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Computational Fluid Dynamic Analysis of a Supersonic Turbine

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ABSTRACT

A supersonic turbine stage is one in which the absolute velocity at the nozzle exit and the relative velocity at rotor inlet are supersonic. Supersonic axial turbines are used in space rocket turbo pumps to rotate the pump feeding fuel or oxygen to the combustion chamber. These turbines are usually impulse type turbines, where the pressure drop happens in the stator and the flow velocity at the stator outlet is very high. In the rotor, the torque comes from changes in the direction of the velocity vector without any pressure drop. The stators of supersonic turbines have subsonic inlet conditions and supersonic outlet conditions. A DeLaval nozzle is designed between two stator blades and it can be handled in three parts: a subsonic converging inlet section, a sonic throat and a symmetrical supersonic diverging outlet section. The efficiencies are typically relatively low, even less than 50% as shown in [1] and [2]. One reason for the lower efficiency is the occurrence of shock waves. Shock waves can cause flow separation in the blade passages when they interact with the blade surfaces either in the stator or in the rotor, or, more frequently, at their interface.

The purpose of this work is to study numerically the flow in a supersonic axial flow impulse turbine. Computations were made with Ansys 15 CFD package, with a 3-dimensional model of one stator-rotor stage. The software implements a “mixing plane model” at the interface between the stator domain, which is stationary, and the rotor domain, which is rotating at a prescribed angular velocity, allowing computing each region separately. The flow information between these domains will be coupled at the mixing plane interface [3]. In order to reduce the model size and computation time, the Transient Blade Row method was used, in its version with Fourier Transformation, which applies “phase shifted boundary conditions”. The Fourier Transformation method can be used to apply periodic conditions that are phase-shifted in time in order to account for unequal pitches between adjacent blade rows. This methodology allows the model simulating the periodic nature of the full blade set using one or two blade passages per row.

Results of the simulation show the appearance of oblique shock waves and their interaction, the turbine performance and the periodic loads on rotor and stator blades.

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