REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 14 December 1999	3. REPORT TYPE AND DATES COVERED Final: 13 August to 14 December, 1999

4. TITLE AND SUBTITLE
Advanced Technology Inlet Design, NRA 8-21 Cycle II:
DRACO Flowpath Hypersonic Inlet Design

5. FUNDING NUMBERS
Purchase Order No. H-31407D

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8. PERFORMING ORGANIZATION REPORT NUMBER
TR-121499

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The report outlines work performed in support of the flowpath development for the DRACO engine program. The design process initiated to develop a hypersonic axisymmetric inlet for a Mach 6 rocket-based combined cycle (RBCC) engine is discussed. Various design parametrics were investigated, including design shock-on-lip Mach number, cone angle, throat Mach number, throat angle, length of distributed compression, and subsonic diffuser contours. Conceptual mechanical designs consistent with installation into the D-21 vehicle were developed. Additionally, program planning for an intensive inlet development program to support a Critical Design Review in three years was performed. This development program included both analytical and experimental elements and support for a flight-capable inlet mechanical design.

14. SUBJECT TERMS
Hypersonic Inlets, Rocket-Based Combined Cycle Propulsion

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Computer Generated STANDARD FORM 298 (Rev 2-89)
Prescribed by ANSI Std 239-18
298-102

ADVANCED TECHNOLOGY INLET DESIGN, NRA 8-21 CYCLE II

Purchase Order No. H-31407D

DRACO FLOWPATH HYPERSONIC INLET DESIGN

Final Report

TechLand Research Report No: TR 121499

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December 1999

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Section I: Introduction

NASA Marshall Space Flight Center in partnership with NASA Glenn Research Center is pursuing the development of a hydrocarbon fueled, Rocket Based Combined Cycle engine called DRACO as part of the Spaceliner 100 activity. TechLand, through this contract with Marshall, is to support the NASA Glenn development of the flow path by providing inlet/propulsion system design expertise.

The engine system operates over a wide range of flight conditions from static to hypersonic speeds. TechLands overall contractual requirement is to work in partnership with NASA Glenn Research Center to support the development of the hypersonic inlet system for the rocket-based combined-cycle DRACO engine. This research is directed toward aerodynamic design of the inlet system, advanced analysis, the development of wind tunnel models and follow-on freejet flow path models and data analysis.

Section II: Results

The initial guidelines for the development of a hypersonic inlet for the DRACO engine were defined during a kickoff meeting of the DRACO Flowpath Team in August 1999. The members of the inlet design team are listed in figure 1. Planning guidelines for the inlet design and development are presented in figure 2. The inlet was to be designed for Mach 5 (shock on lip), allow overspeed operation to Mach 6, be axisymmetric and include variable geometry and bleed. It was also to be compatible with installation in the D-21 vehicle. Even though the D-21 vehicle is capable of flying to Mach numbers slightly higher than Mach 3, a Mach 6 capable inlet design was required. The planned program included ground testing that simulated Mach 6 flight conditions.

D-21 installation and operation requirements for the inlet are shown in figure 3. The inlet would be required to operate from Mach 0.6 to 3.5 when installed in the D-21. The cowl lip radius is 14 inches with a diffuser exit geometry of a 10 inch radius cowl and a 2.5 inch centerbody. The 2.5 inch centerbody at the diffuser exit allows the inlet to be close coupled to the engine during ground testing. The 10 inch radius of the cowl matches the long duct of the D-21. While a match of the inlet to the D-21 duct flange would be desirable, it imposes a rather severe length restriction on the hypersonic inlet. This would require that the Mach 6 hypersonic inlet fit in the same length as the existing Mach 3+ inlet. Results presented in this write up will indicate that this constraint can not be met, particularly for inlets with low centerbody cone angles.

The aerodynamic design details are shown in figures 4, 5 and 6. The inlet is an axisymmetric configuration that was to be designed for Mach 5 with an overspeed capability to Mach 6.0. The shock from the cone tip intersects the cowl lip (shock on lip) at the design Mach number of 5.0. The shock wave generated by the cowl lip is canceled at the centerbody shoulder by a turn in the centerbody surface. The remaining supersonic compression is isentropic from the centerbody shoulder to the throat station. A terminal shock is maintained at the inlet throat to transition the flow from supersonic to subsonic conditions. The length of this distributed compression to the throat and the throat Mach number are important parameters in the design process. The length must be sufficiently large to avoid too large a pressure rise over a short distance. Throat Mach numbers must be compatible with the placement of a terminal shock . If the shock strength is too large, the pressure rise across the shock will result in boundary layer separation. Therefore, nominal terminal shock Mach numbers of 1.2 to 1.4 are generally selected. Inlets designed during this work effort have been designed to provide inviscid throat Mach numbers of 1.5 to 1.6. These levels were chosen with the intention that viscous effects would effectively reduce the Mach number to a lower level. Inlets designed with these throat Mach numbers will allow the first phase of a later viscous analysis to be performed.

The initial inlet designs presented in this report do not represent optimum designs. As indicated in figure 7, this purpose of the initial design process was to begin to develop an understanding of the type of configuration that is required for the DRACO vehicle (i.e., what does the inlet want to look like). Two initial inlets with 12° and 15° cones were designed. Aerodynamic characteristics for the 15° configuration are shown in figure 8. The characteristic net is presented above, and plots of surface Mach number and static pressure recovery are shown below. Dashed curves indicate conditions on the ramp, and solid curves indicate conditions on the cowl surface. This inlet was designed for a Mach number of 5 with an inviscid throat Mach number of 1.5. It generates a rather steep static pressure rise from the inlet shoulder to the throat station (red curves from a station of about 3.3 to 4.0). An inviscid analysis of the inlet with the NPARC code is presented in figure 9. Color Mach number contours are plotted. This figure is similar to sketch shown in figure 5. The results of a fully viscous analysis are presented in figures 10 (Mach number), 11 (temperature) and 12 (detail near shoulder). Obviously, the viscous analysis indicates some flow field problems within the inlet. This was expected since the design was not totally compensated for boundary layer and this preliminary analysis did not include bleed modeling. The higher design throat Mach number of 1.5 did allow a converged viscous solution to be obtained. The prime reason for the CFD viscous analysis was to evaluate the interaction of the cowl shock with the boundary layer at the centerbody shoulder, as shown in detail at the top of figure 12. The desire is to design the inlet such that the pressure rise from the cowl shock centerbody boundary layer interaction will be placed at the shoulder station. Viscous effects resulted in the cowl shock interacting with the centerbody boundary layer upstream of the centerbody shoulder. The results presented in figure 12 indicate that the flow field generated by this initial design is not as bad as might be expected. The interaction did not result in a major disruption of the total inlet flow field. Adjustment of the surfaces for boundary layer effects would be part of a follow-on design effort

A sketch of this inlet and a possible variable geometry scheme is presented in figure 13. The sketch was made to begin an evaluation of how a subsonic diffuser would be integrated with the supersonic diffuser and how the entire inlet would be installed into the D-21. As indicated in the figure, the cowl lip station for the D-21 is Station 100. The beginning of the long D-21 duct is at Station 141. This allows 41 inches for installation of the DRACO inlet (cowl lip to diffuser exit), and is probably not long enough. Since the supersonic diffuser for a Mach 5 inlet is much longer than the D-21 Mach 3+ inlet, there is very little available remaining length for the subsonic diffuser of the DRACO inlet. As shown in the figure, the available room for inlet struts is also very limited. The struts in this sketch are just large enough to pass 5% bleed from the centerbody. The airflow in the subsonic diffuser will most definitely be separated. The centerbody translated for off-design operation is shown in figure 14. The centerbody is translated downstream to provide close-off of the inlet duct for rocket operation, figure 13. A sketch in which the centerbody is shown in both the design and at a forward off design position is shown in figure 16.

Several inlets (cone angles from 10° to 20°) were designed to develop trends for different amounts of external compression. The results of this effort are presented in figures 17 to 19. As shown in figure 17, the length of the inlet to the throat station decreases as the cone angle is increased. This increased inlet length due to smaller cone angle can be more easily seen in figure 18. At the top of this figure, the centerbody for each of the inlets of figure 17 was translated upstream until each centerbody shoulder matched the same cowl lip station to allow the results of figure 19 to be determined. Figure 19 indicates that the available flow area at the shoulder increases with decreased cone angle (from an A_{sh}/A_c of 0.164 at 20° to about 0.34 at 10°).

The data in figure 19 indicate that increased flow area (mass flow) would be available at off-design conditions if a lower cone angle were utilized. Therefore, a 12.5° angle was chosen for continued design as indicated in figure 20. Aerodynamic characteristics of the 12.5° inlet are presented in figure 21. A sketch showing the inlet and subsonic diffuser is presented in figure 22. A comparison of this figure with figure 13 shows that the subsonic diffuser length is even more restricted if an attempt is made to meet the 41 inch restriction of the D-21. The airflow in this subsonic diffuser will also be separated. This is the result of the longer inlet (cowl lip to throat) resulting from the lower cone angle.

A centerbody translation schedule for the 12.5° inlet is presented in figure 23. This centerbody schedule was selected to maintain the cowl shock on the inlet shoulder at the off-design conditions. The desire was to place the cowl shock on the shoulder and to also provide an acceptable throat Mach number. For the translation schedule of figure 23, the throat Mach numbers at off-design conditions are higher than would be acceptable for a good inlet. This schedule was used only as a means of determining the next step needed in the design process. Translation is presented in inches and in non-dimensional values. Inlet geometries for Mach numbers of 5, 4, 3 and 2.0 are presented in figure 24. The inlet geometry for a condition in which the centerbody is translated such that the shoulder is at the cowl lip is also shown. The downstream end of the centerbody does not translate. The translating portion of the centerbody slides on a cylinder with a r/Ri slightly greater than 0.3. Vertical cross-sectional duct-area distributions for the inlet configurations of figure 24 are shown in figure 25. These curves indicate that the throat remains near the design position for the off-design Mach numbers of 4 and 3. However, the throat moves a large distance upstream for the Mach 2 centerbody position. The throat location as a function of Mach number is shown in figure 26. Throat areas at off-design conditions are shown in figure 27. The resulting capture mass-flow ratios are presented in figure 28. The capture mass-flow for the Trailblazer inlet is shown for purpose of comparison.

If the inlet is installed within the available D-21 length, the length for struts is severely restricted, as shown in figure 29. The more desirable option would be to extend the inlet contours into the long duct of the D-21 as shown in figure 30 or as shown in figure 31. These installations assume that the D-21 duct can provide structural support.

Guidelines for generating a program plan are presented in figure 32. A preliminary layout of a test program is presented in figures 32 and 33, respectively. The overall program guidelines in figure 32 indicate that a CDR occurs in 3 years and a flight ready inlet must be ready in 6 years. Figure 33 shows the first three years of the development program to meet these goals. It includes a flight-weight inlet design effort and inlet test models for the Glenn 1X1 SWT, 10X10 SWT and HTF facilities. The planned small-scale inlet program for the Glenn 1X1 SWT is described in figure 34. A sketch of the 1X1 SWT test parametrics is presented in figure 35. The program plans for the Glenn 10X10 SWT and HTF test programs are presented in figures 36 and 37. These design and planning efforts were presented during the first review (midterm report).

Due to a desire for a large capture mass flow at off-design conditions and the indication of the data presented in figure 38 (also figure 19), an additional inlet design was initiated. A cone angle of 10° was chosen for the centerbody of this new inlet. Three inlets were designed. Each of these inlets incorporated a single initial cone angle of 10° and throat angles were set at -5°, -10° and -15°, respectively. These inlets are presented in figures 39 to 41. Evaluation of the throat region of these inlets shows that a selected amount of centerbody translation for the inlet with the -15° throat of figure 39 would provide a larger amount of change in throat area than would a similar amount of centerbody translation for the inlet with the -5° throat of figure 41. As the throat angle approaches 0°, the amount of increased area approaches 0.0 for all values of translation. The diffuser area curves of figure 25 indicate that the throat area changes rather rapidly and tends to move forward in an inlet with a throat angle of -15°; therefore, a throat angle of -10° was selected for the 10° cone inlet.

Aerodynamic contours for the 10° cone inlet are presented in figure 42. The design of the subsonic diffuser for this inlet is based on the assumption that it can either be installed inside the existing D-21 duct or that the D-21 duct can be replaced with a duct that matches the inlet diffuser exit. A sketch of the inlet, with the cowl lip located at D-21 station 100 and a part of the subsonic diffuser placed inside the long D-21 duct, is presented in figure 43. Strut mounting of the centerbody would be similar to the sketches of figures 30 and 31. Diffuser cross-sectional area distributions for several centerbody translations (from 0 to 14.4 in. in 0.4 in. increments) are shown in figure 44. An expanded version of this figure is presented in figure 45. The area curves of this figure indicate that the minimum area remained at approximately the design throat station (about station 88.4) for translations from 0 to about 6.4 inches. Addition translation results in a sudden shift of the throat to a downstream station of about station 100. The rate of diffusion for the subsonic diffuser is presented in figure 46. The subsonic diffuser was designed to maintain a total equivalent diffusion angle of less than 8° for the initial part of the diffuser. This diffusion angle was maintained for a significant distance to allow the flow to diffuse to a Mach number of about 0.3. The continued diffusion beyond this level at diffusion angles much larger than 8° should not present a problem due to the very low Mach numbers.

A centerbody translation schedule is presented in figure 47. Two curves are shown. The desired operation would be to keep the cowl shock on the centerbody shoulder for the off-design conditions. However, throat Mach number is an equally important consideration. For the centerbody positions represented in figure 47 for the cowl shock on shoulder (magenta squares), the throat Mach number was too low. The other translation schedule (blue diamonds) is required to provide a reasonable throat Mach number. Throat terminal shock Mach numbers should be maintained at 1.3 to 1.4. The centerbody must be translated upstream of the cowl shock/shoulder interaction to provide the translation schedule presented in figure 47. Therefore, the cowl shock will intersect the centerbody downstream of the shoulder for the lower flight Mach numbers.

Capture mass-flow ratios as a function of centerbody translation are presented in figure 48. The Mach 5 design is represented by one data point. Several mass-flows are plotted for the off-design Mach numbers. The data points at each Mach number represent a variation in mass-flow with centerbody translation. The cowl shock on centerbody shoulder and the translation schedule of figure 47 are also shown. If a Mach 3 condition is selected, this figure shows that a reduction from a mass flow ratio of about 0.54 to about 0.49 is obtained when the centerbody is translated forward of the cowl shock on shoulder point to obtain a more desirable throat Mach number. A comparison of throat location for various amounts of translation is presented in figure 49. Data for the 12.5° and 10° cone inlets are presented. The inlet design parameter that provides the greater impact on the data of figure 49 is the inlet throat angle. The curve for the 12.5° inlet with a -15° throat angle shows that the throat remains in the same place then moves forward in the inlet for the larger values of translation. The data for the 10° inlet with the 10° throat indicates that the throat initially remains in the same location then abruptly moves downstream for the larger translation values. These curves would tend to indicate that the throat could be maintained in the same location if the inlet was designed with a throat angle near -12.5°.

An analysis of figure 45 indicates that an increase in design diffuser area from inlet stations of about 95 to 115 would also impact the off-design area distribution and would effectively move all of the area curves upward in this region. The throat station would not shift downstream for the larger values of centerbody translation. Therefore, the 10° inlet was redesigned with a modified cowl geometry downstream of the throat station, as shown in figure 50. Area distributions are shown in figures 51 and 52. The data in these figures show that the inlet throat station is maintained at the same location for all values of translation. This design would allow the terminal shock to be maintained at the throat bleed station for all started inlet conditions. However, the problem with this configuration is shown in figure 53. A comparison of equivalent conical diffusion between the original 10° and the modified 10° inlets is presented. The diffusion rate for the modified inlet is too large and would most certainly result in flow separation. Therefore, contour fixes to the inlet surfaces are not adequate. A redesign of the inlet is required.

A comparison of inlet capture mass-flow ratio for the 10° and 12.5° cone inlets is shown in figure 54. Both translation schedules (shock-on-shoulder and the chosen translation schedule) are shown for the 10° inlet. Comparison of the 12.5° data (shock on shoulder) with the 10° inlet data for the shock on shoulder provides the best basis for evaluation of the inlet capture mass flow characteristics. The curve presented in figure 19 indicated that the available flow area was larger (and thus larger mass-flow rates) when the centerbody was translated such than the shoulders for the 10° and 12.5° inlets were at the cowl lip station. The comparison of the data in figure 54 does not support this trend. Obviously, the determination of capture mass-flow is influenced by more factors than area comparison at a given centerbody translation. The first factor is that the centerbody is translated different distances for a given Mach number. The second significant factor is local Mach number. The local entrance Mach number into the inlet is different for the different cone angles. Since mass-flow is a direct function of A/A*, a small change in local Mach number due to cone angle can effect a big difference in mass-flow, even for the same flow area. Therefore, the differences in mass flow of figure 54 are the result of area and local Mach number.

Inlet total pressure recovery is presented in figure 55. Inlet recovery was not determined for the inlet of this design effort. However, an attempt has been made to provide a realistic estimate of the recovery levels that could be achieved in this type of inlet. This estimate assumes that inlet bleed will be utilized in the inlet throat and, perhaps, at the inlet centerbody shoulder location. Mil Spec recovery, several curves for selected levels of η_{ke}, and recovery schedules calculated for the Trailblazer inlet are shown. The estimated recoveries tend to be lower at the low off-design Mach numbers. This is due to the estimate of larger subsonic diffuser losses than for the other recovery curves. A better estimate of inlet recovery would require a full CFD analysis on an inlet that had been designed to account for viscous effects.

Results and recommendations based on the inlet design effort are presented in figure 56. Several inviscid inlet designs were completed. These results indicate that capture mass-flow is a function of local Mach number and area. A more complete design effort will be required to maximize capture flow at the off-design conditions. The lower cone angle inlets were longer and were more difficult to integrate with the D-21 vehicle. Conceptual sketches of the inlet, including a variable geometry system, were completed. The installation with the D-21 forces a short subsonic diffuser unless a part of the inlet can be placed inside the D-21 duct. Modification of the inlet duct would be preferred. If possible, a schedule for engine airflow demand should be established. The next step would be to design an acceptable inlet to provide this airflow.

Recommendations for a continued design effort are presented in figure 57. The next phase of the inlet design effort should concentrate on a 12.5° cone inlet with a –12.5° throat. The inlet should be adjusted for viscous effects and provide the proper throat Mach numbers while maximizing off-design capture flow.

Section III: Current Problems

This report completes the work effort defined in the contract.

Section IV: Work Planned

No additional work is planned

TechLand Research, Inc.

DRACO Engine Flowpath Team

Marshall
Glenn
Dryden

Inlet Aerodynamic Design Team:

- NASA Glenn:
  - Dave Saunders
- TechLand Research, Inc.:
  - Bob Sanders
  - Lois Weir
  - Supporting the flowpath design effort through a contract with NASA Marshall

Figure 1

TechLand Research, Inc.

DRACO Hypersonic Inlet Design Requirements

Marshall
Glenn
Dryden

- Inlet design assumptions based on planning during flowpath meeting in August, 1999

Inlet Design Requirements:

- Installation in D-21
- Axisymmetric Design Mach number, $M_d = 5.0$ (shock on lip)
- Overspeed operation to Mach 6
- Translating centerbody, allow close-off of duct
- Initial internal cowl angle of 0°
- Bleed ducted overboard

Figure 2

TechLand Research, Inc.

DRACO D-21 Hypersonic Inlet
Design Requirements

Marshall
Glenn
Dryden

D-21 Installation/Operation Requirements:

- Operating Mach range on D-21: Mach 0.6 to 3.5
- Match front flange of long engine duct
  - D-21 fuselage station of 141.0
  - Cowl radius of 10 in. at duct flange
  - Centerbody radius of 2.5 in.
- Cowl lip at D-21 fuselage station of 100.0
  - Cowl lip radius of 14 in.

Figure 3

Inlet Design Process

Aerodynamic design characteristics:

- Axisymmetric translating centerbody inlet
- Design Mach number of 5.0
- Overspeed to Mach 6

Design and evaluation considerations :

- Design Mach number
- Compression system
  - Cone angle
  - Single, bi-cone, etc.
- Throat Mach number
- Throat angle
- Bleed / no bleed
- Centerbody shoulder design; sharp, rounded, bleed
- Distributed compression length (shoulder to throat)
- Off-design operation aerodynamic characteristics
- Subsonic diffuser, integration of struts
- Etc.

Figure 4

DRACO Inlet Design
Aerodynamic Characteristics

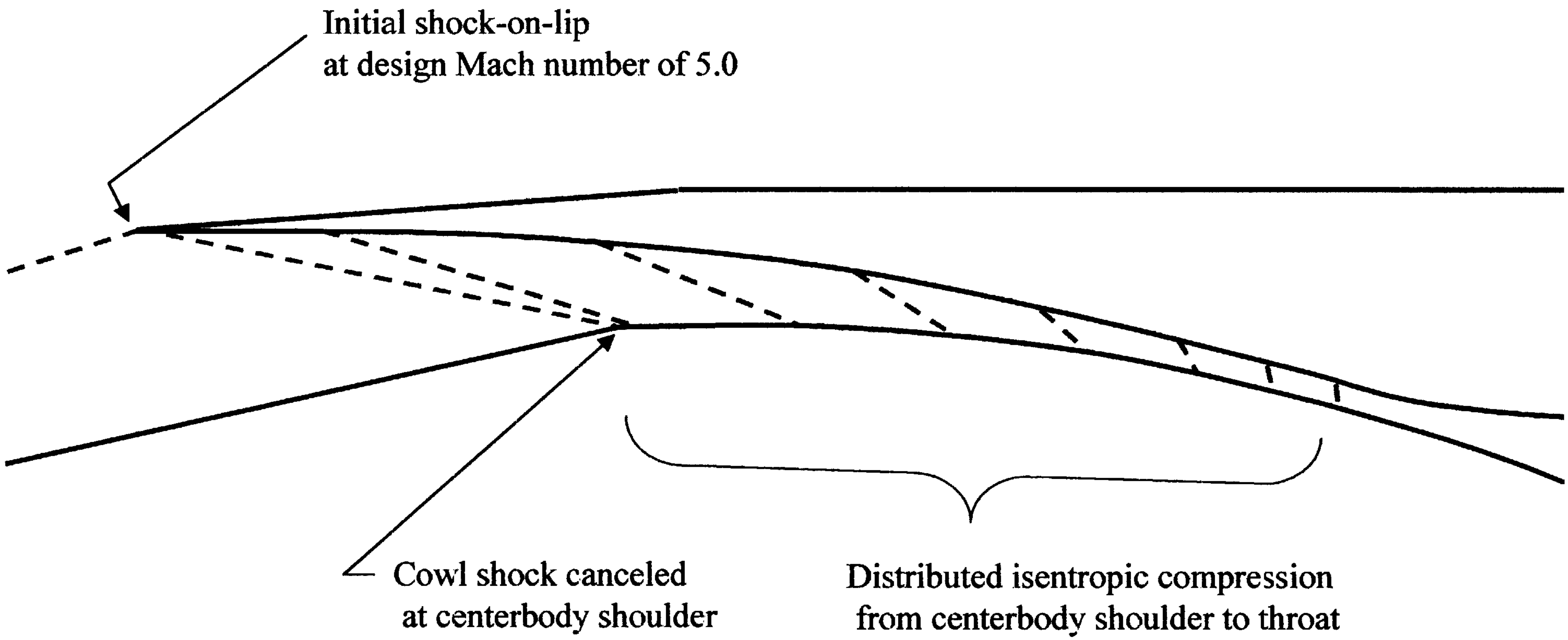


Figure 5

DRACO Hypersonic Inlet Design

Initial Inlet Design Characteristics:

- Single cone, between 10° and 15°
- Internal cowl angle of 0°
- Cowl shock canceled at inlet shoulder with isentropic compression to throat
- Inviscid throat Mach number of 1.5
- Terminal shock in throat
- Bleed functions for performance and operability
- Maneuvering requirements?

