



Canard Aeronautics & Rocket-Powered Aircrafts

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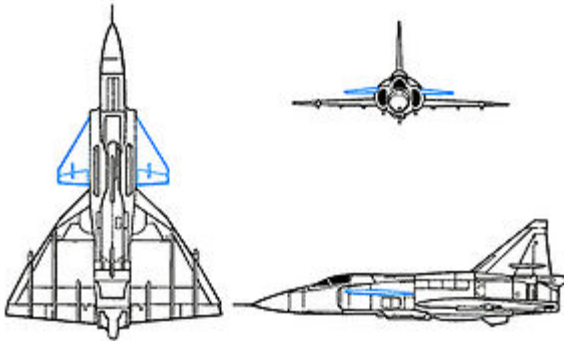
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Chapter 1

Canard (Aeronautics)

Canard



Canards (blue) on the Saab Viggen

In aeronautics, **canard** (French for duck) is an airframe configuration of fixed-wing aircraft in which the forward surface is smaller than the rearward, the former being known as the "canard", while the latter is the main wing. In contrast a conventional aircraft has a small horizontal stabilizer behind the main wing.

Some early fixed-wing aircraft such as the Brazilian Santos-Dumont 14-bis and French Canard Voisin had tail-first configuration which were seen by observers to resemble a flying duck — hence the name.

General characteristics

Unlike a conventional tailplane, in order to achieve longitudinal stability a canard surface is trimmed to increase lift as speed increases. This equates to a negative coefficient for trim drag.

A canard design tends to be less controllable than a conventional design because ailerons on the main wing may be subject to turbulence from the canards that varies widely at different Angle of attack, leading to conditions of deep stall. If the ailerons were located

on the canards, the lever arm would be too short due to the narrow span, and also the twisting motion would be too far forwards of the center of mass.

Canards have poor stealth characteristics because they present large, angular surfaces that tend to reflect radar signals. The Eurofighter Typhoon uses software control of its canards in order to reduce its radar cross section.

Canard classes

Canard designs fall into two main classes: the lifting-canard and the control-canard.

Other classes include the close-coupled type and active vibration damping.



Rutan Long-EZ, with lifting-canard ahead of the cockpit



A deflected control-canard on an RAF Typhoon F2



Canard (yellow) on a Mirage III

Lifting-canard

The first airplane to fly, the Wright Flyer, was a lifting-canard. In this configuration, the weight of the aircraft is shared between the main wing and the canard wing. The pros and cons of the canard versus conventional configurations are numerous and complex, and it is impossible to say which is superior without considering a specific design application.

For example, a lifting-canard generates an upload, in contrast to a conventional aft-tail which typically generates a download that must be counteracted by extra lift on the main wing, which may appear to unambiguously favor the canard. However, the downwash interaction between the two surfaces is unfavorable for the canard, and favorable for the

downloaded conventional tail, so the difference in overall induced drag is actually not obvious, and depends on the details of the configuration.

Another example is that the upward canard lift appears to increase the overall lift capability of the configuration. However, pitch stability flight safety requirements dictate that the canard must stall before the main wing, so the main wing can never reach its maximum lift capability. Hence, the main wing must then be larger than on the conventional configuration, which increases its weight and profile drag. Again, the relative merit depends on the details of the configuration and cannot be generalized.

In any case, pitch stability requires that the lift generated by the canard wing is significant, so in order to minimise induced drag on the canard, it is usually of higher aspect ratio and greater airfoil camber than a control-canard. To achieve stability, the change in lift coefficient with angle of attack should be less than that for the main plane.

One way in which this can be achieved is to use the same aerofoil for both planes, but to rig the canard at a higher angle of incidence. This tends to increase drag induced by the foreplane, which may be given a high aspect ratio in order to limit drag.

With a lifting-canard, the main wing must be located further aft of the center of gravity range than with a conventional aft tail, and this increases the pitching moment caused by trailing-edge flaps. Aircraft with lifting canards cannot readily be designed with sophisticated trailing-edge flaps.

Control-canard

In the later control-canard, most of the weight of the aircraft is carried by the main wing and the canard wing is used primarily for longitudinal control during maneuvering. A control-canard mostly operates at zero angle of attack. Combat aircraft of canard configuration typically have a control-canard. In combat aircraft, the canard is usually driven by a computerized flight control system.

One benefit obtainable from a control-canard is avoidance of pitch-up. An all-moving canard capable of a significant nose-down deflection will protect against pitch-up. As a result, the aspect ratio and wing-sweep of the main wing can be optimized without having to guard against pitchup.

Close-coupled canard

In the close-coupled canard, the foreplane is located just above and forward of the main wing. At high angles of attack the canard surface directs airflow downwards over the wing, reducing turbulence which results in reduced drag and increased lift.

The canard foreplane may be fixed as on the IAI Kfir, or have landing flaps as on the Saab Viggen, or it may be moveable and also act as a control-canard during normal flight as on the Dassault Rafale.

A close-coupled canard is very useful for a supersonic delta wing design which gains lift in both transonic flight (such as for supercruise) and also in low speed flight (such as take offs and landings).

A **moustache** is a small, high aspect ratio foreplane of close-coupled configuration. The surface is typically retractable at high speed and is deployed only for low-speed flight. First seen on the Dassault Milan, and later on the Tupolev Tu-144.

Active vibration damping

A large aircraft flying fast at low altitude can experience significant aerodynamic buffeting, leading to crew fatigue and reduced airframe life. Aircraft such as the B-1 Lancer incorporate small canard surfaces as part of an active vibration damping system that reduces these adverse effects.

Examples of canard aircraft

Some aircraft that have employed this configuration are listed below. A few types are listed twice, for example where the foreplane acts as a control-canard during normal flight and as a close-coupled type at high angles of attack.

Lifting-canard types

- AEA Silver Dart
- Beech Starship
- Berkut 360
- Chengdu J-9
- Cozy MK IV
- Freedom Aviation Phoenix
- Gyroflug Speed Canard
- Kyūshū J7W1 *Shinden*
- MacCready Gossamer Albatross
- MacCready Gossamer Condor
- MiG-8 *Utka*
- Miles Libellula
- North American SM-64 Navaho
- North American X-10
- OMAC Laser 300
- Peterson 260SE (a Cessna 182 with an added canard for STOL operations)
- Piaggio P180 Avanti (3 surfaces aircraft with flapped canard for pitch trim)
- Rutan Defiant
- Rutan Long-EZ
- Rutan VariEze
- Rutan VariViggen
- Rutan Voyager
- Rutan Quickie

- Santos-Dumont 14-bis
- Steve Wright Stagger-Ez
- Sukhoi T-4
- Tupolev Tu-144
- Velocity SE
- Velocity XL
- Wright Flyer
- XB-70 Valkyrie
- XP-55 Ascender

Control-canard types

- Atlas Cheetah
- Chengdu J-10
- Dassault Rafale
- Eurofighter Typhoon
- Grumman X-29A
- IAI Lavi
- McDonnell Douglas (now Boeing) F-15 S/MTD
- Pterodactyl Ascender
- Rockwell-MBB X-31
- Saab JAS 39 Gripen
- Sukhoi Su-30 MKI
- Sukhoi Su-33
- Sukhoi Su-34
- Sukhoi Su-27(27M variant)
- Sukhoi Su-37
- Sukhoi Su-47
- Chengdu J-20

Close-coupled canard types

- Atlas Cheetah
- Dassault Rafale
- IAI Kfir
- IAI Lavi
- Saab Viggen
- Tupolev Tu-144
- Novi Avion

Active vibration damping types

- B-1 Lancer

Concept aircraft

Lifting-canard types

- Lockheed L-133

Gallery



The first powered airplane, the Wright Flyer, used dual, vertically-stacked canards



Eurofighter Typhoon of the Royal Air Force displaying at the Farnborough Airshow, 2006



Dassault Rafale, in service with the French Navy (Marine Nationale) and the French Air Force (Armée de l'Air)



Canards visible on a JAS 39 Gripen at the Farnborough Airshow



Grumman X-29, an experimental aircraft for forward swept wing research



The Rockwell-MBB X-31 Enhanced Fighter Maneuverability Demonstrator Aircraft



Canards (just behind the flight deck) on the XB-70 Valkyrie experimental bomber aircraft



Closeup of a Piaggio P180 Avanti's canards



The Beechcraft Starship Executive Transport



A Pterodactyl Ascender II+2 showing its canard control surface



Saab 37 Viggen of the Swedish Air Force

Chapter 2

Beechcraft Starship

Model 2000 Starship



Role	Executive transport
Manufacturer	Beech Aircraft Corporation
Designed by	Burt Rutan
First flight	15 February 1986
Number built	53
Unit cost	US\$ 3.9 million

The **Beechcraft Starship** was a twin-turboprop six- to eight-passenger pressurized business aircraft produced by Beech Aircraft Corporation (now Beechcraft Division of Hawker Beechcraft).

Development

Development of the Starship began in 1979 when Beech decided to explore designs for a successor to its King Air line of turboprops that would fly faster and carry more passengers. The design was originated by Beechcraft in January 1980 as Preliminary Design 330 (PD 330). On August 25, 1982 Beech contracted with Scaled Composites to refine the design and build an 85% scale proof-of-concept (POC) aircraft. One of the significant changes made to the design by Scaled Composites was the addition of variable geometry to the canard.

The POC aircraft first flew in August 1983. This aircraft had no pressurization system, no certified avionics, and a different airframe design and material specifications than the planned production Model 2000. Only one POC was built and it has since been scrapped.

Prototypes were produced even as development work was continuing—a system demanded by the use of composite materials, as the tooling required is very expensive and has to be built for production use from the outset. Beech built three airworthy full-scale prototypes. NC-1 was used for aerodynamic testing and was the only Starship equipped with conventional electro-mechanical avionics. NC-2 was used for avionics and systems testing and NC-3 was used for flight management system and powerplant testing. NC-1 first flew on February 15, 1986.

The program was delayed several times, at first due to underestimating the development complexity involved and later to overcome technical difficulties concerning the stall-warning system. By the end of development, the Starship had grown larger in cabin volume than the King Air 350 while having the same gross ramp weight of 15,010 lb (6,808 kg). Starship development cost \$300 million. The first production Starship flew on April 25, 1989.

Design

The Starship is noteworthy for its carbon fiber composite airframe, canard design, lack of centrally located vertical tail, and pusher engine/propeller configuration.

Carbon fiber composite was used to varying degrees on military aircraft, but at the time the Starship was certified, no civilian aircraft certified by the US Federal Aviation Administration had ever used it so extensively. Beech chose carbon fiber composite for its durability and high strength-to-weight ratio. According to Beech the Starship weighs less than it would have if it were built from aluminum. Nonetheless, the empty weight of production aircraft exceeded the target by several thousand pounds.

Beech studied several configurations before settling on a canard configuration in early 1980. As configured, the Starship is difficult to stall—the forward surface stalls before the main lifting surface, which allows the nose to drop and more-normal flight to resume.

A traditionally located vertical tail would have transmitted propeller noise into the airframe. In its place, directional stability and control is provided by rudders mounted in the winglets (Beechcraft called them tipsails) at the tips of the wings.

Mounting the engines so that the propellers are facing rearward, pushing rather than pulling the aircraft, has the potential of a quieter ride since the propellers are further from the passengers and because vortices from the propeller tips do not strike the fuselage sides. However, the propellers are operating in a turbulent airflow in the pusher configuration (due to airflow past the wings moving aft in vortex sheets) and high-velocity exhaust gasses are discharged directly into the props, thus the resulting external propeller noise is more choppy and raucous than otherwise.

Flight instrumentation for the Starship included a 14-tube Proline 4 AMS-850 "glass cockpit" supplied by Rockwell Collins, the first application of an all-glass cockpit in a business aircraft.

Operational history

Sales



Beechcraft Starship

Beech sold only eleven Starships in the three years following its certification. Beech attributed the slow sales to the economic slowdown in the late-1980s, the novelty of the Starship, and the tax on luxury items that was in effect in the United States at the time. In an effort to stimulate demand, Beech began offering two-year leases on new Starships in 1991.

End of the program

The last Starship, NC-53, was produced in 1995. In 2003 Beechcraft determined that supporting such a small fleet of airplanes was cost-prohibitive and began scrapping and incinerating the aircraft under its control. The aircraft were sent to the Evergreen Air Center located at the Pinal Airpark in Arizona for destruction. Beech worked with owners of privately-owned Starships to replace their airplanes with other Beech aircraft such as the Premier I jet.

In 2004 Raytheon sold its entire inventory of Starship parts to a Starship owner for a fraction of its retail value.

Hawker Beechcraft continues to offer support by phone. Rockwell Collins has maintained full support for the AMS-850 avionics suite.

Variants

Model 2000

Initial production version. 20 produced including three pre-production airworthy prototypes.

Model 2000A

Beech did not serialize the 2000A as a distinct model and it was not issued a new FAA type certificate.

The final 2000A configuration had tuning-fork-type noise dampers and improved insulation to reduce cabin noise and redesigned exhaust stacks for more efficient engine airflow. Stall strips placed on the front wing to enhance stall behavior were removed. Elimination of the stall strips reduced stall speed by up to 9 knots (10 mph; 17 km/h), which allows the 2000A to takeoff from shorter runways. The 2000 had standpipes in the fuel tanks to artificially limit fuel capacity so the aircraft would meet a target payload weight. The standpipes were removed in the 2000A, increasing fuel capacity by 31 US gal (117 l). Both the maximum ramp weight and takeoff weight were increased by 500 lb (227 kg) and zero fuel weight was increased 400 lb (181 kg).

Beech produced a kit to upgrade serial numbers NC-4 through NC-28 to 2000A specifications.

Aircraft on display

Several Starships have been donated to museums since the decommissioning program began. The Kansas Aviation Museum received the first donated aircraft, NC-41, in August 2003 and the Beechcraft Heritage Museum in Tullahoma, TN, received the second donated aircraft, NC-49, in September 2003. NC-42 was donated to the Museum of Flight in Seattle, WA, and is currently on loan to the Future of Flight at Paine Field in Everett, WA. NC-27 was donated to Evergreen Aviation & Space Museum in McMinnville, Oregon in late-2003 and is currently on static display. NC-23 is on Airline Row at the Pima Air & Space Museum.

Survivors

As of January 2010, nine Starships hold an active registration with the FAA. Three Starships are registered in Oklahoma (NC-29, NC-35 & NC-45), one in Washington (NC-50), one in Colorado (NC-51), and four are registered to Hawker Beechcraft in Wichita, Kansas (NC-2, NC-8, NC-19 & NC-24). NC-51 was used as a chase plane during the re-entry phase of Burt Rutan's SpaceShipOne. In October 2008 NC-29 was the first of the five remaining privately-owned airworthy Starships to complete RVSM certification, returning the aircraft's service ceiling to the original FL410 limit.

Evergreen Air Center sold eight airframes back to private owners for \$50,000 each. Most are being used for parts, however, one of these aircraft has since been made airworthy again. Some former Starship parts have been used on the Epic turboprop kitplane.

Queensland Institute for Aviation Engineering in Caloundra, Queensland, Australia, purchased NC-28 in November 2004 for use in various training programs. Salt Lake Community College uses a Starship in their Aviation Maintenance program.

Specifications (2000A)



A Beechcraft Starship chasing a Scaled Composites SpaceShipOne during a test flight
Data from Flying Magazine, NC-53 POH where noted

General characteristics

- **Crew:** One
- **Capacity:** Six
- **Length:** 46.1 ft (14.1 m)
- **Wingspan:** 54.5 ft (16.6 m)
- **Height:** 12.9 ft (3.9 m)
- **Wing area:** 281 sq ft (26.1 m²)
- **Empty weight:** 10,085 lb (4,574 kg) standard empty weight
- **Gross weight:** 15,010 lb (6,808 kg) max ramp weight
- **Max takeoff weight:** 14,900 lb (6,759 kg)
- **Fuel capacity:** 3,785 lb

- **Powerplant:** 2 × Pratt & Whitney Canada PT6A-67A turboprop, 1,200 shp (890 kW) each
- **Propellers:** 5-bladed McCauley, 8 ft 8 in (2.64 m) diameter

Performance

- **Maximum speed:** 385 mph (620 km/h; 335 kn)
- **Cruise speed:** 353 mph (307 kn; 568 km/h)
- **Stall speed:** 112 mph; 180 km/h (97 kn) max weight with flaps retracted & idle power
- **Minimum control speed:** 108 mph; 174 km/h (94 kn) flaps retracted
- **Range:** 1,576 mi (1,370 nmi; 2,536 km)
- **Service ceiling:** 41,000 ft (12,497 m)
- **Rate of climb:** 2,748 ft/min (13.96 m/s)
- **Wing loading:** 53 lb/sq ft (260 kg/m²)
- **Power/mass:** 6.2 lb/shp

Chapter 3

Berkut 360

Berkut 360



Role	Homebuilt aircraft
Manufacturer	Berkut Aircraft
Introduced	1989
Primary user	Private Users
Variants	Rutan Long-EZ and Rutan VariEze



Berkut 360

The **Berkut 360** is a tandem-seating two-seat homebuilt canard aircraft built primarily of carbon fiber and fiberglass.

Development

The prototype Berkut was designed and built by Dave H. Ronneberg and Kerry Beresford as part of a business partnership between Ronneberg and Donald S. Murphy (called Experimental Aviation) between 1989 and 1992.

In 1992 the partnership dissolved, and Ronneberg (incorporating as Experimental Aviation, Inc.) brought the aircraft to market as a kit, while Murphy wanted to shelve the project entirely. A subsequent series of lawsuits between the two resulted in bankruptcy for Ronneberg and Murphy as individuals, and for EAI as a corporation. The kit was resurrected by Renaissance Composites, in 1996, with Ronneberg working as a consultant.

In January 2001, under pressure from Ronneberg, Renaissance sold the assets to Vicki Cruse who then formed Berkut Engineering Inc. That company withdrew the aircraft from the market in 2002. Ronneberg continues with the project, which is now directed at UAV markets. In 2003 a deal was struck to sell the project to Republic Aerospace but the

deal fell through. Cruse is no longer involved with day-to-day operations, but maintains ownership.

Through the various incarnations approximately 75 kits were sold, and 20 airplanes completed.

Configuration

The Berkut is descended from the Rutan Long-EZ, with the primary differences being retractable main landing gear, dual canopies, and molded fuselage, strakes, and spar. Like the Long EZ, the Berkut carries 2 people in tandem seats. The front seat occupant has access to all instrumentation and controls. The rear seat, normally holding the passenger, is equipped with a side stick and throttle, but no rudder pedals, brakes, or instruments. Aerodynamically only minor changes were made. The fuselage was stretched, and the nose, canard, instrument panel and pilot moved forward one foot, to allow a heavier engine to be used in the back. The main wing trailing edge was straightened, removing a small bend in the trailing edge of the Long EZ wing. The lower winglet was removed and the aileron size increased in both chord and span, increasing roll rate.

Early Berkuts used wings and canard that were structurally similar to the Long-EZ and used hot-wired solid blue 2 lb/cu. ft. density Dow STYROFOAM PI cores, but with carbon fiber skins instead of fiberglass. The fuselage and winglets remained fiberglass. Later versions (kits produced after spring 1999) used fully-molded carbon fiber canards and wings with high density, 5 lb/cu. ft. 1/4" thick PVC or SAN foam cores, leaving only minor fairings and tip surfaces to be carved from foam. The Berkut has always used the Roncz 1145MS canard airfoil, which is more tolerant of bug and rain contamination than the original GU 25-5(11)8 airfoil originally used on the Long-EZ.

Berkuts used a retractable main (rear) landing gear system designed by Shirl Dickey for his E-Racer homebuilt. Originally Berkut used gear parts produced by Dickey, but over time they were repeatedly re-engineered and strengthened. Later kits had gear components produced entirely in-house. Like the earlier Vari-Eze and Long EZ, the Berkut parks with its nose gear retracted to prevent the plane from tipping over backwards when parked without a pilot in the front seat. Some early Berkuts utilized hydraulic nose-gear extension systems, but most have used an electro-mechanical jack-screw. With the electric system the pilot can climb into the cockpit with the nose down, then extend the nose gear, raising the airplane with him inside.

While the Long-EZ was closer in the design of the Berkut it was originally designed for the Lycoming O-235 108-118 hp engine, the Berkut was designed from the outset for the larger Lycoming IO-360 180 hp engine. The aircraft was later adapted (with a different engine mount, cowls and battery location) to accept the 260-hp Lycoming IO-540, which most builders chose. With the 540, some have reportedly reached speeds of 300 mph in level flight.

Selected accidents

The Berkut has a poor safety record, with about a quarter of all completed airplanes crashing at some point. However, there is no single cause which has resulted in more than one crash. Each crash has been the result of construction error or pilot error.

N91DR. The original prototype, crashed by Rick Fessenden at an airshow at Santa Paula, California. Although the NTSB investigation concluded that an accelerated stall during Fessenden's "wind up turn" - a level 360-degree very high-G turn - caused the airplane to crash, examination of videotapes of the crash gave a strong indication that the pilot blacked out under 9+ Gs. Fessenden was killed.

N260DG. The first Berkut 540, built by Dan Gray, also crashed at Santa Paula. Gray started and finished his first flight at nearby Camirillo airport but on his second flight he chose to return to Santa Paula. On final approach his engine stopped and, in attempting to set down on a nearby freeway, he collided head-on with a Honda station wagon. The aircraft was extensively damaged but Gray was only bruised. The cause was found to be an incorrectly rebuilt fuel pump.

N600SE. Built by Michael Kasyan, this airplane served as the company demonstrator for several years. While being flown by another pilot, the plane encountered a dust devil on final approach. This flipped the airplane upside down and it tumbled down the runway. Both wings were broken, the right strake and spar were broken halfway between the fuselage and the end of the spar, the main gear was torn out, and the nose crushed back to the instrument panel. The pilot's legs were broken but the passenger suffered only a minor cut to the scalp. The airplane was rebuilt and is flying again.

N538AJ. This airplane, owned by John Daniels, has had several accidents, all involving the landing gear. The NTSB report concerns its first, a gear collapse at Jackson Hole, Wyoming. Later the airplane overran the runway at First Flight airport, tearing out its gear legs. There have been no injuries from any of the accidents.

N287CM. Built by Steve Drybread. During a test flight Drybread left out the main canard attach bolts. The canard separated in flight, Drybread was killed.

N5439N. Built by Steve Drybread. While being flown by its owner, Charles Bracken, the aircraft struck high tension power wires and crashed into the ground. The airplane was destroyed, the nose crushed back to the pilot's seat. Bracken's legs were broken.

Variants

- **Berkut 360** - Original configuration, retractable gear, Lycoming 4 cylinder 360 cubic inch, fuel injected, 180 hp engine.
- **Berkut FG360** - Fixed-gear version of the 360. (Offered but never built, except as a UAV by Geneva Aerospace)

- **Berkut 540** - Lycoming 6 cylinder, 540 cubic inch, 260 hp engine upgrade. Changes consisted of larger cowls, a different engine mount, custom engine mount ears, stiffer engine isolators, a custom sump modification and different cooling baffles.
- **Berkut FG540** - Fixed-gear version of the 540. (Offered but never built)
- **Mobius** - a modified Berkut with a single canopy and automated flight equipment located where the second seat would be located, for UAV research and development. Two aircraft have been built with a third one in development. N442LT is the first tail number. N497LT is the second.
- **Berkut Jet** - a Berkut using a modified GE T-58 turbine engine, built by Jerrold Jorritsma. Crashed in Loveland, CO on May 9, 2010

Specifications

General characteristics

- **Crew:** 2
- **Capacity:** 2
- **Length:** 5.67 m (18 ft 6 in)
- **Wingspan:** 8.25 m (26 ft 8 in)
- **Height:** 2.29 m (7 ft 6 in)
- **Wing area:** 33.53 m² (110 ft²)
- **Empty weight:** 521.6 kg (1150 lb)
- **Loaded weight:** 952.5 kg (2100 lb)
- **Useful load:** 433.6 kg (965 lb)
- **Powerplant:** 1× Lycoming IO-540 Light Speed Engineering Composite 67" diameter, 91/103" pitch, (260 hp)

Performance

- **Never exceed speed:** 563.3 km/h (350 mph)
- **Maximum speed:** 442 km/h (275 mph)
- **Cruise speed:** 370 km/h (230 mph)
- **Stall speed:** 104.6 km/h (65 mph)
- **Range:** 2433 km (1512 mi)
- **Rate of climb:** 610 m/min (2000 ft/min)

Chapter 4

Chengdu J-20

Chengdu J-20



Artist's impression of the Chengdu J-20

Role	Stealth air superiority fighter, multirole fighter Strike fighter
National origin	People's Republic of China
Manufacturer	Chengdu Aircraft Industry Group
First flight	11 January 2011
Introduced	2017–2019 (planned)
Status	In development/flight testing
Primary user	People's Liberation Army Air Force
Number built	2
Unit cost	US\$110 million (est.)

The **Chengdu J-20** (simplified Chinese: 歼二十; traditional Chinese: 殲二十; pinyin: *Jiān èr shí*; literally "Annihilator Twenty") is a fifth generation stealth, twin-engine fighter aircraft prototype developed by Chengdu Aircraft Industry Group for the Chinese People's Liberation Army Air Force. In late 2010, the J-20 underwent high speed taxiing tests. The J-20 made its first flight on 11 January 2011. General He Weirong, Deputy Commander of the People's Liberation Army Air Force said in November 2009 that he expected the J-20 to be operational in 2017–2019.

Development

The J-20 was one of the stealth fighter programs under the codename J-XX that was launched in the late 1990s. It has been also designated "Project 718". Two prototypes (#2001-01 & #2001-02) have been built as of the end of 2010.

On 22 December 2010, the J-20 was under-going high speed taxiing tests outside the Chengdu Aircraft Design Institute with no confirmed flight tests. The J-20 made its first flight, which lasted about 20 minutes, on 11 January 2011.

James R. Clapper has testified that the United States has known about the program for a "long time" and that the test flight was not a surprise.

Technology transfer

Globalsecurity.org states that China probably declined to participate in joint development and production of new fifth generation fighter with Russia given the belief that Russia stood to gain more from Chinese participation. Chinese leaders may have determined that their design was superior to the Russian PAK FA. United States House Committee on Armed Services chairman Howard McKeon said on the J-20 "my understanding is that they built it on information that they received from Russia, from a Russian plane, that they were able to copy". However Australian Aviation writer Steve Creedy has said that the Russians and Chinese are working on a similar aircraft, in addition to the Chengdu J-20.

Balkan military officials told the *Associated Press* that China and Russia may have adopted some stealth technology from a Lockheed F-117 Nighthawk, which was shot down by the Serbian military in 1999 during the Kosovo war. If Chinese experts used the F-117 stealth coatings, the result would be decades behind current American state-of-the-art. However, Chinese test pilot Xu Yongling said that the J-20 was a "masterpiece" of home-grown innovation, he also said the F-117 technology was already "outdated" even at the time it was shot down, and could not be applied to a next-generation stealth jet. *Janes* editor James Hardy agrees that it was unlikely China would have learned much from the wreckage.

Retired USAF general Thomas G. McInerney has suggested that the J-20 design may have been based on cyber-espionage of the Lockheed Martin FB-22 project.

Chief of the Air Staff of the Indian Air Force Pradeep Vasant Naik has suggested that the J-20 is entirely reverse engineered with no Chinese R&D involved, and questioned if the practice was ethical. The Deccan Chronicle has called Naik's comment a "unusual outburst of helplessness" as China surpasses Indian airpower.

Russian military commentator Ilya Kramnik conjectures that China is still 10 to 15 years behind the United States and Russia in fighter technology and may not be able to manufacture all the advanced composite materials, avionics and sensor packages needed

for such aircraft, and could instead turn to foreign suppliers. However, he speculates that China may be able to produce the J-20 at a cost 50% to 80% lower than US and Russian fifth-generation jet fighters, and that potential customers may include Pakistan, the Middle East, Latin America, Southeast Asia and the richest countries in Africa. Konstantin Sivkov of the Academy for Geopolitical Issues argued that the US is correct to be alarmed at the progress of Chinese military technology.

Bill Sweetman speculates that China will have problems meeting its production requirements, as it has several other jet fighter projects in production. Aviation Week raised the question of whether the aircraft is a prototype, like the Sukhoi T-50, or a technology demonstrator similar to the Lockheed YF-22.

Despite the current arms embargo, China may use ongoing economic problems to pressure the European Union into selling advanced military technologies.

Design

Characteristics

The J-20 is a single-seat, twin-engine aircraft which appears to be somewhat larger and heavier than the comparable Sukhoi T-50 and Lockheed Martin F-22 Raptor. Bill Sweetman estimates that it is approximately 75 feet (23 m) in length, has a wingspan of 45 feet (14 m) or more, and is expected to have a takeoff weight of 75,000 to 80,000 pounds (34,000 to 36,000 kg) with internal stores only. The prototype could be powered by twin 32,000 pounds (15,000 kg) thrust Saturn 117S engines provided by Russia, a sign of problems in the development of the aircraft, according to Pentagon spokesman Col. David Lapan. Chinese sources have claimed that production aircraft will be powered by two 13,200 kilograms (29,000 lb)/WS-10 class high thrust turbofan engines fitted with Thrust Vector Controlled (TVC) nozzles, both made in China. However Richard Aboulafia has said that the WS-10 engine has suffered catastrophic failures in flight.

The J-20 may have lower supercruise speed (yet greater range) and less agility than a Lockheed Martin F-22 Raptor or PAK FA, but might also have larger weapons bays and carry more fuel. The J-20 has a long and wide fuselage and low jet engine intakes with a forward chine, a main delta wing, forward canards, a bubble canopy, conventional round engine exhausts and canted all-moving fins. The front section of the J-20 is similarly chiseled as the F-22 Raptor and the body and tail resemble those of the Sukhoi T-50 prototype. As early photographs of the prototype surfaced, Bill Sweetman commented that the design may suggest a large, long range ground attack aircraft, not unlike a "stealth version" of the General Dynamics F-111 Aardvark. Douglas Barrie has noted that the canard-delta configuration with canted vertical fins appears to resemble the MiG 1.42. Yet, Barrie notes that key differences include greater forward fuselage shaping as the basis for low observable characteristics, along with the different engine intake configuration. It is suspected that cyberespionage may have assisted the development of the J-20, with information used by subcontractors of Lockheed Martin for the F-35

project in particular having been significantly compromised during development of the J-20.

The J-20 has a pair of all-moving tailfins that are swept back in the F-35 style instead of being trapezoid like the F-22 and PAK-FA tails and ventral stabilizing fins. It also has an F-22 style nose section, but with F-35 style dropped nose, forward swept intake cowls with diverterless supersonic inlet (DSI) bumps and a one-piece canopy. It was reported in November 2006 that a T/W=10 17,000 kilograms (37,000 lb) class turbofan (WS-15/"large thrust") was being developed for the J-20. One (#2001-01) prototype is fitted with AL-31F, the other (#2001-02) is fitted with the improved WS-10G with a new "stealth" nozzle possibly to reduce RCS and IR emission.

The J-20 may become the first operational combat aircraft that carries sufficient fuel to supercruise throughout its missions, doubling its sortie rate.

Pentagon spokesman Geoff Morrell has said that it was premature to call the J-20 a stealth fighter or to judge if it had any other fifth generation characteristics.

Avionics



Displays which may be used in the Chendu J-20 cockpit

The production J-20 may incorporate an advanced fly-by-wire (FBW) system fully integrated with the fire-control and the engine systems. Its fire-control radar is expected to be Active Electronically Scanned Array (AESA) (Type 1475/KLJ5?).

Cockpit

The aircraft features a "pure" glass cockpit (two large color liquid crystal display (LCD) and several smaller ones and a wide-angle holographic head-up display (HUD)). Many of these subsystems have been tested onboard J-10Bs to speed up the development.

Armament

The J-20 has a large belly weapon bay for short/long-range air-to-air missiles (AAM) (PL-10, PL-12C/D & PL-21) and two smaller lateral weapon bays behind the air inlets for short-range AAMs (PL-10).

Stealth

Carlo Kopp has suggested that the J-20's overall stealth shaping is "without doubt considerably better" than the F-35 and PAK FA, but he agrees with others, such as Shih Hiao-wei of Defense International monthly and Bill Sweetman of *Aviation Week*, that some parts on the J-20 will challenge its ability to remain stealthy from all directions: "The aft fuselage, tailbooms, fins/strakes and axi-symmetric nozzles are not compatible with high stealth performance, but may only be stop-gap measures to expedite flight testing of a prototype." As of January 2011 the engine nozzles were clearly non-stealthy; this may be due to the fact that the final "fifth generation" engines had not been completed yet. However, one of the prototypes uses WS-10G engines with stealthy jagged-edge nozzles and tiles.

Robert Gates has also questioned how stealthy the J-20 might be although he did say the development of the J-20 had the potential to "put some of our capabilities at risk, and we have to pay attention to them, we have to respond appropriately with our own programs." Kopp and Goon have further speculated that the J-20 is designed to operate as a heavy interceptor, destroying opposing AWACS and tanker aircraft. If true, this would make it more similar to a MiG-25 with stealth capability. Sweetman agrees that this is the most likely role for such a large aircraft with low thrust to weight ratio and limited agility that is optimized for range and speed. Lewis Page has said that it is unlikely that the Chinese will soon have an American style Low Probability of Intercept Radar and so the J-20 would be limited to attacking ground targets like previous generations of American stealth aircraft such as the Lockheed F-117 Nighthawk. In that case the J-20 would carry a radar, but using it would instantly give away its location. However, the J-20 is expected to use a AESA radar, which should have Low Probability of Intercept modes. Given that the F-35 can already track and jam even the F-22's radar, this might not be sufficient.

Loren B. Thompson has said that this combination of forward sector only stealth and long range will allow the J-20 to make attacks on surface targets while the United States lacks sufficient bases for F-22s in the area to counter these attacks and American allies have no comparable aircraft. Thompson has also said that a long-range maritime strike aircraft may cause the United States more trouble than a shorter range air-superiority fighter like the F-22.

A canard delta offers greater efficiency in both subsonic and supersonic flight (which may help supercruise range), but it is unknown if the Chinese have the same software used on the Eurofighter Typhoon to control the otherwise non-stealthy canards. Teal Group analyst Richard Aboulafia has also raised doubts about the use of canards on a design that is intended to be low-observable: "There's no better way of guaranteeing a radar reflection and compromise of stealth". Aboulafia has also called the J-20 a kludge made of mismatched parts and questioned if the Chinese have the skills or technology to produce a true fifth generation fighter. Nevertheless, canards greatly boost the aircraft's maneuverability over that of a pure delta wing without canards. Sweetman notes that the canard delta works with the Whitcomb area rule for a large-volume mid-body section supersonic aircraft. Also, while the DSI intakes are easier to maintain than more complex

stealth-compatible intakes, such as on the F-22, their fixed form limits the aircraft to around Mach 2.0. J.D. McFarlan of Lockheed Martin has said that the J-20 DSI inlets resemble those of the F-35, but it is unclear if the Chinese have perfected their own design.

Operational history

On 22 December 2010, the J-20 was under-going high speed taxiing tests outside the Chengdu Aircraft Design Institute with no confirmed flight tests. Several Chinese military websites and photos revealed that on 10 January 2011 Chinese Vice President Xi Jinping and Chairman of the Standing Committee of the National People's Congress Wu Bangguo came to the Chengdu facility to witness the first flight test. The test flight was cancelled that day due to bad weather.

Flight testing

The J-20 made its first flight, which lasted about 15 minutes, on 11 January 2011. A Chengdu J-10S served as the escort aircraft. After successful first flight, an ceremony was held. J-20 first flight test pilot Li Gang, Chief designer Yang Wei and General Li Andong (Deputy-Director of General Armaments Department, and Director of Science and Technology Commission of General Armaments Department of the PLA since 2000) attended the ceremony.

China thus became the third nation in the world to "develop and test-fly a full-size stealth combat aircraft demonstrator", after the United States and Russia. *The Guardian* reported that experts, on the one hand, expressed "surprise" at the speed with which the aircraft was developed, but on the other hand "said the country's military prowess was still relatively backward and way behind that of the US" and that its military interests were limited to its region.

The first test flight coincided with a visit of United States Secretary of Defense Robert Gates to China, and was initially interpreted by Pentagon officials and media pundits as a possible signal to the visiting delegation from the U.S. However, after meeting with senior Chinese officials including Chinese President Hu Jintao, Secretary Gates remarked, "The civilian leadership seemed surprised by the test and assured me it had nothing to do with my visit." Jin Canrong, a professor at Renmin University in Beijing who specializes in China-U.S. relations, suggested that President Hu's ignorance of the test raises questions about the nature of civilian control of the Chinese military. However, as Michael Swaine, an expert on the PLA and United States – China military relations, explained, although it's possible and even likely that "senior officials in the [Chinese] leadership did not know that this flight test would occur on this precise day," this is not necessarily evidence of a military-backed effort to insult Secretary Gates' delegation or embarrass President Hu. Rather, decisions regarding the production, development and testing of such military aircraft are routinely managed by engineers and low-level officials more than by senior civilian or military leadership. Coupled with the fact that there was relatively limited coverage of the event in Chinese media initially, it is likely

that the test may not have been considered a significant enough event to warrant notification to President Hu. Moreover, the Chinese military has conducted important tests (including the 2007 anti-satellite missile test) on 11 January in the past; thus, the test may have been related to this.

The U.S. China Economic and Security Review Commission took testimony on the implications for PRC civilian control of the PLA.

Role in future conflicts

Pacific Air Forces commander Gary L. North has said that the Next-Generation Bomber may prove the key to defeating the J-20 in future conflicts by knocking the Chinese airbases out of action.

Specifications

Because the aircraft is in development, these specifications are preliminary and are taken as estimates from the available images.

General characteristics

- **Crew:** 1
- **Length:** 62 ft (19 m)
- **Wingspan:** 41 ft (12.5 m)
- **Height:** ()
- **Wing area:** 630 ft² ()
- **Max takeoff weight:** 66,000–80,000 lb (34,000 - 37,000 kg)
- **Powerplant:** 2× WS-10G thrust-vectoring turbofan (155 kN) on production aircraft. Possible WS-15 on production aircraft.

Performance

Armament

- **Guns:** None on prototype.
Expected to have internal and external hardpoints for missiles, bombs and fuel tanks.

Avionics

Anticipated AESA radar with LPI modes for use against air and surface targets, and low observable data links, infrared missile warning and radar warning sensors.

Chapter 5

Chengdu J-10

J-10 Vigorous Dragon F-10 Vanguard



J-10A seen at Zhuhai airshow.

Role	Multi-role combat aircraft
National origin	People's Republic of China
Manufacturer	Chengdu Aircraft Industry Corporation
Designed by	Chengdu Aircraft Design Institute
First flight	23 March 1998
Introduced	2005
Status	In service
Primary user	People's Liberation Army Air Force
Produced	2002-Present
Number built	168-196
Program cost	500 million RMB allocated in 1982 (Project #10)
Unit cost	190 million RMB (27.84 million USD; 2010)
Developed from	Chengdu J-9

The **Chengdu J-10** (simplified Chinese: 歼十; traditional Chinese: 殲十; pinyin: *Jiān Shí*; literally "Annihilator Ten") is a multirole fighter aircraft designed and produced by the People's Republic of China's Chengdu Aircraft Industry Corporation (CAC) for the People's Liberation Army Air Force (PLAAF). Known in the West as the "Vigorous Dragon", the J-10 is a multi-role combat aircraft capable of all-weather day/night operation.

Development

The program was originally backed by the Chinese leader, Deng Xiaoping, who authorized spending of half a billion Renminbi to develop an indigenous aircraft, but the program did not start until several years later, in January 1988, when the Chinese government began initial development of the Project #10 to develop a fighter to counter new fourth generation fighters then being introduced by the USSR. The 611th Institute, also known as the Chengdu Aircraft Design Institute, was tasked as the main developer, with Song Wencong (宋文聰), the chief designer of the J-7III, assigned as the chief designer and Xue Chishou (薛焯寿) as the chief engineer. The deputy general designer was Mr. Su Longqing (苏隆清). Initially designed as a specialized fighter, it was later recast as a multirole aircraft capable of both air to air combat and ground attack missions.

