

# 2016 Sessions

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Hariharan N., Narducci, R., Egolf, T.A., Reed, E., “[Helicopter Rotor Aerodynamic Modeling of S-76 Rotor with Tip-Shape Variations](#),” AIAA-2016-0031, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Good hover performance is a very important rotorcraft design criteria, but despite advancements in the ability to predict and preserve the tip vortex, a limiting aspect of accurate hover performance prediction, the capability to consistently and reliably predict the performance for a new rotor-blade has not yet been demonstrated. This challenge provides the motivation for the AIAA Applied Aerodynamics Technical Committee Rotorcraft Simulation Working Group’s efforts. This paper compares and summarizes results from the AIAA 2nd Hover Invited Session at SciTech 2015, to assess in a standardized fashion the different approaches by government, industry and academic participants to evaluate and further rotor-in-hover performance predictions. A baseline S-76 rotor planform was used in the 1st Hover Invited Session at SciTech 2014. The 2nd Hover Session at SciTech 2015 built upon this work by refining the baseline results and adding additional tip geometries to the study as the next step.

Jain, R., “[A Comparison of CFD Hover Predictions for the Sikorsky S-76 Rotor](#),” AIAA-2016-0032, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Hover performance calculations are performed for the S-76 model-scale rotor using different Computational Fluid Dynamics solvers to assess the variability in predictions. Time-accurate Navier-Stokes calculations are performed using the U.S. Department of Defense Computational Research and Engineering Acquisition Tools and Environments—Air Vehicles (CREATE™-AV) Helios with OVERFLOW and FUN3D as near-body solvers, and using the standalone OVERFLOW solver. Different modeling options are exercised including structured and unstructured meshes for the blades, adaptive mesh refinement (AMR) in the blade mesh, AMR in the wake mesh, and inviscid and detached eddy simulation (DES) modeling in the wake. Rotor performance, blade airloads, and wake geometry from the different calculations are compared to assess the variability.

Hwang, J., Choi, J., Kwon, O., “[Assessment of S-76 Rotor Hover Performance in Ground Effect Using an Unstructured Mixed Mesh Method](#),” AIAA-2016-0033, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

In the present study, the aerodynamic performance of an S-76 rotor in hover was numerically investigated by using an unstructured mixed mesh flow solver. The study was made for the rotor for both OGE (out-of-ground-effect) and IGE (in-ground-effect) conditions, and the results are compared against each other. In the present mixed mesh methodology, body-fitted prismatic/tetrahedral mesh was adopted in the near-body flow domain to easily treat complex geometries and to capture the viscous layer on the solid surface accurately, while in the off-body region away from the blades Cartesian mesh was used. To better resolve the flow characteristics and to prevent numerical dissipation, high order accurate weighted essentially non-oscillatory (WENO) scheme was employed in the off-body flow region. An overset mesh technique was adopted to treat the rotating blades and to exchange the flow variables between the two different mesh regions. The calculations were made for three different blade configurations, having swept-tapered, rectangular, and swept-tapered-anhedral tip shapes, and the results are compared with experimental rotor performance data in terms of thrust, torque and figure of merit. The predictions were obtained for a collective pitch angle sweep from 5 to 10 degrees at a tip Mach number of 0.60 for both cases with and without ground effect. The detailed flow characteristics, such as the vorticity contours and the tip-vortex trajectory, were also investigated.

Gardarein, P., Le Pape, A., “[Numerical Simulation of Hover S-76 Helicopter Rotor Including Far-Field Analysis](#),” AIAA-2016-0034, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

The paper presents the numerical prediction by the ONERA software elsA of the aerodynamic performance of the S-76 rotor in hover. The rotor loads are compared to experimental data for different collective pitch angles showing an overall good agreement. The investigations focus on the influence of the tip Mach number as well as the tip planform (straight or swept). The influence of taking into account the laminar-turbulent transition by the transport equation model of Menter-Langtry is presented. All numerical results are post-processed with the far-field approach recently extended to rotating frame. The physical decomposition of the torque obtained with this method provides additional information that enriches the numerical simulation analysis.

