE+198.6)
 639 POVPO(N)=(1.0+GM1O2*(EME(N)**2))**GO1MG
     RHOE=(POVPO(N)*PO*WATE)/(49764.*TE)
     REL=RHOE*UE/GMUE
     IF(L-4)146,147,148
 146 TADTE = 1. + PRSQR*((TO-TE)/TE)
     GO TO 150
 147 TADTE = 1.+PRSQR*(1.+((PR2MI6-1.)/1600.)*DELTRE)*((TO-TE)/TE)
     GO TO 150
```

```
148 TADTE = 1. + PRQBRT*((TO-TE)/TE)
150 TAD=TADTE*TE
  GO TO (154,155,160),INDTW
154 TW(N)=TWALL
  GO TO 160
155 TW(N)=TAD
160 TWTE=TW(N)/TE
  DUEDS=(AE*(TO-((GAMMA-1.)/2.)*TE*(EME(N)**2))*DMDS(N))/TO
  DPDS=0.0-RHOE*UE*DUEDS
  IF(L-3) 170,180,180
170 CALL CHLOE
175 CALL LAM IT E
  GO TO 190
180 CALL TRATUR
  IF(L.GE.4) GO TO 190
  L=4
  GO TO 300
190 DTHDS=CFOV2-THETA*((DMDS(N)*(H+2.-EME(N)**2)*TETO)/EME(N))
  IT=IT+1
  IF(IT.GT.100) THEN
     WRITE(*,191)
191    FORMAT(1X,'PROGRAM DID NOT COMPLETE RUN; PROGRAM REQUIRES',
  1    'THREE OR MORE TEMPERATURES FOR THE DISTRIBUTION IN ORDER',
  2    'TO COMPLETE RUN')
     STOP
  END IF
  IF (N.LE.MIN) GO TO 200
225 THETA=THETA2+((OLDDTH+DTHDS)*(S(N)-S(N-1)))/2.
  THTCOR=THBAR-THETA
  IF(ABS (THTCOR/THETA)-.005)200,200,226
226 THBAR=THETA
227 IF(L-3)175,180,180
200 IF(L-3)240,250,250
240 HA= (CP/(PR**.6))*RHOE*UE*CFOV2*(SQRT (((TE+216.)/(TW(N)+216.))*
  1SQRT (TWTE)))/(1.-A1*(ABS (ENBAR))**B1)
  GO TO 260
250 HA=(0.27477951*POVPO(N)*PO*EME(N)/SQRT (TE))*CFOV2
260 DHEAT=HA*(TAD-TW(N))
  IF(N.EQ.MIN) GO TO 265
265 TAUWAL=CFOV2*RHOE*(UE**2)
  DELTA=H*THETA
  DELTAS(N)=DELTA

  CALL OUT(DELIN,THEIN,DELSIN)

  blayer(N) = DELIN

  dispth(N) = DELSIN

  IF(N.EQ.1) GO TO 288
  QSUM=QSUM+(DHEAT+DHL)/2.*(S(N)-S(N-1))
288 DHL=DHEAT
```

```
      WRITE(26,289) QSUM
  289 FORMAT(15X,E15.6)
      IF(INDMO.LE.2)GO TO 1642
  290 CALL IPSO
 1642 OLDDTH=DTHDS
 1643 THBAR=THETA
 1644 THETA2=THETA
      IF(L.EQ.3) GO TO 180

  300 CONTINUE

      N=MAX
      IF(LAP.EQ.1) GO TO 390
      IF(LAP.EQ.2) GO TO 410
  390 WRITE(26,400)
  400 FORMAT(1X,19X,////,55X,'* WALL RESULTS *',//,9X,'N',8X,
     1'X(INCHES)',6X,'DELSTAR(INCHES)',3X,'YCORE+DELSTAR',9X,
     2'MWALL',12X,'DELTAY',9X,'YCORE+DELTAY',//)
  425 DO 426 I7=MIN,MAX
      YSAV(I7)=0.0
  426 CONTINUE
      GO TO 430
  410 WRITE(26,420)
  420 FORMAT(1X,19X,////,60X,'* CENTERLINE RESULTS *',//,9X,'N',8X,
     1'X(INCHES)',6X,'DELSTAR(INCHES)',4X,'0.0+DELSTAR',11X,
     2'M(CL)',11X,'DELTAY',12X,'0.0+DELTAY',//)
  430 DO 450 IA=MIN,MAX
      X(IA)=X(IA)*12.
      YYY(IA)=YY(IA)*12.
      YY(IA)=(YY(IA)+DELTAS(IA))*12.
      DELTAS(IA)=DELTAS(IA)*12.

      DELY(IA)=(2.*YYY(IA)*DELTAS(IA)+(B-2.*DELTAS(IA))*DELTAS(IA))/B

      YYY(IA)=YYY(IA)+DELY(IA)
      YC2DLY(IA)=YSAV(IA)+2*DELY(IA)
      YSAV(IA)=YSAV(IA)+YY(IA)
  450 CONTINUE
      WRITE(26,440)(IA,X(IA),DELTAS(IA),YY(IA),EME(IA),DELY(IA),
     1YYY(IA),IA=MIN,MAX)
  440 FORMAT(5X,I5,6E18.6)

C  Output to 'visdata':
C  1. Point
C  2. X
C  3. Wall Mach #
C  4. Displacement Thickness (sidewall included)
C  5. Y
C  6. boundary layer thickness
C  7. dispacement thickness (no sidewall)
C  8. static to stagnation pressure ratio
```

```
      WRITE(20,441)(IAA,X(IAA),EME(IAA),DELY(IAA),YYY(IAA),
     >blayer(IAA),dispth(IAA),POVPO(IAA),IAA=MIN,MAX)
  441 FORMAT(I5,7E18.6)

C write the last Y value to the screen for iteration on exit dimension

      write(*,*) 'Exit Half Height: ',YYY(MAX)


      IF(INDWC.EQ.3.AND.LAP.EQ.1) GO TO 10
      IF(INDWC.NE.3) GO TO 600
  490 WRITE(26,500)
  500 FORMAT(1X,19X,////,45X,'* WALL AND CENTERLINE RESULTS COMBINED *',
     1//,39X,'N',9X,'X(INCHES)',8X,'YCORE+(2)DELSTAR',4X,'YCORE+(2)',
     2'DELTAY',//)
      WRITE(26,510)(I6,X(I6),YSAV(I6),YC2DLY(I6),I6=MIN,MAX)
  510 FORMAT(35X,I5,5X,E15.6,5X,E15.6,5X,E15.6)
  600 IF(XINC.EQ.0.0) GO TO 9
      WRITE(26,630)(FMT(I),I=1,10)
  630 FORMAT(1X,10A8,//,30X,'CONTOUR FOR FLAT PLATE',//,T25,'N',
     1T42,'X',T62,'Y',//)
      S(1)=0.0
      DO 599 I=2,500
      MINC=I-1
      S(I)=S(I-1)+XINC
      IF(S(I).GT.X(MAX)) GO TO 489
  599 CONTINUE
  489 MINX=MIN+1
      DO 620 I=MIN,MAX
      YS(I)=YSAV(I)
      IF(INDWC.NE.3)YS(I)=YY(I)
  620 CONTINUE
      CALL SETXEQ(S,MINX,X,YS,MINC)
      WRITE(26,610)(I,S(I),YS(I),I=2,MINC)
  610 FORMAT(20X,I5,2F20.4)
      WRITE(26,631)(FMT(I),I=1,10)
  631 FORMAT(1X,10A8,//,30X,'CONTOUR FOR TAPERED PLATE',//,T25,'N',
     1T42,'X',T62,'Y',//)
      DO 615 I=2,MINC
      YS(I)=YS(I)+0.021+3.5777E-03*S(I)
  615 CONTINUE
      WRITE(26,610)(I,S(I),YS(I),I=2,MINC)
      GO TO 9
  699 return
      END

C
C   END MAIN PROGRAM
C


      SUBROUTINE RESTOR
```

```
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      CHARACTER*8,FMT
      DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
     1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
     2DELY(1000),YYY(1000)

      COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
     1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
     2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
     3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
     4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
     5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
     6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
     7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG

 1910 CFOV2 =0
 1911 CFOV2L=0.
 1912 CFOV2T=0.
 1913 DELRAT=0.
 1914 DELTA =0.
 1915 DELTRE=0.
 1916 DELTTH=0.
 1917 DHEAT =0.
 1918 DTHDS =0.
 1919 DUEDS =0.
 1920 EN    =0.
 1921 ENBAR =0.
 1922 ENTURB=0.
 1923 H     =0.
 1924 HINC  =0.
 1925 OLDDTH=0.
 1927 QUAY  =0.
 1928 REL   =0.
 1929 RETH  =0.
 1930 RETHTR=0.
 1931 RHOE  =0.
 1932 TAUWAL=0.
 1933 THBAR =0.
 1934 THETA2=0.
 1935 THOVDL=0.
 1936 TLTE  =0.
 1937 ULUE  =1.0E-4
 1938 IT    =0
 1939 L     =0
 1945 N     =0
      MIN=1
   60 DO 61 IA=1,1000
   61 YY(IA)=0.
 1946 RETURN
      END
```

```
      SUBROUTINE IN
C     SUBROUTINE IN READS INPUT FROM char6 AND KEYBOARD INPUT
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      INTEGER COUNT,COUNT1,ERROR,INVALD
      CHARACTER*8, FMT
      REAL B
      CHARACTER*1,INRSP,INCON,INOUT,INANS,INYN,INDIR
      CHARACTER*2,INCHG
      DIMENSION XXX(100),TWW(100),YYS(600),EMES(600),YS(600),EMS(600),
     1X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),
     2S(1000),POVPO(1000),DMDS(1000),FMT(10),DELY(1000),YYY(1000),
     >cnd(10)

      COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
     1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
     2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
     3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
     4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
     5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
     6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
     7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG,B


    9 LAP = LAP+1


      IF(LAP.EQ.2) go to 850

      IF (ITMES .EQ. 1) GO TO 14
      GO TO 71
C
C     INPUTS FROM ISENTROPIC CORE DATA GENERATED BY PROGRAM char6
C
   14 ITMES=2
C     READ(17,15)(FMT(I),I=1,10)
C  15 FORMAT(10A8)
      READ(17,20) MAX,YTH,YEXIT,XT,XEXIT
   20 FORMAT(I5,4E20.7)
      READ(17,25)(X(I),YS(I),EMS(I),YYS(I),EMES(I),I=1,MAX)
   25 FORMAT(5E20.7)
   71 IF (INDWC .EQ. 3) THEN
C           GO TO 29
      END IF

CRead from input file (first 10 variables are dummies)

C     do 90 iii = 1, 10
C        write(*,*) cnd(iii)
C  90 continue

      read(*,*) INDMO
```

```
      read(*,*) INDTW
      read(*,*) INDTR
      read(*,*) INDWC
      read(*,*) TRCON
      read(*,*) THZERO
      read(*,*) PO
      read(*,*) TO
      read(*,*) TWALL
      read(*,*) XTEND
      read(*,*) DL
      read(*,*) B
      read(*,*) GAMMA
      read(*,*) OMEGA
      read(*,*) WATE
      read(*,*) CP
      read(*,*) PR


c     INDWC = 2
c     INDMO = 2
c     INDTW = 1
c     INDTR = 1

      IF (INDWC .EQ. 3) THEN
         GO TO 224
      END IF
  224 COUNT=0

      IF (INDMO .EQ. '3') THEN
         ERROR=0
         IF (INDTR .EQ. '1') THEN
  231        WRITE(*,235)
  235        FORMAT(1X,/////,'INPUT REYNOLDS NUMBER FOR TRANSITION',
     1       /,5X,'(*****REYNOLDS NUMBER BASED ON MOMENTUM THICKNESS'
     2       ' OF BOUNDARY LAYER*****)')
c            READ(*,240,IOSTAT=ERROR) TRCON
c 240        FORMAT(E10.3)
            IF (ERROR .GT. 0) THEN
               GO TO 231
            END IF
         ELSE IF (INDTR .EQ. '2') THEN
  241        WRITE(*,245)
  245        FORMAT(1X,//,'INPUT TRANSITION DISTANCE FROM THE'
     1       'THROAT IN FEET')
c            READ(*,250,IOSTAT=ERROR) TRCON
c 250        FORMAT(E10.3)
            IF (ERROR .GT. 0) THEN
               GO TO 241
            END IF
         END IF
      END IF
```

```
c    THZERO = .00001
c    PO = 115.
c    TO = 520.
c    TWALL = 520.
c    XTEND = 20.
c    DL = .0625
c    B = 3.2
c    GAMMA = 1.4
c    OMEGA = 0.76
c    WATE = 28.97
c    CP = 0.24
c    PR = 0.72

      IF(XTEND.LE.X(MAX)) GO TO 640
      DO 645 I=1,600
      NT=I+MAX
      IF(NT.EQ.600) GO TO 650
      X(NT)=X(NT-1)+DL
      YS(NT)=YS(MAX)
      EMS(NT)=EMS(MAX)
      YYS(NT)=YYS(MAX)
      EMES(NT)=EMES(MAX)
      IF(X(NT).GE.XTEND) GO TO 650
  645 CONTINUE
  650 MAX=NT
  640 GO TO (710,710,655), INDTW
      ERROR=0
  655 WRITE(*,660)
  660 FORMAT(1X,///,'INDICATE THE NUMBER OF TEMPERATURE POINTS TO BE',
     1' ENTERED',/,'THREE OR MORE POINTS ARE REQUIRED OR PROGRAM WILL',
     2' TERMINATE THE DATA OUTPUT PRIOR TO COMPLETION')
      READ(*,665,IOSTAT=ERROR) NUM
  665 FORMAT(I5)
      IF (ERROR .EQ. 0) THEN
         GO TO 655
      END IF
      DO 670 I4=1,NUM
      ERROR=0
  666 WRITE(*,675) 'INPUT THE "X" LOCATION FOR POINT NUMBER ',I4,
     1'RELATIVE TO THE THROAT IN INCHES'
  675 FORMAT(1X,//,A40,I5,/,A32)
      READ(*,680,IOSTAT=ERROR)XXX(I4)
  680 FORMAT(F10.4)
      IF (ERROR .EQ. 0) THEN
         GO TO 666
      END IF
      ERROR=0
  681 WRITE(*,685) 'INPUT TEMPERATURE IN DEGREES R FOR POINT NUMBER',
     1I4
  685 FORMAT(1X,//,A47,I5)
      READ(*,690,IOSTAT=ERROR) TWW(I4)
  690 FORMAT(F10.4)
```

```
   IF (ERROR .EQ. 0) THEN
      GO TO 681
   END IF
670 CONTINUE
   K=1
   DO 695 J=1,MAX
700 IF(X(J).LT.XXX(K+1)) GO TO 705
   K=K+1
   GO TO 700
705 TW(J)=TWW(K)+ (X(J)-XXX(K))/(XXX(K+1)-XXX(K))*(TWW(K+1)-TWW(K))
695 CONTINUE
710 IF(INDWC.EQ.1) GO TO 715
   IF(LAP.EQ.1) GO TO 725
715 LAP=2
   DO 720 I=1,MAX
   EME(I)=EMES(I)
   YY(I)=YYS(I)
720 CONTINUE
   GO TO 735
725 LAP=1
   DO 730 I1=1,MAX
   EME(I1)=EMS(I1)
   YY(I1)=YS(I1)
730 CONTINUE
735 WRITE(26,740)(FMT(I),I=1,10)
740 FORMAT(1X,20X,10A8,////)
   WRITE(26,745) INDINP,INDPRG,INDMO,INDTW,INDTR,INDWC,INDCF,INDOUT,
  1TRCON,THZERO,PO,TO,TWALL,XTEND,DL,GAMMA,OMEGA,
  2WATE,CP,PR,XINC
745 FORMAT(1X ,20X,////,30X,'**** INPUT DATA ****',//,32X,
  1'INDINP =',I5,/,32X,'INDPRG =',I5,//,
  115X,'CARD 1',12X,'INDMO =',I5,
  2/,33X,'INDTW =',I5,/,33X,'INDTR =',I5,/,33X,'INDWC =',I5,/,
  233X,'INDCF =',I5,/,32X,'INDOUT =',I5,//,
  315X,'CARD 2',12X,'TRCON =',E15.6,/,32X,'THZERO =',E15.6,
  4/,36X,'PO =',E15.6,/,36X,'TO =',E15.6,/,33X,'TWALL =',E15.6,
  6/,33X,'XTEND =',E15.6,/,36X,'DL =',E15.6,
  8//,15X,'CARD 3',12X,'GAMMA =',E15.6,/,33X,
  5'OMEGA =',E15.6,/,34X,'WATE =',E15.6,/,36X,'CP =',E15.6,
  7/,36X,'PR =',E15.6,/,34X,'XINC =',E15.6)
   PO=PO*144.
   IF (INDTW.EQ.3) GO TO 750
   GO TO 755
750 WRITE(26,760) NUM
760 FORMAT(1X,/,15X,'CARD 4',14X,'NUM =',I5)
   DO 765 J1=1,NUM
   NUMB=J1+4
   WRITE (26,770)NUMB,XXX(J1),TWW(J1)
770 FORMAT(1X,/,15X,'CARD',I3,13X,'XXX =',E15.6,/,35X,'TWW =',E15.6)
765 CONTINUE
755 IF(LAP.EQ.2) GO TO 775
   WRITE(26,780)
```

```
780 FORMAT(1X,20X,////,52X,'* WALL DATA *',//,
  136X,'X(IN)',16X,'Y(IN)',16X,'M',//)
   GO TO 785
775 WRITE(26,790)
790 FORMAT(1X,20X,////,50X,'* CENTERLINE DATA *',//,
  136X,'X(IN)',16X,'Y(IN)',16X,'M',//)
785 WRITE(26,795)(X(L),YY(L),EME(L),L=1,MAX)
795 FORMAT(25X,3E20.6)
   DO 800 I1=1,MAX
   X(I1)=X(I1)/12.0
   YY(I1)=YY(I1)/12.0
800 CONTINUE
850 RETURN
   END


C    SUBROUTINE DATA COMPUTES DM/DS
   SUBROUTINE DATA
   IMPLICIT DOUBLE PRECISION (A-H, O-Z)
   CHARACTER*8, FMT
   DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
  1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
  2DELY(1000),YYY(1000)

   COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
  1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
  2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
  3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
  4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
  5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
  6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
  7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG

   IF(LAP.EQ.2)GO TO 15
   S(1)=X(1)
   DO 10 I=2,MAX
   S(I)=S(I-1)+SQRT((X(I)-X(I-1))**2+(YY(I)-YY(I-1))**2)
 10 CONTINUE
   GO TO 21
 15 DO 20 I=1,MAX
   S(I)=X(I)
 20 CONTINUE
 21 DO 101 J=1,MAX
 50 FORMAT(20X,I5,3E15.6)
   IF (J.EQ.1) GO TO 91
   IF (J.GE.MAX) GO TO 92
 90 DMDS(J)=(EME(J+1)-EME(J-1))/(S(J+1)-S(J-1))
   GO TO 100
 91 DMDS(J)=(EME(J+1)-EME(J))/(S(J+1)-S(J))
   GO TO 100
 92 DMDS(J)=(EME(J)-EME(J-1))/(S(J)-S(J-1))
```

```
100 IF(DMDS(J).LT.0.0) DMDS(J)=0.0
101 CONTINUE
    RETURN
     END
    SUBROUTINE CHLOE
    IMPLICIT DOUBLE PRECISION (A-H, O-Z)
    CHARACTER*8, FMT
    DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
   1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
   2DELY(1000),YYY(1000)

    COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
   1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
   2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
   3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
   4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
   5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
   6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
   7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG

1110 SW=TW(N)/TO-1.
1111 A1=50.71*((ABS (SW))**0.182)-51.8
1112 B1=1.51-0.722*((ABS (SW))**0.625)
1113 A2=((7.776*SW+16.125)*SW+7.151)*SW-2.363
1114 B2=((0.328*SW+0.034)*SW-0.174)*SW+0.73
1115 C2=2.6*(SW+1.0)
1116 A3=1.28-1.106*((ABS (SW))**0.964)
1117 B3=0.903-0.088*((ABS (SW))**4.533)
1118 GNUE=GMUE/RHOE
1119 RETURN
     END
    SUBROUTINE LAM IT E
    IMPLICIT DOUBLE PRECISION (A-H, O-Z)
    CHARACTER*8, FMT
    DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
   1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
   2DELY(1000),YYY(1000)

    COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
   1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
   2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
   3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
   4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
   5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
   6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
   7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG

1210 ENBAR=((THETA**2)*DUEDS)/(GNUE*TETO)
1211 HINC=A2*(ENBAR**B2)+C2
1212 H=HINC/TETO+(TO-TE)/TE
     EN=ENBAR
1213 EL=A3*(ENBAR**B3)+0.22
```

```
1214 RETH=REL*THETA
1215 CFOV2=EL/RETH
   CFOV2L=CFOV2
   DDOT=0.
   IF (ENBAR+.3) 10,15,15
 10 D5=-.3
   DDOTND=-28.613546-((14.046635*SW+62.021031)*SW
  $+75.901060)*SW
   DDOT=DDOTND*(ENBAR+.3)
   GO TO 16
 15 D5=ENBAR
 16 DOT=7.9160948+(((30.38170*D5+59.418345*SW+82.319725)*D5+
  1(52.310133*SW+112.21677)*SW+65.130652)*D5+((-14.046635*SW
  2-30.634951)*SW-24.61395)*SW-8.2910568)*D5+(((
  3-.34832207*SW-0.99506674)*SW-.94367191)*SW+2.254166)*SW
   DOT=DOT+DDOT
   THOVDL=1./(DOT+(TO/TE-1.)*(HINC+1.))
   DELRAT=H*THOVDL
1216 RETURN
    END
   SUBROUTINE TRATUR
   IMPLICIT DOUBLE PRECISION (A-H, O-Z)
   CHARACTER*8, FMT
   DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
  1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
  2DELY(1000),YYY(1000)

   COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
  1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
  2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
  3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
  4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
  5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
  6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
  7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG

1310 RETH=REL*THETA
   GO TO (1311,311),INDCF
 311 ENTURB=0.85*LOG(RETH)-1.29
   GO TO 1312
1311 ENTURB=.89030368*LOG(RETH)-1.65
1312 IF(L-4) 1315,1315,1313
1313 EN=ENTURB
1314 GO TO 1317
1315 DELTRE=RETH-RETHTR
1316 EN=((5.25E-3)-(1.9E-6)*DELTRE)*DELTRE+1.25
1317 A=1.-TADTE
1318 B=TADTE-TWTE
1319 POWR=EN
1320 DO 1331 J=1,2
1321 SUM=0.
1322 DO 1324 I=1,16
```

```
1323 GIZMO=HALFA(I)*(EXP (XILN(I)*POWR))/((A*XI(I)+B)*XI(I)+TWTE)
1324 SUM=SUM+GIZMO
1325 IF(J-1) 1328,1328,1331
1328 GADGET=EN*SUM
1329 DELRAT=1.-GADGET
1330 POWR=EN+1.
1331 CONTINUE
1332 THOVDL=GADGET-EN*SUM
1333 H=DELRAT/THOVDL
1334 DO 1336 I=1,2
1335 TLTE=1.+.448*(GAMMA-1.)*(EME(N)**2)*(1.-(ULUE**2))+(TWTE-TADTE)*
   1    (1.-ULUE)
1336 ULUE=(20.*EN*THOVDL*(TLTE**(1.+OMEGA))/RETH)**(1./(EN+1.))
    GO TO (1337,337),INDCF
 337 CFOV2=.002205*TETO**0.5*(TWTE/TADTE)**0.345/RETH**0.1
    GO TO 1338
1337 CFOV2=((20.*ENTURB)**((1.-ENTURB)/(1.+ENTURB)))*((THOVDL/RETH)
   1  **(2./(ENTURB+1.)))*(TLTE**((1.+2.*OMEGA-ENTURB)/(ENTURB+1.)))
1338 IF(L-4) 1339,1342,1343
1339 QUAY=(CFOV2-CFOV2L)*(RETH**2)
1340 GO TO 1343
1342 CFOV2=CFOV2-QUAY/(RETH**2)
1343 RETURN
     END


     SUBROUTINE OUT(DELIN,THEIN,DELSIN)
     IMPLICIT DOUBLE PRECISION (A-H, O-Z)
     CHARACTER*8, FMT
     DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
    1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
    2DELY(1000),YYY(1000)

     COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
    1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
    2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
    3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
    4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
    5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
    6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
    7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG


     XCOR=X(N)*12.
     SCOR=S(N)*12.
     YCOR=YY(N)*12.
     BCLAUS=THETA/TAUWAL*DPDS
     THEIN=THETA*12.
     DELSIN=DELTA*12.
     DELIN=THEIN/THOVDL
     TWTAD=TW(N)/TAD
     TWTO=TW(N)/TO
```

```
      TADTO=TADTO
      CF=CFOV2*2.
      IF(N.GT.MIN) GO TO 12
      WRITE(26,4)
    4 FORMAT(1X,19X,////,56X,'*** OUTPUT CODE ***',///)
      WRITE(26,5)
    5 FORMAT(20X,'X(IN)',10X,'S(IN)',10X,'Y(IN)',12X,'M',10X,
     1'REL(1/FT)',8X,'RETH',11X,'PE/PO',///)
      WRITE(26,6)
    6 FORMAT(17X,'UE(FT/SEC)',4X,'MUE(PSEC/FT2)',1X,'RHOE(PSEC2/FT4)',
     15X,'TE(R)',10X,'TW(R)',9X,'TAD(R)',10X,'TE/TO',///)
      WRITE(26,7)
    7 FORMAT(18X,'DELTA(IN)',6X,'THETA(IN)',6X,'DELSTAR(IN)',9X,'H',11X
     1,'TW/TO',10X,'TW/TAD',10X,'TAD/TO',///)
      WRITE(26,8)
    8 FORMAT(17X,'DPDS(P/FT2)',4X,'DMDS(1/FT)',7X,'DUDS(1/SEC)',6X,
     1'DTHDS',6X,'TAUWAL(P/FT2)',7X,'CF',11X,'BETATH',///)
      WRITE(26,9)
    9 FORMAT(16X,'Q(BTU/FT2/SEC)',1X,'HA(BTU/FT2SECR)',8X,'N',///)
   12 IF (L-4)13,18,22
   13 WRITE(26,15)N,IT
   15 FORMAT(1X,//,15X,'POINT NO.',I4,4X,'LAMINAR',5X,I3,1X,
     1'ITERATIONS')
      GO TO 30
   18 WRITE(26,20)N,IT
   20 FORMAT(1X,//,15X,'POINT NO.',I4,4X,'TRANSITION',5X,I3,1X,
     1'ITERATIONS')
      GO TO 30
   22 WRITE(26,25)N,IT
   25 FORMAT(1X,//,15X,'POINT NO.',I4,4X,'TURBULENT',5X,I3,1X,
     1'ITERATIONS')
   30 WRITE(26,35)XCOR,SCOR,YCOR,EME(N),REL,RETH,POVPO(N),UE,GMUE,RHOE,
     1TE,TW(N),TAD,TETO, DELIN,THEIN,DELSIN,H,TWTO,TWTAD,TADTO,DPDS,
     1DMDS(N),DUEDS,DTHDS,TAUWAL,CF,BCLAUS,DHEAT,HA,EN
   35 FORMAT(15X,7E15.6)
      IT=0

      RETURN
      END

      SUBROUTINE IPSO
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      CHARACTER*8,FMT
      DIMENSION X(1000),YY(1000),EME(1000),HALFA(16),XI(16),XILN(16),
     1TW(1000),S(1000),POVPO(1000),DMDS(1000),FMT(10),
     2DELY(1000),YYY(1000)

      COMMON CFOV2,CFOV2L,CFOV2T,DELRAT,DELTA,DELTRE,DELTTH,DHEAT,DTHDS
     1,DUEDS,EN,ENBAR,ENTURB,H,HINC,OLDDTH,REL,RETH,RETHTR,RHOE,THETA,
     2TAUWAL,THBAR,THETA2,THOVDL,TLTE,ULUE,TRCON,THZERO,PO,TO,TWALL,
     3GAMMA,OMEGA,WATE,CP,PR,GMUO,SW,A1,B1,A2,B2,C2,A3,B3,GNUE,TE,TAD,
     4TADTE,TWTE,QUAY,TETO,UE,GMUE,HA,DPDS,DL,XINC,X(1000),YY(1000),
```

```
   5EME(1000),HALFA(16),XI(16),XILN(16),TW(1000),S(1000),POVPO(1000),
   6DMDS(1000),FMT(10),IT,L,N,LINES,KOUNT,LAP,NN,INDCF,INDMO,INDMU,
   7INDTW,INDTR,INDWC,MAX,MIN,INDINP,INDOUT,ITMES,INDPRG
1610 IT=0
   GO TO (1614,1614,1624,1624,1647,1647),L
1614 L=2
   IF (INDTR.EQ.2) GO TO 1616
1615 IF(TRCON-RETH) 1618,1618,1642
1616 IF(TRCON-X(N)) 1618,1618,1642
1618 L=3
1620 RETHTR=RETH
1621 ULUE=1.0E-4
1622 CFOV2L=CFOV2
1623 GO TO 1642
1624 L=4
   IF(1600.-DELTRE)1647,1647,1642
1647 L=5
1642 RETURN
   END
```

The output file from the method of characteristics and boundary layer code contained the following information: (1) the point along the wall, (2) the x coordinate of the wall shape, (3) the wall Mach number, (4) the displacement thickness with side wall growth included, (5) the y coordinate of the wall shape, (6) the boundary layer thickness, (7) the displacement thickness without side wall growth included and (8) the static to stagnation pressure ratio.

The coordinate system and nomenclature are shown in Figure 21.

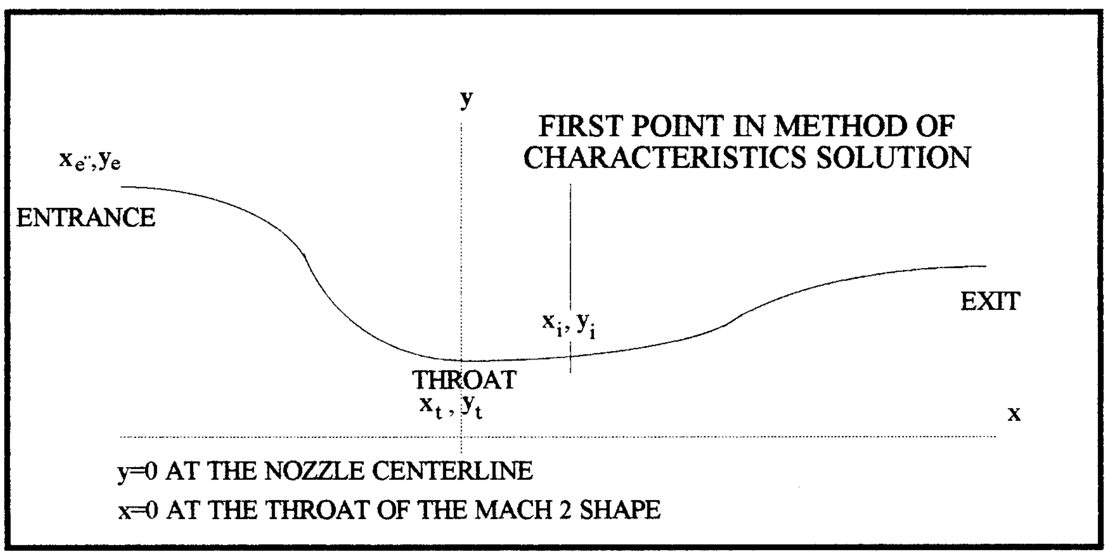


Figure 21. Nozzle Shape Coordinate System and Nomenclature

The shapes produced by this code were based on a specified length of 25 inches. This length was measured from the throat to the exit along a line perpendicular to the exit plane. With this dimension and the exit height constant, the lengths of each curve were different. The goal of this design was to produce a mechanism made from a constant length piece of metal. In order to have mathematical solutions which reflected this goal, the curves had to be constant in length and the horizontal position of the throat free to move. To satisfy this condition, ninth order polynomials were used to model each shape. By holding the nozzle exit point fixed and varying the throat position along a line parallel to the nozzle centerline, the curves were modified so that they were all equal in curve length.

B. THROAT TRANSITION POLYNOMIAL

The addition of displacement thickness to the inviscid shape produced a non-zero slope at the throat. To correct this discrepancy, a seventh order polynomial was used to produce a continuous faring between the throat condition and the first point of the method of characteristics solution. Continuity in slope was assured by ensuring equality in the slopes of curvature at the boundaries of the transition polynomial. The following nomenclature was used in the development of the transition polynomial:

x_t - horizontal coordinate of throat

x_i - horizontal coordinate of first point in method of characteristics solution

y_t - vertical coordinate of throat

y_i - vertical coordinate of first point in the method of characteristics solution

The general form of a seventh order polynomial was assumed:

$$y = Ax^7 + Bx^6 + Cx^5 + Dx^4 + Ex^3 + Fx^2 + Gx + H \tag{18}$$

The following values in addition to the spatial coordinates listed above were known from the method of characteristics solution and the throat condition and were applied as boundary conditions:

$\frac{dy_t}{dx}$ - slope at the throat

$\frac{dy_i}{dx}$ - slope at the first point in the method of characteristics solution

$\frac{d^2y_t}{dx^2}$ - curvature at the throat

$\frac{d^2y_i}{dx^2}$ - curvature at the first point in the method of characteristics solution

$\frac{d^3y_t}{dx^3}$ - slope of curvature at the throat

$\frac{d^3y_i}{dx^3}$ - slope of curvature at he first point in the method of characteristics solution

A matrix equation was assembled to solve for the coefficients of the polynomial.

$$\begin{bmatrix} x_t^7 & x_t^6 & x_t^5 & x_t^4 & x_t^3 & x_t^2 & x_t & 1 \\ 7x_t^6 & 6x_t^5 & 5x_t^4 & 4x_t^3 & 3x_t^2 & 2x_t & 1 & 0 \\ 42x_t^5 & 30x_t^4 & 20x_t^3 & 12x_t^2 & 6x_t & 2 & 0 & 0 \\ 210x_t^4 & 120x_t^3 & 60x_t^2 & 24x_t & 6 & 0 & 0 & 0 \\ x_i^7 & x_i^6 & x_i^5 & x_i^4 & x_i^3 & x_i^2 & x_i & 1 \\ 7x_i^6 & 6x_i^5 & 5x_i^4 & 4x_i^3 & 3x_i^2 & 2x_i & 1 & 0 \\ 42x_i^5 & 30x_i^4 & 20x_i^3 & 12x_i^2 & 6x_i & 2 & 0 & 0 \\ 210x_i^4 & 120x_i^3 & 60x_i^2 & 24x_i & 6 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \end{bmatrix} = \begin{bmatrix} y_t \\ \frac{dy_t}{dx} \\ \frac{d^2y_t}{dx^2} \\ \frac{d^3y_t}{dx^3} \\ y_i \\ \frac{dy_i}{dx} \\ \frac{d^2y_i}{dx^2} \\ \frac{d^3y_i}{dx^3} \end{bmatrix} \tag{19}$$

The slope of curvature at the throat was assumed to conform with the trend of the method of characteristics solution. The polynomial remained monotonic due to the small ratio of the range of x to the y values.

C. SUBSONIC SECTION

The subsonic section was a somewhat arbitrary shape. The constraints included, continuity in curvature at the throat, zero slope at the entrance point and monotonicity across the range. Because of the ratio of x to y values involved, polynomials of high enough order to satisfy the boundary conditions did not remain monotonic. A parameterized series of curves were used to achieve the subsonic shape (Verhoff, 1995).

The axes were transformed so that the range of coordinates along the curves scaled between zero and one. This required

$$\xi = \frac{x_t - x}{x_t - x_e} \tag{20}$$

and

$$f(\xi) = \frac{y_e - y}{y_e - y_t} \tag{21}$$

Two parameterized exponentials were used to describe the coordinates of the curves, namely

$$\xi = 1 - e^{-bt} \tag{22}$$

and

$$f(\xi) = e^{-a_1 t^2 - a_2 t^3} \tag{23}$$

The following entrance conditions were known:

x_e - horizontal coordinate of nozzle entrance

y_e - vertical coordinate of nozzle entrance

$\frac{dy_e}{dx}$ - slope at the nozzle entrance (zero)

The spatial and slope constraints were satisfied by the parameterization and the following transformed boundary conditions applied to find the unknown constants a_1 and a_2:

$$\frac{d^2f(0)}{d\xi^2} = -\frac{d^2y_t}{dx^2}\frac{(x_t - x_e)^2}{(y_e - y_t)} \tag{24}$$

$$\frac{d^3f(0)}{d\xi^3} = \frac{d^3y_t}{dx^3}\frac{(x_t - x_e)^3}{(y_e - y_t)} \tag{25}$$

The constants a_1 and a_2 were given by

$$a_1 = \frac{d^2y_t}{dx^2}\frac{(x_t - x_e)^2}{(y_e - y_t)}\frac{b^2}{2} \tag{26}$$

and

$$a_2 = \frac{\dfrac{d^3y_t}{dx^3}\dfrac{(x_t - x_e)^3}{(y_e - y_t)}b^3 + 6a_1b}{-6} \tag{27}$$

where b was the constant in the exponential that described ξ. The constant b was used as a 'prettying factor' to control the shape of the subsonic curve.

D. SHAPE DETERMINATION USING MATLAB™ CODE

The mathematical development presented here was coded in a series MATLAB™ script files. The program also determined the coordinates of the jack-mounting points on the curves based on a specified curve distance. Calculations were performed to determine the jack length required to achieve a specific shape.

MATLAB script files used in the nozzle shape determination are listed below:

