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Pollutant Emissions Chemistry in Axial Turbines

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The need to reduce pollutants emitted by aircraft engines requires advances in combustion, fuels, and aircraft configuration. The reduction in CO_2 emissions might only be achieved by increase in efficiency or the use of alternative energy sources such as H_2, liquefied natural gas (LNG), biofuels or electric propulsion. The reduction of nitrogen oxides (NO_x), sulphur oxides (SO_x) and CO is, on the other hand, mostly dependent on the combustion technology.

As an attempt to overcome these challenges, a hybrid engine configuration has been proposed[1]: cryogenic fuels (either H_2 or LNG) stored in tanks inside the blended-wing body would fuel the first combustion chamber, while conventional or biofuels would fuel the Interturbine burner - ITB (see Fig. 1). The configuration has shown promising results with respect to efficiency[2], and it can potentially attain the Flameless combustion regime more easily, which is advantageous especially because of its lower NO_x emissions[3].

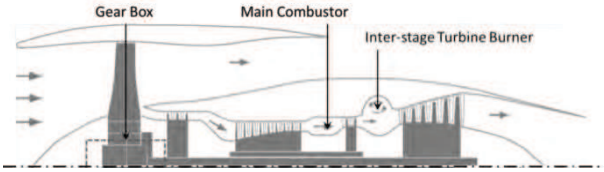

Figure 1 – Engine concept with sequential combustion chambers[1].

The high pressure turbine (HPT) is located between the two combustion chambers. Usually, the chemistry in turbine sections is considered to be "frozen", with the composition at the end of the combustion chamber being considered as the engine's emissions. The increasing trend in turbine inlet temperatures and pressures in order to achieve higher efficiencies makes the behaviour within the turbine relevant for the prediction of emissions[4]. Moreover, the progression of chemistry in the turbine is even more important for the dual-combustor configuration, since the composition at the inlet of the ITB depends on it.

Simulations aiming at investigating the chemistry in the HPT were performed. A CRN (Chemical Reactor Network) was developed based on the operational conditions of the hybrid engine[2] and the Aachen turbine stator geometry[5]. Simulations were performed using Cantera and the GRI 3.0 chemical reaction mechanism. The perfectly stirred reactors were arranged along the estimated flow path, as to form a plug flow reactor (Fig. 2). Residence times were determined based on the estimated flow velocities of a modern transonic turbine. Pressure and temperature were assumed to drop linearly within the turbine, in accordance with the preliminary design calculations[2]. The composition at the inlet was estimated using another CRN representing the first combustor burning LNG.

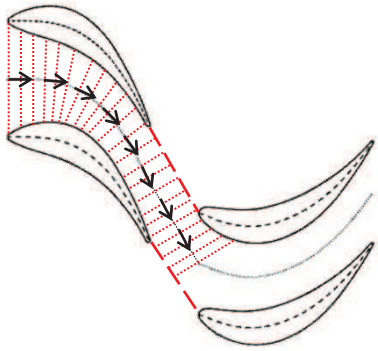

Figure 2 – Representation of the created CRN with the reactors defined along the flow path of the Aachen turbine[5].

The results of Fig. 3 show significant variation in both CO and NOx values. The oxidation of CO seems to continue in the stator, while NO_x has a non-monotonic behaviour. The concentration of NO seems to dictate the NO_x trend, as NO_2 values are lower and display the opposite trend (a peak around 0.05 m). Previous analyses did not show the effect on CO emissions, while NO_x showed a similar trend[4]. However, it is not yet clear what parameters affect the chemistry or which reaction pathways are active.

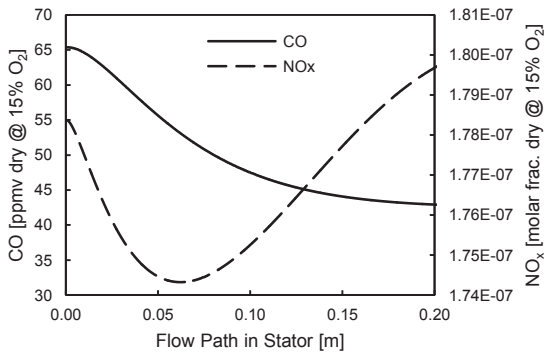

Figure 3 – CO and NO_x along the turbine stator in the CRN calculation.

