TECH TRANSFER,

A SOLAR-POWERED AIRPLANE INTRODUCES SOPHISTICATED

Five months to circle the globe by air doesn't sound like a technological advance. After all, the record for circumnavigation by bicycle, set in 2010, is only 125 days. But the remarkable thing about this flight is that it will not burn a drop of fossil fuel. The only source of power will be sunlight.

The plane, *Solar Impulse 2*, started on its world tour in March from Abu Dhabi. The founders of the project, Bertrand Piccard and Andre Borschberg, are taking turns as pilots. Its exact itinerary will be subject to wind and weather, but planners expect the plane to make about a dozen stops before it gets back to Abu Dhabi this summer.

It is unlikely to launch an industry based on solar-power aircraft, but then, that wasn't the point of the exercise. Instead, its purpose was to stimulate interest in alternatives—not only alternative power, but also alternative materials and other technologies for a future that makes more-efficient use of Earth's resources.

About a decade ago, the Altran Group, the international technology consulting firm, became an early partner in the Solar Impulse project. Altran developed a sophisticated mathematical model to evaluate thousands of interacting parameters, including flight paths, weather, and design configurations. Altran's engineers simulated over 100 billion combinations in all, to see whether

Solar Impulse 2 soars over Switzerland during an early test flight.

ULTRA-LIGHT PRODUCTS TO THE MARKETPLACE.

BY R.P. SIEGEL

the mission could actually be accomplished. After eighteen months of analytical effort, the Altran team, led by Christophe Béesau, determined that the mission sat at the very edge of what was technologically possible, with little or no margin of safety.

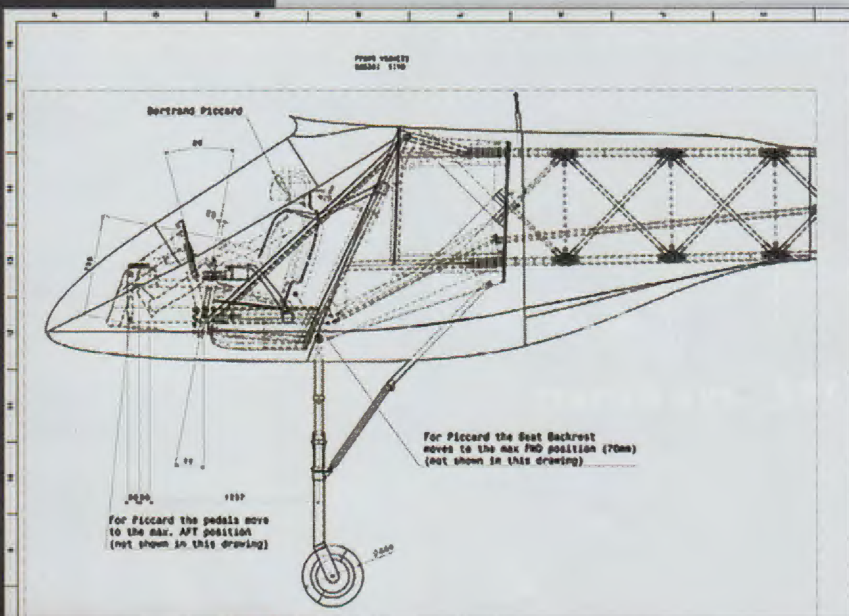
It was at that point that Borschberg and Piccard began to ask suppliers for breakthroughs in every aspect of the aircraft, especially those affecting its weight and its ability to capture, store, and use energy as efficiently as possible.

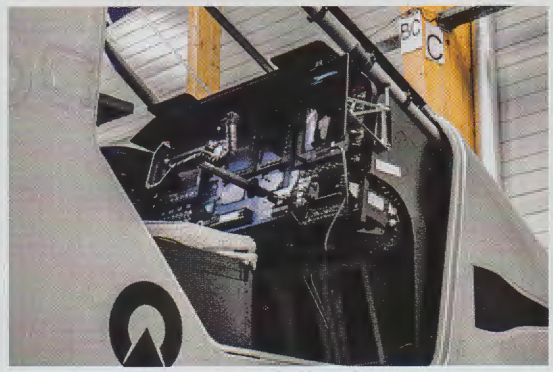
Solvay, a French company that makes high-performance polymers, became an early partner. According to Claude Michel, Solvay's vice president in charge of the Solar Impulse partnership, the two key challenges were optimizing energy efficiency and reducing weight. These goals aligned with the company's strategic direction: to support a growing population in a world of diminishing natural resources.

