Focus

Vito Tartamella - articles translated in English

Science

In London, we visited the world's oldest biobank: it stores and despatches thousands of viruses and bacteria all over the planet, from plague to Ebola. All in aid of research.

The most dangerous bank on Earth

Photos by Christian Sinibaldi - Translation by Simon Knight

HANDLE WITH CARE. A biologist at the Culture Collections in London, where thousands of viruses, bacteria, cells and fungi are conserved.

Their website is simplicity itself: you just type in the name of the product you are looking for and the details are displayed, along with the price. But the catalogue is terrifying: for € 390 you can order the SARS coronavirus. More affordable is *Yersinia pestis*, the bacillus responsible for bubonic plague: € 348. But the real bargain is the Ebola virus (*Zaire Ebolavirus*): it comes free; you only have to pay the cost of carriage.

You might think this was a website run by bio-terrorists, but the masthead features the reassuring logo of the British NHS. The UK's public health agency provides an extraordinary service: conserving and sending by post, in unbreakable packaging, thousands of micro-organisms –including some of the most deadly – to scientists worldwide.

Culture Collections (www.phe-culturecollections.org.uk) is in fact one of many bio-banks established in different parts of the world (*see box on following page*). Rather than conserving agricultural seeds, their freezers contain dangerous infectious agents: 400 viruses and 5,000 bacterial cultures, as well as 40,000 cell lines and 4,000 strains of fungi. One of the most important international collections of its kind, and by far the oldest, it has been going for almost a century. How does it operate? What purpose does it serve? And, above all, is it safe? *Focus* magazine went to find out.

DEEP-FROZEN. Access is permitted only after a lengthy bureaucratic process. The most deadly viruses, those with a bio-security rating of 4 (fatal and infectious even when airborne), are kept at Porton Down, to the west of London, in airtight rooms, which can be entered only after strict security checks via armoured doors with combination locks. The bacteria, meanwhile, are stored by the Health Protection Agency in Colindale, north London. At these facilities, the cells, handled with long rubber gloves protruding into sealed biosafety cabinets, are carefully monitored and conserved in vials: first they are frozen in liquid nitrogen at -196°C, then kept in special freezers at -80°C.

«To keep the cultures alive and free from contamination, we need to carry out lots of tests» explains Julie Russell, the bank's director. «First we have to get them to ▸

PREPARATION.
Vials of bacteria in a dryer: without water they can be stored for many years.

There is a bacterium that Fleming extracted from his nose

proliferate and, in some cases, as with the Koch bacillus, which causes tuberculosis, this may take up to six weeks. Then we perform a whole battery of bio-chemical, genomic and morphological tests. It takes three months to carry out all the checks on just one strain of micro-organism: all it takes to contaminate them is one micro-plasma (a very small bacterium - *ed.*), which is invisible using an optical microscope. We then freeze and store them, checking each year to make sure they are still alive».

BUDGET. So what is the purpose of this complex organization? Conserving this delicate biological material is only part of the work. The crucial phase is the shipping. «Our collections», explains Russell, «are used by scientists who study these pathogens to perform diagnostic tests or develop new treatments, whether antibiotics or vaccines».

LIVING ARCHIVE.
A filing cabinet full of test tubes: each contains a strain of bacteria, which are stored in refrigerated rooms.

One of the items most in demand this year is the Zika virus, which has raised enormous concern in Brazil because it causes malformations of the foetus. «We have three strains in our collection», continues Russell. «One was extracted in 1962 from a mosquito captured in the Zika Forest in Uganda. A second strain was isolated in the USA from a man from Puerto Rico in 2015, and a third was taken from the sperm of a patient from Guadeloupe, hospitalized in the United Kingdom: it will be available shortly, for € 298.50».

But why make people pay? Maintaining a biobank is expensive. For the first fifty years of its existence, the British institution was financed by the Ministry of Health. «But since 1970 we have been self-supporting», says Russell. «Our annual budget is £ 5 million (€ 5.83 million): 80% is derived from sales of biological material, the remainder from funding by other organizations».

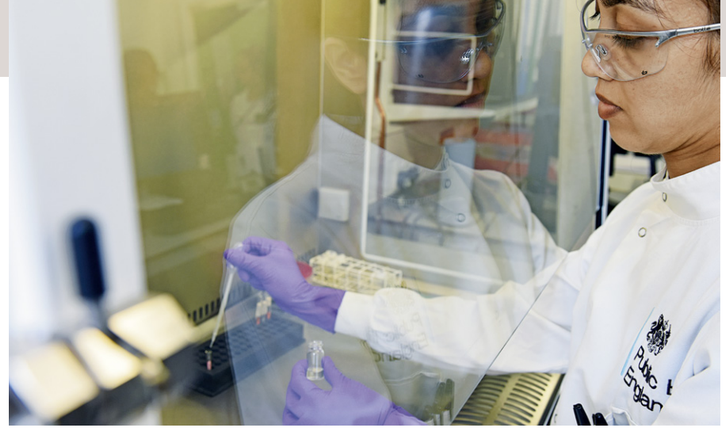
How do you send a test tube containing millions of Ebola viruses or anthrax bacilli weighing just 0.15 grams? «We run a very tightly controlled operation, largely automated, in which time is the crucial factor: we cannot allow the material to be destroyed or lost. Or end up in the wrong hands», replies Ana Deheer-Graham, scientific coordinator of the Bacteria Collection.

The first step is to check the scientific credentials of those requesting micro-organisms. Recipients must be scientists working for a public or private laboratory equipped with the necessary safety structures. They must also complete a number of forms explaining why the virus or bacterium is needed, and undertake not to pass it on to others. «We do not send anything until we have checked every detail», adds Russell. «All request must be authorized by the Foreign Office. Checks can take two or three months, and not even we know what factors they take into account. Authorization may also depend on political circumstances».

PERMITS. The most critical countries? «Arab States and Iran. And less developed countries, which often do not have adequate laboratories for storing these organisms», replies Deheer-Graham. «But even shipping material to the USA or Australia is beset with bureaucratic complications: they have very rigid legislation on imports of biological material. It takes three months to obtain all the necessary permits, then you have to add the delivery time».

The bacteria are transported in vials, dehydrated, with 97% of the water removed. We then extract the air and seal the vial under intense heat. Treated in this way, bacteria can survive for up to 50 years. Viruses, on the other hand, are freeze-dried in small plastic test tubes, or in a liquid suspension, and placed in a container with dry ice, which keeps them at a temperature of –80°C. Clients can request just the RNA extracted from the virus, which is not infectious and can be used for diagnosing infections. Both types of product are transported in unbreakable packaging. A team of 20 people work exclusively on the logistics: preparing the material, packaging it and handing it over it to one of the two specialized courier firms approved by the British government. And shipments are tracked up to the moment of delivery.

Micro-organisms also travel in the opposite direction: scientists who discover new sources of infection, or mutations of al- ▸



DROP BY DROP.
A biologist prepares a culture: she must take care not to contaminate it and herself avoid getting infected.

THE 9 MOST DANGEROUS MICRO-ORGANISMS IN THE COLLECTION

BEWARE. The British Culture Collections conserve many deadly organisms. The most high-risk bacteria are: ***Bacillus anthracis*** (which causes anthrax), ***Francisella tularensis*** (tularemia), ***Yersinia pestis*** (plague), ***Salmonella typhi*** (typhoid fever), ***Mycobacterium tuberculosis*** (tuberculosis), ***Brucella*** (brucellosis). The most dangerous viruses are: ***Zaire ebolavirus*** (Ebola), the yellow fever virus and the dengue virus.

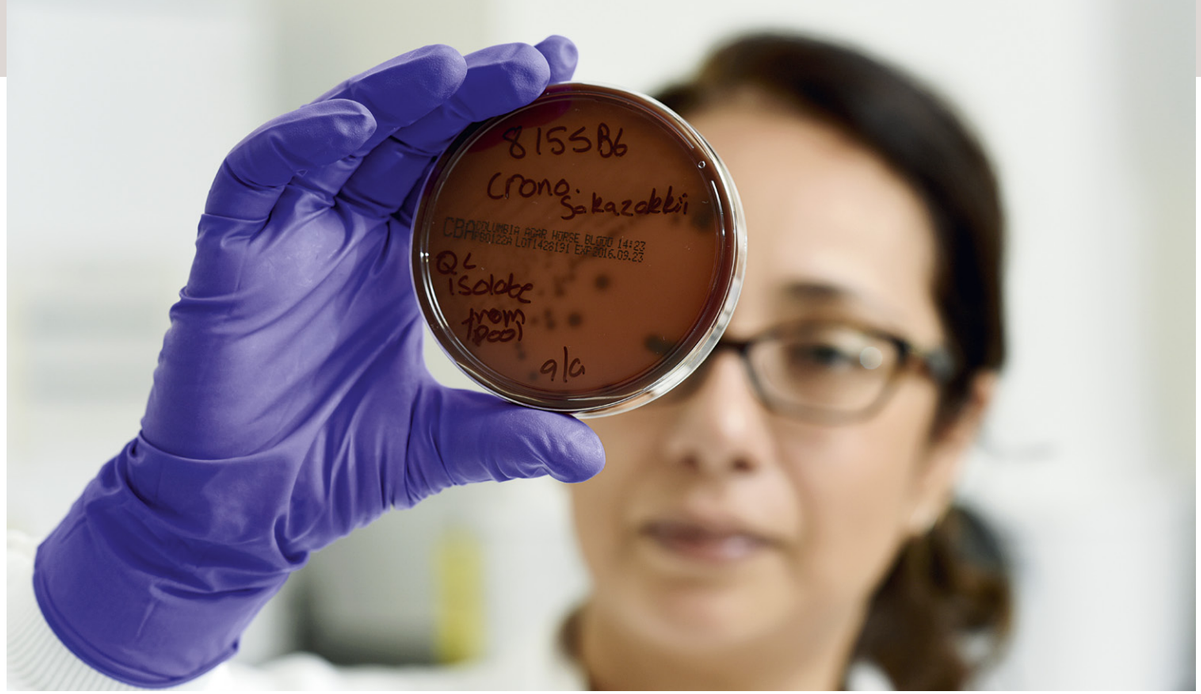
BIOBANKS: 700 AROUND THE WORD (15 IN ITALY)

