NASA Technical Memorandum 102258

Shock Layer Vacuum UV Spectroscopy in an Arc-Jet Wind Tunnel

G. Palumbo

January 1990

National Aeronautics and
Space Administration

(NASA-TM-102258) SHOCK LAYER VACUUM UV SPECTROSCOPY IN AN ARC-JET WIND TUNNEL (Eloret Corp.) 17 p CSCL 14B

N90-17112

Unclas
G3/35 0264344

NASA Technical Memorandum 102258

Shock Layer Vacuum UV Spectroscopy in an Arc-Jet Wind Tunnel

G. Palumbo
Eloret Institute, Sunnyvale, California

January 1990

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

SUMMARY

An experimental program is being developed to obtain measurements of the incident surface radiation in the 1000 A to 2000 A range from the shock stagnation region of a blunt model in the Ames 20 MW Arc-Jet Wind Tunnel. The setup consists of a water-cooled blunt model, with a magnesium fluoride forward-viewing window. Radiation incident on the window is optically imaged via an evacuated system and reflective optical elements onto the entrance slit of a spectrograph. The model will be exposed to the supersonic plasma stream from the exit nozzle of the arc-jet tunnel. The resulting bow shock radiation will be measured. It is expected that this experiment will help evaluate the importance of atomic N and O lines to the radiative heating of future Aeroassist Space Transfer Vehicles (ASTVs).

INTRODUCTION

Vehicles entering the Earth's atmosphere at orbital and super-orbital speeds are heated by optical radiation as well as by conduction from the hot-gas shock layer that forms around the vehicle. The radiation component of this heating increases as the flight speed increases and is strongly affected by the thermal-chemical state of the gas. In fact, for some missions radiative heating can be a large, or even a major, portion of the total heating load to the vehicle. One such case is the proposed Aeroassist Space Transfer Vehicle (ASTV) (ref. 1).

The proposed ASTV vehicle will be used to transport or transfer people or cargo from one point in space to another. For example, consider the return of an expensive communication satellite from geosynchronous orbit (38,000 km above the Earth) to the space station (776 km above the Earth) for repair. The maneuver to place the vehicle in low Earth orbit after a return from a higher orbit will require the vehicle to loose or dissipate its excess velocity. Using retrorockets for this maneuver is possible but expensive in loss of payload capacity. A more cost-effective method being investigated is to enter the vehicle into the Earth's atmosphere, fly it at high altitude (above 75 km) until the required velocity increment is lost by atmospheric aerobraking, and then to skip it out of the atmosphere and circularize to a low Earth orbit.

The flight trajectory of an ASTV in the atmosphere will be entirely at high altitudes and thus at low density. This is considerably different from the Apollo and Space Shuttle trajectories which rapidly pass through this atmospheric region for a surface landing. The peak heating rate and total heat load for the ASTV vehicle will be lower than that for Apollo or the Shuttle. However, cost-effectiveness requires that the heat protection system be as light as possible without compromising safety. Thus, great precision is needed in its design and the heating profile must be known accurately.

Further, with the flight conditions of the ASTV (high altitude and low density) the shock layer will be characterized by a significant region where the gas is not in chemical or thermodynamic equilibrium, making the prediction of the radiative heating far more difficult. The requirement of great precision and the reality of thermo-chemical nonequilibrium in the flow field has led to the initiation of a test program called the Aeroassist Flight Experiment (AFE). The forthcoming AFE is designed to collect a data base to validate computational models for future ASTV design. This experiment consists of a Space Shuttle deployed spacecraft designed to function as an aerobrake. The AFE will be placed in a Shuttle altitude orbit and then rocket-driven into the Earth's upper atmosphere to simulate a return from geosynchronous orbit. The aeropass will be to approximately 75 km. The mission profile is designed to simulate important features, especially the nonequilibrium shock-layer radiation, of an actual ASTV maneuver. Since this radiation is expected to be an important heat source to an ASTV, experiments are planned to measure and spectrally characterize it for purposes of model development and validation.

Figure 1 shows the stagnation-point heat transfer rate for peak heating during the AFE mission. Heating occurs over about 500 sec with a the peak occurring at about 100 sec into the mission. The maximum heating is about 35 W/cm^2 (about 50 W/cm^2 when catalyticity is included) with radiation accounting for about one-third. Vacuum ultraviolet radiation in the 1000 A to 2000 A range is assumed in the present baseline calculation to be insignificant due to self-absorption and boundary layer absorption. However, this assumption is being re-examined because of the strength of the atomic N and O ultraviolet lines and their potential for surface heating if they are not well absorbed. At present, line-by-line radiative transport solutions are being performed in this region and these results are being prepared for publication (Whiting, E. E., private communication). The radiative heating profile for the AFE has been estimated by two other theoretical methods and the results differ markedly. Calculated AFE radiative heating rates for these two methods and for the AFE Project Baseline are shown in following table. These values are at peak heating during the aeropass (50 W/cm^2).

