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Study of Non-Equilibrium Transport Phenomena

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16. Abstract

Nonequilibrium phenomena due to real gas effects are very important features of low-density hypersonic flows. Computational efforts by numerous authors to account for these effects are underway. However, there are no experimental data available to verify the accuracy of these CDF codes. The present report identifies the shock shape and emitted non-equilibrium radiation as the bulk flow behavior parameters which are very sensitive to the non-equilibrium phenomena. These parameters can be measured in shock tubes, shock tunnels, and ballistic ranges and used to test the accuracy of CDF codes. Since the CDF codes, by necessity, are based on multi-temperature models, it is also desirable to measure various temperatures, most importantly, the vibrational temperature. The CDF codes would require high temperature rate constants, which are not available at present. Measurement of such rates is imparative.

Experiments conducted at the NASA Ames E.A.S.T. facility reveal that radiation from steel contaminants overwhelm the radiation from the test gas. For the measurement of radiation and the chemical parameters, further investigative research and then appropriate modifications of the E.A.S.T. facility are required.

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ABSTRACT

Nonequilibrium phenomena due to real gas effects are very important features of low density hypersonic flows. Computational efforts by numerous authors to account for these effects are underway. However there are no experimental data available to verify the accuracy of these CFD codes. The present report identifies the shock shape and emitted nonequilibrium radiation as the bulk flow behavior parameters which are very sensitive to the nonequilibrium phenomena. These parameters can be measured in shock tubes, shock tunnels and ballistic ranges and used to test the accuracy of CFD codes. Since the CFD codes, by necessity, are based on multi temperature models, it is also desirable to measure various temperatures, most importantly, the vibrational temperature. The CFD codes would require high temperature rate constants, which are not available at present. Measurements of such rates is imperative.

Experiments conducted at Ames E.A.S.T. facility reveal that radiation from steel contaminants overwhelm the radiation from the test gas. For the measurement of radiation and the chemical parameters, further investigative research and then appropriate modifications to the E.A.S.T. facility are required.

Table of Contents:

I. Review of Simulation and Diagnostic Techniques for Hypersonic Nonequilibrium Flows:

Abstract

The possible means of simulating nonequilibrium reacting flows in hypersonic environments, and the required diagnostic techniques, are surveyed in two categories: bulk flow behavior and determination of chemical rate parameters. Flow visualization of shock shapes for validation of computational-fluid-dynamic calculations is proposed. The facilities and the operating conditions necessary to produce the required nonequilibrium conditions, the suitable optical techniques, and their sensitivity requirements, are surveyed. Shock-tubes, shock-tunnels, and ballistic ranges in a wide range of sizes and strengths are found to be useful for this purpose, but severe sensitivity requirements are indicated for the optical instruments, which can be met only by using highly-collimated laser sources. Likewise, for the determination of chemical parameters, this paper summarizes the quantities that need to be determined, required facilities and their operating conditions, and the suitable diagnostic techniques and their performance requirements. Shock tubes of various strengths are found to be useful for this purpose. Vac-

uum ultra-violet absorption and fluorescence spectroscopy and coherent anti-Stokes Raman spectroscopy are found to be the techniques best suited for the measurements of the chemical data.

For full text please see the attached AIAA paper-87-0406.

II. Preliminary Experiments at Ames E.A.S.T. Facility:

Shock tubes are unique in creating a homogeneous sample of gas, heated to an enthalpy and pressure calculable and selectable from the state of the undisturbed gas and the measured shock velocity, and are excellent tool for studying the thermal and kinetic phenomena in gases at high temperatures.

The Electric Arc-Driven Shock Tube (E.A.S.T.) facility at NASA Ames is driven by a 3.6 m conical driver section with a 10 cm exit diameter. The arc driver is powered by a 1.24 MJ, 40 kV capacitor bank. Two driven section are available: one with 60 cm i.d. and the other with 15 cm i.d. A 343 mm long .25 mm diameter steel wire is used to trigger the arc discharge and rapture a .356 mm thick Mylar diaphragm placed between the driver and driven section. The driver is charged with He to a nominal pressure of 135 psi.

