Chapter 6 ADVANCES IN AERONAUTICS

The aeronautics research flights so important in the early 1950s continued into the early 1960s. From the latter part of the 1960s up to the present, flight-testing has been primarily of prototypes of various operational aircraft rather than of research aircraft.

Objectives

Discuss the flights of the X-15.
Discuss the XB-70.
Discuss the importance of composite materials.
Discuss solar aircraft.
Discuss the advancements in military aerospace.
Discuss the advancements in civil aviation and general aviation.

Aeronautical Research

The X-15

The two *X*-series aircraft, which were flown during the 1950s and 1960s, were the *X*-15 and the *XB*-70.

The X-15 project was a joint Air Force, Navy and NACA project aimed at building an airplane that could fly at a speed of 4,500 mph and reach an altitude of 250,000 feet. At this speed and altitude, the temperature of the aircraft would reach 1,200° F. To withstand this temperature, the X-15 was constructed of a nickel-steel alloy called Inconel X.

The X-15 was 50 feet long and had a 22-foot wingspan. It weighed about 33,000 pounds, of which over 18,000 pounds was fuel. The X-15 was rocket powered and was launched by dropping it from a specially modified B-52. The first powered flight took place in September 1959, and the aircraft reached a speed of almost 1,400 mph. The first eight flights of the X-15 were piloted by North American Aviation test pilot Scott Crossfield. The first government flight was performed in March 1960, by NASA test pilot Joe Walker.

Flight testing continued through 1967 with the three X-15s performing over 200 flights. In the end, the X-15 exceeded both of its design goals. It reached a speed of 4,534 mph (Mach 6.72), which is twice as fast as a rifle bullet, and it reached an altitude of 314,750 feet, which is 59.6 miles straight up. The pilots on these record-setting flights were Major Robert White, USAF, for the speed record, and NASA test pilot Joe Walker for the altitude record.

The X-15, piloted by Scott Crossfield, is carried aloft by a B-52. Because of the altitude and speeds attained by Crossfield, many aviation historians consider him to be America's first astronaut. The color photo shows the X-15 in 1960.

XB-70

In 1954, the United States Air Force requested bids on a contract to build a supersonic replacement for the B-52. This aircraft would have to fly three times the speed of sound and at an altitude of 70,000 feet. North American Aviation won the competition and received a contract to build two prototypes. The result was the XB-70, one of the largest, fastest and most controversial aircraft ever built. The first XB-70's initial flight was September 1964, and the second one first flew in July 1965.

In 1964, Congress decided the Air Force did not need a supersonic bomber and canceled the program. The Air Force and NASA used the two prototypes for supersonic research. In October 1964, the XB-70 reached its design speed (2,000 mph) and altitude (70,000 feet) requirements. In June 1966, the second XB-70 prototype was destroyed in a mid-air collision. The first is now at the United States Air Force Museum at Wright-Patterson Air Force Base, OH.

Since the Wright Flyer, aircraft research and design have been continually changing as aircraft designers determined which configuration produced the best performance characteristics—especially at high speeds. While performance has always been the major design factor in the past, today other factors are also important.

The XB-70

Other Research

For the military, changing air tactics, advanced weapons systems and new technology advantages in aerodynamics, structures and propulsion have entered the design picture. Beginning in the mid-1970s, fuel efficiency and environmental considerations became driving forces in commercial aviation, as well as in military aviation.

Research in the past was always limited by weight and stress limitations. Many designs looked good on paper, but could not be tested because the aircraft would be too heavy and/or unable to withstand the in-flight stresses. However, advances in construction materials in the 1970s overcame some of these limitations.

Super-strong, but lightweight, nonmetallic, epoxy graphite composite materials were developed that were stronger than many common metals used in aircraft construction. These composites were tested in every major structural component of an aircraft—from the wings and fuselage to helicopter rotor blades. Research tests demonstrated their strength and opened new doors either to go back to old designs that were more efficient or to advance to new, previously untested designs.

One such advance came in 1988 when the FAA certified Beech Aircraft Corporation's all composite Model 2000 Starship I. The business airplane's fuselage and wing structure use epoxy graphite and honeycomb sandwich panels made of epoxy resin.

Other research was conducted on airfoil design, which produced some revolutionary concepts. The list contains forward-swept wings (FSW), oblique wings, joined wings, mission-adaptive wings, supercritical wings, winglets and canards.

Sweeping the wings forward goes back more than 100 years to pre-Wright experiments of the 1870s. The concept was flight tested earlier in this century and has theoretical advantages. Its use had

been overshadowed by rearward-swept wings, since forward-swept wings needed to be structurally stronger in high-speed flight.

