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You Could Design the Airplanes of the Future

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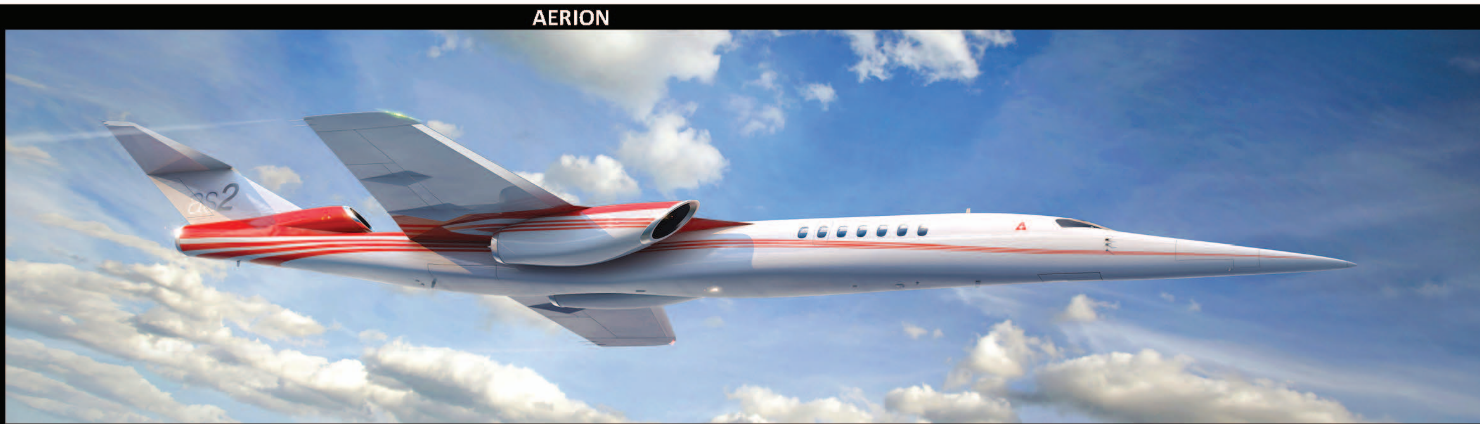

Inspiration for the Next Generation of Aerospace Engineers

by Bernardo Malfitano

XS-1 / XSP

LILIUM

You Could Design the Airplanes of the Future

Bernardo Malfitano

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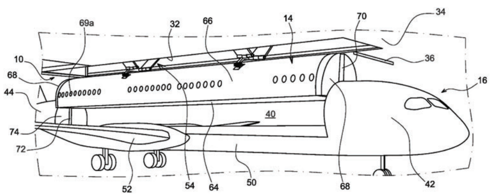
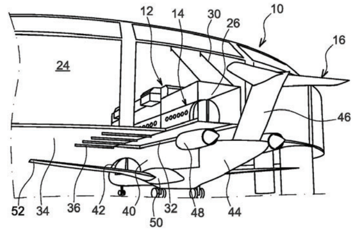
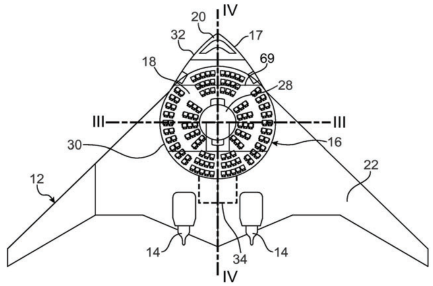
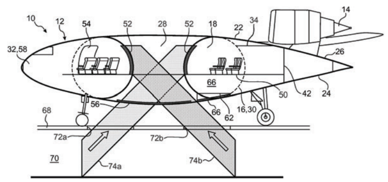
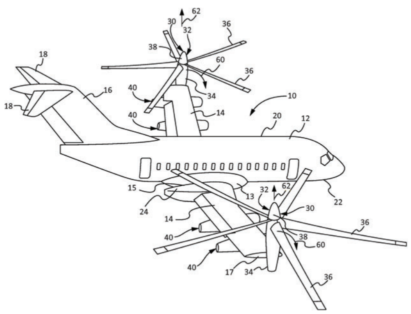
ISBN: XXX-X-XXXXX-XXX-X

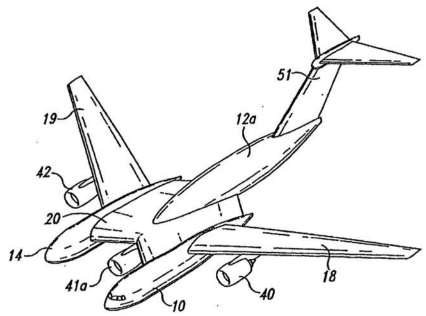


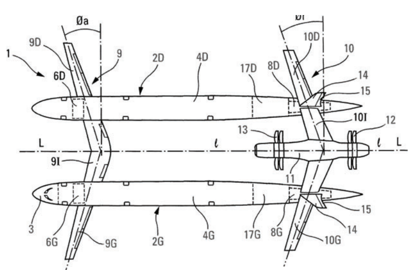


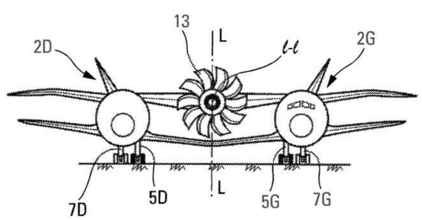


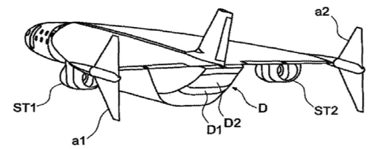


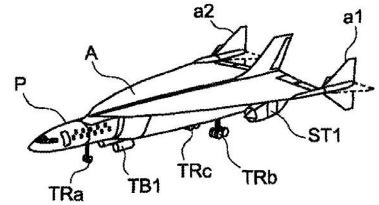












You could design the airplanes of the future

When visiting the airport or even an airshow or air museum, it's easy to get the idea that airplanes are all pretty similar. Airliners all have the same "tube and wing" design. Small airplanes flown for fun all have piston engines and little propellers. And all this has been true since the 1950s! It sometimes feels like airplanes will never change, that their design requires little or no creativity.

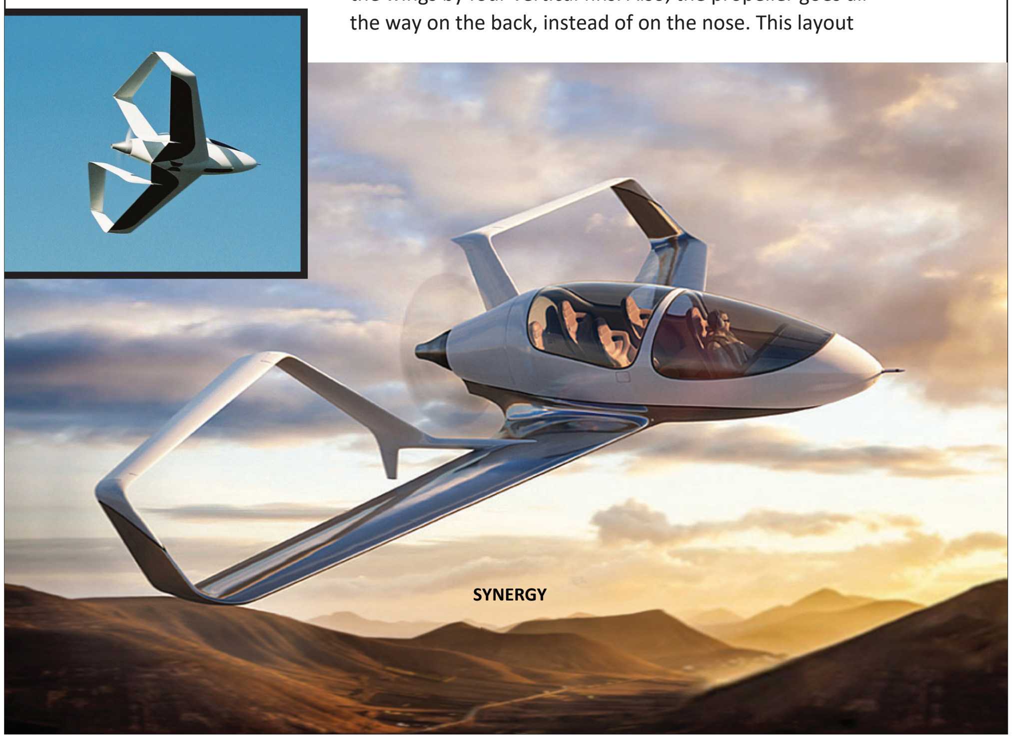
But nothing could be further from the truth! Many exciting new ideas are being introduced into the world of aviation. They will shape the airplanes of the future. Designing these airplanes will require creativity, innovation, inventiveness, and imagination.

