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HYPERVELOCITY SCRAMJET COMBUSTOR-NOZZLE ANALYSIS AND DESIGN

Final Report

for

NASA Grant NAG-1-854

for the period

15 February 1988 to 31 December 1991

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I. INTRODUCTION

This is the Final Technical Report for NASA Grant NAG-1-854 entitled "Hypervelocity Scramjet Combustor-Nozzle Analysis and Design." The first phase of the Grant was for the period 15 February 1988 through December 1988, with a no cost extension through 28 February 1989. The second phase was for the period 1 March 1989 through 28 February 1990. The third phase was for the period 1 March 1990 through 28 February 1991, with a no cost extension through 31 December 1991. The research was performed at Purdue University, West Lafayette, IN, under the direction of Professors H. Doyle Thompson and Joe D. Hoffman, both of the School of Mechanical Engineering. The technical monitor is Mr. John Weidner of NASA Langley Research Center.

There are three tasks associated with this Grant. The first has been renamed in keeping with the redirected emphasis from a Vitiated Air Study to a Combustor Modeling Study. The three main tasks in the program are:

I. Combustor Modeling Study

II. Development of Analysis Capabilities for Hypersonic Scramjet Nozzles

III. Development of Optimum Design Methods for Hypersonic Scramjet Nozzles

The research performed under NASA Grant NAG 1-854 has been documented in a series of technical publications and presentations at various conferences. A brief description of the research in each of the above three areas and a list of the resulting technical publications constitutes this final report.

II. COMBUSTOR MODELING

DESCRIPTION

The objective of this task was to develop an analysis capability and a computer code for modeling the processes occurring in a scramjet combustor. The computer code that was developed is called 3STREAM.

3STREAM utilizes the one dimensional chemical kinetics code GKSP87 developed by D. Bittker and V. Scullin* at NASA Lewis Research Center. A procedure for incorporating the effects of mixing, heat transfer, and friction into the GKSP87 kinetics code was developed. The procedure involves a three-stream flow model composed of oxidizer, fuel, and products streams; an ignition source; a mixing schedule; interstream and environmental heat transfer; wall friction for the oxidizer and fuel streams; and turbulent mixing losses in the products stream. The code was developed and tested, and is currently being used by several government laboratories and contractors to parametrically evaluate the effect of various parameters on supersonic combustion, and for modeling a variety of supersonic combustion processes.

PUBLICATIONS

1. Houck, S.W., "3STREAM: An Engineering Tool for Modeling Complex Combustion Processes," MSE Thesis, Purdue University, W. Lafayette, IN, December 1989.
2. Houck, S.W., Hoffman, J.D., and Thompson, H.D., "3STREAM: A Simple Engineering Tool for Modeling Supersonic Combustion," Paper Number 58, *Seventh National Aero-Space Plane Technology Symposium*, NASA Lewis Research Center, October 23-27, 1989.
3. Houck, S.W., Hoffman, J.D., and Thompson H.D., "3STREAM: An Engineering Tool for Modeling Complex Combustion Processes: Volume 1: Theory, Development and Results," NASP Contractor Report 1093, August 1990.
4. Houck, S.W., Hoffman, J.D., and Thompson, H.D., "3STREAM: An Engineering Tool for Modeling Complex Combustion Processes: Volume 2: Program Users Guide," NASP Contractor Report 1094, August 1990.
5. Trexler, C.A., Weidner, J.P., and Thompson, H.D., "Summary of Hypersonic Inlet TMP-101 and Nozzle TMP-103," 10th National Aero-Space Plane Symposium, Monterey, CA, Paper Number 111, April 23-26, 1991.
6. Houck, S.W., Hoffman, J.D., and Thompson, H.D., "3STREAM: An Engineering Tool for Modeling Complex Combustion Processes," paper in preparation for the *AIAA Journal of Propulsion and Power*.

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* Bittker, David A., and Scullin, Vincent J., "GCKP84 - General Chemical Kinetics Code for Gas-Phase Flow and Batch Processes Including Heat Transfer Effects," NASA Technical Paper 232D, September 1984.