STRAINS. According to the World Federation for Culture Collections (WFCC), there are currently 710 biobanks in 72 different countries. Together they conserve more than 2.5 million bacteria, fungi, viruses and cell lines. The largest, in the USA, is the ATCC, which has 18,000 strains of bacteria and more than 2 million viruses. In Europe, there are biobanks in Germany, Sweden, Belgium, Spain, France and the Netherlands. And many are joining together to form pan-European institutions: France hosts the virus archive (Evag), the United Kingdom the stem-cell biobank (Ebisc).

So what about Italy? It has 15 biobanks, mostly concerned with food and agriculture. The Umcc at the University of Reggio Emilia, for example, conserves the yeasts and bacteria used in producing wines, vinegars and cheeses, especially Parmesan.

Per gentile concessione Culture Collections

WAREHOUSE. Right, the Collection's logistics department: the cylindrical containers are liquid-nitrogen freezers, operating at temperatures as low as -196°C. Below, testing to ensure that the vials are hermetically sealed.



CATALOGUED AND CONTROLLED. A culture of *Cronobakter sakazakii*, a bacterium that infects new-born babies and may be fatal. Bacteria can be stored for up to 50 years.

ready known bacteria or viruses, can send them to the Collection, which will store them for future research. One such sender was Australian doctor Barry Marshall: in 1984 he hypothesized that ulcers and gastritis were caused by a bacterium, *Helicobacter pylori*. But the scientists of the day disagreed with him, convinced that it was killed off by the natural acidity of the stomach. To demonstrate the validity of his theory, Marshall drank a culture of the bacterium: two weeks later, he was afflicted with gastritis. Marshall won the Nobel Prize and sent his Heliobacters to London! Indeed, a number of organisms that have made history are conserved in the Collection: 16 cultures were deposited by Alexander Fleming, the discoverer of penicillin. He extracted *Haemophilus influenzae*, a bacterium that can cause meningitis, directly from his nostrils. The earliest samples in the Collection, founded in 1920 by the bacteriologist Frederick William Andrewes, are specimens of another bacterium, Shigella dysenteriae, taken from the body of Ernest Cable, the first British soldier to die of dysentery in the trenches of the First World War.

PROFILES. «Those old strains are useful for studying the evolution of micro-organisms», comments Russell. «We supplied them for an international study of 330 strains of Shigella isolated during the last century. It was discovered that dysentery, now a scourge of Asia and Africa, in fact originated in Europe. Ninety-eight per cent of its genome has remained unchanged, but in the meantime it has become resistant to antibiotics».
Since 2014, the biobank has begun studying the genome (DNA and RNA) of every micro-organism. Using cutting-edge computerized sequencers, it tales just 24 hours to trace the genetic profile of each of the items in the catalogue. The project, known as NCTC3000, was funded by a grant of £1 million from the Wellcome Trust Sanger Institute, and the results are published free of charge on its website for the benefit of the international scientific community.
The Collection is perfectly placed to monitor new sources of infection, reported by hospitals in the United Kingdom and through international contacts. In 2011, for example, the Collection was involved when more than 3,000 people in Germany were affected by an epidemic of *Escherichia coli*, a food-borne bacterium that eventually claimed 53 victims. Microbiologists discovered that the source was a producer of salad vegetables who was using contaminated sainfoin seeds imported from Egypt. And this particular strain had developed a gastro-resistant capsule that made it all the more virulent.
The Collection also includes the fearsome new virus that causes Middle East respiratory syndrome coronavirus infection (MERS-COV), which has a death rate higher even than SARS. «It was first isolated in 2012, in the lungs of a patient from Arabia. It may be that this disease is disseminated via camels».
Unfortunately, it is becoming more difficult to send these micro-organisms abroad: anti-terror laws, and legislation governing biological materials and GMOs, are making the biobank's work more problematic. «And», adds Deheer-Graham, «there are no international regulations on shipping bio-material. In the past, it was easier to send material abroad; nowadays, the Nagoya Protocol (2010) stipulates that any economic benefits deriving from the use of an organism must be shared between the sending and the receiving countries. It is easier to do this within Europe than elsewhere».

TISSUES. Despite these difficulties, the Culture Collections have sent 25,000 items to all parts of the world (especially Europe) over the last year. Those most in demand, however, are not bacteria or viruses, but cell lines, i.e. samples of human tissue, both sick and healthy. At Porton Down, they have over 40,000 such cell lines, covering 50 different kinds of tissue. And this section includes the biobank's most expensive item: cancer of the cervix, costing € 574.
«Cell lines are essential for testing new drugs and checking the toxicity of substances without having to use animals», explains Russell. «Many discoveries concerning breast cancer, diabetes or the effects of cosmetics on the skin have been made using such samples. But they must of course be certified».
This is something that cannot be taken for granted. In 2012, the authoritative scientific review *Nature* invited 56 laboratories to replicate their cancer experiments in the presence of an independent expert. It emerged that only 11% had used appropriate cell models. «Some biologists think they are studying cells from breast cancer tumours, when instead they are experimenting on cervical cancer cultures», says Russell. «For this reason laboratories are increasingly turning to us for genuine samples».
What will happen to the Culture Collections after Brexit? «We don't know», replies Russell. «We are worried, like all British scientists: cooperation with Europe is fundamental and continues for the time being. We were established in 1920 to supply certified resources for the progress of science. And we still believe in this mission. This is why we send the Ebola virus free of charge: to support the search for a cure». F

Vito Tartamella

Artificial viruses? Possible, but...

EXPENSIVE. These biobanks are not accessible to criminals. But could a terrorist create an artificial virus or bacterium? The question is certainly not fanciful: as long ago as 2002, the University of New York was successful in creating the poliomyelitis virus – whose RNA has only 7,500 bases – in the laboratory. But would it be possible to create and more complex and powerful virus? «Nowadays various companies are synthesizing the genome for payment», replies Massimo Pizzato, virologist at the Integrated Biology Centre of the University of Trento, Italy. «Assembling the genome of a virus might cost between 2 and 3 million euro. But in some cases, such as the smallpox virus, assembling the DNA is a long process: it has 200,000 bases, and the cost would be much greater». However, adds Pizzato, simply replicating a virus or bacterium's DNA or RNA is not enough: «Bacteria have membranes, walls and cytoplasm that cannot be reconstructed artificially. So it would be necessary to transfer the DNA to an existing bacterium. This was achieved by Craig Venter in 2010, but very few laboratories have the resources and skills to do so. Viruses, meanwhile, contain enzymes and have a proteinic and often also lipoid involucre, which is what makes them infectious. To replicate them, a criminal would need to have an in-depth knowledge of molecular and cellular biology. And it would take months. Not to mention the fact that he or she would need expensive equipment to manipulate these organisms safely».

Every year they send 25,000 biological samples all over the world. Under strict conditions.