TABLE 1.– AFE RADIATIVE HEATING ESTIMATES WATTS/CM^2

	Project baseline	Moss (ref. 2)	Carlson (ref. 3)
Near UV, visible and IR	10.2	3.3	4.0
Vacuum UV	0.0	5.6	44.0
Total	10.2	8.9	48.0

It is important to point out that the results in table 1 differ both in the long wavelength region above 2000 A where the shock layer is nearly optically thin, and below 2000 A where the shock layer is probably optically thick, or at least so near the center of the strong N and O lines radiating in this region. The differences in these results is not understood at this time. AFE Project Baseline estimates of the total radiation below 2000 A that would reach the surface if the shock layer were optically thin in this region is 1600 W/cm^2. Moss calculates that only 0.35% of this radiation reaches the surface, whereas Carlson calculates 2.75% reaches the surface. Although these estimates differ by an order of magnitude, both are small values. This result illustrates the potential difficulty in achieving the precision required for this project, particularly when the high estimated value of Carlson indicates that the radiative heating rate might be approximately equal to the peak convective heating rate.

This table shows that there is possibly significant UV radiation to the surface that is being overlooked in the baseline calculations. An experiment is being developed to help resolve this issue by making spectroscopic measurements in the Ames 20 MW Arc-Jet Facility and comparing the results with computational predictions. The experiment consists of a spectrograph optically coupled with a magnesium fluoride window on the surface of a blunt model in the arc-jet wind tunnel. The optical path is evacuated and uses front-surface optics. A similar setup was used by Wells and Snow (ref 4) to study spectral absorption from test gases (typically ablation products) but they used the arc as a light source. In the present case the arc will not be observed because the viewing direction from the window into the shock is at an angled to not admit radiation from the arc heater. Thus the experiment will measure the emission from the shock layer.

The theoretical background and the experimental setup will be described in the next two sections.

The author wishes to acknowledge technical assistance through many consultations with Chul Park, Ellis Whiting, William Davy, Roger Craig, Warren Winovich, John Balboni, and Imelda Terrazas-Salinas. Special credit is due to Tom Foster who built the assembly.

COMPUTATIONAL METHODS

Table 1 indicates three computational methods for calculating AFE radiation. The AFE baseline is the two temperature model, SPRAP, developed by Park (ref. 5). This model solves the chemically reacting flow along the stagnation streamline in the shock layer. The radiation code, NEQAIR (ref. 5), updated by E. E. Whiting (private communication), is used in the present paper. The details of the nonequilibrium shock layer are represented in this model by a kinetic temperature overshoot close to the shock as high as 45,000 K. This high temperature drops rapidly as chemical reactions and collisions occur to advance the state of the gas toward equilibrium. During this process, chemical species—for example, N, O, N2+ and CN—are formed and radiate strongly at these elevated temperatures. Nonequilibrium shock layers typically radiate comparatively little in the equilibrated region. The vibration and electron temperature start at low values near the shock and increase through the nonequilibrium region toward the surface, to eventually equilibrate with the kinetic temperature at a value about 8500 K. The rotational temperature is assumed to follow the kinetic temperature. The chemistry is developed kinetically in this calculation and the energy level populations are determined by use of the quasi-steady-state approximation. These results are used to determine the spectral emission from elements within the shock layer to estimate surface fluxes. Spectra of the AFE shock layer radiation from 2000 A to 1.0 μ are presented by Davy, Park and Arnold (ref. 6). At present, this technique is being extended to evaluate the effects of absorption at selected regions of the spectrum. The model used by Moss is a Monte Carlo method. In this model each particle has its own energy and its own partition of energy among internal modes. A hard sphere model is used for intermolecular collisions. Forty-one reactions for eleven species are used. The reactions used are from Park and Menees (ref. 7). The model used by Carlson is a thick-thin slab approximation in which the upstream nonequilibrium region is taken to be optically thick and the downstream equilibrium region is taken to be optically thin. The nongray spectrum was approximated by a series of steps (5 or 8) for radiative cross-sections. Carlson and Moss predict substantial amounts of UV radiative heating, but the baseline assumes that this radiation is absorbed within the shock and boundary layers. Indeed, Carlson predicts that the UV radiative heating is greater than the baseline total heating. There is also no agreement in the longer wavelength region, but the differences are less. This lack of agreement indicates that we do not yet have an adequate understanding of the radiative heating.

Vacuum Ultraviolet Radiation

A line-by-line calculated vacuum UV source strength near maximum entry heating for the AFE is shown in figure 2. The calculation is from the Park model described above, but modified to obtain the UV emissions. The main spectral features in the region below 2000 A are spectral lines from atomic nitrogen and oxygen. The only significant continuum system is from the NO(l) system but it does not contribute significant radiation compared to the lines. The UV emission resulting in 1600 W/cm^2, if not absorbed is from these lines. Because of their intensity and narrow width these lines must be self-absorbed near their line centers, so that any significant surface radiation must come from the lower intensities in the wings of the lines. Thus, line shapes must be accurately represented in the calculations to properly evaluate the absorption and hence the unabsorbed portion reaching the body. Since an important objective of the AFE is to determine the radiative fluxes to the surface, the issue of potentially large amounts of UV radiation needs to be carefully examined to assure that the AFE radiation experiments are properly designed. In this paper we will discuss the research approach to validate the AFE baseline calculations from the standpoint of these intense UV lines.

To appreciate the importance of the assumptions used in the baseline model, and the relationship to the arc-jet experiment designed for direct measurements, we will discuss in detail some UV spectral features.