Figure 6

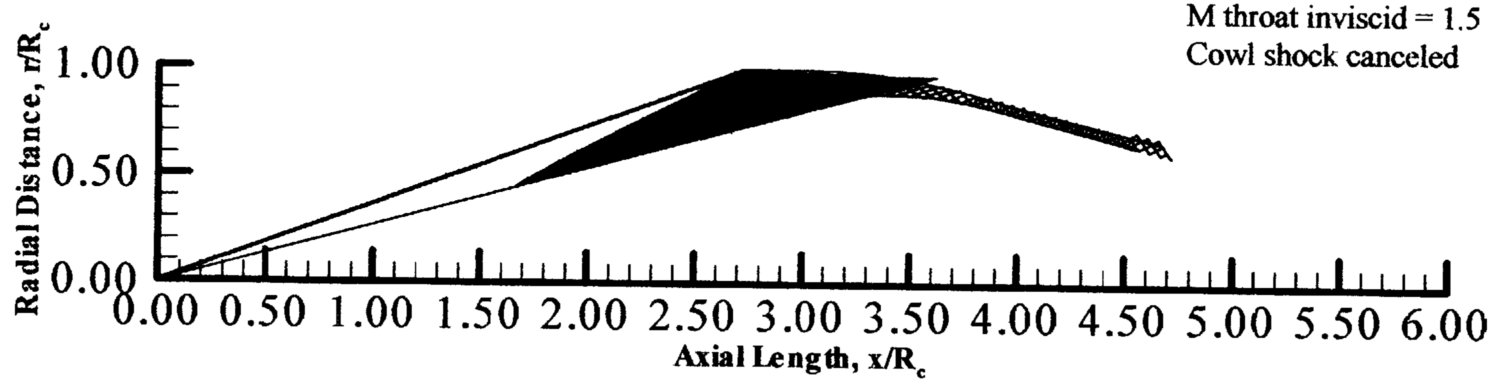
DRACO Engine Flowpath

Initial Inlet Designs:

- Start the design process
- Scope the inlet design aerodynamics
  What does the inlet want to look like?
- Initial designs of 12° and 15° single cone inlets

Figure 7

Cone angle = 15°
Throat angle = -15°
M throat inviscid = 1.5
Cowl shock canceled



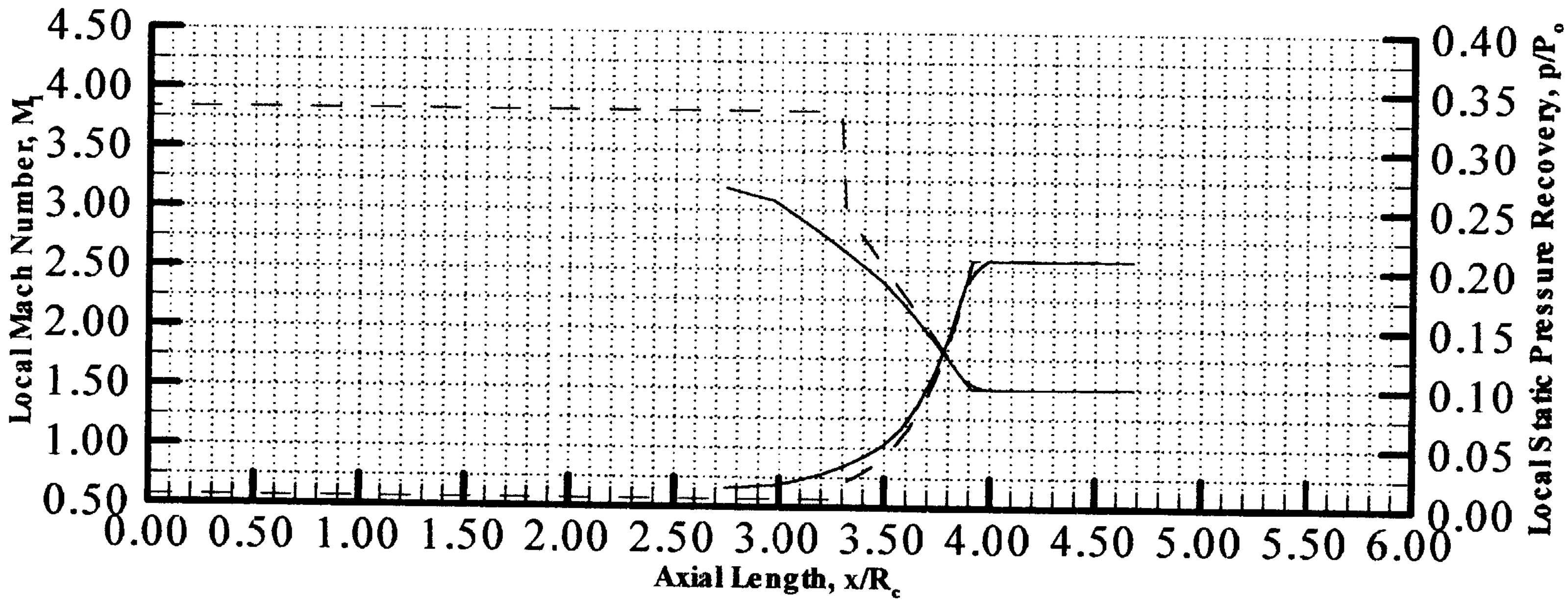


Figure 8

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NPARC Inviscid Analysis: Mach Number
15° Cone Inlet

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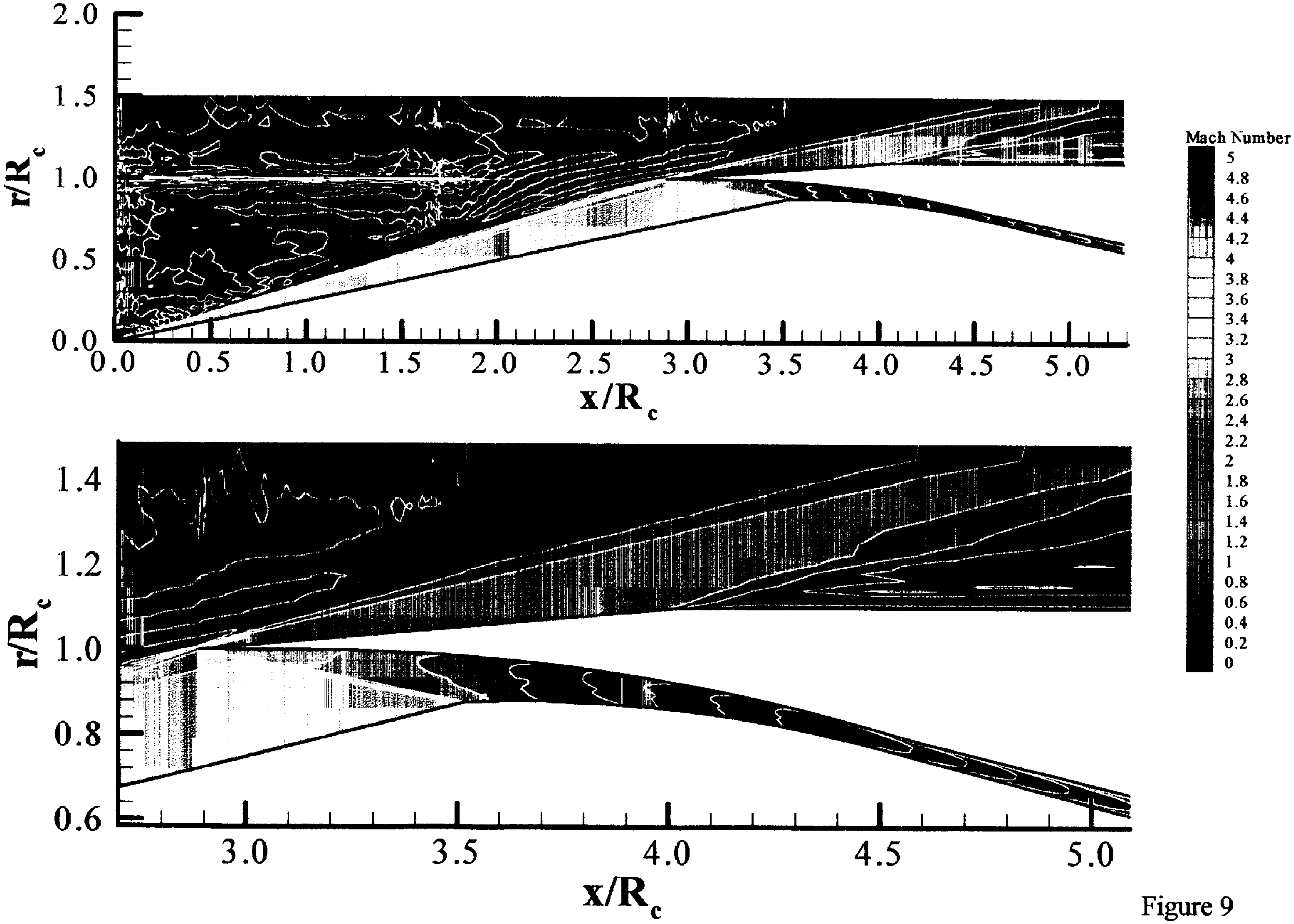


Figure 9

NPARC Viscous Analysis: Mach Number
15° Cone Inlet

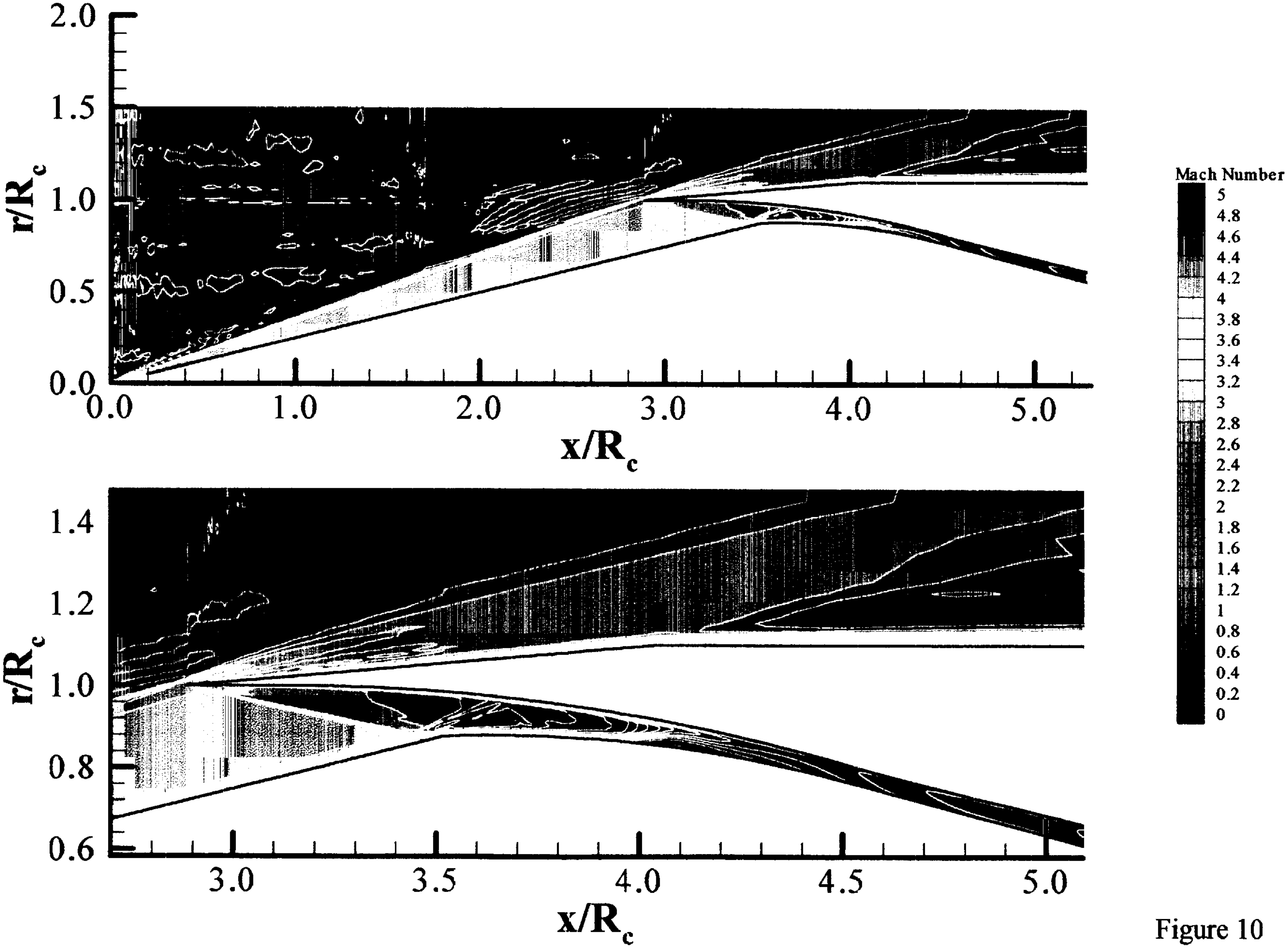


Figure 10

NPARC Viscous Analysis: Temperature
15° Cone Inlet

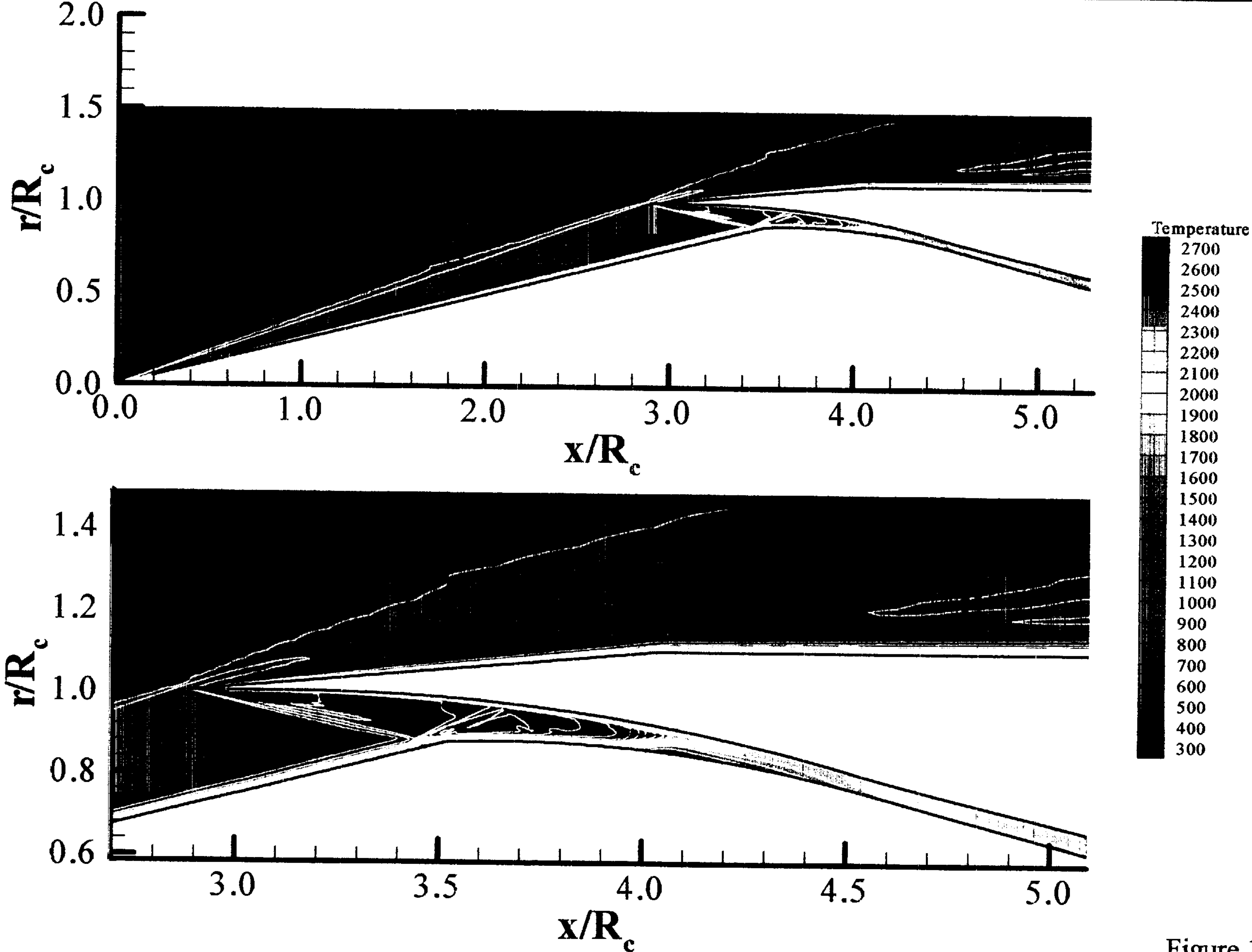


Figure 11

NPARC Viscous Analysis: 15° Cone Inlet

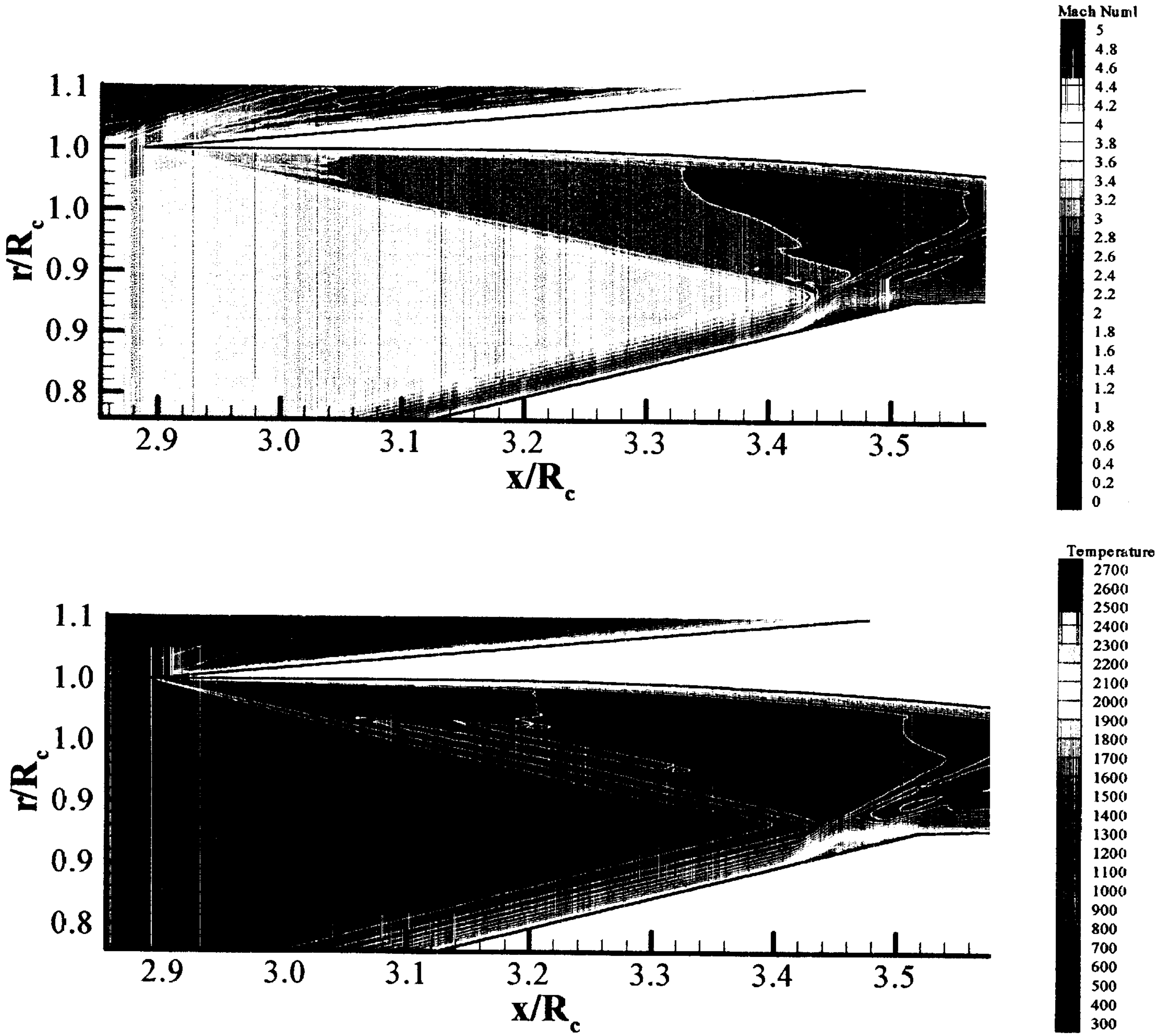


Figure 12

DRACO Inlet for D-21, 15° Cone (Design Centerbody Position)

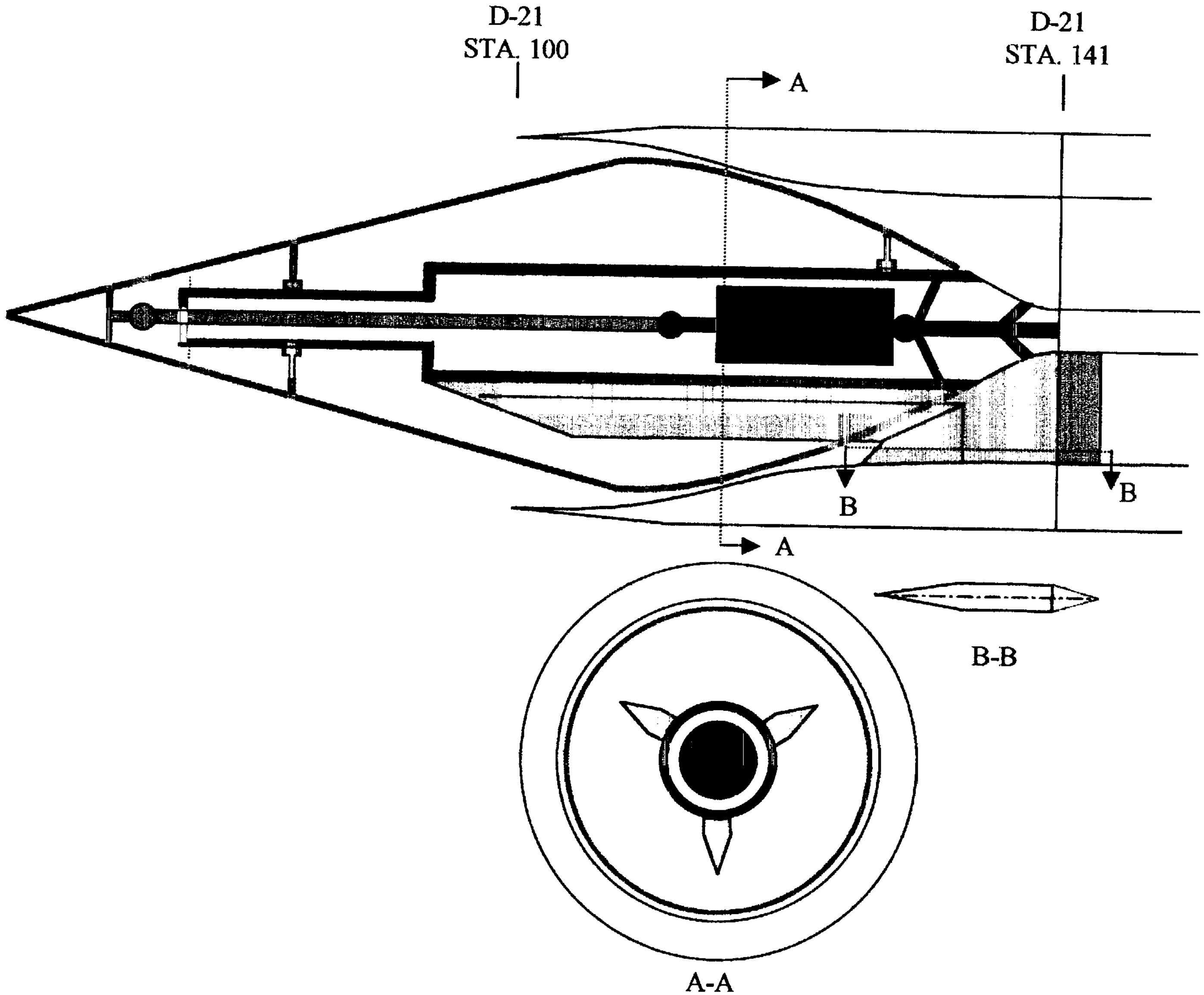


Figure 13

DRACO Inlet For D21, 15° Cone (Off-Design Centerbody Position)