A quick look at patents by Boeing and Airbus – the world's two largest airplane companies – is one way to check out some of their creative ideas for future airplanes. For example, Airbus has invented an airplane cabin that can be separated from the rest of the airplane: At the airport, the next flight's passengers would enter one cabin, the airplane would pull up to the terminal, the previous flight's full cabin would be swapped for the next flight's cabin, and the passengers from the previous flight would exit their cabin while the airplane takes off for the next flight, thus reducing the airplane's turn-around time so that each airplane can fly more flights per day. Another clever Airbus idea is a fuselage "tube" that has been bent around into a doughnut shape and placed inside a flying-wing airplane, with doors facing into the hole in the middle! Meanwhile, Boeing has patented ideas like a jetliner with tilt-rotor engines on the wingtips so that it can take off and land anywhere, with no need for long runways... and an airliner with two forward fuselages, connected by the wings to a single tail, a layout that reduces bending loads on the wing. Not to be outdone, Airbus has come up with various double-fuselage designs. Some inventors have even patented triple-fuselage jetliner designs (along similar lines to the Global Flyer, White Knight 1, and Voyager, shown later in this book). Perhaps most exciting is Airbus's "ultra-rapid air vehicle" (shown above), meant to reach record speeds using a combination of ramjet engines, rocket engines, and conventional jet engines.

Now: It’s important to remember that, when a company files a patent, they do not necessarily plan on building such an aircraft in the future. A patent effectively calls “dibs” on an idea: ***If*** it ever looks like it would be profitable to build such an aircraft, then anyone who wants to build one must pay a licensing fee to the patent owner, i.e., to the first inventor. Right now, all the designs shown on the previous page are impractical. But if this ever changes, then whoever wants to build one will have to pay Boeing or Airbus for permission to use their ideas. If you ever think of a new airplane shape, maybe you should file a patent for it, so that if an airplane maker ever wants to actually make an airplane like that, they would have to pay you!

Even more interestingly, airplane manufacturers are currently developing actual airplanes that implement many unusual and futuristic ideas, as you’ll see throughout the rest of this book.

The Synergy, for example, incorporates the “box-wing” configuration: The horizontal tail fins, instead of sticking out the sides of the fuselage, are held above and behind the wings by four vertical fins. Also, the propeller goes all the way on the back, instead of on the nose. This layout might significantly reduce drag (air resistance), allowing for higher speeds and lower fuel burn than other small propeller airplanes are capable of. Computer simulations and flight-tests with models are currently investigating the airflow around this unusual shape.



SYNERGY

TRIFAN

And must airplanes always require long runways, making us drive to an airport if we want to go flying? Maybe not. Check out the TriFan 600, currently in development by XTI Aircraft. The two propellers on its wings are located in ducts that can point forward, like a regular airplane, or be rotated upward. When pointed up, they (along with a third propeller hidden in the back of the fuselage) allow the TriFan to take off and land vertically, like a helicopter, from any flat location, not just from an airport. Like Synergy, XTI is also currently flying a 60-percent-scale prototype to test their innovative configuration. Other companies – such as Transcend Air, Samad Aerospace, and Pegasus Universal – have recently unveiled similar designs.

Aeronautical engineers get to invent, develop, and test futuristic airplane design ideas, like the ones in this book. When you grow up, you could become an aeronautical engineer, and help implement these ideas into the airplanes of the future, or come up with new design ideas of your own!

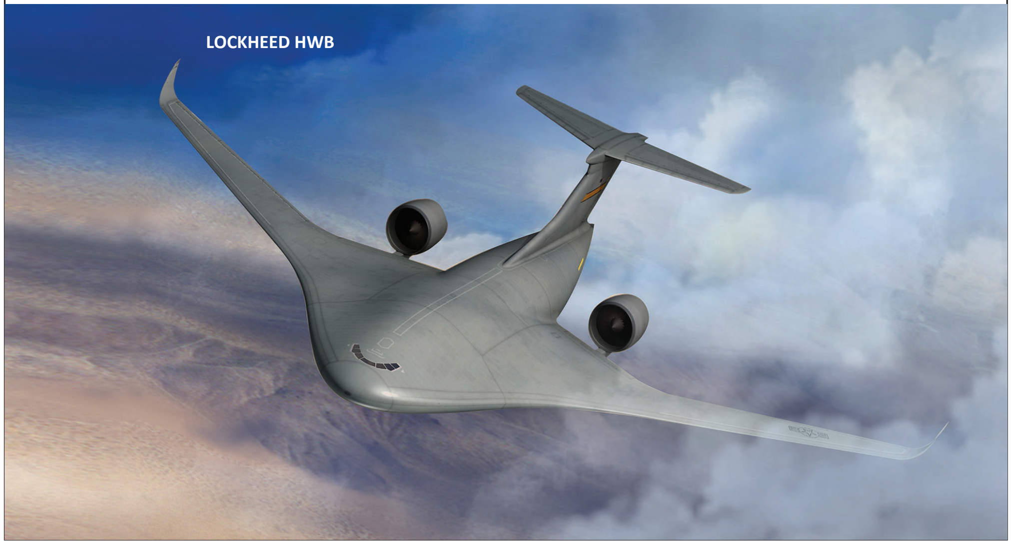
The most low-drag, super fuel-efficient, futuristic airplane configuration being studied right now is the Blended Wing Body, or BWB. These are a kind of "flying wing" design like the B-2 bomber – that is, an airplane that is "all wing," with little or no tail, and a wide flat fuselage that works as part of the wing. A company named Natilus is looking into whether it would be a good idea to create large BWB cargo planes – so large that their wingtips would have to fold up after the airplane lands, in order to fit in parking spaces at airports.

One problem with BWBs is that their "stall and spin" behavior – how and when control and lift decrease as the airplane slows down too much – is poorly

understood, difficult to manage, and sometimes dangerous. The Boeing X-48 was recently flown to help us understand slow-speed BWB flight. The third version of the X-48 added small tail fins to the back, making the airplane much easier to handle and safer to fly at slower speeds, and also easier to load, because the internal weight does not have to be quite as perfectly balanced as it would on a tail-less BWB. This approach of adding tail fins to a BWB is called a Hybrid Wing Body, or HWB.

Lockheed has developed an HWB cargo airplane design and proposed it to the US Air Force, claiming that it would only burn about 30 percent as much fuel as a typical modern cargo plane like the C-17. Samad Aerospace intends to compete against the XTI TriFan with an HWB airplane called the Starling; they have flown a 20-percent-scale prototype.

Will we ever see this extremely efficient design really take off? How would you like to fly inside a passenger airplane with a super-wide cabin? It would be like sitting in a theater! There would be relatively few windows, and the people sitting along the sides (farther from the center than on a normal airplane) would go up and down quite a bit when the airplane banks to make a turn. These issues need to be studied carefully before large BWBs/HWBs are allowed to carry passengers.



