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INVESTIGATION OF AEROTHERMODYNAMICS AND OPTICAL RADIATION IN THE HYPERSONIC FLOW FIELD

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16. Abstract Research for the radiation experiments on the Aeroassist Flight Experiment (AFE) was performed, to obtain a data base for development of engineering requirements for Aerobrakes. Due to funding restrictions, the necessary Aerobrake design data were obtained from ground based experiments, specifically arc-jet wind tunnels.

Except for the instrument windows, final development of the AFE radiometers was completed. Window definition included several designs to be flight validated in arc-jets. This work has been completed, and successful designs have evolved which will yield full scientific return from the flight experiment.

The theoretical work includes final code development to describe the spacecraft environment to support instrument definition, optical radiation codes that operate at significantly improved speeds, and calculation of radiation forebody loads and effects on experiment objectives for varying AFE weights and trajectories. Furthermore, radiant flux vectors at the AFE base have been predicted to be used for afterbody instrument definition.

The Vacuum Ultraviolet Experiment for the Arc-Jet has been completed, and arc-jet experiment conditions and experiment objectives have been refined to incorporate the most current thinking.

Ballistic range experiments have been completed. Several shadowgraphs indicating corner turning angles and waviness structures have been obtained, and the results have been used to estimate the compression region location for the AFE flight. The waviness measured has helped to model the temporal variations of wake radiation for purposes of defining radiometers to measure the energy content of wake dynamics.

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Final Technical Report

for
Cooperative Agreement NCC2-653

for the period

December 1, 1989 - January 31, 1993

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William C. Davy, Principal Investigator (12/1/89 - 7/31/90)

March, 1993

A major portion of the effort under this cooperative agreement has been research and support required for Spacecraft Principal Investigator Activities for the radiation experiments on the Aeroassist Flight Experiment (AFE), which was in turn designed to obtain a data base for development of engineering requirements for Aerobrakes. These activities require the specification of the experiment conditions at the state of the art to help define the instrument requirements. Due to funding restrictions, NASA canceled the program at the beginning of FY1992. The ensuing effect on this agreement was to change the thrust to obtain the necessary Aerobrake design data from ground based experiments, specifically arc-jet wind tunnels.

Objective 1: Spacecraft Principal Investigator Activities

Except for the instrument windows, final development of the AFE radiometers was completed, and a CDR was successfully held on 1/23/91 by the instrument contractor. The CDR involved extensive participation by the Principal Investigators, Mr. W. Davy and Dr. R. Craig. (Overview sheets are attached as APPENDIX 1).

Window definition continued after the CDR. Several designs were considered to be flight validated in arc-jets. This work has been completed, and successful designs have evolved which will yield full scientific return from the flight experiment. Early results of the tests have been reported in internal document AFE 9004-003 (APPENDIX 2).

Objective 2: Flow Field Computation on the ASTV Vehicle

Final Code development work was done to describe the spacecraft environment to support instrument definition. The results were made available to the instrument contractor for final specifications.

Objective 3: Theoretical Investigation of the AFE Nonequilibrium Chemistry and Optical Radiation

The radiation codes continued to be developed. New species have been added (C_2 and CO). An improved data base has been incorporated utilizing results from the NASA Ames Computational Chemistry Branch. Refinement of the code has led to a large improvement in speed (by a factor 10 to 100 faster). These results have been described in AIAA 92-2968.

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Radiation forebody loads and effects on experiment objectives have been calculated in response to proposed changes in the AFE weight and trajectory. Results have been transmitted to the Program Office.

Radiant flux vectors at the AFE base have been predicted to be used for afterbody instrument definition. Participation with researchers from the NASA Ames Aerothermodynamics Branch, especially in conjunction with work performed under NASA-Eloret Cooperative Agreements NCC2-420 and NCC2-582, has helped establish that these results are at the state of the art in knowledge of wake flows. This work has been presented at a conference and was published as AIAA 91-1408 as well as in the AIAA journal (APPENDIX 3).

The OAHRS instrument was canceled due to budget limitations, and a NASA Ames in-house design was proposed. Work was done to support the definition of this alternative instrument.

Objective 4: Experimental Arc-Jet and Ballistic Range Studies

The Vacuum Ultraviolet Experiment for the Arc-Jet is completed, and arc-jet experiment conditions and experiment objectives have been refined to incorporate the most current thinking.