In the past, this meant making the wing heavier using conventional metal alloys. Composite-material technology made the FSW practical. This technology enables the wings to be made lighter, smaller and less costly than equivalent performance planes with rearward-swept metal wings. The FSW design also reduces weight cost and drag.

Test data showed that this technology provided an aircraft that can weigh less, fly longer and turn very tight at supersonic speeds. The X-29A was built in the early 1980s to demonstrate the capabilities of forward-swept wings.

The forward-swept wings of the X-29A

Another research project was on oblique-winged aircraft. This type of aircraft is also known as adaptive-wing, skewed-wing or pivoting-wing aircraft. The oblique-wing aircraft (OWA) changes form during flight for optimum lift under different circumstances and can be rotated to different positions for the best aerodynamic characteristics.

The ability to change the wing angle provides efficiency at both low and high speeds. For takeoff, landing and low-speed cruise, the wing is perpendicular to the fuselage; at high speeds, the wing is pivoted to different oblique angles.

NASA flight-tested an oblique-wing aircraft in 1982 and called the aircraft the AD-1 *Scissors*. In this aircraft, the wing rotates around its vertical axis with one end pointing forward and the other end rearward. This design explored the feasibility of using an adaptive wing as a low-drag, supersonic airfoil for future transport airplanes.

Another project explored winglets. An airfoil produces lift by creating pressure differences on its upper and lower surfaces. At the wingtips, this difference in pressure produces wingtip vortices. This swirling air increases drag, decreases lift and can produce potentially dangerous air turbulence around airports. The winglets, placed in a vertical position at the end of the wings, eliminates the vortices and improves the efficiency of the wing.

Two other projects explored canards, and mission adaptive wings. Canards are horizontal surfaces forward of the main wings and are used for trim and control. The use of canards increases maneuverability and can allow the main wings of an aircraft to be smaller and lighter. The picture of the *X*-29*A* shows an excellent view of the canards forward of the wings.

Mission adaptive wings are now used on several different aircraft. This type of wing is similar to the one used on the B-1B bomber. This wing maintains its best efficiency under most flying conditions by moving forward for slow speed flight and folding to the rear for supersonic flight.

The research and development benefited military, as well as commercial aircraft. Both military and commercial aviation wanted aircraft to be faster, with higher performance. Two of these advanced aircraft were developed to fly over enemy territory at high altitude. They were the U-2 and SR-71.

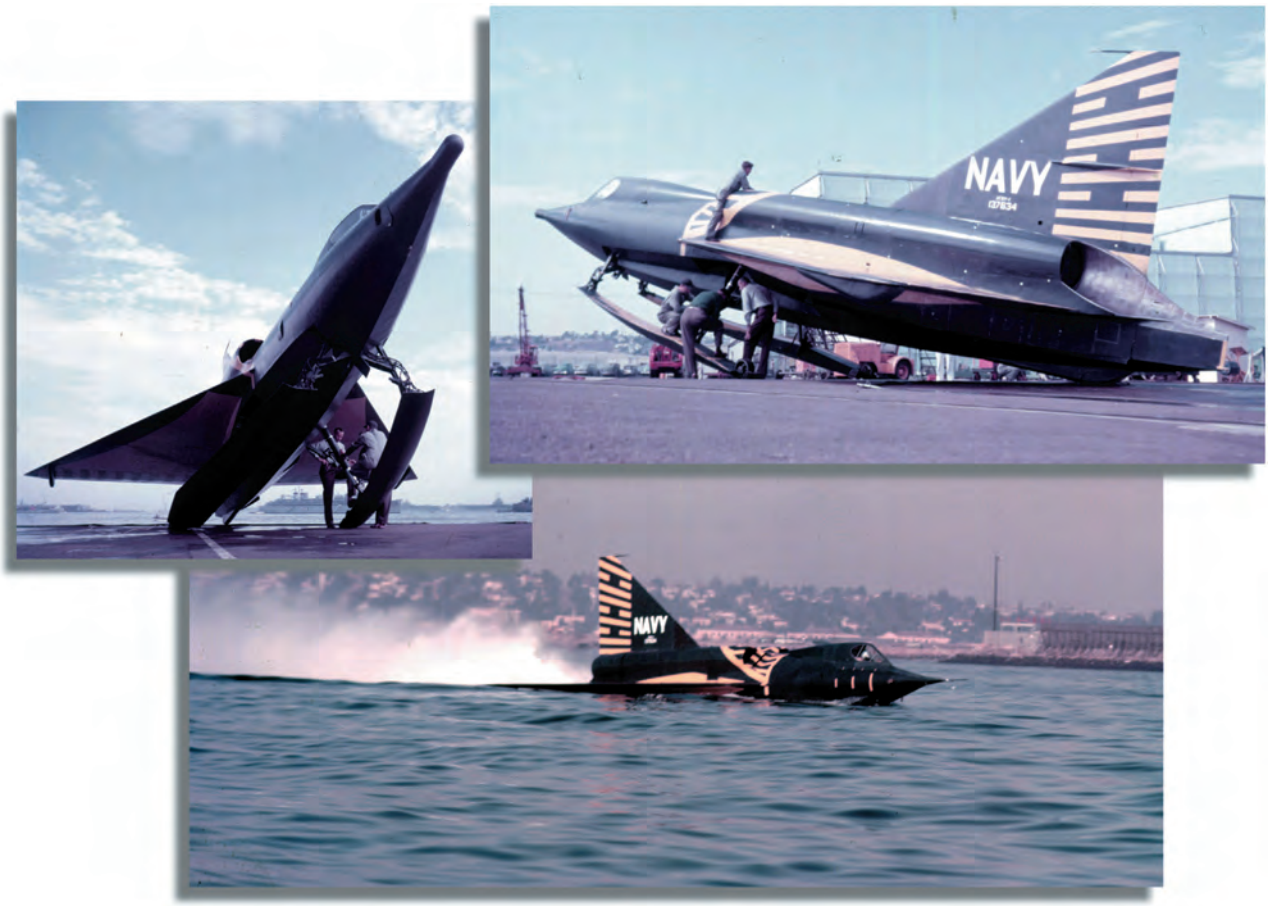
The B-1B Lancer is affectionately known as the "*Bone*."

