THE ROLE OF OPERATIONAL VARIABILITY ON THE NON-IDEAL FLOW IN SUPERSONIC TURBINES FOR SUPERCRITICAL ORGANIC RANKINE CYCLES

Alessandro Romei[1], Davide Vimercati[2], Alberto Guardone[2], Giacomo Perisco[1*]

[1] Department of Energy, Politecnico di Milano
Via Lambruschini, 4, 20156, Milano, Italy

[2] Department of Aerospace Science and Technology, Politecnico di Milano
Via La Masa 34, 20156, Milano, Italy

* Corresponding Author: giacomo.persico@polimi.it

ABSTRACT

The potential efficiency gain in supercritical organic Rankine cycle (ORC) must face an increase of complexity in the fluid-dynamic design of the first nozzle cascade, as severe non-ideal gas effects may possibly occur. Examples of these non-ideal effects are a non-monotonic variation of the Mach number along isentropic expansions, oblique shocks featuring an increase of the Mach number and a significant dependence of the flow field on the thermodynamic upstream conditions.

In this work, two uncertainty-propagation scenarios, targeting the field operational variabilities, are analysed for representative first-stage nozzle cascades, whose expansion processes occur in the so-called non-ideal gasdynamic regime ($0 < \Gamma < 1$, where Γ is the fundamental derivative of gasdynamic). Realistic variabilities, derived from field measurements in running ORC power plants, are propagated through a turbulent compressible flow solver via non-intrusive Polynomial Chaos representations to compare the cascade performance when Γ is either $\lessapprox 1$ or $\ll 1$.

The analysis of cascade-loss distributions indicates that the considerable dependence of the flow field on the upstream total conditions induces different cascade operations from a stochastic perspective. Given uncertainties of $\approx 1\%$ in cycle design conditions, the turbine cascade operating with $\Gamma \ll 1$ exhibits cascade-loss variations as high as ± 0.75%pts, compared to approximately ± 0.15%pts when $\Gamma \lessapprox 1$. Finally, the decomposition of variance contributions reveals that the most influencing parameter on the turbine performance migrates from the expansion ratio to the upstream total temperature when approaching supercritical conditions characterised by $\Gamma \ll 1$. This finding suggests that, when devising supercritical ORCs, a realistic estimate of the heat-load variability during plant operation should be taken into account in the early stage of the turbomachinery design.