Validation of Actuator Disk, Actuator Line and Sliding Mesh Methods within the LAVA solver

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In this study the implementation of actuator-disk, actuator-line and sliding-mesh methodologies in the Launch Ascent and Vehicle Aerodynamics (LAVA) solver is described and validated against several test-cases. The different models are validated against available numerical as well as experimental data. Both steady and unsteady Reynolds-Averaged Navier-Stokes (RANS) simulations using the Spallart Allmaras (SA) turbulence model are performed on four different configurations representative of different aeroscience applications. The first validation case is a theoretical rotor in hover, compared with the 1D analytical solution derived from momentum theory. The second validation is the Rotor-Airframe Interaction Model of Georgia Institute of Technology (GIT), representing the application of actuator disks to top-mounted rotorcraft vehicles or unmanned aerial vehicles (UAVs). The third case is a representative configuration for tip-mounted rotorcraft vehicles such as NASA's X57 airplane. The final configuration is an internal propulsion case similar to a turbofan, NASA's R4 Advanced Ducted Propellor (ADT). Simulations will be performed with both steady and unsteady RANS comparing all three propulsion modeling methods; actuator-disck, actuator-line, and sliding mesh; with each other and experimental data. Several proposed strategies will be discussed in the final paper in order to address the aforementioned drawbacks of each simulation methodology.

I. Introduction

Several propulsion modeling capabilities have recently been implemented within the Launch Ascent and Vehicle Aerodynamics (LAVA) computational solver Framework[1]. These propulsion models include an actuator-disk model, an actuator-line model, and the implementation of relative motion capabilities using a slide mesh method. This study serves as a validation report for the propulsion models in the LAVA framework, and demonstrates the capabilities using test cases representative of a majority of aircraft propulsion applications. Three different application types have been identified. The first application being a tip-mounted rotor in which the rotor is mounted on the outside of a nacelle or fuselage. Such an application can be seen in NASA's X57 Maxwell electric aircraft [2], which has a total of 14 tip-mounted rotors and aims to make flying cleaner, quieter and more sustainable. The second application is a top-mounted configuration, typical in helicopters or unmanned aerial vehicles (UAV). A bridge between tip- and top-mounted applications can often be found in so called electric vertical take-off and landing vehicles (eVTOL). Such vehicles often transition from a top-mounted rotor during take-off and landing to a tip-mounted rotor in forward flight. EVTOL's have been gaining more traction in recent years and are likely to play a major role in the future. An example of such a vehicle currently developed by Joby Aviation. The last configuration is relevant for internal turbo-machinery commonly found in turbofans used in conventional commercial aircraft.

II. Description of Work

In summary, this study will utilize time-accurate as well as steady-state RANS simulations in combination with different propulsive models on four different configurations. The first step is to compare the implementation of a source based actuator disk model with an analytical solution derived from momentum theory for a constantly loaded rotor

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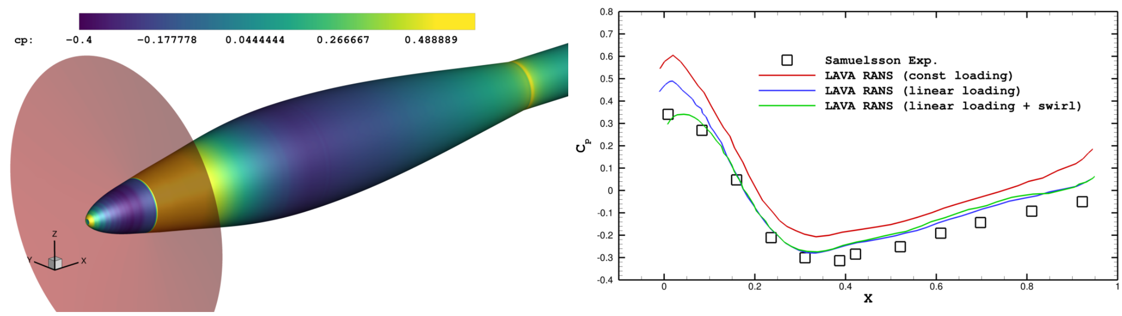
in free-stream. Second, simulations for a rotor mounted at the tip of a nacelle shown in Figure 1 are performed with steady-state RANS and differently loaded actuator disk models. These are compared to experiments from Samuelsson [3]. The third case is representative for top-mounted rotors in forward flight and the interaction with a fuselage. This is done on a common test case introduced by Georgia Institute of Technology (GIT) and commonly known as the GIT rotorcraft test-case. Lastly, we will perform a simulation using both steady as well as unsteady RANS comparing actuator disk, actuator line and sliding mesh with each other. This last test-case will be performed for NASA's R4 SDT test-case [4–6]. For a depiction of the mach number utilizing an actuator disk method at 4000N thrust can be seen in Figure 2. The final paper will make detailed comparisons and show advantages and shortcoming's of each of these methods.



(a) C_p contour on the surface.

(b) C_p contour along the upper symmetry plane.

Fig. 1 Pressure coefficient over the nacelle without wings when the propeller is powered on for differently loaded actuator disks. Comparisons made with experiments in [3].

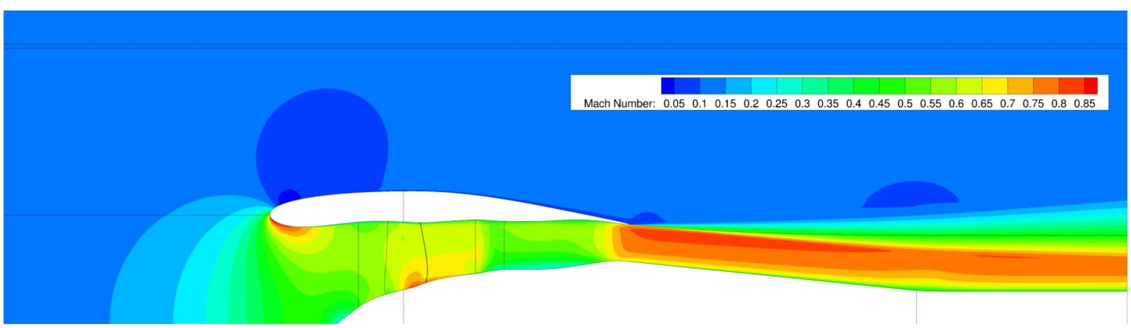


Fig. 2 Contour plot of mach number for R4 STD. Thrust of 4000N representative of cruise condition applied to system using linearly loaded actuator disk.

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