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# ANALYSIS OF FLOW FROM ARC-JET SPECTRA

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# ANALYSIS OF FLOW FROM ARC-JET SPECTRA

## Final Report

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## ABSTRACT

Materials testing is carried out at the JSC Atmospheric Reentry Materials and Structures Facility. A flow diagnostics program is under development to characterize the energy distribution in arc-jet flows used to simulate atmospheric entry. Heat transfer to materials depends on flow properties which includes the composition of and energy distribution among the atoms, ions, molecules, and molecular ions which make up the flow.

This project involves analysis of shock layer characteristics from the radiation emitted and experimentally collected from near the front of the shock to near the surface of the material. The analysis has yielded information on relative populations of neutral molecules and molecular ions within the layer. In determining non-equilibrium temperatures within the layer, some insight into the spectral constants used to compute radiative emission has been gained.

## NOMENCLATURE

$A^3\Sigma_u^+$  = electronic state of molecular nitrogen  
 $A^2\Pi_u$  = electronic state of molecular nitrogen ion  
 $B^2\Sigma_u^+$  = electronic state of molecular nitrogen ion  
 $B^3\Sigma_g^-$  = electronic state of molecular nitrogen  
 $B^3\Pi_g$  = electronic state of molecular nitrogen  
 $X^1\Sigma_g^+$  = electronic ground state of nitrogen  
 $X^2\Sigma_g^+$  = electronic ground state of nitrogen ion  
 $T_e$  = electron temperature  
 $T_r$  = rotational temperature  
 $T_v$  = vibrational temperature

## INTRODUCTION

It is now generally agreed that additional experimental shock front and shock layer measurements are necessary in order to clarify issues such as rotational coupling and provide additional data on rates at high temperature for a number of processes. The flow diagnostics program under development at JSC will characterize the energy distribution in arc-jet flows which are used to simulate atmospheric entry. In this work we pay particular attention to those flow properties which include the composition of and energy distribution among the atoms, ions, molecules, and molecular ions which make up the flow.

## ANALYSIS

Shocks in pure nitrogen have been analyzed because the spectral regions used for analysis are cleaner, i.e., they contain less undesired radiation which increases the complexity to analysis. The electronic states and the systems which place radiation within the wavelength range covered, 3000 Å to 8500 Å, is shown in Figure 1. The principal radiation from the nitrogen molecule and the molecular ion is generally grouped into regions which represent transitions between upper,  $v'$ , and lower,  $v''$ , vibrational states which differ by the same number, i.e.,  $v' - v'' = \Delta v = 0, 1, 2$ , etc. In the spectrum between 200 nm and 500 nm the bands of primary interest are  $N_2^+(1-)$ ,  $\Delta v = -2, -1, 0, 1, \text{ and } 2$ , resulting from electronic molecular state transitions  $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ . Above 500 nm the bands of primary interest come from  $N_2$ ,  $B^3\Pi_g \rightarrow ^3\Sigma_u^+$ , called the first positive system.

