Electric and Mixed-Power Aircrafts

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Table of Contents

Chapter- 1

Electric Aircraft

Helios electric-powered UAV

An **electric aircraft** is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultracapacitors, power beaming, and/or batteries.

Currently flying electric aircraft are mostly experimental demonstrators, including manned and unmanned aerial vehicles. Electrically powered model aircraft have been flown since the 1970s, with one report in 1957.

History

In 1883 Gaston Tissandier was the first to use electric motors in airship propulsion. The following year, Charles Renard and Arthur Krebs flew La France with a more powerful motor.

Nikolai Tesla envisaged using electrically powered aircraft, powered by beams from the ground or the ionosphere.

Electric motors have been used for model fixed-wing aircraft since from at least 1957, with a challenged claim from 1909.

In 1964 William C. Brown demonstrates on CBS News with Walter Cronkite a model helicopter that receives all of the power needed for flight from a microwave beam.

In 2007 the non-profit CAFE Foundation held the first Electric Aircraft Symposium in San Francisco.

Experimental projects

1970s and 1980s

Sunrise

The 27 lb (12 kg) unmanned AstroFlight Sunrise, the result of an ARPA contract, made the world's first solar-powered flight from Bicycle Lake, a dry lakebed on the Fort Irwin Military Reservation, on 4 November 1974. The improved Sunrise II flew on 27 September 1975 at Nellis AFB.

Solar Riser

The world's first official flight in a solar powered, man carrying aircraft took place on April 29, 1979. The Mauro Solar Riser was built by Larry Mauro and was based on the UFM Easy Riser biplane hang glider. The aircraft used photovoltaic cells that produced 350 watts at 30 volts, which charged a Hughes 500 helicopter battery, which in turn powered the electric motor. The aircraft was capable of powering the motor for 3 to 5 minutes, following a 1.5 hour charge, enabling it to reach a gliding altitude.

Solar One

The Solar-Powered Aircraft Developments Solar One was designed by David Williams under the direction of Freddie To, an architect and member of the Kremer prize committee and produced by Solar-Powered Aircraft Developments. A motor-glider type aircraft originally built as a pedal powered airplane to attempt the Channel crossing, the airplane proved too heavy to be successfully powered by human power and was then converted to solar power, using an electric motor driven by batteries that were charged before flight by a solar cell array on the wing. The maiden flight of Solar One took place at Lasham Airfield; Hampshire on June 13, 1979, one day after Brian Allen had successfully pedalled the Gossamer Albatross across the English Channel.

Gossamer Penguin and Solar Challenger

The Gossamer Penguin, a smaller version of the human powered Gossamer Albatross was completely solar powered. A second prototype, the Solar Challenger, flew 262 km (163 mi) from Paris to England. On 7 July 1981, the aircraft, under solar-power, flew 163 miles from Cormeilles-en-Vexin Airport near Paris across the English Channel to RAF Manston near London, flying for 5:23. Designed by Dr. Paul MacCready the Solar Challenger set an altitude record of 14,300 feet.

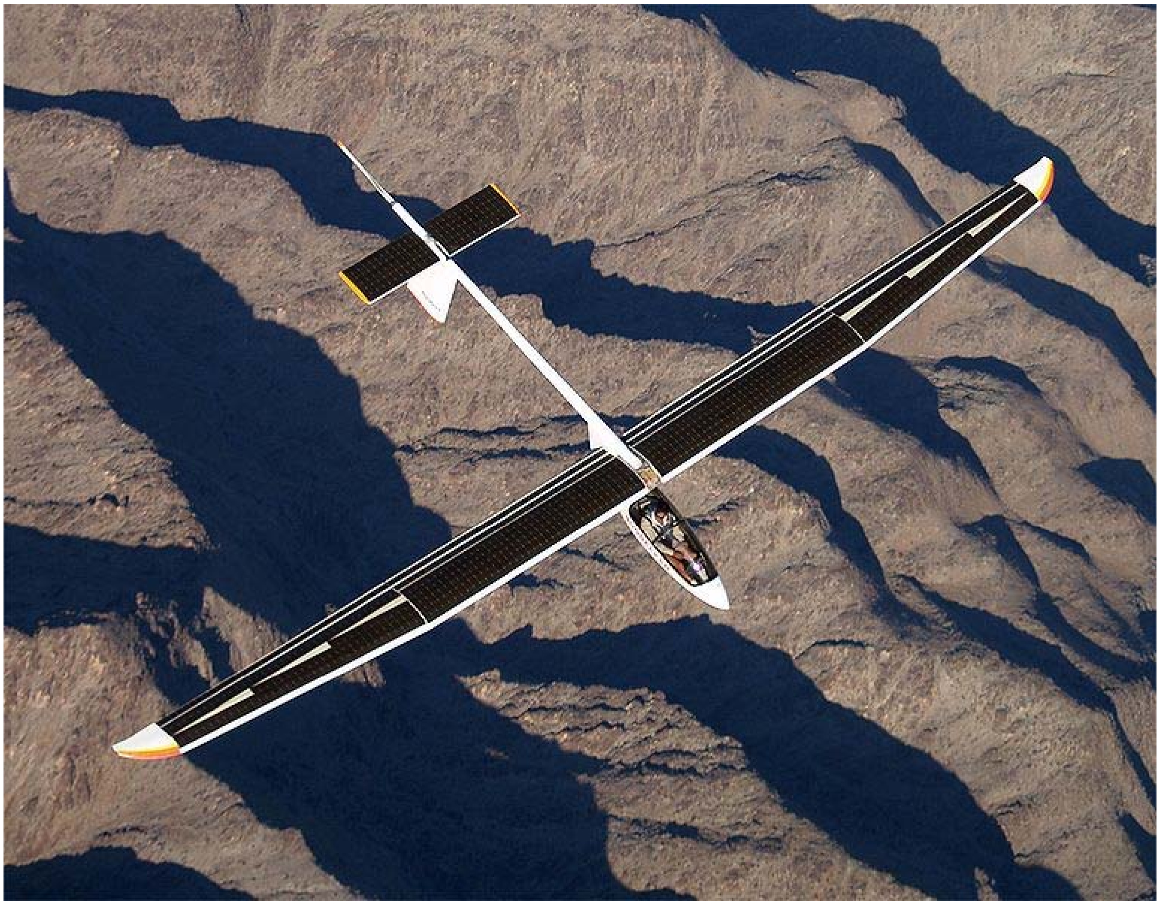
Solair 1

The human piloted Solair 1 was developed by Günther Rochelt and based on a Farner canard design. It employed 2499 wing-mounted solar cells giving an output of between 1.8 kW (2 hp) and 2.2 kW (3 hp). The aircraft first flew at Unterwössen, Germany on 21 August 1983. It flew for 5 hours and 41 minutes, "mostly on solar energy and also thermals". The aircraft is now displayed at the German Museum in Munich. The newly developed piloted Solair II made its first flight in May 1998 and further test flights that summer but the propulsion system overheated too fast. Development stopped when Günther Rochelt suddenly died in September 1998.

NASA Pathfinder and Helios

NASA's Pathfinder and Helios were a series of solar and fuel cell system-powered unmanned aircraft. AeroVironment, Inc. developed the vehicle under NASA's Environmental Research Aircraft and Sensor Technology program.

1990s



Solar Flight's *Sunseeker* flying over Southern California's high desert

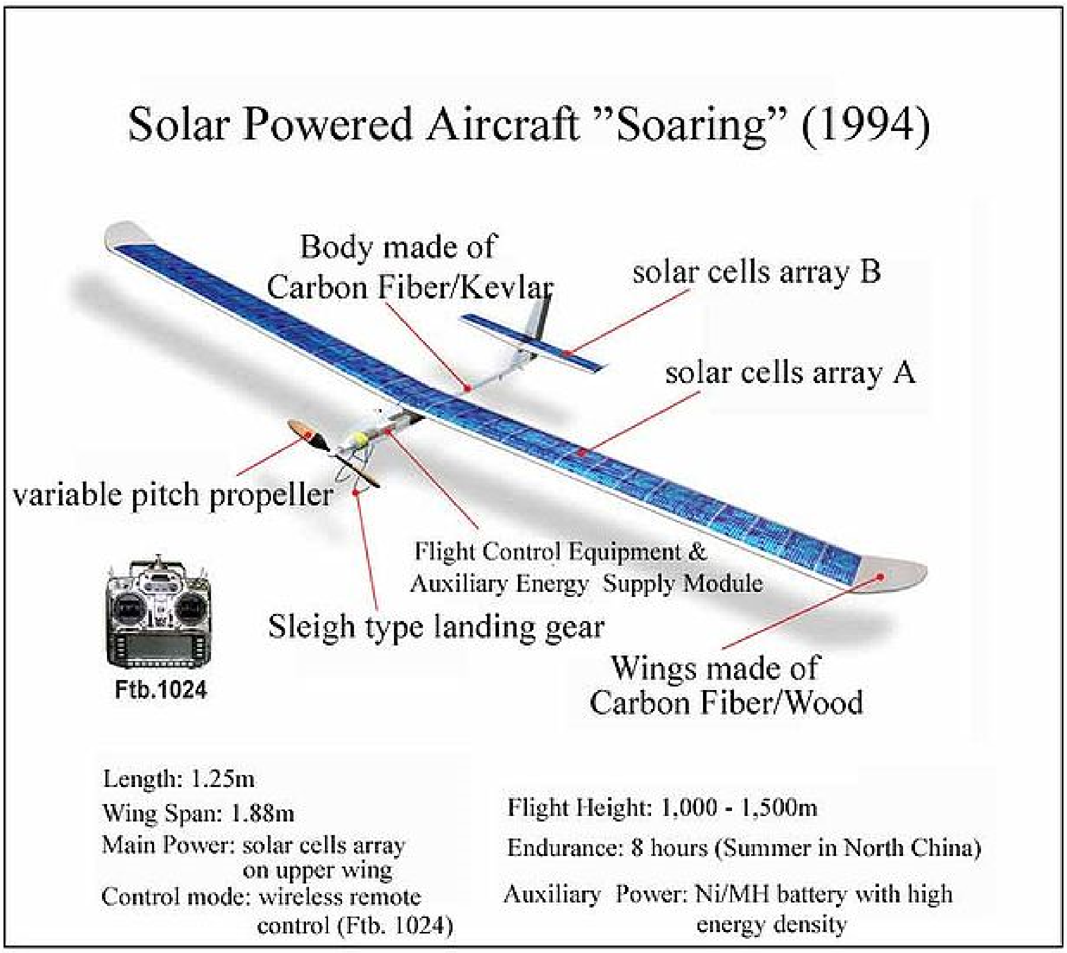
Sunseeker

In 1990 the solar powered airplane *Sunseeker* successfully flew across the USA, piloted by Eric Raymond. It used a small battery charged by solar cells on the wing to drive a propeller for takeoff, and then flew on direct solar power and took advantage of soaring conditions when possible.

The *Sunseeker II*, built in 2002, was updated in 2005-2006 with a more powerful motor, larger wing, lithium battery packs and updated control electronics. As of Dec, 2008 it was the only manned solar powered airplane in flying condition and is operated regularly by Solar Flight. In 2009 it became the first solar-powered aircraft to cross the Alps, 99 years after the first crossing of the Alps by an aircraft.

Soaring

Test Flight of *Soaring* in 1994



Summary of Configuration and Performance Parameter of "Soaring"

China's first solar powered aircraft "Soaring" was designed and built by Danny H. Y. Li and Zhao Yong in 1992. The body and wings are hand-built predominantly of carbon fiber, Kevlar and wood. The design uses winglets to increase the effective wing span and reduce induced drag.

2000s

Antares 20E

The Antares 20E is an electric, self-launching sailplane with a 42-kW DC/DC brushless motor (called EM42) and lithium-ion batteries. It can climb up to 3,000 meters with fully charged cells.

Solar Impulse

The first short-hop (350m) test flight of the Solar Impulse prototype was made on 3 December 2009.

In its present configuration it has a wingspan of 210 ft (64 m), weighs 3,500 lb (1,588 kg) and is powered by four 10-horsepower (7 kW) electric motors. The aircraft has over 11,000 solar cells on its wings and horizontal stabilizer. Power from the solar cells is stored in lithium polymer batteries and used to drive 3.5-metre (11 ft) propellers turning at a speed of 200–400 rpm. Take-off speed is 19 knots (35 km/h) and cruising speed is 60 kn (111 km/h).

The aircraft had its first high flight on 7 April 2010, when it flew to an altitude of 1,200 meters (3,937 feet) in a 1.5 hour flight on battery power alone. The Solar Impulse team is planning to use the aircraft to circumnavigate the globe in 2012.

The aircraft first flew on purely solar power, charging its batteries in flight, on 28 May 2010

On 8 July 2010 it completed the first manned 24 hour flight completely powered by solar power.

APAME Electra

The Association pour la Promotion des Aéronefs à Motorisation Électrique (APAME) *(English: Association for the Promotion of Electric Powered Aircraft)* first flew their Electra electric-powered open-cockpit airplane at 1150 hrs (local) on Sunday, 23 December 2007 at Aspres sur Buech airfield, Hautes Alpes, France. Test pilot Christian Vandamme flew the strut-equipped aircraft for 48 minutes, covering 50 km (31 miles). The Electra is powered by an 18-kW (24 hp) disk-brush electrical motor driven by a 47 kg (104 lb) lithium polymer battery power pack.

First manned AA battery powered aircraft

Matsushita Electric Industrial Co. and undergraduates at the Tokyo Institute of Technology teamed up to build an aircraft powered by 160 AA battery cells and successfully flew it for a distance of 391 meters (1,283 ft) in July, 2006.

Boeing-FCD Project

In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

The FCD (Fuel Cell Demonstrator) is a project led by Boeing that uses a Diamond Super Dimona HK-36 motor glider as a test bed for a fuel cell powered light airplane research project.

Successful test flights took place in February and March 2008.

Boeing's partners in the project are Intelligent Energy of Britain (fuel-cell); Diamond Aircraft of Austria (Airframe); Spanish Sener (control system); Spanish Aerlyper (integrate motor with airframe); Advanced Technology Products, a U.S. company (motor, batteries, flight testing).

QinetiQ Zephyr

The QinetiQ Zephyr is a lightweight solar-powered unmanned aerial vehicle engineered by the United Kingdom defence firm, QinetiQ. As of 23 July 2010 it holds the endurance record for an unmanned aerial vehicle of over 2 weeks (336 hours).