```
%Program nozzles.m
%Terry Emmert
%Last modification 10 Mar 95
%
%Used to analyze output data of Method of Characteristics
```

```
%and Viscous Boundary Layer Codes obtained from the U.S.
%Naval Ordnance Laboratory.  Input files for this code
%must be in ASCII text format, oriented in columns.
%Specific information required is:
%  Nozzle contour in x(streamwise direction along
%     centerline(inches)) and y(perpendicular distance
%     from centerline to nozzle wall(inches)).
%  Boundary Layer data in x(streamwise direction along
%     centerline(inches)) and t(thickness of boundary
%     layer(inches)).
%
%Ninth order polynomials are derived from the input data
%as representations of the supersonic section of the nozzle.
%Because of the Method of Characteristics (MOC) solution
%begins at some finite distance downstream of the throat,
%a transition polynomial is derived as a faring between
%the throat condition(as determined isentropically from
%known exit conditions and coinciding with inputs to MOC
%code) and the first point of the MOC solution.
%A parameterized exponential function is used to describe
%the subsonic section (from the nozzle entrance to the
%throat.
%--------------------------------------------------

%--------------------------------------------------
%Specify program run options:  1 - invokes, 0 - ignores
%--------------------------------------------------

clear

clock_invoke = 0;       %print internal clock time at program
                        %start and end

makepoly_invoke = 0;    %to run program makepoly.m; reads input
                        %files and finds polynomials.  Saves
                        %solutions to polyspot.mat.  If not
                        %invoked, program looks for existing
                        %polyspot.mat file.  Becuase of run-
                        %time, this option stops program after
                        %polyspot.mat is created


compare_invoke = 0;     %compare actual data to polynomials
   closexy = 0;         %looks at every tenth set of actual
                        %data

slope_curve_inv = 0;    %takes derivatives of contour data
   plot_slope = 0;      %to arrive at slope and curvature
   plot_curve = 0;      %solutions

fix_len_inv    = 0;     %find length of specific contour and
   fix_plot_in=0;       %use that length to force determination
```

```
                    %of all other contours.  If not invoked
                    %program looks for existing specspot.mat
                    %file.

jack_track_inv  = 0;    %takes series of curves based on one
    plot_track = 0;    %fixed length curve and determines path
                    %of specified points along curve length
                    %(s).  If not invoked, program looks for
                    %specspo1.mat file.

slope_curvef_inv = 1;    %takes derivatives of contour data
    plot_slopef = 0;    %to arrive at slope and curvature
    plot_curvef = 0;    %solutions

throat_to_super = 1;    %polynomial to fit between throat
                    %and first point of method of
                    %charateristics solution.
                    %must make up for positive
                    %slope created by displacement
                    %thickness addition, ensuring
                    %slope at throat is zero.

exponetial_ss = 1;      %determines shape of subsonic
                    %section based on parameterized
                    %exponential functions

jack_length = 0;   %find jack lengths for specified
                              %jack mount point.  Specify the
                              %center of jack pivot point in this
                              %code and the code will return the
                              %necessary jack length between the
                              %pivot point and the jack mount
                              %eyelet center for each shape


num_points = 250;

if clock_invoke
    clock
end

if makepoly_invoke
        %must specify order of polynimial fit to use
        %(in this case 10)
        %and number of contours contained in the input
        %files (in this case 61)
        %in the file makepoly.m
    makepoly
        %once run, polyspot.mat contains contour, blayer,
        %order(10) and numcurve(61)

    disp('Control C and restart program with makepoly_invoke = 0;');
```

```
   pause

else
   load polyspot
end

if compare_invoke
      %load selected actual data as a basis for
      %comparision of polynomials
   load l25m140;load l25m150;load l25m160;load l25m170;load l25m180;load l25m190;load l25m200
      %generate vectors based on polynomials for
      %plotting
   x = linspace(0,25,10);y140 = polyval(contour(1,:),x);y150 = polyval(contour(11,:),x);y160 =
polyval(contour(21,:),x);y170 = polyval(contour(31,:),x);y180 = polyval(contour(41,:),x);y190 =
polyval(contour(51,:),x);y200 = polyval(contour(61,:),x);
      %plot polynomials and actual data for
      %comparison
   if closexy
      subplot(3,1,1);
   end

plot(x,y140,'*',l25m140(:,2),l25m140(:,5),x,y150,'*',l25m150(:,2),l25m150(:,5),x,y160,'*',l25m160(:,2),l2
5m160(:,5),x,y170,'*',l25m170(:,2),l25m170(:,5),x,y180,'*',l25m180(:,2),l25m180(:,5),x,y190,'*',l25m19
0(:,2),l25m190(:,5),x,y200,'*',l25m200(:,2),l25m200(:,5));
   axis([-.1,4,1.5,2.5]);grid
end

if slope_curve_inv
      %find the slope and curvature of the contour
   contour_slope = zeros(numcurve,order);
   contour_curve = zeros(numcurve,order);
   curve_slope   = zeros(numcurve,order);

   contour_slope = dydx(contour);
   contour_curve = dydx(contour_slope);
   curve_slope   = dydx(contour_curve);

   if plot_slope
      xx = linspace(0,25,100);

plot(xx,polyval(contour_slope(1,:),xx),xx,polyval(contour_slope(11,:),xx),xx,polyval(contour_slope(21,:),
xx),xx,polyval(contour_slope(31,:),xx),xx,polyval(contour_slope(41,:),xx),xx,polyval(contour_slope(51,:),
xx),xx,polyval(contour_slope(61,:),xx));
   end
   if plot_curve
      xx = linspace(0,25,100);

plot(xx,polyval(contour_curve(1,:),xx),xx,polyval(contour_curve(11,:),xx),xx,polyval(contour_curve(21,:),
xx),xx,polyval(contour_curve(31,:),xx),xx,polyval(contour_curve(41,:),xx),xx,polyval(contour_curve(51,:)
,xx),xx,polyval(contour_curve(61,:),xx));
   end
end
```

```
%find the lenths of the curves
%    curve_start = 0;
%    curve_end = 25;
%    contour_length = lenfind(contour,num_points,curve_start,curve_end)

if fix_len_inv
       %find length of Mach 2.0 contour then develope shapes for
       %all other curves based on that length.
    chosen_Mach = 61;    %equates to Mach 2 contour
    curve_start = 0;
    curve_end = 25;

    contourM20_length = lenfind(contour(chosen_Mach,:),num_points,curve_start,curve_end);
    [horz_dim,fixed_contour] = conforce(contour,contourM20_length,num_points,curve_start,curve_end);

       %save contours in specspot.mat
    out = savespec(horz_dim,fixed_contour);
else
    load specspot
end

if fix_plot_in
    %take a look at curves

plot(horz_dim(1,:),fixed_contour(1,:),'k',horz_dim(11,:),fixed_contour(11,:),horz_dim(21,:),fixed_contour
(21,:),horz_dim(31,:),fixed_contour(31,:),horz_dim(41,:),fixed_contour(41,:),horz_dim(51,:),fixed_contou
r(51,:),horz_dim(61,:),fixed_contour(61,:),'k');
    grid;title('Fixed Length Contours (based on M=2.0 shape)');
    ylabel('Y (inches)');xlabel('X (inches)');
    text(-4.5,2.4,'M=1.4 >');text(-4.5,1.6,'M=2.0 >');
    axis([-.05,.01,1.5,2.5]);
end

if slope_curvef_inv

    contourf      = zeros(numcurve,order);
    contour_slopef = zeros(numcurve,order);
    contour_curvef = zeros(numcurve,order);
    curve_slopef  = zeros(numcurve,order);

%    for r = 1:numcurve
%         contourf(r,:) = polyfit(horz_dim(r,:),fixed_contour(r,:),order-1);
%    end
    contour_slopef = dydx(contour);
    contour_curvef = dydx(contour_slopef);
    curve_slopef  = dydx(contour_curvef);

    if plot_slopef
        xx = linspace(-.1,25,100);

plot(xx,polyval(contour_slopef(1,:),xx),'k',xx,polyval(contour_slopef(11,:),xx),xx,polyval(contour_slopef(2
```

```
1,:),xx),xx,polyval(contour_slopef(31,:),xx),xx,polyval(contour_slopef(41,:),xx),xx,polyval(contour_slopef
(51,:),xx),xx,polyval(contour_slopef(61,:),xx),'k');
        grid;title('Slopes of Fixed Length Contours');
        ylabel('dY/dX');xlabel('X (inches)');
        text(6,.022,'M=1.4 >');text(5.5,.085,'M=2.0 >');

    end
    if plot_curvef
        xx = linspace(-.1,25,100);

plot(xx,polyval(contour_curvef(1,:),xx),'k',xx,polyval(contour_curvef(11,:),xx),xx,polyval(contour_curvef(
21,:),xx),xx,polyval(contour_curvef(31,:),xx),xx,polyval(contour_curvef(41,:),xx),xx,polyval(contour_curv
ef(51,:),xx),xx,polyval(contour_curvef(61,:),xx),'k');
        grid;title('Curvatures of Fixed Length Contours');
        ylabel('d^2Y/dX^2');xlabel('X (inches)');
        text(1,.001,'M=1.4 >');text(6.5,.008,'< M=2.0');

    end
end

if throat_to_super

    Trad_curve = 95;
    ttp_order = 8;              %throat transition polynomial order
    ttppts = 50;                %number of points used in ttp
    ttpxx = zeros(numcurve,ttppts);
    ttpyy = zeros(numcurve,ttppts);
    ttpoly = zeros(numcurve,ttp_order);
    xxss = zeros(numcurve,num_points);
    yyss_slope = zeros(numcurve,num_points);
    yyss_curve = zeros(numcurve,num_points);
    yyss_slope_curve = zeros(numcurve,num_points);

    grab_bc    = zeros(numcurve,2);
    slope_curve_throat = zeros(numcurve,1);
    ttpyy_slope = zeros(numcurve,ttppts);
    ttpyy_curve = zeros(numcurve,ttppts);
    ttpyy_slope_curve = zeros(numcurve,ttppts);

    for r = 1:numcurve
        xt = horz_dim(r,1);     %x at throat
        yt = isoTheight(r);     %y at throat
        Sxt = 0;                %slope at throat
        Cxt = 1/Trad_curve;     %curvature at throat
        SCxt = -.005;           %slope of curvature at throat
                                %this value had to be imposed
                                %to ensure a satisfactory solution
                                %in the subsonic section.
                                %set to a small negative value
                                %within an order of maginitude
                                %of third derivatives of contours.
                                %because the subsonic section
```

```
                              %is exponential in nature, change
                              %in sign could not be allowed.

        xi = first_x(r)- (horz_dim(numcurve,1) - horz_dim(r,1));
           %x at first point on contour
        yi = polyval(contour(r,:),xi);
           %y at first point on contour
        Sxi = polyval(contour_slopef(r,:),xi);
           %slope at first point on contour
        Cxi = polyval(contour_curvef(r,:),xi);
           %curvature at first point on contour
        SCxi = polyval(curve_slopef(r,:),xi);
           %slope of curvature at first point on contour
        tranpoly = findttp(xt,yt,Sxt,Cxt,SCxt,xi,yi,Sxi,Cxi,SCxi);
        ttpoly(r,:) = tranpoly';
        ttpxx(r,:) = linspace(xt,xi,ttppts);
        ttpyy(r,:) = polyval(tranpoly,ttpxx(r,:));
        xxss(r,:)  = linspace(xi,25,num_points);
        yyss(r,:)  = polyval(contour(r,:),xxss(r,:));
        yyss_slope(r,:) = polyval(contour_slopef(r,:),xxss(r,:));
        yyss_curve(r,:) = polyval(contour_curvef(r,:),xxss(r,:));
        yyss_slope_curve(r,:) = polyval(curve_slopef(r,:),xxss(r,:));

    end

%   plot(ttpxx(61,:),ttpyy(61,:),xxss(61,:),yyss(61,:),ttpxx(1,:),ttpyy(1,:),xxss(1,:),yyss(1,:));
%   axis([-.1,.5,0,3]);

    ttp_slope = dydx(ttpoly);
    ttp_curve = dydx(ttp_slope);
    ttp_slope_curve = dydx(ttp_curve);

    for r = 1:numcurve
        xt = horz_dim(r,1);
        grab_bc(r,:) = [polyval(ttp_curve(r,:),xt) polyval(ttp_slope_curve(r,:),xt)];
        slope_curve_throat(r) = polyval(ttp_slope_curve(r,:),xt);
        ttpyy_slope(r,:) = polyval(ttp_slope(r,:),ttpxx(r,:));
        ttpyy_curve(r,:) = polyval(ttp_curve(r,:),ttpxx(r,:));
        ttpyy_slope_curve(r,:) = polyval(ttp_slope_curve(r,:),ttpxx(r,:));

    end

%
plot(ttpxx(61,:),ttpyy(61,:),xxss(61,:),yyss(61,:),ttpxx(51,:),ttpyy(51,:),xxss(51,:),yyss(51,:),ttpxx(41,:),ttpy
y(41,:),xxss(41,:),yyss(41,:),ttpxx(31,:),ttpyy(31,:),xxss(31,:),yyss(31,:),ttpxx(21,:),ttpyy(21,:),xxss(21,:),yy
ss(21,:),ttpxx(11,:),ttpyy(11,:),xxss(11,:),yyss(11,:),ttpxx(1,:),ttpyy(1,:),xxss(1,:),yyss(1,:));
%   axis([-.1,.5,1.4,2.6]);
%
plot(ttpxx(61,:),ttpyy_slope(61,:),xxss(61,:),yyss_slope(61,:),ttpxx(51,:),ttpyy_slope(51,:),xxss(51,:),yyss_s
lope(51,:),ttpxx(41,:),ttpyy_slope(41,:),xxss(41,:),yyss_slope(41,:),ttpxx(31,:),ttpyy_slope(31,:),xxss(31,:),
yyss_slope(31,:),ttpxx(21,:),ttpyy_slope(21,:),xxss(21,:),yyss_slope(21,:),ttpxx(11,:),ttpyy_slope(11,:),xxss
(11,:),yyss_slope(11,:),ttpxx(1,:),ttpyy_slope(1,:),xxss(1,:),yyss_slope(1,:));
```

```
%    axis([-.1,.4,-.001,.015]);
%
plot(ttpxx(61,:),ttpyy_curve(61,:),xxss(61,:),yyss_curve(61,:),ttpxx(51,:),ttpyy_curve(51,:),xxss(51,:),yyss_
curve(51,:),ttpxx(41,:),ttpyy_curve(41,:),xxss(41,:),yyss_curve(41,:),ttpxx(31,:),ttpyy_curve(31,:),xxss(31,:
),yyss_curve(31,:),ttpxx(21,:),ttpyy_curve(21,:),xxss(21,:),yyss_curve(21,:),ttpxx(11,:),ttpyy_curve(11,:),x
xss(11,:),yyss_curve(11,:),ttpxx(1,:),ttpyy_curve(1,:),xxss(1,:),yyss_curve(1,:));
%    axis([-.1,.1,0,.02]);
%
plot(ttpxx(61,:),ttpyy_slope_curve(61,:),xxss(61,:),yyss_slope_curve(61,:),ttpxx(51,:),ttpyy_slope_curve(5
1,:),xxss(51,:),yyss_slope_curve(51,:),ttpxx(41,:),ttpyy_slope_curve(41,:),xxss(41,:),yyss_slope_curve(41,:
),ttpxx(31,:),ttpyy_slope_curve(31,:),xxss(31,:),yyss_slope_curve(31,:),ttpxx(21,:),ttpyy_slope_curve(21,:),
xxss(21,:),yyss_slope_curve(21,:),ttpxx(11,:),ttpyy_slope_curve(11,:),xxss(11,:),yyss_slope_curve(11,:),ttp
xx(1,:),ttpyy_slope_curve(1,:),xxss(1,:),yyss_slope_curve(1,:));
%    axis([-.1,.4,-2,2]);

end

if exponetial_ss
   numSpts = 150;           %number of points used in the
                            %subsonic section

   sub_expo_sX = zeros(numcurve,numSpts);
   sub_expo_sY = zeros(numcurve,numSpts);
   sub_expo_sYp = zeros(numcurve,numSpts);
   sub_expo_sYpp = zeros(numcurve,numSpts);
   sub_expo_sYppp = zeros(numcurve,numSpts);

   b = .7;                  %prettying factor

   xi = -20;                %inlet x dimension
   yi = 5;                  %inlet y dimension
   Sxi = 0;                 %inlet slope
   Sxt = 0;                 %throat slope
   Cxt = 1/95;              %throat curvature

already_done = 1;
if already_done
   for r = 1:numcurve
%r=31
      xt = ttpxx(r,1);
      yt = ttpyy(r,1);
      SCxt = slope_curve_throat(r);
      [x,y,yp,ypp,yppp] = exposhp(xi,xt,yi,Sxi,yt,Sxt,Cxt,SCxt,b,numSpts);
      sub_expo_sX(r,:) = x;
      sub_expo_sY(r,:) = y;
      sub_expo_sYp(r,:) = yp;
      sub_expo_sYpp(r,:) = ypp;
      sub_expo_sYppp(r,:) = yppp;
   end
end

%********* plot all curves *******
```

```
%plot(sub_expo_sX(r,:),sub_expo_sY(r,:),'+',ttpxx(r,:),ttpyy(r,:)),xxss(r,:),yyss(r,:));
%    subplot(4,1,2);
%
plot(sub_expo_sX(61,:),sub_expo_sY(61,:),'k',ttpxx(61,:),ttpyy(61,:),'k',xxss(61,:),yyss(61,:),'k',sub_expo_
sX(51,:),sub_expo_sY(51,:),'k',ttpxx(51,:),ttpyy(51,:),'k',xxss(51,:),yyss(51,:),'k',sub_expo_sX(41,:),sub_ex
po_sY(41,:),'k',ttpxx(41,:),ttpyy(41,:),'k',xxss(41,:),yyss(41,:),'k',sub_expo_sX(31,:),sub_expo_sY(31,:),'k',
ttpxx(31,:),ttpyy(31,:),'k',xxss(31,:),yyss(31,:),'k',sub_expo_sX(21,:),sub_expo_sY(21,:),'k',ttpxx(21,:),ttpy
y(21,:),'k',xxss(21,:),yyss(21,:),'k',sub_expo_sX(11,:),sub_expo_sY(11,:),'k',ttpxx(11,:),ttpyy(11,:),'k',xxss(
11,:),yyss(11,:),'k',sub_expo_sX(1,:),sub_expo_sY(1,:),'k',ttpxx(1,:),ttpyy(1,:),'k',xxss(1,:),yyss(1,:)),'k';
%    subplot(4,1,2);
%
plot(sub_expo_sX(61,:),sub_expo_sY(61,:),'k',ttpxx(61,:),ttpyy(61,:),'k',xxss(61,:),yyss(61,:),'k',sub_expo_
sX(41,:),sub_expo_sY(41,:),'k',ttpxx(41,:),ttpyy(41,:),'k',xxss(41,:),yyss(41,:),'k',sub_expo_sX(31,:),sub_ex
po_sY(31,:),'k',ttpxx(31,:),ttpyy(31,:),'k',xxss(31,:),yyss(31,:),'k',sub_expo_sX(21,:),sub_expo_sY(21,:),'k',
ttpxx(21,:),ttpyy(21,:),'k',xxss(21,:),yyss(21,:),'k',sub_expo_sX(1,:),sub_expo_sY(1,:),'k',ttpxx(1,:),ttpyy(1,
:),'k',xxss(1,:),yyss(1,:),'k');

plot(sub_expo_sX(61,:),sub_expo_sY(61,:),'r',ttpxx(61,:),ttpyy(61,:),'r',xxss(61,:),yyss(61,:),'r',sub_expo_s
X(31,:),sub_expo_sY(31,:),'r',ttpxx(31,:),ttpyy(31,:),'r',xxss(31,:),yyss(31,:),'r',sub_expo_sX(1,:),sub_expo
_sY(1,:),'r',ttpxx(1,:),ttpyy(1,:),'r',xxss(1,:),yyss(1,:),'r');
%   title('Range of Nozzle Shapes');
%   ylabel('Y (inches)');xlabel('X (inches)');
%    text(-2.5,1.8,'Mach 2.0');text(-2.5,2.6,'Mach 1.4');text(-2.5,2.2,'Mach 1.7');
%    axis([-20,25,0,5]);grid
%
plot(sub_expo_sX(61,:),sub_expo_sYp(61,:),ttpxx(61,:),ttpyy_slope(61,:),xxss(61,:),yyss_slope(61,:),sub_e
xpo_sX(51,:),sub_expo_sYp(51,:),ttpxx(51,:),ttpyy_slope(51,:),xxss(51,:),yyss_slope(51,:),sub_expo_sX(4
1,:),sub_expo_sYp(41,:),ttpxx(41,:),ttpyy_slope(41,:),xxss(41,:),yyss_slope(41,:),sub_expo_sX(31,:),sub_e
xpo_sYp(31,:),ttpxx(31,:),ttpyy_slope(31,:),xxss(31,:),yyss_slope(31,:),sub_expo_sX(21,:),sub_expo_sYp(
21,:),ttpxx(21,:),ttpyy_slope(21,:),xxss(21,:),yyss_slope(21,:),sub_expo_sX(11,:),sub_expo_sYp(11,:),ttpx
x(11,:),ttpyy_slope(11,:),xxss(11,:),yyss_slope(11,:),sub_expo_sX(1,:),sub_expo_sYp(1,:),ttpxx(1,:),ttpyy_
slope(1,:),xxss(1,:),yyss_slope(1,:));
%
plot(sub_expo_sX(61,:),sub_expo_sYp(61,:),ttpxx(61,:),ttpyy_slope(61,:),xxss(61,:),yyss_slope(61,:),sub_e
xpo_sX(31,:),sub_expo_sYp(31,:),ttpxx(31,:),ttpyy_slope(31,:),xxss(31,:),yyss_slope(31,:),sub_expo_sX(1,
:),sub_expo_sYp(1,:),ttpxx(1,:),ttpyy_slope(1,:),xxss(1,:),yyss_slope(1,:));
%    title('Entire Nozzle Slope Variation(Throat Detail)');
%    ylabel('dY/dX');xlabel('X');grid
%    axis([-.1,.4,-.0025,.015]);
%        text(.27,.0095,'Mach 2.0');text(.31,.0135,'Mach 1.4');text(.27,.0115,'Mach 1.7')
%
plot(sub_expo_sX(61,:),sub_expo_sYpp(61,:),ttpxx(61,:),ttpyy_curve(61,:),xxss(61,:),yyss_curve(61,:),sub
_expo_sX(51,:),sub_expo_sYpp(51,:),ttpxx(51,:),ttpyy_curve(51,:),xxss(51,:),yyss_curve(51,:),sub_expo_s
X(41,:),sub_expo_sYpp(41,:),ttpxx(41,:),ttpyy_curve(41,:),xxss(41,:),yyss_curve(41,:),sub_expo_sX(31,:),
sub_expo_sYpp(31,:),ttpxx(31,:),ttpyy_curve(31,:),xxss(31,:),yyss_curve(31,:),sub_expo_sX(21,:),sub_exp
o_sYpp(21,:),ttpxx(21,:),ttpyy_curve(21,:),xxss(21,:),yyss_curve(21,:),sub_expo_sX(11,:),sub_expo_sYpp(
11,:),ttpxx(11,:),ttpyy_curve(11,:),xxss(11,:),yyss_curve(11,:),sub_expo_sX(1,:),sub_expo_sYpp(1,:),ttpxx
(1,:),ttpyy_curve(1,:),xxss(1,:),yyss_curve(1,:));
%    title('Entire Nozzle Curvature Variation(Throat Detail)');ylabel('d^2Y/dX^2');xlabel('X');grid
%    axis([11,14,-.005,0]);
%
plot(sub_expo_sX(61,:),sub_expo_sYppp(61,:),ttpxx(61,:),ttpyy_slope_curve(61,:),xxss(61,:),yyss_slope_c
```

```
urve(61,:),sub_expo_sX(51,:),sub_expo_sYppp(51,:),ttpxx(51,:),ttpyy_slope_curve(51,:),xxss(51,:),yyss_sl
ope_curve(51,:),sub_expo_sX(41,:),sub_expo_sYppp(41,:),ttpxx(41,:),ttpyy_slope_curve(41,:),xxss(41,:),y
yss_slope_curve(41,:),sub_expo_sX(31,:),sub_expo_sYppp(31,:),ttpxx(31,:),ttpyy_slope_curve(31,:),xxss(
31,:),yyss_slope_curve(31,:),sub_expo_sX(21,:),sub_expo_sYppp(21,:),ttpxx(21,:),ttpyy_slope_curve(21,:)
,xxss(21,:),yyss_slope_curve(21,:),sub_expo_sX(11,:),sub_expo_sYppp(11,:),ttpxx(11,:),ttpyy_slope_curve
(11,:),xxss(11,:),yyss_slope_curve(11,:),sub_expo_sX(1,:),sub_expo_sYppp(1,:),ttpxx(1,:),ttpyy_slope_cur
ve(1,:),xxss(1,:),yyss_slope_curve(1,:));
%   title('Entire Nozzle Slope of Curvature Variation(Throat
Detail)');ylabel('d^3Y/dX^3');xlabel('X');grid
%   axis([-.2,.4,-2,1.5]);

end

if jack_track_inv
        %take curves based on fixed M=2 contour and determine x, y
        %coordinates for given distances along contour.
        %this data should define a polynomial for the
        %path that a specific point on the flex wall follows
        %through shape changes
        %this information will be required for jack path.
    XXforjack = [sub_expo_sX ttpxx xxss];
    YYforjack = [sub_expo_sY ttpyy yyss];

    %s_dim is measured from the nozzle exit back to the
    %point of interest
    s_dim = [7 10 12.75 16 19 22 28.5 31.5];
    [x_for_s,y_for_s,c_ind] = findxy(XXforjack,YYforjack,s_dim);
    out = savespe1(x_for_s,y_for_s,c_ind);
else
    load specspo1
end

if plot_track

plot(x_for_s,y_for_s,ttpxx(:,1),ttpyy(:,1),'k:',sub_expo_sX(61,:),sub_expo_sY(61,:),'k',ttpxx(61,:),ttpyy(61,
:),'k',xxss(61,:),yyss(61,:),'k',sub_expo_sX(41,:),sub_expo_sY(41,:),'k',ttpxx(41,:),ttpyy(41,:),'k',xxss(41,:),
yyss(41,:),'k',sub_expo_sX(31,:),sub_expo_sY(31,:),'k',ttpxx(31,:),ttpyy(31,:),'k',xxss(31,:),yyss(31,:),'k',su
b_expo_sX(21,:),sub_expo_sY(21,:),'k',ttpxx(21,:),ttpyy(21,:),'k',xxss(21,:),yyss(21,:),'k',sub_expo_sX(1,:)
,sub_expo_sY(1,:),'k',ttpxx(1,:),ttpyy(1,:),'k',xxss(1,:),yyss(1,:),'k');
    grid;title('Paths of Jack Mounting Locations');
    ylabel('Y (inches)');xlabel('X (inches)');
%   axis([-20,-15,2.2,2.7]);


%
subplot(2,1,1);plot(x_for_s,y_for_s,horz_dim(1,:),fixed_contour(1,:),horz_dim(11,:),fixed_contour(11,:),h
orz_dim(21,:),fixed_contour(21,:),horz_dim(31,:),fixed_contour(31,:),horz_dim(41,:),fixed_contour(41,:),
horz_dim(51,:),fixed_contour(51,:),horz_dim(61,:),fixed_contour(61,:),horz_dim(:,1),fixed_contour(:,1));
%
subplot(2,1,2);plot(x_for_s,y_for_s,horz_dim(1,:),fixed_contour(1,:),horz_dim(11,:),fixed_contour(11,:),h
orz_dim(21,:),fixed_contour(21,:),horz_dim(31,:),fixed_contour(31,:),horz_dim(41,:),fixed_contour(41,:),
horz_dim(51,:),fixed_contour(51,:),horz_dim(61,:),fixed_contour(61,:),horz_dim(:,1),fixed_contour(:,1));
```

```
%   axis([-.05,.01,1.5,2.5]);
end

if jack_length

        t = .25;            %thickness of flex plate
        d = .5;                     %distance from upper surface of
                                    %plate to center of jack mount
                                    %eyelet

        %Jack pivot points Xmount, Ymount are with respect to the
        %throat coordinates of the Mach 2.0 shape
        Xmount = [17.821 14.648 11.872 8.598 5.679 2.760 -2.842 -5.522 0];
        Ymount = [10.750 10.750 10.750 10.750 10.750 10.750 10.750 10.750 10.750 ];

        [rnum,cnum] = size(c_ind);
        dydxjack = zeros(rnum,cnum+1);
        Xjack = [x_for_s ttpxx(:,1)];
        Yjack = [y_for_s ttpyy(:,1)];
        slope_bin = [sub_expo_sYp ttpyy_slope yyss_slope];
        column_index = [c_ind ones(r,1)*(length(sub_expo_sX(1,:))+1)];
        for r = 1:rnum
                dydxjack(r,:) = slope_bin(r,column_index(r,:));
        end

        jacklength = zeros(rnum,cnum+1);
        Xmount = ones(rnum,1)*[17.821 14.648 11.872 8.598 5.679 2.760 -2.842 -5.522 0];
        Ymount = ones(rnum,1)*[10.750 10.750 10.750 10.750 10.750 10.750 10.750 10.750 10.750 ];


        ys = (Ymount - (Yjack +  (t./cos(atan(dydxjack))) + (d*cos(atan(dydxjack))))).^2;
        xs = (Xmount - (Xjack - (d*sin(atan(dydxjack))))).^2;
        jacklength = sqrt(ys + xs);

end

%detemine the difference in shape between the Mach 1.7 curve
%and the Mach 1.4 and 2 curves.

dely20 = [sub_expo_sY(61,:)-sub_expo_sY(31,:)  ttpyy(61,:)-ttpyy(31,:) yyss(61,:)-yyss(31,:)];
x20 = [sub_expo_sX(31,:) ttpxx(31,:) xxss(31,:)];
dely14 = [sub_expo_sY(1,:)-sub_expo_sY(31,:)  ttpyy(1,:)-ttpyy(31,:) yyss(1,:)-yyss(31,:)];
x14 = [sub_expo_sX(31,:) ttpxx(31,:) xxss(31,:)];

%subplot(3,1,1)
%x17 = linspace(-20,25,50);y17 = zeros(1,length(x17));
%plot(x14,dely14,'r',x20,dely20,'r',x17,y17,'r');grid
%title('Extreme Shape Divergence from Mach 1.7 Contour');
%ylabel('Y (inches)');xlabel('X (inches)');
%text(-5,-.39,'Mach 2.0');text(-5,0.03,'Mach 1.7');text(-5,.43,'Mach 1.4');

if clock_invoke
```

```
   clock
end


%Program makepoly.m
%reads in ideal nozzle data
%converts data to polynomials
%saves polynomials polyspot.mat
clear

numcurve = 61;
order = 10;

contour = zeros(numcurve,order);
blayer = zeros(numcurve,order);
displace = zeros(numcurve,order);
Tdisthick = zeros(numcurve,1);
isoTheight = zeros(numcurve,1);
first_x = zeros(numcurve,1);

load l25m140;load l25m141;load l25m142;load l25m143;load l25m144;load l25m145;
load l25m146;load l25m147;load l25m148;load l25m149;load l25m150;load l25m151
load l25m152;load l25m153;load l25m154;load l25m155;load l25m156;load l25m157
load l25m158;load l25m159;load l25m160;load l25m161;load l25m162;load l25m163
load l25m164;load l25m165;load l25m166;load l25m167;load l25m168;load l25m169
load l25m170;load l25m171;load l25m172;load l25m173;load l25m174;load l25m175
load l25m176;load l25m177;load l25m178;load l25m179;load l25m180;load l25m181
load l25m182;load l25m183;load l25m184;load l25m185;load l25m186;load l25m187
load l25m188;load l25m189;load l25m190;load l25m191;load l25m192;load l25m193
load l25m194;load l25m195;load l25m196;load l25m197;load l25m198;load l25m199
load l25m200