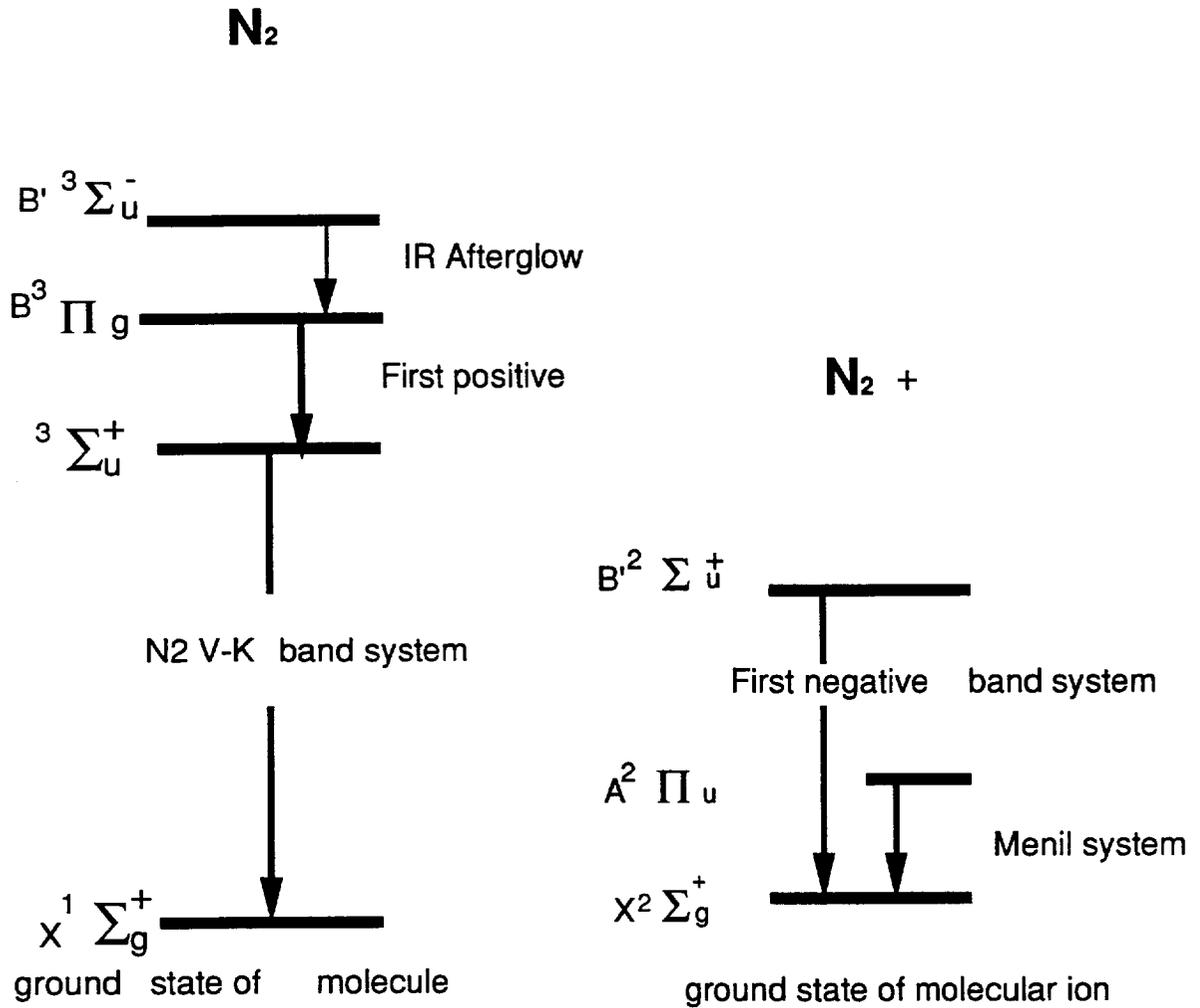


Figure 1. N<sub>2</sub> and N<sub>2</sub><sup>+</sup> energy states and band systems.

Measurements were obtained using a constricted arc heater in the arc jet facility at the NASA Johnson Space Center. The arc, powered by a direct current power supply, heats the gas to high enthalpy. The hot gas flows through a small settling chamber, then through a converging-diverging conical nozzle with an exit diameter of 38.1 cm, and into the chamber which contains the shock-forming test article. Radiation from the shock layer was focused on the entrance slit of a spectrometer using a 0.5 m focal length lens fixed at a perpendicular distance of 0.5 m from the nozzle axis of symmetry. The spectra were measured with a SPEX Triplemate 0.6 m spectrometer having a 1024-element linear diode array detector and were recorded using an optical multichannel analyzer (OMA) system.

A typical spectrum from the shock layer collected from near the front of the shock is shown in Figure 2.