It is of carbon fiber-reinforced polymer construction, the 2010 version weighing 50 kg (110 lb) (the 2008 version weighed 30 kg (66 lb)) with a span of 22.5 metres (the 2008 version had 18 metres (59 feet)). It uses sunlight to charge lithium-sulphur batteries during the day, which power the aircraft at night. The aircraft has been designed for use in observation and communications relay.

The 2008 Zephyr version flew for 82-hours, reaching 61,000 foot in altitude in July 2008, the then unofficial world record for the longest duration unmanned flight. In July 2010 the 2010 version of the Zephyr made a world record unmanned aerial vehicle endurance flight of 336 hours, 22 minutes and 8 seconds (more than two weeks) and also set an altitude record of 70,000 feet.

SkySpark

Skyspark in flight 2009

The SkySpark is a joint project of engineering company DigiSky and Polytechnic University of Turin. The two-seat Pioneer Alpi 300 has a 75 kW (101 hp) brushless electric motor powered by lithium polymer batteries. The aircraft achieved a world record of 250 km/h (155 mph) for a human-carrying electric aircraft on 12 June 2009.

Green Pioneer I

Test Flight of “Green Pioneer I” in 2004

The *Green Pioneer* solar powered aircraft research programme was announced at the 4th China International Aviation and Aerospace Exhibition in 2002. The experimental programme was intended to provide research data for future Chinese solar powered aircraft. The programme was run by New Concept Aircraft (Zhuhai), the China Aviation Industry Development Research Center, and China Academy of Space Technology. The project leader and chief designer was Danny H. Y. Li.

EADS Cri-Cri

In June 2010 European aerospace company EADS unveiled an electric version of the 1970s vintage Colomban Cri-cri ultralight aircraft powered by four electric engines. The Cri-Cri will have lithium batteries and will be able to fly for 30 minutes at 60 kn (111 km/h) or 15 minutes of aerobatics at speeds up to 135 kn (250 km/h), with a climb rate of 1,000 feet per minute. The aircraft is a demonstrator for future technology, as Jean Botti, EADS's chief technical officer explained: "The Cri-Cri is a low-cost test bed for system integration of electrical technologies in support of projects like our hybrid propulsion concept for helicopters." The Cri-Cri first flew on 2 September 2010 at Le Bourget airport near Paris.

ENFICA-FC

The ENFICA-FC is a project of the European Commission, to study and demonstrate an all-electric aircraft with fuel-cells as the main or auxiliary power system. During the three year project, a fuel-cell based power system was designed and flown in a Rapid 200FC ultralight aircraft.

Design concepts

Puffin

The *Puffin* is a proposed hover-capable, electric-powered, low-noise, personal, vertical takeoff and landing (VTOL) technology-concept, proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour. Range is expected to be less than 50 miles with initial battery technology. The design has a 13.5 foot wingspan and stands 12 feet tall on the ground in its take-off or landing configuration.

As of January 2010, a one third–size, hover-capable Puffin demonstrator was planned for March 2010. Future designs might incorporate additional rotors to provide redundant systems.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for filming for the Discovery network series “Dean of Invention.” The Puffin simulator was also demonstrated. The Puffin will appear in the eighth and final episode of the show.

Production aircraft

1990s

Alisport Silent Club

The first commercially available production electric aircraft was the Alisport Silent Club self-launching sailplane, first tested in 1997. It is optionally driven by a 13 kW (17 hp) DC electric motor running on 40 kg (88 lb) of batteries that provide 1.4 kWh of power.

2000s

Electraflyer

In April 2007 the Electric Aircraft Corporation began offering complete electric ultralights and engine kits under the ElectraFlyer brand name, to convert existing ultralight aircraft to electric power, in what is the first commercial offering of an electric aircraft.

The 18 hp (13 kW) engine package weighs 26 lbs and an efficiency of 90% is claimed by the company. The battery consists of two lithium-polymer battery packs which provides 1.5 hours of flying in the trike application.

In January 2008 the company introduced their new ElectraFlyer-C at the Sebring Light Sport Aircraft Show. This aircraft is a converted Monnett Moni motor glider equipped with an 18-hp electric motor, regenerative-braking-capable controller package and two lithium polymer battery packs. The engine weighs 29 lbs and the battery packs weigh 78 lbs total. The aircraft has a climb rate of 500 ft/min, cruise of 70 mph and an endurance of 90 minutes. It is capable of being recharged from a 110 volt source in six hours or from a 220 volt source in two hours. The aircraft began flying in May 2008 and was demonstrated before the crowds on August 2 at AirVenture 2008.

In April 2009 the ElectraFlyer-C prototype was offered for sale on eBay. The designer intends to use the funds from the sale, plus a Lindbergh Foundation grant of $10,580 to complete two-place design that will eventually qualify for Light-sport aircraft status. The new design will incorporate composite construction, detachable wingtips to aid storage and will be powered by a 50 hp (37 kW) electric motor. Its design goals include a 28:1 glide ratio and a cruise speed of 80 mph (129 km/h) for two hours.

Electraflyer president Randall Fishman announced in April 2010 that the company's latest model, the Electraflyer-X, would fly in May or June 2010. The aircraft will be a two-seater and will utilize a new 20 hp (15 kW) single rotor electric powerplant. Fishman is also developing 40 hp (30 kW) two-rotor and 60 hp (45 kW) three rotor engine designs.

Sonex Aircraft

During AirVenture 2007 Sonex Aircraft announced that they are working on a series of alternate power initiatives, including an electric-powered aircraft. The electric powered Waiex motor glider was first flown in December 2010 and is powered by a 54 kW (72 hp) brushless DC electric motor, managed by a newly-designed controller. Power is from a collection of 14.5 kW-hour lithium polymer batteries, giving the aircraft an endurance of one hour at low-speed cruise or 15 minutes of aerobatics.

Yuneec International E430

A new Chinese aircraft was announced in 2009. The Yuneec International E430 is a two seat, V tailed, composite aircraft with a high-aspect ratio wing. Take-off speed is 40 mph and top speed is 93 mph. The aircraft is being developed as a homebuilt aircraft for the US market.

The prototype E430 was displayed at EAA AirVenture Oshkosh in July 2009, by which time it had flown over 22 hours. The company claims that the battery packs have an expected lifespan of 1500 hours and cost US$7000 each, with the aircraft carrying 3-5 battery packs, giving two to two and half hours endurance. The batteries can be recharged in 3 hours. The company projects that by the time the first customers require replacement battery packs that improved and less expensive ones will be available. Projected price for a commercially available light sport aircraft production version of the E430 is US$89,000.

Flightstar e-Spyder

The e-Spyder is an electric-powered version of the Flightstar Spyder ultralight, developed by Flightstar Sportplanes president Tom Peghiny of South Woodstock, Connecticut, USA in cooperation with electric engine manufacturer Yuneec. The aircraft replaces the Spyder's two-stroke engine with a Yuneec 20 kW (27 hp) electric motor and two 28 lb (13 kg) lithium-polymer battery packs which provide a 40 minute endurance. The aircraft was exhibited at EAA AirVenture Oshkosh in July 2009 and is intended as a commercially available kit plane, forecast to be available for under US$25,000.

Lange Antares 20E

A Lange Antares 20E in a hangar

The Lange Antares 20E is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. The motor actuates 2-blade fixed pitch propeller. It can climb up to 3,000 meters with fully charged cells. After launch it can function as a conventional, though heavy, glider. As of January 2010, over 50 had been built.

2010s

Cessna 172

In July 2010 Cessna announced it was developing an electrically-powered Cessna 172 as a proof-of-concept in partnership with Bye Energy. Cessna CEO Jack Pelton stated that the project reflects "encouraging news for the future of mainstream general aviation." Pelton pointed out "the electric power plant offers significant benefits, but there are significant challenges to get there."

PC-Aero Elektra One

The Elektra One is a development of a commercial electric aircraft design by PC-Aero of Germany. The single seat composite aircraft is expected to have its first flight in early 2011. The Elektra One is powered by a 21 hp (16 kW) electric motor and is expected to have an endurance of three hours, with a 100 mph (161 km/h) top speed.

The company is planning a whole line of aircraft including a version of the Elektra One with longer wings and built-in solar panels and an aerobatic version with double Elektra One's power and airframe strength. The company is also planning two and four seat developments.

Pipistrel Taurus Electro G2

First made available commercially in February 2011 the Taurus Electro G2 is a two-seat self-launching sailplane. The 40 kW (54 hp) engine will powered the aircraft from internally-mounted lithium batteries for a 17 minute climb, after which the engine is retracted and the aircraft then soars as a sailplane.

Design and operation of electric aircraft

Regenerative flight

A design concept has been put forward for soaring-type aircraft called regenerative soaring. In this approach, a propeller, using symmetrical blade sections, would be used as a turbine to recharge stored energy when the aircraft encounters an updraft. At high altitudes, the energy available from vertical atmospheric motion within a thermal can exceed available solar power by a factor of ten or more.

Chapter- 2

AeroVironment RQ-11 Raven and AeroVironment Wasp III

AeroVironment RQ-11 Raven

RQ-11 Raven UAV

Army Cpl. Jerry Rogers assembles an RQ-11

Raven unmanned aerial vehicle	
Role	Remote controlled UAV
Manufacturer	AeroVironment
First flight	October 2001
Introduction	May 2003
Status	In use on combat field
Primary users	United States Army United States Air Force
Produced	2004-present
Number built	13,000+ airframes
Developed from	FQM-151 Pointer

The AeroVironment **RQ-11 Raven** is a small hand-launched remote-controlled unmanned aerial vehicle (or SUAV) developed for the U.S. military, but now adopted by the military forces of many other countries.

The RQ-11 Raven was originally introduced as the FQM-151 in 1999, but in 2002 developed into its current form. The craft is launched by hand and powered by an electric motor. The plane can fly up to 6.2 miles (10.0 km) at up to altitudes of 10,000 feet (3,000 m) above ground level (AGL), and 15,000 feet (4,600 m) mean sea level (MSL), at flying speeds of 28-60 mph (45–97 km/h).

Design and development

The Raven RQ-11B UAV system is manufactured by AeroVironment. It was the winner of the US Army's SUAV program in 2005, and went into Full-Rate Production (FRP) in 2006. Shortly afterwards, it was also adopted by USSOCOM, the US Marines, and the US Air Force for their ongoing FPASS Program. It has also been adopted by the military forces of many other countries. More than 13,000 Raven airframes have been delivered to customers worldwide to date. A new Digital Data Link-enabled version of Raven now in production for US Forces has improved endurance, among many other improvements.

The Raven can be either remotely controlled from the ground station or fly completely autonomous missions using GPS waypoint navigation. The UAV can be ordered to immediately return to its launch point simply by pressing a single command button. Standard mission payloads include CCD color video cameras and an infrared night vision camera.

A single Raven costs about $35,000 and the total system costs $250,000. The RQ-11B Raven UAV weighs about 1.9 kg (4.2 lb), has a flight endurance of 60–90 minutes and an effective operational radius of approximately 10 km (6.2 miles).

The RQ-11B Raven UAV is launched by hand, thrown into the air like a free flight model airplane. The Raven lands itself by auto-piloting to a pre-defined landing point and then performing a near-vertical (1 foot down for every 1 foot forward) "Autoland" descent.

The UAV can provide day or night aerial intelligence, surveillance, target acquisition, and reconnaissance.

Variants

- RQ-11A Raven A (no longer in production)
- RQ-11B Raven B
- RQ-11B eight channel
- RQ-11B DDL(Digital Data Link)

Operators

A soldier prepares to launch the Raven in Iraq

The Raven is launched.

The Raven is used by the United States Army, Air Force, Marine Corps, and Special Operations Command. Additionally, US allies such as Australia, Estonia, Italy, Denmark, Spain and Czech Republic have also begun acquiring it, with more countries expected over the next few years. As of early 2008, over 8,000 airframes have already been shipped, making it the most widely adopted UAV system in the world today.

The British forces in Iraq are using U.S. Raven equipment and personnel on loan. The Royal Danish Army acquired 12 Raven systems in September 2007 - three systems will be delivered to the Huntsmen Corps, while the remainder will be deployed with soldiers from the Artillery Training Center.

The Netherlands MoD has acquired 72 operational RQ-11B systems with a total value of $23.74 million for use within Army reconnaissance units, its Marine Corps and its Special Forces (KCT). At the turn of the year 2009 to 2010 the systems were deployed above the village Veen, as part of the Intensification of Civil-Military Cooperation.

Current operators

Australia
Czech Republic

- Denmark
- Estonia
- Spain
- Iraq
- Italy
- Lebanon 12 systems
- Netherlands
- Norway
- United Kingdom
- United States

Specifications

- Wing Span 55in (130 cm)
- Length 36in (109 cm)
- Weight 4.2 lb (1.9 kg)
- Engine Aveox 27/26/7-AV electric motor
- Cruising speed approx. 30 kn (56 km/h)
- Range 6.2 miles (10 km)
- Endurance approx. 60-90 min

AeroVironment Wasp III

Wasp III Small Unmanned Aircraft System

Role	Remote controlled UAV
Manufacturer	AeroVironment Inc.
Introduction	2007
Primary user	United States Air Force
Unit cost	$49,000

The **Wasp III Small Unmanned Aircraft System** is an unmanned aerial vehicle (UAV) developed for United States Air Force special forces to provide a small, light-weight vehicle to provide beyond-line-of-sight situational awareness. The aircraft is equipped with two on-board cameras to provide real-time intelligence to its operators. It is also equipped with GPS and an Inertial Navigation System enabling it to operate autonomously from takeoff to recovery. It was designed by AeroVironment Inc. and was first added to the Air Force inventory in 2007. There are two Wasp variants: the traditional version that lands on land ("Terra Wasp") and a version that lands into the sea or fresh water ("Aqua Wasp").

Operators

United States

- **United States Air Force**
- **United States Marine Corps**

France

- **French Navy**

Australia

- **Australian Army**

Specifications

General characteristics

- **Crew:** none
- **Length:** 1.25 ft (38 cm)
- **Wingspan:** 2.375 ft (72.3 cm)
- **Height:** ()
- **Empty weight:** 0.95 lb (430 g (Land version))
- **Loaded weight:** 14.4 lbs (6.53 kg)
- **Powerplant:** 1× Electric motor, rechargeable lithium ion batteries, ()

Performance

- **Maximum speed:** 40mph 65 km/h
- **Cruise speed:** 40 - 65 km/h
- **Range:** 5 km ()

Armament

High resolution, day/night cameras with digital image stabilization and digital pan/tilt/zoom

Chapter- 3

ElectraFlyer, Lange Antares 20E and Puffin (Aircraft)

ElectraFlyer

ElectraFlyer	
Role	ultralight aircraft
Manufacturer	Electric Aircraft Corporation
Designed by	Randall Fishman
First flight	April, 2007
Primary user	Private individuals
Produced	2007–Present
Unit cost	$16,000-$21,000

The **ElectraFlyer** trike is an ultralight aircraft that flies using an electric motor, instead of a traditional gasoline engine.

