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A Computational Tool for Two-Dimensional, External-Compression, Supersonic Inlet Design and Analysis

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Abstract

A shape optimisation tool to design and analyse two-dimensional (2D), external-compression, supersonic inlets developed. The tool provides the user with an inlet geometry based on user-defined inputs. The tool also provides the user with the performance parameters of the generated inlet. The performance parameters include the total pressure recovery and the mass flow ratio of the inlet when it is operating in the critical mode. Furthermore, the user is provided with the Mach number of the airflow at the aerodynamic interface plane (AIP) to ensure that it does not exceed the combustion chamber blow-off limit.

The theory of inviscid compressible flow was the starting point in developing the tool. Inviscid compressible flow calculations were used to generate inlet geometries that were optimised for maximum total pressure recovery and mass flow ratio. The assumption of inviscid flow is not always applicable to real-world compressible flows. Therefore, the effects of viscosity on the supersonic inlet flow fields and performance parameters were investigated with a detailed computational fluid dynamics (CFD) model.

The CFD model was developed in both the 2D and three-dimensional (3D) space. The 2D CFD model provided reasonable approximations of the 2D, external-compression, supersonic inlet flow field and captured the essential flow features. However, the 3D CFD model produced results that were in better agreement with experimental data compared to the results that were produced by the 2D CFD model. The accuracy of the 3D CFD model has a high computational cost and requires too much time to design, mesh, and run a simulation. The computational cost is greatly reduced in the 2D CFD model. Therefore, the 2D CFD model was used to analyse the air flowing through the generated supersonic inlets.

The CFD analyses showed that viscous flow phenomena, such as boundary layer development, shock-wave/boundary-layer interactions and boundary layer separation, are frequently occurring phenomena in supersonic inlet flow fields. Furthermore, viscous flow phenomena cause a difference between the optimised supersonic inlet performance parameters computed by inviscid flow calculations and the performance parameters obtained from viscous CFD analyses.

A sensitivity study was performed to investigate how changing the user-defined inputs varies the impact of viscous flow phenomena on the total pressure recovery and mass flow ratios of the inlets generated by the tool. The data obtained from the sensitivity study were used to develop a method to apply viscous corrections to the supersonic inlet performance parameters. The viscous corrections provide the user with an improved approximation of the supersonic inlet performance parameters. They also provide the user with an improved understanding of the quality of the air that the inlet supplies to the combustion chamber.