STARSHIP

EZ

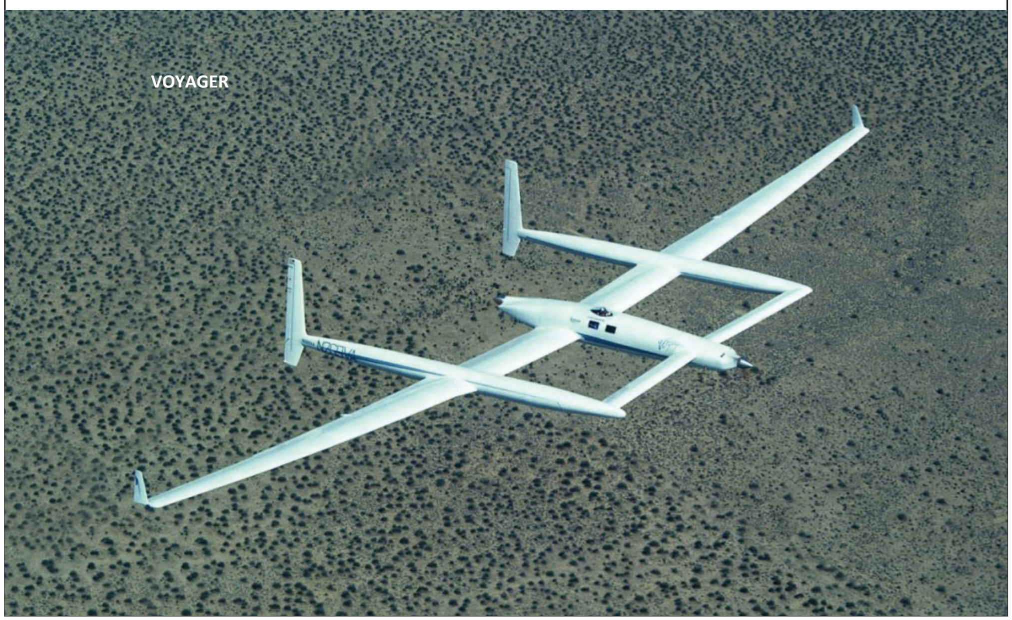
On most airplanes, tail fins provide *stability* – that is, the tendency of an airplane to naturally point the way it's flying, like an arrow. The horizontal tail fins also provide *balance*: The airplane does not pitch up and down like a seesaw if people inside walk toward the front or the back. However, some airplanes (such as the Long EZ, Boeing X-36, and Beech Starship) achieve stability and balance in a different way. The wing placement, all the way in the back, provides stability. To balance the airplane, a second set of little wings called *canards* go near the nose. While most airplanes' tail fins generate down-force, "fighting" the wing lift, canards always generate upward lift, "helping" the wing. This reduces drag and allows the airplane to carry more weight.

Canard airplanes have an additional feature that makes them exceptionally safe. When any airplane slows down, its wings must fly at a higher angle of attack relative to the air, in order to generate enough lift. (Notice how most airplanes land with a nose-up attitude). But if an airplane slows down too much and this wing angle becomes too steep, the airflow "unsticks" off the top of the wing: The wing stops generating lift, and the airplane loses altitude. This is known as a stall, and it can be dangerous if it happens at low altitude. However, canards are set at a higher angle of incidence than the main wings. So if a canard airplane slows down too much, the canards stall before the wings. This causes the nose to pitch down slightly, until the lower angle allows the canards to un-stall so they can balance the airplane again. This nose-down angle correction (which tells the pilot that the airplane has hit its minimum speed) happens while the wings are still making lift. That means it's almost impossible to dangerously stall a canard airplane. The flipside of this safety feature: It's impossible to fly a canard airplane as slowly as a conventional airplane. So canard airplanes need more speed – and more runway – to take off and land.

Still, many modern airplanes are made with canards, including most jet fighters in Europe (like the Typhoon, Gripen, and Rafale). The Wright Flyer also used canards, so this idea goes way back!

Some airplanes are designed for unusual missions, such as the ability to fly very high, or to be as fuel-efficient as possible. For example, the Voyager and Global Flyer – respectively designed by Burt Rutan and by his company, Scaled Composites – were made to fly farther than any other airplane: all the way around the world, without landing or refueling! The Proteus, also by Scaled Composites, was made to fly at high altitudes while carrying large payloads under its fuselage such as cameras, telecommunications antennas, and various kinds of research pods for NASA.

Unusual missions lead to unusual design features. Both high-altitude flight and extremely long range are mission goals more easily accomplished with wings that have a “high aspect ratio” – that is, thin wings with a large wingspan but a short distance from the front to the back, as you see here. These kinds of wings can generate lift while making very little drag, allowing the airplane to use significantly less fuel and to fly for long distances or in thin high-altitude air. Sailplane gliders use high-aspect-ratio wings to soar without any fuel burn at all! The disadvantages: These wings tend to be structurally heavy (so the airplane can’t carry as much load) and not very stiff (so the airplane can’t fly very fast, or the wings might flutter).



SUGAR

D8

Fuel is expensive. When you buy an airplane ticket, you are paying for the airplane's fuel (among other things). Airlines know that whoever can sell the least expensive tickets, will sell the most tickets! So, a lot of research focuses on how to make transport airplanes more efficient – that is, how to fly while burning less fuel. This has environmental benefits too, because burning fuel releases carbon dioxide, a "greenhouse gas" that worsens global warming.

One idea is to use high-aspect-ratio wings, as shown here on the Boeing SUGAR (Subsonic Ultra-Green Aircraft Research) and Lockheed X-56. The SUGAR would fly more slowly in order to avoid flutter, using propellers for slow-speed efficiency, and bracing the wings with struts to minimize structural weight. NASA flies the X-56 at jet speeds, and is testing an active vibration suppression system to prevent its thin wings from fluttering, similarly to how noise-canceling headphones work. If these tests are successful, this vibration suppression system could allow faster jets to fly with thinner wings that are less stiff, reducing drag and structural weight.

Unlike the circular fuselage on most airliners, the Aurora D8 concept explores the idea of an extra-wide "flattened" oval fuselage, which would allow it to carry more people to split those fuel costs. It is currently being tested in wind tunnels. Another interesting feature is how the D8's engines ingest the slow air off the upper surface of the fuselage. Although this helps the engines be more efficient – and quieter! – the turbofan blades take a real beating: As each blade spins around, it cuts through slower air at the bottom of the cycle (near the fuselage) and then faster air at the top, over and over. More durable fan blades are currently being tested for their ability to deal with the quickly-changing loads from this uneven air speed.

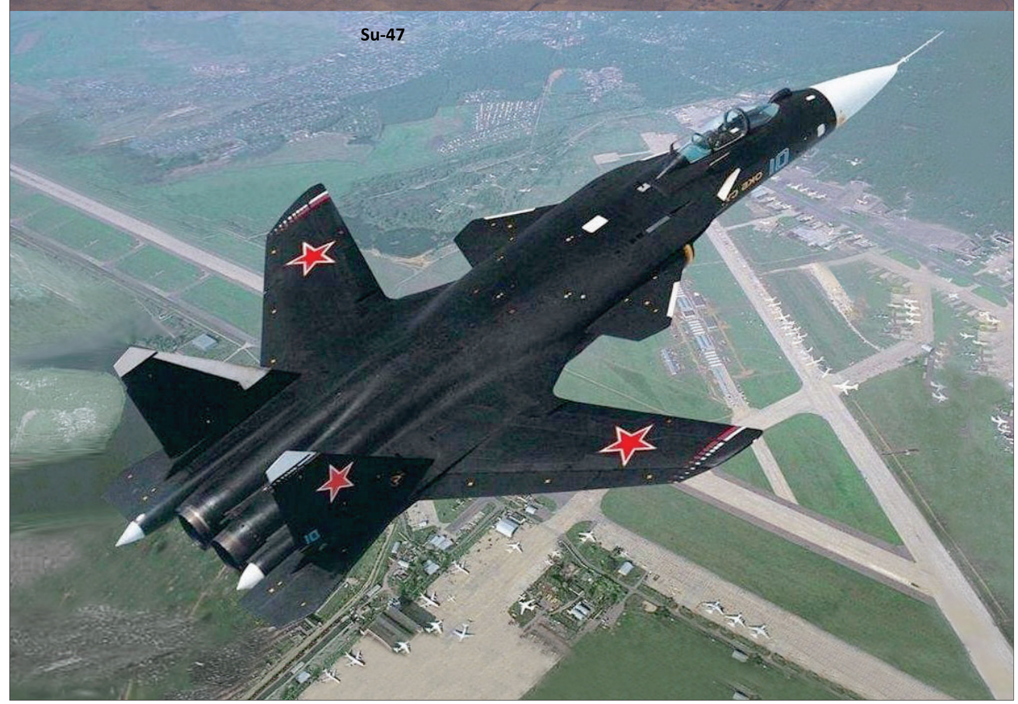
X-56

ECOJET

easyJet has proposed their own futuristic airliner concept – the ecoJet. Its engines use un-ducted fan blades (i.e., a "naked" turbofan jet engine, without the tube around it), which are more fuel-efficient... but make a lot of noise. The ecoJet solves that problem by placing the engines within a U-shaped set of tail fins, which absorb most of the noise or reflect it upward, away from people.

