

Handbook of Spaceplanes



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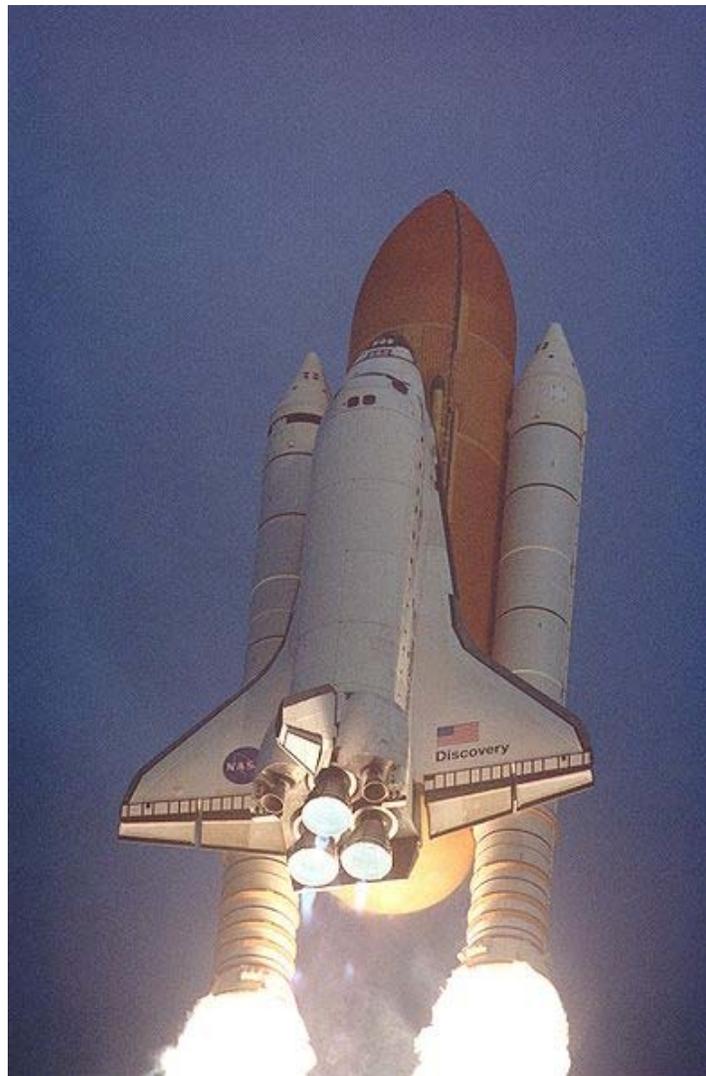
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Chapter-1

Spaceplanes



Liftoff of NASA Space Shuttle *Discovery*. The American Space Shuttles are manned orbital spaceplanes.



Boeing X-37B being prepared for launch in 2010

A **spaceplane** is an aircraft designed to fly up to extreme altitudes into space and back to the Earth's surface. It combines some of the features of an aircraft and some of a spacecraft. Typically, it takes the form of a spacecraft equipped with wings, although lifting bodies have been designed. The propulsion to reach space may be purely rocket based or may use the assistance of air-breathing engines.

To date, only pure rocket spaceplanes have succeeded in reaching space, although several have been carried up to an altitude of several tens of thousands of feet by conventional aircraft before release.

Description

A spaceplane features some differences from rocket launch systems.

Aerodynamic lift

All aircraft utilize aerodynamic surfaces in order to generate lift. Typically the force of lift generated by these surfaces is many times that of the drag that they induce. The ratio of these forces (the Lift-to-drag ratio or L/D) varies between different aircraft designs. It can be as high as 60 in high performance gliders, but is usually closer to 7 or less for typical supersonic aircraft configurations including aerospace planes.

In practice a lift to drag ratio of 7 means that a thrust force equal to 1/7th of the weight of the aircraft is sufficient to support it in flight. This low thrust requirement significantly reduces the amount of fuel required to carry the weight of an aerospace plane in comparison to rocket launch systems which must provide thrust greater than the weight of the vehicle.

A partially off-setting difference between these systems is that the aerospace plane would typically experience powered flight for much longer periods of time than a rocket. In addition winged vehicles need extra dry mass for the wings, and this penalizes vehicles towards the end of the flight. Rockets are also able to use their high thrust at an angle which gives reasonable lifting efficiency when burning for orbit. However, spaceplanes typically undergo what is called a "zoom maneuver" when transitioning from air-breathing flight to pure rocket propulsion to reach space, in which they change their attitude and climb rate significantly, translating some forward velocity into vertical velocity in order to get above the remaining atmosphere so the rocket engine can operate most efficiently.

Atmospheric reentry

Because suborbital spaceplanes are designed for trajectories that do not reach orbital speed, they do not need the kinds of thermal protection orbital spacecraft required during the hypersonic phase of atmospheric reentry. The Space Shuttle thermal protection system, for example, protects the orbiter from surface temperatures that could otherwise reach as high as 3,000 °F (1,650 °C), well above the melting point of steel.

Propulsion

Rocket engines

All spaceplanes to date have used rocket engines with chemical fuels. Due to the orbital insertion burn necessarily being done in space, orbital spaceplanes require rocket engines for at least that portion of the flight.

Air breathing engines

A difference between rocket based and air-breathing aerospace plane launch systems is that aerospace plane designs typically include minimal oxidizer storage for propulsion. Air-breathing aerospace plane designs include engine inlets so they can use atmospheric oxygen for combustion. Since the mass of the oxidizer is, at takeoff, the single largest mass of most rocket designs (the Space Shuttle's liquid oxygen tank weighs 629,340 kg, more than one of its solid rocket boosters), this provides a huge potential weight savings benefit. However, air breathing engines are usually very much heavier than rocket engines and the empty weight of the oxidiser tank, and since, unlike oxidiser, this extra weight must be carried into space it greatly offsets the overall system performance.

Types of air breathing engines proposed for spaceplanes include scramjet, liquid air cycle engines, precooled jet engines, pulse detonation engine and ramjets. Some engine designs combine several types of engines features into a combined cycle. For instance, the Rocket-based combined cycle (RBCC) engine uses a rocket engine inside a ramscoop so that at low speed, the rockets thrust is boosted by ejector augmented thrust. It then transitions to ramjet propulsion at near-supersonic speeds, then to supersonic combustion or scramjet propulsion, above Mach 6, then back to pure rocket propulsion above Mach 10.

Complexity

Because air-breathing aerospace planes must operate in harsh environments, utilize a number of different propulsion systems, and require more control systems (e.g. aerodynamic as well as thrust vectoring), they are typically far more complicated in design than equivalent rocket systems.

In fact, just a comparison of a typical jet engine to that of a rocket engine gives some indicator of the difference in complexity of the engine components.

However, modern combined cycle air-breathing engines, such as Rocket Based Combined Cycle or scramjets, have minimal number of parts, far less than turbopump-fed rocket engines, which burn rocket fuel in a closed turbine to power propellant pumps for the main combustion chamber. The X-43 and X-51 experimental test vehicles utilize such advanced propulsion. While earlier spaceplane designs typically had to depend on multiple types of engines on board, this is not necessary with modern technologies.

Harsh flight environment

The flight trajectory required of air-breathing aerospace vehicles to reach orbit is to fly what is known as a 'depressed trajectory' which places the aerospace plane in the high-altitude hypersonic flight regime of the atmosphere. This environment induces high dynamic pressure, high temperature, and high heat flow loads particularly upon the leading edge surfaces of the aerospace plane. These loads typically require special advanced materials, active cooling, or both for the structures to survive the environment.

However, even rocket powered spaceplanes can face a significant thermal environment if they are burning for orbit, but this is nevertheless far less severe than air-breathing spaceplanes.

Suborbital space planes designed to briefly reach space do not require significant thermal protection, as they experience peak heating for only a short time during re-entry. Intercontinental suborbital trajectories require much higher speeds and thermal protection more similar to orbital spacecraft reentry.

Center of mass issues

A wingless launch vehicle has lower aerodynamic forces affecting the vehicle, and attitude control can be active perhaps with some fins to aid stability. For a winged vehicle the centre of lift moves during the atmospheric flight as well as the centre of mass; and the vehicle spends longer in the atmosphere as well. Historically, the X-33 and HOTOL spaceplanes were rear engined and had relatively heavy engines. This puts a heavy mass at the rear of the aircraft with wings that had to hold up the vehicle. As the wet mass reduces, the centre of mass tends to move rearward behind the centre of lift, which tends to be around the centre of the wings. This can cause severe instability that is usually solved by extra fins which add weight and decrease performance.