The ElectraFlyer-C is a prototype aircraft that uses the same electric motor configuration as the ElectrFlyer Trike.

Specifications

The Electraflyer Trike is built to comply with Federal Aviation Regulations, part 103. The standard ElectraFlyer is equipped with a 5.6—kWh Lithium-ion polymer battery which powers an 18 hp electric motor — which can be optionally upgraded to a 40 hp motor. Depending on the number of battery packs attached, the aircraft can fly for between one and two hours before it must be recharged for 5–6 hours using a standard 120 volt AC outlet. Charging time can be reduced to 2 hours using a 240 volt outlet.

Mounting a Stratus-model Rogallo wing design, the total aircraft weight is less than 249 pounds, depending on the options selected for engine, batteries, and other accessories such as a ballistic parachute.

It was awarded the Grand Champion Ultralight at the 2007 EAA AirVenture Oshkosh Fly-In.

The ElectraFlyer-C is a converted metal Monnett Moni motoglider equipped with the same power plant as the Electraflyer Trike. This airplane cruises at 70 mph (113 km/h), stalls at 45 mph (72 km/h) and has a top speed of 90 mph (145 km/h) with a flight duration of 1½ to 2 hours and a climb rate of 500 to 600 fpm (2.5 – 3 m/s).

Lange Antares 20E

Antares 20E

Lange Flugzeugbau Antares 20E

Role	Open Class sailplane
National origin	Germany
Manufacturer	Lange Aviation GmbH
First flight	2003
Number built	50 as of April 2009

The **Antares 20E** is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. It can climb to 3,000 meters on one battery charge.

The EM 42 is a fixed-shaft brushless DC electric motor running at 190-288 V, and drawing up to 160 A, the 42 kW motor can deliver up to 216 N.m of torque over a speed range of 160-1600 RPM with a total efficiency of 90%. Maximum continuous power is

38.5 kW, the motor weighs 29 kg, and the weight of power electronics is 10 kg. The motor turns a 2-blade fixed-pitch propeller LF-P42 constructed of composite materials with 2.00 m diameter.

The battery system consists of two battery packs positioned in the leading edges of both inner wings (72 cells divided into 24 modules containing 3 cells each). The battery life is expected to 3000 cycles or 20 years. Capacity of battery is 41 Ah (specific energy 136 Wh/kg and specific peak power 794 W/kg). The batteries can deliver 13 minutes at maximum power and maximum climb speed. The charger is integrated inside the fuselage so when landing elsewhere the pilot merely has to find an electric outlet socket. The glider has a modem connected to its main computer so that technicians can run diagnostics remotely.

The undercarriage is hydraulically operated. The tailwheel is steerable.

Specifications

General characteristics

- **Crew:** one pilot
- **Capacity:** 100 l water ballast
- **Length:** 7.40 m (24 ft 3 in)
- **Wingspan:** 20.00 m (65 ft 7 in)
- **Height:** 1.64 m (5 ft 5 in)
- **Wing area:** 12.6 m^2 (135.6 ft^2)
- **Aspect ratio:** 31.7
- **Empty weight:** 460 kg (1 014 lb)
- **Gross weight:** 660 kg (1 455 lb)
- **Powerplant:** 1 × EM42 (brushless DC electric motor), 42 kW (57 hp)

Performance

- **Maximum speed:** 280 km/h (174 mph)
- **Maximum glide ratio:** 56
- **Rate of climb:** 4.4 m/s (866 ft/min)
- **Rate of sink:** 0.49 m/s (96 ft/min)

Puffin

The **Puffin** is a proposed hover-capable, electric-powered, low-noise, personal vertical takeoff and landing (VTOL) technology-concept proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour (241 km/h). Range is expected to be less than 50 miles (80 km) with 2010-vintage Lithium-iron-phosphate battery technology. The design has a 13.5 foot (4.1 m) wingspan and stands 12 feet (3.65 m) tall on the ground in its take-off or landing configuration.

Development

As of January 2010, NASA expected to achieve the first flight of a one-third scale, hover-capable Puffin demonstrator by March 2010. By mid-summer 2010, they hoped to "begin investigating how well it transitions from cruise to hover flight.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for the filming of the Discovery network series “Dean of Invention.” The Puffin simulator was also demonstrated. The Puffin is slated to appear in the eighth and final episode of the show.

Chapter- 4

Avro 720 and Blohm & Voss P.194

Avro 720

Avro 720	
Role	Interceptor
National origin	United Kingdom
Manufacturer	Avro
Status	Cancelled before completion of first prototype
Number built	0

The **Avro 720** was a planned British single-seat interceptor of the 1950s. It was to be of mixed propulsion, with a rocket engine to give high performance and a small jet engine for cruising flight. At least one prototype was ordered, but the project was cancelled before any were completed.

Design and development

In the early 1950s, the British Air Ministry, impressed by the performance of the rocket-powered Messerschmitt Me 163 fighter, and facing the potential threat of Soviet supersonic bombers armed with nuclear weapons, issued Specification F.124T for a rocket powered point-defence interceptor. This was to be of similar concept to the Me 163, using its rocket to climb rapidly to meet its target, before gliding back to earth, fuel exhausted, to land on a retractable skid. Proposals to meet the specification were received from a number of companies, including Avro, Bristol, Blackburn, Shorts and Saunders-Roe. It was soon realised, however, that a rocket-only fighter with the performance required by the specification, which would have to glide back to ground from heights of up to 100,000 ft (30,500 m), land without power many miles away and then be recovered and taken back to the airfield by ground vehicle, was impracticable. Revised specifications were therefore issued to Avro and Saunders-Roe for aircraft with auxiliary turbojet engines, giving sufficient power to allow the aircraft to fly back to its airbase after combat.

Avro's design, the Avro Type 720, designed to meet specification F.173D, was a small tailless delta-winged aircraft. It was constructed of metal honeycomb sandwich. The main power-plant was an 8,000 lbf (36 kN) Armstrong Siddeley Screamer rocket engine, using liquid oxygen as oxidant and kerosine fuel. This differed from the competing Saunders-Roe SR.53, which used a de Havilland Spectre powered by Hydrogen Peroxide and kerosine. Both types used a 1,750 lbf (7.8 kN) Armstrong-Siddeley Viper as the auxiliary turbojet, with the Avro design fed with air from a small chin inlet under the aircraft's nose. Two de Havilland Firestreak Infrared homing air-to-air missiles could be carried on underwing pylons.

Two prototypes were ordered, and the Screamer engine successfully completed flight clearance tests in December 1956. Official concern about the practicality of using liquid oxygen, which boils at -183°C (90 K), in an operational environment led to the Screamer engine being cancelled late in 1956, together with the Avro 720. One structural test airframe was part complete at the time of cancellation, and photographs of this airframe, with the port wing fitted and the serial number *XD696* painted on are sometimes claimed to be the "almost complete" first prototype. The Avro 720 had cost £1 Million by the time of cancellation, while its Screamer powerplant cost a further £0.65 million.

Specifications (Performance estimated)

General characteristics

- **Crew:** 1
- **Length:** 42 ft 3 in (12.88 m)
- **Wingspan:** 27 ft 3.5 in (8.319 m)
- **Wing area:** 166 sq ft (15.4 m^2)
- **Empty weight:** 7,812 lb (3,543 kg)
- **Max takeoff weight:** 17,575 lb (7,972 kg)
- **Powerplant:** 1 × Armstrong Siddeley Screamer liquid-fuelled rocket, 8,000 lbf (36 kN) thrust
- **Powerplant:** 1 × Armstrong Siddeley Viper ASV.8 turbojet, 1,750 lbf (7.8 kN) thrust

Performance

- **Maximum speed:** 1,320 mph (2,120 km/h; 1,150 kn) at 40,000 ft (12,200 m)
- **Maximum speed:** Mach 2.0
- **Service ceiling:** 60,000 ft (18,288 m)
- **Time to altitude:** 1 min 50 s to 40,000 ft (12,200 m)

Armament

- **Missiles:** Provision for 2× de Havilland Firestreak infra-red homing air-to-air missiles

Blohm & Voss P.194

P.194

Model photo of a Blohm & Voss BV P.194.02

Role	Tactical bomber
National origin	Germany
Manufacturer	Blohm & Voss
Designed by	Richard Vogt
Status	Unrealised project

The **Blohm & Voss P.194** was a design for a mixed-power ground-attack aircraft and tactical bomber developed in Germany during World War II. Like some of Richard Vogt's other designs for Blohm & Voss, the P.194 featured an asymmetric layout.

Along with the P.192, P.193, and P.196, the P.194 was one of four designs Blohm & Voss submitted in response to a requirement issued by the RLM in February 1944 for a replacement for the venerable Junkers Ju 87. The basic design of the aircraft echoed that of the BV 141: the crew and weapons carried in a nacelle separate from the main fuselage structure that carried a propeller-driven engine at one end and the empennage at the other, joined together by a common wing. In the P.194, however, a turbojet was to be added at the rear of the cockpit pod and the design intended that the thrust from this engine would help balance the thrust from the propeller. A powerful cluster of guns was to be located in the nose, and a bombload of up to 500 kg (1,100 lb) was to be carried in an internal bomb bay in the fuselage.

All four Blohm & Voss designs were rejected by the RLM, which instead selected the Messerschmitt Me 262 to fill the tactical bomber role instead.

Design stages

- **P.194.00-101** - version with 16 m (52 ft) wingspan and jet intake under cockpit pod
- **P.194.01-02** - version with 15.3 m (50.2 ft) wingspan, bubble canopy and jet intake under cockpit pod
- **P.194.02-01** - as above, but with turbojet located beneath cockpit
- **P.194.03-01** - as P.194.01-02, but with jet intakes located in the wing roots at the sides of the cockpit pod.

Specifications (194-01, as designed)

General characteristics

- **Crew:** One pilot
- **Length:** 12.10 m (39 ft 8 in)
- **Wingspan:** 15.30 m (50 ft 2 in)
- **Height:** 3.70 m (12 ft 2 in)
- **Wing area:** 36.4 m² (391 ft²)
- **Empty weight:** 6,500 kg (14,300 lb)
- **Gross weight:** 9,350 kg (20,600 lb)
- **Powerplant:** 1 × BMW 801D, 1,200 kW (1,600 hp)

  1 × Junkers Jumo 004, 8.7 kN (2,000 lbf) thrust

Performance

- **Maximum speed:** 775 km/h (484 mph)
- **Range:** 1,070 km (669 miles)
- **Service ceiling:** 11,100 m (36,400 ft)

Armament

- 2 × fixed, forward-firing 30 mm (1.18 in) MK 103 cannons
- 2 × fixed, forward-firing 20 mm MG 151/20 cannons
- 500 kg (1,102 lb) of bombs in internal bay

Chapter- 5

Curtiss XF15C and Focke-Wulf Ta 400

Curtiss XF15C

XF15C	
Role	Fighter
National origin	United States
Manufacturer	Curtiss Aeroplane and Motor Company
First flight	27 February 1945
Number built	3

The **Curtiss XF15C** was a mixed-propulsion fighter prototype of the 1940s.

Development

By the late 1940s, the United States Navy was interested in the mixed-power concept for its shipborne fighters - i.e. aircraft with a mixture of propellor and turbojet engines, such as the FR Fireball. As such, an order was placed with Curtiss on 7 April 1944 for delivery of three mixed-power aircraft, designated the F15C. Powered by both a 2,100 hp (1,566 kW) Pratt & Whitney propellor engine, and an Allis-Chalmers J36 turbojet, the aircraft was in theory the fastest fighter in the US Navy at that time.

Operational history

The first flight of the first prototype was on 27 February 1945, without the turbojet installed. When this was completed in April of the same year, the aircraft flew several mixed-power trials, however on May 8 it crashed on a landing approach. The second prototype flew for the first time on 9 July, again in 1945, and was soon followed by a third prototype. Both aircraft showed promise, however by October 1946 the Navy had lost interest in the mixed-power concept and cancelled further development.

Specifications

General characteristics

- **Crew:** 1
- **Length:** 44 ft 0 in (13.41 m)
- **Wingspan:** 48 ft 0 in (14.63 m)
- **Height:** 15 ft 3 in (4.65 m)
- **Wing area:** 37.16 ft² (400 m²)
- **Empty weight:** 12,648 lb (5,739 kg)
- **Gross weight:** 16,630 lb (7,543 kg)
- **Powerplant:** 1 × Pratt & Whitney R-2800-34W 18-cylinder two-row radial, 2,100 hp (1,566 kW)

  1 × Allis-Chalmers J36 turbojet, 2,700 lbf (1,226 kN) thrust

Performance

- **Maximum speed:** 469 mph (755 km/h)
- **Range:** 1,385 miles (2,228 km)
- **Rate of climb:** 5,020 ft/min (25.5 m/s)

Armament

- 4 × wing-mounted 20 mm (.79 in) cannon

Focke-Wulf Ta 400

Ta 400	
Role	Amerika Bomber
Manufacturer	Focke-Wulf
Designed by	Kurt Tank
Primary user	*Luftwaffe*
Number built	1 prototype, never completed

The **Focke-Wulf Ta 400** was a large six-engined bomber prototype developed in Nazi Germany in 1943 by Focke-Wulf as a serious contender for the Amerika Bomber project.

One of the first aircraft to be developed from components from multiple countries, it was also one of the most advanced Focke-Wulf designs of World War II, though it never progressed beyond a wind tunnel model.

Designed as a bomber and long-range reconnaissance plane by Kurt Tank, the Ta 400 had a shoulder-mounted wing with 4° dihedral. One of the most striking features was the six BMW 801D radial engines, to which two Jumo 004 jet engines were later added.

Design and development

In response to the RLM guidelines of 22 January 1942, Kurt Tank of the Focke-Wulf company designed the Ta 400 as a bomber and long-range reconnaissance aircraft to be powered by six BMW 801D radial engines, to which two Jumo 004 jet engines were later added. Design work was begun in 1943, much of it being carried out by French technicians working at Châtillon-sous-Bagneux near Paris, with contracts for design and construction of major components being awarded to German, French, and Italian companies in an attempt to speed the process and begin construction of prototypes as soon as possible.