2.1. Tests :

In order to investigate the suitability of the E.A.S.T. facility for the investigation of the nonequilibrium phenomena, a series [TEST # 31] of preliminary tests were conducted using the 60 cm driven section. Three test gases were used: air, dry air and dry nitrogen. The initial pressure in the shock tube were maintained between .010 and .020 mm Hg. Shock velocities in the range of 3.0 to 13.0 km/sec were achieved (Figure 1).

Using a broad band radiometer the total radiation from the test gas was recorded. A typical scope trace is shown in figure 2. The radiometer signals were used to determine the useful test times for each run. A plot of the test times as a function of shock velocity is shown in figure 3. As it is clear from the figure 3, for a typical shock velocity of 10 km/sec test times on the order of 5 μsec have been achieved.

Single shot time integrated spectra of the test gas between 4000-6000 Å were also recorded using a still spectrograph. The spectrograph shot as analysed by a densitometer for the test run # 26 is shown in figure 4. The radiation from the test gas as seen in figure 4 is overwhelmed by the spurious line radiation from steel components such as Fe and Cr. The radiation from Na, probably derived from atmospheric salt, is also prominent.

2.2. <u>Discussion of the Results</u>:

Although the test times for shock velocities in the range of 3.0 to 13.0 km/sec seem adequate for diagnostic purposes, the test gas contains steel vapor responsible for spurious line radiation. For spectroscopic measurements the test gas must be free of such contaminants. Therefore, in its present condition the E.A.S.T. facility can not be used for spectroscopic measurements.

AVCO [Reference 1] had produced contamination free gas samples for nonequilibrium radiation research using aluminum shock tubes. Therefore, it may be possible that if the E.A.S.T. facility is modified either by applying an aluminum liner (in the 60 cm driven section) or by replacing the steel tube (in the 15 cm driven section) with an aluminum tube. However this concept must be proved experimentally before undertaking any modification to the E.A.S.T. facility.

References

1. Allen, R.A., Rose, P.H. and Camm, J.C., "Nonequilibrium and Equilibrium Radiation at Super-Satellite Re-Entry Velocities," AVCO Everett Research Laboratory, Research Report No. 156, September 1962.

III. Concluding Remarks:

For the purpose of validating computational-fluid-dynamic calculations including nonequilibrium chemical reactions, comparison with the experimental data on radiation intensity and Schlieren or holographic interferogram seem most appropriate, because of the strong influence of nonequilibrium phenomena on radiation and shock shapes. Various shock-tubes, shock-tunnels, and ballistic ranges can be used for producing required nonequilibrium conditions by charging the devices with initial pressures in the range of 0.1 to 15 torr depending on the reactions to be studied. Almost exact simulation is possible using a reflectionless shock-tube in the relatively low Mach number range, or using a ballistic range over most of the interested Mach number range. Shock-tubes and shock-tunnels can be used for the same purpose if the CFD calculation is carried out for the experimental conditions. Because of the relatively low pressures, sensitivity requirements on the flow visualization techniques are stringent. A Schlieren system using a highly-collimated laser source and a graded filter should improve the sensitivity by a factor of 20 over that of a conventional spark-powered system, and meet the requirement. Holographic interferometry can be useful if its sensitivity can be increased by a factor of about 4.

Experimental data relating to the chemical state of the gas crucial to high Mach number regimes are mostly unknown, and need to be obtained experimentally. For the determination of such chemical parameters, shock-tubes of various sizes and strengths are needed. Absorption, fluorescence, and CARS all look promising in determining vibrational state distributions, species concentrations, and chemical rate parameters.