Faster Than a Bullet - The SR-71 Blackbird High-Altitude Reconnaissance Aircraft

The U-2 High-Altitude Reconnaissance Aircraft

The X-33 Advanced Technology Demonstrator is an unmanned vehicle, launched vertically like a rocket and lands horizontally like an airplane.

The X-43A, shown below, is part of NASAs experimental hypersonic flight research program that seeks to demonstrate airframe-integrated, "air-breathing" engine technologies that promise to increase payload capacity for future vehicles including faster than Mach 5 and reusable space launchers.



The Convair XF2Y-1 Sea Dart was an experimental jet-powered sea plane. It is on permanent display at the San Diego Aerospace Museum.

Significant developments in new materials and designs allowed the construction of stealthy aircraft, which were almost invisible to radar. The B-1B grew out of studies beginning in 1962. Unlike America's past bomber designs, which emphasized high-altitude capabilities, the B-1 was designed to be a low-altitude penetration bomber. To defeat Soviet defenses, the bomber was designed with low-observable technology, which produces a radar cross section 1 percent that of the older B-52.

Two other aircraft, the B-2 bomber and the F-117A, are true "stealth" aircraft designed to be invisible to enemy radar. The B-2 bombers have a unique flying-wing design and can only be described as a radical departure from conventional aircraft designs.

Research and Development and Civil Aviation

Armed with the experience of building large jet aircraft for the military, the Boeing Company unveiled the 707-120 in 1954. The 707 outclassed every airliner in use at that time in all aspects… size, speed, range and capacity. It was the 707 that revolutionized the commercial aviation industry and went on to become the standard long-range jet of the 1960s. The 707 also found service with the

Air Force as the C-135. It was followed shortly by other similar long-haul jets—the Douglas DC-8 and the Convair 880 and 990.

So immediate was the success of the 707 and DC-8 airliners that both Boeing and Douglas began working on smaller, short-haul jets. The first short-haul jet was the French Caravelle I which first flew in 1955 and went into service with Air France in 1959. More than 200 Caravelles in four models were manufactured. This aircraft had a jet engine attached to either side of the rear fuselage and carried between 65 and 90 passengers. United Airlines was the only US carrier to fly the Caravelle I.

In February 1963, Boeing unveiled a new short- and medium-haul trijet called the 727. The 727s have been produced in five models and is the most successful jet ever built. Over 1,700 of these aircraft have been manufactured. The other short-haul Boeing aircraft, the 737, is a twinjet airliner. It went into service in 1968 and carries 80 to 113 passengers. More than 800 of the 737s have been built.

Douglas entered the short-haul market in 1962 with the announcement of their twinjet DC-9. The DC-9 flew for the first time in February 1965. The DC-9 resembles the Caravelle in the placement of the engines, but is a larger aircraft that carries from 80 to 115 passengers. More than 1,000 of these aircraft have been sold.