Duque, E., Toyoda, M., Burklund, M., Hariharan, N., Narducci, R., Stone, C., “[Direct Comparison of Hover Prediction Workshop Results](#),” AIAA-2016-0035, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Comparing many different CFD cases of the same problem is complicated by the use of differing meshes, solver codes, etc. The Helicopter Hover Prediction Workshop 2016 provides an opportunity to apply a standardized, automated post-processing workflow that eases dataset comparison, report generation and knowledge extraction for a diverse set of CFD results. This paper presents direct comparisons of the CFD simulation results submitted by the participants of the workshop. A standardized post-processing scheme based upon FieldView was developed that tracks a helicopter rotor tip vortex core to determine its first passage and lift distance for quantitative comparisons. For qualitative comparisons, iso-surfaces and coordinate cut planes of Q-criterion were created and saved as FieldView XDB files. These surface extracts allow interactive viewing and direct comparisons of the predicted wakes using multi window graphical displays. By comparing the rotor blade boundary surfaces against one consistent boundary surface, geometry differences were identified that may affect the comparisons. Proper comparisons require that all the datasets have similar normalizations. All appropriate normalizations were made to be consistent with PLOT3D normalization conventions. Several participants use wake filaments. These participants used FieldView particle file formats (.fvp ) that enabled the creation of images and XDB's that directly compare the filaments between the various filament based solvers and the tip vortex paths predicted by the grid based solvers. The paper herein presents select participant submissions that utilized Reynolds-averaged Navier-Stokes solvers with overset structured, overset unstructured, and hybrid Navier-Stokes/wake filaments.

Abras, J., Hariharan, N., “[Performance Impact of Tip Shape Variations on the S-76 Rotor Using kCFD](#),” AIAA-2016-0298, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

The planned integration of KCFD into the HELIOS solver requires the evaluation of KCFD for rotorcraft applications. One important rotorcraft case is hover prediction. The S-76 rotor is used as a baseline case to assess predictions made by the KCFD solver on different blade tip shapes. These predictions are compared to the available test data. This paper includes both grid and parametric studies of the options available, and then uses the results of these studies to look at the impact of different tip shapes on the results.

Barakos, G., Jimenez-Garcia, A., “[Hover Predictions of the S-76 Rotor using HMB2 – Model to Full Scale](#),” AIAA-2016-0299, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Hover performance on a 1/4.71 model-scale and full-scale Sikorsky S-76 main rotor is presented using the multi-block CFD solver of Glasgow University. Three different tip shapes were compared for a range of

collective pitch and tip Mach numbers. It was found that the anhedral tip provided 1.25% and 2.8% higher Figure of Merit compared with rectangular and swept-taper tips, respectively. Rigid and elastic full-scale S-76 rotor blades were investigated using a loosely coupled CFD/CSD method. Results showed that aeroelastic effects were more significant for high thrust cases. An acoustic study was performed in the tip-path plane of both rotors, where thickness and loading noise predictions were compared with the theory. A reduction of 5% of the total noise level was predicted for the anhedral tip of the model-scale blade. The overall good agreement with the theory and experimental data demonstrated the capability of the present CFD method to predict rotor flows accurately.

Eschol, R., Zhoa, C., Kim, J., Sankar, L., “[A Comparative Study of Two Hover Prediction Methodologies](#),” AIAA-2016-0300, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

The performance of S-76 model scale rotor in hover is assessed using two hover prediction methods and compared against experimental data collected in the Sikorsky Model Hover Test Facility. A comparison of computed thrust, power, and figure of merit values for various blade tip shapes have been generated using a hybrid Navier-Stokes/free-wake method and a time-accurate wake capturing approach. The near-wake tip vortex trajectories extracted using the two methods have been compared to isolate the effect of the induced inflow on the integrated performance parameters. The simulations are in reasonable agreement with published data for the thrust, power, and the figure of merit.