III. ANALYSIS CAPABILITY

DESCRIPTION

The objective of this task was to develop the analysis and the computer codes that are capable of analyzing steady flow through scramjet nozzles. The nozzle geometries to be analyzed include both test geometries and flight geometries. The codes have the capability of handling arbitrary free stream conditions, so that the effects of different flight conditions can be considered. They require the specification of the exit conditions from the combustor, although these conditions may be specified as any realistic set of values.

The original intent was to develop both two-dimensional and three-dimensional analysis codes. However, the three-dimensional code has not been successfully developed.

A two-dimensional code has been developed and has been used as part of the optimum nozzle design study in both the hinged flap design study and the direct optimization maximum thrust nozzle design procedure.

The details of the two-dimensional computer code and its use are contained in the following publications.

PUBLICATIONS

7. Doty, J.H., "Performance Prediction and Design of Maximum Thrust Planar Supersonic Nozzles Using a Flux-Difference-Splitting Technique," Ph.D. Thesis, Purdue University, W. Lafayette, IN, August 1991.
8. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "Performance Prediction and Design of Maximum Thrust Planar Supersonic Nozzles Using a Flux-Difference-Splitting Technique; Volume 1: Theory, Development and Results," Technical Report submitted to NASA-Langley (Mr. John Weidner) for approval, publication, and distribution, August, 1991.
9. Doty, J.H. Thompson, H.D., and Hoffman, J.D., "Performance Prediction and Design of Maximum Thrust Planar Supersonic Nozzles Using a Flux-Difference-Splitting Technique; Volume 2: Program Users Guide," Technical Report in progress.

IV. OPTIMUM NOZZLE DESIGN CAPABILITY

DESCRIPTION

The objective of this task is to develop the criteria, and the associated computer codes, to implement optimum design procedures for scramjet type nozzles. Optimum design implies the determination of the variables that are at the designer's discretion, subject to the fixed constraints of the problem, that will produce the maximum net nozzle thrust. Several optimization problems have been identified that have direct application to the scramjet nozzle problem. They include:

1. Determination of the optimum supersonic nozzle contour for maximum thrust, subject to constraints on geometric parameters such as overall length, etc.,
2. Determination of the optimum flap angle for a fixed geometry nozzle operating at off-design conditions,
3. Determination of the optimum nozzle contour as in 1 above, but subject to a trim drag penalty, and
4. Determination of the effect of non-uniform inlet conditions on the optimum contours.

The publications listed below include the results of all of the applicable optimization problems, including the analysis, development of the requisite computer codes, and the computation of optimum designs. It should be noted that the determination of optimum geometries requires the use of an accurate analysis computer code. Thus the analysis capability is an important part of the optimum nozzle design capability.

As a final note a comparison of the optimum two-dimensional contours determined under this program with those generated by the Rao optimization techniques* revealed that under certain conditions the Rao technique gives a minimum (local minimum) thrust instead of a maximum thrust.

PUBLICATIONS

10. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "Generalized Optimization of Two-Dimensional Nozzles Including Trim Drag," *Proceedings of the 1989 JANNAF Propulsion Conference*, May 1989.

11. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "Maximum Thrust Nozzles With Non-Uniform Inlet Conditions," NASP CR-1069, October 1989.

12. Doty, J.H. Thompson, H.D., and Hoffman, J.D., "Maximum Thrust Airframe-Integrated Scramjet Nozzles," Paper Number 83, Seventh National Aero-Space Plane Technology Symposium, NASA Lewis Research Center, October 23-27, 1989.

* Rao, G.V.R., "Exhaust Nozzle Contour for Optimum Thrust," *Jet Propulsion*, 28, 1958, pp. 377-382.

13. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "Optimum Thrust Supersonic Nozzles for Hypersonic Vehicles; Volume 1: Theory and Results," Technical report submitted to NASA-Langley (Mr. John Weidner) for approval, publication and distribution on 24 January 1992.

14. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "Optimum Thrust Supersonic Nozzles for Hypersonic Vehicles; Volume 2: Program Users Guide," Technical Report in progress.

15. Doty, J.H., Thompson, H.D., and Hoffman, J.D., "A Rao Thrust Nozzle Optimization Sometimes is a Minimum," technical note, in preparation for the *AIAA Journal of Propulsion and Power*.