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 ▶

Illustration by Stefano Carrara

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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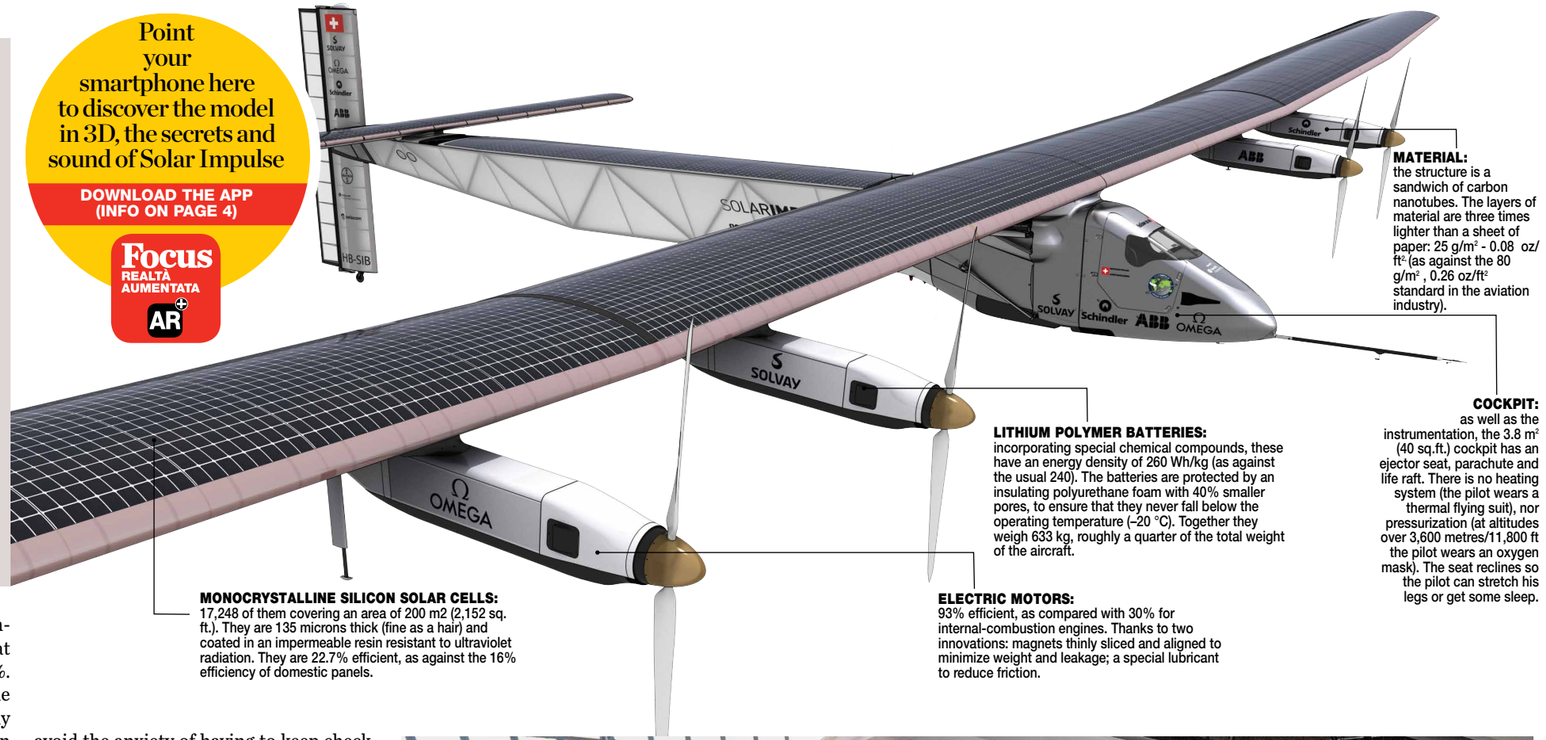


MONOCRYSTALLINE SILICON SOLAR CELLS: 17,248 of them covering an area of 200 m2 (2,152 sq. ft.). They are 135 microns thick (fine as a hair) and coated in an impermeable resin resistant to ultraviolet radiation. They are 22.7% efficient, as against the 16% efficiency of domestic panels.

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.

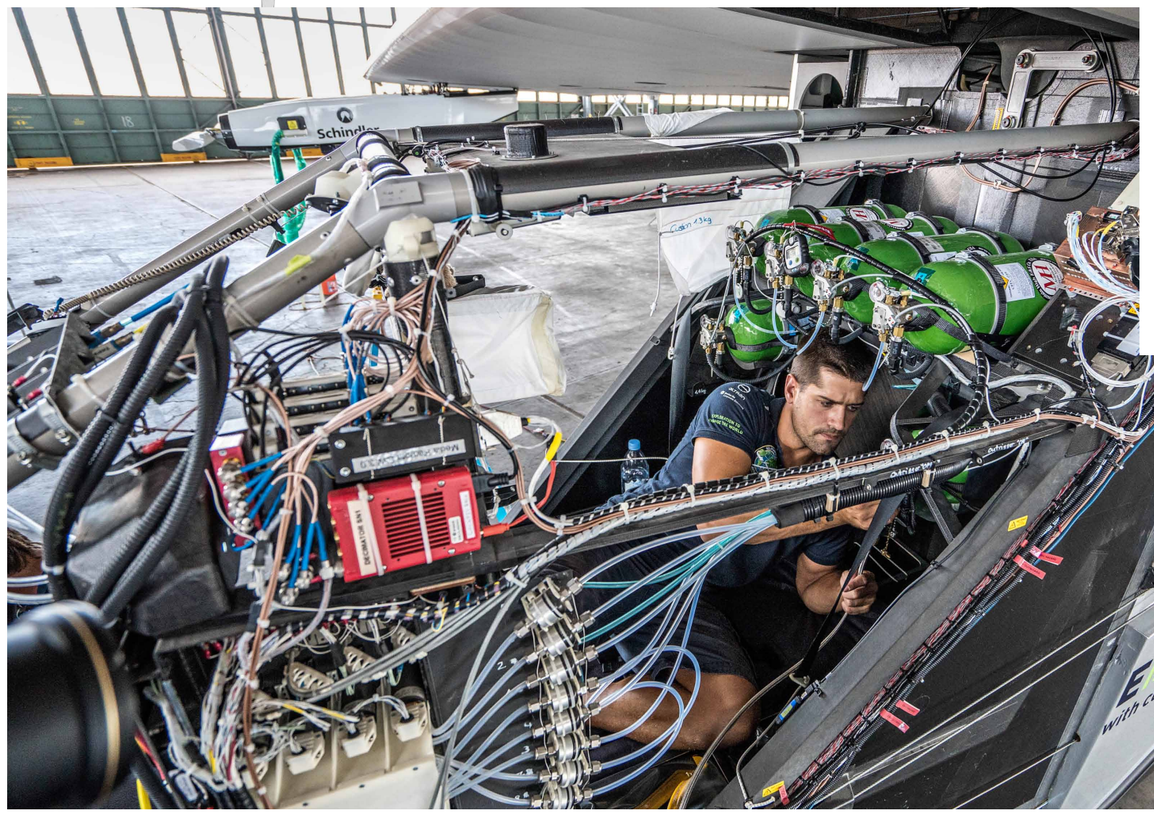
But how have these results been achieved? What spurred Piccard and Borschberg, not far short of their 60th birthdays, to risk life and limb to fly 43,041 km (26,744 miles) in an aircraft with the wingspan of a Boeing 747, the weight of a commercial van and the speed of a scooter?

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



Solar Impulse, Rezo.ch (5)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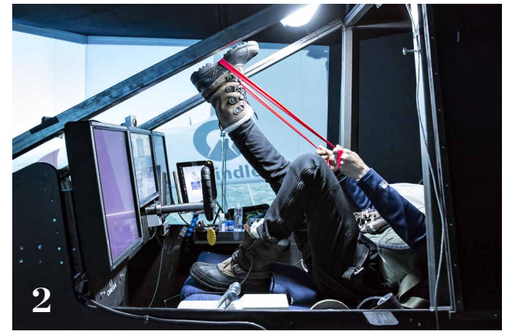
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LIGHT BUT TOUGH. Left, the cockpit: note the oxygen cylinders (green). Space is reduced to a minimum: the seat tilts backwards (photograph 1) to allow for some exercises (2). To maintain concentration, the pilots practised yoga techniques (3).

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.

Solar Impulse, Rezo.ch (3)

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).

ON A MISSION
The submarine *Scirè* leaves the Gulf of Taranto, with two sailors scanning the horizon from the fin.

SUMMARY

- In August, a *Focus* journalist sailed aboard **submarine *Scirè*,** one of the eight belonging to the Italian Navy.
- Built in partnership with Germany, it is one of the most modern of its kind, with a **long range** and the ability to operate in **silence**.
- The sub patrols the Mediterranean, on the look-out for **arms**, **drugs** and **human traffickers**.

A day on board a submarine

On board an Italian Navy vessel: an amalgam of technology, spartan living and intelligence.

A a voice comes over the tannoy: "Last man aboard. Upper and lower hatch sealed. Vessel ready to dive". I am in a room full of monitors, push-buttons and piping. A dozen men in uniform are aligned before a bank of flickering consoles. In the centre, a man is looking into the eyepiece of a large metal cylinder and turning around it...

No, this is not a film set. The cylinder is a real periscope, and I am in the control room of a real submarine: the Scirè, one of the technological jewels of the Italian Navy. *Focus* wanted to see close up how a modern submarine operates, and how the submariners live on board. So this summer, with a photographer, we set sail from the Gulf of Taranto, HQ of the national submarine fleet, and participated, for a day, in a real underwater mission.

60 METRES BELOW. After sailing a few miles on the surface to reach the open sea, we slow down for a while: the time it takes to fill the ballast tanks with more than 100 tonnes of water, the weight that will take us down into the depths. And finally the long-awaited moment arrives: the commander, Raffaele Martino, has the periscope lowered into the floor-well and gives the order: "Helmsman, dive to 60 metres". In a few minutes we shall be 60 metres below the surface. My heart is racing. I watch the helmsman manoeuvring the submarine using two small black joysticks. But were it not for the slight pitching of the bow, I would have thought we were standing still.

Not the first of my illusions punctured, nor the only fascinating discovery on this voyage. Starting with the portholes through which I expected to admire some breath-taking underwater seascapes: "Submarines don't have portholes", points out 35-year-old Martino. "They would weaken the structure of the hull. To navigate under water, we have no eyes, only ears". The submarine's "eyes" are in fact functional only to a depth of 14 metres, below which it is not possible to use the periscope. Peering through it, you can see all vessels as far as the horizon, miles away, and at night too, thanks to infrared cameras. At greater depths, you have to rely on other instruments. Not radar, which works only on the surface, nor the GPS navigator, which cannot capture signals under water. Submarines therefore have to estimate their position: via GPS they log the point at which they submerge, then, using a computer connected to gyroscopic compasses and accelerometers, they estimate subsequent positions with a margin of error of a few miles (depending on underwater currents). Maybe this is why there is a red lucky charm dangling from the instruments in question...