3

Ballistic range experiments have been completed. Launching the asymmetric shape has been difficult, but several shadowgraphs indicating corner turning angles and waviness structures have been obtained, and the results have been used to estimate the compression region location for the AFE flight. The waviness measured has helped to model the temporal variations of wake radiation for purposes of defining radiometers to measure the energy content of wake dynamics.

The following scientific publications, reports, and presentations resulted from this research (fully or in part):

(1)   RHARE Science Status Review, 8/1/90.

(2)   E.E. Whiting and C. Park, "*Radiative Heating at the Stagnation Point of the AFE Vehicle,*" NASA Technical Memorandum 10289 (11/1990).

(3)   RHARE Critical Design Review, 1/23/91.

(4)   E. E. Whiting, I. Terrazas-Wqlinas, R. A. Craig, C. K. Sobeck, G. L. Sarver III, L. J. Salerno, W. Love, S. Maa, and A. Covington, "*Arcjet Exploratory Tests of ARC Olptical Window Design for the AFE Vehicle,*" Report AFE-9004-003, 4/1991 (Appendix 2).

(5)   E. Venkatapathy, G. Palmer, and D.K. Prabhu, *"AFE Base Flow Computations,"* AIAA Paper 91-1372, presented at the AIAA 26th Thermophysics Conference in 6/1991.

(6)   A.W. Strawa, C. Park, W.C. Davy, R.A. Craig, D.S. Babikian, D.K. Prabhu, and E. Venkatapathy, *"Radiometric Investigation of the Wake Flow of the Forthcoming Aeroassist Flight Experiment,"* AIAA Paper 91-1408, presented at the AIAA 26th Thermophysics Conference in 6/91 (Appendix 3).

(7)   I.D. Boyd and E.E. Whiting, *"Decoupled Predictions of Radiative Heating in Air Using Particle Simulation Method,"* AIAA Paper 92-2971, Presented at the AIAA 23rd Plasmadynamics & Lasers Conference in 6/92 (Appendix 3).

(8)   G. Palumbo, *"Shock Layer Spectroscopy in the 20 MW Arc Jet Tunnel at the NASA Ames Research Center, Moffett Field, CA,"* report, 12/92.

APPENDIX 1

RHARE Critical Design Review

Wednesday, January 23, 1991

- RHARE Overview
- TRD Design
- HRS Design

What is a CDR?

This CDR is a joint Martin Marietta and NASA review of the detailed RHARE design that has evolved from the design approach established at PDR and other technical interchange meetings. CDR will review unreleased engineering drawings for manufacturing and "code to" specifications for software. Successful completion of CDR will result in the release of detailed engineering for fabrication of hardware and the coding of software.

At CDR we will have available:

- Not less than 80% of engineering drawings

- Equipment Specification

- Test, Assembly and Calibration Plans

- Nonstandard Processes List and Description

- Part and Material Lists

- Updated Analyses

- Breadboard Test Results

- Software VCLR's and Test Procedures
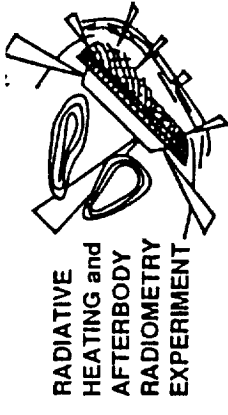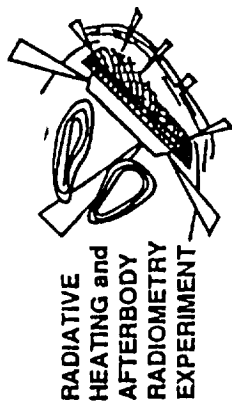
	Tue, 1/22/91	Wed., 1/23/91	Thurs., 1/24/91	Fri., 1/25/91
Morning	Introduction Window Working Group	RHARE Overview TRD Design	MEU Design	Software Solar Cal Contamination Control Verification & Test
Afternoon	Window HRS Heatsink	HRS Design	MEU Design CCU Design	SR&QA RID Review
Evening	Vortek Lamp Tour	RHARE Lab Tour		