In order to investigate the three-dimensional effects on the chemistry of pollutants, the next step in the research

is the simulation of a turbine stator in CFD. The chosen geometry was the General Electric's two-stage HPT presented within the framework of the Energy Efficient Engine program[6], due to its operating conditions and available geometry and experimental data. The 46-blade first stage stator geometry was employed.

The CFD simulations were performed in ANSYS CFX®, and the fully hexahedral meshes were created in TurboGrid. Mesh independence tests were conducted, and a mesh composed of 2.04 million elements was selected (Fig. 4). Total pressure and temperature were imposed at the inlet, while static pressure was imposed at the outlet.

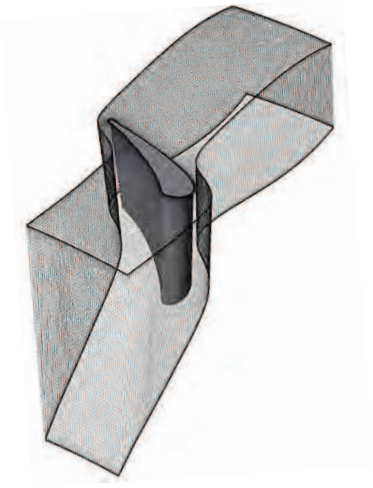

Figure 4 – Computational mesh of the stator.

Simulations were performed using RANS equations along with the *k-ω* SST turbulence model. Comparison to experimental data was performed, as the vane efficiency displayed in Fig. 5. The error was less than 1% (except for the data point at 95% span), showing good agreement.

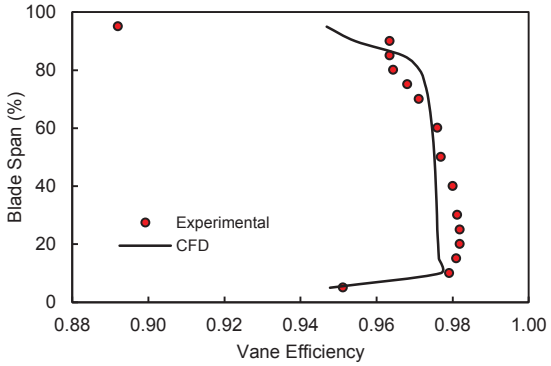

Figure 5 – Comparison between simulated and experimental values of vane efficiency as defined by Timko[6] measured between the stator and the rotor.

The comparison of the blade pressure distribution also has good agreement. Fig. 6 displays the distribution in the form of the isentropic Mach number for two different blade spans. Given the good agreement, the fluid model was considered validated. Operating conditions were then modified to match those of the hybrid engine, while aiming to maintain the Mach number distribution across the stator.

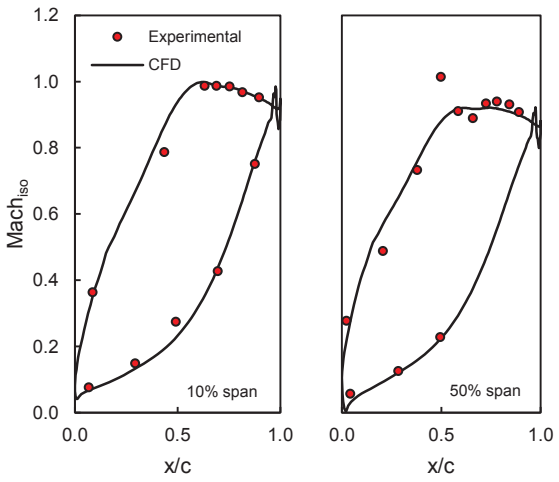

Figure 6 – Comparison between simulated and experimental values of isentropic Mach number for two blade spans.

Within the work in progress, CFD simulations including chemistry will be performed in order to access the effect of local conditions and flow structures on the reaction rates. Finite-rate chemistry with a reduced chemical reaction mechanism will be employed, as well as approaches considering turbulence-chemistry interaction (Eddy Dissipation Model and Eddy Dissipation Concept). This approach shall identify the importance of turbulence for the reaction rates for the conditions found in axial turbines. Additionally, higher operating pressures and temperatures shall be tested.

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