INVISIBLE. They navigate by dead reckoning, steering in response to sounds. To measure distance from the sea bed, they use an echo-sounder, which bounces an electro-acoustic signal off the bottom. To monitor the presence of other vessels at depth, they use passive sonar: a sort of underwater microphone that can capture sounds under water, even at a distance of several miles. "By listening to its acous- ▸

CONTROL ROOM. The Scirè's war room. Centre: the captain looking through the periscope. Right: the helmsman controlling the vessel using joysticks (photograph 1); the torpedo tubes (2).

Cosmo Laera (3)

tic signature we can calculate the number of propeller shafts and blades of another craft and work out whether it is a fishing boat, a rubber dinghy or a merchant ship. Or another submarine", says Martino.
Only rarely do they use active sonar, which detects obstacles by measuring the time it takes for a signal emitted from the submarine to bounce back: "Emitting sounds would reveal our presence. Which we definitely don't want", explains the commander. The Scirè, two railway carriages in length, is powered by hydrogen (see drawing). And it must remain invisible. "A military aircraft could find us even at a depth of 40 metres, using a sensor to detect magnetic anomalies under water", explains lieutenant Carlo Faggiana. "That's why the hull is made of a special non- magnetic stainless steel".

12 TORPEDOES. There is the same obsessive control of sound emissions. Not for nothing, the British refer to their submarines as "the silent service". The propeller, for instance, has been designed to minimize noise (the patent is top secret), and the engine room with its electric motors is installed in a soundproof box suspended on springs. When the commander closes the door of the engine room, the deafening 80 decibels of noise within becomes almost imperceptible: "See how quiet it is!", Martino remarks proudly.
Thanks to this advanced technology, during a NATO exercise in the Atlantic in 2008, the Todaro, the Scirè's sister submarine, was able to escape the attentions of a whole naval squadron and come up a

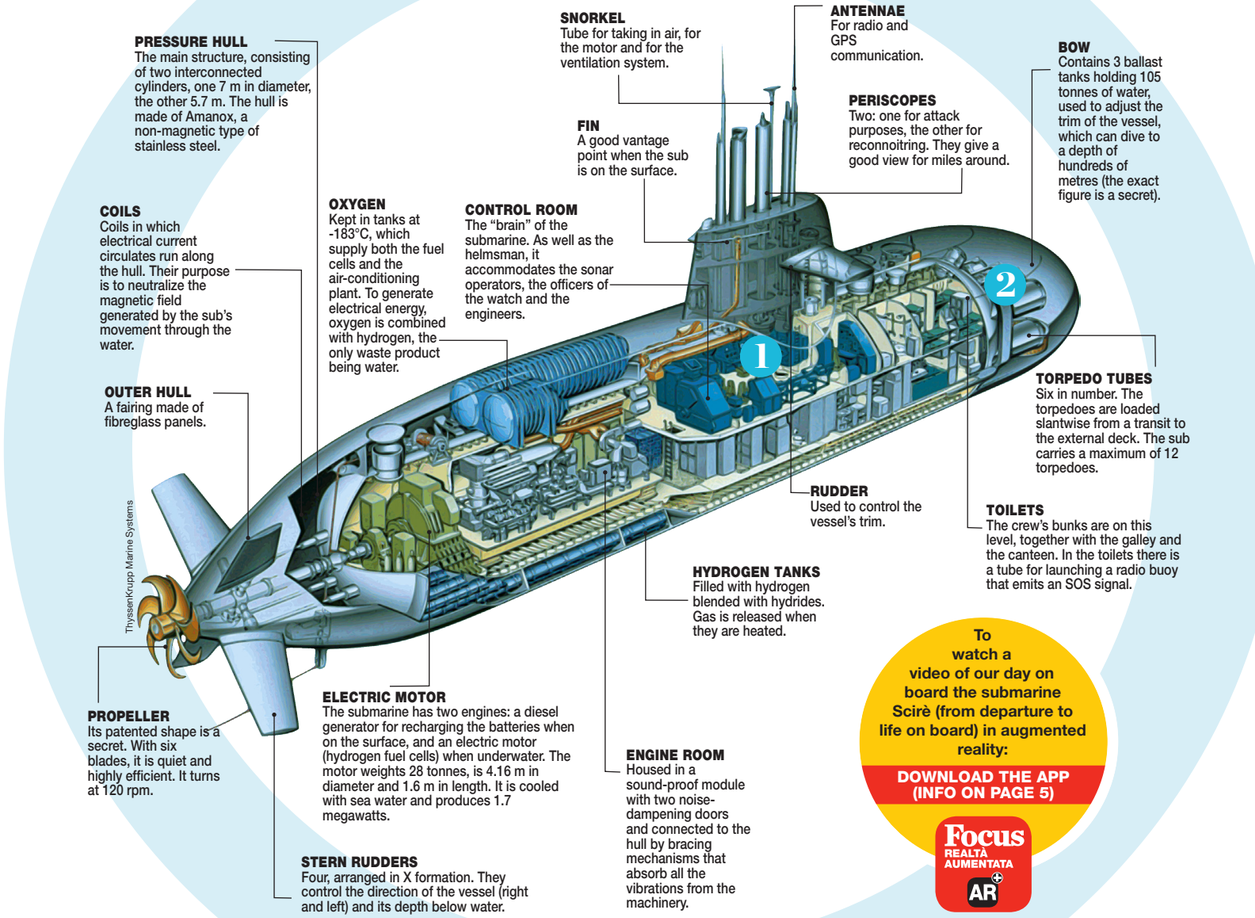
The vessel is designed to be silent. And invisible

few miles from an American aircraft carrier, the Theodore Roosevelt, taking photographs of it through its periscope. From that position, it could have hit the carrier with one of its torpedoes: all you need do is press the "Fire" icon on one of the monitors. "We have 12 torpedoes here on board", says Martino. "It would take two to send a 300-metre-long carrier to the bottom. The technique is to explode the torpedo under the enemy's keel, creating a shock wave violent enough to break a ship in two." A theoretical scenario, of course! As we shall see, the submarine's mission is something very different.
But all this "invisibility" comes at a price, above all the total isolation of the 27-man crew. "Radio waves do not penetrate under water", Faggiana points out. "Or rather, they penetrate to a depth of just a few metres and only very very slowly, using the lowest frequencies on the radio spectrum." How this system works, we were not to find out . The only area off bounds to us during our visit was in fact the radio room, the door of which bears the inscription 'Top secret SS/NATO'. "At night we come up to periscope depth, raise the antenna and communicate via satellite with our command centre", says Martino. "As well as transmitting service communications, we send messages to the crew members' families: twice a week, my colleagues give me a file of texts for their families and, before sending it, I have to check that it contains no sensitive information. In addition, we receive a compendium of news flashes from Italy and the world at large." A way of not feeling totally isolated. And for checking whether or not someone has won the football pools... Such modest activities, together with films, books and fitness training (there are exercise bikes and weights in the most unexpected corners of the sub), of passing the time between one 6-hour shift and another in this steel cylinder secretly prowling the ocean depths.
Shifts are interspersed with meals prepared in the sub's galley. Today's menu is fresh pasta with a tomato, ricotta and a spicy salami sauce, and roast chicken with savoy cabbage. "And at one o'clock in the morning, we traditionally have pizza baked in the ship's oven", adds Faggiana.

BUNK BEDS AND LOOS. There are minor comforts in this spartan way of life, despite the many myths concerning submarines: "I joined the Navy because I was fascinated by the film *The Hunt for Red October*", the commander tells us. "But then I discovered that there was nothing very realistic about it." For example, sailors smoking in shirt-sleeves, but all the crew of the Scirè wear heavy flame-proof suits, even at the height of summer. And smoking is forbidden. "The greatest ▸

THE SUBMARINE *SCIRÈ*

Built by Fincantieri, the vessel is the result of twenty years' technical cooperation between Italy and Germany. The Germans supplied the electric motor (Siemens) and the optical components of the periscope (Zeiss). Italian suppliers contributed the stainless steel hull (AST), the torpedoes (Leonardo), and the automated steering system (Avio).
Surface displacement: 1,450 tonnes
Length: 56 m
Beam: 7 m
Height : 14 m (fin included, but excluding periscopes)
Speed: 12 knots (22 km/h) on the surface, 20 knots (37 km/h) under water
Range on the surface: 8,000 miles (14.816 km)
Range under water: 420 miles (778 km)
Crew: 27 sailors (including 6 officers)
Engines: 1 permanent magnet motor, 1 diesel generator
Armament: six 533 mm torpedo tubes



