

Short Course on Rotorcraft and Horizontal Axis Wind Turbine Simulation
to be presented¹ at
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Phoenix, AZ
May 20, 2013

Rotorcraft and horizontal axis wind turbines (HAWT) have far more in common than first meet the eye, but they are also as different as night and day despite their obvious commonality. In this six to seven hour course, we will explore some of the most important problems associated with modeling rotorcraft and HAWTs, discussing how their similarities allow the attendee to accurately predict performance while recognizing, through their differences, how and why rotorcraft and HAWTs require their own specialized analyses. Students new to the rotorcraft industry and seasoned professionals who want a refresher course on rotorcraft basics comprise the target audience. But this year, we invite also those who want a first look at HAWTs.

This will be a 6-7 hour short course, divided roughly equally between rotorcraft and wind turbine modeling. Participants will receive course notes, a CD with some executables, and a copy of the book *Introduction to Helicopter and Tiltrotor Flight Simulation*.

This course reprises the 2010 AHS Forum short course “A Short Course on Rotorcraft Modeling,” based on the presenter’s AIAA textbook *Introduction to Helicopter and Tiltrotor Flight Simulation*. In the spirit of a good mystery, we will present this course as a “Howdunnit”, developing the fundamentals as a way of solving several intriguing problems in rotorcraft modeling. We will then apply the same techniques to model HAWTs.

We will solve the problems by providing clues on how to model kinematics, motion in inertial space, basic aerodynamics, downwash, interference, hub models, blade modes and control systems. The solution techniques and overall simulation flowchart will enable you to overcome the most common problems that are associated with modeling.

We will start with the obvious common element – the rotor – and show how to express mathematically your intuition about the forces that affect a rotor. We will also show how intuition deceives and why rigor is important – that is to say, practically all the similarity between helicopters and wind turbines ends there! For instance, the useful property of a helicopter rotor is its thrust and propulsive force, both of which are paid for by a hefty power requirement. On the other hand, the HAWT rotor produces power by extracting energy from the wind; the penalties are the size and weight of the rotors. One of the intriguing questions we pose is this: “Can helicopter blades be used for wind turbines?” The answer may surprise you.

Whether acting as a helicopter or wind turbine rotor, the rotor produces thrust no matter if it is adding or extracting energy from the freestream. Downwash models are vital to correct

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performance prediction and loads analysis, and their radial and azimuthal variation and dynamic behavior make them challenging. A simple experiment with a table fan and a pack of matches will make you question your sanity. But have no fear, we will elaborate upon various methods to model the downwash with techniques ranging from the tried and mostly true Glauert hypothesis through vortex methods to CFD solutions.

How is induced velocity like a cowboy trying to pick himself up by his own bootstraps? How does a wing cause a rotor vibration? How does a tower cause a wind turbine blade to ring? How does the wind cause a HAWT to nod in agreement one moment and disagreement the next? In short, how do we model the aerodynamic coupling between rotors and their support structures? We will use potential flow and basic momentum theory as starting points.

And speaking of rotors and their support, the manner in which the rotors attach to the shaft varies greatly, and that attachment affects the handling and ride quality of a helicopter and the signal quality of the power that a wind turbine generates. We will model hub attachments that run the gamut from the rigid cantilevers that we find with propellers and wind turbines, to the fully articulated, teetering, underslung and gimbaled rotors one finds in rotorcraft.

Flexibility of the blades is also very important. Who hasn't seen the internet video of the helicopter that shakes itself apart? Can you explain why it happens without waving your hands? We will look at the modeshapes and frequencies of flexible blades, and discuss the role that the lightly damped in-plane and torsional modes play in ringing, fatigue and unintended catastrophic resonance conditions that, putting it politely, lead to unscheduled disassemblies. Designing a blade so that its frequencies do not coalesce with the fixed system frequencies is easier said than done. Its natural frequency is dependent on its rotational speed, and the calculation of the modeshapes and frequencies is not possible with the usual structural analysis tools because rotor blades operate in a centrifugal field. We'll see how Holzer and Myklestad solved those problems.

Finally, meaningful performance estimates and stability and control derivative calculations can only be made from a set or "trim" point. But how can a pilot with only four controls trim a six degree of freedom aircraft? PFM is not the answer. Conversely, does a wind turbine require any trim at all, or is it just a set and forget machine? What of the dynamic modes of a rotor? The lightly damped modes in this world betray the false economy of running a dynamic problem until the transients die. We provide three popular techniques to achieve a combined static and periodic trim.

