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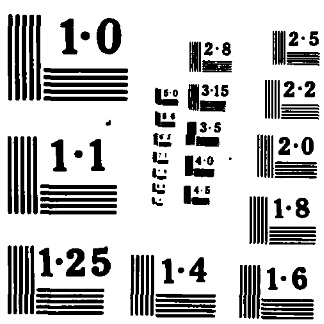
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HIGH MACH NUMBER ~~AERODYNAMIC~~ PREDICTIVE METHODS FOR MISSILE CONFIGURATIONS

by

Goetz H. Klopfer

NEAR TR 350
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides an overview of the numerical research conducted on steady supersonic inviscid flows with crossflow separation during the period of May 1982 through May 1985. The publications resulting from that research are summarized.

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HIGH MACH NUMBER AERODYNAMIC PREDICTIVE METHODS

FOR

MISSILE CONFIGURATIONS

I. INTRODUCTION

When this research was initiated in late 1981 a need existed in U.S. Army tactical air defense for ground troops in the field of high speed missiles capable of speeds up to M = 7. In addition, there was an interest in gun-launched winged projectiles capable of speeds up to M = 5, Ref. 1. Reliable aerodynamic methods were not available at the time for estimating the performance, stability, and control of such missiles. At the same time NEAR, Inc. had just developed a method which accounts for the nonlinear effects of compressibility and vorticity shed from the body and fins. The method is based on the Euler equations of gas dynamics and determined the loading on bodies alone and bodies with fins for supersonic flows, References 2-4. The present research was undertaken to investigate the application of Euler solvers to the study of some of the important problems of missile aerodynamics. These problems include drag, body vortex effects, wing-body interference, wing-tail interference, and control effectiveness. It was anticipated that such a program of research would provide needed insight for the development of better engineering prediction methods and would also provide benchmark data for constructing and evaluating the approximate methods. It was

The title on the DD Form 1473 is correct for this report per Ms. Sylvia Hall, ARO/IPL also anticipated that, if the Euler solvers could be made efficient enough, they themselves could be used as an engineering predictive method.

Many of the aspects of the research conducted under this project have been submitted for publication. Other aspects will be covered at length in papers currently under preparation. Some of the research associated with the earlier (and unsuccessful) efforts have been covered in some of the progress reports and will be briefly summarized in this report but will not be otherwise reported. A list of publications resulting from the sponsorship of this contract is presented in the Appendix. Thus, for purposes of this Final Technical Report it will suffice to provide a summary of the accomplishments.

2. INITIAL PHASE

During the initial stages of this research project the effort was concentrated on an investigation of several numerical algorithms, mesh generation procedures, and boundary conditions for the bow shock wave and missile surface. The purpose was to establish some requirements or properties that an Euler solver applicable to calculating supersonic flow fields about missiles with arbitrary number of fins and arbitrary roll angles should have. Several codes were investigated and only one came close to meeting most of the requirements set forth. This was the parabolized Navier-Stokes (PNS) code, Reference 5, initially developed at the NASA/Ames Research Center. It was decided to use the PNS code with the viscous options removed as the starting point for our code development. Several problems existed with the PNS code at that time. The most serious being the instability of the bow shock fitting procedure at high incidence. This problem also occured with several of the other codes that were investigated.

The PNS code was extensively modified to make it applicable to the research project. However, while verifying the code (called SEKAM, Supersonic Euler Kutta code with Arbitrary Meshes) with some standard test cases (mostly conical flows) and some complex missile and projectile shapes, it was found that the predicted flow field data showed some differences with experimental data and other numerical solutions obtained by the explicit MacCormack's method. Typically, the size and strength of the vortex on the lee side of the body was much too small. The main cause seemed to be the more dissipative nature of the implicit Beam and Warming algorithm used in the SEKAM code. The excessive dissipation suppressed the formation of the lee side separation bubble and rapidly dissipated the vortex once it had been formed. Ways of reducing the dissipation of the implicit algorithm were investigated and none were successful.

For the more complex missile shapes it was also found that the implicit code became unstable unless the finite difference mesh was sufficiently fine. This was due to both the linearization of the flow variables used in the code and the splitting error. For a time marching implicit code both of these errors vanish in the steady state. However, for a space marching code such as the PNS code, these errors do not vanish and become worse as the geometry becomes more complex. The only way to alleviate these errors was to reduce the mesh size, but, for the missile and projectile shapes of interest in this contract, the number of mesh points had to be increased to such a level that it was no longer cost effective to use the implicit algorithm. It was more cost effective to use a coarser mesh (mesh size determined by accuracy consideration) and solve with the explicit MacCormack scheme. Furthermore, it was possible to vectorize the explicit scheme. For this reason the use of the implicit Beam and Warming scheme was dropped.

3. INTERMEDIATE PHASE

The code was rewritten to use the explicit algorithm (SEKAM2). A further modification in the predictive code had to do with the computation of the metrics and Jacobians resulting from the curvilinear mesh used with the finite difference algorithm (SEKAM3). If the metrics and Jacobians were written in the special form as proposed by Hindman (Ref. 6) the accuracy of the numerical solution increased dramatically. For the example of a circular cone at zero incidence the numerical solution was within

0.1% of the exact results for a relatively coarse mesh of 20x20 points. Without this modification (e.g. as in SEKAM2), accuracies of no better than 2-3% could be expected.

Using the SEKAM3 code a flow field calculation required about 30 CPU minutes on the CRAY-XMP computer for a complete configuration. A complete configuration consisted of a tangent ogive cylinder with up to 6 fins at arbitrary angles of incidence, roll and yaw and required a mesh of 200x40 points. The slow run times were due to the mesh generator. A new mesh had to be generated at each marching step and this was quite time consuming. A good predictive method should have execution times of under 10 minutes per case. For this reason, some effort was expended to reduce the mesh generation time required at each marching step.

