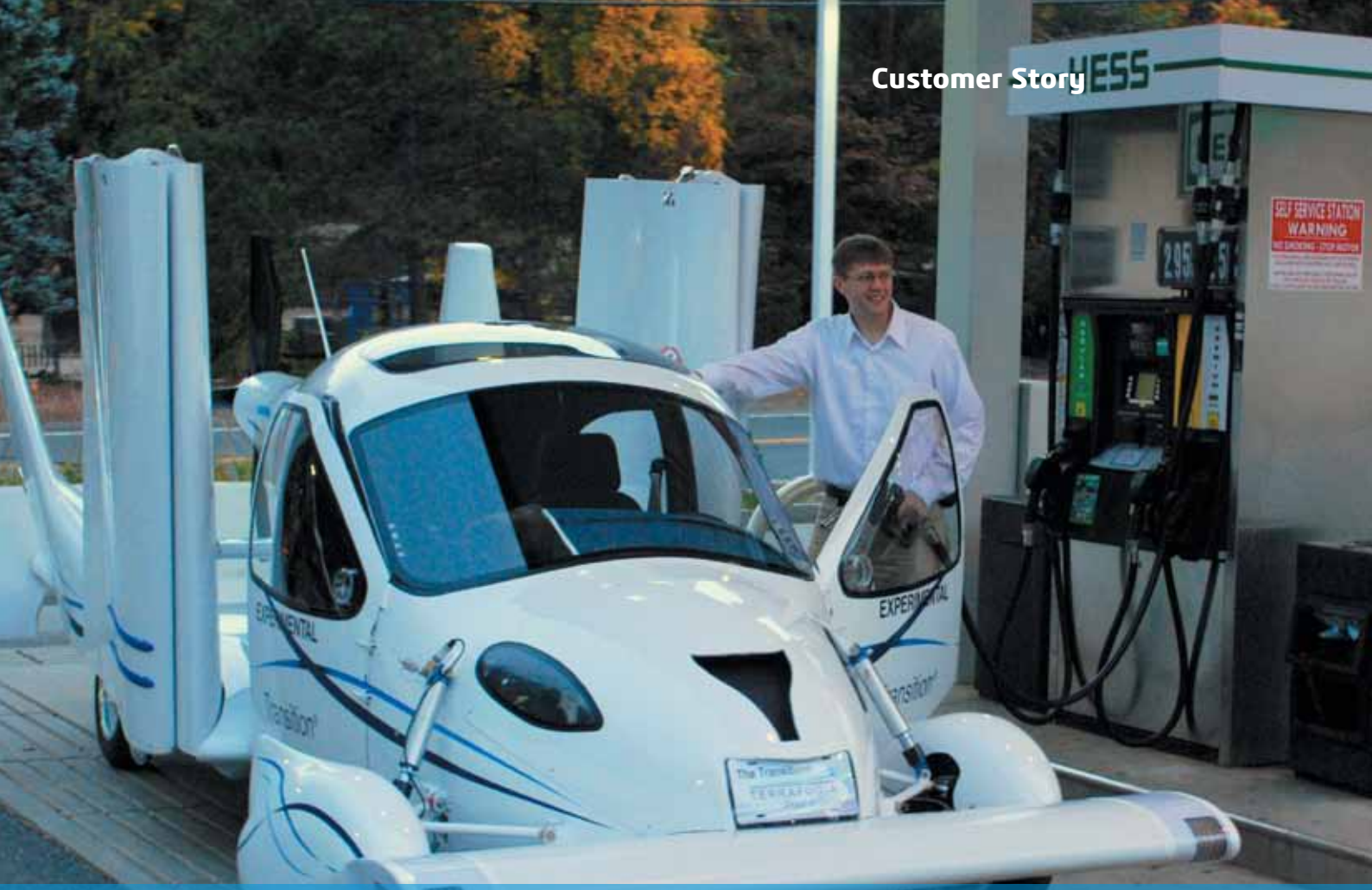


Terrafugia

Creating the first road-worthy airplane with DS SolidWorks and CATIA Composites Design

We had to be confident the design would succeed before we could build it, and DS software became a critical tool that we used to help build that confidence.

Carl Dietrich
CEO/CTO
Terrafugia

Challenge

Broaden access to general aviation by resolving the design challenges of a lightweight vehicle that is both a plane and an automobile.

Solution

Terrafugia chose SolidWorks professional 3D software to design its Transition Roadable Aircraft and CATIA Composites Design integrated with Simulayt to optimize composite lay-ups to maximize strength and durability while minimizing weight.