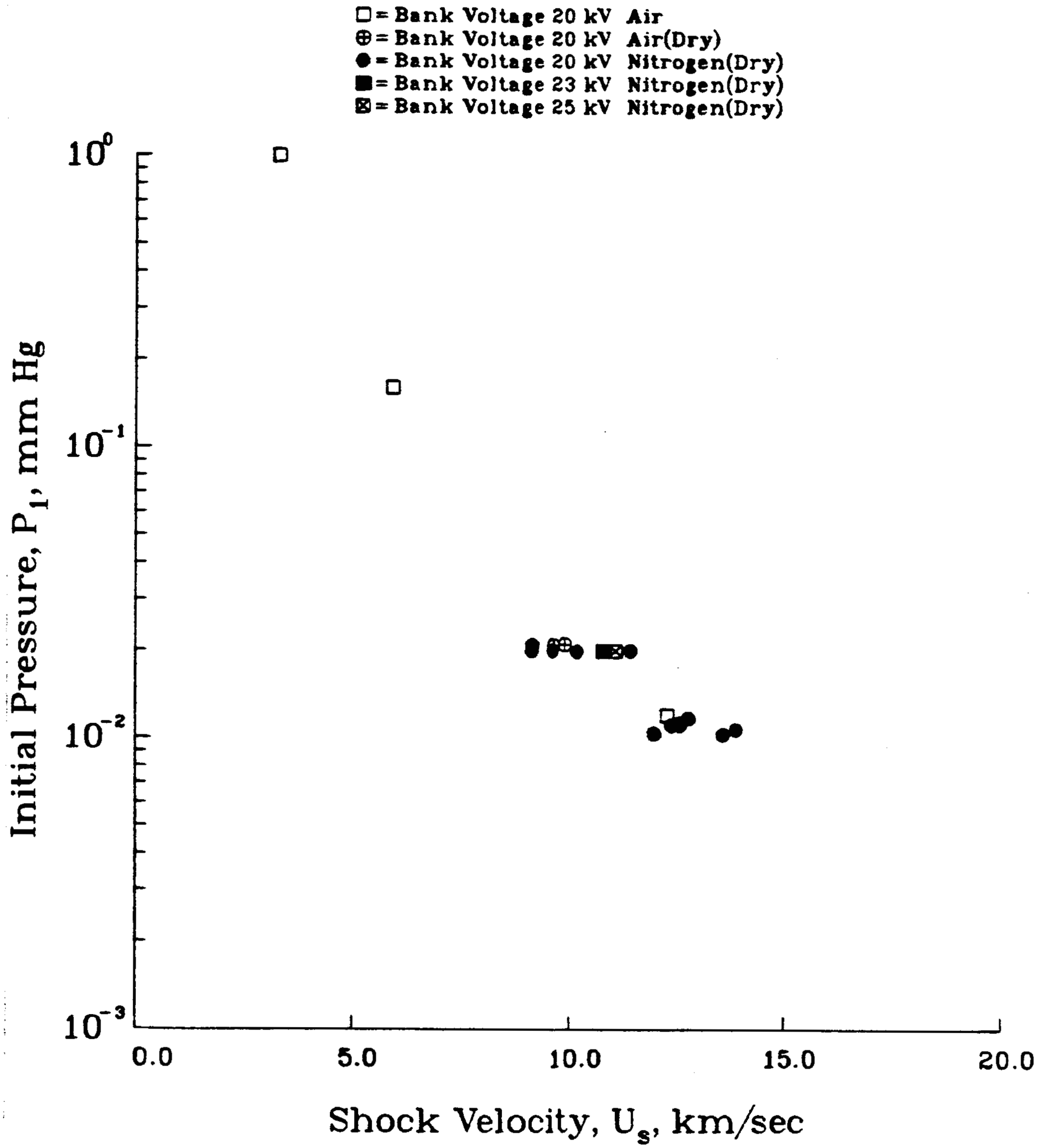

Fig. 1 Shock velocities achieved in 60 cm E.A.S.T. facility (Test No. 31).

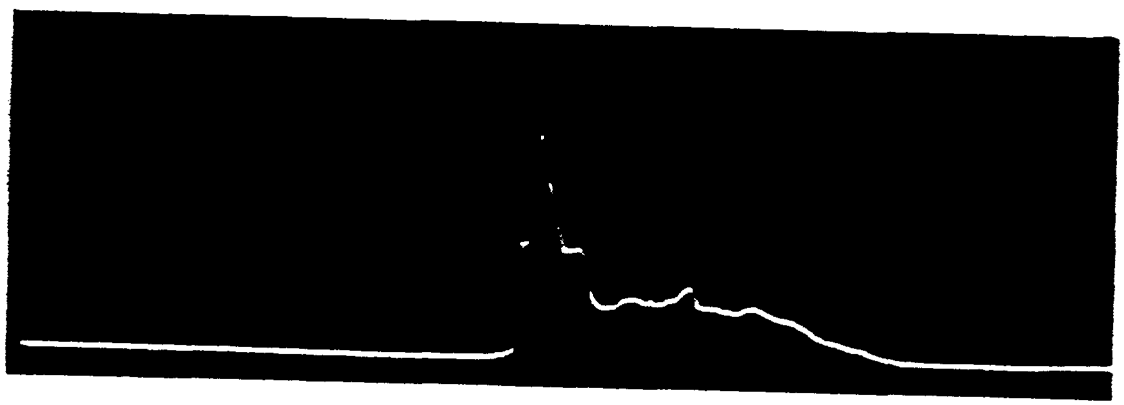

Fig. 2 Typical scope trace of the radiometer signal.

