NASA TM-85711

NASA Technical Memorandum 85711

ANALYTICAL PREDICTION OF AEROTHERMAL ENVIRONMENT IN A WING-ELEVON COVE

KIM S. BEY

NOVEMBER 1983

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

Analytical Prediction of Aerothermal Environment in a Wing-Elevon Cove

Kim S. Bey

SUMMARY

The fluid/thermal environment in the cove between the wing and elevon surfaces has been a concern throughout the design and initial operational phases of the Space Shuttle. Experimental and analytical investigations provided some understanding of the environment in the wing-elevon cove. This paper describes an incompressible finite element analysis of flow through straight parallel walls and curved parallel walls to determine the effects of cove geometry on the fluid/thermal environment. Results from this analysis agree qualitatively with experimental data. The centerline gas temperatures and cold wall heating rates are virtually identical for the two cases indicating that the slight curvature has little effect on the overall thermal environment.

INTRODUCTION

The gap between the Space Shuttle wing and elevon surface is closed by seals at the elevon hinge line to prevent through flow of hot boundary layer gases. The environment within the resulting sealed cove, as well as the environment in the cove should the seal leak, has been an area of concern throughout the design and initial operational phases of the Space Shuttle because the hot boundary layer gas flowing into the cove has the potential of damaging the thermally unprotected inner wing and elevon structures. Experimental investigations(1) provided some understanding of the fluid/thermal environment in a wing-elevon cove. A simplified partial cross-sectional view of the 1/2 in. wide by 12 in. long wing-elevon cove used in these studies is shown in fig. 1. The cove wall formed by the wing was instrumented with pressure orifices and thermocouples which were used to determine the cold wall heating rates. The gas temperature distribution in the cove was measured with beaded thermocouples. A finite difference 2D Navier Stokes analysis(2) of the external hypersonic and internal subsonic flow provided a qualitative understanding of the flow phenomena associated with the cove, but further analytical studies were needed to provide a better understanding of the flow inside the cove.

In an effort to better understand the effects of cove geometry on the flow field and cold wall convective heat transfer to the cove surfaces, an incompressible finite element analysis of steady flow in the cove was performed by modeling the cove as both straight and curved parallel walls. This paper presents brief descriptions of the finite element model and code methodology, analytical results, and a comparison of the predicted heating rates with experimental data.

DESCRIPTION OF ANALYSIS

Governing Equations. - Flow in the cove was mathematically modeled with the conservation of mass, momentum (Navier-Stokes), and energy equations in two-dimensions for laminar, steady-state flow of a viscous fluid. The previous analysis(2) and the experimental data(1) indicated the Mach number in the cove was less than 0.3; therefore the flow was considered incompressible and viscous dissipation was neglected. The fluid viscosity and thermal conductivity were temperature dependent. The resulting governing equations are a set of four partial differential equations in the four dependent variables: velocity components U and V, pressure, P, and temperature, T.

Finite Element Methodology. - The finite element program NACHOS[3] was used to obtain a numerical solution to the governing equations. NACHOS was written to solve relatively small problems of free and low-speed forced convection. The program uses 8-noded subparametric and isoparametric quadrilateral elements. The flow and energy equations, coupled by the temperature dependent properties, are solved iteratively using Picard or Newton-Raphson algorithms. They are decoupled by solving each set separately, alternating between the two and updating the solution with each iteration. Models were generated and displayed using the built in features. Boundary conditions were applied in global coordinates. Results were displayed using NACHOS graphics and an added post-processor.

Finite Element Model. - The entire flow region from thermocouple TC1 to pressure orifice P01 (fig. 1) was modeled. However, because of element limitations in NACHOS, the changes in cross-sectional area and geometry beyond thermocouple TC4 were not considered. The cove was first modeled as straight parallel walls and then, to determine the effects of curvature, it was modeled as curved parallel walls. The straight cove, using a symmetry boundary at the centerline, was modeled with 340 subparametric elements (17 x 20) resulting in over 3400 unknowns. The curved cove, inside/outside radius of curvature of 6 in./6.5 in., was modeled with 400 isoparametric elements (20 x 20) resulting in over 3600 unknowns. Elements in both models were concentrated at the inlet and walls where gradients are steep.

