Without Richard T. Whitcomb, supersonic flight wouldn’t be such a smooth ride. Whitcomb was an aviation pioneer whom NASA has dubbed “the most significant aerodynamic contributor of the second half of the twentieth century.” The celebrated engineer made three major discoveries that reduced drag on aircraft during his career with the aeronautics and space agency.

Whitcomb started at what is now NASA’s Langley Research Center in 1943—during World War II. He had just graduated with highest honors from Worcester Polytechnic Institute with a degree in mechanical engineering. One of his first challenges was how to achieve transonic (aircraft speeds nearing the speed of sound) and supersonic flight. When aircraft neared the speed of sound, they were hit with a sharp increase in drag. Whitcomb and other scientists spent years trying to understand what caused this drag.

One day in the 1950s, while sitting with his feet propped up on his desk, an idea struck Whitcomb. He had learned from a visiting German scientist that although air flows easily around a plane at lower speeds, the area of the airflow remains constant at higher speeds and can no longer flow smoothly around the airplane structure. Whitcomb had been working on streamlining the wings and fuselage as independent areas of a plane, but now the notion came to him to consider the whole aircraft body at once—wings, fuselage, and tail. In particular, he focused on an aircraft’s cross-sectional area where wings and fuselage meet. He used the curved shape of a Coke bottle as his model. His newly shaped fuselages tested beautifully in the wind tunnels. The increased drag disappeared. This is often referred to as Whitcomb’s area rule.
In the 1960s Whitcomb struck aerodynamic gold again. He invented the supercritical wing (airfoil) for jet liners. These airfoils were flatter on top and rounder on the bottom, with a downward curve on the trailing edge. This innovative shape delayed the formation of the supersonic shock wave that forms just below and just above the speed of sound. This increased fuel efficiency as the airliners neared Mach 1.

In the next decade Whitcomb came up with the winglet, which you first read about in Lesson 3 of this chapter. Other engineers had thought of adding plates to wingtips to reduce drag. But an article Whitcomb read about birds sparked a more complete idea. “It is a little wing. That’s why I called them winglets,” he said. “It’s designed with all the care [with which] a wing was designed.” The winglet reduces drag as well as fuel consumption.

Whitcomb retired in 1980 and passed on in 2009 at the age of 88. Yet his three aerodynamic contributions continue to impress. “Dick Whitcomb’s three biggest innovations have been judged to be some 30 percent of the most significant innovations produced by NASA Langley through its entire history,” said Langley chief scientist Dennis Bushnell, who worked with the legendary engineer.

Vocabulary

- transonic
- biofuel
- acoustic
- decibel
- air traffic control
- autonomous
- prototype
- micro-UAV
- nanotechnology
- nano-UAV
- cure
- tensile strength
- compressive strength

Richard Whitcomb looks at a model that sports his supercritical wing concept.

Courtesy of NASA
The Latest Topics of Aviation Research

Aircraft research is taking dramatic turns in the twenty-first century. As you read in the previous lesson, some of the main goals driving innovation include cutting fuel consumption, emissions, and noise. Engineers are studying lighter materials and new fuels, among other possibilities. Shorter travel time that incorporates green goals is another big aim.

Hypersonic Aircraft

If you’ve ever traveled long distances—East Coast to West Coast, North America to Europe, or Los Angeles to Tokyo, for instance—then you know how very long and tiring a long-distance flight can be. Imagine cutting the travel time from Los Angeles to New York from six hours to no more than 35 minutes!

Figure 6.1 The HyperSoar would bounce along Earth’s atmosphere, giving the aircraft improved fuel efficiency and shorter flight times. Reproduced from the Lawrence Livermore National Laboratory/DOE
Building on decades of research in hypersonic flight, engineers at the US government’s Lawrence Livermore National Laboratory in California have come up with a futuristic concept that would do just that. It’s called the HyperSoar. While still just in the conceptual phase, this aircraft would be capable of taking off from any airport, traveling at Mach 10 (10 times the speed of sound), and climbing to 40 kilometers (about 24.8 miles) to skip along Earth’s atmosphere to its destination (Figure 6.1).

