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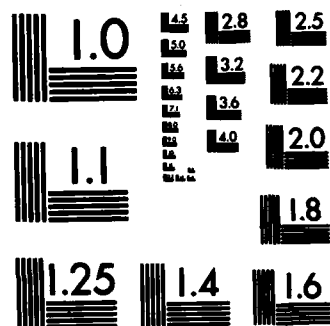
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This research was concerned with four rocket related topics: forced longitudinal wave motors, nonsteady burning in randomly layered media, insitu burning rate measurements, and thermal protection systems for radiant energy deposition powered thrus- tors. Apparatus for the forced longitudinal wave motor procured from Princeton, a test cell was readied and pressure instrumen- tation purchased. In addition, preliminary theoretical and flow		

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visualization studies were conducted. The latter showed the following: (1) when port Mach number is not small, both response and admittance functions enter as unknowns, and (2) port and near burning surface flows are not in phase so that periodically inflected velocity profiles accompany axial mode oscillations. Nonsteady burning studies showed that extinguishments can occur in fine particle psuedopropellant to coarse propellant psuedopropellant transitions and that the constant pressure burning rate auto-spectra contains "resonance" at the layer frequencies, twice layer frequencies, and characteristic frequencies; previous models assumed resonances solely at the layer frequencies. A survey of thermal protection methods applied to chemical rocket engines showed that transpiration methods were particularly promising because radiation from the direct energy deposition region could be re-deposited in the fluid entering through the wall. Relative to insitu rate measurement flash/radiographs of Sparrow motors statically tested at DREV were received and a "fast" technique for treating bulk mode nonsteady internal ballistics was developed.



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November 4, 1982

Interim Report
Covering the Period 1 October 1981 to 30 September 1982

SOLID ROCKET AND SPACE PROPULSION STUDIES

By: R.L. Glick and J.R. Osborn

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I. INTRODUCTION

The ability to accurately predict the performance of solid propellant rocket motors is a necessary step to achieving near optimal designs in a timely and economical fashion. Performance prediction typically entails prediction of quasi-steady performance and linear stability margins. Prediction of nonlinear instability thresholds, limit cycle behavior, etc. would be very useful; however, little real predictive capability currently exists. Important (both technically and cost wise) ingredients in these predictions are the "interfacial parameters" (burning rate, acoustic admittances, etc.) that couple the flow field to the deflagration process. At present, these must be determined experimentally. Of particular interest are the crossflow dependent phenomena - erosive burning, velocity coupled admittance/response, acoustic erosivity - because they are very important in high mass fraction motors and because they are currently difficult and expensive to measure.¹ The thrust of the rocket related research in this program is in this direction. Three lines of attack have been pursued:

- The forced longitudinal wave motor (FLWM) for instability research,
- the random psuedo-propellant sandwich for nonsteady combustion modeling, and
- flash radiography for insitu burn rate measurements.

The FLWM provides a realistic and controllable motor environment for assessing stability questions. The need for a realistic flow environment has come from a realization that crossflow related properties are not intrinsic propellant parameters.² Considerable theoretical activity has been directed at sandwich models for modeling nonsteady combustion of heterogeneous propellants.³⁻⁶ However, two central issues that have

not been attacked are the effects of a randomized structure and finite changes; Heterogeneous propellants are mixed and do not exhibit significant anisotropies as one would expect if they possessed long range order and the very essence of heterogeneity is finite property changes. Erosive burning has been and continues to be a significant design problem. The realization that turbulence transport in the gas phase reaction zone is the driver, that turbulence first appears relative far away from the deflagrating surface, and that transition to turbulence and the spread of turbulence can be controlled by design offers hope for fluid dynamical control of this phenomena; accurate (and economical) data in motor environments are a precursor to achieving this control.

Considerable interest has developed in rocket thrusters whose energetics are largely controlled by deposited radiant energy. Major attention appears to be devoted to the physics of the deposition process which leads to very high temperature fluids with little to the thermal protection aspects. Accordingly, attention to this area is warranted.

II. RESEARCH OBJECTIVES

The long range objectives of this research program are as follows,

- I. To define the interactions between the internal flowfield and the propellant deflagration process to the extent that same can be employed in the motor design process in a timely and economical fashion.
- II. To explore techniques to protect the structural components of the thrusters "powered" by radiant energy deposition.