Although the existence of the J-10 was long reported both inside and outside of China, the Chinese government did not officially admit the existence of the aircraft until January 2007, when the first photographs of the J-10 were allowed to be published to the public by the Xinhua News Agency. Having been designed under such secrecy, before its official disclosure many details of the J-10 were subject to much speculation. Rumors of a crash during flight testing, however, have been openly denied by the government. During the official announcement of the J-10, on 1 January 2007, both the Xinhua News Agency and the PLA Daily listed no crashes since the start of the project as one of the accomplishments of the test pilots. However, later reports reveal that one of the prototype J-10s did crash and the Chinese government tried to cover up the details regarding the crash.

According to Chinese media reports, the first plane, "J-10 01", was rolled out in November 1997, and the aircraft made its successful maiden flight on 23 March 1998, flown by test pilot Lei Qiang (雷強) and lasting for twenty minutes. Another test pilot, Li Zhonghua (李中华), test flew the prototype on aerodynamic performance trials that lasted till early December, 2003, during which time aerial refueling tests were also successfully completed. In these aerodynamic tests, the aircraft was pushed beyond its parameters of the original design and it was discovered that the aircraft could easily withstand the greater requirements. The last part of the test flight programme was the live firing of air-to-air missiles by test pilot Xu Yongling (徐勇凌), which lasted from 21 December 2003 to 25 December 2003.

The aircraft were first delivered to the 13th Test Regiment on 23 February 2003. The aircraft was given the status 'operational' in December of the same year, after 18 years in development. The first operational regiment was the 131st Regiment of the 44th Division. It is rumored that a regiment of the 3rd Division has also J-10s.

Export

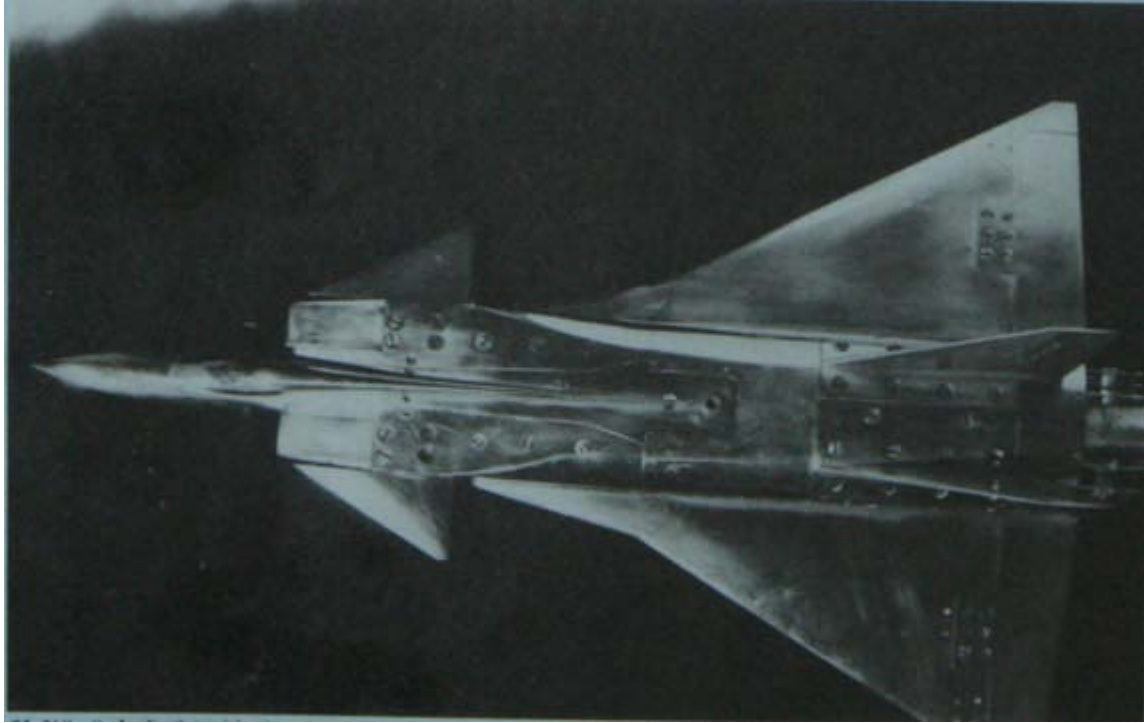
Plans are in place for AVIC to aggressively market an upgraded J-10 variant, most likely the J-10B, once its development is complete. Several countries have shown interest and Pakistan is likely to be the first export customer, with deliveries taking place in 2014-2015.

In late February 2006 the then President of Pakistan, Pervez Musharraf, was shown the J-10 and JF-17 production facilities, also taking the opportunity to sit in the cockpits of both aircraft. He later said the Chinese had offered to sell the J-10 to Pakistan and the offer would be considered by the government and Pakistan Air Force (PAF). On 12 April 2006 the Pakistani cabinet approved the purchase of at least 36 J-10. On 7 March 2009 Air Chief Marshal Tanvir Mehmood Ahmed, then Chief of the Air Staff of the PAF, stated that the high-tech fighters would be designated FC-20 and two squadrons (36 aircraft) would be delivered to the PAF in 2014–2015, after some improvements in accordance with PAF requirements.

Foreign participation



Drawing of the canceled Chengdu J-9



Wind tunnel model of the canceled Chengdu J-9



The canceled Israeli IAI Lavi

According to official Chinese sources, the J-10 is said to have been developed from the now canceled Chengdu J-9. However, there have been conflicting reports about a possible relationship between the J-10 and the Israeli IAI Lavi fighter program, the latter having a similar canard-configuration. The J-9 program predated both of the other aircraft. In an interview, the general designer of J-10, Mr. Song Wencong (宋文聰) said,

"Our nation's new fighter's external design and aerodynamics configuration are completely made by us and did not receive foreign assistance, this made me very proud. Our nation developed J-9 in the 1960s, this adopted the canard configuration. So, those statements that said J-10 is a copy of Israeli Lavi are just laughable."

The strongest admission of Israeli involvement in the J-10's development by Israeli authorities appeared in a statement made by an official as American authorities investigated alleged Lavi technology transfers to China. Without mentioning either Lavi or J-10, the Director General of Israel's Ministry of Defense David Lavi "acknowledged in an Associated Press interview that 'some technology on aircraft' had been sold to China and that some Israeli companies may not have 'clean hands'".

In May 2008, Jane's Information Group reported several interviews with Russian sources claiming to be involved with various Chengdu military projects. A number of engineers, designers and technical specialists described their visits to Chengdu and other areas of China in the 1980s. A source alleged that high-level Chengdu officials described the possession of a single Lavi prototype at one of Chengdu's facilities. They also claim that in 2000, two years after the J-10's maiden flight, aerodynamic models were sent to Russian wind tunnel testing facilities to study the J-10's aerodynamics.

During the 2006 Farnborough Airshow, the Russian Siberian Aeronautical Research Institute (SibNIA) confirmed its participation in the J-10 program. According to the article, this participation was limited to observation and instruction as "scientific guides." The sources also called the J-10 "more or less a version of the [Israel Aircraft Industries] Lavi", but also a "a melting pot of foreign technology and acquired design methods" Left unelaborated is the degree of Israeli participation - if any - in J-10 development.

Kommersant's reporter Kostantin Lantratov affirmed that Russian consent was required to export the J-10, given its Russian AL-31 engine.

It has been reported that composite materials tested in the Delsen Testing Laboratories in Glendale, California during the year 1990 were related to the J-10 project.

Design

J-10 was designed by the Chengdu Aircraft Design Institute (CADI), a subordinate research institute of Chengdu Aircraft Industry Corporation (CAIC). Some of the designers and their roles are identified as follows; Xue Chishou (薛炽寿, chief engineer, also deputy general manager of CAIC), Zhou Ziquan (周自全, chief test engineer, also deputy director of CADI). In a rather unusual agreement, the single seat version of the J-10 and the twin seat version of J-10 were designed by two different general designers; Song Wencong for the single seat version and Yang Wei (杨伟) for the twin seat version, also the general designer of the JF-17 light-weight fighter. Sang Jianhua (桑建华) of CADI was responsible for airframe design features that reduce radar signature.

Airframe and cockpit

Constructed from metal alloys and composite materials for high strength and low weight, the airframe's aerodynamic layout adopts a "tail-less canard delta" wing configuration. A large delta wing is mid-mounted towards the rear of the fuselage, while a pair of canards (or foreplanes) are mounted higher up and towards the front of the fuselage, behind and below the cockpit. This configuration provides very high agility, especially at high speed. A large vertical tail is present on top of the fuselage and small ventral fins underneath the fuselage provide further stability.

A rectangular air intake is located underneath the fuselage, providing the air supply to the engine. Also under the fuselage and wings are 11 hardpoints, used for carrying various types of weaponry and drop-tanks containing extra fuel.

The retractable undercarriage comprises a steerable pair of nose-wheels underneath the air intake and two main gear wheels towards the rear of the fuselage.

The cockpit is covered by a two-piece bubble canopy providing 360 degrees of visual coverage for the pilot. The canopy lifts upwards to permit cockpit entry and exit. The Controls take the form of a conventional centre stick and a throttle stick located to the left of the pilot. These also incorporate "hands on throttle and stick" (HOTAS) controls. A zero-zero ejection seat is provided for the pilot, permitting safe ejection in an emergency even at zero altitude and zero speed.

Avionics (aircraft related)

Flight control system

Due to the J-10's aerodynamically unstable design, a digital quadruplex-redundant fly-by-wire flight control system aids the pilot in flying the aircraft. Chinese aircraft designer Yang Wei is claimed to be the chief designer of the fly-by-wire flight control system, although this is disputed by analyst Richard Fisher who credits Israeli consultants for developing the system. The flight control computer provides automatic flight coordination and keeps the aircraft from entering potentially dangerous situations such as unintentional stalls or skids. This therefore frees the pilot to concentrate on his intended tasks during the combat.

Flight instrumentation

Information is provided visually to the pilot via three liquid crystal (LCD) Multi-function displays (MFD) in the cockpit. Chief designer of the flight instrumentation panel was Zhou Han (周寒, unrelated to the chief test engineer), who was in charge of both the CRT display design at the early stages of development and the later LCD design that is currently adopted by J-10 in service.

The LCD display panel entered service shortly after 2000. The LCD displays and earlier CRT displays for J-10 (and that of WZ-10, J-11 and JH-7) are manufactured by the Suzhou Long Wind Machinery Plant (苏州长风机械总厂), later reorganized as AVIC Radar and Avionics Equipment Research Institute (中航雷达与电子设备研究院).

In addition to the flight instrumentation, a Chinese holographic head-up display (HUD) is also present. The HUD shows important flight and combat related information such as targeting cues. It can also be used as a radar scope, a feature believed to be inspired by the HUDs of Russian aircraft, that allows the pilot to keep his eyes focused at infinity while working with his radar. Monochrome images from electro-optical avionics pods (FLIR and targeting pods) can also be displayed on the HUD. The HUD was designed to overcome issues with the HUDs of Russian fighters, which experienced significant fogging problems when deployed in humid and tropical zones of China, as they were originally designed for deployment in arid Arctic/sub-Arctic zones. The modular design of the HUD system and use of the MIL-STD-1553B databus architecture allows HUDs of Western origin to be integrated if desired by the user.

Avionics (mission related)

Electronic warfare

A comprehensive internal electronic counter-measures (ECM) suite is likely to be present, which can be supplemented by active jammer pods such as the BM/KG300G carried externally on the aircraft's hardpoints. Additionally, the KZ900 signals intelligence (SIGINT) pod can be carried for reconnaissance missions.

Infra-Red Search and Track

A Chinese infra-red search and track (IRST) system developed by the Sichuan Changhong Electric Appliance Corporation, the Type Hongguang-I (Rainbow Light-I) Electro-Optical Radar (虹光- I 型光电雷达), is integrated with the J-10. It is a third generation optronics system utilising a HgCdTe focal array with imaging infra-red (ImIR) capability. Receiving its certification on 3 March 2005 and subsequently entering service with the PLAAF, the system was revealed to the public one year later at a conference on the Sichuan province of China, during which the system was demonstrated to visiting officials. Based on the limited information released, Type Hongguang-I has a maximum range of 75 km.

Although the Type Hongguang-I was designed to be lighter and more compact than similar Russian systems so that it could be fitted in the nose of J-10 while leaving enough space for a suitable radar, the current production model J-10 does not have enough space and must carry a podded version externally on one of the aircraft's hardpoints. However, recently released images show a modified variant of the J-10 with what is believed to be an IRST device fitted to the upper starboard side of the nose. Type Hongguang-I is also designed to be compatible with China's Shenyang J-11, Shenyang J-8 and Xian JH-7

combat aircraft, as well as the Xian H-6 bomber and Sino-Pakistani JF-17 light-weight fighter.

Radar and targeting

According to Chengdu Aircraft Industry Corporation officials the J-10 uses a multi-mode fire-control radar designed in China. The radar has a mechanically scanned planar array antenna and is capable of tracking 10 targets. Of the 10 targets tracked, 2 can be engaged simultaneously with semi-active radar homing missiles or 4 can be engaged with active radar homing missiles.

The radar is believed to be designed by the Nanjing Research Institute of Electronic Technology (NRIET), designated KLJ-10 and a smaller variant is claimed to be installed on the JF-17 light-weight fighter. Believed to be based on technologies from Russia, Israel or a combination of both, the radar should be comparable to Western fighter radar designs of the 1990s. It may also be replaced by more advanced radars of other origin on export versions of the J-10. The Italian FIAR (now SELEX Galileo) Grifo 2000/16, has been offered to the Pakistan Air Force for installation on the J-10, should the PAF induct the aircraft. On June 14, it was announced by Chinese state media that a version of J-10 has been equipped with a phased array radar.

In Chinese military technology related exhibitions, various helmet-mounted display (HMD) systems developed by Chinese organisations have been shown. It is believed that the J-10 is integrated with such a system to assist the pilot in targeting enemy aircraft. The J-10 has also been featured in photos and models carrying the FILAT (Forward-looking Infra-red Laser Attack Targeting) pod for laser designation of targets and the Blue Sky forward looking infra-red (FLIR) pod for low visibility, low altitude flights.

Propulsion

The J-10 is powered by a single Russian Lyulka-Saturn AL-31FN turbofan engine giving a maximum static power output of 12,500 kgf (123 kN, 27,600 lbf). The most significant difference between the AL-31FN and the AL-31F is the arrangement of certain parts and mechanisms due to spacial limitations of the engine bay in the J-10. The AL-31F is designed for a twin engine aircraft such as the Su-27. For the J-10's AL-31FN variant, protruding parts of the engine such as the gearbox and pump are mounted opposite to that of AL-31F.

The AL-31FN was initially expected to be replaced by a domestic powerplant developed and manufactured in China, the WS-10A (WoShan-10A) Taihang turbofan, giving a thrust of 129 kN (13,200 kgf or 29,101 lbf); however, the PLAAF delayed integration of the WS-10 onto the aircraft given development difficulties with the engine.

Weaponry and external loads

The aircraft's internal armament consists of a 23 mm twin-barrel cannon, located underneath the port side of the intake. Other weaponry and equipment is mounted externally on 11 hardpoints, to which 6,000 kg (13,228 lb) of weaponry such as missiles and bombs, drop-tanks containing fuel and other equipment such as avionics pods can be attached.

Air-to-air missiles deployed may include short range air-to-air missiles such as the PL-8 and PL-9, medium-range radar-guided air-to-air missiles such as the PL-11 and PL-12, unguided and precision guided munitions such as laser-guided bombs, anti-ship missiles such as the YJ-9K and anti-radiation missiles such as the PJ-9.

Variants

- **J-10A:** Single seat multi-role variant. The export designation is **F-10A**.
- **J-10S:** Twin-seat fighter-trainer variant of the J-10A. The forward fuselage of the aircraft is stretched to accommodate an additional pilot seat, two pilots sit in tandem with a single large bubble canopy. Also incorporates an enlarged dorsal spine which may accommodate additional avionics equipment or fuel. As well as serving as training aircraft, the J-10S may also be used for the ground attack role where the rear seat pilot would act as the weapon systems operator.
- **J-10B:** An upgraded variant of the J-10, also known as the "Super-10." The existence of the J-10B is not confirmed by official Chinese sources, but numerous images of a new J-10 variant have surfaced, showing a prototype J-10 modified with a diverterless supersonic inlet (DSI), an infra-red search and track (IRST) sensor, modified vertical stabiliser, ventral fins, housings fitted under the wings, and a modified nose that could indicate an AESA radar. It had its first flight in December 2008.
- **FC-20:** An export variant of the J-10B designed for the Pakistan Air Force. First flight stated to take place in 2009.
- **J-10C:** A carrier-based (possibly twin-engined) variant of the J-10B with more powerful engines, developed for future Chinese aircraft carrier.

Operators

 People's Republic of China

- People's Liberation Army Air Force - 120+ J-10A and AS in service according to 2010 IISS Military Balance, page 404

Incidents

Notable accidents

There have been four known crashes of the J-10 to date. The first crash was of a prototype combat aircraft during testing in 1998 with the most likely cause cited as failure of the fly-by-wire flight control system.

In 2007, a second crash occurred near Guilin involving a J-10 of the PLAAF's 2nd Division.

A third crash occurred in August 2009 when pilot Meng Fansheng was forced to eject from his aircraft when the aircraft suffered an abrupt loss of engine power. An official investigation by the PLAAF also echoed that the crash was the result of the failure of the AL-31F engine on the aircraft.

A fourth crash involving the aircraft occurred on April 22, 2010 when an active duty J-10 of the PLAAF crashed killing a Senior Colonel. A report that the Chinese government tried to cover up the crash but was unable to do so when the funeral for the dead pilot gained prominence was published by the German based Defense Professionals website.

In addition, it was reported that on March 7, 2009 that an active duty J-10 suffered a loss of all onboard avionics during a tactical training exercise. However, the pilot of the aircraft, Lieutenant Colonel Li Feng was able to land the aircraft safely. The pilot cited the cause of the avionics failure as smoke in the cockpit presumably generated by the engine which had leaked in from the environmental control system.

J-10 footage controversy

On January 23, 2011 the CCTV news program Xinwen Lianbo showcased the J-10 in the air by firing a missile at a plane. The target then exploded. This footage lasted half a second. The footage shown was that of a F-5, US fighter jet. It turns out the clip was taken from the 1986 US movie Topgun.

Specifications (J-10A)

General characteristics

- **Crew:** 1 (basic), 2 (trainer variant)
- **Length:** 16.43 m (53 ft 10 in)
- **Wingspan:** 9.75 m (31 ft 11 in)
- **Height:** 4.78 m (15.7 ft)
- **Wing area:** 39 m² (419.8 ft²)
- **Empty weight:** 9,750 kg (21,495 lb)
- **Loaded weight:** 14,876 kg (32,797 lb)
- **Useful load:** 4,500 kg (9,920 lb)

- **Max takeoff weight:** 19,277 kg (42,500 lb)
- **Powerplant:** 1× Saturn-Lyulka AL-31FN or WS-10A Taihang turbofan
 - **Dry thrust:** 79.43 kN / 89.17 kN (17,860 lbf / 20,050 lbf)
 - **Thrust with afterburner:** 122.5 kN / 132 kN (27,557 lbf / 29,101 lbf)

Performance

- **Maximum speed:** Mach 2.0 at altitude, Mach 1.2 at sea level
- **g-limits:** +9/-3 g (+88/-29 m/s², +290/-97 ft/s²)
- **Combat radius:** 1100 km (688 mi)
- **Service ceiling:** 18,000 m (59,055 ft)
- **Wing loading:** 335 kg/m² (69 lb/ft²)
- **Thrust/weight:** .98

Armament

- **Guns:** 1× 23mm twin-barrel cannon
- **Hardpoints:** 11 in total (6× under-wing, 5× under-fuselage) with a capacity of 6,000 kg (13,228 lb) external fuel and ordnance
- **Rockets:** 90 mm unguided rocket pods
- **Missiles:**
 - **Air-to-air missiles:** PL-8, PL-9, PL-11, PL-12
 - **Air-to-surface missiles:** PJ-9, YJ-9K
- **Bombs:** laser-guided bombs (LT-2), glide bombs (LS-6) and unguided bombs
- **Others:**
 - Up to 3 external fuel drop-tanks (1× under-fuselage, 2× under-wing) for extended range and loitering time

Avionics

- NRIET KLJ-10 multi-mode fire-control radar
- Externally-mounted avionics pods:
 - Type Hongguang-I infra-red search and track pod
 - BM/KG300G self-protection jamming pod
 - KZ900 electronic reconnaissance pod
 - Blue Sky navigation/attack pod
 - FILAT (Forward-looking Infra-red Laser Attack Targeting) pod

Chapter 6

Dassault Rafale

Rafale



A Rafale B (foreground), and a Rafale C (background) of the French Air Force

Role	Multirole fighter aircraft
National origin	France
Manufacturer	Dassault Aviation
First flight	4 July 1986
Introduced	4 December 2000
Status	Active
Primary users	French Air Force French Navy
Program cost	€39.6 billion (1 January 2008)
Unit cost	Rafale C: €64 million, US\$82.3 million (flyaway cost, 2008) Rafale M: €70 million, US\$90.5 million (flyaway cost, 2008)

The **Dassault Rafale** is a French twin-engined delta-wing multi-role jet fighter aircraft designed and built by Dassault Aviation. Introduced in 2000, the Rafale is being produced both for land-based use with the French Air Force and for carrier-based

operations with the French Navy. It has also been marketed for export to several countries but has not yet received orders.

Development



The logo of the Dassault Rafale programme

In the mid-1970s, both the French Air Force (*Armée de l'Air*) and Navy (*Aéronavale*) had requirements (the Navy's being rather more pressing) to find a new generation of fighters (principally to replace Air Force SEPECAT Jaguars and Navy F-8 Crusaders), and their requirements were similar enough to be merged into one project. In 1983, France awarded Dassault a contract for two *Avion de Combat expérimental* (ACX) demonstrators. European nations, Germany, France, Italy, Spain and the United Kingdom agreed to jointly develop a new fighter in the early 1980s. Disagreement over the fighter's size and project leadership led France and the other nations to split in 1985. France developed the smaller Rafale, while the other nations developed what would later be named the Eurofighter Typhoon.



Prototype Dassault Rafale A

The **Rafale A** technology demonstrator was rolled out in late 1985 and made its maiden flight on 4 July 1986. The SNECMA M88 engine was being developed and was not considered sufficiently mature for the initial trials programme, so the demonstrator flew with General Electric F404-GE-400 afterburning turbofans as used on the F/A-18 Hornet. Production orders were placed in 1988.

Further testing continued, including carrier touch-and-go landings and test-flying early M88 engines, before the Rafale A was retired in 1994. Though the Rafale A and British

Aerospace EAP were broadly comparable, when the first Eurofighter made its maiden flight in March 1994, pre-series Rafales had been flight-testing for three years, including carrier trials; Rafale C01, Rafale M01, and Rafale B01 first flew in May 1991, December 1991, and April 1993 respectively.

Three versions of Rafale were in the initial production order:

- **Rafale C** (Chasseur) Single-seat fighter for the *AdA* (*Armée de l'Air*, French Air Force)
- **Rafale B** (Biplace) Two-seat fighter for the *AdA*
- **Rafale M** (Marine) Single-seat carrier fighter for the *Aéronavale*

The prototype Rafale C flew in 1991, the first of two Rafale M prototypes flew later that year. The prototype Rafale B flew in early 1993, and the second Rafale M prototype flew later that year. Catapult trials were initially carried out between 13 July and 23 August 1992 at NAS Lakehurst in New Jersey, USA and NAS Patuxent River, Maryland, USA, as France had no land-based catapult test facility. The aircraft then undertook trials aboard the carrier FS *Foch*.



A French Navy Rafale M performing a touch and go on the deck of the carrier USS John C. Stennis (CVN-74).

Initially, the Rafale B was to be just a trainer, but Gulf War and Kosovo experience showed that a second crew member is invaluable on strike and reconnaissance missions, and therefore more Rafale Bs were ordered, replacing some Rafale Cs. 60% of the aircraft will be two seaters. The navy investigated a naval version of the two-seat version. No production aircraft or prototypes were built.

Political and economic uncertainty meant that it was not until 1999 that a production Rafale M flew.

The French forces were expected to order 294 Rafales: 234 for the Air Force and 60 for the Navy. To date, 120 Rafales have been officially ordered. These are being delivered in three separate batches, the most recent being the December 2004 order for 59 Rafales.

The marine version has priority since the aircraft it is replacing are much older F-8E(FN) Crusader fighters. Service deliveries began in 2001 and the type "entered service" on 4 December 2000, though the first squadron, Flotille 12, did not actually reform until 18 May 2001. The unit embarked on the *Charles de Gaulle* in 2002, becoming fully operational on 25 June 2004, following an extended operational evaluation that included flying limited escort and tanker missions in support of Operation Enduring Freedom over Afghanistan.

The *Armée de l'Air* received its first three Rafale Bs (to F2 standards) in late December 2004. They went to the *Centre d'Expériences Aériennes Militaires* (CEAM) at Mont-de-Marsan for operational evaluation and associated pilot conversion training.

Costs

The total programme cost, as of 2008, is around €39.6 billion, which translates to a unit programme cost of approximately €138.5 million. The unit flyaway price as of 2008 is €64 million for C version (Air Force), and €70 million for the Navy version.

Total costs, as of 2011, have been estimated to have escalated to €53 billion.

Programme milestones

Important dates from the Rafale programme include:

- **1985** France formally withdraws from Eurofighter programme, committing to Rafale project.
- **1986** July 4: First flight of Rafale A; December: Development of SNECMA M88 engines commences
- **1988** April: First order signed (for Rafale C prototype).
- **1990** February: Flight tests of M88 begin
- **1991** May 19: First flight of Armée de l'Air single seat prototype (Rafale C); December 12: First flight of *Aéronavale* prototype (Rafale M)
- **1992** Rafale M carrier trials programme begins

- **1993** March: First contract for production aircraft signed. April: Start of carrier compatibility trials with *Foch*. 30 April: First flight of *Armée de l'Air* twin seat prototype (Rafale B)
- **1995** June: First MICA fired from Rafale in self guided mode. July: OSF system and helmet-mounted sight/display installed and tested. September: Rafale M tested on board carrier (4th series). November: First non-stop long-range flight by Rafale B01 (3,020 nm in under 6 hours 30 minutes). October: Final land-based carrier test series of Rafale M in the USA. December: First production model fuselage assembly.
- **1996** March: M88 engine "flightworthiness" qualified. April: Production suspended, restarted in January 1997 following cost reductions. May: Low level tests with digital terrain database. July: Spectra electronic warfare system integration tests in anechoic chamber. November: Spectra flight tested. December: First deliveries of production standard engines.
- **1997** February: Rafale B01 flight tested in heavyweight configuration (2 Apache ASMs, three 2,000 l drop tanks, two Magic and two MICA AAMs). May: First inertially-guided MICA firing. June: Flight testing of Spectra countermeasures system. October: First production RBE2 radar flown for the first time. November: Inertially-guided firing of missiles against two targets, with aircraft-to-missile link, with countermeasures.
- **1998** June: Qualification of MICA fire control system. Proposed initial operational capability evaluated by Navy and Air Force pilots flying Rafale B01 and M02 development aircraft. 24 November: First flight of production Rafale (a Rafale B)
- **1999** May: First test launch of SCALP EG cruise missile. 6 July: First deck landing on *Charles de Gaulle*. 7 July: First flight of production Rafale M
- **2000** 20 July: First Rafale M delivered to *Flotille 12F*
- **2002** Rafale M entered service with 12F (*Aéronavale*, evaluation)
- **2004** Full service entry with 12F (Navy); 9 September: First Meteor GHTM (General Handling Training Missiles) carriage trials by Rafale M from CEV Istres; June:December: Three Rafale Bs delivered to CEAM, Mont de Marsan
- **2005** September 11: First Meteor GHTM carriage trials by Rafale M from the carrier *Charles de Gaulle*.
- **2006** Summer: Formation of EC 1/7 with 8–10 aircraft
- **2007** Full service entry (Air Force) expected with EC7; First landing of Rafale M on US Navy carrier USS *Enterprise*
- **2008** Rafale qualified to full F3 standard

Design

Aerodynamics

The Rafale features a delta wing combined with active integrated (Close-coupled) canard to maximize maneuverability (withstanding +9 g or -3 g) while maintaining stability in flight, a maximum of 11 g can be reached in case of emergency. The canard also reduces landing speed to 115 knots. According to internal sources (Les essais en vol du Rafale)

low speed limit is 100 kt but 80 kt is sometimes demonstrated during airshows by pilots willing to underline low speed qualities of the aircraft." "A minimum of 15 kt have been reached during simulated combat vs a Mirage 2000 by an aggressive pilot." The aircraft can operate from 400 meter runways.

Combat systems



Weapon complement of the Rafale

The Rafale carries an integrated electronic survival system named SPECTRA which features a software-based virtual stealth technology. The most important sensor is the Thales RBE2 passive electronically scanned multi-mode radar. Thales claims to have achieved unprecedented levels of situational awareness through the earlier detection and tracking of multiple air targets for close combat and long-range interception, as well as real time generation of three-dimensional maps for terrain-following and the real time generation of high resolution ground maps for navigation and targeting.

In circumstances when signature management is required, the Rafale can use several passive sensor systems. The front-sector electro-optical system or Optronique Secteur Frontal (OSF), developed by Thales, is completely integrated within the aircraft and can operate both in the visible and infrared wavelengths.

The SPECTRA electronic warfare system, jointly developed by Thales and EADS France, provides the aircraft with the highest survivability assets against airborne and ground threats. The real-time data link allows communication not only with other aircraft, but also with fixed and mobile command and control centres. For those missions requiring it, the Rafale will also eventually use the Damoclès electro-optical/laser designation pod that brings full day and night LGB capability, though the Armée de l'Air's current plans call for Rafale to use stand off weapons, and for the LGB role to be handled by Dassault Mirage 2000s.

The Rafale core systems employ an Integrated Modular Avionics (IMA), called MDPU (Modular Data Processing Unit). This architecture hosts all the core functions of the aircraft as Flight management system, Data Fusion, Fire Control, Man-Machine Interface, etc.

The total value of the radar, electronic communications and self-protection equipment is about 30% of the cost of the entire plane.

The Rafale's ground attack capability is limited by the lack of an advanced targeting pod, but this will be rectified with the addition of Thales Optronique's Reco NG/Areos reconnaissance and Damocles targeting pods on the F-3 standard.



Rafale B



Rafale C



Rafale M



Rafale B/C

AESA Radar

The new Thales RBE2 AA Active Electronically Scanned Array (AESA) radar is planned to replace the existing passively scanned array of the RBE2. Thales will begin deliveries of the new radar in August 2010 for use on the fourth tranche of Rafale aircraft. A total of 60 tranche four aircraft have been ordered to date. The first AESA-equipped squadron of aircraft is expected to become operational in 2012. Thales also claims that the AESA radar will improve the operational capabilities of the aircraft in terms of range, interception, tracking ability and countermeasures. Rafale's attempts at export sales have been hindered by a lack of AESA capability, "a baseline requirement for a 21st-century aircraft."

Cockpit

The cockpit uses a Martin-Baker Mark 16F "zero-zero" ejection seat, i.e., capable of being used at zero speed and zero altitude. The seat is inclined 29 degrees backwards to improve G force tolerance. The canopy hinges open to the right. An on-board oxygen generating system is provided to eliminate the need for multiple oxygen canisters.

The cockpit includes a wide-angle holographic head-up display (HUD), two head-down flat-panel colour multi-function displays (MFDs) and a center collimated display. Display interaction is by means of touch input for which the pilot wears silk-lined leather gloves. In addition, in full development, the pilot will have a head-mounted display (HMD).

The pilot flies the aircraft with a side-stick controller mounted on his right and a throttle on his left. These incorporate multiple hands on throttle and stick (HOTAS) controls. The Rafale cockpit is also planned to include Direct Voice Input (DVI), allowing for pilot action by voice commands.

Radar signature reduction features

Although not a true stealth aircraft, the Rafale has reduced radar signature according to Dassault, while most of the stealth design features are classified, extensive use of composite materials and serrated patterns on the trailing edges of the wings and canards help to reduce the radar cross section.

Standards

Initial deliveries of the Rafale M were to the *F1* ("France 1") standard. This meant that the aircraft was suitable for air-to-air combat, replacing the obsolescent F-8 Crusader as the Aviation Navale's carrier-based fighter, but not equipped or armed for air-to-ground operations. Actual deliveries (to *Flotille 11* some time after 2007) are to the "F2" standard, giving air-to-ground capability, and replacing the Dassault-Breguet Super Étendard in the ground attack role and the Dassault Étendard IVP in the reconnaissance role. This will leave the Rafale M as the only fixed-wing combat aircraft flown by the Aviation Navale, and plans are to upgrade all airframes to the "F3" standard, with terrain-following 3D radar and nuclear capability, from early in the decade following 2010. This upgrade has been brought forwards to 2010 for the first 10 French Navy Rafale F-1's.

The first Rafale C delivered to the *Armée de l'Air*, in June 2005, was to the "F2" standard, and it is anticipated that upgrades similar to those of the navy will take place in the future. The Rafale replaces the SEPECAT Jaguar, Mirage F1 and the Mirage 2000 in the Armée de l'Air.

Operational history

France



A Rafale M landing on an aircraft carrier

The Rafale is now in service in the trials and training role with the French Air Force (CEAM/EC 5/330) and EC 1/7 at Saint-Dizier is expected to receive a nucleus of 8–10 Rafale F2s during the Summer of 2006, and it looks set to enter full operational service (with robust air-to-air and stand off air-to-ground precision attack capabilities) during mid-2007 (when EC 1/7 will have about 20 aircraft, 15 two-seaters and 5 single-seaters). The aircraft is already in limited operational service with the French Navy (*Flotille 12F*) in the air-to-air role, and has undertaken a great deal of air-to-ground trials and evaluation work.

The Rafale M is fully compatible with US Navy aircraft carriers and some French Navy pilots have qualified to fly the aircraft from US Navy flight decks.

The first Rafale deployed in a combat zone were those of the French Navy during *Opération Héraclès*, the French participation in "Operation Enduring Freedom". They flew from the *Charles de Gaulle* over Afghanistan as early as 2002, but the F1 standard precluded air-to-ground missions and the Rafale did not see any action.

In June 2002, while *Charles de Gaulle* was in the Arabian Sea, armed Rafale fighters participated in interposition patrols near the India-Pakistan border, marking a significant point in the Rafale M's operational career and its integration with the carrier.

In 2007, after a "crash program" enhancement six Rafales were given the ability to drop laser-guided bombs, in view of engaging them in Afghanistan. Three of these aircraft belonging to the Air Force were deployed to Dushanbe in Tajikistan, while the three others were *Rafale Marines* of the Navy on board the *Charles De Gaulle*. The first mission occurred on 12 March 2007, and the first GBU-12 was launched on 28 March in support of embattled Dutch troops in Southern Afghanistan, marking the operational début of the Rafale. They still have to rely on Mirage 2000Ds and Super Étendards carrying laser designation pods to designate their targets.

The Rafale is planned to be the French Air Force's primary combat aircraft until 2040 or later.

In November 2009 the French government ordered an additional 60 aircraft to take the total order for the French Air Force and Navy to 180.

On 4 June 2010, a French Rafale became the first jet fighter of a foreign navy to have its jet engine changed on board an American aircraft carrier, during an exercise on the USS Harry S. Truman (CVN-75).

Export

Several countries have shown interest in purchasing the Rafale. The Rafale is one of the six fighter jets competing for India's tender for 126 multi-role fighters. In April 2009, news reports stated the Rafale had been disqualified from the competition for not meeting minimum performance requirements of the Indian Air Force and that other competing aircraft, namely Mikoyan MiG-35, General Dynamics F-16 Fighting Falcon, Boeing F/A-18E/F Super Hornet, JAS 39 Gripen and Eurofighter Typhoon, qualified for the next round of evaluation. The Indian Defence Ministry denied this report; an IAF spokesman stated, "we have not ruled anyone out yet in the MMRCA competition". Reports suggested Rafale and Typhoon have entered the final stage of the contest.

In January 2006, the French newspaper *Journal du Dimanche* reported that Libya wanted to order 13–18 Rafales "in a deal worth as much as \$3.24 billion". In December 2007, Saif al-Islam Gaddafi openly declared the Libyan interest in the Rafale. Greece has also expressed an interest in the French fighter, possibly in exchange for its fleet of Mirages.

In 2006 the British Royal Navy considered the Rafale as an alternative to the F-35 JSF but decided to proceed with the F-35. However the British aircraft carriers will be modified in order to operate French Rafales.

In February 2007, it was reported that Switzerland was considering the Rafale and other fighters to replace its F-5 Tiger IIs. The one month evaluation started in October 2008 at

Emmen Airforce Base consisting of approx. 30 evaluation flights. The Rafale along with the Gripen and the Eurofighter were to be evaluated.

In September 2007, *La Tribune* reported that a sale to Morocco had fallen through, the government selecting Lockheed Martin's F-16 instead. In October 2007, *La Tribune's* earlier report appeared to have been confirmed that the Rafale would not be bought.

In January 2008, *O Estado de São Paulo* reported that the Brazilian Defence Minister visited France to discuss the possibility of acquiring Rafale fighters for the F-X2 program. In June 2008, the Brazilian Air Force divulged a Request For Information to the following companies and their aircraft: Boeing F/A-18E/F Super Hornet and Lockheed Martin F-35 Lightning II, Dassault Rafale, Sukhoi Su-35, Saab Gripen NG and Eurofighter Typhoon. In October 2008, it was reported that Brazilian Air Force had selected three finalists for F-X2; Dassault Rafale, Saab Gripen NG and Boeing F/A-18E/F. On 7 September 2009, during a visit by French President Nicolas Sarkozy, Brazil announced a pact with France and that the nations are in contract negotiations to buy 36 Rafales. The crash of two Rafales in the Mediterranean off Perpignan on 24 September 2009 after a midair collision, comes at a delicate time for the Brazil-France negotiations. On 5 January 2010, media reports stated that the final evaluation report by the Brazilian Air Force placed the Gripen ahead of the other two contenders. The decisive factor was apparently the overall cost of the new fighters, both in terms of unit cost, and operating and maintenance costs. Some sources say that Rafale was chosen by the Defense Ministry, but there has been no confirmation on this. In February, 2011, the press announced that the new president of Brazil, Dilma Roussef, had decided in favor of the American F-18 fighter. On February 28, 2011, the Minister of Finance, Guido Mantega, said the issue would not be resolved in the current year, citing "lack of resources", due to budgetary constraints for the new fiscal year.

In February 2009, French President Nicolas Sarkozy announced that Kuwait was considering buying up to 28 Rafales, but with no firm order then. The same month, France offered Rafales to Oman to replace its ageing fleet of SEPECAT Jaguars. But in 2010, Oman prefers to order the Typhoon.

The UAE was interested in a version of the Rafale that would be upgraded with more powerful engines and radar and advanced air to air missiles. They have now started to explore a purchase of the Boeing F/A-18E/F Super Hornet. This is reported to be because France's Defense Minister Hervé Morin has asked the UAE to pay 2 billion euros of the total cost to upgrade the Rafale to match the Super Hornet's advancements.

Leaked United States State Department cables have said that "French representatives have tried to spin the Rafale's dismal performance in the global market to be the result of U.S. government political pressure rather than the aircraft's shortcomings".

Variants



Dassault Rafale M



Rafale B at the Paris Air Show 2007

Rafale A

A technology demonstrator that first flew in 1986. It has now been retired.

Rafale D

Dassault used this designation (D for *discret* or stealthy) in the early 1990s for the production versions for the *Armée de l'Air*, to emphasise the new semi-stealthy features they had added to the design.

Rafale B

This is the two-seater version for the *Armée de l'Air*; delivered to EC 330 in 2004.

Rafale C

This is the single-seat version for the *Armée de l'Air*; delivered to EC 330 in June 2004.

Rafale M

This is the carrier-borne version for the *Aéronavale*, which entered service in 2002. The Rafale M weighs about 500 kg (1,100 lb) more than the Rafale C. Very similar to the Rafale C in appearance, the M differs in the following respects:

- Strengthened to withstand the rigors of carrier-based aviation
- Stronger landing gear
- Longer nose gear leg to provide a more nose-up attitude for catapult launches
- Deleted front centre pylon (to give space for the longer gear)
- Large stinger-type tailhook between the engines
- Built-in power operated boarding ladder
- Carrier microwave landing system
- "Telemir" inertial reference platform that can receive updates from the carrier systems.

Rafale N

The Rafale N, originally called the Rafale BM, was planned to be a two-seater version for the *Aéronavale*. Budget constraints and the cost of training extra crew members have been cited as the grounds for its cancellation.