Once the aircraft reaches the 40-kilometer mark, its engines would be turned off and it would coast up to about 60 kilometers. At that point it would fall back down to about 35 kilometers, well inside the atmosphere’s upper level. Here it would be pushed up by aerodynamic lift, and the engines would fire briefly, propelling it back into space. Outside the atmosphere, the engines would shut off and the process would repeat. Each skip would take about two minutes.

Besides saving time, HyperSoar would burn liquid hydrogen, which emits water vapors. Liquid hydrogen is a clean fuel. Also, by spending so much of its travel distance out of Earth’s atmosphere, HyperSoar should be able to radiate any heat it generates into space. To deal with heat issues, engineers generally add heavy, strong materials to engines and airframes (another name for an aircraft body). This added weight cuts into fuel efficiency and decreases the amount of cargo an aircraft can carry. HyperSoar’s trajectory along the top of Earth’s atmosphere addresses these problems. HyperSoar could also have many other uses: move passengers and cargo, deliver satellites to space, or bomb enemy targets. These other uses would bring down the aircraft’s cost.

In 2004 NASA and the Air Force successfully tested the scramjet engines such an aircraft would need with the X-43A hypersonic technology demonstrator. Another successful flight took place in 2010, when a scramjet engine burned for more than 200 seconds to power the Air Force’s X-51 vehicle to five times the speed of sound (Mach 5).

**New Fuels**

Another area of aviation research concerns new fuels for powering aircraft. In 2008 Boeing and several international partners flew a small motor-glider powered by hydrogen fuel cells. They made history with that manned flight.

**Hydrogen Fuel Cells**

This two-seat motor-glider used a combination of hydrogen fuel cells and lithium-ion batteries to power an electric motor that turned a propeller. Once the plane reached 3,300 feet—cruising altitude—the pilot disconnected the batteries. For the next 20 minutes, the plane flew 62 miles per hour using only power generated by the fuel cells.
Hydrogen fuel cells are electrochemical devices that convert hydrogen (a gas) into electricity and heat. They do not produce any of the typical products of combustion such as carbon dioxide. Instead, they exhaust only heat and water.

**Biofuels**

Researchers in both the Air Force and private industry are exploring the use of **biofuel**, a fuel made from plants. In March 2011, an Air Force F-22 Raptor successfully flew at Mach 1.5 on a 50/50 blend of conventional petroleum and biofuel derived from *camelina*, a weedlike plant not used for food.

The flight was a milestone in the Air Force’s goal to obtain 50 percent of its domestic fuel requirement using alternative fuel blends. These blends should come from domestic sources produced in a way that is “greener”—more environmentally friendly—than fuels produced from conventional petroleum.

In February 2011, the Air Force certified the entire C-17 Globemaster fleet for flight operations using a biofuel blend. The C-17 was the first Air Force aircraft to receive such certification.

Several aircraft manufacturers have also combined efforts to study biofuel. In early 2008 Boeing, Virgin Atlantic, and GE Aviation all took part in the first commercial airline flight with a biofuel mix. Virgin Atlantic airlines flew a Boeing 747 from London to Amsterdam with a 20 percent biofuel/80 percent kerosene mix in one of four engines.
In its 2009 Environment Report, Boeing listed among its reasons to study biofuels a desire to be less dependent on fossil fuels, especially when oil prices can be unpredictable. The company also said that the types of plants it’s investigating would not compete with food crops (unlike ethanol, which uses corn), and it argued that plants absorb carbon dioxide, a greenhouse gas. The report further stated that a plant such as algae could produce up to 2,000 gallons of oil per year per acre.

It’s Not Just Science Fiction Anymore

Engineers at NASA have built an amazing machine that’s reminiscent of the replicator from Star Trek: Next Generation. That fictional replicator let Captain Picard order a cup of his favorite tea, and out it would pop from a hole in the wall. NASA’s real-life contraption requires only a drawing and the right materials—and the Electron Beam Freeform Fabrication, or EBF3, does the rest.