Another unusual design feature of the ecoJet is its forward-swept wings, tested in airplanes like the NASA X-29 and Sukhoi Su-47. As is the case with "normal" (aft-) swept wings, forward-swept wings allow the airplane to fly very close to the speed of sound without experiencing "sound barrier" effects such as starting to make shockwaves. Forward-sweep has additional benefits: As with winglets, airflow over this wing shape is deflected in a way that opposes wingtip vorticity, reducing drag. This layout also causes the wings to meet the fuselage at the very back, "out of the way" of the landing gear and other features, instead of right in the middle where everything else is, thus simplifying the structure. Their main disadvantage: Forward-swept wings try to twist themselves apart, as the tips are "blown" upward and back by the airflow. (Try walking fast while holding a sheet of paper horizontally in front of you, held at the back edge). Therefore, extremely stiff structure is necessary in such wings. Until carbon fiber became available, forward-swept wings that could survive jet speeds would have been impractically heavy.


X-29


Su-47

ALPHA ELECTRO

Many engineers are currently working on electric airplanes. Like electric cars, electric airplanes don't need fuel, and don't pollute the atmosphere; they just need to recharge their batteries between flights. Compared with piston engines, electric motors are more efficient, weigh less, make less noise, and require less maintenance. Companies such as Advanced Composites Solutions, Airbus, Bye Aerospace, Electraflyer, Evektor, Extra, Siemens, and Sonex have all flown prototype single-seat or two-seat electric airplanes. Electric ultralights and electric motorgliders are already available for sale.

The Pipistrel Alpha Electro is the first electric airplane being used for flight-training and being rented for recreational flying. It can even carry a passenger!

NASA's all-electric X-57, currently being built, will test the idea of a "blown wing": During takeoff and landing, in addition to the two main engines, many small

X-57

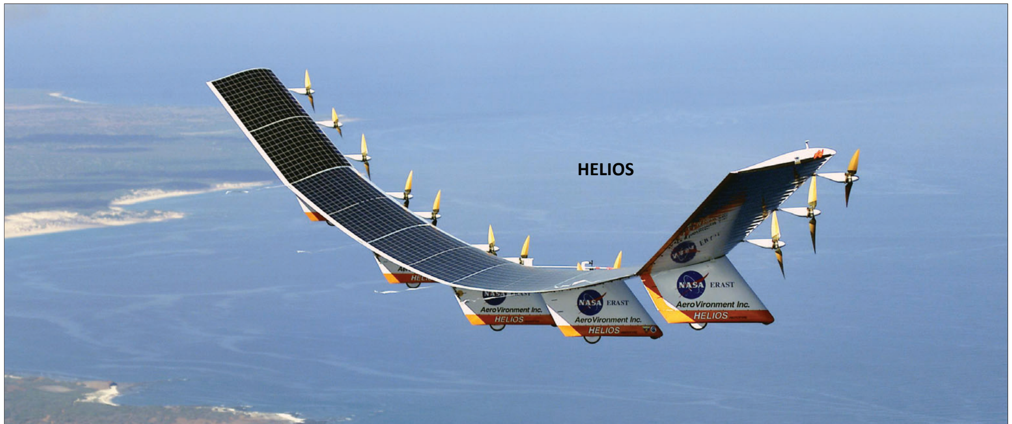
ALICE

propellers will envelop the wing in higher-speed "prop-wash" air, to make more lift. This will allow the wing to be smaller, reducing drag at faster speeds. During cruise flight, the small propellers will be folded away.

The Eviation Alice is an electric airplane that aims to make flying in a small nine-seater as inexpensive as flying in a 737. Eviation believes it can do this thanks to electric propulsion. The Alice also features exceptionally large windows, and a luxurious interior similar to a business jet.

The Equator Xcursion is a small two-seater seaplane. It's hybrid-electric, like a plug-in hybrid car: The propeller is spun by an electric motor, powered by batteries, but the batteries can be recharged in flight by a generator that burns fuel from a small tank. This generator system is known as a "range extender," for the occasional long trip. Shorter flights are all-electric and do not require burning any fuel.

XCURSION

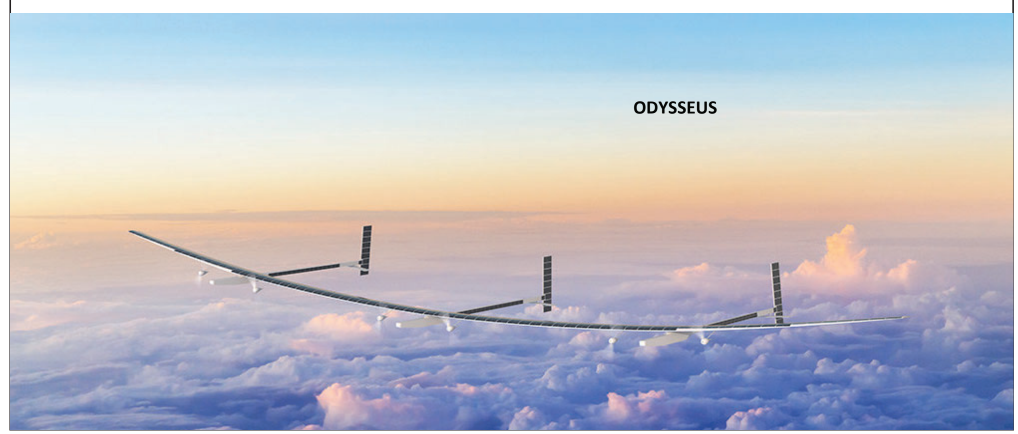


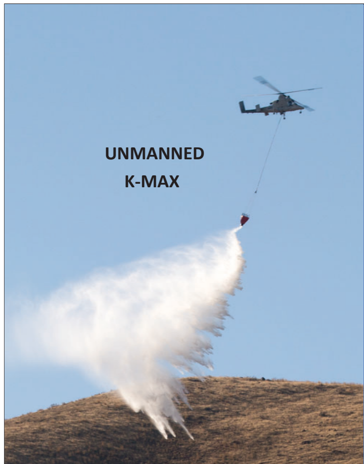
Part of the reason why electric airplanes are not very common yet is the fact that batteries are very heavy: Per pound, batteries carry much less energy than fuel. This means electric airplanes can't fly as far as fuel-powered airplanes. You may then wonder: Why not use solar cells (which can pick up energy from the Sun as they go) rather than carrying heavy batteries? One reason: Solar cells can't generate enough power to go very fast; most solar airplanes can only fly at about 30 miles per hour. However, they can fly for a long, long time.

NASA's Helios – a rectangular flying wing with a bigger wingspan than a 747 but less than 0.3 percent of the weight – is the highest-flying airplane ever, capable of reaching nearly 100,000 feet. Its ability to stay aloft in such thin air means it could fly in the atmosphere around Mars... if only we could somehow get it there.

Another solar airplane with a 747-like wingspan is the Solar Impulse. By storing energy during each day to keep flying overnight, it was flown all the way around the world... with many stops. At 35 miles per hour, just the leg from Japan to Hawaii took five days, a record for the longest flight with a single pilot.

UAVs ("unmanned aerial vehicles," a.k.a. "drones," i.e., aircraft that do not carry a human on board) could use solar power to fly nonstop for months. They could carry cameras like a police helicopter, or relay communications signals like a cell phone tower. In other words, they could do things currently done by satellites – but unlike satellites, UAVs can circle over one location, fly at lower altitudes, and be launched more quickly and much less expensively. Shown here is the KARI EAV-3. A similar airplane – the Zephyr, built by Qinetiq – has flown for 26 days without landing. Aurora has recently unveiled the Odysseus, an even bigger solar UAV.