The Ta 400 had a shoulder-mounted wing with 4° dihedral, with a long straight center section extending to the middle engine on each wing, and highly tapered outer wing panels. It had twin vertical stabilizers mounted at the tips of the tailplane. Like the American Boeing B-29 Superfortress the Ta 400 was to have a pressurized crew compartment and tail turret, connected by pressurized tunnel, as well as multiple remote-controlled turrets. The crew of nine was to be protected by a heavy defensive armament including ten 20 mm MG 151 cannons. The Ta 400 was to use a staggering 32 fuel tanks. Another design feature was tricycle landing gear.

Maximum bomb load was to be 24 t (53,000 lb). With a gross weight of 80.27 tonnes (88.48 short tons), the Ta 400 with DB 603 engines was estimated to have a range of 12,000 km (7,500 mi) in the reconnaissance role, cruising at 325 km/h (202 mph). The two bomber versions would have 76.07 tonnes (83.85 short tons) and 80.87 tonnes (89.14 short tons) gross weights with estimated ranges of 4,500 km (2,800 mi) and 10,600 km (6,600 mi) respectively. The projected Jumo-powered aircraft would have had a maximum range of 14,000 km (8,700 mi) for long range reconnaissance and 13,000 km (8,100 mi) as a bomber. Because no prototype was ever built, it never progressed beyond a wind tunnel model, and performance, range and dimensions are based solely on the designers' estimates.

The Ta 400 was essentially a backup design for the Messerschmitt Me 264. As the design required more materials and labor than the Me 264, the RLM became convinced that further development of the Ta 400 was a waste and on 15 October 1943, notified Focke-Wulf that the program would be terminated, but the minutes of a meeting in Italy of Tank with Italian aviation industrialists on 18 April 1944 confirmed that the design was still active and proposed the cooperation of Italian industry to the project.

Specifications

General characteristics

- **Crew:** 6
- **Length:** 28.7 m (94 ft 2 in)
- **Wingspan:** 45.8 m (150 ft 3 in)
- **Height:** ()
- **Loaded weight:** 60,000 kg (132,000 lb)
- **Powerplant:**
    - 2× Junkers Jumo 004 turbojets, 1,980 lbf (8.8kN) each
    - 6× BMW 801D radials, 1,700 hp (1.3 MW) each

Performance

- **Maximum speed:** 343 knots (395 mph, 635 km/h)
- **Range:** 4,860 nmi (5,592 mi, 9,000 km)

Armament

- **Guns:** 10 × MG 151/20 in five twin turrets
- **Bombs:** 22,046 lb / 10,000 kg total

Chapter- 6

Gulfstream American Hustler and McDonnell XF-88 Voodoo

Gulfstream American Hustler

Hustler	
Role	Executive or utility aircraft
Manufacturer	American Jet Industries/Gulfstream American
First flight	1978
Number built	1

The **Gulfstream American Hustler** was a 1970s American mixed-power executive/utility aircraft designed by American Jet Industries (later Gulfstream American). The aircraft had a nose-mounted turbprop and with a tail-mounted turbofan.

Development

In 1974, American Jet Industries started work on a seven-seat executive transport with a Pratt & Whitney Canada PT6 engine in the nose supplemented by a Williams Research Corporation WR19-3-1 turbofan mounted in the tail. The turbofan was originally intended to be a standby emergency power unit that could also be used if extra thrust was needed for take-off. The prototype designated **Hustler 400** (*N400AJ*) first flew on the 11 January 1978. The Hustler was a low-wing cantilever monoplane with retractable tricycle landing gear, and a high-mounted tailplane.

It was originally intended to be certified as a single-engined aircraft because the Williams turbofan had not been certified. But the company (by then called Gulfstream American) decided it should be approved as a twin and the Williams turbofan was replaced with a Pratt & Whitney Canada JT15D turbofan. To enable the engine to be fitted a 2 ft 8 in

(0.81m) extension to the forward fuselage. The cabin entrance door was moved in front of the wing and other aerodynamic changes. The intake for the rear engine was also moved from the lower rear fuselage to the base of the fin.

Another change was made in 1979 when the front engine was replaced by a Garrett TPE331 turboprop and the aircraft was re-designated the '*Hustler 500*. The aircraft was flown in this configuration in 1981 but the programme was suspended due to a recession in the general aviation market. Element for the design were used in the prototype jet trainer the Peregrine 600.

Variants

Hustler 400

Prototype mixed-power aircraft with a Pratt & Whitney Canada PT6A-41 in the nose.

Hustler 500

Modified aircraft with a Garrett TPE331 Turboprop in the nose.

Specifications (Hustler 500)

General characteristics

- **Crew:** One
- **Capacity:** Four or five passengers
- **Length:** 41 ft 3 in (12.57 m)
- **Wingspan:** 34 ft 5 in (10.49 m)
- **Height:** 13 ft 2½ in (4.03 m)
- **Wing area:** 190.71 ft² (17.72 m²)
- **Empty weight:** 5430 lb (2463 kg)
- **Gross weight:** 10,000 lb (4536 kg)
- **Powerplant:** 1 × Garrett TPE331-10-501 turboprop, 900 hp (671 kW)

  1 × Pratt & Whitney Canada JT15D-1 turbofan, 2,200 lbf (kN) thrust

Performance

- **Maximum speed:** 402 mph (647 km/h)
- **Range:** 2303 miles (3706 km)
- **Service ceiling:** 38,000 ft (11580 m)

McDonnell XF-88 Voodoo

XF-88 Voodoo

Role	Escort fighter
Manufacturer	McDonnell
First flight	20 October 1948
Status	Cancelled
Primary user	United States Air Force
Number built	2
Program cost	US$6.6 million
Developed into	F-101 Voodoo

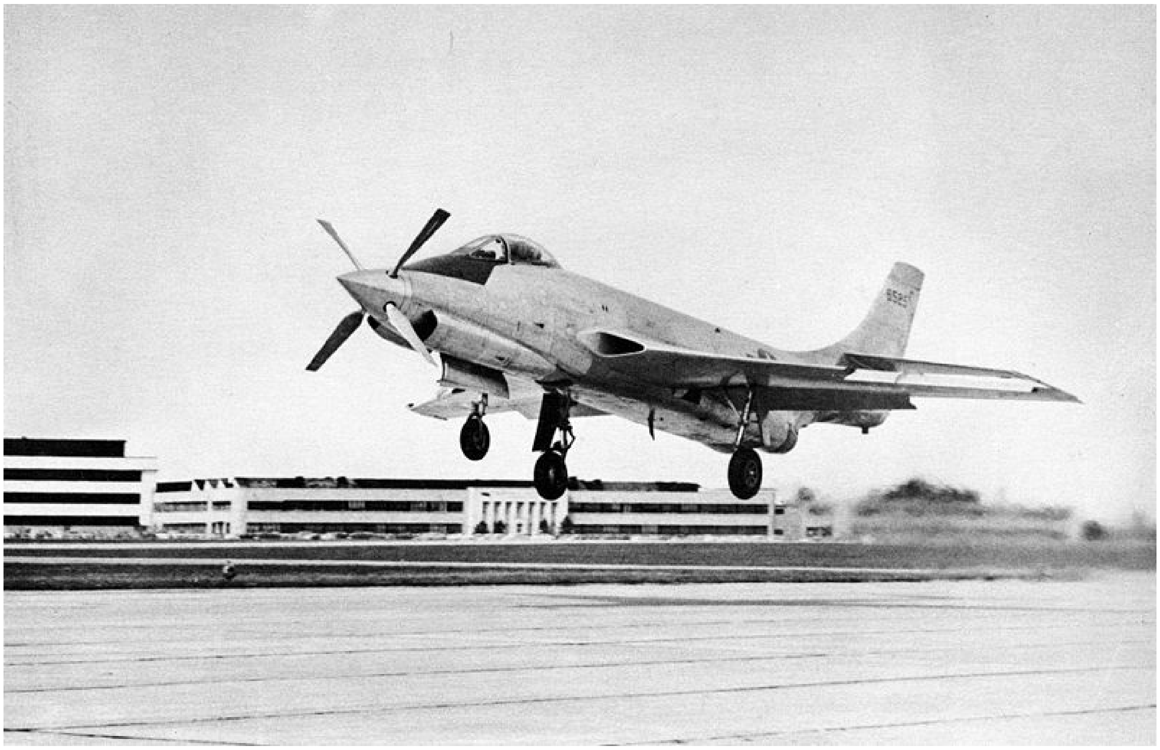
The **McDonnell XF-88 Voodoo** was a long-range, twin-engine jet fighter aircraft designed for the United States Air Force. Although it never entered service, its design was adapted for the subsequent F-101 Voodoo.

Design and development

The XF-88 originated from a 1946 United States Army Air Forces requirement for a long-range 'penetration fighter' to escort bombers to their targets. It was to be essentially a jet-powered replacement for the wartime P-51 Mustang that had escorted B-17 Flying Fortress bombers over Germany. It was to have a combat radius of 900 mi (1,450 km) and high performance. McDonnell began work on the aircraft, dubbed **Model 36**, on 1 April 1946. On 20 June the company was given a contract for two prototypes designated **XP-88**. Dave Lewis was Chief of Aerodynamics on this project.

The engineering team stands after Flight 100.

Supersonic jet-turboprop hybrid XF-88B



Landing the XF-88

The initial design was intended to have a V-shaped tail, but wind tunnel tests indicated aerodynamic problems that led to an extensive redesign. The USAAF (which became the United States Air Force on 17 September 1947) approved the changes. When the USAF altered its designation scheme in 1948, the still unflown prototypes were redesignated **XF-88**. It was dubbed **Voodoo**.

The Voodoo had a low/mid-mounted wing, swept to 35°. The two engines were in the lower fuselage, with jetpipes beneath the rear fuselage. The prototypes carried XJ34 engines, although the production **F-88A** would have had two Westinghouse J46 turbojets with 5,920 lbf (26.33 kN) each. Intakes were mounted in the wing roots. The Voodoo's short nose had no radar, being intended to house an armament of six 20 mm (.79 in) M39 cannon.

The first XF-88 made its maiden flight on 20 October 1948. It had non-afterburning engines and no armament. It proved to be underpowered, leading to the decision to install afterburners on the second prototype, which was designated **XF-88A** and made its first flight on 26 April 1949. (The first prototype was modified to the same standard.)

In a subsequent paper competition against the Lockheed XF-90 and North American YF-93, the Voodoo lost to the XF-93, but the decision on production was later delayed until a 'fly-off' competition could be held. In that fly-off, held in the summer of 1950, the XF-88 proved the winner, but changes in Air Force requirements led the penetration fighter to be cancelled entirely.

McDonnell proposed a naval version of the XF-88, a two-seat operational trainer, and a reconnaissance variant, but none were built. The first prototype was modified to **XF-88B** standard, with a nose-mounted Allison T38 turboprop engine added to the two existing turbojets. This was used for flight testing through 1956, and achieved speeds slightly exceeding Mach 1.0, the first propeller-equipped aircraft to do so. Both prototypes were scrapped by 1958.

A considerably enlarged version of the basic design was developed following the cancellation of the XF-88, becoming the F-101 Voodoo, the first production version of which flew on 29 September 1954. The basic layout of two engines under the tail would also appear in the redesign of an upgraded F3H Demon which would see service as the very successful F-4 Phantom II.

Operators

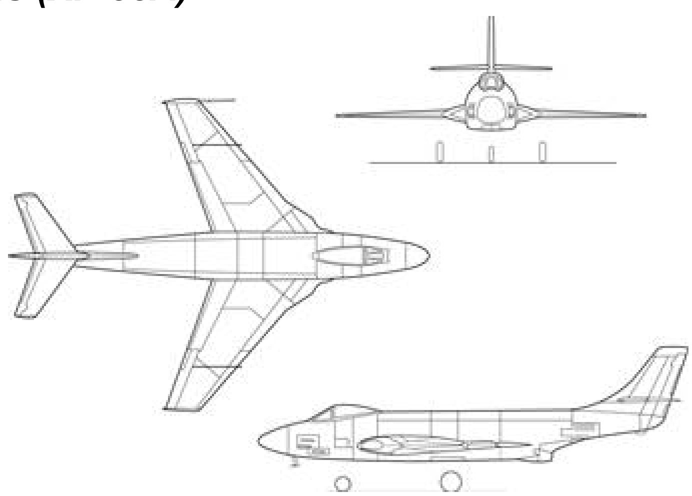
United States

- United States Air Force

Variants

XF-88A
XF-88B

Specifications (XF-88A)



General characteristics

- **Crew:** one
- **Length:** 54 ft 1.5 in (16.5 m)
- **Wingspan:** 39 ft 8 in (12.1 m)
- **Height:** 17 ft 3 in (5.3 m)
- **Wing area:** 350 ft² (32.5 m²)
- **Empty weight:** 12,140 lb (5,508 kg)

- **Loaded weight:** 18,500 lb (8,394 kg)
- **Max takeoff weight:** 23,100 lb (10,477 kg)
- **Powerplant:** 2× Westinghouse J34-WE-22 afterburning turbojets, 4,825 lbf (21.4 kN) each

Performance

- **Maximum speed:** 706 mph (1,130 km/h)
- **Range:** 1,737 mi (2,779 km)
- **Service ceiling:** 39,400 ft (12,012 m)
- **Rate of climb:** 8,000 ft/min (40 m/s)
- **Wing loading:** 52.9 lb/ft² (258 kg/m²)
- **Thrust/weight:** 0.44

Armament

- 6 × 20 mm (.79 in) M39 cannon

Chapter- 7

Mikoyan-Gurevich I-250

I-250

An I-250 showing its motorjet exhaust

Role	Fighter aircraft
Manufacturer	Mikoyan-Gurevich
First flight	3 March or 4 April 1945
Status	Cancelled
Produced	1945–1946
Number built	12

The **Mikoyan-Gurevich I-250** (a.k.a. *Samolet N*) was a Soviet fighter aircraft developed as part of a crash program in 1944 to develop a high-performance fighter to counter German turbojet-powered aircraft such as the Messerschmitt Me-262. The Mikoyan-Gurevich design bureau decided to focus on a design that used something more mature than the jet engine, which was still at an experimental stage in the Soviet Union, and chose a mixed-power solution with the VRDK motorjet powered by the Klimov VK-107 V12 engine. While quite successful when it worked, with a maximum speed of 820 km/h (510 mph) being reached during trials, production problems with the VRDK fatally delayed the program and it was canceled in 1948 as obsolete.

