# COMBUSTION INSTABILITY WITH PARTIAL LENGTH

# ACOUSTIC LINERS

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Report of Research

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by

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## Introduction

This report outlines the work accomplished in the past year at Colorado State University with the support of NASA Grant NGR-06-002-095. The overall goal of this project is the development of analytical techniques and numerical methods for the prediction of the stability behavior of liquid propellant rocket combustors. During the past four years an integral equation iteration technique for the study of this problem has been developed at C.S.U. and applied with success to the determination of the linear stability of combustors with partial length liners and either concentrated or distributed combustion zones. Effort during the past year has been directed at the extension of this method in two primary directions.

The first of these involves inclusion of nonlinear wave propagation effects and nonlinear combustion zone, liner, and nozzle responses. This work has been separated further into two problems. One of these is the study of nonlinear wave propagation effects using a simplified linear response model for the combustion zone (the sensitive time lag model). The other is a study of wave distortion effects using a nonlinear vaporization controlled combustion response model. This latter work does not consider nonlinear wave propagation effects.

The second primary extension of the theory has been directed at the inclusion of the effects of injector face baffles in the theory. Here attention has so far been restricted to the linear (small amplitude) problem, though finite Mach numbers, three dimensional oscillations, and distributed combustion effects are being considered.

A summary of the accomplishments and progress made in the nonlinear analyses and the baffle work follows.

## Nonlinear Analyses

The first area of work on the nonlinear problem, the study of nonlinear propagation effects using the sensitive time lag model, is essentially completed. A contractors report giving details of the analysis, results of calculations and a computer program documentation and sample run is currently being prepared and will be distributed early in 1975. Major conclusions from this effort are

1) A Green's function integral technique was successfully applied in the solution of the nonlinear stability problem.
2) The technique can predict experimentally observed nonlinear phenomena.
    a) Regions where finite amplitude disturbances may trigger instability in a linearly stable regime.
    b) Nonlinear pressure waveforms similar to those observed experimentally.
3) The technique is applicable to a wide range of combustor configurations including variable liner location and impedances, mean Mach number, combustion response, and length to radius ratio.

4) The technique requires only a reasonable expenditure of computer time to determine the stability behavior of a given combustor.

Details of the technique will be given in the contractors report mentioned above and will not be presented here.

The second nonlinear problem, which will be referred to here as the wave distortion work, involves modeling the chamber with nonlinear combustion zone, acoustic absorber, and nozzle boundary conditions but using the linear wave equation to describe the wave motion in the combustor. If the flow field is taken to be irrotational, then a velocity potential may be introduced. The mathematical statement of the problem then becomes

$$\nabla^2\Phi - \Phi_{tt} = 0$$

$$\overrightarrow{\nabla\Phi} \cdot \vec{n} = F_{N.L.}(\Phi)$$

where $F_{N.L.}(\Phi)$ varies from surface to surface (liner nozzle, concentrated combustion zone).

The problem is solved by separating $\Phi$ into two harmonic components and ignoring all others. Thus $\Phi = \phi_1 e^{i\omega t} + \phi_2 e^{2i\omega t}$ where $\omega$ is the complex frequency. Substitution of this form into the governing equations yields two equations for $\phi_1$ and $\phi_2$. These are solved using the Green's function integral approach as it has been developed at C.S.U.[1]

The nonlinear boundary condition at the concentrated combustion zone is developed from Heidmann's vaporization limited model.[2] The nonlinear boundary conditions at the liner and nozzle have been developed from models available in the literature.

Solution of the system of equations and boundary conditions yields the spatial form of $\phi_1$ and $\phi_2$. For given nozzle, liner and combustion zone parameters the frequency of oscillation and decay (or growth) rate for the chamber are also determined.

Because of the nonlinear nature of the boundary conditions the integrals which must be evaluated become quite complicated. Consideration of only travelling waves reduces the algebra substantially. At the present time results for the travelling waves only are available. These indicate that nonlinear velocity effects in the vaporization model can provide a strong driving effect and cause a substantial amount of second harmonic content to appear in the solutions. (That is, the amplitude of $\phi_2$ is of the order of the amplitude of $\phi_1$).

The analysis is currently being extended to include standing modes of oscillation, as well as finite Mach number flows in the combustor.

## Baffle Studies

The purpose of this work is to include the effects of injector face baffles on the stability of liquid rocket combustors. Previous analyses available in the literature[2] have led to predictions of destabilizing influences by the addition of baffles. Experiment indicates, however, that they often have a strong stabilizing effect.[2]

Earlier analyses have not included finite Mach number effects nor distributed combustion effects. Consequently an attempt is being made to include both these effects and the baffles in our stability model at the same time. Two approaches are being pursued. One is an eigenfunction matching technique in which pressure and normal velocity are matched at the baffle cavity--main chamber interface. This matching solution is used in conjunction with an integral stability condition of the type developed by Cantrell and Hart[4] in order to determine the global stability of the combustor.

The second approach involves modification of the Green's function integral iteration technique so that baffle blades may be included. This second approach is both more general and more complex.

At the present time preliminary results indicate that the mean flow terms can have a substantial effect on baffle influence predictions. These results have been obtained using the eigenfunction matching method. Convergence of this method is rapid and good pressure and normal velocity matches are obtained. Sufficient numbers of calculations have not been made yet to state definitively whether the model including mean flow effects predicts overall stabilizing or destabilizing baffle influences.

## References


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3) Harrje, D. T., editor, Liquid Propellant Rocket Combustion Instability, NASA SP-194, 1972.
4) Cantrell, R. H. and Hart, R. W., "Interaction Between Sound and Flow in Acoustic Cavities: Mass Momentum and Energy Considerations," The Journal of the Acoustical Society of America, Vol. 36, No. 4, 1964.

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Gentlemen:

Enclosed are five copies of the annual report for NASA Grant NGR-06-002-095. The report covers the period from December 1, 1973 to December 31, 1974.

Very truly yours,

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Associate Professor

CEM:rm
cc: James A. McCambridge, Director
Office of Sponsored Research
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