Overall weight

A vertically-launched rocket forms the shape of a cylinder stood on end. This structure can be made very light and strong. A horizontally-launched spaceplane approximates a cylinder on its side. This structure experiences greater bending forces, so must be strengthened. This makes it heavier, requiring advanced materials and design techniques to reduce weight. For example Burt Rutan of Scaled Composites recently patented a method of gluing the fuel tank directly to the vehicle skin, saving the weight of fasteners while also stiffening both parts.

Single stage to orbit

Future orbital spaceplanes may take off, ascend, descend, and land like conventional aircraft, providing true single stage to orbit (SSTO) capability.

Proponents of scramjet technology often cite such a vehicle as being a possible application of that type of engine, however pure rocket and subsonic combustion jet designs have also been proposed and may be easier to design and build. The main problem with SSTO operation is overall weight.

Flown spaceplanes

Orbital spaceplanes

All four of the *orbital* spaceplanes successfully flown to date utilize a VTHL (vertical takeoff, horizontal landing) design. They include the piloted United States Space Shuttle and three unmanned spaceplanes: the early-1980s BOR-4 (subscale test vehicle for the Spiral spaceplane that was subsequently cancelled), the late-1980s Soviet Buran, and the early-2010s Boeing X-37.

These vehicles have used wings to provide aerobraking to return from orbit and to provide lift, allowing them to land on a runway like conventional aircraft. These vehicles are still designed to ascend to orbit vertically under rocket power like conventional expendable launch vehicles. One drawback of spaceplanes is that they have a significantly smaller payload fraction than a ballistic design with the same takeoff weight. This is in part due to the weight of the wings — around 9-12% of the weight of the atmospheric flight weight of the vehicle. This significantly reduces the payload size, but the reusability is intended to offset this disadvantage.

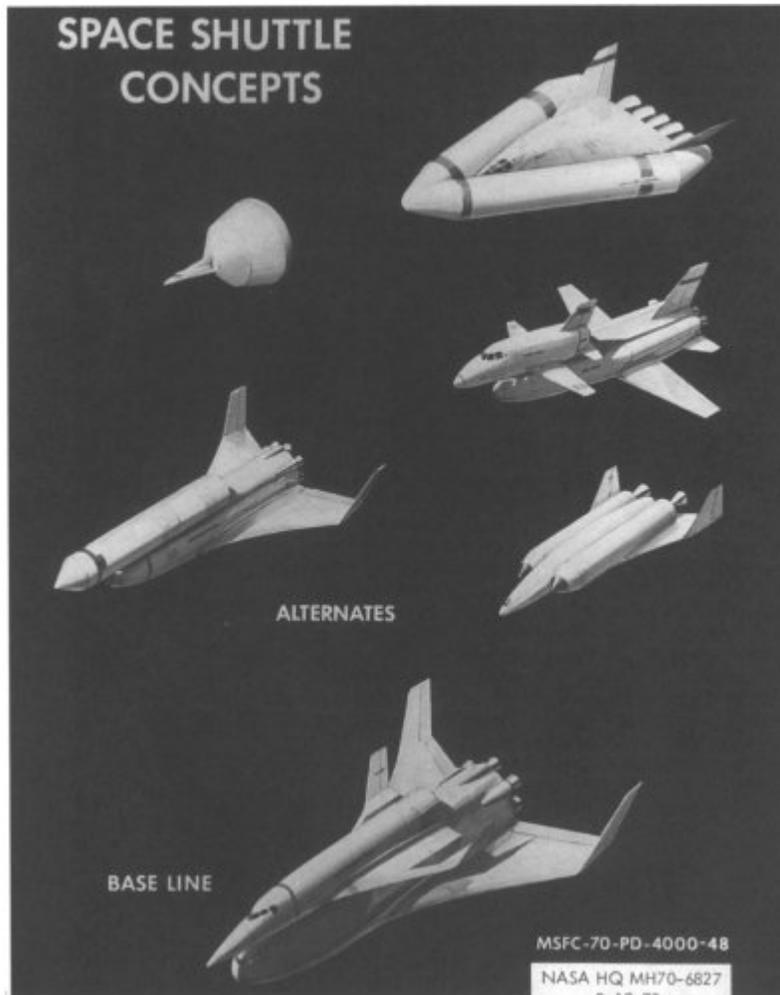
Suborbital spaceplanes

Other spaceplane designs are suborbital, requiring far less energy for propulsion, and can use the vehicle's wings to provide lift for the *ascent to space* in addition to the rocket. As of 2010, the only such craft to reach space have been the X-15, SpaceShipOne and ASSET (flown as a subscale precursor to the X-20 Dyna-Soar spaceplane program that was subsequently canceled). None of these craft were capable of entering orbit. The X-15 and SpaceShipOne both began their independent flight only after being lifted to high altitude by a carrier aircraft.

Scaled Composites and Virgin Galactic unveiled on December 7, 2009, the SpaceShipTwo space plane, the VSS Enterprise, and its WhiteKnightTwo mothership, "Eve". SpaceShipTwo is designed to carry two pilots and six passengers on suborbital flights, with flight testing scheduled to be completed in the 2012 time frame.

XCOR Aerospace signed a \$30 million contract with Yecheon Astro Space Center to build and lease its Lynx Mark II spaceplane, which would be designed to take off from a runway under its own rocket power, and to reach the same altitude and speed range as SpaceShipOne and SpaceShipTwo, due to the fact that Lynx is propelled by higher specific impulse fuels. Lynx is designed to only carry a pilot and one passenger, although tickets are expected to be around half those quoted for Virgin Galactic services.

Other projects



United States STS Space shuttle concepts circa 1970s

Various types of spaceplanes have been suggested since the early twentieth century. Notable early designs include Friedrich Zander's spaceplane equipped with wings made of combustible alloys that it would burn during its ascent, and Eugen Sänger's Silbervogel bomber design. Also in Nazi Germany and then in the USA, winged versions of the V2 rocket were considered during and after World War II, and when public interest in space exploration was high in the 1950s and '60s, winged rocket designs by Wernher von Braun and Willy Ley served to inspire science fiction artists and filmmakers.

United States

The U.S. Air Force invested some effort in a paper study of a variety of spaceplane projects under their Aerospaceplane efforts of the late 1950s, but later ended these when they decided to use a modified version of Sänger's design. The result, Boeing X-20 Dyna-Soar, was to have been the first orbital spaceplane, but was canceled in the early 1960s in lieu of NASA's Project Gemini and the U.S. Air Force's Manned Orbiting Laboratory

program. The Rockwell X-30 National Aero-Space Plane (NASP), begun in the 1980s, was an attempt to build a scramjet vehicle capable of operating like an aircraft and achieving orbit like the shuttle. It was canceled due to increasing technical challenges, growing budgets, and the loss of public interest. In 1994 Mitchell Burnside Clapp proposed a single stage to orbit peroxide/kerosene spaceplane called "Black Horse". This was notable in that it was to take off almost empty and undergo mid-air refueling before accelerating to orbit.

The Lockheed Martin X-33 was a prototype made as part of an attempt by NASA to build a SSTO hydrogen-fuelled spaceplane VentureStar that failed when the hydrogen tank design proved to be unconstructable in the planned way. The March 5, 2006 edition of Aviation Week & Space Technology published a story purporting to be "outing" a highly classified U.S. military two-stage-to-orbit spaceplane system with the code name Blackstar, SR-3/XOV among other nicknames. The alleged system, using an XB-70-like first-stage mother ship, capable of Mach 3, is said to launch an upper-stage "waverider" spaceplane capable of carrying small payloads and crews near to or into orbit or on skip-diving flights, ostensibly for reconnaissance and other missions, achieving surprise that cannot be attained by satellite. There has been considerable controversy over this story and its claims.

In December 2010, Orbital Sciences made a commercial proposal to NASA to develop the Prometheus, a lifting-body spaceplane vehicle about one-quarter the size of the Space Shuttle, in response to NASA's Commercial Crew Development (CCDev) phase 2 solicitation. The vehicle would be launched on a human-rated (upgraded) Atlas V rocket but would land on a runway. For the same solicitation, Sierra Nevada Corporation proposed phase 2 extensions of its Dream Chaser spaceplane technology, partially developed under the first phase of NASA's CCDev program. Both the Orbital Sciences proposal and the Dream Chaser are lifting body designs. Sierra Nevada will utilize Virgin Galactic to market Dream Chaser commercial services and may use "Virgin's WhiteKnightTwo carrier aircraft as a platform for drop trials of the Dream Chaser atmospheric test vehicle" NASA expects to make approximately \$200 million of phase 2 awards by March 2011, for technology development projects that could last up to 14 months.

