Composite Rotor Blade Analysis using Altair HyperWorks

Overview

As part of a senior design project – the design and analysis of a coaxial rotor craft – Christopher Van Damme, at the time of the project senior undergraduate student within the department of Engineering Mechanics at the University of Wisconsin-Madison, had to analyze a composite made helicopter rotor blade. In his analysis he had to employ Computer-Aided Engineering tools to cover the required studies regarding static, modal, frequency response, and dynamic analysis of the rotor. The CAE tools of choice were Altair's HyperWorks suite, mainly HyperMesh, the pre-processor of the suite, and Altair's FE-solver and optimization tool OptiStruct. Thanks to HyperMesh, a quick, high fidelity meshing of the complex rotor blade cross sections over the entire length of the rotor blade could be performed. OptiStruct was applied to solve a static load case of the highest load the rotor blade would be exposed to in flight. The use of these tools allowed for a streamlined analysis of the composite made rotor blade. Additionally, Van Damme conducted a modal analysis of the rotor blade to obtain the rotor blade's natural frequencies which he had to make sure not to coincide with the harmonic forcing frequencies experienced during forward flight.

College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

Rotors are the most critical parts of helicopters providing thrust and lift and enabling maneuvers

University Profile

University of Wisconsin-Madison's many core strengths across engineering disciplines reflect not only its history of innovation, but also a tremendous opportunity. The faculty strongly supports collaboration structures across disciplinary boundaries including departments such as healthcare, energy, advanced manufacturing, and materials innovation. The faculty, staff, and students are making extraordinary strides to ensure that UW-Madison engineers remain key drivers of economic and social progress. In academia, industry, and public service alike, Wisconsin engineers are better equipped than ever to apply what they know to society's greatest challenges.

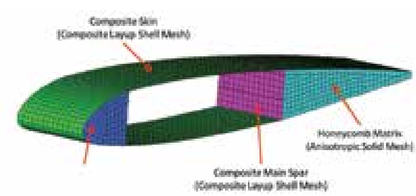
The Department of Engineering Physics at the UW-Madison ranks among the top engineering physics departments in national surveys. The department is collaborating with Civil Engineering and Mechanical Engineering departments to develop new mechanics research and education initiatives across the college campus. For more information please visit: **www.engr.wisc.edu**.

"It was easy to work with HyperWorks, since it has a user friendly GUI and there are a lot of tutorials available online, showing you how to set up the model and handle the analysis step by step. HyperMesh and OptiStruct allowed me to handle a detailed and streamlined analysis of the composite made rotor blade and to handle the given task in an efficient manner."

Christopher Van Damme,
Master student at the Department of Engineering Physics of the College of Engineering, University of Wisconsin-Madison

Challenge

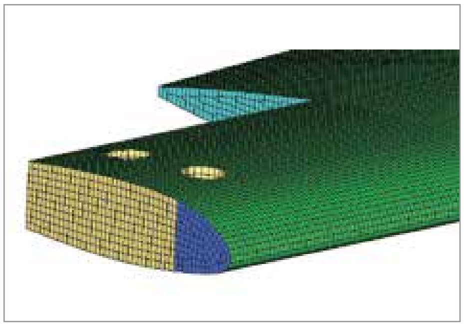
Rotors are the most critical parts of helicopters because they provide thrust and lift and enable maneuvers. As rotor blades in modern helicopters are made of composite material, they offer a very good strength to weight ratio and show excellent characteristics in damage tolerance and fatigue life. In addition, designers use the material's anisotropy to structurally tailor their components to the occurring load cases and the required stiffness. As part of a senior design project for a coaxial rotor craft, Christopher Van Damme had to analyze a composite helicopter rotor blade. Since composite material is difficult to compute using analytical methods or reduced order models he had to apply suitable Computer-Aided Engineering (CAE) tools with which he could cover the required studies. The studies he performed included static, modal, frequency response, plus dynamic analysis of the rotor for the design and analysis process.



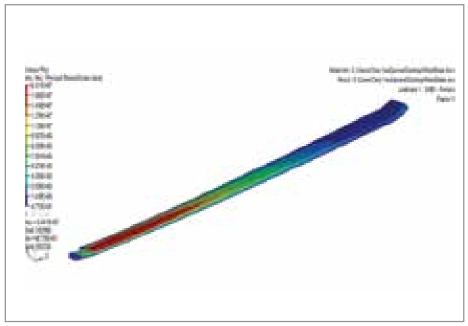
Composite material offers a very good strength to weight ratio and shows excellent characteristics in damage tolerance and fatigue life. Picture: rotor blade cross section.