To watch a video of our day on board the submarine Scirè (from departure to life on board) in augmented reality:
DOWNLOAD THE APP (INFO ON PAGE 5)
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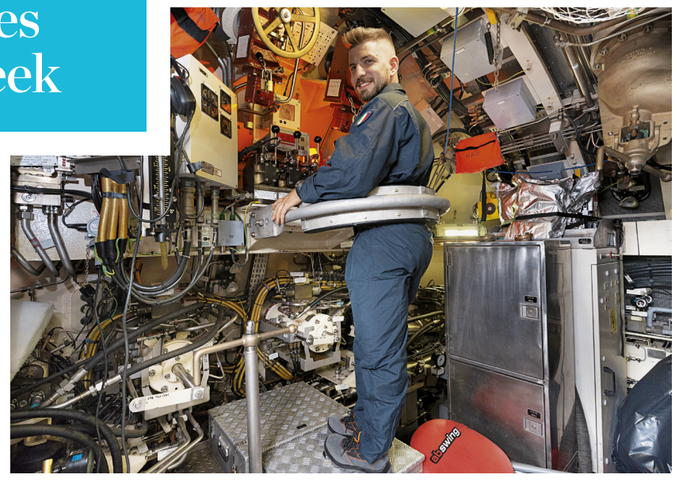
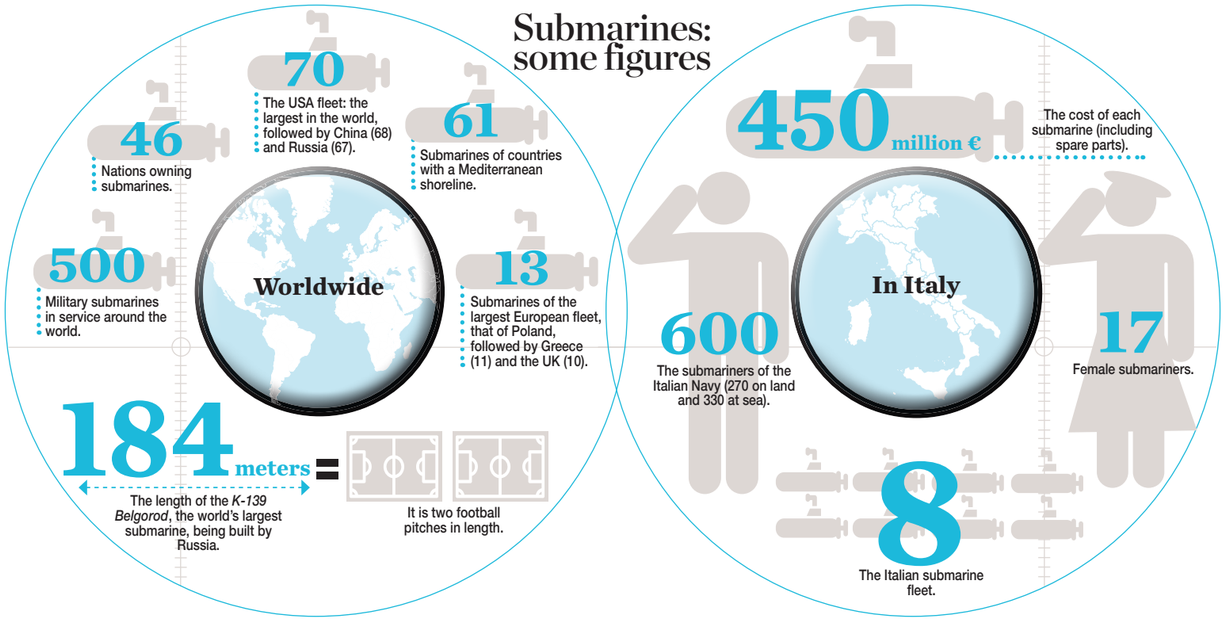
Courtesy Marina Militare

Family contact: two short text messages each week



Cosmo Laera (2)

LIKE SARDINES. Above: maintenance being carried out inside a torpedo tube. Below: the emergency steering stand. Right: the crew's couchettes, with lockers for personal items in the centre.



danger on board is not a crack in the hull, but fire", explains Faggiana.

All along the submarine (the terms "submersible" is incorrect: it refers to craft that go underwater only occasionally) runs a tube fitted with valves at half-metre intervals: "This is the Built-In Breath System (BIBS)", explains lieutenant Faggiana. "It supplies air when you plug into it with a rebreather, in the event of a fire or emergency, for instance if the sub becomes stranded on the sea bed and we have to evacuate."

In the last 19 years there have been 34 recorded accidents affecting submarines: the most recent in 2017 when the Argentinean ARA San Juan went down with 44 men on board. But these are rare occurrences in a job that is nevertheless very demanding. Nowadays, fortunately, the tradition of hot racking (two sailors sharing a bunk and changing places at the end of each shift) has died a death. Every crew member now has his own berth, but they are just cramped couchettes separated by curtains, each equipped with a 30-cm-square locker. Only the commander has his own private space, the size of a lift cabin. And there are just two toilets. One houses an ejector tube designed to launch an emergency buoy that transmits an SOS signal, the other a tube used to dispose of organic wastes (but not excrement, which is treated chemically on the submarine).

POTATOES AND ONIONS. "On board, we are careful about managing and sorting wastes. We avoid using glass, while plastics and cardboard are stored in bins and offloaded when we are in port. And to save space, we have a compactor", Martino tells us. Every square inch is precious: in the torpedo room, stowed in odd corners, are sacks of potatoes, courgettes, onions and apples. Everywhere there are stacks of mineral water bottles.

A mission lasts an average of three weeks, followed by one week of shore leave, then another three weeks on the submarine. Now I understand why their wives were hugging the submariners so ardently on the quay in Taranto before we sailed.

In three weeks' time, the crew are due to land on a Greek island, where they will find a change of clothing and other personal effects, transported there by container. Every mission requires complex logistics involving a hundred or so people. But what is the point of all these sacrifices? What are they doing in the ocean depths?

STRANGE GOINGS-ON. In recent years, the international strategic websites inform us that the Russian presence has intensified, both above and beneath the Mediterranean... But this is something commander Martino prefers not to discuss.

"Ours is an intelligence function", he tells us. "We monitor mercantile shipping and the risk of smuggling. We are on the lookout for trafficking in drugs, weapons and human beings. Also polluters and possible terrorists. If we observe suspicious movements, vessels sailing unusual routes or failing to transmit their data to the automatic identification system (a sort of automated register of maritime traffic), we keep tabs on them. Through the periscope we can film things that are happening miles away. A few years ago, one of our submarines filmed a fishing boat that was towing two craft carrying migrants, then it cut them adrift. Thanks to our video, the police were able to arrest the traffickers. A satisfying outcome, even though, in the best traditions of the service, our contribution remained secret: no one knew anything about it."

Vito Tartamella

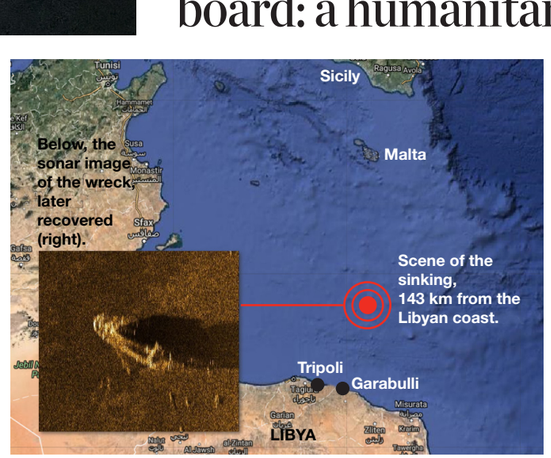
(translated by Simon Knight)

READY TO DIVE.
One of the divers of Comsubin, the specialised unit of the Italian Navy that took part in the recovery of the fishing boat and the victims.

Marina Militare (3)

ANATOMY OF A SHIPWRECK

The recovery of the boat that went down in the Strait of Sicily with 800 migrants on board: a humanitarian and scientific challenge.



Below, the sonar image of the wreck, later recovered (right).

THE STORY: A TRAGEDY OF OUR TIMES

NAVIGATION. The traffickers first sailed from Egypt in a fishing boat. On 18 April 2015, they reached the Libyan coastline and waited offshore while the migrants were ferried across on rubber dinghies from the beach at Garabulli. Their passengers, numbering roughly 800, mostly young men, were from Syria, Ethiopia, Somalia, Senegal, Mali, Gambia, Côte d'Ivoire and Bangladesh. Each had paid at least $US 1,500 for the trip. Those who had paid more were accommodated on deck; the others were packed into the hold and the engine room. After several hours' sailing, one of the two traffickers on board (a Tunisian and a Syrian) telephoned the Italian Coast Guard requesting assistance. The nearest vessel, the Portuguese container ship King Jacob, was diverted to the area. But one of the traffickers miscalculated and steered the fishing boat into the larger vessel, causing it to sink. Only 28 of the occupants (including the two traffickers, who were subsequently arrested and given custodial sentences) escaped alive.

A reconstruction of how the fishing boat was raised from the seabed: watch the video in enhanced reality.

DOWNLOAD THE APP (INFO. ON PAGE 5)

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Marina Militare (2)

DELICATE MANOUEVRES. Right, a naval rating monitors the recovery of the wreck, which is hitched to a crane (below). The boat will go on show at Milan's Museum of Human Rights.

After almost three years of hard work, it may be possible to identify 80 of the victims.