The boundary conditions applied to both models were determined from experimental data[1] for a cove leak area of 12.5 percent of the entrance area and the free stream conditions noted on fig. 1. The inlet conditions were a specified uniform velocity of 258 ft/s, calculated from the data, and a uniform temperature of 1940°R, measured by TC1. The exit conditions were a uniform pressure of 73 psf, measured by P01. The wall temperature (T_w) was specified to be a constant 550°R.

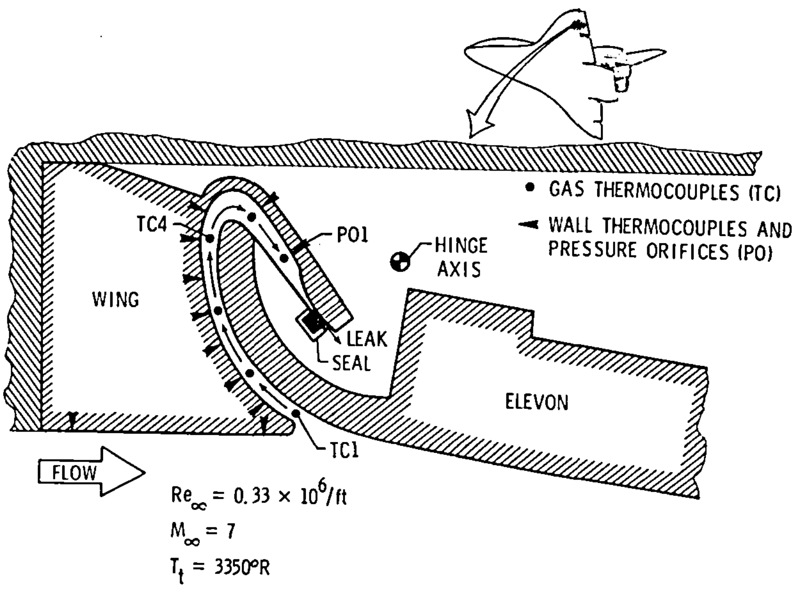


Fig. 1. - Partial cross-section of experimental cove model.

RESULTS AND DISCUSSION

Selected velocity and temperature profiles from the straight sided model are shown in fig. 2. The velocity profiles, fig. 2a, show that the flow is developing throughout the cove. The slight overshoot in the profile near the inlet is resolvable by mesh refinement, but has an insignificant effect on the downstream velocity and temperature. The temperature profiles, fig. 2b, show that the centerline gas temperature decreases with distance downstream as the gas loses energy to the cold wall. This decrease causes the gradients at the wall, and thus the cold wall heating rate to also decrease with distance downstream. The same profiles for the curved sided model are shown in fig. 3. The velocity profiles, fig. 3a, show the flow at the inner wall accelerates and flow at the outer wall decelerates. This is due to curvature induced variations in the pressure gradients between the inner and outer walls. Further downstream, only centrifugal forces act, causing the profiles to skew toward the outer wall. The temperature profiles, driven by convective forces, behave similarly. Except at the exit where the model is inexact, the temperature gradients at the inner and outer walls are nearly the same and the heating rates vary by less than 1 percent.

The predicted cold wall heating rate (Q_w) distributions are compared with experimental data in fig. 4. The straight and curved wall models give nearly the same results. The finite element analysis captures the general trend of the experimental data in the region where the cove walls are parallel, but is low and in some cases by a factor of 2. The scatter in the data in this region could be caused by the measurements being in the range of the error band of the instrumentation. The difference in the data and the analysis arises from uncertainties in the boundary conditions applied to the finite element model, since they were obtained from experimental data. Since the finite element model did not include the change in curvature and area past 60 percent of the cove length, the analysis does not predict the increase in the downstream heating rate found in the experiment.