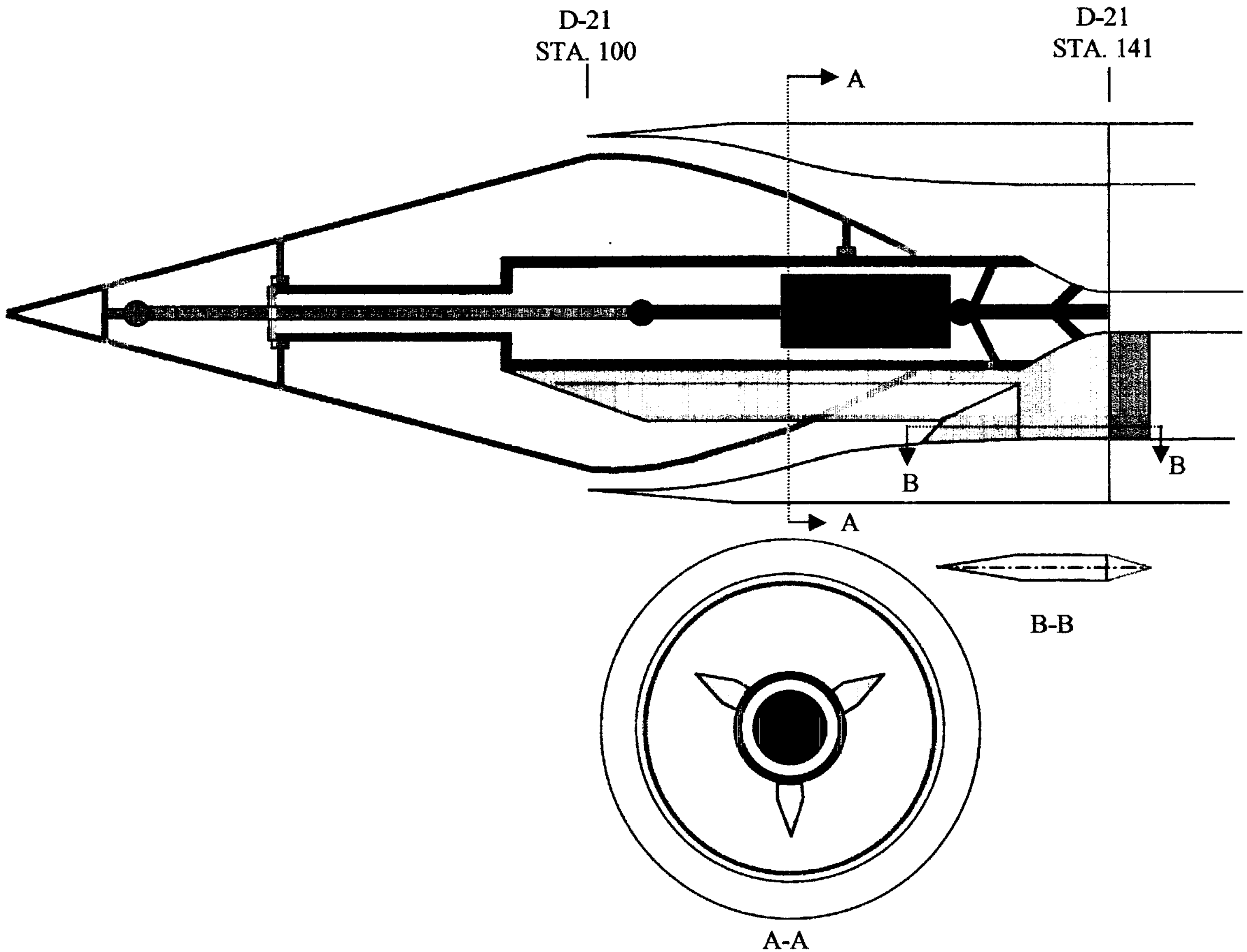


Figure 14

DRACO Inlet For D-21, 15° Cone (Close-off Centerbody)

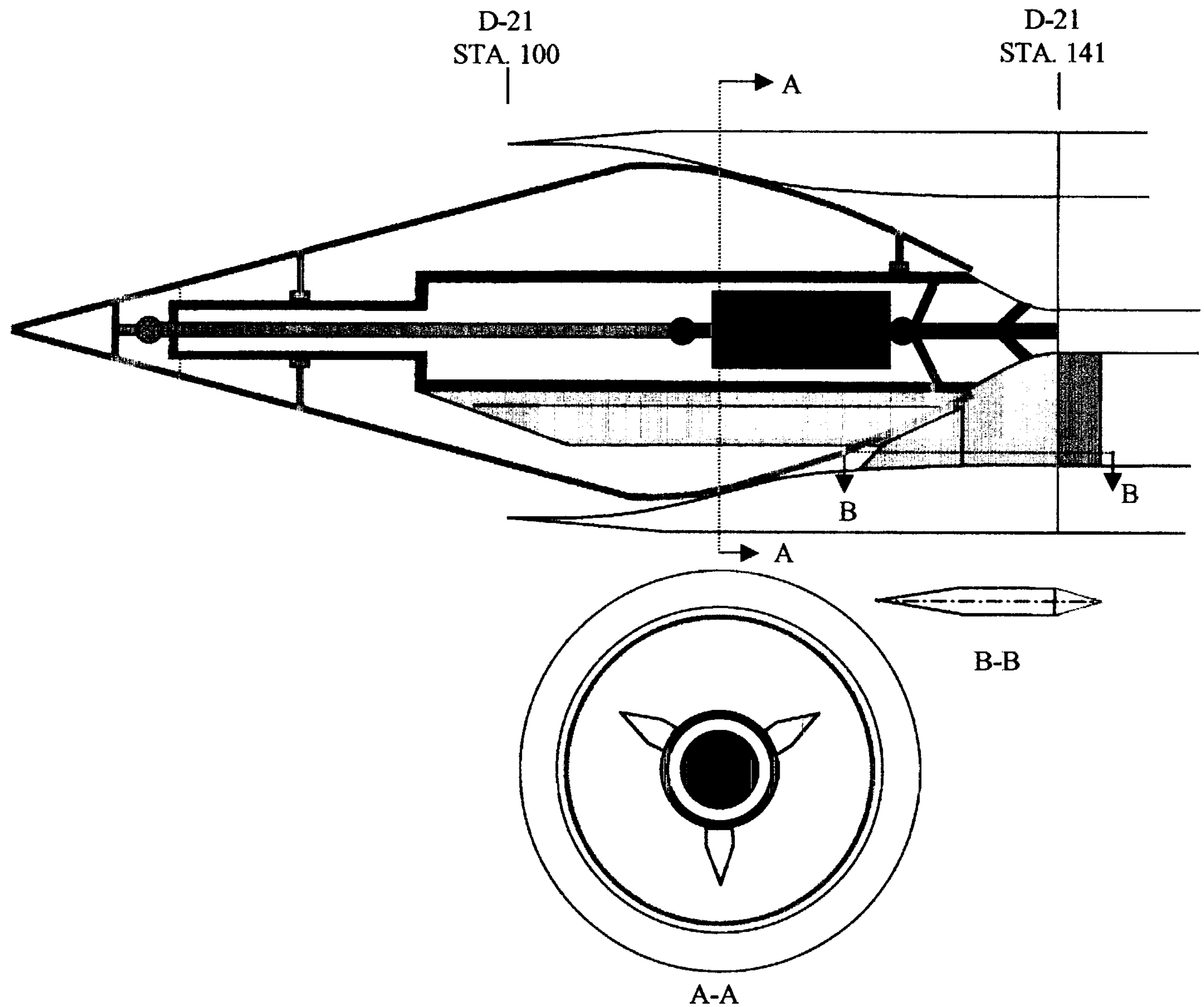


Figure 15

DRACO Inlet For D-21, 15° Cone (Centerbody Translation)

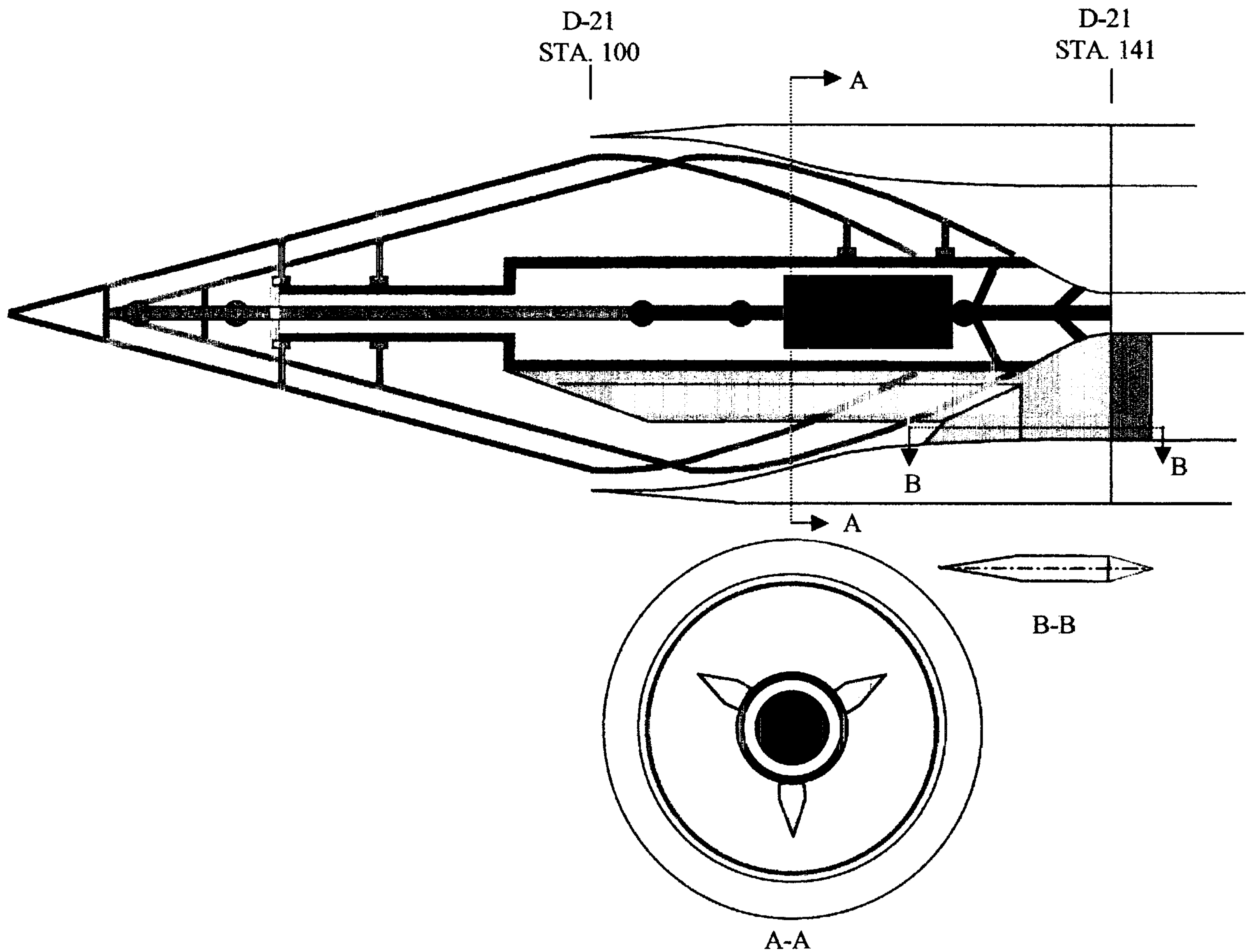
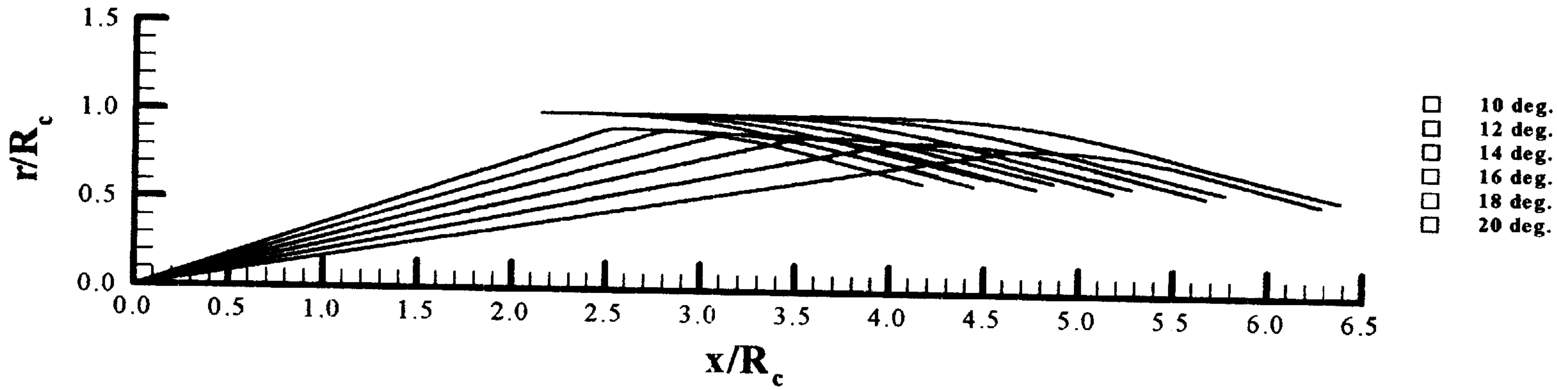


Figure 16

Effect of Cone Angle on Inlet Length



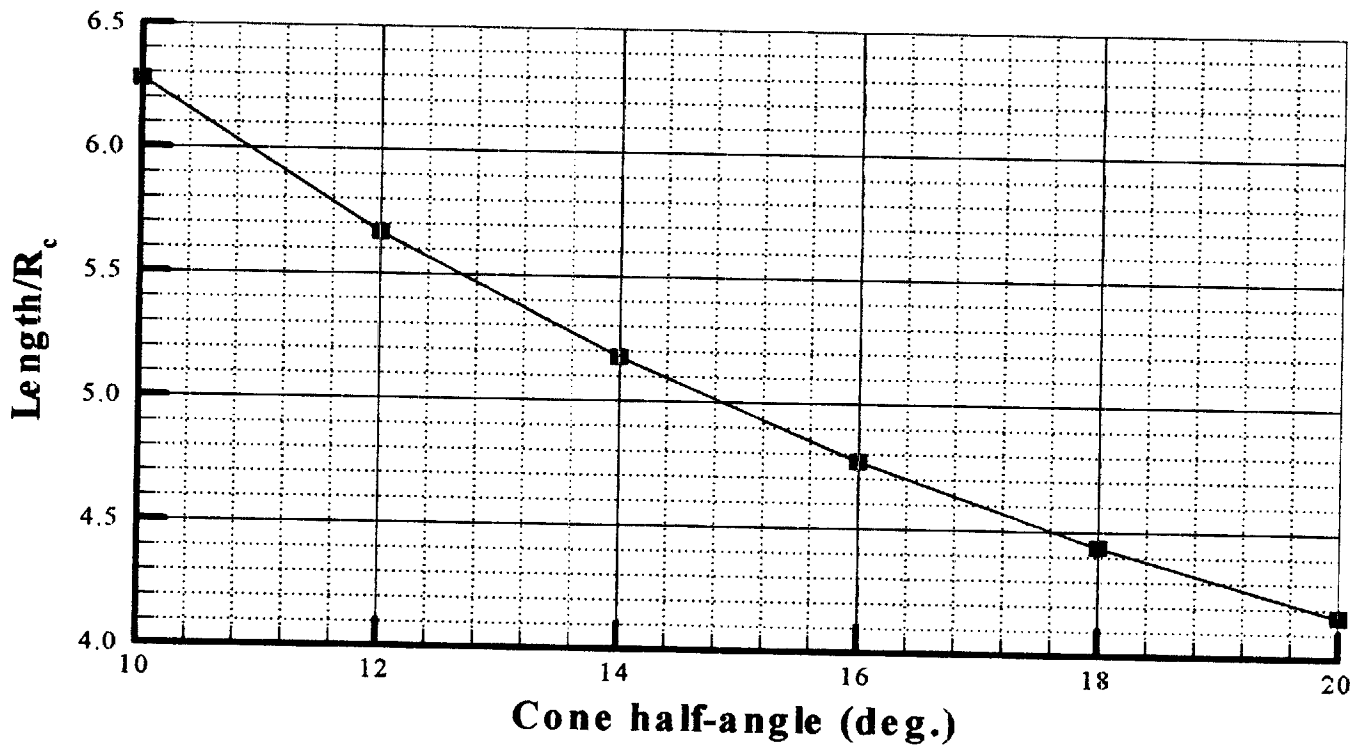


Figure 17

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Effect of Cone Angle on Inlet Length

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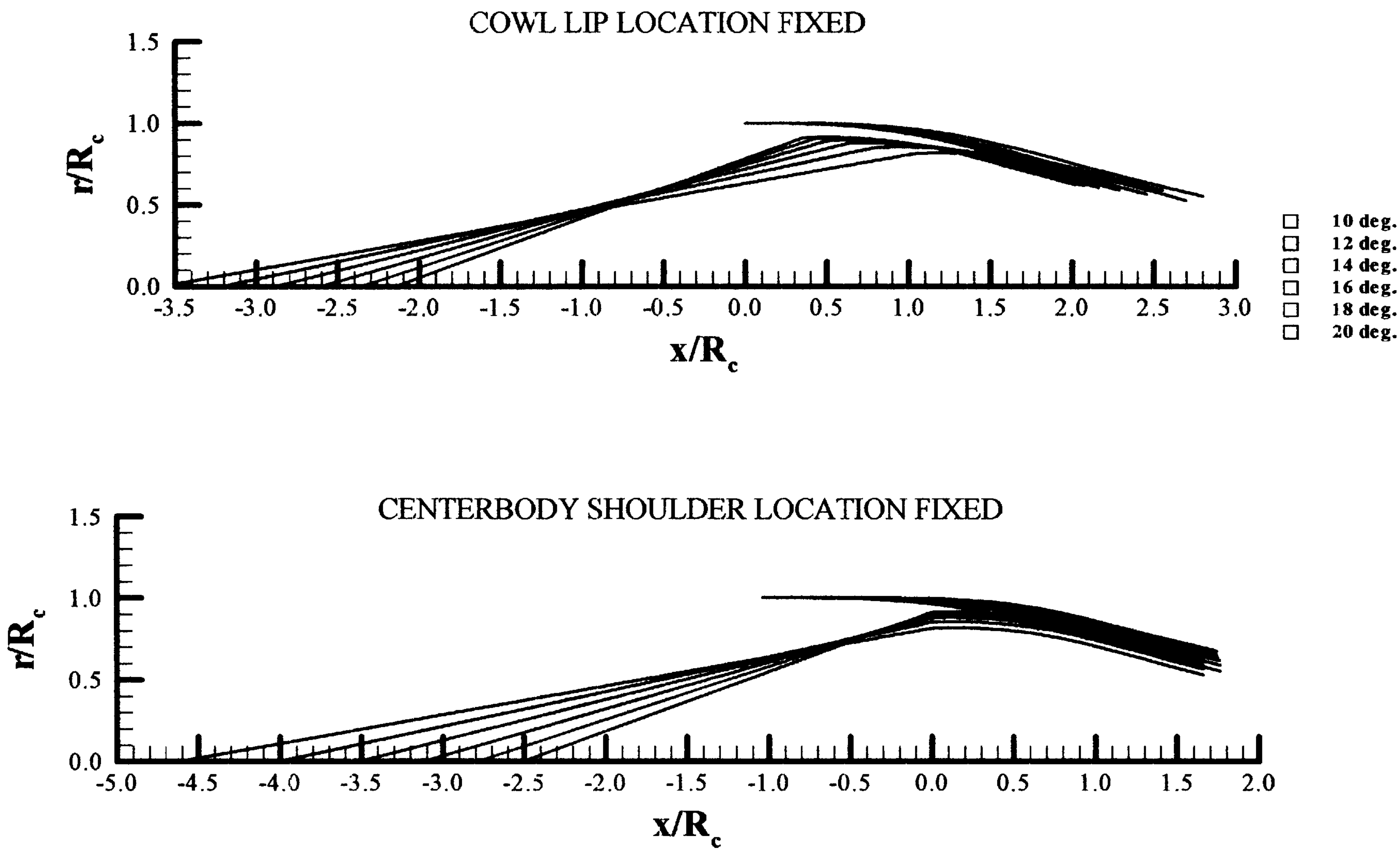

Figure 18

Effect of Cone Angle on Radius at Shoulder and on Capture Area When Shoulder Is at the Cowl Lip Station

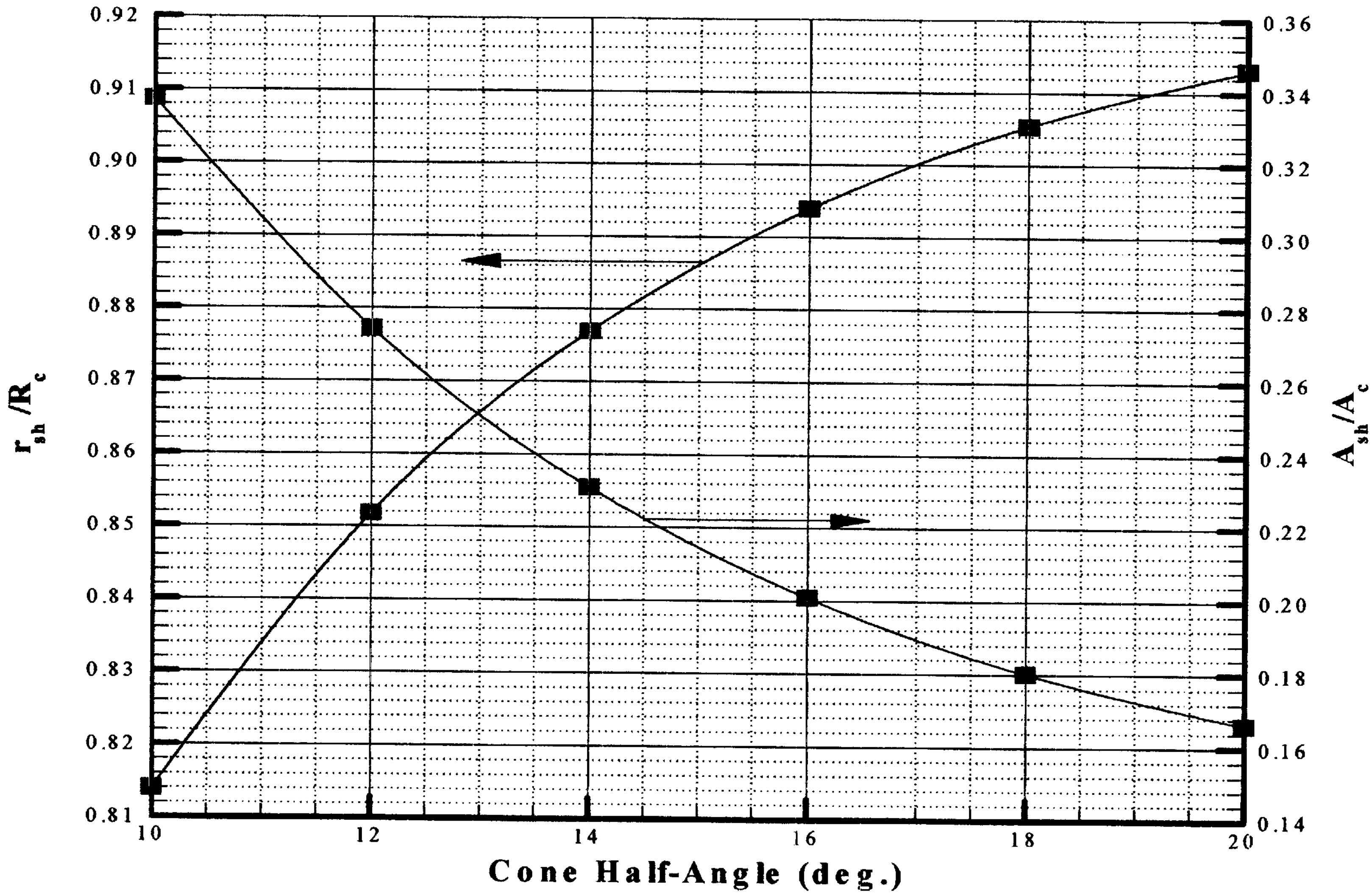

Figure 19

DRACO Hypersonic Inlet Design

Second-Round Inlet Design:

- Axisymmetric translating centerbody inlet
- Design Mach number of 5.0 (shock on lip)
- Single cone, 12.5°
- Internal cowl angle of 0°
- Throat angle of -15°
- Cowl shock canceled at inlet shoulder with isentropic compression to throat
- Inviscid throat Mach number of 1.6
- Terminal shock in throat
- Bleed functions for performance and operability