The jacket had a strange feel to it . In the lining was in fact concealed a plastic bag. It contained a sheet of paper covered in writing, rubber stamps and figures. They were marks: an eighth-grade report card issued by a school in Mali. It belonged to Ibrahim, a 16-year-old. He had carried it with him throughout his dangerous 5,000-kilometre journey. He wanted to prove he had completed his secondary studies, so he could continue his education or find a job. Ibrahim's story – we have changed his name as a matter of respect – could have remained buried for ever on the seabed. The fact that we now know his identity, and that his parents will be able to grieve over his tragic loss, is thanks to a historic achievement in maritime technology. And the operation to recover a boat packed with migrants that sank on 19 April 2015 off the coast of Libya is also revolutionising the science of identifying disaster victims.

This was the most tragic shipwreck in the recent history of the Mediterranean, claiming at least 800 lives. And it was also the most complex recovery operation ever attempted: the fishing boat transporting the young people, aged between 10 and 30, from the poorest countries in sub-Saharan Africa, lay in open water at a depth of 370 metres. Hundreds of people – naval personnel, forensics experts, firefighters and volunteers – have been involved for almost three years in this arduous mission. And now we are beginning to see some results: after circulating requests for information via the consulates and International Red Cross offices of dozens of countries, the Office of the Commissioner for Missing Persons – the Italian authority that coordinates investigations concerning nameless victims – has received the details of 156 missing migrants, supplied by families living in Africa, Asia and Europe.

THE CHALLENGE. «There is a good chance that we shall be able to identify 80 of them», the outgoing Commissioner, Vittorio Piscitelli told *Focus*. «And in the case of six of them – five young people from Mali and one from Côte d'Ivoire – we have an almost perfect match».

How has this been achieved? The operation has been an unprecedented challenge, from a technical/scientific and human point of view. According to Rear-Admiral Paolo Pezzuti, commander of Comsubin, the Navy diver and special forces unit that has coordinated the operation: «The wreck had settled on the seabed in the Strait of Sicily, 143 km from the Libyan coast, at a depth of 370 metres. No one had ever undertaken a recovery operation of this kind». In 1997, it is true, an Albanian launch was raised from a depth of 800 metres in the Strait of Otranto: «But on this occasion we had to recover a wreck in open water, where the weather conditions are often hostile. And rather than transport it 74 km to the nearest harbour (Brindisi), we had to make for Augusta (Siracusa): a distance of 365 km».

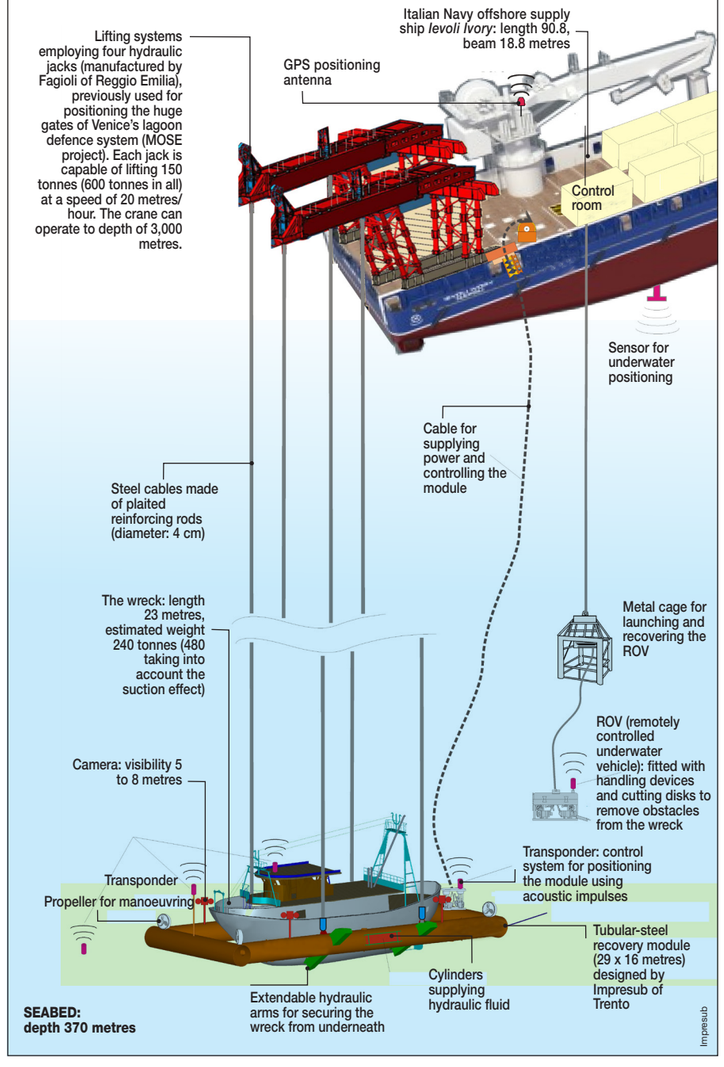
To further complicate matters, the wreck weighed 240 tonnes, as compared with 35 for the Albanian launch. Moreover, the fishing boat was embedded in the mud, so the load to be raised was in fact 480 tonnes because of the suction effect drawing it to the seabed. It was like lifting a 12-coach railway train to the height of the Empire State Building. «We entrusted this mission» Pezzuti told us «to Impresub, the same company as had recovered the Albanian launch».

DUMBSTRUCK. While a remote-controlled vehicle belonging to the Italian Navy was beginning to recover the migrants' bodies, Impresub produced a digital reconstruction of the wreck, using an underwater robot (ROV) equipped with laser sensors to carry out a 3D survey. They then designed a made-to-measure recovery module to support and lift the wreck (see drawing on left): a steel rectangle a third the size of a football pitch, fitted with propellers for manoeuvring, sensors and cameras: the largest ROV ever created. And to lower it to the seabed and secure the fishing boat, they used one of the cranes deployed to lay the huge underwater gates of Venice's lagoon defences (MOSE project).

The recovery mission began on 19 April 2016, one year after the sinking: «We had to work within tight limits», explains Captain Giampaolo Trucco. «We could only operate in grade 2 conditions or less (waves up to 50 cm), and we needed five consecutive days of good weather to complete ▶

AN OPERATION THAT TOOK MORE THAN A YEAR

THREE PHASES. The recovery of the sunken fishing boat was a 3-phase operation:
1) May 2015: an Italian Navy minesweeper, using an autonomous underwater vehicle (AUV), finds the wreck.
2) October - December 2015: A naval Remotely Operated Underwater Vehicle (ROV), using its mechanical arms, recovers 169 bodies from the seabed. The company responsible for the operation, Impresub, designs a module for raising the wreck.
3) April - June 2016: the recovery operation begins. The offshore supply ship Ievoli Ivory sets sail from Ravenna, escorted by a flotilla of naval vessels: the salvage ship *Anteo*, carrying the specialised divers; the *San Giorgio*, to ensure security in the area; the *Tremiti*, fitted with refrigeration units for the bodies; and the support ship *Alghero*. 200 people in all. On 27 June, the wreck is raised to the surface and on 30 June is brought in to the port of Augusta after a 365-km journey. Here, at the NATO base of Melilli, a team of forensics experts performs autopsies on the bodies. The operation has cost EUR 9.5 million.



ONGOING INVESTIGATIONS. Remains of the victims being examined in a tent erected at the Melilli NATO base. Below and in the larger photograph: forensics expert Cristina Cattaneo examines some of the artefacts recovered from the seabed: clothing and personal effects.

Ap/Ansa (2)

Roberto Caccuri (Contrasto)

Tattoos, teeth, birthmarks: all useful in reconstructing a person's identity.

the operation. This was because it took the ROV 20 hours to reach the seabed, and another 20 to return to the surface. But in that area conditions change very quickly: twice we hooked on to the wreck but had to lower it back to the bottom because of sudden rough seas».
They had to wait more than two months for favourable conditions. Then, on the evening of 27 June, at 22.28, the wreck broke surface. «In the stern and on deck were an undefinable number of skeletons. It was a sight that affected us profoundly: we were all struck dumb».

A LAST EMBRACE. On 30 June, the wreck arrived at the NATO base of Melilli (Siracusa), where the second and no less difficult part of the operation began: the autopsies to identify the victims. The fire brigade removed from the boat, refrigerated with liquid nitrogen, hundreds of corpses in pitiful condition: saponified bodies, with the parts not covered by clothing (faces and hands) gnawed to the bone by fish . Many of those trapped in the hold were holding each other in their arms.
How could their identities possibly be established? The currents had scattered the bodies over an area of 2 km², often mixing their remains, which filled 450 body bags. All were examined by a team of volunteer forensics experts, coordinated by Cristina Cattaneo of the Milan-based University Laboratory of Forensic Anthropology and Dentistry (Labanof). «Those nights», Cattaneo tells us, «I dreamed of walking along a path and finding other bones on the ground; I was afraid I had lost some».
But why so much effort to be able to name these victims? The recovery operation was decided on by the then prime minister, Matteo Renzi, as a wake-up call to the EU authorities to take political measures to stem the flow of migrants. But the operation also had an important humanitarian purpose: to provide answers for the living. «Many people think that no one is searching for those unfortunates, but they are wrong", explains Cattaneo in her book *I diritti annegati* (*Drowned rights*, pub. Angeli). «A nameless body is unfinished business . The loss of a family member leaves their relatives in a kind of limbo, their suffering unresolved. And it leaves people unable to get on with their lives: widows who cannot remarry or inherit their spouse's property, or children who cannot be adopted by other relatives. So, identifying migrants who die trying to reach Europe is an act of respect for their dignity. After all, no one is scandalised when people and resources are mobilised to identify the victims of a plane crash or an earthquake».
Identifying the victims of this particular shipwreck, though, was very difficult. Only 70 identity documents were found on the seabed: many migrants travel without them, so they are not obliged to apply for asylum in the first country they come to. Then there was the terrible state of the bodies after twelve months under water. And the remoteness of the family members from whom confirmation was needed.