APPENDIX 2

Arcjet Exploratory Tests of ARC Optical Window Design for the AFE Vehicle,

December 14, 1990 to March 6, 1991

Ellis E. Whiting, Imelda Terrazas-Salinas,
and Roger A. Craig
Eloret Institute

Charles K. Sobeck, George L. Sarver III, Louis J. Salerno,
Wendell Love, Scott Maa and Al Covington
NASA, Ames Research Center

April 1991

Abstract

Tests were made in the 20 MW arcjet facility at the NASA Ames Research Center (ARC) to determine the suitability of sapphire and fused silica as window materials for the AFE entry vehicle. Twenty nine (29) tests were made; 25 at a heating rate about 80% of that expected during the AFE entry and 4 at approximately the full, 100% AFE heating rate profile, that produces a temperature of about 2900 $^{\circ}$F on the surface of the tiles that protect the vehicle. These tests show that a conductively cooled window design using mechanical thermal contacts and sapphire is probably not practical. Cooling the window using mechanical thermal contacts produces thermal stresses in the sapphire that cause the window to crack. An insulated design using sapphire, that cools the window as little as possible, appears promising although some spectral data in the vacuum-ultra-violet (vuv) will be lost due to the high temperature reached by the sapphire. The surface of the insulated sapphire windows, tested at the 100% AFE heating rate, showed some slight ablation (T_{melt}=3722 $^{\circ}$F), and cracks appeared in two of three test windows. One small group of cracks were obviously caused by mechanical binding of the window in the assembly, which can be eliminated with improved design. Other cracks were long, straight, thin crystallographic cracks that have very little effect on the optical transmission of the window. Also, the windows did not fall apart along these crystallographic cracks when the windows were removed from their assemblies. Theoretical results from the thermal analysis computer program SINDA indicate that increasing the window thickness from 4 to 8 mm may enable surface ablation to be avoided. An insulated design using a fused silica window tested at the nominal AFE heating rate experienced severe ablation (T_{soften}=3029 $^{\circ}$F), thus fused silica is not considered to be an acceptable window material.

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APPENDIX 3

THEORETICAL INVESTIGATION OF AFE NONEQUILIBRIUM
CHEMISTRY AND OPTICAL RADIATION

(1) Analysis of the radiative field around the AFE: The radiative field around the Aeroassist Flight Experiment (AFE) vehicle was analysed using the code NONEQ (an enhanced version of the code NEQAIR). The effects of electronic equilibrium and QSS were studied for a number of lines of sight (both in the aft and forebody regions of the flowfield). The lines of sight considered in the calculations roughly corresponded to the locations of the radiometers and spectrometers. The results of these calculations are partially reported in the following publications:

(a) Venkatapathy, E., Palmer, G. and Prabhu. D. K., "AFE Base Flow Computations," AIAA Paper 91-1372. Presented at the AIAA 26th Thermophysics Conference at Hawaii in June.

(b) Strawa, A. W., Park, C., Davy, W. C., Craig, R. A., Babikian, D. S., Prabhu, D. K., and Venkatapathy, E., " Radiometric Investigation of the Wake Flow of the Forthcoming Aeroassist Flight Experiment," AIAA Paper 91-1408. Presented at the AIAA 26th Thermophysics Conference at Hawaii in June.

The results were also used in determining the dynamic range/integration times of the high resolution spectrometers. A typical result of the application of this analysis is shown in the attached figure.

Currently, the radiation package, NONEQ, used in conjunction with the flow simulation is being optimized and enhanced. The results of this effort will be reported at a later date.

(2) ARC 16" shock tunnel startup simulation: An axisymmetric, explicit TVD code of J.-L. Cambier was used in the simulation of the startup process of the 16" shock tunnel at NASA Ames. The gas was assumed to be chemically and thermally frozen and fully turbulent. The simulation of the startup process was expanded to include the proposed test section. The transient flow past a simple axisymmetric body (roughly equivalent in frontal area to the actual three-dimensional geometry to be tested) in test section was also computed. The primary aim of this study was to study the startup process and "choking" phenomena in a pulse facility such as the shock tunnel.

The time histories of the pressures at the measurement stations N1, N2, and N3 are shown in the attached figure. The calculations were performed for a driver gas pressure of 6000 psi with the nozzle being evacuated to 100 mtorr. The figure clearly indicates our ability to simulate the unsteady startup flow in the shock tunnel nozzle. These calculations are being extended to the case of a reacting mixture of N, O, N2, O2, and NO.