Design and development

By January 1944 the Soviets were aware of successful British and American jet aircraft projects and that the Germans were about to deploy jet and rocket-propelled aircraft of their own. The GKO ordered on 18 February that the NKAP (People's Commissariat for Aviation Industry) centralize jet research under its control and that the NKAP was to present proposals to alleviate the situation within a month. As a result of this meeting the NKAP ordered the Lavochkin, Sukhoi, Yakovlev and Mikoyan-Gurevich design bureaux (OKBs) to develop and build jet aircraft with the utmost dispatch. Aware of earlier problems encountered with other novel propulsion systems such as ramjets both Sukhoi and Mikoyan-Gurevich chose to use the VRDK (*Vozdushno-Reaktivnyy Dvigatel' Kompressornyy* — Air-reactive compressed engine) jet booster engine that had been under development since 1942.

The VRDK was a motorjet, a rudimentary type of jet engine where an external power source drove the engine's compressor. It forced air into the stainless steel combustion chamber where fuel was sprayed from seven nozzles and ignited to exhaust out the variable rear nozzle. In the I-250 a 1,650-horsepower (1,230 kW) Klimov VK-107R V-12 piston engine was used as the primary powerplant. After takeoff a clutch at the end of the crankshaft could be engaged which drove a step up gearbox with a ratio of 13:21 to an extension shaft that powered the compressor of the VRDK. The air for the compressor was fed through a long duct that ran from the inlet underneath the propeller spinner, thence under the engine and through the belly of the aircraft. This duct also fed air to the oil cooler near the engine, but the water radiator was positioned behind the compressor to maximize airflow over it. A secondary duct led from the main duct to the VK-107's supercharger; when the VRDK was running the secondary duct diverted some of that additional air to the supercharger which boosted the engine's output to 2,500-horsepower (1,900 kW) at 7,000 m (22,966 ft). The increased airflow over the engine radiator helped to dump the engine's excess heat into the exhaust stream. However the VRDK was limited to only ten minutes' operating time per sortie, which meant that it was useless weight during the rest of the flight.

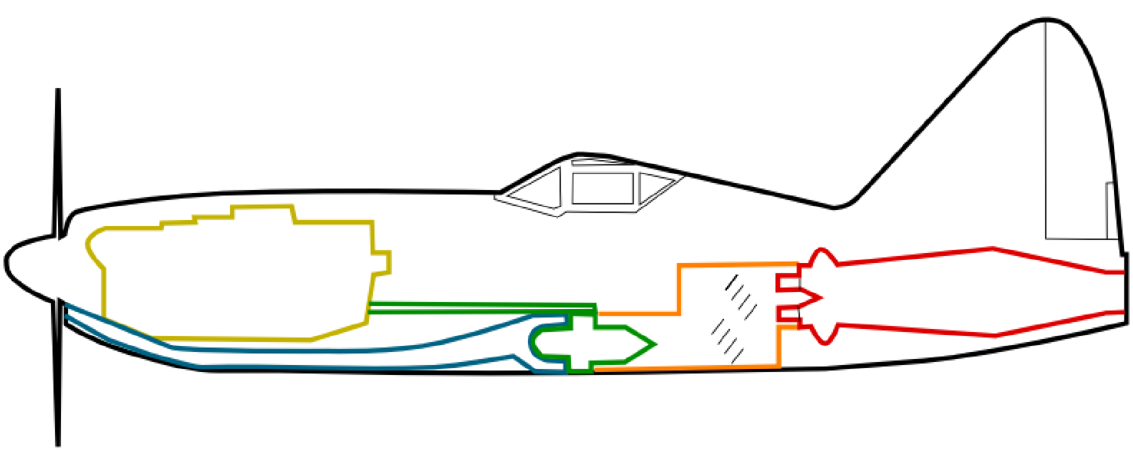


Diagram of the I-250's engine installation

The I-250 was a low-wing, all-metal aircraft with a monocoque fuselage. Other than the VRDK the aircraft was largely conventional in layout, although the cockpit was set very far back in the fuselage, almost to the base of the vertical tail. The two-spar wings had a thickness of 10% to preserve aileron control and avoid tip stall. They were fitted with Frise ailerons and slotted flaps. Fuel was contained in a 412-litre (91 imp gal; 109 US gal) fuselage tank and a 100-litre (22 imp gal; 26 US gal) tank in each wing. The conventional landing gear mainwheels had a levered suspension and retracted inwards. The tail wheel retracted aft into the very small ventral fin. The VK-107A engine initially drove a 3.1-metre (10 ft) VISh-105SV propeller.

The NKAP had asked Mikoyan to begin preliminary design work on a high-altitude interceptor in January 1944, but ordered two prototypes of an all-metal interceptor using the VRDK for testing in February and March 1945. The aircraft was to reach an altitude of 5,000 m (16,000 ft) in 4.5 minutes with full power and 5.5 minutes using the piston engine alone. Its maximum speed was to be 810 km/h (500 mph) at 7,000 m (22,966 ft) with full power and 700 km/h (430 mph) at 7,000 m (22,966 ft) using the VK-107 by itself. Its intended armament was one 23 mm (0.91 in) autocannon and two 12.7 mm (0.50 in) machine guns. To assist Mikoyan TsAGI was ordered to provide help with aerodynamic and stress calculations and to test a full-size mockup in their wind tunnel in one month's time. TsIAM was ordered to deliver three VRDK engines with 9-kilonewton (2,000 lb_f) at 7,000 m (22,966 ft) with a specific fuel consumption of 1,200 kg (2,600 lb) per hour. The plane was designated **I-250** by the NKAP; but the internal OKB designation was **N**.

The NKAP approved the preliminary specifications of the I-250 on 19 September 1944 which included a maximum speed of 825 km/h (513 mph) a take-off weight of 3,500 kg (7,700 lb) and a time to 5,000 metres (16,404 ft) of 3.9 minutes. A mock-up was inspected on 26 October and rejected because of the poor cockpit layout, although this decision was reversed because the fuselage of the first prototype was too far along for major changes that would have significantly delayed the program. That same month the combustion chamber was sent to TsIAM for testing which revealed it to be too weak. The complete powerplant was tested in December, but the drive shaft connecting them failed several times.

The first prototype was completed on 26 February 1945, although the VRDK was not yet ready. It was fitted with a new 3.1-metre (10 ft) AV-10P-60 propeller before making its first flight on 4 April according to Gordon and Komissarov, although Belyakov and Marmain say 3 March. It was armed with three 20 mm Berezin B-20 cannon with 160 rounds each. One gun was fitted on each side of the nose and the third fired through the hollow propeller shaft. The VRDK was tested for the first time on 8 April in a dive, attaining a speed of 710 km/h (440 mph), but a leak was found in the oil cooler after landing and the VRDK had to be returned to the factory for repairs. The VRDK was reinstalled by 14 April, but was still troublesome. It twice reached 809 km/h (503 mph) at about 7,000 m (22,966 ft) during these early tests, but its service life had been exceeded by 30 May and it had to be returned to TsIAM, which postponed any further tests until the second aircraft was finished.

The unarmed second prototype was completed on 19 May, but did not make its first flight until 26 May. It was later discovered to have several major defects, including an oil leak from the VRDK compressor's sleeve. The VRDK's designer was summoned in an attempt to solve its problems although not all of these were design issues. The first prototype was grounded for most of June to remedy magneto problems and to add extra air intakes to cool the spark plugs. It attained a speed of 820 km/h (510 mph) at 6,700 m (21,982 ft) on 3 July. Unfortunately its port tailplane failed at low altitude two days later, killing the test pilot, Alexandr Deyev, when his parachute failed to open in time. Post-crash analysis revealed that he had exceeded the airframe's G limit while maneuvering.

Despite the accident, a pre-production batch of ten aircraft was ordered on 27 July 1945 as it was felt that mixed-power aircraft would be of some use easing the transition of pilots from piston-engine fighters to jet-engined ones. At the same time Sukhoi's Su-5 was cancelled as it was judged inferior to the I-250.

In the meantime the horizontal stabilizer of the second prototype was strengthened and it resumed flying on 20 July. The pilot complained of excess torque pull to the right so the vertical stabilizer was enlarged by 0.63 m^2 (6.8 sq ft), but this was just one of numerous problems, and it was not ready to pass State acceptance trials without more development work on the powerplant. However, the second prototype continued flight testing until 12 July 1946 when an engine fire forced an emergency landing and it was damaged beyond repair.

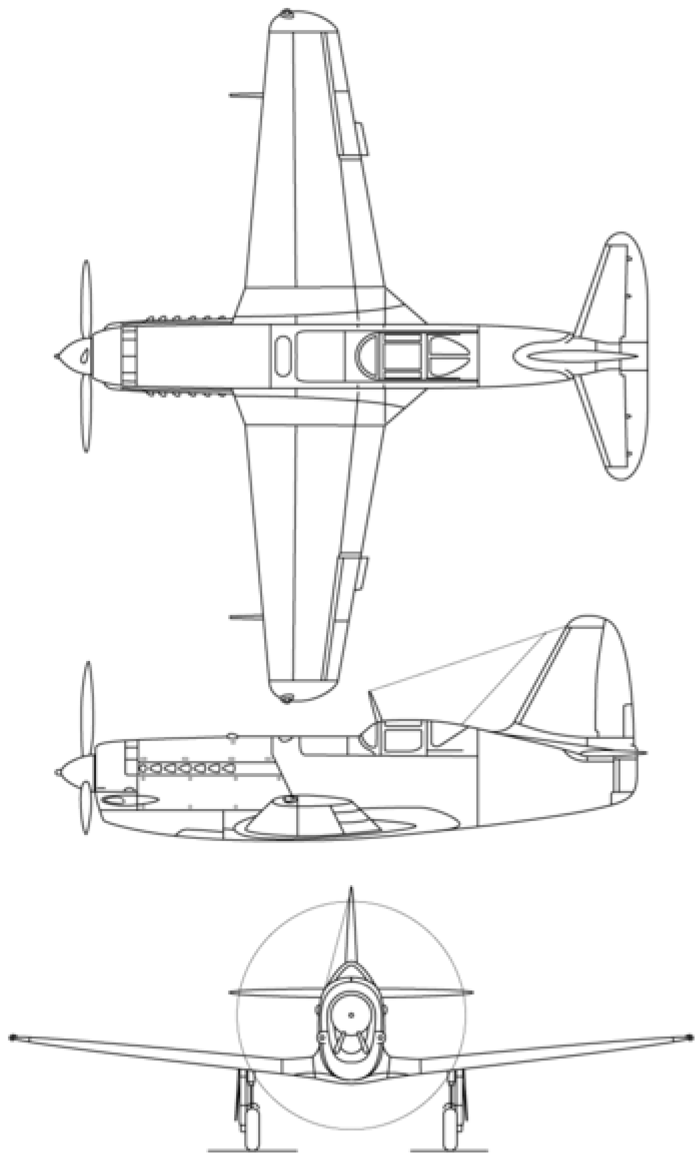
The order for the pre-production I-250s had been placed with Factory No. 381 in Moscow for two aircraft to be delivered in September, three more in October and the remainder by the end of the year. This proved to be very optimistic and it was revised to a single aircraft by the end of the year. The airframe was completed on this revised schedule, but its engine was not ready in time. The factory management was much criticized for these problems which were not entirely under their control as changes to the design and drawings were constant. The criticism was not limited to just the I-250 program as the other jet programs could not be developed as fast as the leadership wanted as well and Alexei Shakhurin, the head of MAP (Ministry of Aviation Industry) and its NKAP predecessor since 1940, was arrested in March 1946 as a sign of their displeasure. The new Minister severely reprimanded the designer of the VRDK and three factory directors on 13 April 1946 and set up a commission to determine why Factory No. 381 and TsIAM had failed to meet their deadlines. He refused to accept its findings as it apportioned blame fairly evenly among those responsible for the production program and he had the director of Factory No. 381 and his quality control manager arrested for industrial sabotage.

Despite these production problems and the fact that the I-250 had yet even to be submitted for State acceptance trails, an order had been placed for fifty more aircraft on 26 February (these aircraft have been referred to as the **MiG-13**, which presumably would have been their designation if they had actually entered service). A new deadline of 5 July 1946 was set for the delivery of the first pre-production aircraft, but it was stymied, again, for a lack of an engine. By this time seven airframes had been completed, but all lacked engines. The first I-250 was finally accepted on 8 August and flown for the first time three days later, although its engine seals failed and a number of ignition cables were scorched. The engine replacement and repairs forced the aircraft to miss its scheduled appearance at the Tushino Air Display. It was handed over to the NII VVS (Air Force Institute) on 15 September to finally begin its State acceptance tests. All ten aircraft had been delivered by 30 October, although construction number 3810107 (Factory No. 381, first batch, seventh aircraft) was used as a static test airframe and 3810110 became a static engine testbed.

Stalin convened a meeting on 29 November 1946 to settle the future policy on jet fighters for the VVS and PVO. The Mikoyan-Gurevich MiG-9 was selected as the primary fighter with the Yakovlev Yak-15 relegated to conversion training and familiarization. The imminent availability of British jet engines and access to German jet technology and engineers meant that there was no longer any need for mixed-power aircraft, but Stalin insisted that the I-250 finish its trials and that the tooling and drawings should be retained along with unassembled parts even though the program was cancelled.

Completion of the trials would be delayed until May 1947 when the trials of the VRDK itself would be completed and Mikoyan tried to sell the aircraft to Naval Aviation for use as escorts for torpedo bombers. Additional fuel tanks were fitted in the wings and fuselage of 3810102 to carry an additional 218 litres (48 imp gal; 58 US gal) of fuel and the capacity of the oil tank was increased to 78 litres (17 imp gal; 21 US gal). These changes increased its empty weight to 3,028 kg (6,680 lb) and its take-off weight to 3,931 l (865 imp gal; 1,038 US gal). A new round of State trials began on 9 October 1947, but these were delayed by bad weather and reliability issues. Only six flights totaling two hours and twenty-five minutes had been completed by 21 January 1948 and the VRDK had only been run for a minute and half during a ground test. The I-250 was unsurprisingly declared to have failed the trials on 3 April 1948.