III. ACCOMPLISHMENTS

The major accomplishments in this program are described below.

- A. Forced Longitudinal Wave Motor - Hardware was obtained from Princeton and partially set-up at Purdue. An analysis of the equations of change to remove the low port Mach number constraint from the procedure employed to deduce admittance related functions from measured pressure and velocity data was completed. This showed that both admittance and response parameters enter when port Mach number is not small. Development of a "computer-motor analysis" code is underway. This code will be employed to define the potential accuracy of data reduction procedures relative to methodology, instrumentation type and location and data signal/noise ratio.

The appearance of both admittance and response function type interactions in the higher Mach number portion of the flow has positive and negative aspects. On the negative side the number of unknowns doubles. On the positive side this doubling is not uniform along the port so that a proper spatial deployment of instrumentation might yield data on both response and admittance functions.

A discussion of the analysis of these aspects has been accepted for presentation at the 1983 Aerospace Sciences Meeting. Therefore, additional details will not be presented here.

A hydraulic analog of the FLWM was constructed and employed to visualize the internal flowfield. Preliminary

studies showed that the flows near the wall and in the core are roughly 90° out of phase. Therefore, the flow reversal phenomena described by Price⁷ simply does not occur. Instead, periodically inflected axial velocity profiles result (refer to Fig. 1). Since an inflected profile is a sufficient condition for laminar instability if the Reynolds number is large, it is hypothesized that a bursting turbulence phenomena will occur (this was not observed in the analog; Reynolds number too low?) This should yield the same DC effects noted by Price but appreciably different AC effects because the phenomena should be distributed over more of the motor. Idealized theoretical analysis showed a very complex acoustic velocity profile (refer to Fig. 2) that was not observed in the analog. It is believed that this is the first observation of this phenomena. This aspect of the FLWM work was presented at the AIAA/SAE/ASME 18th Joint Propulsion Conference.

- B. Nonsteady Burning in Randomly Layered Media - A precursor study of the ZN methodology in which non-Fourier heat conduction was embedded was completed. This study showed that these effects were negligible for frequencies of interest to combustion instability. This work was presented at the AIAA/SAE/ASME 18th Joint Propulsion Conference.

A numerical model for the randomly layered sandwich was developed. Very limited results are in hand at present because of long run times. However, some very interesting results as well as problems have appeared. A major problem is that transitions from fast burning to slow burning layers can lead to self-extinguishment (refer to Fig. 3.). Physically this is very intriguing because Miller has observed very long ignition delays for large AP particles in composite propellants. Theoretically, this means that an additional scenario is necessary for all but very narrow particle size distribution propellants. Two scenarios were explored—radiation from the gaseous products and conduction from adjacent flames. Neither modification is satisfactory at present. This and the long run times present the major technical difficulties.

Burning rate auto-spectra and pressure coupled response functions were computed for a narrow distribution reduced smoke propellant. The autospectra was extremely interesting because it showed resonances at the layer frequencies, twice layer frequency, and at the thermal resonance frequency (refer to Fig. 4). Previous models showed only the layer frequency. The additional resonances arise from the finite amplitude nature of the heterogeneities. Figure 5 illustrates a rate, time history segment for this propellant. Note that the general trend is a square wave (mean rate change from layer to layer) with damped resonances (response of a layer to step change). With a square

wave one expects fundamental plus harmonics; the response to a step change occurs at the layer resonance frequency. Thus, the autospectra is showing precisely what hindsight expects. The autospectra of the constant pressure burning rate history is analogous to Cohen and Strand's heterogeneity response. Consequently, this work shows that long range order is not necessary for layer frequency phenomena. However, it is also shown that Cohen and Strand's linearized analysis of heterogeneity effects may be over simplified.

A "philosophical question" in Cohen and Strand's analysis of heterogeneity effects is "how do they correlate with periodic pressure perturbations?" For a propellant with long range order Lengelle and Williams showed that phase synchronization occurred such that after a period there was a definable coupling. However, in the random layer model rate changes due solely to heterogeneity will not correlate with pressure fluctuations of infinitesimal amplitude. Thus, in the randomly layered model a separate heterogeneous component to the response does not occur. However, as the amplitude of pressure oscillations increase this will no longer be the case; correlation will now occur. First attempts to compute these effects failed!