In addition, a time sequence of Mach contours in the test section are also shown. These figures clearly indicate that the model does not "choke" the tunnel since the primary shock is easily passed through. Currently, there are no plans to extend these calculations for the realistic three-dimensional geometry due to the lack of computer resources.

(3) Shock tunnel nozzle design: In order to achieve the flow conditions required for testing the combustor model in the shock tunnel, the existing throat (geometric area ratio = 270) had to be modified. Based on quasi-one dimensional analysis of the exit conditions of the nozzle the required geometric area ratio was deteremined to be 190. With the existing nozzle as the baseline, the nozzle contour was modified using simple curve-fitting routines. The old and new nozzle contours are shown in the attached figure. The new nozzle was successfully tested recently.
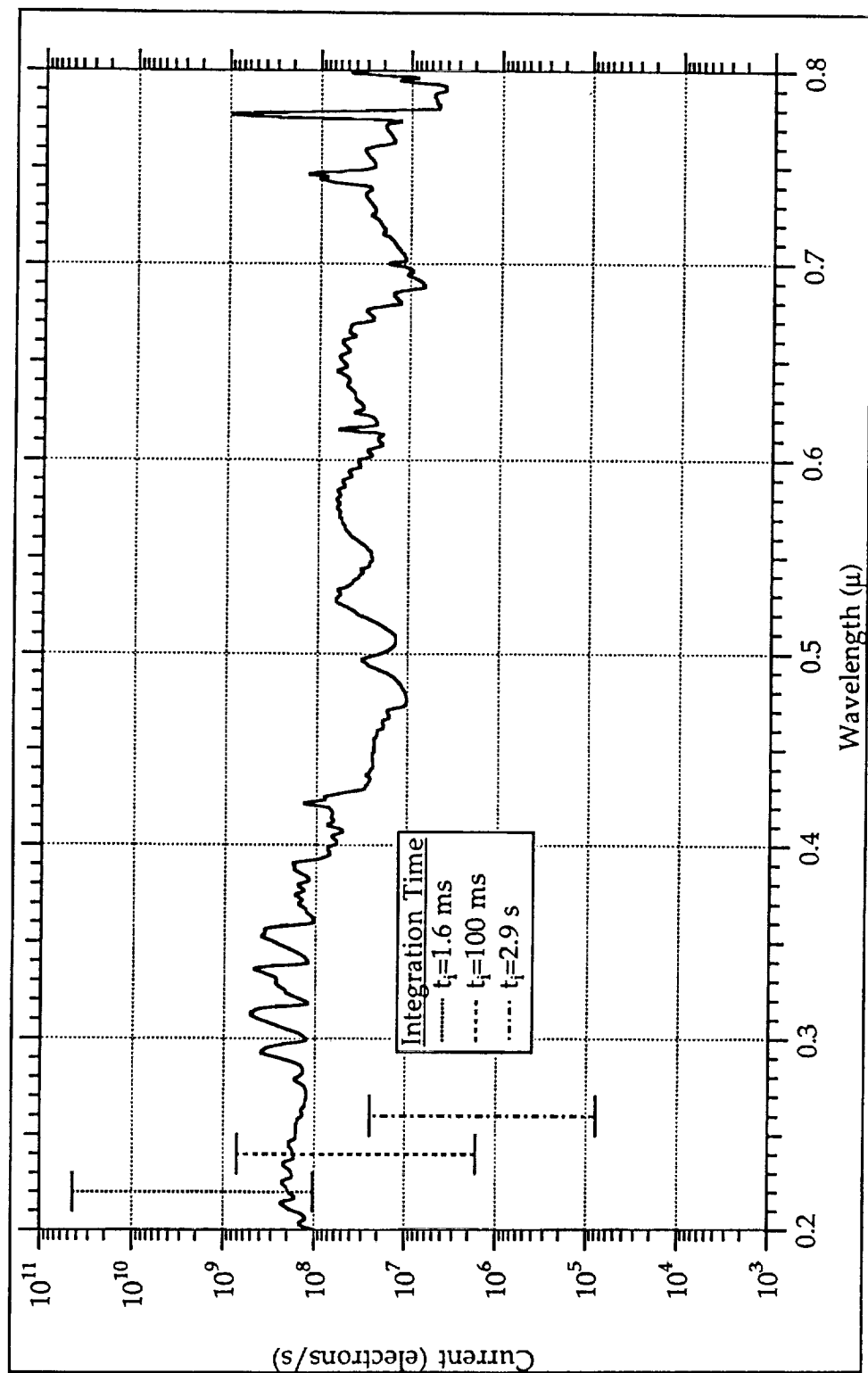