Figure 20

DRACO Hypersonic Inlet

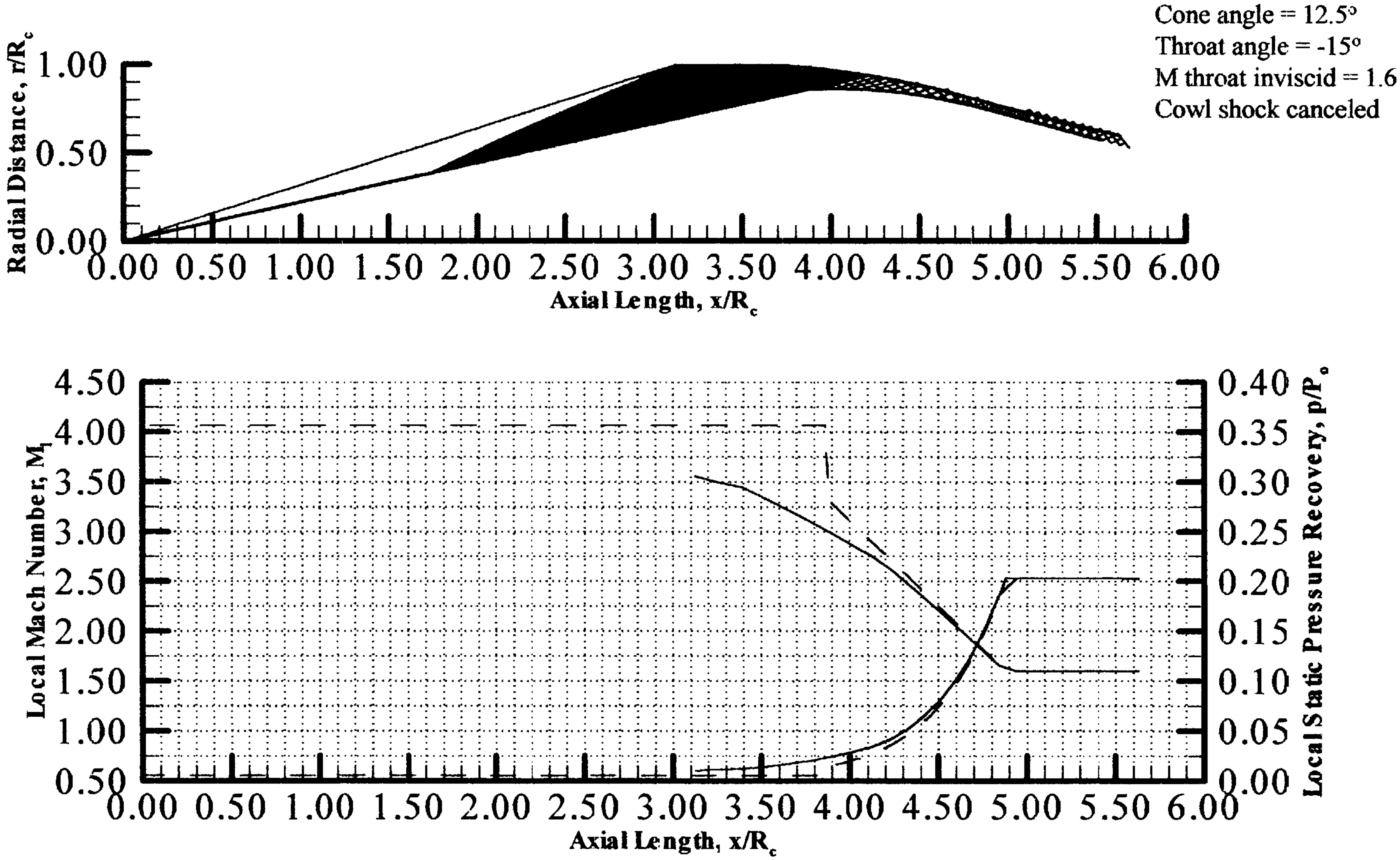

Figure 21

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DRACO Inlet For D-21
M_o = 5.0, Cone Half-Angle 12.5°

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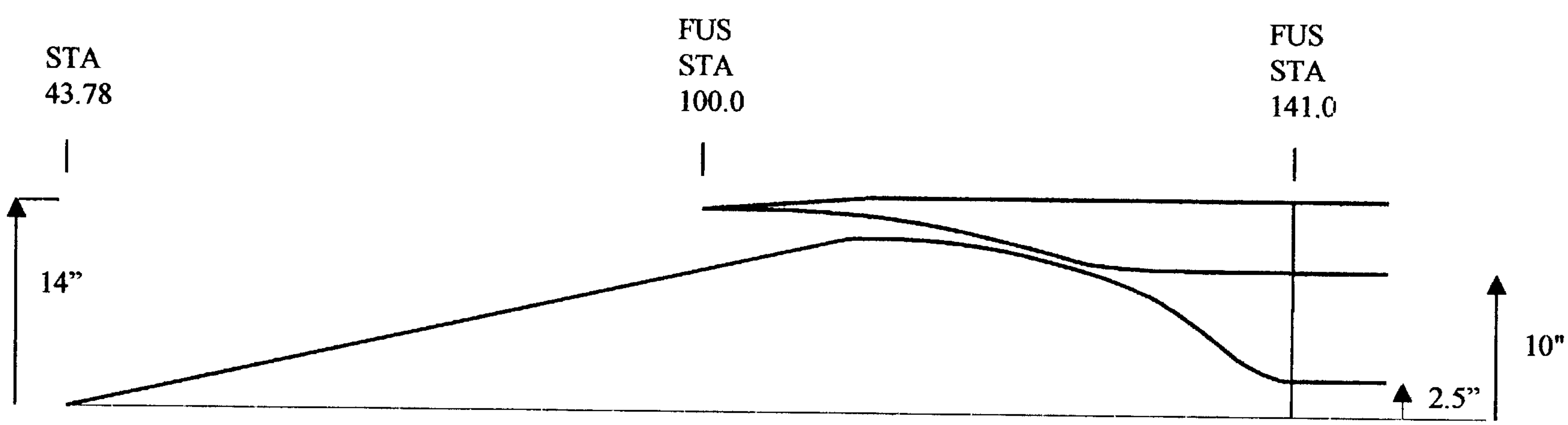

Figure 22

Inlet Centerbody Translation Schedule
$M_o = 5.0$, Cone Half-Angle 12.5°

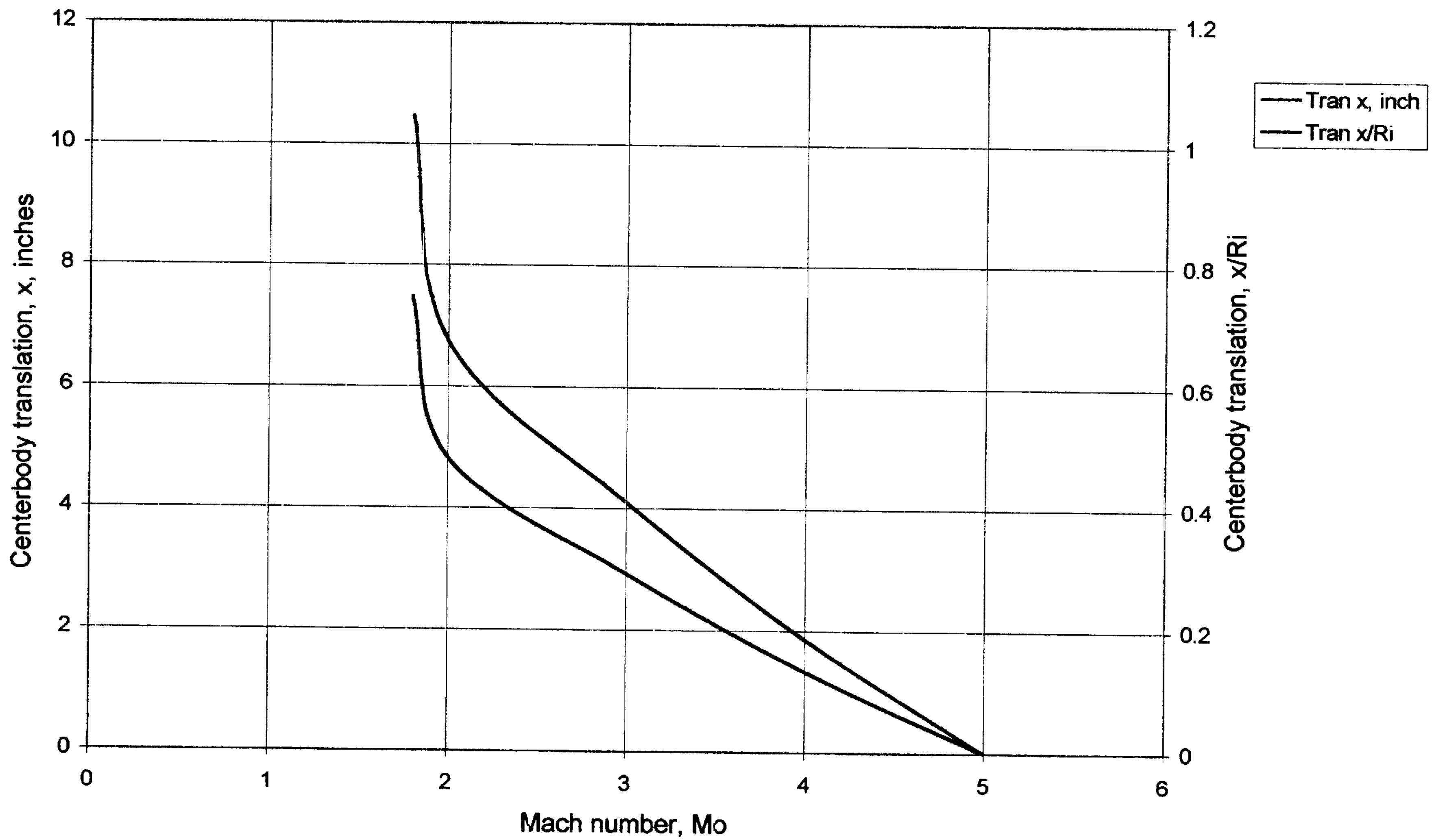

Figure 23

TechLand Research, Inc.

DRACO Inlet Contours for a Range of Freestream Mach Numbers

Marshall
Glenn
Dryden

M design = 5.0, Cone half-angle of 12.5 degrees

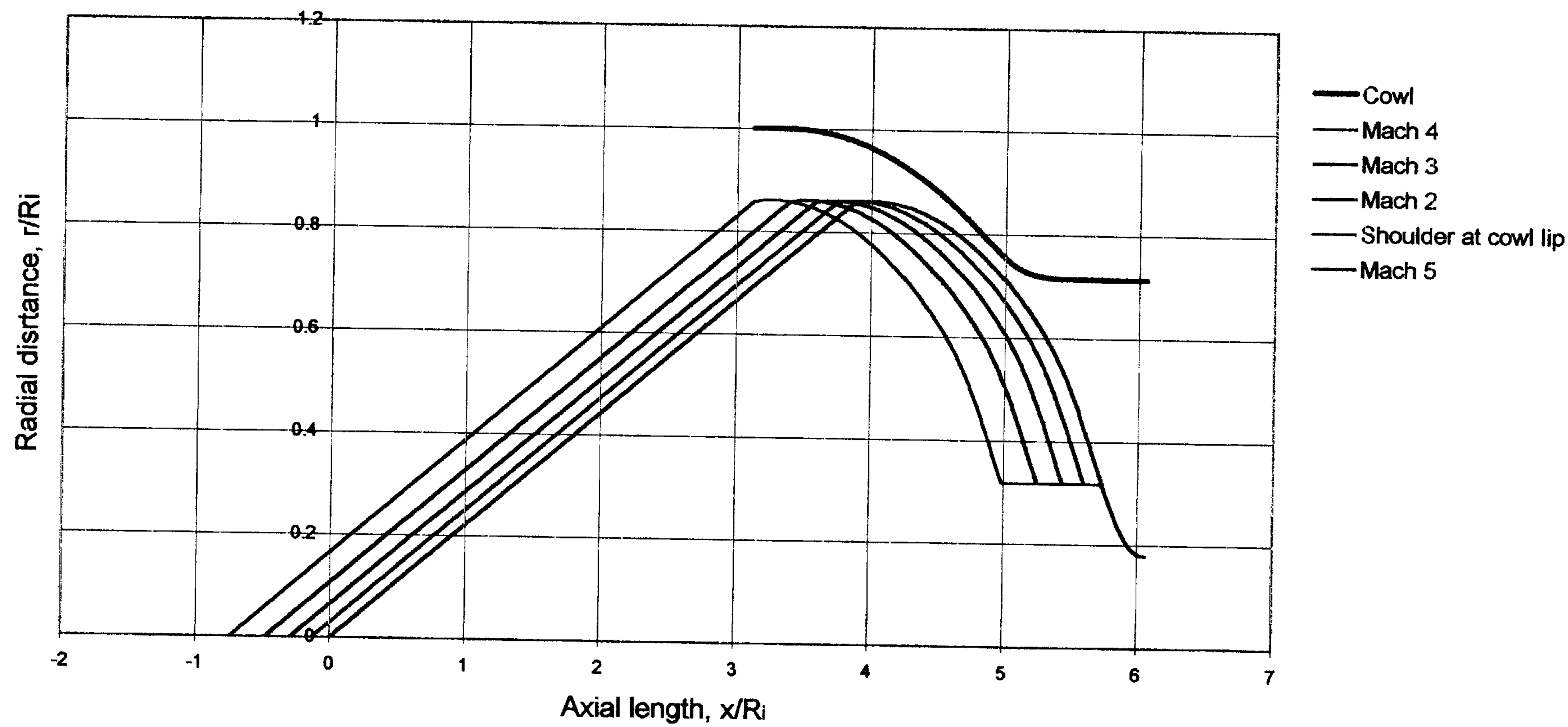

Figure 24

DRACO Inlet Area Distribution
$M_{design} = 5.0$, Cone Half-Angle 12.5°

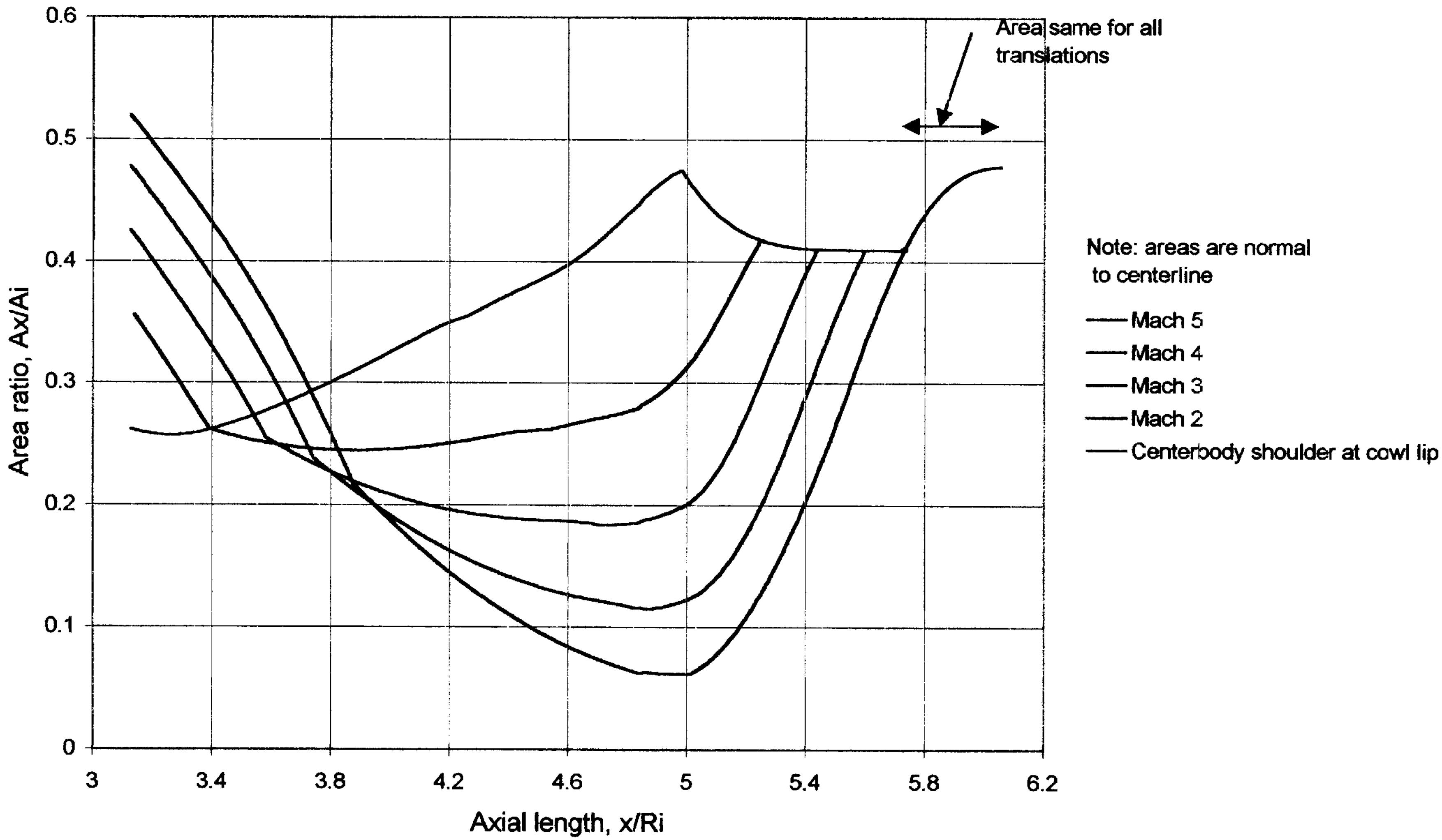

Figure 25

Inlet Throat Axial Location
$M_o = 5.0$, Cone Half-Angle 12.5°

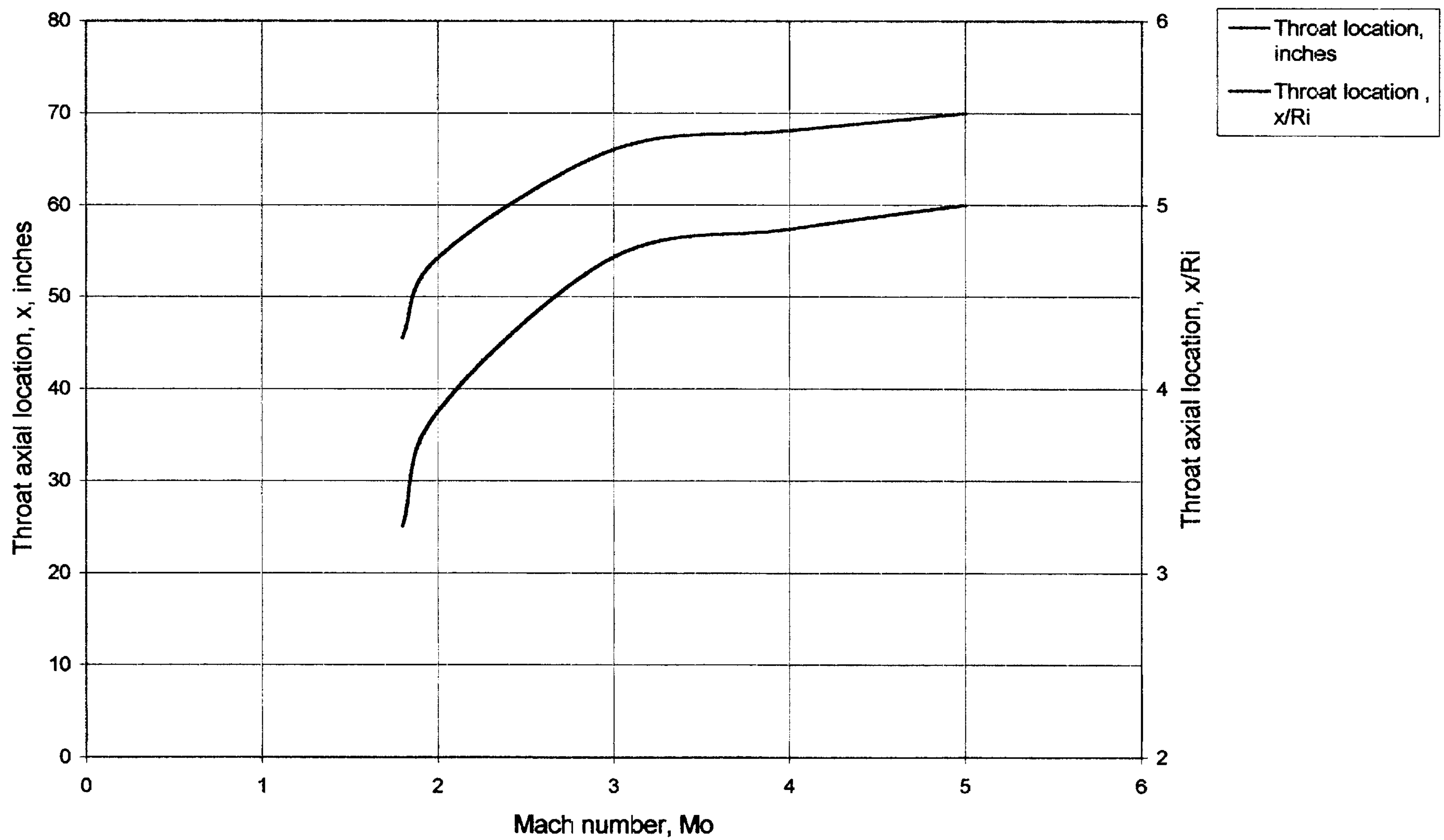

Figure 26

TechLand Research, Inc.

Throat Area Variation
M_o = 5.0, Cone Half-Angle 12.5°

Marshall Glenn Dryden

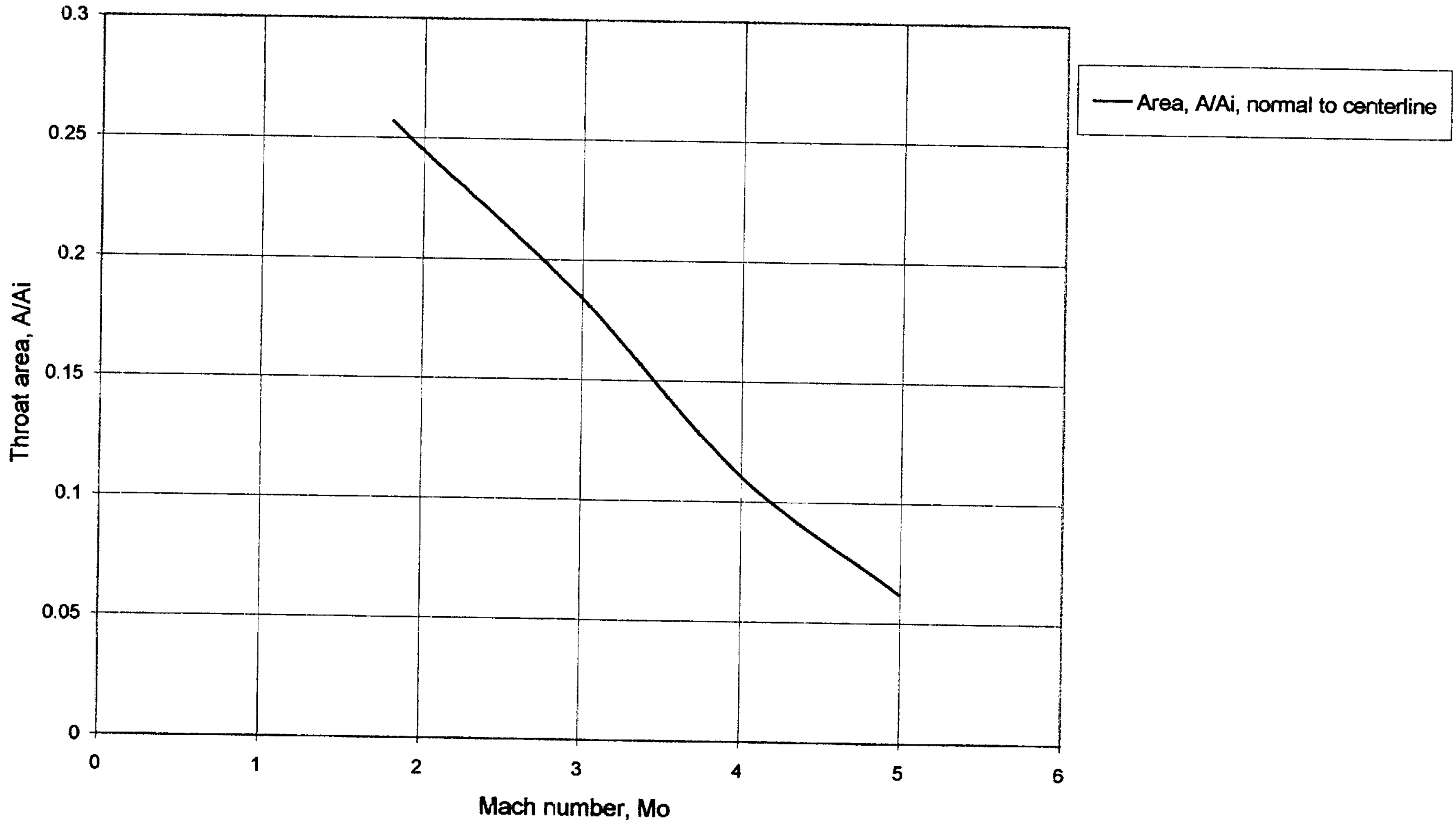

Figure 27

TechLand Research, Inc.

