The round-the-world flight of the Swiss aircraft Solar Impulse marks the beginning of a new era. And not just for aviation.

Moving on with the Sun

MISSION ACCOMPLISHED. Bertrand Piccard, (left), aged 59, psychiatrist, and André Borschberg, aged 64, a former soldier. They took turns to pilot Solar Impulse.

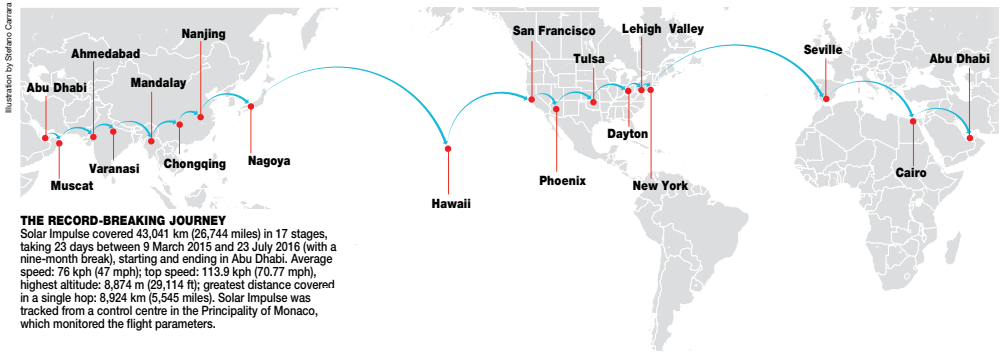
Solar Impulse, Rezo.ch

Now dismantled and stored in six sections in a hangar at the military airbase of Dübendorf near Zurich, Solar Impulse broke 12 world records in becoming part of aviation history.

Crossing four continents to complete its epic journey just a few months ago, , the first solar-powered aircraft to circle the globe was airborne for a total of 23 days. And soon it will be reassembled and put on display in a museum, most likely the National Air and Space Museum in Washington.

But it is not yet time for showboating and self-congratulation. The inspirational project undertaken by Bertrand Piccard and André Borschberg, the two Swiss who dreamed, planned and made it happen, is far from over: the technological innovations which took 13 years to develop are finding many further applications. And not only in the field of aviation. As with the moon missions of the late 1960s, this solar adventure will have many technological spin-offs.

BATTERIES. «Our experiment has shown just how efficient electric motors can be», Piccard explains to *Focus*. «They make use of 93% of the energy they produce, whereas internal-combustion engines waste 70% in the form of heat. Within 10 years, we shall have electric aeroplanes capable of transporting 50 people up to 1,000 km (620 miles) in three hours. And our countries will be monitored by solar-powered drones rather than satellites». A significant achievement, when you consider that the 100,000 planes taking to the air each day produce 3.5% of the CO_2 emissions currently polluting our planet. But it is on solid ground, in everyday life, that the developments pioneered by Solar Impulse will be having the most impact: the aircraft's batteries, capable of storing large quantities of energy to keep the plane flying at night, can be used in power grids, releasing energy when most needed. The insulating foam designed ▸



THE RECORD-BREAKING JOURNEY
Solar Impulse covered 43,041 km (26,744 miles) in 17 stages, taking 23 days between 9 March 2015 and 23 July 2016 (with a nine-month break), starting and ending in Abu Dhabi. Average speed: 76 kph (47 mph); top speed: 113.9 kph (70.77 mph), highest altitude: 8,874 m (29,114 ft); greatest distance covered in a single hop: 8,924 km (5,545 miles). Solar Impulse was tracked from a control centre in the Principality of Monaco, which monitored the flight parameters.

A FLYING LABORATORY

FACTS & FIGURES. Solar Impulse's real name is HB-SIB. It was preceded by a prototype known as HB-SIA. Here are its main technical characteristics:

- **length:** 25 m (82 ft)
- **wingspan:** 72 m (236 ft) (4 m - 13 ft more than a Boeing 747)
- **height:** 6.37 m (20.89 ft)
- **weight:** 2.300 kg
- **propeller diameter:** 4 m (13 ft)
- **capacity:** 13.5 kW (17.5 hp) for each of its four motors, in total 70 horsepower
- **batteries:** 4, each with a capacity of 38.5 kWh
- **take-off speed:** 36 kph (22 mph)
- **top speed:** 140 kph/h (87 mph)
- **cruising speed:** 45-55 kph (28-34 mph)
- **altitude:** 8.500 m (27,890 ft) by day (commercial airliners fly at 12,400 m / 40,700 ft), 1,500 m (4,920 ft) by night

Point your smartphone here to discover the model in 3D, the secrets and sound of Solar Impulse