Specifications (first prototype)



General characteristics

- **Crew:** 1
- **Length:** 8.19 m (26 ft 10 in)
- **Wingspan:** 9.5 m (31 ft 2 in)
- **Height:** 3.7 m (12 ft 2 in)
- **Wing area:** 15 m^2 (160 sq ft)
- **Empty weight:** 2,797 kg (6,166 lb)
- **Gross weight:** 3,680 kg (8,113 lb)
- **Fuel capacity:** 612 litres (135 imp gal; 162 US gal)

- **Powerplant:** 1 × Klimov VK-107R liquid-cooled V12 engine, 1,230 kW (1,650 hp)
- **Powerplant:** 1 × VRDK motorjet, 6 kN (1,300 lbf) thrust
- **Propellers:** 3-bladed AV-10P-60, 3.1 m (10 ft 2 in) diameter

Performance

- **Maximum speed:** 820 km/h (510 mph; 440 kn)
- **Range:** 790 km (491 mi; 427 nmi)
- **Service ceiling:** 11,900 m (39,042 ft)
- **Time to altitude:** 5,000 m (16,400 ft) in 3.9 min (with VRDK)
- **Wing loading:** 245 kg/m² (50 lb/sq ft)

Armament

- **Guns:** 3 × 20 mm Berezin B-20 cannons (160 rounds each)

Chapter- 8

Lockheed NF-104A

NF-104A

Lockheed NF-104A, *56-0756*, climbing with rocket power

Role	Aerospace trainer
Manufacturer	Lockheed Aircraft Corporation
Designed by	Clarence "Kelly" Johnson
First flight	9 July 1963
Introduction	1 October 1963

Retired	June 1971
Primary user	United States Air Force
Number built	3
Unit cost	$5,363,322 (modification cost for all three aircraft)
Developed from	F-104A Starfighter

The **Lockheed NF-104A** was an American mixed power, high-performance, supersonic aerospace trainer that served as a low cost astronaut training vehicle for the X-15 and projected X-20 Dyna-Soar programs.

Three aircraft were modified from existing Lockheed F-104A airframes and served with the Aerospace Research Pilots School between 1963 and 1971, the modifications included a small supplementary rocket engine and a reaction control system for flight in the upper atmosphere. During the test program the maximum altitude reached was over 120,000 ft (36,600 m). One of the aircraft was destroyed in an accident while being flown by Chuck Yeager. The accident was depicted in the book *The Right Stuff* and the film of the same name.

Development

With the advent of manned spaceflight in the early 1960s, the United States Air Force Experimental Flight Test Pilot's School at Edwards Air Force Base was renamed the Aerospace Research Pilots School (ARPS), with the emphasis on training moving away from the traditional test pilot course to a more spaceflight oriented curriculum.

Initial use of unmodified F-104 aircraft

A number of standard production F-104 Starfighter aircraft were obtained (including F-104D two-seat versions) and used by the ARPS to simulate the low lift/high drag glide approach path profiles of the X-15 and the projected X-20 Dyna-Soar program. These maneuvers were commenced at 12,000 ft (3,700 m) where the F-104 engine was throttled back to 80% power; and with the flaps, speedbrakes and landing gear extended, the aircraft was established in a 30˚ dive with a pull-out for the landing flare starting at 1,500 ft (460 m) above the ground. These glide approaches gave little room for error. A modified Gulfstream G-II has been used by NASA for similar training for the Space Shuttle program.

Reaction Control System

JF-104 during RCS testing.

It was realized that normal aircraft control surfaces had little or no effect in the thin atmosphere of the stratosphere and that any aircraft operating at extremely high altitudes would need to be equipped with a reaction control system (RCS). A modified version of the Bell X-1 was used for initial RCS tests, but was grounded after technical problems and was replaced with a NASA-modified Lockheed F-104A (55-2961) in 1959 which carried RCS systems on its wing tips and in the fuselage nose. This aircraft (designated JF-104) achieved a maximum altitude of 83,000 ft (25,000 m) during the test program. Pilots who flew this aircraft included Neil Armstrong who gained valuable experience in using the RCS system. Pilots complained that the instrument displays were difficult to read and were not accurate enough for the critical zoom climb profiles required to reach high altitudes.

Lockheed contract

Lockheed was awarded a contract by the USAF to modify three F-104A aircraft for the dedicated role of aerospace trainer (AST) in 1962. The airframes were taken out of storage at AMARC and transported to the company factory for modification.

Design and flight profile

The F-104A design was already established as a lightweight, high performance aircraft; but for the AST project, emphasis was placed on removing unnecessary equipment, fitting a rocket engine to supplement the existing jet engine, fitting an onboard RCS system and improving the instrumentation required. The following details give the main differences between the production version and the AST:

Wing

The wingspan of the NF-104A was increased by adding tip extensions to the existing planform. This modification was needed to house the RCS roll control thrusters and would also decrease the type's wing loading.

Tail surfaces

The vertical fin and rudder were replaced by the larger area versions from the two-seat F-104 and were structurally modified to allow installation of the rocket engine.

Fuselage

The fiberglass nose radome was replaced with an aluminum skin and housed the pitch and yaw RCS thrusters. The air intakes originally designed by Ben Rich were of the same fixed geometry as the F-104A but included extensions to the inlet shock cones for optimum jet engine operation at higher Mach numbers. Internal fuselage differences included provision for rocket fuel oxidizer tanks, deletion of the M61 Vulcan cannon, Radar equipment and unnecessary avionics. A nitrogen tank was installed for cabin pressurization purposes, this was required as there would be no bleed air available from the engine after its normal and expected cutoff in the climb phase. Contrary to popular misconception, the jet engine was not allowed to flameout but had to be gradually throttled down and then cutoff as EGT temperatures ramped up towards the danger point for the turbojet's integrity.

Rocket engine

In addition to the standard J79 jet engine a Rocketdyne AR2-3 rocket engine was fitted at the base of the vertical fin. This engine burned a mixture of JP-4 jet fuel and 90% hydrogen peroxide oxidizer solution. The NF-104 carried enough oxidizer for approximately 100 seconds of rocket engine operation. The thrust level could be adjusted to maximum or approximately half power by the pilot using an additional throttle lever on the left side of the cockpit.

Reaction Control System

The Reaction Control System or RCS consisted of eight pitch/yaw motors (four for each axis) and four roll motors. They used the same kind of hydrogen peroxide fuel as the main rocket engine from a dedicated 155 lb (70 kg) fuel tank and were controlled by the pilot using a handle mounted in the instrument panel. The pitch/yaw motors were rated at 113 lbf (500 N) thrust each and the roll motors were rated at 43 lbf (190 N) thrust.

Typical flight profile

Chuck Yeager in the cockpit of an NF-104A, 4 December 1963

The NF-104A was able to reach great altitudes through a combination of zoom climbing (trading speed for altitude) and use of the rocket engine. A typical mission involved a level acceleration at 35,000 ft (11,000 m) to Mach 1.9 where the rocket engine would be ignited, and on reaching Mach 2.1 the aircraft would be pitched up to a climb angle of 50-70° by carefully applying a load equal to 3.5 *g*. The J79 afterburner would start to be throttled down at approximately 70,000 ft (21,000 m) followed shortly after by manual fuel cutoff of the main jet engine itself around 85,000 ft (26,000 m) to prevent fast rising engine temperatures from damaging the turbojet. After continuing over the top of its ballistic arc the NF-104 would descend back into denser air where the main engine could be restarted using the windmill restart technique for recovery to a landing.

Operational history

First NF-104A

The first NF-104A (USAF *56-0756*) was accepted by the USAF on 1 October 1963. It quickly established a new unofficial altitude record of 118,860 ft (36,230 m) and surpassed this on 6 December 1963 by achieving an altitude of 120,800 ft (36,800 m). It suffered an inflight rocket motor explosion in June 1971. Although the pilot was able to land safely, the damaged aircraft was retired and marked the end of the NF-104 project. This aircraft was reported as scrapped.

Second NF-104A

NF-104A Tail Number 760 at the USAF Test Pilot School

The second NF-104A (USAF *56-0760*) was accepted by the USAF on 26 October 1963. After retirement, this aircraft was mounted on a pole outside the U.S. Air Force Test Pilot School at Edwards Air Force Base and can still be seen there today. The extended wing tips, RCS metal nose cone and other parts from *56-0760* were loaned to Daryl Greenamyer for his civilian aviation record attempts using a highly modified F-104. When he was forced to eject during a record flight, his aircraft was destroyed and the parts were never returned.

Third NF-104A

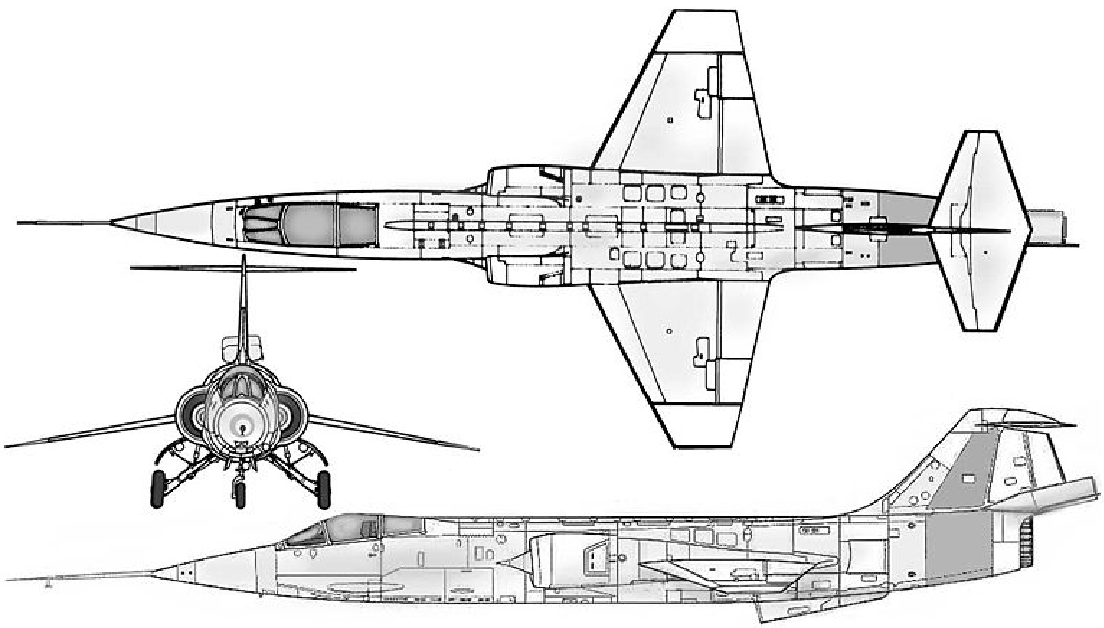
The third NF-104A (USAF *56-0762*) was delivered to the USAF on 1 November 1963, and was destroyed in a crash while being piloted by Chuck Yeager on 10 December 1963. This accident was depicted in the book *The Right Stuff* and the film of the same name; although the aircraft used for filming was a standard F-104G flying with its wingtip fuel tanks removed, but otherwise lacking any of the NF-104A's modifications, most visibly the rocket engine pod at the base of the vertical stabilizer.

Operators

United States

- United States Air Force

Specifications (NF-104A)



General characteristics

- **Crew:** 1
- **Length:** 54 ft 9 in (16.6 m)
- **Wingspan:** 25 ft 9 in (7.84 m)
- **Height:** 13 ft 6 in (4.1 m)
- **Wing area:** 212.8 ft² (19.77 m²)
- **Airfoil:** Bi-convex 3.36%
- **Empty weight:** 13,500 lb (6,080 kg)
- **Loaded weight:** 21,400 lb (9,890 kg)
- **Max takeoff weight:** 21,400 lb (9,890 kg)
- **Powerplant:**

    - 1× General Electric J79-GE-3B turbojet, 9,600 lbf (43.54 kN)
    - 1× Rocketdyne AR2-3 liquid fuelled rocket engine, 6,000 lbf (27.2 kN)

Performance

- **Maximum speed:** Mach 2.2

Chapter- 9

Republic XF-91 Thunderceptor

XF-91 Thunderceptor

Role	Interceptor
Manufacturer	Republic Aviation
First flight	9 May 1949
Status	Cancelled
Number built	2
Unit cost	US$11.6 million for the program
Developed from	F-84 Thunderjet

The **Republic XF-91 Thunderceptor** was a mixed-propulsion interceptor using a jet engine for most flight, and a cluster of four small rocket engines for added thrust during climb and interception. The design was largely obsolete by the time it was completed due to the rapidly increasing performance of contemporary jet engines, and was built to the extent of two prototypes only. One of these was the first US fighter to exceed Mach 1 in level flight.

Design and development

The Thunderceptor design was one of two swept-wing modifications based on the original F-84 Thunderjet, the other being the F-84F Thunderstreak which was developed later. A serious problem with most swept wing designs of the era was dangerous performance at low speeds and high angle of attack. The stagnant airflow over the wing tended to "slide" towards the wingtips, which caused them to stall before the rest of the wing at high angles of attack. In this situation the center of lift would rapidly shift forward relative to the center of mass, pitching the nose up and leading to an even greater angle of attack or, in extreme cases, end-over-end tumbling of the aircraft. Aircraft caught in this regime would often stall and crash, and a rash of such accidents on the F-100 Super Sabre led to the term Sabre dance. The most famous incident was the loss of F-100C-20-NA Super Sabre 54-1907 during an attempted emergency landing at Edwards AFB, California on 10 January 1956 which was caught by film cameras set up for an unrelated test. The pilot fought to retain control as he rode the knife-edge of the flight envelope but fell off on one wing, hit the ground and exploded with fatal results.

The Thunderceptor's most notable design feature was intended to address this problem. The wings were built to have considerably more chord (distance from front to back) at the tip than root, allowing them to generate more lift. This neatly addressed the problem of Sabre dance by delaying the point of stall on the tip to that of the entire wing. A side effect of this design was that the tips had more internal room, so the landing gear was mounted to retract outward with the wheels lying in the wingtips, using two small tires instead of one larger one. Another design change was the ability to vary the angle of incidence of the wing as a whole, tilting it up for low speed operations during takeoff and landing, and then "leveling it off" for high-speed flight and cruise. This allowed the fuselage to remain closer to level while landing, greatly improving visibility.

In keeping with its intended role as an interceptor, the nose was redesigned to incorporate radar, forcing them to move the air intake for the engine from its original nose-mounted position to a new intake below it. The fuselage was otherwise very similar to the F-84's. The first prototype did not include the radome, although this was fitted to the second prototype.

Testing and evaluation

The first prototype made its first flight on 9 May 1949, breaking the speed of sound in December 1951. It was later modified with a small radome for gunnery ranging (although not the "full" radome from the second prototype). The second prototype included the full radome and chin-mounted intake, but was otherwise similar. This airframe was later modified to use a V-tail for testing. With both the jet and rockets running, the aircraft could reach Mach 1.71, rather respectable for the early 1950s. Both prototypes completed 192 test flights over the course of five years.

