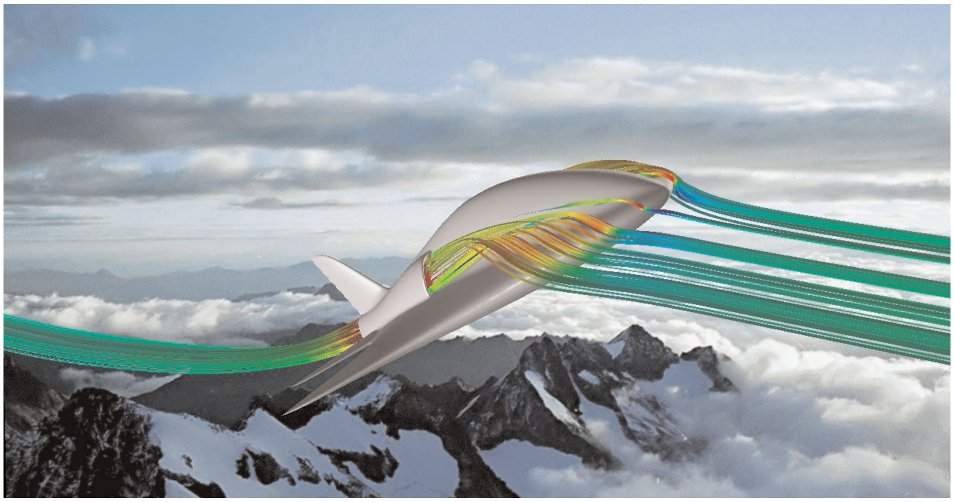
Intelligent Light FIELDVIEW POST-PROCESSING EXCELLENCE

CASE STUDY

A Fish for Inspiration & A Blank Sheet of Paper: CAE Tools Bring Unique Aircraft Design to Life

SmartFish Concept Features Improved Aerodynamics, Safety at Lower Cost

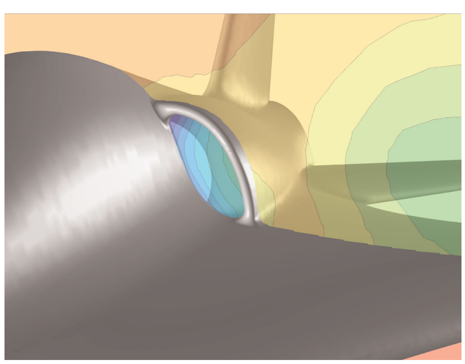


In its first 50 years, aircraft design developed enormously, from the Wright flyer to swept-wing, aft-engine designs such as the Dassault Mystere, first flown in 1963. In this time, commercial aircraft designs have evolved without fundamental changes so that, for example, the recent Bombardier Global Express is aerodynamically very similar to the Mystere. Airframe manufacturers have gained a tremendous amount of engineering and manufacturing experience based on designs that have proven themselves over the past five decades. Certainly, the systems engineering developed and applied throughout the aviation industry has increased safety and reliability over these five decades. While it may be easier and less risky to continue making incremental improvements to existing designs, what would happen if a small team of engineers were to start with a blank sheet of paper and use the latest computer-aided engineering tools to optimize the geometry of a design from an aerodynamic standpoint? That's essentially what Koni Schafroth and his team did in developing the SmartFish aircraft concept.

With the goal of reducing the drag of an aircraft, Schafroth noted that 3D shapes have much lower drag coefficients than similar 2D shapes. The long length of current aircraft wings makes them act similarly to 2D bodies from an aerodynamic standpoint. Much of the drag in current aircraft comes from interference between the wings and the fuselage. Schafroth resolved to improve on current designs by developing a 3D shape that incorporates wings and fuselage that flow smoothly into each other. To his surprise, the resulting shape resembled a fish. Fishes' fins are attached on their trunk at a position just forward of the maximum thickness of their body, the point where pressure equilibration occurs. The resulting increase in aspect ratio reduces the induced drag coefficient.
Schafroth spent months researching fish in books, at aquariums, and even went snorkeling to study how fish move through the water. While he found the vast natural variety of fish fascinating, it was one of the world's fastest fish, the tuna, that provided the final inspiration for his design.

Technology enables creation of unique design

Not having the extensive knowledge base and experienced staff of current airframe manufacturers made it seemingly impossible for Schafroth, with a tiny team and limited funding, to pursue the goal of building a more efficient aircraft by starting from a clean sheet of paper. "Two technological developments make it possible to develop an airplane that offers a much higher level of efficiency and is also safer than conventional aircraft," Schafroth said. "The first and most important is the recent development of simulation tools that allow us to evaluate the performance of conceptual airframe geometry and visualize the airflow around the plane in a way that helps us understand its performance to a higher level than was possible in the past. We can also view the performance of one



Inlet placement and design is critical to the efficiency of SmartFish. Using FieldView and its unique Partial Integration feature, mass flow rate through the inlet can be computed accurately.

shape overlaid on another to identify tiny differences that will help us quickly compare two design alternatives. The second is the advances in computerized numerical control milling that allow us to easily produce any shape we can conceive."