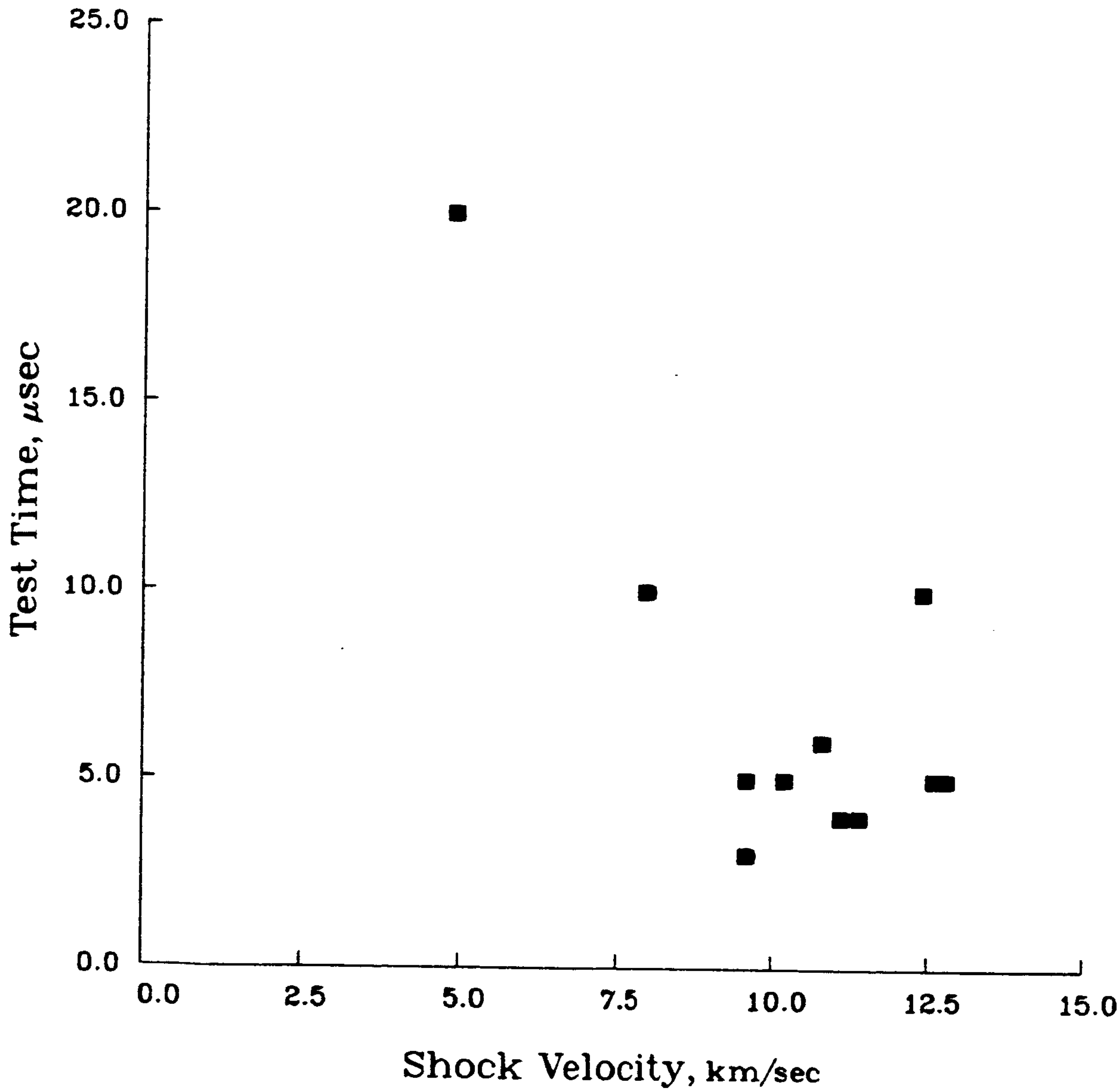

Fig. 3 Test times recorded in 60 cm E.A.S.T. facility during test 31.