4. FINAL PHASE

Two methods were developed to reduce the mesh generation time to acceptable levels. The first method was to avoid having to generate a curvilinear mesh for most of the flow field. The second method was to make the mesh generation process itself as efficient as possible. The former method involved utilizing a uniform cartesian background mesh for most of the flow field and a body conforming mesh only locally at the body. A conservative interpolation procedure was also developed to interpolate the flow field variables between the local curvilinear mesh and the uniform cartesian background mesh. There are three advantages to this procedure: (1) the background mesh does not need to be generated, (2) advancing the numerical solution on a uniform cartesian mesh is much more efficient (by a factor of 10 or more) than on a curvilinear mesh, and (3) neither the metrics nor the node point locations are required for the uniform cartesian mesh. This work is fully discussed in References A2 and A4 and the resulting code is referred to as SEKAM4.

The second method replaces the conformal mapping or elliptic grid generation used in SEKAM and SEKAM2 with a hyperbolic grid generation method. While the conformal mapping is extremely fast, there is no control over the mesh point clustering at the missile surface with the result that the meshes are usually much too finely clustered near the fin leading and side edges and much too coarse in the flow field to properly resolve the vorticity shed by the missile forebody or fins. Elliptic mesh generation procedures (e.g. Ref. 7) do not have this mesh clustering problem, but they are so slow as to make their use for time dependent or space marching methods impractical. The hyperbolic grid generation procedure developed under this contract is described in Reference A1 and is based on the same hyperbolic grid equations used by Steger and Chaussee (Ref. 8) and by Barth et al (Ref. 9). However, from the experience gained with the PNS code and the original SEKAM code, the Beam and Warming algorithm used by the authors of References 8 and 9 is not deemed suitable for solving the hyperbolic grid equation. The numerical algorithm presently used in the hyperbolic grid generation was designed such that the leading truncation errors had desirable mesh properties by themselves. This makes it possible for the hyperbolic grid procedure to generate meshes for the missile configuration of interest in this research project. In particular, it is now possible to produce meshes inside square cavities or sharp fin-body root junctures as well as around sharp fin edges.

The hyperbolic grid generation procedure was recently incorporated into the last two versions of the aerodynamic predictive codes (SEKAM3 and SEKAM4). The fourth version (SEKAM4) of the code which uses the cartesian background mesh is several times faster than the full curvilinear mesh code (SEKAM3) and is the only one with run times of under 10 minutes per case for a complete missile configuration. It is somewhat more complex and difficult to use and for this reason both versions are being maintained. User's manuals are being prepared for both versions of the code (Ref. A5 and A6). The basic theory of both predictive methods and the results obtained with them are discussed in References A3 and A4.

Due to the unsuccessful initial efforts, not enough time remained at the end of the contract period to test the codes with all the missile configurations as we had originally proposed.

5. CONCLUDING REMARKS

Most of the research effort has been devoted to developing an aerodynamic predictive method applicable to complex missile configurations. The method is based on the numerical solution of the Euler equations with special boundary conditions to control the vorticity and vortex shedding rate so important in missile aerodynamics. The two computer codes produced are fast, reliable, and accurate. They are fast and simple enough to use as engineering design tools by themselves and not just as research codes for providing benchmark data for simpler engineering methods as originally envisioned.

6. PERSONNEL

During the course of research project, NEAR, Inc. underwent a major management change and this had an effect on the personnel working on the contract. Of the original two co-principal investigators, Drs. Jack N. Nielsen and Goetz H. Klopfer, the former left the company during the second year of the project and the latter became the sole principal investigator. Three other members of the engineering staff were associated with the research project, namely, Drs. Steve S. Stahara, David Nixon, and Gary D. Kuhn. However the major portion of the work was done by Drs. Klopfer and Kuhn. In addition the two programmers that contributed to the effort were Mrs. Mary M. Keirstead and Mrs. S. M. Nazario.

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APPENDIX

List of publications resulting from sponsorship
of the present contract

A1. Klopfer, G. H: Hyperbolic Grid Generation for Complex Aerodynamic Configurations, NEAR, Inc. Paper No. 199, July 1985. Submitted to the Journal of Computational Physics.

A2. Klopfer, G. H: Conservative Interpolation for Overlapping Meshes, NEAR, Inc. Paper No. 200, July 1985. To be submitted to the Journal of Applied Mechanics.

A3.* Klopfer, G. H: High Mach Number Aerodynamic Prediction Method for Missile Configurations - Part I, Euler Equations with Curvilinear Meshes, NEAR, Inc. Paper No. 201, July 1985. To be submitted to the AIAA Journal.

A4.* Klopfer, G. H.: High Mach Number Aerodynamic Prediction Method for Missile Configurations - Part II, Euler Equations with Cartesian Meshes, NEAR, Inc. Paper No. 202, July 1985. To be submitted to the AIAA Journal.

A5.* Klopfer G. H.: User's Manual for SEKAM3 Supersonic Euler Kutta Code with Arbitrary Meshes, Version 3 - Fully Curvilinear Mesh. NEAR, Inc. TR 348, August 1985.

APPENDIX (Cont.)

A6.* Klopfer G. H.: User's Manual for SEKAM4 - Supersonic Euler Kutta Code with Arbitrary Meshes, Version 4 - Cartesian Background Mesh with Local Curvilinear Mesh. NEAR, Inc. TR 349, September 1985.

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