Some comments should be made on the lessons learned in applying the finite element method to a realistic aerospace problem and on desirable features of future finite element codes. For user convenience, model generation and display, which includes boundary conditions shown on the model, and graphical representation of results are absolute necessities. Also, boundary conditions should be applied in a local element coordinate system so that complex geometries can easily be modeled. Approximately 10,000 unknowns are needed to accurately model the wing-elevon cove. Other than computer storage limits, the code should not have a self-imposed element restriction. The implicit algorithm, which requires reassembly of the matrices for each iteration, resulted in large execution times (5000 CP seconds). Execution time for this type of problem could be reduced by using a more efficient algorithm, perhaps an explicit transient formulation.

CONCLUDING REMARKS

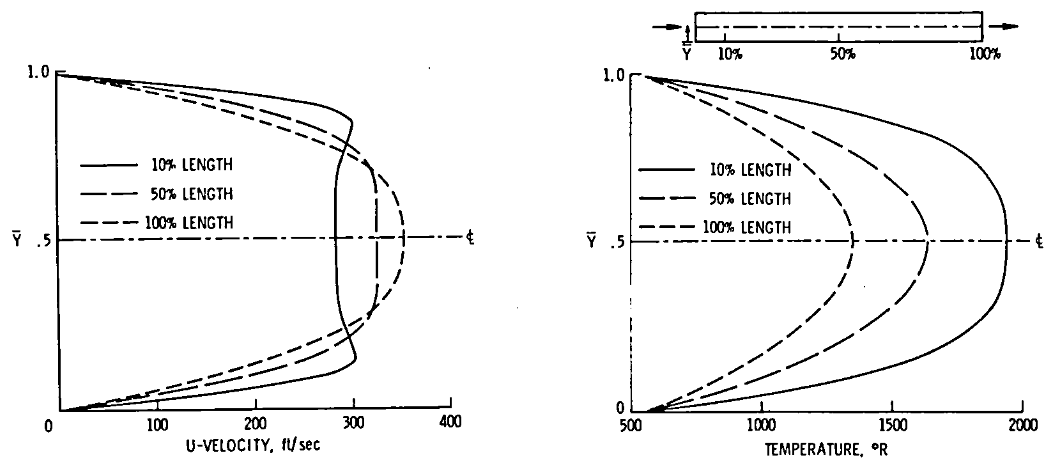
An incompressible finite element analysis was performed to determine the effects of geometry on the fluid/thermal environment in a wing-elevon cove. To determine the effects of curvature, the flow in the cove was first modeled as straight parallel flow, and then as curved parallel flow. The results were compared to experimental data from a geometry which the finite element models only approximated. The curvature in the section of the cove where the walls are parallel has little effect on the overall thermal environment in the cove; the heating rates are virtually the same for both straight and curved flow. The analysis gives results which agree qualitatively with experiment in this region. More detailed modeling is required at the cove exit, where the change in curvature and area could have a significant effect on the fluid/thermal environment. The analysis showed that finite element programs with significantly larger solution capacity and faster execution times are needed to solve realistic aerospace flow problems. The analysis has provided a fundamental understanding of the fluid/thermal environment in a portion of the wing-elevon cove, but further studies are needed for a detailed definition of the flow in the entire cove.

REFERENCES

1. Deveikis, William D.: Effects of Flow Separation and Cove Leakage on Pressure and Heat-Transfer Distributions Along a Wing-Cove-Elevon Configuration at Mach 6.9. NASA TP 2127, 1983.