“You start with a drawing of the part you want to build, you push a button, and out comes the part,” says Karen Taminger, technology lead for the research project that’s a branch of NASA’s Fundamental Aeronautics Program in Virginia.

The technique is called rapid prototyping, a technology that first became available in the late 1980s. It’s been evolving ever since.

The EBF3 actually manufactures objects one layer at a time. It works in a vacuum chamber in which an electron beam focuses on a source of metal constantly being fed in. The beam melts the metal, which is then applied one layer at a time on top of a rotating surface. The drawing supplied to the EBF3 must be very detailed and three-dimensional. The object created must also be made out of materials compatible for use with an electron beam.

Once perfected, aircraft manufacturers could use the EBF3 to build major structural parts of a plane for much less per pound than on a typical manufacturing floor. The electron beam concept is also more environmentally friendly. For instance, rather than having to trim a 6,000-pound block of titanium to a 300-pound part, with all the rest left as recyclable waste, the EBF3 could work with a 350-pound initial block and have only 50 lbs. of recyclable material left over.
Noise Reduction

As you read in the last lesson, researchers are trying to reduce aircraft noise. Noise suppressors such as chevrons are one way to muffle the racket. But engineers are working on a number of other ideas as well.

NASA acoustic researchers have been tinkering with metallic foam made from stainless steel that they install around engines. (Acoustic is having to do with sound.) The foam is firm, tightly packed like a honeycomb, gently abrasive, and lighter than you might expect. While just about any foam will absorb noise, most would catch fire from engine heat. Metallic foam solves that problem. NASA has joined forces with a Michigan-based company called Williams International to refine the concept in a way that doesn’t add weight or cost, or hurt performance.

Taking a wider view, NASA is also crafting a plan for noise-reduction strategies 10, 20, and 30 years out. The space agency refers to this as “next” generation technology, or N+1 for 10 years out, N+2 for 20 years into the future, and N+3 for anything 30 years and beyond. For instance, N+1 aircraft would look just like today’s aircraft with a tube-shaped fuselage. But engineers could modify the noisy parts, such as flaps and slats, by doing away with their sharp edges. They could also slow fan speeds or streamline landing gear.

N+2 aircraft might meld wings and body into one smooth unit and mount engines on top of the “blended or hybrid wing body.” By placing the engines on top, the airplane body itself could block noise from reaching communities below.
No one really knows what an N+3 aircraft will look like. One of the trickiest aspects to inventing new technologies is making sure they don’t improve flight in one way while damaging it in another. As NASA aerospace engineer Edmane Envia says, “What makes our job very hard is that we are asked to reduce the noise but limit as much as possible any negative impacts on the overall performance characteristics of the airplane, including fuel burn, aircraft weight, and range.”
Air Traffic Control

How efficiently planes can take off, fly, and land also impacts noise pollution, emissions levels, and fuel use. Since World War II, the United States has relied on radars to manage its military and commercial air traffic. This system currently services a huge number of planes. For instance, at any given moment, 5,000 airplanes—civilian and military—are in the air over the United States. In 2009 they carried 689 million passengers around the country. In addition, planes move an average of 36 billion pounds of cargo each year. The Federal Aviation Administration (FAA), which monitors aviation, expects air traffic to grow 50 percent by 2025.

Certain authorities such as the FAA are working on new technologies to improve air traffic efficiency and safety, particularly as these numbers continue to grow. They have formed a plan called NextGen that uses satellite technology, much like the GPS people use in their cars. Introducing NextGen is an ongoing process. Its satellite-based system should provide information to pilots and air traffic control (a management system for coordinating air traffic at airports and in the air) on the ground in real time. This would allow planes to safely fly closer together, take more direct routes, and be more aware of their position relative to other aircraft. These more precise flight paths should result in fewer delays for passengers and thus lower fuel consumption, emissions, and noise.