Min, B., Wake, B., “[Parametric Validation Study for a Hovering Rotor Using UT-GENCAS](#),” AIAA-2016-0301, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Analysis of rotors in hover has always been a significant challenge. The presence of strong vortices underneath the rotor requires a large amount of grid points to properly capture the vorticity and many time steps are required to reach a time-independent state. In order to bring the simulation to a more practical state for industry, a modified hybrid Navier-Stokes/Free-wake method has been introduced, which successfully reduced grid count and simulation time by one order of magnitude compared to full Navier-Stokes simulations. In this hybrid method, Navier-Stokes and free-wake solvers are loosely coupled for fast convergence in hover. The S-76 model-scale blades with three tip designs were studied to assess current approaches. The proposed approaches showed reasonable-to-good correlation with measured Figure of Merit, thrust and torque data. The impacts of tip design and tip-speed variations were captured well. Furthermore, solution sensitivity to grid density, sub-iteration convergence, and turbulence model were investigated. The physical mechanisms of tip-design impact on hover performance were also studied.

Jacobson, K., Grubb, A., Smith, M., “[Performance and Physics of an S-76 Rotor in Hover with Non-Contiguous Hybrid Methodologies](#),” AIAA-2016-0302, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

Modifications to allow non-contiguous, moving grids have been made to a hybrid computational fluid dynamics - free-wake (CFD-FW) solver for aeroelastic rotors. In the CFD-FW approach, a CFD code resolves the unsteady Reynolds-Averaged Navier-Stokes equations in the near-field, and a vortex free-wake analysis models the wake beyond the near-field CFD grids. Blade loading from the CFD solver is utilized to calculate circulation and advance the free-wake solver. The outer boundaries of the CFD domain have boundary conditions that are modified based on the induced velocities from the free-wake code. Previous studies have demonstrated that the application of the free-wake code in the far-field allows the computational domain to be smaller than in a traditional CFD analysis which saves computational cost and memory while maintaining the accuracy of the solution. Before the current modifications, the hybrid solver was limited to CFD domains that included off-body grids with outer boundaries that were stationary in an inertial frame. By allowing grid systems with moving outer boundaries, the inertial grids can be removed, further reducing

the computational cost and memory required by the hybrid solver. The resulting meshes consist of only near-body grids that can be non-contiguous, i.e., not requiring overlap of the meshes. In this work, hover performance predictions of a scaled S-76 rotor are performed using the hybrid CFD non-contiguous grid approach and compared to those of the hybrid solver with the inertial background grids and full CFD simulations. The non-contiguous grid approach predicts comparable thrust coefficients, torque coefficients, and figures of merit, within 2.0 counts of the experimental data, at 7.6% of the computational cost of full CFD simulations. A preliminary study of sensitivity to different model inputs is performed.

Sheng, C., Zhao, Q., Hill, M., “[Investigation of XV-15 Rotor Hover Performance and Flow Field Using U<sup>2</sup>NCLE and Helios Codes](#),” AIAA-2016-0303, AIAA SciTech 54<sup>th</sup> Aerospace Sciences Meeting, 4-8 January 2016, San Diego, CA.

The full-scale tiltrotor XV-15 hover performance and flow field are numerically investigated using two unsteady Reynolds-averaged Navier-Stokes flow solvers: U<sup>2</sup>NCLE and Helios. The rotor Figure of Merit (FM) is predicted over a range of collective pitch angles from 0° through 17° at designed blade tip Mach number of 0.69, and computed skin frictions are compared with the measured data at two collective angles of 3° and 10°. Both Spalart-Allmaras’ full turbulence model (SA) and transition model (SA-TM) are employed to assess their numerical effects on hover predictions and capturing the rotor flow physics. Studies of grid resolutions and numerical schemes are also carried out for capturing the hovering rotor flow field, which indicates that good correlations between computed and measured hover FM can be obtained on moderately refined computational grid for most collective angles. However, refined surface and volume grids are necessary in order to capture the correct transitional flow phenomenon and obtain an accurate prediction of FM at high thrust levels.