"Of course, the leading airframe manufacturers have been using simulation tools over the past three decades," Schafroth continued. "But the software available in the past typically ran on supercomputers, required teams of highly trained specialists with advanced degrees, and took several hours to get results, even for simple geometries. Software and hardware have been greatly improved so that today the same case will run on a modern PC in a few seconds. Aerospace engineers with a background in fluid dynamics can solve relatively fine meshes and complex geometries using modern workstations or laptops in just hours of processing time.

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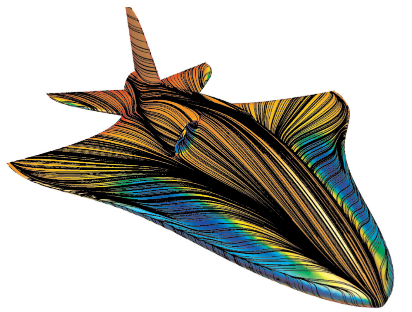
"We use the CFD++ solver [Metacomp Technologies] because it converges quickly and provides accurate results with a coarse mesh that is ideal for use in the conceptual stages of design. We use FieldView [Intelligent Light] for post-processing these results. By coupling the CFD codes with an optimizer software like modeFrontier [Esteco] and a mesh deformation software like Sculptor [Optimal Solutions Software], an automated process can produce simulation results of more than 100 different design variations overnight." Schafroth creates unstructured tetrahedral meshes ranging from 300,000 to 2 million cells.

"The FieldView post-processor gives us a huge advantage by enabling us to get more information in less time from each simulation," Schafroth continued. "FieldView is very simple to work with and easy to learn which is important because so much of the designer's time is spent with this tool visualizing the simulation results. In addition, since I wear many hats, I don't work with CFD every day. FieldView's user interface is intuitive enough that I can go without using the tool for several weeks and then come back and pick up right where I left off."

When Schafroth first applied this simulation capability, one of the first questions he faced was determining how closely it reflected physical reality. He ran tests in a wind tunnel on a model and used surface oil flow techniques to visualize the flow field on the model surface. Color pigments were mixed with oil and painted onto the surface of the wind tunnel model. During the wind tunnel test, the oil was blown away or evaporated, leaving the color behind. The colored streak-like patterns on the surface make it easy to visualize the direction of the flow close to the solid walls. When Schafroth simulated the conditions in the wind tunnel using CFD++ and analyzed the results with FieldView, he discovered that the simulation very closely matched the physical testing results.

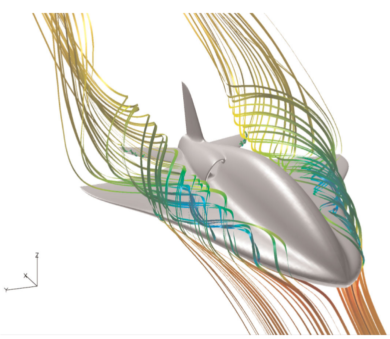


Surface restricted flows, shown with FieldView, highlight separation along the wing tip at high angle of attack. The resulting vortex generates a significant contribution to lift due to low pressure areas on wings, as shown in blue.

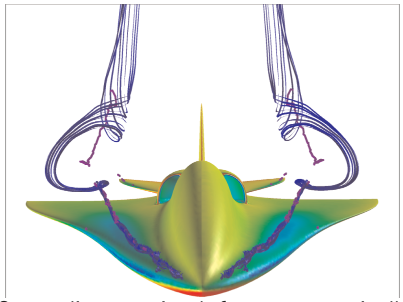
High lift-to-drag ratio increases efficiency

Schafroth named the aircraft SmartFish due to its resemblance to a tuna fish. The aircraft is optimized for transonic speeds, meaning it flies at subsonic speeds but flow over the wing is partly supersonic. Working in FieldView, Schafroth quickly evolved the design based on his original concept of a 3D design with a low aspect ratio. FieldView goes beyond conventional post-processors by identifying flow structures such as vortex cores in the CFD results and generating streamlines that make it easy to visualize the airflow over the surface. These streamlines provide the ability in most cases to quickly understand why a design is performing the way it is and immediately improve it.