%find polynomials of displacement thickness
disp_thick_invoke = 0;

if disp_thick_invoke
displace(1,:) = polyfit(l25m140(:,2),l25m140(:,4),order-1);
displace(2,:) = polyfit(l25m141(:,2),l25m141(:,4),order-1);
displace(3,:) = polyfit(l25m142(:,2),l25m142(:,4),order-1);
displace(4,:) = polyfit(l25m143(:,2),l25m143(:,4),order-1);
displace(5,:) = polyfit(l25m144(:,2),l25m144(:,4),order-1);
displace(6,:) = polyfit(l25m145(:,2),l25m145(:,4),order-1);
displace(7,:) = polyfit(l25m146(:,2),l25m146(:,4),order-1);
displace(8,:) = polyfit(l25m147(:,2),l25m147(:,4),order-1);
displace(9,:) = polyfit(l25m148(:,2),l25m148(:,4),order-1);
displace(10,:) = polyfit(l25m149(:,2),l25m149(:,4),order-1);

displace(11,:) = polyfit(l25m150(:,2),l25m150(:,4),order-1);
displace(12,:) = polyfit(l25m151(:,2),l25m151(:,4),order-1);
displace(13,:) = polyfit(l25m152(:,2),l25m152(:,4),order-1);
displace(14,:) = polyfit(l25m153(:,2),l25m153(:,4),order-1);
displace(15,:) = polyfit(l25m154(:,2),l25m154(:,4),order-1);
```

```
displace(16,:) = polyfit(l25m155(:,2),l25m155(:,4),order-1);
displace(17,:) = polyfit(l25m156(:,2),l25m156(:,4),order-1);
displace(18,:) = polyfit(l25m157(:,2),l25m157(:,4),order-1);
displace(19,:) = polyfit(l25m158(:,2),l25m158(:,4),order-1);
displace(20,:) = polyfit(l25m159(:,2),l25m159(:,4),order-1);

displace(21,:) = polyfit(l25m160(:,2),l25m160(:,4),order-1);
displace(22,:) = polyfit(l25m161(:,2),l25m161(:,4),order-1);
displace(23,:) = polyfit(l25m162(:,2),l25m162(:,4),order-1);
displace(24,:) = polyfit(l25m163(:,2),l25m163(:,4),order-1);
displace(25,:) = polyfit(l25m164(:,2),l25m164(:,4),order-1);
displace(26,:) = polyfit(l25m165(:,2),l25m165(:,4),order-1);
displace(27,:) = polyfit(l25m166(:,2),l25m166(:,4),order-1);
displace(28,:) = polyfit(l25m167(:,2),l25m167(:,4),order-1);
displace(29,:) = polyfit(l25m168(:,2),l25m168(:,4),order-1);
displace(30,:) = polyfit(l25m169(:,2),l25m169(:,4),order-1);

displace(31,:) = polyfit(l25m170(:,2),l25m170(:,4),order-1);
displace(32,:) = polyfit(l25m171(:,2),l25m171(:,4),order-1);
displace(33,:) = polyfit(l25m172(:,2),l25m172(:,4),order-1);
displace(34,:) = polyfit(l25m173(:,2),l25m173(:,4),order-1);
displace(35,:) = polyfit(l25m174(:,2),l25m174(:,4),order-1);
displace(36,:) = polyfit(l25m175(:,2),l25m175(:,4),order-1);
displace(37,:) = polyfit(l25m176(:,2),l25m176(:,4),order-1);
displace(38,:) = polyfit(l25m177(:,2),l25m177(:,4),order-1);
displace(39,:) = polyfit(l25m178(:,2),l25m178(:,4),order-1);
displace(40,:) = polyfit(l25m179(:,2),l25m179(:,4),order-1);

displace(41,:) = polyfit(l25m180(:,2),l25m180(:,4),order-1);
displace(42,:) = polyfit(l25m181(:,2),l25m181(:,4),order-1);
displace(43,:) = polyfit(l25m182(:,2),l25m182(:,4),order-1);
displace(44,:) = polyfit(l25m183(:,2),l25m183(:,4),order-1);
displace(45,:) = polyfit(l25m184(:,2),l25m184(:,4),order-1);
displace(46,:) = polyfit(l25m185(:,2),l25m185(:,4),order-1);
displace(47,:) = polyfit(l25m186(:,2),l25m186(:,4),order-1);
displace(48,:) = polyfit(l25m187(:,2),l25m187(:,4),order-1);
displace(49,:) = polyfit(l25m188(:,2),l25m188(:,4),order-1);
displace(50,:) = polyfit(l25m189(:,2),l25m189(:,4),order-1);

displace(51,:) = polyfit(l25m190(:,2),l25m190(:,4),order-1);
displace(52,:) = polyfit(l25m191(:,2),l25m191(:,4),order-1);
displace(53,:) = polyfit(l25m192(:,2),l25m192(:,4),order-1);
displace(54,:) = polyfit(l25m193(:,2),l25m193(:,4),order-1);
displace(55,:) = polyfit(l25m194(:,2),l25m194(:,4),order-1);
displace(56,:) = polyfit(l25m195(:,2),l25m195(:,4),order-1);
displace(57,:) = polyfit(l25m196(:,2),l25m196(:,4),order-1);
displace(58,:) = polyfit(l25m197(:,2),l25m197(:,4),order-1);
displace(59,:) = polyfit(l25m198(:,2),l25m198(:,4),order-1);
displace(60,:) = polyfit(l25m199(:,2),l25m199(:,4),order-1);

displace(61,:) = polyfit(l25m200(:,2),l25m200(:,4),order-1);
end
```

```
clear_invoke = 1;
add_throat_condition = 1;
gam = 1.4;
TbTt = zeros(numcurve,1);
pbpt = zeros(numcurve,1);
AbAs = zeros(numcurve,1);
M = 1.4:.01:2;
for c = 1:length(M)
   TbTt(c) = 1./(1+(((gam-1)/2).*M(c).^2));
   pbpt(c) = TbTt(c).^(gam/(gam-1));
   AbAs(c) = (1./M(c)).*( (1+(((gam-1)/2).*M(c).^2))./((gam+1)/2) ).^((gam+1)/(2*(gam-1)));
end

Tpt = 0;
Tx = 0;
WallM = 1;
Dispt = .00001;
Blay = .00001;
MT = WallM;
   TbTtT = 1./(1+(((gam-1)/2).*MT.^2));
   pbptT = TbTtT.^(gam/(gam-1));

%extract isentropic throat height


isoTheight(1) = (max(l25m140(:,5))-max(l25m140(:,4)))/AbAs(1);
isoTheight(2) = (max(l25m141(:,5))-max(l25m141(:,4)))/AbAs(2);
isoTheight(3) = (max(l25m142(:,5))-max(l25m142(:,4)))/AbAs(3);
isoTheight(4) = (max(l25m143(:,5))-max(l25m143(:,4)))/AbAs(4);
isoTheight(5) = (max(l25m144(:,5))-max(l25m144(:,4)))/AbAs(5);
isoTheight(6) = (max(l25m145(:,5))-max(l25m145(:,4)))/AbAs(6);
isoTheight(7) = (max(l25m146(:,5))-max(l25m146(:,4)))/AbAs(7);
isoTheight(8) = (max(l25m147(:,5))-max(l25m147(:,4)))/AbAs(8);
isoTheight(9) = (max(l25m148(:,5))-max(l25m148(:,4)))/AbAs(9);
isoTheight(10) = (max(l25m149(:,5))-max(l25m149(:,4)))/AbAs(10);

isoTheight(11) = (max(l25m150(:,5))-max(l25m150(:,4)))/AbAs(11);
isoTheight(12) = (max(l25m151(:,5))-max(l25m151(:,4)))/AbAs(12);
isoTheight(13) = (max(l25m152(:,5))-max(l25m152(:,4)))/AbAs(13);
isoTheight(14) = (max(l25m153(:,5))-max(l25m153(:,4)))/AbAs(14);
isoTheight(15) = (max(l25m154(:,5))-max(l25m154(:,4)))/AbAs(15);
isoTheight(16) = (max(l25m155(:,5))-max(l25m155(:,4)))/AbAs(16);
isoTheight(17) = (max(l25m156(:,5))-max(l25m156(:,4)))/AbAs(17);
isoTheight(18) = (max(l25m157(:,5))-max(l25m157(:,4)))/AbAs(18);
isoTheight(19) = (max(l25m158(:,5))-max(l25m158(:,4)))/AbAs(19);
isoTheight(20) = (max(l25m159(:,5))-max(l25m159(:,4)))/AbAs(20);
isoTheight(21) = (max(l25m160(:,5))-max(l25m160(:,4)))/AbAs(21);
isoTheight(22) = (max(l25m161(:,5))-max(l25m161(:,4)))/AbAs(22);
isoTheight(23) = (max(l25m162(:,5))-max(l25m162(:,4)))/AbAs(23);
```

```
isoTheight(24) = (max(l25m163(:,5))-max(l25m163(:,4)))/AbAs(24);
isoTheight(25) = (max(l25m164(:,5))-max(l25m164(:,4)))/AbAs(25);
isoTheight(26) = (max(l25m165(:,5))-max(l25m165(:,4)))/AbAs(26);
isoTheight(27) = (max(l25m166(:,5))-max(l25m166(:,4)))/AbAs(27);
isoTheight(28) = (max(l25m167(:,5))-max(l25m167(:,4)))/AbAs(28);
isoTheight(29) = (max(l25m168(:,5))-max(l25m168(:,4)))/AbAs(29);
isoTheight(30) = (max(l25m169(:,5))-max(l25m169(:,4)))/AbAs(30);

isoTheight(31) = (max(l25m170(:,5))-max(l25m170(:,4)))/AbAs(31);
isoTheight(32) = (max(l25m171(:,5))-max(l25m171(:,4)))/AbAs(32);
isoTheight(33) = (max(l25m172(:,5))-max(l25m172(:,4)))/AbAs(33);
isoTheight(34) = (max(l25m173(:,5))-max(l25m173(:,4)))/AbAs(34);
isoTheight(35) = (max(l25m174(:,5))-max(l25m174(:,4)))/AbAs(35);
isoTheight(36) = (max(l25m175(:,5))-max(l25m175(:,4)))/AbAs(36);
isoTheight(37) = (max(l25m176(:,5))-max(l25m176(:,4)))/AbAs(37);
isoTheight(38) = (max(l25m177(:,5))-max(l25m177(:,4)))/AbAs(38);
isoTheight(39) = (max(l25m178(:,5))-max(l25m178(:,4)))/AbAs(39);
isoTheight(40) = (max(l25m179(:,5))-max(l25m179(:,4)))/AbAs(40);

isoTheight(41) = (max(l25m180(:,5))-max(l25m180(:,4)))/AbAs(41);
isoTheight(42) = (max(l25m181(:,5))-max(l25m181(:,4)))/AbAs(42);
isoTheight(43) = (max(l25m182(:,5))-max(l25m182(:,4)))/AbAs(43);
isoTheight(44) = (max(l25m183(:,5))-max(l25m183(:,4)))/AbAs(44);
isoTheight(45) = (max(l25m184(:,5))-max(l25m184(:,4)))/AbAs(45);
isoTheight(46) = (max(l25m185(:,5))-max(l25m185(:,4)))/AbAs(46);
isoTheight(47) = (max(l25m186(:,5))-max(l25m186(:,4)))/AbAs(47);
isoTheight(48) = (max(l25m187(:,5))-max(l25m187(:,4)))/AbAs(48);
isoTheight(49) = (max(l25m188(:,5))-max(l25m188(:,4)))/AbAs(49);
isoTheight(50) = (max(l25m189(:,5))-max(l25m189(:,4)))/AbAs(50);

isoTheight(51) = (max(l25m190(:,5))-max(l25m190(:,4)))/AbAs(51);
isoTheight(52) = (max(l25m191(:,5))-max(l25m191(:,4)))/AbAs(52);
isoTheight(53) = (max(l25m192(:,5))-max(l25m192(:,4)))/AbAs(53);
isoTheight(54) = (max(l25m193(:,5))-max(l25m193(:,4)))/AbAs(54);
isoTheight(55) = (max(l25m194(:,5))-max(l25m194(:,4)))/AbAs(55);
isoTheight(56) = (max(l25m195(:,5))-max(l25m195(:,4)))/AbAs(56);
isoTheight(57) = (max(l25m196(:,5))-max(l25m196(:,4)))/AbAs(57);
isoTheight(58) = (max(l25m197(:,5))-max(l25m197(:,4)))/AbAs(58);
isoTheight(59) = (max(l25m198(:,5))-max(l25m198(:,4)))/AbAs(59);
isoTheight(60) = (max(l25m199(:,5))-max(l25m199(:,4)))/AbAs(60);

isoTheight(61) = (max(l25m200(:,5))-max(l25m200(:,4)))/AbAs(61);


%extract first x value of real data

first_x(1) = l25m140(1,2);first_x(2) = l25m141(1,2);first_x(3) = l25m142(1,2);
first_x(4) = l25m143(1,2);first_x(5) = l25m144(1,2);first_x(6) = l25m145(1,2);
first_x(7) = l25m146(1,2);first_x(8) = l25m147(1,2);first_x(9) = l25m148(1,2);
first_x(10) = l25m149(1,2);first_x(11) = l25m150(1,2);first_x(12) = l25m151(1,2);
first_x(13) = l25m152(1,2);first_x(14) = l25m153(1,2);first_x(15) = l25m154(1,2);
first_x(16) = l25m155(1,2);first_x(17) = l25m156(1,2);first_x(18) = l25m157(1,2);
```

```
first_x(19) = l25m158(1,2);first_x(20) = l25m159(1,2);first_x(21) = l25m160(1,2);
first_x(22) = l25m161(1,2);first_x(23) = l25m162(1,2);first_x(24) = l25m163(1,2);
first_x(25) = l25m164(1,2);first_x(26) = l25m165(1,2);first_x(27) = l25m166(1,2);
first_x(28) = l25m167(1,2);first_x(29) = l25m168(1,2);first_x(30) = l25m169(1,2);
first_x(31) = l25m170(1,2);first_x(32) = l25m171(12,2);first_x(33) = l25m172(1,2);
first_x(34) = l25m173(1,2);first_x(35) = l25m174(1,2);first_x(36) = l25m175(1,2);
first_x(37) = l25m176(17,2);first_x(38) = l25m177(1,2);first_x(39) = l25m178(1,2);
first_x(40) = l25m179(1,2);first_x(41) = l25m180(1,2);first_x(42) = l25m181(1,2);
first_x(43) = l25m182(1,2);first_x(44) = l25m183(1,2);first_x(45) = l25m184(1,2);
first_x(46) = l25m185(1,2);first_x(47) = l25m186(1,2);first_x(48) = l25m187(1,2);
first_x(49) = l25m188(1,2);first_x(50) = l25m189(1,2);first_x(51) = l25m190(1,2);
first_x(52) = l25m191(1,2);first_x(53) = l25m192(1,2);first_x(54) = l25m193(1,2);
first_x(55) = l25m194(1,2);first_x(56) = l25m195(1,2);first_x(57) = l25m196(1,2);
first_x(58) = l25m197(1,2);first_x(59) = l25m198(1,2);first_x(60) = l25m199(1,2);
first_x(61) = l25m200(1,2);


if add_throat_condition
l25m140 = [Tpt Tx WallM Dispt (max(l25m140(:,5))-max(l25m140(:,4)))/AbAs(1) Blay Dispt
pbptT;l25m140];
l25m141 = [Tpt Tx WallM Dispt (max(l25m141(:,5))-max(l25m141(:,4)))/AbAs(2) Blay Dispt
pbptT;l25m141];
l25m142 = [Tpt Tx WallM Dispt (max(l25m142(:,5))-max(l25m142(:,4)))/AbAs(3) Blay Dispt
pbptT;l25m142];
l25m143 = [Tpt Tx WallM Dispt (max(l25m143(:,5))-max(l25m143(:,4)))/AbAs(4) Blay Dispt
pbptT;l25m143];
l25m144 = [Tpt Tx WallM Dispt (max(l25m144(:,5))-max(l25m144(:,4)))/AbAs(5) Blay Dispt
pbptT;l25m144];
l25m145 = [Tpt Tx WallM Dispt (max(l25m145(:,5))-max(l25m145(:,4)))/AbAs(6) Blay Dispt
pbptT;l25m145];
l25m146 = [Tpt Tx WallM Dispt (max(l25m146(:,5))-max(l25m146(:,4)))/AbAs(7) Blay Dispt
pbptT;l25m146];
l25m147 = [Tpt Tx WallM Dispt (max(l25m147(:,5))-max(l25m147(:,4)))/AbAs(8) Blay Dispt
pbptT;l25m147];
l25m148 = [Tpt Tx WallM Dispt (max(l25m148(:,5))-max(l25m148(:,4)))/AbAs(9) Blay Dispt
pbptT;l25m148];
l25m149 = [Tpt Tx WallM Dispt (max(l25m149(:,5))-max(l25m149(:,4)))/AbAs(10) Blay Dispt
pbptT;l25m149];

l25m150 = [Tpt Tx WallM Dispt (max(l25m150(:,5))-max(l25m150(:,4)))/AbAs(11) Blay Dispt
pbptT;l25m150];
l25m151 = [Tpt Tx WallM Dispt (max(l25m151(:,5))-max(l25m151(:,4)))/AbAs(12) Blay Dispt
pbptT;l25m151];
l25m152 = [Tpt Tx WallM Dispt (max(l25m152(:,5))-max(l25m152(:,4)))/AbAs(13) Blay Dispt
pbptT;l25m152];
l25m153 = [Tpt Tx WallM Dispt (max(l25m153(:,5))-max(l25m153(:,4)))/AbAs(14) Blay Dispt
pbptT;l25m153];
l25m154 = [Tpt Tx WallM Dispt (max(l25m154(:,5))-max(l25m154(:,4)))/AbAs(15) Blay Dispt
pbptT;l25m154];
l25m155 = [Tpt Tx WallM Dispt (max(l25m155(:,5))-max(l25m155(:,4)))/AbAs(16) Blay Dispt
pbptT;l25m155];
```

```
l25m156 = [Tpt Tx WallM Dispt (max(l25m156(:,5))-max(l25m156(:,4)))/AbAs(17) Blay Dispt
pbptT;l25m156];
l25m157 = [Tpt Tx WallM Dispt (max(l25m157(:,5))-max(l25m157(:,4)))/AbAs(18) Blay Dispt
pbptT;l25m157];
l25m158 = [Tpt Tx WallM Dispt (max(l25m158(:,5))-max(l25m158(:,4)))/AbAs(19) Blay Dispt
pbptT;l25m158];
l25m159 = [Tpt Tx WallM Dispt (max(l25m159(:,5))-max(l25m159(:,4)))/AbAs(20) Blay Dispt
pbptT;l25m159];

l25m160 = [Tpt Tx WallM Dispt (max(l25m160(:,5))-max(l25m160(:,4)))/AbAs(21) Blay Dispt
pbptT;l25m160];
l25m161 = [Tpt Tx WallM Dispt (max(l25m161(:,5))-max(l25m161(:,4)))/AbAs(22) Blay Dispt
pbptT;l25m161];
l25m162 = [Tpt Tx WallM Dispt (max(l25m162(:,5))-max(l25m162(:,4)))/AbAs(23) Blay Dispt
pbptT;l25m162];
l25m163 = [Tpt Tx WallM Dispt (max(l25m163(:,5))-max(l25m163(:,4)))/AbAs(24) Blay Dispt
pbptT;l25m163];
l25m164 = [Tpt Tx WallM Dispt (max(l25m164(:,5))-max(l25m164(:,4)))/AbAs(25) Blay Dispt
pbptT;l25m164];
l25m165 = [Tpt Tx WallM Dispt (max(l25m165(:,5))-max(l25m165(:,4)))/AbAs(26) Blay Dispt
pbptT;l25m165];
l25m166 = [Tpt Tx WallM Dispt (max(l25m166(:,5))-max(l25m166(:,4)))/AbAs(27) Blay Dispt
pbptT;l25m166];
l25m167 = [Tpt Tx WallM Dispt (max(l25m167(:,5))-max(l25m167(:,4)))/AbAs(28) Blay Dispt
pbptT;l25m167];
l25m168 = [Tpt Tx WallM Dispt (max(l25m168(:,5))-max(l25m168(:,4)))/AbAs(29) Blay Dispt
pbptT;l25m168];
l25m169 = [Tpt Tx WallM Dispt (max(l25m169(:,5))-max(l25m169(:,4)))/AbAs(30) Blay Dispt
pbptT;l25m169];

l25m170 = [Tpt Tx WallM Dispt (max(l25m170(:,5))-max(l25m170(:,4)))/AbAs(31) Blay Dispt
pbptT;l25m170];
l25m171 = [Tpt Tx WallM Dispt (max(l25m171(:,5))-max(l25m171(:,4)))/AbAs(32) Blay Dispt
pbptT;l25m171];
l25m172 = [Tpt Tx WallM Dispt (max(l25m172(:,5))-max(l25m172(:,4)))/AbAs(33) Blay Dispt
pbptT;l25m172];
l25m173 = [Tpt Tx WallM Dispt (max(l25m173(:,5))-max(l25m173(:,4)))/AbAs(34) Blay Dispt
pbptT;l25m173];
l25m174 = [Tpt Tx WallM Dispt (max(l25m174(:,5))-max(l25m174(:,4)))/AbAs(35) Blay Dispt
pbptT;l25m174];
l25m175 = [Tpt Tx WallM Dispt (max(l25m175(:,5))-max(l25m175(:,4)))/AbAs(36) Blay Dispt
pbptT;l25m175];
l25m176 = [Tpt Tx WallM Dispt (max(l25m176(:,5))-max(l25m176(:,4)))/AbAs(37) Blay Dispt
pbptT;l25m176];
l25m177 = [Tpt Tx WallM Dispt (max(l25m177(:,5))-max(l25m177(:,4)))/AbAs(38) Blay Dispt
pbptT;l25m177];
l25m178 = [Tpt Tx WallM Dispt (max(l25m178(:,5))-max(l25m178(:,4)))/AbAs(39) Blay Dispt
pbptT;l25m178];
l25m179 = [Tpt Tx WallM Dispt (max(l25m179(:,5))-max(l25m179(:,4)))/AbAs(40) Blay Dispt
pbptT;l25m179];
```

```
l25m180 = [Tpt Tx WallM Dispt (max(l25m180(:,5))-max(l25m180(:,4)))/AbAs(41) Blay Dispt
pbptT;l25m180];
l25m181 = [Tpt Tx WallM Dispt (max(l25m181(:,5))-max(l25m181(:,4)))/AbAs(42) Blay Dispt
pbptT;l25m181];
l25m182 = [Tpt Tx WallM Dispt (max(l25m182(:,5))-max(l25m182(:,4)))/AbAs(43) Blay Dispt
pbptT;l25m182];
l25m183 = [Tpt Tx WallM Dispt (max(l25m183(:,5))-max(l25m183(:,4)))/AbAs(44) Blay Dispt
pbptT;l25m183];
l25m184 = [Tpt Tx WallM Dispt (max(l25m184(:,5))-max(l25m184(:,4)))/AbAs(45) Blay Dispt
pbptT;l25m184];
l25m185 = [Tpt Tx WallM Dispt (max(l25m185(:,5))-max(l25m185(:,4)))/AbAs(46) Blay Dispt
pbptT;l25m185];
l25m186 = [Tpt Tx WallM Dispt (max(l25m186(:,5))-max(l25m186(:,4)))/AbAs(47) Blay Dispt
pbptT;l25m186];
l25m187 = [Tpt Tx WallM Dispt (max(l25m187(:,5))-max(l25m187(:,4)))/AbAs(48) Blay Dispt
pbptT;l25m187];
l25m188 = [Tpt Tx WallM Dispt (max(l25m188(:,5))-max(l25m188(:,4)))/AbAs(49) Blay Dispt
pbptT;l25m188];
l25m189 = [Tpt Tx WallM Dispt (max(l25m189(:,5))-max(l25m189(:,4)))/AbAs(50) Blay Dispt
pbptT;l25m189];

l25m190 = [Tpt Tx WallM Dispt (max(l25m190(:,5))-max(l25m190(:,4)))/AbAs(51) Blay Dispt
pbptT;l25m190];
l25m191 = [Tpt Tx WallM Dispt (max(l25m191(:,5))-max(l25m191(:,4)))/AbAs(52) Blay Dispt
pbptT;l25m191];
l25m192 = [Tpt Tx WallM Dispt (max(l25m192(:,5))-max(l25m192(:,4)))/AbAs(53) Blay Dispt
pbptT;l25m192];
l25m193 = [Tpt Tx WallM Dispt (max(l25m193(:,5))-max(l25m193(:,4)))/AbAs(54) Blay Dispt
pbptT;l25m193];
l25m194 = [Tpt Tx WallM Dispt (max(l25m194(:,5))-max(l25m194(:,4)))/AbAs(55) Blay Dispt
pbptT;l25m194];
l25m195 = [Tpt Tx WallM Dispt (max(l25m195(:,5))-max(l25m195(:,4)))/AbAs(56) Blay Dispt
pbptT;l25m195];
l25m196 = [Tpt Tx WallM Dispt (max(l25m196(:,5))-max(l25m196(:,4)))/AbAs(57) Blay Dispt
pbptT;l25m196];
l25m197 = [Tpt Tx WallM Dispt (max(l25m197(:,5))-max(l25m197(:,4)))/AbAs(58) Blay Dispt
pbptT;l25m197];
l25m198 = [Tpt Tx WallM Dispt (max(l25m198(:,5))-max(l25m198(:,4)))/AbAs(59) Blay Dispt
pbptT;l25m198];
l25m199 = [Tpt Tx WallM Dispt (max(l25m199(:,5))-max(l25m199(:,4)))/AbAs(60) Blay Dispt
pbptT;l25m199];

l25m200 = [Tpt Tx WallM Dispt (max(l25m200(:,5))-max(l25m200(:,4)))/AbAs(61) Blay Dispt
pbptT;l25m200];
end


contour(1,:) = polyfit(l25m140(:,2),l25m140(:,5),order-1);
contour(2,:) = polyfit(l25m141(:,2),l25m141(:,5),order-1);
contour(3,:) = polyfit(l25m142(:,2),l25m142(:,5),order-1);
contour(4,:) = polyfit(l25m143(:,2),l25m143(:,5),order-1);
contour(5,:) = polyfit(l25m144(:,2),l25m144(:,5),order-1);
```

```
contour(6,:) = polyfit(l25m145(:,2),l25m145(:,5),order-1);
contour(7,:) = polyfit(l25m146(:,2),l25m146(:,5),order-1);
contour(8,:) = polyfit(l25m147(:,2),l25m147(:,5),order-1);
contour(9,:) = polyfit(l25m148(:,2),l25m148(:,5),order-1);
contour(10,:) = polyfit(l25m149(:,2),l25m149(:,5),order-1);

contour(11,:) = polyfit(l25m150(:,2),l25m150(:,5),order-1);
contour(12,:) = polyfit(l25m151(:,2),l25m151(:,5),order-1);
contour(13,:) = polyfit(l25m152(:,2),l25m152(:,5),order-1);
contour(14,:) = polyfit(l25m153(:,2),l25m153(:,5),order-1);
contour(15,:) = polyfit(l25m154(:,2),l25m154(:,5),order-1);
contour(16,:) = polyfit(l25m155(:,2),l25m155(:,5),order-1);
contour(17,:) = polyfit(l25m156(:,2),l25m156(:,5),order-1);
contour(18,:) = polyfit(l25m157(:,2),l25m157(:,5),order-1);
contour(19,:) = polyfit(l25m158(:,2),l25m158(:,5),order-1);
contour(20,:) = polyfit(l25m159(:,2),l25m159(:,5),order-1);

contour(21,:) = polyfit(l25m160(:,2),l25m160(:,5),order-1);
contour(22,:) = polyfit(l25m161(:,2),l25m161(:,5),order-1);
contour(23,:) = polyfit(l25m162(:,2),l25m162(:,5),order-1);
contour(24,:) = polyfit(l25m163(:,2),l25m163(:,5),order-1);
contour(25,:) = polyfit(l25m164(:,2),l25m164(:,5),order-1);
contour(26,:) = polyfit(l25m165(:,2),l25m165(:,5),order-1);
contour(27,:) = polyfit(l25m166(:,2),l25m166(:,5),order-1);
contour(28,:) = polyfit(l25m167(:,2),l25m167(:,5),order-1);
contour(29,:) = polyfit(l25m168(:,2),l25m168(:,5),order-1);
contour(30,:) = polyfit(l25m169(:,2),l25m169(:,5),order-1);

contour(31,:) = polyfit(l25m170(:,2),l25m170(:,5),order-1);
contour(32,:) = polyfit(l25m171(:,2),l25m171(:,5),order-1);
contour(33,:) = polyfit(l25m172(:,2),l25m172(:,5),order-1);
contour(34,:) = polyfit(l25m173(:,2),l25m173(:,5),order-1);
contour(35,:) = polyfit(l25m174(:,2),l25m174(:,5),order-1);
contour(36,:) = polyfit(l25m175(:,2),l25m175(:,5),order-1);
contour(37,:) = polyfit(l25m176(:,2),l25m176(:,5),order-1);
contour(38,:) = polyfit(l25m177(:,2),l25m177(:,5),order-1);
contour(39,:) = polyfit(l25m178(:,2),l25m178(:,5),order-1);
contour(40,:) = polyfit(l25m179(:,2),l25m179(:,5),order-1);

contour(41,:) = polyfit(l25m180(:,2),l25m180(:,5),order-1);
contour(42,:) = polyfit(l25m181(:,2),l25m181(:,5),order-1);
contour(43,:) = polyfit(l25m182(:,2),l25m182(:,5),order-1);
contour(44,:) = polyfit(l25m183(:,2),l25m183(:,5),order-1);
contour(45,:) = polyfit(l25m184(:,2),l25m184(:,5),order-1);
contour(46,:) = polyfit(l25m185(:,2),l25m185(:,5),order-1);
contour(47,:) = polyfit(l25m186(:,2),l25m186(:,5),order-1);
contour(48,:) = polyfit(l25m187(:,2),l25m187(:,5),order-1);
contour(49,:) = polyfit(l25m188(:,2),l25m188(:,5),order-1);
contour(50,:) = polyfit(l25m189(:,2),l25m189(:,5),order-1);

contour(51,:) = polyfit(l25m190(:,2),l25m190(:,5),order-1);
contour(52,:) = polyfit(l25m191(:,2),l25m191(:,5),order-1);
```

```
contour(53,:) = polyfit(l25m192(:,2),l25m192(:,5),order-1);
contour(54,:) = polyfit(l25m193(:,2),l25m193(:,5),order-1);
contour(55,:) = polyfit(l25m194(:,2),l25m194(:,5),order-1);
contour(56,:) = polyfit(l25m195(:,2),l25m195(:,5),order-1);
contour(57,:) = polyfit(l25m196(:,2),l25m196(:,5),order-1);
contour(58,:) = polyfit(l25m197(:,2),l25m197(:,5),order-1);
contour(59,:) = polyfit(l25m198(:,2),l25m198(:,5),order-1);
contour(60,:) = polyfit(l25m199(:,2),l25m199(:,5),order-1);

contour(61,:) = polyfit(l25m200(:,2),l25m200(:,5),order-1);


blayer(1,:) = polyfit(l25m140(:,2),l25m140(:,6),order-1);
blayer(2,:) = polyfit(l25m141(:,2),l25m141(:,6),order-1);
blayer(3,:) = polyfit(l25m142(:,2),l25m142(:,6),order-1);
blayer(4,:) = polyfit(l25m143(:,2),l25m143(:,6),order-1);
blayer(5,:) = polyfit(l25m144(:,2),l25m144(:,6),order-1);
blayer(6,:) = polyfit(l25m145(:,2),l25m145(:,6),order-1);
blayer(7,:) = polyfit(l25m146(:,2),l25m146(:,6),order-1);
blayer(8,:) = polyfit(l25m147(:,2),l25m147(:,6),order-1);
blayer(9,:) = polyfit(l25m148(:,2),l25m148(:,6),order-1);
blayer(10,:) = polyfit(l25m149(:,2),l25m149(:,6),order-1);

blayer(11,:) = polyfit(l25m150(:,2),l25m150(:,6),order-1);
blayer(12,:) = polyfit(l25m151(:,2),l25m151(:,6),order-1);
blayer(13,:) = polyfit(l25m152(:,2),l25m152(:,6),order-1);
blayer(14,:) = polyfit(l25m153(:,2),l25m153(:,6),order-1);
blayer(15,:) = polyfit(l25m154(:,2),l25m154(:,6),order-1);
blayer(16,:) = polyfit(l25m155(:,2),l25m155(:,6),order-1);
blayer(17,:) = polyfit(l25m156(:,2),l25m156(:,6),order-1);
blayer(18,:) = polyfit(l25m157(:,2),l25m157(:,6),order-1);
blayer(19,:) = polyfit(l25m158(:,2),l25m158(:,6),order-1);
blayer(20,:) = polyfit(l25m159(:,2),l25m159(:,6),order-1);

blayer(21,:) = polyfit(l25m160(:,2),l25m160(:,6),order-1);
blayer(22,:) = polyfit(l25m161(:,2),l25m161(:,6),order-1);
blayer(23,:) = polyfit(l25m162(:,2),l25m162(:,6),order-1);
blayer(24,:) = polyfit(l25m163(:,2),l25m163(:,6),order-1);
blayer(25,:) = polyfit(l25m164(:,2),l25m164(:,6),order-1);
blayer(26,:) = polyfit(l25m165(:,2),l25m165(:,6),order-1);
blayer(27,:) = polyfit(l25m166(:,2),l25m166(:,6),order-1);
blayer(28,:) = polyfit(l25m167(:,2),l25m167(:,6),order-1);
blayer(29,:) = polyfit(l25m168(:,2),l25m168(:,6),order-1);
blayer(30,:) = polyfit(l25m169(:,2),l25m169(:,6),order-1);

blayer(31,:) = polyfit(l25m170(:,2),l25m170(:,6),order-1);
blayer(32,:) = polyfit(l25m171(:,2),l25m171(:,6),order-1);
blayer(33,:) = polyfit(l25m172(:,2),l25m172(:,6),order-1);
blayer(34,:) = polyfit(l25m173(:,2),l25m173(:,6),order-1);
blayer(35,:) = polyfit(l25m174(:,2),l25m174(:,6),order-1);
blayer(36,:) = polyfit(l25m175(:,2),l25m175(:,6),order-1);
blayer(37,:) = polyfit(l25m176(:,2),l25m176(:,6),order-1);
```