The emission at the stagnation region toward the surface from the N multiplet feature near 1493 A is shown in figure 3. The shock is at 0.0 cm, and the body is at 15.5 cm. The flux toward the surface, as a function of distance from the shock is plotted for two cases; the optically thin case, that is, assuming no absorption takes place, shows the radiation is emitted mainly from the region near the shock. This is where the temperature is very high and the radiating species, N, has reached relatively high concentrations. Past about 5 or 6 cm the temperature is reduced and there is very little added radiation toward the surface. Ultimately, in this case, the accumulated flux reaches 261 W/cm^2 at the surface. This level, from just these lines, is about fives times the convective heating. The lower curve is the calculated flux, but includes self-absorption. Most of the radiation is produced near the shock, but in this case there is substantial self-absorption there also. The radiation is absorbed not only near the peak level, but all along the shock layer, and only 0.7 W/cm^2 reaches the body.

The model calculates the strength of each line, but assumes a line shape. If the assumed shape is narrower than the actual case, the line will be calculated to be more intense at the line center, and the absorption, in turn, to be more than the actual case and vise versa. Thus it is seen that the radiation calculated to reach the surface depends on a realistic representation of the line shape.

A thorough discussion of atomic line shapes is given by Griem (ref. 8). A Voigt profile is used to represent the line shape in the AFE calculations. The line and its component features are indicated in figure 4. In this profile the line center is mainly influenced by thermal effects, called Doppler broadening, which give a Gaussian profile to the line shape. The wings have a Lorentzian shape, which is dominated by other effects, e.g., pressure and natural broadening. Pressure broadening is due to the resonance—Stark and Van der Waal's effects: Natural broadening is the result of the natural width of the energy levels resulting from the uncertainty principle. Pressure broadening is the result of the influence of the presence of charged and neutral particles on the radiating species. The charged particles are responsible for Stark effects. Neutrals of the same species as the radiating species result in resonance effects. Van der Waal's effects results from the presence of neutrals of other species. The natural, resonance and linear Stark effects contribute symmetrically to the line, and are represented by a Lorentzian line shape; while higher-order Stark and Van der Waal's effects contribute asymmetrically to the line shape. The Voigt profile assumed is the convolution of a Gaussian and a Lorentzian line shape, and this implies that the AFE calculated line wings are determined by the natural, resonance, and linear Stark effects. It will be one of the goals of the experimental studies to measure the wing shapes of the lines to determine whether there is an asymmetries component. This finding, alone, would impose extra considerations on the AFE calculations.

Figure 5 shows the detailed spectral shape of the surface flux from one of the features of the multiplet at 1493 A. The feature is a doublet—two lines very close together. The left figure shows the shape assuming no absorption. The right figure shows the main effect of absorption, greatly reduced intensity, and mainly at the line center. There is absorption in both the hot, nonequilibrium regions and the cooler, equilibrated regions; the enhanced absorption at the center is due to the narrower spectral width of the absorption in the cooler regions of the shock layer as compared to the greater width of the emission in the hotter portion of the shock. The difference between these two curves is the amount of radiation absorbed; it is seen that the line wings contain the radiation that is not absorbed and reaches the surface. The peak intensity is reduced by about 103 W/cm^2. It is the integrated energy over the spectral surface flux that is the radiative heat source, and this is seen to be determined by the line wing shape.

ARC-JET WIND TUNNEL

The arc-jet wind tunnels considered for these tests each consist of a constricted arc heater coupled with a supersonic nozzle. These wind tunnels were developed for aerodynamic testing and will provide stagnation temperatures up to 15,000 K and stagnation pressures up to one atmosphere (ref. 9). These facilities have been used extensively to study the thermal protection systems for the Space Transportation System and other atmospheric entry thermal protection systems.

Figure 6 is a schematic picture of an arc-jet wind tunnel. At the left is the constricted arc air heater where electric energy is dissipated in air in the form of an arc along the length of a tube. The resulting high-enthalpy air is expanded through a supersonic nozzle, typically M = 5 to M = 7.5. The test section contains a fixed model on a sting. The test air is exhausted through a diffuser wherein low pressure is maintained by a large vacuum system. Because of the high enthalpy, the model and sting typically require water cooling or some form of thermal protection.

Experimental Condition

The required experiment conditions are that a shock be produced with stagnation conditions suitable to examine the line shape effects needed to validate the AFE computational method. It is impossible to simulate both the nonequilibrium and equilibrium effects in a ground based facility. The full-scale vehicle will exhibit a shock layer with the nonequilibrated regions reaching equilibrium before merging with the cool boundary layer. This is the environment we would ideally study. However, as has been discussed, ground-based experiments, necessarily of small scale, cannot produce these features. Indeed, this is the motivation for doing the AFE. The smaller-scale model in the arc jet, with a much thinner shock, will exhibit the same high-temperature overshoot as the AFE, but it will not equilibrate at the stagnation conditions, rather it will merge with the cool boundary layer near the surface. This condition will have features that we wish to study, namely nonequilibrium high-temperature emission from the atomic lines and lower-temperature absorption from the cooler regions. The same computational model will be used to calculate the surface flux at the arc jet conditions for comparison with the measurements.