DRACO Inlet Capture Mass-Flow Schedule Compared to Trailblazer

Marshall
Glenn
Dryden

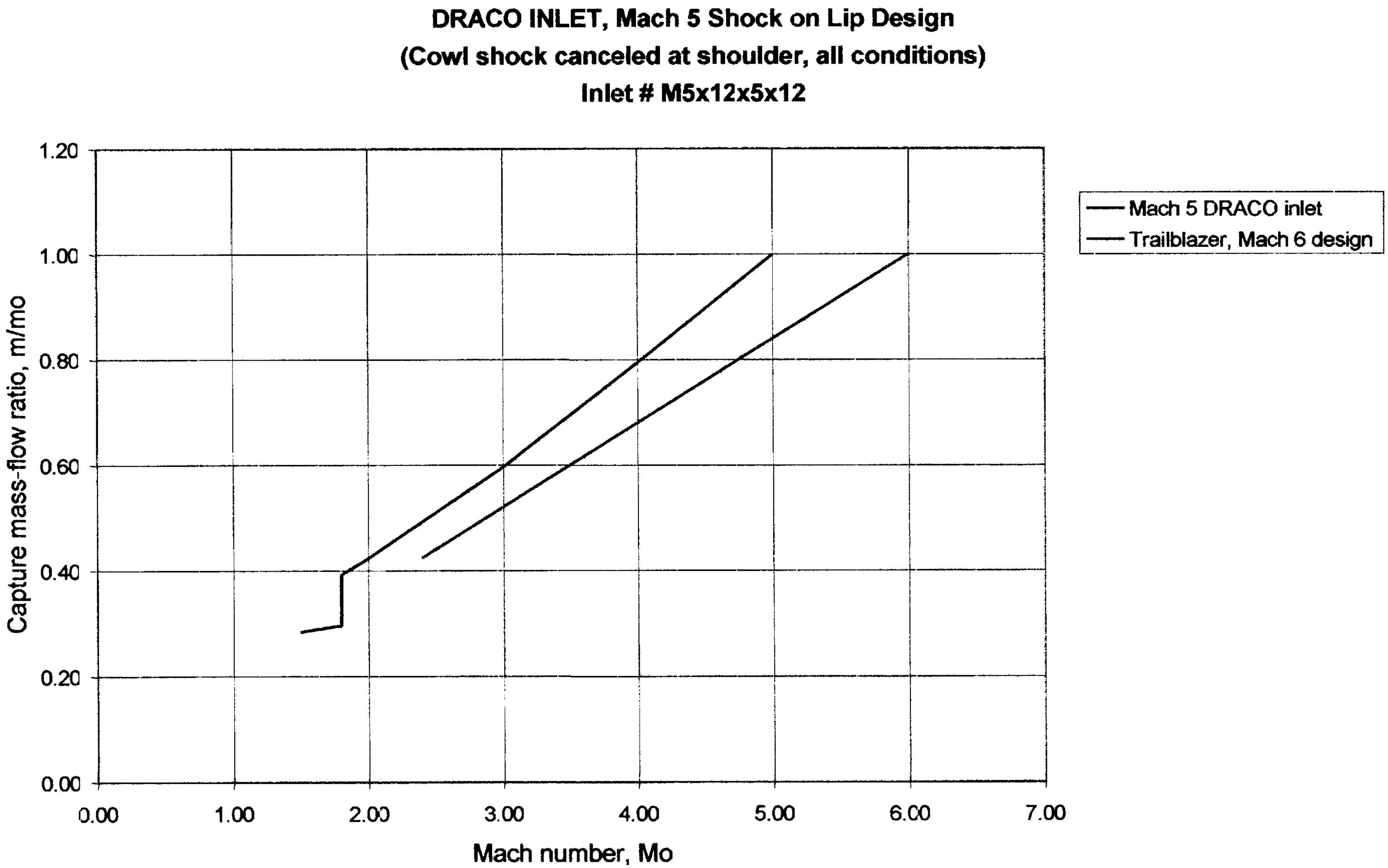

Figure 28

TechLand Research, Inc.

DRACO Inlet for D-21, 12.5° Cone (Design Centerbody Position)

Marshall
Glenn
Dryden

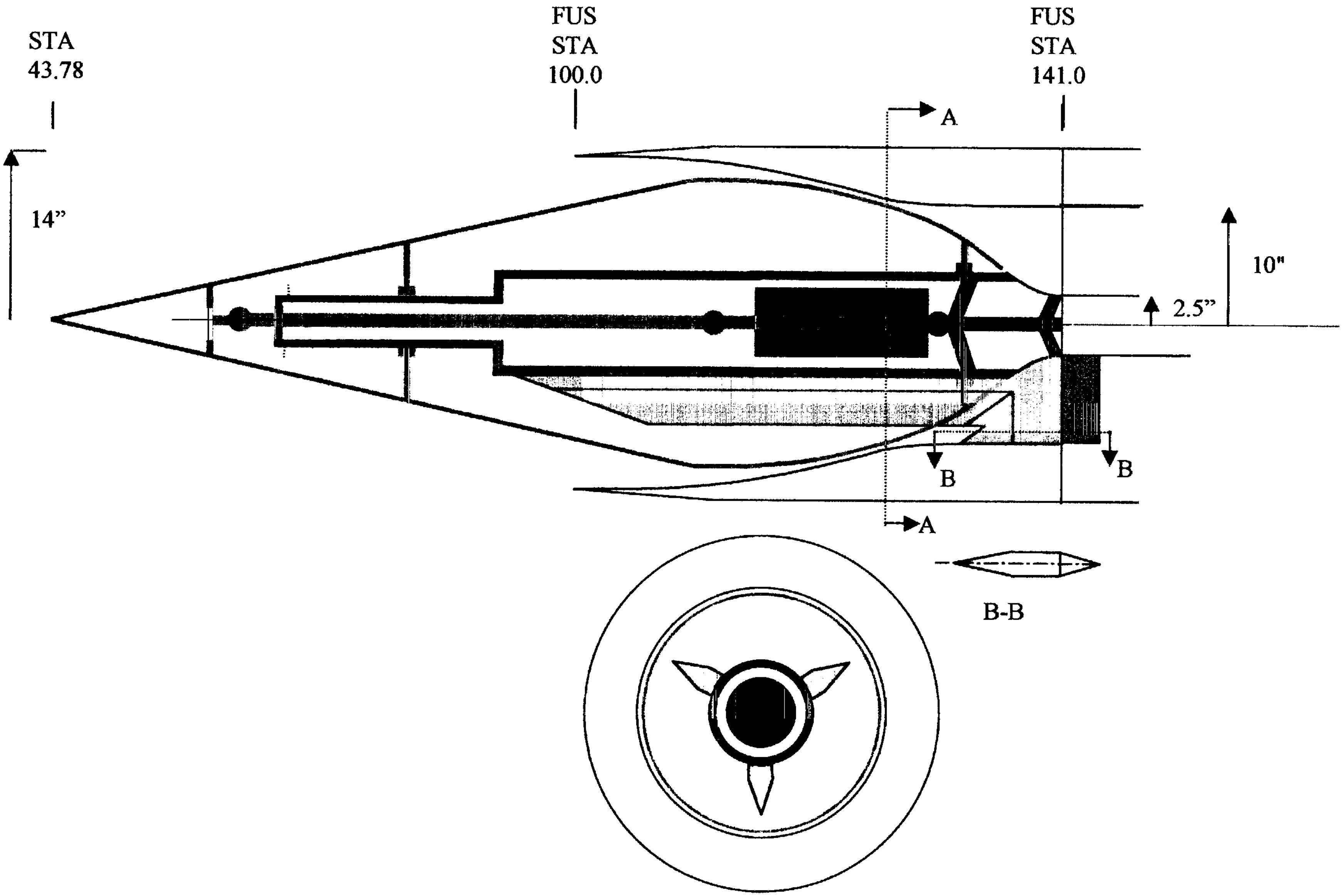

Figure 29

TechLand Research, Inc.

DRACO Inlet for D-21, 12.5° Cone (Design Centerbody Position)

Marshall
Glenn
Dryden

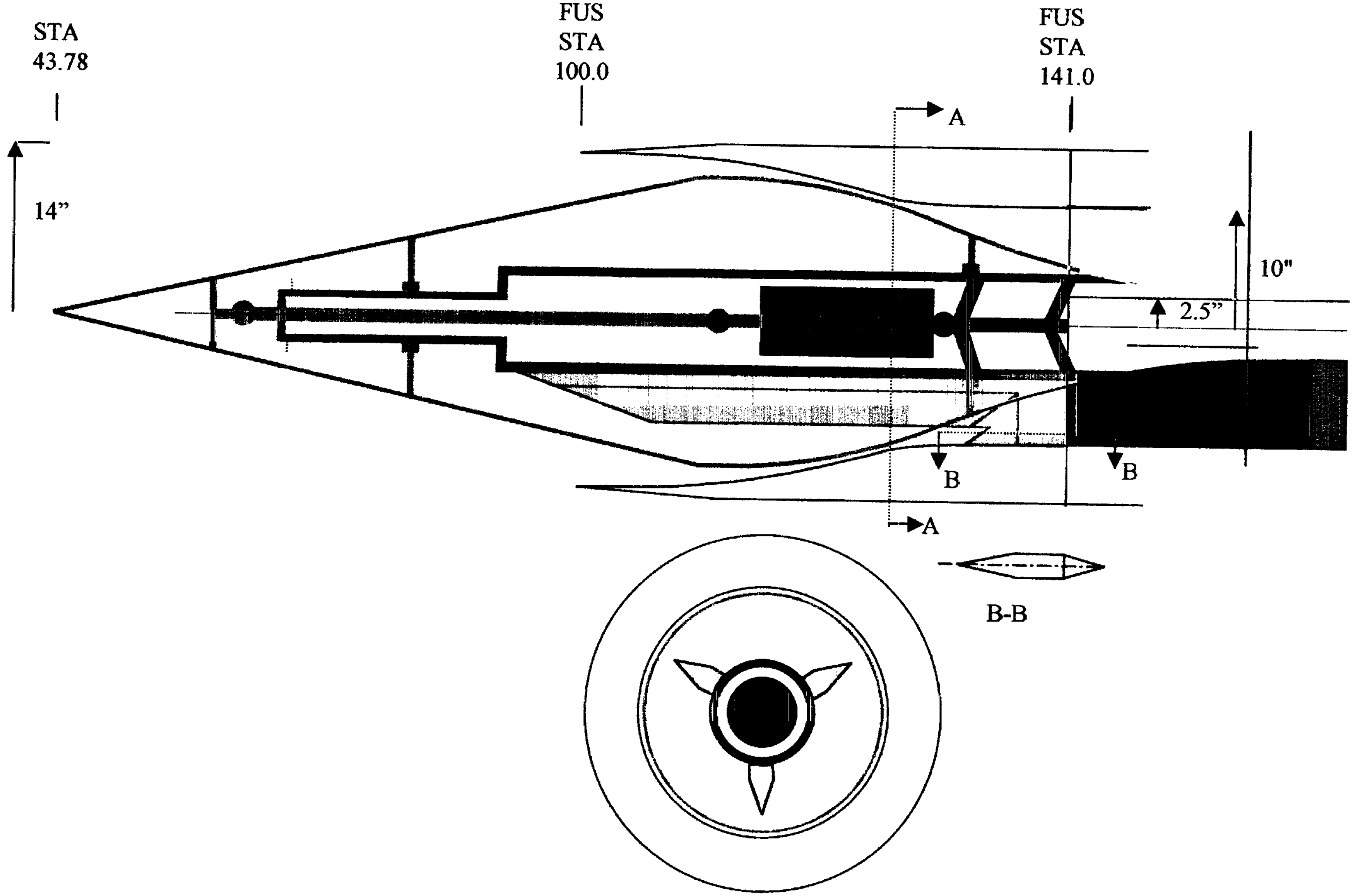

Figure 30

TechLand Research, Inc.

DRACO Inlet for D-21, 12.5° Cone (Design Centerbody Position)

Marshall
Glenn
Dryden

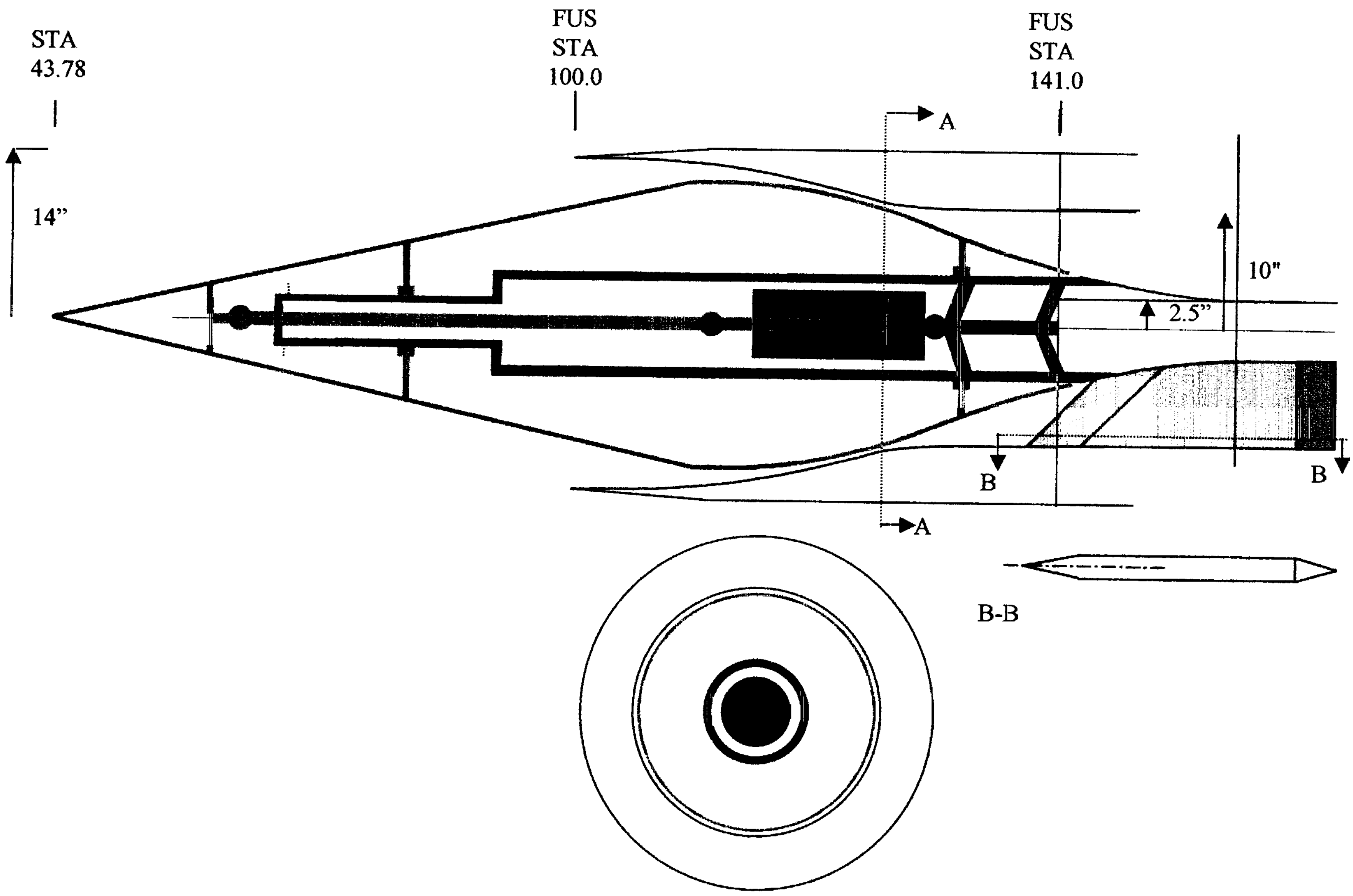

Figure 31

Planning Guidelines

- Inlet design assumptions based on planning during flowpath meeting in August
- Need proven design by CDR
- CDR in 3 years
- Mach 6 flight inlet ready in 6 years
- Support for flight weight inlet design
- Reduce risk of high risk program

Figure 32

DRACO Inlet Development Test Schedule

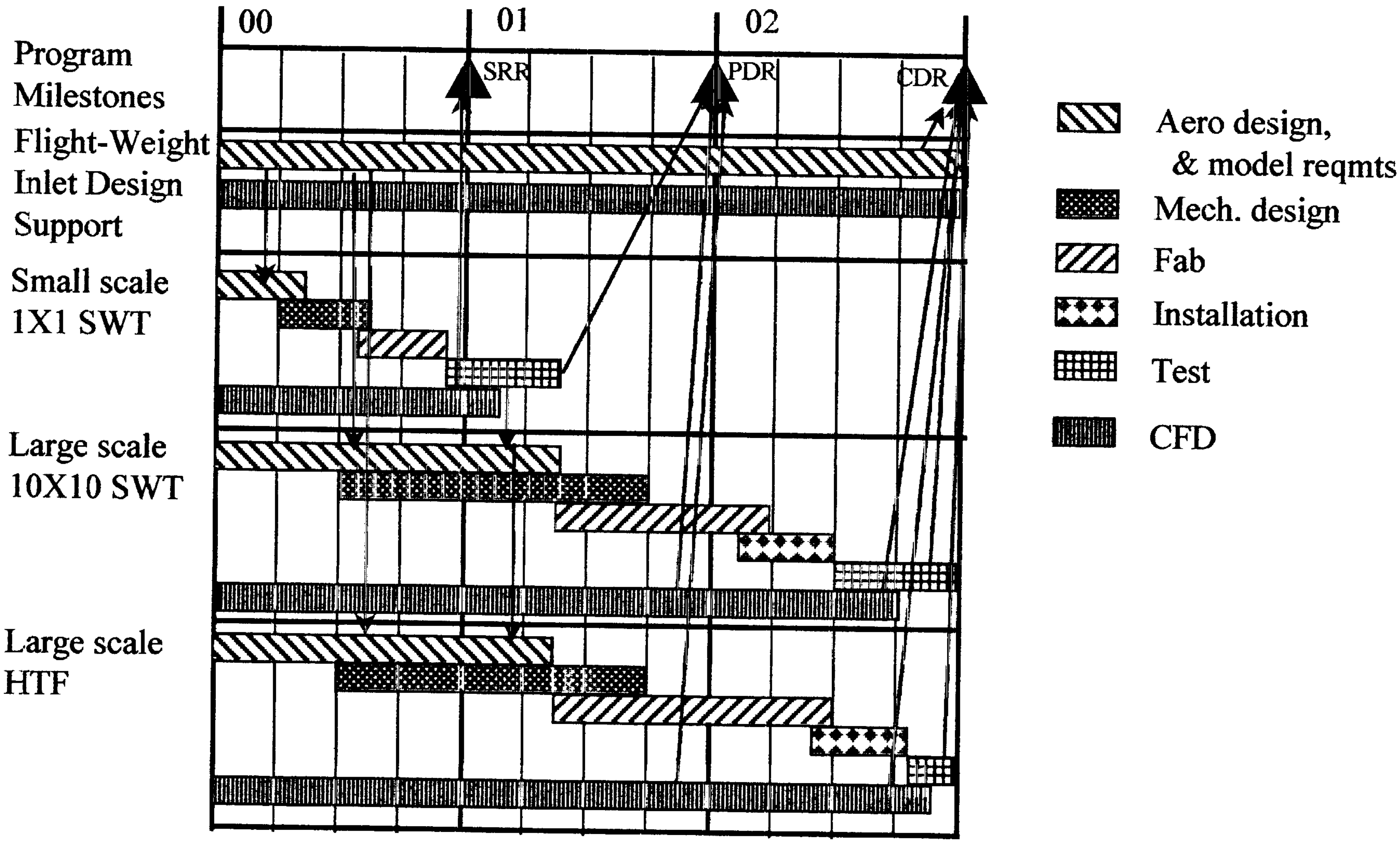

Figure 33

1X1 SWT Inlet Model

- Small-scale exploratory test model for high Mach numbers (Mach 3 to 6)
- Parametrics only, develop aerodynamic performance trends
- Develop design data base
- Develop configurations for HTF test program, centerbody translation, back pressure and bleed schedules
- Near-term data to lead to support development of flight inlet
- Only data to support PDR

Figure 34

TechLand Research, Inc.