```
blayer(38,:) = polyfit(l25m177(:,2),l25m177(:,6),order-1);
blayer(39,:) = polyfit(l25m178(:,2),l25m178(:,6),order-1);
blayer(40,:) = polyfit(l25m179(:,2),l25m179(:,6),order-1);

blayer(41,:) = polyfit(l25m180(:,2),l25m180(:,6),order-1);
blayer(42,:) = polyfit(l25m181(:,2),l25m181(:,6),order-1);
blayer(43,:) = polyfit(l25m182(:,2),l25m182(:,6),order-1);
blayer(44,:) = polyfit(l25m183(:,2),l25m183(:,6),order-1);
blayer(45,:) = polyfit(l25m184(:,2),l25m184(:,6),order-1);
blayer(46,:) = polyfit(l25m185(:,2),l25m185(:,6),order-1);
blayer(47,:) = polyfit(l25m186(:,2),l25m186(:,6),order-1);
blayer(48,:) = polyfit(l25m187(:,2),l25m187(:,6),order-1);
blayer(49,:) = polyfit(l25m188(:,2),l25m188(:,6),order-1);
blayer(50,:) = polyfit(l25m189(:,2),l25m189(:,6),order-1);

blayer(51,:) = polyfit(l25m190(:,2),l25m190(:,6),order-1);
blayer(52,:) = polyfit(l25m191(:,2),l25m191(:,6),order-1);
blayer(53,:) = polyfit(l25m192(:,2),l25m192(:,6),order-1);
blayer(54,:) = polyfit(l25m193(:,2),l25m193(:,6),order-1);
blayer(55,:) = polyfit(l25m194(:,2),l25m194(:,6),order-1);
blayer(56,:) = polyfit(l25m195(:,2),l25m195(:,6),order-1);
blayer(57,:) = polyfit(l25m196(:,2),l25m196(:,6),order-1);
blayer(58,:) = polyfit(l25m197(:,2),l25m197(:,6),order-1);
blayer(59,:) = polyfit(l25m198(:,2),l25m198(:,6),order-1);
blayer(60,:) = polyfit(l25m199(:,2),l25m199(:,6),order-1);

blayer(61,:) = polyfit(l25m200(:,2),l25m200(:,6),order-1);

%pressure data

pressure(1,:) = polyfit(l25m140(:,2),l25m140(:,8),order-1);
pressure(2,:) = polyfit(l25m141(:,2),l25m141(:,8),order-1);
pressure(3,:) = polyfit(l25m142(:,2),l25m142(:,8),order-1);
pressure(4,:) = polyfit(l25m143(:,2),l25m143(:,8),order-1);
pressure(5,:) = polyfit(l25m144(:,2),l25m144(:,8),order-1);
pressure(6,:) = polyfit(l25m145(:,2),l25m145(:,8),order-1);
pressure(7,:) = polyfit(l25m146(:,2),l25m146(:,8),order-1);
pressure(8,:) = polyfit(l25m147(:,2),l25m147(:,8),order-1);
pressure(9,:) = polyfit(l25m148(:,2),l25m148(:,8),order-1);
pressure(10,:) = polyfit(l25m149(:,2),l25m149(:,8),order-1);

pressure(11,:) = polyfit(l25m150(:,2),l25m150(:,8),order-1);
pressure(12,:) = polyfit(l25m151(:,2),l25m151(:,8),order-1);
pressure(13,:) = polyfit(l25m152(:,2),l25m152(:,8),order-1);
pressure(14,:) = polyfit(l25m153(:,2),l25m153(:,8),order-1);
pressure(15,:) = polyfit(l25m154(:,2),l25m154(:,8),order-1);
pressure(16,:) = polyfit(l25m155(:,2),l25m155(:,8),order-1);
pressure(17,:) = polyfit(l25m156(:,2),l25m156(:,8),order-1);
pressure(18,:) = polyfit(l25m157(:,2),l25m157(:,8),order-1);
pressure(19,:) = polyfit(l25m158(:,2),l25m158(:,8),order-1);
pressure(20,:) = polyfit(l25m159(:,2),l25m159(:,8),order-1);
```

```
pressure(21,:) = polyfit(l25m160(:,2),l25m160(:,8),order-1);
pressure(22,:) = polyfit(l25m161(:,2),l25m161(:,8),order-1);
pressure(23,:) = polyfit(l25m162(:,2),l25m162(:,8),order-1);
pressure(24,:) = polyfit(l25m163(:,2),l25m163(:,8),order-1);
pressure(25,:) = polyfit(l25m164(:,2),l25m164(:,8),order-1);
pressure(26,:) = polyfit(l25m165(:,2),l25m165(:,8),order-1);
pressure(27,:) = polyfit(l25m166(:,2),l25m166(:,8),order-1);
pressure(28,:) = polyfit(l25m167(:,2),l25m167(:,8),order-1);
pressure(29,:) = polyfit(l25m168(:,2),l25m168(:,8),order-1);
pressure(30,:) = polyfit(l25m169(:,2),l25m169(:,8),order-1);

pressure(31,:) = polyfit(l25m170(:,2),l25m170(:,8),order-1);
pressure(32,:) = polyfit(l25m171(:,2),l25m171(:,8),order-1);
pressure(33,:) = polyfit(l25m172(:,2),l25m172(:,8),order-1);
pressure(34,:) = polyfit(l25m173(:,2),l25m173(:,8),order-1);
pressure(35,:) = polyfit(l25m174(:,2),l25m174(:,8),order-1);
pressure(36,:) = polyfit(l25m175(:,2),l25m175(:,8),order-1);
pressure(37,:) = polyfit(l25m176(:,2),l25m176(:,8),order-1);
pressure(38,:) = polyfit(l25m177(:,2),l25m177(:,8),order-1);
pressure(39,:) = polyfit(l25m178(:,2),l25m178(:,8),order-1);
pressure(40,:) = polyfit(l25m179(:,2),l25m179(:,8),order-1);

pressure(41,:) = polyfit(l25m180(:,2),l25m180(:,8),order-1);
pressure(42,:) = polyfit(l25m181(:,2),l25m181(:,8),order-1);
pressure(43,:) = polyfit(l25m182(:,2),l25m182(:,8),order-1);
pressure(44,:) = polyfit(l25m183(:,2),l25m183(:,8),order-1);
pressure(45,:) = polyfit(l25m184(:,2),l25m184(:,8),order-1);
pressure(46,:) = polyfit(l25m185(:,2),l25m185(:,8),order-1);
pressure(47,:) = polyfit(l25m186(:,2),l25m186(:,8),order-1);
pressure(48,:) = polyfit(l25m187(:,2),l25m187(:,8),order-1);
pressure(49,:) = polyfit(l25m188(:,2),l25m188(:,8),order-1);
pressure(50,:) = polyfit(l25m189(:,2),l25m189(:,8),order-1);

pressure(51,:) = polyfit(l25m190(:,2),l25m190(:,8),order-1);
pressure(52,:) = polyfit(l25m191(:,2),l25m191(:,8),order-1);
pressure(53,:) = polyfit(l25m192(:,2),l25m192(:,8),order-1);
pressure(54,:) = polyfit(l25m193(:,2),l25m193(:,8),order-1);
pressure(55,:) = polyfit(l25m194(:,2),l25m194(:,8),order-1);
pressure(56,:) = polyfit(l25m195(:,2),l25m195(:,8),order-1);
pressure(57,:) = polyfit(l25m196(:,2),l25m196(:,8),order-1);
pressure(58,:) = polyfit(l25m197(:,2),l25m197(:,8),order-1);
pressure(59,:) = polyfit(l25m198(:,2),l25m198(:,8),order-1);
pressure(60,:) = polyfit(l25m199(:,2),l25m199(:,8),order-1);

pressure(61,:) = polyfit(l25m200(:,2),l25m200(:,8),order-1);

%temperature data
```

```
if clear_invoke
clear l25m140;clear l25m141;clear l25m142;clear l25m143;clear l25m144;clear l25m145
clear l25m146;clear l25m147;clear l25m148;clear l25m149;clear l25m150;clear l25m151
clear l25m152;clear l25m153;clear l25m154;clear l25m155;clear l25m156;clear l25m157
clear l25m158;clear l25m159;clear l25m160;clear l25m161;clear l25m162;clear l25m163
clear l25m164;clear l25m165;clear l25m166;clear l25m167;clear l25m168;clear l25m169
clear l25m170;clear l25m171;clear l25m172;clear l25m173;clear l25m174;clear l25m175
clear l25m176;clear l25m177;clear l25m178;clear l25m179;clear l25m180;clear l25m181
clear l25m182;clear l25m183;clear l25m184;clear l25m185;clear l25m186;clear l25m187
clear l25m188;clear l25m189;clear l25m190;clear l25m191;clear l25m192;clear l25m193
clear l25m194;clear l25m195;clear l25m196;clear l25m197;clear l25m198;clear l25m199
clear l25m200
end

save polyspot


function derivative = dydx(f_of_x)

%function derivative = dydx(f_of_x)
%Takes a polynomial of any order and
%returns the derivative.
%    f_of_x is a vector in the form:
%        [a b c . . . d]
%    where
%        f(x) = a*x^n + b*x^(n-1) + c*x^(n-2) + ... d

[numr,numc] = size(f_of_x);
derivative = zeros(numr,numc);

for r = 1:numr

   derivative(r,1) = 0;

   for c = numc:-1:2

      derivative(r,c) = f_of_x(r,c-1) * (numc+1-c);

   end
end


function contour_length = lenfind(contour,num_points,curve_start,curve_end)

%function contour_length = lenfind(contour,num_points,curve_start,curve_end)
%Finds the lengths of a series of curves described by the
%matrix of polynomials, 'contour'.  num_points is the
%number of points to be used for the length determination.
%curve_start and curve_end specify curve start and end points
%respectively.
```

```
[numr,numc] = size(contour);
contour_length = zeros(numr,1);


x = linspace(curve_start,curve_end,num_points);

for r = 1:numr

    y = polyval(contour(r,:),x);
    contour_length(r) = curvlen(x,y);

end


function len = curvlen(x,y)

%function len = curvlen(x,y)
%Finds the length of a curve described
%in x, y coordinates.  x and y are vectors
%containing x and y coordinate pairs
%Method used is simple summation of
%linear distance between points.
%The more data points used along the
%curve, the more accurate the length
%calculation

xlen = length(x);
len = 0;

for count = 1:xlen-1
    len = len + sqrt(((x(count+1)-x(count))^2)+((y(count+1)-y(count))^2));
end


function [X,fixed_contour] = conforce(contour,contour_length,num_points,curve_start,curve_end)

%function [X,fixed_contour] = conforce(contour,contour_length,num_points,curve_start,curve_end)
%Takes series of shapes describes by matrix of polynimials
%'contour' and forces all of the lengths to be equal to
%contour_length.  Number of points along curve is specified
%in num_points.  curve_end and curve_start specify curve
%start and end points respectively.
%Strategy used is to fix end of curve specified by
%curve_end.  Then iteratively move the start point
%(curve_start) and reevaluate the curve length until
%a tolerance with the specified contour_length is
%achieved.  Because of the extremely small degree of
%movement invoved with the start point (~.04 compared to
%a length of ~25) this extrapolation was considered
%resonably safe.

[numr,numc] = size(contour);
```

```
maxit =300;  %maximum iteration allowed per curve
tol = .0005;  %tolerance of evaluated curve to contour_length
step_size = .00005;  %stepping interval in moving the start point.

%X and fixed_contour are matices storing x and y values
%respectivley, of the forced length contours.

X = zeros(numr,num_points);
fixed_contour = zeros(numr,num_points);

move_end = curve_end;
move_start = curve_start;

for r = numr:-1:1
        r
    for iter = 1:maxit

     x = linspace(move_start,move_end,num_points);
     y = polyval(contour(r,:),x);
     len = curvlen(x,y);
     if abs(len-contour_length) < tol
         X(r,:) = x;
         fixed_contour(r,:) = y;
%           move_start

         break
     else
         %move_end = move_end + step_size;
         move_start = move_start - step_size;
     end

  end
%iter
if iter == maxit;disp('Maxit Reached');end
end


function tranpoly = findttp(xt,yt,Sxt,Cxt,SCxt,xi,yi,Sxi,Cxi,SCxi)

%function tranpoly = findttp(xt,yt,Sxt,Cxt,SCxt,xi,yi,Sxi,Cxi,SCxi)
%subspoly found by:
%     Ax=B    where tranpoly = x

%BC's Y at throat and entrance, slope at throat and entrance
%curvature at throatand entrance
%specify third derivative at the entrance to ensure
%continuous second derivative

B1 = [yt;Sxt;Cxt;yi;Sxi;Cxi;SCxi];

A1 = [xt^6      xt^5      xt^4      xt^3   xt^2  xt   1;
```

```
    6*xt^5     5*xt^4     4*xt^3     3*xt^2  2*xt  1    0;
    30*xt^4    20*xt^3    12*xt^2    6*xt    2     0    0;
    xi^6       xi^5       xi^4       xi^3    xi^2  xi   1;
    6*xi^5     5*xi^4     4*xi^3     3*xi^2  2*xi  1    0;
    30*(xi)^4  20*(xi)^3  12*(xi)^2  6*xi    2     0    0;
    120*xi^3   60*xi^2    24*xi      6       0     0    0];

%tranpoly = A1\B1;

%BC's Y at throat and entrance, slope at throat and entrance
%curvature at throat and entrance
%specify third derivative at the throat and entrance to ensure
%continuous second derivative

B2 = [yt;Sxt;Cxt;SCxt;yi;Sxi;Cxi;SCxi];

A2 = [xt^7     xt^6      xt^5      xt^4      xt^3    xt^2  xt   1;
    7*xt^6     6*xt^5    5*xt^4    4*xt^3    3*xt^2  2*xt  1    0;
    42*xt^5    30*xt^4   20*xt^3   12*xt^2   6*xt    2     0    0;
    210*xt^4   120*xt^3  60*xt^2   24*xt     6       0     0    0;
    xi^7       xi^6      xi^5      xi^4      xi^3    xi^2  xi   1;
    7*xi^6     6*xi^5    5*xi^4    4*xi^3    3*xi^2  2*xi  1    0;
    42*xi^5    30*(xi)^4 20*(xi)^3 12*(xi)^2 6*xi    2     0    0;
    210*xi^4   120*xi^3  60*xi^2   24*xi     6       0     0    0];

tranpoly = A2\B2;


function [x,y,yp,ypp,yppp] = exposhp(xi,xt,yi,Sxi,yt,Sxt,Cxt,SCxt,b,numSpts);

%function [x,y,yp,ypp,yppp] = exposhp(xi,xt,yi,Sxi,yt,Sxt,Cxt,SCxt,b,numSpts);
%finds exponential function to describe subsonic shape
%also finds first three derivatives of function

A = -Cxt.*((xt-xi).^2)./(yi-yt);
B = SCxt.*((xt-xi).^3)./(yi-yt);

%t = [linspace(1,0,numSpts)];
t = [logspace(1,0,numSpts*(1/3)) linspace(.99,0,numSpts*(2/3))];
z = 1 - exp(-b.*t);

a1 = (-A./2)*b^2;   %./((z./(b.*(1-z))).^2)
a2 = ((B*b^3)+(6*a1*b))/(-6);   %./((z./(b.*(1-z))).^3);

f = exp( (-a1*t.^2) - (a2*t.^3) );
fslope = (1/b).*( (-2*a1*t)-(3*a2*t.^2) ).*(exp( (-a1*t.^2) - (a2*t.^3) + (b*t) ));
fcurve = ((1/b)^2)*( (-2*a1)+(((-6*a2)-(2*a1*b))*t)+(((4*a1.^2)-
(3*a2*b))*t.^2)+(12*a1*a2*t.^3)+(9*a2.^2*t.^4) ).*(exp( (-a1*t.^2) - (a2*t.^3) + (2*b*t) ));
fslope_curve = ((1/b)^3)*( ((-6*a2)-(6*a1*b))+(((12*a1^2)-(18*a2*b)-
(4*a1*b^2))*t)+(((54*a1*a2)+(12*b*a1^2)-(6*a2*b^2))*t.^2)+(((54*a2^2)+(48*a1*a2*b)-
(8*a1^3))*t.^3)+(((-36*a2*a1^2)+(27*b*a2^2))*t.^4)+((-54*a1*a2^2)*t.^5)+((-27*a2^3)*t.^6) ).*(exp(
(-a1*t.^2) - (a2*t.^3) + (3*b*t) ));
```

```
x = (xt - (z.*(xt-xi)));
y = yi - f*(yi-yt);
yp = fslope*(yi-yt)./(xt-xi);
ypp = -fcurve*(yi-yt)./((xt-xi).^2);
yppp = fslope_curve*(yi-yt)./((xt-xi).^3);

%plot(t,z,t,f,':');
%subplot(3,1,3);
%plot(x,y);
%axis([-15.1,-14.9,4.5,5.5]);


function [x_for_s,y_for_s,c_ind] = findxy(x,y,s_dim);

%function [x_for_s,y_for_s] = findxy(x,y,s_dim);
%finds the x and y values for a given distance
%along a curve specified in s_dim

[numr,numc] = size(x);

x_for_s = zeros(numr,length(s_dim));
y_for_s = zeros(numr,length(s_dim));
clen    = zeros(numr,length(s_dim));
c_ind   = zeros(numr,length(s_dim));

for s_dim_count = 1:length(s_dim)
%s_dim_count=10;
length(s_dim)- s_dim_count

   for r = 1:numr
      len = 0;
      for c = numc-1:-1:1

            len = len + sqrt(((x(r,c+1)-x(r,c))^2)+((y(r,c+1)-y(r,c))^2));
            if len > s_dim(s_dim_count);
              gt_x = x(r,c+1);lt_x = x(r,c);
              gt_y = y(r,c+1);lt_y = y(r,c);
%                [gt_x lt_x gt_y lt_y len]
              dist_gt_lt = (sqrt(((gt_x-lt_x)^2)+((gt_y-lt_y)^2)));
              lin_ratio = (len - s_dim(s_dim_count))/dist_gt_lt;
              x_for_s(r,s_dim_count) = lt_x + (lin_ratio*abs(gt_x-lt_x));
              if lt_y < gt_y
                 y_for_s(r,s_dim_count) = lt_y + (lin_ratio*abs(gt_y-lt_y));
              elseif lt_y > gt_y
                 y_for_s(r,s_dim_count) = lt_y - (lin_ratio*abs(gt_y-lt_y));
              else
                 y_for_s(r,s_dim_count) = lt_y;
              end

                        c_ind(r,s_dim_count) = c;
```

```
                clen(r,s_dim_count) = len - sqrt(((lt_x-x_for_s(r,s_dim_count))^2)+((lt_y-
y_for_s(r,s_dim_count))^2));
                break

              end
        end
    end
end


function out = savespec(horz_dim,fixed_contour)

%function out = savespec(horz_dim,fixed_contour)
%dummy function to save specific variable to a file
out = 0;
save specspot

function out = savespe1(x_for_s,y_for_s,c_ind)

out = 0;
save specspo1
```

The jack pivot points were determined from the layout of the nozzle mechanism. The coordinates of the pivot point and the geometry associated with each nozzle shape was used to determine a jack length programming schedule for each Mach number. This schedule is shown in Table 5.

Mach Number	Jack Mounting Point Measured Along the Lenght of the Curve								
	18 (in)	15 (in)	12.25 (in)	9 (in)	6 (in)	3 (in)	0 (in)	-3.5 (in)	-6.5 (in)
1.4	7.2445	7.2837	7.3292	7.4015	7.4776	7.5553	7.6061	7.5268	7.1384
1.41	7.2459	7.2872	7.335	7.4101	7.4881	7.5668	7.6178	7.5384	7.1498
1.42	7.2474	7.2908	7.3409	7.4187	7.4988	7.5785	7.6296	7.5501	7.1613
1.43	7.2489	7.2944	7.347	7.4276	7.5097	7.5905	7.6417	7.5621	7.173
1.44	7.2505	7.2982	7.3532	7.4366	7.5207	7.6026	7.6539	7.5743	7.1848
1.45	7.252	7.3018	7.3593	7.4456	7.5317	7.6147	7.6663	7.5866	7.1968
1.46	7.2536	7.3056	7.3656	7.4548	7.543	7.627	7.6787	7.599	7.2089
1.47	7.2551	7.3094	7.3719	7.4641	7.5543	7.6395	7.6913	7.6115	7.2211
1.48	7.2567	7.3133	7.3784	7.4736	7.5659	7.6521	7.7041	7.6242	7.2335
1.49	7.2583	7.3171	7.3849	7.483	7.5775	7.6648	7.7169	7.6369	7.246
1.5	7.2599	7.3211	7.3915	7.4927	7.5893	7.6777	7.7299	7.6498	7.2586
1.51	7.2614	7.325	7.398	7.5023	7.601	7.6905	7.743	7.6628	7.2713
1.52	7.2631	7.3289	7.4047	7.5121	7.613	7.7036	7.7562	7.676	7.2841
1.53	7.2646	7.3329	7.4114	7.5219	7.625	7.7167	7.7694	7.6892	7.297
1.54	7.2662	7.3369	7.4182	7.5318	7.6371	7.73	7.7828	7.7024	7.31
1.55	7.2678	7.3408	7.4249	7.5418	7.6493	7.7433	7.7962	7.7158	7.3231
1.56	7.2694	7.3448	7.4317	7.5518	7.6615	7.7566	7.8097	7.7292	7.3362
1.57	7.2709	7.3488	7.4386	7.5619	7.6739	7.7701	7.8234	7.7428	7.3495
1.58	7.2726	7.3529	7.4455	7.5721	7.6863	7.7837	7.8371	7.7564	7.3628
1.59	7.2741	7.3568	7.4523	7.5822	7.6987	7.7972	7.8508	7.77	7.3761
1.6	7.2757	7.3609	7.4593	7.5925	7.7113	7.8109	7.8646	7.7837	7.3896
1.61	7.2773	7.3649	7.4663	7.6028	7.7239	7.8247	7.8785	7.7975	7.4031
1.62	7.2789	7.369	7.4732	7.6132	7.7365	7.8385	7.8924	7.8114	7.4166
1.63	7.2804	7.3729	7.4801	7.6234	7.7491	7.8522	7.9064	7.8252	7.4302
1.64	7.282	7.377	7.4872	7.6339	7.7619	7.8662	7.9204	7.8392	7.4439
1.65	7.2836	7.381	7.4942	7.6443	7.7747	7.8801	7.9344	7.8531	7.4575
1.66	7.2851	7.385	7.5011	7.6548	7.7874	7.894	7.9485	7.8671	7.4712
1.67	7.2866	7.3889	7.5081	7.6652	7.8002	7.908	7.9626	7.8811	7.4849
1.68	7.2881	7.3929	7.5151	7.6757	7.8131	7.9219	7.9767	7.8952	7.4987
1.69	7.2897	7.3969	7.5221	7.6862	7.826	7.936	7.9909	7.9093	7.5125
1.7	7.2912	7.4009	7.5291	7.6967	7.8389	7.9501	8.0051	7.9234	7.5263
1.71	7.2927	7.4047	7.536	7.7072	7.8517	7.9641	8.0193	7.9374	7.5401
1.72	7.2942	7.4086	7.543	7.7177	7.8646	7.9782	8.0335	7.9515	7.554
1.73	7.2958	7.4126	7.5499	7.7283	7.8776	7.9923	8.0478	7.9657	7.5679
1.74	7.2972	7.4165	7.5569	7.7388	7.8905	8.0064	8.062	7.9798	7.5817
1.75	7.2987	7.4203	7.5638	7.7493	7.9034	8.0205	8.0762	7.9939	7.5956
1.76	7.3002	7.4241	7.5707	7.7598	7.9163	8.0346	8.0904	8.008	7.6094
1.77	7.3016	7.4279	7.5775	7.7703	7.9292	8.0487	8.1046	8.0221	7.6232
1.78	7.3031	7.4317	7.5844	7.7808	7.9421	8.0627	8.1188	8.0363	7.6371
1.79	7.3045	7.4354	7.5911	7.7913	7.955	8.0768	8.133	8.0503	7.6509
1.8	7.3059	7.4392	7.5979	7.8017	7.9679	8.0908	8.1471	8.0644	7.6647

Table 5. Jack Screw Program (Length from Pivot Point to Jack Mount Eyelet)

Mach Number	Jack Mounting Point Measured Along the Lenght of the Curve								
	18 (in)	15 (in)	12.25 (in)	9 (in)	6 (in)	3 (in)	0 (in)	-3.5 (in)	-6.5 (in)
1.81	7.3074	7.4429	7.6047	7.8122	7.9808	8.1049	8.1613	8.0785	7.6785
1.82	7.3088	7.4466	7.6114	7.8226	7.9936	8.1189	8.1754	8.0925	7.6923
1.83	7.3102	7.4502	7.6181	7.8329	8.0064	8.1329	8.1896	8.1065	7.7061
1.84	7.3116	7.4538	7.6248	7.8433	8.0192	8.1468	8.2036	8.1205	7.7198
1.85	7.313	7.4574	7.6314	7.8536	8.032	8.1608	8.2177	8.1345	7.7335
1.86	7.3143	7.461	7.638	7.8639	8.0448	8.1747	8.2317	8.1484	7.7472
1.87	7.3157	7.4645	7.6445	7.8742	8.0575	8.1886	8.2457	8.1623	7.7608
1.88	7.3171	7.468	7.651	7.8844	8.0701	8.2024	8.2597	8.1762	7.7745
1.89	7.3184	7.4715	7.6575	7.8946	8.0828	8.2162	8.2736	8.19	7.788
1.9	7.3198	7.4749	7.6639	7.9048	8.0954	8.23	8.2875	8.2037	7.8016
1.91	7.3211	7.4783	7.6703	7.9149	8.108	8.2437	8.3013	8.2175	7.8151
1.92	7.3224	7.4817	7.6766	7.925	8.1205	8.2574	8.3151	8.2312	7.8285
1.93	7.3237	7.485	7.6829	7.935	8.133	8.271	8.3289	8.2448	7.842
1.94	7.3251	7.4883	7.6892	7.945	8.1455	8.2846	8.3426	8.2584	7.8553
1.95	7.3263	7.4916	7.6954	7.955	8.1579	8.2982	8.3562	8.272	7.8687
1.96	7.3276	7.4948	7.7015	7.9648	8.1702	8.3117	8.3698	8.2855	7.8819
1.97	7.3289	7.4981	7.7076	7.9747	8.1825	8.3251	8.3834	8.2989	7.8951
1.98	7.3302	7.5012	7.7137	7.9845	8.1947	8.3385	8.3969	8.3123	7.9083
1.99	7.3314	7.5044	7.7197	7.9942	8.207	8.3518	8.4103	8.3257	7.9215
2	7.3327	7.5075	7.7256	8.0039	8.2191	8.3651	8.4237	8.339	7.9346

Table 5. (cont) Jack Screw Program (Length from Pivot Point to Jack Mount Eyelet)

Figure 22 shows the jack mount and jack pivot-point geometry. The length specified in Table 5 was called d3 in Figure 22. The thickness of the plate was .25 inches. The distance from the center of the jack-mount eyelet to the midpoint of the attachment surface between the mounting fixture and the plate (d2) was .5 inches. The coordinates (x1, y1) and (x3, y3) were known from the individual Mach contour solutions and the pivot point was found using AutoCad. The slope of the contour at the jack-mounting point was also known from the aerodynamic analysis. From the geometry, the following relations applied,

$$\theta = \tan^{-1}\frac{dy}{dx} \tag{28}$$

and

$$d1 = \frac{t}{\cos\theta} \tag{29}$$

so that the jack length was given by

$$d3 = \sqrt{\left[y_3 - \left(y_1 + \frac{t}{\cos\left(\tan^{-1}\frac{dy}{dx}\right)} + \cos\left(\tan^{-1}\frac{dy}{dx}\right)\right)\right]^2 + \left[x_3 - \left(x_1 - d2\sin\left(\tan^{-1}\frac{dy}{dx}\right)\right)\right]^2}$$

(30)

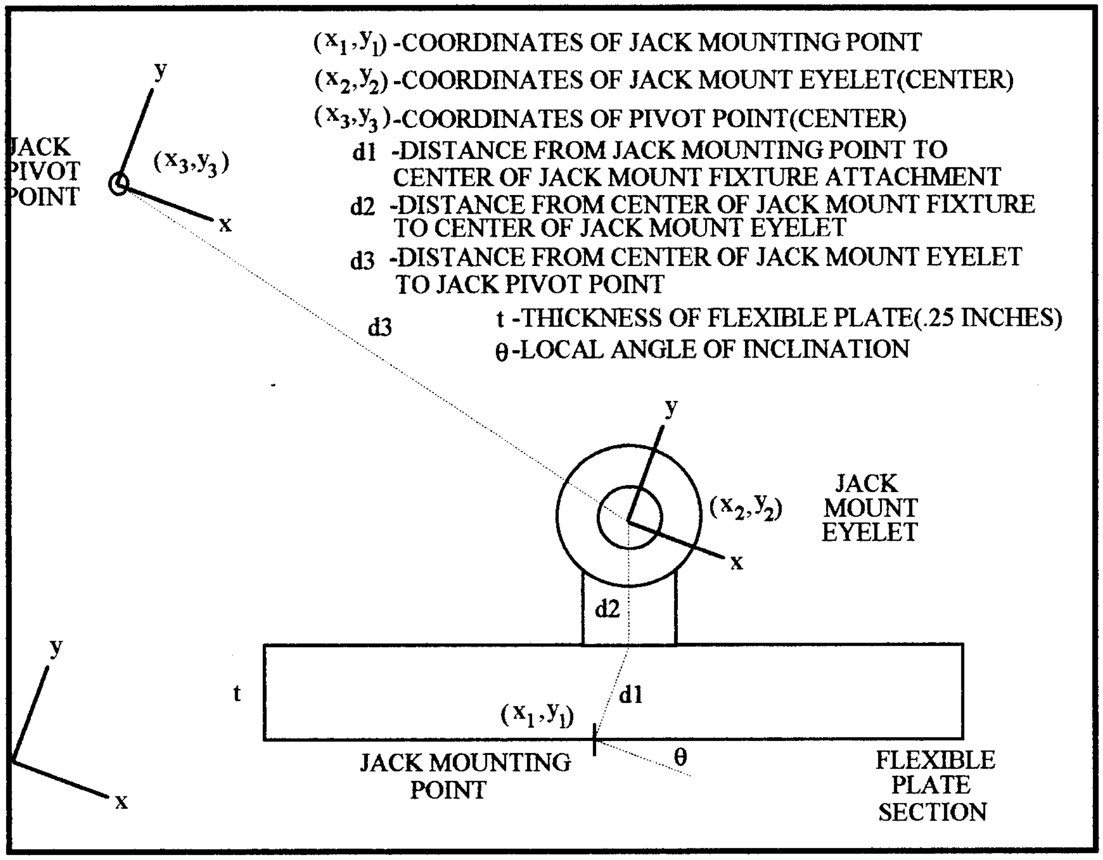


Figure 22. Jack Mount Geometry

The shapes generated and their derivatives are shown in Figures 23 through 28. The blue and cyan curves represent the method of characteristics solution. The green and magenta curves represent the throat transition polynomial. The yellow and red curves represent the parameterized exponential solutions for the subsonic section.

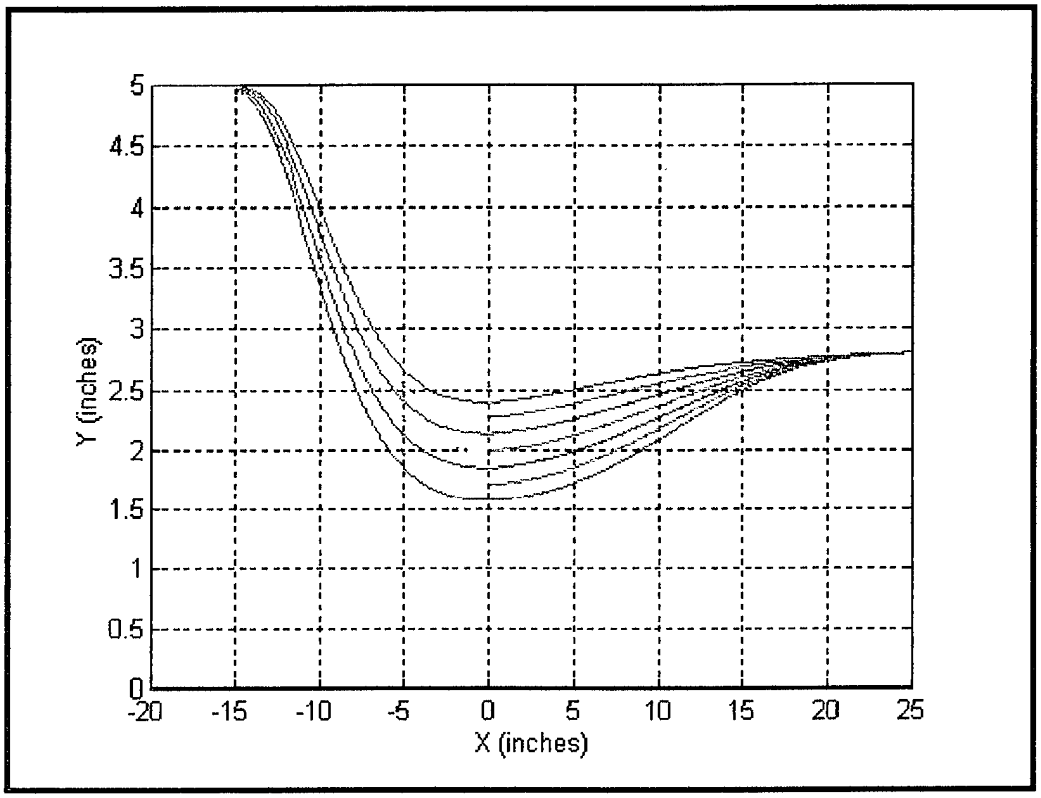


Figure 23. Nozzle Shapes, Mach 1.4 - 2 in Steps of .1

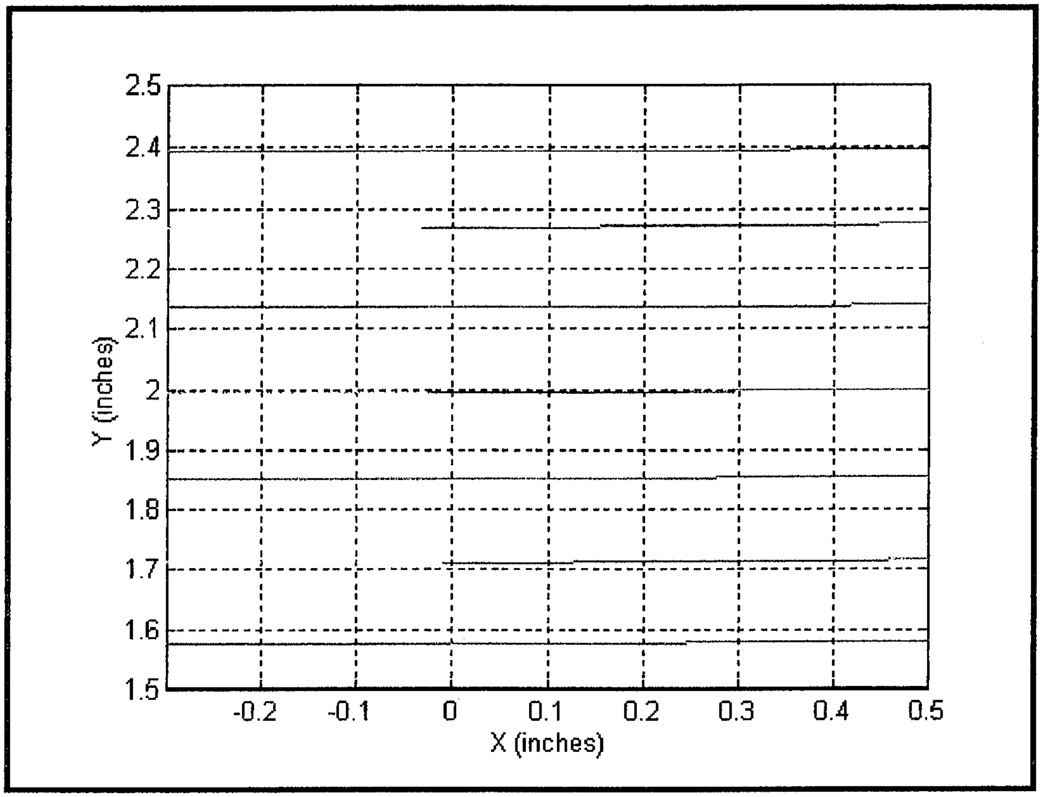


Figure 24. Nozzle Shapes (Throat Detail)

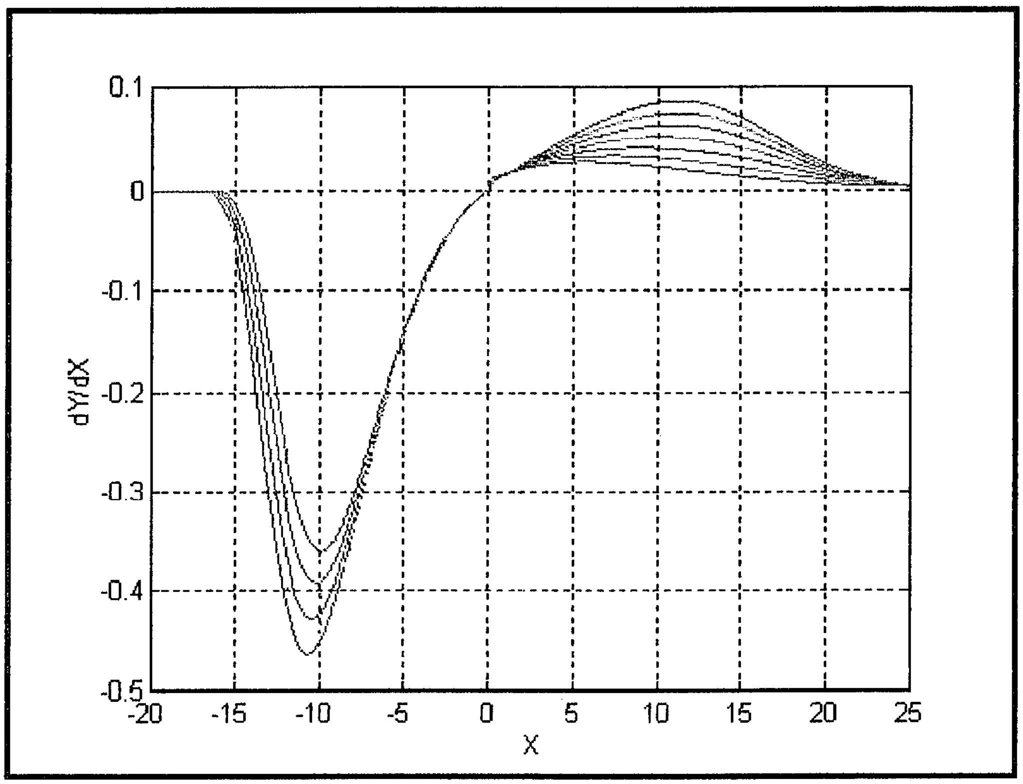


Figure 25. Slope Variation, Mach 1.4 - 2 in Steps of .1

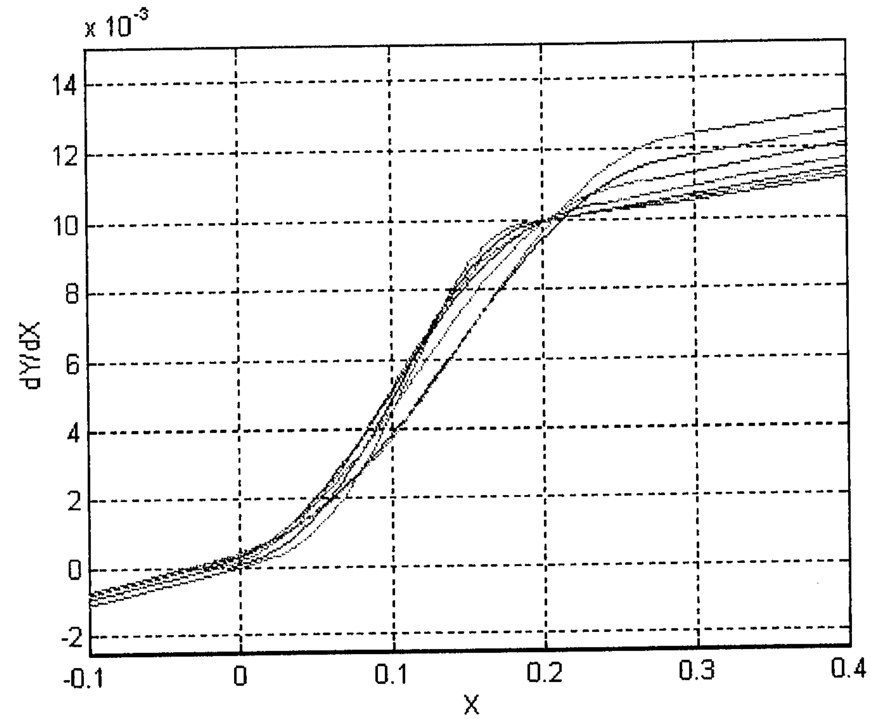


Figure 26. Slope Variation (Throat Detail)

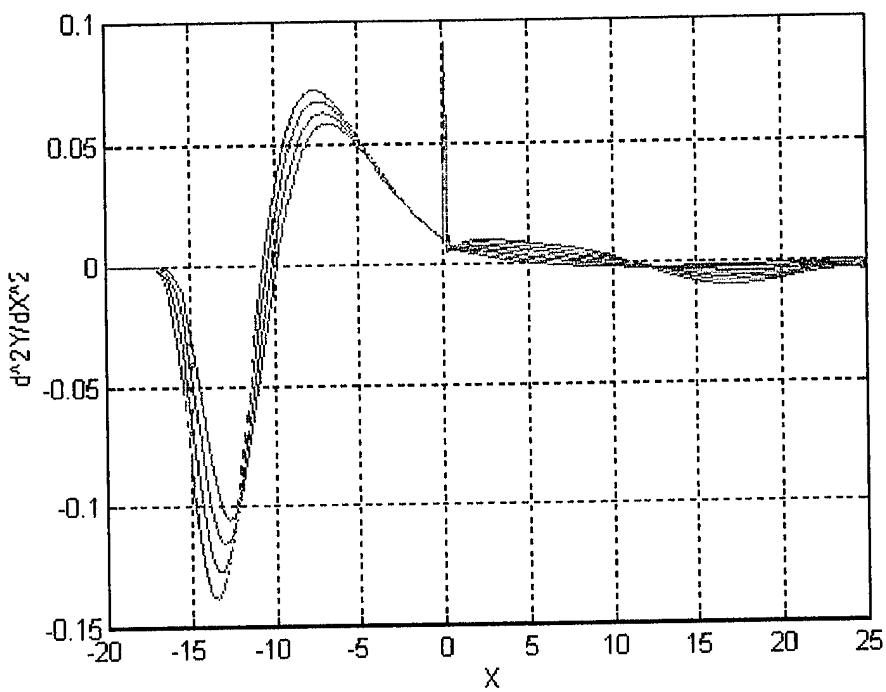


Figure 27. Curvature Variation, Mach 1.4 - 2 in Steps of .1

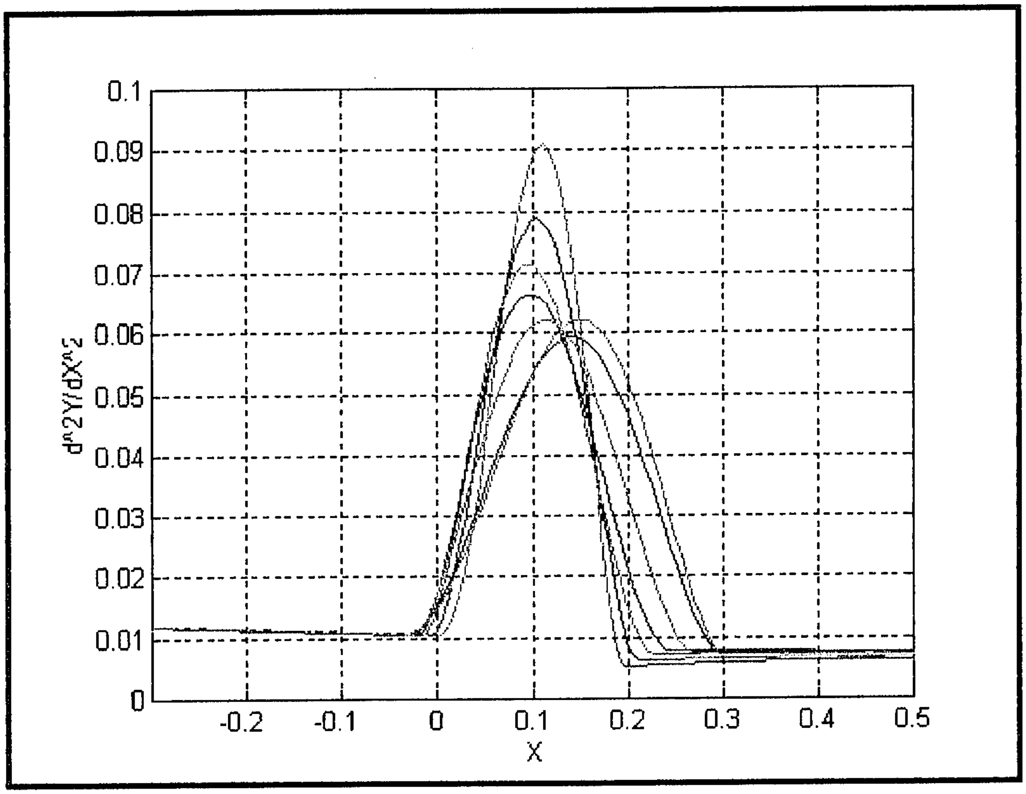


Figure 28. Curvature Variation (Throat Detail)

The following MATLAB script file was used to convert one specific shape into a **.dxf** formatted file which was then imported into AutoCad™.