By the mid-1960s, jet airline travel had reached a peak. In April 1966, Boeing announced they would begin production of the Boeing 747. This jumbo jet was huge even when compared to the 707. It had a wingspan 65 feet longer than the 707, and its fuselage was nearly 90 feet longer and almost twice the diameter. The 747 offered a new standard of luxury that included seating for 385 passengers and an upstairs cocktail lounge.

The Boeing 707

The Boeing 747

The Boeing 757 and 767 *(Boeing photo)*

Both Lockheed and Douglas entered the jumbo-jet field in 1966 with announcements of intent to build a medium-haul jumbo jet. The Douglas DC-10 flew first in August 1970, while the Lockheed L-1011 flew in November 1970. In addition to following a very similar timetable, the two aircraft are very similar both in appearance and in performance. They are both trijets with one engine under each wing and the third on the tail. In the DC-10, the rear engine is mounted above the fuselage, while in the L-1011, it is mounted inside the rear fuselage. They both carry about 350 passengers for distances up to 4,000 miles. Both aircraft have been very successful. Over the years, improvements to the basic models of the 747, DC-10 and L-101 have continued to keep these aircraft in the marketplace.

Before 1978, the Americans had the technological edge over foreign aircraft manufacturers, with 85 percent of all world airliners being US manufactured and designed. By 1978, the technology gap had narrowed to the point that US aircraft manufacturers began to feel a technological threat from abroad, especially from the A-310 advanced-technology transport. This threat gave rise to the introduction of a new family of advanced-technology jetliners for the 1980s. The DC-9 Super 80, the Boeing 767 and the Boeing 757 are three aircraft that were developed to improve efficiency using advanced technology.

Airbus Industry continues to put the pressure on American aircraft manufacturers with the introduction of the Airbus A-320 in late 1988. This commercial transport is designed for short and medium ranges powered by twin turbofans. It also incorporated several technological firsts. It was the first subsonic commercial aircraft to have control by fly-by-wire throughout normal flight. It also has a centralized maintenance system, side stick controls in the cockpit in place of control columns, and has composite materials that makeup the major elements of the airplane's primary structures.

In the early 1960s, the Bristol Aeroplane Company (which later became part of the British Aircraft

The Boeing 777's "Glass Cockpit"

Corporation (BAC)) in England and Sud-Aviation (which later became Aerospatiale) in France were both working on designs for a supersonic passenger airliner. They both came up with very similar designs for a delta-wing aircraft, which could carry about 100 passengers and fly at about Mach 2.2 (1,400 mph). They also both discovered that the development costs of such an aircraft would be so high that neither nation could afford to build it.

In November 1962, an international agreement was signed which would allow BAC and Sud-Aviation to jointly build the aircraft, and the governments of Britain and France would share the development costs. Thus, the Concorde was born.

At that time, unknown to anyone in the Western World, the Soviet Union was also working on a supersonic transport (SST) known as the TU-144. The TU-144 was very similar to the Concorde in size and shape, but was designed to fly a little faster at Mach 2.35 (1,500 mph).

The United States, not to be outdone, decided to enter the SST competition. However, the Concorde and the TU-144 already had a head start because the United States did not start its SST program until 1965. The American SST contract was awarded to Boeing. They called their SST the Model 2707. Due to its late start, it was evident that the 2707 could not beat either the British or the Russian SST into service and lost both public and government support. The project was eventually canceled

The Concorde *(EAA)*

before the 2707 ever flew.

The TU-144 won the race into the air, but a disastrous crash allowed the Concorde to beat the Russian SST into commercial service. On May 24, 1976, the Concorde began flying from London and Paris to Washington, DC. The flight took less than 4 hours.

General Aviation

From 1958 to 1982, general aviation in the United States grew at a faster rate than military or commercial aviation. This is not generally true in other nations of the world (with the exception of Canada). There are three main reasons for this: (1) geography, (2) expense and (3) freedom to fly.

The United States is a very large nation, while some European countries are smaller than most of our states. To fly from Amsterdam to Rome would require crossing through four independent nations and asking permission of each to enter its airspace. This trip is shorter than the trip from San Francisco to San Diego in California. Because of the short distances and excellent ground transportation, there is no real reason to fly within any of the European countries.

Also, the expense of owning and operating a general aviation aircraft is very high, and the United States is one of the few nations in the world with a standard of living that will permit the average person to own an airplane. Most nations of the world do not have a developed aviation manufacturing industry, so if a citizen of one of these nations wants to own an airplane, he or she would have to import one from the United States. In addition, the cost of fuel in most foreign countries is almost twice as high as in the United States. Finally, many nations of the world are ruled by a government that does not want its citizens to have the right to fly whenever and wherever they want.