Operators

 France

180 ordered, 82 delivered as of December 2009

- French Air Force - 54
- French Navy - 28

Accidents

- On 6 December 2007, a French Air Force twin-seat Rafale crashed during a training flight. The pilot, who was the only person on board the fighter, was killed in the accident.
- On 24 September 2009, two French Navy Rafales collided in mid-air off Perpignan during exercises on the *Charles de Gaulle*.

- On 28 November 2010, a Rafale from carrier "Charles de Gaulle" crashed in the Arabian Sea. This aircraft was supporting Allied operations in Afghanistan. The pilot ejected safely and was recovered by a SAR helicopter from the carrier. Later reports said the engine stopped after being starved of fuel due to confusion by the pilot over the operation of valves in the fuel tanks.

Specifications



A Rafale M flies above the aircraft carrier USS *John C. Stennis*.
Data from Dassault Rafale characteristics, Superfighters French Navy page

General characteristics

- **Crew:** 1–2
- **Length:** 15.27 m (50.1 ft)
- **Wingspan:** 10.80 m (35.4 ft)
- **Height:** 5.34 m (17.5 ft)
- **Wing area:** 45.7 m² (492 ft²)
- **Empty weight:** 9,500 kg (C), 9,770 kg (B), 10,196 kg (M) ()
- **Loaded weight:** 14,016 kg (30,900 lb)
- **Max takeoff weight:** 24,500 kg (C/D), 22,200 kg (M) (54,000 lb)
- **Powerplant:** 2× Snecma M88-2 turbofans
 - **Dry thrust:** 50.04 kN (11,250 lbf) each
 - **Thrust with afterburner:** 75.62 kN (17,000 lbf) each

Performance

- **Maximum speed:**
 - **High altitude:** Mach 2 (2,390 km/h, 1,290 knots)
 - **Low altitude:** 1,390 km/h, 750 knots
- **Range:** 3,700+ km (2,000+ nmi)
- **Combat radius:** 1,852+ km (1,000+ nmi) on penetration mission .
- **Service ceiling:** 16,800 m (55,000 ft)
- **Rate of climb:** 304.8+ m/s (1,000+ ft/s)
- **Wing loading:** 306 kg/m² (62.8 lb/ft²)
- **Thrust/weight:** 1.10 (100% fuel, 2 EM A2A missile, 2 IR A2A missile)

Armament

- **Guns:** 1× 30 mm (1.18 in) GIAT 30/719B cannon with 125 rounds
- **Hardpoints:** 14 For Armée de l'Air version (Rafale B,C), 13 for Aéronavale version (Rafale M) with a capacity of 9,500 kg (21,000 lb) external fuel and ordnance
- **Missiles:**
 - **Air-to-air:**
 - MICA IR/EM *or*
 - Magic II and in the future
 - MBDA Meteor
 - **Air-to-ground:**
 - MBDA Apache *or*
 - SCALP EG *or*
 - AASM *or*
 - GBU-12 Paveway II *or*
 - AM 39 Exocet *or*
 - ASMP-A nuclear missile
- **Others:**

- Thales Damocles targeting pod
- RECO NG reconnaissance pod
- up to 5 drop tanks
- The Rafale can also carry a buddy-buddy refuelling pod

Avionics

- Thales RBE2 radar
- Thales SPECTRA electronic warfare system.
- Thales/SAGEM OSF (*Optronique Secteur Frontal*) infrared search and track system.

Chapter 7

Eurofighter Typhoon

Eurofighter Typhoon



A Eurofighter Typhoon of the Italian Air Force

Role	Multirole fighter
Manufacturer	Eurofighter GmbH
First flight	27 March 1994
Introduced	4 August 2003
Status	Operational
Primary users	Royal Air Force Luftwaffe Italian Air Force Spanish Air Force
Number built	>260 as of January 2011 471 ordered (as of January 2009)
Unit cost	€90 Million (system cost Tranche 3A)
Developed from	British Aerospace EAP
Variants	Eurofighter Typhoon variants

The **Eurofighter Typhoon** is a twin-engine, canard-delta wing, multirole combat aircraft, designed and built by a consortium of three companies: Alenia Aeronautica, BAE Systems, and EADS; working through a holding company, Eurofighter GmbH, which was formed in 1986. The project is managed by the NATO Eurofighter and Tornado Management Agency, which acts as the prime customer.

The series production of the Eurofighter Typhoon is underway, and the aircraft is being procured under three separate contracts (named "tranches"), each for aircraft with generally improved capabilities. The aircraft has entered service with the British Royal Air Force, the German Luftwaffe, the Italian Air Force, the Spanish Air Force, the Austrian Air Force and the Royal Saudi Air Force.

Development



Official Eurofighter logo

The UK had identified a requirement for a new fighter as early as 1971. A specification, AST 403, issued by the Air Staff in 1972, resulted in a conventional "tailed" design known as P.96, which was presented in the late 1970s. While the design would have met the Air Staff's requirements, the UK air industry had reservations as it appeared to be very similar to the McDonnell Douglas F/A-18 Hornet, which was then well advanced in its development. The design had little potential for future growth, and when it entered production it would secure few exports in a market in which the Hornet would be well established. Simultaneously, by 1979 the West German requirement for a new fighter had led to the development of the TKF-90 concept. This was a cranked delta wing design with forward canard controls and artificial stability. Although the British Aerospace designers rejected some of its advanced features such as vectoring engine nozzles and vented trailing-edge controls, they agreed with the overall configuration.

In 1979 British Aerospace and Messerschmitt-Bölkow-Blohm presented a formal proposal to their respective governments for the ECF, the **European Collaborative Fighter** or **European Combat Fighter**. In October 1979 Dassault joined the ECF team for a tri-national study, which became known as the **European Combat Aircraft**. It was at this stage of development that the Eurofighter name was first attached to the aircraft. The development of different national prototypes continued. France produced the ACX.

The UK produced two designs; the P.106 was a single-engined "lightweight" fighter, superficially resembling the JAS 39 Gripen, the P.110 was a twin-engined fighter. The P.106 concept was rejected by the RAF, on the grounds that it had "half the effectiveness of the two-engined aircraft at two thirds of the cost". West Germany continued to refine the TFK-90 concept. The ECA project collapsed in 1981 for several reasons including differing requirements, Dassault's insistence on "design leadership" and the British preference for a new version of the RB199 to power the aircraft versus the French preference for the new SNECMA M88.

As a result the Panavia partners (BAe, MBB and Aeritalia) launched the **Agile Combat Aircraft** (ACA) programme in April 1982. The ACA was very similar to the BAe P.110, having a cranked delta wing, canards and a twin tail. One major external difference was the replacement of the side mounted engine intakes with a chin intake. The ACA was to be powered by a modified version of the RB199. The German and Italian governments withdrew funding, and the UK Ministry of Defence agreed to fund 50% of the cost with the remaining 50% to be provided by industry. MBB and Aeritalia signed up with the aim of producing two aircraft, one at Warton and one by MBB. In May 1983 BAe announced a contract with the MoD for the development and production of an ACA demonstrator, the **Experimental Aircraft Programme**.

In 1983 the UK, France, Germany, Italy and Spain launched the **Future European Fighter Aircraft** (FEFA) programme. The aircraft was to have Short Take Off and Landing (STOL) and Beyond Visual Range (BVR) capabilities. In 1984 France reiterated its requirement for a carrier-capable version and demanded a leading role. The UK, West Germany and Italy opted out and established a new EFA programme.

In Turin on 2 August 1985 Italy, West Germany and the UK agreed to go ahead with the Eurofighter. The announcement of this agreement confirmed that France, along with Spain, had chosen not to proceed as a member of the project. Despite pressure from France, Spain rejoined the Eurofighter project in early September 1985. France officially withdrew from the project to pursue its own ACX project, which was to become the Dassault Rafale.



Close up view of an RAF Typhoon F2, showing the deflected canard control surface immediately below the pilot

By 1986, the cost of the program had reached £180 million. When the EAP program had started, the cost was supposed to be equally shared by both government and industry, but the West German and Italian government wavered on the agreement and the three main industrial partners had to provide £100 million to keep the program from ending. In April 1986 the BAe EAP was rolled out at BAe Warton, by this time also partially funded by MBB, BAe and Aeritalia. The EAP first flew on 6 August 1986. The Eurofighter bears a strong resemblance to the EAP. Design work continued over the next five years using data from the EAP. Initial requirements were: UK: 250 aircraft, Germany: 250, Italy: 165 and Spain: 100. The share of the production work was divided among the countries in proportion to their projected procurement - British Aerospace (33%), DASA (33%), Aeritalia (21%), and Construcciones Aeronáuticas SA (CASA) (13%).

The Munich based Eurofighter Jagdflugzeug GmbH was established in 1986 to manage development of the project and EuroJet Turbo GmbH, the alliance of Rolls-Royce, MTU Aero Engines, FiatAvio (now Avio) and ITP for development of the EJ200. The aircraft was known as Eurofighter EFA from the late 1980s until it was renamed EF 2000 in 1992.

By 1990, the selection of the aircraft's radar had become a major stumbling block. The UK, Italy and Spain supported the Ferranti Defence Systems-led ECR-90, while Germany preferred the APG-65 based MSD2000 (a collaboration between Hughes (of the USA), AEG and GEC-Marconi). An agreement was reached after UK Defence Secretary

Tom King assured his West German counterpart Gerhard Stoltenberg that the British government would approve the project and allow GEC to acquire Ferranti Defence Systems from its troubled parent. GEC thus withdrew its support for the MSD2000.

Testing

The maiden flight of the Eurofighter prototype took place on 27 March 1994. Dasa chief test pilot Peter Weger took the prototype on a test flight around Bavaria. The 1990s saw significant arguments over work share, the specification of the aircraft and even participation in the project.

On 9 December 2004, Eurofighter Typhoon IPA4 began three months of Cold Environmental Trials (CET) at the Vidsel Air Base in Sweden, the purpose of which was to verify the operational behaviour of the aircraft and its systems in temperatures between -25 and -31 °C.

In May 2007, Eurofighter Development Aircraft 5 made the first flight with the CAESAR demonstrator system, a development of the Euroradar CAPTOR incorporating Active Electronically Scanned Array (AESA) technology.

The maiden flight of Instrumented Production Aircraft 7 (IPA7), the first fully equipped Tranche 2 aircraft, took place from EADS' Manching airfield on 16 January 2008.

The production version of the CAPTOR-E radar was being proposed as part of Tranche 3 of the Typhoon from 2012. Tranche 2 aircraft use the non AESA, mechanically scanned Captor-M which incorporates weight and space provisions for possible upgrade to CAESAR (AESA) standard in the future. The Italian Air Force doubted that the AESA radar would be ready in time for Tranche 3 production. In July 2010, Eurofighter announced that the AESA radar would enter service in 2015.



A German Luftwaffe Eurofighter Instrumented Production Aircraft

Orders

The first production contract was signed on 30 January 1998 between Eurofighter GmbH, Eurojet and NETMA. The procurement totals were as follows: UK 232, Germany 180, Italy 121, and Spain 87. Production was again allotted according to procurement: British Aerospace (37%), DASA (29%), Aeritalia (19.5%), and CASA (14%).

On 2 September 1998, a naming ceremony was held at Farnborough, England. This saw the Typhoon name formally adopted, initially for export aircraft only. This was reportedly resisted by Germany; perhaps because the Hawker Typhoon was a fighter-bomber aircraft which served with the RAF during the Second World War against German targets. The name "Spitfire II" (for the famous British WWII fighter, the Supermarine Spitfire) had also been considered and rejected for the same reason early in the development program. In September 1998 contracts were signed for production of 148 Tranche 1 aircraft and procurement of long lead-time items for Tranche 2 aircraft. In March 2008 the final aircraft out of Tranche 1 was delivered to the German Luftwaffe, with all successive deliveries being at the Tranche 2 standard. On 21 October 2008, the first two of 91 Tranche 2 aircraft, ordered four years before, were delivered to RAF Coningsby.

In October 2008, the Eurofighter nations were considering splitting the 236-fighter Tranche 3 into two parts. In June 2009, RAF Air Chief Marshal Sir Glenn Torpy suggested that the RAF fleet might only be 123 jets, instead of the 232 previously planned. In spite of this reduction in the number of required aircraft, on May 14, 2009, British Prime Minister Gordon Brown confirmed that the UK would move ahead with the third batch purchase. A contract for the first part, Tranche 3A, was signed at the end of

July 2009 for 112 aircraft split across the four partner nations, including 40 aircraft for the UK, 31 for Germany, 21 for Italy and 20 for Spain. These 40 aircraft were said to have fully covered the UK's obligations in the project by Air Commodore Chris Bushell, due to cost overruns in the project.

Costs

In 1988, the Parliamentary Under-Secretary of State for the Armed Forces told the UK House of Commons that the European Fighter Aircraft would "be a major project, costing the United Kingdom about £7 billion". It was soon apparent that a more realistic estimate was £13 billion, made up of £3.3 billion development costs plus £30 million per aircraft. By 1997 the estimated cost was £17 billion; by 2003, £20 billion, and the in-service date (2003; defined as the date of delivery of the first aircraft to the RAF) was 54 months late. After 2003 the Ministry of Defence have refused to release updated cost estimates on the grounds of 'commercial sensitivity', however in 2011 the National Audit Office estimated the UK's "total programme cost [would] eventually hit £37 billion".

By 2007, Germany estimated the system cost (aircraft, training plus spare parts) to 120 M€ and said it was in perpetual increase. On 17 June 2009, Germany ordered 31 aircraft of Tranche 3A for 2,800 M€, leading to a system cost of 90 M€ per aircraft.

Delays

Political

The financial burdens placed on Germany by reunification caused Helmut Kohl to make an election promise to cancel the Eurofighter. In early to mid-1991 German Defence Minister Volker Rühle sought to withdraw Germany from the project in favour of using Eurofighter technology in a cheaper, lighter plane. Due to the amount of money already spent on development, the number of jobs dependent on the project, and the binding commitments on each partner government, Germany was unable to withdraw; "Rühle's predecessors had locked themselves into the project by a punitive penalty system of their own devising."

In 1995 concerns over workshare appeared. Since the formation of Eurofighter the workshare split had been agreed at the 33/33/21/13 (United Kingdom/Germany/Italy/Spain) based on the number of units being ordered by each contributing nation. All the nations then reduced their orders. The UK cut its orders from 250 to 232, Germany from 250 to 140, Italy from 165 to 121 and Spain from 100 to 87. According to these order levels the workshare split should have been 39/24/22/15 UK/Germany/Italy/Spain, Germany was unwilling to give up such a large amount of work. In January 1996, after much negotiation between UK and German partners, a compromise was reached whereby Germany would purchase another 40 aircraft. The workshare split is now 43% for EADS MAS in Germany and Spain; 37.5% BAE Systems in the UK; and 19.5% for Alenia in Italy.

The next major milestone came at the Farnborough Airshow in September 1996. The UK announced the funding for the construction phase of the project. In November 1996 Spain confirmed its order but Germany again delayed its decision. After much diplomatic activity between the UK and Germany, an interim funding arrangement of DM 100 million (€ 51 million) was contributed by the German government in July 1997 to continue flight trials. Further negotiation finally resulted in German approval to purchase the Eurofighter in October 1997.

Technical

On 21 November 2002, DA-6, the Spanish twin-seat prototype crashed due to a "double engine flame-out", said to be specifically related to the experimental trial standard of engine being used by that aircraft. The aircraft went down but the two crew members escaped unhurt.

The distribution of the parts supply and repairs over several countries has led to parts shortages, long timescales for repairs and cannibalisation of some aircraft to keep others flying.

Production



Eurofighter Typhoon F2, RAF single-seat fighter variant



A Luftwaffe twin-seat trainer version of the Eurofighter







The Eurofighter Typhoon is unique in modern combat aircraft in that there are four separate assembly lines. Each partner company assembles its own national aircraft, but builds the same parts for all 683 aircraft (including exports). A fifth assembly line will be established for the final 48 Saudi aircraft.

- **Alenia Aeronautica** – Left wing, outboard flaperons, rear fuselage sections
- **BAE Systems** – Front fuselage (including foreplanes), canopy, dorsal spine, tail fin, inboard flaperons, rear fuselage section
- **EADS Deutschland** – Main centre fuselage
- **EADS CASA** – Right wing, leading edge slats

Production is divided into three tranches. Tranches are a production/funding distinction, and do not necessarily imply an incremental increase in capability with each tranche. Tranche 3 will most likely be based on late Tranche 2 aircraft with improvements added. Tranche 3 has been split into A and B parts.

Tranches are further divided up into production standard/capability 'blocks' and funding/procurement 'batches', though these do not coincide, and are not the same thing e.g. the Eurofighter designated 'FGR4' by the RAF is a Tranche 1, Block 5. Batch 1 covered Block 1, but Batch 2 covered Blocks 2, 2B and 5.

Expected production summary

Country	Tranche 1	Tranche 2	Tranche 3A	Total
 Austria	15	0	0	15
 Germany	33	79	31	143
 Italy	28	47	21	96
 Saudi Arabia	1	24	48	72
 Spain	19	34	20	73
 United Kingdom	53	67	40	160
TOTAL	148	299	112	559

Note: The change in Austria's order from 6 Tranche 1 and 12 Tranche 2 aircraft to 15 Tranche 1 jets led to a reduction in Tranche 1 quantities for the four partner nations, with a commensurate increase in Tranche 2 numbers. 24 Saudi aircraft were taken from UK Tranche 2 production, and were to have been replaced at the end of Tranche 2, but will now 'count' against the UK's Tranche 3A total. This marks an effective reduction of 24 aircraft in the UK order total.

Exports



Countries operating or ordering the Eurofighter Typhoon

Austria

On 2 July 2002, the Austrian government announced the decision to buy the Typhoon as its new air defence aircraft. The purchase of 18 Typhoons was agreed on 1 July 2003, and included training, logistics, maintenance, and a simulator. On 26 June 2007, Austrian Minister for Defense Norbert Darabos announced a reduction to 15 aircraft. The first aircraft was delivered on 12 July 2007 and formally entered service in the Austrian Air Force.

Saudi Arabia

After unsuccessful campaigns in South Korea and Singapore (losing in both cases to versions of the Boeing F-15E), on 18 August 2006 it was announced that Saudi Arabia had agreed to purchase 72 Typhoons. In November and December it was reported that Saudi Arabia had threatened to buy French Rafales because of a UK Serious Fraud Office investigation into the Al Yamamah ("the dove") defence deals which commenced in the 1980s.

On 14 December 2006 Britain's attorney general, Lord Goldsmith, ordered that the Serious Fraud Office discontinue its investigation in the BAE Systems' alleged bribery to senior Saudi officials in the al-Yamamah contracts, citing "the need to safeguard national and international security". *The Times* has raised the possibility that RAF production aircraft will be diverted as early Saudi Arabian aircraft, with the service forced to wait for its full complement of aircraft. This arrangement would mirror the diversion of RAF Tornados to the RSAF. *The Times* has also reported that such an arrangement will make the UK purchase of its tranche 3 commitments more likely. On 17 September 2007, Saudi Arabia confirmed it had signed a GB£4.43 billion contract for 72 aircraft. 24 aircraft will be at the Tranche 2 build standard, previously destined for the UK RAF, the first being delivered in 2008. The remaining 48 aircraft will be assembled in Saudi Arabia and delivered from 2011. Saudi Arabia is considering an order of 24 additional jets in the future, more recent reports suggest that number may be as high as 60 or 72, but this may have been superseded by Saudi Arabia's request in August 2010 to purchase 84 new F-15s.

On 22 October 2008 an aircraft in the full two-tone grey livery of the Royal Saudi Air Force flew for the first time at BAE Systems' Warton Aerodrome, marking the start of an initial test flight programme for RSAF aircraft.

Also in October 2008, the United States Department of State gave its approval for the sale that was needed because the Eurofighter contains a significant amount of American technology (ITAR).

Following the official handover event of the first Eurofighter Typhoon to the Royal Saudi Air Force on 11 June 2009, the delivery ferry flight took place, as planned, on 23 June 2009.

BAE has been training Saudi Arabian personnel at their factory in Warton, in preparation for setting up an assembly plant in Saudi Arabia.

Potential customers

India

Eurofighter Typhoon is one of the bidders in the Indian MRCA Competition, worth \$10.5 billion, to supply the Indian Air Force with 126 'Multi-Role Combat Aircraft'. The other

competitors are the Boeing F/A-18IN, Dassault Rafale, JAS 39 GripenNG/IN, Mikoyan MiG-35, and F-16IN Fighting Falcon. Bernhard Gerwert, CEO of military air systems, said that India is invited to join the Eurofighter Typhoon programme as a partner. The production of the Eurofighter Typhoon will create thousands of new jobs in India and Europe. He also said that in order to win the contract, EADS would move avionics jobs from Germany to India. The campaign is fully supported by the four European nations (Germany, United Kingdom, Spain and Italy), their four Air Forces and Europe's leading aerospace companies Alenia/Finmeccanica, BAE Systems and EADS.

In January 2010, India's ambassador to Italy, Arif Shahid Khan, said that the Eurofighter was "leading the race" to win the MRCA competition.

Japan

In March 2007, Jane's Information Group reported that the Typhoon was the favourite to win the contest for Japan's next-generation fighter requirement. The other competitors then were the F/A-18E/F Super Hornet and F-15E Strike Eagle. On 17 October 2007, Japanese Defence Minister Shigeru Ishiba confirmed that Japan may buy the Typhoon. Although the F-22 Raptor was in his words "exceptional", it was not "absolutely necessary for Japan", and the Typhoon was the best alternative. The F-22 is currently unavailable for export per US law. During a visit to Japan in June 2009, Andy Latham of BAE pointed out that while F-22 exports were restricted to keep advanced military technology from falling into the wrong hands, selling the Typhoon would take a "no black box approach", that is that even licensed production and integration with Japanese equipment would not carry the risk of leakage of restricted military technology. In July 2010 it was reported that the Japan Air Self-Defense Force favoured acquiring the F-35 ahead of the Typhoon and the F/A-18E/F to fulfil its F-X requirement due to its stealth characteristics, but the Defense Ministry was delaying its budget request to evaluate when the F-35 would be produced and delivered. David Howell of the UK foreign office has asked Japan to help develop and adapt the Eurofighter.

Greece

In 1999, the Greek government agreed to acquire 60 Typhoons in order to replace its existing second-generation combat aircraft. The purchase was put on hold due to budget constraints, largely driven by other development programs and the need to cover the cost of the 2004 Summer Olympics. In June 2006 the government announced a 22 billion euro multi-year acquisition plan intended to provide the necessary budgetary framework to enable the purchase of a next-generation fighter over the next 10 years. The Typhoon is currently under consideration to fill this requirement.

Others

During the 2008 Farnborough Airshow it was announced that Oman was in an "advanced stage" of discussions towards purchasing EF Typhoons as a replacement for its Jaguar aircraft. Oman remained interested in ordering Typhoons in April 2010 though the Saab

JAS 39 Gripen was also being considered. Oman asked the USA for an order of 18 F-16s, which makes a Eurofighter order less likely.

Other potential customers of the Typhoon are Denmark and Romania. BAE Systems itself reports that Typhoon is "actively being promoted in a number of other markets including Greece, Switzerland, Turkey and Japan". Turkey has indicated that it would rather just buy more F-35 Lightning II fighters and that the "Eurofighter is off Turkey's agenda".

On 2 December 2009, BAE Systems stated it will propose the Typhoon as replacement for the Royal Malaysian Air Force (RMAF) Mikoyan MiG-29N which is to be phased out in late 2010. According to the Regional Director-Business Development Dave Potter, the Typhoon's multi-role capabilities allow it to replace the MiG-29N. Other contenders include Boeing F/A-18E/F Super Hornet, F-15 Eagle, Dassault Rafale, JAS 39 Gripen NG, Sukhoi Su-35, and Lockheed F-16C/D Block 52 Fighting Falcon.

Serbia's government has shown interest in Eurofighter.

The Qatari Air Force is, as of January 2011, evaluating the Typhoon together with the Lockheed Martin F-35 Joint Strike Fighter, the Boeing F/A-18E/F Super Hornet, the Boeing F-15 and the Dassault Rafale to replace its current fighter inventory of Dassault Mirage 2000-5s. The total order will be between 24-36 aircraft with a procurement decision to be made by the end of 2012.

Upgrades

In 2002, the MBDA Meteor was selected as the long range air-to-air missile armament of Eurofighter Typhoon. Pending Meteor availability, Typhoon will be equipped with the Raytheon AMRAAM. The current in-service date for Meteor is predicted to be August 2012.

In 2009, Eurofighter operators and manufacturers are considering upgrading the current fleet with the possibility of adding the MBDA Meteor missile and an Active Electronically Scanned Array radar.

Eurojet is attempting to find funding to test a thrust vectoring nozzle (TVN) on a flight demonstrator.

The RAF is working on fitting conformal fuel tanks (CFT) to free up limited underwing space for weapons.

Design

Airframe and avionics

The Typhoon features lightweight construction (82% composites consisting of 70% carbon fibre composites and 12% glass reinforced composites) with an estimated lifespan of 6000 flying hours.

The fighter achieves high agility at both supersonic and low speeds by having a relaxed stability design. It has a quadruplex digital fly-by-wire control system providing artificial stability, as manual operation alone could not compensate for the inherent instability. The fly-by-wire system is described as "carefree" by preventing the pilot from exceeding the permitted manoeuvre envelope.



Spanish Air Force Typhoon taking off in the RIAT 2007

Roll control is primarily achieved by use of the wing flaperons. Pitch control is by operation of the foreplanes and flaperons, the yaw control is by rudder. Control surfaces are moved through two independent hydraulic systems that are incorporated in the aircraft, which also supply various other items, such as the canopy, brakes and undercarriage. Each hydraulic system is powered by a 4000 psi engine-driven gearbox.

Navigation is via both GPS and an inertial navigation system. The Typhoon can use Instrument Landing System (ILS) for landing in poor weather.

The aircraft employs a sophisticated and highly integrated Defensive Aids Sub-System named Praetorian (formerly called EuroDASS). Threat detection is provided by a Radar Warning Receiver (RWR) and a Laser Warning Receiver (LWR, only for UK Typhoons). Protection is provided by Chaff, Jaff and Flares, Electronic Counter Measures (ECM) and a Towed Radar Decoy (TRD).

Praetorian monitors and responds automatically to the outside world. It provides the pilot with an all-round prioritised assessment of Air-to-Air and Air-to-Surface threats. It can respond to single or multiple threats.

The aircraft also features an advanced ground proximity warning system based on the TERPROM Terrain Referenced Navigation (TRN) system used by the Panavia Tornado but further enhanced and fully integrated into the cockpit displays and controls.

The Multifunctional Information Distribution System (MIDS) provides the Link 16 data link.

Cockpit

General features



MHDDs and Pedestal Panel with centre stick in the Typhoon cockpit

The Eurofighter Typhoon features a "glass cockpit" without any conventional instruments. It includes: three full colour Multi-function Head Down Displays (MHDDs) (the formats on which are manipulated by means of softkeys, XY cursor and voice (DVI) command), a wide angle Head Up Display (HUD) with Forward Looking Infra Red (FLIR), Voice & Hands On Throttle And Stick (Voice+HOTAS), Helmet Mounted Symbology System (HMSS) (known to test pilots as 'The Electric Hat'), Multifunction Information Distribution System (MIDS), a Manual Data Entry Facility (MDEF) located on the left glareshield and a fully integrated aircraft warning system with a Dedicated Warnings Panel (DWP). Reversionary flying instruments, lit by LEDs, are located under a hinged right glareshield.

The pilot flies the aircraft by means of a centre stick and left hand throttles. Emergency escape is provided by a Martin-Baker Mk.16A ejection seat, with the canopy being jettisoned by two rocket motors.

Voice control

The Typhoon DVI system utilises a Speech Recognition Module (SRM), developed by Smiths Aerospace (now GE Aviation Systems) and the then Computing Devices (now General Dynamics UK). It was the first production DVI system utilised in a military cockpit. DVI provides the pilot with an additional natural mode of command and control over approximately 26 non-critical cockpit functions, to reduce pilot workload, improve aircraft safety, and expand mission capabilities. An important technological breakthrough during the development of the DVI occurred in 1987 when Texas Instruments produced their TMS-320-C30 Digital Signal Processor (DSP). This greatly advanced the packaging of DVI from large complex systems to a single card module. This early advance allowed a viable high performance system. The project was given the go ahead in July 1997, with development and pilot assessment carried out on the Eurofighter Active Cockpit Simulator at BAE Systems Warton.

The DVI system is speaker-dependent, i.e. requires each pilot to create a template. It is not used for any safety-critical or weapon-critical tasks, such as weapon release or lowering of the undercarriage, but is used for a wide range of other cockpit functions. Voice commands are confirmed by visual or aural feedback. The system is seen as a major design feature in the reduction of pilot workload and even allows the pilot to assign targets to himself with two simple voice commands, or to any of his wingmen with only five commands.

g protection

In the standard aircraft, *g* protection is provided by the *full-cover anti-g trousers* (FCAGTs). This specially developed *g* suit provides sustained protection up to 9 *g*. The Typhoon pilots of the German Air Force and Austrian Air Force wear a hydrostatic *g*-suit called *Libelle (dragonfly) Multi G Plus* instead, which also provides protection to the arms, theoretically allowing for more complete *g* tolerance.

Design process

The design of the cockpit had involved the inputs from both test and operational pilots from each of the four partner nations from the feasibility and concept stage and throughout the design process. This has necessitated the use of specially commissioned lighting and display modelling simulation facilities and the extensive employment of rapid prototyping techniques.

PIRATE IRST

The Passive Infra-Red Airborne Track Equipment (PIRATE) system is an Infrared Search and Track System (IRST) mounted on the port side of the fuselage, forward of the windscreen. SELEX Galileo is the lead contractor which, along with Thales Optronics (system technical authority) and Tecnobit of Spain, make up the EUROFIRST consortium responsible for the system's design and development.

PIRATE operates in two IR bands, 3-5 and 8-11 micrometres. When used with the radar in an air-to-air role, it functions as an Infrared Search and Track system (IRST), providing passive target detection and tracking. In an air-to-surface role, it performs target identification and acquisition. It also provides a navigation and landing aid. PIRATE is linked to the pilot's helmet mounted display.

Eurofighters starting with Tranche 1 Block 5 have the PIRATE. The first Eurofighter Typhoon with PIRATE-IRST was delivered to the Italian Aeronautica Militare in August 2007. More advanced targeting capabilities can be provided with the addition of a targeting pod such as the LITENING pod.

Performance



Flight demonstration at WTD61 Manching/Germany



A Royal Air Force Eurofighter Typhoon T1

In 2004, United States Air Force Chief of Staff General John P. Jumper said after flying the Eurofighter, "I have flown all the air force jets. None was as good as the Eurofighter."

The Typhoon's combat performance, compared to the F-22 Raptor and the upcoming F-35 Lightning II fighters and the French Dassault Rafale, has been the subject of much discussion. In March 2005, Jumper, then the only person to have flown both the Eurofighter Typhoon and the Raptor, talked to Air Force Print News about these two aircraft. He said,

“ The Eurofighter is both agile and sophisticated, but is still difficult to compare to the F/A-22 Raptor. They are different kinds of airplanes to start with; it's like asking us to compare a NASCAR car with a Formula One car. They are both exciting in different ways, but they are designed for different levels of performance. ...The Eurofighter is certainly, as far as smoothness of controls and the ability to pull (and sustain high g forces), very impressive. That is what it was designed to do, especially the version I flew, with the avionics, the color moving map displays, etc. — all absolutely top notch. The maneuverability of the airplane in close-in combat was also very impressive.”

In July 2007, the Indian Air Force fielded the Su-30MKI during the *Indra-Dhanush* exercise with Royal Air Force's Typhoon. This was the first time that the two jets had taken part in such an exercise. The IAF did not allow their pilots to use the MKI's radar during the exercise to protect the highly-classified N011M Bars. During the exercise, the RAF pilots candidly admitted that the Su-30MKI displayed maneuvering superior to that

of the Typhoon but they had studied, prepared and anticipated this. The IAF pilots on their part were also visibly impressed by the Typhoon's agility in the air.

The Typhoon is capable of supersonic cruise without using afterburners (referred to as *supercruise*). According to the official German Luftwaffe and Austrian Eurofighter website, the maximum speed possible without reheat is between Mach 1.2 and Mach 1.5. *Air Forces Monthly* gives a maximum supercruise speed of Mach 1.1 for the RAF FGR4 multirole version. It has been suggested, in contradiction to other sources that the Eurofighter Typhoon could only supercruise in a clean configuration without external missiles and fuel tanks. While this is untrue, attention is drawn by these suggestions to the fact that not all weapons loadouts are necessarily certified for supersonic flight at all, even with afterburner.

The Eurofighter consortium claims their fighter has a larger sustained subsonic turn rate, sustained supersonic turn rate, and faster acceleration at Mach 0.9 at 20,000 feet (6,100 m) than the F-14 Tomcat, F-15 Eagle, F-16 Fighting Falcon, F/A-18 Hornet, Dassault Mirage 2000, Dassault Rafale, the Sukhoi Su-27, and the Mikoyan MiG-29.

In 2005, a trainer Eurofighter T1 was reported to have had a chance encounter the previous year with two U.S. Air Force F-15Es over the Lake District in the north of England. The encounter became a mock dogfight with the Eurofighter allegedly emerging "victorious".

In the 2005 Singapore evaluation, the Typhoon won all three combat tests, including one in which a single Typhoon defeated three RSAF F-16s, and reliably completed all planned flight tests. In July 2009, Former Chief of Air Staff for the Royal Air Force, Air Chief Marshal Sir Glenn Torpy, said that "The Eurofighter Typhoon is an excellent aircraft. It will be the backbone of the Royal Air Force along with the JSF".

In 2010, during a DACT exercises over the Canary Islands involving USAF and Spanish Air Force units, two Spanish Typhoons engaged 8 F-15Cs from Lakenheath, UK. 7 F-15s were "downed" while one managed to escape, with no losses for the Typhoons.

Air-to-ground capabilities



A Royal Air Force Eurofighter Typhoon FGR4 at Nellis AFB in Nevada, USA

The Typhoon is a multi-role fighter with maturing air-to-ground capabilities. Earlier than scheduled, the RAF integrated the air to ground capability, based on the Rafael/Ultra Electronics Litening III laser designator and the Enhanced Paveway II/III laser guided bomb under the "Austere" programme. A more comprehensive air-to-ground attack capability including Paveway IV, EGBU-16 bombs and a higher degree of automation will be achieved for all partner nations with the Phase 1 Enhancements currently in development.

The absence of such a capability is believed to have been a factor in the type's rejection from Singapore's fighter competition in 2005. At the time it was claimed that Singapore was concerned about the delivery timescale and the ability of the Eurofighter partner nations to fund the current capability packages. With the planned Phase 2 Enhancements Eurofighter GmbH hopes to increase the appeal of Typhoon to possible export customers and to make the aircraft more useful to partner air forces.

Radar signature reduction features

Although not designated a stealth fighter, measures were taken to reduce the Typhoon's radar cross section (RCS), especially from the frontal aspect. An example of these measures is that the Typhoon has jet inlets that conceal the front of the jet engine (a

strong radar target) from radar. Many important potential radar targets, such as the wing, canard and fin leading edges, are highly swept, so will reflect radar energy well away from the front sector. Some external weapons are mounted semi-recessed into the aircraft, partially shielding these missiles from incoming radar waves. In addition radar absorbent materials (RAM) developed primarily by EADS/DASA coat many of the most significant reflectors, e.g. the wing leading edges, the intake edges and interior, the rudder surrounds, strakes, etc. The Typhoon does not use internal storage of weapons. External mounting points are used instead, which increases its radar cross section but allows for more and larger stores.

The Eurofighter operates automatic Emission Controls (EMCON) to reduce the Electro-Magnetic emissions of the current mechanically scanned Radar. The Captor-M was the first NATO-Radar with three rather than two working channels, one intended for classification of jammer and for jamming suppression. The German BW-Plan 2009 indicates that Germany will equip/retrofit the Luftwaffe's Eurofighters with the AESA Captor-E from 2012. The conversion to AESA will give the Eurofighter a Low Probability of Intercept Radar with much better jam resistance. These include an innovative design with a gimbal to meet RAF requirements for a wider scan field than a fixed AESA. The coverage of a fixed AESA is limited to 120 degree in azimuth and elevation.

According to the RAF, the Eurofighter's RCS is better than RAF requirements. Comments from BAE Systems suggest the radar return is around one quarter of that of the Tornado it replaces. The Eurofighter is thought to have an RCS of less than one square metre in a clean configuration by author Doug Richardson, although no official value is available. This compares with the estimated RCS of the Rafale of 2 square metres, the 20 square metres of the Sukhoi Su-30MKI, the 1 square metre of the Su-35BM, the American F-22A of 0.0001 square metres, and the American F-117 of 0.025 square metres. The manufacturers have carried out tests on the early Eurofighter prototypes to optimize the low observability characteristics of the aircraft from the early 1990s. Testing at BAE's Warton facility on the DA4 prototype measured the RCS of the aircraft and investigated the effects of a variety of RAM coatings. Another measure to reduce the likelihood of discovery is the use of passive sensors, which minimises the radiation of treacherous electronic emissions. While canards generally have poor stealth characteristics, the flight control system is designed to minimise the RCS in flight, maintaining the elevon trim and canards at an angle to minimise RCS.

Operational history



A Royal Air Force Eurofighter Typhoon

On 4 August 2003, Germany accepted the first series production Eurofighter (GT003). Also that year, Spain took delivery of its first series production aircraft.

On 16 December 2005, the Typhoon reached initial operational capability (IOC) with the Italian Air Force. Its Typhoons were put into service as air defence fighters at Grosseto Air Base, and immediately assigned to Quick Reaction Alert (QRA) at the same base.

On 9 August 2007, the UK's Ministry of Defence reported that No. XI Squadron of the RAF, which stood up as a Typhoon squadron on 29 March 2007, had taken delivery of its first two multi-role Typhoons. Two of XI Squadron's Typhoons were sent to intercept a Russian Tupolev Tu-95 approaching British airspace on 17 August 2007.

The RAF Typhoons were declared combat ready in the air-to-ground role by 1 July 2008. The RAF Typhoons were projected to be ready to deploy for operations by mid-2008. On or around 25 April 2008 a Typhoon from 17 Squadron at RAF Coningsby, operating at the US Naval Air Weapons Station China Lake test centre in California, USA, suffered extensive damage during landing when its landing gear did not deploy. Although no immediate cause was determined it was speculated that pilot error may have been to blame. A Board of Enquiry was convened.

On 11 September 2008, the combined flying time of the five customer Air Forces and the industrial Flight Test programme saw aircraft surpass the 50,000 flight hours milestone.

On 31 March 2009 a Eurofighter Typhoon fired an AMRAAM for the first time whilst having its radar in passive mode, the necessary target data for the missile was acquired by the radar of a second Eurofighter Typhoon and transmitted using the Multi Functional Information Distribution System (MIDS).

On 17 July 2009, Italian Air Force Eurofighters were deployed to protect Albania's airspace.

In September 2009, four RAF Typhoons deployed to RAF Mount Pleasant replacing the Tornado F3s defending the Falkland Islands. The government of Argentina "is understood to have made a formal protest".

On 24 August 2010, the project suffered its first fatality when a two seat Typhoon crashed, for unknown reasons, killing a Saudi Air Force Lieutenant Colonel, the front seat occupant, shortly after taking off from Moron Air Base in Spain. Experts suspect that a bird strike had destroyed "important sensors". The Spanish instructor ejected and sustained only minor injuries. Following this incident the German Luftwaffe grounded its 55 planes on 16 September 2010, amidst concerns that after ejecting successfully the pilot had fallen to his death. In response to the investigation of the crash, on 17 September 2010, the RAF temporarily grounded all Typhoon training flights. Quick Reaction Alert duties were unaffected. On 21 September, the RAF announced that the harness system had been sufficiently modified to enable routine flying from RAF Coningsby. The Austrian Air Force also said that all its aircraft had been cleared for flight. On 24 August 2010, the ejection seat manufacturer Martin Baker commented: "... under certain conditions, the quick release fitting could be unlocked using the palm of the hands, rather than the thumb and fingers and that this posed a risk of inadvertent release," and added that a modification had been rapidly developed and approved "to eliminate this risk" and was being fitted to all Typhoon seats.

In January 2011 the aircraft passed the milestone of 100,000 flying hours across the entire fleet.