UNMANNED K-MAX


WING (GOOGLE) DELIVERY DRONE

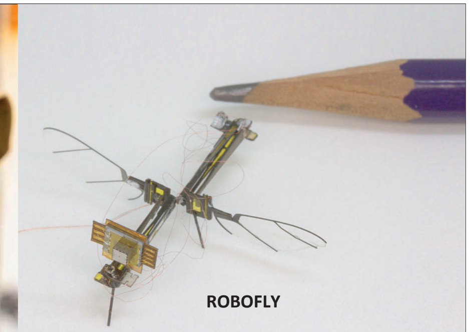
UAVs are a growing part of the aviation world. They are flying more and more kinds of missions, from cargo delivery to border patrol, from aerial photography to search-and-rescue. NASA uses drones to monitor wildfires, and also for research: to test futuristic design concepts (Helios, X-36, X-48, X-56...) and to carry sensors that study the weather. All kinds of videos are shot by camera-equipped UAVs, both by hobbyists and by professional filmmakers. UPS, DHL, Google, Amazon, and the US military are testing drones to deliver packages, such as to customers who shop online, to soldiers in combat zones, or to people in remote villages who need medical supplies. There are even projects testing the use of UAVs to help control the populations of mosquitoes that carry disease, and modifying helicopters like the K-Max so that they can fly themselves without a human on board and then go on risky missions such as fighting wildfires.

NASA is working on two interplanetary drones: the Mars Helicopter (currently being tested) will be taken to the Red Planet in 2020, and the Dragonfly (still being designed)


MARS HELICOPTER


DRAGONFLY


BLACK HORNET


ROBOFLY

will be launched in 2026 and reach Saturn's moon Titan in 2034. They'll each leave the Earth in a large rocket, arrive at their destinations in a capsule, and then become the first aircraft to fly in another world's atmosphere. They will then use cameras and sensors to gather data for scientists, like the Mars rovers and various space probes do.

Some UAVs, like the Global Hawk, have a greater wingspan than a 757. Others, like the Black Hornet helicopter, fit on the palm of your hand. In fact, research projects at many universities are currently exploring just how small a "Micro Air Vehicle" (MAV) can be. Some, like the RoboBee (Harvard), RoboFly (University of Washington), and Delfly (Delft), are no bigger than an insect, and fly by flapping their wings like a hummingbird! (Flapping-wing aircraft are called *ornithopters*). The RoboFly even has a tiny pinhole camera!

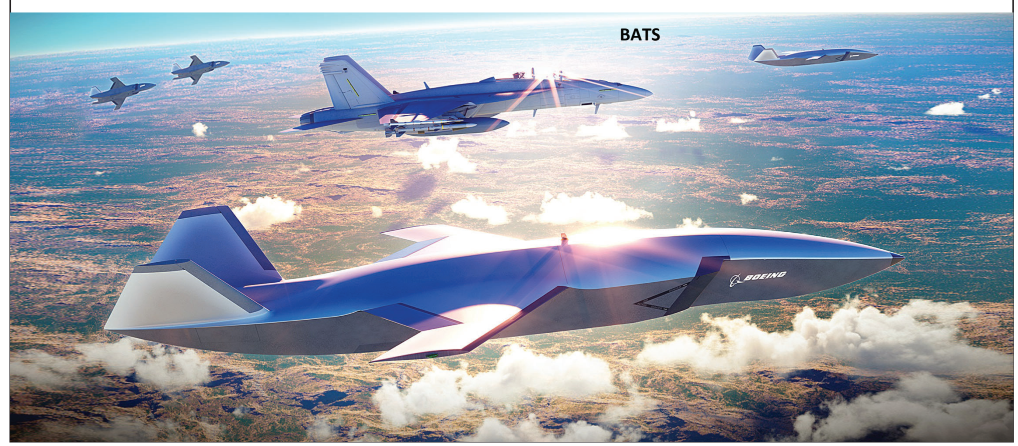
The military has been using UAVs as spy-planes since the 1950s. The rationale is simple: Machines, rather than humans, can go into dangerous territory to look for enemy forces. These drones carry cameras on or under their noses, often visible as a "ball" sticking out from the underside. They also have a variety of antennas to transmit images and video back to base, and to receive commands about where to go next. A large bulge on top is typically a fairing (an aerodynamic cover) for a satellite dish, for when the people controlling the UAV and/or looking at its images are thousands of miles away. Some of these military drones can fly for over 24 hours and go halfway around the world!


GLOBAL HAWK

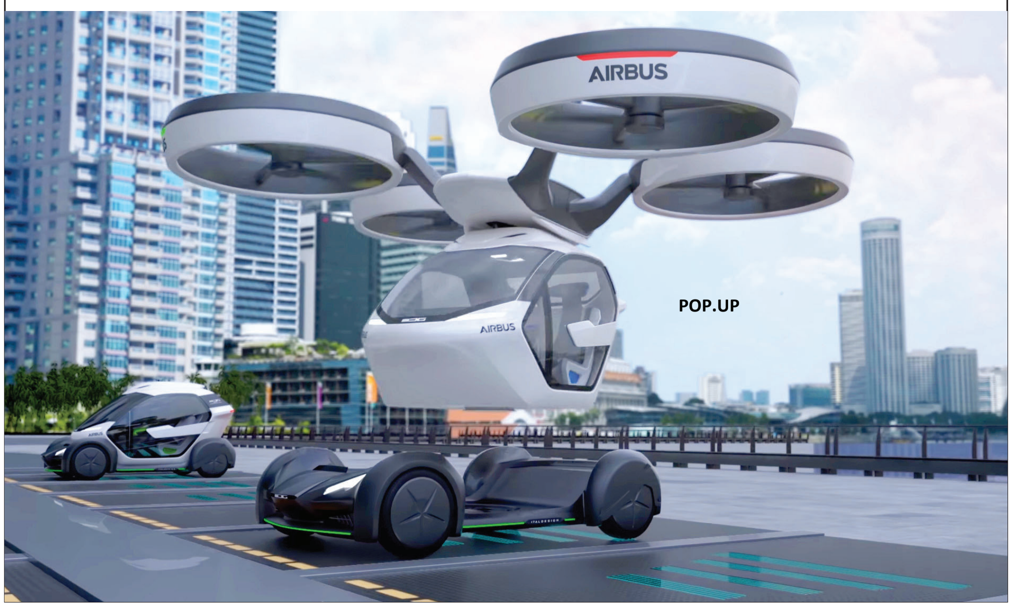
Ever since Predator UAVs started carrying missiles in 2001, the US military has been developing combat drones, like the Northrop X-47B, a mini stealth bomber that can take off and land on aircraft carriers. The US Navy's next UAV – the MQ-25, made by Boeing – will even be able to refuel other military airplanes in the air.

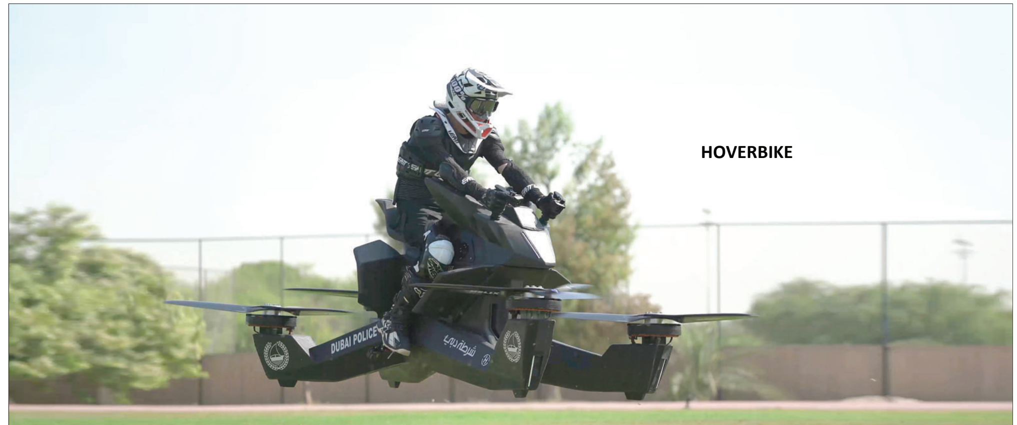
UAVs are not simply big remote-controlled airplanes. Many are robots with artificial intelligence. After being given their mission, the most autonomous drones can take off, find their targets, take pictures, fire their weapons (the one action where they must always first ask permission from a human), return, and land, all by themselves. UAVs can even work as a team, figuring out how to engage multiple unexpected threats depending on each UAV's weapons, speed, range, stealth characteristics, etc.