```
function [shapex,shapey] = makedxf1(curve1x,curve1y,curve2x,curve2y,curve3x,curve3y)

%function [shapex,shapey] = makedxf1(curve1x,curve1y,curve2x,curve2y,curve3x,curve3y)
shapex = [curve1x(1:length(curve1x)-1) curve2x(1:length(curve2x)-1) curve3x(1:length(curve3x))];
shapey = [curve1y(1:length(curve1y)-1) curve2y(1:length(curve2y)-1) curve3y(1:length(curve3y))];
shapez = zeros(length(shapex));

diary dxffile1.dxf
disp('  0');
disp('SECTION');
disp('  2');
disp('ENTITIES');
disp('  0');

for r = 1:length(shapex)-1

disp('LINE')
disp('  8');
```

```
disp('0');

disp(' 10');
disp(num2str(shapex(r)));

disp(' 20');
disp(num2str(shapey(r)));

disp(' 30');
disp(num2str(shapez(r)));

disp(' 11');
disp(num2str(shapex(r+1)));

disp(' 21');
disp(num2str(shapey(r+1)));

disp(' 31');
disp(num2str(shapez(r+1)));
disp(' 0');

end

disp('ENDSEC');
disp(' 0');
disp('EOF');

diary off
```

The following list contains the range of 'x' values for the supersonic contour shapes and the coefficients for the ninth order polynomials used to fit the method of characteristics solution. The rows represent the following information: row 1, starting x value, row 2, ending x value, rows 3 through 12, the coefficients for the polynomials arranged in decreasing order of x.

Mach 1.4	Mach 1.41	Mach 1.42
0.30487800000000	0.30698300000000	0.30917200000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000039	-0.00000000000052	-0.00000000000063
0.00000000003593	0.00000000005038	0.00000000006329
-0.00000000128954	-0.00000000195624	-0.00000000254174
0.00000002268543	0.00000003905141	0.00000005317353
-0.00000031673950	-0.00000054225768	-0.00000073238856
0.00001060931799	0.00001216533775	0.00001339527013
-0.00030767740282	-0.00031162037178	-0.00031380756585
0.00356896347146	0.00361692134664	0.00366012403665
0.01036963014123	0.01027272558865	0.01018167020439
2.39254386433153	2.38085840987376	2.36901983237482

Mach 1.43	Mach 1.44	Mach 1.45
0.31140200000000	0.31366300000000	0.28841700000000
25.00000000000000	25.00000000000000	25.00000000000000

-0.00000000000079	-0.00000000000094	-0.00000000000071
0.00000000008042	0.00000000009710	0.00000000006876
-0.00000000332465	-0.00000000407783	-0.00000000260165
0.00000007232162	0.00000009045023	0.00000004821542
-0.00000099878504	-0.00000124494040	-0.00000052013729
0.00001533101967	0.00001701960420	0.00000927857827
-0.00031987382943	-0.00032407111129	-0.00027469785820
0.00371560926355	0.00376364348956	0.00365082028944
0.01007130498266	0.00997430481370	0.01006735763084
2.35695808825769	2.34475198617514	2.33253627935510

Mach 1.46	Mach 1.47	Mach 1.48
0.28974400000000	0.29206300000000	0.29446500000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000085	-0.00000000000107	-0.00000000000129
0.00000000008346	0.00000000010728	0.00000000013070
-0.00000000323703	-0.00000000429965	-0.00000000534177
0.00000006275248	0.00000008817331	0.00000011303886
-0.00000070465675	-0.00000105302843	-0.00000139250703
0.00001035146575	0.00001290081701	0.00001535861412
-0.00027530851652	-0.00028358176890	-0.00029119567559
0.00368843928134	0.00374734334853	0.00380364598357
0.00998223083302	0.00987158008618	0.00976527127038
2.32007529715504	2.30749571342674	2.29471417425332

Mach 1.49	Mach 1.5	Mach 1.51
0.29688800000000	0.29939400000000	0.27412600000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000150	-0.00000000000170	-0.00000000000153
0.00000000015319	0.00000000017399	0.00000000015248
-0.00000000632121	-0.00000000722261	-0.00000000602322
0.00000013584493	0.00000015674181	0.00000012068919
-0.00000169492047	-0.00000197097139	-0.00000133112828
0.00001743703419	0.00001930707895	0.00001229409064
-0.00029664268280	-0.00030112008897	-0.00025526448089
0.00385431462164	0.00390246882854	0.00380030462750
0.00966331961739	0.00956509118123	0.00964100619507
2.28191068774307	2.26891603674968	2.25594809559862

Mach 1.52	Mach 1.53	Mach 1.54
0.27664300000000	0.27918200000000	0.28174400000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000176	-0.00000000000199	-0.00000000000221
0.00000000017530	0.00000000020025	0.00000000022174
-0.00000000699489	-0.00000000807111	-0.00000000896659
0.00000014279534	0.00000016773093	0.00000018766152
-0.00000161753561	-0.00000194954128	-0.00000220163930
0.00001418752820	0.00001651945367	0.00001809848976
-0.00025938377252	-0.00026589018358	-0.00026826073347
0.00384630119301	0.00389942754204	0.00394049997622
0.00954644481201	0.00944167762570	0.00935259087113
2.24276154074788	2.22949152409276	2.21613450557234

Mach 1.55	Mach 1.56	Mach 1.57
0.28338000000000	0.28603200000000	0.26268500000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000246	-0.00000000000268	-0.00000000000254
0.00000000024780	0.00000000027040	0.00000000025100
-0.00000001006719	-0.00000001100498	-0.00000000989894
0.00000021260645	0.00000023343172	0.00000019995372
-0.00000252650374	-0.00000279030807	-0.00000219848007
0.00002031337952	0.00002198293484	0.00001552627024
-0.00027385044272	-0.00027651068091	-0.00023410598677
0.00399064632048	0.00403218982340	0.00394202454920
0.00925039111459	0.00916039567695	0.00921789656670
2.20271324637669	2.18920812968315	2.17567066614398

Mach 1.58	Mach 1.59	Mach 1.6
0.26534000000000	0.26805700000000	0.26982300000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000276	-0.00000000000299	-0.00000000000314
0.00000000027260	0.00000000029502	0.00000000030938
-0.00000001077796	-0.00000001168352	-0.00000001223583
0.00000021912552	0.00000023869348	0.00000024992460
-0.00000243808900	-0.00000267950408	-0.00000280622336
0.00001700659621	0.00001845972995	0.00001897665289
-0.00023595638461	-0.00023731405288	-0.00023424980819
0.00398227815474	0.00401983617789	0.00404670138369
0.00912716490314	0.00904226666279	0.00896602406560
2.16195425587554	2.14825895758319	2.13443501752049

Mach 1.61	Mach 1.62	Mach 1.63
0.27262700000000	0.27539700000000	0.25283500000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000332	-0.00000000000352	-0.00000000000340
0.00000000032647	0.00000000034506	0.00000000032700
-0.00000001288482	-0.00000001360871	-0.00000001253315
0.00000026299065	0.00000027812014	0.00000024502323
-0.00000295387191	-0.00000313570039	-0.00000255091258
0.00001964323575	0.00002065257791	0.00001431411398
-0.00023178457084	-0.00023131584013	-0.00018972440783
0.00407455210629	0.00410900008659	0.00402238927113
0.00889099255891	0.00880503344092	0.00885488291605
2.12055484161548	2.10663669008140	2.09278871729892

Mach 1.64	Mach 1.65	Mach 1.66
0.25474600000000	0.25756100000000	0.26043800000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000347	-0.00000000000358	-0.00000000000375
0.00000000033179	0.00000000034113	0.00000000035673
-0.00000001263724	-0.00000001292313	-0.00000001348808
0.00000024514372	0.00000024931217	0.00000026018553
-0.00000251991322	-0.00000254488739	-0.00000266385396
0.00001351524872	0.00001321138741	0.00001368069134

-0.00018015200596	-0.00017326610129	-0.00016993040949
0.00403172334353	0.00404939042714	0.00407554643649
0.00879961972700	0.00873338477807	0.00865695416657
2.07871033599613	2.06467700409960	2.05062203394949

Mach 1.67	Mach 1.68	Mach 1.69
0.26332700000000	0.24154300000000	0.24353600000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000384	-0.00000000000354	-0.00000000000356
0.00000000036333	0.00000000032535	0.00000000032382
-0.00000001364642	-0.00000001169564	-0.00000001146980
0.00000026120092	0.00000020779843	0.00000019921606
-0.00000264365394	-0.00000179171954	-0.00000163438863
0.00001298315785	0.00000463354617	0.00000279347477
-0.00016088721127	-0.00011081501021	-0.00009628881908
0.00408668996271	0.00398224721625	0.00397939599436
0.00859844742915	0.00866186528196	0.00861817067718
2.03653555498925	2.02246317798176	2.00826400121888

Mach 1.7	Mach 1.71	Mach 1.72
0.24646200000000	0.57120200000000	0.25233500000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000365	-0.00000000000350	-0.00000000000352
0.00000000032999	0.00000000031054	0.00000000030926
-0.00000001159720	-0.00000001060669	-0.00000001039945
0.00000019943031	0.00000017338067	0.00000016560685
-0.00000160610756	-0.00000121744040	-0.00000107916689
0.00000208338408	-0.00000156576692	-0.00000317580302
-0.00008745640961	-0.00006470462722	-0.00005145657334
0.00399179118679	0.00396887640257	0.00396907367233
0.00855642674655	0.00853486167102	0.00848848318859
1.99405514434684	1.97989987924680	1.96567205197434

Mach 1.73	Mach 1.74	Mach 1.75
0.23044900000000	0.23340400000000	0.23636700000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000315	-0.00000000000312	-0.00000000000281
0.00000000026392	0.00000000025672	0.00000000022012
-0.00000000809604	-0.00000000761947	-0.00000000586849
0.00000010375576	0.00000008956106	0.00000004567423
-0.00000011974151	0.00000010502035	0.00000073228577
-0.00001223952308	-0.00001452004022	-0.00002001838535
0.00000089954521	0.00001713123827	0.00004808142566
0.00386284347096	0.00385599112212	0.00381374060300
0.00854522257184	0.00850527373802	0.00850294689879
1.95148514118891	1.93725695672591	1.92302080705842

Mach 1.76	Mach 1.77	Mach 1.78
0.73115200000000	0.24145000000000	0.22121500000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000276	-0.00000000000248	-0.00000000000212
0.00000000021046	0.00000000017625	0.00000000013153

-0.00000000528124	-0.00000000358548	-0.00000000134352
0.00000002896956	-0.00000001458841	-0.00000007363572
0.00000098774870	0.00000162094414	0.00000251399413
-0.00002250623826	-0.00002812337211	-0.00003635242146
0.00006515418718	0.00009703626872	0.00014401123203
0.00380475610384	0.00375919344771	0.00366989969037
0.00846561034919	0.00846601389274	0.00849964369472
1.90880202954196	1.89458995411688	1.88044200605437

Mach 1.79	Mach 1.8	Mach 1.81
0.22419500000000	0.22723000000000	0.23021900000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000166	-0.00000000000146	-0.00000000000107
0.00000000007951	0.00000000005325	0.00000000000777
0.00000000109020	0.00000000241678	0.00000000458495
-0.00000013350243	-0.00000016759945	-0.00000022133016
0.00000335515567	0.00000384378118	0.00000459662058
-0.00004352597656	-0.00004782691814	-0.00005421106596
0.00018263181317	0.00020779008975	0.00024233450915
0.00360839813407	0.00358014074349	0.00352950860502
0.00851809289663	0.00849938246594	0.00850402535290
1.86624810443883	1.85205084177772	1.83786997797765

Mach 1.82	Mach 1.83	Mach 1.84
0.23237400000000	0.21283800000000	0.21587900000000
25.00000000000000	25.00000000000000	25.00000000000000
-0.00000000000073	0.00000000000007	0.00000000000041
-0.00000000003338	-0.00000000012360	-0.00000000016425
0.00000000656279	0.00000001075060	0.00000001270925
-0.00000027056223	-0.00000037381061	-0.00000042251014
0.00000528747734	0.00000675594008	0.00000743650867
-0.00006009413638	-0.00007266792091	-0.00007844138786
0.00027463080010	0.00034013046303	0.00037194918565
0.00348390663282	0.00335354318196	0.00330805391202
0.00850316237497	0.00857480446534	0.00857634114151
1.82372054427473	1.80966869642700	1.79555632201802

Mach 1.85	Mach 1.86	Mach 1.87
0.21887200000000	0.22105600000000	0.22410000000000
25.00000000000000	25.00000000000000	25.00000000000000
0.00000000000097	0.00000000000147	0.00000000000227
-0.00000000022773	-0.00000000028478	-0.00000000037386
0.00000001564213	0.00000001830939	0.00000002234051
-0.00000049319601	-0.00000055816741	-0.00000065422462
0.00000839959464	0.00000929475902	0.00001060001132
-0.00008629425151	-0.00009371648931	-0.00010430892528
0.00041216585533	0.00045116877200	0.00050409953520
0.00324592636295	0.00318423992953	0.00309037501330
0.00858998925428	0.00860487443485	0.00865343799705
1.78148237107564	1.76742756094007	1.75340058444018

Mach 1.88	Mach 1.89	Mach 1.9

0.20524200000000	0.20828300000000	0.21048600000000
25.00000000000000	25.00000000000000	25.00000000000000