The results achieved to date - though sketchy - present pioneering results. A paper plus calculations to be made has been accepted for presentation at the 1983 Aerospace Sciences Meeting.

- C. **Insitu Burning Rate Measurement** - Flash radiographs of statically tested Sparrow motors (CP gains) have been obtained from DREV. However, as the data reduction methodology is presently incomplete, they have not been analysed. An important aspect of this methodology is utilization of the continuous pressure, time history(s) to extract the "instantaneous" burning rate from the sequential grain geometry data encoded in the flash radiographs. A fast technique for doing internal ballistics was developed as an improvement on that described by Lamberty.⁸

Completion of the analytical portions of the methodology is projected for January and will be presented at the Aerospace Sciences Meeting.

- D. **Radiant Energy Deposition Thrustor Thermal Protection** - Literature pertaining to thermal protection systems for chemical rockets were reviewed relative to application to radiant energy deposition thrustors. Major problem with this thrustor is uniform transfer of radiant energy to the working fluid. As conduction cooling transports energy from the working fluid, convection cooling creates a "hot wall" boundary layer limited by wall structure constraints, and film cooling yields a wall region at the vaporization temperature, these techniques are inappropriate for this type thrustor. However, transpiration cooling can supply fluid to the thrustor at near wall temperature. With refractory material walls, this

presents potential for combining thermal protection with energy transfer to the working fluid at very low heat loss to the surroundings. This is precisely what is required for the chamber walls of a radiant energy deposition thruster.

The "window" of a radiant energy deposition thruster appears to be potentially the most difficult portion of the thruster to protect.

A report of findings was made to the AFOSR sponsored mini-conference concerned with this topic.

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V. PAPERS PRESENTED DURING PROGRAM YEAR

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2. Geyer, M.S., and Wilson, M.G., "On the Effect of Port Mach Number on the Shape and Frequency of Axial Mode Oscillations", AIAA-82-1065.
3. Deur, J.M. and Glick, R.L., "The Effect of Non-Linear Heat Conduction on the Pressure Coupled Response of Solid Propellant", AIAA-82-1102.
4. Swanson, E.R., Geyer, M.S., and Wilson, M.G., "On the Axial Velocity Profile in Nozzleless Solid Rocket Motors", AIAA-82-1145.
5. Wickliff, J.L. and Geyer, M.S., "On the Flow Reversal Condition in Combustion Instability", AIAA-82-1221.
6. *Becker, R.J. and Glick, R.L., "Application of Hilbert Transforms to Response Function Data", AIAA-82-1224.
7. *Glick, R.L. and Yerushalmi, S., "On the Internal Ballistics of Spin Stabilized Nozzleless Rocket Motors", AIAA-82-1144.
8. Glick, R.L., Comment on "Turbulent Flow Analysis of Erosive Burning of Cylindrical Composite Solid Propellants", to be published in AIAA J.

VI. ABSTRACTS ACCEPTED FOR PRESENTATION BASED PARTLY ON WORK DURING PROGRAM YEAR

1. Deur, J.M. and Glick, R.L., "Nonsteady Burning in a Randomly Layered Composite Propellant", abstract accepted for 1983 Aerospace Sciences Meeting.
2. Bielak, M. and Glick, R.L., "Local Admittance Measurements in Forced Longitudinal Wave Motors", abstract accepted for 1983 Aerospace Sciences Meeting.
3. Pressley, H. and Glick, R.L., "Measurement of Burning Rate in Solid Rocket Motors", abstract accepted for 1983 Aerospace Science Meeting.

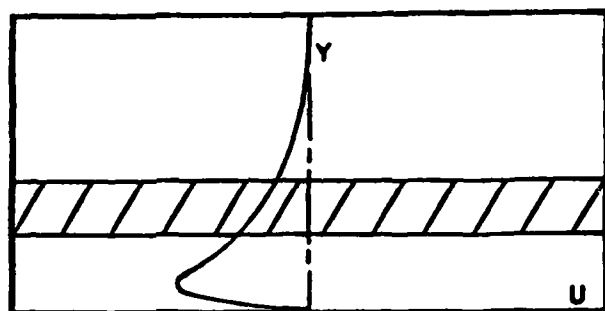
VII. STUDENTS GRADUATING DURING PROGRAM YEAR

Deur, John Mark, Master of Science in Aeronautics and Astronautics.