Benefits

Using DS software enabled Terrafugia to accelerate design of its Proof of Concept vehicle, reduce the vehicle weight significantly during the composites design process, and cut development time through integration of composite design and analysis.

DASSAULT SYSTEMES

Cover Image: *In automotive mode, the Transition fits in a standard home garage and runs on regular unleaded gasoline, which is considerably less expensive and less polluting than airplane fuel.*

Drive or fly … why not both?

Planes fly through the sky. Cars drive on roads. Vehicles designed to do both have only succeeded in science fiction. Until now.

Terrafugia Inc. was formed in 2006 by engineers and flying enthusiasts to create just such a vehicle. The company is closing in on the successful realization of that dream with delivery of the first Transition Roadable Aircraft, scheduled for 2012.

The Transition was conceived as a vehicle that makes aviation more accessible to private pilots. It reduces the costs of maintaining and operating a plane by enabling owners to keep the vehicle at home, eliminating airport hangar fees and tie-down costs. It also runs on regular automobile gasoline, which is less expensive and less polluting than aviation fuel.

What makes the Transition most revolutionary, though, is how it gets from place to place after it lands or before it takes off: it drives on the same roads as standard automobiles.

Terrafugia is self-certifying the Transition to meet the U.S. Federal Aviation Administration's new Light Sport Aircraft standard, as well as safety standards of the U.S. National Highway Transportation Safety Administration (NHTSA).

"As a small company with limited resources, it was critical for us to design the Transition and test it virtually," Terrafugia CEO/CTO Carl Dietrich says. "We had to be confident the design would succeed before we could build it, and DS software became a critical tool that we used to help build that confidence."

Developing the first-ever roadable aircraft

The design challenge facing Terrafugia's innovators was twofold: first, to merge the abilities of an aircraft and a street-legal automobile; and second, to translate that design into a lightweight, manufacturable reality.

Terrafugia used SolidWorks professional 3D software to design the Transition's body and interior. "We needed a design package that could handle mechanical assemblies such as the engine, suspension and drive train systems, as well as the complex, aerodynamic surfaces of the fuselage, wings and controls," engineer Gregor Cadman says.

The team used the SolidWorks Routing solution to automate design of distributed systems including electrical wiring, brake lines, fuel lines and control cables. SolidWorks Routing enabled Terrafugia's engineers to plan efficiently for these systems while balancing the need to conserve material and reduce weight, Cadman says.

SolidWorks also enabled designers to download models of off-the-shelf components, including the 100 horsepower, four-cylinder engine. "Instead of modeling everything from scratch, we downloaded models online and imported them directly

SUSTAINABLE INNOVATION* AT TERRAFUGIA

Virtual design and testing with DS solutions allow Terrafugia to optimize its designs in virtual 3D, enabling innovation that supports all three facets of sustainability:

- **People:** Virtual testing for structural integrity and vehicle performance enhances passenger safety.
- **Planet:** Right-first-time designs eliminate trial and error on the shop floor and minimize trims, reducing waste materials.
- **Profit:** By validating performance virtually, Terrafugia ensures success without the expense of multiple prototypes.

** Sustainable Innovation is a creative approach to developing products and services that benefit the health and safety of people, the environment, and the economy while fostering a self-perpetuating climate of innovation.*

With CATIA Composites you design as efficiently as possible, with the least amount of material and the least amount of waste.

Ben Zelnick, *Vehicle Engineer, Terrafugia*

> CATIA has saved us significant time and allowed us to design structures more efficiently to reduce weight of our composite parts and of the total vehicle.
>
> **Danny Bouldin**, *Structural Analyst, Terrafugia*

into our design," Cadman says, helping to speed the Transition's development. "The more time we can save the better. SolidWorks software has proven to be a good solution for that."

From concept to reality with CATIA Composites Design

Terrafugia successfully demonstrated its proof of concept (POC) vehicle in 2008, building and then flying a single prototype of the Transition. Translating that POC design into a practical, manufacturable vehicle remained a significant challenge, however.

To overcome that hurdle, the company turned to another Dassault Systèmes solution, CATIA Composites Design.

From the start, reducing weight was the most significant design challenge. "In developing the final design and composites using CATIA, we have been able to take a lot of weight out of the prototype, as compared to the proof-of-concept vehicle," vehicle engineer Ben Zelnick says. "That is a critical part of successfully creating a commercially viable light sport aircraft."

To reduce weight, the Transition was designed using lightweight aluminum and carbon fiber composites. While the properties of aluminum are well-known, composites consist of many materials that may vary widely, and working with them traditionally has been as much art as science.