(4) Flow diagnostics support: An experiment has been proposed in which the absorption due to NO (γ) band system will be used as a flow diagnostic (yielding the vibrational and translational temperature and the number density of NO) at the measurement station N3. The light source to be used is a blackbody at 48000 K. An absorption measurment of the O-lines at 1300 Å has also been proposed. The flow solution obtained from a quasi-one dimensional analysis was used in conjunction with the high resolution spectral code NONEQ to determine the sturcture of the NO (γ) band system in absorption. The results of these calculations are very preliminary since they do not account for the boundary layer and non-uniformities in the flow. The current estimates will be refined once the high precision reacting calculations are completed. The attached figure shows the NO (γ) band system based on a quasi-one dimensional analysis.
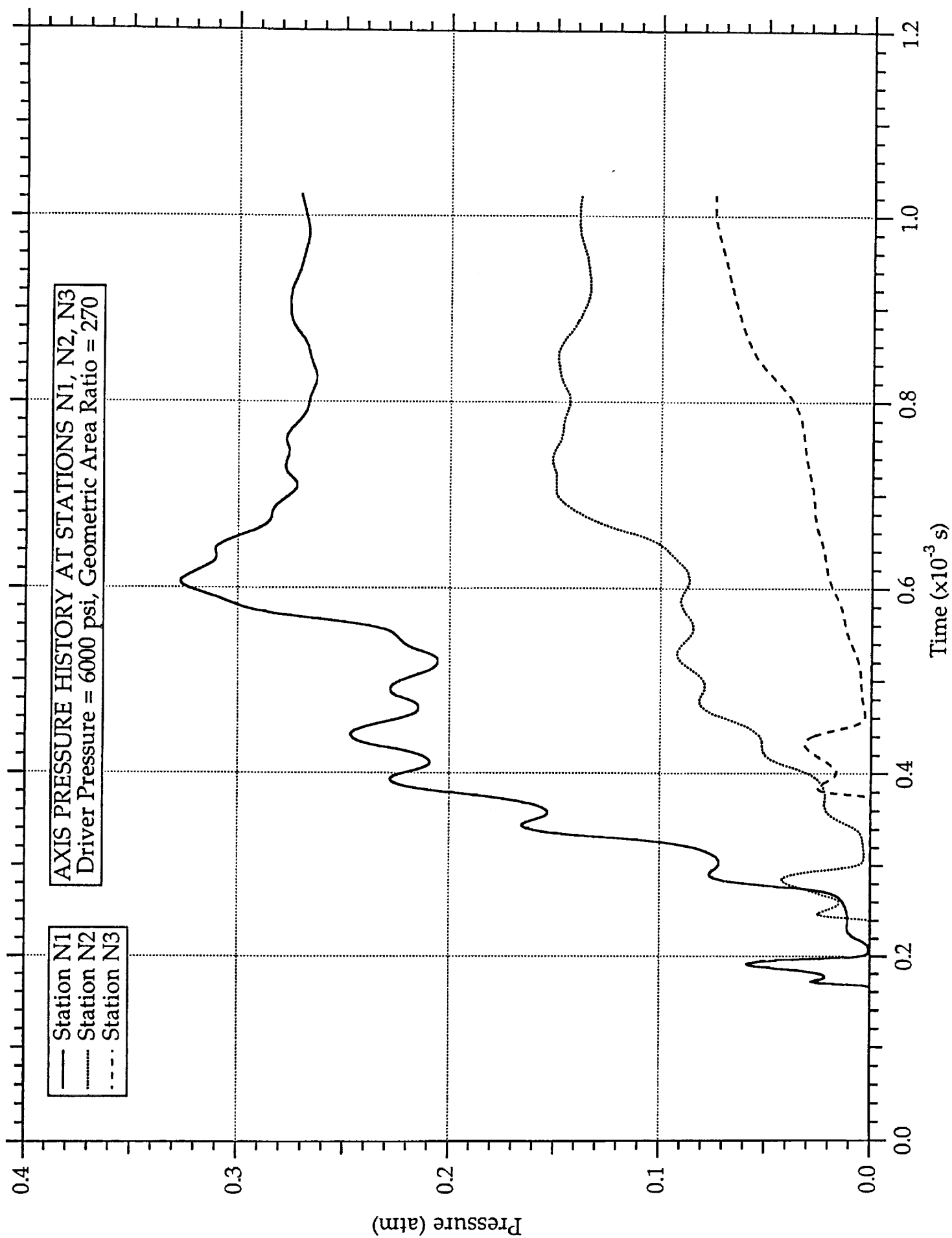
(5) Shock tunnel contamination study: The iron/nickel/chromium contaminants in the flow will disrupt the OH-absorption diagnostic. The