Soviet Union

The Soviet Union firstly considered a preliminary design of rocket-launch small spaceplane Lapotok in early 1960s. Then the Spiral airspace system with small orbital spaceplane and rocket as second stage was widely developed in the 1960s-1980s. Although test flights of prototypes of spaceplane were fulfilled in air (MiG-105) and space (BOR-4), program was canceled in 1987, a year before the first Buran flight. Project of Tupolev Design Bureau of military suborbital spaceplane-bomber Tu-136/139 Zvezda was canceled in early stage. Another project of Uragan spaceplane, a smaller sibling to Buran, launched by Proton and Zenit rockets, never been confirmed by Soviet or Russian authorities as really conducted, although an existence of similar project of Chelomei's LKS (Kosmolyot) spaceplane was confirmed.

Germany

After the German Sänger-Bredt RaBo and Silbervogel of the 1930s and 1940s, Eugen Sänger worked for time on various space plane projects, coming up with several designs for Messerschmitt-Bölkow-Blohm such as the MBB Raumtransporter-8. In the 1980s, West Germany funded design work on the MBB Sänger II with the Hypersonic Technology Program. Development continued on MBB/Deutsche Aerospace Sänger II/HORUS until the last 1980s, when it was canceled in favor of participation in the Ariane rocket, Columbus space station and Hermes spaceplane of ESA, Spacelab of ESA-NASA and *Deutschland* missions (non-U.S. funded Space Shuttle flights with Spacelab), despite predicted cost savings of up to 30 percent. The Daimler-Chrysler Aerospace RLV was a much later small reusable spaceplane prototype for ESA FLPP/FLTP program.

France

Initiated by France joint European program of ESA of Hermes manned spaceplane launched by Ariane rocket continued a few years before it was canceled in early 1990s. Earlier France Dassault-Avion company proposed Astrobus spaceplane and now develops ARES spaceplane as prototype for FLPP. Hopper was proposed as European spaceplane by EADS which also develops ARES spaceplane as prototype for ESA FLPP/FLTP program and commercial suborbital spaceplane for space tourism.

United Kingdom

The Multi-Unit Space Transport And Recovery Device (MUSTARD) was a concept explored by the British Aircraft Corporation (BAC) around 1964-1965 for launching payloads weighing as much as 5,000 lb into orbit. It was never constructed. The British Government also began development of a SSTO-spaceplane, called HOTOL, but the project was canceled due to technical and financial issues.

The lead engineer from the HOTOL project has since set up a private company dedicated to creating a similar plane called Skylon with a different combined cycle rocket/turbine precooled jet engine called SABRE. This vehicle is intended to be capable of a single stage to orbit launch also and, if successful, would be far in advance of anything currently in operation.

Chapter-2

Boeing X-20 Dyna-Soar

X-20 Dyna-Soar



Artist's impression of the X-20 during re-entry

Country	United States
Contract award	24 October 1957 to 10 December 1963
Status	Canceled just after spacecraft construction had begun
First flight	Not built proposed for 1 January 1966
Last flight	multi-orbit, crew of 1 proposed for 1 March 1968
Number of missions	10 missions planned

The **X-20 Dyna-Soar** ("Dynamic Soarer") was a United States Air Force (USAF) program to develop a spaceplane that could be used for a variety of military missions, including reconnaissance, bombing, space rescue, satellite maintenance, and sabotage of enemy satellites. The program ran from 24 October 1957–10 December 1963, cost

US\$660 million (\$4.73 billion today), and was cancelled just after spacecraft construction had begun.

Other spacecraft under development at the time, such as *Mercury* or *Vostok*, were based on space capsules which returned on ballistic re-entry profiles. Dyna-Soar was much more like the much later Space Shuttle; it could not only be boosted and travel to distant targets at the speed of an intercontinental ballistic missile, it was designed to glide to earth like an airplane under the control of the pilot. It could land at an airfield, rather than simply falling to earth and landing with a parachute. Dyna-Soar could also reach earth orbit, like *Mercury* or *Gemini*.

These characteristics made Dyna-Soar far more advanced in concept than the other human spaceflight missions of the period. Data collected during the X-20 program would prove useful in designing the Space Shuttle. The much larger Shuttle would also be boosted into orbit by large rockets for launch, and the final design would also pick delta wings for controlled landings, but it (and the Soviet *Buran*) would not fly until decades after the X-20 cancellation.

Background



Artist's impression of the X-20 after test flight

The development of Dyna Soar can be traced back to Eugen Sänger's *Silbervogel*, a German bomber project of World War II. The concept was to create a rocket-powered bomber that could travel vast distances by gliding to its target after being boosted to high speed (>5.5 km/s) and high altitude (50–150 km) by A-4 or A-9 rocket engines.

Essentially, these rocket engines would place the vehicle onto an exoatmospheric intercontinental ballistic missile-like trajectory and then fall away. However, when the vehicle reentered the atmosphere, instead of fully reentering, bleeding off its speed and landing, the vehicle would use its wings and some of its speed to generate lift and bounce the vehicle back into space again. This would repeat until the speed was low enough that the pilot of the vehicle would need to pick a landing spot and glide the vehicle to a landing. This use of hypersonic atmospheric lift meant that the vehicle could greatly extend its range over a ballistic trajectory using the same engines.

Such boost-glide systems could potentially strike at targets anywhere in the world (so called "antipodal bombers") at hypersonic speeds, be very difficult to intercept, and the aircraft itself could be small and lightly armed, compared to a typical heavy bomber. In addition, a boost-glide aircraft may be recoverable, acting as a manned bomber, or as an unmanned non-recoverable missile.

Following World War II, many German scientists were taken to the United States by the Office of Strategic Services's "Operation Paperclip". Among them was Dr. Walter Dornberger, the former head of Germany's wartime rocket program, who had detailed knowledge of the Silbervogel project. Working for Bell, he attempted to create interest in a boost-glide system in the USAF, and elsewhere. This resulted in the USAF requesting a number of feasibility and design studies — carried out by Bell, Boeing, Convair, Douglas, Martin, North American, Republic, and Lockheed — for boost-glide vehicles during the early 1950s:

- Bomi (bomber missile);
- Hywards (HYpersonic Weapons Research and Development Supporting system);
- The Brass Bell reconnaissance vehicle; and
- Rocket Bomber "Robo".

Development



NASA mock-up of X-20 Dyna-Soar

On 24 October 1957, the USAF Air Research and Development Command issued a proposal for a "Hypersonic Glide Rocket Weapon System" (Weapons System 464L): Dyna Soar. The proposal drew together the existing boost-glide proposals, as the USAF believed a single vehicle could be designed to carry out all the bombing and reconnaissance tasks intended for the separate studies, and act as successor to the X-15 research program. The Dyna-Soar program was to be conducted in three stages: a research vehicle (**Dyna-Soar I**), a reconnaissance vehicle (**Dyna-Soar II**, previously Brass Bell), and a vehicle that would add strategic bombing capability (**Dyna-Soar III**, previously Robo). The first glide tests for Dyna-Soar I were expected to be carried out in 1963, followed by powered flights, reaching Mach 18, the following year. A robotic glide missile was to be deployed in 1968, with the fully operational weapons system (Dyna-Soar III) expected to be deployed by 1974.

In March 1958, nine U.S. aerospace companies tendered for the Dyna-Soar contract. Of these, the field was narrowed to proposals from Bell and Boeing. Even though Bell had the advantage of six years' worth of design studies, the contract for the spaceplane was awarded to Boeing in June 1959 (by which time their original design had changed markedly and now closely resembled what Bell had submitted). In late 1961, the Titan III was eventually finalized as the launch vehicle. The Dyna-Soar was to be launched from Cape Canaveral Air Force Station, Florida.



An artist's impression of Dyna-Soar being launched using a Titan booster.

In April 1960, seven astronauts were secretly chosen for the Dyna-Soar program. Neil Armstrong and Bill Dana left the program in the summer of 1962. On 19 September

1962, Albert Crews was added to the Dyna-Soar program and the names of the six Dyna-Soar astronauts were announced to the public:

- Neil Armstrong (NASA) 1960–1962
- Albert H. Crews, Jr. (Air Force) 1962–1963
- Bill Dana (NASA) 1960–1962
- Henry C. Gordon (Air Force) 1960–63
- Pete Knight (Air Force) 1960–1963
- Russell L. Rogers (Air Force) 1960–1963
- Milt Thompson (NASA) 1960–1963
- James W. Wood (Air Force) 1960–1963

By the end of 1962, Dyna-Soar had been designated "X-20", the booster (to be used in the Dyna Soar I drop-tests) successfully fired, and the USAF had held an "unveiling" ceremony for the X-20 in Las Vegas.

Problems

Besides the funding issues that often accompany research efforts, the Dyna-Soar program suffered from two major problems: uncertainty over the booster to be used to send the craft into orbit, and a lack of a clear goal for the project.