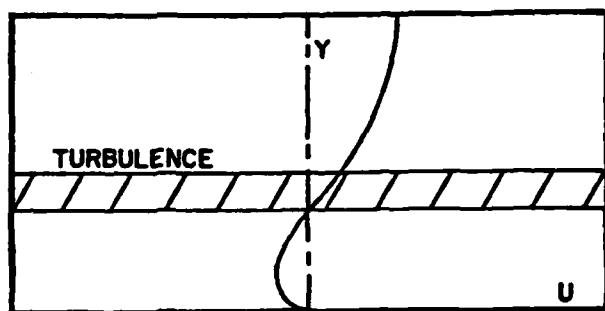
Thesis topic: "A Study of Non-steady Combustion of Heterogeneous

*Work performed under AFOSR 79-0022.

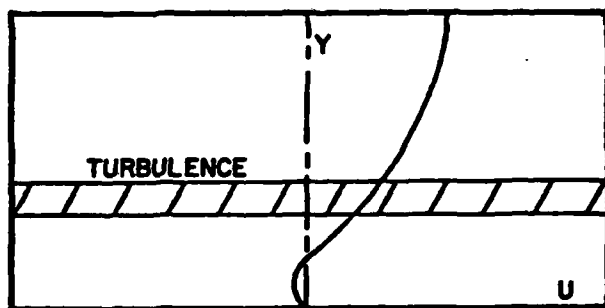
Propellants". Accepted employment with Thiokol Corporation, Huntsville, Alabama.



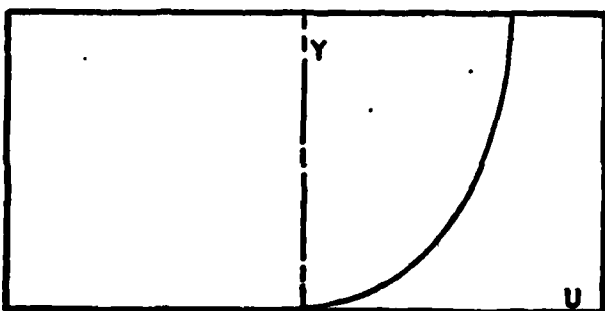
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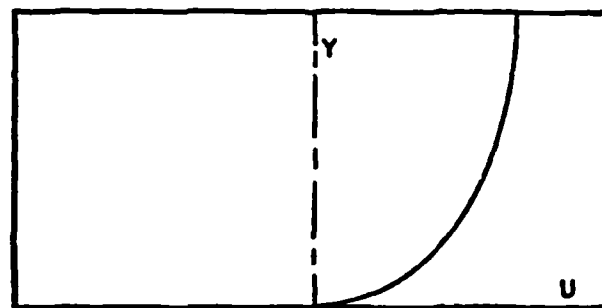


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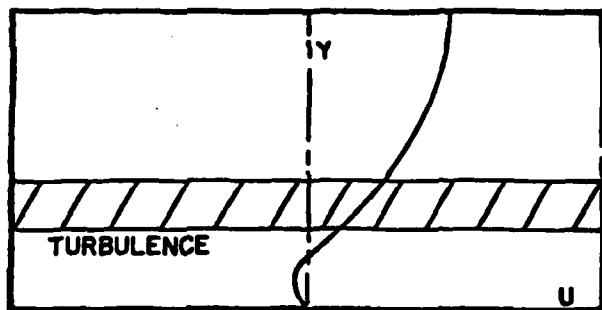


(A)

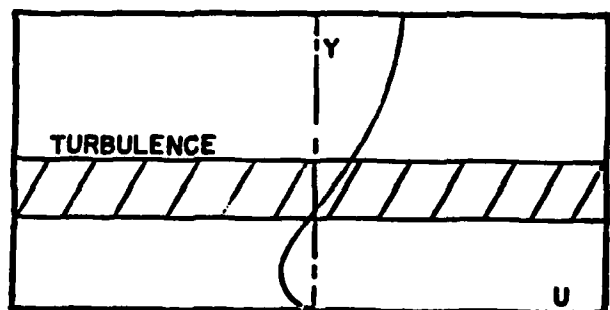
Figure 1 Sketch of Flow Reversal Cycle



(A)