Solution

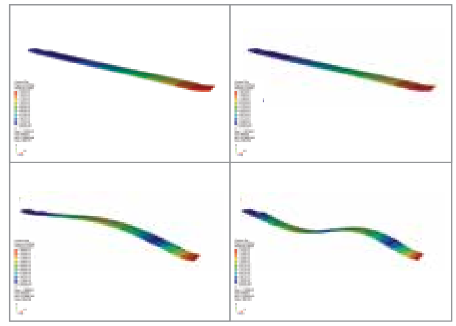
For the analysis of the composite made rotor blades of the helicopter Van Damme used Altair's HyperWorks suite. The rotor blade was originally designed within a 3D CAD package and imported into HyperMesh for preprocessing tasks including geometry editing and mesh generation. Thanks to the functions included in HyperMesh this was a quick and streamlined process. In order to obtain an accurate representation of the response of the rotor blade a full 3D finite element modeling was performed. Due to the critical dependence of the aircraft's performance on the rotor hub and the rotor blades, these parts were of particular interest in the analysis.



Root spar view of the HyperMesh model with anisotropic solid mesh



Stress analysis of the rotor blade



Eigenmode analysis: the natural frequencies of the rotor blade must not coincide with the rotational frequencies

Model setup in HyperWorks

The 3D CAD model was imported into HyperMesh via a .step file as separate solid parts. To prepare the model for a composite structure analysis the geometry was converted to surfaces to allow for shell meshing. Once the outer skin and main spar were converted to surfaces, the geometry could be properly meshed as shell elements with a composite layup property. The aerospace foam in the center of the blade was not meshed. Despite being a composite layup, the leading edge was modeled as 3D solid mesh elements because it was not possible to accurately predict the stress field at the leading edge with 2D shell elements. The root of the rotor blade, where the highest stress occurs, was meshed as 3D solids representing the material properties of a continued ply layup through the thickness of the airfoil. The aerodynamic loads were applied at discrete set of points along the length of the rotor for lift and drag. There are various types of restraining methods to connect the rotor blade to the rotor hub. This design used an articulated or rigid connection for which the root of the blade is constrained by two titanium lugs, acting as constraints within the model. Rigid elements were used on the inner surface within the root spar where the lugs are located. In addition, the loadings took into account the inertia forces due to the angular rotation of the rotor blade.

Rotor-Blade Analysis

The rotor craft has two commonly analyzed flight conditions; hover and trim. Steady state static loading was performed to receive the maximum aerodynamic loads that occur due to the forward velocity of the aircraft and the rotation of the rotor blades.

In order to properly design for the trimmed case the natural frequencies of the rotor blade must not coincide with the rotational frequencies while in forward flight. Due to the velocity of the aircraft in forward flight the asymmetry of the loading conditions result in a sinusoidal loading of the rotors. If this frequency coincides with a structural natural frequency of the system, the failure of the rotor blade could be the result. The first step to a proper design of the rotor blade is to ensure that natural frequencies of the structure do no line up with the rotational frequencies. This is accomplished by a normal modes analysis of the system representing an eigenvalue problem of the undamaged equations of motion of the system. The next step in the study of the rotor blades will be a frequency response (FRF) and dynamic loading analysis.

Benefits

The use of Altair HyperWorks, specifically HyperMesh and OptiStruct, allowed for a streamlined geometry creation and analysis of the composite rotor blade. HyperMesh enabled a quick, high fidelity meshing of the complex rotor blade cross sections over the entire length of the rotor blade and OptiStruct was used to solve a static load case of the highest load that the rotor blade would experience in flight.

In detail, HyperWorks enabled the student to:

- Create an accurate high-fidelity model of the composite rotor blade
- Handle all involved analysis techniques
- Solve the static load case of the highest load of the rotor blade in flight

Altair Engineering, Inc., World Headquarters: 1820 E. Big Beaver Rd., Troy, MI 48083-2031 USA
Phone: +1.248.614.2400 • Fax: +1.248.614.2411 • www.altair.com • info@altair.com