A Novel Approach to 3D Thrust Vectoring CFD via Mesh Morphing

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Abstract : Thrust vectoring, especially in military aviation, is a concept that sees much use to improve maneuverability in already agile aircraft. As this concept is fairly new and cost intensive to design and test, computational methods are useful in easing the preliminary design process. Computational Fluid Dynamics (CFD) can be utilized in many forms to simulate nozzle flow, and there exist various CFD studies in both 2D mechanical and 3D injection based thrust vectoring, and yet, 3D mechanical thrust vectoring analyses, at this point in time, are lacking variety. Additionally, the freely available test data is constrained to limited pitch angles and geometries. In this study, based on a test case provided by NASA, both steady and unsteady 3D CFD simulations are conducted to examine the aerodynamic performance of a mechanical thrust vectoring nozzle model and to validate the utilized numerical model. Steady analyses are performed to verify the flow characteristics of the nozzle at pitch angles of 0, 10 and 20 degrees, and the results are compared with experimental data. It is observed that the pressure data obtained on the inner surface of the nozzle at each specified pitch angle and under different flow conditions with pressure ratios of 1.5, 2 and 4, as well as at azimuthal angle of 0, 45, 90, 135, and 180 degrees exhibited a high level of agreement with the corresponding experimental results. To validate the CFD model, the insights from the steady analyses are utilized, followed by unsteady analyses covering a wide range of pitch angles from 0 to 20 degrees. Throughout the simulations, a mesh morphing method using a carefully calculated mathematical shape deformation model that simulates the vectored nozzle shape exactly at each point of its travel is employed to dynamically alter the divergent part of the nozzle over time within this pitch angle range. The mesh morphing based vectored nozzle shapes were compared with the drawings provided by NASA, ensuring a complete match was achieved. This computational approach allowed for the creation of a comprehensive database of results without the need to generate separate solution domains. The database contains results at every 0.01° increment of nozzle pitch angle. The unsteady analyses, generated using the morphing method, are found to be in excellent agreement with experimental data, further confirming the accuracy of the CFD model.

Keywords : thrust vectoring, computational fluid dynamics, 3d mesh morphing, mathematical shape deformation model
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