As mentioned previously in this text, immediately following World War II, Beech, Cessna and Piper began to build all metal, single-engine monoplanes. These aircraft evolved through the years to become more and more sophisticated. The pilots wanted them to fly higher, faster and further, so many became turbocharged and were equipped with retractable landing gear. More instruments and electronic aids were added, all of which led to the general aviation aircraft of today.

Navajo

The Beechcraft King Air

In the 1950s, the manufacturers began adding twin-engine aircraft to their inventories. This was an answer to the need for business and executive aircraft. The first of these twin-engine aircraft was the Beechcraft Twin Bonanza in 1951, followed by the Aero Commander in 1952, and the Cessna 310 and Piper Apache in 1953. During the 1960s, more and more innovations were added to these twins, and by the end of that decade, most manufacturers had twin-engine aircraft as fancy as the commercial airliners.

It was also during the 1960s that the first turbojet business and executive aircraft were built. The first was the British Hawker Siddeley 125, a twinjet that entered service in 1963. American business jets included the Learjet (1964), the North American Sabreliner (1966) and the Grumman Gulfstream II (1967).

During the 1980s, aircraft such as the Gulfstream IV (1986), Learjet 55 (1981) and Beechcraft Starship I (1988) were built using the newest technologies in composites, airfoils and engines to increase performance, while making the aircraft economical to operate.

As research and development continues, military, commercial and general aviation aircraft will continue to benefit. Aviation will continue to get better, faster and less expensive.

The Lockheed Martin F-35 Joint Strike Fighter.
(*Courtesy of Lockheed Martin*)

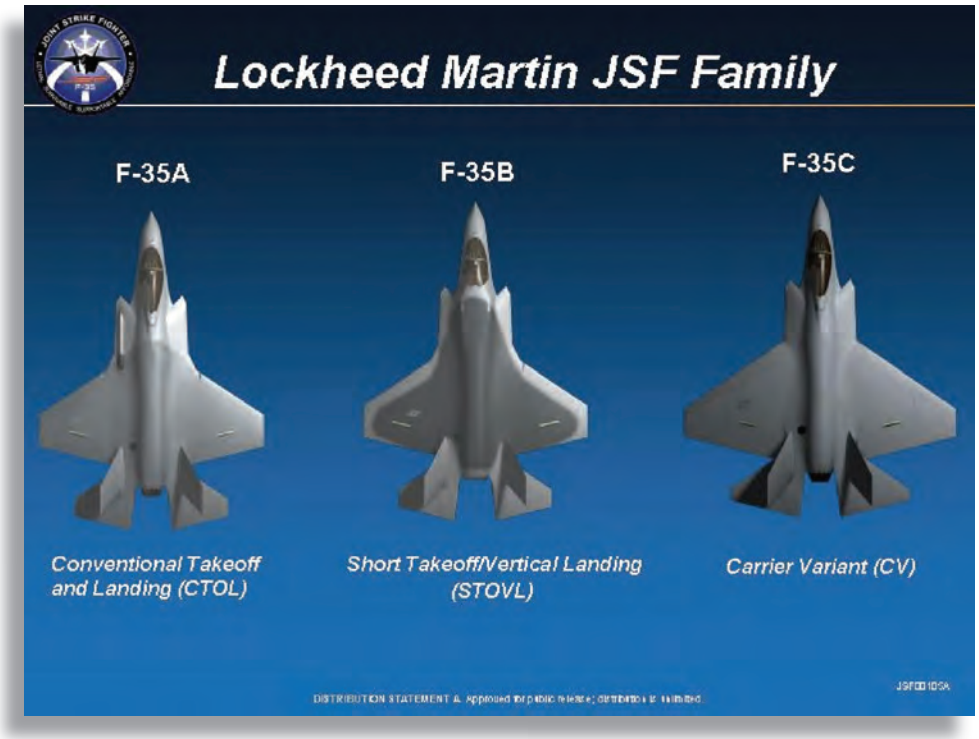
The Joint Strike Fighter

The Lockheed Martin F-35 Lightning II, is the next generation of stealthy, supersonic, multi-role aircraft. It is part of a family known as a Joint Strike Fighters. It will be built in three versions: the F35A, which will be a conventional take-off and landing (CTOL) aircraft for the USAF. The F-35B is a short take-off and vertical landing (STOVL)vehicle for the Army and Marine Corp, and the F-35C (CV for carrier version) is specifically designed for the Naval operations.

