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The results of this research provide further evidence that the secondary vortex/saddle point region is critical to the formation of vortex asymmetry in conical Navier-Stokes equation set simulations. In addition, the proper technique for tracking the perturbations is explained. Sample perturbation contour plots are provided. The work continues under support from the University of Cincinnati, exploring perturbation growth rate and propagation.

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Understanding How Saddle Points Affect the Onset of Vortex Asymmetry

March 3, 1999

By

Dr. Paul D. Orkwis
University of Cincinnati

Executive Summary

The results of this research provide further evidence that the secondary vortex/saddle point region is critical to the formation of vortex asymmetry in conical Navier-Stokes equation set simulations. In addition, the proper technique for tracking the perturbations is explained. Sample perturbation contour plots are provided. The work continues under support from the University of Cincinnati, exploring perturbation growth rate and propagation.

Research Goal

The goal of this research was to determine the flow field region(s) that are the most important to the formation of vortex asymmetry. This was to be accomplished in the framework of conical Navier-Stokes equation set simulations, as such, it would not offer insight into the convective/absolute instability debate. The genesis of this work was previously support ARO research that indicated flow field saddles play an important role in the formation of vortex asymmetries. Grid resolution studies suggested that both the primary and secondary saddles are critical. It was the role of the current research to explore which region(s) were most critical.

Research Objectives

The original objectives of this research were to:

1.) observe how field perturbations grow and propagate to form an asymmetric solution from the non-converged symmetric solution,
2.) develop growth rate maps,
3.) learn whether the primary or secondary saddles are the vortex asymmetry generating regions.

The idea was to apply the conical Navier-Stokes solver used previously to compute a non-converged symmetric solution as a starting point for comparisons. Research specific software would be developed to form difference solutions which would then be visualized. Solutions would be obtained for perturbations placed at many locations in the flow so as to learn the preferred paths for perturbation propagation. In addition, single iteration perturbation solutions would be obtained at a relatively fine grid of solution locations so that perturbation growth rate maps could be generated. From this information the critical regions of the flow field could be ascertained.

Results Obtained

The Principal Investigator initiated the research in June 1998, first year graduate student Dinesh Godavarty assisted. Research funds were expended by December 1, 1998, although the work continues under the support of university resources.

Objective 1 was satisfied by computing simulations with perturbations placed at many locations in the field. The first series of which were solutions with perturbations at many surface locations. Typical results are shown in Figure 1 where a perturbation was placed at 135° from the vertical (clockwise). The results indicate that the perturbations travel through the boundary layer until they reach the secondary vortex region, where they begin to amplify considerably. They then travel along the vortex feeding-sheet.