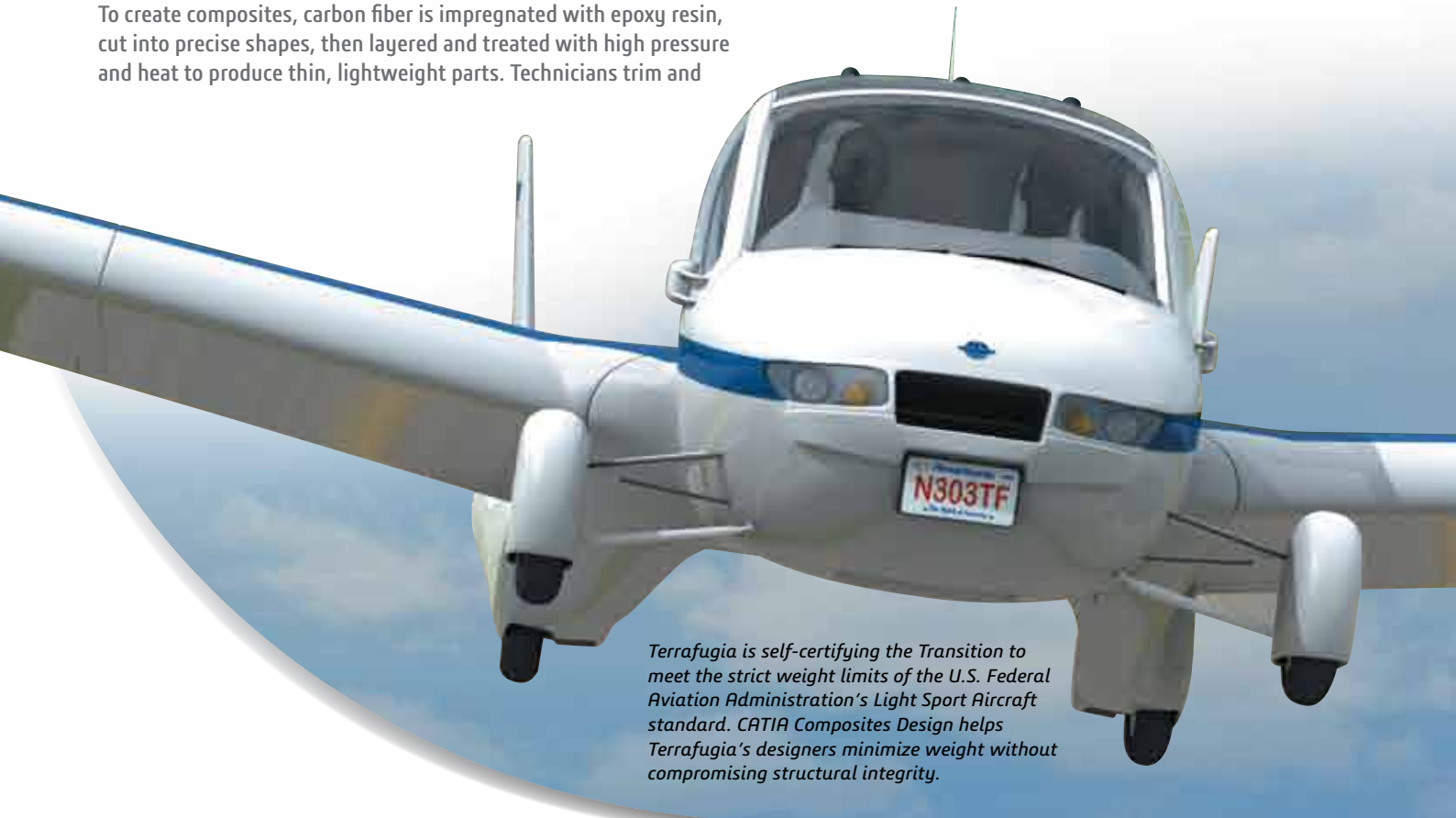
To create composites, carbon fiber is impregnated with epoxy resin, cut into precise shapes, then layered and treated with high pressure and heat to produce thin, lightweight parts. Technicians trim and splice layers of fiber to fit onto molds that can curve and flow into complex shapes, a slow, expensive process known as "the paper-doll method" and long defined by trial and error.

"When you work with a complex structure, it is difficult to determine exactly how it will carry load," Zelnick says. "With traditional tools, you have to make educated guesses when designing component structures."

