NAVIER-STOKES CALCULATIONS OF
SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS

By
Oktay Baysal, Principal Investigator

Final Report
For the period ended August 15, 1991

Prepared for
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Research Grant NAG-1-811
James L. Pittman, Technical Monitor
SMD-Aerothermal Loads Branch

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369

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The geometry of a wind tunnel model, which had been built for similar purposes, has been adopted in order to facilitate the necessary CFD code validation with the experimental results. Internal and external portions of the nozzle were included in the computational domain. All the calculations have assumed cold exhaust gases as have the wind tunnel tests. Also, the thermodynamic similitude has been maintained in one set of computations by using a cold gas mixture, which has a specific heat ratio ($\gamma$) equal to that of the hot exhaust gas.

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Oktay Baysal
Mohamed E. Eleshaky
Walter C. Engelund

Old Dominion University
Mechanical Engineering and Mechanics Department
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Tel. (804) 683-3720

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A computational investigation is conducted to study the expansion of a supersonic air flow through an internal-external nozzle and its mixing with a hypersonic air flow. The impetus is to help the design of the nozzle-afterbody section of a hypersonic transport vehicle which is powered by a scramjet engine. Three-dimensional compressible Navier-Stokes equations are solved by the finite-volume and alternating-direction-implicit method. The convective and the pressure terms are differenced by an upwind-biased algorithm which uses the flux-difference splitting and various flux limiters. The Reynolds stresses are modeled algebraically. The simulated flowfield also allows detailed analyses of a supersonic duct flow, a supersonic flow through an asymmetric internal nozzle, a hypersonic flow over a double-corner, and three-dimensional shear layers. The computed pressure distributions compare favorably with the experimentally obtained surface and off-surface flow surveys.

INTRODUCTION

Propulsion-airframe integration for hypersonic airbreathing vehicles is an important feature for the design of a national aero-space plane configuration. The lower afterbody expands the supersonic exhaust gases from the scramjet engine, therefore it becomes a part of the nozzle. This strong coupling between the engine and the airframe necessitates a combined analysis of internal and external flows. The hypersonic freestream and the supersonic exhaust flow mix through a shear layer, where mass, momentum, and energy transfers occur. The interference of the exhaust on the control surfaces of the aircraft can have adverse effects on the stability of the aircraft. Therefore, some method of simulating this type of flow is required to properly design the nozzle and the afterbody region.

A simplified configuration is assumed to model the single-module scramjet nozzle and afterbody. A rectangular duct precedes the internal nozzle, which has a 12° upper surface and a 20° lower surface. The external part of the nozzle is bounded by a 20° ramp and a vertical reflection plate. The external hypersonic flow is initially over a double-corner formed by the reflection plate, the top surface of the nozzle, the exterior of the nozzle sidewall, and a side flat plate. The viscous effects become dominant in all the corner regions. Then both of the flows expand over the 20° ramp. The supersonic jet expands in the axial, the normal, and the spanwise directions as it clears the exit plane. A three dimensional shear layer structure is formed between these coflowing streams which are at different speeds.
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MONDAY 4 – WEDNESDAY 6 SEPTEMBER 1989
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W. C. Engelund²

Department of Mechanical Engineering and Mechanics
Old Dominion University
Norfolk, Virginia 23529

K. E. Tatum³

NASA Langley Research Center,
Hampton, Virginia 23665.

Symposium on Advances and Applications
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¹Associate Professor, Mech. Eng. & Mechs. Dept.
³Research Engineer, PRC Kentron, SHAB/HSAD
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