Flight Simulator

Aeroelastic Prediction Workshop assesses computational methods for predicting unsteady flow fields.

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The early stages of aerodynamic design typically are based on the assumption that the mechanical structures are rigid, a concept that greatly simplifies the design process. As the process progresses, the designer must take into account the elasticity of the mechanical structures, because this often has a major impact on aerodynamic performance and structural integrity. Aeroelasticity refers to the interaction between the aerodynamic flow field and the mechanical structure. It is one of the most challenging aspects of designing aerospace structures because it's difficult to model the tightly coupled multiple physics involved in the phenomenon. Traditionally, companies have developed in-house methods that use custom aeroelasticity codes. However, with the relentless demand for higher-fidelity information to support improved aerodynamic efficiency, coupled with the high cost of maintaining these codes, the industry is actively exploring the development of new techniques.

To address this challenge and assess state-of-the-art methods and tools for the prediction and assessment of aeroelastic phenomena, the American Institute of Aeronautics and Astronauts hosts the Aeroelastic Prediction Workshop as a continuing education event. It provides an impartial forum to evaluate the effectiveness of current simulation tool codes and modeling techniques as well as to determine whether or not they are able to accurately simulate challenging nonlinear aeroelastic problems involving vortices, shock waves and separated flow that result from aeroelasticity. In preparation for the 2012 workshop, ANSYS used ANSYS Fluent and ANSYS CFX computational fluid dynamics (CFD) software to solve the problems, then presented the results at the meeting. A select set of

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results is illustrated in this article. The full data set is available online (see endnote).

The Aeroelastic Prediction Workshop challenges the simulation community to apply best practices to predict unsteady aerodynamics characteristics for rigid or weakly coupled aeroelastic systems. The test configurations were selected to increase in complexity, from fully turbulent with attached flow and weak shocks to transient separation conditions with strong shocks and significant interactions between flow features. For each configuration, participants were asked to provide a convergence study, steady-state analysis, and time-accurate response to forced oscillations using best practice guidelines to quantify numerical and model errors. The simulation results were compared with wind tunnel test data. Aeroelasticity problems have a high computational intensity, so the ANSYS team used high-performance computing (HPC) platforms with up to 2,048 cores on a Cray XE6™ to solve the workshop challenges.

RECTANGULAR SUPERCRITICAL WING

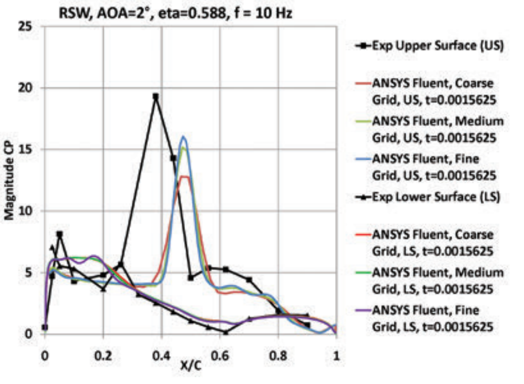
The first test configuration, called the rectangular supercritical wing (RSW), is a structurally rigid rectangular planform wing that oscillates at a designated pitch amplitude and frequency. The wing is mounted to a small splitter plate that is offset 6 inches from the wind tunnel wall. The RSW was originally tested in the NASA Langley Transonic Dynamics Tunnel in 1983. The study was performed at Mach 0.825 with a 4 million Reynolds number. Steady-state data was obtained with the model held at a fixed angle of attack. Separate dynamic data was acquired by oscillating the model in a pitching motion about the 46 percent chord line. Forced pitch oscillation frequencies of 10 Hz and 20 Hz were used in the two dynamic test cases.

The RSW was meshed with ANSYS ICEM CFD using hexahedral elements and a scalable grid that provides consistent mesh quality after grid refinement. This application appeared to be quite simple at first glance. However, the simulation conducted with both Fluent and CFX revealed modeling complications because the splitter plate and wing model were enveloped in the boundary layer. Despite that fact, both the static and dynamic simulation results showed general agreement with experimental data at higher span locations where the influence of the wind tunnel boundary layer and splitter blade is low.

BENCHMARK SUPERCRITICAL WING

The benchmark supercritical wing (BSCW) is another structurally rigid rectangular planform wing that oscillates at a designated pitch amplitude and frequency. The BSCW has a NASA SC(2)-0414 airfoil. All data in this study was obtained at Mach 0.85 with a dynamic pressure of 200 psi, fixing the Reynolds number at 4.49 million based on the wing chord. Dynamic data was obtained for the BSCW by oscillating the model in a pitching motion about the 30 percent chord. Steady-state information was calculated as the mean value of oscillatory time histories. This configuration was chosen because the experimental data shows highly nonlinear unsteady behavior, particularly shock-separated transient flow.

Pressure coefficient results determined by the CFX solver show a significant influence on the turbulence model for shock prediction on the upper surface for the static solution. The dynamic simulation was solved with a converged steady-state solution as the



▲ Comparison of ANSYS Fluent CFD results to wind tunnel experiment for RSW dynamic test case at 10 Hz

▶ Rectangular supercritical wing in wind tunnel

PHOTO COURTESY NASA.

initial conditions and displacing the mesh to match the harmonic wing motion. Simulation showed this test configuration to have a very complex flow field driven by the shock-induced separated flow. The dynamic cases were harder to predict, and some variations were seen between test results and simulation.