Another unique feature of FieldView is the ease of comparing alternative designs. "We can make designs transparent and superimpose them on top



Streamlines and high angle of attack vortex at low speed.

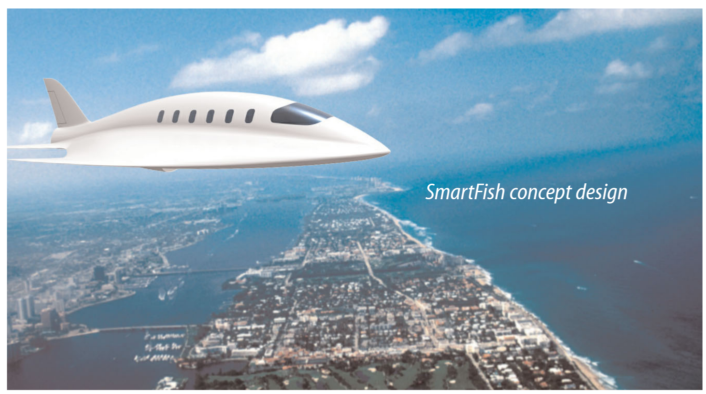


Streamlines emitted from automatically detected vortex cores, shown in purple, help highlight the vortex position.

of each other in order to quickly highlight differences in flow and pressure and determine if our latest design iteration is better or worse than the last one," Schafroth said.

Based on the simulation results, Schafroth developed the external contours of the plane to provide smooth flow around the entire aircraft without flow separation in order to minimize drag. The shear layer that develops from the leading edge at high angles of attack tends to wrap into a tightly bound vortex that has a high local velocity and hence low pressure. This so-called vortex lift makes a very significant contribution to the total lift for highly swept wings at high angles of attack. At some downstream position, which is dependent on the angle of attack and past motion, the vortex suffers from a rapid deceleration and expansion of the vortex core known as vortex breakdown.

Vortex breakdown is often asymmetric, causing a loss of lift in just one wing. Schafroth designed the leading edge of the SmartFish wing to delay vortex lift to higher angles of attack, and in the same time the vortex breakdown is now always symmetric.

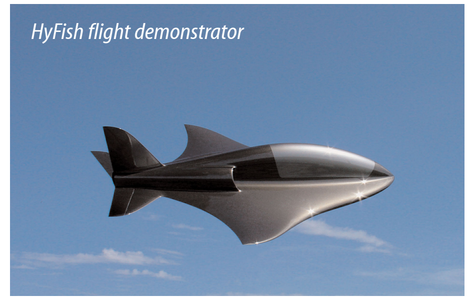


SmartFish has an astonishingly high lift-to-drag (L/D) ratio compared to conventional aircraft designs, but will have a lower empty weight and be able to carry a greater load. "This aircraft looks like a Porsche but has the utility of a VW bus," Schafroth said.

Improved safety and lower manufacturing costs

SmartFish's unique aerodynamics make the aircraft safer. There is a safety factor of three between the angle of attack (AOA) at approach and the maximum AOA that can be flown. Unlike conventional aircraft, there is no stall when ice forms on the surfaces because vortex lift is created at lower AOA when ice is present. SmartFish also does not require complex high lift systems such as flaps, adding to safety. SmartFish has a larger margin between stall and buffeting than conventional aircraft. It also has a high critical Mach number and a large safety margin to stall so the coffin corner is at higher altitudes and greater speeds than with conventional designs. The coffin corner is the altitude at which an aircraft's stall speed is equal to the critical Mach number, the maximum speed at which air can travel over the wings without losing lift to flow separation and shock waves.

SmartFish has no complex wing-fuselage joints at highly loaded structures at 90 degrees to one another and no intersections with fillets. The trailing edge control surfaces on the elevator have simple hinges and there are no spoilers, flaps, or slats. The result is that SmartFish will be less expensive to build and maintain than conventional aircraft.



Last spring, the SmartFish team, together with the German Aerospace Research Centre, built HyFish, a small unmanned plane based on the SmartFish design and powered by a fuel cell. HyFish has a wingspan of 1m, a total length of 1.3m, and a weight of 6.1kg. The fuel cell system including electronics and hydrogen tank has a weight of 3kg and an electrical output of 1kW. The plane was successfully flown at speeds close to 200 km/h. It demonstrated excellent handling qualities while maneuvering using elevons only. The plane can even fly aerobatic stunts such as small radius loops without losing control.

The next challenge is obtaining funding to design, build, and test full-size manned versions of the aircraft. Producing an entirely new form of aircraft requires imagination, courage, and determination. As the design continues to evolve, the combination of investment, creativity, engineering skills, and capable and accessible simulation tools will bring SmartFish to reality.

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