(NASA-CR-162803) COMBUSTION STABILITY WITH BAFFLES, ABSORBERS AND VELOCITY SENSITIVE COMBUSTION Final Report, Dec. 1969 - Feb. 1980 (Colorado State Univ.) 9 p HC A02/MF A01 CSCL 21B G3/25

N80-18128

Unclas 47326

COMBUSTION STABILITY WITH BAFFLES, ABSORBERS AND VELOCITY SENSITIVE COMBUSTION

Grant NGR-06-002-095

FINAL REPORT

Covering the Period December 1969 - February 1980

Research Conducted at Colorado State University
Fort Collins, Colorado 80523

Principal Investigator: C. E. Mitchell
Department of Mechanical Engineering

Report Prepared for
National Aeronautics and Space Administration
February 1980

The NASA Technical Officer for this Grant
is Dr. R. J. Priem, NASA Lewis Research Center

INTRODUCTION

The overall goal of this work was the development of analytical and computational techniques for the prediction of the stability behavior of liquid propellant rocket combustors using damping devices such as acoustic liners, slot absorbers, and injector face baffles. The research included development of predictive models for determining the frequency and decay rate of combustor oscillations, determination of spatial and temporal pressure waveforms, and the prediction of stability limits in terms of combustion response model parameters.

The work began with the development of a relatively simple predictive model based on a simplified combustor. This basic model was linear in nature and ignored some features of real combustors. Nonetheless the stability predictions based on this model proved qualitatively correct. Sequential sophistication of the model followed, gradually including such real combustor features as distributed combustion, nonlinear combustion, nozzle and absorber responses, finite amplitude waveforms, and injector face baffles.

In what follows brief summaries of the accomplishments in each of the several areas of stability model development will be given. In addition the reports, papers, publications and theses prepared with grant support which document the work in detail in each area will be cited. The reference numbers used refer to the comprehensive list of grant-related publications which follows the text.

SUMMARY OF RESEARCH

A. Basic Model

The basic analytical technique employed in all the work done under this grant depends upon the use of an integral-iteration formulation following the Green's function approach. The first application of this technique was to a simplified combustor model. This model featured a concentrated combustion zone at the injector which responded to the combustor oscillations in a linear, pressure-sensitive way, a short nozzle, linear (small amplitude) pressure oscillations, and either an acoustic liner or an acoustic slot which served as a damping device.

References 1 and 2 give the earliest results obtained for this model; these were presented at JANNAF combustion meetings. The M.S. thesis of W. R. Espander (Ref. 3) presents this early work in more detail. The most comprehensive presentation of this basic model is given in two contractor reports, References 4 and 5. The first of these makes use of the iteration technique and simplified combustor model to make frequency and decay rate predictions for several combustor configurations similar to space shuttle main engine and preburners being proposed at that time. The second presents results of calculations for the overall stability behavior and pressure spatial waveforms in similar combustors. Both of these reports include computer programs with user manuals and sample inputs and outputs. A formal presentation of the mathematical technique as well as a summary of results is given in a journal publication, Reference 6.

B. Effects of Distributed Combustion

Recognizing that, in fact, the combustion zone in liquid propellant rocket engines is not concentrated at the injector face but rather is distributed along the motor axis, a considerable effort was made in order to evaluate the effects of distributing the combustion on the stability behavior of the combustor. The rest of the basic model remained the same in this work; that is, a short nozzle was assumed, either a partial length acoustic liner or a slot absorber served as an acoustic damper, and small amplitude pressure oscillations were assumed. Two approaches were used. In the first of these the combustion distribution was modeled by a series of planar sources. Details of the mathematical development and results of stability calculations using this first approach appear in the M.S. thesis of M. R. Baer (Ref. 7). Some of the results of these calculations were presented at the 9th JANNAF Combustion Meeting (Ref. 8) as well. A formal journal presentation of the multi-zone approach is given in Reference 9.

A second approach to the problem of distributed combustion allows consideration of continuous distribution of combustion sources in the axial direction. The mathematical sophistication is somewhat greater than in the multi-zone approach mentioned above. Predictions of stability behavior are similar qualitatively to those of the multi-zone approach, though quantitatively the multi-zone predictions underestimate combustor stability. Both approaches predict enhanced combustor stability and simplification of the overall stability picture with distributed combustion. The continuous combustion approach is described in a JANNAF meeting paper, Reference 10, and in a journal paper, Reference 11.