0.00000000000287	0.00000000000359	0.00000000000458
-0.00000000044259	-0.00000000052345	-0.00000000063115
0.00000002556226	0.00000002923945	0.00000003406015
-0.00000073331863	-0.00000082076817	-0.00000093446544
0.00001170503269	0.00001288269872	0.00001441211544
-0.00011358527639	-0.00012303475262	-0.00013527349131
0.00055249312556	0.00059964121406	0.00065946017562
0.00300575354258	0.00292649434315	0.00281712099547
0.00867075440334	0.00870313013421	0.00876515158660
1.73951638482135	1.72556273019463	1.71164952108481

Mach 1.91	Mach 1.92	Mach 1.93
0.21347500000000	0.21651200000000	0.19837700000000
25.00000000000000	25.00000000000000	25.00000000000000
0.00000000000518	0.00000000000579	0.00000000000680
-0.00000000069943	-0.00000000076723	-0.00000000087837
0.00000003717712	0.00000004025622	0.00000004526261
-0.00000100838461	-0.00000108088414	-0.00000119943167
0.00001539754093	0.00001635503263	0.00001795283732
-0.00014310108807	-0.00015063604963	-0.00016341724179
0.00069884796130	0.00073668436913	0.00079882961895
0.00275665586437	0.00270001716722	0.00258774565854
0.00877833286899	0.00878668592128	0.00882584868898
1.69777733870189	1.68396840086963	1.67027656635207

Mach 1.94	Mach 1.95	Mach 1.96
0.20054500000000	0.20357000000000	0.20659300000000
25.00000000000000	25.00000000000000	25.00000000000000
0.00000000000792	0.00000000000867	0.00000000000944
-0.00000000100035	-0.00000000108309	-0.00000000116770
0.00000005067587	0.00000005438070	0.00000005815319
-0.00000132587529	-0.00000141209353	-0.00000149942911
0.00001963425136	0.00002076095863	0.00002189481554
-0.00017666929551	-0.00018539275437	-0.00019410579766
0.00086240817420	0.00090494144104	0.00094722965117
0.00247040236890	0.00240342019763	0.00233665922268
0.00889486424476	0.00891342884216	0.00893315465024
1.65653654636131	1.64285854681983	1.62924137147161

Mach 1.97	Mach 1.98	Mach 1.99
0.20961500000000	0.19130600000000	0.19426500000000
25.00000000000000	25.00000000000000	25.00000000000000
0.00000000001046	0.00000000001176	0.00000000001266
-0.00000000127875	-0.00000000141855	-0.00000000151686
0.00000006304389	0.00000006921066	0.00000007354887
-0.00000161186891	-0.00000175495874	-0.00000185448151
0.00002335210160	0.00002523957031	0.00002652073182
-0.00020524183134	-0.00021992049914	-0.00022964618008
0.00099974917057	0.00106839921452	0.00111462376334
0.00224746995878	0.00212502462661	0.00204942217505

0.00897343118596	0.00901390855776	0.00904291552541
1.61565643102735	1.60223414425180	1.58875580453989

Mach 2.0
0.19676900000000
25.0000000000000
0.00000000001355
-0.00000000161314
0.00000007776764
-0.00000195028106
0.00002773529688
-0.00023868636964
0.00115696378651
0.00198487738110
0.00905788963067
1.57536198056976

The following list contains the range of 'x' values for the throat transition polynomials and the coefficients for these seventh order polynomials (Equation 18). The rows represent the following information: row 1, starting x value, row 2, ending x value, rows 3 through 9, the coefficients for the polynomials arranged in decreasing order of x.

Mach 1.4	Mach 1.41	Mach 1.42
-0.03485000000000	-0.03465000000000	-0.03440000000000
0.30487800000000	0.30698300000000	0.30917200000000
3.79440994520268	3.56823400152118	3.32703763798460
-1.46795727781507	-1.35973801033422	-1.23196836404500
-0.71606249126068	-0.70897558737324	-0.70915413735749
0.25274378162748	0.24813029464503	0.24403461583068
0.04165733646450	0.04075827559078	0.03997160255191
0.00751014912255	0.00745071433510	0.00739610623122
0.00041924755858	0.00041547823184	0.00041125657902
2.39397441331458	2.38228558625431	2.37044417031013

Mach 1.43	Mach 1.44	Mach 1.45
-0.03415000000000	-0.03390000000000	-0.03365000000000
0.31140200000000	0.31366300000000	0.28841700000000
3.11496001150867	2.72130721544026	3.69776201225538
-1.13029748497588	-0.84301578204264	-0.60208509400623
-0.70142974277375	-0.75010624182661	-1.19472906808352
0.23948872089842	0.23668386228604	0.29096742681204
0.03901246133980	0.03909865695956	0.05123430904578
0.00733094444658	0.00733452542245	0.00801815393596
0.00040678427261	0.00040406414451	0.00041739269536
2.35837758658468	2.34616245253660	2.33382413199897

Mach 1.46	Mach 1.47	Mach 1.48
-0.03335000000000	-0.03310000000000	-0.03280000000000
0.28974400000000	0.29206300000000	0.29446500000000
3.34858689894953	2.95927524855381	2.75862420544780
-0.37361238795502	-0.16010447584142	-0.10888988553452

-1.22776365279964	-1.23893598845069	-1.20971531100032
0.28924060805970	0.28462237877366	0.27985537332901
0.05098468049795	0.05018412643342	0.04870969153017
0.00798839967271	0.00793148647722	0.00782692476461
0.00041309132578	0.00040877512651	0.00040268837068
2.32135575959659	2.30877015525996	2.29598680126603

Mach 1.49	Mach 1.5	Mach 1.51
-0.03250000000000	-0.03215000000000	-0.03180000000000
0.29688800000000	0.29939400000000	0.27412600000000
2.28757893704022	2.12744271877720	1.79677590132942
0.20080119743413	0.23200126175912	1.82927096039062
-1.25312598934528	-1.22337529219125	-2.05213869219468
0.27678583453587	0.27268892737587	0.33673696847198
0.04843350505455	0.04695418574869	0.06386384069278
0.00779950121072	0.00769202183661	0.00862588949119
0.00039851521772	0.00039181164708	0.00040901250442
2.28317593888181	2.27018084029812	2.25708534639065

Mach 1.52	Mach 1.53	Mach 1.54
-0.03145000000000	-0.03110000000000	-0.03075000000000
0.27664300000000	0.27918200000000	0.28174400000000
1.32772244275014	0.69145529875843	0.52652317543870
2.06740734930375	2.46299910196168	2.46751714330287
-2.06442636272360	-2.11919126235970	-2.07935042117815
0.33371890360207	0.33151579331615	0.32821291426273
0.06280856264212	0.06236337294409	0.06061684928972
0.00853698479216	0.00848619122344	0.00835560570991
0.00040259942211	0.00039711198294	0.00038979076872
2.24389600318023	2.23061899235766	2.21726264516941

Mach 1.55	Mach 1.56	Mach 1.57
-0.03035000000000	-0.02995000000000	-0.02950000000000
0.28338000000000	0.28603200000000	0.26268500000000
0.18248534531018	0.03646676021508	-2.69436349916207
2.68223963489117	2.68626395451038	6.25160625601419
-2.10987945228988	-2.07411197812351	-3.35433323101306
0.32831747443752	0.32569661185817	0.39821796264169
0.05995326074150	0.05823227181043	0.07862876156263
0.00828350109548	0.00815280601075	0.00920908867404
0.00038321372169	0.00037538176317	0.00039250121449
2.20383350062508	2.19032892807979	2.17667402536131

Mach 1.58	Mach 1.59	Mach 1.6
-0.02910000000000	-0.02865000000000	-0.02820000000000
0.26534000000000	0.26805700000000	0.26982300000000
-2.43402889588291	-2.86686410472777	-2.48501888843186
5.87586039711888	6.08760565494899	5.67754727687714
-3.22179177624369	-3.23724494785300	-3.11503891537114
0.39531942505549	0.39618368007874	0.39553487946122
0.07542127119886	0.07407214694838	0.07115650768842
0.00898068359495	0.00885450631015	0.00864236765174

0.00038233699260	0.00037385208538	0.00036361684659
2.16296211062438	2.14926547441401	2.13544560549913

Mach 1.61	Mach 1.62	Mach 1.63
-0.02770000000000	-0.02725000000000	-0.02675000000000
0.27262700000000	0.27539700000000	0.25283500000000
-2.79334185601022	-3.00227789526810	-8.33671978335983
5.80827692380134	5.86239680953501	11.46812770545675
-3.11688350389649	-3.09866887450936	-4.84815571042553
0.39709344374335	0.39716143299272	0.48814249599407
0.06960668897304	0.06789724862398	0.09062919736569
0.00850464887326	0.00836780939428	0.00942189407570
0.00035444342251	0.00034601787089	0.00036026932893
2.12156624316047	2.10764769711319	2.09369262708121

Mach 1.64	Mach 1.65	Mach 1.66
-0.02620000000000	-0.02570000000000	-0.02515000000000
0.25474600000000	0.25756100000000	0.26043800000000
-8.03794677295924	-6.89131070262041	-6.44819383248542
11.15551809851162	10.09515104712624	9.59653211139184
-4.76978259081621	-4.48834801958721	-4.33986542090733
0.49432525742080	0.49130756830867	0.49159544520217
0.08785879021740	0.08285061711572	0.07921530885189
0.00919414755046	0.00887435704679	0.00862494472161
0.00034848731133	0.00033581805980	0.00032407177001
2.07961902477300	2.06559759632455	2.05154909912320

Mach 1.67	Mach 1.68	Mach 1.69
-0.02460000000000	-0.02405000000000	-0.02345000000000
0.26332700000000	0.24154300000000	0.24353600000000
-5.80632242051302	-15.15686416575276	-13.91242315191867
8.93948299385402	17.71049006212431	16.70000360639828
-4.15228340803712	-6.65850571690492	-6.43679868622093
0.49022556785905	0.61746152288731	0.62464578587591
0.07526887445971	0.10218416773992	0.09760880611917
0.00836965806119	0.00947522460473	0.00916111164076
0.00031242530590	0.00032481807133	0.00031130884995
2.03747277127029	2.02329752844891	2.00910813899456

Mach 1.7	Mach 1.71	Mach 1.72
-0.02285000000000	-0.02225000000000	-0.02165000000000
0.24646200000000	0.57120200000000	0.25233500000000
-12.35149674613173	-1.03269625760690	-8.67281476082239
15.35616062320531	2.08914026043627	12.17890300763105
-6.10854299753303	-1.42424253454036	-5.31241858857280
0.62453706236953	0.29525929243329	0.61410749648012
0.09192541557412	0.03296473637646	0.07978735862669
0.00881494653222	0.00642184233498	0.00813817296121
0.00029757078079	0.00025163700768	0.00027130550201
1.99491130572210	1.98077332729275	1.96656331578481

Mach 1.73	Mach 1.74	Mach 1.75
-0.02100000000000	-0.02035000000000	-0.01970000000000
0.23044900000000	0.23340400000000	0.23636700000000
-23.69477308502587	-20.32259621026120	-16.63267807696737
25.38559582952659	22.77556013874253	19.88848222961645
-8.90708020572145	-8.32694102385256	-7.66985819282011
0.80762379378055	0.80562193112298	0.79798244287061
0.11115049552176	0.10318878463274	0.09494241203410
0.00922769440670	0.00879925346585	0.00838376256371
0.00027972625414	0.00026471565916	0.00025032194222
1.95227163952977	1.93806084955796	1.92384812920442

Mach 1.76	Mach 1.77	Mach 1.78
-0.01905000000000	-0.01835000000000	-0.01765000000000
0.73115200000000	0.24145000000000	0.22121500000000
-0.29485341637918	-11.22956727742464	-29.44925959225816
0.76634609210702	15.50032002102958	31.29013771558354
-0.67773008290222	-6.63102860166389	-10.91932063428794
0.19321529494126	0.78377708826185	1.04727637991373
0.01645649015953	0.08098411881127	0.11066144405744
0.00573455353118	0.00770126701003	0.00851818737712
0.00020637111455	0.00022415605838	0.00022593089008
1.90964798618532	1.89545519960127	1.88121169764047

Mach 1.79	Mach 1.8	Mach 1.81
-0.01695000000000	-0.01620000000000	-0.01550000000000
0.22419500000000	0.22723000000000	0.23021900000000
-22.36240279926369	-16.92906356331887	-11.12562296706782
26.06115457136489	21.86538616300034	17.29042833327258
-9.77673714962000	-8.81317599840195	-7.72132852112588
1.02451579429596	1.00171532700480	0.96441215171438
0.09932049306662	0.08910715445470	0.07882093572901
0.00803849952657	0.00761874366907	0.00723541957104
0.00021111418919	0.00019691028229	0.00018417549071
1.86704707090553	1.85287379374797	1.83872138151665

Mach 1.82	Mach 1.83	Mach 1.84
-0.01475000000000	-0.01400000000000	-0.01320000000000
0.23237400000000	0.21283800000000	0.21587900000000
-8.64905760559781	-24.81136905451505	-17.64330327237555
15.25885284473409	30.71208065876448	25.30747935316158
-7.23867061996354	-11.80354401052184	-10.58483486572128
0.95743091865080	1.30384859605613	1.26962488460342
0.07239737975352	0.09703597366736	0.08582875221044
0.00697368261137	0.00746347583565	0.00707953868209
0.00017253823394	0.00016859885170	0.00015538406246
1.82458969633024	1.81045488035417	1.79636785853818

Mach 1.85	Mach 1.86	Mach 1.87
-0.01245000000000	-0.01165000000000	-0.01085000000000
0.21887200000000	0.22105600000000	0.22410000000000
-7.55125213952866	-1.75072967043862	4.69914483025170

17.64348175536304	13.12124767869101	7.81934421982999
-8.78665795024184	-7.71429534659802	-6.37022362316132
1.19182177496300	1.15118848867291	1.08306222995786
0.07282624157453	0.06369815118198	0.05386822589558