DRACO Inlet Test Parametrics, 1x1 SWT

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Dryden

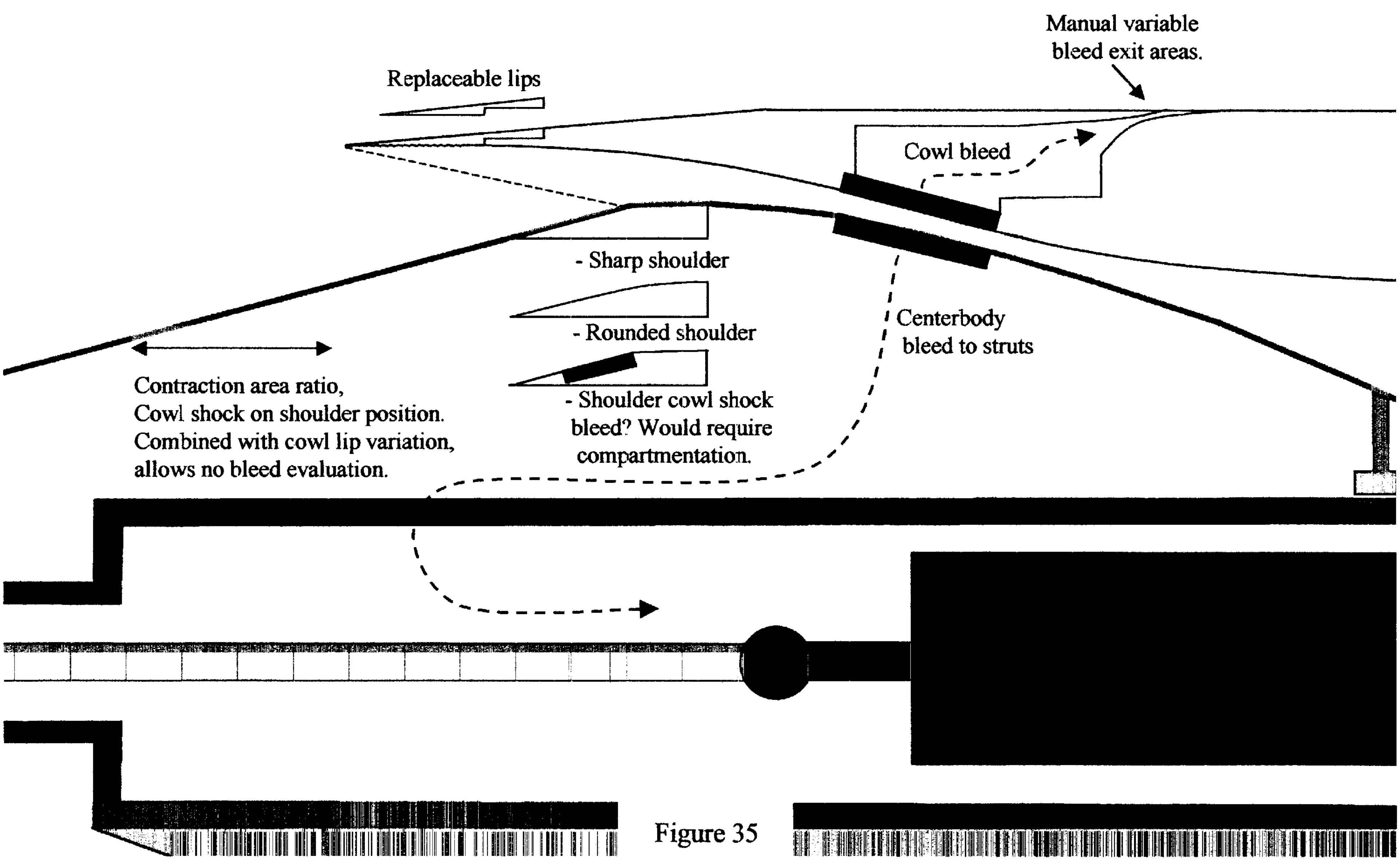

Figure 35

10X10 SWT Inlet Model

- Large-scale inlet test model for intermediate Mach numbers of 2 to 3.5
- Database to support the D-21 Flight test program
- J-85 size, 16.07 in. diffuser exit diameter: reuse available test hardware
  - Support hardware
  - Cold-pipe and variable mass-flow plug
  - Instrumentation, etc.
- Extensive instrumentation
- Some parametrics
- Controls development, data and integrated
- Support CDR

Figure 36

HTF Inlet Model

- Large scale inlet test model, D-21 size
- Water cooled
- Variable geometry centerbody and mass-flow plug
- Test Mach numbers of 5 and 6, Mach 4 ?? (cost)
- Data base to support design of flight inlet
- Data base to support out-year testing of Mach 6 propulsion system.
- Limited instrumentation
- Some parametrics
- Controls development, data and integrated
- Support CDR

Figure 37

Effect of Cone Angle on Radius at Shoulder and on Capture Area When Shoulder Is at the Cowl Lip Station

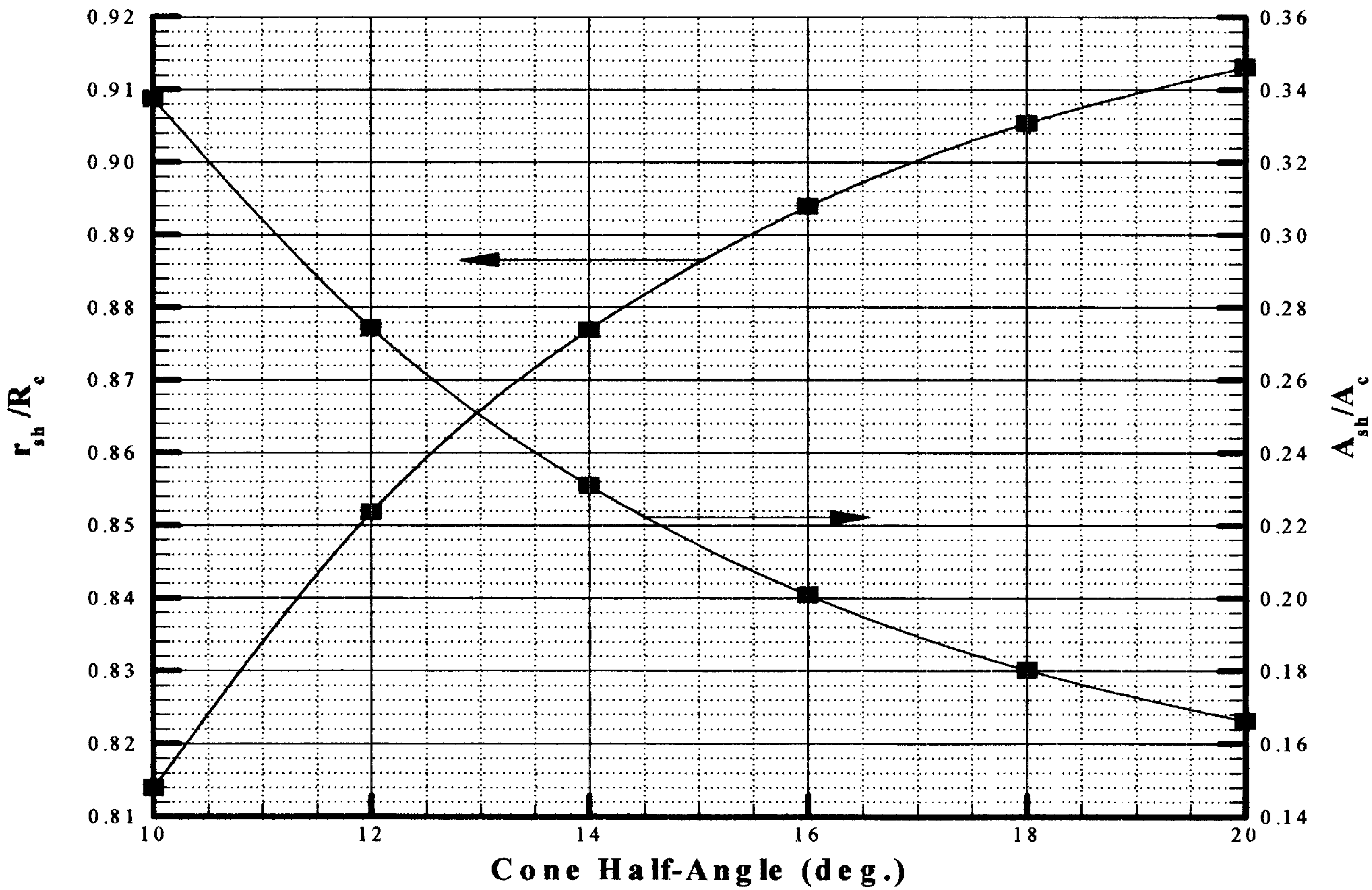

Figure 38

DRACO Hypersonic Inlet
$M_{design} = 5.0$, 10° Cone, 15° Throat

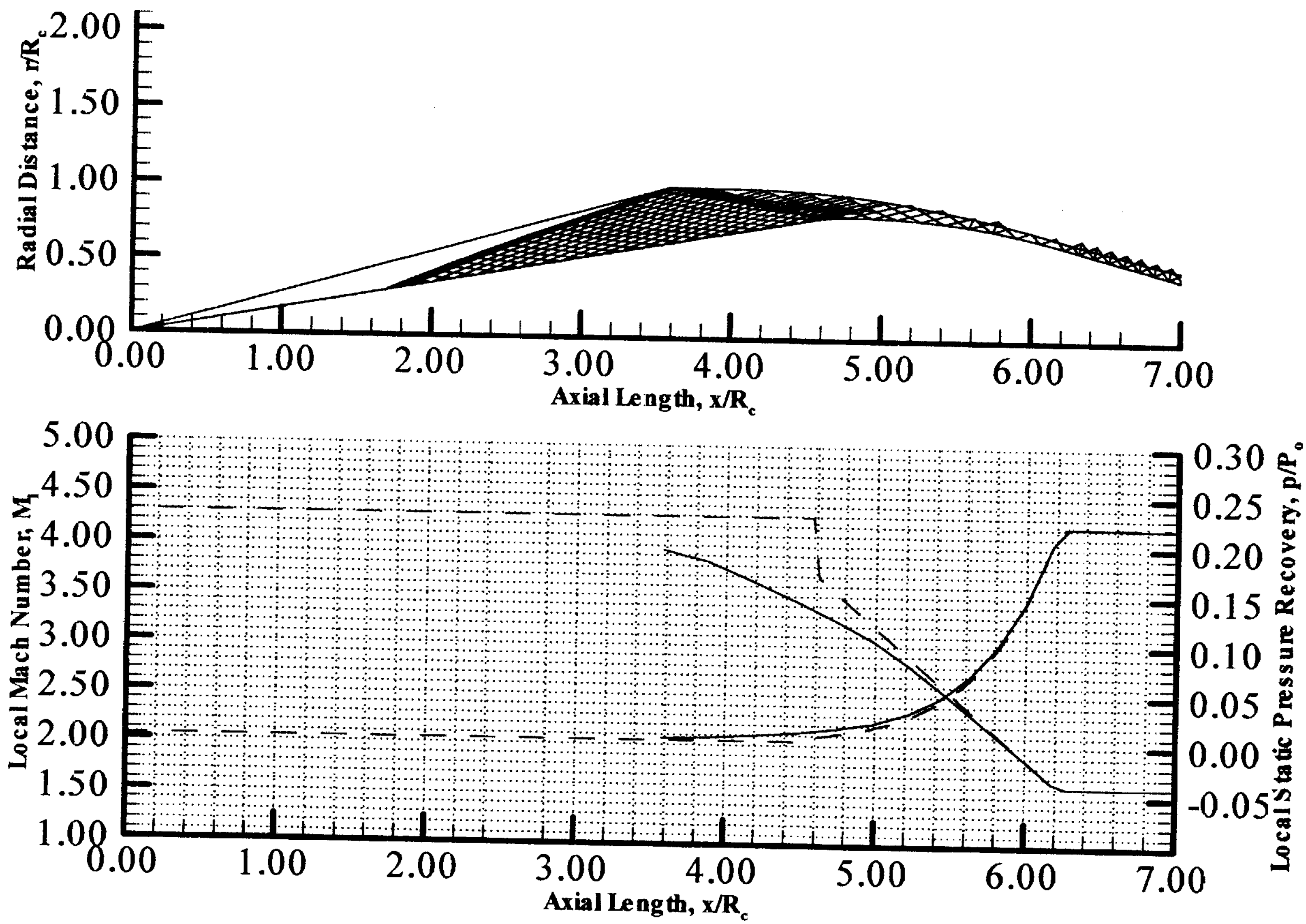

Figure 39

510x15g1.6

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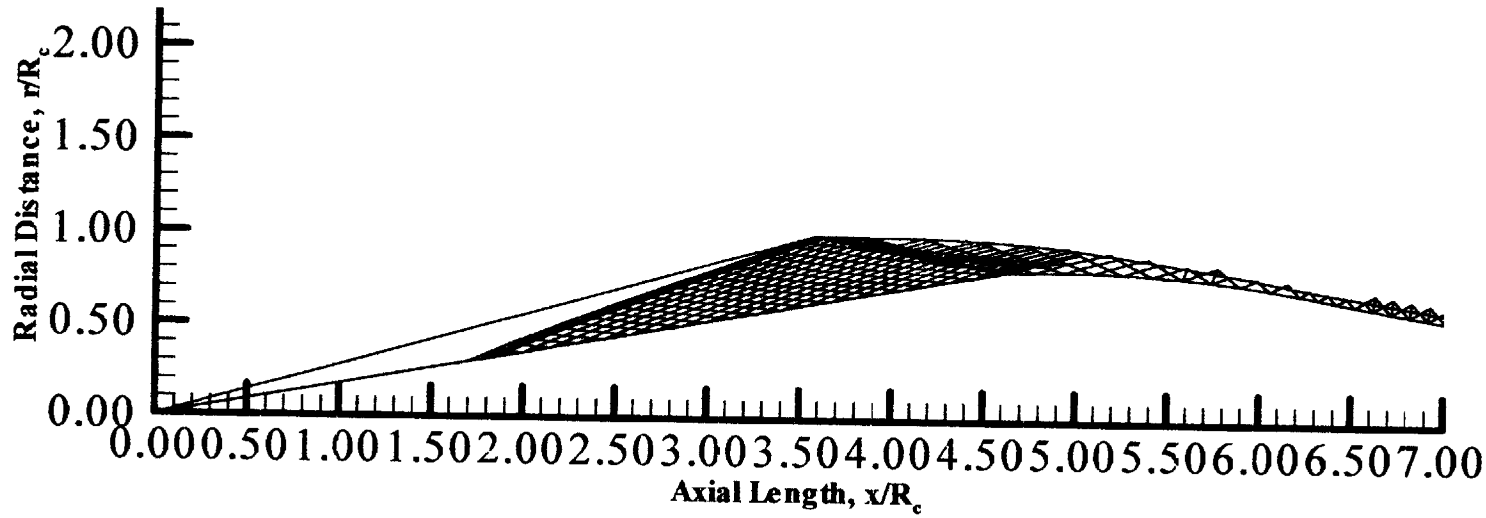
Research, Inc.

DRACO Hypersonic Inlet
$M_{design} = 5.0$, 10° Cone, 10° Throat

Marshall
Glenn
Dryden



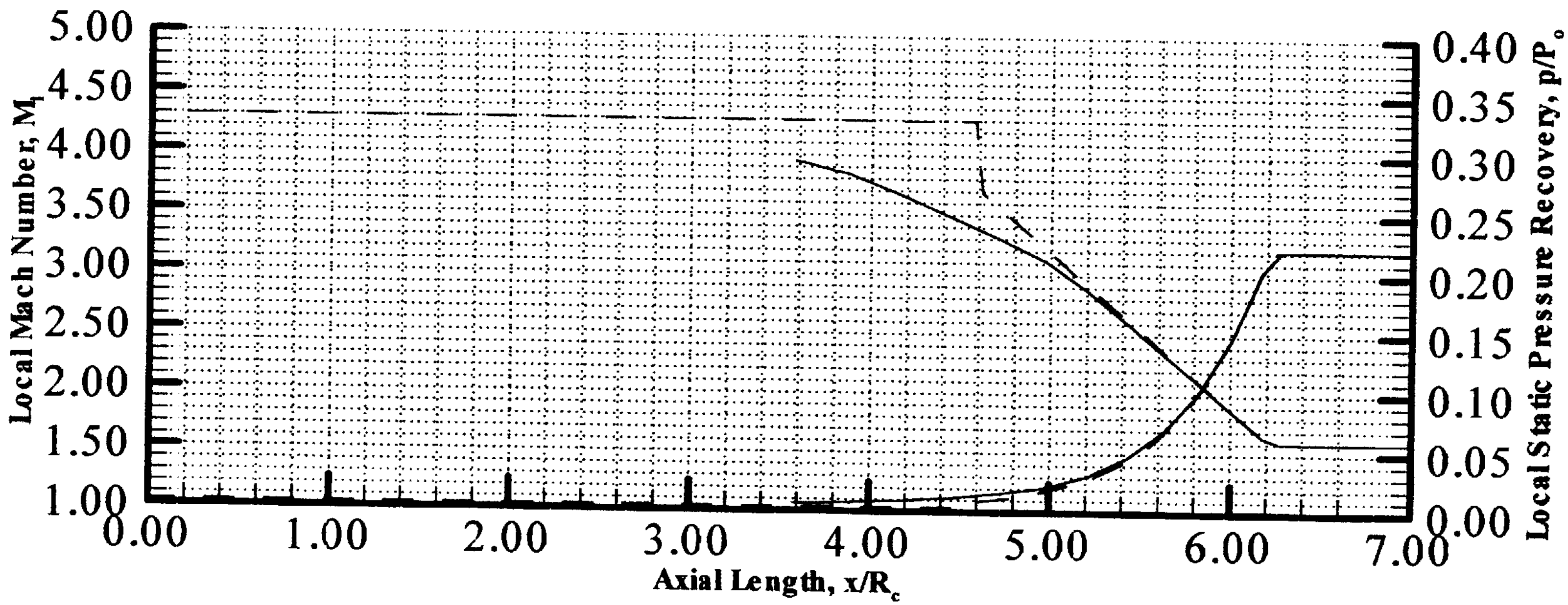
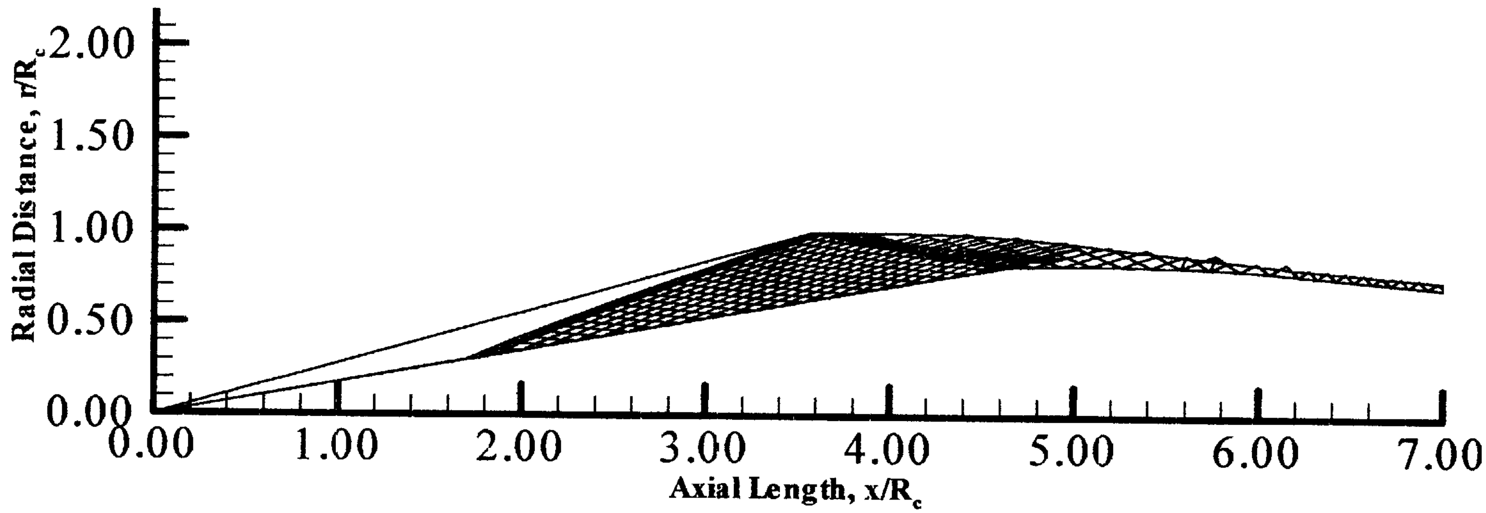
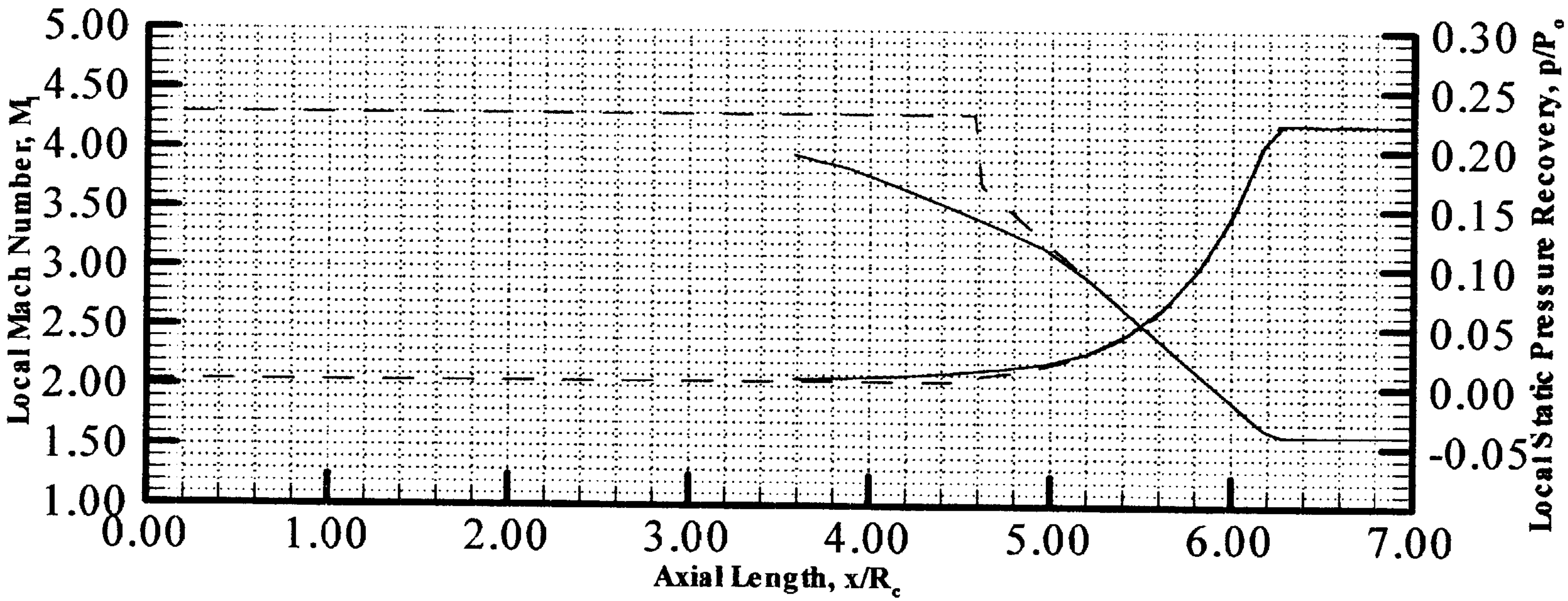


Figure 40

510x10k1.6

DRACO Hypersonic Inlet
$M_{design} = 5.0$, 10° Cone, 5° Throat





510x5n1.2

Figure 41

DRACO Inlet Aerodynamic Surface Contours
10° Cone, 10° Throat

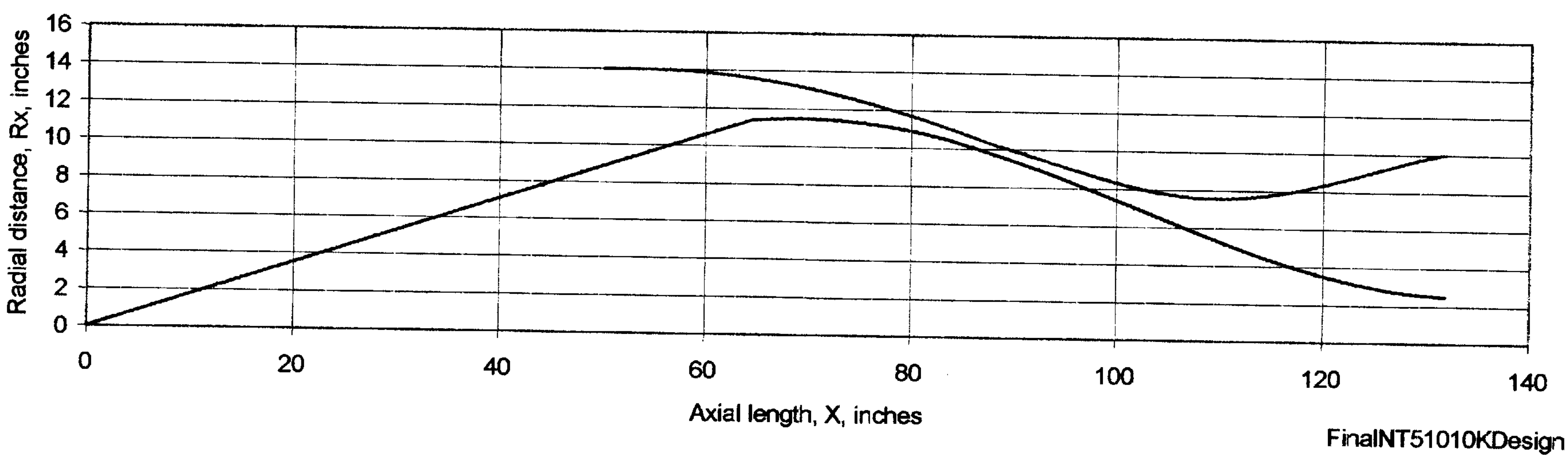


Figure 42

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Research, Inc.

DRACO Inlet Aerodynamic Surface Contours
10° Cone, 10° Throat

Marshall
Glenn
Dryden

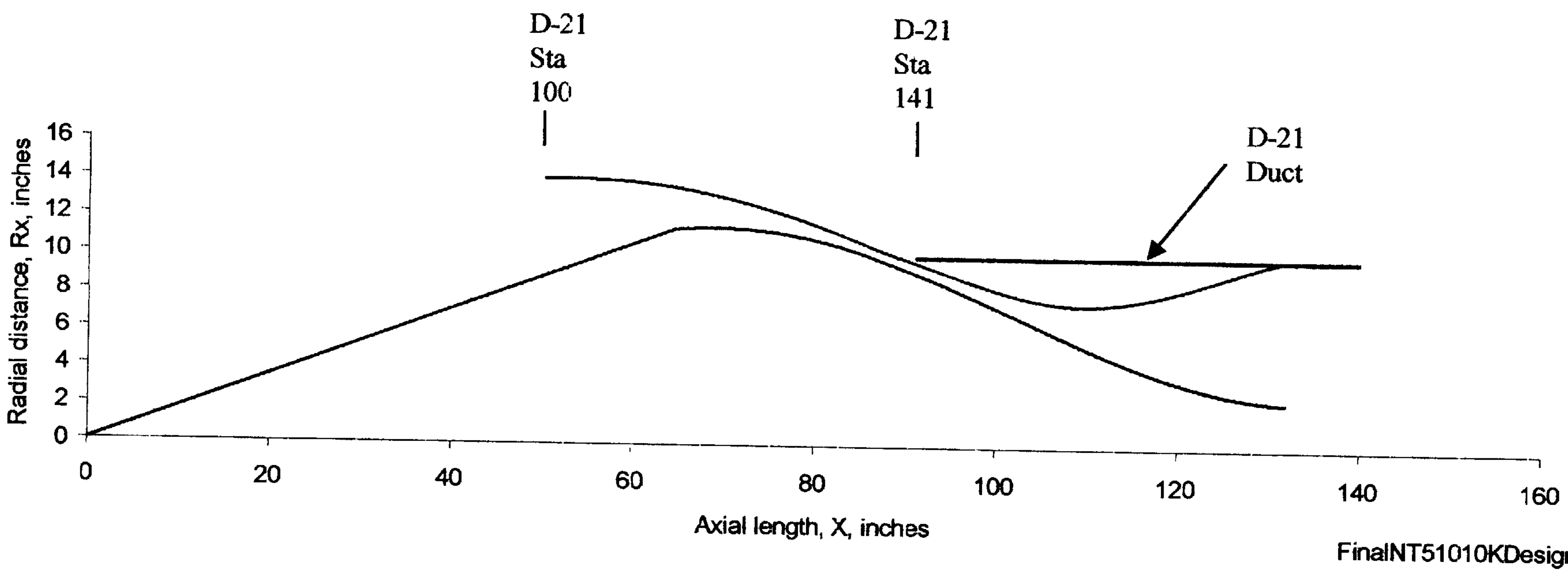


Figure 43

TechLand Research, Inc.

