Proceedings of the 11th World Congress on Mechanical, Chemical, and Material Engineering (MCM'25)
Paris, France - August, 2025
Paper No. HTFF 160
DOI: 10.11159/htff25.160

Isomorphic Modelling-Based Simulation Method for Overall Performance of Water Enhanced Turbofan and Its Applications

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Extended Abstract

Under the background of increasingly severe climate and environmental deterioration, the aviation industry, as an important source of global greenhouse gas and pollutant emissions, is facing huge pressure for low-carbon and green transformation. In recent years, people have paid more and more attention to the impact of pollutants represented by NOx in engine exhaust on climate change. However, at present, the performance improvement space of traditional aero engines is decreasing, which are difficult to meet the needs of the new generation of civil aviation industry for sustainable development, and it is urgent to achieve a breakthrough in the thermal cycle of aero engines. In this context, MTU's Water Enhanced Turbofan (WET) has achieved a key breakthrough. WET improves engine efficiency by absorbing engine heat and converting it into work through the Brayton-Rankine coupled cycle of gas-water mixture. It is expected to reduce fuel consumption by more than 20% and NOx emissions by more than 90%. Thanks to its unique advantages in reducing fuel consumption and nitrogen oxide emissions, WET concept has quickly attracted wide attention from scholars at home and abroad, and has become a hot research direction for the green development of future aero engines.

As a new aero engine concept, the research foundation of WET is still very weak. To analyse the thermodynamic properties of WET, simulation calculation is needed. The traditional aero-engine is a thermal system based on the process of heat and work conversion. The traditional solution method requires presetting the parameters of each component, iterating the mutual boundary of each component according to the flow direction of the working medium, in order, describing the local topological characteristics of the system with flow balance equation and pressure balance equation, and describing the energy balance constraint of the coaxial rotating machinery with power balance equation. The obtained system governing equations are a stack of linear and nonlinear equations. This not only cannot reflect the overall topology and transport characteristics of the system, but also introduces a large number of unknown intermediate variables into the system model, so it belongs to the local analysis method. For the system solution with complex flow, this method will inevitably cause multiple iterations of implicit nonlinear constraints, and its convergence process is subject to the choice of the initial value of the solution independent variable, which has low computational efficiency and poor convergence. WET is a thermal system coupled with heat transfer process and heat work conversion process. The traditional log-mean temperature difference model of heat transfer process has the most difficult transcendental form in nonlinear equations. At the same time, many phase transition processes make the influence of components on physical properties become significant. This makes the limitations of traditional simulation methods further amplified and difficult to meet the needs.

To solve this problem, this paper proposes an isomorphic modelling-based simulation method for overall performance. Based on electric analogy, the isomorphic model of each component/link is established without introducing additional simplification hypothesis, and the constraints are classified according to the physical and mathematical properties of the equation, and the corresponding "divide and conquer" solution strategy is adopted. This method can minimize the number of iterations of nonlinear implicit constraints and improve the convergence and computational efficiency.

Finally, based on the method proposed in this paper, the overall performance of WET is simulated. The performance boundary of wet engine and the influence mechanism of engine parameters on the overall performance are obtained, and the optimum performance curve is given. The results show that this method can be used for quantitative analysis and optimization of complex engines.