C. Baffle Damping

In addition to the slot absorbers and partial length acoustic liners, injector face baffles have been frequently used to stabilize liquid propellant combustors. A significant effort was made to develop a model capable of exploring the mechanism through which these baffles work and their impact on overall combustor stability. Two- and three-dimensional geometries were investigated with the fundamental damping mechanism assumed to be viscous dissipation near the tips of the baffle blades. Frequency and decay rate predictions were found to be well-predicted using the model. Because of the complex geometries involved (baffle cavities as well as main chamber) the mathematical approach used in this part of the work was somewhat different from that used in other phases of the work. The Ph.D. thesis of M. R. Baer (Ref. 12) gives a presentation of the two- and three-dimensional theory as well as results of calculations performed. Some results are also to be found in Reference 13, which is a paper presented at the 12th JANNAF Combustion Meeting. A contractor's report (Ref. 14) gives a summary of the theory and documents the computer program used in calculations. A paper in the AIAA Journal (Ref. 15) summarizes results of calculations and the analytical approach for three-dimensional oscillations.

D. Nonlinear Effects

Modeling of nonlinear effects in two areas was pursued. The first of these was the inclusion of nonlinear wave propagation effects in the theory. That is, waves of finite amplitude instead of the vanishing amplitude waves were to be considered. In this first part of the work the boundary conditions at the combustion zone and acoustic absorber were still taken to be linear, as before. Even with this simplified model nonlinear effects such as triggering of oscillations and nonlinear stability limits, as well as spatial and temporal pressure waveforms were predicted. This theory was presented in the Ph.D. thesis of W. R. Espander

(Ref. 16) and subsequently in a contractor's report (Ref. 17) which included the complex computer program.

A second area of effort in the modeling of nonlinear combustor stability was the inclusion of nonlinear combustion responses and absorber responses. Of primary interest here was to include velocity and wave distortion dependent effects in the combustion response. Physically this models a combustion process that is dominated by droplet vaporization. Initially the work here assumed that nonlinear waveforms were generated primarily by the combustion zone, and thus, nonlinear wave propagation terms in the partial defferential equations were ignored. Predictions based on this theory were presented at the 13th JANNAF Combustion Meeting (Ref. 18) and indicated that wave distortion response mechanisms could be significant, particularly if a characteristic time of combustion was assumed to exist. The restriction ignoring wave propagation terms was later relaxed using a successive approximation method. Both traveling and standing waveforms were also included. This extended work is reported in detail in the Ph.D. thesis of Yodchai Jotiban (Ref. 19).

E. Simplified Computer Models

The final effort under grant sponsorship was the development of a simplified computer program which included the most important aspects of the models and computer programs discussed previously. The idea here was to produce a designer's tool which could be used simply and effectively in making stability predictions at the design stage. Toward this end many simplifications were made both in the theory and in the computer program so that a person without an extensive background in either advanced mathematics or combustion stability could use the program and understand input, output and the significance of the predictions. Basic work was done in the development of both a linear and nonlinear program of this type. These are discussed in the M.S. thesis of K. Eckert (Ref. 20). For the case of linear stability a particularly useful program resulted. The nature of this program is discussed in a paper presented at the 15th JANNAF Combustion Meeting (Ref. 21). The final form of the program along with a user's manual and a simplified discussion of the theory is presented in a "low number" NASA contractor's report (Ref. 22).

REPORTS, PAPERS, THESES AND PRESENTATIONS

1. "Analysis of Combustion Instability in Motors with Partial Length Acoustic Liners," C. E. Mitchell, P. J. Wilbur, W. R. Espander, Proceedings of the 7th JANNAF Combustion Meeting, CPIA Publication 204, Vol. I, pp. 721-726, February 1971.

2. "A Study of tne Effects of Partial Length Acoustic Liners in Liquid Propellant Rocket Motors," C. E. Mitchell, W. R. Espander, M. R. Baer, Proceedings of the 8th JANNAF Combustion Meeting, CPIA Publication 220, Vol. I, pp. 795-805, November 1971.