DOWNLOAD THE APP (INFO ON PAGE 4)

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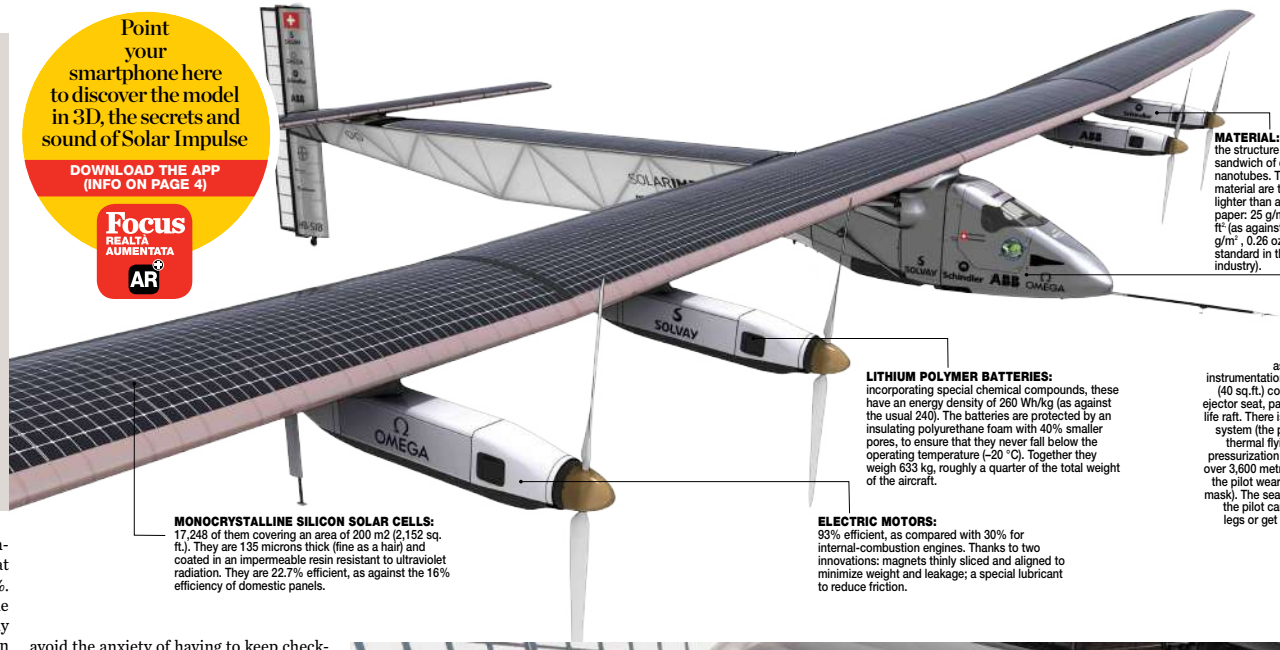

MONOCRYSTALLINE SILICON SOLAR CELLS: 17,248 of them covering an area of 200 m2 (2,152 sq. ft.). They are 135 microns thick (fine as a hair) and coated in an impermeable resin resistant to ultraviolet radiation. They are 22.7% efficient, as against the 16% efficiency of domestic panels.

LITHIUM POLYMER BATTERIES: incorporating special chemical compounds, these have an energy density of 260 Wh/kg (as against the usual 240). The batteries are protected by an insulating polyurethane foam with 40% smaller pores, to ensure that they never fall below the operating temperature (–20 °C). Together they weigh 633 kg, roughly a quarter of the total weight of the aircraft.

ELECTRIC MOTORS: 93% efficient, as compared with 30% for internal-combustion engines. Thanks to two innovations: magnets thinly sliced and aligned to minimize weight and leakage; a special lubricant to reduce friction.

MATERIAL: the structure is a sandwich of carbon nanotubes. The layers of material are three times lighter than a sheet of paper: 25 g/m² - 0.08 oz/ft² (as against the 80 g/m² , 0.26 oz/ft² standard in the aviation industry).

COCKPIT: as well as the instrumentation, the 3.8 m² (40 sq.ft.) cockpit has an ejector seat, parachute and life raft. There is no heating system (the pilot wears a thermal flying suit), nor pressurization (at altitudes over 3,600 metres/11,800 ft the pilot wears an oxygen mask). The seat reclines so the pilot can stretch his legs or get some sleep.

to protect the plane against ultra-low temperatures at high altitudes can reduce heat loss through the walls of our homes by 20%. And the communication system used by the pilots to transmit flight data, weighing only 5 kg and using barely 50 watts of energy, can be fitted to boats and cars operating in extreme conditions.

