Propulsion Aeroelastic Analysis Developed for Flutter and Forced Response

The NASA Glenn Research Center at Lewis Field develops new technologies to increase the fuel efficiency of aircraft engines, improve the safety of engine operation, reduce emissions, and reduce engine noise. With the development of new designs for fans, compressors, and turbines to achieve these goals, the basic aeroelastic requirements are that there should be no flutter (self-excited vibrations) or high resonant blade stresses (due to forced response) in the operating regime. Therefore, an accurate prediction and analysis capability is required to verify the aeroelastic soundness of the designs. Such a three-dimensional viscous propulsion aeroelastic analysis capability has been developed at Glenn with support from the Advanced Subsonic Technology (AST) program.

This newly developed aeroelastic analysis capability is based on TURBO, a three-dimensional unsteady aerodynamic Reynolds-averaged Navier-Stokes turbomachinery code developed previously under a grant from Glenn. TURBO can model the viscous flow effects that play an important role in certain aeroelastic problems—such as flutter with flow separation, flutter at high loading conditions near the stall line (stall flutter), flutter in the presence of shock and boundary-layer interaction, and forced response due to wakes and shock impingement. In aeroelastic analysis, the structural dynamics representation of the blades is based on normal modes. A finite-element analysis code is used to calculate these in-vacuum vibration modes and the associated natural frequencies.

In an aeroelastic analysis using the TURBO code, flutter and forced response are modeled as being uncoupled. To calculate if a blade row will flutter, one prescribes the motion of the blade to be a harmonic vibration in a specified in-vacuum normal mode. An aeroelastic analysis preprocessor is used to generate the displacement field required for the analysis. The work done by aerodynamic forces on the vibrating blade during a cycle of vibration is calculated. If this work is positive, the blade is dynamically unstable, since it will extract energy from the flow, leading to an increase in the blade's oscillation amplitude. The forced-response excitations on a blade row are calculated by modeling the flow through two adjacent blade rows using the TURBO code. The blades are assumed to be rigid. As an option, a single blade row can be modeled with the upstream blade row influence represented by a time-varying disturbance (gust) at the inlet boundary. The unsteady forces on a blade row from such analyses are used in a structural analysis along with the blade structural dynamics characteristics and aerodynamic damping associated with blade vibration to calculate the resulting dynamic stresses on the blade.

As part of the verification and validation of the aeroelastic analysis capability in TURBO, flutter and forced-response calculations were performed in collaboration with engine companies for various standard configurations and industry configurations. The aeroelastic analysis capability in the TURBO code will allow engine manufacturers to reduce design cycle times by allowing new blade designs to be verified for aeroelastic soundness before they are built and tested. With this prediction capability, it will be possible to build thinner, lighter, and faster rotating blades without encountering aeroelastic problems like stall flutter and high-cycle fatigue due to forced vibrations.

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