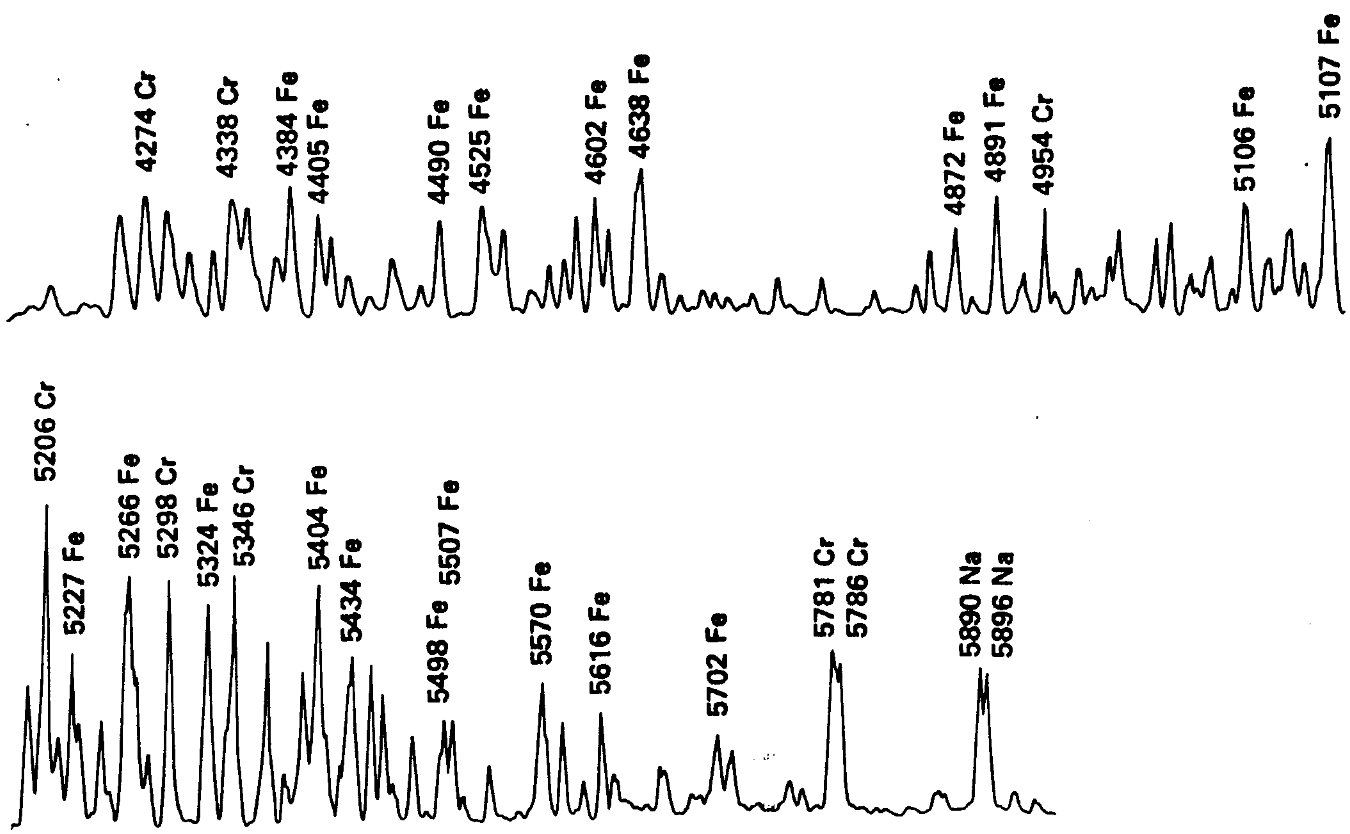

Fig. 4 Emission spectrum of the test gas (Nitrogen):

$U_s = 9.1\ km/sec$ and $P_1 = .020\ mm\ Hg$ (run # 26).