"Loyal wingman" UAVs are currently being developed, such as the Kratos XQ-58 and the Boeing Airpower Teaming System (BATS). These unmanned fighter jets could escort military pilots into combat, or fly by themselves into the most dangerous areas while receiving sensor data (e.g., targeting info or enemy coordinates) from manned aircraft... or all on their own, in radio silence; whatever minimizes the risk to the lives of human service members. Companies in China, Russia, France, Germany, and England are all working on combat UAVs similar to the X-47B or to the XQ-58.



If airplanes can fly themselves, then could we have self-flying cars? The idea is not as crazy as it used to be. Advances in electric motors make vertical flight cheaper and safer than it was in the past. And thanks to today's "ride-sharing" services, individuals would not have to own a flying car – which would be prohibitively expensive – and could instead just get a ride in a flying taxi each time they need to go somewhere. Dozens of companies are currently working on self-flying,





electric, vertical-takeoff-and-landing (eVTOL) multicopters to be used as flying cars, such as the Volocopter, EHang 184, Lift Hexa, and Workhorse SureFly. Airbus and Audi have a car/multicopter concept called Pop.Up, where a passenger rides in a pod that can either be driven by a skateboard-like base or flown by a quadcopter top. They recently flew a 25-percent scale model Pop.Up, as well as a full-size prototype of their CityAirbus flying taxi. Companies such as Bell Helicopter, Rolls Royce, Embraer, and Aston Martin have all unveiled eVTOL designs. An electric Robinson helicopter recently made a record-breaking 30-mile flight, and its engineers claim that even longer flights will be possible after a new motor and battery system are installed.

Meanwhile, some companies such as Aerofex, Hoversurf, Kalishnikov, KittyHawk, and Malloy – and individuals like Colin Furze and Zhou Deli – have designed, built, and flown various open-cockpit multicopters, or "hover bikes." They are not just toys: A Malloy multicopter has been evaluated by the US Marine Corps, and the Hoversurf Hoverbike has been tested for use by the police in Dubai.

Even more impressive are the eVTOL aircraft able to take off and land like electric helicopters… and also to fly forward using their wings and electric engines like an airplane, allowing for increased speed and range. Lilium has created and flown a cool jet-like eVTOL airplane, with electrically powered fans hidden inside the wings and canards; Aurora has also developed a similar prototype, for the XV-24 program.

Cora and BlackFly have flown airplanes that took off straight up in vertical helicopter mode, transitioned to wing-borne forward-flight airplane mode, transitioned back into a hover, and landed straight down again, the two first all-electric flying machines to do so with a human inside. Boeing, Zee.Aero, Beta Technologies, Vahana, and other companies have all flown similar prototypes.

CORA

LILIUM

Flying cars (or, to use the latest buzzword; “urban air mobility”) may be just around the corner! The hardest part will be air traffic management, i.e., creating air traffic laws and systems that make it possible for self-flying cars and drones to all safely navigate a city’s airspace without mid-air collisions! People at NASA, the FAA, and multiple labs and airplane manufacturers are all working to create and test rules and electronics that will help manage this “airspace integration” challenge.

BLACKFLY

Vertical-takeoff-and-landing (VTOL, or hovering) technology is also being applied to larger airplanes. An airplane that can hover could take off and land anywhere, not just at an airport with a runway. A few aerospace companies are working on this idea. For example, you may have heard about Bell Helicopter's V-22 Osprey. Bell's latest design is the V-280 Valor, about half the size of an Osprey. The Agusta 609 is a similar airplane, but even smaller, and designed for civilian use. V-280 and AW609 prototypes are currently being test-flown. These "tilt-rotor" aircraft take off and land like helicopters, but once in flight, the propellers point forward. They can then fly twice as fast and twice as far as a helicopter.

Some fighter jets can also take off and land straight up and down. The Harrier "jump-jet" is one of the most famous examples. The newest is the Lockheed F-35B, a stealthy, supersonic fighter. The engine nozzle (or "tail pipe") rotates downward to release jet exhaust straight down, and doors open up on the top and bottom of the fuselage to reveal a fan inside that blows air downward. Few things are as cool as watching a fighter jet roar by, slow down, and stop in the air like a hummingbird.

V-280

AW609


F-35B

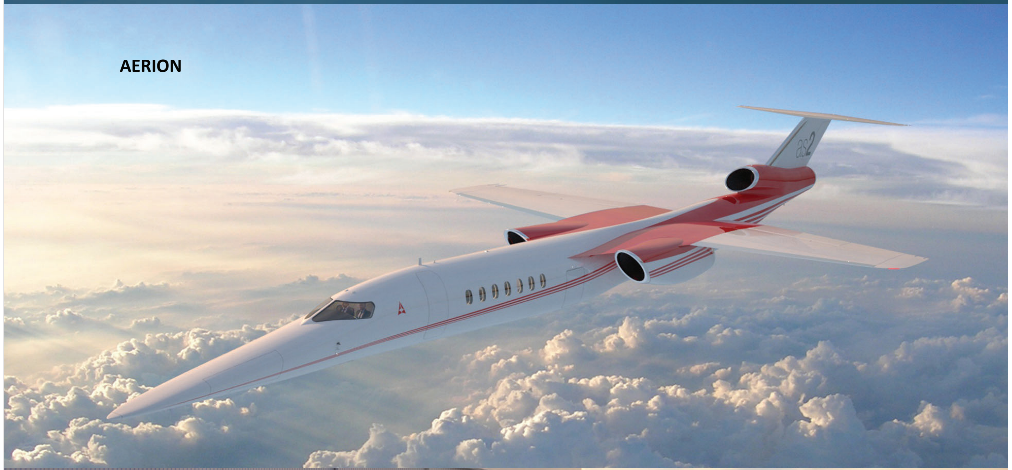
Not only are aircraft designers trying to make some airplanes more like helicopters, they are also trying to make some helicopters faster by making them more like airplanes. The Sikorsky X2 and S-97 and the Airbus X^3 have propellers to generate forward thrust like an airplane, allowing them to fly faster than normal helicopters. The SB-1 Defiant – a larger helicopter with the same configuration as the S-97 – is currently being tested, and may become the US Army's next helicopter.

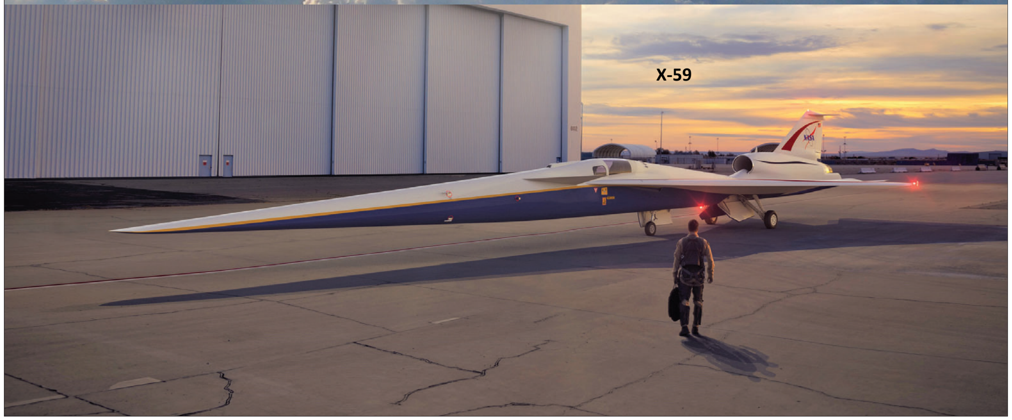
The Boeing X-50 has rotor blades powered by a jet engine inside the fuselage. During flight, the rotor blades can be stopped to become airplane wings. The exhaust from the back of the jet engine then pushes the X-50 forward. In short, the X-50 can transition from rotary wings (helicopter) to fixed wings (jet airplane). This configuration is called a "canard rotor-wing" aircraft. But it was just an experiment. Could such a design ever be made in large numbers, to be used every day?