The effects are noticeable on the ground as well. Because of this still-evolving system’s improved precision, airports can install runways closer together. For instance, in 2008 O’Hare (Chicago), Dulles (Washington, DC), and Seattle airports installed additional runways within their existing airfield footprints. With these new strips, the three airports, together, can handle 300,000 additional flights per year. This speeds the rate of takeoff and landing patterns, which decreases delays, fuel use, noise, and emissions.

Continuous Descent Approach

NASA has also been developing a fuel-saving idea called continuous descent approach. It tested this idea in 2007 and 2009 at different US airports. Today when planes land, they follow an arrival path that looks like a set of stairs. It is not very efficient because it requires planes to frequently change altitude, direction, and speed to keep a safe distance from other aircraft. NASA’s continuous descent approach allows airplanes to coast during their final flight stages, which uses less power. Planes coming in at a continuous, gliding descent at low engine power cut fuel burn and all the emissions and noise that go with it.
Of course, the new landing approach requires careful coordination. Using continuous descent approach, planes must follow specific landing routes at specific speeds for safety’s sake. NASA is researching a system called Efficient Descent Advisor, which will be a tool for air traffic controllers. The agency estimates that this system could cut fuel use for a large aircraft by up to 3,000 pounds per flight and carbon dioxide emissions by about 10,000 pounds. That’s 27 percent less than normal. Research is continuing on the system.

The Use of Remotely Piloted Aircraft

Another heavily researched area is the unmanned aircraft system (UAS), also referred to as unmanned aerial vehicle, or UAV. A UAS consists of one or more aircraft, along with equipment and operations and maintenance personnel. The US military and intelligence services use UASs for reconnaissance and combat. (You may sometimes see them referred to in the press as drones.) They’ve flown many missions in recent years, including into Afghanistan, Iraq, and Pakistan. Because pilots control the aircraft remotely—from the ground rather than from the cockpit—UASs are also called remotely piloted aircraft, or RPAs.

One of the more familiar RPAs is the Predator, which has seen a lot of action overseas. It is propeller driven; conducts intelligence, surveillance, and reconnaissance (ISR); and is armed. The earliest armed Predator generation—designated the MQ-1—first flew in 1994 and has around 920,000 hours in the air. The Air Force received its very last MQ-1 in March 2011 from manufacturer General Atomics Aeronautical Systems. Each costs about $5 million, and the Air Force has bought 268 of them in all.

General Atomics has also built a larger and more powerful generation of Predator called the MQ-9 Reaper for the Air Force. It has a turboprop engine. Like the MQ-1, it can be taken apart and shipped in a single container for duty anywhere in the world. Each MQ-9 costs about $13 million. The company has recently manufactured yet another Predator generation called the Predator C with a jet engine.

The RQ-4 Global Hawk is another well-known UAS. It is a large-size UAS, compared with the MQ-9 and MQ-1, which are both midsize. Its function is solely intelligence gathering, so it flies at high altitudes. It went to work in November 2001 to support the global war on terror. The Global Hawk's power plant is a turbofan. Northrop Grumman is the prime contractor, and each Global Hawk costs anywhere from $55 million to $81 million.

Wing Tips

The letters and numbers in MQ-1 mean something. The M stands for multirole (intelligence, surveillance, reconnaissance, and kill capability), the Q stands for unmanned aircraft system, and the 1 indicates the aircraft is the first of the series of remotely piloted aircraft systems. Some aircraft have the initials RQ. The R stands for reconnaissance; these aircraft do not carry weapons.
Autonomous refueling will be the next big leap forward in UASs. Something that's autonomous is independent of outside control. While still in the development phase, this type of midair refueling will let UASs take on longer missions. A UAS like the Reaper holds about 4,000 pounds of fuel and has a range of only 1,150 miles before it has to head back to base for refueling. The Air Force is eyeing missions that could last at least a couple of days without a similar pit stop.

A project dubbed the Joint Unmanned Combat Air System has been studying the possibilities for autonomous midair refueling since the turn of the millennium. It involves Boeing, the Defense Department's Defense Advanced Research Projects Agency (known as DARPA), the US Air Force, the US Navy, and NASA.