But how have these results been achieved? What spurred Piccard and Borschberg, not far short of their 60th birthdays, to risk life and limb to fly 43,041 km (26,744 miles) in an aircraft with the wingspan of a Boeing 747, the weight of a commercial van and the speed of a scooter?

OUT OF GAS. The idea grew out of another exploit of Piccard's, the psychiatrist son of Jacques Piccard (the first man to plumb the Mariana Trench in a bathyscaphe): an attempt to circle the world in a hot air balloon. «That was in 1999», he recalls. «We had taken off from Switzerland with 3.7 tonnes of liquid propane gas on board. We landed three weeks later in the Egyptian desert with just 40 kg of fuel remaining, having run the risk of running out completely and being at the mercy of the winds. So I made myself a promise: my next flight around the Earth would be fuel-free, to avoid the anxiety of having to keep checking the fuel gauge». A challenging prospect: back in the 1980s, inventors were beginning to experiment with solar-powered aircraft (*see box*), but no one had ever flown for more than 6 hours, and never at night: how could the batteries be recharged without sunlight? And how could a light aircraft be made self-sufficient and safe enough for a transoceanic crossing?

The only way was to maximize the efficiency of each and every aspect of the aircraft: the aerodynamics, the airframe, the motors, the solar cells and batteries. In short, squeeze out the last ounce of energy, while cutting waste (and weight) to the bone.

To get this result, Piccard went knocking on the door of every aircraft constructor, but his idea was roundly rejected. «The experts told us it was an impossible ambition, which made us all the more determined to achieve it», he told us. Only the French aeronautics firm Dassault Aviation shared his vision, eventually joined by dozens of other partners, from the Swiss Federal Institute ▸

The plane generated enough energy to power 200 lightbulbs: like flying a Christmas tree


1


2


3

LIGHT BUT TOUGH. Left, the cockpit: note the oxygen cylinders (green). Space is reduced to a minimum: the seat tilts backwards (photograph 1) to allow for some exercises (2). To maintain concentration, the pilots practised yoga techniques (3).

FOOD AND FLYING SUIT. Right, the provisions carried on board: 2.4 kg of food, 2.5 litres of water and 1 litre of supplements for each day in the air. Below, Piccard with his oxygen mask and thermal flying suit.

AT REST. The inflatable hangar used to protect the aircraft between stages. It could be erected and dismantled in just a few hours.

The lesson from this experiment: the future of flight is electric

of Technology (Lausanne) to Omega and Google. But it took 10 years of calculations and simulations before a prototype took to the air on its maiden flight – a modest 350 metres (380 yards), one metre (3 ft) off the ground – in Switzerland in 2010. «It is not easy to replace fuel with solar energy», Piccard explains. «Exploiting the surface of the aircraft to the maximum by cladding it with highly efficient solar cells no thicker than a hair, we created 200 m^2 (2,152 sq.ft.) of solar panels, producing enough energy to power 200 light bulbs. As if we were taking to the air on a giant Christmas tree».

This is why the engineers had to work on two fronts: to maximize the energy generated and to reduce weight to an absolute minimum. The first limiting factor, according to Piccard, were the batteries: new ones were needed, lighter and capable of storing more energy, to power the plane at night.

A tricky problem, as they were to realize in June 2015, after flying across the Pacific from Japan to Hawaii: Solar Impulse was grounded for nine months because the batteries had been damaged by overheating. «I had to return to Switzerland and raise more money so we could make improvements», recalls Piccard.

YOGA AND HYPNOSIS. It was nothing short of a flying laboratory. Futuristic and spartan at one and the same time. The other headache for the technicians, given the very limited energy available, was how to reduce consumption to incredibly low levels.

Thanks to a carbon-fibre airframe, as used for America's Cup yachts, the aircraft weighs only 2.3 tonnes, the fuselage accounting for a mere 50 kg. Not surprisingly, the aircraft can accommodate only one pilot, in a cockpit the size of a lift cubicle, unpressurized and without a heating system (though it does have a toilet, fitted beneath the sliding seat). Whoever was flying the plane therefore had to be attached to an oxygen cylinder and wear a thermal suit on reaching an altitude of 8,000 metres (26,250 ft), where the air temperature is 40° C below zero and the portholes ice over.

Moreover, while flying, the pilot could sleep for only 20 minutes at a time, having to constantly monitor the performance of the aircraft, which was highly susceptible to side winds. Piccard and Borschberg therefore taught themselves to concentrate by practising yoga and auto-hypnosis. And they carried an alarm system in their flying suits: the automatic pilot roused them by gently shaking their forearms if the plane listed by more than 5 degrees.