Subtle technological advances can lead to dramatic improvements in aircraft performance. For example: Most helicopter rotors only spin within a narrow range of RPMs. Lower RPMs would allow for more fuel-efficient rotor blades, but then resonant frequencies would cause the helicopter to vibrate until it comes apart. Recently, Boeing's A160 Hummingbird tested an "Optimum Speed Rotor", which changes its RPM to be more efficient, depending on the helicopter's speed, altitude, and weight. Engineers carefully designed the A160's structure to not resonate or flutter in any of those frequencies, using detailed simulations to predict how the structure would vibrate and bend during flight. Shapes were adjusted to tweak the aerodynamic forces around each blade, and the orientation of the carbon fibers was tailored to achieve the desired resonance and stiffness in each direction. This is what prevents the A160 from shaking itself apart at low RPMs. As a result, it's drastically more fuel-efficient than any other helicopter. It needs so little horsepower that the first prototype was powered by a four-cylinder Subaru car engine. The Hummingbird can fly for 24 hours without refueling, going as far as 2,500 miles nonstop. Other helicopters don't come even close to this range and endurance, and can only fly for a few hours at most.

Airplanes that can hover are exciting, but so are airplanes that can fly extra fast. For example, the Concorde used to carry airline passengers almost three times as fast as current jetliners. Why do we no longer have supersonic transport (SST) airplanes? Partly, because of their "sonic boom." When an airplane flies faster than sound, the air in front of it does not have time to get out of the way; the airplane slams into the air and shoves it aside, like a fast boat and its wake. And like the wake of a boat, this high-pressure layer of air – the "shockwave" – expands outward behind the supersonic airplane. Some of it eventually hits the ground, where people hear it as a "boom," similar to an explosion or gunfire. Shockwaves are so intense, they can break the windows of houses and buildings. Therefore, supersonic flight is illegal over the United States (except for military operations, of course).

But research is currently exploring ways to reduce the sonic boom, e.g., shaping an airplane so it makes more of a dull "thump." NASA will soon start flying the Lockheed X-59 QueSST (Quiet SuperSonic Technology) to test the first "soft boom" design. Aerion, and other companies like Spike and Boom, are already using this technology to design supersonic airliners and business jets that could carry people at twice the speed of modern jetliners. We may soon be able to fly to far-away destinations much more quickly!

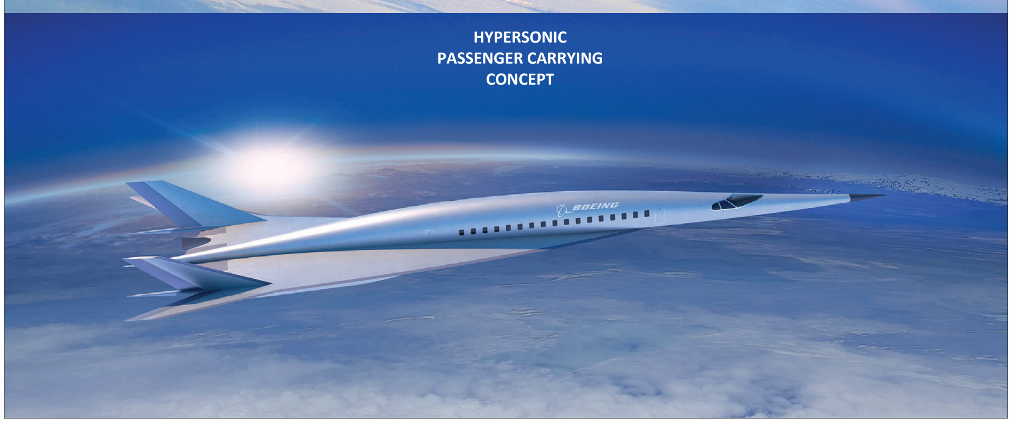




X-43

SR-72

HYPERSONIC PASSENGER CARRYING CONCEPT




X-51

Jets can go even faster, thanks to ramjet and scramjet technology. Scramjets – engines where the airflow remains supersonic all the way through the engine – were thought to be impossible, until recently. Then, two UAVs, the NASA X-43 and the Boeing X-51, did the impossible and achieved speeds that no jet had ever reached before. The X-43, for example, flew at 9.6 times the speed of sound. They could fly for only a few minutes at a time, but a few minutes gets you pretty far when you can go at two miles per second! Raytheon is currently using scramjet technology to develop hypersonic missiles.

Lockheed is working on a new jet, nicknamed the SR-72 (in reference to the SR-71, one of the most impressive airplanes ever designed). It will use ramjet technology and high-temperature materials to fly at six times the speed of sound – twice the speed of any jet that has ever carried a pilot. Using similar technologies, Boeing could create a Mach 5 airliner, a futuristic concept currently being worked on by a group of experts.

Hypersonic speeds require these airplanes to fly at extreme altitudes, near the edge of space, where the air is very thin, in order to minimize the drag and the heating from shockwaves. If they flew any higher, there would not be enough oxygen for a jet engine to work, and they would need to carry an oxygen tank as well as a fuel tank... which is what rockets do. A company called Reaction Engines is developing a new engine called SABRE: It can work either as a jet engine (using oxygen from the air) or as a rocket engine (using oxygen from a tank). This could allow for rockets that can reach orbit with a single stage (because they don't have to carry as much oxygen), or for airliners that carry passengers at hypersonic speeds, skimming the upper layers of the atmosphere.

FALCON

Space travel is being revolutionized by the introduction of reusable rockets.

Why is this so exciting? Well... a 777 costs about $350 million and carries about 350 people. Does a trip in a 777 cost a million dollars per person? No! Why not? Because a 777 is not destroyed at the end of each flight; it's flown many, many times. So, for each flight, the passengers have to pay just for the fuel and for operational costs (such as paying for the pilots and the ground crew), not for the 777 itself.

Until recently, rockets were used only once, then destroyed at the end of each flight, making it enormously expensive for people and satellites to reach space. But now that reusable rockets are being introduced, it becomes possible to get to space just for the cost of the fuel and operations, not for the cost of the rocket. Some of these rockets use jet fuel, making flights even less expensive than traditional rockets, which use super-cooled liquid hydrogen.

XS-1 / XSP

SpaceX has already launched many satellites with reusable Falcon rockets, which can land vertically (i.e., straight down, as shown on the opposite page) at the end of each spaceflight. Soon they will face a competitor – Boeing's XSP (previously known as the "XS-1"), a rocket that flies up into space, releases its payload (or a "piggyback" second stage), and then uses its wings to land on a runway like an airplane. Meanwhile, SpaceX has started to build the enormous Starship (previously: "BFR") rocket, which will take astronauts to Mars. SpaceX has said that the Starship could also be used as a super-fast sub-orbital airliner, flying passengers from one "spaceport" on Earth to another.

BFR / STARSHIP

X-37B

Ever since the X-15 program in the late 1950s, the idea of a "spaceplane" has been exciting pilots, engineers, and hopeful astronauts. Although the Space Shuttle is a fairly well-known spaceplane, it was retired in 2011, and most people don't know about the spaceplanes currently being flown.

Boeing's secretive X-37B – a mini unmanned Space Shuttle – has been flown into orbit five times (and counting) for the Air Force, staying up in space for one to two years during each flight. Very few details have been revealed about this mysterious project, only short statements about testing Hall thrusters (a kind of ion propulsion), and changing the orbital trajectory by turning while flying through the thin outer atmosphere.

SPACESHIP 2

Scaled Composites' SpaceShip Two has been flown only in test flights, including some flights into space. Once it is shown to be safe and reliable, it will be certified to carry commercial passengers into space, a.k.a. "space tourists." It will be operated by the airline Virgin Galactic, which is paying for its development.

Sierra Nevada's DreamChaser has flown only a couple of autonomous glide tests: It was lifted up to ten thousand feet by a helicopter and dropped, proving that it can reliably land itself. It was then selected by NASA to fly supplies to and from the International Space Station, and also by the UN to fly microgravity science research missions for countries without their own space programs, over the next few years.

