Overcoming Big Challenges for Small Turbojet Engines

In developing an impeller for a microjet turbine engine for unmanned drone aircraft, engineers used FEA to reduce stresses by 20 percent, prevent fatigue in high-speed rotating parts and study resonances in the assembly.

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The concept of the unmanned air vehicle (UAV) is thought to have been envisioned first by Leonardo Da Vinci in 1488. The idea was not put into action until World War I, however, when radio control and gyro-stabilization technology were available to make such an aircraft feasible. UAVs became more advanced during the Second World War, when they were used to train anti-aircraft gunners and fly attack missions. Most of these early machines were remote-controlled, full-sized aircraft, but more recent technology advancements have led to the development of miniaturized UAVs, providing opportunities for cheaper, highly functional military aircraft that can be used without risk to aircrews.

One of the most challenging aspects in the development of these small aircraft is designing compact, lightweight propulsion systems for delivering the required performance. In one recent project, Tusas Engine Industries, Inc. (TEI), based in Turkey, used finite element analysis (FEA) in developing the high-speed, precision radial compressor impeller for a microjet turbine engine to be used in UAV applications such as target drones for testing the accuracy of surface-to-air and air-to-air weapon systems.

Recognized as a leader in developing and producing a range of high-quality aircraft engine parts for the worldwide aerospace industry, TEI was established in 1985 for aircraft engine assembly primarily in the Turkish region and later expanded into design, testing and manufacturing of components for gas turbine engines and other precision systems. The firm began advanced research and development activities in 1996; since then, it has participated in major international projects such as the Joint Strike Fighter (JSF) and the A400M Airbus military transport aircraft with the advanced TP400 turboprop engine.

One of the most critical parts of the Tusas TEI-TJ-1X microjet engine, the impeller compresses air entering the engine inlet to a high pressure and delivers it to the combustion chamber. Rotational speeds in the order of 100,000 rpm are necessary to achieve high compression, resulting in design challenges related to vibration, resonance, transonic flow, shock waves in diffusers and high stress levels.

Studies performed for the TEI-TJ-1X using FEA included structural analysis to determine stresses and deformation of the impeller, modal analysis of the impeller and rotor, and rotordynamics analysis of the entire assembly.
to study the response of the components to rotational effects. TEI used ANSYS Mechanical software to minimize stress and deformation in their impeller designs. Various combinations of mechanical, fluid and thermal loads were considered. By using this approach, stresses in the critical regions of the impeller were reduced by 20 percent.

TEI engineers also used ANSYS Mechanical technology to examine the centrifugal and aerodynamic loads that can affect vibration of the blade and potential deformation of its geometry. Such deformation is a major concern in maintaining proper tip clearance — the spacing between the outer edge of the impeller blade and the inlet housing — under the range of operating conditions. If not carefully accounted for, excessive deformation could create the risk of contact between the blades and their housing.

Following the initial structural analyses that minimized stress and deformation, Tusas engineers performed modal analyses to determine dynamic characteristics of the impeller. Analyses indicated that none of the impeller frequencies coincide with any of the resonance frequencies for the engine in the operational range of impeller speeds of 100,000 to 120,000 rpm. Since rotational speed is very high, rotating parts (such as impeller and turbine) can undergo millions of cycles in a relatively very short time. Vibration characteristics of the impeller were investigated in detail to prevent high cycle fatigue (HCF) as well as contact between the impeller blade tips and the stationary inlet as a result of excessive vibration.

TEI performed full rotordynamics modal analysis on the complete assembly, including the impeller, shaft and turbine, to determine the resonant frequencies of each individual component. The most challenging aspect of the full modal analyses was defining realistic boundary conditions for the rotor’s bearings and bearing housings, whose stiffnesses substantially affect modal response. In order to calculate the bearing housing stiffness values correctly and precisely, the engineering team created a whole engine model. ANSYS contact elements were used to blend the different mesh patterns of the impeller, shaft and turbine for dynamic analysis of the assembly.

As a result of the analyses, three critical frequencies were determined. The first and second frequencies affect the impeller and turbine respectively, while the last frequency has impact on the shaft. The impeller and turbine critical frequencies are especially important since they may exist in operational range and/or during startup or shutdown cycles of the engine. This led the TEI team to make design modifications, including incorporation of integrated blades. Subsequent tests validated that critical frequencies for the impeller and turbine were within approximately 10 percent of the FEA simulated values, which was acceptable. The shaft-related critical speed occurred 25 percent above the maximum operation speed. Critical shaft speeds could not be validated due to the requirement that rotational speeds were higher than operational speeds. The Tusas engineers noted that, while the test apparatus was operated at its maximum speed, there were no indications of vibration-induced problems related to the shaft.

Simulation in the early stages of the development cycle provided valuable insight for quickly identifying potential problems and evaluating alternative solutions. This prevented large numbers of costly and time-consuming late-stage design changes, and it enabled TEI engineers to verify the design with the minimum number of physical tests. Simulation was a critical tool in TEI’s successful development of the TEI-TJ-1X microjet engine, which has successfully undergone initial performance tests and is being used as a basis for the design of an advanced turboprop engine TEI-TP-1X, now under development.