The AFE at peak heating flies at a velocity of 9.3 km/sec at an altitude of 74.6 km. This results in a stagnation pressure of about 10^{-2} atmospheres and a stagnation temperature of about 8500 K. The mass density is about 1.5×10^{-7} gm/cm^3. This condition is easily met in the Ames 20 MW Arc-Jet Facility using an area ratio nozzle of 64, an upstream pressure at 0.38 atmospheres, and a flow rate of 38 gm/sec. These conditions require 1.25 MW to drive the gas.

The shock layer produced will result in radiation in the UV from these lines of interest, and the resulting radiation and absorption will be measured. The electron density will be the same as for the AFE equilibrium region (10^{12} to 10^{14} cm^{-3}). At this electron density the line shape is dominated by thermal broadening and thus has a Gaussian profile near the center, but the wings will be determined more by neutral particles than by charged particles. The wing levels and symmetry will be measured to provide data to help resolve the issue of absorption in the UV.

EXPERIMENTAL SETUP

This section describes the experimental device which will be installed in the 20 MW Arc-Jet Facility at NASA Ames.

Internal Optics: Figure 7 shows a schematic of the mechanical arrangement (left) shown installed in the wind tunnel. The setup consists of a blunt model with a magnesium fluoride window in the stagnation region, an optical tube with internal reflective optics,and a spectrograph. The mechanical section near the model is water cooled. The model (right), which is 2.0 in. in diameter, is water cooled, and the window is cooled by helium transpiration. The stagnation region is flat and has a 0.315 cm aperture. The optical path through the model is off-axis to avoid direct radiation from the arc. A flat turning-mirror directs the radiation to a collimating mirror. Figure 8 shows the optical setup. The collimating mirror directs the radiation to a focusing mirror outside the facility and images the model aperture onto the spectrograph slit. The shock layer radiation will be viewed over a cone of 15°.

The internal optics are adjustable from f/8.5 to f/16. The collimating and focusing mirrors are 4 in. in diameter. Initial measurements will be made with a 0.5-m vacuum ultraviolet spectrograph using film. The setup, however, can accommodate either a 1.0-m or a 3.7-m spectrograph. The optical system of the spectrograph is a modified Czerney-Turner which uses two concave mirrors and a flat grating (fig. 9). This instrument is designed to operate at wavelengths as short as 1000 A. A vacuum of less than 10^{-4} torr will be maintained and all optical elements will be freshly coated with magnesium fluoride. Thus the stagnation-region surface flux, passing through the window, will be imaged through an evacuated system employing only UV-grade mirrors.

Measurements: Primary measurements will be made in the 1000 A to 2000 A region using UV film (Kodak SWR).

The wing contributions to the triplet of the nitrogen line at 1492 A is approximately 1 A wide according to the estimate of the AFE calculation, which only includes symmetric effects. The 0.5-m spectrograph will provide 0.2 A resolution. This is not adequate to study the line center region, but is adequate to measure the wing shapes. In addition, we will calibrate the system to measure the line strengths. Spectra will also be made to 1.0 μ. The region from 2000 A to 1.0 μ should be optically thin, and these spectra will provide data to assist in characterizing the gas condition in the shock layer.

ANALYSIS

Line-shape symmetry will be obtained directly from the primary data, namely the film record of the spectra. The system will be calibrated to obtain absolute flux levels to compare with calculations of the stagnation-region surface flux using the AFE baseline computational methods described earlier. There is uncertainty about the upstream conditions of the arc-jet plasma. These conditions are needed as boundary conditions for the computation. Approximations will be made to perform the analysis and the results will be compared with the optically-thin 2000 A to 1.0 μ spectral range results. Once the computational method can model stagnation stream line with confidence, then the vacuum UV lines will be analyzed. This analysis will consist of predicting the observed line strengths incident on the magnesium fluoride window, and performing sensitivity studies to validate the theoretical line shape and optical thickness.

EXPERIMENT STATUS

The experimental apparatus is completed. Figure 10 is a photograph of the assembly in the machine shop. The over[illegible]l length is about 3.4 m. The large flange to right of middle is the primary mounting flange to the a[illegible] facility. The assembly extends into the supersonic plasma stream, with the stream center moving out [illegible]n the paper at the location of the machinist's hand. That section is water cooled. The spectrograph will be mounted on a platform at the right of the large flange. Its viewing port can be seen to the right of the flange. The vacuum pump outlet will be at that same location. Access for optical alignment of the system is through the various removable end caps and ports.

REFERENCES

1. Menees, G. P.; Park, C.; and Wilson, J.: Design and performance analysis of a conical aerobrake orbital transfer vehicle concept. AIAA Paper 84-0410, 1984.

2. Moss, J. N.: Non-equilibrium thermal radiation from aeroassist flight experiment. AIAA 26th Aerospace Science Mtg., Jan 11-14, 1988, Reno, NV, AIAA Paper 88-0081.

3. Carlson, L. A.: Approximation for hypervelocity, non-equilibrium radiating, reacting, and conducting stagnation regions. AIAA Thermophysics, Plasmadynamics and Laser Conf., June 27-29, 1988, San Antonio, TX, AIAA Paper 88-2672.