0.00669883671453	0.00642634589061	0.00616858707632
0.00014322349971	0.00013180636303	0.00012081577971
1.78232662085575	1.76829596880246	1.75430238673915

Mach 1.88	Mach 1.89	Mach 1.9
-0.01005000000000	-0.00920000000000	-0.00835000000000
0.20524200000000	0.20828300000000	0.21048600000000
-8.22770715507505	0.12533309902303	18.11627388143557
23.24819689640894	16.70775826936938	3.55222791919128
-11.53082438980671	-9.97434704887919	-6.91353478962862
1.55314251936088	1.48529586945287	1.31651262002925
0.07372432790155	0.06252801319642	0.04799675603840
0.00642409697357	0.00615517413648	0.00587424033081
0.00011369406953	0.00010236830341	0.00009129511993
1.74032777767046	1.72640254151559	1.71252980359230

Mach 1.91	Mach 1.92	Mach 1.93
-0.00755000000000	-0.00670000000000	-0.00580000000000
0.21347500000000	0.21651200000000	0.19837700000000
24.76393281277613	29.08623711885884	27.72896117016362
-2.27077634411554	-6.53450662877932	4.64707990512762
-5.34324318914758	-4.09382585316890	-9.24595283992646
1.21615213644679	1.12906670841646	1.72445539420583
0.03891788167940	0.03122201470038	0.04230140608731
0.00570583341996	0.00557451061268	0.00563302325941
0.00008168285335	0.00007189279928	0.00006247235118
1.69868514321435	1.68490184544619	1.67112238658627

Mach 1.94	Mach 1.95	Mach 1.96
-0.00495000000000	-0.00405000000000	-0.00315000000000
0.20054500000000	0.20357000000000	0.20659300000000
51.75715183544227	56.76848041464736	63.16364630849947
-12.70049286104780	-18.03597524249974	-24.42474257892694
-5.18531871497983	-3.58597815450975	-1.68400904959568
1.46522290843937	1.34618897900176	1.19240218932198
0.02941671720811	0.02153862099279	0.01434254405664
0.00547841486794	0.00539005886716	0.00532721540278
0.00005280014383	0.00004296202937	0.00003328437677
1.65742121307232	1.64376909214756	1.63017999130190

Mach 1.97	Mach 1.98	Mach 1.99
-0.00225000000000	-0.00135000000000	-0.00045000000000
0.20961500000000	0.19130600000000	0.19426500000000
72.6636812418950	100.684159639541	112.183780303250
-33.1435129101020	-35.1465143191700	-045.903417821063
0.84109688114000	-2.89579661068300	0.17200711643400
0.97629481378700	1.63891053752500	1.38076668627900
0.00790312377400	0.00806781828600	0.00165161456800

0.00528695766100	0.00527784158500	0.00526371012800
0.00002371564400	0.00001422223800	0.00000473683900
1.61662914089900	1.60311667331100	1.58966781607400

Mach 2.0
0
0.19676900000000
124.934972990805
-57.3904439893380
3.47405251744300
1.07515569392200
-0.00083333333300
0.00526315789500
0
1.57629985185200

The following list contains the range of 'x' values for the subsonic shapes and the coefficients described in equations 26 and 27. The rows represent the following information: row 1, starting x value, row 2, ending x value, rows 3 the coefficient a_1, and row 4, the coefficient a_2.

Mach 1.4	Mach 1.41	Mach 1.42
-19.98179413977541	-19.98179395739902	-19.98179372942853
-0.03485000000000	-0.03465000000000	-0.03440000000000
0.39446440268570	0.39271089471799	0.39095225010117
0.59674737554859	0.59410336655332	0.59145367537456

Mach 1.43	Mach 1.44	Mach 1.45
-19.98179350145804	-19.98179327348754	-19.98179304551705
-0.03415000000000	-0.03390000000000	-0.03365000000000
0.38917619816803	0.38739460967027	0.38561150909261
0.58877755152711	0.58609295293606	0.58340596793348

Mach 1.46	Mach 1.47	Mach 1.48
-19.98179277195246	-19.98179254398197	-19.98179227041738
-0.03335000000000	-0.03310000000000	-0.03280000000000
0.38382814615554	0.38204275014569	0.38024807345137
0.58072061422451	0.57802994872182	0.57532724957156

Mach 1.49	Mach 1.5	Mach 1.51
-19.98179199685279	-19.98179167769411	-19.98179135853542
-0.03250000000000	-0.03215000000000	-0.03180000000000
0.37846645113368	0.37667801944528	0.37489278488193
0.57264418319022	0.56995278251096	0.56726608078394

Mach 1.52	Mach 1.53	Mach 1.54
-19.98179103937673	-19.98179072021804	-19.98179040105935
-0.03145000000000	-0.03110000000000	-0.03075000000000
0.37311183727375	0.37133609731082	0.36956676779441
0.56458572749142	0.56191311633866	0.55925006808103

Mach 1.55	Mach 1.56	Mach 1.57
-19.98179003630657	-19.98178967155378	-19.98178926120690
-0.03035000000000	-0.02995000000000	-0.02950000000000
0.36780660822097	0.36605344869396	0.36429946374814
0.55660279766478	0.55396596468179	0.55132974589633
Mach 1.58	Mach 1.59	Mach 1.6
-19.98178889645411	-19.98178848610722	-19.98178807576034
-0.02910000000000	-0.02865000000000	-0.02820000000000
0.36255328785826	0.36082765006084	0.35910306718512
0.54870316159338	0.54610950615965	0.54351727526094
Mach 1.61	Mach 1.62	Mach 1.63
-19.98178761981936	-19.98178720947247	-19.98178675353149
-0.02770000000000	-0.02725000000000	-0.02675000000000
0.35738944738869	0.35568567208321	0.35399552131607
0.54094344648691	0.53838235782865	0.53584368435772
Mach 1.64	Mach 1.65	Mach 1.66
-19.98178625199641	-19.98178579605543	-19.98178529452034
-0.02620000000000	-0.02570000000000	-0.02515000000000
0.35230901165053	0.35064315694926	0.34899168973826
0.53331228768497	0.53081001022739	0.52833126297586
Mach 1.67	Mach 1.68	Mach 1.69
-19.98178479298526	-19.98178429145018	-19.98178374432100
-0.02460000000000	-0.02405000000000	-0.02345000000000
0.34735262190693	0.34571754995146	0.34409809206949
0.52587108630188	0.52341675955877	0.52098778102668
Mach 1.7	Mach 1.71	Mach 1.72
-19.98178319719183	-19.98178265006265	-19.98178210293347
-0.02285000000000	-0.02225000000000	-0.02165000000000
0.34249307915191	0.34090982600566	0.33933323032402
0.51858045872025	0.51620587160642	0.51384115509972
Mach 1.73	Mach 1.74	Mach 1.75
-19.98178151021019	-19.98178091748691	-19.98178032476363
-0.02100000000000	-0.02035000000000	-0.01970000000000
0.33776398547959	0.33621828521080	0.33468665551867
0.51148923230118	0.50917273956986	0.50687733378153
Mach 1.76	Mach 1.77	Mach 1.78
-19.98177973204036	-19.98177909372298	-19.98177845540560
-0.01905000000000	-0.01835000000000	-0.01765000000000
0.33317048526161	0.33167059865851	0.33017900311314
0.50460512148013	0.50235919239911	0.50012558913756
Mach 1.79	Mach 1.8	Mach 1.81
-19.98177781708823	-19.98177713317675	-19.98177649485938
-0.01695000000000	-0.01620000000000	-0.01550000000000
0.32870925344589	0.32725347226518	0.32581126341259

0.49792484630503	0.49574684932609	0.49358736624280
Mach 1.82	Mach 1.83	Mach 1.84
-19.98177581094790	-19.98177512703643	-19.98177439753086
-0.01475000000000	-0.01400000000000	-0.01320000000000
0.32438565056018	0.32297235063256	0.32157793231092
0.49145460039128	0.48934025302865	0.48725606215657
Mach 1.85	Mach 1.86	Mach 1.87
-19.98177371361938	-19.98177298411381	-19.98177225460824
-0.01245000000000	-0.01165000000000	-0.01085000000000
0.32019867664276	0.31883404595827	0.31748483937802
0.48519282542590	0.48315328852628	0.48113688430876
Mach 1.88	Mach 1.89	Mach 1.9
-19.98177152510267	-19.98177075000300	-19.98176997490332
-0.01005000000000	-0.00920000000000	-0.00835000000000
0.31614905620621	0.31483100223377	0.31352912115270
0.47914058471610	0.47717266404261	0.47522900894367
Mach 1.91	Mach 1.92	Mach 1.93
-19.98176924539775	-19.98176847029808	-19.98176764960431
-0.00755000000000	-0.00670000000000	-0.00580000000000
0.31223927496370	0.31096751378538	0.30970819074754
0.47330162113832	0.47140314328154	0.46952499855181
Mach 1.94	Mach 1.95	Mach 1.96
-19.98176687450464	-19.98176605381087	-19.98176523311710
-0.00495000000000	-0.00405000000000	-0.00315000000000
0.30846493221763	0.30723785159150	0.30602643669911
0.46766924895664	0.46583949685648	0.46403325418061
Mach 1.97	Mach 1.98	Mach 1.99
-19.98176441242334	-19.98176359172957	-19.98176277103580
-0.00225000000000	-0.00135000000000	-0.00045000000000
0.30482819944503	0.30364295349599	0.30247274191576
0.46224675262606	0.46047971355867	0.45873523941090
Mach 2.0		
-19.98176236068891		
0		
0.30130528455490		
0.45697968157493		

APPENDIX D. STRUCTURAL ANALYSIS

The structural analysis was carried out using I-DEAS Master Series™. Alioth, the eight processor Silicon Graphics 4D/380 computer located in the NPS Visualization Laboratory was the platform used for the structural analysis. Alioth was the server for I-DEAS and if the user established a home account on this machine, processing time was minimized.

The three structural questions addressed were: (1) the jack distribution and loading necessary to achieve the necessary curvatures in the steel plate, (2) the interaction between the jack mounting fixture and the plate and (3) the effect of the aerodynamic pressure loading on the plate.

Figure 29 shows the finite element model of the idealized Mach 1.4 shape. Nine fixtures were attached to the model corresponding to the jack mounting points and one inch element lengths were used. Figure 30 shows a loading combination which produced a close approximation of the Mach 2 curvatures. The loads were oriented perpendicular to the long dimension of the plate (y direction) with the positive sense defined upward. A load of -225 pounds was applied at the -3.5 inch jack station (measured with respect to the throat, positive in the downstream direction). A 275 pound load and a -140 pound load were applied at the 0 inch or throat station and the 3 inch station respectively. Figure 31 shows the stress distribution in the deflected steel shape.

Figure 32 presents the model used to analyze the jack mounting fixture and the pressure loading effects. A six inch section of flat plate, representative of the length between three jacks, was used. A single jack-mounting fixture was modeled. An element length of .1 inches was required to avoid excessive distortion of the finite-element mesh throughout the jack-mount fixture and eyelet. To avoid large memory and processor demands, the model was simplified by modeling a .1 inch two dimensional slice through the plate. This simplification kept processor time to less than five minutes and Hypermatrix size to less than 50 megabytes. Figure 33 shows the stress effects of applying a 250 pound load to the top of the inside of the eyelet at an off-perpendicular angle of 4.5 degrees. Figure 34 shows the deflection of this same load. Figure 35 shows the displacement of the isolated horizontal component of the 250 pound load. Figure 36 highlights the stress at the fixture joint.

Figure 37 represents an approximation of the pressure loading associated with Mach 2 operation on the plate section surrounding the throat jack. In this figure, the stress distribution is presented. Finally, Figure 38 shows the displacement of the plate as a result of the Mach 2 pressure loading in the vicinity of the throat.

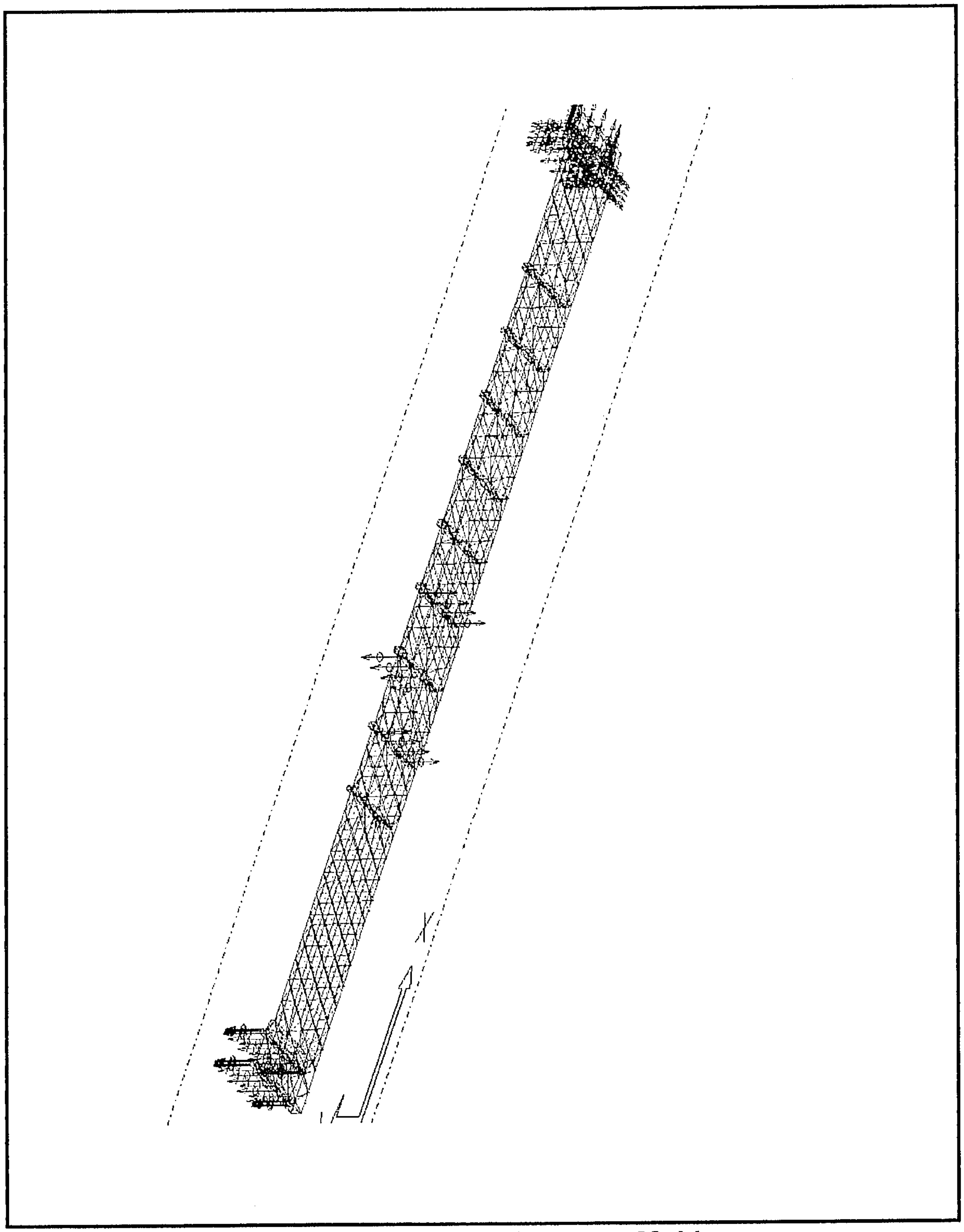


Figure 29. Flat Plate Finite Element Model

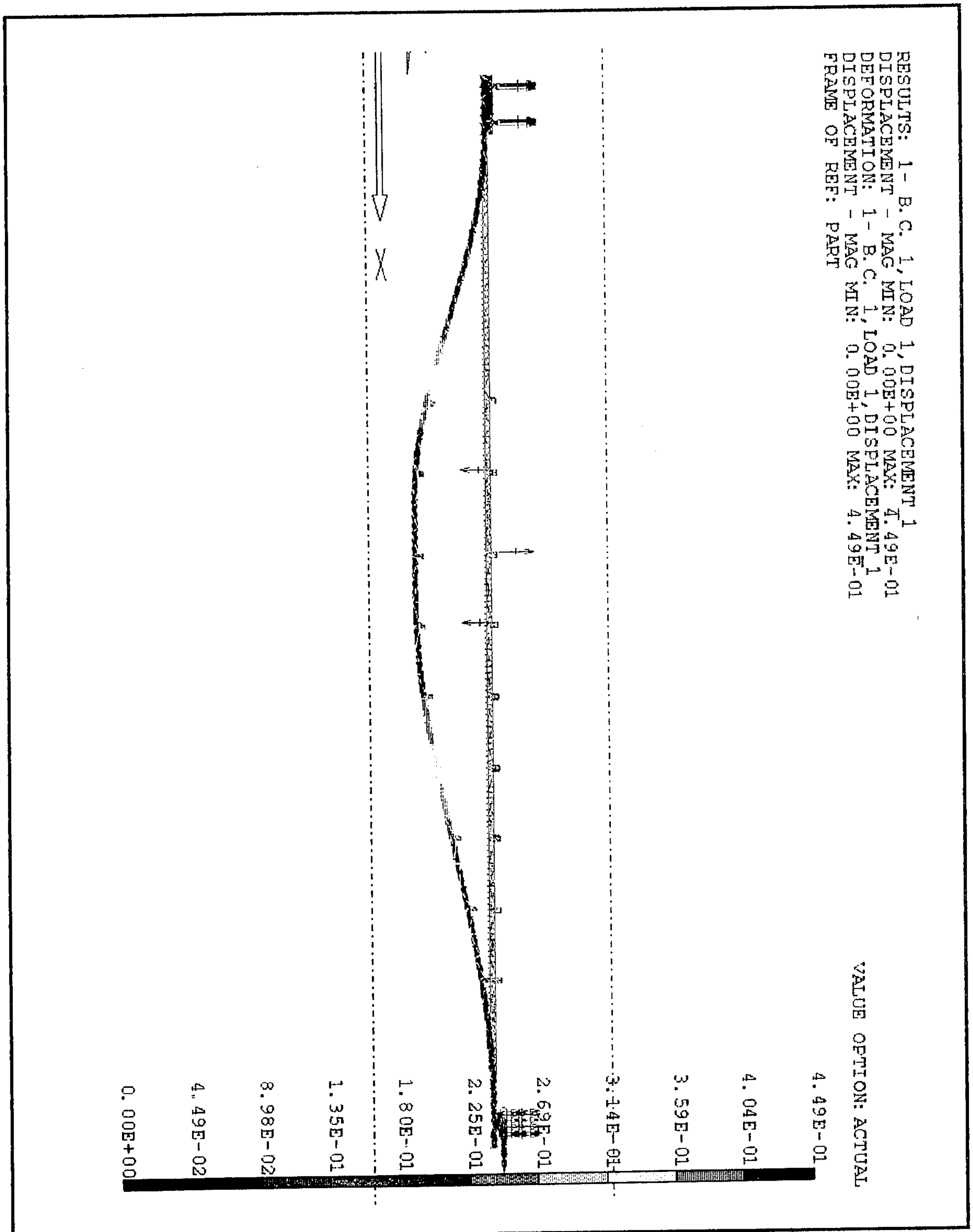


Figure 30. Flat Plate Deflection Under Combined Loading

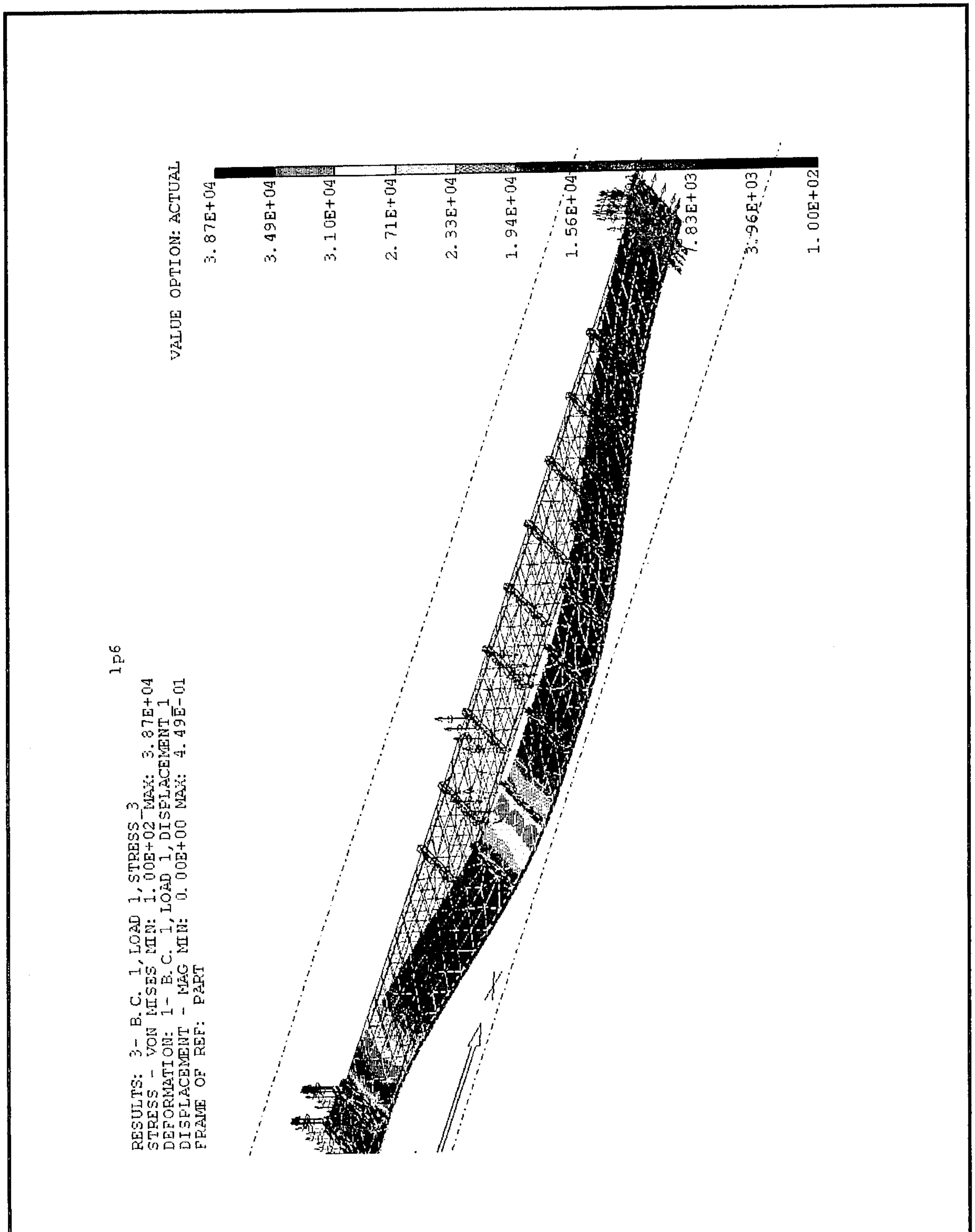


Figure 31. Flat Plate Stress Distribution Under Combined Load

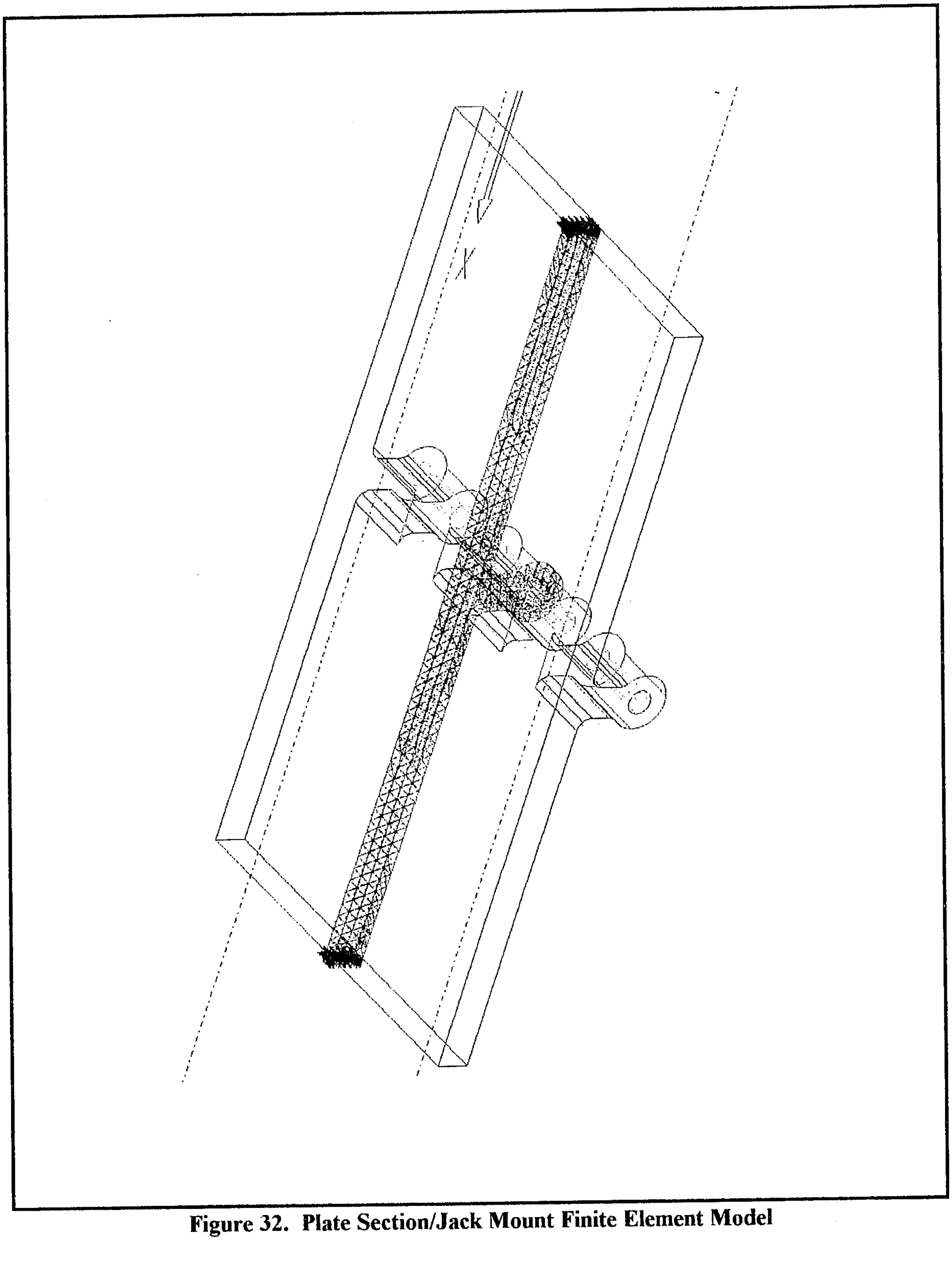


Figure 32. Plate Section/Jack Mount Finite Element Model

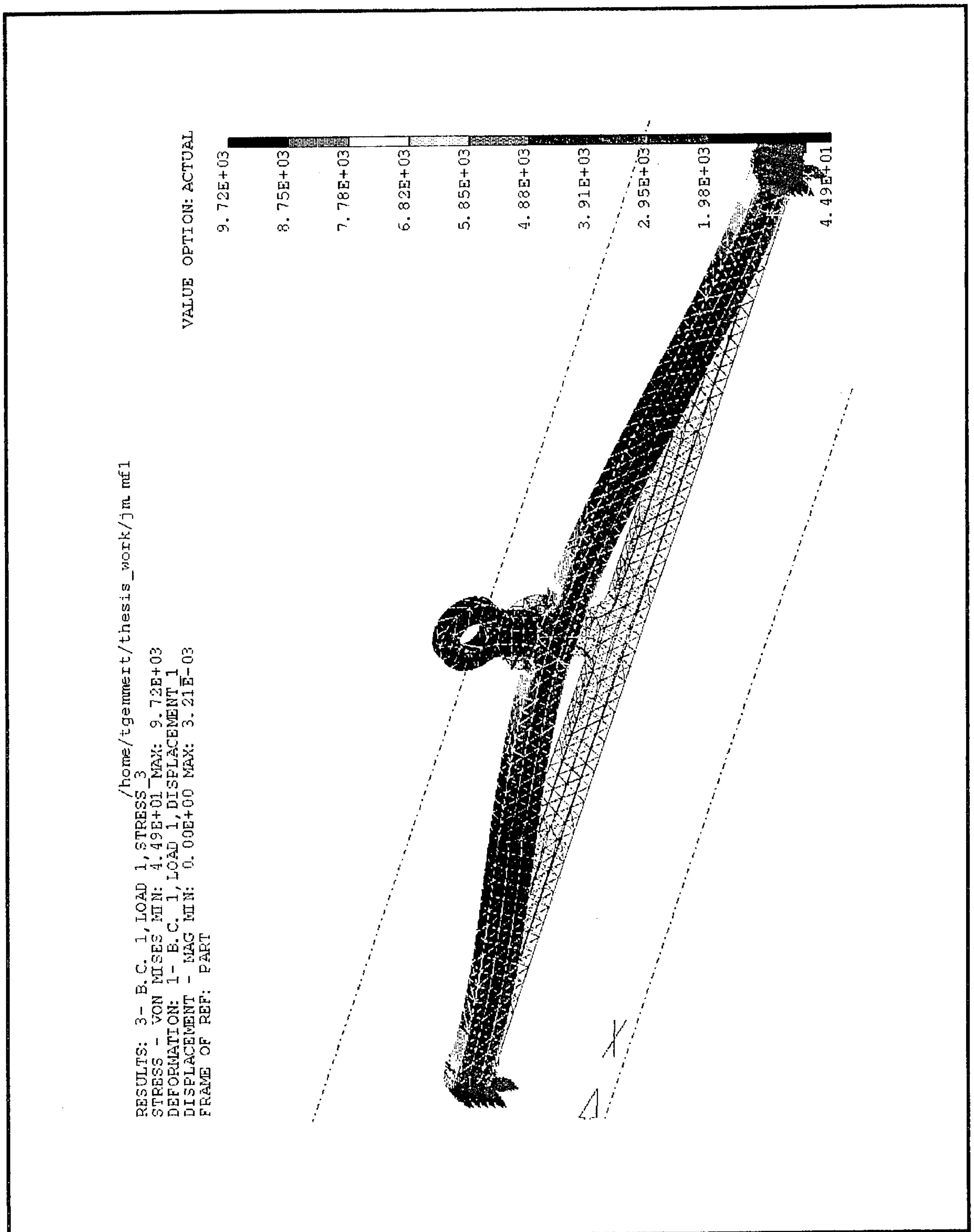


Figure 33. Jack Mount Stress Distribution, Off Perpendicular Load

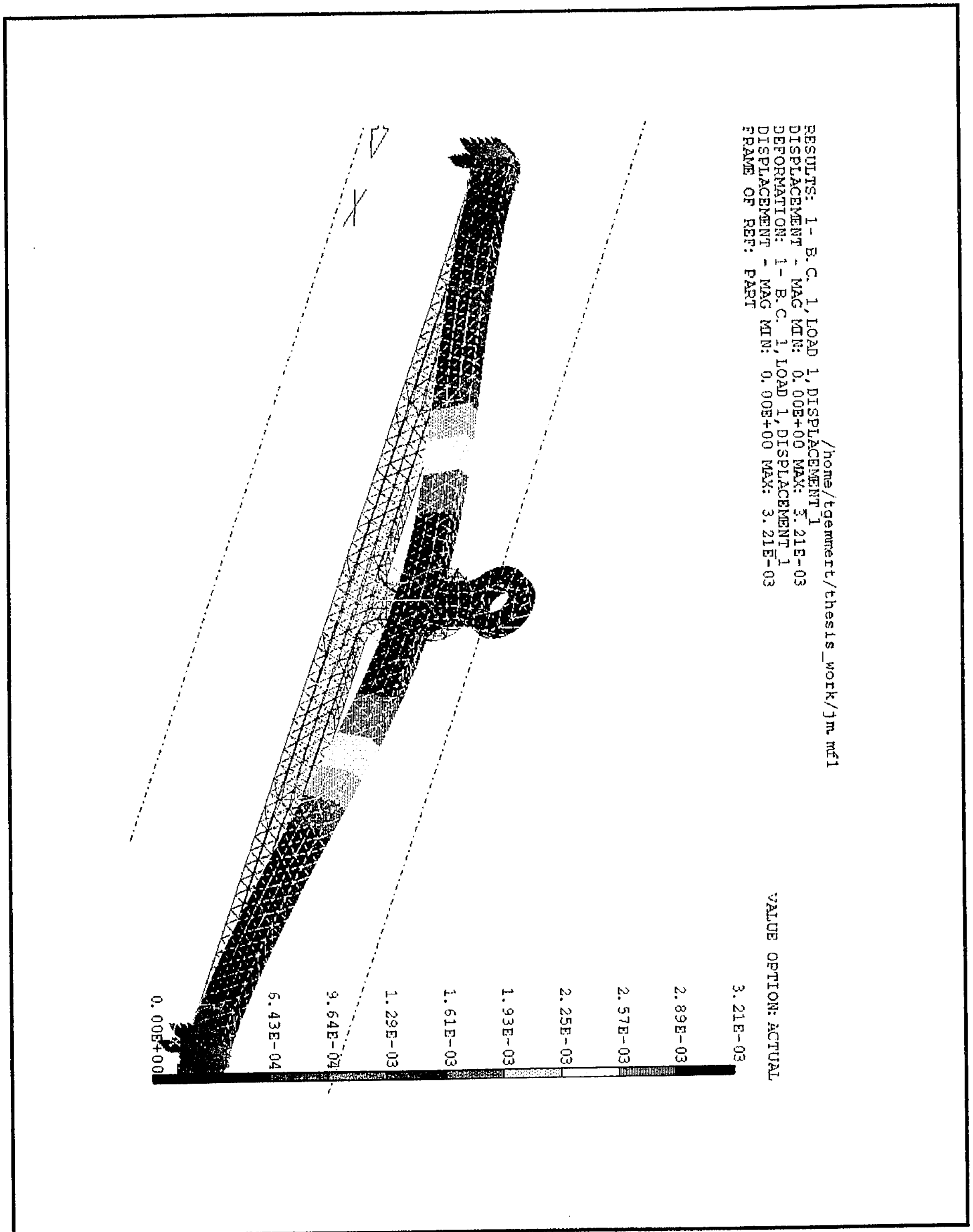


Figure 34. Jack Mount Displacement, Off Perpendicular Load

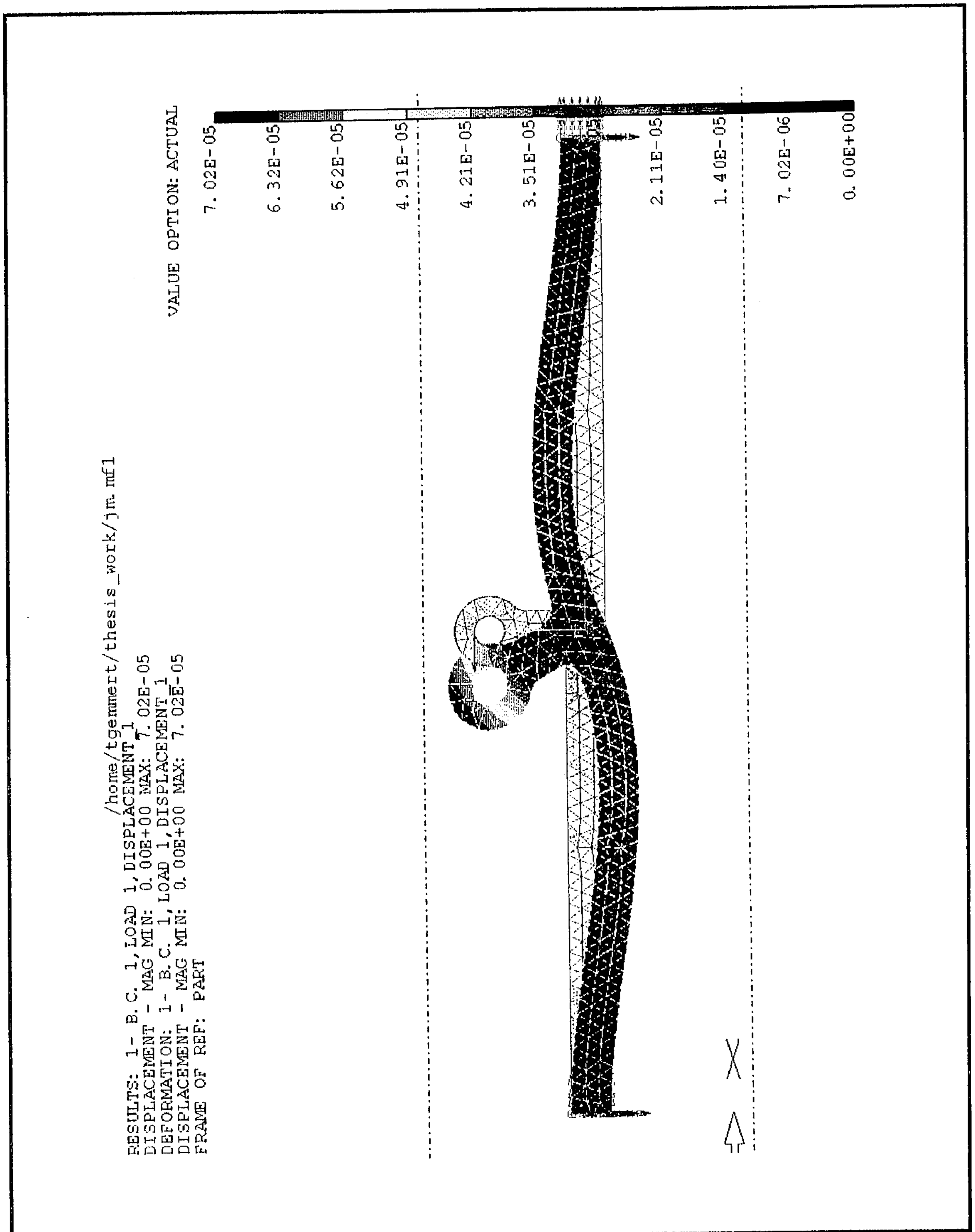


Figure 35. Jack Mount Deflection, Horizontal Component of Off Perpendicular Load

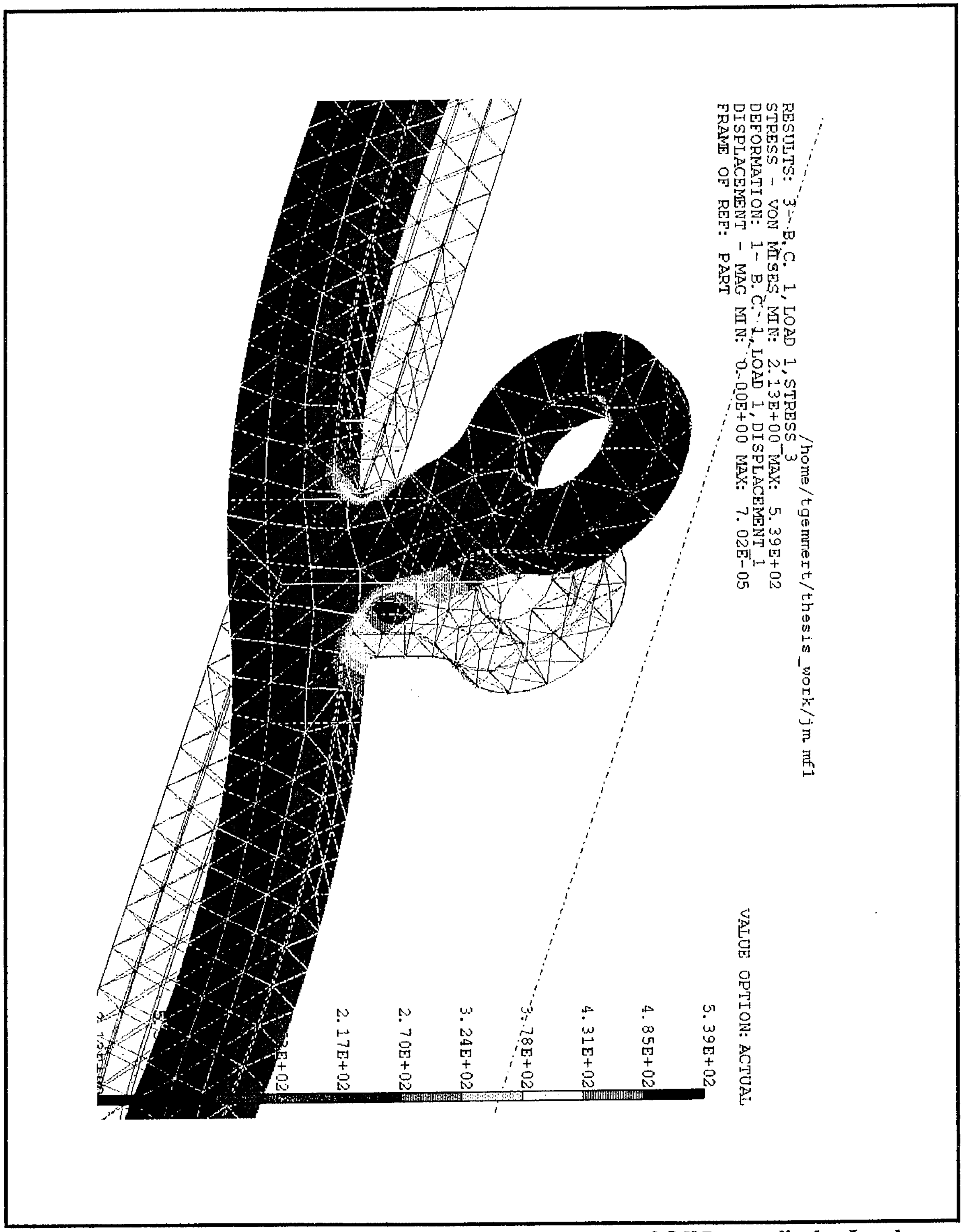


Figure 36. Jack Mount Stresses, Horizontal Component of Off Perpendicular Load

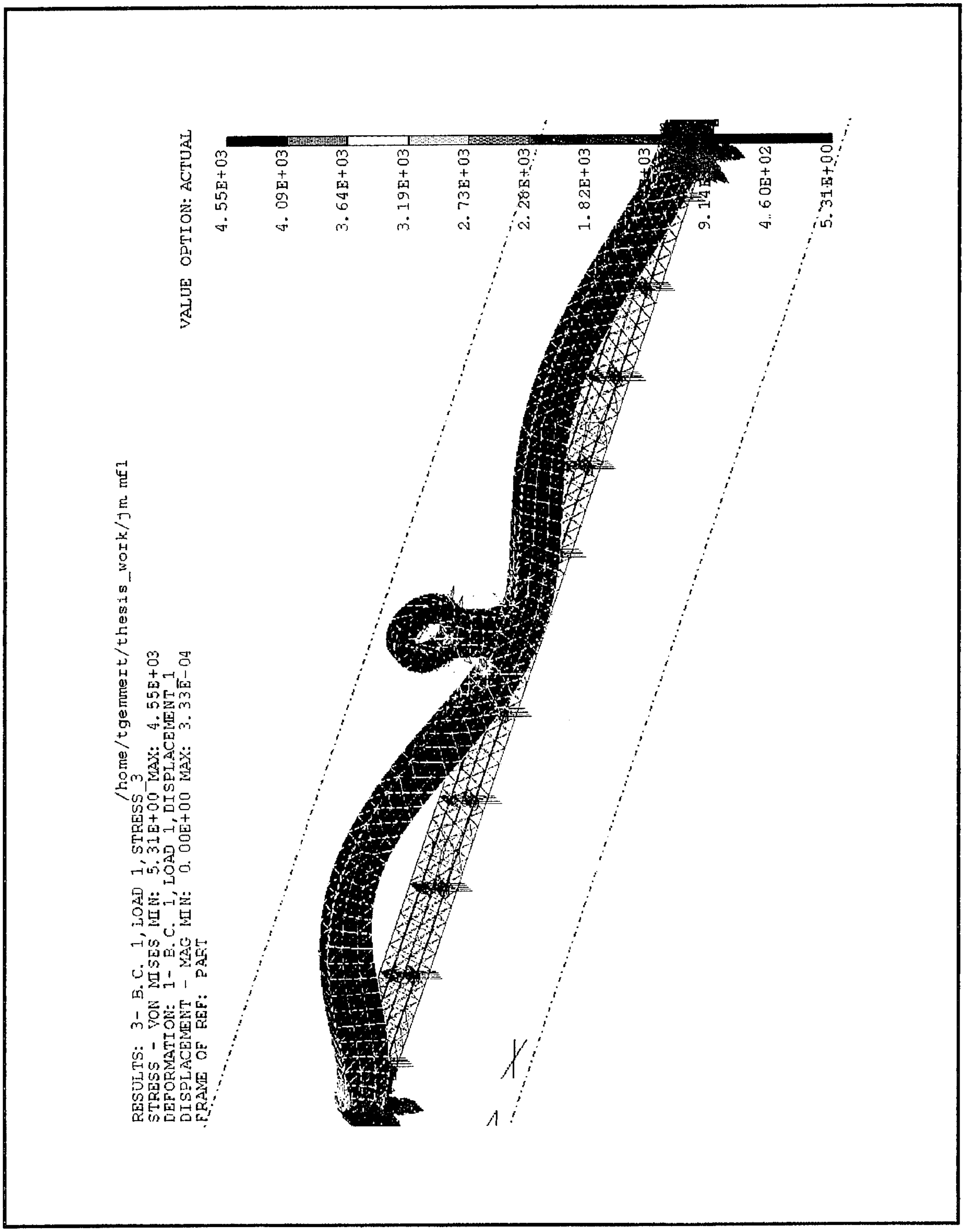


Figure 37. Plate Stresses, Mach 2 Pressure Load (Throat)

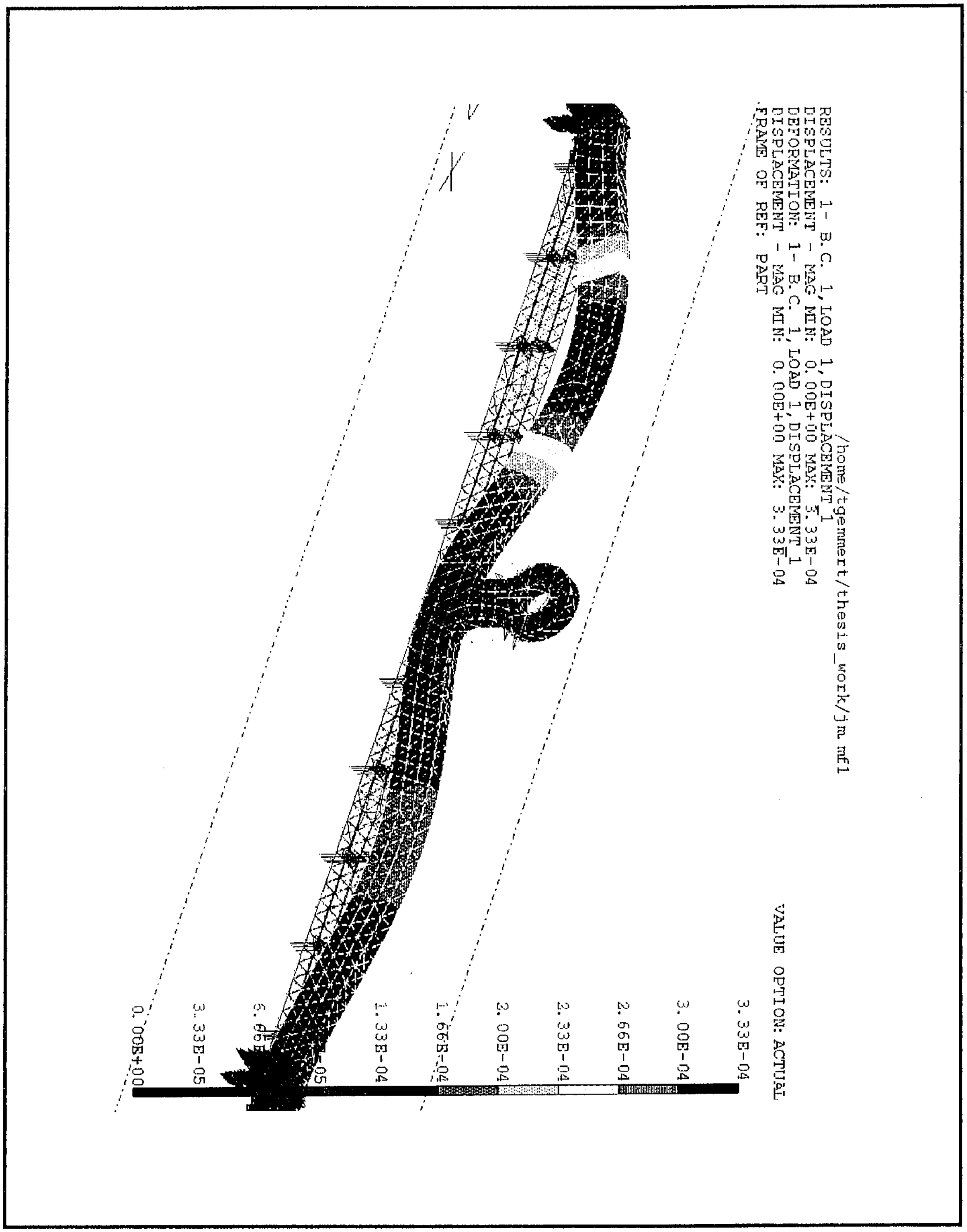


Figure 38. Plate Deflection, Mach 2 Pressure Load (Throat)

APPENDIX E. COORDINATES OF MACH 1.7 SHAPE AND PRELIMINARY DRAWINGS