Solvay, like many of the suppliers who eventually became involved, was already addressing these problems when it began to work with Solar Impulse. The partnership presented its own unique challenges, but more important, it also provided an aggressive schedule and a flying laboratory that tested numerous developments under difficult real-world conditions.

Solvay saved weight by providing fasteners and bushings made of polyether ketone, which are half to one-fifth the weight of metal alternatives. It saved energy by providing a new PFPE-based liquid lubricant called Fomblin to minimize mechanical losses.

The company also developed materials for lightweight, high-performance lithium-ion batter-





Drawings of the *Solar Impulse 2*'s cockpit, and the finished structure. The entire space is 3.8 cubic meters.

ies. More than a quarter of *SI2*'s total weight and all of its electric energy storage is in the batteries. Solvay supplied a new monofluoroethylene carbonate additive to help increase the energy density and improve the cycle life of the battery's electrolyte.

Solvay contributed an improved version of its Solef PVDF copolymer, as a binder in the electrodes. PVDF is a fluorinated semi-crystalline thermoplastic which is obtained by polymerizing vinylidene fluoride. These additions resulted in batteries that were 10 percent more efficient, 2 percent lighter, and safer as well. All told, the battery's energy density grew from 180 to 260 watt-hours per kilogram over the course of the project.

In order to protect the very thin silicon photovoltaic cells while allowing the arrays to conform to the curvature and flexion of the wings, Solvay's engineers came up with a thin-film encapsulation method involving layers less than 20 micrometers thick of optically clear Halar (ethylene chlorotrifluoro ethylene) film above and below the solar cells. This, combined with a Solstick bonding agent made of PVDF, completely weatherproofed the array while allowing for minor movement.

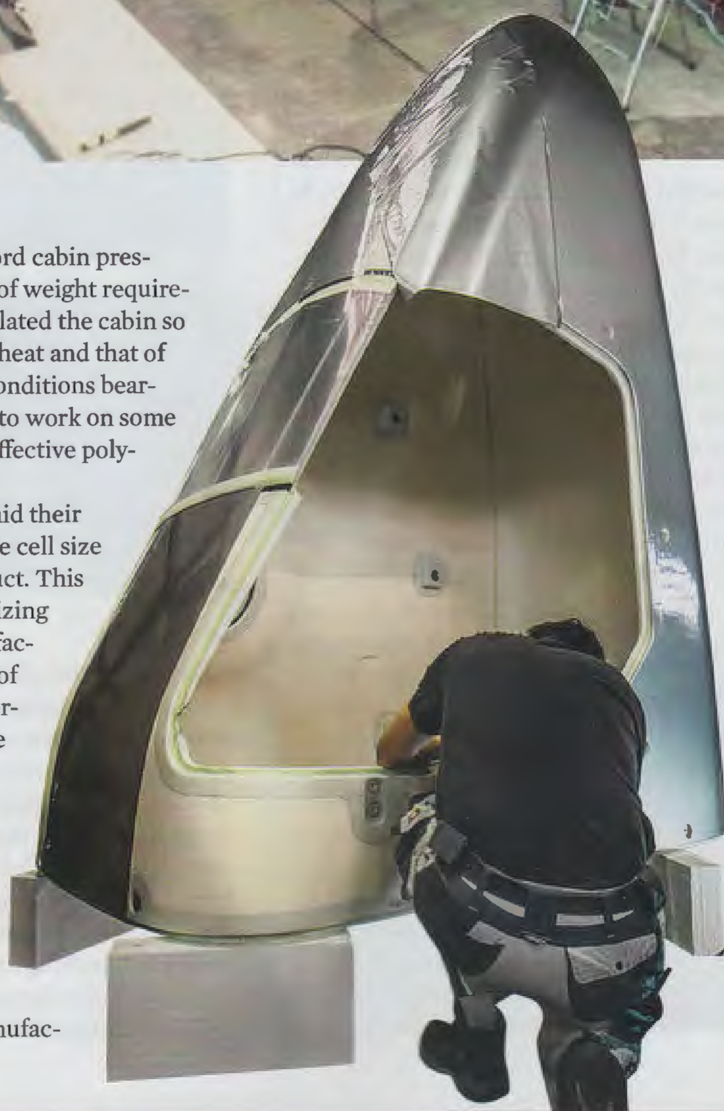
To improve integrity, Solvay developed an electric discharge corona technique to attach the film to the arrays. The corona discharge, which is passed over the film as it is extruded or being unspooled, ionizes the nitrogen in the nearby air, thereby increasing the film's surface energy and its adhesion. The film was produced by Aledium Films and the corona treatment was applied offline. This capability is now being used to install liners in tanker trucks, rail cars, and airport cargo bays, mobile applications where a rugged waterproof and flexible surface is needed.

