

Sun-Powered Flight

UNLV researchers use multiphysics to optimize a solar-powered unmanned aerial vehicle.

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Solar power is an increasingly attractive way to sustain aircraft aloft for extended time periods without refueling. Advances in photovoltaic and battery technologies have progressed to a point where it is possible to charge and store sufficient power in the sunlight to run the vehicle off a battery all night. But solar-powered flight is, by default, underpowered. A delicate optimization of properties — weight, surface materials, and geometry, for example — is required to minimize flight power requirements so that an aircraft can fly for days at a time.

My teammates and I used COMSOL Multiphysics® extensively to model, analyze, and optimize a solar-powered unmanned aerial vehicle (UAV) under development at the University of Nevada Las Vegas. The refinement of wingtip devices in particular was recognized as an area where we could improve the UAV's aerodynamics.

Winglets for All Flight Conditions

The UAV we designed is propelled by an electric motor that spins a nose-mounted propeller. The wingspan is approximately 10 feet, and thin-film solar panels are arrayed across the top of the wings. Power is stored in rechargeable lithium-ion batteries, which are housed within the main fuselage along with avionics.

Winglets are an economical way of modifying an aircraft to lessen induced drag and reduce power requirements at a given airspeed. Winglet design, however, gets complicated because the aim is to reduce

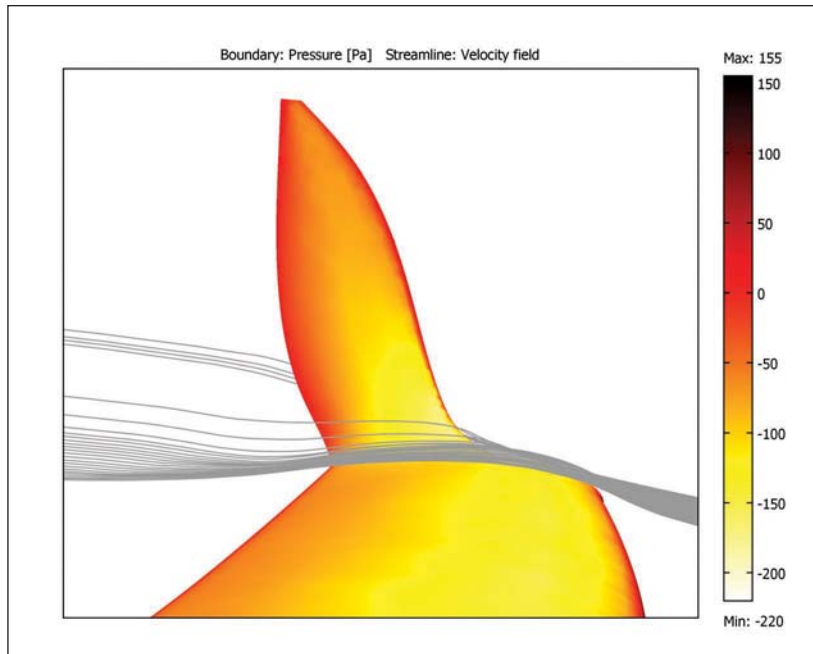


Figure 1: COMSOL Multiphysics simulation showing boundary pressure distribution and streamline detail on the inside face of non-planar winglet in loiter at +2° angle of attack. Notice the progressive dissipation of the useful pressure gradient, starting nearly one third of the way up the winglet. The reason for this drop off in performance is likely due to the formation of a laminar separation bubble, propagating down the span of the device.

overall drag in all flight conditions — as opposed to designing for a single operating point — while simultaneously ensuring that the design does not induce penalties under the complete flight regime. The design is also a highly proprietary problem without a general solution, so each design requires unique consideration. Planar winglets usually try to either capture the strength of the trailing vortices or delay their creation further outboard. Non-planar versions usually aim to do the same but tend to be more efficient since they are out of the wing's plane. Our focus here is on non-planar devices.

Winglets can increase wing bending moment, especially if they increase a wingspan or if they are non-planar lifting surfaces. They act like a cantilever beam that's loaded. So, such questions as "Am I adding stresses to the wing? How is this going to behave in a dynamic setting? Will it flutter?" arise. For these answers, we

performed a structural study to ensure the appropriateness of our fabrication techniques and material selections.

Fluid-Structure Interaction Simulation

As with most fluid flow problems, a virtual wind tunnel was ideal. COMSOL enabled us to test different geometries and materials without machining every single design for a wind tunnel test. What we did was export our SolidWorks® models into COMSOL where we then created a fluid box surrounding the model. We left room around the object to

analyze flow, yet kept the box tight enough to lower the number of internal nodes to a minimum.

Typically, the fluid box had one inlet and one outlet, three slip surfaces, and one symmetry boundary at the root of the geometry being analyzed. The geometry consisted of non-slip interior

“The aim is to reduce overall drag in all flight conditions.”

boundaries. The box also provided easy boundary specifications for the structural problems. Additionally, this method let us estimate drag forces produced by various components easily.

We used COMSOL to assess different geometries numerically, which, for the winglets alone, meant seven distinct

configurations. We used various solvers for the fluid-flow problems but, generally speaking, the turbulent flow segregated solvers gave the best results when paired with geometric multigrid preconditioning.