4. Wells, W. L.; and Snow, W. L.: Some experience with arc-heater simulation of outer planet entry radiation. NASA TM-80192, Jan. 1980.

5. Park, C.: Calculation of nonequilibrium radiation in the flight regimes of aeroassisted orbital transfer vehicles. Reprint from Thermal Design of Aeroassisted Orbital Transfer Vehicles, H. F. Nelson, ed., Progress in Astronautics and Aeronautics, Volume 96, 1985.

6. Davy, W. C.; Park, C.; and Arnold, J. A.: Radiometer experiment for the aeroassist flight experiment, AIAA 20th Thermophysics Conf., June 19-21, 1985, Williamsburg, VA, AIAA Paper 85-0967.

7. Park, C.: Problems of rate chemistry in the flight regimes of aeroassisted orbital transfer vehicles. Reprinted from Thermal Design of Aeroassisted Orbital Transfer Vehicles, H. F. Nelson, ed., of Progress in Astronautics and Aeronautics, Volume 96, 1985.

8. Griem, H. R.: Plasma Spectroscopy. Mc Graw-Hill Company.

9. Winovich, W.: Total radiant measurements at the stagnation point of blunt bodies at stagnation temperatures up to 15,000 K. AIAA 3rd Aerodynamics Testing Conf., San Francisco, CA, April 8-10, 1968, AIAA Paper 68-405.

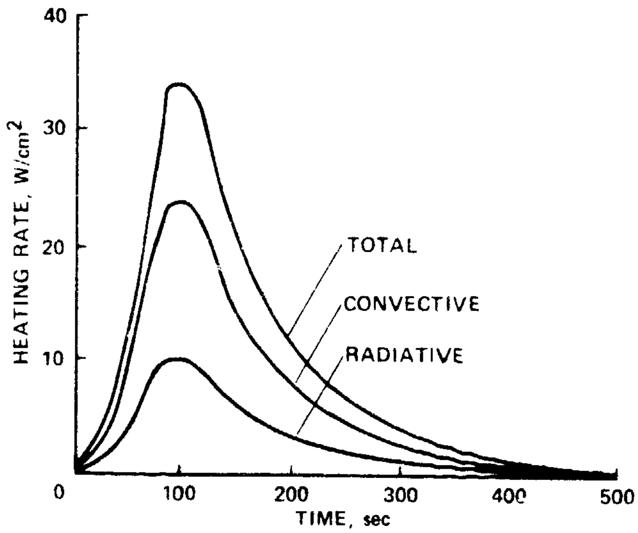

Figure 1.– AFE stagnation-point heating rate during atmospheric pass for non-catalytic surface.

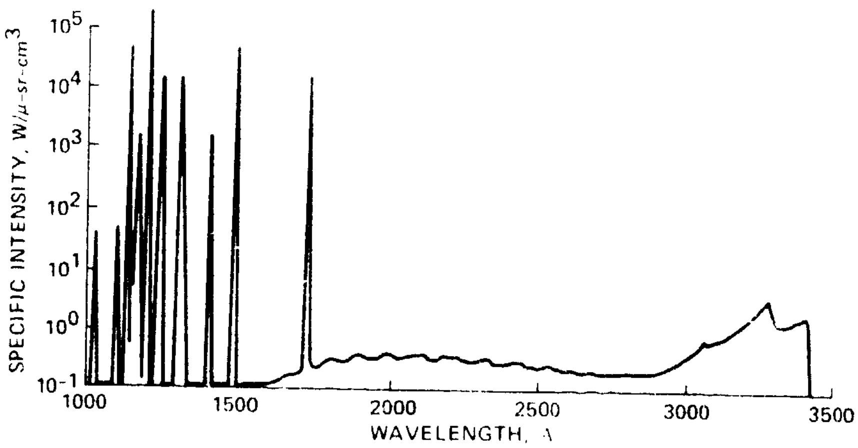

Figure 2.– Calculated non-equilibrium vacuum UV stagnation region source strength for the AFE at peak heating.

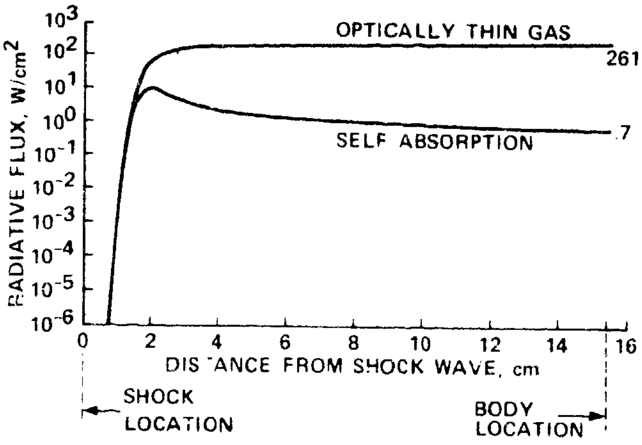

Figure 3.– Accumulated radiative flux from the three N lines near 0.1493 μ along the stagnation stream line.