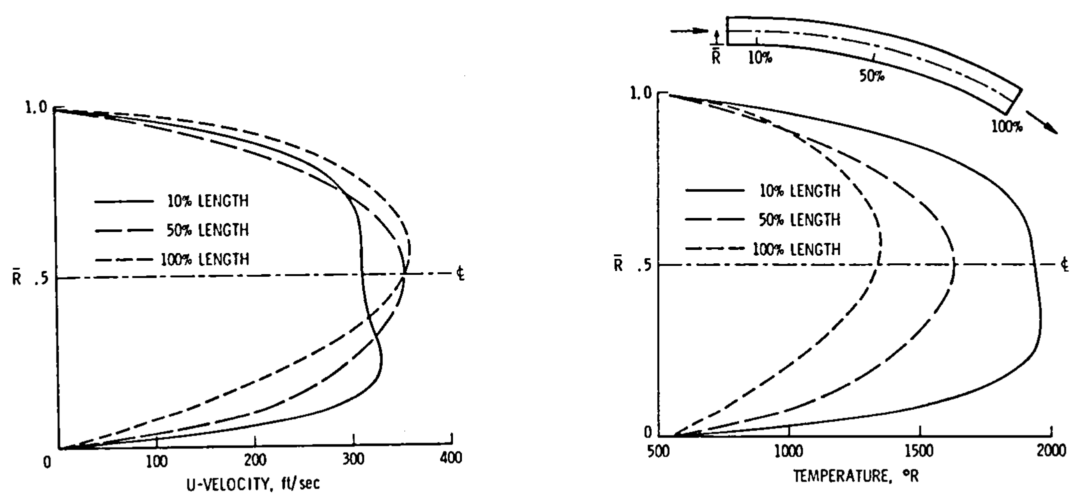
2. Wieting, A. R.; Walsh, J. L.; Bey, K. S.: Aerothermal Environment in Control Surface Gaps in Hypersonic Flow--An Overview. Presented at AIAA 18th Thermophysics Conference, AIAA Paper No. 83-1483, June 1983.

3. Gartling, David K.: NACHOS--A Finite Element Computer Program for Incompressible Flow Problems, Part I - Theoretical Background. Sandia National Laboratories, SAND 77-1333, April 1978.



(a) Velocity Profiles (b) Temperature Profiles

Fig. 2. - Profiles for straight cove model.



(a) Velocity Profiles (b) Temperature Profiles

Fig. 3. - Profiles for curved cove model.

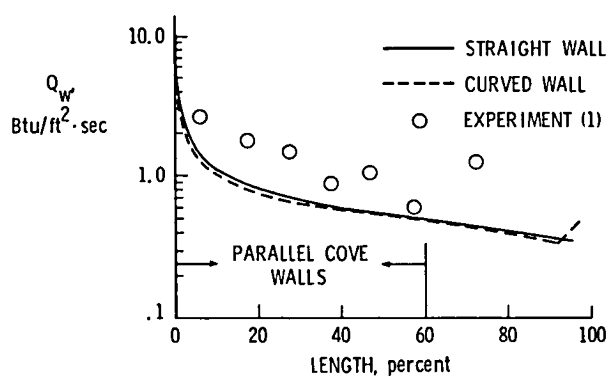


Fig. 4. - Cold wall heating rate distribution.

1. Report No. NASA TM-85711	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Analytical Prediction of Aerothermal Environment in a Wing-Elevon Cove		5. Report Date November 1983
		6. Performing Organization Code 506-53-53
7. Author(s) Kim S. Bey		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

This paper to be presented at the 5th Symposium of Finite Elements in Flow Problems, University of Texas, January 23-26, 1984

16. Abstract

The fluid/thermal environment in the cove between the wing and elevon surfaces has been a concern throughout the design and initial operational phases of the Space Shuttle. Experimental and analytical investigations provided some understanding of the environment in the wing-elevon cove. This paper describes an incompressible finite element analysis of flow through straight parallel walls and curved parallel walls to determine the effects of cove geometry on the fluid/thermal environment. Results from this analysis agree qualitatively with experimental data. The centerline gas temperatures and cold wall heating rates are virtually identical for the two cases indicating that the slight curvature has little effect on the overall thermal environment.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Finite-Element Aerothermal Environment Incompressible Flow	Unclassified - Unlimited Subject Category 34

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	9	A02