The USAF F-35A is primarily an

air-to-ground strike aircraft used as a complement to the F-22. The USMC F-35B is slated to replace the F/A -18B/C and the AV-88. Orders from the United Kingdom are scheduled to replace the Sea Harriers. The C model is also designed to replace the F/A -18B and C models as well as the A-6 while complementing the F/A -18 E and F models.

In order to minimize weight, the aircraft is made of an approximate 40% carbon fiber composite construction. In order to minimize the structural weight and complexity of assembly, the wingbox section integrates the wing and fuselage section into one piece. To minimize radar signatures, sweep angles are identical for the leading and trailing edges of the wing and empennage. The fuselage and canopy also have sloping sides. The seam of the canopy and the weapons bay doors are sawtoothed and the vertical fins are canted at an angle.



The A, B, and C models of the Lockheed Martin Joint Strike Fighter.
(Illustration Courtesy of Lockheed Martin Communications)

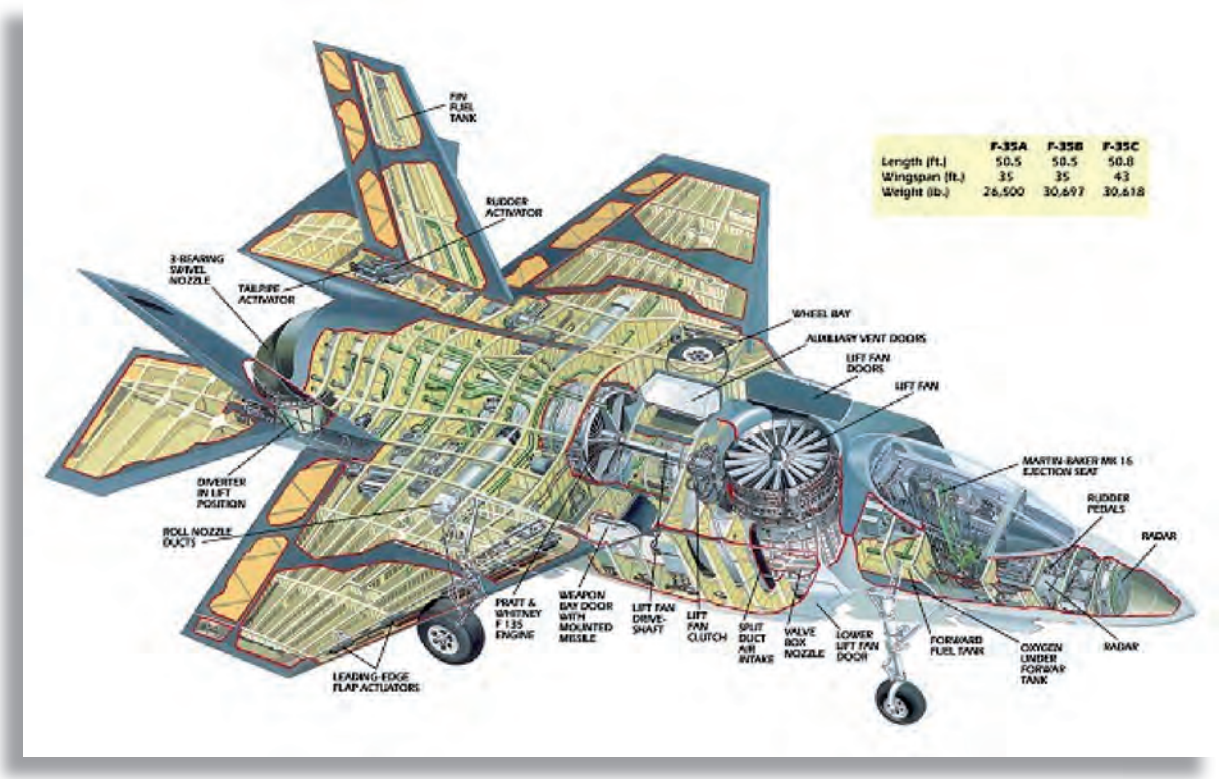
The main difference between the naval and other JSF versions is related to carrier operations. The internal structure of the naval version is stronger due to the high loading of catapult launches and tail hook landings.

The CV aircraft has larger wing and tail control surfaces giving more control authority during low-speed carrier landing operations. A larger wing area provides for an increased payload and higher fuel capacity giving the aircraft an extended range.

Weapons are located within two parallel bays located forward of the landing gear. The "A" version has an internally-mounted gun while the Navy/Marine can be fitted with an external gun pod.