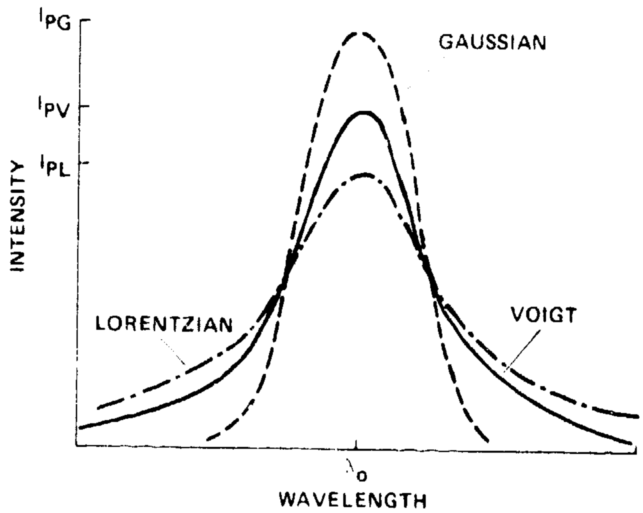

Figure 4.– Voigt profile shape as developed from a Gaussian (thermal) shape, and a Lorentzian shape.

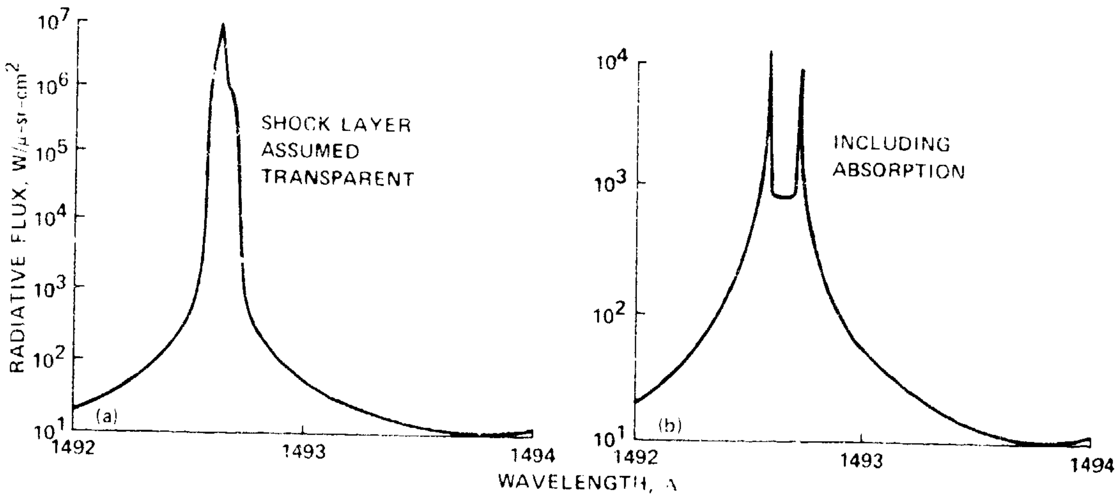

Figure 5.– Calculated flux toward the surface from the N multiplet resonance lines near 1493 A to the AFE stagnation region at peak heating: (a) optically thin case (assuming no absorption) and (b) optically absorbing shock layer.

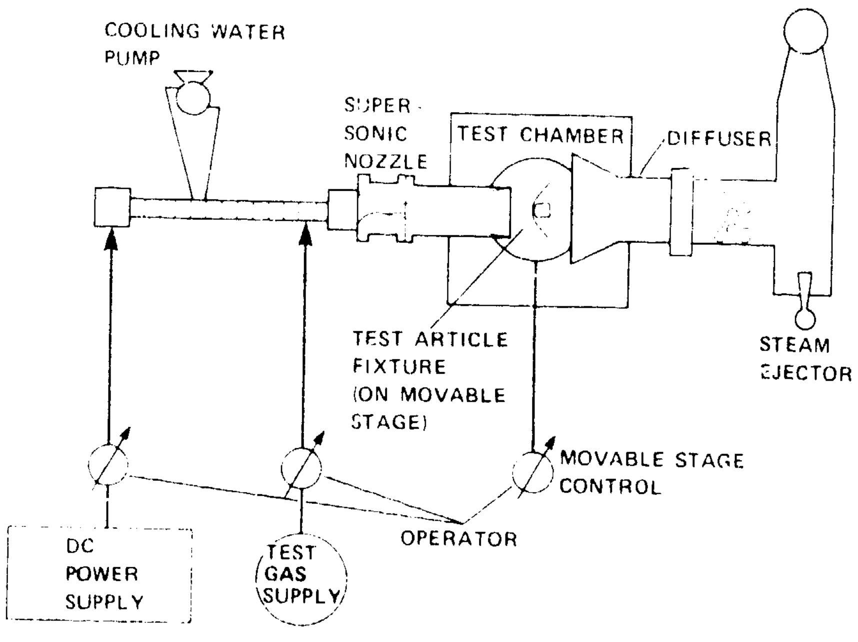

Figure 6.– Schematic diagram of an arc-jet wind tunnel.