The airplane's 72-meter-long wing spars had extraordinary structural and weight requirements. The Solar Impulse team came up with a laminate, consisting of a honeycomb structure, made of a high-performance Torlon (polyamide-imide) polymer provided by Solvay, sandwiched between super-thin layers of carbon fiber composite.

The carbon fiber composite sheets were developed for Solar Impulse by the Swiss company Decision SA, which claims they are likely the lightest ever made, coming in at 25 g/m^2, about one-third the weight of a sheet of paper. According to Bertrand Cardis, Decision's general manager, these composite sheets are already being used in a C-class racing catamaran and are currently being qualified for future manned and unmanned aircraft.

That was not the only carbon fiber innovation spawned by the project. Bayer MaterialScience, a supplier of industrial raw materials and a partner since 2010, has contributed carbon nanotubes that can be mixed with the epoxy bonding resin. Adding the nanotubes increases bond strength and reduces the weight of the epoxy mixture by 5 percent. This development work is now being continued under license by Future Carbon GmbH.

Solar Impulse 2 under construction in Switzerland.



Solar Impulse could not afford cabin pressurization or heating because of weight requirements. Instead, designers insulated the cabin so that retaining the pilot's body heat and that of the instruments would keep conditions bearable. Engineers at Bayer went to work on some ultra-lightweight and highly effective polyurethane foam insulation.

Team leader Bernd Rothe said their solution involved shrinking the cell size of an existing insulation product. This was achieved by jointly optimizing several chemical and process factors, including the dispersion of the blowing agent, the polymerization reaction speed, and the mold-filling speed.

This sufficiently reduced the density and increased the amount of trapped air and corresponding R-value to meet Solar Impulse's stringent requirements. This same foam is now being tested by major appliance manufac-

Lightweight, highly efficient foam insulation is being tested by Bayer in affordable housing in the Philippines (top) and Malaysia (above).
A panoramic roof made of a Bayer polycarbonate used in *Solar Impulse 2* has been designed for the Smartcar (below).

turers for use in refrigerators. Because of its superior performance, this foam will allow manufacturers to reduce wall thickness in refrigerators, for instance, thus providing more interior volume while maintaining overall size.

The same foam, sandwiched between thin layers of metal, is also being using to produce building panels. A prototype house constructed with these panels was recently completed in Malaysia as part of an Industrialized Building System Show Village. Using the panels is expected to reduce construction time by 35 percent. The Construction Industry Development Board is building 200 more of these homes for evaluation.

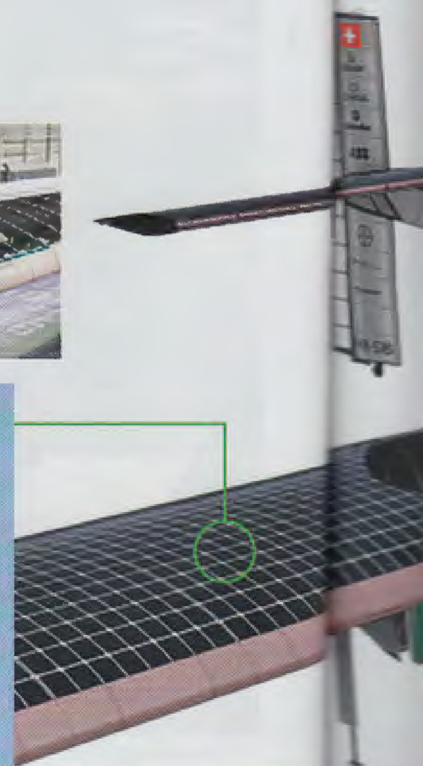
Bayer also developed a cockpit windshield that weighs roughly half as much as its glass equivalent. It is made of dual-layer polycarbonate.