To make matters even worse, the aircraft could not be flown at more than 9,000 metres (29,525 ft) above ground level, because at this altitude the propellers would lose efficiency, nor fly in winds stronger than 18 kph (11 mph) without becoming unstable. They had to contend with a myriad unknown factors, with just one objective in mind: to keep flying until sunrise next day without the batteries running out of energy.

SCIENCE FICTION. After all this painstaking preparation, Solar Impulse began its great adventure on 9 March 2015, setting off from the airport of Abu Dhabi. In 17 stages taking 23 days, the aircraft touched down on four continents, landing back in the UAR at four in the morning on 26 July last year. «Flying was a magical sensation», says Piccard. «I would watch the Sun and the aircraft's propellers and think: I'm not carrying any fuel, not making any noise, not causing any pollution. I am in the future! It was like being in a science fiction film: absolutely thrilling». From his cockpit, Piccard observed the Statue of Liberty and the pyramids of Giza. But the most moving moment was a live videoconference with UN headquarters in New York, last April, during the signature of the Paris Agreement on climate change. While flying over the Pacific towards California, Piccard commented over the radio to Secretary-General Ban Ki-moon: «If a plane can fly day and night without fuel, then the world can be a much cleaner place». Solar Impulse was not so much carrying its pilots as conveying a message: sustainable energy is within our grasp and the possibilities are almost infinite.

ON MARS. But was it worth spending 177 million dollars and risking the lives of two men? Is it true that, in the next few years, commercial aircraft will transition to solar power? Giancarlo Genta, professor of engineering design at the Polytechnic of Turin, does not think so: «Solar-powered aircraft are notoriously slow, and in bad weather downright dangerous. The Sun emits massive quantities of energy, but in diluted form: at most 1.4 kW per square metre. Even if solar cells could achieve 75% efficiency, it would take 1 m2 of them to generate 1 kW (the power of a domestic iron). But to fly a plane you need tens of megawatts (= 1,000 kW): entire football pitches covered with solar cells. Solar propulsion makes sense for space travel: a cargo ship bound for Mars could take off using conventional fuels then, once in orbit, deploy 20,000 m^2 (215,278 sq.ft) of solar panels. It would then travel slower, but would need far less fuel».

A HYBRID SOLUTION. But one aspect of Solar Impulse really will revolutionize air transport: the use of electric motors, which are far more efficient than internal combustion engines. «The future of flight will be hybrid», predicts Giulio Romeo, professor of aerospace engineering at the Polytechnic of Turin. «The planes of the future will have electric motors powered by a combination of hydrogen fuel cells and solar cells. This will enable them to fly at 500 kph (310 mph) and transport dozens of passengers. Another promising application are drones: powered by the Sun, as well as by hydrogen, they can remain airborne at high altitude (20-25 km / 12-15 miles) for six to eight months, without having to land. They could be used for monitoring immigration, forest fires, smuggling and agriculture. The great advantage is that, while conventional aircraft cost 9,000 euro per hour to deploy, drones cost a mere 1,500. In Turin, we have designed an aircraft of this kind, Heliplat, with a wingspan of 73 metres (240 ft). The prototype performs well and we are looking for sponsors».

In short, the quest for clean sources of energy is hotting up. Piccard is well aware of this, having founded the International Committee of Clean Technology, a 400-strong group of companies, to offer governments environmentally friendly energy solutions for everyday life. «The Committee also includes Watly, an Italian start-up that has invented a solar-powered water purifier which also generates electricity», reveals Piccard. «Within two years, we hope to be able to offer a thousand-solution package to national governments. It has been well worth the effort: we are on the right track».

Vito Tartamella

A 35-YEAR OLD DREAM

SOLE MIO. The dream of solar-powered flight is nothing new: it has been around for more than 35 years. More than 40, if you count the earliest experiments with solar-powered models (weight: 12 kg, 26.4 pounds), first flown in the USA in 1974. The first solar-powered aircraft able to carry a person dates from 1981: the Solar Challenger, a 90-kg (198 pounds) ultralight, with which its constructor, the American Paul MacCready, managed to cross the English Channel, covering 262 km (163 miles) in five hours. The stage was set. Two years later, in 1983, the German Günter Rochelt built Solair I, a machine with a wingspan of 16 metres (52 ft) that flew in Germany for five hours 41 minutes. Another record was broken in 1990: the American Eric Raymond, on board Sunseeker, flew 400 km (250 miles) across the USA in 21 stages, airborne for 121 hours, but only in the daytime. In 1996 an Italian , Antonio Bubbico, built an aircraft called "O sole mio", but was unable to test it. Meanwhile, between 1997 and 2003, NASA experimented with large solar-powered drones (wingspan 30 metres / 98 ft), which reached altitudes of 29.5 km (18 miles).