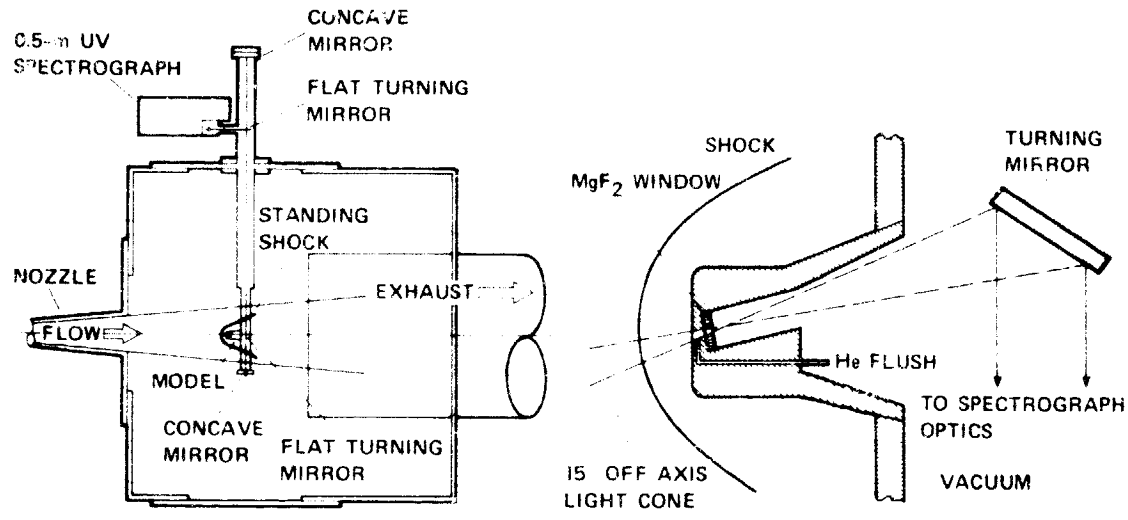

Figure 7.– Mechanical arrangement of the experiment showing the test chamber (left) and the model (right).

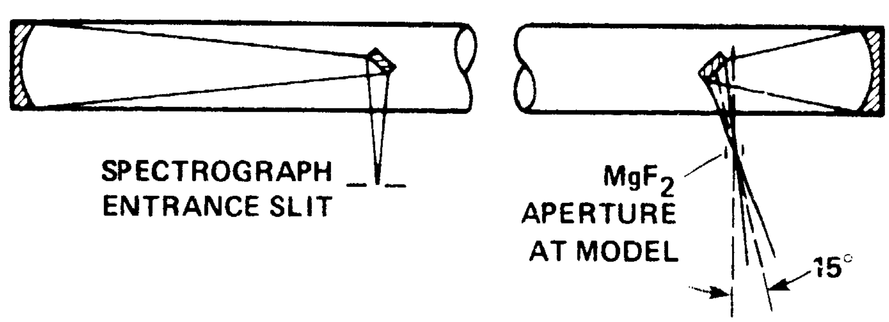

Figure 8.– Optical setup showing model, internal optical arrangement, and spectrograph.

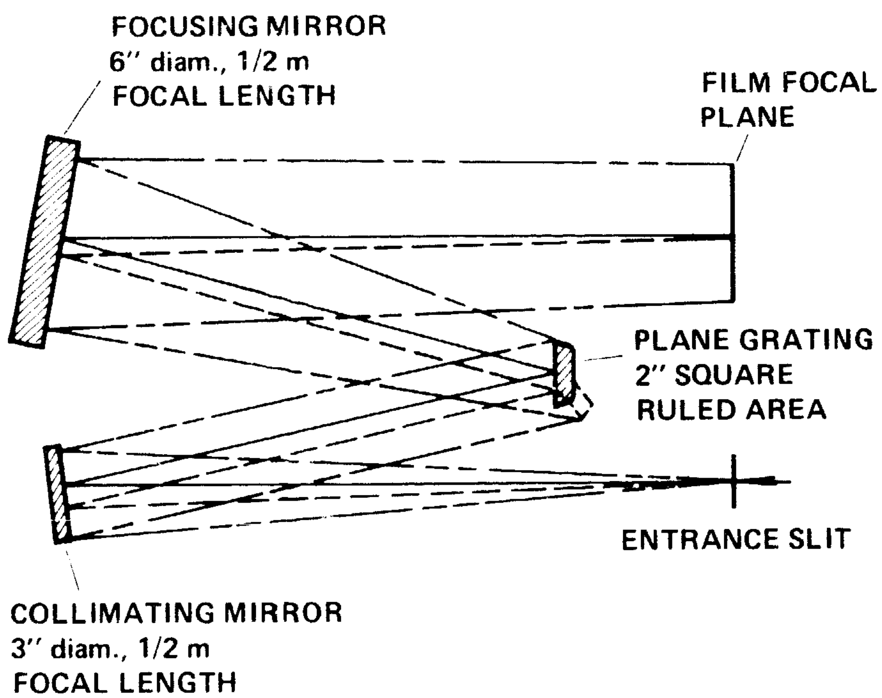

Figure 9.– Optical system of the modified Czerney-Turner spectrograph.