The company also came up with a proprietary fog-proof coating that water vapor will not adhere to. The coating eliminates the need for a defroster thus saving weight and energy.

In the end, the complete cockpit fairing came in weighing 26 kg. Many of these elements are now being migrated to the automotive sector. Polycarbonate headlights are already becoming a new industry standard. The material is highly transparent, extremely light, exceptionally shatterproof, and easy to form into any desired shape. A lightweight panoramic roof, produced by Webasto, based on this material from Bayer is being incorporated into the latest Smartcar for Two.

Bayer also developed a polyurethane resin to be used as a replacement for epoxy in bonding carbon fiber parts. The polyurethane has a much shorter cure time than that of epoxy. This innovation will enable shorter cycle times for mass production of assemblies composed of bonded carbon fiber elements. This technique was tested but not qualified in time for use in *Solar Impulse 2*. The company is moving forward, however, pursuing applications for the automobile industry.

The Solar Impulse team calls the current ven-

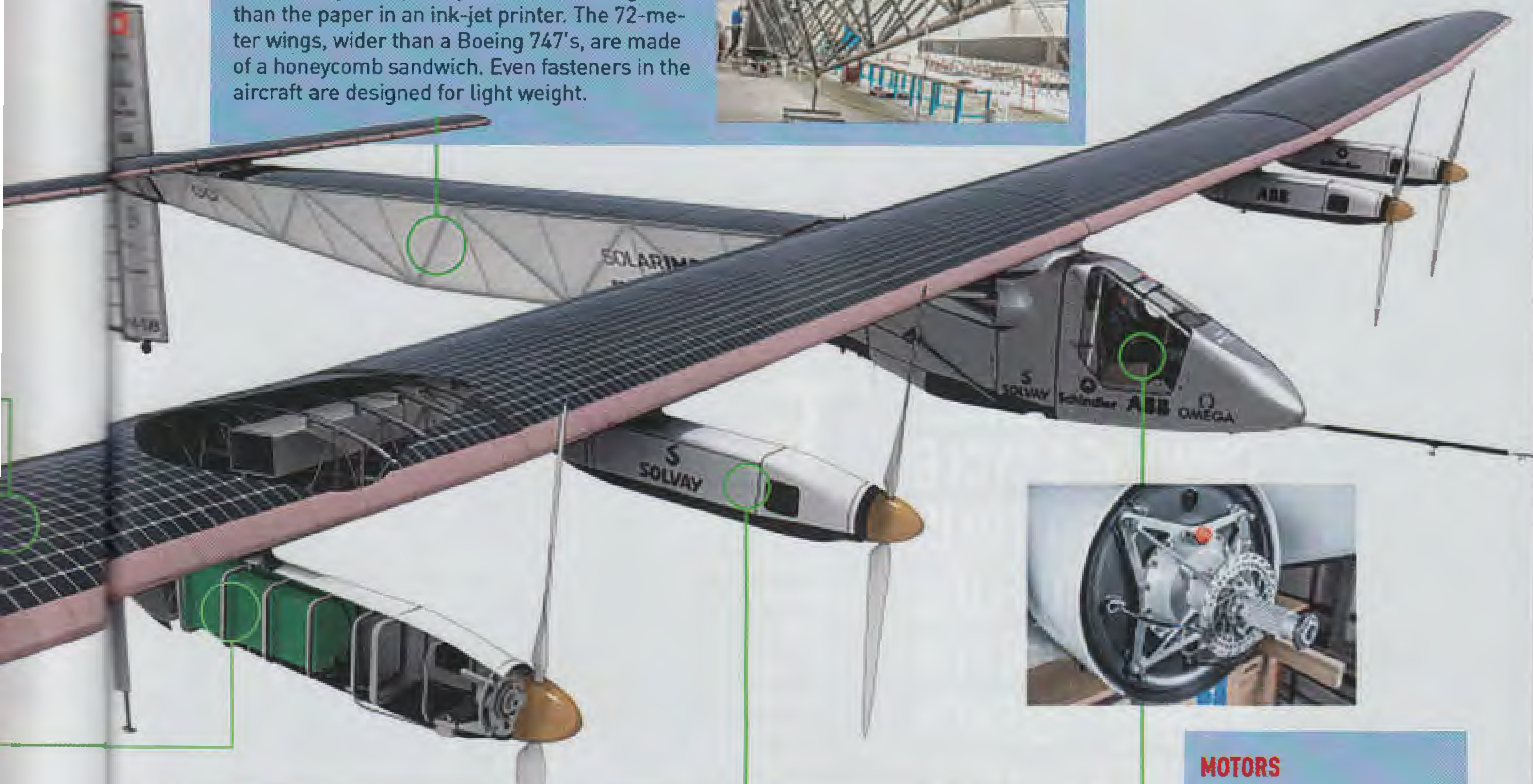


SOLAR CELLS
17,248 monocrystalline silicon photovoltaic cells on the wings, fuselage, and horizontal tailplane of *Solar Impulse 2* can provide up to 340 kWh of electricity per day. Cells are 135 micrometers thick and are rated at 23 percent efficiency. They are protected by a coating developed for the aircraft.

BATTERIES
Solar-generated electricity is stored in lithium polymer batteries for use when the sun is down. The batteries, with an energy density of 260 Wh/kg, are insulated by high-density foam and include a system to control charging thresholds and temperature. Their total mass, 633 kg, makes up a little more than a quarter of the aircraft's weight.