The X-45A was the project's first prototype—a model. In May 2010 Boeing introduced the Phantom Ray, a stealthy, jet-powered UAS based on the X-45C model. Later that year NASA hitched the Phantom Ray to the back of its shuttle carrier aircraft to move it to Edwards Air Force Base in Southern California for test flights. Until that date the shuttle carrier had never ferried anything other than a space shuttle.
Midair collisions between unmanned and manned aircraft are another issue that UAS research is attempting to address. A number have run into each other over Afghanistan. A pilot in the cockpit can see a building or aircraft in his or her flight path, but this isn’t such a simple task for an RPA or more especially an autonomous UAS. Consequently, UAS research also includes what’s called sense and avoid technology, a kind of electronic eye.

**Pint-Sized UAV Developments**

The opposite end of the spectrum is the micro-UAV—an aircraft that weighs as little as a few ounces or a few pounds. The Air Force uses a number of models in Iraq and Afghanistan to gather information about the enemy.

The Battlefield Air Targeting Micro Air Vehicle, or BATMAV, weighs only a pound—yet carries a camera that can look both forward and to the side. It can send images (day or night) to the person controlling it from as far as three miles away, and can remain in the air for 45 minutes. These images give troops situational awareness (that is, an understanding of the dangers and opportunities a situation may present) and possible targets.

The 4.5-pound RQ-11B Raven is another useful battlefield tool in the micro-UAV class. It can fly for 90 minutes, reach 14,000 feet, fit into a backpack, and radio images back to a controller from about six miles away. It also has an infrared camera for night operations.
Even smaller than the micro-UAV is another category based on nanotechnology, the science and technology of building electronic circuits and devices from single atoms and molecules. Although not yet invented, a nano-UAV—a UAV so small it is invisible to the naked eye—is part of the Air Force’s image of the future. If engineers can create it, it could zoom about enemy camps to collect information, interrupt communications, or conduct a cyber attack.

### The Most Recent Innovations in Aircraft Design

Aircraft design is also going through an evolution. Two big advances are in lightweight materials that reduce fuel consumption and aircraft size.

#### Boeing 787 Dreamliner

Boeing's 787 Dreamliner incorporates lightweight composite materials into its design. The manufacturer says that composite materials will make up about 50 percent of its main body parts, including its fuselage and wings. Composites include materials such as fiberglass and carbon fiber; the 787 uses carbon fiber. Engineers work with composite materials because they are extremely smooth and can be formed into curved or streamlined structures. The smoothness reduces drag.

Composite materials are fiber-reinforced matrix systems. This might sound confusing but when you break the term down, it's actually quite simple. The matrix is a kind of glue that engineers use to hold fibers together. They shape this glue-fiber mixture and cure it (allow it to harden). The fibers bear most of the weight. Manufacturers work with many different types of fibers and matrix systems.

Fiberglass and carbon fiber are the two most common composite materials used in aircraft design. Fiberglass has good tensile strength (the ability to experience up to a certain amount of tension or stretching without tearing), has good compressive strength (the ability to experience up to a certain amount of force that presses together without being crushed), bears up well when something hits it, is easy to work with, and is inexpensive. However, it's fairly heavy. An aluminum aircraft body tends to be lighter than fiberglass if it's well designed.
Carbon fiber, such as the Dreamliner uses, has more tensile and compressive strength than fiberglass. It is also much lighter—as much as 30 percent lighter than aluminum. But because its fibers are brittle, they shatter under sharp impact. The Boeing 787 Dreamliner addresses this problem by using a tougher glue in its horizontal and vertical stabilizers. Carbon fiber is also more expensive than fiberglass—but the price has come down in part because of innovations driven by the Air Force’s B-2 stealth bomber program in the 1980s.

The Boeing 787 Dreamliner’s carbon fiber is also more resistant to corrosion than previous composites. Moisture can get into a fuselage’s out-of-the-way places and eat away at the structure. But humidity isn’t such a danger to the Dreamliner’s new fuselage. This means it won’t require as much maintenance in the long run.