The structural analysis proved demanding because of its multiple physics and our desire to solve our fluid and structure problems simultaneously. COMSOL's fluid-structure interaction (FSI) modeling interface handled these problems properly and efficiently with its default segregated solver settings and minor modifications to the geometric multigrid solver. The FSI application mode couples Navier-Stokes equations with a solid stress-strain analysis type and uses a moving mesh (ALE method) for shape deformation. The FSI model was later modified to use the turbulent flow solvers.

Validating Simulation Results

COMSOL's output capabilities allowed us to analyze the results from simulations easily and quickly to gather a lot of information simply by inspection. The winglet design study showed an overall drag reduction of 8.1% at cruise conditions over the original wing design, with smaller reductions in other flight conditions, such as banking flight or shallow climbs. Superimposing gathered data from COMSOL onto the UAV's flight polars showed no performance penalties and good correlation.

COMSOL's boundary integration capabilities was especially powerful when coupled with weak constraint variables. This allowed us to find changes in overall drag quickly. The weak constraint variables offered an easy way to compute drag and lift coefficients. We used this feature numerous times during the fluid-flow analysis, both as a way to benchmark the accuracy

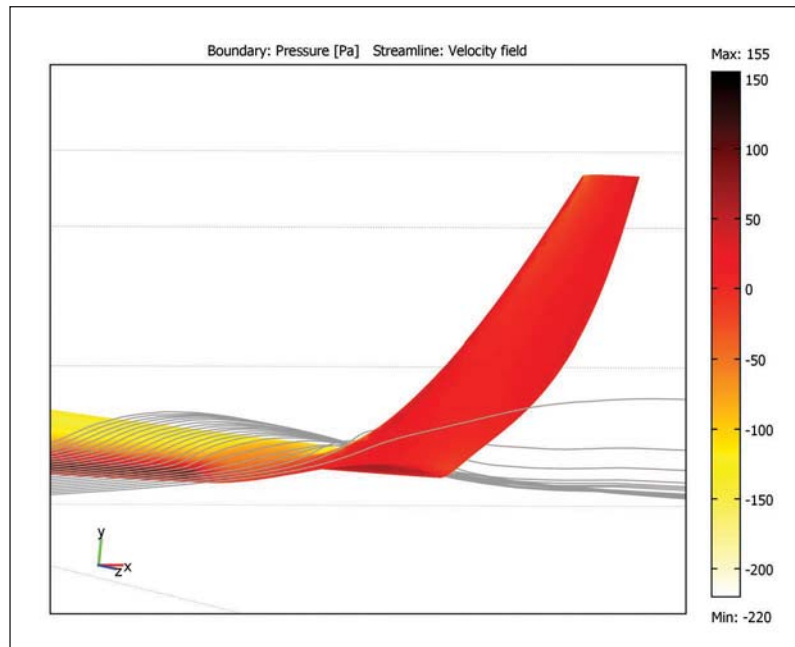


Figure 2: This pressure distribution and streamline detail shows a +4° angle of attack. The flow in the area near the winglet root still displays outstanding adherence. Notice how the fluid spills from underneath the bottom of the leading edge into the bottom surface of the winglet.

of the models against known values and the obtained results against predicted data using various panel methods.

FSI allowed us to observe the effect of winglets on the airframe dynamically from an aerodynamics and structural point of view. The results were numerically compared to the original cases, and direct considerations regarding the manufacturing of the airframe were completed on the fly. For example, with polystyrene, a building material we evaluated, the original wing showed a deflection of 0.0004 inch at the tip as

compared to a 0.007 inch tip deflection with a winglet device.

All-Inclusive Design

COMSOL Multiphysics proved a valuable tool in the development of the UNLV solar-powered UAV. We demonstrated that COMSOL can be used for small-scale evaluation of flying platforms, such as UAVs, and that it provides an all-inclusive way to approach a design problem and arrive at a development solution quickly.

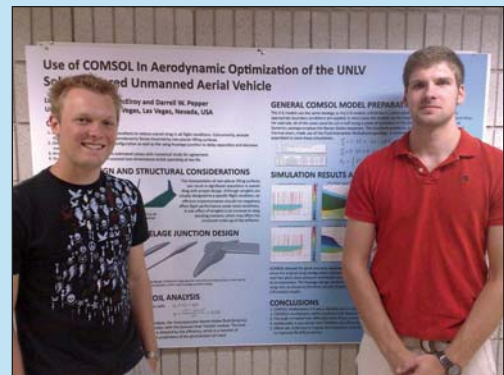
COMSOL provided results in a timely manner, allowed us to optimize key parts of the airframe, and to observe the structural side effects

of modifications. The ability to simulate various flight conditions using single or multiple physics enabled an iterative design process and facilitated the development of the design into a numerically ready airframe. ■

This article was excerpted from the Proceedings of the COMSOL Conference 2008 Boston. The full technical paper entitled "Use of COMSOL in Aerodynamic Optimization of the UNLV Solar-Powered Unmanned Aerial Vehicle" is available as a PDF download at www.comsol.com/papers/5424/.

About the Authors

At the time of this research, Louis P. Dube was a graduate student at the University of Nevada Las Vegas. He is now a practicing engineer. Wade A. McElroy is currently an engineering student at UNLV. Dr. Darrell W. Pepper is the Director of the Nevada Center for Advanced Computational Methods at the University of Nevada Las Vegas.



Louis Dube (right) and Wade McElroy.