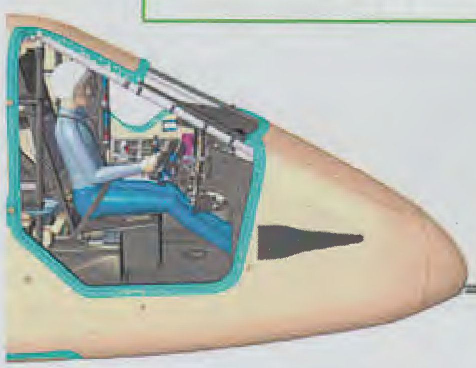
WEIGHT

Solar Impulse 2 weighs roughly the same as a small van, about 2,300 kg. The airframe is made of composite materials, such as sheets of carbon that, at 25 grams per square meter, are lighter than the paper in an ink-jet printer. The 72-meter wings, wider than a Boeing 747's, are made of a honeycomb sandwich. Even fasteners in the aircraft are designed for light weight.



MOTORS

Four brushless, sensorless motors generating 17.4 hp each are mounted below the wings, and fitted with a reduction gear limiting the rotation speed of the 4-meter two-bladed propellers to 525 rpm. The energy efficiency of the entire system is rated at 94 percent.



ture an "attempt." Whether the solar-powered aircraft completes its circumnavigation or not is less important than its demonstration of what engineering can achieve. What was impossible yesterday becomes possible today.

Solar Impulse has helped push technological limits. Ten years ago, the idea of flying around the world on solar power was just at the verge of possibility. Today, there's a solar-powered airplane attempting to make its way around the globe. **ME**

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THE COCKPIT

In less than 4 cubic meters, the cockpit holds six oxygen bottles, food and water for a week, and survival equipment. Ocean crossings will require the pilot to remain in place for several days.

The seat serves as a reclining berth and toilet. A parachute and life raft are packed into the seat-back. When fully reclined, the seat allows the pilot to perform physical exercises. It allows more legroom, has an ergonomic inflatable cushion, and has been developed for minimum weight.

There is no heating system for the cockpit. Protection from exterior temperatures that can range from +40 to -40 °C comes from high-density thermal insulation in the cockpit structure.