(F)



(E)

Figure 1 Continued

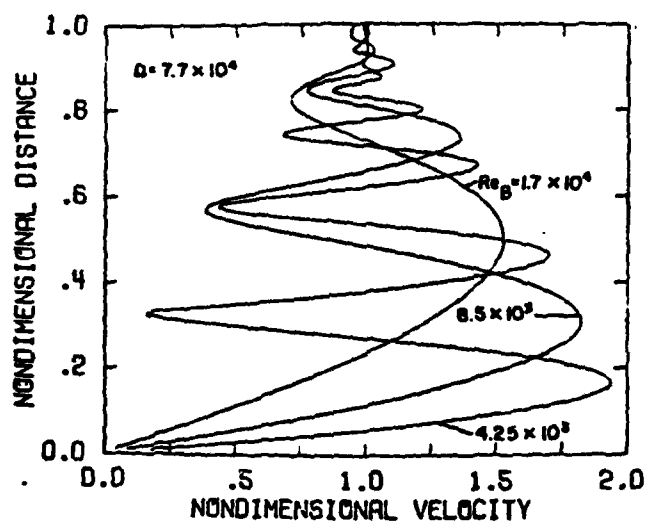


Figure 2 Effect of Blowing Reynolds Number on Amplitude of Velocity Fluctuation

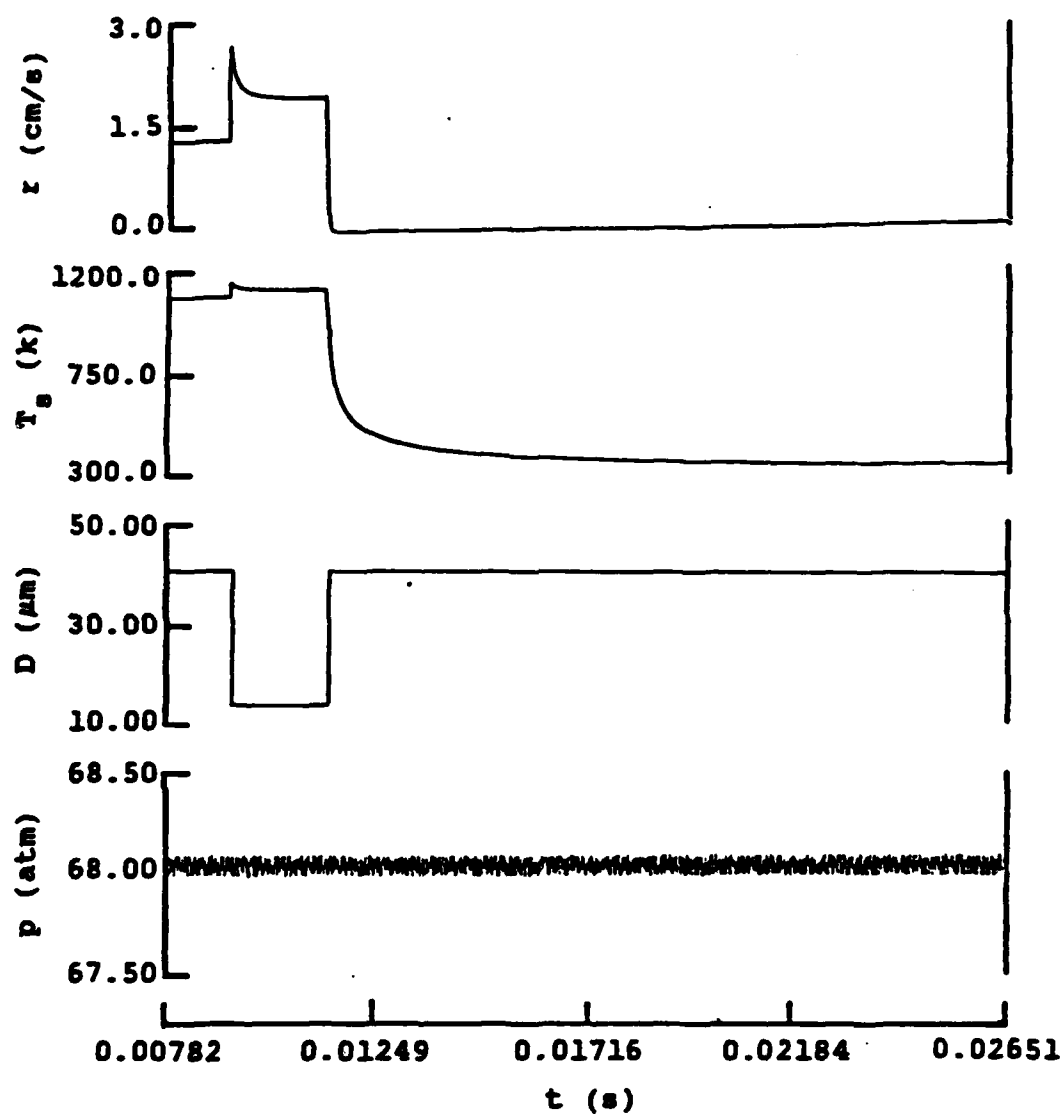