3. "Partial Length Liners in Rocket Motors," W. R. Espander, M.S. Thesis, Colorado State University, 1971.

4. "Determination of Decay Coefficients for Combustors with Acoustic Absorbers," C. E. Mitchell, W. R. Espander, M. R. Baer, NASA CR 120 836, January 1972.

5. "Stability of Combustors with Partial Length Acoustic Liners," C. E. Mitchell, W. R. Espander, M. R. Baer, NASA CR 120 889, March 1972.

6. "Stability of Combustors with Partial Length Acoustic Liners," C. E. Mitchell, Combustion Science and Technology, Vol. 6, pp. 61-70, 1972.

7. "Combustion Instability in Rocket Motors with Distributed Combustion and Acoustic Liners," M. R. Baer, M.S. Thesis, Colorado State University, 1972.

8. "Combustion Instability in Chambers with Distributed Combustion," C. E. Mitchell, M. R. Baer, W. R. Espander, Proceedings of the 9th JANNAF Combustion Meeting, CPIA Publication 231, Vol. I, pp. 187-192, November 1972.

9. "Stability of Partially Lined Combustors with Distributed Combustion," M. R. Baer, C. E. Mitchell, W. R. Espander, AIAA Journal, Vol. 12, No. 4, pp. 475-480, 1974.

10. "Stability of Lined Combustors with Continuous Combustion Distributions," C. E. Mitchell, M. R. Baer, Proceedings of the 10th JANNAF Combustion Meeting, CPIA Publication 243, Vol. II, pp. 255-271, December 1973.

11. "Stability Predictions for Combustors with Acoustic Absorbers and Continuous Combustion Distributions," C. E. Mitchell, M. R. Baer, AIAA Journal, Vol. 13, No. 8, pp. 1107-1109, August 1975.

12. "A Theoretical Evaluation of Rigid Baffles in Suppression of Combustion Instability," M. R. Baer, Ph.D. Thesis, Colorado State University, 1975.

13. "Theoretical Evaluation of Rigid Baffles to Suppress Combustion Instability," M. R. Baer, C. E. Mitchell, Proceedings of the 12th JANNAF Combustion Meeting, CPIA Publication 273, Vol. I, pp. 509-521, December 1975.

14. "A Theoretical Evaluation of Rigid Baffles in Suppression of Combustion Instability," M. R. Baer, C. E. Mitchell, NASA CR 134 986, March 1976.

15. "Theoretical Evaluation of Rigid Baffles in Suppression of Combustion Instability," M. R. Baer, C. E. Mitchell, AIAA Journal, Vol. 15, No. 2, pp. 135-137, February 1977.

16. "Acoustic Liner Suppression of Nonlinear Combustion Oscillations," W. R. Espander, Ph.D. Thesis, Colorado State University, 1974.

17. "Suppression of Nonlinear Oscillations in Combustors with Partial Length Acoustic Liners," W. R. Espander, C. E. Mitchell, M. R. Baer, NASA CR 134 767, February 1975.

18. "Wave Distortion Effects on Vaporization Limited Combustion Stability," C. E. Mitchell, Y. Jotiban, Proceedings of the 13th JANNAF Combustion Meeting, CPIA Publication 281, Vol. III, pp. 145-156, December 1976.

19. "Nonlinear Analysis of Wave Distortion Response," Yodchai Jotiban, Ph.D. Thesis, Colorado State University, 1977.

20. "Computer Programs for Linear and Nonlinear Analysis of Rocket Engine Stability," K. R. Eckert, M.S. Thesis, Colorado State University, 1978.

21. "Simplified Computer Program for Liquid Rocket Combustor Stability Analysis," C. E. Mitchell, K. R. Eckert, Proceedings of the 15th JANNAF Combustion Meeting, CPIA Publication 297, Vol. II, pp. 449-460, February 1979.

22. "A Simplified Computer Program for the Presiction of the Linear Stability Behavior of Liquid Propellant Combustors," C. E. Mitchell, K. Eckert, NASA Contractor's Report 3169, August 1979.