Many different boosters were proposed to launch Dyna-Soar into orbit. The original USAF proposal suggested LOX/JP-4, fluorine-ammonia, fluorine-hydrazine, or RMI (X-15) engines. Boeing, the principal contractor, favored an Atlas-Centaur combination, but eventually the Air Force stipulated a Titan, as suggested by failed competitor Martin. However, the Titan I would not be powerful enough to launch the five-ton X-20 into orbit.

The Titan II and Titan III boosters could launch Dyna-Soar into Earth orbit, as could the Saturn C-1 (later renamed the Saturn I), and all were proposed with various upper-stage and booster combinations. While the Titan IIIC was eventually chosen to send Dyna-Soar into space, the vacillations over the launch system delayed the project as it complicated planning.

The original intention for Dyna-Soar, outlined in the Weapons System 464L proposal, called for a project combining aeronautical research with weapons system development. Many questioned whether the USAF should have a manned space program, when that was the primary domain of NASA. However, it was frequently emphasized by the Air Force that, unlike the NASA programs, Dyna-Soar allowed for controlled re-entry, and this was where the main effort in the X-20 program was placed. On 19 January 1963 the Secretary of Defense, Robert McNamara, directed the Air Force to undertake a study to determine whether *Gemini* or Dyna-Soar was the more feasible approach to a space-based weapon system. In the middle of March 1963, after receiving the study, Secretary McNamara "stated that the Air Force had been placing too much emphasis on controlled re-entry when it did not have any real objectives for orbital flight". This was seen as a

reversal of the Secretary's earlier position on the Dyna-Soar program. Dyna-Soar was also an expensive program that would not launch a manned mission until the mid-1960s at the earliest. This high cost and questionable usefulness made it hard for the Air Force to justify the program. Eventually, the X-20 Dyna-Soar program was canceled on 10 December 1963.

On the day that X-20 was canceled, the Air Force announced another program, the Manned Orbiting Laboratory, a spin-off of *Gemini*, but this program was also eventually canceled.

Another black program ISINGLASS which was to be air-launched from a B-52 bomber was evaluated, and some engine work was done, however this eventually was cancelled also.

Description



Artist's impression of the X-20 on landing approach at Edwards Air Force Base

The overall design of the X-20 Dyna-Soar was outlined in March 1960. It had a low-wing delta shape, with winglets for control rather than a more conventional tail. The framework of the craft was to be made from the René 41 "super alloy", as were the upper surface panels. The bottom surface was to be made from molybdenum sheets placed over insulated René 41, while the nose-cone was to be made from graphite with zirconia rods.

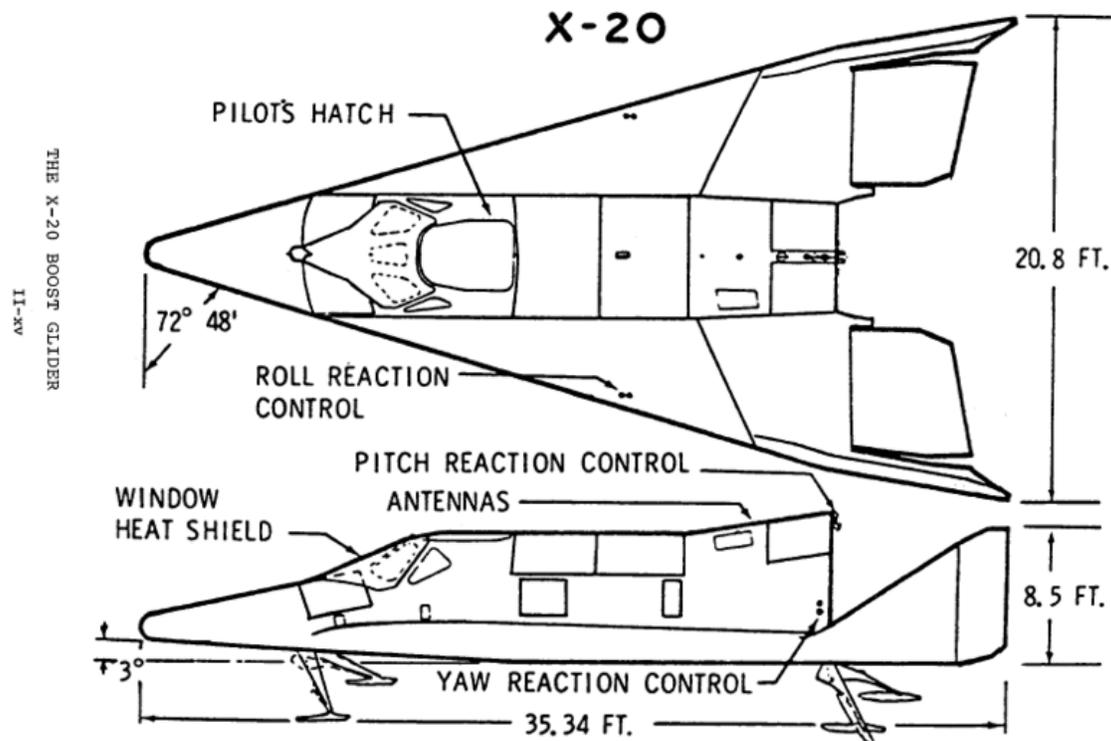
Due to the changing requirements, various forms of the Dyna-Soar were designed, but all variants shared the same basic shape and layout. A single pilot sat at the front, while an equipment bay was situated behind. This bay contained either data-collection equipment, weapons, reconnaissance equipment, or (in the X-20X "shuttle space vehicle") a four-man mid-deck.

After the equipment bay was the transition-stage rocket engine, which was used to maneuver the craft in orbit or fired during launch as part of an abort. This trans-stage would be jettisoned before descent into the atmosphere. While falling through the atmosphere an opaque heat shield would protect the window at the front of the craft. This heat shield would then be jettisoned after aerobraking so the pilot could see, and safely land.

A drawing in *Space/Aeronautics* magazine from before the project's cancellation depicts the craft dipping down into the atmosphere, skimming the surface, to change its orbital inclination. It would then fire its rocket to resume orbit. This would be a unique ability for a spacecraft, for the laws of celestial mechanics mean it requires an enormous expenditure of energy for a rocket to change its orbital inclination once it has reached orbit. Hence the Dyna-Soar could have had a military capacity of being launched into one orbit and rendezvousing with a satellite, even if the target were to expend all its propellant in changing its orbit. Acceleration forces on the pilot, however, would be severe in such a maneuver.

Unlike the later Space Shuttle, Dyna-Soar did not have wheels on its undercarriage as it was thought the rubber would burn during re-entry. Instead Goodyear developed retractable wire-brush skis made of the same René 41 alloy as the airframe.

Specifications (as designed)



General characteristics

- **Crew:** one pilot
- **Length:** 35 ft 4 in (10.77 m)
- **Wingspan:** 20 ft 10 in (6.34 m)
- **Height:** 8 ft 6 in (2.59 m)
- **Wing area:** 345 ft² (32 m²)
- **Empty weight:** 10,395 lb (4,715 kg)
- **Max takeoff weight:** 11,387 lb (5,165 kg)
- **Powerplant:** 1× Martin Trans-stage rocket engine, 72,000 lbf (323 kN)

Performance

- **Maximum speed:** 17,500 mph (28,165 km/h)
- **Range:** earth orbit 22,000 nautical miles, (40,700 km)
- **Service ceiling:** 530,000 ft (160 km)
- **Rate of climb:** 100,000 ft/min (510 m/s)
- **Wing loading:** 33 lb/ft² (161 kg/m²)

Chapter-3

Boeing X-37

X-37



X-37B being prepared for launch

Role	Spaceplane
National origin	United States
Manufacturer	Boeing
First flight	7 April 2006 (drop test);

	22 April – 3 December 2010 (first spaceflight)
Status	Development and testing, one spaceflight completed
Primary users	NASA/DARPA (X-37A) USAF (X-37B)
Number built	2
Developed from	Boeing X-40

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

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

Development

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

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

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

As part of its Space Support mission goals, X-37 was designed to rendezvous with friendly satellites to refuel them, or to replace failed solar arrays using a robotic arm. Its payload could also support Space Control (Defensive Counter-Space, Offensive Counter-Space), Force Enhancement and Force Application. An early requirement for the spacecraft called for a delta-v of 7,000 mph (3.1 km/s) to change its orbit.

