DLR-Project 3DCeraTurb: New materials and manufacturing technologies for the turbine

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New materials and manufacturing technologies are crucial for developing ultra-efficient and low-emission flight engines. Therefore, DLR's 3DCeraTurb project [1] aims to consolidate and advance DLR's capabilities in new materials, component design, manufacturing technologies and overall assessment competencies. The project focuses on developing and manufacturing a turbine guide vane using two of the most relevant new classes of manufacturing technologies and materials: additively manufactured (AM) metals and SiC/SiC fiber reinforced ceramic matrix composites (CMC) [2] [3].

The project has two main goals: First, to establish a process chain for CMC component design, manufacturing, EBC-coating, wind tunnel validation, and damage assessment. Second, to advance the AM design and assessment capabilities and develop a manufacturing strategy for additively manufactured guide vanes with a protective TBC coating system and AM-conformal cooling structure design [4].

The manufacturing process development will transfer individual competencies of several DLR institutes predominantly focused on small-scale sample level and conventional metallic construction to a realistic and engine relevant component level. The target component is an inlet guide vane for the high-pressure turbine. A new turbine profile was designed based on the engine boundary conditions of the existing UHBR-GTF engine pre-design from the DLR project Perfect [5]. The complex vane geometry presents a major challenge for the manufacturing process, particularly for CMC materials. Therefore, upscaling of CMC manufacturing competence from sample to component level is a main objective of the project and a significant contribution towards improving the operational readiness of new ceramic materials with significantly higher temperature resistance in the hot gas path.

Manufacturing process information and data will be integrated into a multi-scale simulation to account for manufacturing-related influences and improve overall lifetime prediction modeling of CMC. Traceability and consistency of the generated data within the project will be ensured through a provenance data system. This forms the first building block of an automated process chain that includes various aspects and details of aerodynamics, structural mechanics, and manufacturability for both classes of materials.

Two different cooling configurations with the same turbine profile geometry, i.e. a state of the art (SoA) geometry [6] as a basic configuration for comparison purposes and a new double-wall hybrid design [7] will be developed and compared to validate any improvement in cooling efficiency of the additively manufactured guide vanes. The double-wall hybrid cooling design will be analyzed with and without thermal barrier coating. To analyze and assess the cooling efficiency and the aerodynamic performance, the vanes will be tested in the Wind Tunnel for Straight Cascades Göttingen (EGG) at TRL-Level 4. These tests are fundamentally important for achieving an increased cooling efficiency of additively manufactured turbines with highly insulating protective coatings proven numerically and experimentally.

Various tests will be carried out to determine the lifetime of ceramic fiber composites and compare them to computed damage models. The degradation mechanisms of the multi-layer coating systems will be investigated in a temperature-gradient test rig (TEGRA), a thermal shock test rig (FCT), and in a high-temperature furnace under corrosive atmospheres. A numerical multi-scale method will be developed as part of the project and applied to simulate these tests and calculate the failure probability using PyPsi.

References

[1] A. Petersen, M. Welter, N. Kind, P.-B. Ebel, M. Hilfer and M. Tegeler, "Aircraft engine: New materials and manufacturing technologies for the turbine," 2021. [Online]. Available: https://www.dlr.de/at/desktopdefault.aspx/tabid-18164#gallery/36923.

[2] B. Mainzer, R. Jemmali, P. Watermeyer, K. Kelm, M. Frieß and D. Koch, "Development of Damage-Tolerant Ceramic Matrix Composites (SiC/SiC) using Si-BN/SiC/pyC Fiber Coatings and LSI Processing," vol. 08, pp. 113-120, 2017.

[3] F. Süß, N. Jain, F. Vogel and L. Klopsch, "The next big challenge in the development of SiC/SiC. 3DCeraTurb: From 2d plates to 3d components," 12 2021. [Online]. Available: https://www.dlr.de/wf/PortalData/23/Resources/dokumente/wf-kolloquium/The_next_big_challenge_in_the_development_of_SiC-SiC.pdf.

[4] U. Schulz, K. Fritscher and A. Ebach-Stahl, "Cyclic behavior of EB-PVD thermal barrier coating systems with modified bond coats," vol. 203, pp. 449-455, 2008.

[5] A. Petersen and C. Grunwitz, "3DCeraTurb:Towards CMC-turbine vane design under engine conditions," 12 2021. [Online]. Available: https://www.dlr.de/wf/en/PortalData/23/Resources/dokumente/wf-kolloquium/3DCeraTurbTowards_CMC-turbine_vane_design_under_engine_conditions.pdf.

[6] R. S. Bunker, "The Effects of Manufacturing Tolerances on Gas Turbine Cooling," *J. Turbomach.,* vol. 131, 2009.

[7] R. S. Bunker, "Evolution of Turbine Cooling," in *ASME Turbo Expo: Power for Land, Sea and Air*, 2017.