Figure 3 Time traces for 14 μm -40 μm transition case (extinguishment).

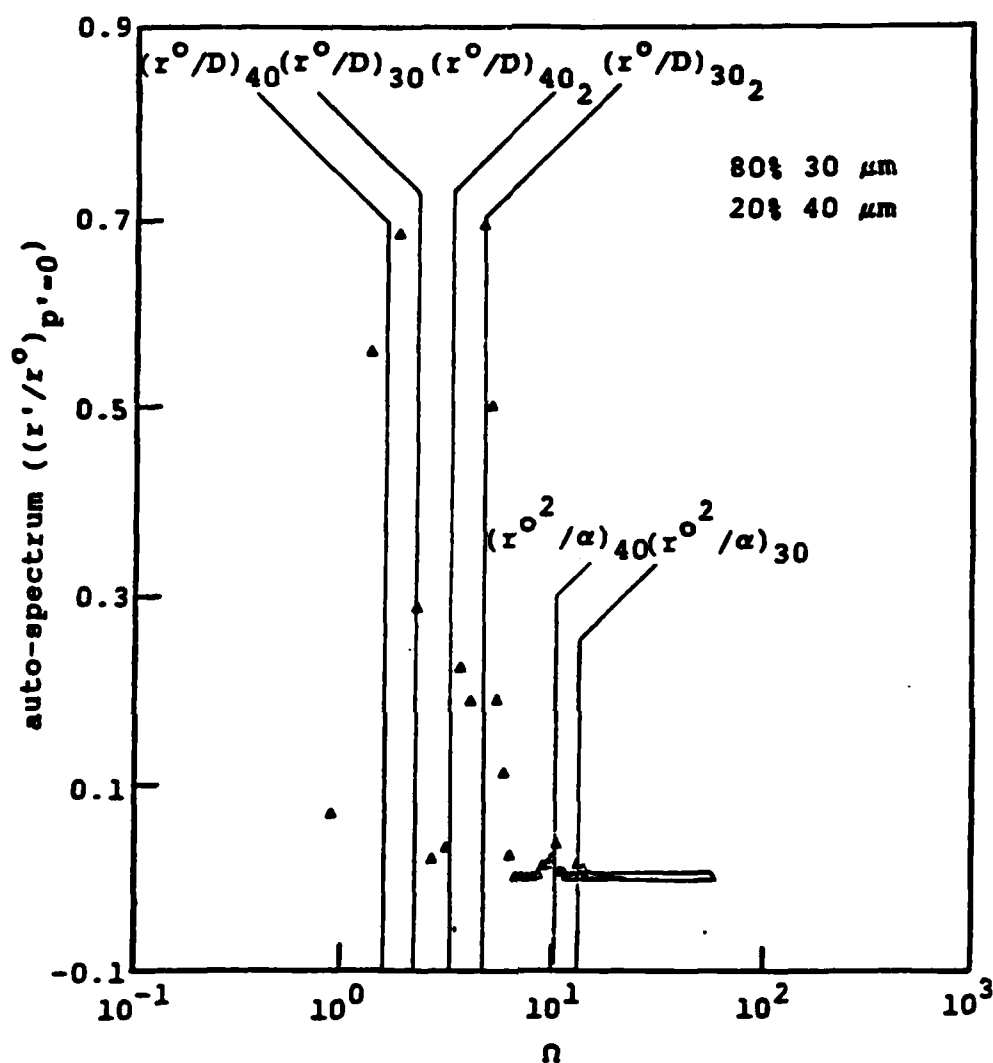


Figure 4 Auto-spectrum of constant pressure burn rate for 30 μm -40 μm transition case.