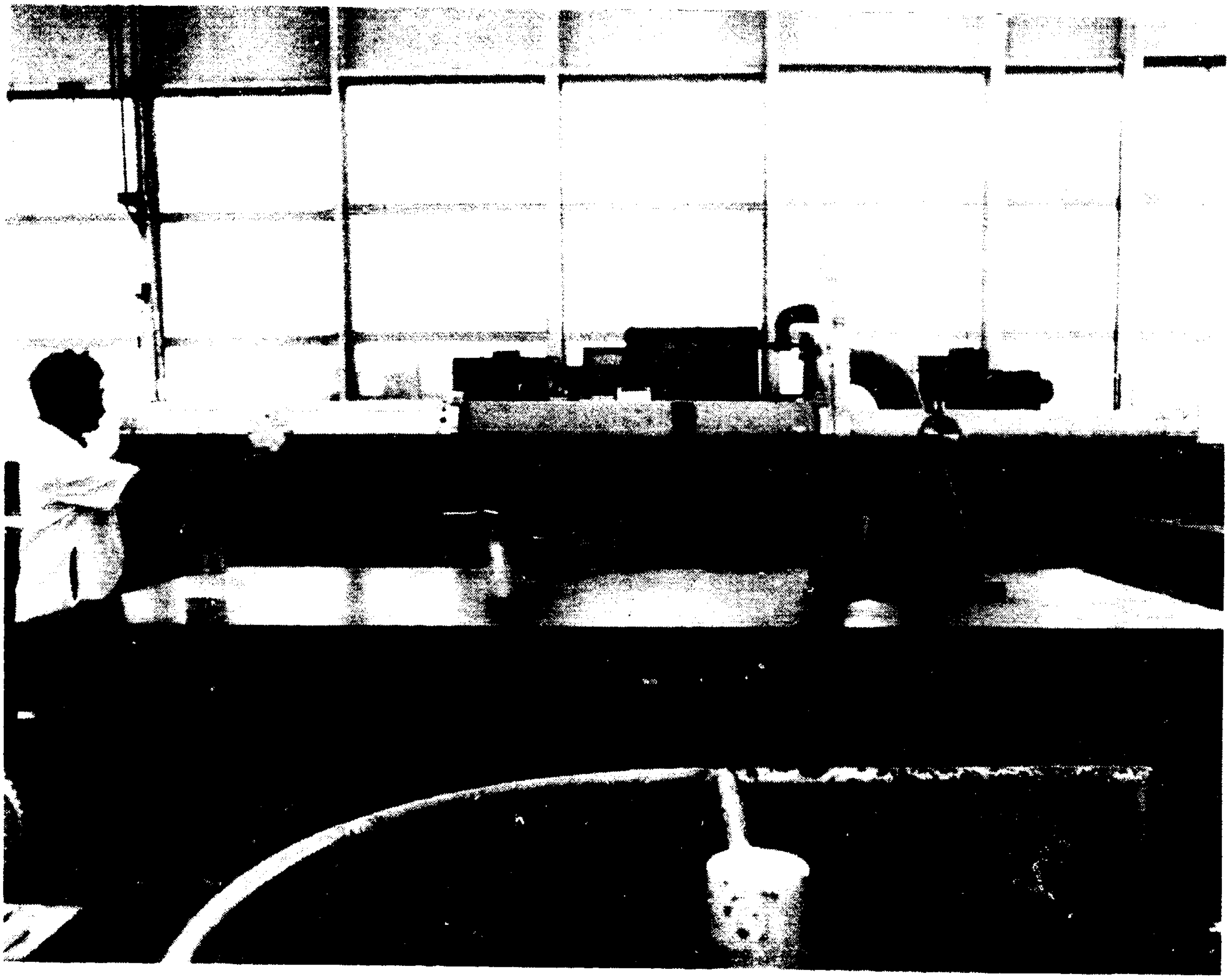

Figure 10.– Vacuum chamber assembled temporarily for mechanical checkout.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-102258	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle: Shock Layer Vacuum UV Spectroscopy in an Arc-Jet Wind Tunnel	5. Report Date: January 1990
	6. Performing Organization Code
7. Author(s): G. Palumbo*	8. Performing Organization Report No.: A-90017
	10. Work Unit No.: 583-01-01
9. Performing Organization Name and Address: Ames Research Center, Moffett Field, CA 94035-1000	11. Contract or Grant No.
	13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Point of Contact: G. S. Deiwert, Ames Research Center, MS 230-2, Moffett Field, CA 94035-1000
(415) 604-6198 or FTS 464-6198
*Eloret Institute, Sunnyvale, California

16. Abstract

An experimental program is being developed to obtain measurements of the incident surface radiation in the 1000 A to 2000 A range from the shock stagnation region of a blunt model in the Ames 20 MW Arc-Jet Wind Tunnel. The setup consists of a water-cooled blunt model, with a magnesium fluoride forward-viewing window. Radiation incident on the window is optically imaged via an evacuated system and reflective optical elements onto the entrance slit of a spectrograph. The model will be exposed to the supersonic plasma stream from the exit nozzle of the arc-jet tunnel. The resulting bow shock radiation will be measured. It is expected that this experiment will help evaluate the importance of atomic N and O lines to the radiative heating of future Aeroassist Space Transfer Vehicles (ASTVs).

17. Key Words (Suggested by Author(s)): Vacuum UV, Spectroscopy, Arc jet	18. Distribution Statement: Unclassified-Unlimited Subject Category – 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	17	A02

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, Virginia 22161