Eliminating guesswork with CATIA

The CATIA Composites Design solution eliminates guesswork by enabling engineers to visualize how the fibers in a structure are being loaded. They can then design the part in the most efficient way to minimize stresses and weight while maximizing strength.

Among the challenges: determining whether an individual ply can be draped on the mold as it has been designed. "With CATIA, we do draping analysis to see where the plies need to be cut or a dart needs to be added, all on the computer," structural analyst Danny



Terrafugia is self-certifying the Transition to meet the strict weight limits of the U.S. Federal Aviation Administration's Light Sport Aircraft standard. CATIA Composites Design helps Terrafugia's designers minimize weight without compromising structural integrity.

Bouldin says. “That makes layup much easier.” He used CATIA in combination with Advanced Fiber Modeler (AFM) from Simulayt Limited, recently acquired by DS, for analysis of fiber orientation and flat-pattern generation.

“Advanced Fiber Modeler is a great complement to CATIA Composites Design,” Zelnick adds. “Being able to realistically model fiber orientations in our ply-by-ply laminate models allows us to completely optimize our design by conducting accurate structural analyses, which is invaluable to reducing the weight of the Transition. The accurate flat patterns from AFM also save time and material during manufacture.”

Performing digital analysis reduces costs and improves quality. “If you get to the shop floor and then find the technicians cannot get the fiber to fit in the mold correctly, you have to make changes there,” Bouldin says. “That takes time and additional material, and it can compromise structural integrity.”

In addition to helping ensure producibility, CATIA optimizes composite design to save on material and weight. A part carrying a heavy load, for example, requires several layers of carbon fiber. CATIA helps designers make each successive ply slightly smaller than the one beneath to distribute the load across the part more uniformly and efficiently.

It also translates such complex designs to the shop floor. “You can export the CATIA file to the cutting machine,” Bouldin says. “CATIA also has ply books, which tell you where to start laying the ply into the mold. All of that information goes straight to our production floor, which is a huge benefit for a small company like ours.”

Integrated analysis heads off part failure, speeds development

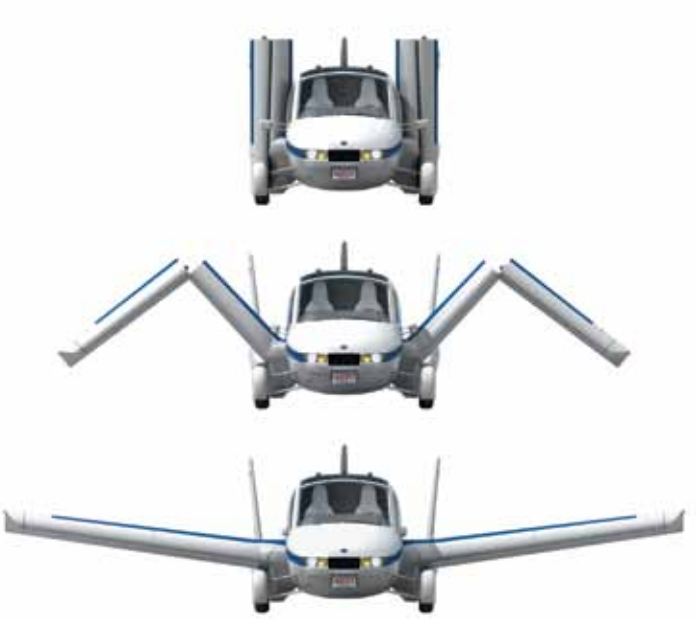
Analysis tools in CATIA indicate how plies will react to loads, both as individual plies and in aggregate. If the analysis indicates a ply will fail, the designer can change its orientation to improve strength.

“In the past, the typical package used to analyze composites was much less powerful than CATIA,” Bouldin says. “You had to simplify the model in order to run the analysis. That simplification always left us guessing whether or not the part was actually as strong as the analysis showed.”

As a result, engineers would over-design parts to ensure structural integrity. That added time, material, cost and weight. Layer-by-layer analysis eliminates such inefficiency, Zelnick says. “With CATIA, you know exactly where you need material and where you don’t.”

CATIA also provides an accurate estimate of a part’s weight before it is laid up in the mold, information has been critical in the Transition’s design.

“CATIA has definitely saved us a lot of time and allowed us to design structures more efficiently to get our composites down in weight,” Bouldin says. “Compared to the proof of concept, which had very overdesigned laminates, the Transition we are building today is significantly lighter, which translates to improved performance.”



As shown in this series of SolidWorks models, the wings of the Transition unfold, converting the vehicle from a road-worthy automobile into a light sport aircraft.

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Images courtesy of Terrafugia.

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