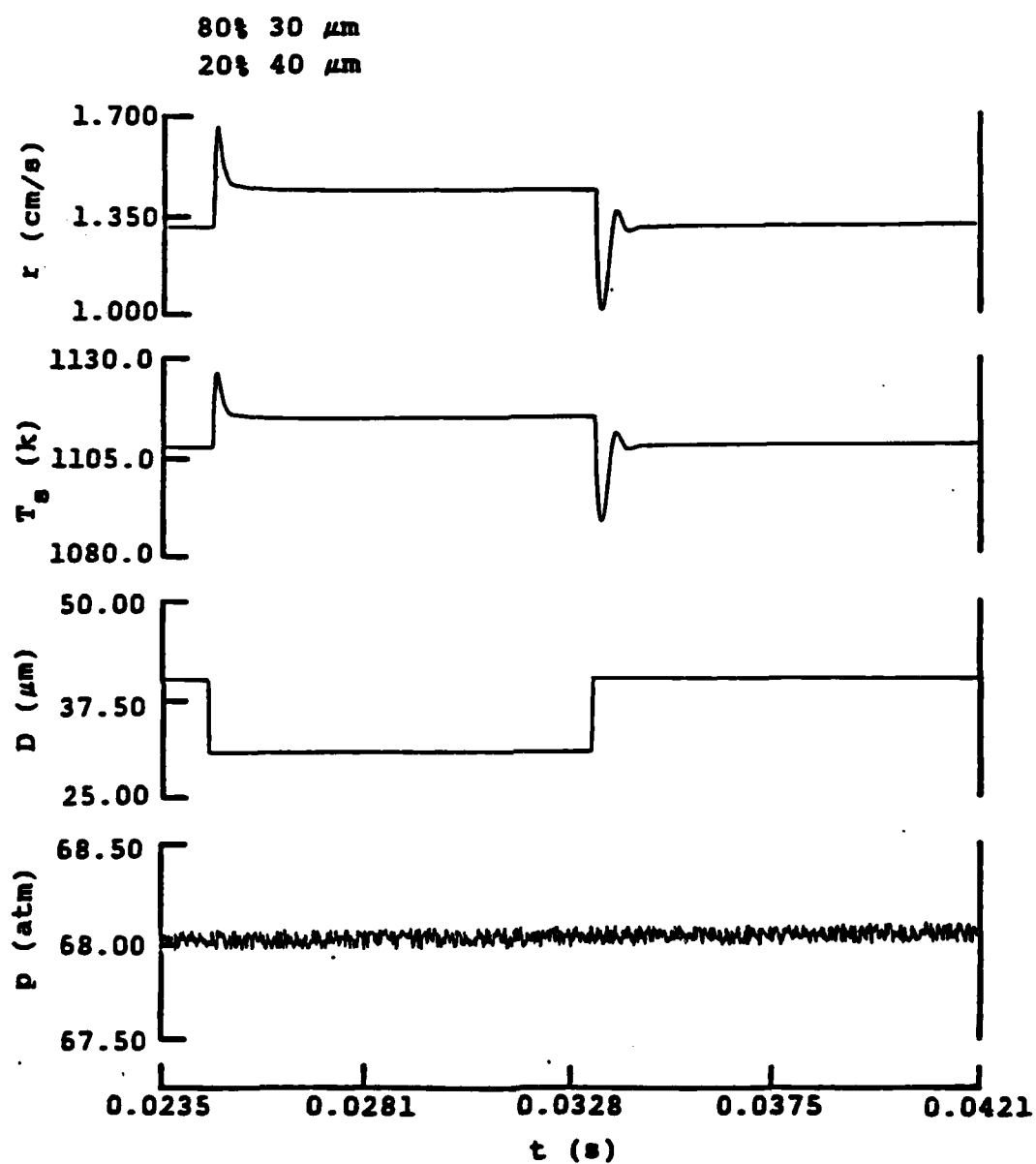


Figure 5 Time traces for 30 μm -40 μm transition case.

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