Variants



Prototype on display at the 1998 Dubai Airshow. The multiple roundels for the air forces are: (left to right) Spanish Ejército del Aire, Italian Aeronautica Militare, British Royal Air Force, and German Luftwaffe.

The Eurofighter is produced in single-seat and twin-seat variants. The twin-seat variant is not used operationally, but only for training. The aircraft has been manufactured in three major standards; seven Development Aircraft (DA), seven production standard Instrumented Production Aircraft (IPA) for further system development and a continuing number of Series Production Aircraft. The production aircraft are now operational with the partner nation's air forces.

The Tranche 1 aircraft were produced from 2000 onwards. Aircraft capabilities are being increased incrementally, with each software upgrade resulting in a different standard, known as blocks. With the introduction of the Block 5 standard, the R2 retrofit programme began to bring all aircraft to that standard.

Tranche 1

- Block 1 : Initial Operational Capability and basic Air Defence Capability.
- Block 2 : Initial air-to-air capabilities.
- Block 2B : Full air-to-air capabilities.
- Block 5 : Full Operational Capability (FOC) by combining existing air-to-air role with air-to-ground capabilities.

Tranche 2

- Block 8 : New mission computers required for the integration of future weapons such as Meteor, Storm Shadow and Taurus. (Differences in the build to Tranche 1 related to changes in production technology or obsolescence).
- Block 10 : Software: EOC 1 (advanced multi role step 1) AIM-120C-5 AMRAAM, IRIS-T digital. A2G: GBU-24, GPS-controlled weapons, ALARM, Paveway III & IV, Rafael Litening III
- Block 15 : Software: EOC 2 (advanced multi role step 2) A2A Meteor A2G: TAURUS, Storm Shadow, Brimstone

Tranche 3

These aircraft will have interfaces for possible future improvements, but will be delivered at a Tranche 2 level of capability.

The Indian Navy has made a request for information for a carrier based variant of the Eurofighter. In this contest it will once again be up against the Rafale, which split from the Eurofighter project over the need for a carrier based variant.

In February 2011, BAE debuted a navalized Typhoon in response to the Indian tender. The model offered is STOBAR (Short Take Off But Arrested Recovery) capable corresponding to the Indian Navy's future Vikrant class aircraft carrier. The changes needed to enable the Typhoon to launch by ski-jump and recover by arrestor hook; added about 500kg to the airframe. If however the Indian Navy pursues a catapult launch carrier, the Typhoon is uncompetitive against tender rivals (e.g. Rafale and Super Hornet) since meeting "... catapult requirements would add too much weight to the aircraft, blunt performance and add substantially to modification costs".

Operators



Typhoon F2 of the RAF



Spanish Eurofighter Typhoon

Austria

- Austrian Air Force - 15
 - Überwachungsgeschwader

Germany

- German Air Force - 55, 125 on order
 - Jagdgeschwader 73 Steinhoff
 - Jagdgeschwader 74
 - Jagdbombergeschwader 31 Boelcke

Italy

- Italian Air Force - 42, 96 on order
 - 9° Gruppo Caccia
 - 20° Gruppo Caccia
 - 12° Gruppo Caccia

Saudi Arabia

- Royal Saudi Air Force - 6, 66 on order, total 72.

Spain

- Spanish Air Force - 28, 59 on order.
 - 111 and 112 Operational Squadrons
 - 113 Squadron, OCU Tactical pilot training and evaluation

United Kingdom

- Royal Air Force - 62 of a confirmed order of 160 aircraft, an additional 72 as of yet uncommitted, total 232.
 - No. 3 Squadron RAF
 - No. 6 Squadron RAF
 - No. 11 Squadron RAF
 - No. 17 Squadron RAF
 - No. 29 Squadron RAF
 - No. 1435 Flight RAF (Falkland Islands)

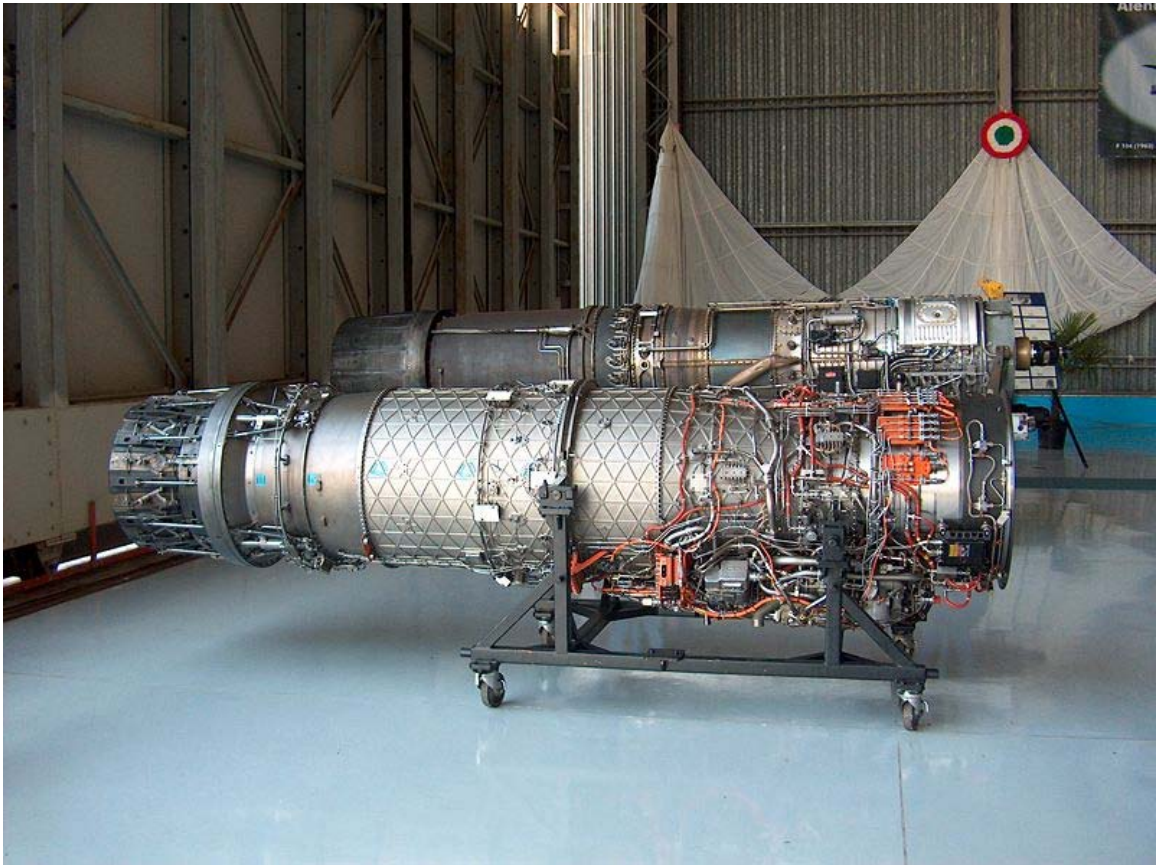
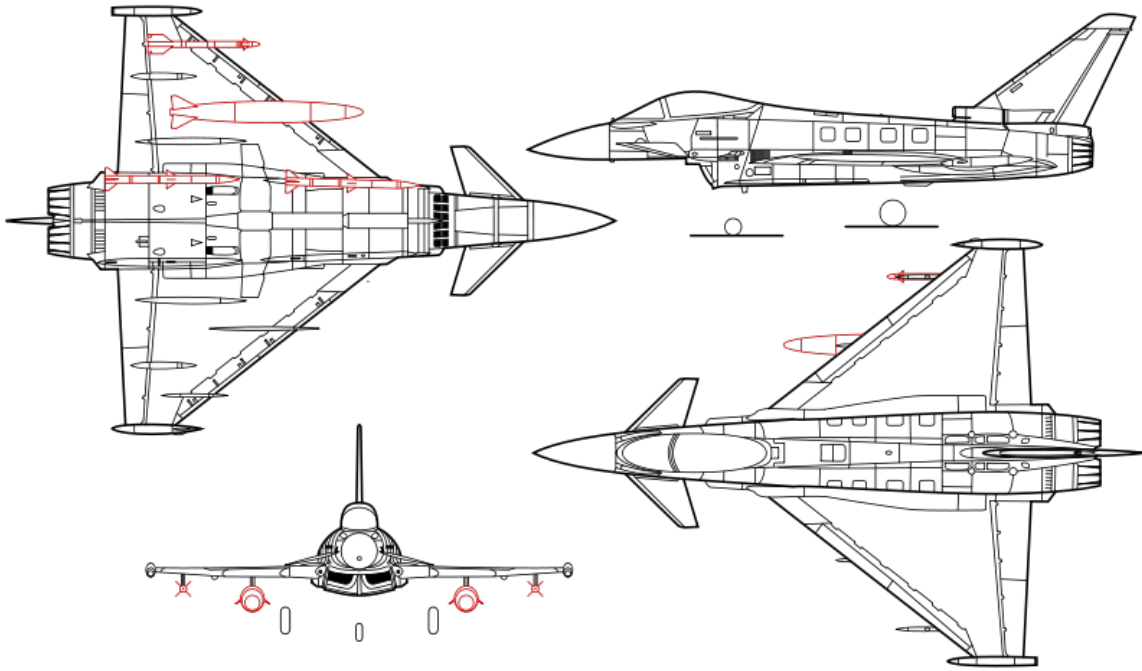
Accidents

- On 21 November 2002, the Spanish twin-seat Eurofighter prototype DA-6 crashed due to a double engine flame-out caused by surges of the two engines. The two crew members escaped unhurt.
- On 24 August 2010, a Eurofighter aircraft crashed at Spain's Morón air base moments after take-off for a routine training flight. It was being piloted by a lieutenant colonel from the Saudi Arabian air force, who was killed, and a Spanish air force commander, who ejected safely.

Aircraft on display

- Eurofighter DA-2 Typhoon (serial number ZH588) is on display at the Royal Air Force Museum London. This aircraft is one of seven EF 2000 development aircraft built by the Eurofighter Partner Companies, and was used for flight testing. The aircraft was delivered by road on 22 January 2008. Engineers from RAF Coningsby and RAF St. Athan assembled the aircraft for display. It is hanging in the Museum's Milestones of Flight Exhibition Hall.
- The first development aircraft Eurofighter DA-1 can be seen at the Deutsches Museum Flugwerft Schleissheim at Oberschleißheim Airport in the north of Munich. Its first flight took place in 1994 and it was handed over to the museum in 2008.
- In summer 2009 Eurofighter DA-4, serial number ZH590, went on display at Imperial War Museum Duxford, having been given to the museum by the Ministry of Defence in 2008. It is exhibited as part of the museum's 'AirSpace' gallery, as an example of the development of aircraft technology.

Specifications



EJ200 engine (foreground)



The aircraft's turbofan engine (front)

General characteristics

- **Crew:** 1 (operational aircraft) or 2 (training aircraft)
- **Length:** 15.96 m (52 ft 5 in)
- **Wingspan:** 10.95 m (35 ft 11 in)
- **Height:** 5.28 m (17 ft 4 in)
- **Wing area:** 51.2 m² (551 ft²)
- **Empty weight:** 11,150 kg (24,560 lb)
- **Loaded weight:** 16,000 kg (35,300 lb)
- **Max takeoff weight:** 23,500 kg (51,800 lb)
- **Powerplant:** 2× Eurojet EJ200 afterburning turbofan
 - **Dry thrust:** 60 kN (13,500 lb_f) each
 - **Thrust with afterburner:** 89 kN ref RR (20,000 lb_f) each
- **Fuel capacity:** 4,500 kg (9,920 lb) internal

Performance

- **Maximum speed:**
 - **At altitude:** Mach 2 (2,495 km/h, 1,550 mph)
 - **At sea level:** Mach 1.2 (1,470 km/h / 913.2 mph)

- **Supercruise:** Mach 1.1–1.5
- **Range:** 2,900 km (1,802 mi)
- **Combat radius:**
 - Ground attack, lo-lo-lo: 601 km (325 nmi)
 - Ground attack, hi-lo-hi: 1,389 km (750 nmi)
 - Air defence with 3-hr CAP: 185 km (100 nmi)
 - Air defence with 10-min loiter: 1,389 km (750 nmi)
- **Ferry range:** 3,790 km (2,300 mi)
- **Service ceiling:** 19,810 m (65,000 ft)
- **Rate of climb:** >315 m/s (62,000 ft/min)
- **Wing loading:** 312 kg/m² (64.0 lb/ft²)
- **Thrust/weight:** 1.15
- **g-Limits:** +9/-3 g



German Luftwaffe soldiers mount an IRIS-T to an Eurofighter

Armament

- **Guns:** 1 × 27 mm Mauser BK-27 Revolver cannon with 150 rounds
- **Hardpoints:** Total of 13: 8 × under-wing plus 5 × under-fuselage pylon stations holding up to 7,500 kg (16,500 lb) of payload
- **Missiles:**
 - **Air-to-air missiles:**

- AIM-9 Sidewinder, AIM-132 ASRAAM, AIM-120 AMRAAM, IRIS-T, and, in the future, MBDA Meteor
- **Air-to-surface missiles:**
 - AGM-65 Maverick, AGM-88 HARM, Storm Shadow (AKA *Scalp EG*), Brimstone, Taurus KEPD 350, Penguin and in the future AGM Armiger
- **Bombs:** Paveway II/III/Enhanced Paveway series of Laser-guided bombs (LGBs), Joint Direct Attack Munition (JDAM), HOPE/HOSBO
- **Others:**
 - Flares/infrared decoys dispenser pod and chaff pod *and*
 - Electronic countermeasures (ECM) pods
 - LITENING III laser targeting pod
 - Up to 3 drop tanks for ferry flight *or* extended range/loitering time.

Avionics

- Euroradar CAPTOR Radar
- Passive Infra-Red Airborne Tracking Equipment (PIRATE)

Chapter 8

Saab JAS 39 Gripen

JAS 39 Gripen



Role	Multirole fighter
Manufacturer	Saab AB
First flight	9 December 1988
Introduction	9 June 1996
Status	Active service
Primary users	Swedish Air Force Czech Air Force Hungarian Air Force South African Air Force
Number built	219 as of 2010
Unit cost	US\$40–61 million (export price VAT excluded)

The **Saab JAS 39 Gripen** (English: *Griffin*) is a lightweight single engine multirole fighter aircraft manufactured by the Swedish aerospace company Saab. Gripen International acts as a prime contracting organisation and is responsible for marketing, selling and supporting the Gripen fighter around the world.

The aircraft is in service with the Swedish Air Force, the Czech Air Force, the Hungarian Air Force, the South African Air Force, and the Royal Thai Air Force. A total of 236 Gripens have been ordered as of 2008.

Development

Origins

By the late 1970s a replacement for Sweden's aging Saab 35 Draken and Saab 37 Viggen was needed. A new fighter was being considered by 1979, with design studies beginning the following year. The development of the Gripen began in 1982 with approval from Swedish Parliament.

The Gripen was designed for performance, flexibility, effectiveness and survivability in air combat. The designation JAS stands for *Jakt* (Air-to-Air), *Attack* (Air-to-Surface), and *Spaning* (Reconnaissance), indicating that the Gripen is a multirole or swingrole fighter aircraft that can fulfill each mission type. The JAS 39 received the name Gripen through a public competition in 1982. The griffin is the heraldry on Saab's logo and suited the multirole characteristics of the aircraft.



Empire Test Pilots' School JAS 39B Gripen taxis after landing at RIAT 2008

Sweden chose to develop the Gripen rather than purchase a variant of the General Dynamics F-16 Fighting Falcon, McDonnell Douglas F/A-18A/B, or the "F-5S" version of the Northrop F-20 Tigershark. The first Gripen was rolled out on 26 April 1987, marking Saab's 50th anniversary. The first prototype first flew on 9 December 1988.

The final aircraft of the 64-jet Batch 3 contract was delivered to FMV on 26 November 2008. This was accomplished at a 10% less than the agreed-upon price for the whole batch, putting the JAS 39C flyaway cost at under US\$30 million. About 33% of the aircraft's content is sourced from the United States, with the other 67% split between Swedish and European suppliers.

Teaming agreements

In 1995, Saab Military Aircraft and British Aerospace or BAe (now BAE Systems) formed the joint venture company *Saab-BAe Gripen AB*, with the goal of adapting, manufacturing, marketing and supporting Gripen internationally. The deal was to take advantage of BAe's global marketing experience. BAe also saw the Gripen as a complementary product to its existing aircraft, fitting between its Hawk light attack/trainer and the larger Panavia Tornado and Eurofighter Typhoon fighters. This cooperation was extended in 2001 with the formation of Gripen International for the same purpose. In December 2004, Saab and BAE Systems agreed that from January 2005 Saab would take full responsibility for marketing of the Gripen in light of Saab's increased export marketing capabilities.

On 26 April 2007, Norway signed an agreement on a joint development programme of the aircraft regarding co-operation in advanced development work on future versions of the aircraft. The value of the deal, which will allow Norwegian companies to take part, is about NOK 150 million over two years.

In June 2007, Thales Norway A/S and Saab signed a contract concerning the development of communications systems for the Gripen fighter. This order for the Norwegian company is the first to be awarded under the provisions of the Letter of Agreement signed by the Norwegian Ministry of Defence and Gripen International in April 2007.

As part of Gripen International's marketing efforts in Denmark, a deal was signed in December 2007 with Danish technology supplier Terma A/S which allows them to participate in an industrial co-operation programme over the next 10–15 years. The total value of the programme is estimated at over 10 billion Danish krone, and is partly dependent on Denmark choosing the Gripen.

Gripen NG and recent developments



Saab Gripen NG demonstrator at RIAT 2010

A two-seat "New Technology Demonstrator" has been built, and was presented on 23 April 2008. It has increased fuel capacity, a more powerful powerplant, increased payload capacity, upgraded avionics and other improvements. The new Gripen NG (Next Generation) is also referred to as the "Gripen Demo", the "Gripen E/F", or MS 21.

The new Gripen NG has many new parts and is powered by the General Electric F414G, a development of the F/A-18E/F Super Hornet's engine. The engine produces 20% more thrust at 98 kN (22,000 lbf), enabling a supercruise speed of Mach 1.1 with air-to-air missiles.

Compared to the Gripen D, the Gripen NG's max takeoff weight has increased from 14,000 to 16,000 kg (30,900–35,300 lb) with an increase in empty weight of 200 kg (440 lb). Due to relocated main landing gear, the internal fuel capacity has increased by 40%, with a significant increase in range. Combat radius will be 1300 km with six AAMs + drop tanks, and 30 min on station. Ferry range will be 4,070 km (2,200 nmi) with drop tanks. The new undercarriage configuration also allows for the addition of two heavy stores pylons to the fuselage. Its PS-05/A radar adds a new AESA antenna for flight testing beginning in mid-2009.

Gripen Demo's maiden flight was conducted on 27 May 2008. The test flight lasted about 30 minutes and reached a maximum altitude of about 6,400 meters (21,000 ft). On 21 January 2009, the Gripen Demo flew at Mach 1.2 without reheat to test its supercruise capability.

Saab performed study work on an aircraft carrier based version in the 1990s. In 2009, Saab launched the Sea Gripen project in response to India's request for information on a carrier-borne aircraft. Brazil also has a potential carrier aircraft need. Sweden awarded Saab a four-year contract in 2010 to improve the Gripen's radar and other equipment, and lower its operating costs. In June 2010, Saab stated that Sweden plans to order the Gripen NG under the JAS 39E/F designation. The new variant is to enter Swedish service in 2017 or possibly earlier if export orders are received. The Swedish MS21 (Gripen E/F) project depends on both the results of the Indian MRCA competition and the Brazilian F-X2 competition, as well as the progress on the Swedish MS20 Gripen update programme. The Swedish MS20 project is to modernize all the Gripens in the Swedish Air Force mainly with the long-range MBDA Meteor missile and the short-range IRIS-T missile. This is to be made no later than 2014.

Design

Overview



Farnborough Airshow 2006

In designing the aircraft, several layouts were studied. Saab ultimately selected a canard design with relaxed stability. The canard configuration gives a high onset of pitch rate and low drag, enabling the aircraft to be faster, have longer range and carry a larger payload.

The combination of delta wing and canards gives the Gripen significantly better takeoff and landing performance and flying characteristics. The totally integrated avionics make it a "programmable" aircraft. It also has a built-in electronic warfare unit, making it

possible to load more ordnance onto the aircraft without losing self defence capabilities. The 300-link is used to share data between fighters.

The Gripen affords more flexibility than earlier generations of combat aircraft used by Sweden, and its operating costs are about two thirds of those for JA 37 Viggen.

In the Swedish Air Force's list of requirements was the ability to operate from 800 m runways. Early on in the programme, all flights from Saab's facility in Linköping were flown from within a 9 m × 800 m outline painted on the runway. Stopping distance was reduced by extending the relatively large air brakes; using the control surfaces to push the aircraft down, enabling the wheel brakes to apply more force and tilting the canards downwards, making them into large air brakes and further pushing the aircraft down. In reality Gripen needs little more than half the specified take off and stopping distance.

Radar

The Gripen uses the modern PS-05/A pulse-doppler X-band radar, developed by Ericsson and GEC-Marconi, and based on the latter's advanced Blue Vixen radar for the Sea Harrier (which inspired the Eurofighter's CAPTOR radar as well).

The radar is capable of detecting, locating, identifying and automatically tracking multiple targets in the upper and lower spheres, on the ground and sea or in the air, in all weather conditions. It can guide four air to air missiles (e.g. AIM-120 AMRAAM, MBDA MICA) simultaneously at four different targets.

On 27 March 2009, Saab and Selex Galileo signed an agreement for joint development of the *Raven* AESA radar based on Selex Galileo's AESA Vixen and PS-05/A. This radar will be able to scan 200 degrees, from slightly behind to the left to slightly behind to the right.

On 9 September 2009, Gripen International offered the source code of their AESA radar as part of their bid for India's fighter competition.

Cockpit

The cockpit has three full colour head down displays and digital emergency instrument presentation unique to the aircraft. The cockpit layout provides a human-machine interface that eases pilot workload substantially and increases situational awareness, but still provides substantial future growth potential. The pilot flies the aircraft by means of a centre stick and left hand throttles.

The cockpit provides a display area some 30 percent larger than that available in most other fighters, with the multi-function displays taking up around 75 percent of available space.

It is dominated by three large (15.7 x 21 cm) active-matrix, liquid crystal, multi-function displays and a wide angle (20 x 28 degree) head-up display (HUD). The displays are equipped with light sensors for computer assisted brightness and contrast control.

Expeditionary capabilities

One interesting feature is the Gripen's ability to take off and land on public roads, which was part of Sweden's war defence strategy. The aircraft is designed to be able to operate even if the air force does not have air superiority.

During the Cold War, the Swedish Armed Forces were preparing to defend against a possible invasion from the Soviet Union. Even though the defensive strategy in principle called for an absolute defence of Swedish territory, military planners calculated that Swedish defence forces could eventually be overrun. For that reason, Sweden had military stores dispersed all over the country, in order to maintain the capacity of inflicting damage on the enemy even if military installations were lost.

Accordingly, among the requirements from the Swedish Air Force was that the Gripen fighter should be able to land on public roads near military stores for quick maintenance, and take off again. As a result, the Gripen fighter can be refueled and re-armed in ten minutes by a five man mobile ground crew operating out of a truck, and then resume flying sorties.

In the post-Cold War era, these dispersed operation capabilities have proved to be of great value for a different purpose. The Gripen fighter system is expeditionary in nature, and therefore well suited for peace-keeping missions worldwide, which has become the new main task of the Swedish Armed Forces.

Operational history

Current operators



Gripen taking off



Gripen in flight



Saab JAS 39 Gripen of the Czech Air Force



Hungarian Air Force Saab JAS39D Gripen at RIAT 2009

The Gripen is in operational service with the Swedish Air Force, which has ordered 204 aircraft (including 28 two-seaters).

The Czech Air Force and the Hungarian Air Force also operate the Gripen, and currently lease 14 Swedish Air Force aircraft each, with the option of eventually acquiring them. In both cases two of the aircraft are two-seaters. The Czech and the Hungarian Air Force are the first Gripen operators within NATO. One of the design modifications required in order to make it NATO compatible was the ability to undertake aerial refuelling. The Gripen refuelling trials was the first time a NATO tanker had refuelled a Swedish fighter.

Deliveries to the South African Air Force (26 aircraft, including nine two-seaters) commenced in April 2008, and are ongoing. As of June 2010, 15 aircraft, nine two-seater aircraft and six single-seaters have been delivered.

The Royal Thai Air Force has ordered 12 JAS 39 Gripens (8 single-seat JAS 39C and 4 four JAS 39D two-seaters). The first 6 aircraft were delivered on 22 February 2011. The order for the last 6 JAS 39C Gripens was finalized in November 2010.

The Empire Test Pilots' School (ETPS) in the United Kingdom uses the Gripen as its advanced fast jet platform for training test pilots from around the world.

Potential and future operators

Brazil

In October 2008, it was reported that the Brazilian Air Force had selected three finalists in their F-X2 program. They are Dassault Rafale, Boeing F/A-18E/F Super Hornet and Gripen NG. The number of aircraft involved is 36 and possibly up to 120 later. The decision was expected on 2 October 2009. On 2 February 2009, Saab submitted a tender for 36 Gripen NGs to the Brazilian Air Force Command. On 5 January 2010, it was reported in the media that the final evaluation report by the Brazilian Air Force placed the Gripen ahead of the other two contenders. The decisive factor was apparently the overall cost of the new fighters, both in terms of unit cost, and operating and maintenance costs. It appears that Brazil is likely to buy the Rafale offering, subject to the outcome of a legal challenge.

Croatia

The Croatian Air Force had announced plans to replace their MiG-21 bis aircraft, possibly with either the JAS 39 Gripen or the F-16 Falcon. The final projection calls for 12-18 aircraft. On 27 March 2008, the Swedish Defence Material Administration and Saab responded to Croatia's request for information regarding the procurement of 12 aircraft. Due to economic and political reasons, the Croatian Air Force postponed the decision and is now looking at a possible joint purchase with Slovenia of 12 aircraft.

Denmark

Denmark has signed a Memorandum of Understanding between the Defence Ministers of Sweden and Denmark to evaluate the Gripen, pending Denmark's future replacement of their fleet of 48 F-16s. Denmark has also requested new variants of Gripens to be developed that will include new avionics, a larger and more powerful engine, larger payload and, most importantly, longer range. This request was the basis for the Gripen NG, which satisfies all Denmark's requirements, such as the more powerful F414G engine.

On 24 March 2010, the Danish Ministry of Defence decided to postpone the decision on which fighter to buy until 2010–2014.

India

The Gripen is a contender in the Indian MRCA competition for 126 multi-role combat aircraft. Gripen International handed over its proposal on 28 April 2008. The company is offering the Gripen IN, a version of the Gripen NG for India's tender, and has opened an office in New Delhi in order to support its efforts in the Indian market. On 4 February 2009, it was announced that Saab had partnered with the Indian Tata Group to develop a new Gripen variant to fit India's needs. The Indian Air Force was rumored to have narrowed the choices to the Eurofighter and the Rafale, implying the exit of the MiG-35, F-16IN, F/A-18E/F and Gripen. Since then the IAF has reconfirmed that all six aircraft

remain in the competition. Senior IAF officers, while happy with Gripen NG's features, also highlight the Gripen NG's downside: a high level of US electronics, weaponry, and the GE F414 engine, which combine for one-third of the entire aircraft.

Netherlands

On 7 July 2008 *Dagens Industri* reported that the Netherlands announced they will evaluate Gripen NG together with four other competitors and announce the result in the end of 2008. Saab responded on 25 August 2008 to a 'Replacement Questionnaire' issued by the Dutch Ministry of Defence, offering 85 aircraft to the Royal Netherlands Air Force. The Netherlands evaluated the Gripen NG against the F-35. On 18 December 2008 media reported that the Netherlands evaluated the F-35 ahead of the Gripen NG, citing better performance and lower price. On 13 January 2009, *NRC Handelsblad* claimed that, according to Swedish sources, Saab has made an offer to the Dutch to deliver 85 Gripens for 4.8 billion euro, about 1 billion euro cheaper than budgeted for the F-35. This price includes training of pilots and maintenance for the next 30 years.

Switzerland

On 17 January 2008 the Swiss Defence Material Administration invited Gripen International to submit initial bids for supplying the Gripen as a replacement for their old F-5s. Saab responded with a proposal on 2 July 2008. The exact number of aircraft has not been disclosed.

Others

Bulgaria announced that they are to replace their aging Mikoyan MiG-21s with possible 16 JAS 39C/D Gripens, or 16 used F-16s.

Serbian officials are currently {{when}} debating on which fighter aircraft will replace the aging MiG-21 fighters in 2010. 24 aircraft are sought and the JAS 39 Gripen is one option.

Other nations that are showing interest in the Gripen include Slovakia and Oman.

Missed contracts

Finland

In 1989 the Finnish Air Force began to look for a new fighter to replace its fleet of MiG-21s and Saab 35 Drakens. During 1991 and 1992, the Dassault Mirage 2000, Gripen, F-16, MiG-29 and F/A-18 Hornet were evaluated. On 6 May 1992, the Hornet was announced as the winner of the fighter competition and a total of 64 aircraft were ordered.

Norway

On 18 January 2008, the Norwegian Ministry of Defence issued a Request for Binding Information (RBI) to the Swedish Defence Material Administration, who responded on 28 April 2008 with a proposal offering 48 aircraft. The rival Lockheed Martin proposal amassed US diplomatic and political support. On 20 November 2008, the Norwegian government released a statement that they have selected the F-35 Lightning II for the Royal Norwegian Air Force. Norway stated the F-35 is the only fighter candidate to meet all of its operational requirements. Saab has criticized the selection, stating that there were flaws in Norway's cost calculations for the Gripen NG.

On 10 February 2009, Swedish defence minister Sten Tolgfors stated that Norway had miscalculated the deal. The offer was for 48 aircraft over 20 years, but Norway had extrapolated it to operating 57 aircraft over 30 years, thus doubling the cost. The Swedish Ministry of Defence has several other objections to Norway's calculations. Among other things, Norway projected the operational costs for their F-16s on both candidates, and did not consider the operational costs of Sweden's Gripens. Norway also calculated with more aircraft losses in accidents than what Sweden considers reasonable based on their operational experience of the type. According to Tolgfors, Norway's decision will make it more difficult to sell the Gripen to other countries. Tolgfors said that the Gripen does not meet the requirements set by the Norwegian government, though some media reports claim those requirements are tilted in favour of the F-35.

Romania

The Romanian Air Force announced they would replace their MiG-21 LanceR aircraft beginning in 2008, possibly with JAS 39 Gripen, F-16 Fighting Falcon or Eurofighter Typhoon. On 23 March 2010, the Romanian Ministry of Defence decided to purchase 24 second hand F-16s.

Variants



JAS 39 Gripen taxiing in after display, Farnborough 2006

JAS 39A

Fighter version that first entered service with the Swedish Air Force in 1996. A modification program has started and 31 of these will be upgraded to C/D standard.

JAS 39B

Two-seat version of the A variant. This variant is 0.9 meter (2 ft 2 in) longer than the single seat version.

JAS 39C

NATO-compatible version of Gripen with extended capabilities in terms of armament, electronics, etc. This variant can also be refueled in flight.

JAS 39D

Two-seat version of the C variant.

Gripen Demo

A two-seat technology demonstrator for improvements slated for the Gripen NG.

Gripen NG/IN

(Next Generation) Proposed version with new engine (F414G), increased fuel capacity, higher payload, upgraded avionics and other improvements. The Gripen IN version is a contender for the Indian MRCA competition.

Sea Gripen

Proposed carrier-based version based on the NG/IN version.

Operators



Gripen users 2010 in blue, orders in green



JAS 39 Gripen of the Hungarian Air Force, Kecskemét open day 2007

There were 155 Gripens in service in January 2010.

Czech Republic

Czech Air Force has 14 Gripens on lease, including 2 two-seaters, with all in operation as of January 2010.

 Hungary

Hungarian Air Force has 14 Gripens on a lease-and-buy arrangement, including 2 two-seaters (C/D versions). The final 3 aircraft were delivered in December 2007.

 South Africa

South African Air Force ordered 26 aircraft (down from 28), 9 two-seater D-models and 17 single seat C-models. The first delivery, a two-seater, took place on 30 April 2008. The South African Air Force has 9 two-seaters and 6 single-seaters in inventory as of June 2010.

 Sweden

Swedish Air Force: 204 aircraft originally ordered, including 28 two-seaters (121 in service). Sweden leases 28 of the aircraft, including 4 two-seaters, to the Czech and Hungarian Air Forces. In 2007 the Swedish government decided that the future Swedish Air Force will deploy no more than 100 JAS 39C/D Gripen fighters. A program to upgrade 31 of the air force's JAS 39A/B fighters to JAS 39C/Ds was started. The SAF has 121 JAS 39s, including 53 JAS 39As, 10 JAS 39Bs, 45 JAS 39Cs and 13 JAS 39D in service in January 2010.

 Thailand

The Royal Thai Air Force ordered 6 Gripens (2 single-seat C-models and 4 two-seat D-models) in February 2008, with deliveries to begin in 2011. 6 more Gripen Cs were ordered in November 2010. The Gripens take the place of retiring F-5B/Es and be based at Surat Thani Airbase.

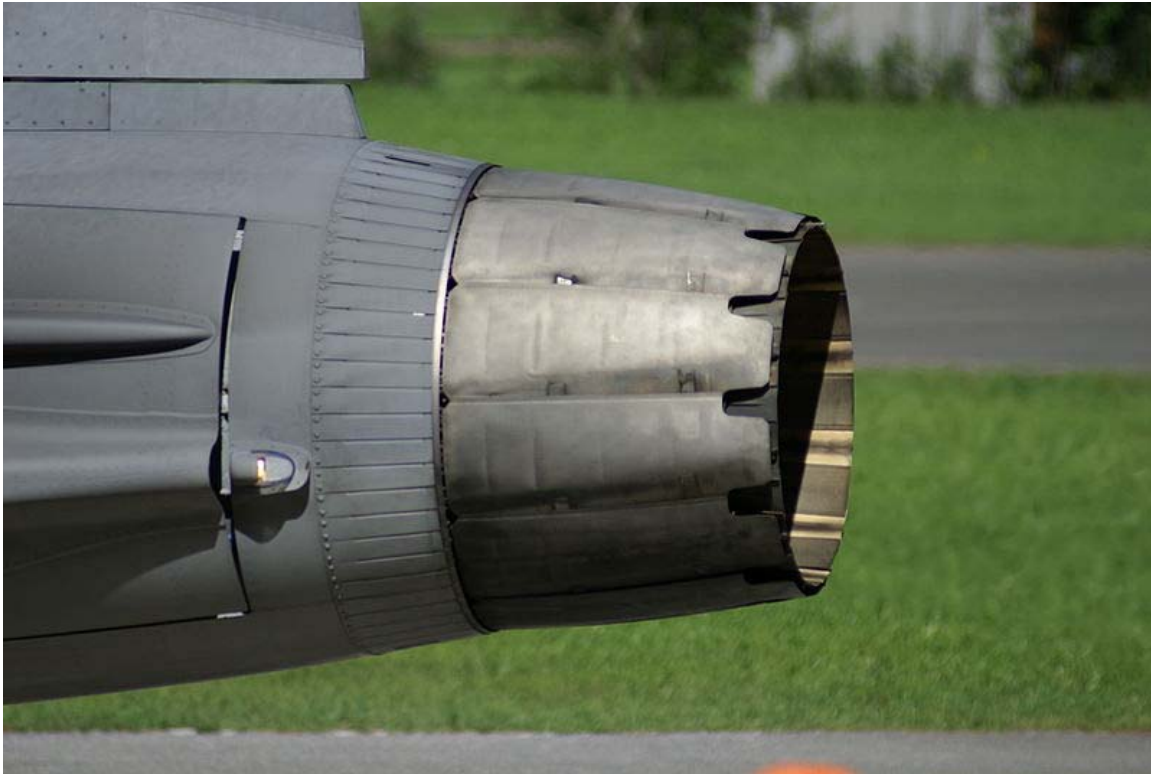
 United Kingdom

Empire Test Pilots' School: Under the agreement, ETPS instructor pilots and students undergo simulator training with the Swedish Air Force, and go on to fly the two-seater Gripen at Saab in Linköping, in two training campaigns per year (spring and autumn). The agreement was renewed in 2008.

Incidents

Six Gripens have crashed causing only minor injuries; one prototype, one production aircraft and four in service with the Swedish Air Force.

Specifications (JAS 39 Gripen C/D)



Gripen engine nozzle

General characteristics

- **Crew:** 1 (2 for JAS 39D)
- **Payload:** 5,300 kg ()
- **Length:** 14.1 m (46 ft 3 in)
- **Wingspan:** 8.4 m (27 ft 7 in)
- **Height:** 4.5 m (14 ft 9 in)
- **Wing area:** 30.0 m² (323 ft²)
- **Empty weight:** 6,800 kg (12,600 lb)
- **Loaded weight:** 8,500 kg (18,700 lb)
- **Max takeoff weight:** 14,000 kg (31,000 lb)
- **Powerplant:** 1× Volvo Aero RM12 afterburning turbofan
 - **Dry thrust:** 54 kN (12,100 lbf)
 - **Thrust with afterburner:** 80.5 kN (18,100 lbf)
- **Wheel track:** 2.4 m (7 ft 10 in)
- **Length (two-seater):** 14.8 m (48 ft 5 in)

Performance

- **Maximum speed:** Mach 2 (2,204 km/h, 1,372 mph)
- **Combat radius:** 800 km (500 mi, 432 nmi)

- **Ferry range:** 3,200 km (2,000 mi) with drop tanks
- **Service ceiling:** 15,240 m (50,000 ft)
- **Wing loading:** 283 kg/m² (58 lb/ft²)
- **Thrust/weight:** 0.97

Armament

- **Hardpoints:** 8 (three on each wing and two under fuselage) and provisions to carry combinations of:
 - **Rockets:** 4× rocket pods 13.5 cm rockets
 - **Missiles:**
 - 6× Rb.74 (AIM-9) or Rb 98 (IRIS-T)
 - 4× Rb.99 (AIM-120) or MICA
 - 4× Rb.71 (Skyflash) or Meteor
 - 4× Rb.75
 - 2× KEPD.350
 - 2× Rbs.15F anti-ship missile
 - **Bombs:**
 - 4× GBU-12 Paveway II laser-guided bomb
 - 2× Bk.90 cluster bomb
 - 8× Mark 82 bombs

Chapter 9

Piaggio P.180 Avanti

P180 Avanti



Aeronautica Militare Piaggio P180 Avanti

Role	Executive transport
Manufacturer	Piaggio Aero
First flight	26 September 1986
Primary users	Italian Armed Force Avantair
Number built	203 delivered to September 2010
Unit cost	US\$ 7 million

The **Piaggio P180 Avanti** is an Italian twin-engine turboprop aircraft produced by Piaggio Aero. It seats up to nine passengers in a pressurized cabin, and may be flown by one or two pilots.

The innovative design places the main wing behind and above the canard-like horizontal stabiliser, features a laminar flow fuselage and has engines in pusher configuration.

Development



Cockpit and instrument panel aboard a P180 Avanti

The P180 design was tested in wind tunnels in Italy and the U.S. in 1980 and 1981. A collaboration with Learjet to develop the aircraft began in 1983 but ended on 13 January 1986, with Piaggio continuing development on its own. The first prototype flew on 23 September 1986. U.S. and Italian certification was obtained on 7 March 1990. Learjet's influence can be seen in the two "delta fins" mounted on the bottom of the tail, as found on most Learjets; these devices provide aerodynamic recovery force in the event of an aerodynamic stall. The first 12 fuselages were manufactured in Wichita, with H & H Parts and Plessey Midwest, then flown to Italy for final assembly. Avanti Aviation Wichita ran out of money in 1994; the project languished until a group of investors led by Piero Ferrari became involved in 1998. The 100th aircraft was delivered in October 2005 and the 150th in May 2008. Piaggio has reported that as of October 2010, the Avanti and Avanti II fleets have now logged over 500,000 flight hours.

An improved **Avanti II** obtained European and U.S. certification in November 2005. Six months later, 70 planes were already ordered, including 36 by Avantair. The Avanti II features uprated Pratt & Whitney Canada PT6 turboprop engines and flies about 18 km/h (11 mph) faster, with better fuel economy; an all-new "glass panel" avionics suite reduces cockpit clutter. In addition to heading, attitude and navigation information, flat panel color LCD displays add collision avoidance (TCAS), ground proximity (TAWS) and real-time graphic weather depiction.