Glide tests

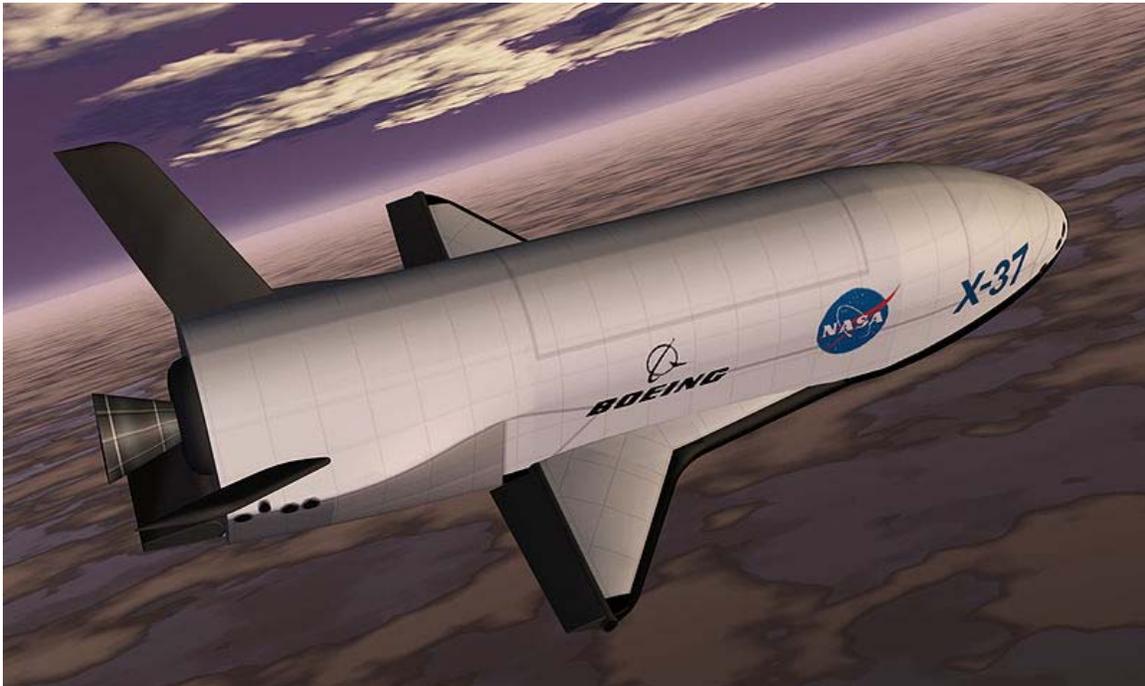
The vehicle that was used as an atmospheric drop test glider had no propulsion system. Instead of an operational vehicle's payload bay doors it had an enclosed and reinforced upper fuselage structure to allow it to be mated with a mothership. In September 2004 DARPA announced that for its initial atmospheric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

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

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

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

X-37B Orbital Test Vehicle



X-37 spacecraft, artist's rendering from 1999

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

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

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

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

Design

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

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

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

Operational history



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

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

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

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



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

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

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

Controversy

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

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

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

Specifications

X-37B

General characteristics

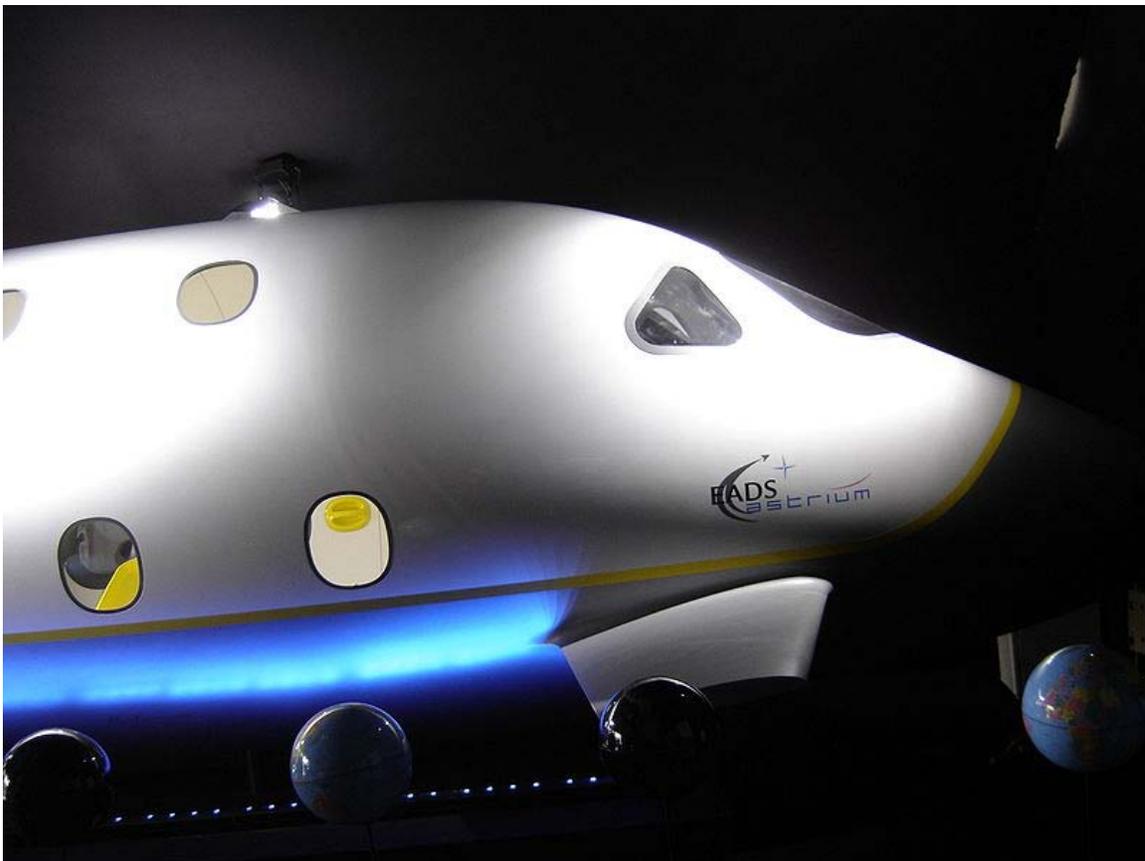
- **Crew:** None
- **Length:** 29 ft 3 in (8.9 m)
- **Wingspan:** 14 ft 11 in (4.5 m)
- **Height:** 9 ft 6 in (2.9 m)
- **Loaded weight:** 11,000 lb (4,990 kg)
- **Power:** Gallium arsenide solar cells with lithium-ion batteries
- **Payload Bay:** 7 × 4 ft (2.1 × 1.2 m)

Performance

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

Chapter-4

EADS Astrium Space Tourism Project



Mock-up of the vehicle at Paris Air Show 2007

The **EADS Astrium Space Tourism Project**, also called **EADS Astrium TBN** according to some sources, is a suborbital spaceplane concept for carrying space tourists, proposed by EADS Astrium, the space subsidiary of the European consortium EADS. A mockup was officially unveiled in Paris on June 13, 2007. The project is the first space tourism entry by a major aerospace contractor. A scale one mock-up of the cockpit has

been exhibited at the 2007 Paris Air Show and is now on display in the Concorde hall of the Musée de l'Air et de l'Espace.

It is a rocket plane with a large wingspan, straight rearwards wing and a pair of canards. Propulsion is ensured by classical jet engines for the atmospheric phase and a methane - oxygen rocket engine for the space tourism phase. It can carry a pilot and four passengers. The dimensions and looks are somewhat similar to those of a business jet.

As of 2007, EADS Astrium hoped to start development of this rocket plane by 2008, with the objective of a first flight in 2011. There was also a possibility that the Tunisian area of Tozeur might be used for the initial flights.