UNIQUE SMILES. «To identify a victim, you have to compare the post-mortem data (the person's physical appearance, DNA, fingerprints, teeth) with ante-mortem information: photographs, genetic samples, dental records», explains Cattaneo. «But in the case of migrants, no such data exists: their relatives are too far away to provide DNA, their fingerprints are not kept in European databases, and they don't have dental records. So we have to focus on secondary data: we photograph the bodies in search of distinguishing features, such as birthmarks, tattoos or scars. Their configuration, when compared with an ante-mortem photo of the deceased is a sure means of recognition». This method was used for the first 169 bodies recovered from the wreck, those in best condition.
For the others, mere skeletons or totally unrecognisable , the Lab adopted a different approach: they performed 3D scans of the skulls, which could be superimposed, using computer technology, on the photographs of possible victims sent by relatives.
«If the two images match, we get the relatives to send us a sample of DNA (e.g. on a toothbrush) to compare with the DNA of the victim, to see if they correspond. But when the smile of a deceased person is visible in a photograph, and the profile of his teeth matches that of a skull we have scanned, the identification is unambiguous: dental profiles are unique».

20,000
The number of migrants lost in the Mediterranean since 2000. At least 65% of them have not yet been identified. (IMO estimate).

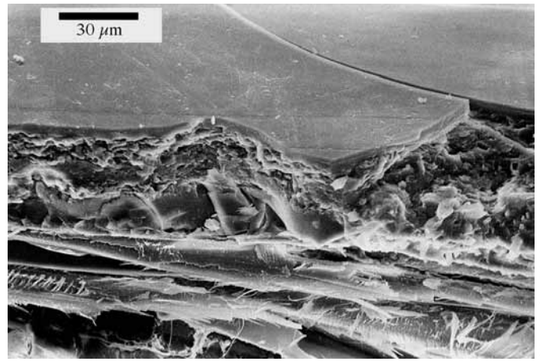
A POCKETFUL OF EARTH. This is why the medical experts have not only taken samples of DNA, photographed the bodies and taken fingerprints, but have also catalogued the personal items recovered: wallets, T-shirts, USB pen drives . Some of the victims had concealed in their clothing a plastic bag containing a handful of their native soil: a souvenir of a one-way journey. "You can't perform these investigations without feeling compassion", says Cattaneo.
The experts are now keen to extend this methodology to all persons lost in the Mediterranean. «We are faced here with a tragedy that defines our day and age», says former Commissioner Piscitelli. «And identifying the victims is an act of respect for their dignity and for their surviving relatives. Existing legislation, however, does not prescribe autopsies and DNA sampling of all dead migrants: the magistrates generally focus on the people-traffickers and how the survivors should be dealt with. I have therefore officially asked the Italian judiciary to ensure that DNA samples of shipwreck victims are taken in all cases and entered in the Italian Lost Persons database, which is managed by the police. But this is just a first step: the database is available only to the security forces and only general parameters are included. Meanwhile our office, with a staff of seven, has to manage 15,000 cases every year. More resources are needed for this operation: data on victims needs to be gathered by the Mediterranean countries and managed by an international authority. But the EU has turned a deaf ear».
In the meanwhile, the Mediterranean continues to swallow up victims each and every day. Many will remain nameless and their families will never know what became of them. As may well happen in the case of young Ibrahim. F

Vito Tartamella
(translated by Simon Knight)

LIVES DESTROYED. Below, some of the items found on migrants: comb, USB pen drive, dental hygiene stick, medicines, money, sim card. All catalogued with the letters "PM" for post mortem.

The Stradivarius mystery

Science investigates the secrets of the luthier from Cremona, creator of the world's most highly prized violins



Gent. conc. C.Y. Barlow e J. Woodhouse, Cambridge University.

UNDER THE MICROSCOPE. Magnification of the surface layer of varnish (0.03mm) of a cello made by Pieter Rombouts, a contemporary of Antonio Stradivari.

SUPREME ELEGANCE. The "Bazzini", a Stradivarius dating from 1715. It is named after its first owner, Antonio Bazzini, director of the Milan Conservatoire.

Roberto Caccuri/Contrasto

The maestro would wander round the Val di Fiemme woods with a torch, when the moon was full. One by one, he would scrutinise the spruces (Picea excelsa). Finding a majestic specimen, he would remove a piece of bark, strike the tree with a hammer and listen. If he liked the sound, the tree would be felled and transported to Cremona...

We do not know if this is how Antonio Stradivari really selected the wood for his violins. What we do know is that, four centuries later, they are still world renowned for their limpid, luminous and richly nuanced sound. The most celebrated violinists, such as Uto Ughi, compare them with Raphael paintings "for their balance and purity".

But how exactly did Stradivari impart a soul to the wood? Did he use special materials, adopt a secret process? Countless stringed-instrument makers have tried in vain to replicate his violins. And, over the last 80 years, physicists and chemists in different parts of the world have tried to discover his secrets, studying the instruments using X-rays, CT scans and spectroscopic techniques. These have yielded some interesting results, but many uncertainties remain.

MISSION IMPOSSIBILE. It is, in any case, an almost impossible challenge: Stradivari did not leave any documents describing his methods, knowledge of which was lost for ever in 1743, when his sons Francesco and Omobono, his only apprentices, died just six years after the master himself. Futhermore – and this is a serious limitation for a researcher – it is not possible to scrape so much as a molecule from one of these instruments, given their historical, musical and financial value: in 2011, the 'Lady Blunt', a Stradivarius dating from 1721, sold for 11.1 million € (over 12 million $).

Their legendary sound? A combination of painstaking design, the very best materials and special processes

AN INIMITABLE SHAPE. The 'Bazzini' in profile and (right) its scroll: it was made during Stradivari's golden period. The kinds of wood used and the inlay decoration depended on how much the customer was prepared to pay.

'Strads' have in fact become an investment: the prices they sell for have increased 200-fold over the last 20 years, 10 times more than gold. This is why many of the surviving violins belong to Russian, American and Japanese millionaires, not to mention financial institutions. Matteo Fedeli, the violinist who has played the largest number of these instruments - 25 in the last 11 years – goes around with armed bodyguards and expensive insurance policies when he performs with the 'Bazzini' (1715), owned by a Swiss collector. "Many of the owners of these legendary violins are not able to play them", he says, "so they contact me to keep them alive by playing them in a concert setting."

GOLDEN PERIOD. Stradivarius violins, together with the Gutenberg Bible and Leonardo's Mona Lisa, are icons of Western culture. This is why, in the last century, Lenin and Hitler were so quick to confiscate them. But they were already a legend during the lifetime of their maker, who died in Cremona in 1737, at the age of 93. His instruments – harps, lutes and mandolins, as well as violins and violas – were sought after by popes and rulers from all over Europe.
Stradivari had succeeded in perfecting the violin, an instrument developed in the workshop of his fellow townsman Andrea Amati at the end of the 16th century. Until 1679, the young man had served as an apprentice in the workshop of Amati's nephew, Niccolò. In 1680, he set up on his own account and in the next 57 years built no fewer than 1,116 musical instruments - a rate of around 20 a year. Just over half have survived, 650, of which 500 are violins. The most highly valued are those of his 'golden period', produced between 1700 and 1720.

GOLDEN FLAME. According to Fedeli, "Their distinguishing features are their golden, flame-like varnish; the carefully cut-out "f"-holes in the sound box, their curvature and scrolls. In some cases, the label glued to the inside of the instrument: Antonius Stradivarius cremonensis faciebat. And, obviously, their unmistakeable sound. Each has its own personality, which is why they bear a name, the name of their original owner."
But to what can their unique sound be ascribed? Research has pointed to three factors: painstaking design, the timber used, and the way in which the timber was treated. "Stradivari", according to Fausto Cacciatori, curator of the Cremona Violin Museum, "would make careful drawings of his violins on paper, before cutting out the wooden shapes. He drew on his wealth of experience and a long tradition, but he was also in close touch with contemporary violinists. He was successful because the violins he built were not only beautiful and harmonious, but also had a powerful 'voice', which was increasingly important in the making of late-Baroque music." And the same is true today: "When I do half a day's practice", explains Fedeli, "I have to use ear-plugs, or I am bound to end up with headache". The sound of a strad is a force to be reckoned with.

ICE AGE. A violin is made up of 70 different parts. For the body of the violin, which acts as a sound box, Stradivari used two kinds of wood: Balkan maple (Acer hyrcanum), lighter and more rigid than its Italian counterpart, for the back; Alpine spruce for the belly, or top. We do not know where he got his supplies: studies of the timber he used suggest that he purchased whole tree-trunks, probably from the woods of the Trentino region. Once felled, they were shipped along the River Po to Cremona. He then left them to season on the *secadùur*, the covered terrace of his workshop. According to Lloyd Burckle, a geochemist at Columbia University, Stradivari was favoured in his selection of timbers by a chance climatic factor: the trees he used were survivors of the Little Ice Age, a period of severe winters which affected Europe in the years 1645 to 1715 and slowed the trees' rate of growth, producing a compact, elastic timber with evenly proportioned rings.