Design

The Avanti's turboprop engines are placed on a mid-fuselage, high aspect ratio wing, located behind the cabin. The design utilizes both a T-tail and a pair of small, fixed anhedral forward wings that lack control surfaces. The arrangement of the wing surfaces allows all three to provide lift, as opposed to a conventional configuration, where the horizontal stabilizer creates a downward force to counteract the nose-down moment generated by the center of gravity being forward of the center of lift. This is patented as "Three-Lifting-Surface Configuration" (3LSC). The Avanti II's forward wing has flaps that move in concert with main wing flaps. The forward wing pitch angle is set so it stalls before the main wing, producing an automatic nose-down effect; its five degree negative dihedral keeps the stream wash interference clear of the engine inlets, the main wing and the horizontal stabilizer

Distinctive design features include a non-constant cross section cabin, the revolutionary shape of which approximates a NACA airfoil section. Piaggio claims the fuselage contributes up to 20% of the Avanti's total lift, with horizontal stabilizer, front and rear wing providing the remaining 80%. Because of the unusual fuselage shape, the mid cabin is considerably wider than the cockpit, and the entire cabin is ahead of the main wing spar. The front and rear airfoils are custom sections designed by Dr. Jerry Gregorek of The Ohio State University's AARL to achieve a drag-reducing 50% laminar flow at cruise.

The company claims the overall design of the P180 Avanti II enables the wing to be 34% smaller than on conventional aircraft and a specific range of 0.84 nmi/lb of fuel. This is significantly better than the 0.31-0.48 nmi/pound of similar small jets.

The P180 makes a distinctive square wave noise when passing overhead, similar to the Beech Starship, due to the wing wake and engine exhaust effects on the pusher propellers.

Variants



Aeronautica Militare P180 Avanti

P.180 Avanti

First production variant.

P180 M

Military version with a combination passenger/freighter configuration for use as a VIP and light utility transport.

P.180 RM

Variant for use in radio calibration.

P.180 AMB

Air ambulance variant.

P.180 APH

Aerial cartography.

P.180 Avanti II

Variant with improved avionics.

Operators



Avanti belonging to Vigili del Fuoco, Rome-Ciampino



Avanti parked on tarmac



Avanti at Colorado Springs Municipal Airport

Civil

Bangladesh

- Youngone - 1

Canada

- Avmax International Aircraft - 3
- Bell Aliant - 1
- Cascades Inc. - 2
- Skyservice Business Aviation - 2
- Royal Canadian Mounted Police - 1
- Starlink Aviation - 1

Czech Republic

- Icarus Aviation Group - 1

France

- Brittany Ferries - 1
- Pan Européenne Air Service - 1
- Transport'Air - 4

Indonesia

- Susi Air - 2

India

- TajAir - 1

Italy

- Blue Panorama Airlines - 2
- Eurofly Service - 1
- Protezione Civile
- State Forestry Corps - 1
- State Police - 1
- Vigili del Fuoco - 2
- Windjet - 2

Jordan

- Saraya Skies - 3 (3 others in option)

 Mexico

- Republicair

 Poland

- Lotnicze Pogotowie Ratunkowe (Polish Medical Air Rescue) - 2

 Netherlands

- JetNetherlands - 1
- Solid Air - 1

 United States

- Avantair - 56 aircraft ordered
- Mountain Aviation - 1

Military

 Italy

- Italian Air Force
- Italian Army
- Italian Navy

 United Arab Emirates

- United Arab Emirates Air Force ordered two aircraft at the 2009 Paris Air Show.

Specifications (P180 Avanti)

Data from Brassey's World Aircraft & Systems Directory 1999-2000

General characteristics

- **Crew:** one or two pilots
- **Capacity:** up to nine passengers
- **Cabin dimensions:** 1.75 m (5 ft 9 in) high, 1.85 m (6 ft 1 in) wide, 4.45 m (14 ft 7 in) long
- **Payload:** 907 kg (2,000 lb)
- **Length:** 14.41 m (47 ft 3½ in)
- **Wingspan:** 14.03 m (46 ft 0½ in)
- **Height:** 3.97 m (13 ft 0¾ in)
- **Wing area:** 16 m² (172.2 ft²)
- **Empty weight:** 3,400 kg (7,500 lb)
- **Useful load:** 1,860 kg (4,100 lb)

- **Max takeoff weight:** 5,239 kg (11,550 lb)
- **Powerplant:** 2× Pratt & Whitney Canada PT6A-66 turboprops, 634 kW (850 shp) each

Performance

- **Maximum speed:** 732 km/h (395 kn, 455 mph)
- **Cruise speed:** 593 km/h (320 kn, 368 mph) (econ cruise)
- **Range:** 2,592 km (1,400 nmi, 1,612 mi) at 11,900 m (39,000 ft) with reserves
- **Service ceiling:** 12,500 m (41,000 ft)
- **Rate of climb:** 14.98 m/s (2,950 ft/min)
- **Wing loading:** 327 kg/m² (67.1 lb/ft²)
- **Power/mass:** 0.24 kW/kg (6.79 lb/hp)

Chapter 10

Bell X-1

X-1



X-1 #46-062, nicknamed "Glamorous Glennis"

Role	rocket plane, Experimental Aircraft
Manufacturer	Bell Aircraft
First flight	19 January 1946
Status	Retired
Primary users	United States Air Force National Advisory Committee for Aeronautics

The **Bell X-1**, originally designated **XS-1**, was a joint NACA-U.S. Army/US Air Force supersonic research project built by Bell Aircraft. It was the first aircraft to exceed the speed of sound in controlled, level flight, and was the first of the so-called X-planes, an American series of experimental aircraft designated for testing of new technologies and usually kept highly secret.

Design and development



Chuck Yeager in front of the X-1, which he named *Glamorous Glennis* after his wife



XLR-11 rocket engine

On 16 March 1945, the United States Army Air Forces' Flight Test Division and the National Advisory Committee for Aeronautics (NACA) (now NASA) contracted Bell Aircraft to build three XS-1 (for "Experimental, Supersonic", later X-1) aircraft to obtain flight data on conditions in the transonic speed range.

The X-1 was in principle a "bullet with wings", its shape closely resembled the Browning .50-caliber (12.7 mm) machine gun bullet that was known to be stable in supersonic flight. The pattern shape was followed to the point of seating the pilot behind a sloped, framed window inside a confined cockpit in the nose, with no ejection seat. After the aircraft ran into compressibility problems in 1947, it was modified to feature a variable-incidence tailplane. An all-moving tail was developed by the British for the Miles M.52,

and first saw actual transonic flight on the Bell X-1 that allowed it to pass through the sound barrier safely.

The rocket propulsion system was a four-chamber engine built by Reaction Motors, Inc., one of the first companies to build liquid-propellant rocket engines in America. It burned ethyl alcohol diluted with water and liquid oxygen. The thrust could be changed in 1,500 lbf (6,700 N) increments by firing one or more of the chambers. The fuel and oxygen tanks for the first two X-1 engines were pressurized with nitrogen and the rest with steam-driven turbopumps. The all-important fuel turbopumps, necessary to raise the chamber pressure and thrust, while lightening the engine, were built by Robert Goddard who was under Navy contract to provide jet-assisted takeoff rockets.

Operational history

Bell Aircraft Chief Test Pilot, Jack Woolams became the first to fly the XS-1, in a glide flight over Pinecastle Army Airfield, in Florida, on 25 January 1946. Woolams would complete nine additional glide flights over Pinecastle before March 1946, when the #1 aircraft was returned to Bell for modifications in anticipation of the powered flight tests, planned for Muroc Army Air Field (now Edwards Air Force Base) in California. Following Woolams' death on 30 August 1946, Chalmers "Slick" Goodlin was the primary Bell Aircraft test pilot of X-1-1 (serial 46-062). He made 26 successful flights in both of the X-1 aircraft from September 1946 until June 1947.

The Army Air Force was unhappy with the cautious pace of flight envelope expansion and Bell Aircraft's flight test contract for aircraft #46-062 was terminated and was taken over by the Army Air Force Flight Test Division on 24 June after months of negotiation. Goodlin had demanded a US\$150,000 bonus for breaking the sound barrier. Flight tests of the X-1-2 (serial 46-063) would be conducted by NACA to provide design data for later production high-performance aircraft.

On 14 October 1947, just under a month after the United States Air Force had been created as a separate service, the tests culminated in the first manned supersonic flight, piloted by Air Force Captain Charles "Chuck" Yeager in aircraft #46-062, which he had christened *Glamorous Glennis* after his wife. The rocket-powered aircraft was launched from the bomb bay of a specially modified B-29 and glided to a landing on a runway. XS-1 flight number 50 is the first one where the X-1 recorded supersonic flight, at Mach 1.06 (361 m/s, 1,299 km/h, 807.2 mph) peak speed.

As a result of the X-1's initial supersonic flight, the National Aeronautics Association voted its 1948 Collier Trophy to be shared by the three main participants in the program. Honored at the White House by President Harry S. Truman were Larry Bell for Bell Aircraft, Captain Yeager for piloting the flights, and John Stack for the NACA contributions.

On 5 January 1949, Yeager used Aircraft #46-062 to carry out the only conventional (runway) take off performed during the X-1 program, reaching 23,000 ft (7,000 m) in 90 seconds.

Legacy

The research techniques used in the X-1 program became the pattern for all subsequent X-craft projects. The NACA X-1 procedures and personnel also helped lay the foundation of America's space program in the 1960s. The X-1 project defined and solidified the post-war cooperative union between U.S. military needs, industrial capabilities, and research facilities. The flight data collected by the NACA in the X-1 tests then provided a basis for American aviation supremacy in the latter half of the 20th century.

Disposition



X-1 at the Smithsonian

Aircraft #46-062 is currently on display in the Milestones of Flight gallery of the National Air and Space Museum in Washington, DC, alongside the Spirit of St. Louis and SpaceShipOne. Aircraft #46-063, now the X-1E, is on display in front of the NASA Dryden Flight Research Center headquarters building.

Variants

Later variants of the X-1 were built to test different aspects of supersonic flight; one of these, the X-1A, with Yeager at the controls, inadvertently demonstrated a very dangerous characteristic of fast (Mach 2 plus) supersonic flight: inertia coupling. Only Yeager's skills as an aviator prevented him from dying that day; later Mel Apt would die testing the Bell X-2 under similar circumstances.

X-1A



X-1A

Ordered by the Air Force on 2 April 1948, the **X-1A** (serial 48-1384) was intended to investigate aerodynamic phenomena at speeds above Mach 2 (681 m/s, 2,451 km/h) and altitudes greater than 90,000 ft (27 km), specifically focusing on dynamic stability and air loads. Longer and heavier than the original X-1, with a bubble canopy for better vision, the X-1A was powered by the same Reaction Motors XLR-11 rocket engine. The aircraft first flew, unpowered, on 14 February 1953 at Edwards AFB, with the first powered flight on 21 February. Both flights were piloted by Bell test pilot Jean "Skip" Ziegler.

After NACA started its high-speed testing with the Douglas Skyrocket, culminating in Scott Crossfield achieving Mach 2.005 on 20 November 1953, the Air Force started a

series of tests with the X-1A, which the test pilot of the series, Chuck Yeager, named "Operation NACA Weep". These culminated on 12 December 1953, when Yeager achieved an altitude of 74,700 feet (22,770 m) and a new air speed record of Mach 2.44 (equal to 1620 mph, 724.5 m/s, 2608 km/h at that altitude). Unlike Crossfield in the Skyrocket, Yeager achieved that in level flight. Shortly after, the aircraft spun out of control, due to the then not yet understood phenomenon of inertia coupling. The X-1A dropped from maximum altitude to 25,000 feet (7,620 m), exposing the pilot to accelerations of up to 8g, during which Yeager broke the canopy with his helmet before regaining control.

The aircraft was transferred to NACA in September 1954. Following modifications, including the installation of an ejection seat, the aircraft was lost on 8 August 1955 while being prepared for launch from the RB-50 mothership, becoming the first of many early X-planes that would be lost to explosions.

X-1B

The **X-1B** (serial 48-1385) was equipped with aerodynamic heating instrumentation for thermal research (over 300 thermal probes were installed on its surface). It was similar to the X-1A except for having a slightly different wing. The X-1B was used for high speed research by the US Air Force starting from October 1954 prior to being turned over to the NACA in January 1955. NACA continued to fly the aircraft until January 1958 when cracks in the fuel tanks forced its grounding. The X-1B completed a total of 27 flights. A notable achievement was the installation of a system of small reaction rockets used for directional control, making the X-1B the first aircraft to fly with this sophisticated control system, later used in the X-15. The X-1B is now at the National Museum of the United States Air Force, Wright-Patterson Air Force Base at Dayton, Ohio, where it is displayed in the Museum's Research & Development Hangar.

X-1C

The **X-1C** (serial 48-1387) was intended to test armaments and munitions in the high transonic and supersonic flight regimes. It was canceled while still in the mock-up stage, as the birth of transonic and supersonic-capable aircraft like the North American F-86 Sabre and the North American F-100 Super Sabre eliminated the need for a dedicated experimental test platform.

X-1D

The **X-1D** (serial 48-1386) was the first of the second generation of supersonic rocket planes. Flown from an EB-50A (s/n #46-006), it was to be used for heat transfer research. The X-1D was equipped with a new low-pressure fuel system and a slightly increased fuel capacity. There were also some minor changes to the avionics set.

On 24 July 1951, with Bell test pilot Jean "Skip" Ziegler at the controls, the X-1D was launched over Rogers Dry Lake, on what was to become the only successful flight of its

career. The unpowered glide was completed after a nine-minute descent, but upon landing, the nose gear failed and the aircraft slid ungracefully to a stop. Repairs took several weeks to complete and a second flight was scheduled for mid-August. On 22 August 1951, the X-1D was lost in a fuel explosion during preparations for the first powered flight. The aircraft was destroyed upon impact after it was jettisoned from its EB-50A mothership.

X-1E



Bell X-1-3, aircraft #46-064, being mated to the B-50 mothership for a captive flight test on 9 November 1951. While being de-fueled after this flight it exploded, destroying itself and the B-50, and seriously burning Joe Cannon. X-1-3 had only completed a single glide flight on 20 July.

The **X-1E** was the result of a reconstruction of the X-1-2 (serial 46-063), in order to pursue the goals originally set out for the X-1D and X-1-3 (serial 46-064), both lost in explosions in 1951. The cause of the mysterious explosions was finally traced to the use of Ulmer leather gaskets impregnated with tricresyl phosphate (TCP), a leather treatment, which was used in the liquid oxygen plumbing. TCP becomes unstable and explosive in the presence of pure oxygen and mechanical shock. This mistake cost two lives, caused injuries and lost several aircraft.



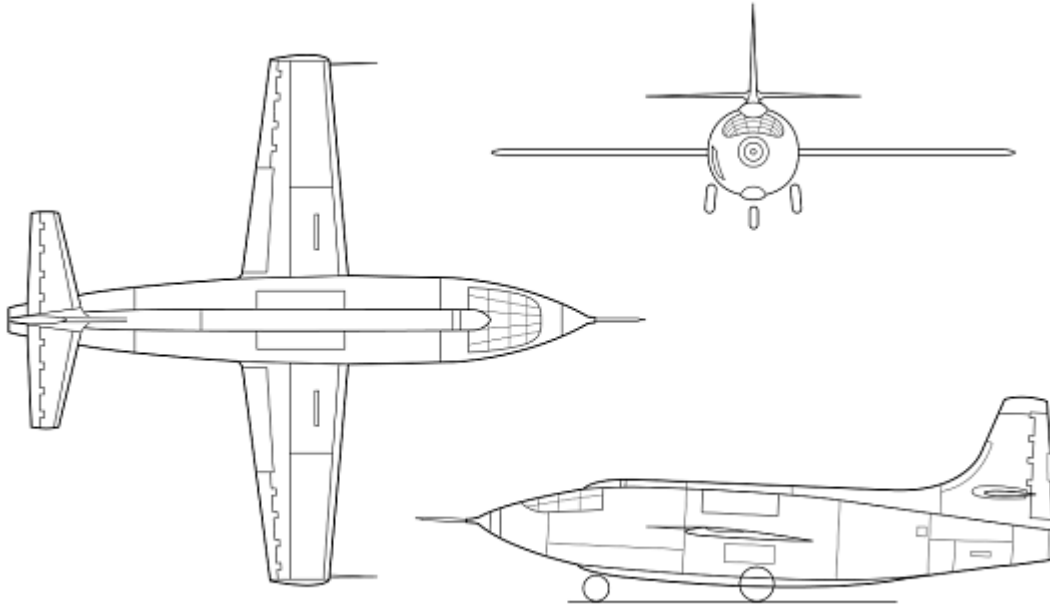
The X-1E, christened 'Little Joe', with pilot Joe Walker

The changes included:

- A turbopump fuel feed system, which eliminated the high-pressure nitrogen fuel system used in '062 and '063. (Concerns about metal fatigue in the nitrogen fuel system resulted in the grounding of the X-1-2 after its 54th flight in its original configuration.)
- A re-profiled super-thin wing ($3\frac{3}{8}$ inches at the root), based on the X-3 Stiletto wing profile, enabling the X-1E to reach Mach 2.
- A 'knife-edge' windscreen replaced the original greenhouse glazing, an upward-opening canopy replaced the fuselage-side hatch and allowed the inclusion of an ejection seat.
- The addition of 200 pressure ports for aerodynamic data, and 343 strain gauges to measure structural loads and aerodynamic heating along the wing and fuselage.

The X-1E first flew on 15 December 1955, a glide flight under the controls of USAF test pilot Joe Walker. Walker left the X-1E program in 1958, after 21 flights, attaining a maximum speed of Mach 2.21 (752 m/s, 2,704 km/h). NACA research pilot John B. McKay took his place in September 1958, completing five flights in pursuit of Mach 3 (1,021 m/s, 3,675 km/h). before the X-1E was permanently grounded following its 26th flight, in November 1958, due to the discovery of structural cracks in the fuel tank wall.

Specification (Bell X-1)



Orthographic diagram

General characteristics

- **Crew:** 1
- **Length:** 30 ft 11 in (9.4 m)
- **Wingspan:** 28 ft (8.5 m)
- **Height:** 10 ft (3.3 m)
- **Wing area:** 130 ft² (12 m²)
- **Empty weight:** 7,000 lb (3,175 kg)
- **Loaded weight:** 12,225 lb (5,545 kg)
- **Max takeoff weight:** 12,250 lb (5,557 kg)
- **Powerplant:** 1× Reaction Motors XLR-11-RM3 liquid fuel rocket, 6,000 lbf (1,500 lbf per chamber) (26.7 kN)

Performance

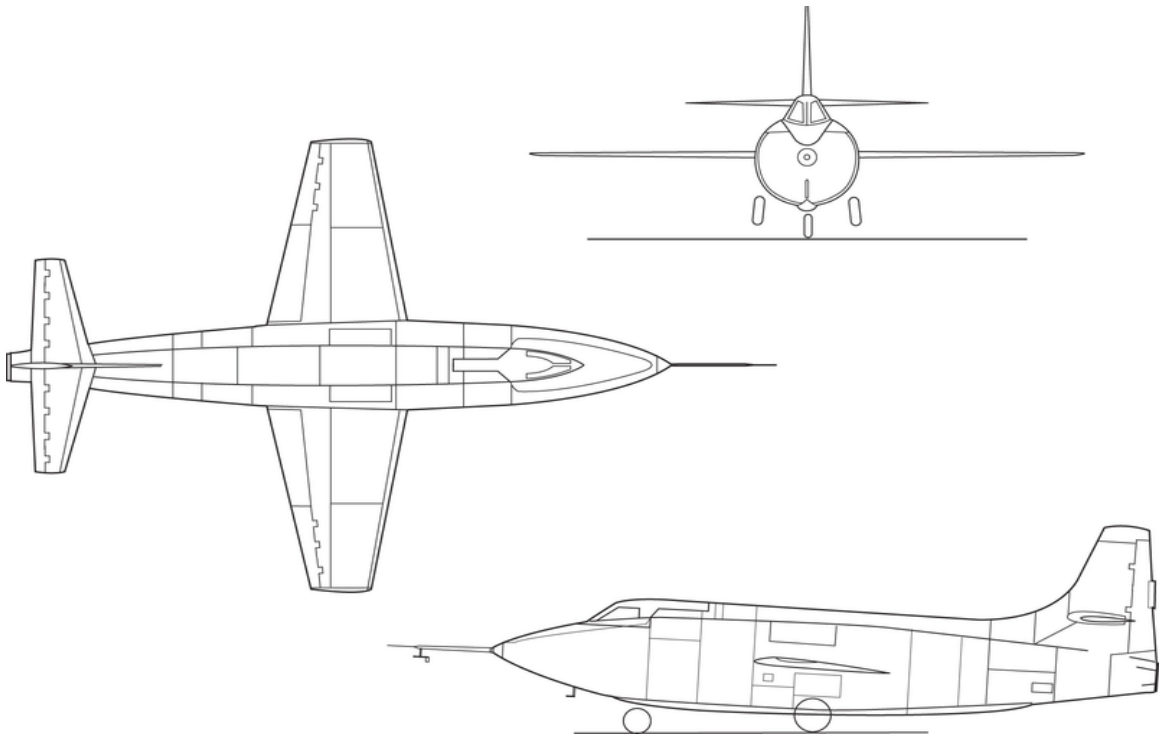
- **Maximum speed:** 957 mph (Mach 1.26) (1,541 km/h)
- **Range:** 5 minutes (powered endurance)
- **Service ceiling:** 71,900 ft (21,900 m)
- **Wing loading:** 94 lb/ft² (463 kg/m²)
- **Thrust/weight:** 0.49







Specification (Bell X-1E)



X-1E line drawing

General characteristics

- **Crew:** 1
- **Length:** 31 ft (9.4488 m)
- **Wingspan:** 22 ft 10 in (6.9596 m)
- **Height:** 10 ft 10 in (3.3 m)
- **Wing area:** 115 ft² (10.684 m²)
- **Empty weight:** 6,850 lb (3,107.107 kg)
- **Loaded weight:** 14,750 lb (6,690.487 kg)
- **Powerplant:** 1× Reaction Motors RMI LR-8-RM-5 rocket, 6,000 lbf (26.7 kN)

Performance

- **Maximum speed:** 1,450 mph (Mach 2.24) (2,333.548 km/h)
- **Range:** 4 minutes 45 seconds ((powered endurance))
- **Service ceiling:** 90,000+ ft (27,432+ m)

Chapter 11

Bereznyak-Isayev BI-1

Bereznyak-Isayev-1



The BI-1

Role	Fighter
Manufacturer	OKB-293
Designed by	A.Y.Bereznyak and A.M.Isayev
First flight	15 May 1942
Retired	9 March 1945
Primary user	Soviet Air Force
Number built	9

Soviet research and development of rocket-powered aircraft began with Sergey Korolev's GIRD-6 project in 1932. His interest in stratospheric flight was also shared by Marshal Mikhail Tukhachevsky who supported this early work. After a long series of unmanned tests of vehicles, Korolev's RP-318-1 rocket plane flew on Feb 28, 1940. That Spring, the Zhukovsky Institute in Moscow (TsAGI) hosted a conference for aircraft chief designers on the subject of ramjet and rocket propulsion. On July 12, the Council of People's Commissioners (SNK) called for the development of high-speed stratospheric aircraft.

Early Design

Aircraft designer and head of OKB-293, Viktor Fedorovich Bolkhovitinov attended the TsAGI conference along with two of his top engineers, A. Ya. Bereznyak and A. M. Isaev. The young Bereznyak had made an impression in 1938 with a high-speed airplane design that some thought could break the world speed record. Bereznyak and Isaev were

excited by the idea of designing a rocket-powered aircraft, and their "patron" Bolkhovitinov approved. By the Autumn of 1940, they were able to show fellow engineer Boris Chertok a preliminary design of "Project G". The design, made up mostly from plywood and duralumin had a take-off weight of 1500 kg, and they planned to use the new 1400 kgf rocket engine under development in the Jet Propulsion Research Institute (RNII). Chertok was astounded that the aircraft could almost climb vertically.

Bereznyak, Isaev and Chertok visited RNII in March 1941, but the new rocket engine was not working yet. The engine was designed by Leonid Dushkin, who had made the engine (RD-A-150) for RP-318-1. Powered by tractor kerosene and red fuming nitric acid, it fell short of the hoped for 1400 kgf of thrust. Designated D-1-A-1100, it was expected to reach 1100 kgf. The "A" stood for "Nitric" (versus "Oxygenic"), a distinction of unusual importance and controversy among Soviet rocket scientists. Dushkin's propellant pump was causing considerable problems. It was a turbine pump driven by hot gas and steam from a small combustion chamber fed with rocket propellants mixed with water. This system was perfected a few years later in Dushkin's RD-2M engine.

The D-1-A-1100 was built from carbon steel with diffusion chrome plating. At this point in time, Russian rocket engines were built with typical aviation piston-engine manufacturing technology. Weighing 48 kg, it could be broken down into discrete forged-steel sections -- a conical head with 60 centrifugal injectors, the cylindrical chamber, and the nozzle -- joined with bolts and copper gaskets. It was ignited with a nichrome glow plug, later replaced with silicon-carbide. The engine was cooled regeneratively by both propellants, the chamber walls by a spiral flow of incoming fuel, and the nozzle section by the flow of oxidizer.

War-Time Development

On June 21, Isaev proposed a new design using compressed air instead of a pump to force propellant to the engine. The next day, Operation Barbarossa brought the Soviet Union into World War II, and the rocket-powered interceptor suddenly became important. Bereznyak and Isaev began a new more detailed design, which they finished in three weeks. On July 9, Bolkhovitinov and his project-G team met with Andrey Kostikov the head of RNII. Dushkin was not happy about the idea of bypassing his fuel pump design, but they backed the plan and cosigned a letter that was eventually shown to Stalin. After giving a report at the Kremlin, they were ordered to build the plane and were given only 35 days to do so. The official order was dated August 1, but work began in late July. The engineers were given leave to visit their families, and then literally lived at the factory until the planes were finished.

The new design was called "BI" for *Blizhnii Istrebitel* (close-range fighter), but the letters were also understood by everyone to stand for its inventors: Bereznyak and Isaev. The original plan to include four machine guns was replaced by a design with a pair of 20 mm ShVAK cannons. The new plane was a low-wing monoplane 6.4 meters long, with a wingspan of 6.5 meters and an estimated take-off mass of 1650 kg (including 710 kg of propellant). Working around the clock, local furniture workers were employed to build

the first two prototypes (BI-1 and BI-2). The skin was 2 mm plywood with a bonded covering of fabric. The Ailerons, elevators and rudder were fabric covered, and the flaps were duralumin. In the forward section were 5 compressed air tanks and 2 kerosene tanks. In the aft were 5 compressed air tanks and three nitric acid tanks. Pressurized to 60 atm, the tanks were made from a high-strength chromium-manganese-silicon steel ("Chromansil") that was not especially resistant to corrosion. Thus, the acid tanks had to be replaced periodically. Compressed air was also used to retract and deploy the landing gear and to power the anti-aircraft cannons.

On September 1, 1941, BI-1 was completed and ready for glider tests by pilot Boris N. Kudrin. Dushkin's engine was still not ready. A few weeks later, rival aircraft designer A.S. Yakovlev took it upon himself to tow the prototype to TsAGI for windtunnel testing. This alarmed Bolkhovitinov's team, because their patron had a rocky history with Yakovlev, but Alexander Sergeevich and aircraft designer Ilya Florov studied the test results and gave them sound advice for improvements. Yaw instability was corrected by enlarging the rudder and adding two circular plates to the tail horizontal stabilizer.

Test Flights In The Urals



Bereznyak, Isaev, Bakhchivandzhi, and Bolkhovitinov

In October, both OKB-293 and RNII were evacuated to the Urals, along with most of Moscow's war industry. Bolkhovitinov's team was stationed in Bilimbay, and Dushkin's team in Sverdlovsk, about 60 km away. A test stand was built on the shore of frozen lake Bilimbay, with a dynamometer cradle to hold the BI-1 during engine testing. A new test pilot, Grigory Yakovlevich Bakhchivandzhi, was assigned to the team. Dushkin was increasingly absorbed by other work, including RNII's own rocket plane project, the Kostikov-302. He assigned his engineer Arvid V. Pallo to oversee the installation and testing of the rocket engine.

Nitric acid presented a constant problem, corroding parts and causing skin burns and respiratory irritation. Tanks of sodium carbonate solution were kept around to neutralize acid spills. On February 20 1942, the engine exploded during a full system test. The nozzle section was blasted into the lake, and the engine head struck the back of the pilot's seat, knocking Bakhchivandzhi against the instrument panel and injuring him slightly.

From a broken propellant line, pressurized nitric acid drenched Pallo. Fortunately, quick thinking mechanics dunked him head-first into a tank of soda solution. His face was yellow from the characteristic acid staining, but his glasses saved him from being blinded. To protect the pilot in the future, a 5.5 mm steel plate was added to the back of the seat.

By April 1942, BI-1 was ready for testing at nearby Koltsove airfield. A test commission was formed, with representatives from OKB-293, RNII and the airforce research lab (NII VVS). On May 2, the pilot let the plane lift off one meter under low thrust.

On May 15, at 19:02 (UTC), Bakhchivandzhi made the first real flight of BI-1, reaching an altitude of 840 meters and a maximum speed of 400 km/h. The mass of the plane had been reduced to 1300 kg (only 240 kg of nitric acid and 60 kg of kerosene loaded), and the engine was operated under a thrust of only 500 kgf. The pilot shut the rocket engine off after about one minute, when a light indicated it was overheating. Landing, the aircraft descended too rapidly because of insufficient forward speed, and the landing gear broke on touchdown. The pilot was unhurt and reported that, aside from the rough landing, the plane handled well. The flight lasted only 3 minutes and 9 seconds.

In July, Dushkin recalled Pallo to help work on the "302" rocket-plane project. Bolkovitinov asked Isaev to take over and master the technology of liquid fuel rocket engines. Isaev got permission to visit Valentin Glushko, the leading Soviet expert on rocket engines, who was then working in a special lab for political prisoners. Glushko taught Isaev the complex techniques of chamber-wall heat transfer calculation and engine design, developed by himself and Fridrikh Tsander in the early 1930s. Isaev's propellant feed system was simple, but it produced an uneven fuel pressure that diminished as compressed air was used up. Bolkovitinov and his engineers wrestled with this problem, designing pressure regulators and even a piston fuel pump driven by compressed air, but none of these improvements were realized.

Too damaged by acid to fly safely, BI-1 was retired and the second prototype BI-2 was made ready. Backchivadzhi made the second flight on Jan 10, 1943, reaching 1100 meters but with the engine still throttled back for a maximum speed of 400 km/h. The first flight had been with landing gear kept down, and some vibration has been observed. This time, the flight was made with landing gear stowed, and no vibration was observed at the cautious speed.

The third flight was made on Jan 12 (some sources say Feb 10) by a temporary test pilot, Konstantin Gruzdev, while Backchivadzhi was consulting on Kostikov's "302" project. This time the engine was opened up to full thrust of 1100 kgf and a speed of 675 km/h was achieved and a maximum altitude of 2190 meters. During the winter, the landing gear was switched from wheels to skis. On Gruzdev's flight, one ski broke off during take-off, but he was able to land safely. Backchivandzhi returned to make flights in the third test plane BI-3 on March 11, 14 and 21. He reached a maximum altitude of 4000 meters with a maximum rate of climb of 83 meters per second.

The March 21 flight was with a full load of ammunition. Most of the BI models did not contain an actual pair of anti-aircraft cannons, and some reports claim that BI-4 was used for the live ammunition tests. The guns were never fired in any flight. The BI-4 model was reportedly used as the template for the mass production of 30 to 50 BI-VS model aircraft by Andrey Moskalev's factory. Moskalev augmented the twin ShVAK guns with a load of ten thermite bombs.

On March 27, during a low-altitude test flight, Backchivandzhi pushed the aircraft's speed. After 78 seconds, the plane went into a 45-degree dive and crashed into the ground, killing the beloved pilot. The accident put a halt to flight tests, and a lengthy investigation began. Eventually, after wind tunnel testing, it was determined that the BI-1 lost control due to the effects of transonic velocity. Estimates of Backchivandzhi's final velocity range from 800 to 990 km/h, but the recording instruments were too damaged by the crash for a reliable measurement. March 27 is considered a black day in Soviet aviation history, also being the date that Yuri Gagarin died in a jet plane crash. In 1973, Backchivadzhi was posthumously awarded Hero of the Soviet Union.

Return To Moscow, Isaev's Engine

In May 1943, OKB-293 returned from its evacuation and set up operation in Khimki, a suburb of Moscow. On May 18, Bolkhovitinov wrote a detailed report "On Rocket Aircraft and Further Prospects". He emphasized the need to study the dangerous regime of "shock stall", and to safely transition through transonic speed and beyond. He proposed the goal of a new rocket plane capable of 2000 km/h.

The next year, Bolkhovitinov had five more aircraft produced, BI-5 through BI-9. In the Spring of 1944, BI-6 was fitted with a pair of Igor A. Merkulov's DM-4 ramjet engines. It did not contain a rocket engine, so it was towed into the air. The pilot, Boris Kudrin, flew the BI-6 three times, but was never able to get both ramjets to start at the same time. The plane was taken to TsAGI for further tests in the T-101 wind tunnel. The DM-4 auxiliary motor was also tested on the YaK-7b fighter.

With the loss of the D-1-A-1100 engine, Isaev began designing a new engine. The RD-1 was completed and tested in October 1944. The general form of the engine was the same as Dushkin's, but with numerous improvements. Isaev fashioned the sections from 12Kh13 stainless chromium steel (13% chromium, 0.12% carbon content). The head had 85 swirling injectors arranged in a honeycomb pattern that promoted improved fuel-oxidizer mixture. It also used a more reliable electric arc starter instead of a glow plug. Isaev also improved the regenerative cooling, increasing the flow rate around the nozzle.

BI-7 was flown twice with the RD-1 engine, on January 24 and March 9 1945. Pallo reports there was an emergency with the landing gear during the January flight. In addition to the new engine, various changes were made to the plane's design: a larger rudder, smaller false keel, and different wing fillets. During the test flights, the pilot Boris Kudrin, noticed some tailfin flutter. On May 29, the pilot M.K. Baykalov tested the BI-7 in glider mode, without starting the engine, and the flutter was not detected. At this point,

the plane was too corroded by nitric acid to fly again, and it was retired. To further investigate the flutter problem, BI-5 was modified in the same fashion as BI-7 (but with no engine) and tested in glider flights; however, the problem was not reproduced.

After BI-6 was sent to TsAGI, BI-9 was put into service as a replacement (marked with a "6" on its tail). Flown by Boris Kudrin and M.A. Baikalov, it was used in glider tests with extra payload weight. The fate of BI-8 is unknown.

Powered Flights

The BI was flown 12 times under power, seven times with Dushkin's D-1-A-1100 engine, three times with the DM-4 ramjets, and twice with Isaev's RD-1 rocket engine.

Date	Model	Pilot	Thrust, kgf	Burn Time, s	Altitude, m	Speed, km/h	Climb, m/s
May 02 1942	BI-1	Bakhchivandzhi	500	13	1	-	-
May 15 1942	BI-1	Backchivandzhi	600	66	840	400	23
Jan 10 1943	BI-2	Backchivandzhi	800	63	1,100	400	-
Jan 12 1943	BI-2	Gruzdev	1100	58	2,190	675	-
Mar 11 1943	BI-3	Backchivandzhi	1,100	80	4,000	600	82
Mar 14 1943	BI-3	Backchivandzhi	1,100	84	3,000	~650	-
Mar 21 1943	BI-3	Backchivandzhi	1,100	30	3,000	550	160
Mar 27 1943	BI-3	Backchivandzhi	1,100	89	2,000	>800	-
Spring 1944	BI-6	Kudrin	-	-	-	-	-
Spring 1944	BI-6	Kudrin	-	-	-	-	-
Spring 1944	BI-6	Kudrin	-	-	-	-	-
Jan 24 1945	BI-7	Kudrin	1,100	72.3	1,250	587	87
Mar 09	BI-7	Baykalov	1,100	73	3,500	550	-

1945							
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Operators

 Soviet Union

- Soviet Air Force

Specifications

General characteristics

- **Crew:** 1
- **Length:** 6.40 m (21 ft 0 in)
- **Wingspan:** 6.48 m (21 ft 3 in)
- **Height:** 2.06 m (6 ft 9 in)
- **Wing area:** 7 m² (75 sq ft)
- **Empty weight:** 958 kg (2,112 lb)
- **Max takeoff weight:** 1,683 kg (3,710 lb)
- **Powerplant:** 1 × Dushkin D-1A-1100 liquid-fuel rocket motor 1100kg

Performance

- **Maximum speed:** 990 km/h (620 mph; 530 kn) estimated
- **Endurance:** 15 minutes under power

Armament

- **Guns:** two nose-mounted 20 mm Sh VAK cannon

Chapter 12

Boeing X-37

X-37



X-37B being prepared for launch

Role	Spaceplane
National origin	United States
Manufacturer	Boeing
First flight	7 April 2006 (drop test); 22 April – 3 December 2010 (first spaceflight)

Status	Development and testing, one spaceflight completed
Primary users	NASA/DARPA (X-37A) USAF (X-37B)
Number built	2
Developed from	Boeing X-40

The **Boeing X-37** (also known as the **Orbital Test Vehicle**) is an American unmanned vertical-takeoff, horizontal-landing (VTHL) spaceplane. The X-37 is operated by the United States Air Force for orbital spaceflight missions intended to demonstrate reusable space technologies. It is a reusable robotic spaceplane that is a 120% scaled derivative of the X-40A.

The X-37 began as a NASA project in 1999, then was transferred to the U.S. Department of Defense in 2004. It had its first flight as a drop test on 7 April 2006, at Edwards Air Force Base. The spaceplane's first orbital mission, USA-212 was launched on 22 April 2010 using an Atlas V rocket. Its return to Earth on 3 December 2010 was the first test of the vehicle's heat shield and hypersonic aerodynamic handling. A second X-37B was launched on 5 March 2011 with the mission designation USA-226.

Development

In 1999 NASA selected Boeing Integrated Defense Systems to design and develop the vehicle, built by the California branch of Boeing's Phantom Works. Over a four-year period NASA contributed \$109 million, the US Air Force \$16 million, and Boeing \$67 million to the project. In late 2002 a new \$301 million contract was awarded to Boeing in the framework of NASA's Space Launch Initiative.

The X-37 was transferred from NASA to the Defense Advanced Research Projects Agency (DARPA) on 13 September 2004. The program has become a classified project, although it is not known whether DARPA will maintain this status for the project. NASA's spaceflight program may be centered around the Crew Exploration Vehicle, while DARPA will promote the X-37 as part of the independent space policy that the US Department of Defense has pursued since the *Challenger* disaster.

The X-37 was originally designed to be carried into orbit in the Space Shuttle cargo bay, but underwent redesign for launch on a Delta IV or comparable rocket after it was determined that a shuttle flight would be uneconomical. The X-37's aerodynamic design was derived from the Space Shuttle, hence the X-37 has a similar lift-to-drag ratio, and a lower cross range at high altitudes and Mach numbers than DARPA's Hypersonic Technology Vehicle.

As part of its Space Support mission goals, X-37 was designed to rendezvous with friendly satellites to refuel them, or to replace failed solar arrays using a robotic arm. Its payload could also support Space Control (Defensive Counter-Space, Offensive Counter-

Space), Force Enhancement and Force Application. An early requirement for the spacecraft called for a delta-v of 7,000 mph (3.1 km/s) to change its orbit.

