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Linear Evolution of Compressible Görtler Vortices Subject to Free-Stream Vortical Disturbances

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Abstract : Görtler instabilities generate in boundary layers from an unbalance between pressure and centrifugal forces caused by concave surfaces. Their spatial streamwise evolution influences transition to turbulence. It is therefore important to understand even the early stages where perturbations, still small, grow linearly and could be controlled more easily. This work presents a rigorous theoretical framework for compressible flows using the linearized unsteady boundary region equations, where only the streamwise pressure gradient and streamwise diffusion terms are neglected from the full governing equations of fluid motion. Boundary and initial conditions are imposed through an asymptotic analysis in order to account for the interaction of the boundary layer with free-stream turbulence. The resulting parabolic system is discretize with a second-order finite difference scheme. Realistic flow parameters are chosen from wind tunnel studies performed at supersonic and subsonic conditions. The Mach number ranges from 0.5 to 8, with two different radii of curvature, 5 m and 10 m, frequencies up to 2000 Hz, and vortex spanwise wavelengths from 5 mm to 20 mm. The evolution of the perturbation flow is shown through velocity, temperature, pressure profiles relatively close to the leading edge, where non-linear effects can still be neglected, and growth rate. Results show that a global stabilizing effect exists with the increase of Mach number, frequency, spanwise wavenumber and radius of curvature. In particular, at high Mach numbers curvature effects are less pronounced and thermal streaks become stronger than velocity streaks. This increase of temperature perturbations saturates at approximately Mach 4 flows, and is limited in the early stage of growth, near the leading edge. In general, Görtler vortices evolve closer to the surface with respect to a flat plate scenario but their location shifts toward the edge of the boundary layer as the Mach number increases. In fact, a jet-like behavior appears for steady vortices having small spanwise wavelengths (less than 10 mm) at Mach 8, creating a region of unperturbed flow close to the wall. A similar response is also found at the highest frequency considered for a Mach 3 flow. Larger vortices are found to have a higher growth rate but are less influenced by the Mach number. An eigenvalue approach is also employed to study the amplification of the perturbations sufficiently downstream from the leading edge. These eigenvalue results are compared with the ones obtained through the initial value approach with inhomogeneous free-stream boundary conditions. All of the parameters here studied have a significant influence on the evolution of the instabilities for the Görtler problem which is indeed highly dependent on initial conditions.

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