HIGH REYNOLDS NUMBER AEROSTRUCTURAL DYNAMICS MODEL

The high Reynolds number aerostructural dynamics (HIRENASD) test configuration is a 34-degree aft-swept, tapered clean wing with a BAC 3-11 supercritical airfoil profile. The semi-span test article is mounted to the ceiling using a noncontacting fuselage fairing connected to a turntable, balance and excitation system. The HIRENASD wing is geometrically more complex and has a small amount of structural flexibility that is used to oscillate the wing in its structural modes to acquire unsteady aerodynamic data. The HIRENASD was excited at the second bending mode frequency at approximately 80 Hz forces applied using piezoelectric stacks in the mounting hardware.

The structural flexibility in this test configuration increased the complexity of the simulation challenge. ANSYS Mechanical was used to simulate the structure and calculate mode shapes. Static aeroelastic equilibrium results predicted by the CFX simulation closely matched experimental values. The dynamic cases were solved by using the converged steady-state solution as the initial conditions and displacing the mesh to match the harmonic wing motion predicted by structural finite element analysis (FEA). Agreement was again good at the mid-span cross sections in the dynamic test cases.

ANSYS software performed consistently in all three test cases. The results with CFX and Fluent converged rapidly to a single solution, both as a function of grid density and time interval. Results were validated by running a grid and time

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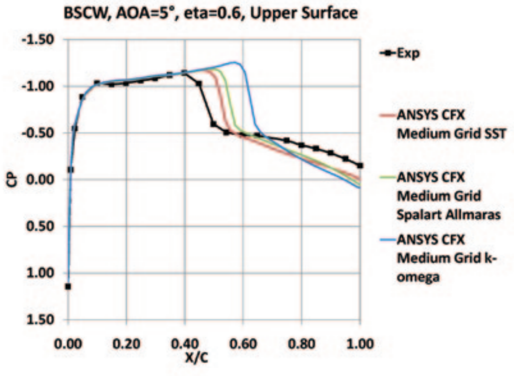
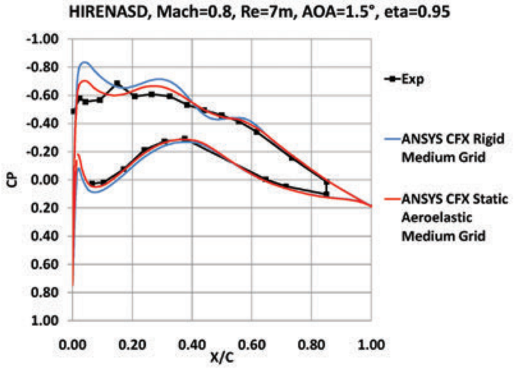
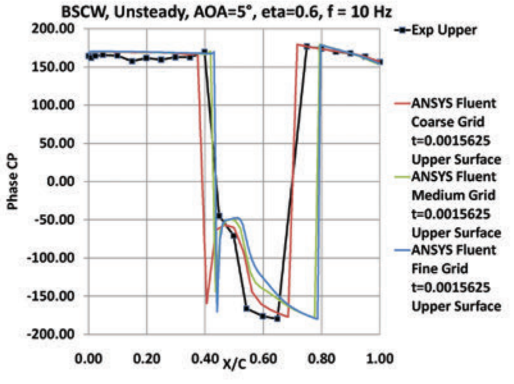


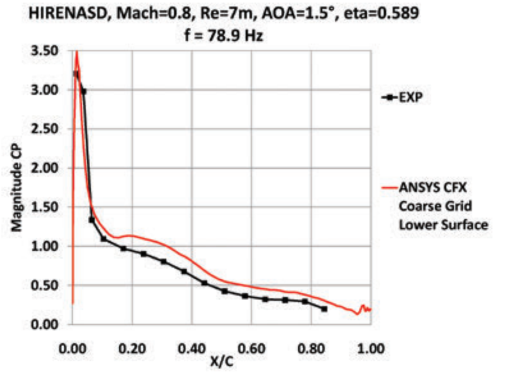
▲ ANSYS CFX turbulence model error for BSCW at steady-state conditions



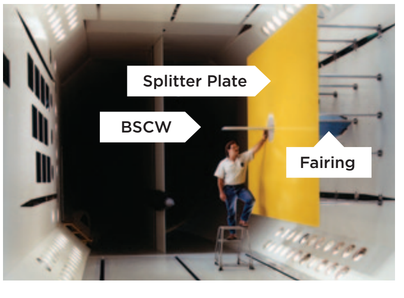
▲ Comparison of static aeroelastic equilibrium simulation predictions to experimental measurements for HIRENASD



▲ Fluent calculations for BSCW show good fit with experimental measurements.



▲ Simulation predictions of unsteady-state coefficient of pressure for HIRENASD correlate well to wind tunnel experiments.



▶ BSCW setup for wind tunnel testing
PHOTO COURTESY NASA.

▶ HIRENASD is 3-D aeroelastic wing with generic fuselage model. PHOTO COURTESY RWTH AACHEN.

step sensitivity study. Despite the complexity of the flow fields in these test configurations, simulation results in most cases showed good agreement with wind tunnel tests. As expected with problems of this difficulty, some deviations were identified in the simulation results, and these are being investigated.

ANSYS continues work on improving capabilities to solve these and other aeroelastic simulations. Publications summarizing the data from the 2012 Aeroelastic Prediction Workshop are being prepared for conferences in 2013. ANSYS is already planning to participate in the next Aeroelastic Prediction Workshop and will use ANSYS Workbench to seamlessly couple the CFD and FEA simulations to more accurately simulate aeroelastic behavior.

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Thanks to Cray for the high-performance computing resources used by ANSYS for this project.

Reference

Aeroelastic Prediction Workshop, https://c3.nasa.gov/dashlink/projects/47/