Glide tests

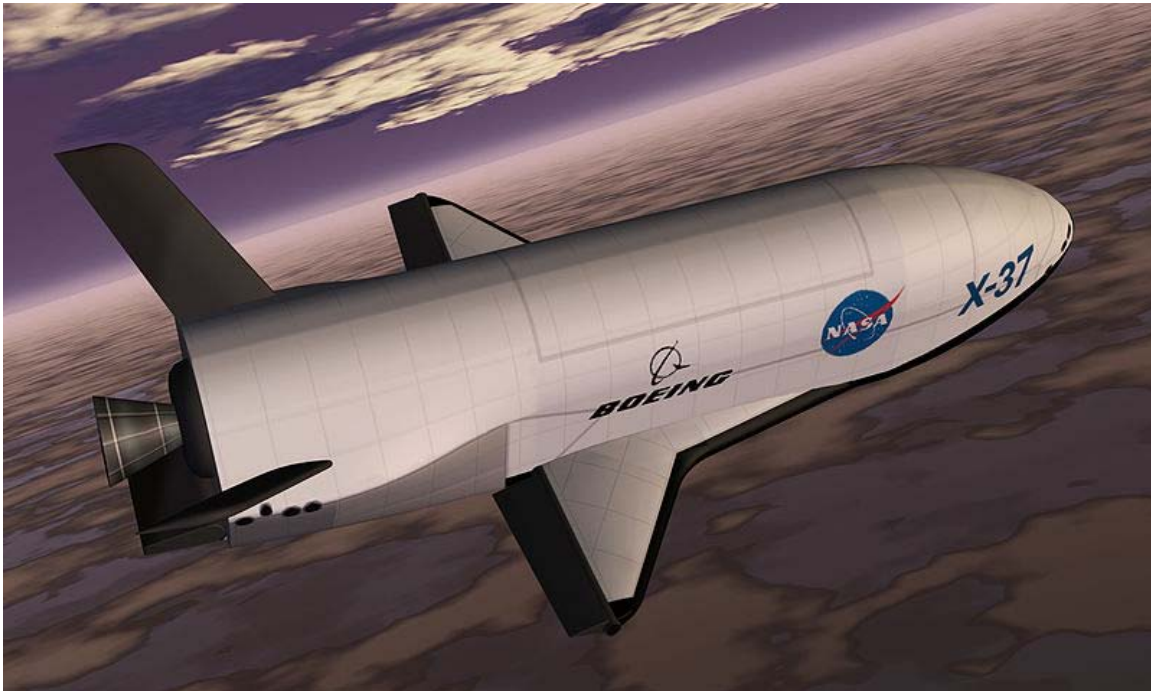
The vehicle that was used as an atmospheric drop test glider had no propulsion system. Instead of an operational vehicle's payload bay doors it had an enclosed and reinforced upper fuselage structure to allow it to be mated with a mothership. In September 2004 DARPA announced that for its initial atmospheric drop tests the X-37 would be launched from the Scaled Composites White Knight, a high-altitude research aircraft.

On 21 June 2005 the X-37 completed a captive-carry flight underneath the White Knight from Mojave Spaceport, Mojave, California. Through the second half of 2005, the X-37 underwent structural upgrades including reinforcement of the nose wheel supports. Further captive-carry flight tests and the first drop test were expected mid-February 2006. The X-37's public debut was scheduled for its first free flight on 10 March 2006, but was canceled due to an Arctic storm. The next attempt at flight on 15 March 2006 was canceled due to high winds.

On 24 March 2006, the X-37 flew, but a data link failure prevented the free flight and the vehicle returned to the ground still attached to its White Knight carrier. On 7 April 2006, the X-37 made its first free glide flight. During landing, the vehicle overran the runway and it sustained minor damage.

Following an extended downtime while the vehicle was repaired, the program moved from Mojave to Air Force Plant 42 (KPMD) in Palmdale, California for the remainder of the flight test program. White Knight continued to be based at Mojave, but would ferry over to Plant 42 when flights were scheduled. Five additional flights were performed, two of which resulted in X-37 releases with successful landings. These free flights occurred on 18 August 2006 and 26 September 2006.

X-37B Orbital Test Vehicle



X-37 spacecraft, artist's rendering from 1999

On 17 November 2006 the U.S. Air Force announced it would develop the X-37B from the NASA X-37A. The Air Force version is designated X-37B Orbital Test Vehicle (OTV). The OTV program builds on industry and government investments by DARPA, NASA and the Air Force. The X-37B effort will be led by the Air Force Rapid Capabilities Office, and includes partnerships with NASA and the Air Force Research Laboratory. Boeing is the prime contractor for the OTV program. The X-37B can remain in orbit for up to 270 days at a time.

The Secretary of the Air Force states the OTV program will focus on "risk reduction, experimentation, and operational concept development for reusable space vehicle technologies, in support of long-term developmental space objectives."

The X-37B was originally scheduled for launch in the payload bay of the Space Shuttle, but following the *Columbia* accident, it was transferred to a Delta II 7920. It was subsequently transferred to a shrouded configuration on the Atlas V following concerns over the unshrouded spacecraft's aerodynamic properties during launch. Following their missions, X-37B spacecraft are to land on a runway at Vandenberg Air Force Base, California, with Edwards Air Force Base as an alternate site.

Manufacturing on the second X-37B, OTV-2 was underway in 2010; it was completed and was first launched in March 2011.

Design

The X-37 Orbital Test Vehicle is a reusable robotic spaceplane. It is a derivative of X-40 and 120% larger. The OTV has a length of over 29 feet (8.8 m) and features two angled tail fins.

The X-37 is expected to operate in a velocity range of up to Mach 25 on reentry. Among the technologies to be demonstrated with the X-37 are improved thermal protection systems, avionics, the autonomous guidance system and an advanced airframe. The vehicle is powered by a Rocketdyne AR2-3 engine. The AR2-3 was the human-rated rocket powerplant for the dual-power NF-104A astronaut training vehicle and was given a new flight certification for use on the X-37 with hydrogen peroxide/JP-8 propellants. The X-37B now uses a hydrazine monopropellant rocket.

The X-37 has a payload bay available for experiments and other space payloads. It features thermal protection systems that are improved from previous generations of spacecraft. The thermal protection system uses improved silica ceramic tiles.

Operational history



OTV-1 sits on the runway at Vandenberg AFB after landing

The first orbital flight of OTV-1, the first X-37B, with a mission name of USA-212, was launched on an Atlas V rocket at Cape Canaveral Air Force Station, Florida on 22 April 2010, at 23:58 GMT. The spacecraft was placed into low Earth orbit for testing.

While the U.S. Air Force revealed few orbital details after the first X-37B was successfully placed in orbit due to the secretive nature of the mission, amateur

astronomers claimed to have identified the experimental spacecraft in orbit and shared their findings. A worldwide network of amateur astronomers reported that as of 22 May it was in an inclination of 39.99 degrees, circling the Earth once every 90 minutes in an orbit 401 by 422 kilometers (249 by 262 mi).



Personnel inspect OTV-1, the first X-37B, after its return

The U.S. Air Force announced on 30 November 2010 that the X-37 would return for a landing during the 3–6 December timeframe. As scheduled, OTV-1 de-orbited, reentered Earth's atmosphere, and landed at Vandenberg AFB on 3 December 2010, at 1:16 PST (09:16 UTC). The X-37B had a tire blowout during landing and sustained minor damage to its underside.

A second X-37B mission, designated USA-226, was launched aboard an Atlas V rocket, on 5 March 2011. The mission was classified and described by the US military as to test out new space technologies.

Controversy

In April 2010, the *China Daily* newspaper wrote that the X-37B program raised concerns about an arms race in space. The Xinhua News Agency took a more moderate tone in questioning if the secretive program might lead to weapons in space. Tom Burghardt wrote for Spacedaily.com that the X-37B could be used as a spy satellite or to deliver

weapons from space. The Pentagon has denied claims that the X-37B's mission supports the development of space-based weapons.

A group of amateur sky watchers, named Visual Satellite Observers reported the X-37B's track took it over North Korea, Afghanistan and other trouble spots; they said the spacecraft's mission is to support space-based surveillance and reconnaissance technology. According to the sky watchers, the spacecraft passes over the same given spot on Earth every four days, and operates at an altitude of 255 miles (410 km), which would be typical for a military surveillance satellite.

Specifications

X-37B

General characteristics

- **Crew:** None
- **Length:** 29 ft 3 in (8.9 m)
- **Wingspan:** 14 ft 11 in (4.5 m)
- **Height:** 9 ft 6 in (2.9 m)
- **Loaded weight:** 11,000 lb (4,990 kg)
- **Power:** Gallium arsenide solar cells with lithium-ion batteries
- **Payload Bay:** 7 × 4 ft (2.1 × 1.2 m)

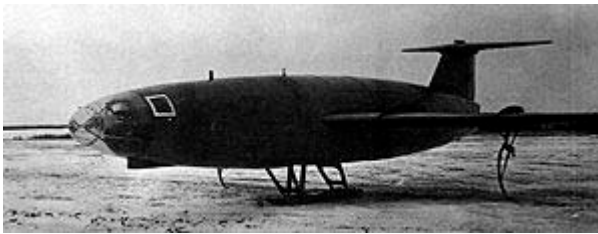
Performance

- **Orbital speed:** 17,500 mph (28,200 km/h)
- **Orbit:** Low Earth orbit
- **Orbital time:** Up to 270 days

Chapter 13

DFS 346

DFS 346



Aircraft 346-P

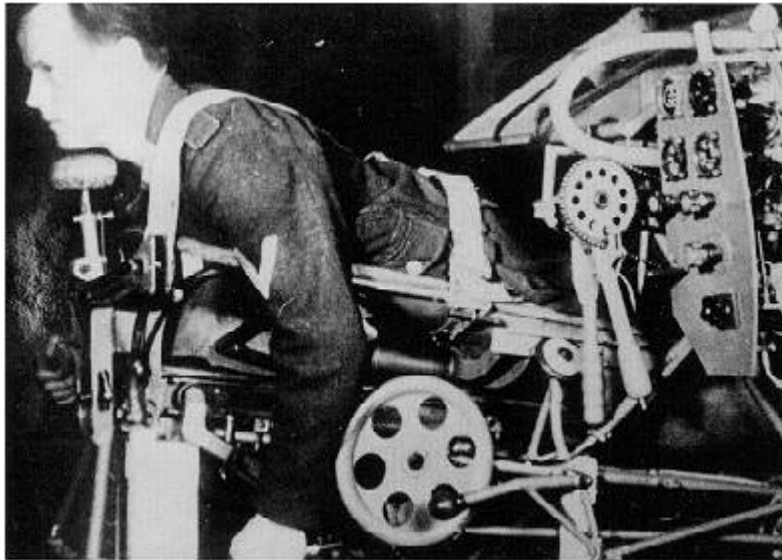
Role	Research aircraft
Manufacturer	Siebel OKB-2
Designed by	Felix Kracht
First flight	346-P in 1948 as glider 346-3 in 13.08 1951 with engine
Retired	14 September 1951
Status	Project cancelled
Primary user	Soviet Air Force
Number built	4
Variants	Bisnovat 5

The **DFS 346** (*Samolyot 346*) was a German rocket-powered, high-speed research aircraft of World War II. It was designed by Felix Kracht at the *Deutsche Forschungsanstalt für Segelflug* (DFS), the "German Institute for Sailplane Flight". The prototype was still unfinished by the end of the war and was taken to the Soviet Union where it was rebuilt, tested and flown.

Concept



Concept art



Test pilot Rolf Mödel tries out the prone position

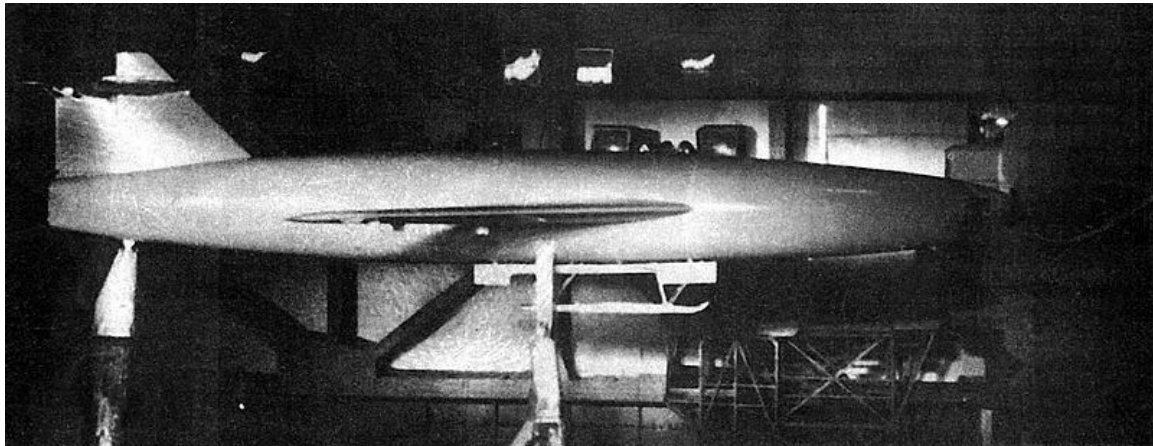
The DFS 346 was a parallel project to the DFS 228 high-altitude reconnaissance aircraft. While the DFS 228 was essentially of conventional sailplane design, the DFS 346 had highly-swept wings and a highly streamlined fuselage that its designers hoped would enable it to break the sound barrier. Like its stablemate, it also featured a self-contained escape module for the pilot, a feature originally designed for the DFS 54 prior to the war. The pilot was to fly the machine from a prone position, a feature decided from experience with the first DFS 228 prototype, mainly because of better g-force handling and aim of reducing the fuselage cross-section as much as possible.

The 346 design was intended to be air-launched from the back of a large aircraft, the baseline being the Dornier Do 217. After launch from the bomber the plane's Walter 509B/C (*ZhRD-109-510*) engine, which consisted of two superimposed combustion chambers, one above the other, with the lower unit of 400 kg (880 lb) thrust for cruising and the upper unit used only for takeoff, in a so-called "sharp start" directly from the ground, or for short periods when the maximum thrust was necessary, would accelerate the craft to proposed speed of Mach 2.6 and altitude of 30,500 meters, at which point the engine would turn off. In an operational use the plane would then glide over England for a photo-reconnaissance run, descending as it flew but still at a high speed. After the run was complete the engine would be briefly turned on again, to raise the altitude for a long low-speed glide back to a base in Germany or northern France.

Design

The DFS-346 was a midwing design of all-metal construction. The front fuselage of the 346 was a rotation body based on the NACA-Profile 0,0121-0,66-50. The middle part was cylindrical and narrowed to the square in the back. Probably for capacity and weight reasons the DFS-346 was equipped with landing skids, both in the original German design and in the later Soviet prototypes; this caused trouble several times. The wings had a 45° swept NACA 0,012-0,55-1,25 profile of 12% thickness. The continuously varying profile shape caused a stall in certain flight conditions, which caused complete loss of control. This was later corrected by use of fences on the top of the wings.

Development

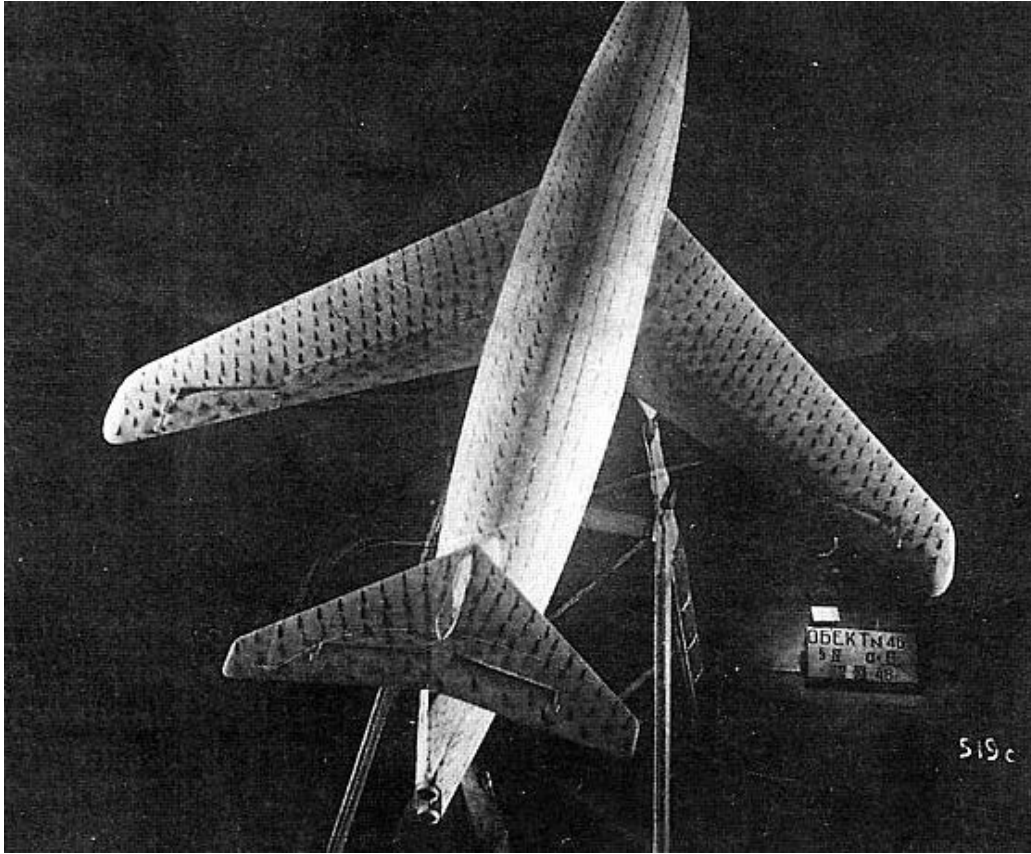


First model in Siebel windtunnel

World War II

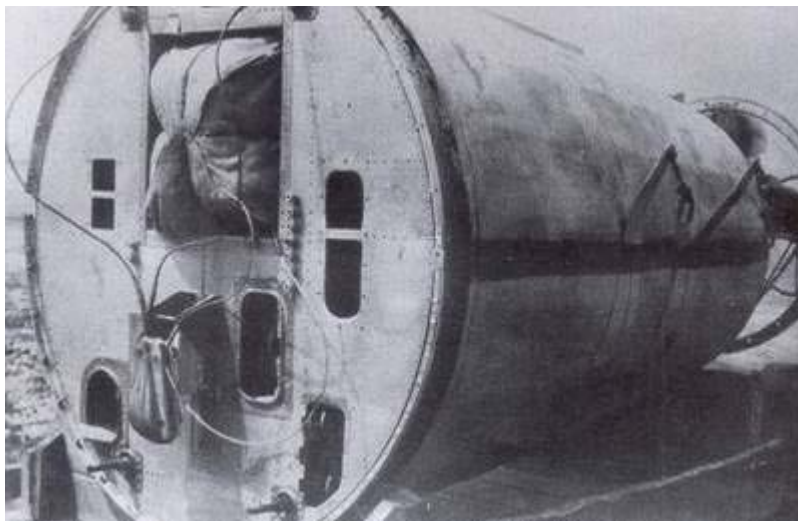
Felix Kracht and his team at DFS began selecting a suitable airframe design in the late World War II period. Since the aircraft was to be of all-metal construction, the DFS lacked the facilities to build it and construction of the prototype was assigned to Siebel Werke located in Halle, where the first windtunnel models and partially built prototype were captured by the advancing Red Army.

Post-War



Plane model in TsAGI wind tunnel

On 22 October 1946, the Soviet OKB-2 (Design Bureau 2), under the direction of Hans Rössing and Alexandr Berezhnyak, was tasked with continuing its development.



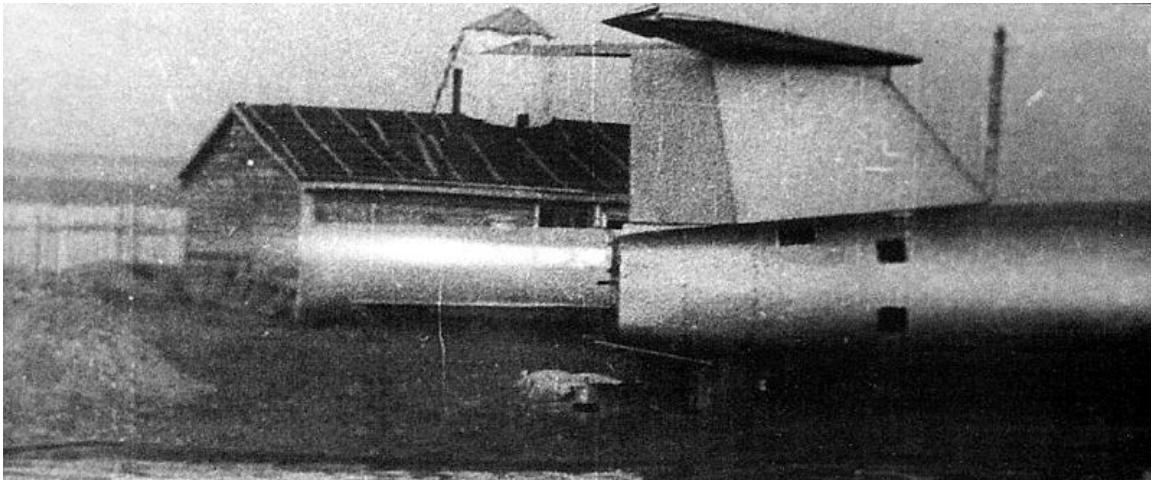
Escape capsule prepared for droptests

The captured DFS 346, now simply called "**Samolyot 346**" ("Samolyot" - *Aircraft*) to distance it from its German origins, was completed and tested in TsAGI wind tunnel T-101. Tests revealed some aerodynamic deficiencies which would result in unrecoverable stalls at certain angles of attack. This phenomenon involved a loss of longitudinal stability of the airframe. After the wind tunnel tests, two wing fences were installed on a more advanced, longer version of the DFS-346, to correct the airstream separation. This solution was used on the majority of the Soviet planes with sweptback wings of the 1950s and 1960s. In the meantime, the escape capsule system was tested from a B-25J and proved promising. Despite results from studies showing that the plane would not have been able to pass even Mach 1, it was ordered to proceed with construction and further testing.

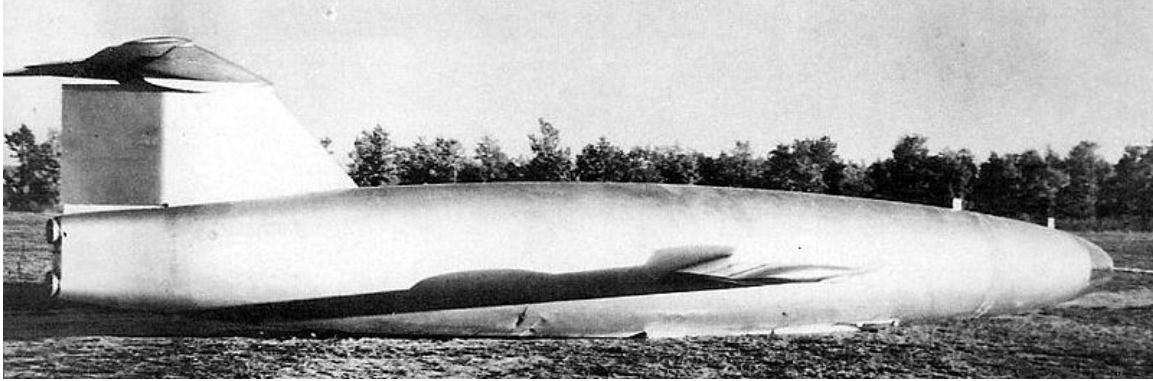
Operational use

In 1947, an entirely new 346 prototype was constructed, incorporating refinements suggested by the tests. This was designated **346-P** ("P" for *planer* - "glider"). No provision was made for a powerplant, but ballast was added to simulate the weight of an engine and fuel. This was carried to altitude by a B-29 Superfortress captured in Vladivostok and successfully flown by Wolfgang Zeise in a series of tests. This led to the construction of three more prototypes, intended to lead to powered flight of the type.

First accidents



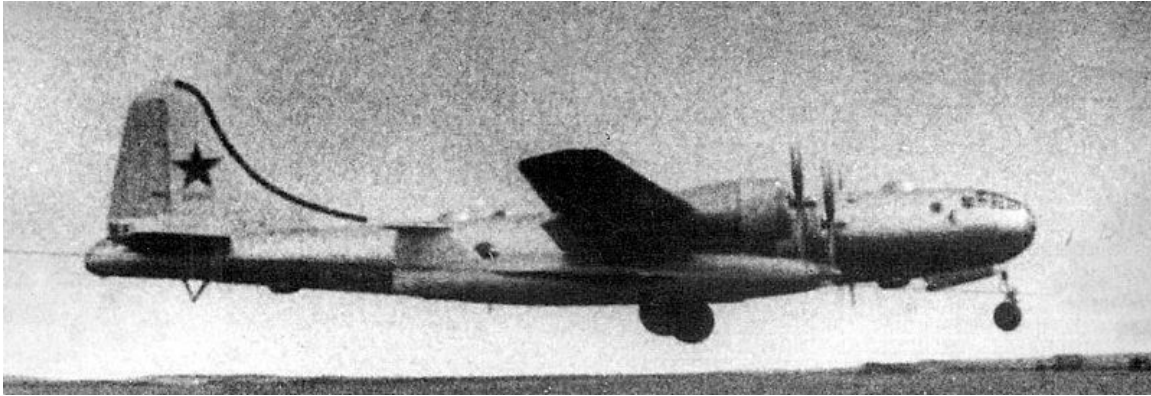
Engine test on ground



Minor landing difficulties resulted with landing on the snow without landing gear

Newly built **346-1** incorporated minor aerodynamic refinements over the 346-P, and was first flown by Zeise on September 30, 1948, with dummy engines installed. The glider was released at an altitude of 9700 m, and the pilot realised that he hardly could maintain control of the aircraft. Consequently, while attempting to land, he descended too fast (his speed was later estimated at 310 km/h). After first touching the ground he bounced up to a height of 3–4 m and flew 700–800 m. At the second descent, the landing ski collapsed and the fuselage hit the ground hard. The pilot seat structure and safety-belt proved to be very unreliable, because at the end of a rough braking course Zeise was thrown forward and struck the canopy with his head, losing consciousness. Luckily, he wasn't seriously injured, and after treatment in hospital he was able to return to flying. Accident investigation research team came to the conclusion that the crash was a result of pilot error, who failed to fully release the landing skid. This accident showed that the aircraft handling was still very unpredictable, as a result, all rocket-powered flights were postponed until pilots were able to effectively control the aircraft in unpowered descent, requiring further glide flights. The damaged 346-1 was later repaired and modified to **346-2** version. It was successfully flown by test pilot P.Kazmin in 1950-1951 winter, but nonetheless these flights also ended "on fuselage". Furthermore, after the last flight of these series, the airframe again required major repairs. On 10 May in 1951, Zeise returned to the program, flying final unpowered test flights with the 346-2, and from 6 June, unpowered tests of the 346-3 without accidents.

Final flights



346-3 taking-off under a wing of B-29

By the mid-1951 **346-3** was completed, and Zeise flew it under power for the first time on 13 August 1951, using only one of the plane engines. Continuing concerns about the aircraft controlling at high speeds had led to a limitation of Mach 0.9 being placed on test flights. Zeise flew it again on 2 September and 14 September. On these last flight, however, things went drastically wrong. Separating from the carrier plane at 9,300 meters (30,500 ft) above Lukovici airfield, pilot fired his engine and accelerated to a speed of 900 km/h (560 mph). The rocket engine worked as expected, and 346-3, quickly accelerating, started ascending and soon had flown in very close proximity to its carrier aircraft. Zeise then reported that the plane was not responding to the controls, and was losing altitude. Ground control commanded him to bail out. He used the escape capsule to leave the stricken aircraft at 6,500 meters (21,000 ft) and landed safely by parachute. With the loss of this aircraft, the 346 program was abandoned.

Variants

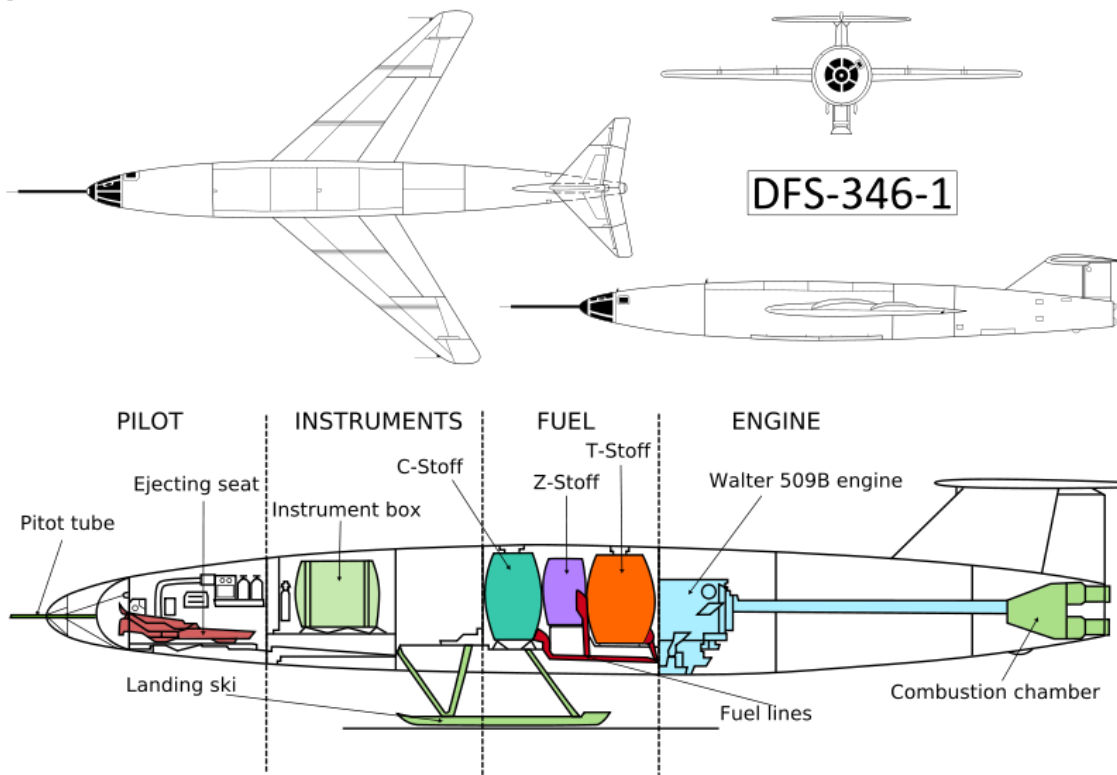
- **DFS-346** - First prototype built by Siebel Werke in the early 1940s. Later taken to USSR where the newly formed OKB-2 tested it in TsAGI wind tunnel. Later scrapped, because it was not flyable.
- **346-P** - This airframe was first post-war build of this plane, and was completed in 1948 by German engineers. Visually 346-P was identical to the earlier design, excepting a landing gear cowl which was removed primarily for lightening the airframe. This prototype also featured mounted under wing supports, to help stop the plane when landed.
- **346-1(A)** - On the 5 May 1949 construction of 346-1 was finished. It had a rocket engine mock up installed, and incorporated some minor changes in the rudder and tail design.
- **346-2(D)** - The same as 346-1, but the rocket engines fitted.
- **346-3** - Only plane that flew rocket-engine powered, and twice went transonic.

Operators

■ Soviet Union

- Soviet Air Force

Specifications (346-3)



346-3 Cross-section

General characteristics

- **Crew:** one, pilot
- **Length:** 44 ft 1 in (13.45 m)
- **Wingspan:** 29 ft 6 in (9 m)
- **Height:** 11 ft 7 in (3.54 m)
- **Wing area:** 213 ft² (19.9 m²)
- **Airfoil:** DFS 346#Design
- **Empty weight:** 4,806 lb (2,100 kg)
- **Loaded weight:** 11,506 lb (5,230 kg)
- **Powerplant:** 1× Walter HWK 109-509 rocket, 33.4 kN (7,500 lbf) 33.4 kN

Performance

- **Never exceed speed:** 2,765 km/h (estimated) (1,723 mph)
- **Maximum speed:** 900 km/h (verified) (560 mph)
- **Service ceiling:** 35,000 m (estimated) (114,800 ft)
- **Rate of climb:** 6,000 m/min (estimated) (19,680 ft/min)

Chapter 14

Douglas Skyrocket

Douglas Skyrocket



Douglas Skyrocket D-558-2

Role	Experimental high-speed research aircraft
Manufacturer	Douglas Aircraft Company
First flight	4 February 1948
Primary user	U.S. Navy
Number built	3
Developed from	D-558-1

The **Douglas Skyrocket (D-558-2 or D-558-II)** was a rocket and jet-powered supersonic research aircraft built by the Douglas Aircraft Company for the United States Navy. On 20 November 1953, shortly before the 50th anniversary of powered flight, Scott Crossfield piloted the Douglas D-558-2 Skyrocket to Mach 2, or more than 1,290 mph (2076 km/h), the first time an aircraft had exceeded twice the speed of sound.

Design and development

The "-2" in the aircraft's designation referred to the fact that the Skyrocket was the phase-two version of what had originally been conceived as a three-phase program. The phase-one aircraft, the D-558-1, was jet powered and had straight wings. The third phase, which never came to fruition, would have involved constructing a mock-up of a combat type aircraft embodying the results from the testing of the phase one and two aircraft. The eventual D-558-3 design, which was never built, was for a hypersonic aircraft similar to the North American X-15.

When it became obvious that the D558-1 fuselage could not be modified to accommodate both rocket and jet power, the D558-2 was conceived as an entirely different aircraft. A contract change order was issued on 27 January 1947 to formally drop the final three D558-1 aircraft and substitute three new D558-2 aircraft instead.

The Skyrocket featured wings with a 35-degree sweep and horizontal stabilizers with 40-degree sweep. The wings and empennage were fabricated from aluminum and the large fuselage was of primarily magnesium construction. The Skyrocket was powered by a Westinghouse J34-40 turbojet engine fed through side intakes in the forward fuselage. This engine was intended for takeoff, climb and landing. For high speed flight, a four-chamber Reaction Motors LR8-RM-6 engine (the Navy designation for the Air Force's XLR-11 used in the Bell X-1), was fitted. This engine was rated at 6,000 lbf (27 kN) static thrust at sea level. A total of 250 gallons (946 liters) of aviation fuel, 195 gallons of alcohol, and 180 gallons of liquid oxygen were carried in fuselage tanks.

The Skyrocket was configured with a flush cockpit canopy, but visibility from the cockpit was poor, so it was re-configured with a raised cockpit with conventional angled windows. This resulted in a greater profile area at the front of the aircraft, which was balanced by an additional 14 inches (36 cm) of height added to the vertical stabilizer. Like its predecessor, the D558-1, the D558-2 was designed so that the forward fuselage, including cockpit, could be separated from the rest of the aircraft in an emergency. Once the forward fuselage had decelerated sufficiently, the pilot would then be able to escape from the cockpit by parachute.

Operational history

Douglas pilot John F. Martin made the first flight at Muroc Army Airfield (later renamed Edwards Air Force Base) in California on 4 February 1948 in an aircraft equipped only with the jet engine. The goals of the program were to investigate the characteristics of swept-wing aircraft at transonic and supersonic speeds with particular attention to pitch-up (un-commanded rotation of the nose of the aircraft upwards), a problem prevalent in high-speed service aircraft of that era, particularly at low speeds during takeoff and landing, and in tight turns.

The three aircraft gathered a great deal of data about pitch-up and the coupling of lateral (yaw) and longitudinal (pitch) motions; wing and tail loads, lift, drag and buffeting

characteristics of swept-wing aircraft at transonic and supersonic speeds; and the effects of the rocket exhaust plume on lateral dynamic stability throughout the speed range. (Plume effects were a new experience for aircraft.) The number three aircraft also gathered information about the effects of external stores (bomb shapes, drop tanks) upon the aircraft's behavior in the transonic region (roughly 0.7 to 1.3 times the speed of sound). In correlation with data from other early transonic research aircraft such as the XF-92A, this information contributed to solutions to the pitch-up problem in swept-wing aircraft.

Its flight research was done at the NACA's Muroc Flight Test Unit in California, redesignated in 1949 the High-Speed Flight Research Station (HSFRS). The HSFRS became the High-Speed Flight Station in 1954 and is now known as the NASA Dryden Flight Research Center.



The Douglas Skyrocket was dropped from a Navy B-29

The three aircraft flew a total of 313 times – 23 by the number one aircraft (Bureau No. 37973—NACA 143), 103 by the second Skyrocket (Bureau No. 37974 – NACA 144), and 87 by aircraft number three (Bureau No. 37975 – NACA 145). Skyrocket 143 flew all but one of its missions as part of the Douglas contractor program to test the aircraft's performance.

NACA aircraft 143 was initially powered by the jet engine only, but was later fitted with the rocket engine. In this configuration, it was tested by Douglas from 1949 to 1951. After Douglas' test program, it was delivered to NACA, who stored it until 1954. In 1954-55 the contractor modified it to an all-rocket air-launch capability with the jet engine removed. In this configuration, NACA research pilot John McKay flew the aircraft only once for familiarization on 17 September 1956. The 123 flights of NACA 143 served to validate wind-tunnel predictions of the aircraft's performance, except for the fact that the aircraft experienced less drag above Mach 0.85 than the wind tunnels had indicated.

NACA 144 also began its flight program with a turbojet powerplant. NACA pilots Robert A. Champine and John H. Griffith flew 21 times in this configuration to test airspeed calibrations and to research longitudinal and lateral stability and control. In the process, during August 1949 they encountered pitch-up problems, which NACA engineers recognized as serious because they could produce a limiting and dangerous restriction on flight performance. Hence, they determined to make a complete investigation of the problem.

In 1950, Douglas replaced the turbojet with an LR-8 rocket engine, and its pilot, Bill Bridgeman, flew the aircraft seven times up to a speed of Mach 1.88 (1.88 times the speed of sound) and an altitude of 79,494 ft (24,230 m), the latter an unofficial world's altitude record at the time, achieved on 15 August 1951. In the rocket configuration, a Navy P2B (Navy version of the B-29) launched the aircraft at approximately 30,000 feet (9,000 m) after taking off from the ground with the Skyrocket attached beneath its bomb bay. During Bridgeman's supersonic flights, he encountered a violent rolling motion known as lateral instability that was less pronounced on the Mach 1.88 flight on 7 August 1951, than on a Mach 1.85 flight in June when he pushed over to a low angle of attack (angle of the fuselage or wing to the prevailing wind direction).

The NACA engineers studied the behavior of the aircraft before beginning their own flight research in the aircraft in September 1951. Over the next couple of years, NACA pilot Scott Crossfield flew the aircraft 20 times to gather data on longitudinal and lateral stability and control, wing and tail loads, and lift, drag, and buffeting characteristics at speeds up to Mach 1.878.

At that point, Marine Lt. Col. Marion Carl flew the aircraft to a new (unofficial) altitude record of 83,235 feet (25,370 m) on 21 August 1953, and to a maximum speed of Mach 1.728.

Following Carl's completion of these flights for the Navy, NACA technicians at the High-Speed Flight Research Station (HSFRS) near Mojave, California, outfitted the LR-8 engine's combustion chambers with nozzle extensions to prevent the exhaust gas from affecting the rudders at supersonic speeds. This addition also increased the engine's thrust by 6.5 percent at Mach 1.7 and 70,000 feet (21,300 m).

Even before Marion Carl had flown the Skyrocket, HSFRS Chief Walter C. Williams had petitioned NACA headquarters unsuccessfully to fly the aircraft to Mach 2 to garner the research data at that speed. Finally, after Crossfield had secured the agreement of the Navy's Bureau of Aeronautics, NACA director Hugh L. Dryden relaxed the organization's usual practice of leaving record setting to others and consented to attempting a flight to Mach 2.

In addition to adding the nozzle extensions, the NACA flight team at the HSFRS chilled the fuel (alcohol) so more could be poured into the tank and waxed the fuselage to reduce drag. With these preparations and employing a flight plan devised by project engineer Herman O. Ankenbruck to fly to approximately 72,000 feet (21,900 m) and push over into a slight dive, Crossfield made aviation history on 20 November 1953, when he flew to Mach 2.005, 1,291 miles per hour (2,078 km/h). He became the first pilot to reach Mach 2 in this, the only flight in which the Skyrocket flew that fast.

Following this flight, Crossfield and NACA pilots Joseph A. Walker and John B. McKay flew the aircraft for such purposes as to gather data on pressure distribution, structural loads, and structural heating, with the last flight in the program occurring on 20 December 1956, when McKay obtained dynamic stability data and sound-pressure levels at transonic speeds and above.

Meanwhile, NACA 145 had completed 21 contractor flights by Douglas pilots Eugene F. May and William Bridgeman in November 1950. In this jet-and-rocket-propelled craft, Scott Crossfield and Walter Jones began the NACA's investigation of pitch-up lasting from September 1951 well into summer 1953. They flew the Skyrocket with a variety of wing-fence, wing-slat and leading edge chord extension configurations, performing various maneuvers as well as straight-and-level flying at transonic speeds. While fences significantly aided recovery from pitch-up conditions, leading edge chord extensions did not, disproving wind-tunnel tests to the contrary. Slats (long, narrow auxiliary airfoils) in the fully open position eliminated pitch-up except in the speed range around Mach 0.8 to 0.85.