As an interceptor the Thunderceptor was soon eclipsed by designs from other companies, but like the Thunderceptor none of these would go into production. The United States Air

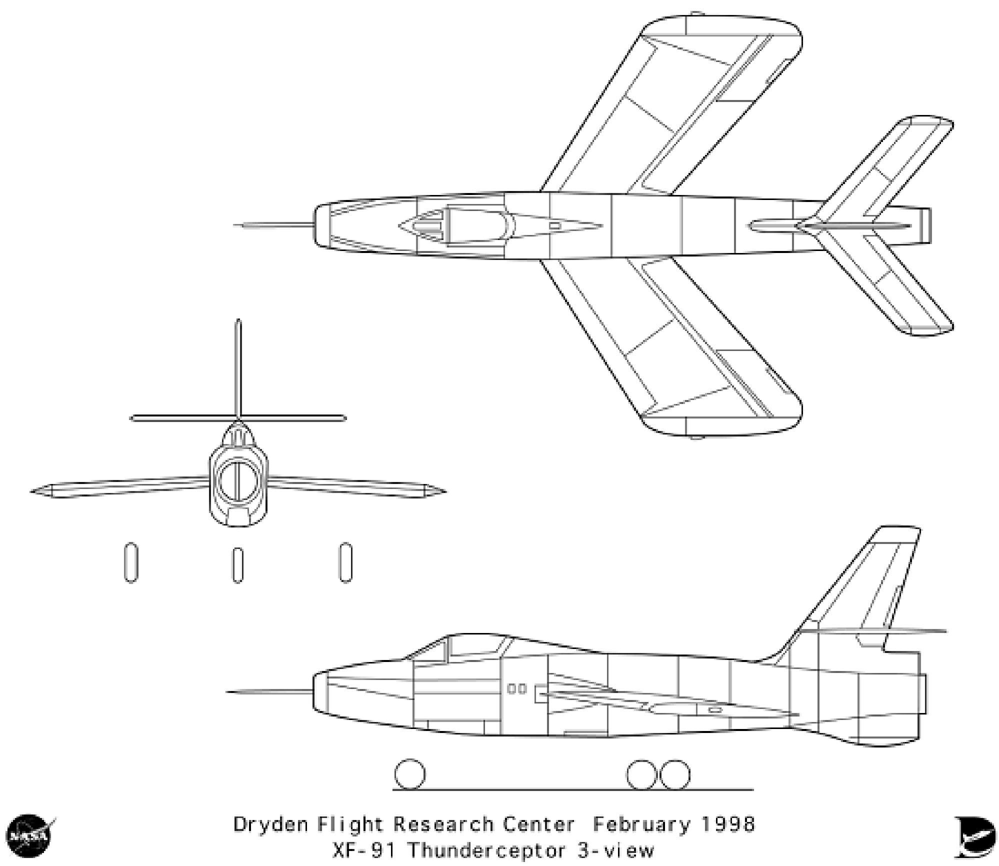
Force decided to wait the short time needed to introduce newer and much more capable designs created as a part of the 1954 interceptor project. The Thunderceptor, like the other interceptor designs of the era, had extremely short flight times on the order of 25 minutes, making them almost useless for protecting an area as large as the United States. The 1954 designs outperformed the XF-91 in speed, range, loiter time, as well as including the radar and fire-control systems needed for night and all-weather operation. The era of the dedicated day fighter-type interceptor was over.

Survivors

The second prototype, *46-681*, had an engine failure during takeoff from Edwards AFB in the summer of 1951. Republic Aviation test pilot Carl Bellinger escaped from the aircraft just as the tail melted off - total flight time was a mere 90 seconds. By the time fire apparatus arrived, driving seven miles across the dry lake bed, the tail section had been reduced to ashes. 46-681 was then fitted with a V or "butterfly" tail (more common on Beechcraft of the era) and was flight tested with this configuration. It was later used at Edwards AFB as a crash-crew training simulator, then scrapped.

The first prototype, serial *46-680*, is preserved at the National Museum of the United States Air Force.

Specifications (XF-91 Thunderceptor)



General characteristics

- **Crew:** 1
- **Length:** 43 ft 3 in (9.52 m)
- **Wingspan:** 31 ft 3 in (13.18 m)
- **Height:** 18 ft 1 in (5.51 m)
- **Wing area:** 320 ft² (29.73 m²)
- **Empty weight:** 14,140 lb (6,410 kg)
- **Loaded weight:** 18,600 lb (8,400 kg)
- **Max takeoff weight:** 28,300 lb (12,840 kg)
- **Powerplant:**
  - 1× General Electric J47-GE-7 (later GE-17) axial-flow turbojet, 5,200 lbs dry, 6,900 lbs with afterburner and water injection (30,6 kN)
  - 4× Reaction Motors XLR11-RM-9 rocket, 1,500 lbf (7 kN) each

Performance

- **Maximum speed:** 984 mph (1,584 km/h)
- **Range:** 1,170 mi (1,880 km)
- **Service ceiling:** 50,000 to 55,000 ft (15,200 to 16,800 m)
- **Rate of climb:** 47,500 ft in 2.5 minutes (14,500 m)
- **Wing loading:** 58.12 lb/ft² (283 kg/m²)
- **Thrust/weight (jet):** 0.60

Armament

- **Guns:** 4 × 20 mm (.79 in) cannon

Chapter- 10

Ryan XF2R Dark Shark and Saunders-Roe SR.177

Ryan XF2R Dark Shark

XF2R Dark Shark

Role	Fighter
Manufacturer	Ryan Aeronautical Company
Status	Cancelled
Number built	1 prototype
Developed from	FR Fireball

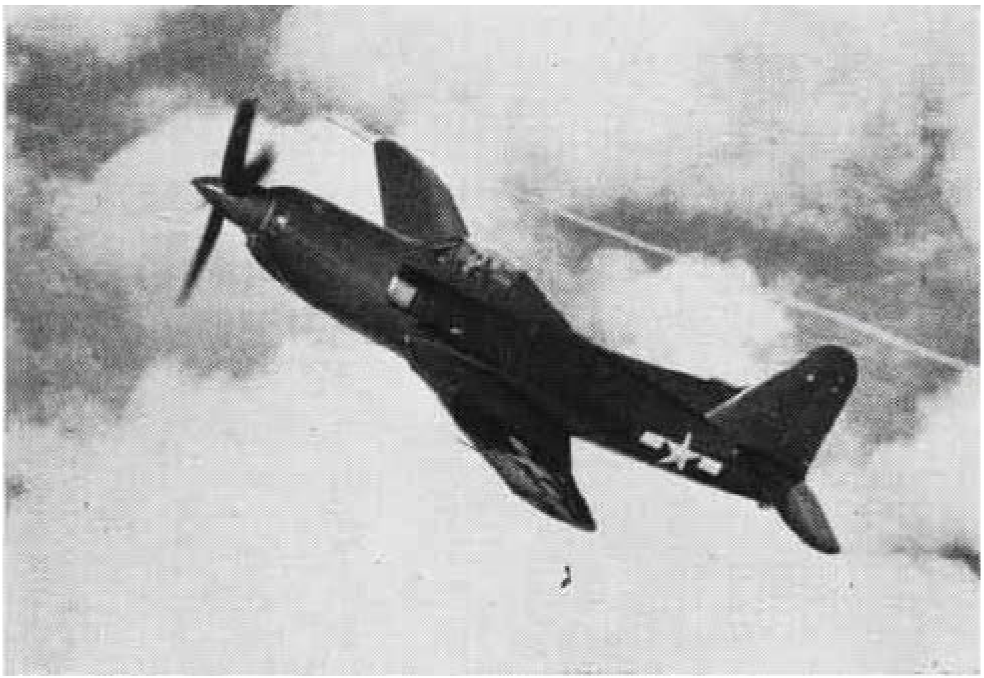
The **Ryan XF2R Dark Shark** was an experimental aircraft built for the United States Navy that combined turboprop and turbojet propulsion. It was based on Ryan's earlier FR Fireball, but replaced the Fireball's piston engine with a General Electric T-31 turboprop engine driving a huge 4-bladed Hamilton Standard propeller.

The turboprop made for much improved performance over the Fireball, but the Navy showed little interest in it; by that time, they had abandoned the idea of the combination fighter and were instead looking into all-jet fighters.

The United States Air Force, however, showed a little more interest; they were at the time evaluating the Convair XP-81 of similar concept, and asked Ryan to modify the XF2R to use the Westinghouse J-34 turbojet instead of the General Electric J-31 used previously. Modifications to the prototype created the XF2R-2, with the jet intakes moved to the sides of the forward fuselage with NACA ducts instead of the inlets in the wing leading edge used before.

Although the Dark Shark proved to be a capable aircraft, it never got further than the prototype stage; all-jet aircraft were considered superior.

Specifications



The XF2R-1 in flight.

General characteristics

- **Crew:** 1
- **Length:** 36 ft 0 in (10.97 m)
- **Wingspan:** 42 ft 0 in (12.80 m)
- **Height:** 14 ft 0 in (4.27 m)
- **Wing area:** 305 ft² (28.3 m²)
- **Loaded weight:** 11,000 lb (4,990 kg)
- **Powerplant:**
  - 1× General Electric J31 turbojet, 1,600 lbf (7.1 kN)
  - 1× General Electric T31 turboprop, 1,760 hp (1,310 kW)

Performance

- **Maximum speed:** 497 mph (432 kn, 800 km/h) (at sea level)
- **Service ceiling:** 39,100 ft (11,900 m)

- **Rate of climb:** 4,850 ft/min (24.64 m/s)
- **Wing loading:** 36.1 lb/ft² (176 kg/m²)

Armament: 4 x 12.7mm machine guns

Saunders-Roe SR.177

SR.177

SR.177 with Red Top missiles

Role	mixed power interceptor
Manufacturer	Saunders-Roe
Number built	0
Developed from	Saunders-Roe SR.53

The **Saunders-Roe SR.177** was a 1950s project to develop a combined jet- and rocket-powered interceptor aircraft for the Royal Air Force and Royal Navy. The German Navy and Airforce also expressed interest and had planned to buy large numbers, but the SR-177 project was cancelled in 1957 after the German Government pulled out and decided to buy Lockheed F-104's instead. Without the orders, the British Government were not prepared to invest the money needed to complete the project. It transpired many years later, that the cancellation was a direct result of multi-million-dollar bribes to German Ministers amongst others by Lockheed in order to secure orders of their F-104 and to remove the SR-177 as competition. A much larger development was studied under the SR.187 project for Operational Requirement F.155, but this work was also cancelled in 1957, after approximately 90% of the first prototype had been completed.

Design and development

In 1952, Saunders-Roe had won a contract to develop a similar aircraft, the **Saunders-Roe SR.53**. However, as development progressed, the shortcomings of the design became increasingly evident. Most particularly, as with the German rocket-powered interceptors of the Second World War, the range and endurance of such an aircraft were limited by the high rate of fuel consumption by the rocket engine. However, as turbojets developed and became increasingly powerful and efficient, soon new powerplants were available that would make the aircraft more practical.

The SR.177 began as an advanced design concept for the SR.53, but when a development contract was issued by the Ministry of Defence (specification F.155), the project was given its own designation.

The most significant difference between the two aircraft was the use of a jet engine with nearly five times the thrust of the one chosen for the earlier aircraft. This meant that while the SR.53 relied mostly on its rocket engine for climbing, the SR.177 would be able to add considerable endurance by conserving use of its rocket for the dash towards a target only. It was expected that the added endurance would allow the SR.177 to perform roles other than pure interception, and these were expected to include strike and reconnaissance. The SR.53 design was considerably enlarged to accommodate the new engine, and the original sleek lines were forfeited for a large, chin mounted intake to supply it with air.

Funding was secured in July 1956 for a total of 27 aircraft, and the first was expected to fly by April (later, October) 1958. However, 1957 was to see a massive re-thinking of air defence philosophy in the UK, outlined in the 1957 Defence White Paper which called for piloted warplanes to be replaced by missiles. By the time that the programme was axed later that year, the aircraft had proceeded little past mock-up stage. In 1957 a development contract for the SR.177 was announced for its use with the Royal Navy.

Work on the aircraft continued a little longer, however, in the anticipation of continued interest from Germany. The British Ministry of Supply agreed to continue funding development of five of the six prototypes, but nothing was to come of it. The German government had changed its priorities from looking for an interceptor to a strike fighter, leading Saunders-Roe to redesign the aircraft for this role. This was followed immediately by another redesign when Rolls-Royce successfully convinced the German government to replace the de Havilland engine intended for the SR.177 with a Rolls-Royce turbojet, the RB.153. Even with Heinkel preparing to manufacture the aircraft locally under licence, Germany withdrew support in December 1957. The Minister had visited the German government in November 1957 as the Germans wanted the arrangements to be between governments instead of between their Government and Saunders-Roe.

Cancellation

Of the remaining aircraft under consideration the West German Government chose to purchase the F-104 Starfighter instead to meet the role of "high-altitude reconnaissance machine, a tactical fighter-bomber, and an all-weather fighter", along with most of the European governments. This Lockheed coup, known as the "Deal of the Century", caused major political controversy in Europe and West German Minister of Defence Franz Josef Strauss was almost forced to resign over the issue. During later investigation into Lockheed's business practices it was discovered that Lockheed had paid out millions of dollars in "sales incentives" in each of these countries to secure the deal. Prince Bernhard of the Netherlands confessed to taking more than one million USD in bribes from Lockheed to buy the F-104.

With the withdrawal of German interest and no requirement for the SR.177 by the RAF, the existing Royal Navy requirement was considered not worth proceeding with and the Ministry of Supply cancelled the project. Saunders-Roe announced an expected 1,000 redundancies as a result.

Specifications

General characteristics

- **Crew:** one
- **Length:** 50 ft (15.2 m)
- **Wingspan:** 30 ft (9.1 m)
- **Height:** 14 ft (4.3 m)
- **Loaded weight:** 25,500 lb (11,570 kg)
- **Powerplant:**
  - 1× de Havilland Gyron Junior turbojet, 8,000 lbf (35.6 kN)
  - 1× de Havilland Spectre liquid fuel rocket, 8,000 lbf (35.6 kN)

Performance

- **Maximum speed:** 1,550 mph (2,500 km/h) estimated
- **Service ceiling:** 67,000 ft (20,500 m) estimated
- **Rate of climb:** 60,000 ft/min (18,300 m/s) estimated

Armament

- **Missiles:** 2 Firestreak air-to-air missiles

Avionics

AI-23 airborne interception radar

Chapter- 11

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'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

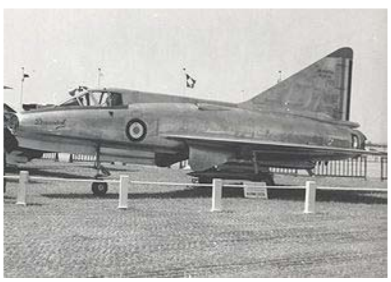
- **Missiles:** 2 × de Havilland Firestreak infra-red guided missiles

Chapter- 12

SNCASE SE-212 Durandal and SNCASO Trident

SNCASE SE-212 Durandal

SE-212 Durandal



SE-212 Durandal No.02 at the Paris Air Salon in May 1957 with AA20 rocket beneath the aircraft

Role	Interceptor
Manufacturer	SNCASE
First flight	20 April 1956
Status	Experimental
Number built	2

The **SNCASE SE-212 Durandal** was a French jet and rocket mixed-power fighter aircraft of the mid 1950s.

