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Computational Methods for Vortex Dominated Compressible Flows

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Summary of activities

The principal objectives of this grant were to:

- Understand the mechanisms by which Euler equation computations model leading edge vortex flows,
- Understand the vortical and shock wave structures that may exist for different wing shapes, angles of incidence, and Mach numbers, and
- Compare calculations with experiments in order to ascertain the limitations and advantages of Euler equation models.

Since the Euler equations were being studied, sharp edge geometries were selected in order to provide a Kutta condition, and have the separation point fixed by the geometry and not by the level of viscosity. It was also felt that much could be learned by adopting a conical Euler equation model. This greatly simplified the computing requirements while not eliminating any of the basic physics.

Our initial approach utilized the cell centered finite volume Jameson scheme. The final calculations utilized a cell vertex finite volume method on an unstructured grid. Both methods used Runge-Kutta four stage schemes for integrating the equations. Blended second and fourth order dissipation terms were added. The principal findings of the grant are contained in the numerous publications which resulted. These are briefly summarized in the following paragraphs. The reader is referred to the cited publications for complete details.

The initial conical Euler equation formulation and solution algorithm was done in the Master's degree studies of Perez [1] and Powell [2]. Based upon this work, a "second generation" conical flow program was written by Murman in the summer of 1984, and a careful comparison was made with the fully three dimensional Euler equation results of Rizzi. These were reported by Murman, Rizzi, and Powell [3] wherein it was noted that the two independently and quite different programs gave very good agreement. A number of interesting features of the flow were discussed, including the nature of the embedded cross flow shock underneath the vortex.

A matter of some interest and concern throughout the investigation involved understanding the reasons for large total pressure losses in the cores of the computed vortex. A model for these losses related to the structure of the feeding sheet was developed and delivered at the July 1985 AIAA Fluid and Plasma Dynamics Meeting and later published in the AIAA Journal [4].

This paper showed that the magnitude of the total pressure loss was insensitive to all computational parameters. An explanation based on the fact that the vortex sheet must have some thickness due to numerical effects was given. A careful comparison between the conical Euler equation prediction and experimentally measured pitot pressure data was reported at the July 1985 NASA Langley workshop on "Studies of Vortex Dominated Flows" [5]. The favorable comparison indicated that the Euler equation model was giving realistic results for the primary vortex. Naturally, the secondary vortex and its effects could not be modeled by an inviscid model.

Further comparisons were made with data for flat plate delta wings tested at NASA Langley in the paper by Murman, Powell, Miller, and Wood [6]. The comparisons included two Mach numbers, zero and 8° yaw, and preliminary results for vortex flap geometries. Again, reasonably good comparison was evident for most cases. A more detailed comparison with the vortex flap geometries was reported six months later by Powell, Murman, Milller, and Wood [7]. Both of these papers have been accepted for AIAA journals and are being edited. In general, very good agreement is found with the wide variety of flow field structures and topology. For the isolated wing cases, reasonable agreement is found for the surface pressure distributions. For the vortex flap geometries, the viscous effects at the hinge line lead to poorer agreement.

A summary of technical issues regarding the modeling of leading edge vortices from sharp edge delta wing geometries was given by Murman and Rizzi [8]. Further investigations into the nature of the total pressure losses were discussed at the January 1987 AIAA meeting by Murman, Powell, Goodsell, and Landahl [9]. In this paper, evidence was given that artificial viscosity played an important role in the vortex core.

The final publication supported by this grant was the PhD thesis of Kenneth Powell [10] completed in June 1987. An embedded mesh finite volume method was developed to permit greater grid resolution in the vortex region. The computational study of total pressure losses was redone and carefully documented. Again, an insensitivity was found to computational parameters and a sensistivity to aerodynamic parameters. An equivalent Reynolds number based upon the artificial viscosity was found to be on the order of 1000 in the vortex cores. A new similarity solution to a high Reynolds number vortex was derived and reported which explains most of the computational observations. Finally, a number of the previously reported calculations for flat plate delta wings, yaw conditions, and vortex flap geometries were carefully reported and discussed.

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