In June 1954, Crossfield began an investigation of the effects of external stores (bomb shapes and fuel tanks) upon the aircraft's transonic behavior. McKay and Stanley Butchart completed the NACA's investigation of this issue, with McKay flying the final mission on 28 August 1956.

Besides setting several records, the Skyrocket pilots had gathered important data and understanding about what would and would not work to provide stable, controlled flight of a swept-wing aircraft in the transonic and supersonic flight regimes. The data they gathered also helped to enable a better correlation of wind-tunnel test results with actual flight values, enhancing the abilities of designers to produce more capable aircraft for the armed services, especially those with swept wings. Moreover, data on such matters as stability and control from this and other early research aircraft aided in the design of the Century Series of fighter aircraft, all of which featured the movable horizontal stabilizers first employed on the X-1 and D-558 series.

Variants

All three of the Skyrockets had 35-degree swept wings.

Until configured for air launch, NACA 143 featured a Westinghouse J-34-40 turbojet engine rated at 3,000 lb force (13 kN) static thrust. It carried 260 U.S. gallons (980 l) of aviation gasoline and weighed 10,572 lb (4,795 kg) at takeoff.

NACA 144 (and NACA 143 after modification in 1955) was powered by an LR-8-RM-6 rocket engine rated at 6,000 pounds force (27 kN) static thrust. Its propellants were 345 U.S. gallons (1,306 l) of liquid oxygen and 378 US gallons (1,431 l) of diluted ethyl alcohol. In its launch configuration, it weighed 15,787 lb (7,161 kg).

NACA 145 had both an LR-8-RM-5 rocket engine rated at 6,000 lb force (27 kN) static thrust and featured a Westinghouse J-34-40 turbojet engine rated at 3,000 lb force (13 kN) static thrust. It carried 170 U.S. gallons (644 l) of liquid oxygen, 192 U.S. gallons (727 l) of diluted ethyl alcohol, and 260 U.S. gallons (984 l) of aviation gasoline for a launch weight of 15,266 lb (6,925 kg).

Aircraft serial numbers

- **D-558-2 Skyrocket**
 - **D-558-2 #1** - #37973 NACA-143, 123 flights
 - **D-558-2 #2** - #37974 NACA-144, 103 flights
 - **D-558-2 #3** - #37975 NACA-145, 87 flights

Survivors

D-558-2 #1 Skyrocket is on display at the Planes of Fame Museum, Chino, California. The number two Skyrocket, the first aircraft to fly Mach 2, is on display at the National Air and Space Museum in Washington D.C. The number three is displayed on a pedestal at Antelope Valley College, Lancaster, California.

Specifications (D-558-2 Skyrocket)

General characteristics

- **Crew:** one pilot
- **Length:** 42 ft 0 in (12.8 m)
- **Wingspan:** 25 ft 0 in (7.6 m)
- **Height:** 22 ft 8 in (3.8 m)
- **Wing area:** 175 ft² (16.2 m²)
- **Empty weight:** 9,421 lb (4,273 kg)
- **Max takeoff weight:** 15,266 lb (6,923 kg)
- **Powerplant:**
 - 1× Westinghouse J34-WE-40 turbojet, 3,000 lbf (13 kN)

- 1× Reaction Motors XLR-8-RM-5 rocket engine, 6,000 lbf (27 kN)

Performance

- **Maximum speed:** 720 mph, 1,250 mph when air-launched (1,160 km/h, 2,010 km/h when air-launched)
- **Stall speed:** 160.1 mph (257.7 km/h)
- **Service ceiling:** 16,500 ft (5,030 m)
- **Rate of climb:** 22,400 ft/min, 11,100 ft/min under rocket power only (6,830 m/min., 3,380 m/min under rocket power only)
- **Wing loading:** 87.2 lb/ft² (426 kg/m²)
- **Thrust/weight (jet):** 0.39

Chapter 15

Saunders-Roe SR.53 and Heinkel He 176

Saunders-Roe SR.53

Saunders Roe SR.53



The second SR.53 on display at the September 1957 Farnborough Air Show

Role	Interceptor
Manufacturer	Saunders-Roe
Designed by	Maurice Brennan
First flight	16 May 1957
Status	Experimental
Primary user	United Kingdom
Number built	2
Variants	Saunders-Roe SR.177

The **Saunders-Roe SR.53** was a prototype interceptor aircraft of mixed jet and rocket propulsion developed for the Royal Air Force in the early 1950s. Although its performance was promising, the need for such an aircraft was soon overtaken by surface-to-air missile development, consequently the project was cancelled after 56 test flights.

Design and development

The Second World War demonstrated the importance of strategic bombing to modern warfare, and as the Cold War developed, devising effective air defence against large waves of enemy bomber aircraft became a priority for many nations. Nazi Germany had looked to rocket-powered aircraft to fill this niche, with machines like the Messerschmitt Me 163 and Bachem Ba 349, which were capable of unparalleled rates-of-climb, enabling them to (at least in theory) rise to meet and intercept enemy bombers before they reached their targets. German rocket technology was studied extensively by the Allies in the aftermath of the war, and in light of the threat of the growing Soviet strategic bomber fleet and that nation's newly-developed atomic weapons, the UK's Air Ministry drafted an Operational Requirement O.R. 301 in May 1951 for a rocket-powered interceptor that could reach an altitude of 60,000 ft (18,300 m) in just 2 minutes 30 seconds. This was circulated to the nation's aircraft manufacturers the following February.

The development of the de Havilland Sprite (5,000 lb thrust) and the Armstrong Siddeley Snarler (2,000 lb thrust) for RATO use led to the possibility of a more powerful rocket engine being developed as the planned powerplant for a "point defence" interceptor. The requirements of the O.R. 301 were considered onerous including a ramp launch and landing on a skid, and with the compliance of the companies approached to tender, the amended Specification G124T allowed for a mixed powerplant configuration and a conventional undercarriage.



Colour drawing of the first SR.53

Of the six companies that tendered proposals, two were selected for development contracts, A.V. Roe with their Avro 720 and Saunders-Roe with their **SR.53**. Further refinement of the concept led to the defined Specification O.R. 337. The SR.53 itself was a sleek aircraft with a sharply pointed nose, delta-like wing, and a T-tail. The Armstrong Siddeley Viper jet and de Havilland Spectre rocket engine and exhausts were mounted one atop the other in the tail.

By September 1953, the programme to develop these aircraft came under scrutiny due to cost cuts, and the Avro 720 was abandoned, although it seemed almost ready to fly at this point. One of the reasons for preferring the SR.53 was although the aircraft was developmentally behind, its use of hydrogen peroxide as an oxidiser was viewed as less problematic than the Avro 720's use of liquid oxygen. With an original contract to build three prototypes, the SR.53 was scheduled for a first flight in July 1954 with a service introduction date set for 1957. At the same time, Saunders-Roe began work on a derivative design, the SR.177, which was large enough to carry a useful radar, essential to interception at the high altitudes where the new fighter was meant to operate, despite the fact that the specification did not require it. The new, larger aircraft was developed into versions for maritime use by the Royal Navy and for West Germany as well as for the RAF.

Operational history

The complexity of the design caused a series of setbacks, notably an explosion during ground tests of the Spectre rocket engine. The SR.53's first flight began to fall further and further behind schedule. On 16 May 1957, Squadron Leader John S. Booth DFC was at the controls of XD145 for the first test flight, following up with the maiden flight of the second prototype XD151, on 6 December 1957. Test results indicated "...an extremely docile and exceedingly pleasant aircraft to fly, with very well harmonized controls." Both prototypes flew a total of 56 test flights, with Mach 1.33 speeds being obtained.

While testing at RAE Boscombe Down, XD151 crashed on 15 June 1958 during an aborted takeoff on its 12th flight. Running off the runway, the aircraft struck a concrete approach light, exploding on impact and killing its pilot, Squadron Leader Booth. The remaining prototype continued to fly with Lt Cdr Peter Lamb taking over the flight test programme.

Cancellation

It was 1957 before the first SR.53 took to the air, just over a month after the infamous 1957 Defence White Paper had been published outlining the British government's policy to largely abandon piloted aircraft in favour of concentrating on missile development. At the same time, jet engine development had progressed a long way in the six years since the SR.53's initial design. Combined with the fact that improvements in radar had meant that any incoming bomber threat could be detected much earlier, the need for an aircraft like the SR.53 had disappeared, and the project was cancelled on 29 July 1960, with the third prototype (XD153) never built.

Aircraft on display

The first SR.53 prototype, *XD145*, is preserved at the Royal Air Force Museum Cosford near Wolverhampton.

Operators

 United Kingdom

- Ministry of Supply

Specifications

General characteristics

- **Crew:** One, pilot
- **Length:** 45 ft 0 in (13.72 m)
- **Wingspan:** 25 ft 1½ in (7.66 m)
- **Height:** 10 ft 10 in (3.30 m)
- **Wing area:** 274 ft² (25.5 m²)
- **Airfoil:** RAE102
- **Empty weight:** 7,400 lb (3,360 kg)
- **Loaded weight:** 18,400 lb (8,360 kg)
- **Powerplant:**
 - 1× Armstrong Siddeley Viper 8 turbojet, 1,640 lb (7.3 kN)
 - 1× de Havilland Spectre rocket, 8,000 lbf (35.7 kN)

Performance

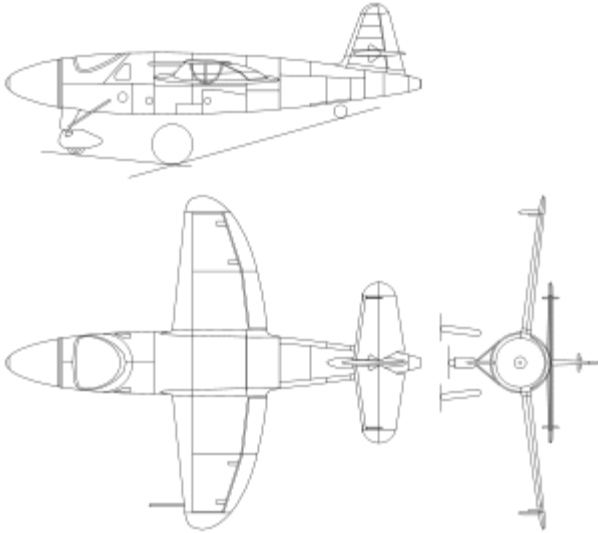
- **Maximum speed:** Mach 2.2
- **Endurance:** 7 minutes at full power
- **Service ceiling:** 67,000 ft (20,420 m)
- **Rate of climb:** 52,800 ft/min (270 m/s) : 2 min 12 sec from brakes to 50,000 ft
- **Wing loading:** 67.2 lb/ft² (328 kg/m²)
- **Thrust/weight (jet):** 0.52

Armament

- **Missiles:** 2 × de Havilland Firestreak infra-red guided missiles

Heinkel He 176

Heinkel He 176



World's first aircraft to be propelled solely by a liquid-fuelled rocket

Role	Experimental
Manufacturer	Heinkel
Designed by	Walter Günter
First flight	June 20, 1939 – at the controls Test pilot Erich Warsitz
Status	Cancelled
Number built	1

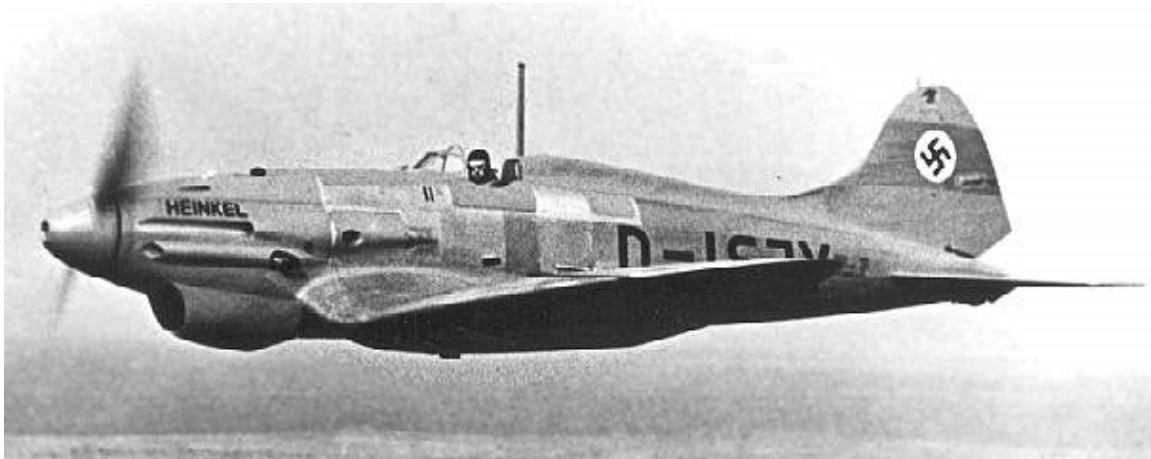
The **Heinkel He 176** was a German rocket-powered aircraft. It was the world's first aircraft to be propelled solely by a liquid-fuelled rocket, making its first powered flight on 20 June 1939 with Erich Warsitz at the controls.

Early experiments

During the 1920s, German daredevils had experimented with using solid-fuel rockets to propel cars, motorcycles, railway carriages, snow sleds, and, by 1929, aircraft such as Alexander Lippisch's *Ente* and Fritz von Opel's RAK.1. Solid-fuel rockets, however, have major disadvantages when used for aircraft propulsion, as their thrust cannot be regulated, and the engines cannot be shut down once fired.

In 1931, the Army Weapons Office testing ground at Kummersdorf had taken over research into liquid-fuel rockets. In 1932, Wernher von Braun designed a rocket of this kind which used high percentage spirit (alcohol) and liquid oxygen. With this he made

the first experiments. In 1934 he fired his second rocket type, the A2, from the North Sea island of Borkum.



A regular He 112.

During 1936 von Braun's rocketry team working at Kummersdorf investigated installing liquid-fuelled rockets in aircraft. Ernst Heinkel enthusiastically supported their efforts, supplying a He 72 and later two He 112s for the experiments. Late in 1936 Erich Warsitz was seconded by the RLM to Wernher von Braun and Ernst Heinkel, because he had been recognized as one of the most experienced test-pilots of the time, and because he also had an extraordinary fund of technical knowledge. In June 1937, at Neuhardenberg (a large field about 70 kilometres east of Berlin, listed as a reserve airfield in the event of war), one of these latter aircraft was flown by test pilot Erich Warsitz with its piston engine shut down during flight, at which time it was propelled by von Braun's rocket power alone. Despite the wheels-up landing and having the fuselage on fire, it proved to official circles that an aircraft could be flown satisfactorily with a back-thrust system through the rear.

At the same time, Hellmuth Walter's experiments into Hydrogen peroxide-based rockets were leading towards light and simple rockets that appeared well-suited for aircraft installation. Also the firm of Hellmuth Walter at Kiel had been commissioned by the RLM to build a rocket engine for the He 112, so there were two different new rocket motor designs at Neuhardenberg: whereas the von Braun's engines were powered by alcohol and liquid oxygen, Walter engines had hydrogen peroxide and calcium permanganate as a catalyst. Von Braun's engine used direct combustion and created fire, the Walter devices hot vapours from a chemical reaction, but both created thrust and provided high speed. The subsequent flights with the He 112 used the Walter-rocket instead of von Braun's; it was more reliable, simpler to operate and the dangers to test pilot Erich Warsitz and machine were less.

Heinkel He 176

Design and development

The allegation often repeated by technical experts that Heinkel made the first rocket aircraft, the He 176, as a 'black machine', without the approval of, or having been contracted by, the RLM, is totally false. In 1936, RLM awarded Heinkel a contract to build the world's first pure rocket aircraft, remaining fully informed of the project's progress and Heinkel's intentions. During the development programme at Neuhardenberg with the He 112, the term "interceptor" had been coined, and the He 176 was seen as the research machine for the project. RLM was really thinking along the lines of a new kind of fighter aircraft. With a fantastic rate of climb it would take off almost vertically to intercept enemy bomber formations at 6000 – 7000 metres, make a swift attack from below at high speed, emptying the MGs or cannons into the enemy machines and then land once the fuel tanks were dry.

Because the He 176 development was classified top secret, Heinkel set up a special department in his Rostock-Marienehe works. A wooden barrack hut was erected first for the initial testing. Only very few employees were allowed access. This "shed" was soon converted into a permanent building. The development then progressed very quickly. Meanwhile work also went ahead to build the He 176 mock-up because time was pressing.

The He 176 was built as an all-metal aircraft to utilise one of the new Walter engines (HWK RI-203). Completely new was the wing-flow profile designed for supersonic speed whose leading edges were razor sharp. This increased the danger of losing the airstream at lower speeds needed for safe landings. The wings had been designed from the beginning as fuel containers but the riveting was problematical because the wings were so flat and only explosive studs were suitable, otherwise they would never have gotten leak-proof.

The He 176 did possess an advanced, totally-enclosed cockpit, with a frameless single-piece clear nose, through which the pilot's rudder pedal mounts were visible, and a flush upper cockpit glazing which was removable for entering the aircraft, making the cockpit fit completely within the forward, bullet-like contours of the fuselage. The landing gear was a combination of conventional and tricycle gear designs, with the main gear's struts intended to retract rearwards into the fuselage, with a fixed, aerodynamically faired nose wheel and strut, and a retractable tail wheel.

A unique feature of the He 176 was its jettisonable nose escape system. Compressed air was used to separate the nose from the aircraft. A drogue parachute was used to reduce the opening force required. After the drogue was deployed, the flush-fitting cockpit canopy was released and a conventional bailout occurred.

Maiden flight



Flight Captain Erich Warsitz.

With a new kind of aircraft like this one does not simply get in and take off. Ground work began with rolling tests to establish the characteristics on the runway at Peenemünde.

Until then Heinkel had intentionally avoided demonstrating the machine to the Luftwaffe generals, but in the end a visit by an RLM party led by Udet, Milch and half the General Staff could no longer be put off.

Once Warsitz was convinced that he knew all the peculiarities and wrinkles of the aircraft through the programme of rolling trials and short leaps, one fine summer's evening (June 20, 1939) he announced spontaneously his decision to attempt the maiden flight immediately. A strange silence fell over all the engineers and assembly workers: nobody spoke, for all sensed that the decisive moment for the future was at hand.

Further flights and demonstrations

On the next day (June 21, 1939) Heinkel, Udet and a whole Staff of Peenemünde officers came to witness the second successful flight. Erich Warsitz had his confidence up this second time and made an impressive pass at low level.

After this maiden flight, systematic development work was no longer possible. Despite all the secrecy the sensational news went round the higher circles at RLM like wildfire, and after that the He 176-Team basically did nothing but give demonstration flights - with immediate effect all future flights, including short leaps, were forbidden because a display had been arranged for the Führer on July 3, 1939. The big air show for Hitler, the Party high-ups and the Luftwaffe Generals was to be at Rechlin.

Further development stopped

Heinkel was now a little bitter at not receiving the support he expected and needed, for after the first flights it seemed interest in it had died away. Not all people in the decisive area at RLM had lost interest, but war was looming and there were other things to think about. The Führer-Directive, ordering all developments not ready for mass-production within a year to be suspended with immediate effect, led to the abandonment of Heinkel's rocket propulsion programme. Testing of the He 176 ended with only one aircraft being built. It was put on display at the Berlin Air Museum and was destroyed by an Allied bombing raid in 1943.

Prior to the cancellation of the programme, plans had been drawn up for a more sophisticated rocket-plane, still designated He 176. This was never constructed, but because it bore the same designation as the aircraft that was actually flown, many books and websites mistakenly publish pictures of it to illustrate its earlier namesake.

Germany did eventually fly an operational rocket-propelled fighter, the Me 163 *Komet*, but this was made by the competing Messerschmitt firm, using an engine that was a further development of the one that powered the He 176.

Specifications (He 176 V1)

General characteristics

- **Crew:** One
- **Length:** 5.2 m (17 ft 1 in)
- **Wingspan:** 5.0 m (16 ft 5 in)
- **Height:** 1.5 m (4 ft 11 in)
- **Wing area:** 5.4 m² (58 ft²)
- **Empty weight:** 900 kg (1,980 lb)
- **Loaded weight:** 1,620 kg (3,570 lb)

Performance

- **Maximum speed:** 345 km/h [750 km/h theoretical] (215 mph [470 mph theoretical])
- **Range:** 95 km [theoretical] (60 mi)
- **Service ceiling:** 9,000 m [theoretical] (29,500 ft)
- **Rate of climb:** 60.6 m/s (199 ft/s)
- **Endurance** 50 s

Chapter 16

SpaceShipOne



Astronaut Mike Melvill after his September 29, 2004 spaceflight



SpaceShipOne in the National Air and Space Museum in Washington D.C. with the Spirit of Saint Louis and Bell X-1 "Glamorous Glennis"

SpaceShipOne is a retired suborbital air-launched spaceplane that completed the first manned private spaceflight in 2004. That same year, it won the \$10 million Ansari X Prize and was immediately retired from active service. Its mothership was named "White Knight". Both craft were developed and flown by Mojave Aerospace Ventures, which was a joint venture between Paul Allen and Scaled Composites, Burt Rutan's aviation company. Allen provided the funding of approximately \$25 million.

Rutan has indicated that ideas about the project began as early as 1994 and the full-time development cycle time to the 2004 accomplishments was about three years. SpaceShipOne's first official spaceflight, known as flight 15P, was piloted by Mike Melvill. A few days before that flight, the Mojave Air and Space Port was licensed as the USA's first commercial spaceport. A few hours after that flight, Melvill became the first licensed U.S. commercial astronaut. The overall project name was "Tier One" which has evolved into Virgin Galactic Tier 1b with a goal of taking a successor ship's first passengers into space within the next few years.

Development and winning the X Prize



(L to R) Marion Blakely (FAA), Mike Melvill; Richard Branson, Burt Rutan, Brian Binnie, and Paul Allen reflect on a mission accomplished (October 4, 2004)

SpaceShipOne was developed by Mojave Aerospace Ventures (a joint venture between Paul Allen and Scaled Composites, Burt Rutan's aviation company, in their Tier One program), without government funding. On June 21, 2004, it made the first privately funded human spaceflight. On October 4, it won the \$10 million Ansari X Prize, by reaching 100 kilometers in altitude twice in a two-week period with the equivalent of three people on board and with no more than ten percent of the non-fuel weight of the spacecraft replaced between flights. Development costs were estimated to be \$25 million, funded completely by Paul Allen.

During its test programme, SpaceShipOne set a number of important "firsts", including first privately funded aircraft to exceed Mach 2 and Mach 3, first privately funded manned spacecraft to exceed 100km altitude, and first privately funded reusable manned spacecraft.

SpaceShipOne is an experimental air-launched rocket-powered aircraft with suborbital flight capability that uses a hybrid rocket motor. The design features a unique "feathering" atmospheric reentry system where the rear half of the wing and the twin tail booms folded upward along a hinge running the length of the wing; this increased drag

while remaining stable. The achievements of SpaceShipOne are more comparable to the X-15 than orbiting spacecraft like the Space Shuttle. Accelerating a spacecraft to orbital speed requires more than 60 times as much energy as accelerating it to Mach 3.



SpaceShipOne connected to its mother ship White Knight



SpaceShipOne landing after its June 21, 2004 space flight (Flight 15P)

SpaceShipOne is registered with the FAA as **N328KF**. *N* is the prefix for US-registered aircraft; *328KF* was chosen by Scaled Composites to stand for 328 K (abbreviation for 1000) feet (about 100 kilometers), the officially designated edge of space. The original choice of registry number, **N100KM**, was already taken. N328KF is registered as a glider, reflecting the fact that most of its independent flight is unpowered.

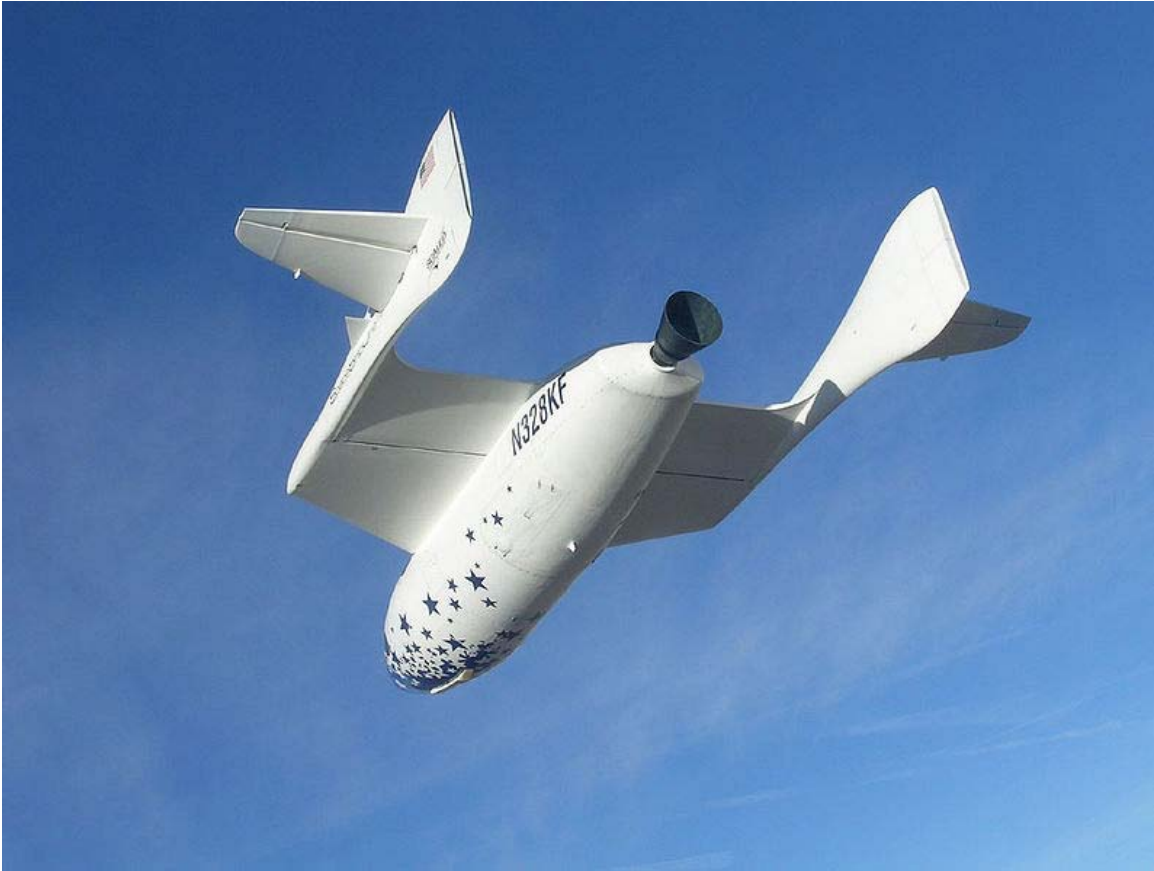
SpaceShipOne's first flight, 01C, was an unmanned captive carry flight test on May 20, 2003. Glide tests followed, starting with flight 03G on August 7, 2003. Its first powered flight, flight 11P, was made on December 17, 2003, the 100th anniversary of the first powered flight.

On April 1, 2004, Scaled Composites received the first license for sub-orbital rocket flights to be issued by the US Office of Commercial Space Transportation. This license permitted the company to conduct powered test flights over the course of one year. On June 17, 2004, Mojave Airport reclassified itself (part-time) as the Mojave Spaceport.

Flight 15P on June 21, 2004, was SpaceShipOne's first spaceflight, and the first privately funded human spaceflight. There were a few control issues, but these were resolved prior to the Ansari X PRIZE flights that followed, with flight 17P on October 4, 2004, winning the prize.

The SpaceShipOne Team was awarded the Space Achievement Award by the Space Foundation in 2005.

Flights



SpaceShipOne in flight



Cockpit of WhiteKnight in flight, EFIS display edited to look like SpaceShipOne

All of the flights of SpaceShipOne were from the Mojave Airport Civilian Flight Test Center. Flights were numbered, starting with flight 01 on May 20, 2003. One or two letters are appended to the number to indicate the type of mission. An appended **C** indicates that the flight was a captive carry, **G** indicates an unpowered glide, and **P** indicates a powered flight. If the actual flight differs in category from the intended flight, two letters are appended: the first indicating the intended mission and the second the mission actually performed.

In the table below, the "top speed" reported is the Mach number at burn-out (the end of the rocket burn). This is not an absolute speed.

SpaceShipOne flights

Flight Date	Top speed	Altitude	Duration	Pilot
01C May 20, 2003	Mach 0.53	14.63 km	1 h 48 min	unmanned
02C July 29, 2003		14 km	2 h 06 min	Mike Melvill
03G August 7, 2003	278 km/h	14.33 km	19 min 00 s	Mike Melvill
04GC August 27, 2003	370 km/h	14 km	1 h 06 min	Mike Melvill
05G August 27, 2003	370 km/h	14.69 km	10 min 30 s	Mike Melvill

06G	September 23, 2003	213 km/h	14.26 km	12 min 15 s	Mike Melvill
07G	October 17, 2003	241 km/h	14.08 km	17 min 49 s	Mike Melvill
08G	November 14, 2003	213 km/h	14.42 km	19 min 55 s	Peter Siebold
09G	November 19, 2003	213 km/h	14.72 km	12 min 25 s	Mike Melvill
10G	December 4, 2003	213 km/h	14.75 km	13 min 14 s	Brian Binnie
11P	December 17, 2003	Mach 1.2	20.67 km	18 min 10 s	Brian Binnie
12G	March 11, 2004	232 km/h	14.78 km	18 min 30 s	Peter Siebold
13P	April 8, 2004	Mach 1.6	32.00 km	16 min 27 s	Peter Siebold
14P	May 13, 2004	Mach 2.5	64.43 km	20 min 44 s	Mike Melvill
15P	June 21, 2004	Mach 2.9	100.124 km	24 min 05 s	Mike Melvill
16P	September 29, 2004	Mach 2.92	102.93 km	24 min 11 s	Mike Melvill
17P	October 4, 2004	Mach 3.09	112.014 km	23 min 56 s	Brian Binnie

The flights were accompanied by two chase planes; an Extra 300 owned and flown by Chuck Coleman, and a Beechcraft Starship.

Astronauts

The SpaceShipOne pilots came from a variety of aerospace backgrounds. Mike Melvill is a test pilot, Brian Binnie is a former Navy pilot, and Doug Shane and Peter Siebold are engineers at Scaled Composites. They qualified to fly SpaceShipOne by training on the Tier One flight simulator and in White Knight and other Scaled Composites aircraft.

Specifications



Rear view

General characteristics

- **Crew:** one, pilot
- **Capacity:** 2 passengers
- **Length:** 16 ft 5 in (8,05 m)
- **Wingspan:** 16 ft 5 in (8,05 m)
- **Height:** ()
- **Wing area:** 161.4 ft² (15 m²)
- **Empty weight:** 2,640 lb (1,200 kg)
- **Loaded weight:** 7,920 lb (3,600 kg)
- **Powerplant:** 1× N2O/HTPB SpaceDev Hybrid rocket motor, 7,500 kgf (74 kN)
- **I_{sp}:** 250 s (2450 Ns/kg)
- **Burn time:** 87 seconds
- **Aspect Ratio:** 1.6

Performance

- **Maximum speed:** Mach 3.09 (2,170 mph, 3,518 km/h)
- **Range:** 35 nm (40 mi, 65 km)
- **Service ceiling:** 367,360 ft (112,000 m)
- **Rate of climb:** 82,000 ft/min (416.6 m/s)
- **Wing loading:** 49.07 lb/ft² (240 kg/m²)
- **Thrust/weight:** 2.08

Retirement



SpaceShipOne now hangs in the National Air and Space Museum in Washington D.C.

SpaceShipOne's spaceflights were watched by large crowds at Mojave Spaceport. A fourth suborbital flight, Flight 18P, was originally scheduled for October 13, 2004. However, Burt Rutan decided not to risk damage to the historic craft, and cancelled it and all future flights.

On July 25, 2005 SpaceShipOne was taken to the Oshkosh Airshow in Oshkosh, Wisconsin. After the airshow, Mike Melvill and crew flew the White Knight, carrying SpaceShipOne, to Wright-Patterson Air Force Base in Dayton, Ohio, where Mike spoke to a group of about 300 military and civilian personnel. Later in the evening, Mike gave a presentation at the Dayton Engineers Club, entitled "Some Experiments in Space Flight", in honor of Wilbur Wright's now famous presentation to the American Society of Mechanical Engineers in 1901 entitled "Some Experiments in Flight." The White Knight then transported SpaceShipOne to the Smithsonian Institution's National Air and Space Museum to be put on display. It was unveiled on Wednesday October 5, 2005 in the Milestones of Flight gallery and is now on display to the public in the main atrium between the Spirit of St. Louis and the Bell X-1.

SpaceShipOne became a popular model rocket in 2004. Estes Industries currently offers several flying model rockets of SpaceShipOne. A piece of SpaceShipOne's carbon fiber material was launched aboard the New Horizons mission to Pluto in 2006.

Replica



SpaceShipOne Replica in normal configuration

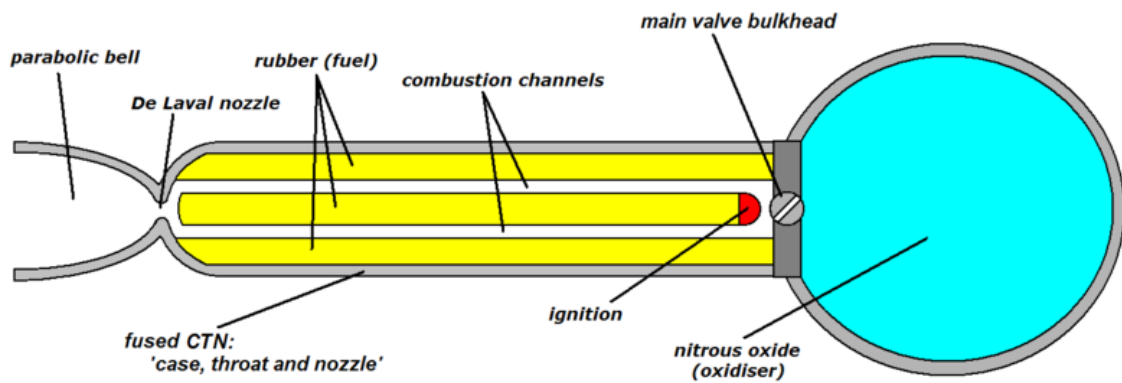
A year after its appearance in the Oshkosh Airventure airshow, the Experimental Aircraft Association featured a full-scale replica of the spacecraft in a wing of its museum which housed other creations of Burt Rutan. Using the same fiberglass molds as the original, it was so exact in its replication - despite not having any doors or interior - that it was dubbed "Serial 2 Scaled" by Scaled Composites. Each and every painstaking detail in its appearance was matched, down to the N328KF registration number on its fuselage. It is so precise that, during a video presentation held every hour in the museum, it can display the two different modes of its 'feathering' ability, albeit through the aid of pulleys and wires (there is no machinery in the replica).

Another full-scale replica of SpaceShipOne hangs in the rotunda of the William Thomas Terminal at Meadows Field Airport in Bakersfield and a third is on display in the Mojave Spaceport's Legacy Park alongside the original Roton Atmospheric Test Vehicle.

Future efforts

With the success of Tier One meeting its project goals, a successor project started in 2004 was Virgin Galactic Tier 1b. The successor ship names SpaceShipTwo and White Knight Two. The name of the joint venture between Virgin Group and Scaled Composites is called The Spaceship Company, with a goal of carrying passengers under the name Virgin Galactic spaceliner with an initial target of a commercial fleet of five spacecraft.

In August 2005, Virgin Galactic stated that if the upcoming suborbital service with SpaceShipTwo is successful, the follow-up SpaceShipThree.



Hybrid rocket engine detail of SpaceShipOne

Chapter 17

North American X-15

X-15



Role	Experimental high-speed rocket-powered research aircraft
Manufacturer	North American Aviation
First flight	8 June 1959
Introduced	17 September 1959
Retired	December 1970
Primary users	United States Air Force NASA
Number built	3

The **North American X-15** rocket-powered aircraft/spaceplane was part of the X-series of experimental aircraft, initiated with the Bell X-1, that were made for the USAAF/USAF, NACA/NASA, and the USN. The X-15 set speed and altitude records in the early 1960s, reaching the edge of outer space and returning with valuable data used in aircraft and spacecraft design. As of 2011, it holds the official world record for the fastest speed ever reached by a manned rocket powered aircraft.

During the X-15 program, 13 of the flights (by eight pilots) met the USAF spaceflight criteria by exceeding the altitude of 50 miles (80.5 km, 264,000 ft), thus qualifying the pilots for astronaut status. The USAF pilots qualified for USAF astronaut wings, while the civilian pilots were later awarded NASA astronaut wings.

Of all the X-15 missions, two flights (by the same pilot) qualified as space flights per the international (Fédération Aéronautique Internationale) definition of a spaceflight by exceeding 100 kilometres (62.1 mi, 328,084 ft) in altitude.

Design and development



X-15 just after release



X-15 touching down on its skids. Compare jettisoned lower ventral fin with color picture, top.

The X-15 was based on a concept study from Walter Dornberger for the NACA for a hypersonic research aircraft. The requests for proposal were published on 30 December 1954 for the airframe and on 4 February 1955 for the rocket engine. The X-15 was built by two manufacturers: North American Aviation was contracted for the airframe in November 1955, and Reaction Motors was contracted for building the engines in 1956.

Like most X-series aircraft, the X-15 was designed to be carried aloft, under the wing of a NASA B-52, the *Balls 8*. Release took place at an altitude of about 8.5 miles (13.7 km, 45,000 ft), and a speed of about 805 km/h (500 mph, 223.5 m/s). The X-15 fuselage was long and cylindrical, with rear fairings that flattened its appearance, and thick, dorsal and ventral wedge-fin stabilizers. Parts of the fuselage were heat-resistant nickel alloy (Inconel-X 750). The retractable landing gear comprised a nose-wheel carriage and two rear skis. The skis did not extend beyond the ventral fin, which required the pilot to jettison the lower fin (fitted with a parachute) just before landing. The two XLR-11 rocket engines for the initial **X-15A** model delivered 16,000 lb_f (71 kN) maximum thrust each, for a total of 32,000 pounds-force. The main engine (installed later) was a single XLR-99 rocket engine delivering 57,000 lb_f (250 kN) at sea level, and 70,000 lb_f (310 kN) at peak altitude. The idle thrust of the XLR-99 was 15,000 lb_f (67 kN).

Engines and fuel

Early flights used two Reaction Motors XLR11 engines. Later flights were undertaken with a single Reaction Motors Inc XLR99 rocket engine generating 57,000 pounds-force (250 kN) of thrust powered the aircraft. This engine used ammonia and liquid oxygen for propellant and hydrogen peroxide to drive the high-speed turbopump that delivered fuel to the engine. The XLR99 could be throttled, and were the first such controllable engines that were "man-rated", that is, declared safe to operate with a human aboard.

Operational history

Three X-15s were built, flying 199 test flights, the last on 24 October 1968. The first X-15 flight was an unpowered test flight by Scott Crossfield, on 8 June 1959; he also piloted the first powered flight, on 17 September 1959, with his first XLR-99 flight on 15 November 1960. Twelve test pilots flew the X-15; among them were Neil Armstrong (first man to walk on the moon) and Joe Engle (later a space shuttle commander). In July and August 1963, pilot Joe Walker crossed the 100 km altitude mark, joining the NASA astronauts and Soviet Cosmonauts as the only humans to have crossed the barrier into outer space (Soviet Yuri Gagarin was the first person in space, reaching 327 km in apogee of his orbital flight, while Alan Shepard was the first American in space, reaching 187 km during suborbital flight) and becoming the first to exceed this threshold twice.

U.S. Air Force test pilot Major Michael J. Adams was killed on 15 November 1967 in X-15 Flight 191 when his craft (X-15-3) entered a hypersonic spin while descending, then oscillated violently as aerodynamic forces increased after re-entry. As his craft's flight control system operated the control surfaces to their limits, the craft's acceleration built to 15 g vertical and 8 g lateral. The airframe broke apart at 60,000 ft (18,000 m) altitude, scattering the craft's wreckage for 50 square miles (130 km²). On 8 June 2004, a monument was erected at the cockpit's locale, near Randsburg, California. Major Adams was posthumously awarded Air Force astronaut wings for his final flight in craft X-15-3, which had reached 81.1 km (50.4 mi, 266,000 ft) of altitude. In 1991, his name was added to the Astronaut Memorial.