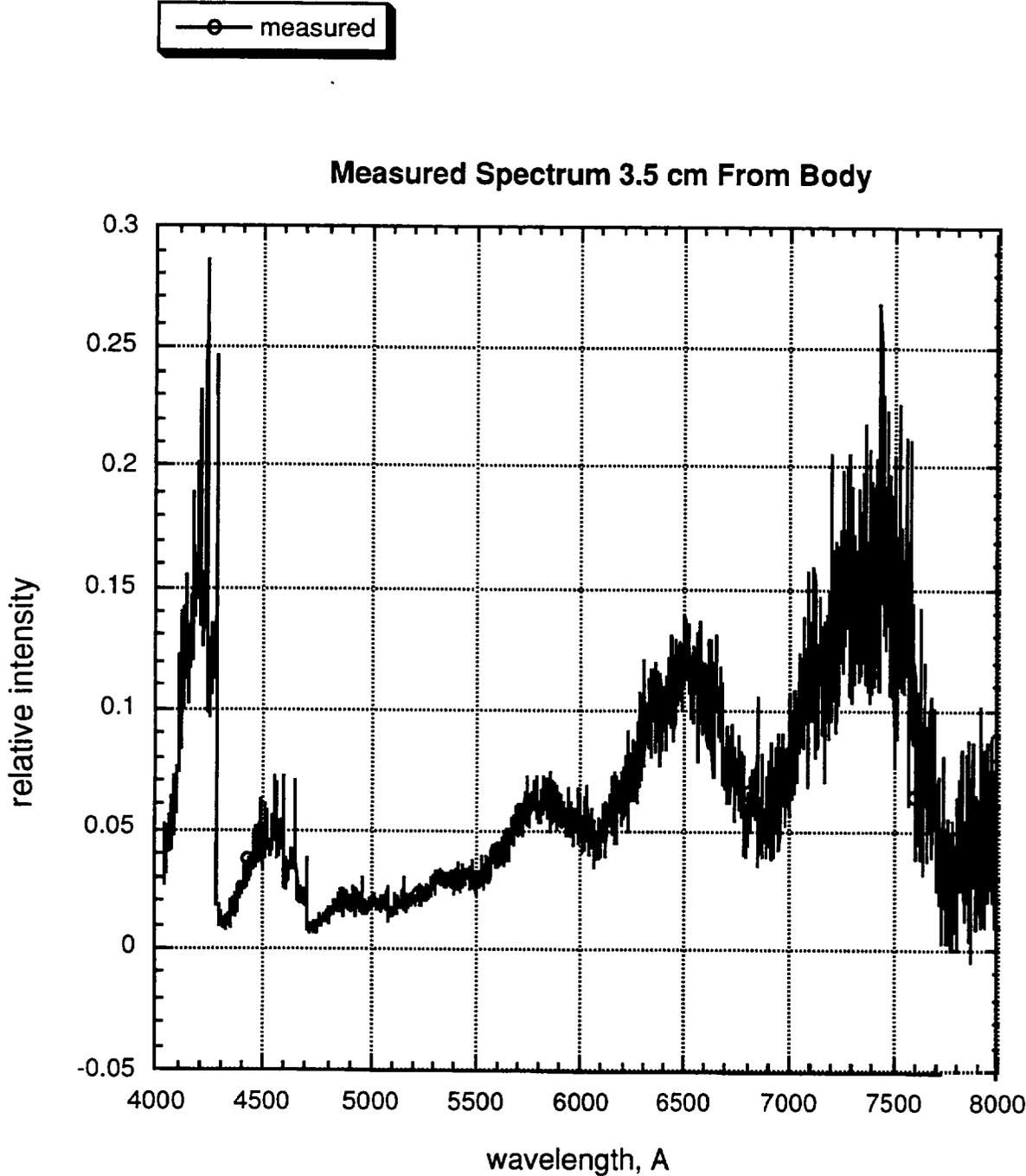


Figure 2. Spectrum obtained experimentally 3.50 cm from the test body.

In the present analysis computed spectra for  $N_2^+$  and  $N_2$  were necessary, as the experimental spectra were obtained from shocks in a nitrogen arc-jet flow. Temperatures within the radiating shock layer may range from 2000 to 10000 K, and may differ for the different species. Also, the energy goes into different modes, translational, electronic, vibrational, and rotational. An earlier technique for determining temperature utilized a Non-Equilibrium Air Radiation code