Design and development

The SNCASE design team under Pierre Satre worked on studies for a light-weight mixed-power interceptor fighter from late 1951. The designs produced a small 60° delta aircraft powered by a SNECMA Atar 101F jet engine equipped with afterburning. The aircraft's speed at height was to be boosted by a SEPR 75 rocket motor. Armament was to be a single AA-20 missile carried under the Durandal's centreline. Alternative armament was to be two 30 mm cannon or 24 SNEB rockets.

Two prototype aircraft were built, the first flying on 20 April 1956 without the rocket motor being fitted. The second Durandal was flown on 30 March 1957. During flight testing a speed of 1,444 kilometres per hour (897 mph) was attained at 12,300 metres (40,400 ft) without the rocket motor, and 1667 km/h at 11,800 m with the rocket lit. These tests were achieved without armament being fitted.

The second Durandal, aircraft No.02, was statically displayed at the Paris Air Show at Paris Le Bourget Airport in May 1957 with the AA-20 missile under the aircraft. The test programme was terminated in 1958 and no further production was undertaken. Sections of the first aircraft were held in store during 2006 by the Musee de l'Air at Le Bourget.

Specification

General characteristics

- **Crew:** 1
- **Length:** 12.07 m (39 ft 7 in)
- **Wingspan:** 7.44 m (24 ft 5 in)
- **Wing area:** 29.60 m^2 (318.6 sq ft)
- **Empty weight:** 4,575 kg (10,086 lb)
- **Gross weight:** 6,700 kg (14,771 lb)
- **Powerplant:** 1 × SNECMA Atar 101F turbojet dry, 43 kN (9,700 lbf) with afterburner
- **Powerplant:** 1 × SEPR 75 rocket engine, 7.35 kN (1,653 lbf) thrust

Performance

- **Maximum speed:** 1,667 km/h (1,036 mph; 900 kn) with rocket at 11,800 m (36,300 ft)
- **Maximum speed:** Mach 1.57
- **Rate of climb:** 200 m/s (39,000 ft/min)

Armament

- 1× AA.20 *or*
- 2× 30 mm DEFA cannon *or*
- 24× 68 mm SNEB rockets

SNCASO Trident

SO.9000/SO.9050 Trident

Role	Research interceptor aircraft
National origin	France
Manufacturer	SNCASO
First flight	2 March 1953
Number built	12

The **SNCASO SO.9000 Trident** was a mixed power French prototype interceptor aircraft of the 1950s. Capable of supersonic flight the project was cancelled in July 1957 after only 12 examples had been built.

Design and development

The French Air Staff tasked SNCASO to develop a point defence interceptor, studies began in October 1948. The aircraft that emerged was a shoulder wing monoplane, to be primarily powered by a SEPR rocket engine and augmented with wing-tip mounted turbojets. First flown on 2 March 1953 by test pilot Jacques Guignard the aircraft used the entire length of the runway to get airborne powered only by its turbojets. From March 1955 the Trident I flew with new turbojets, the more powerful Dassault-built MD 30 Viper ASV.5, which produced 7.34 kN (1,654 lbf) thrust each. With these engines it soon exceeded Mach 1 in a shallow dive without rocket power.

Test flights of the SO.9000 were described by the author Bill Gunston as 'hairy' until the rocket motor was added in September 1954. During the 18-month test programme the aircraft completed over 100 flights, eventually reaching a speed of Mach 1.8 and an altitude of 20,000 metres (65,000 ft).

A Trident II was lost due to an accident on 21 May 1957

The project was cancelled in July 1957; the decision was influenced by the manned fighter cuts announced by the British Defence Minister, Duncan Sandys.

Variants

SO.9000 Trident I

Two aircraft built. The first aircraft was built at Istres and was completed in late-1952, the second aircraft *02* crashed on its first flight in September 1953. Three-chamber SEPR 481 rocket engine, each chamber producing 2,755 lbf (12,250 N) thrust.

SO.9050 Trident II

Ten pre-production aircraft ordered in 1953. Higher power Turbomeca Gabizo turbojets (2,645 lb thrust) with two-chamber SEPR 631 rocket engine (each chamber now being individually ignited for finer thrust control). First flight 21 December 1955.

Aircraft on display

The preserved SO.9000-01 Trident has been on public display since 1956 at the Musée de l'Air et de l'Espace, near Paris.

Specifications (SO.9000)

General characteristics

- **Crew:** 1
- **Length:** 14.00 m (45 ft 11 in)
- **Wingspan:** 8.15 m (26 ft 9 in)
- **Height:** 3.70 m (12 ft 1.5 in)
- **Wing area:** 14.50 m² (156 ft²)
- **Empty weight:** 3,350 kg (7,385 lb)
- **Gross weight:** 5,500 kg (12,125 lb)
- **Powerplant:** 1 × SEPR 481 rocket, 12.37 kN (2,775 lbf) thrust

  2 × Turbomeca Marboré turbojet, 3.92 kN (880 lbf) thrust each

Performance

- **Maximum speed:** 1,707 km/h (1,060 mph)
- **Maximum speed:** Mach 1.6

Chapter- 13

Sukhoi Su-6 and Sukhoi Su-5

Sukhoi Su-6

Su-6

Su-6 second prototype, single-seater with M-71 engine

Role	Ground attack
Manufacturer	Sukhoi
Designed by	Pavel Sukhoi
First flight	1 March 1941
Status	Prototype only
Primary user	Soviet Air Force
Number built	3
Variants	Su-7

Su-6 third prototype, two-seater with AM-42 engine

The **Sukhoi Su-6** was a Soviet ground attack aircraft developed during World War II. The mixed-power (rocket and piston engines) high-altitude interceptor **Su-7** was based on the single-seat Su-6 prototype.

Design and development

Development of the Su-6 began in 1939, when the Sukhoi design bureau began work on a single-seat armoured ground-attack aircraft. An order for two prototypes was placed on 4 March 1940, and on 1 March 1941 fight testing of the first prototype was begun by test pilot A.I. Kokin.

The flight tests indicated that the Su-6 was superior to the Ilyushin Il-2 in nearly all performance categories, however its engine exceeded its age limit before testing could be completed, and no further Shvetsov M-71 engines were available.

The second prototype flew only in January 1942 because the OKB had to be evacuated after the start of the Great Patriotic War. It was armed with two 23 mm cannon, four machine guns and ten rails for aerial rockets. Test results were very favorable, and the AFRA Scientific Research Institute recommended the acquisition of a small production batch for testing under front-line conditions. A draft resolution for the production of 25 aircraft was prepared, however unfortunately for Sukhoi, it was never officially issued.

Meanwhile, combat experience with single-seat Il-2s demonstrated the need for a rear gunner. The third prototype was therefore designed with the second crewman at the expense of bomb load (decreased from 400 kg/881 lb to 200 kg/440 lb), and was fitted with a more powerful M-71F engine. Official tests revealed that the two-seat Su-6 had a 100 km/h (54 kn, 62 mph) greater top speed than the Il-2, although with a considerably smaller payload. When the troublesome M-71 was canceled, Sukhoi was directed to utilize the liquid-cooled Mikulin AM-42 engine. When flight tests began on 22 February

1944, the re-engined Su-6 proved inferior to the Ilyushin Il-10 using the same engine thanks to the additional 250 kg (551 lb) of armor required to protect the liquid-cooled engine and the lower power output of the AM-42 compared with M-71F.

Although Su-6 never entered production, in 1943 Pavel Sukhoi was awarded the Stalin Prize of the 1st Degree for the development of the aircraft.

Su-7

As an experiment, the basic single-seat Su-6 design was converted into a mixed-power high-altitude interceptor named **Su-7** (the name was reused in 1950s for a supersonic fighter-bomber). The armor was removed and the fuselage was of all-metal construction. Power came from a Shvetsov ASh-82FN piston engine with two TK-3 turbochargers in the nose and a Glushko RD-1-Kh3 rocket engine in the tail. The piston engine produced 1,380 kW (1,850 hp), while the rocket engine utilized kerosene and nitric acid for fuel and generated 2.9 kN (600 lbf) of thrust for up to 4 minutes. Armament consisted of three 20 mm ShVAK cannon with 370 rounds of ammunition. The sole Su-7 was completed in 1944. Test flights demonstrated a top speed of 510 km/h (275 kn, 315 mph) at 12,000 m (39,370 ft) without the rocket motor, and 705 km/h (380 kn, 440 mph) with the rocket. In 1945, the rocket motor exploded during flight testing, killing the pilot and destroying the aircraft.

Sukhoi OKB designations

A
: The initial design for the Su-6.

S
: The second prototype with various modifications.

SA (modified)
: The SA with 2 x OKB-16 37mm Cannon and 2x ShKAS 7.62 mm machine-guns.

S2A
: The Su-6 fitted with a second cockpit with rear wards firing machine-gun. Testing revealed better performance and armour than the Il-2, but despite recommendations, production was not carried out due to the M-71 engine not enterring production.

Operators

Soviet Union

- Soviet Air Force

Specifications (Su-6 3rd prototype)

General characteristics

- **Crew:** 2 (pilot and gunner)

- **Length:** 9.24 m (30 ft 4 in)
- **Wingspan:** 13.50 m (44 ft 3 in)
- **Height:** 3.89 m (12 ft 9 in)
- **Wing area:** 26 m² (280 ft²)
- **Empty weight:** 4,000 kg (8,820 lb)
- **Loaded weight:** 5,534 kg (12,200 lb)
- **Powerplant:** 1× Shvetsov M-71F radial engine, 1,620 kW (2,200 hp)

Performance

- **Maximum speed:** 514 km/h (280 kn, 320 mph) at 3,800 m (12,465 ft)
- **Range:** 973 km (525 nmi, 605 mi)
- **Service ceiling:** 8,100 m (26,575 ft)
- **Rate of climb:** 10.6 minutes to 5,000 m (16,405 ft)
- **Takeoff roll:** 410 m (1,345 ft)
- **Landing roll:** 730 m (2,395 ft)

Armament

- 2 × 37 mm Nudelman N-37 cannons in wings, 90 rounds
- 2 × 7.62 mm ShKAS machine guns in the wings, 1,400 rounds
- 1 × 12.7 mm Berezin UBT machine gun in rear turret, 196 rounds
- Up to 400 kg (882 lb) of bombs

Sukhoi Su-5

Su-5 (I-107)

Role	Fighter
Manufacturer	Sukhoi
Designed by	Pavel Sukhoi
First flight	6 April 1945

Status	Cancelled
Number built	1

The **Sukhoi Su-5** or **I-107** was a Soviet mixed-power (propeller and motorjet) prototype fighter aircraft built toward the end of World War II.

Development

The appearance of German turbojet-powered Messerschmitt Me 262 near the end of WWII prompted Soviet Union to develop faster fighter aircraft. Since USSR lacked a production-ready turbojet engine, the efforts were directed toward mixed-power aircraft utilizing a conventional piston engine-driven propeller for the majority of propulsion with a small rocket or jet engine for bursts of speed.

The Su-5 (initially I-107) and the conceptually similar Mikoyan-Gurevich I-250 were designed in 1944. The aircraft first flew on 6 April 1945 and underwent limited flight testing. It was subsequently fitted with a laminar flow wing and attained 793 km/h (428 kn, 493 mph) at 4,350 m (14,270 ft) with the motorjet functioning. On 15 June 1945, the Klimov VK-107A piston engine was damaged beyond repair in flight. Following acquisition of another VK-107A, flight testing continued until 18 October when the engine reached the end of its service life. No further VK-107As could be procured and the project was canceled.

The Su-5 was a conventional monoplane of all-metal construction. The VRDK (Russian: Воздушно-Реактивный Двигатель Компрессорный) motorjet in the rear of the fuselage was powered by a driveshaft from the VK-107 piston engine and could provide an additional 100 km/h (54 kn, 62 mph) of speed for three minutes.

Specifications (Su-5)

General characteristics

- **Crew:** 1
- **Length:** 8.51 m (27 ft 11 in)
- **Wingspan:** 10.56 m (34 ft 8 in)
- **Height:** 3.53 m (11 ft 7 in)
- **Wing area:** 17 m² (183 ft²)
- **Empty weight:** 2,954 kg (6,510 lb)
- **Loaded weight:** 3,804 kg (8,390 lb)
- **Powerplant:**
  - 1× VDRK motorjet, 2.9 kN (660 lbf)
  - 1× Klimov VK-107A liquid-cooled V12 engine, 1,230 kW (1,650 hp)

Performance

- **Maximum speed:** 810 km/h (437 kn, 503 mph) projected at 7,800 m (25,590 ft)
- **Range:** 600 km (325 nmi, 375 mi)
- **Service ceiling:** 12,000 m (39,370 ft)
- **Rate of climb:** 5.7 min to 5,000 m (16,405 ft)

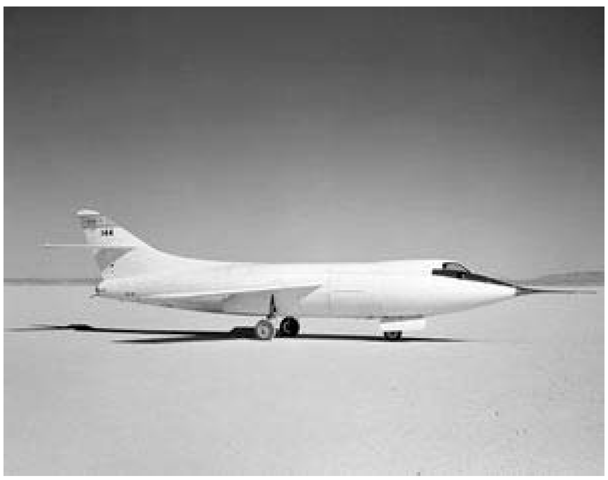
Armament

- 1 × 23 mm (0.91 in) Nudelman-Suranov NS-23 cannon
- 2 × 12.7 mm (0.50 in) Berezin UB machine guns

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)

(Configured with mixed propulsion)

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