DRACO Inlet Area Distribution as a Function Of Translation: 10° Cone, 10° Throat

Marshall
Glenn
Dryden

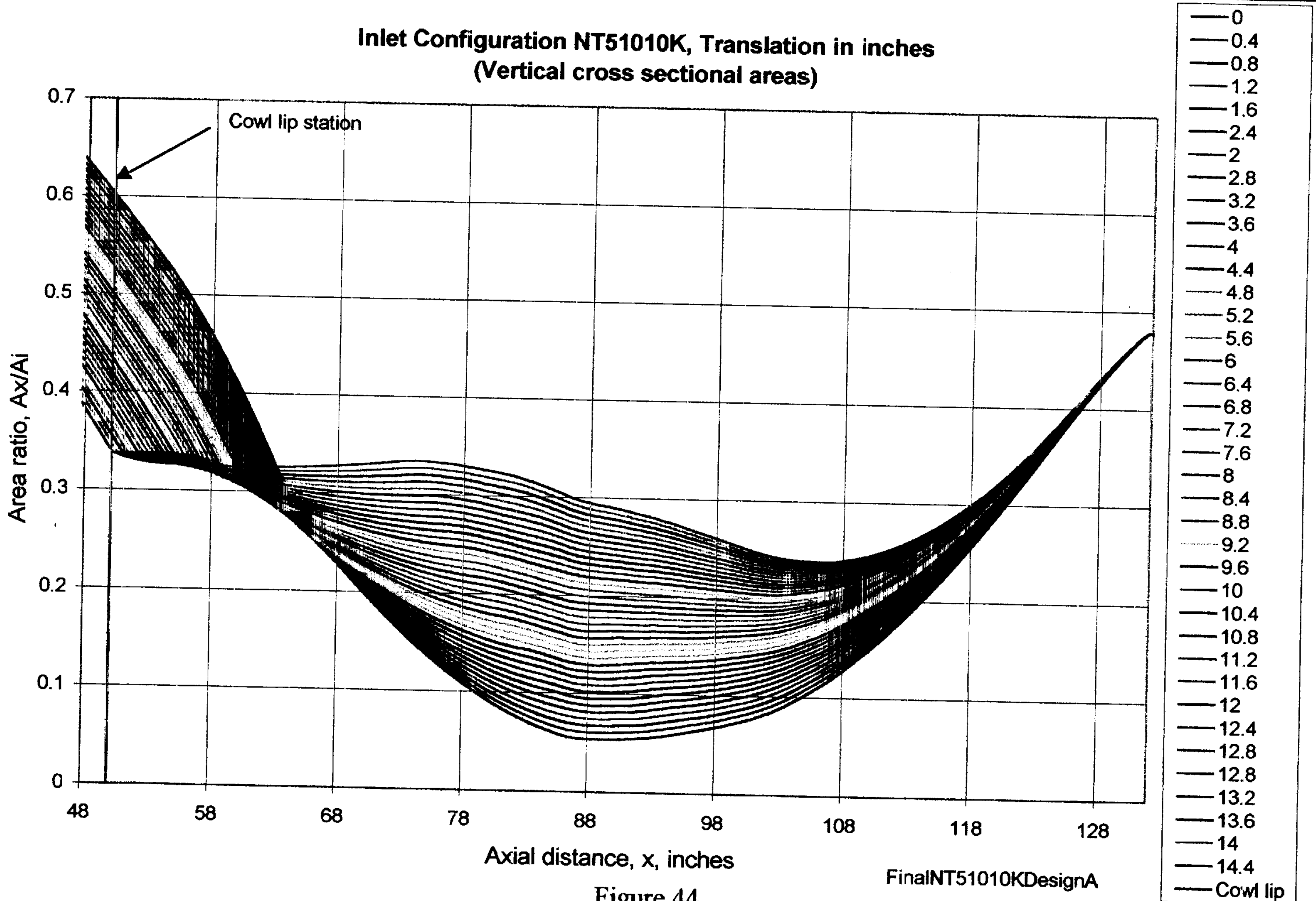


Figure 44

TechLand Research, Inc.

DRACO Inlet Area Distribution as a Function Of Translation: 10° Cone, 10° Throat

Marshall
Glenn
Dryden

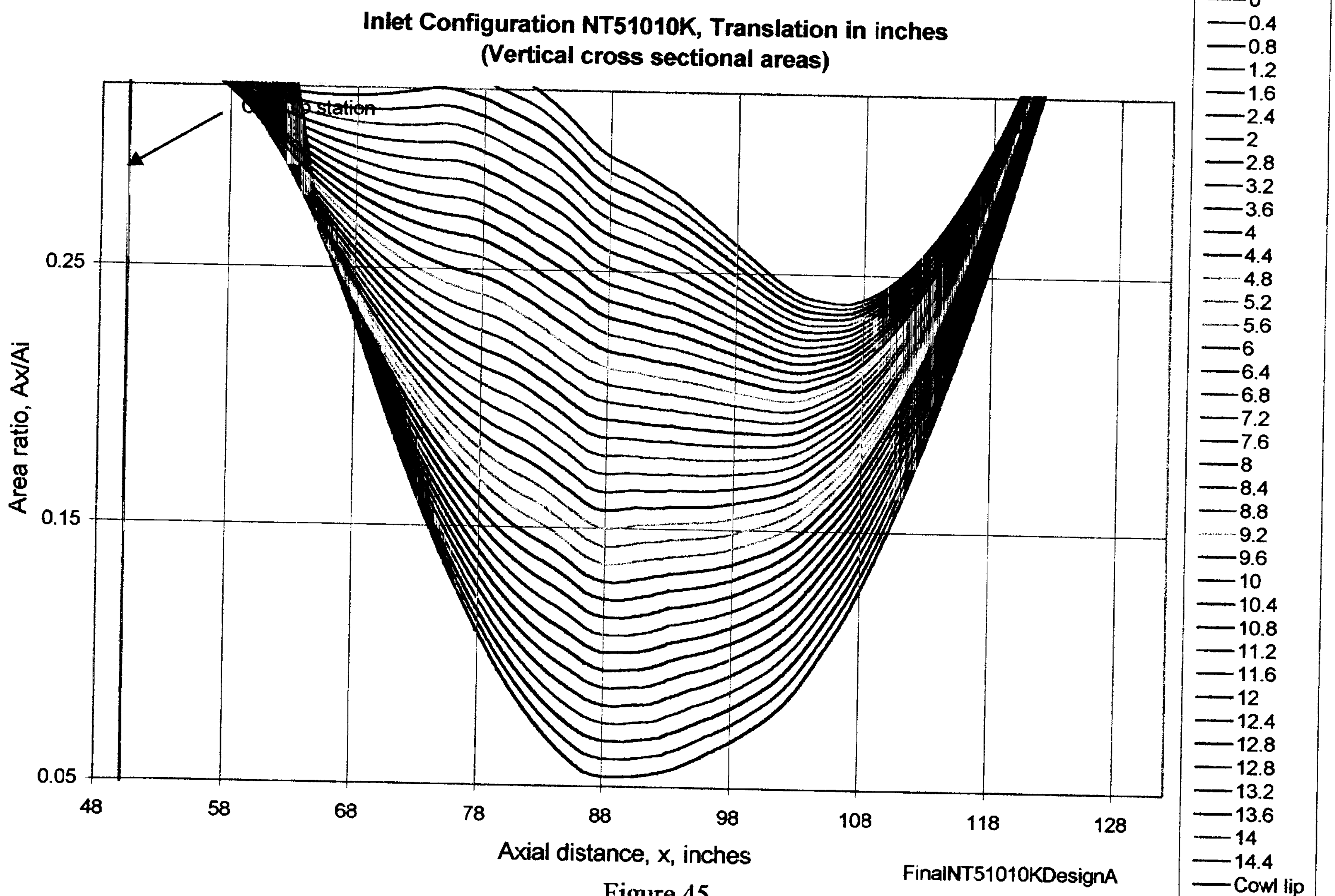


Figure 45

Subsonic Diffuser Diffusion Conical Angle
10° Cone, 10° Throat

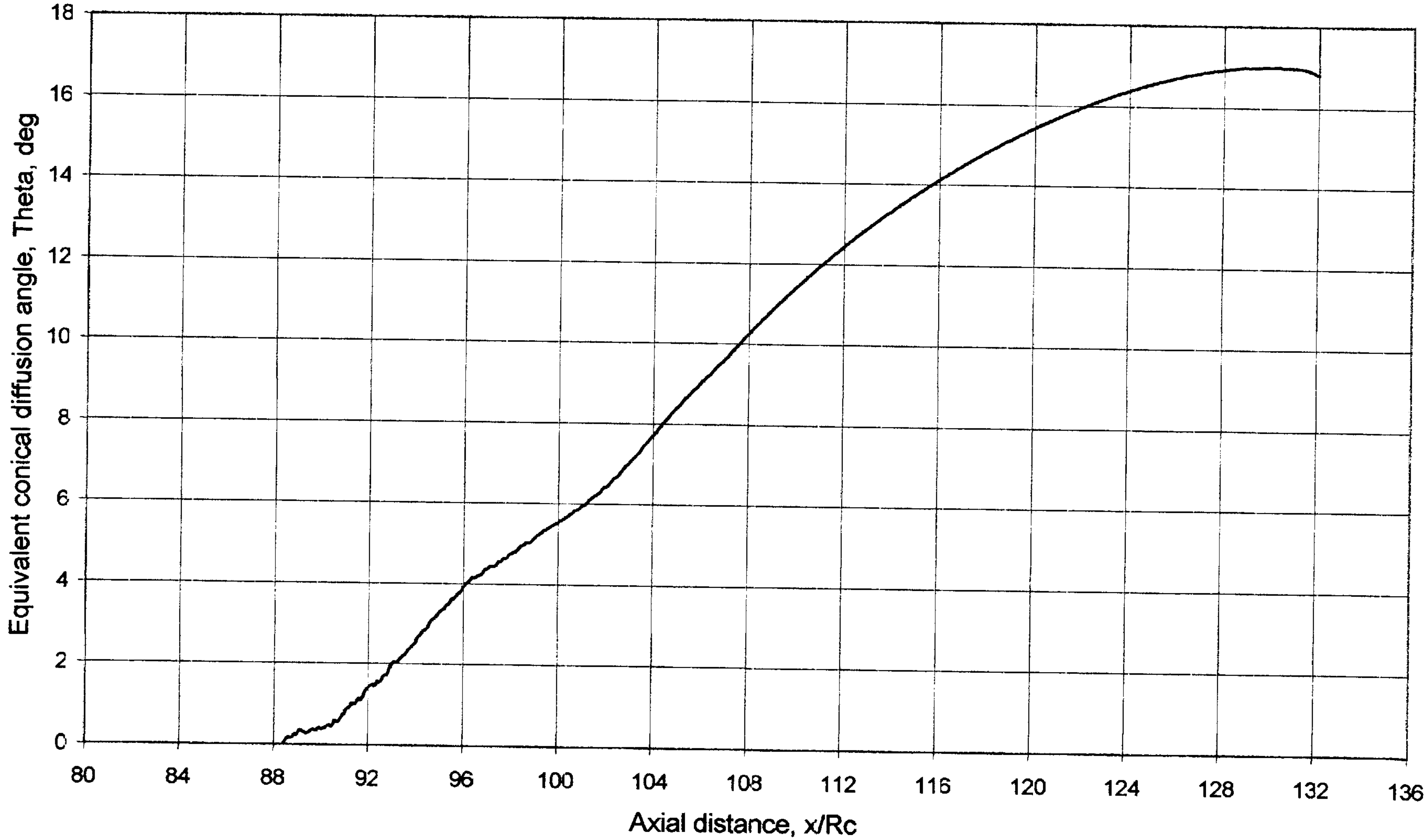
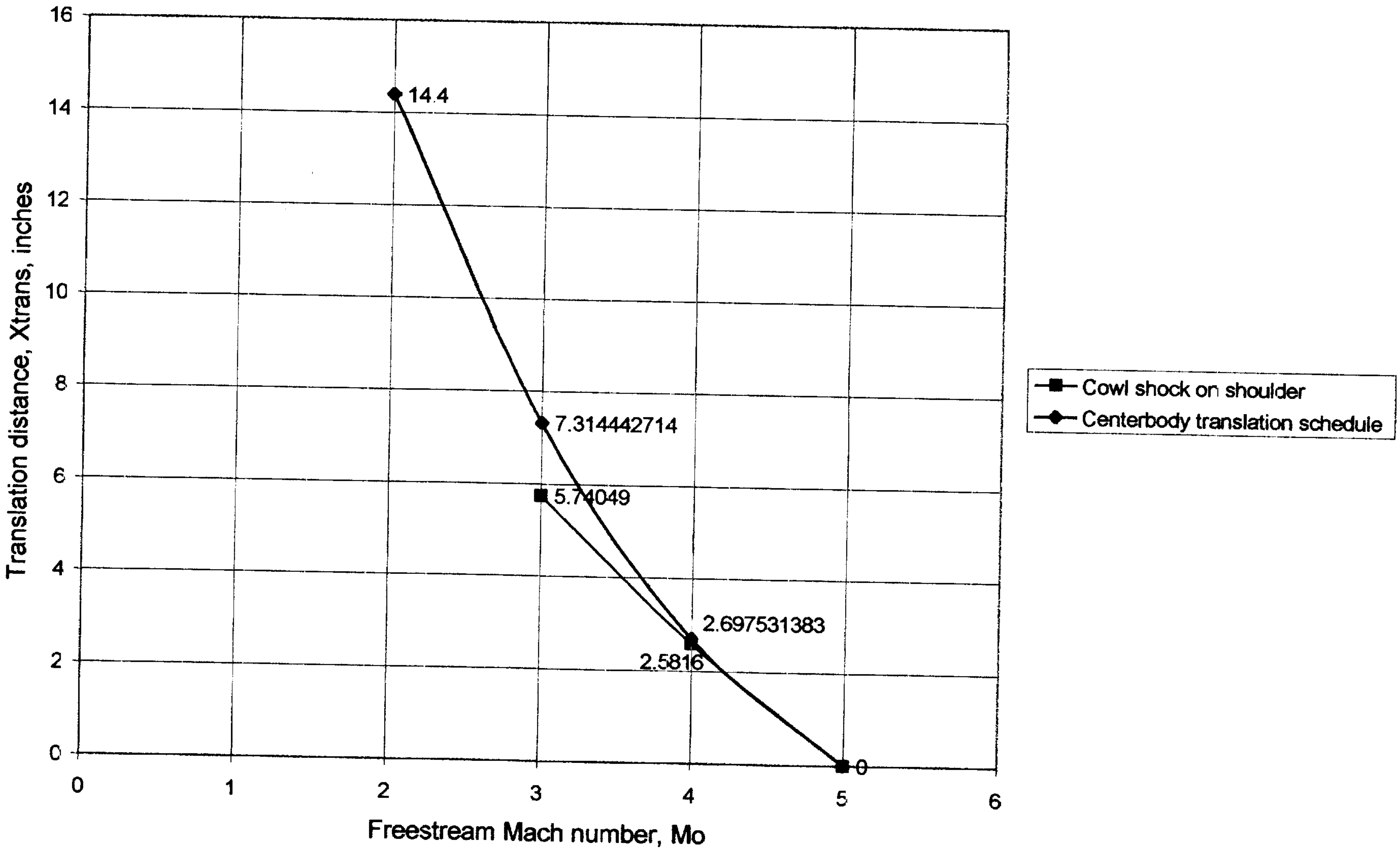


Figure 46

Centerbody Translation Schedule
10° Cone, 10° Throat



FinalNT51010KDesign

Figure 47

Mass Capture Schedule
10° Cone, 10° Throat

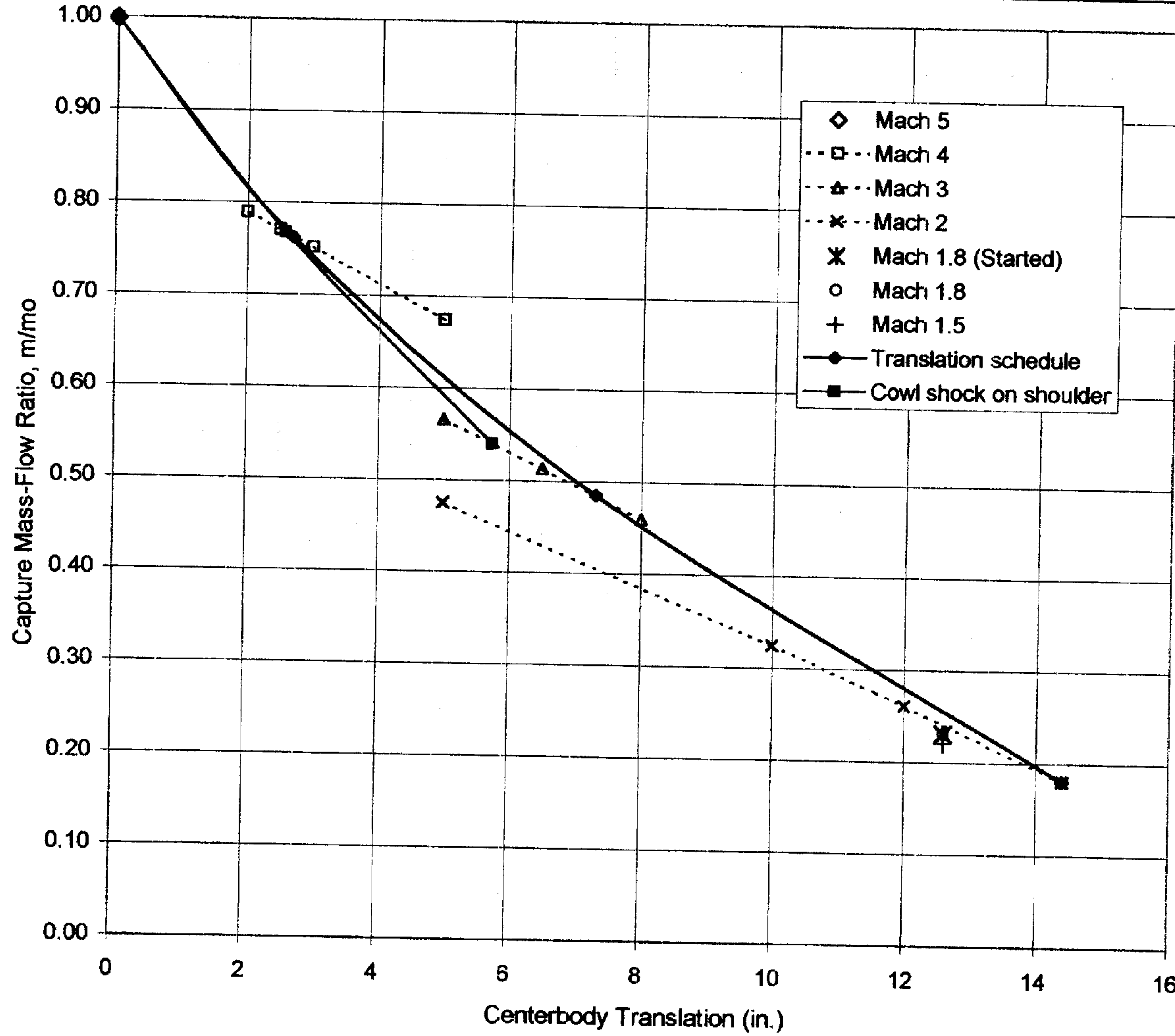


Figure 48

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Throat Station Variation with Centerbody Translation

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Glenn
Dryden

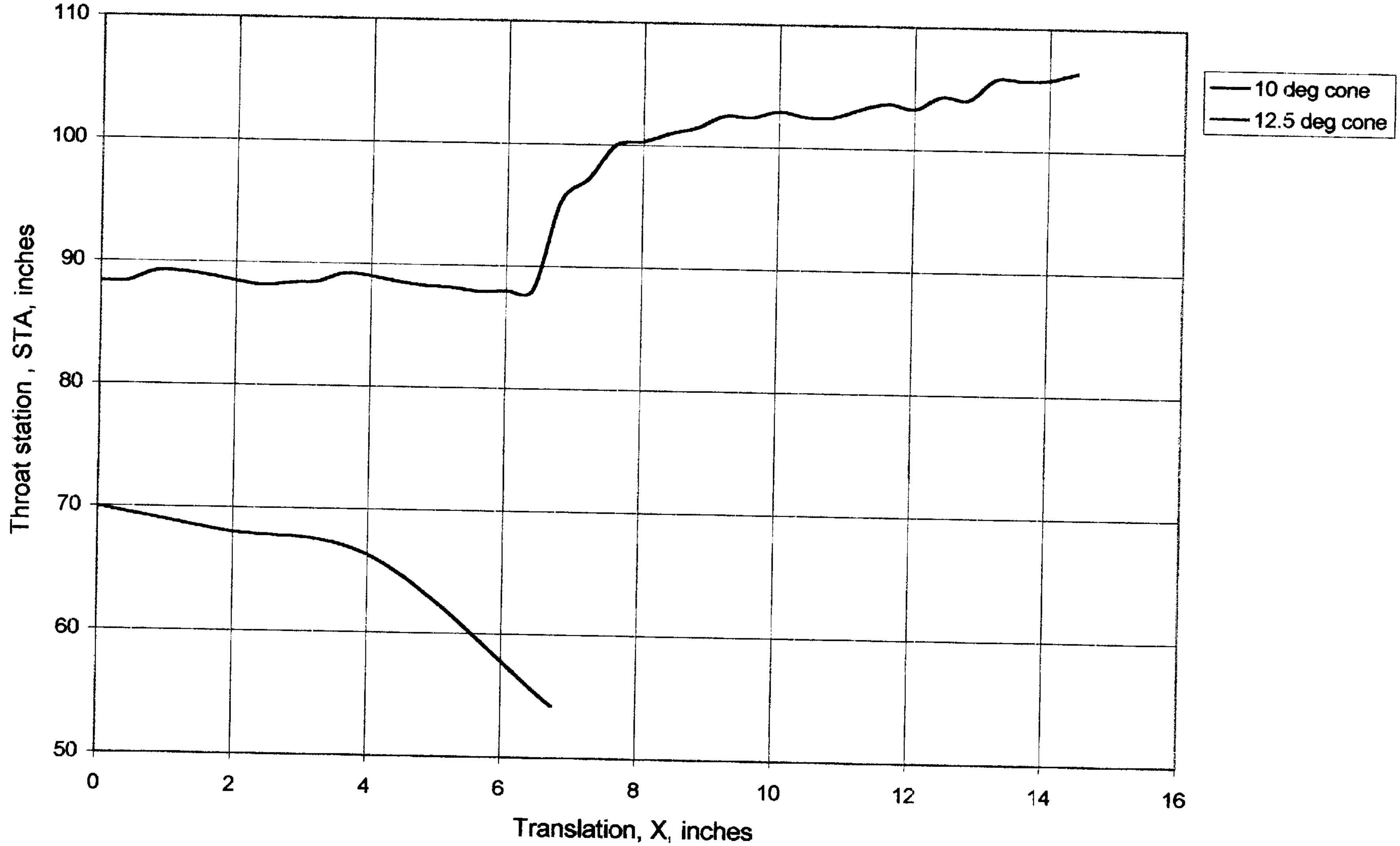

Figure 49

TechLand Research, Inc.