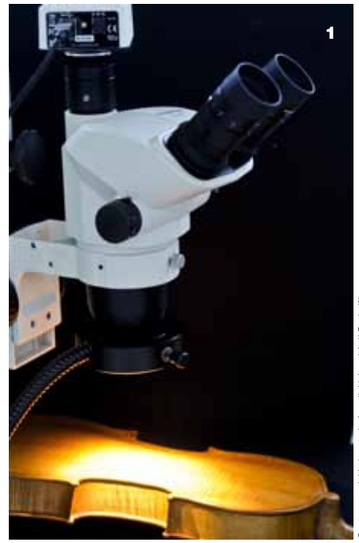
11,1
million € (over 12 million $): the highest figure ever paid for a Stradivarius (the 'Lady Blunt', 1721), in 2011.

VARNISHES. Finally, there are the varnishes Stradivari used to embellish and protect his violins. Rivers of ink have flowed on this subject. Without these 50 microns (thousandths of a millimetre) of varnish, strads would make a much poorer sound. So what exactly did the maestro use? The only documentary evidence we have is a letter in which he apologises for late delivery of an instrument, due to the time required for the varnish to dry: "You will bear with me if the violin is delayed because of the varnish, so that the sun does not open up any big cracks". In the 1970, Simone Sacconi, a luthier who in the course of his career restored 350 strads, suggested that the varnish was used to improve the sound quality of the wood: "Stradivari prepared a vitreous substance which made the wood harden and become more homogeneous as it penetrated into the pores in the timber. Thin though the wood was, this increased its capacity to vibrate and produce a more powerful sound." According to Sac- ▶

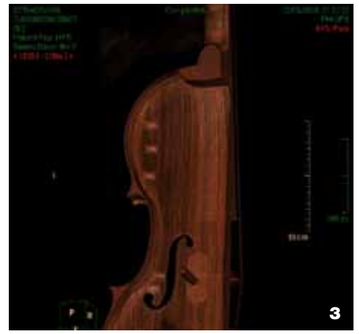
Roberto Caccuri/Contrasto (2)

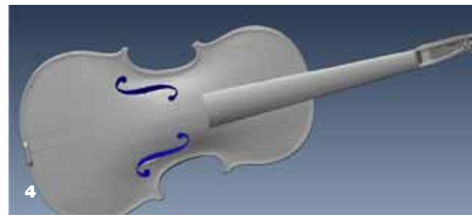
"For balance and sound purity, they are like Raphael's paintings"
Uto Ughi, violinist

SCIENTIFIC RESEARCH. Gli studi non invasivi sugli
Non-invasive studies of Stradivarius violins
1. An old instrument under the stereomicroscope: showing small scratches.
2. A violin lit by an ultra-violet fluorescent lamp: the darkest areas are those where the varnish is thickest.



Gent. concessione Matteo Fedeli (2)





Gent. conc. del Laboratorio Arvedi, Università di Pavia (2)

INITIAL RESULTS. Results of the investigations
3. A TC scan: the small rectangles on the body show where the wood has been repaired (with filler).
4. Three-dimensional model of a Stradivarius, used for replicating the various shapes.

OF 650 INSTRUMENTS, ONLY ONE IS ALMOST 100% ORIGINAL

ALTERATIONS. Over four centuries, Stradivarius violins have inevitably undergone alterations. The wooden parts have been filled and revarnished, and various components have been replaced without undue reverence. The important thing was that they could be played. In the 19th century, for example, all violin fingerboards were replaced with longer, more angled versions so they could play higher notes.
Of ther 650 instruments that have come down to us, the only Stradivarius still in original condition (including varnish), is the 'tenore mediceo', a 1690 viola on display at the Galleria dell'Accademia in Florence. Because of its large size, it has been little played over the years. And yet, nobody, according to the Florentine luthier Fabio Chiar, has really studied it, though some X-rays and UV photographs have been taken. More searching investigations could reveal the secrets of Stradivari's varnishes.

After Stradivari's death, his 'recipe' was lost. Luthiers adopted 'Chinese' varnishes, easier to use for producing more violins.

"To the refinement of his instruments, Stradivari adds nobility, embellishing them with graceful purfling"

Desiderio Arisi, friend of Stradivari.

Gent. conc. Laboratorio di Acustica Musicale, Politecnico di Milano (2).

RECORDINGS. Violinist Anastasiya Petrishak playing the 'Vesuvius' in order to record its acoustic properties; above, a bow fitted with a movement-monitoring system for studying the interaction between musician and instrument.

An unmistakeable sound? Not according to scientific testing...

A SURPRISING RESULT. Not so unmistakeable after all. A French researcher studying acoustics, Claudia Fritz (Institut Jean Le Rond D'Alembert, Paris), has put the Stradivarius legend to the test. In 2012, she invited ten famous soloists to a concert hall in Paris, blindfolded them and presented them with 12 violins, 6 ancient (including five strads) and 6 modern. They each played for two 75-minute sessions, solo and accompanied by an orchestra. Result: six out of ten preferred a modern instrument. The one that got the most votes overall was a modern instrument, while a Stradivarius from the golden period came only third.

Can one generalise from the judgement of 10 musicians? "Probably not", replies Fedeli. "A couple of hours is not enough to form a relationship with an antique instrument. Especially since the sound of a violin needs to be judged from a distance. The performer himself is too close to the source to assess it effectively." Indeed, Claudia Fritz also asked 50 experts present in the concert hall to say which of the 12 violins sounded best.

The jury is still out: the results will be published in 2015. The mystery remains unresolved.

FULL IMMERSION. The Milanese violinist Matteo Fedeli – the musician who has played the greatest number of strads: 25 in the last 11 years.

Roberto Caccuri/Contrasto (2)

coni, Stradivari used silica, carbon and potash, the ash produced by burning the dregs from the grape press. These ingredients were reduced to a powder, dissolved in water, boiled again and then decanted. Spread on the wood, the varnish took weeks, if not months, to dry. Some researchers from Cambridge University, have hypothesised that he used volcanic ash.

X-RAY ANALYSIS. To get a better understanding, researchers at the University of Pavia's Arvedi Laboratory, inaugurated in 2013 at the Cremona Violin Museum, have been using scene-of-crime techniques. They first shone an ultra-violet fluorescent lamp on the Museum's violins to identify the areas with the thickest covering of varnish. Using radiography, they pinpointed the least restored areas, then investigated them with spectroscopic techniques to identify the molecules contained in the wood, based on how they absorb light.

The result? "We have found calcium and potassium", reveals Marco Malagodi, lecturer in restoration chemistry at the University of Pavia. "It is probable that Stradivari treated his violins with a mixture of casein (a milk protein) and slaked lime (calcium hydroxide). After a week, this yields calcium caseinate, a glue. This substance has been found in other instruments by Austrian researchers". Stradivari followed this up with two further layers: "an insulator, made of linseed or walnut oil and pine resin (rosin); and a layer of coloured varnish consisting of oil, rosin and, in some cases, cinnabar, a mineral rich in sulphur and mercury that Leonardo da Vinci had previously used as a red pigment. These varnishes took many weeks to dry." This also explains why Stradivari produced fewer than two instruments a month.

SHARP EYES, SKILLED HANDS. No alchemist's magic, then? "The techniques and materials employed by Stradivari were the same as those used by his contemporaries", comments Bruce Tai, a chemist at the California Institute of Technology. "He obtained his supplies from vendecolori, pharmacists who sold pigments for painters and furnituremakers. But the processes he adopted were complex, with many variable parameters (dosage of the mineral particles, type and quantity of rosins and pigments, heating and drying times). Using the same ingredients, luthiers could obtain very different results. Stardivari's success depended on a combination of sharp eyesight, acute hearing, manual dexterity, attention to detail, creativity through constant tweaking, and, most of all, artistic inclination. Augusto Sarti, director of the Musical Acoustics Laboratory at the Polytechnic of Milan, is trying to identify the physical parameters typical of the Stradivarius sound, whatever they may have been. "Our objective", he says, "it to replicate them in modern instruments."

650

The number of Strads that have survived. Stradivari is reckoned to have made 1,116 instruments in 57 years.

CHINESE VARNISHES. The processes used by the luthier from Cremona were lost for ever after his workshop closed. At the end of the 18th century, oil-based varnishes were replaced by alcohol and essential oils. These were 'Chinese' varnishes, based on sandarac resin (obtained from a North-African tree) and shellac, a polymer derived from an Asiatic insect, the lac bug (Kerria lacca). Strong and shiny, cheap and easy to apply, they were ideally suited to the growing demand for violins in Europe.

Maybe the secret of Stradivarius violins was simply a question of slowness – like the heart-rending slowness of Oblivion, a piece by Astor Piazzola that Fedeli performed for this Focus reporter on the instrument dating from 1715. It brings tears to one's eyes. Whether this should be ascribed to the violinist or the elusive luthier is also a mystery. And maybe it is better it remain so.

Vito Tartamella