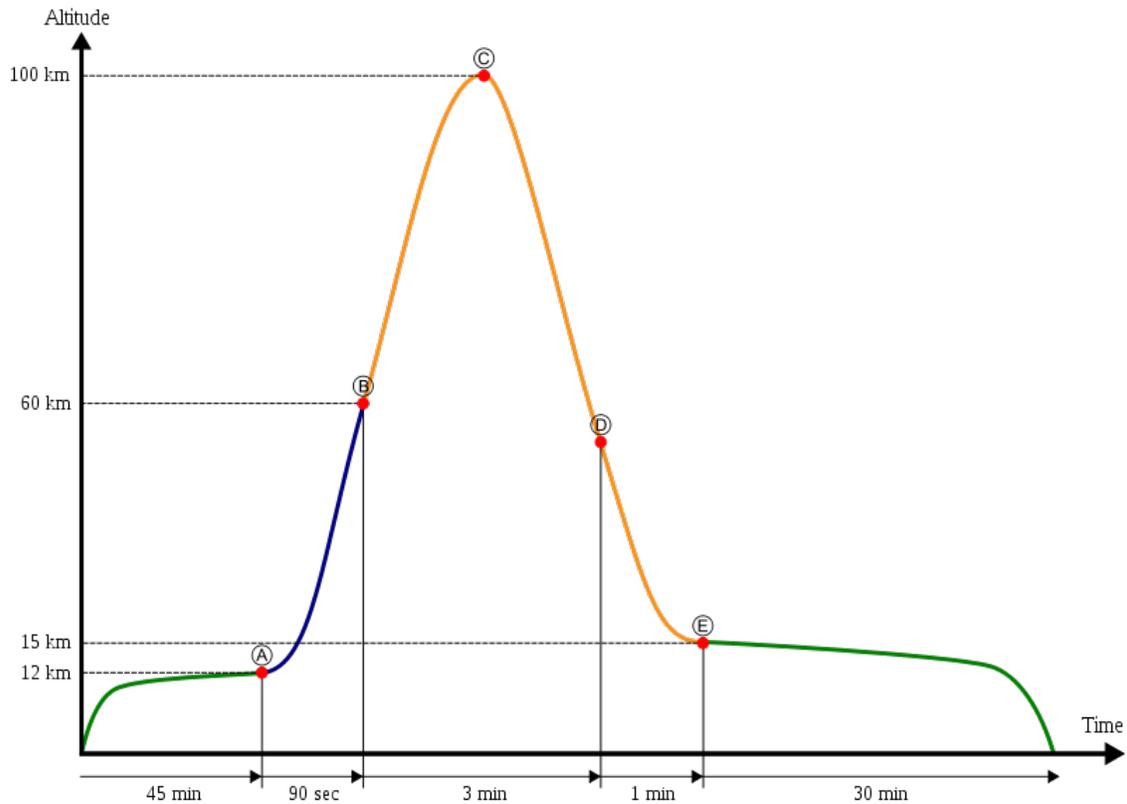
EADS Astrium plans to raise public and private money for its project.

Origin of the project

The origin of the project is a proposal by a group of young French, German, British and Spanish engineers from EADS Astrium. It has been studied in great secrecy for two years and finally approved by the chairman of EADS Astrium, François Auque. The design is similar in concept to the Rocketplane XP. They looked at the main concepts under development and their studies showed that Rocketplane's jet and rocket combination made the most sense.

In the following months, a core team came up with a detailed concept and assembled the required expertise from different areas of Astrium and other EADS subsidiaries, such as Socata, as well as several external industry partners. Australian designer Marc Newson, who earned his reputation in the field of aviation as Creative Director of Qantas, was also invited to join the project.

Flight profile



- █ Turbofan propulsion
- █ Rocket propulsion
- █ No propulsion

A: Ignition of rocket engine followed by turbofan shutdown

B: Shutdown of rocket engine. Acceleration 3 g. Start of Weightlessness phase.

C: Culmination

D: Beginning of atmospheric deceleration. Max acceleration 4.5 g.

E: Turbofan ignition. Transition to aeronautical mode.

After takeoff the plane reaches an altitude of 12 km. This classical aeronautical phase can last for 45 minutes. The pilot shuts down the jets and starts the methane oxygen rocket engine at the rear of the vehicle. The plane then raises along a vertical trajectory. For 90 seconds of flight with a top speed of Mach 3, the plane is rocketed upwards. The maximum acceleration is 3 g (30 m/s²). At an altitude of 60 km, the rocket engine is shut down and the plane continues to climb up to a maximum altitude of 100 km.

This is the weightlessness phase.

Then the plane gets down to 15 km at a high angle of attack, being progressively decelerated by the atmosphere; at this altitude, after transition to aeronautical mode, the jets are reignited to bring the plane back to a classical landing strip.

Characteristics



Interior layout of the vehicle at Paris Air Show 2007

The total mass of the vehicle is 18 metric tons (39,700 lb) at takeoff. The plane has two jet engines, and an oxygen methane engine with a thrust of 30 tons. The rocket engine uses the technology of the Vulcain (the main engine of Ariane 5), but is reusable thirty times and burns methane instead of hydrogen (hydrogen would require too much tank volume).

The cabin has a diameter of 2.3 m (7 ft 6 in), and provides 3 m³ (106 ft³) of cabin space to each passenger. The seats are attached to a pendular system which allows the acceleration to be perpendicular to the back of the passengers. They pivot around the attachment points so that the passengers are aligned rearside to the spacecraft x-axis (body aligned on Gx-axis) during launch acceleration and they are rearside on the negative z-axis during weightlessness and reentry.

The plane is designed for ten years service at a flight rate of once a week.

Industrial organisation

The development will be led by EADS Astrium. Its technical responsibility currently resides with the CTO Robert Lainé.

In 2007, development cost of \$1 billion was projected by some sources. EADS Astrium plans to raise mostly private money for its project. One of the possible public investors mentioned by François Auque is the southern German state of Bavaria where the engines are to be produced. Astrium could produce up to 5 planes a year and have a fleet of 20 planes, which would require a production of 20 rocket engines a year. They do not exclude selling models to other entrepreneurs such as Sir Richard Branson from Virgin Galactic.

The final assembly would be in France, while the other industrial facilities of Astrium would provide the rocket engines (Ottobrunn, Germany) or the carbon fiber structures (Spain). Other European industrial partners are associated with the project.

The target of Astrium is to secure 30% of the market of space tourism by 2020, 5000 passengers a year.

The ticket price will be 200,000 euros, including a round trip to the spaceport, training, and luxury accommodation in a theme park/resort.

Competition

The closest concept is the Rocketplane XP of Rocketplane Limited, Inc., which shares the same overall rocket plane principle. Other competitors include the SpaceShipTwo of Virgin Galactic and Blue Origin.

Criticisms

Burt Rutan, founder of Scaled Composites, a competitor in space tourism to EADS, expressed scepticism towards the EADS Project.

“ The non-recurring development cost of a suborbital spaceship that has rocket and jet engines — both of which leave the atmosphere and experience reentry — will be far more than our SpaceShipTwo program. ”

The reaction of the European Union's industry commissioner Günter Verheugen was also negative.

“ It's only for the super rich, which is against my social convictions [...] I have no sympathy for this. It deserves no support. ”

Chapter-5

Lockheed Martin X-33 and Lynx Rocketplane

Lockheed Martin X-33

X-33



Simulated in-flight view of the X-33

Function	Unmanned Re-usable Spaceplane technology demonstrator
Manufacturer	Lockheed Martin
Country of origin	United States
Size	
Height	20 m (69 ft)
Diameter	N/A
Mass	285,000 lb (130,000 kg)
Stages	1

	Capacity
	Launch history
Status	Canceled (2001)
Launch sites	Edwards Air Force Base
Total launches	1
	First stage - X-33
Engines	2 J-2S Linear Aerospike
Thrust	410,000 lbf (1.82 MN)
Burn time	
Fuel	LOX/LH2

The **Lockheed Martin X-33** is an unmanned, sub-scale technology demonstrator suborbital spaceplane developed in the 1990s under the U.S. government-funded Space Launch Initiative program. X-33 was a technology demonstrator for the VentureStar orbital spaceplane. The VentureStar was planned to be a next-generation, commercially-operated reusable launch vehicle. The X-33 would flight-test a range of technologies that NASA believed it needed for single-stage-to-orbit reusable launch vehicles (SSTO RLVs), such as metallic thermal protection systems, composite cryogenic fuel tanks for liquid hydrogen, the aerospike engine, autonomous (unmanned) flight control, rapid flight turn-around times through streamlined operations, and its lifting body aerodynamics.

Failures led to the cancellation of the program as a federal program in 2001, but Lockheed Martin has conducted related testing, and has had successes as recently as 2009.

Design and development

Through the use of the lifting body shape, composite liquid fuel tanks, and the aerospike engine, NASA and Lockheed Martin hoped to test fly a craft that would demonstrate the viability of a single-stage-to-orbit (SSTO) design. An SSTO craft would not require external fuel tanks or boosters to reach low-earth orbit. Doing away with the need for "staging" with launch vehicles, such as with the Shuttle and the Apollo rockets, would lead to an inherently more reliable and safer space launch vehicle. While the X-33 would not approach airplane-like safety, the X-33 would attempt to demonstrate that 0.997 reliability, or 3 mishaps out of 1,000 launches, which would be an order of magnitude more reliable than the Space Shuttle system, was achievable. The 15 planned experimental X-33 flights could only begin this statistical evaluation.



X-33 launch facility already completed at Edwards Air Force Base.

The unmanned craft would have been launched vertically from a specially designed facility constructed on Edwards Air Force Base, and landed horizontally (VTHL) on a runway at the end of its mission. Initial sub-orbital test flights were planned from Edwards AFB to Dugway Proving Grounds southwest of Salt Lake City, Utah. Once those test flights were completed, further flight tests were to be conducted from Edwards AFB to Malmstrom AFB in Great Falls, Montana, to gather more complete data on aircraft heating and engine performance at higher speeds and altitudes.