Aerodynamic Surface Contours for the DRACO Inlet: 10° Cone, 10° Throat, Modified Diffuser

Marshall
Glenn
Dryden

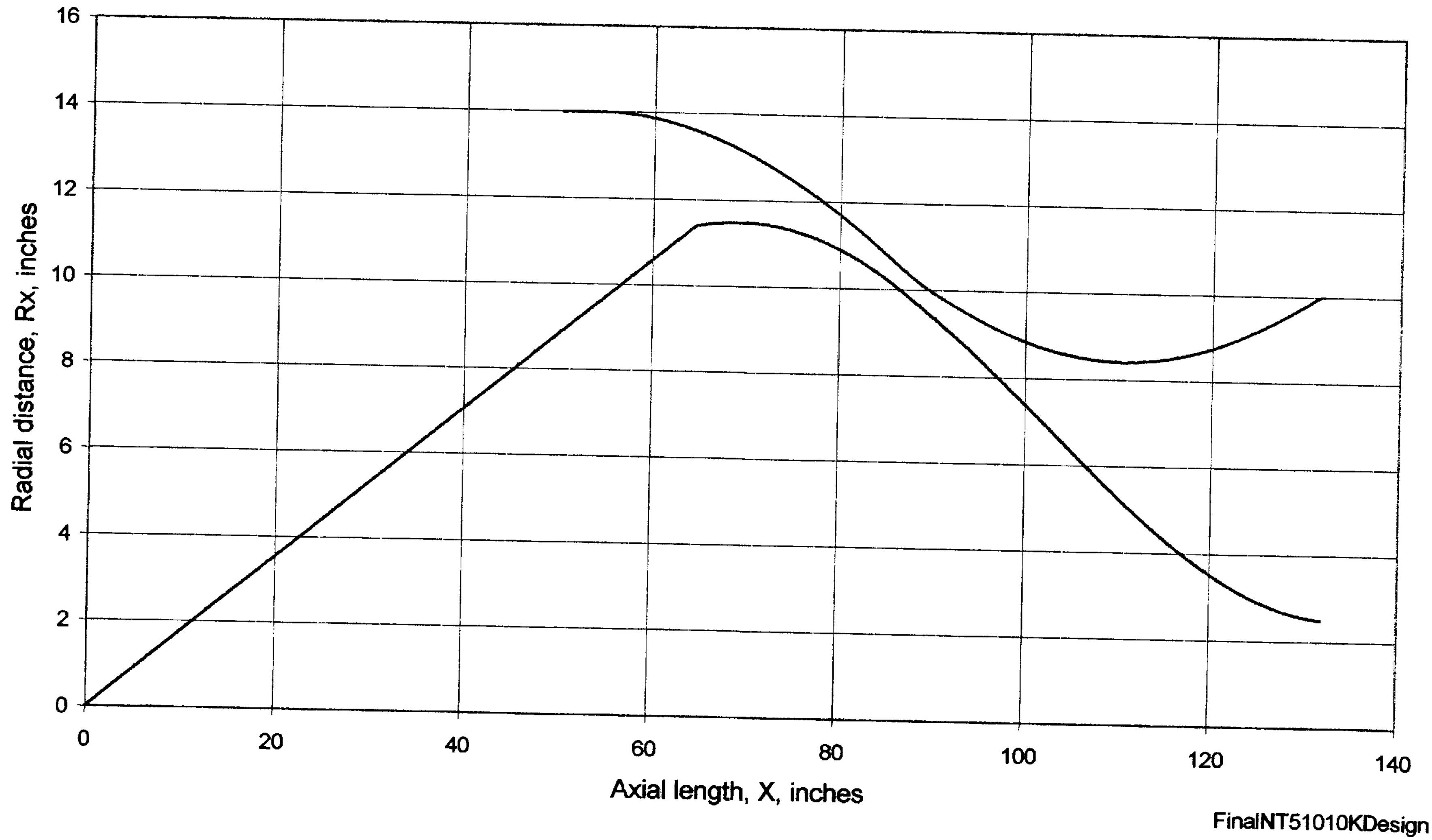

Figure 50

DRACO Inlet Area Distribution as a Function of Translation: 10° Cone, 10° Throat, Modified Diffuser

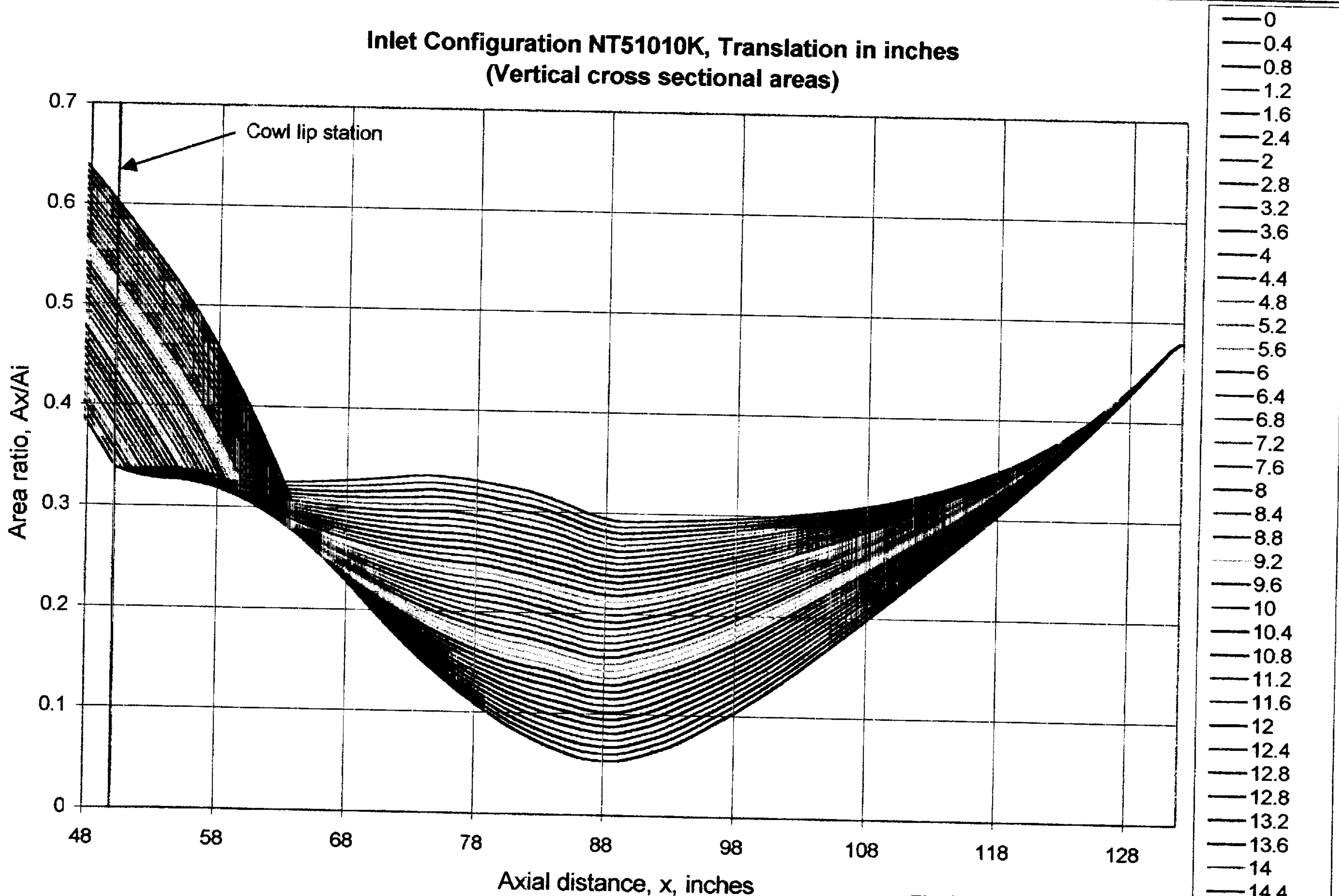

Figure 51

DRACO Inlet Area Distribution as a Function of Translation: 10° Cone, 10° Throat, Modified Diffuser

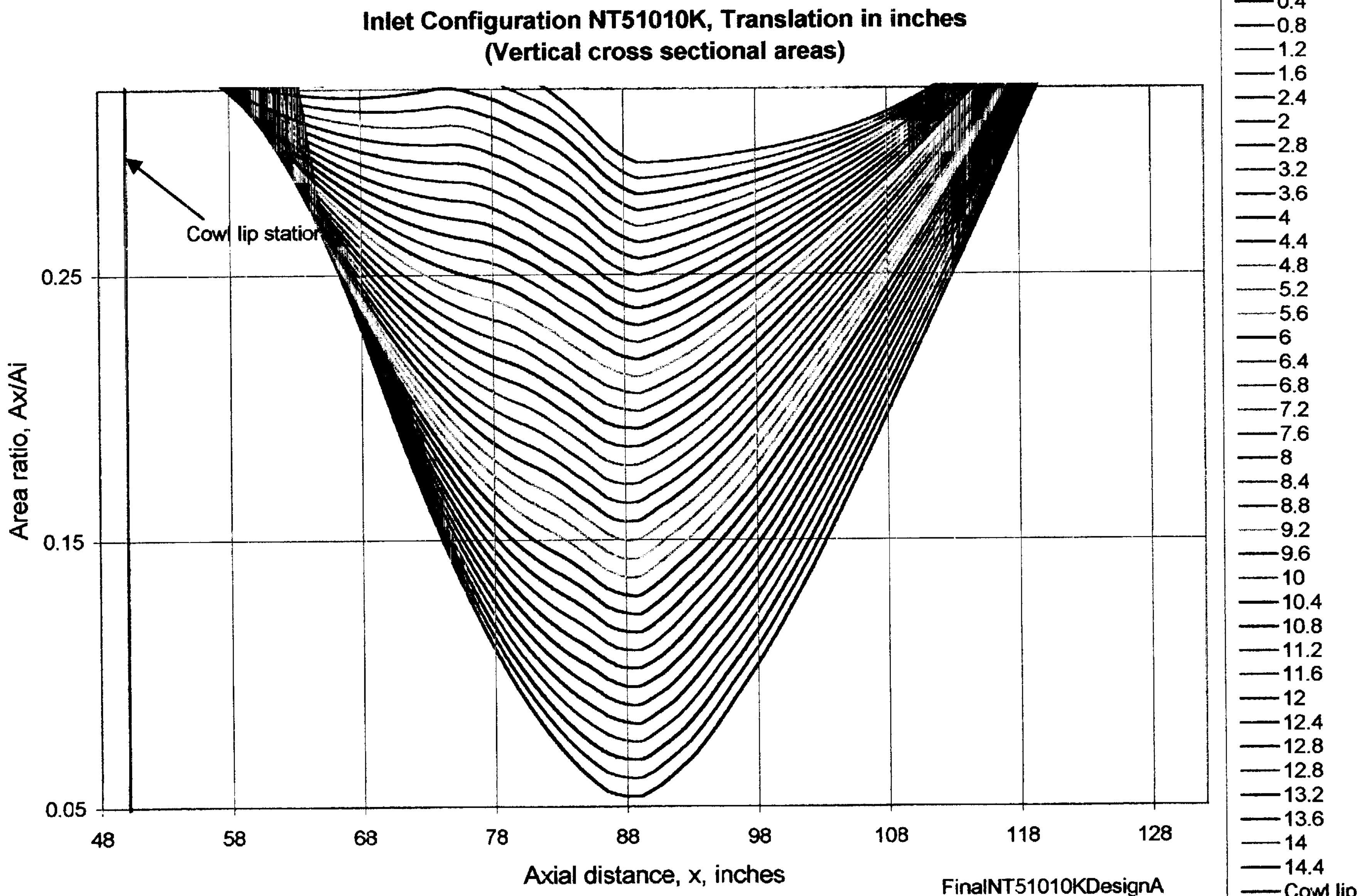

Figure 52

DRACO Inlet Subsonic Diffuser Conical Angle
10° Cone, 10° Throat, Modified and Original Diffuser

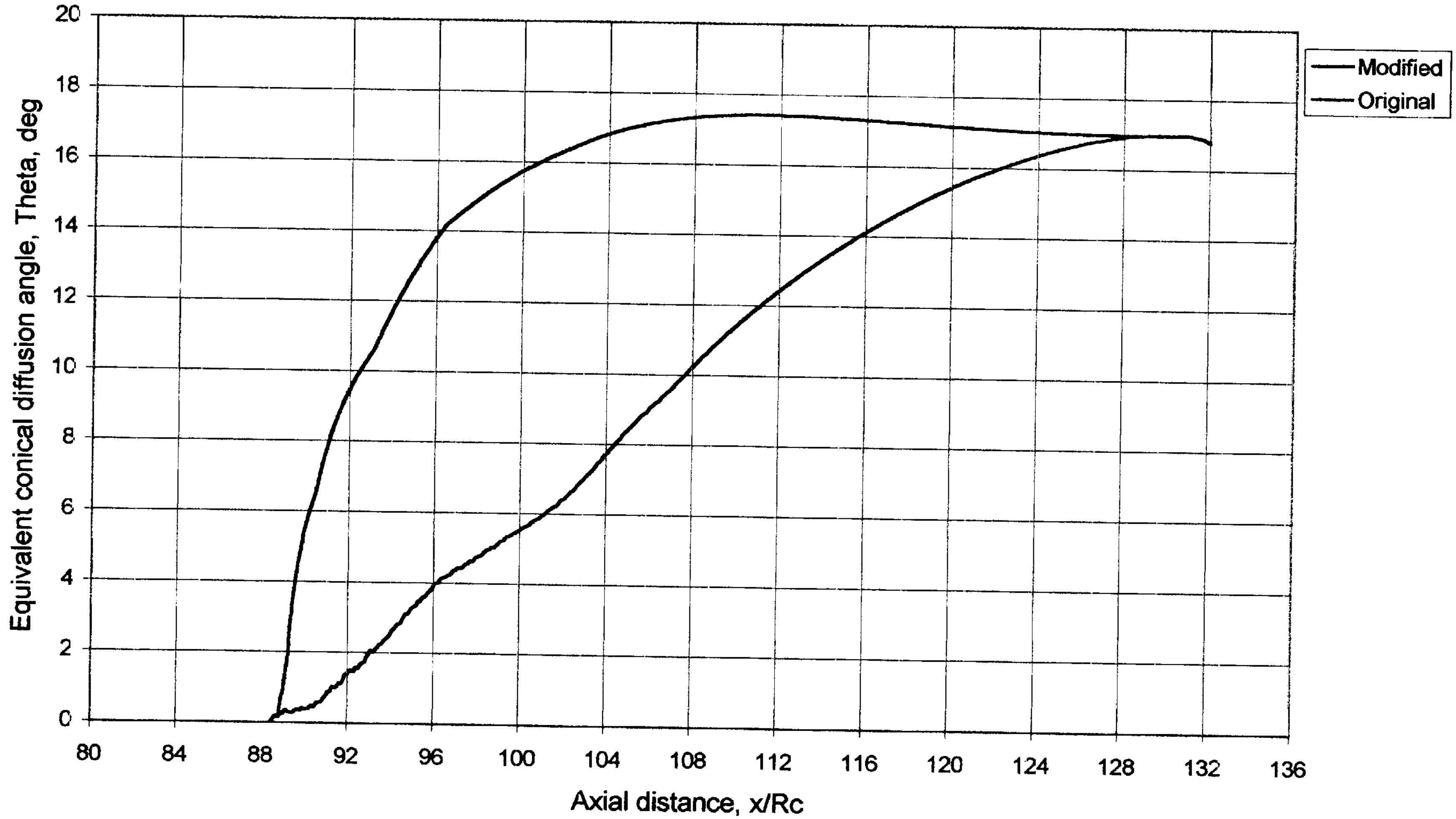

Figure 53

Comparison of Capture Mass Flow for the 10° and 12.5° Inlets

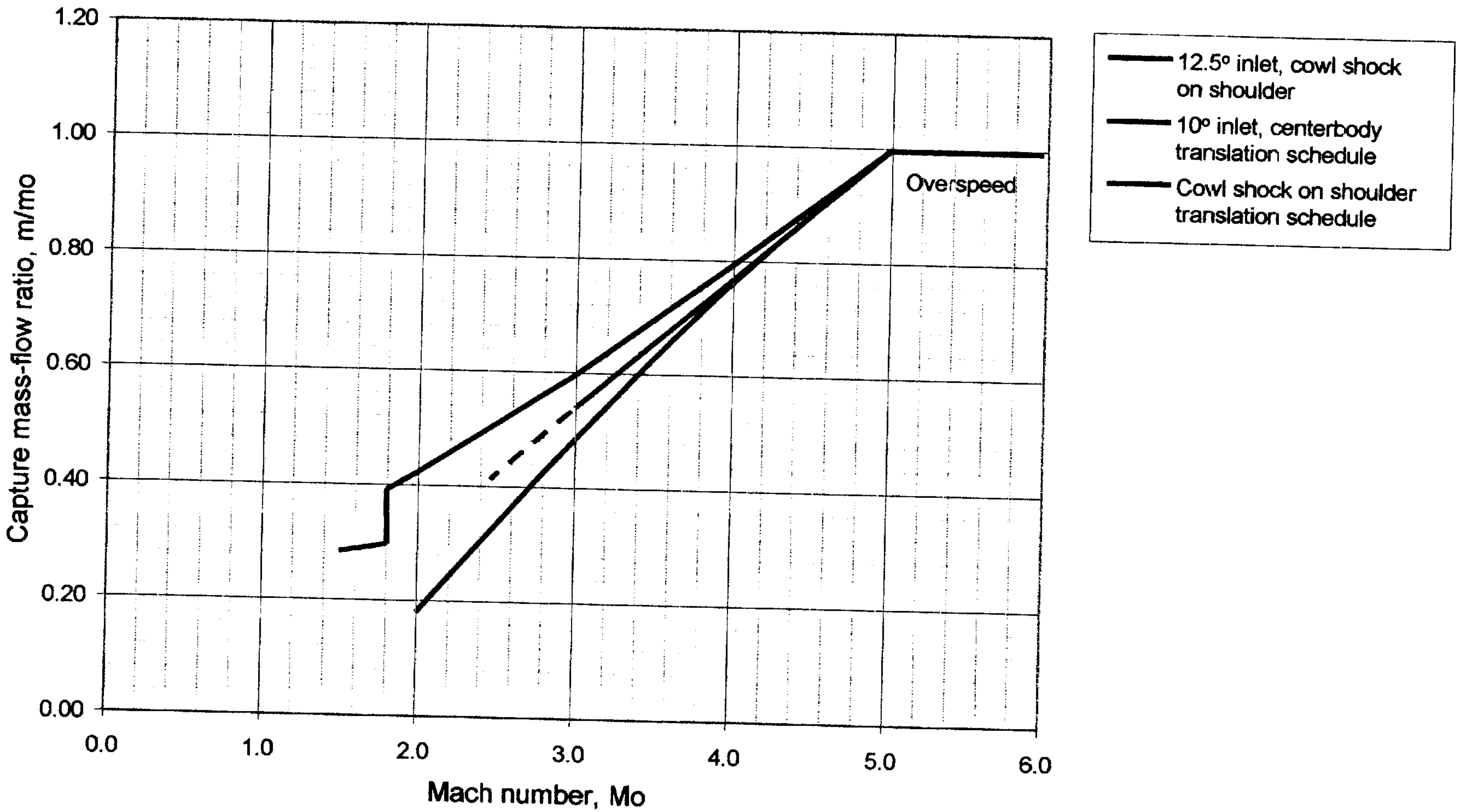

Figure 54

Inlet Diffuser Exit Total Pressure Recovery

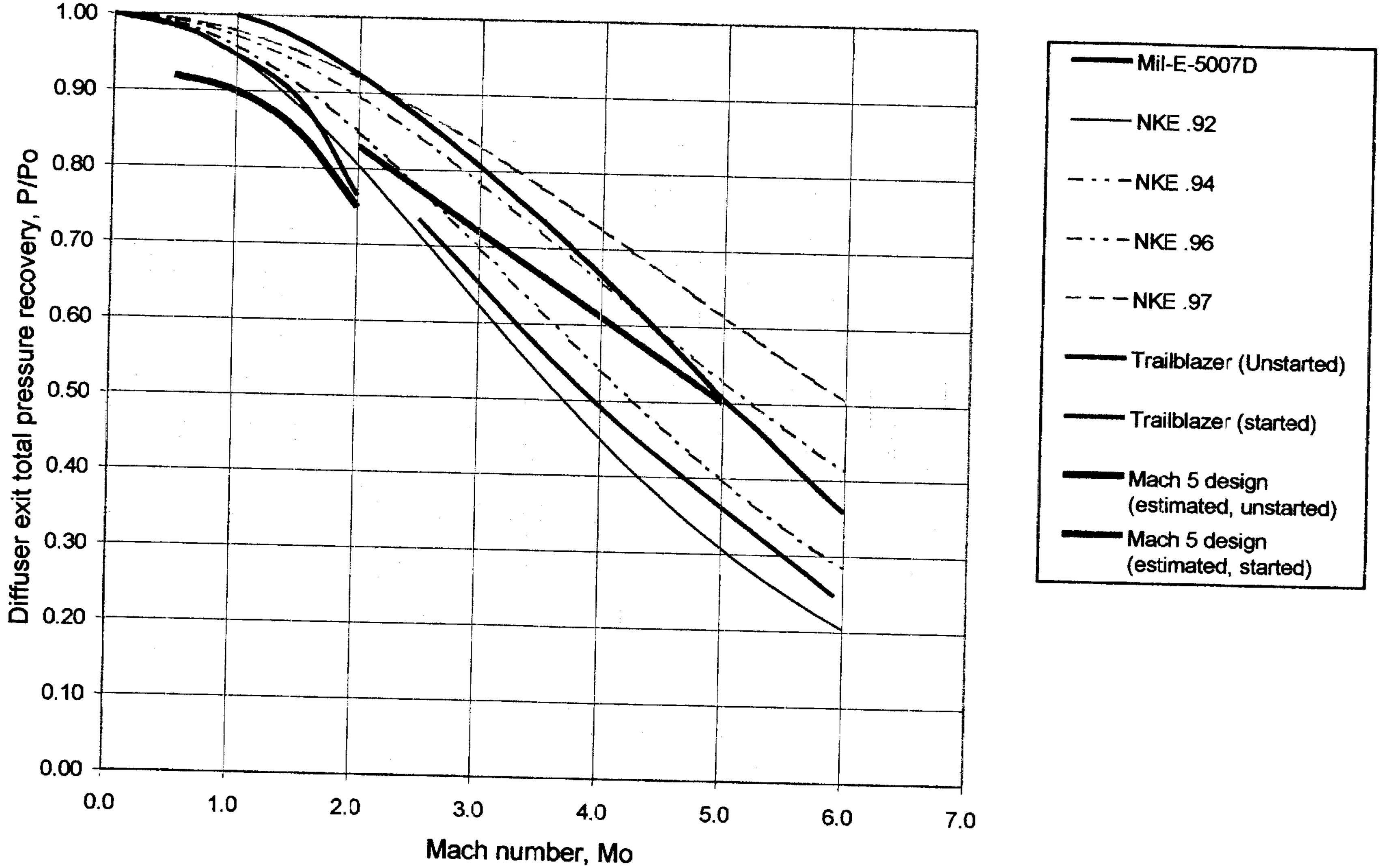

Figure 55

Results and Recommendations

- Multiple inlets of several cone angles designed
  - Lower cone angles provide increased off-design capture area.
  - Off-design capture mass-flow is a function of both area and local Mach number. These are determined at each off-design condition by:
    - Cone angle
    - Translation schedule
    - Internal surface contours
  - Analysis of multiple designs required to select configuration with maximum mass capture
  - Lower cone angle inlet longer and more difficult to integrate into D-21

- Conceptual sketches of inlet including a variable geometry system completed
  - D-21 installation forces short subsonic diffuser
  - Restricted length for centerbody support struts
  - More information on requirements of D-21 installation required to complete design
    - Can long duct be replaced?
    - Can the existing duct be used for structural support of inlet (strut attachment)?

- Establish engine airflow demand schedule

- Initiate a design process to develop an inlet to provide the required airflow

Figure 56

Next phase of inlet design

- Cone angle: 12.5°
- Throat angle: -12.5°
- Initial subsonic diffusion rate: ~8°
- Translation schedule that provides:
  - Shock on shoulder
  - Realistic throat Mach numbers
- Adjust inviscid design for viscous effects

Figure 57