For targeting, Lockheed Martin's Missile & Fire Control and Northrop Grumman Electronic Sensors and Systems are jointly integrated in the JSF's electro-optical system. The LM Electro-optical Targeting System provides long-range detection and precision targeting capability. As a stealth design, the F-35 has the radar signature of a golf ball!

Power is provided by Pratt & Whitney's afterburning turbofan F-135 engine. This is a derivative of the F-119 fitted to the F-22 Raptor. On the F-35B version, the engine is coupled with a shaft-driven "lift fan" system for STOVL propulsion. The counter-rotating lift fans, developed by Rolls-Royce, can



	F-35A	F-35B	F-35C
Length (ft.)	50.5	50.5	50.8
Wingspan (ft.)	35	35	43
Weight (lb.)	26,500	30,697	30,618

Cutaway Illustration Courtesy of Lockheed Martin

generate more than 20,000 pounds of thrust.

The main engine has a three-bearing, swiveling exhaust nozzle. The nozzle, which is supplemented by roll control ducts on the inboard section of the wing, together with the vertical lift fan, provides the required STOVL capability.

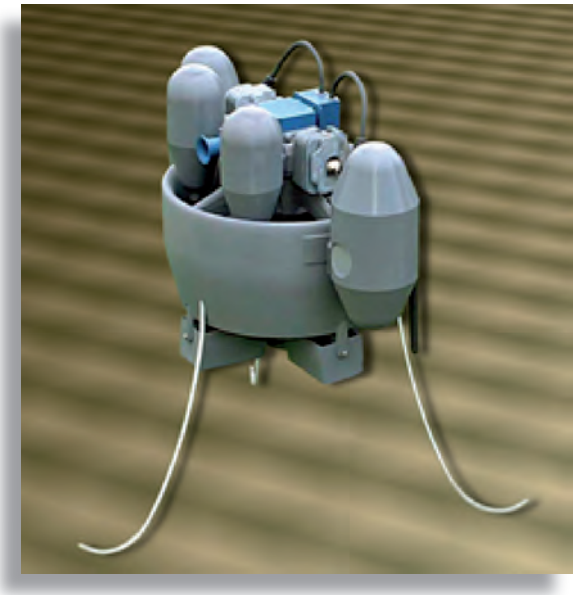
The aircraft is a joint effort of Lockheed Martin, Northrop-Grumman, BAE Systems, Pratt & Whitney, and Rolls Royce. Final assembly of the aircraft will take place at Lockheed Martin's plant in Fort Worth, Texas. Major subassemblies will be produced by Northrup Grumman Integrated Systems at El Segundo, California and BAE Systems at Samiesbury, Lancashire, England. BAE Systems is responsible for the design and integration of the aft fuselage, horizontal/vertical empennage and the folding-wing mechanism of the CV variant.

Micro Air Vehicles

A whole new generation of Micro Air Vehicles (MAV) has been developed since the turn of the century. Most of these "micros" are battery-powered and made of lightweight composite compounds. Some of the MAVs currently under development are as small as 6 inches in height and even smaller "insect-sized" craft are in the experimental stages. Military MAVs have already been used for flight into buildings during terrorist surveillance.

All of the current MAVs carry on-board cameras and can be operated by one soldier in or near a battlefield environment. These have the capability of gathering real-time information that can, through a field-operated lap-top computer, be relayed a command post for planning and attack decisions.

The Honeywell MAV is currently the front runner in what is known as the UAVs, or Unmanned Aerial Vehicles. The *Micro Air Vehicle,* shown here, has flown hundreds of successful flights between ground level and 500 feet AGL. Honeywell says it will function as high as 10,500' if required. As a recon vehicle, it allows soldiers, police officers, and other combatants, to see over a hill, in or around buildings and into other non-secured areas.



Micro Air Vehicle
(Image Courtesy of Honeywell Aerospace)

These are all part of a new technology that falls into a category called "FCS," or Future Combat Systems. They are small, lightweight, and affordable, man-portable, backpackable UAVs that can be used by dismounted infantry, Marines, and Special Operations personnel can use the UAVs for reconnaissance, security, and target acquisition operations in open, rolling, mountain, desert, and urban warfare. The small airborne vehicles have the capability to loiter either in the air or on the ground. While on task, they can "hover and stare," and "perch and stare." The vehicle can then transmit real-time data back to an individual or a command post.