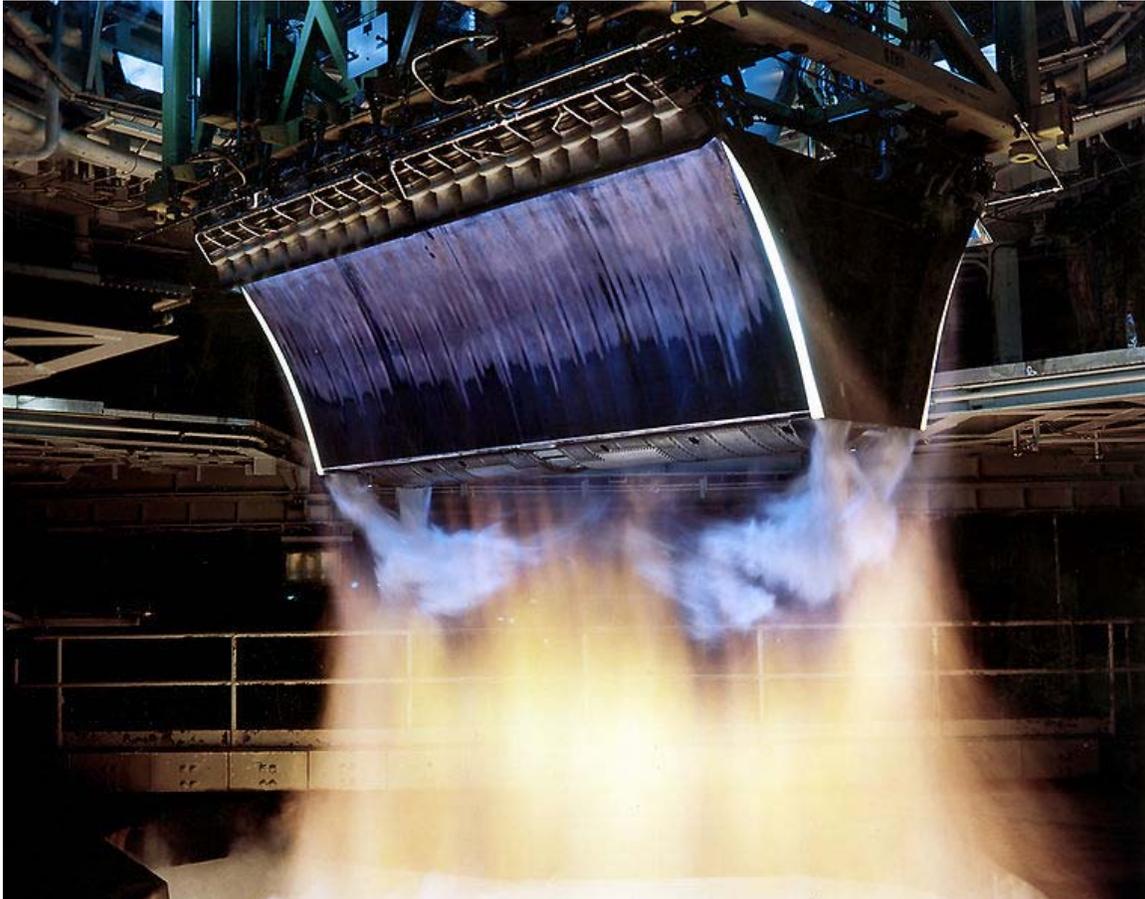
On July 2, 1996, NASA selected Lockheed Martin Skunk Works of Palmdale, California, to design, build, and test the X-33 experimental vehicle for the RLV program. Lockheed Martin's design concept for the X-33 was selected over competing designs from Boeing and McDonnell Douglas. Boeing featured a Space Shuttle-derived design, and McDonnell Douglas featured a design based on its vertical takeoff and landing (VTOL) DC-XA test vehicle.

The X-33 was never intended to fly higher than an altitude of 100 km, nor faster than one-half of orbital velocity. Had any successful tests occurred, extrapolation would have been necessary to apply the results to a proposed orbital vehicle.

Commercial spaceflight

Based on the X-33 experience shared with NASA, Lockheed Martin hoped to make the business case for a full-scale SSTO RLV, called VentureStar, that would be developed and operated through commercial means. The intention was that rather than operate space transport systems as it has with the Space Shuttle, NASA would instead look to private industry to operate the reusable launch vehicle and NASA would purchase launch services from the commercial launch provider. Thus, the X-33 was not only about honing space flight technologies, but also about successfully demonstrating the technology required to make a commercial reusable launch vehicle possible.

The VentureStar was to be the first commercial aircraft to fly into space. The unmanned X-33 was slated to fly 15 suborbital hops to near 75.8 km altitude. It was to be launched upright like a rocket and rather than having a straight flight path it would fly diagonally up for half the flight, reaching extremely high altitudes, and then back down for the rest of the flight. The VentureStar was intended for long inter-continental flights and supposed to be in service by 2012, but this project was never funded or begun.



Aerospike engine test at Stennis Space Center, August 6, 2001

The decision to design and build the X-33 grew out of an internal NASA study titled "Access to Space". Unlike other space transport studies, "Access to Space" was to result in the design and construction of a vehicle.

NASA Cancellation

Construction of the prototype was some 85% assembled with 96% of the parts and the launch facility 100% complete when the program was canceled by NASA in 2001, after a long series of technical difficulties including flight instability and excess weight.

In particular, the composite liquid hydrogen fuel tank failed during testing in November 1999. The tank was constructed of honeycomb composite walls and internal structures to

reduce its weight. A lighter tank was needed for the craft to demonstrate necessary technologies for single-stage-to-orbit operations. A hydrogen fueled SSTO craft's mass fraction requires that the weight of the vehicle without fuel be 10% of the fully-fueled weight. This would allow for a vehicle to fly to low earth orbit without the need for the sort of external boosters and fuel tanks used by the Space Shuttle. But, after the composite tank failed on the test stand during fueling and pressure tests, NASA came to the conclusion that the technology of the time was simply not advanced enough for such a design. While the composite tank walls themselves were lighter, the odd hydrogen tank shape resulted in complex joints increasing the total mass of the composite tank to above that of an aluminum-based tank.

NASA had invested \$922 million in the project before cancellation and Lockheed Martin a further \$357 million. Due to changes in the space launch business—including the challenges faced by companies such as Globalstar, Teledesic, and Iridium and the resulting drop in the number of anticipated commercial satellite launches per year—Lockheed Martin deemed that continuing development of the X-33 privately without government support would not be profitable.

Continued research

After the cancellation in 2001, engineers were able to make a working liquid oxygen tank out of carbon fiber composite.

On September 16, 2004, Northrop Grumman and NASA engineers unveiled a liquid hydrogen tank made of carbon fiber composite material that had demonstrated the ability for repeated fuelings and simulated launch cycles. Northrop Grumman concluded that these successful tests have enabled the development and refinement of new manufacturing processes that will allow the company to build large composite tanks without an autoclave; and design and engineering development of conformal fuel tanks appropriate for use on a single-stage-to-orbit vehicle.

Lockheed Martin has been testing a new and different 1/5 scale rocket described to be similar in capabilities and design, known now simply as a "Space Reusable Launch Vehicle". Two tests were conducted secretly at the Spaceport America in New Mexico. The first on December 19, 2007 was billed as a complete success, while the August 12, 2008 launch ended in an irreparable crash after 12.5 seconds of flight. A third test on October 10, 2009, was another success.

Lynx rocketplane



The Lynx rocketplane in flight (artists' conception) - XCOR Aerospace

The **Lynx rocketplane** is a suborbital horizontal-takeoff, horizontal-landing (HTHL), rocket-powered spaceplane being developed by the California-based company XCOR to compete in the emerging suborbital space flight market. The Lynx is projected to carry one pilot, a ticketed passenger, and/or a payload or small satellites above 100 km altitude. As of December 2008, the passenger ticket was to cost \$95,000. The Lynx was initially announced on March 26, 2008, with plans for an operational vehicle within two years. That date has since fallen to late 2011.

Description

The Lynx will have four liquid rocket engines at the rear of the fuselage burning a mixture of LOX-Kerosene and each of them will produce 2,900 pounds-force (13,000 N) of thrust.

Mark I Prototype

- Maximum Altitude: 62 km (203,000 ft)
- Primary Internal Payload: 120 kg (260 lb)
- External Dorsal Mounted Pod: 280 kg (620 lb)

- Secondary payload spaces include a small area inside the cockpit behind the pilot or outside the vehicle in two areas in the aft fuselage fairing.