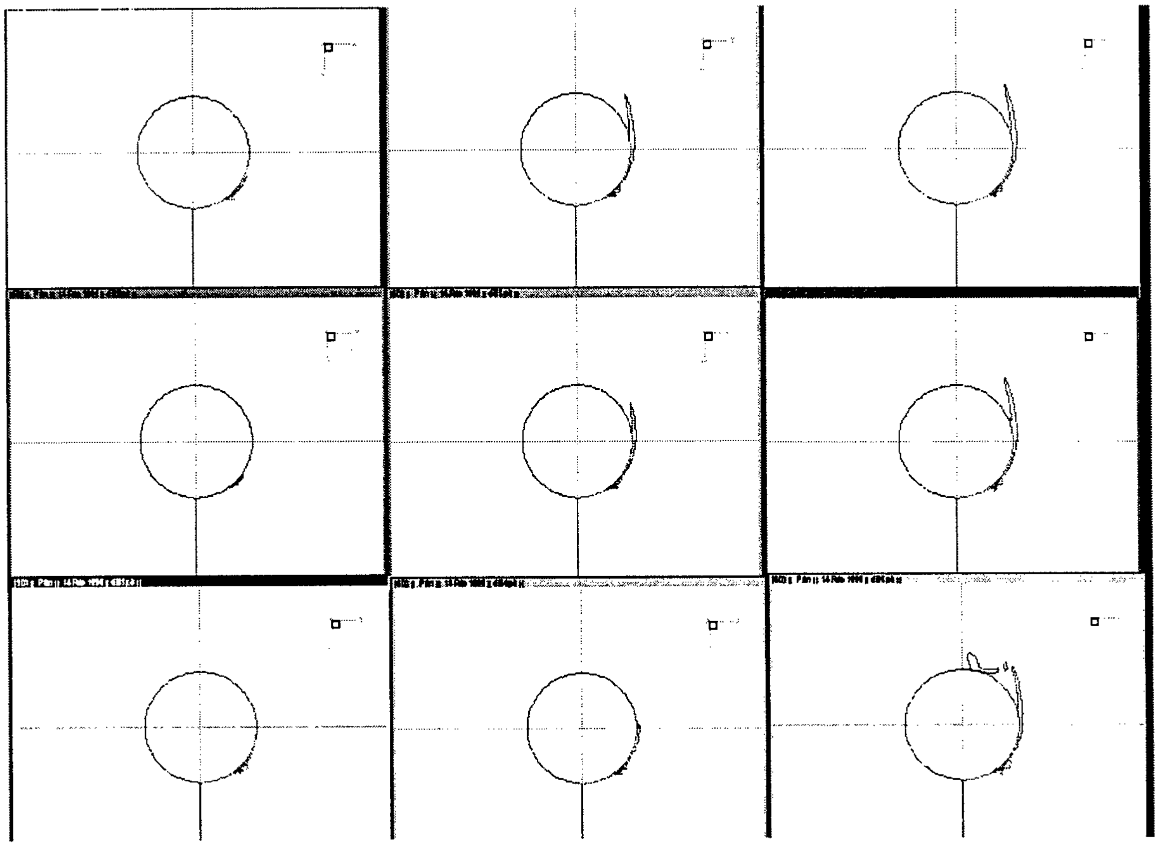

Figure 1 – Contours of Density Difference Comparing Perturbed and Base Solutions. Solution advances downward in the far left panels, upward in the center panels and downward in the right panels.

The plots in Figure 1 are not differences from the symmetric initial condition, rather they are differences between the perturbed solution and an unperturbed but developing solution. The difficulty with plotting differences between the "base" solution and the developing perturbation solution is that the entire solution continues to develop. This can be counteracted in part by using a very large perturbation, but this was felt to be undesirable because it might cloud the important physical features being studied. Comparisons with the developing unperturbed solution show better the perturbation history, at least until the solution becomes very asymmetric and hence different from the developing "base" solution. A third approach was also attempted to visualize the perturbation in which the differences between consecutive solutions were plotted. While this shows the growth of the perturbation it is once again combined with the developing solution changes and hence also undesirable.

Growth rates were computed at only a few points in the field, as such maps for the entire flow field have not yet been developed. However, the maps are being created in the continuing research effort for a series of perturbation sizes so as to assess whether the growth rate is independent of perturbation magnitude. This is important for control issues because it is related to control effectiveness and can be useful to control surface designers.

The results obtained to date offer further evidence that the secondary saddle region is more important than the primary, however, additional field perturbation solutions are needed to completely resolve the issue.

Continuing Research

Research support for activities through May 1999 has been secured from the University of Cincinnati. The following items will be explored:

1.) additional perturbation locations and time history plots,
2.) detailed growth rate maps at selected field points, developed in part from the results of task 1,
3.) more detailed perturbation histories, "zoomed-in" on the important flow features, relating the actual solution, the perturbation solution, and a measure of vortex asymmetry (probably the cross-flow force vector),
4.) several cases at symmetric vortex incidence ratios.

Recommendations for Future Work

The current work appears to be a rather cost effective way to study asymmetry related stability problems and should be attempted with the three-dimensional equation set. In this way the issue of convective and absolute instability might be explored.