These are just some of the challenges of simulating these stimulating machines. The course material includes the textbook and a CD with several programs that illuminate the lessons.

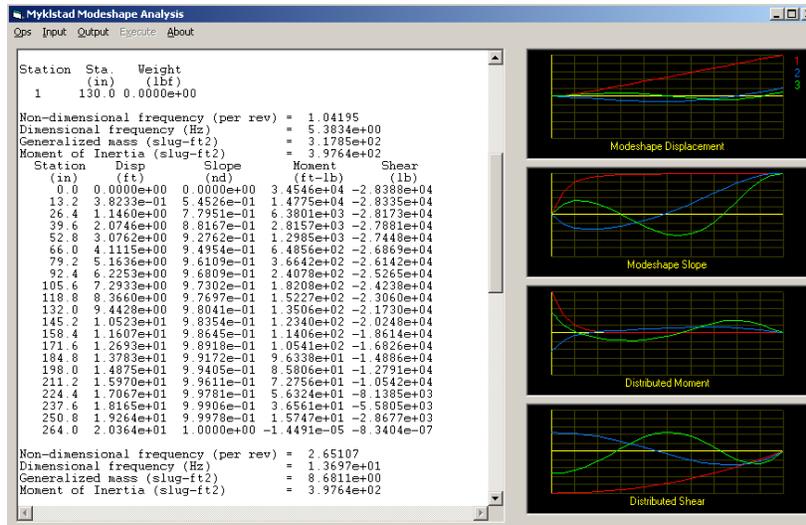


Figure 1 – Output from the Simplified Rotor Blade Modeshape Calculator. This program calculates the out-of-plane modeshapes for a blade with distributed EI and mass and discrete tuning weights. The mast connection is cantilevered or hinged.

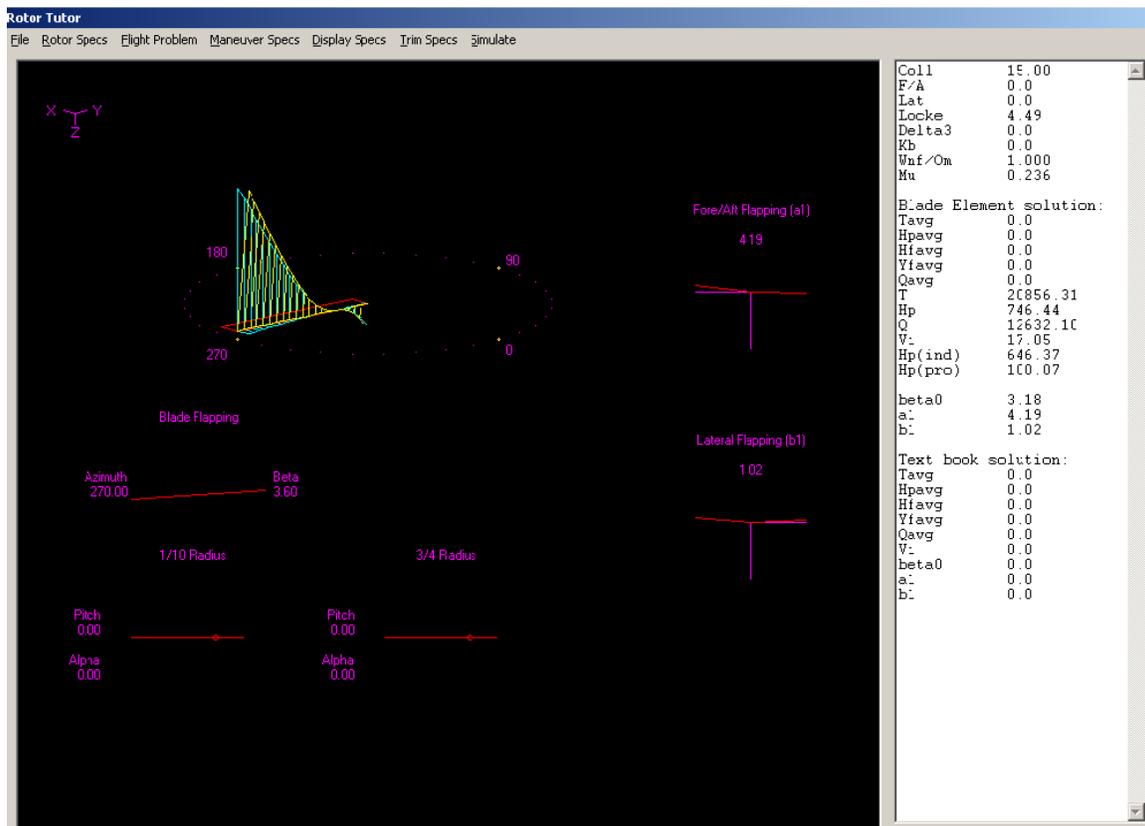


Figure 2 – One of the output pages from the rotor tutor program. This program lets the user visualize the performance of a many classes of rotor.