Bomber NB-52A (s/n 52-003), permanent test variant, carrying an X-15, with mission markings; horizontal X-15 craft silhouettes denote glide flights, diagonal silhouettes denote powered flights.

The second X-15A was rebuilt after a landing accident. It was lengthened 2.4 feet (0.73 m), a pair of auxiliary fuel tanks attached under the fuselage, and a heat-resistant surface treatment applied. Re-named the **X-15A-2**, it first flew on 28 June 1964, reaching 7,274 km/h (4,520 mph, 2,021 m/s).

The altitudes attained by the X-15 aircraft do not match that of Alan Shepard's 1961 NASA space capsule flight nor subsequent NASA space capsules and space shuttle flights. However, the X-15 flights did reign supreme among rocket-powered aircraft until the second spaceflight of Space Ship One in 2004.

Five aircraft were used for the X-15 program: three X-15s, two B-52 bombers:

- **X-15A-1** – 56-6670, 82 powered flights
- **X-15A-2** – 56-6671, 53 powered flights
- **X-15A-3** – 56-6672, 64 powered flights
- **NB-52A** – 52-003 (retired in October 1969)
- **NB-52B** – 52-008 (retired in November 2004)

A 200th flight over Nevada was slated for 21 November 1968, piloted by William J. Knight. Technical problems and bad weather delayed the flight six times, and on 20

December 1968, the 200th flight was finally cancelled. The X-15 was detached from the NB-52A wing and prepared for indefinite storage.

X-15 gallery



X-15A-2 on the flight line



X-15 on Boeing B-52 Mothership wing pylon



Dryden Flight Research Center ECN-1770 Photographed 1967
X-15 #2 full scale seal coat (NASA photo)



X-15 in full scale ablative coating



X-15 on display at the National Air and Space Museum



X-15 nose

Current static displays



X-15 at the National Air and Space Museum

- X-15-1 (s/n 56-6670) is on display in the National Air and Space Museum "Milestones of Flight" gallery, Washington, D.C.
- X-15-2A (s/n 56-6671) is at the National Museum of the United States Air Force, at Wright-Patterson Air Force Base, near Dayton, Ohio. It was retired to the Museum in October 1969. The aircraft is displayed in the Museum's Research & Development Hangar alongside other "X-planes", including the Bell X-1 and X-3 Stiletto.
- X-15-3 (s/n 56-6672) was destroyed. Parts have been recovered at the crash site as late as the 1990s.

Mock-ups

- Dryden Flight Research Center, Edwards AFB, California, USA (painted with s/n 56-6672)
- Pima Air Museum, Tucson, Arizona (painted with s/n 56-6671)
- Evergreen Aviation Museum, McMinnville, Oregon (painted with s/n 56-6672). A full-scale wooden mock-up of the X-15, displayed along with one of the rocket motors.

Stratofortress motherships

- NB-52A (s/n 52-003) is at the Pima Air and Space Museum, Tucson, Arizona. It launched the X-15 #1 30 times, the X-15 #2, 11 times, and the X-15 #3 31 times (as well as the M2-F2 four times, the HL-10 11 times and the X-24A twice).

- NB-52B (s/n 52-008) is at the Dryden Flight Research Center, Edwards AFB, California, USA. It launched the majority of X-15 flights.

Aftermath

Before 1958, USAF and NACA, (later NASA), officials discussed an orbital X-15 spacecraft—the **X-15B**—for launching to outer space atop an SM-64 Navajo missile. This was canceled when NACA became NASA, and Project Mercury was approved instead. By 1959, the X-20 Dyna-Soar space-glider program became the USAF's preferred means for launching military manned spacecraft into orbit; however, this program was canceled in the early 1960s before an operational vehicle could be built.

Record flights

Highest flights

There are two definitions of how high a person must go to be referred to as an astronaut. The USAF decided to award astronaut wings to anyone who achieved an altitude of 50 miles (80.5 km) or more. However, the FAI set the limit of space at 100 kilometres (62.1 mi). Thirteen X-15 flights went higher than 50 miles and two of these reached over 100 kilometres.

X-15 flights higher than 50 mi (80 km)				
Flight	Date	Top speed	Altitude	Pilot
Flight 62	17 July 1962	3,831 mph (6,165 km/h)	59.6 miles (95.9 km)	Robert M. White
Flight 77	17 January 1963	3,677 mph (5,918 km/h)	51.4 miles (82.7 km)	Joe Walker
Flight 87	27 June 1963	3,425 mph (5,512 km/h)	53.9 miles (86.7 km)	Robert Rushworth
Flight 90	19 July 1963	3,710 mph (5,970 km/h)	65.8 miles (105.9 km)	Joe Walker
Flight 91	22 August 1963	3,794 mph (6,106 km/h)	67.0 miles (107.8 km)	Joe Walker
Flight 138	29 June 1965	3,431 mph (5,522 km/h)	53.1 miles (85.5 km)	Joseph H. Engle
Flight 143	10 August 1965	3,549 mph (5,712 km/h)	51.3 miles (82.6 km)	Joseph H. Engle
Flight 150	28 September 1965	3,731 mph (6,004 km/h)	55.9 miles (90.0 km)	John B. McKay
Flight 153	14 October 1965	3,554 mph (5,720 km/h)	50.4 miles (81.1 km)	Joseph H. Engle
Flight	1 November	3,750 mph	58.1 miles	Bill Dana

174	1966	(6,040 km/h)	(93.5 km)	
Flight 190	17 October 1967	3,856 mph (6,206 km/h)	53.1 miles (85.5 km)	Pete Knight
Flight 191	15 November 1967	3,569 mph (5,744 km/h)	50.3 miles (81.0 km)	Michael J. Adams [†]
Flight 197	21 August 1968	3,443 mph (5,541 km/h)	50.6 miles (81.4 km)	Bill Dana

[†] fatal

Fastest flights

X-15 10 fastest flights				
Flight	Date	Top Speed	Altitude	Pilot
Flight 45	9 November 1961	4,092 mph (6,585 km/h)	19.2 miles (30.9 km)	Robert M. White
Flight 59	27 June 1962	4,104 mph (6,605 km/h)	23.4 miles (37.7 km)	Joe Walker
Flight 64	26 July 1962	3,989 mph (6,420 km/h)	18.7 miles (30.1 km)	Neil Armstrong
Flight 86	25 June 1963	3,910 mph (6,290 km/h)	21.7 miles (34.9 km)	Joe Walker
Flight 89	18 July 1963	3,925 mph (6,317 km/h)	19.8 miles (31.9 km)	Robert Rushworth
Flight 97	5 December 1963	4,017 mph (6,465 km/h)	19.1 miles (30.7 km)	Robert Rushworth
Flight 105	29 April 1964	3,905 mph (6,284 km/h)	19.2 miles (30.9 km)	Robert Rushworth
Flight 137	22 June 1965	3,938 mph (6,338 km/h)	29.5 miles (47.5 km)	John B. McKay
Flight 175	18 November 1966	4,250 mph (6,840 km/h)	18.7 miles (30.1 km)	Pete Knight
Flight 188	3 October 1967	4,519 mph (7,273 km/h)	36.3 miles (58.4 km)	Pete Knight

X-15 pilots

X-15 pilots and their achievements during the program

Pilot	Organization	Total Flights	USAF space flights	FAI space flights	Max Mach	Max speed (mph)	Max altitude (miles)
Michael J. Adams [†]	U.S. Air Force	7	1	0	5.59	3,822	50.3
Neil Armstrong	NASA	7	0	0	5.74	3,989	39.2

Scott Crossfield	North American Aviation	14	0	0	2.97	1,959	15.3
Bill Dana	NASA	16	2	0	5.53	3,897	58.1
Joseph H. Engle	U.S. Air Force	16	3	0	5.71	3,887	53.1
Pete Knight	U.S. Air Force	16	1	0	6.70	4,519	53.1
John B. McKay	NASA	29	1	0	5.65	3,863	55.9
Forrest S. Petersen	U.S. Navy	5	0	0	5.3	3,600	19.2
Robert A. Rushworth	U.S. Air Force	34	1	0	6.06	4,017	53.9
Milt Thompson	NASA	14	0	0	5.48	3,723	40.5
Joe Walker	U.S. Air Force	25	3	2	5.92	4,104	67.0
Robert M. White*	U.S. Air Force	16	1	0	6.04	4,092	59.6

† Killed • * White was backup for Captain Iven Kincheloe

Chapter 18

Messerschmitt Me 163

Messerschmitt Me 163 *Komet*



Me 163B-1a at the National Museum of Flight in Scotland

Role	Interceptor
Manufacturer	Messerschmitt
Designed by	Alexander Lippisch
First flight	Me 163 A V4 in 1 September 1941
Introduction	1944
Primary user	<i>Luftwaffe</i>
Number built	~370

The **Messerschmitt Me 163 *Komet***, designed by Alexander Martin Lippisch, was a German rocket-powered fighter aircraft. As of 2011, it remains the only rocket-powered fighter aircraft to have ever been operational. Its design was revolutionary, and the Me 163 was capable of performance unrivaled at the time. Messerschmitt test pilot Rudy Opitz in 1944 reached 1,123 km/h (698 mph). Over 300 aircraft were built, however the *Komet* proved ineffective as a fighter, having been responsible for the destruction of only about nine Allied aircraft (16 air victories for 10 losses, according to other sources).

Development

Work on the design started under the aegis of the *Deutsche Forschungsanstalt für Segelflug* (DFS) - the German Institute for the Study of sailplane flight. Their first design was a conversion of the earlier Lippisch Delta IV known as the **DFS 39** and used purely as a glider testbed of the airframe.

A larger follow-on version with a small propeller engine started as the DFS 194. This version used wingtip-mounted rudders, which Lippisch felt would cause problems at high speed. He later redesigned them to be mounted on a conventional vertical stabilizer at the rear of the aircraft. The design included a number of features from its glider heritage, notably a skid used for landings, which could be retracted into the aircraft's keel in flight. For takeoff, a pair of wheels, each mounted onto the ends of a specially designed cross-axle, together comprising a takeoff "dolly" mounted under the landing skid, were needed due to the weight of the fuel, but these were released shortly after takeoff. It was planned to move to the Walter R-1-203 *cold engine* of 400 kg (880 lb) thrust when available.

Heinkel had also been working with Hellmuth Walter on his rocket engines, mounting them in the He 112 for testing, and later in the first purpose-designed rocket aircraft, the He 176. Heinkel had also been selected to produce the fuselage for the DFS 194 when it entered production, as it was felt that the highly volatile fuel would be too dangerous in a wooden fuselage, with which it could react. Work continued under the code name *Projekt X*.

However the division of work between DFS and Heinkel led to problems, notably that DFS seemed incapable of building even a prototype fuselage. Lippisch eventually requested to leave DFS and join Messerschmitt instead. On 2 January 1939, he moved along with his team and the partially completed DFS 194 to the Messerschmitt works at Augsburg.

The delays caused by this move allowed the engine development to "catch up". Once at Messerschmitt, the decision was made to skip over the propeller-powered version and move directly to rocket power. The airframe was completed in Augsburg and shipped to Peenemünde West in early 1940 to receive its engine. Although the engine proved to be extremely unreliable, the aircraft had excellent performance, reaching a speed of 342 mph (550 km/h) in one test.

Me 163 A



Bundesarchiv, Bild 146-1072-058-02
Foto: o. Ang. | 1941

The Me 163 A V4 prototype, in 1941

Production of a prototype series started in early 1941, known as the *Me 163*. Secrecy was such that the number, 163, was actually that of the earlier, pre-July 1938 Messerschmitt Bf 163 project to produce a small two-passenger light plane, which had competed against the Fieseler Fi 156 *Storch* for a production contract. It was thought that intelligence services would conclude any reference to the number "163" would be for that earlier design. The **Me 163 A V4** was shipped to Peenemünde to receive the HWK RII-203 engine on May 1941. By 2 October 1941, the Me 163 A V4, bearing the radio call sign letters, or *Stammkennzeichen*, "KE+SW", set a new world speed record of 1,004.5 km/h (624.2 mph), piloted by Heini Dittmar. This would not be officially approached until the postwar period by the new jet fighters of the British and U.S., and was not surpassed until the American Douglas Skystreak turbojet-powered research aircraft did so on 20 August 1947. Five prototype Me 163 *Anton* A-series experimental V-aircraft were built, adding to the original DFS 194 (V1), followed by eight pre-production examples designated as "Me 163 A-0".

During testing, the jettisonable main landing gear arrangement was a serious problem. The landing gear caused many aircraft to be damaged at takeoff, when the wheels rebounded and crashed into the aircraft. Malfunctioning hydraulic dampers in the skid could cause back injuries to the pilot when landing, as the aircraft lacked steering or braking control during landing, and was unable to avoid obstacles. Once on the ground, the aircraft had to be retrieved by a tractor-like vehicle, towing a special retrieval trailer

that rolled on a pair of short continuous-track setups (one per side), with twin trailing lifting arms, that lifted the stationary aircraft off the ground, from under each wing. The tractor was originally meant for agricultural use, the three-wheeled *Scheuch-Schlepper*, as the *Komet* was unpowered and lacked wheels at this point.

During flight testing, the superior gliding capability of the *Komet* proved detrimental to safe landing. The aircraft would rise back into the air with the slightest updraft. Since the approach was unpowered, there was no opportunity to make another landing pass. For production models, a set of landing flaps allowed somewhat more-controlled landings. This issue remained a problem throughout the program.

Nevertheless, the overall performance was tremendous, and plans were made to put Me 163 squadrons all over Germany in 40-kilometre rings (25 mi). Development of an operational version was given the highest priority.

Me 163 B



An **Me 163B** on display at the National Museum of the USAF - the small red rectangles on the rudder and elevons are control locks to prevent wind-damage to the control surfaces while on the ground, and are removed before flight

Meanwhile, Walter had started work on the newer HWK 109-509 *hot engine*, which added a true fuel of hydrazine hydrate and methanol, designated *C-Stoff*, that burned with the oxygen-rich exhaust from the *T-Stoff*, used as the oxidizer, for added thrust. This resulted in the significantly modified **Me 163 B** of late 1941. Due to the *Reichsluftfahrtministerium* (RLM) requirement that it should be possible to throttle the engine, the original power plant grew complicated and lost reliability. The new fuel proved an unfortunate choice as well, since hydrazine hydrate was also used in the launcher of the V-1 "Doodlebug" flying bomb and was in short supply throughout the 1943-45 period.

The fuel system was particularly troublesome, as leaks experienced during hard landings easily caused fires and explosions. Metal fuel lines and fittings, which failed in unpredictable ways, were used as this was the best technology available. Both fuel and oxidizer were toxic and required extreme care when loading in the aircraft, yet there were occasions when *Komet*s exploded on the tarmac. The corrosive nature of the liquids required special protective gear for the pilots.

Two prototypes were followed by 30 **Me 163B-0** aircraft armed with two 20 mm MG 151/20 cannon and some 400 **Me 163B-1** planes armed with two 30 mm (1.18-inch) MK 108 cannons, but which were otherwise similar to the B-0. Occasional references to B-1a or Ba-1 subtypes are found in the literature on the aircraft, but the meanings of these designations are somewhat unclear. Early in the war, when German aircraft firms created versions of their aircraft for export purposes, the **a** was added to export (*ausland*) variants (B-1a) or to foreign-built variants (Ba-1) but for the Me 163, there were neither export nor a foreign-built version. Later in the war, the "a" and successive letters were used for aircraft using different engine types: as Me 262A-1a with Jumo engines, A-1b with BMW engines. As the Me 163 was planned with an alternative BMW P3330A rocket engine, it is quite safe to assume the "a" was used for this purpose on early examples. Only one Me 163, the V10, was tested with the BMW engine, so this designation suffix was soon dropped. The Me 163 B-1a didn't have any wingtip "washout" built into it, and as a result, it had a much higher critical Mach number than the Me 163 B-1.

The Me 163B had very docile landing characteristics, mostly due to its integrated leading edge slots, located directly forward, along the wing's leading edge, of the elevon control surfaces. It would neither stall nor spin. One could fly the *Komet* with the stick full back, and have it in a turn and then use the rudder to take it out of the turn, and not fear it snapping into a spin. It would also slip well. Because it was derived from a glider, it had excellent gliding qualities, and had tendency to continue flying above the ground due to ground effect. On the other hand, making a too close turn from base onto final, the sink rate would increase, and one could quickly lose altitude and come in short. Another main difference from a propeller-driven aircraft is that there was no slipstream over the rudder. On takeoff, one had to attain the speed at which the aerodynamic controls become effective - about 129 km/h (80 mph) - and that was always a critical factor. Pilots used to flying propeller driven aircraft had to be careful the control stick wasn't somewhere in the corner when the control surfaces began working. These, like many other specific Me 163 problems, would be resolved by specific training.

The performance of the Me 163 far exceeded that of contemporary piston engine fighters. At a speed of over 320 km/h (200 mph) the aircraft would take off, in a so-called "sharp start" from the ground, from its two-wheeled dolly. The aircraft would be kept at low altitude until the best climbing speed of around 676 km/h (420 mph) was reached, at which point it would jettison the dolly, pull up into a 70° angle of climb, and rapidly climb to a bomber's altitude. It could go higher if required, reaching 12,000 m (39,000 ft) in an unheard-of three minutes. Once there, it would level off and quickly accelerate to speeds around 880 km/h (550 mph) or faster, which no Allied fighter could match. The usable Mach Number was similar to the Me-262, but because of the high thrust to drag ratio, it was much easier for the pilot to lose track of the onset of severe compressibility and loss of control. A Mach warning system was installed as a result. The aircraft was remarkably agile and docile to fly at high speed. According to Rudolf Opitz, chief test pilot of the Me 163, it could "fly circles around any other fighter of its time".

By this point, Messerschmitt was completely overloaded with production of the Bf 109 and attempts to bring the Me 210 into service. Production in a dispersed network was handed over to Klemm, but quality control problems were such that the work was later given to Junkers, who was, at that time, underworked. As with many German designs of World War II, parts of the airframe (especially wings) were made of wood by furniture manufacturers.



Me 163 S model in Soviet post-war test livery

The older Me 163A and first Me 163B prototypes were used for training. It was planned to introduce the **Me 163 S**, which removed the rocket engine and tank capacity and placed a second seat for the instructor above and behind the pilot, with its own canopy. The 163 S would be used for glider landing training, which as explained above, was essential to operate the Me 163. It appears the 163 Ss were converted from the earlier Me 163B series prototypes.

In service, the Me 163 turned out to be difficult to use against enemy aircraft. Its tremendous speed and climb rate meant a target was reached and passed in a matter of seconds. Although the Me 163 was a stable gun platform, it required excellent marksmanship to bring down an enemy bomber. The *Komet* was equipped with two 30 mm (1.18 inch) MK 108 cannons which had a relatively low muzzle velocity, with the characteristic ballistic drop of such a weapon. The drop meant they were only accurate at short distance, and that it was almost impossible to hit a slow-moving bomber when the *Komet* was traveling very fast. Plus, four or five hits were typically needed to take down a B-17.

A number of innovative solutions were implemented to ensure kills by less experienced pilots. The most promising was a unique weapon called the *Sondergerät 500 Jägerfaust*. This consisted of a series of single-shot, short-barreled 50 mm (2-inch) guns pointing upwards. Five were mounted in the wing roots on each side of the aircraft. The trigger was tied to a photocell in the upper surface of the aircraft, and when the *Komet* flew under the bomber, the resulting change in brightness caused by the underside of the aircraft could cause the rounds to be fired. As each shell shot upwards, the disposable gun barrel that fired it was ejected downwards, thus making the weapon recoilless. It appears that this weapon was used in combat only once, resulting in the destruction of a Halifax bomber, though other sources say it was a Boeing B-17.

Later versions



Model of the Me 163 C



Model of the Me 163 BV18 (alias D)

The biggest concern about the design was the short flight time, which never met the projections made by Walter. With only seven and a half minutes of powered flight, the fighter truly was a dedicated point defense interceptor. To improve this, the Walter firm began developing two more advanced versions of the 509A rocket engine, the 509B and C, each with two separate combustion chambers of differing sizes, oriented one above the other, with greater efficiency. The upper chamber, intended as the motor's primary power output, was larger, and supported by the "thrust tube" exactly as the 509A motor's single chamber had been. It was tuned for "high power" for takeoff and climb. The smaller-volume, lower chamber, with approximately 400 kg (880 lb) of thrust at its top performance level, was intended for more efficient, lower-power cruise flight. This HWK 109-509 C would improve endurance by as much as 50%. Two 163 Bs, models V6 and V18, were experimentally fitted with the new engine, a retractable tailskid, and tested in spring 1944. On 6 July 1944, the Me 163 B V18 (VA+SP) set a new world speed record of 1,130 km/h (702 mph), piloted by Heini Dittmar, and landed with almost all of the vertical rudder surface broken away from flutter. This record was not broken in terms of absolute speed until 6 November 1947 by Chuck Yeager in a flight that was part of the Bell X-1 test program, with a 1,434 km/h (891 mph), or Mach 1.35 supersonic speed, recorded at an altitude of nearly 14,820 m (48,620 ft) altitude. However, the X-1 never exceeded Dittmar's speed from a normal runway liftoff. Heini Dittmar had reached the 1,130 km/h (702 mph) performance, after a normal "sharp start" ground takeoff, without an air drop from a mother ship. Neville Duke exceeded Heini Dittmar's record mark in 31 August 1953, with the Hawker Hunter F Mk3 at a speed of 1,171 km/h (728 mph), after a

normal ground start. Aircraft of the configuration the Me 163 used were found to have serious stability problems when entering transonic flight, like the similarly configured, and turbojet powered, Northrop X-4 Bantam and de Havilland DH 108, which made the V18's record with the Walter 509C "cruiser" rocket more remarkable.

Waldemar Voigt (aerospace engineer) of Messerschmitt's *Oberammergau* project and development offices started a redesign of the 163 to incorporate the new engine, as well as fix other problems. The resulting **Me 163 C** design featured a larger wing through the addition of an insert at the wing root, an extended fuselage with extra tank capacity through the addition of a "plug" insert behind the wing, and a new pressurized cockpit topped with a bubble canopy for improved visibility. The additional tank capacity and cockpit pressurization allowed the maximum altitude to increase to 15,850 m (52,000 ft), as well as improving powered time to about twelve minutes, almost doubling combat time (from about five minutes to nine). Three **Me 163C-1a** prototypes were planned, but it appears only one was flown, without its intended engine.

By this time the project was moved to Junkers. There, a new design effort under the direction of Heinrich Hertel at Dessau attempted to improve the *Komet*. The Hertel team had to compete with the Lippisch team and their Me 163C. Hertel investigated the Me 163 and found it was not well suited for mass production and not optimized as a fighter aircraft, with the most glaring deficiency being the lack of retractable landing gear. For this, the Me 163V-18 was equipped with a non-retractable tricycle landing gear. (This prototype is often called the "Me 163D", but it is now clear that there never was a 163 D.) The resulting *Junkers Ju 248* used a three-section fuselage to ease construction. The V1 prototype was completed for testing in August 1944, and was glider tested behind a Junkers Ju 188. Some sources state that the Walter 109-509 C engine was fitted in September, but it was probably never tested under this power. At this point the RLM re-assigned the project to Messerschmitt, where it became the *Me 263*. This appears to have been a formality only, with Junkers continuing the work and planning production.

By the time the design was ready to go into production, the plant where it was to be built was overrun by Soviet forces. While it did not reach operational status, the work was briefly continued by the Soviet Mikoyan-Gurevich (MiG) design bureau as the Mikoyan-Gurevich I-270.

Operational history

Active combat operations began in May 1944, although on a small scale. As expected, the aircraft was extremely fast; and for a time, the Allied fighters were at a complete loss as what to do about it. Singly or in pairs, the *Komets* attacked, often faster than the opposing fighters could dive in an attempt to intercept them. A typical Me 163 tactic was to zoom through the bomber formations at 9,000 m (30,000 ft), rise up to an altitude of 10,700–12,000 m (35,100–39,000 ft), then dive through the formation again. This approach afforded the pilot two brief chances to fire a few rounds from his cannons before gliding back to his airfield. The pilots reported that it was possible to make four passes on a bomber, but only if it was flying alone.

As the cockpit was unpressurized, the operational ceiling was limited by what the pilot could endure for several minutes while breathing oxygen from a mask, without losing consciousness. Pilots underwent altitude-chamber training to harden them against the rigors of operating in the thin air of the stratosphere without a pressure suit. Special low-fiber diets were prepared for pilots, as gas in the gastrointestinal tract would expand rapidly during ascent.

More than three years passed before Major Wolfgang Späte could form the first Me 163 combat wing, (*Jagdgeschwader 400* (JG 400)), in Brandis near Leipzig, which followed the establishment of the *Erprobungskommando 16* Me 163B-dedicated test and evaluation unit at Peenemunde-West eleven months earlier. JG 400's purpose was to provide additional protection for the Leuna synthetic gasoline works which were raided particularly heavily and frequently at the end of 1944. A further group was stationed at Stargard near Stettin to protect the large synthetic plant at Pölitz (today Police, Poland). Further defensive units of rocket fighters were planned for Berlin, the Ruhr and the German Bight.

The first actions involving the Me 163 occurred at the end of July, when two USAAF B-17 Flying Fortress were attacked without confirmed kills. Combat operations continued from May 1944 to spring 1945. During this time, there were nine confirmed kills with 14 Me 163s lost. Feldwebel Siegfried Schubert was the most successful pilot, with three bombers to his credit.

Allied fighter pilots soon noted the short duration of the powered flight. They would wait, and when the engine died they would pounce on the unpowered *Komet*. However, the *Komet* was extremely manoeuvrable and could pull out of a turn much later than any Allied fighter. Another Allied method was to attack the fields the Komets operated from, and strafed them after the Me 163s landed. Establishing a defensive perimeter with anti-aircraft guns ensured that Allied fighters avoided these bases. At the end of 1944, 91 aircraft had been delivered to JG 400 but a continuous lack of fuel had kept most of them grounded. It was clear that the original plan for a huge network of Me 163 bases was never going to happen. Up to that point, JG 400 had lost merely six aircraft due to the enemy actions. Nine were lost to other causes, remarkably low for such a revolutionary and technically advanced aircraft. In those last days of the Third Reich the Me 163 was given up in favour of the more successful and threatening Me 262. In May 1945, Me 163 operations were stopped, the JG 400 disbanded, and many of their pilots sent to fly Me 262s.

In any operational sense, the *Komet* was a failure. Although they shot down 16 aircraft, mainly expensive four-engined bombers, that did not warrant the efforts put into the project. With the projected Me 263, things could have turned out differently, but the *Komet* was an ineffective fighter aircraft. Due to fuel shortages late in the war, few went into combat, and it took an experienced pilot with excellent shooting skills to achieve "kills" with the Me 163.

The *Komet* was a remarkable design that pointed the way to the future. It was one more piece of evidence that the day of the propeller fighter was over, and it also spawned later weapons like the Bachem Ba 349 Natter and Convair XF-92. Ultimately, the point defense role that the Me 163 played would be taken over by the surface-to-air missile (SAM), Messerschmitt's own example being the Enzian. The airframe designer, Alexander Martin Lippisch went on to design delta-winged supersonic aircraft for the Convair Corporation.

Flying the Me 163

Capt. Eric Brown, CBE, DSC, AFC, RN, Chief Naval Test Pilot and C.O. Captured Enemy Aircraft Flight, that tested the Me 163 at the RAE Farnborough, said that "The Me 163 was an aeroplane that you could not afford to just step into the aircraft and say 'You know, I'm going to fly it to the limit.' You had very much to familiarise with yourself with it because it was state-of-the-art and the technology used."

Acting unofficially, after a spate of accidents involving Allied personnel flying captured German aircraft resulting in official disapproval of such flights, Brown was determined to fly a powered *Komet*, and on around the 17th of May 1945, he flew an Me 163B at Husum with the help of a co-operative German ground crew, after initial towed flights in an Me 163A to familiarise himself with the handling. The day before the flight, Brown and his ground crew had performed an engine run on the chosen Me 163B to ensure that everything was running correctly, the German crew being apprehensive should an accident befall Brown, until being given a disclaimer signed by him to the effect that they were acting under his orders. On the take-off the next day, after dropping the take-off trolley and retracting the skid, Brown later described the resultant climb as "like being in charge of a runaway train", the aircraft reaching 32,000ft in two and a three-quarter minutes. During the flight, while practising attacking passes at an imaginary bomber, he was surprised at how well the *Komet* accelerated in the dive with the engine shut down. When the flight was over Brown had no problems on the approach to the airfield apart from the rather restricted view from the cockpit due to the flat angle of glide, the aircraft touching down at 125 mph. Once down safely, Brown and his much-relieved ground crew celebrated with a drink.

However, apart from Brown's unauthorised flight, the British never tested the Me 163 under power themselves, from the danger of its hypergolic propellants - it was only flown in unpowered form in their postwar tests, Brown himself flying the RAE's *Komet VF241* on a number of occasions, the rocket motor being replaced with test instrumentation.

Surviving aircraft

It has been claimed that at least 29 *Komet*s were shipped out of Germany after the war and that of those at least 10 have been known to survive the war to be put on display in museums around the world. Most of the 10 surviving Me 163s were part of JG 400, and were captured by the British at Husum, the squadron's base at the time of Germany's surrender in 1945. According to the RAF museum, 48 aircraft were captured intact and

24 were shipped to the United Kingdom for evaluation, although only one, *VF241*, was test-flown (unpowered).

United States

- Five Me 163s were originally brought to the United States in 1945, receiving the Foreign Equipment numbers FE-495 and FE-500 to 503. An Me 163 B-1a, Werknummer (serial number) *191301*, arrived at Freeman Field, Indiana, during the summer of 1945, and received the foreign equipment number FE-500. On 12 April 1946, it was flown aboard a cargo aircraft to the U.S. Army Air Forces facility at Muroc dry lake in California for flight testing. Testing began on 3 May 1946 in the presence of Dr. Alexander Lippisch and involved towing the unfueled *Komet* behind a B-29 to an altitude of 9,000–10,500 m (30,000–34,400 ft) before it was released for a glide back to earth under the control of test pilot Major Gus Lundquist. Powered tests were planned, but not carried out after delamination of the aircraft's wooden wings was discovered. It was then stored at Norton AFB, California until 1954, when it was transferred to the Smithsonian Institution. The aircraft remained on display in an unrestored condition at the museum's Paul E. Garber Restoration and Storage Facility in Suitland, Maryland, until 1996, when it was lent to the Mighty Eighth Air Force Museum in Pooler, Georgia for restoration and display but has since been returned to the Smithsonian for display at the Steven F. Udvar-Hazy Center near Washington D.C.. Werknummer *191301* is held by NASM, Silver Hill.
- Me 163 B, Werknummer *191095* is held at the USAFM and was gifted from the National Aviation Museum, Ottawa in 1999. It was placed on display at the National Museum of the United States Air Force near Dayton, Ohio on 10 December 1999. The aircraft had been owned and restored by the Canadian National Aviation Museum. *Komet* test pilot Rudolf "Rudi" Opitz was on hand for the dedication of the aircraft and discussed his experiences of flying the rocket-propelled fighter to a standing room only crowd. During the aircraft's restoration in Canada it was discovered that the aircraft had been assembled by French "forced labourers" who had deliberately sabotaged it by placing stones between the rocket's fuel tanks and its supporting straps. There are also indications that the wing was assembled with contaminated glue. Inside the fuselage was found patriotic French writing. The aircraft is displayed without any unit identification or Werk Nummer.
- Me 163 B, Werknummer *191660*, "Yellow 3", is held by the Flying Heritage Collection. Between 1961 and 1976, this aircraft was displayed at the Imperial War Museum in London. In 1976, it was moved the Imperial War Museum Duxford. It underwent a lengthy restoration, beginning in 1997, that was frequently halted as the restorers were diverted to more pressing projects. In May 2005, it was sold, reportedly for £800,000, to raise money for the purchase of a de Havilland/Airco DH.9 as the Duxford museum had no examples of a World War I bomber in its collection. Permission for export was granted by the British

government's Department for Culture, Media and Sport as three other *Kometes* were held in British museums. "Yellow 3" has since been sold to Paul Allen.

United Kingdom

Of the 21 aircraft that were captured by the British, at least three have survived until today. They were assigned the British serial numbers *AM200* to *AM220*.

- Me 163 B, Werknummer *191316*, "Yellow 6", has been on display at the Science Museum in London, England since 1964 with the Walter motor removed for separate display. A second Walter motor and a takeoff dolly are part of the museum's reserve collection and are not generally on display to the public.
- Me 163 B, Werknummer *191614*, has been at the RAF Museum site at RAF Cosford, since 1975. Before then, it was at the Rocket Propulsion Establishment at Westcott, Buckinghamshire. This aircraft last flew on 22 April 1945, when it shot down an RAF Lancaster.
- Me 163 B-1a, Werknummer *191659* and RAF Air Ministry serial number *AM215*, "Yellow 15", was captured at Husum in 1945 and was sent to the College of Aeronautics at Cranfield, England in 1947. After many years of touring airshows and various outdoor gatherings around the UK it was finally loaned to the National Museum of Flight at East Fortune Airfield, East Lothian, Scotland in 1976.

Germany



Messerschmitt Me 163 at the *Luftwaffenmuseum* in Berlin-Gatow

- A Me 163 B, Werknummer *191904*, "Yellow 25", belonging to JG 400 was captured by the RAF at Husum in 1945. It was sent to England, arriving first at Farnborough, receiving the RAF Air Ministry number *AM219* and then transferred to Brize Norton on 8 August 1945, before finally being placed on

display at the Station Museum at Colerne. When the museum closed in 1975 the aircraft went to RAF St Athan, receiving the ground maintenance number *8480M*. On 5 May 1988 the aircraft was returned to the *Luftwaffe* and moved to the *Luftwaffe* Alpha Jet factory at the air base in Oldenburg (JBG 43). The airframe was in good condition but the cockpit had been stripped and the rocket engine was missing. Eventually an elderly German woman came forward with Me 163 instruments that her late husband had collected after the war, and the engine was reproduced by a machine shop owned by Me 163 enthusiast Reinhold Opitz. The factory closed in the early 1990s and the "Yellow 25" was moved to a small museum created on the site. The museum contained aircraft that had once served as gate guards, monuments and other damaged aircraft previously located on the air base. In 1997 "Yellow 25" was finally moved to the official Luftwaffe Museum located at the former RAF base at Berlin-Gatow, where it is displayed today alongside a restored Walter HWK 109-509 rocket engine. This particular Me 163B is one of the very few World War II-era German military aircraft, restored and preserved in a German aviation museum, to have a swastika national marking of the Third Reich, in a "low-visibility" white outline form, currently displayed on the tailfin. The marking could likely be in violation of the German criminal law section known as Strafgesetzbuch § 86a.

- Me 163 B, Werknummer *120370*, "Yellow 6" of JG 400, is displayed at the Deutsches Museum, Munich. It was originally sent to Britain, where it had received the RAF Air Ministry number *AM210*. It was given to the Deutsches museum by RAF Biggin Hill station. Some claim this is *191316*, but that is still at the London Science Museum.

Canada



Me 163 B Komet, Werknummer 191914 at the Canada Aviation and Space Museum

- Me 163 B, Werknummer *191659 (AM215)* or *191914 (AM220)*, is held at the Canada Aviation and Space Museum, Ottawa. Like two of the British Komets, this aircraft was part of JG 400 and captured at Husum. It was shipped to Canada in 1946.

Werknummer *19116* (but more probable *191916*) and *191095 (AM211)* also seem to have been held at one time in this museum.

Australia

- Me 163 B, Werknummer *191907*, is part of the collection of the Australian War Memorial. This aircraft was also part of JG 400 and captured at Husum.

Japanese versions

As part of their alliance, Germany provided the Japanese Empire with plans and an example of the Me 163. One of the two submarines carrying Me 163 parts did not arrive in Japan, so at the time, the Japanese lacked a few important parts, including the

turbopump which they could not make themselves. The Japanese Me 163 crashed on its first flight and was completely destroyed. The Japanese versions were designed as trainers, fighters, and interceptors. Differences between the versions were fairly minor. The Mitsubishi Ki-200 *Shusui* ("Shu" means "autumn", "sui" means "water" in Japanese) was the equivalent of the 163 B, armed with two 30 mm (1.18 in) Ho 155-II cannon. The Navy version, the Mitsubishi J8M1 *Shusui*, simply replaced the Ho 155 cannon with the Navy's 30 mm (1.18 in) Type 5.

Mitsubishi also planned on producing a version of the 163 C for the Navy, known as the J8M2 *Shusui* Model 21. A version of the 163 D/263 was known as the J8M3 *Shusui* for the Navy with the Type 5 cannon, and a Ki-202 *Shusui-kai* ("kai" means "modified" in Japanese) with the Ho 155-II for the Army.

Trainers were planned, roughly the equivalent of the Me 163 A-0/S. These were known as the Yokoi Ku-13 *Akigusa* ("Aki" means also "autumn" and "*gusa (kusa)*" means "grass" in Japanese) or Ki-200 *Syusui* Rocket Interceptor practice glider ("Syusui" with "y").

Other trainer variants included:

- **Yokoi Experimental Ki-13 *Shusui* Heavy Glider.** This glider was created as the Ki-200 *Syusui* Rocket Interceptor practice glider. The project was cancelled due to high costs.
- **Kugisho/Yokosuka MXY-8 *Akigusa* Rocket Interceptor practice glider (Experimental *Shusui* Light Glider).** Created as the J8M1 *Syusui* Rocket Interceptor practice glider.
- **Kugisho/Yokosuka MXY-9 Experimental *Shusui* Heavy Glider.** This glider was created as the J8M1 *Syusui* Rocket Interceptor practice glider, but was cancelled due to high costs.
- **Kugisho/Yokosuka MXY-9 *Shuka* Rocket Interceptor Operative training glider.** This aircraft would have used the Hitachi "Hatsukaze-11" fan jet engine on the MXY-8 "*Akigusa*" airframe.

Replicas



Me 163 replica glider

A flying replica Me 163 was constructed between 1994 and 1996 by Joseph Kurtz, a former *Luftwaffe* pilot who trained to fly Me 163s, but who never flew in combat. He subsequently sold the aircraft to EADS. The replica is an unpowered glider whose shape closely matches that of an Me 163, although its weight and internal construction differ considerably. Reportedly, it has excellent flying characteristics.

XCOR Aerospace, an aerospace and rocketry company, proposed a rocket-powered replica, the *Komet II*. Although outwardly the same as a wartime aircraft, the design would have differed considerably for safety reasons. It would have been partially constructed with composite materials, powered by one of XCOR's own simpler and safer, pressure fed, liquid oxygen/alcohol engines, and retractable undercarriage would have been used instead of a takeoff trolley and landing skid. The project is no longer discussed on the company's website, and it appears work has ceased on this project.

Several static replicas of the aircraft are exhibited in museums.

Specifications: Me 163 B-1

General characteristics

- **Crew:** 1
- **Length:** 5.70 m (18 ft 8 in)
- **Wingspan:** 9.33 m (30 ft 7 in)

- **Height:** 2.75 m (9 ft 0 in)
- **Wing area:** 18.5 m² (200 ft²)
- **Empty weight:** 1,905 kg (4,200 lb)
- **Loaded weight:** 3,950 kg (8,710 lb)
- **Max takeoff weight:** 4,310 kg (9,500 lb)
- **Powerplant:** 1× Walter HWK 109-509A-2 liquid-fuel rocket, 17 kN (3,800 lbf)

Performance

- **Maximum speed:** 1,060 km/h (596 mph)
- **Range:** 40 km (25 mi)
- **Service ceiling:** 12,100 m (39,700 ft)
- **Rate of climb:** 160 m/s (31500 ft/min)
- **Wing loading:** 213 kg/m² (43 lb/ft²)
- **Thrust/weight:** 0.42

Armament

- **Guns:** *2 × 30 mm (1.18 in) Rheinmetall Borsig MK 108 cannons (60 rpg)

The oft quoted top speed of 596 mph (959 km/h) up to the tropopause is impossible, as it corresponds to a Mach Number of over .89—the Me-163B ran into severe compressibility above .82 and complete loss of control at M=.84. This anomaly has not been explained.