Personal Air Vehicles

Currently under development is an aircraft that has revolutionary possibilities. This is called the ***Personal Air Vehicle*** and one company, Carter Aviation Technologies, has created and flown a rotor-craft that has an unpowered rotor above and a pusher propulsion system at the rear of the fuselage. A four-place model is in the final stages of development and will have the capability of flying forward at a top speed of 270 mph and slow to a speed which allows it to land vertically. It is fully pressurized allowing it to fly comfortably at 35,000 feet. Carter Aviation Technologies has

Carter Aviation Technologies PAV in flight.
Photo by Jason Bynum /Courtesy of Carter Aviation Technologies

developed a method of automatically controlling the collective pitch of the rotor that is independent of any electronics. This will provide the proper pitch from a jump takeoff, transitioning to high speed cruise and then back to a hovercraft type of landing.

CarterCopter in Flight. (*Courtesy of Carter Aviation Technologies)*

Their "slowed-rotor" compound design allows this aircraft to have a vertical takeoff & landing and a highly efficient small wing for horizontal speeds up to 500 miles per hour.

On June 17, 2005, test pilot Larry Neal, achieved a milestone for rotorcraft while flying the CarterCopter. It reached what is known as Mu-1. This is the first time in history that any rotorcraft has reached this mathematical point. The condition was achieved during normal flight-testing while collecting data on a newly developed speed controller for the rotor. It was not planned, but evolved because the rotor remained very stable as the rpm was decreased. Neal decreased the rotor rpm in small increments when he was near Mu-1.

With all systems stable the decision was made to proceed. Data from the flight shows that the airspeed was 170 mph and the rotor was slowed to 107 rpm. Previously, the lowest rotor speed every achieved was 115 rpm. The Mu-1 flight time was just 1.5 seconds before Neal reduced the throttle to slow the aircraft, but it was operated continuously above 0.9 Mu for over over 20 seconds.

The CarterCopter has the potential of becoming an aircraft that any qualified operator can land and takeoff from a non-dedicated airfield location, such as a driveway or street near one's home. With wings folded and rotor stowed, the aircraft can safely land near and taxi to a gas station for re-fueling. In various other configurations, this aircraft has the capability of operating from a carrier, or a standard Naval vessel, yet achieve forward speeds in the subsonic range. Because of its simplicity, the CarterCopter can provide a very effective service in many aerospace applications with a very low production cost.

Aging Airliners get a new life as firefighters

Several aging airliners are now being used as high-capacity slurry bombers in the fight against America's forest fires. The featured image shows a DC-10 that has been converted to carry 3 tanks each with 12,000 gallons of water, or fire-retardant. The engines of the former passenger liner have been up-graded to 42,000 pounds of thrust and in its fully operational state, can drop a layer of retardant 50 feet wide and ¾ of a mile long! This kind of power can bring an enormous amount of life-saving liquid to the fire-line.

DC10 dropping a payload water.
(*Photo courtesy of Omni Air International and Cargo Conversions LLC.*)

Key Terms and Concepts

- X-15 and XB-70
- composites
- forward-swept wings
- oblique-wing aircraft
- winglets
- canards
- mission-adaptive wings
- joined wings
- supercritical wings
- solar powered aircraft
- stealth technology
- B-1B, B-2, F-117
- long-haul jets vs short-haul jets
- jumbo jets
- advanced technology jets
- supersonic transports

? Test Your Knowledge ?

TRUE OR FALSE

1. *Epoxy graphite composite materials have been developed that are stronger than many common metals used in aircraft construction.*
2. *The Boeing 747-600 is the world's first airliner to be built totally out of composite materials.*
3. *The first twin-engine General Aviation aircraft was the Beechcraft Twin Bonanza.*
4. *The U-2 and the SR-71 were developed to fly over enemy territory.*
5. *The B-52 is a "stealth" aircraft.*
6. *The first turbojet business land executive aircraft was the British Hawker Siddeley 125.*
7. *The Boeing 727 was the most successful jet ever built.*
8. *The DC-4 was the Douglas entry into the jet-powered, short-haul market.*
9. *Douglas built the first jumbo jet, the DC-10.*
10. *The A-320 is an advanced-technology airliner using composite materials for the majority of the aircraft's primary structures.*
11. *The TU-144 is the US equivalent to the Concorde supersonic transport.*
12. *Between 1922 and 1928, general aviation aircraft sales reached an all-time high.*

SELECT THE CORRECT ANSWER

13. The (XB-15 / XB-70) was designed as a bomber.
14. The (XB-15 / XB-70) was rocket-powered.
15. The (XB-15 / XB-70) was constructed of a nickel-steel alloy called Inconel X.

MATCHING

16. X-29A
17. AD-1 Scissors
18. Eliminates wingtip vortices
19. B-1B

a. Oblique wings
b. Winglets
c. Forward-swept wings
d. Mission-adaptive wings