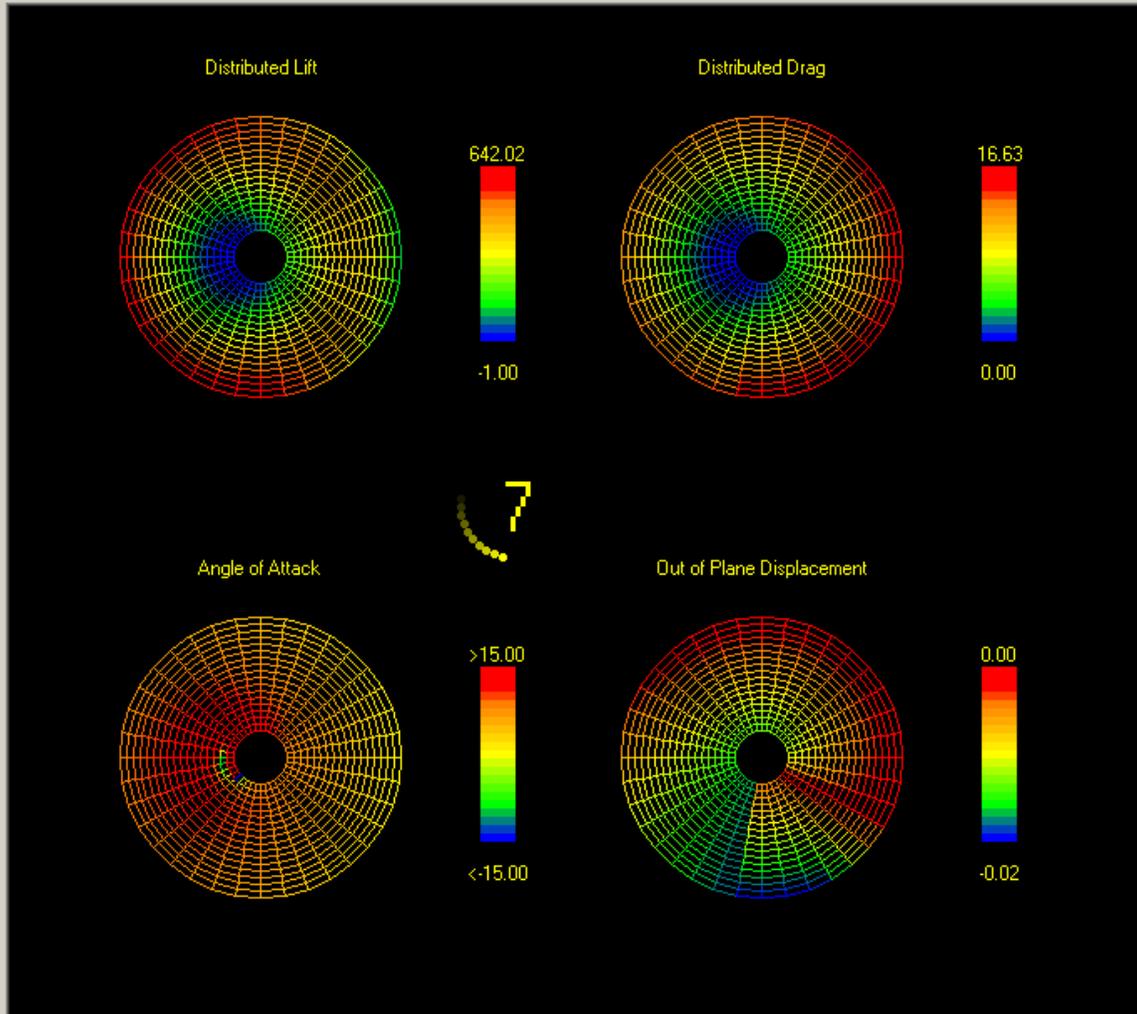


Figure 3 – This is another page from the rotor tutor program showing several key performance parameters as they evolve in time for a rotor flying forward at 100 knots. The reverse-flow region is clearly visible.