Table 6 lists the coordinates describing the surface of the Mach 1.7 shape exposed to the air flow. The origin of the reference system is the most down-stream point in the solution which is at the nozzle exit. The positive sense for 'x' is in the down stream or test section direction, therefore all of the x values are negative. The positive sense for 'y' is perpendicular to and directed away from the nozzle centerline.

X	Y	X	Y	X	Y	X	Y
-44.9818	2.2003	-36.4166	1.4668	-31.7819	-0.1976	-26.8877	-0.7805
-44.9749	2.2003	-36.0772	1.3355	-31.689	-0.2201	-26.7605	-0.7841
-44.9659	2.2003	-35.7409	1.2008	-31.5955	-0.2421	-26.6324	-0.7873
-44.9543	2.2003	-35.4082	1.0649	-31.5014	-0.2638	-26.5034	-0.7903
-44.9395	2.2003	-35.0796	0.93	-31.4065	-0.2851	-26.3734	-0.793
-44.9211	2.2003	-35.01	0.9015	-31.311	-0.3059	-26.2426	-0.7953
-44.8983	2.2003	-34.9398	0.8728	-31.2149	-0.3264	-26.1108	-0.7974
-44.8704	2.2003	-34.8691	0.844	-31.1181	-0.3464	-25.9781	-0.7992
-44.8367	2.2003	-34.7979	0.8151	-31.0205	-0.3659	-25.8445	-0.8008
-44.7963	2.2003	-34.7263	0.7861	-30.9223	-0.3851	-25.71	-0.802
-44.7486	2.2003	-34.6541	0.757	-30.8235	-0.4038	-25.5745	-0.8031
-44.6927	2.2003	-34.5814	0.7278	-30.7239	-0.422	-25.438	-0.8038
-44.6278	2.2003	-34.5083	0.6986	-30.6236	-0.4398	-25.3006	-0.8044
-44.5531	2.2003	-34.4346	0.6693	-30.5226	-0.4571	-25.1622	-0.8047
-44.468	2.2003	-34.3603	0.64	-30.4209	-0.474	-25.0229	-0.8048
-44.3716	2.2003	-34.2856	0.6108	-30.3185	-0.4905	-25.0229	-0.8048
-44.2635	2.2003	-34.2103	0.5815	-30.2154	-0.5065	-25.0174	-0.8048
-44.143	2.2003	-34.1345	0.5522	-30.1115	-0.522	-25.0119	-0.8048
-44.0097	2.2003	-34.0582	0.523	-30.0069	-0.5371	-25.0064	-0.8048
-43.8633	2.2003	-33.9814	0.4939	-29.9016	-0.5517	-25.0009	-0.8048
-43.7034	2.2003	-33.904	0.4648	-29.7955	-0.5658	-24.9954	-0.8048
-43.53	2.2003	-33.826	0.4358	-29.6887	-0.5796	-24.9899	-0.8048
-43.3429	2.2003	-33.7475	0.4069	-29.5812	-0.5928	-24.9844	-0.8048
-43.1423	2.2003	-33.6685	0.3782	-29.4729	-0.6056	-24.9789	-0.8048
-42.9283	2.2003	-33.5889	0.3495	-29.3638	-0.618	-24.9734	-0.8048
-42.7012	2.2003	-33.5087	0.321	-29.254	-0.6299	-24.9679	-0.8048
-42.4613	2.2003	-33.428	0.2927	-29.1433	-0.6413	-24.9624	-0.8048
-42.2091	2.2003	-33.3467	0.2645	-29.032	-0.6523	-24.9569	-0.8048
-41.9452	2.2003	-33.2648	0.2366	-28.9198	-0.6629	-24.9514	-0.8047
-41.6702	2.2002	-33.1824	0.2088	-28.8068	-0.6731	-24.9459	-0.8047
-41.3848	2.2001	-33.0994	0.1813	-28.6931	-0.6828	-24.9404	-0.8047
-41.0897	2.1996	-33.0158	0.1539	-28.5785	-0.6921	-24.9349	-0.8047
-40.7857	2.1984	-32.9316	0.1269	-28.4632	-0.7009	-24.9294	-0.8047
-40.4736	2.1957	-32.8468	0.1001	-28.347	-0.7094	-24.9239	-0.8047
-40.1544	2.1902	-32.7615	0.0735	-28.23	-0.7174	-24.9184	-0.8047
-39.8288	2.1802	-32.6755	0.0472	-28.1122	-0.7251	-24.9129	-0.8046
-39.4978	2.1635	-32.5889	0.0213	-27.9936	-0.7323	-24.9074	-0.8046
-39.1623	2.1378	-32.5017	-0.0044	-27.8741	-0.7391	-24.9019	-0.8046
-38.8232	2.1008	-32.4139	-0.0298	-27.7538	-0.7456	-24.8964	-0.8046
-38.4812	2.0507	-32.3255	-0.0548	-27.6327	-0.7516	-24.8909	-0.8045
-38.1373	1.9863	-32.2365	-0.0795	-27.5107	-0.7573	-24.8854	-0.8045
-37.7923	1.9074	-32.1468	-0.1038	-27.3878	-0.7627	-24.8799	-0.8045
-37.447	1.8144	-32.0566	-0.1278	-27.2641	-0.7676	-24.8745	-0.8044
-37.1021	1.7086	-31.9656	-0.1515	-27.1395	-0.7722	-24.869	-0.8044
-36.7584	1.592	-31.8741	-0.1747	-27.0141	-0.7765	-24.8635	-0.8043

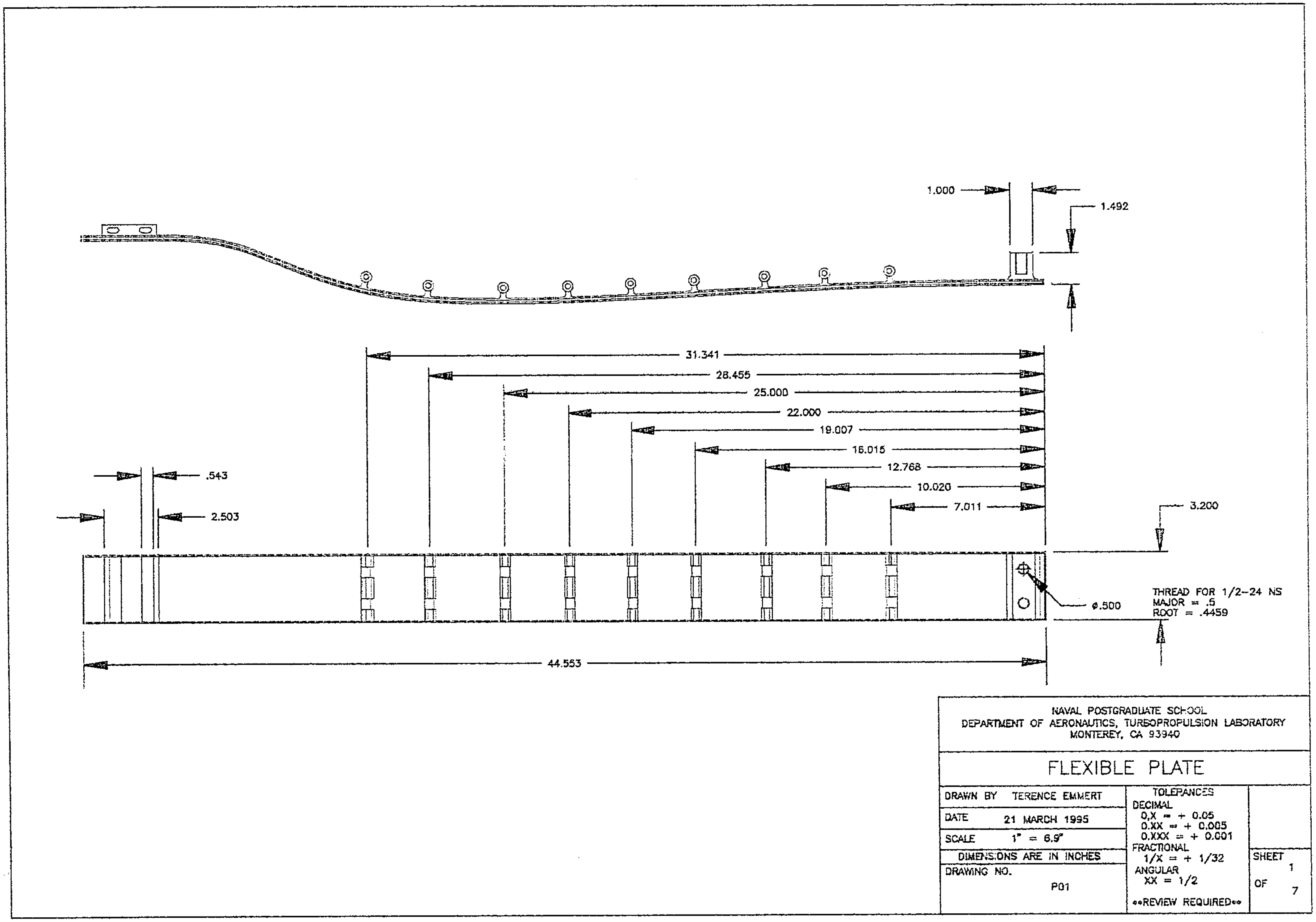
Table 6. Coordinates of Mach 1.7 Nozzle Contour

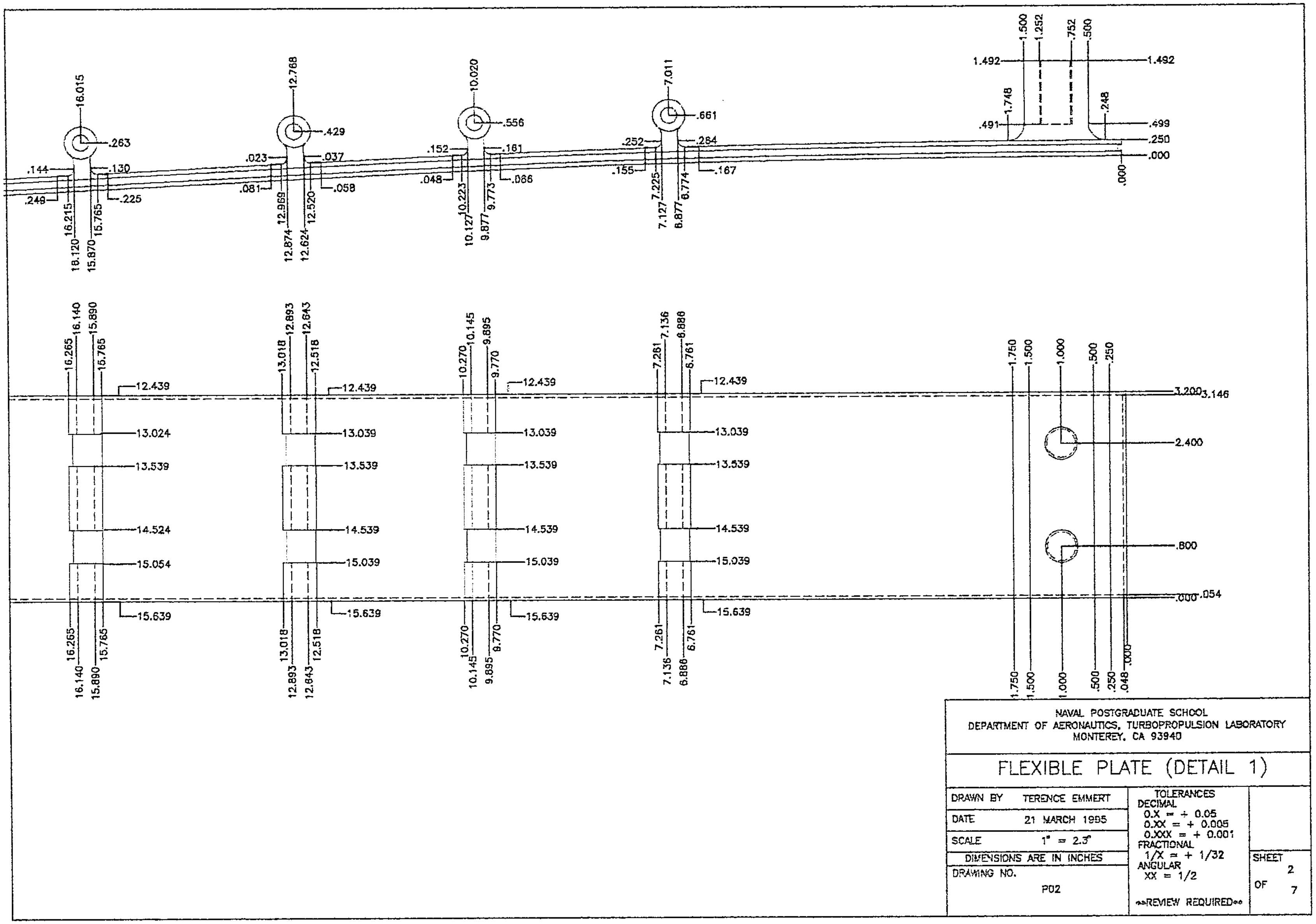
X	Y	X	Y	X	Y
-24.858	-0.8043	-22.2682	-0.7543	-17.7947	-0.5766
-24.8525	-0.8043	-22.1688	-0.7515	-17.6953	-0.5718
-24.847	-0.8042	-22.0694	-0.7486	-17.5959	-0.567
-24.8415	-0.8042	-21.97	-0.7456	-17.4965	-0.5621
-24.836	-0.8041	-21.8706	-0.7426	-17.3971	-0.5573
-24.8305	-0.8041	-21.7712	-0.7395	-17.2977	-0.5524
-24.825	-0.804	-21.6718	-0.7364	-17.1982	-0.5475
-24.8195	-0.804	-21.5724	-0.7332	-17.0988	-0.5425
-24.814	-0.8039	-21.4729	-0.7299	-16.9994	-0.5376
-24.8085	-0.8039	-21.3735	-0.7266	-16.9	-0.5326
-24.803	-0.8038	-21.2741	-0.7232	-16.8006	-0.5276
-24.7975	-0.8038	-21.1747	-0.7198	-16.7012	-0.5226
-24.792	-0.8037	-21.0753	-0.7163	-16.6018	-0.5176
-24.7865	-0.8036	-20.9759	-0.7128	-16.5024	-0.5126
-24.781	-0.8036	-20.8765	-0.7092	-16.4029	-0.5075
-24.7755	-0.8035	-20.7771	-0.7055	-16.3035	-0.5024
-24.77	-0.8035	-20.6777	-0.7018	-16.2041	-0.4974
-24.7645	-0.8034	-20.5782	-0.6981	-16.1047	-0.4923
-24.759	-0.8034	-20.4788	-0.6943	-16.0053	-0.4872
-24.7535	-0.8033	-20.3794	-0.6905	-15.9059	-0.4821
-24.7535	-0.8033	-20.28	-0.6866	-15.8065	-0.477
-24.6541	-0.8022	-20.1806	-0.6827	-15.7071	-0.4719
-24.5547	-0.8011	-20.0812	-0.6787	-15.6077	-0.4668
-24.4553	-0.7998	-19.9818	-0.6747	-15.5082	-0.4616
-24.3559	-0.7985	-19.8824	-0.6706	-15.4088	-0.4565
-24.2565	-0.7971	-19.7829	-0.6665	-15.3094	-0.4513
-24.1571	-0.7957	-19.6835	-0.6623	-15.21	-0.4462
-24.0577	-0.7941	-19.5841	-0.6581	-15.1106	-0.4411
-23.9582	-0.7925	-19.4847	-0.6539	-15.0112	-0.4359
-23.8588	-0.7908	-19.3853	-0.6496	-14.9118	-0.4308
-23.7594	-0.7891	-19.2859	-0.6453	-14.8124	-0.4256
-23.66	-0.7872	-19.1865	-0.641	-14.7129	-0.4205
-23.5606	-0.7853	-19.0871	-0.6366	-14.6135	-0.4153
-23.4612	-0.7834	-18.9877	-0.6322	-14.5141	-0.4102
-23.3618	-0.7813	-18.8882	-0.6277	-14.4147	-0.405
-23.2624	-0.7792	-18.7888	-0.6232	-14.3153	-0.3999
-23.1629	-0.777	-18.6894	-0.6187	-14.2159	-0.3948
-23.0635	-0.7748	-18.59	-0.6141	-14.1165	-0.3897
-22.9641	-0.7724	-18.4906	-0.6096	-14.0171	-0.3845
-22.8647	-0.77	-18.3912	-0.6049	-13.9177	-0.3794
-22.7653	-0.7676	-18.2918	-0.6003	-13.8182	-0.3743
-22.6659	-0.7651	-18.1924	-0.5956	-13.7188	-0.3692
-22.5665	-0.7625	-18.0929	-0.5909	-13.6194	-0.3641
-22.4671	-0.7598	-17.9935	-0.5862	-13.52	-0.3591
-22.3677	-0.7571	-17.8941	-0.5814	-13.4206	-0.354

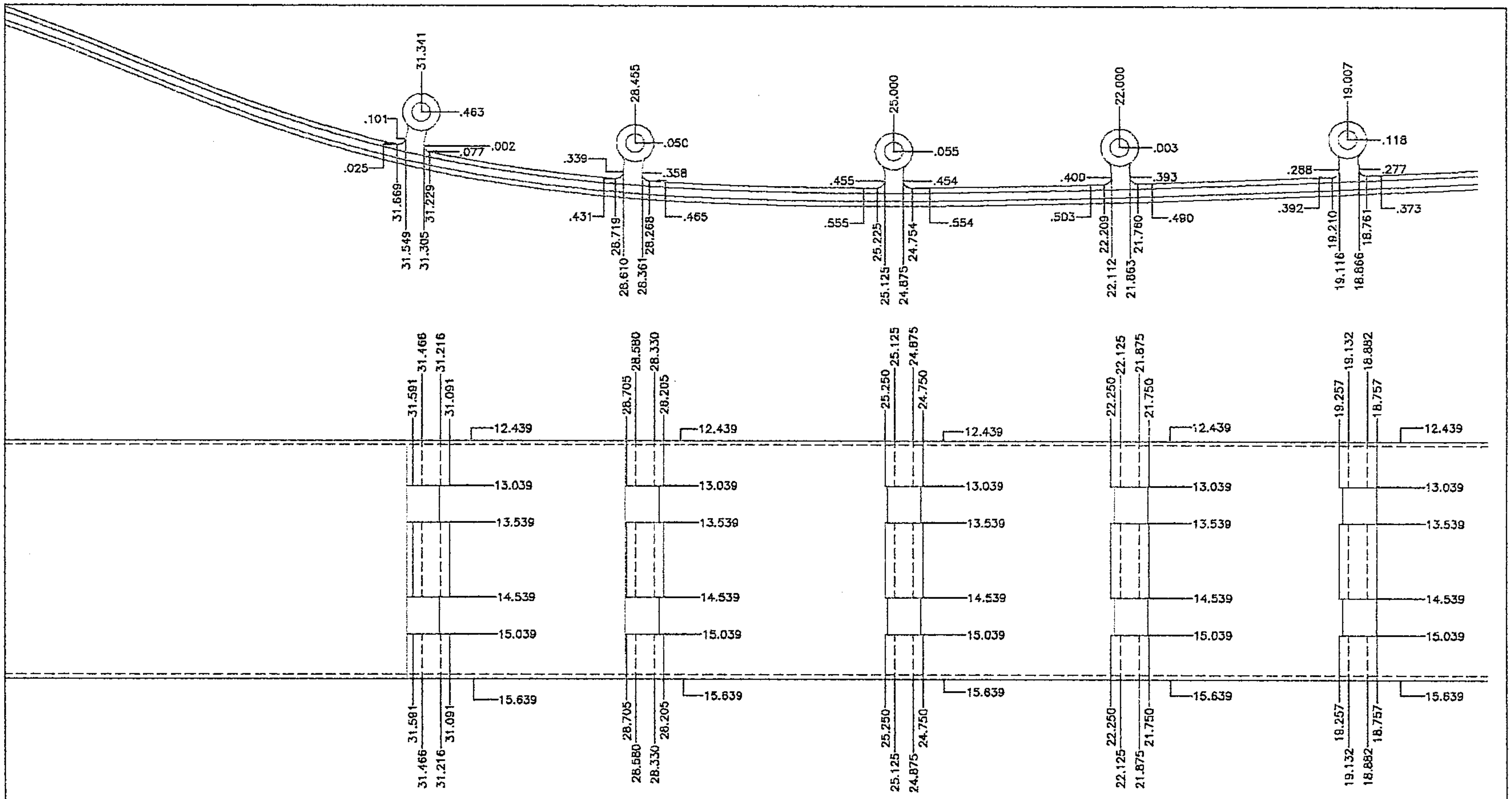
Table 6. (cont) Coordinates of Mach 1.7 Nozzle Contour

X	Y	X	Y	X	Y
-13.3212	-0.349	-8.8477	-0.1478	-4.3741	-0.036
-13.2218	-0.3439	-8.7482	-0.1442	-4.2747	-0.0346
-13.1224	-0.3389	-8.6488	-0.1406	-4.1753	-0.0333
-13.0229	-0.3339	-8.5494	-0.1371	-4.0759	-0.032
-12.9235	-0.3289	-8.45	-0.1336	-3.9765	-0.0307
-12.8241	-0.3239	-8.3506	-0.1302	-3.8771	-0.0295
-12.7247	-0.319	-8.2512	-0.1269	-3.7776	-0.0283
-12.6253	-0.314	-8.1518	-0.1236	-3.6782	-0.0271
-12.5259	-0.3091	-8.0524	-0.1203	-3.5788	-0.026
-12.4265	-0.3042	-7.9529	-0.1171	-3.4794	-0.0249
-12.3271	-0.2993	-7.8535	-0.1139	-3.38	-0.0238
-12.2277	-0.2944	-7.7541	-0.1108	-3.2806	-0.0228
-12.1282	-0.2896	-7.6547	-0.1078	-3.1812	-0.0218
-12.0288	-0.2848	-7.5553	-0.1048	-3.0818	-0.0208
-11.9294	-0.28	-7.4559	-0.1018	-2.9824	-0.0199
-11.83	-0.2752	-7.3565	-0.0989	-2.8829	-0.019
-11.7306	-0.2705	-7.2571	-0.0961	-2.7835	-0.0181
-11.6312	-0.2658	-7.1576	-0.0933	-2.6841	-0.0172
-11.5318	-0.2611	-7.0582	-0.0906	-2.5847	-0.0163
-11.4324	-0.2564	-6.9588	-0.0879	-2.4853	-0.0155
-11.3329	-0.2518	-6.8594	-0.0852	-2.3859	-0.0147
-11.2335	-0.2472	-6.76	-0.0827	-2.2865	-0.0139
-11.1341	-0.2426	-6.6606	-0.0801	-2.1871	-0.0131
-11.0347	-0.2381	-6.5612	-0.0777	-2.0876	-0.0123
-10.9353	-0.2336	-6.4618	-0.0752	-1.9882	-0.0116
-10.8359	-0.2291	-6.3624	-0.0729	-1.8888	-0.0108
-10.7365	-0.2247	-6.2629	-0.0706	-1.7894	-0.0101
-10.6371	-0.2203	-6.1635	-0.0683	-1.69	-0.0094
-10.5377	-0.2159	-6.0641	-0.0661	-1.5906	-0.0087
-10.4382	-0.2116	-5.9647	-0.0639	-1.4912	-0.0081
-10.3388	-0.2073	-5.8653	-0.0618	-1.3918	-0.0074
-10.2394	-0.203	-5.7659	-0.0598	-1.2924	-0.0068
-10.14	-0.1988	-5.6665	-0.0578	-1.1929	-0.0061
-10.0406	-0.1946	-5.5671	-0.0558	-1.0935	-0.0055
-9.9412	-0.1905	-5.4676	-0.0539	-0.9941	-0.0049
-9.8418	-0.1864	-5.3682	-0.052	-0.8947	-0.0043
-9.7424	-0.1823	-5.2688	-0.0502	-0.7953	-0.0038
-9.6429	-0.1783	-5.1694	-0.0485	-0.6959	-0.0032
-9.5435	-0.1743	-5.07	-0.0468	-0.5965	-0.0027
-9.4441	-0.1704	-4.9706	-0.0451	-0.4971	-0.0022
-9.3447	-0.1665	-4.8712	-0.0435	-0.3976	-0.0017
-9.2453	-0.1627	-4.7718	-0.0419	-0.2982	-0.0012
-9.1459	-0.1589	-4.6724	-0.0403	-0.1988	-0.0008
-9.0465	-0.1551	-4.5729	-0.0388	-0.0994	-0.0004
-8.9471	-0.1514	-4.4735	-0.0374	0	0

Table 6. (cont) Coordinates of Mach 1.7 Nozzle Contour


1.000
1.492
31.341
28.455
25.000
22.000
19.007
16.015
12.768
10.020
7.011
.543
2.503
3.200
ø.500
THREAD FOR 1/2-24 NS
MAJOR = .5
ROOT = .4459
44.553
NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940
FLEXIBLE PLATE
DRAWN BY TERENCE EMMERT
DATE 21 MARCH 1995
SCALE 1" = 6.9"
DIMENSIONS ARE IN INCHES
DRAWING NO.
P01
TOLERANCES
DECIMAL
0.X = + 0.05
0.XX = + 0.005
0.XXX = + 0.001
FRACTIONAL
1/X = + 1/32
ANGULAR
XX = 1/2
REVIEW REQUIRED
SHEET 1
OF 7


NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940
FLEXIBLE PLATE (DETAIL 1)
DRAWN BY TERENCE EMMERT
DATE 21 MARCH 1995
SCALE 1" = 2.3"
DIMENSIONS ARE IN INCHES
DRAWING NO. P02
TOLERANCES
DECIMAL
0.X = ± 0.05
0.XX = ± 0.005
0.XXX = ± 0.001
FRACTIONAL
1/X = ± 1/32
ANGULAR
XX = 1/2
REVIEW REQUIRED
SHEET 2
OF 7



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DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

FLEXIBLE PLATE (DETAIL 2)

DRAWN BY TERENCE EMMERT

DATE 21 MARCH 1995

SCALE 1" = 2.5"

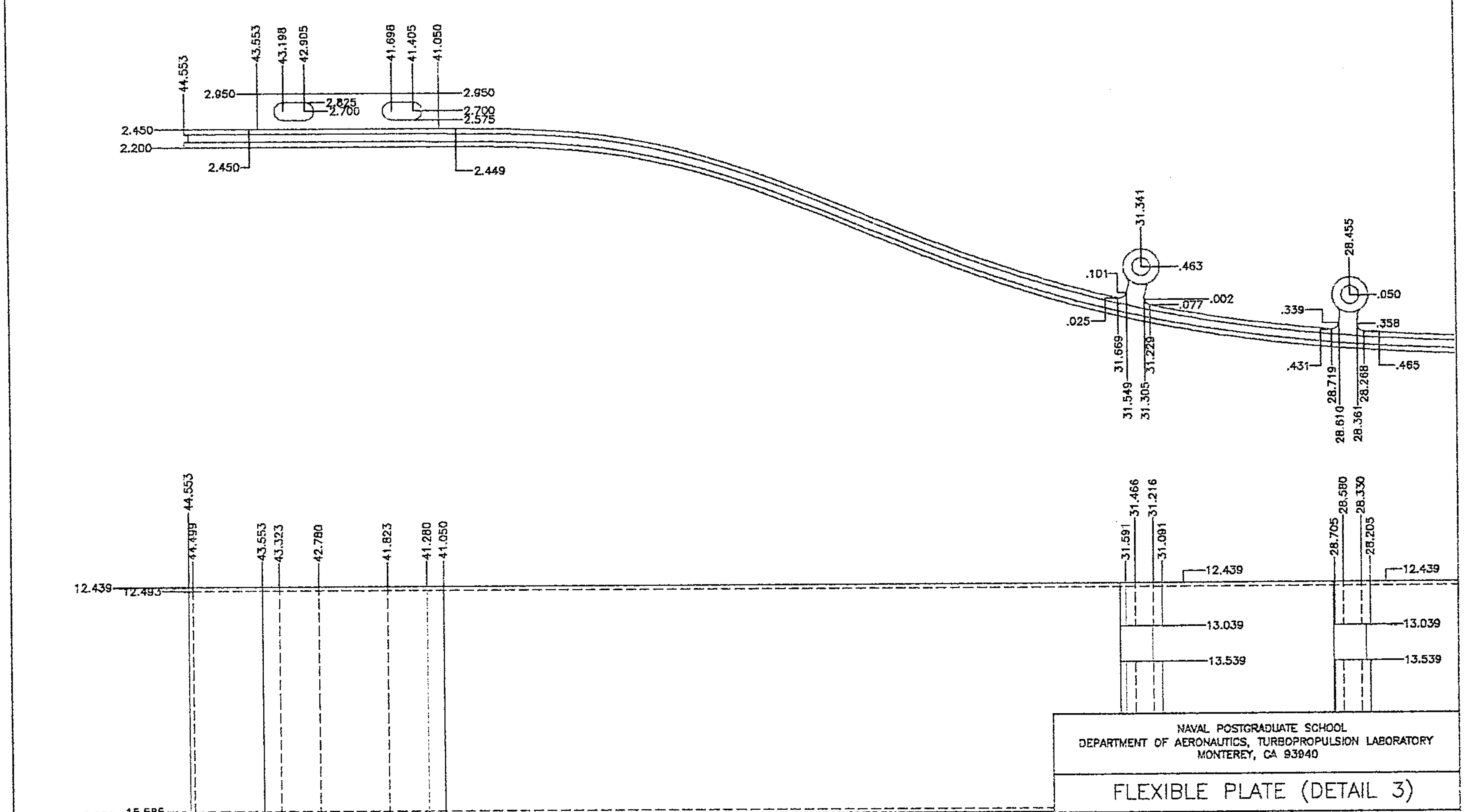
DIMENSIONS ARE IN INCHES

DRAWING NO. P03

TOLERANCES
DECIMAL
0.X = + 0.05
0.XX = + 0.005
0.XXX = + 0.001
FRACTIONAL
1/X = + 1/32
ANGULAR
XX = 1/2

REVIEW REQUIRED

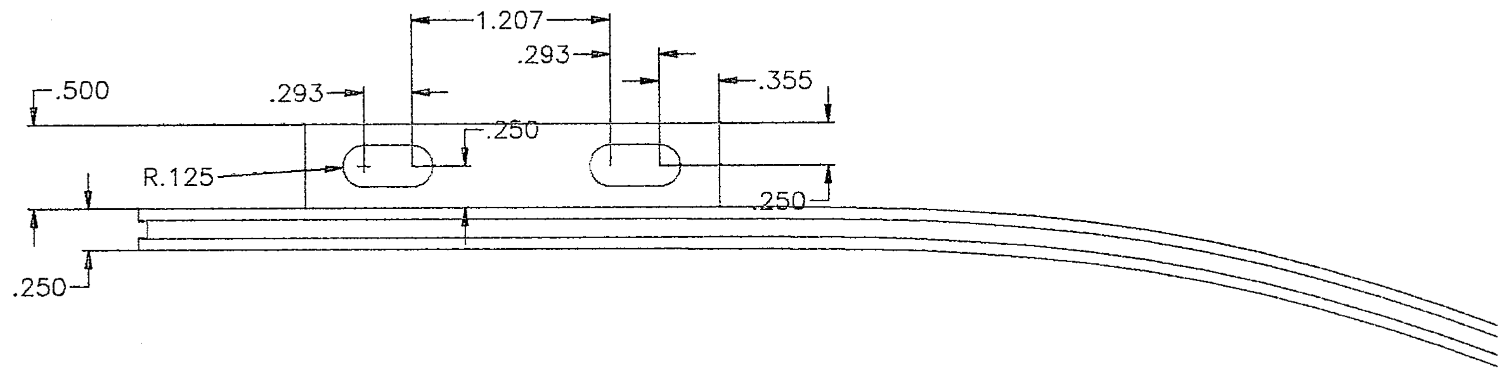
SHEET 3 OF 7



NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

FLEXIBLE PLATE (DETAIL 3)

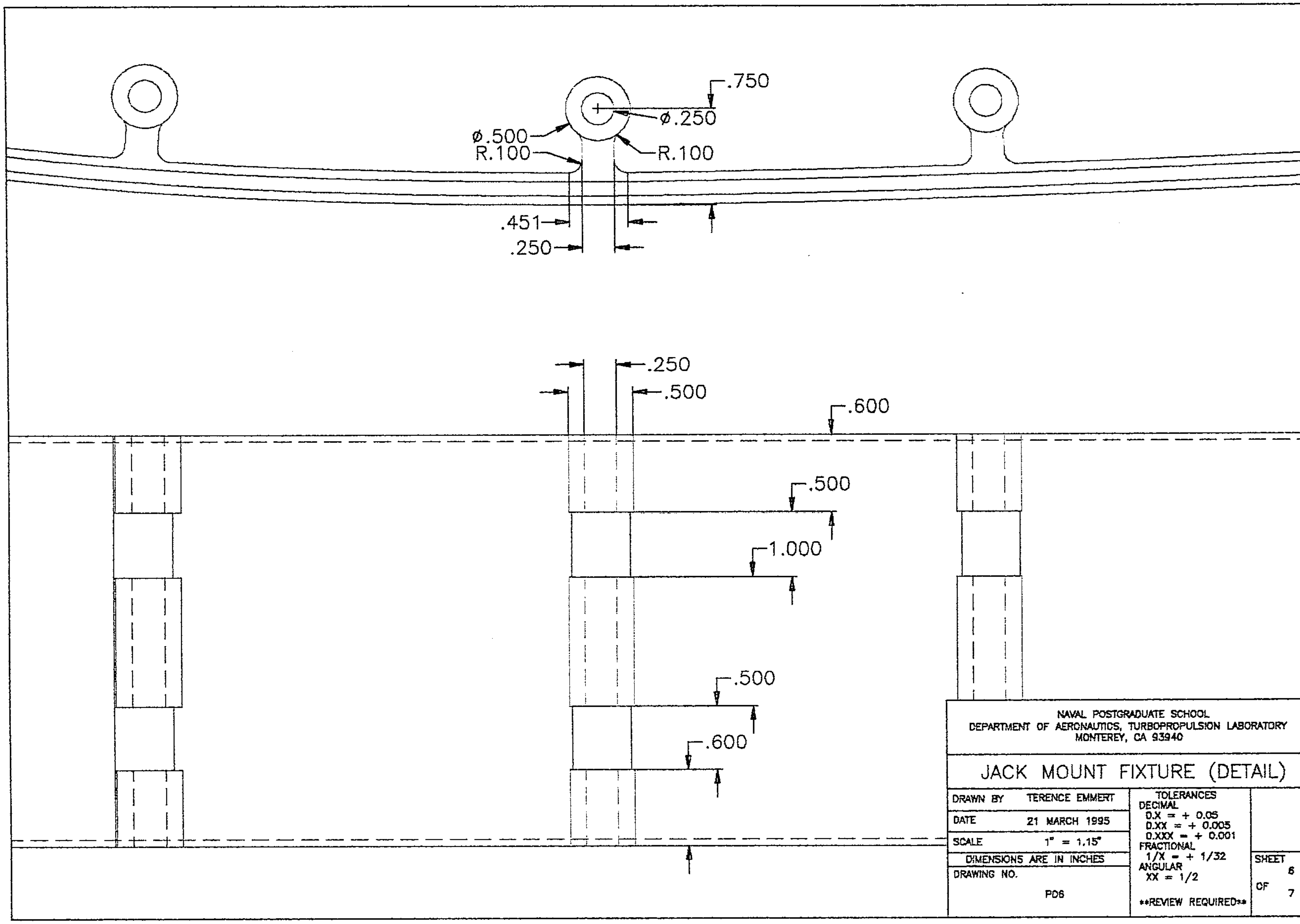
DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	
DATE	21 MARCH 1995		
SCALE	1" = 2.3"		
DIMENSIONS ARE IN INCHES			SHEET 4
DRAWING NO.	F04		OF 7



NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

SLIP JOINT

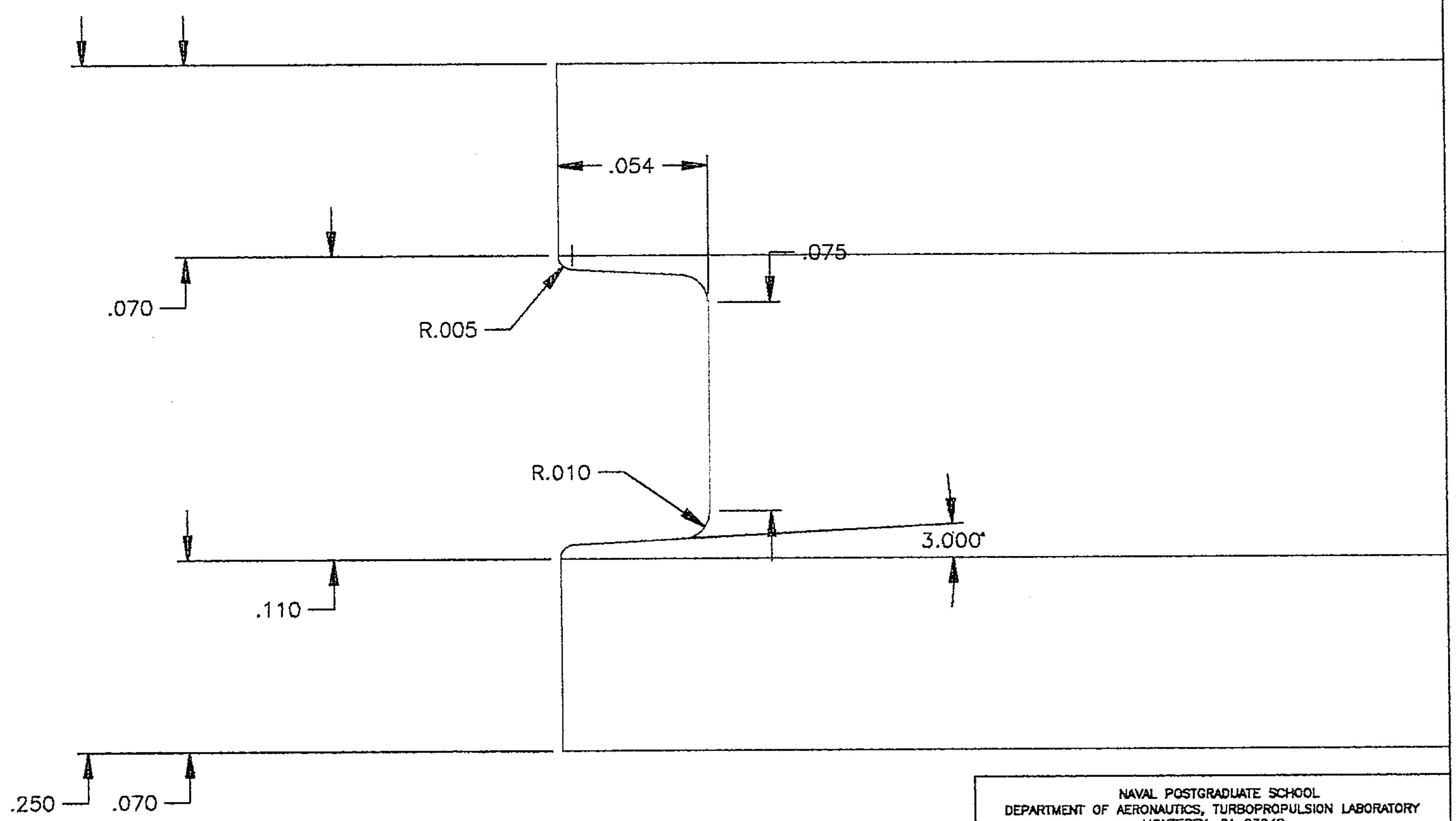
DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	SHEET 5 OF 7
DATE	21 MARCH 1995		
SCALE	1" = 1.15"		
DIMENSIONS ARE IN INCHES			
DRAWING NO.	P05		



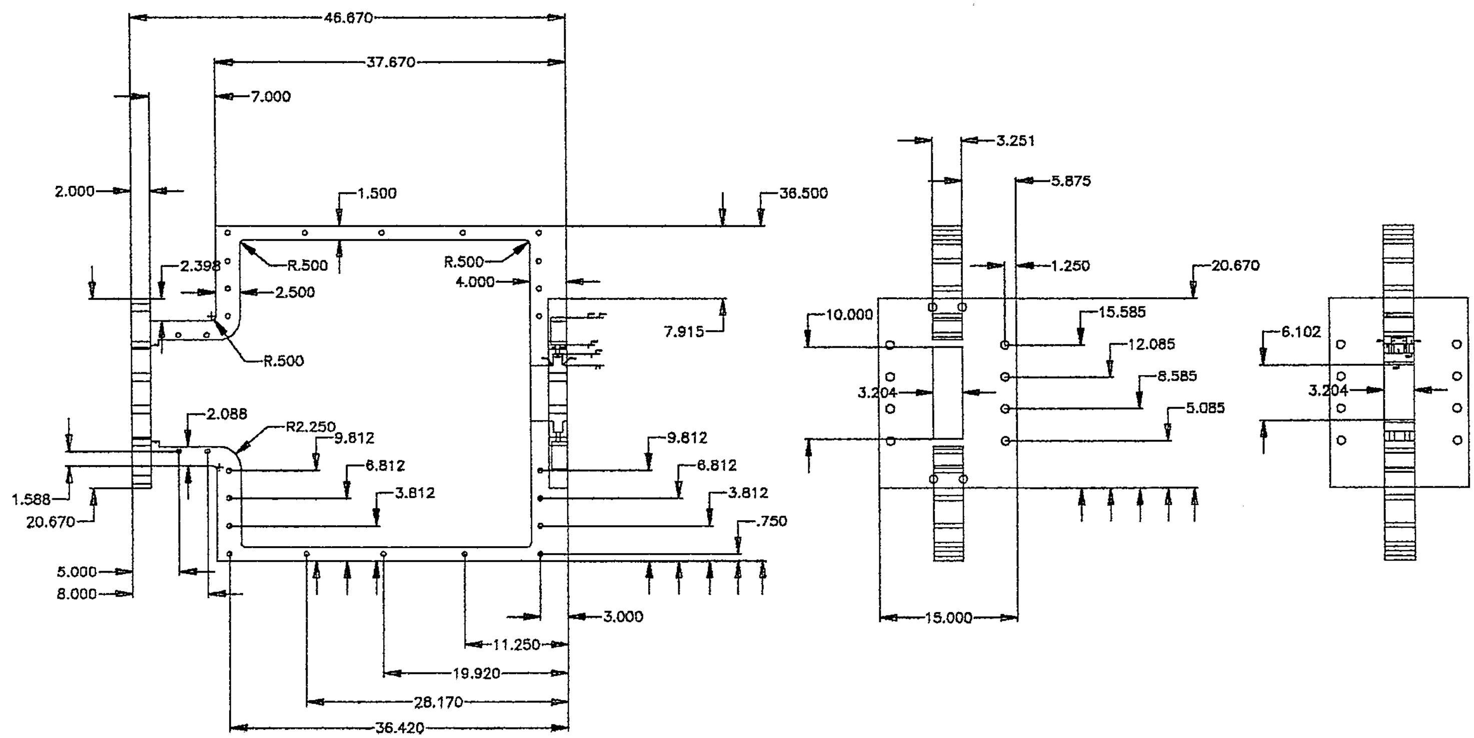
NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

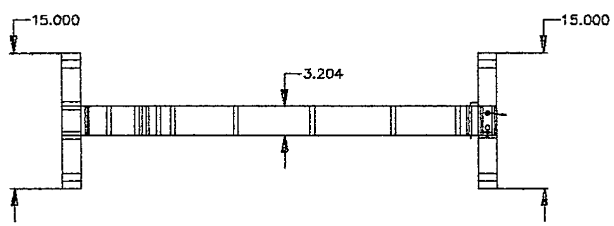
JACK MOUNT FIXTURE (DETAIL)

DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	
DATE	21 MARCH 1995		
SCALE	1" = 1.15"		
DIMENSIONS ARE IN INCHES			SHEET 6
DRAWING NO.	PD6		OF 7

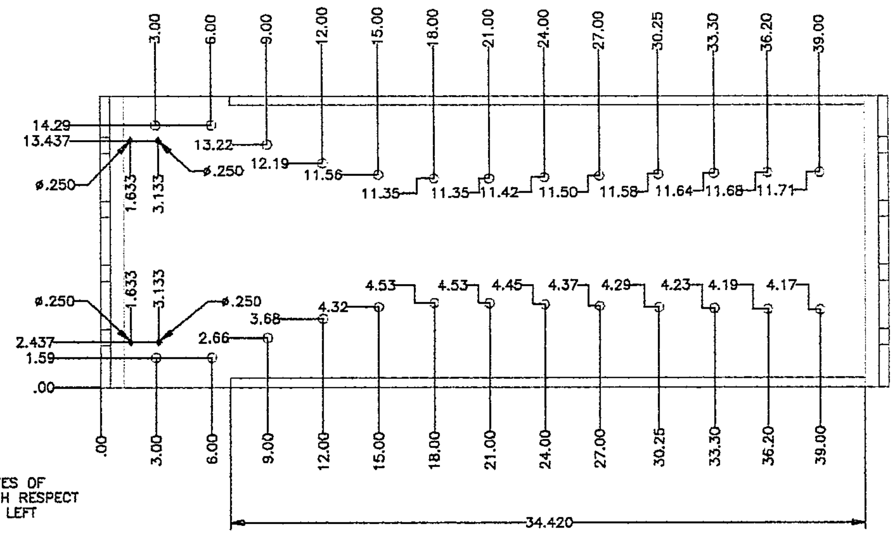


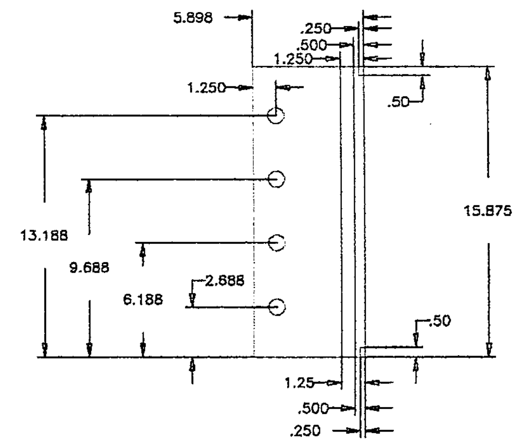
NAVAL POSTGRADUATE SCHOOL DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY MONTEREY, CA 93940			
O-RING GLAND (DETAIL)			
DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	
DATE	21 MARCH 1995		
SCALE	1" = .069"		SHEET 7 OF 7
DIMENSIONS ARE IN INCHES			
DRAWING NO.	P07		

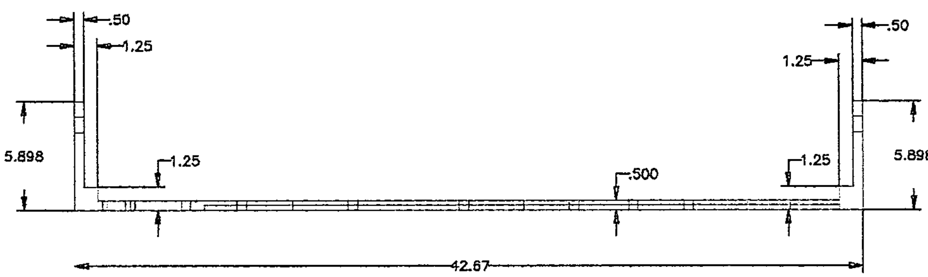




NAVAL POSTGRADUATE SCHOOL DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY MONTEREY, CA 93940	
INNER FRAME	
DRAWN BY TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRE**
DATE 19 MAR 1995	
SCALE 1" = 20.7"	
DIMENSIONS ARE IN INCHES	SHEET 1 OF 1
DRAWING NO. F01	







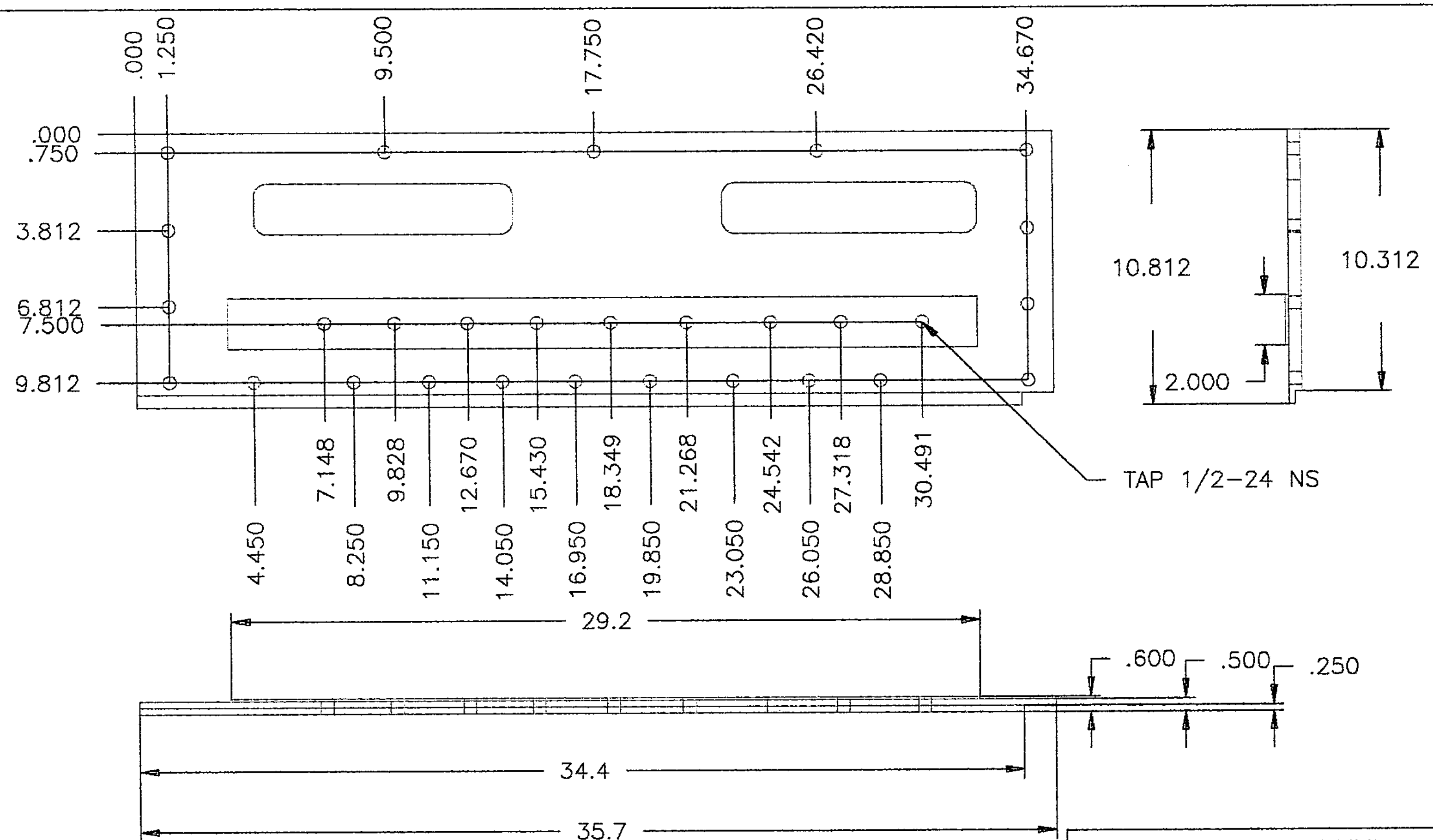
TWO NOZZLE SIDEPLATES ARE REQUIRED

ALL HOLES 1/2 INCH DIAMETER
UNLESS OTHERWISE SPECIFIED

NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

NOZZLE SIDEPLATE

DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	SHEET 1 OF 1
DATE	20 MARCH 1995		
SCALE	1" = 10.35"		
DIMENSIONS ARE IN INCHES			
DRAWING NO.	NP01		



COORDINATES OF HOLES WITH RESPECT TO UPPER LEFT CORNER

HOLES ARE 1/2 INCH DIAMETER UNLESS OTHERWISE SPECIFIED

NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF AERONAUTICS, TURBOPROPULSION LABORATORY
MONTEREY, CA 93940

JACK SIDEPLATE

DRAWN BY	TERENCE EMMERT	TOLERANCES DECIMAL 0.X = + 0.05 0.XX = + 0.005 0.XXX = + 0.001 FRACTIONAL 1/X = + 1/32 ANGULAR XX = 1/2 **REVIEW REQUIRED**	SHEET 1 OF 1
DATE	20 MARCH 1995		
SCALE	1" = 6.9"		
DIMENSIONS ARE IN INCHES			
DRAWING NO.	JP01		

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