The Dreamliner is the next big thing in passenger airliners, although it’s about three years behind schedule as of early 2011. During a test flight in November 2010, a cabin fire forced an emergency landing. Still, the aircraft already has many orders lined up and tests continue to perfect it. It’s a midsize commercial aircraft that will be able to travel as far as big jets because of the advantages composites give it. One version of the plane—the 787-8—will hold 210–250 passengers and travel up to 9,430 miles (15,200 km). The 787-9 will move up to 290 passengers and fly as far as 9,775 miles (15,750 km).

The 50 percent composites will reduce weight and drag enough that the plane’s fuel use will drop by 20 percent. It can travel at Mach 0.85. Furthermore, engineers have found a way to simplify the structure: its fuselage will be made of only one piece, which does away with 40,000–50,000 fasteners holding together what would have been some 1,500 aluminum sheets. That’s a lot of labor saved, too.
Airbus A380 Superjumbo Jet

The Airbus A380 Superjumbo jet may be the biggest commercial airliner on the market, yet it also sports green features. Airbus is a European manufacturer and competes with Boeing as one of the world’s two leading aircraft designers and builders.

Introduced in 2007, the Airbus A380 is a double-decker aircraft (it has two floors) with stairs forward and aft. It can carry anywhere from 525 passengers (when seats are split into coach, business, and first class) to 853 passengers (all coach). With its tremendous fuel capacity, it can fly 9,550 miles (15,350 km). As the FAA expects air traffic to grow 50 percent by 2025, it could help handle some of this increase.

Despite its size, the A380 is fuel efficient. As Airbus says, it provides the lowest fuel burn per seat. This means that if you divide the amount of carbon dioxide emitted by the number of passengers, it emits less gas than any other aircraft. It also creates 50 percent less noise during takeoff than Airbus’s nearest competitor, and three to four times less when landing even though it can carry far more passengers. And because its passenger capacity is greater than any other commercial airliner, it can cut down on the number of flights needed.

As with many innovations, the Airbus has faced challenges. November 2010 was a busy month for new aircraft. Only a week before the Dreamliner cabin fire, an Airbus A380 flown by Quantas made an emergency landing in Singapore after one of its Rolls Royce engines exploded. All 459 passengers were safe.
An electronic sensor far smaller than the quarter in your pocket may save a lot of fuel. Vijay Chandrasekharan, a student at the University of Florida, created this tiny technological marvel while pursuing his PhD.

Aircraft bodies in motion are subject to a force called shear stress. This stress, which occurs when air flows over the body, results in drag and friction. The airflow generates a force between the aircraft skin and the air molecules, which pull on each other as they move in opposite yet parallel directions. The drag and friction slow the plane, and as a result the plane burns more fuel.

Chandrasekharan’s invention—unveiled in 2010—measures shear stress. NASA says it “beats anything seen in 20 years” for this type of research. If engineers can more accurately measure shear stress on aircraft bodies during wind tunnel tests, for instance, they can design and build more fuel-efficient and safer aircraft. Chandrasekharan also says his invention may have other applications, such as in the medical and environmental fields.

Universities receive funding for such studies from many different sources. NASA funded this particular project with $475,000 over a three-year period. “This collaboration led to an extremely satisfying experience for me as I worked on my dissertation,” Chandrasekharan said. “Without NASA’s involvement my PhD could have been a strictly academic pursuit, without subsequent practical, real-world importance.”
Lesson 6 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. What is the name of the futuristic concept that engineers at the US government’s Lawrence Livermore National Laboratory in California have come up with? What would this aircraft be capable of doing if ever built?

2. What does NASA’s continuous descent approach allow airplanes to do?

3. What do the US military and intelligence services use UASs for?

4. Which micro-UAV weighs only a pound yet carries a camera that can look both forward and to the side?

5. Why do engineers work with composite materials?

6. What does Airbus mean when it says that its A380 provides the lowest fuel burn per seat?

7. If commercial air traffic really does increase 50 percent by 2025, what challenges will that create for the industry and for federal, state, and local governments?