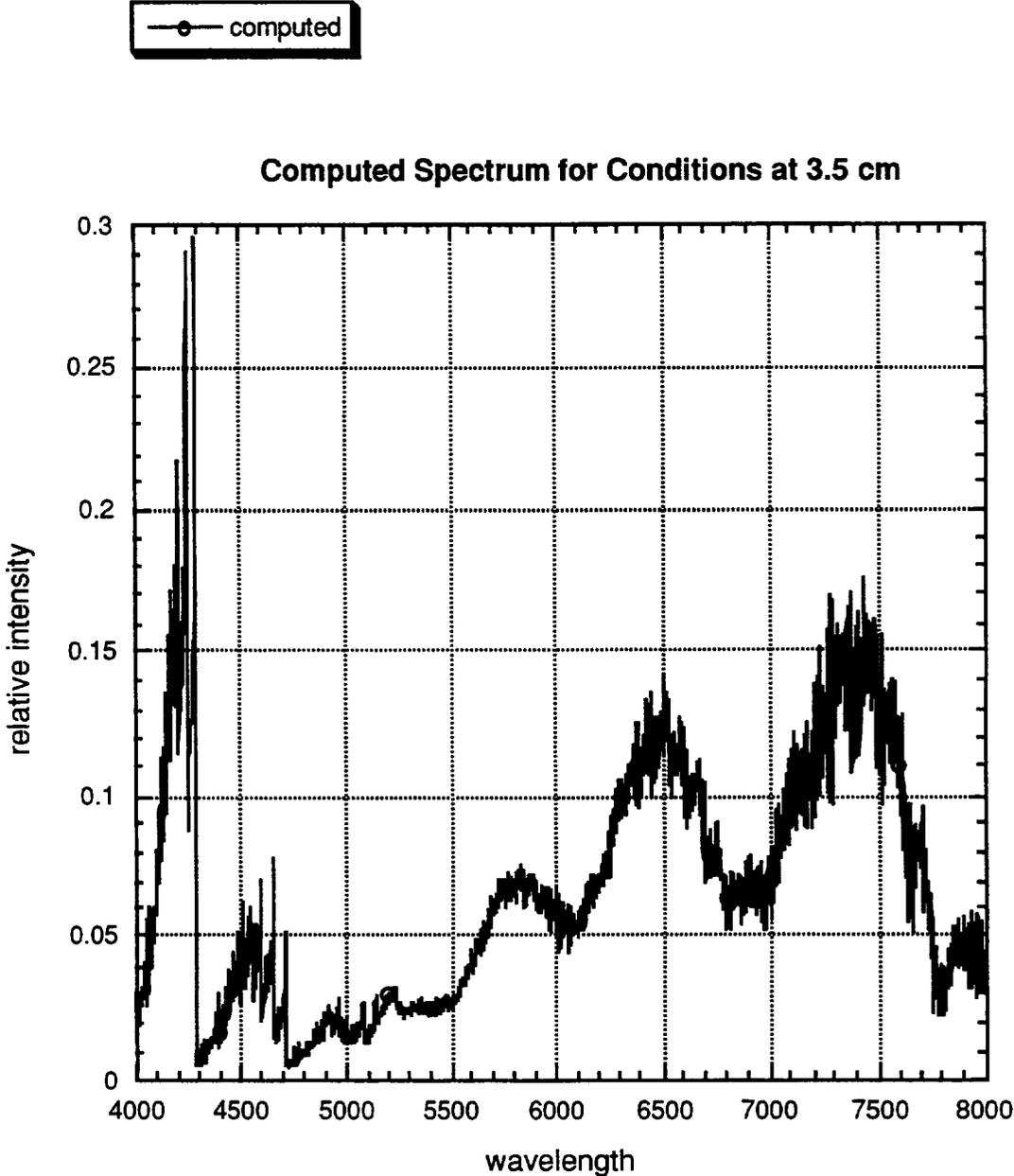


Figure 3. Spectrum computed using PSI code.

(NEQAIR) to determine the rotational temperature of the molecular nitrogen ion. The measurement was made using NEQAIR to attempt a match of the spectra or find appropriate rotational line emission ratios for  $N_2^+$ ,  $\Delta v = -1$ , the band at 4280 Å.

All species are generally assumed to have the same rotational temperature. The temperature obtained was then input to a spectral fitting code by Physical Sciences, Inc. for simulation of the measured spectra in other wavelength regions in order to obtain a vibrational temperature.

This study uses the PSI code alone to estimate both rotational and vibrational temperatures. Using that code the spectrum shown in Figure 3 could be obtained.

## RESULTS

This work concentrated more on the long wavelength region of the spectrum, between 5000 Å and 8000 Å. While radiation from the neutral molecule, 1st positive system, dominates the radiation near the front of the shock, radiation from the A state of the molecular ion, the Menil system, is present. Vibrational temperature for the two systems were found to differ.

Radiation from the ion begins to dominate as one moves into the layer toward the body. At the closest observation point to the body, radiation from the neutral atom becomes strong indicating that  $N_2$  populations have decreased due to dissociation. We will soon prepare a paper discussing these results.

Study of populations led to a measurement, for the first time, of the electronic excitation temperature. This temperature appears to differ from both rotation and vibration for the non-equilibrium layer. This matter also, with some additional work, will be published.

A review of the total spectrum, the range shown in Figure 2, has uncovered a number of problems associated with the analysis and determination of rotational and vibrational temperatures. The radiation from higher lying states must be incorporated in the calculated spectra for better fit with measurement.

Accuracy of the work depends on the accuracy of constants used in the simulation of the spectra. We have made some progress in this area, uncovering some fundamental relations, which should merit an early publication in order to assist other analysts with their work.