levels of these contaminants must be estimated. The spectral code NONEQ has been modified to include the metallic species Ni, Cr, and Fe. The spectroscopic data for these species were acquired very recently and the code has not been fully tested.

The tasks to be accomplished in the next reporting period are - (1) NO (γ) diagnostic in conjunction with a realistic axisymmetric simulation, (2) spectroscopic study of the contaminants, (3) combustor model design and analysis, (4) three-dimensional analysis of the wedge model being tested in the shock tunnel, (5) enhancements and performance improvements of the spectroscopic code.

DETECTOR CURRENT
Upper Shoulder Line (LOS 3)
Flowfield Solution - Palmer, Spectrum - Prabhu
Ω_d=0.0129 sr, A_d = 6.25 x 10^{-4} cm^2, $\Delta\lambda_d$=6 x 10^{-4} μ, Filter=1.0

Integration Time
t_i=1.6 ms
t_i=100 ms
t_i=2.9 s

AXIS PRESSURE HISTORY AT STATIONS N1, N2, N3
Driver Pressure = 6000 psi, Geometric Area Ratio = 270

—— Station N1
········ Station N2
– · – Station N3
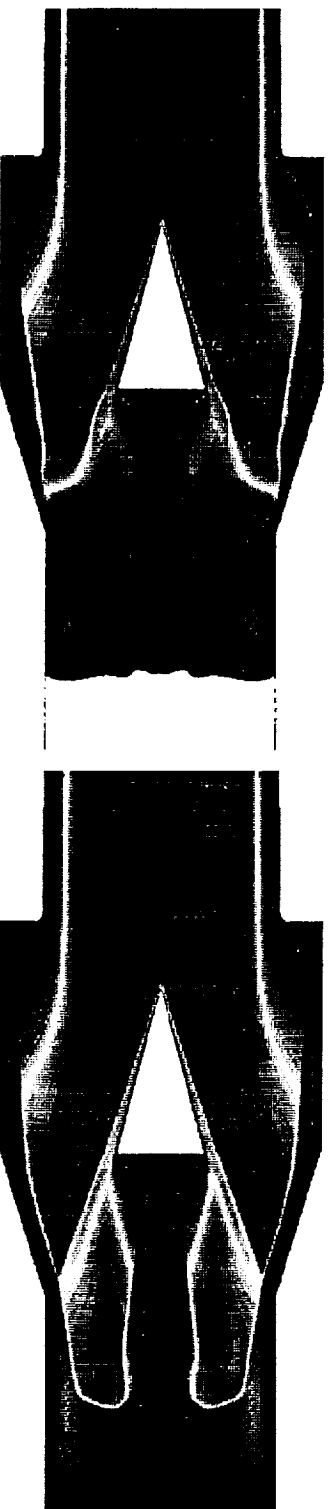
Pressure (atm)

Time (x10^{-3} s)

ARC 16" SHOCK TUNNEL – CHOKING STUDY
Mach Contours – Turbulent Flow

Time = 1.075 ms

Time = 1.275 ms

Time = 1.475 ms

Time = 1.675 ms

Driver Pressure = 6000 psi, Nozzle Area Ratio (Geom.) = 270

ORIGINAL AND MODIFIED NOZZLE CONTOURS
(ONLY THROAT SECTION SHOWN)

y (x10^{-3} m)

x (m)

—— $A/A^* = 270.8$ (New)
········ $A/A^* = 190.0$

NO(γ) Absorption Spectrum (High Resolution) at N3
48000 K Blackbody Source
Driver Pressure = 6000 psi, Gas Temperature = 1412 K