DREAMCHASER

WHITE KNIGHT ONE

Many reusable spacecraft (as well as some UAVs like the X-43 and X-51 scramjets) launch from a “mothership,” an airplane that carries another airplane or spacecraft to a high altitude and speed, then releases it. With such a boost, the dropped vehicle can go higher and faster than if it took off or launched from the ground. An L-1011 mothership has even dropped Pegasus rockets that flew satellites to orbit. The LauncherOne, a larger rocket currently being tested, will be dropped from a 747.

SpaceShip One – and later, the X-37 during gliding test flights – was flown up to the drop altitude under the belly of a mothership called White Knight One. The newer and larger SpaceShip Two is released from the newer and larger White Knight Two, after being taken aloft hanging under the “bridge” wing between the two fuselages. Both White Knights were created by Scaled Composites. The company’s latest design is the largest airplane in history: Built to carry and release even heavier spacecraft, the StratoLaunch Roc is almost the size of two 747s joined at one wing.

The awkward shapes of some of these motherships reveal how tricky it is to design an airplane with the mission of carrying a large, bulky spacecraft to high altitudes and then releasing it smoothly and safely in flight!

WHITE KNIGHT ONE & X-37

WHITE KNIGHT TWO

747 & LAUNCHER ONE

STRATOLAUNCH ROC

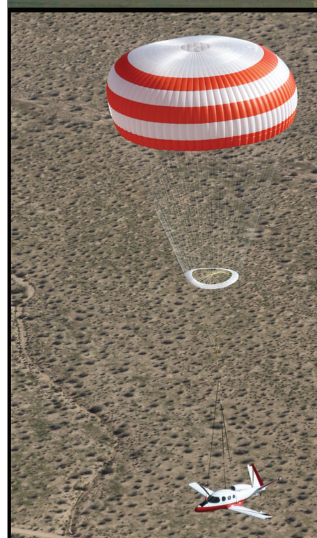

ERAOLE

But innovation isn't happening only around spacecraft and expensive fast jets. Small airplanes have also been the source of significant advances lately.

A team in France has created a small, carbon-neutral hybrid airplane called the Eraole, powered by biofuel and sunlight. (Biofuel is made out of plants that have taken carbon out of the atmosphere, so in the end, the airplane releases no new carbon.) Raphael Dinelli plans to fly the Eraole across the Atlantic!

The Rutan Boomerang is an asymmetric airplane with five seats and a Z-shaped forward-swept wing. This unusual layout allows for the two engines to be placed very close together, minimizing the turning force that would be caused by an engine failure – one of the key safety factors in twin-engine airplanes.

BOOMERANG



The Cirrus SF50 Vision is a small business jet with a single engine on top... and a parachute that, in case of emergency, can lower the entire airplane slowly and safely to the ground. Some Cirrus parachutes have been deployed in emergencies, saving many lives... and a few of those airplanes were even returned to flight!

SF50

It doesn't take big companies to invent cool new airplanes. Individuals in their garages are coming up with incredibly creative flying machines. For example, we have mentioned the Synergy, the EZ, and Colin Furze and Zhou Deli's hoverbikes.

The SubSonex is a kit, designed so that the airplane can be built – and highly customized – by anyone in their garage. That makes it possible for many pilots to realize their dream: owning a private little fighter jet! (By the way: Like the Cirrus, the SubSonex also has a whole-airplane parachute.) A two-seat version is currently in development.

Barnaby Wainfan designed, built, and flew the Facetmobile, which uses a "lifting body" fuselage, a design similar to the F-117 stealth fighter. And a small group in Germany has created and flown many small flying wings, like the PUL-10 seen here, and has recently released an improved design for sale: the Horten HX-2, named after the Horten brothers' flying wings of the 1930s and '40s.

If you had the time, money, and expertise, what interesting airplanes, modifications, or aeronautical technologies would you design and test in your garage?

PUL-10

FACETMOBILE

SUBSONEX

Good news: You don't have to wait until you're a professional aeronautical engineer – or an adult with a garage full of tools – to invent and test new aeronautical ideas. Remote-control (RC) models are real airplanes too! NASA knows this: Airplanes like the X-36, X-37, X-43, X-47, X-48, X-50, X-51, and X-56 are all too small to carry a human, but still made very important contributions to aeronautical technology by flight-testing new design concepts. Control-system kits and electric motors make it easier than ever to create flying model airplanes. Some of these kits, like the PowerUp, can even be controlled from a smartphone! Arguably, the best way to get started with airplane design is to buy a ready-to-fly RC model, learn to fly it, and then start modifying it.

Software like NASA Vehicle SketchPad (VSP) and X-Plane's Plane Maker allow you to design airplanes, measure their performance, improve them by making tweaks, and even fly your designs in a simulator on your computer! Some new aircraft designs, like the CarterCopter, were developed by being "built," "flown," and improved inside X-Plane before being actually built and flown. Up until the twenty-first century, this kind of computing power was available only to big airplane companies! Now anyone in the world can download these software tools for free, and watch YouTube tutorials about how to use them.

Aeronautical engineering is a very exciting field. Right now, people in university labs and big companies – and at home in their garages and on their computers – are inventing, building, testing, and refining creative ideas that will shape the airplanes of the future. We are making airplanes more fuel-efficient, more sustainable, safer, less expensive, easier to fly, faster, and more fun. Some of us get paid to do this kind of work; others just do it because we think it's super cool.

Would you like to join us?

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Airbus double fuselage: US8157204B2
[see also US20130256451A1, US20140263831A1, and US7419120B2]

Airbus "ultra-rapid air vehicle": US9079661B2

[For combinations of multiple fuselages ***and*** VTOL tilt-rotors, see US20120318908 and US8857755B2]

Bernardo Malfitano works in the Airplane Configuration group within the *Product Strategy and Future Airplane Development* organization of Boeing Commercial Airplanes. He performs analyses, studies, and sometimes tests, on proposed features and configurations for future airplanes. The results determine the optimal shapes, materials, locations, and manufacturing processes for new airplane parts, so as to minimize drag, weight, cost, and risk.

In short; he's an airplane designer.

For the previous eleven years, Bernardo worked as a structures engineer / researcher, specializing in fatigue testing, analysis models, and maintenance planning. Bernardo is one of Boeing's experts on "airplane aging" issues, and has taught hundreds of Boeing engineers how to do fatigue analysis and how to plan airplane maintenance: in other words, how to design parts that last, and how to catch any form of deterioration before it impacts the safety of flight. Bernardo designed, ran, and documented fatigue tests on new parts for the 787-9, 767 Tanker, 737MAX, and 777X while those airplanes were being designed, and on technologies and materials that have not yet been implemented on commercial airplane structure, such as next-generation composites and new kinds of 3D-printed titanium.

Bernardo earned a Bachelor of Science degree from Stanford University and a Master of Science degree from Columbia University, both in Mechanical Engineering. Most of his academic career focused on aerodynamics and propulsion: He has spent many hours designing and running experiments in the wind tunnel and in the engines lab. He also has academic and professional experience designing and testing control systems for UAVs and spacecraft.

In his spare time, Bernardo is a private pilot, co-owns an RV-6 (which he has flown to EAA Oshkosh multiple times) and enjoys flying aerobatics. He also occasionally works as an aviation journalist, and has been interviewed on TV shows as an aeronautics expert. Bernardo has built and flown all kinds of model aircraft including rockets, gliders, quadcopters, and flying wings.

Bernardo is originally from Rio de Janeiro, Brazil. He lives in Seattle with his wife, Jill, and their two cats. This is his first book, although he has written a three-hundred-page reader for his airplane design course, "Understanding Airplanes," which you can download at UnderstandingAirplanes.com . If you have any questions about airplanes, feel free to email Bernardo at UnderstandingAirplanes@Gmail.com .

WHITE KNIGHT 2 & SPACESHIP 2

A book for kids of all ages, showing the latest, most creative, and most innovative ideas in the field of airplane design. These concepts are currently being tested and figured out. If you become an engineer in 10 or 20 years, you will use these ideas - and your creativity! - to make the airplanes of the future better than the airplanes of the past.

CORA

PUL-10

SOLAR IMPULSE

X-59

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