Mark II Production Model

- Maximum Altitude: +100 km (330,000 ft)
- Primary Internal Payload: 120 kg (260 lb)
- External Dorsal Mounted Pod: 650 kg (1,400 lb) and is large enough to hold a two stage carrier to launch a microsatellite or multiple nanosatellites into low Earth orbit.
- Secondary payload spaces include the same as the Mark I.
- Non-toxic (non-hydrazine) reaction control system (RCS) thrusters, type 3N22

Test program

Tests of the XR-5K18 main engine began in 2008 and, as of February 2011, are largely complete.

As of February 2011, the vehicle aerodynamic design has completed two rounds of wind tunnel testing. A third and final round of tests is planned for later in 2011.

Flight tests of the Mark I prototype are expected to start in 2011.

Operations



Artists' depiction of Lynx on ground with people - XCOR Aerospace

The first engine hot fire tests were conducted on December 15, 2008. Wind tunnel tests were conducted in July 2009.

NASA sRLV program

As of March 2011, XCOR has submitted the Lynx as a reusable launch vehicle for carrying research payloads in response to NASA's suborbital reusable launch vehicle

(sRLV) solicitation, which is a part of NASA's Flight Operations Program. XCOR projects 110 km (68 mi) altitude in flights of 30 to 45 minutes duration, while carrying up to 140 kg (310 lb) internal—or 650 kg (1,400 lb) external—of research payload. Flights will provide up to three minutes of microgravity below 0.01 g

Commercial operations

According to XCOR, the Lynx will fly four or more times a day, and will also have the capacity to deliver payloads into space. A Lynx prototype called Mark I is expected to perform its first test flight in early 2011, followed with a flight of the Mark II production model nine to eighteen months after. XCOR currently plans to have the Lynx's initial flights from the Mojave Air and Spaceport in Mojave, California or any licensed spaceport with a 2,400 meter (7900 ft) runway. Beginning in January, 2014 the Lynx is expected to be flying suborbital space tourism flights and scientific research missions from a new spaceport on the Caribbean island of Curaçao.

Because it lacks any propulsion system other than its rocket engines, the Lynx will have to be towed to the end of the runway. Once positioned on the runway, the pilot will ignite the four rocket engines and begin a steep climb. The engines will be shut off at approximately 138,000 feet (42 km) and Mach 2. The spaceplane will then continue to climb, unpowered until it reaches an apogee of approximately 200,000 feet (61 km). The spacecraft will experience a little over four minutes of weightlessness before re-entering the Earth's atmosphere. The occupants of the Lynx may experience up to four times normal gravity during re-entry. Once it has completed re-entry, the Lynx will then glide down and perform an unpowered landing. The total flight time is projected to last about 30 minutes. The Lynx is expected to be able to perform 40 flights before maintenance is required.

The occupants would wear pressure suits made by Orbital Outfitters.

The successor to the Mark II is planned to be a two stage fully-reusable orbital vehicle that takes off and lands horizontally.

Chapter-6

Mikoyan-Gurevich MiG-105

MiG-105

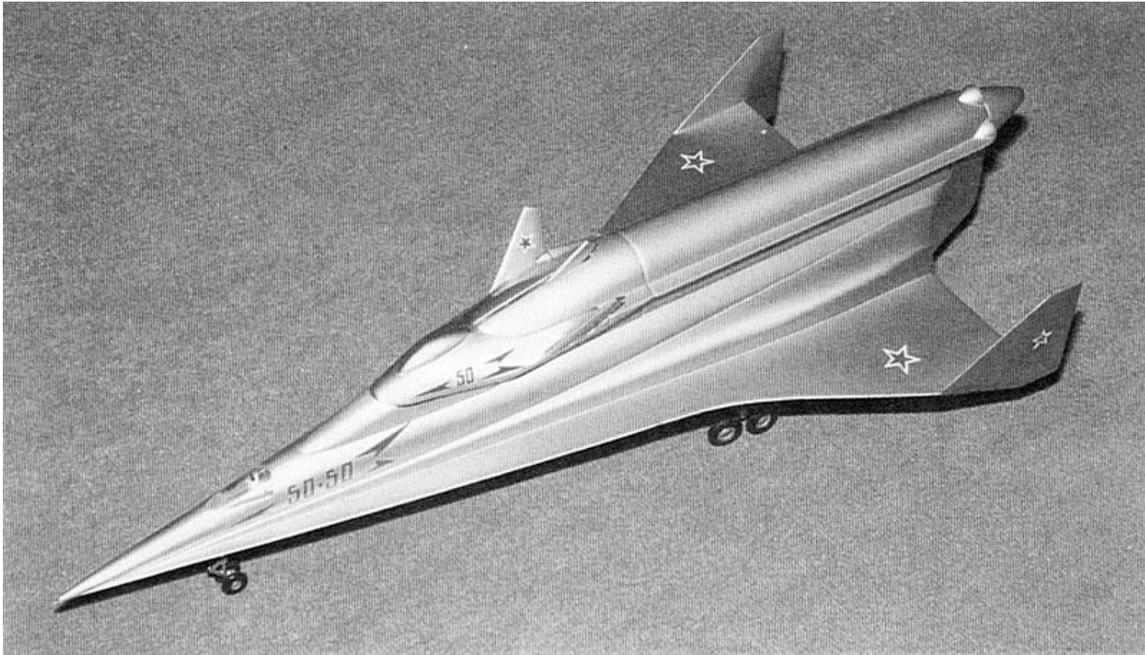


MiG 105-11 test vehicle at the Monino Air Force museum.

Role	Test vehicle
Manufacturer	Mikoyan-Gurevich
First flight	1976
Status	Cancelled
Primary user	Soviet Air Force

The **Mikoyan-Gurevich MiG-105** was a manned test vehicle to explore low-speed handling and landing. It was a visible result of a Soviet project to create an orbital spaceplane. This was originally conceived in response to the American X-20 Dyna-Soar military space project and may have been influenced by contemporary manned lifting body research being conducted by NASA's Flight Research Center in California. The MiG 105 was nicknamed "Lapot" Russian: лапотъ, or bast shoe (the word is also used as a slang for "shoe") for the shape of its nose.

Development



Spiral 50 / 50. The spaceplane and its liquid fuel booster stage mated to its hypersonic mothership carrier

The program was also known as EPOS (Russian acronym for Experimental Passenger Orbital Aircraft). Work on this project finally began in 1965, two years after Dyna-Soar's cancellation. The project was halted in 1969, to be briefly resurrected in 1974 in response to the US Space Shuttle Program. The test vehicle made its first subsonic free-flight test in 1976, taking off under its own power from an old airstrip near Moscow. It was flown by pilot A. G. Festovets to the Zhukovskii flight test center, a distance of 19 miles. Flight tests, totaling eight in all, continued sporadically until 1978. The actual space plane project was cancelled when the decision was made to instead proceed with the Buran project. The MiG test vehicle itself still exists and is currently on display at the Monino Air Force Museum in Russia.

Gleb Lozino-Lozinskiy was the leader of the Spiral development programme.

Differences between Dyna-Soar and Spiral

Although having basically the same mission, Dyna-Soar and Spiral were radically different vehicles. For example:

- While the X-20 Dyna-Soar was designed for launch atop a conventional expendable rocket such as the Titan III-C or Saturn I, Soviet engineers opted for a midair launch scheme for Spiral. Known as "50 / 50", the idea was that the spaceplane and a liquid fuel booster stage would be launched at high altitude from the back of a large, airbreathing mothership travelling at hypersonic speeds. The

idea was similar to that used by the United States in launching the D-21 Tagboard reconnaissance drone from the back of the A-12 Oxcart. The mothership was to have been built by the Tupolev Design Bureau (OKB-156) and utilize many of the same technologies developed for the Tu-144 'Charger' supersonic transport (The Soviet equivalent of the Concorde) and the Sukhoi T-4 mach-3 bomber (somewhat similar to the XB-70 Valkyrie). It never made it off the drawing boards. The U.S. purportedly flew a similar design in the 1990s under the secret Blackstar project.

- Dyna-Soar was designed with a fixed, delta-wing planform, while Spiral featured an innovative variable-geometry wing. During launch and reentry, these were folded against the sides of the vehicle at a 60-degree angle, acting as vertical stabilizers. After dropping to subsonic speeds post-reentry, the pilot activated a set of electric actuators which lowered the wings into the horizontal position, giving the spaceplane better flight characteristics.
- Spiral was built to allow for a powered landing and go-around maneuver in case of a missed landing approach. An air intake for a single Koliesov turbojet was mounted beneath the central vertical stabilizer. This was protected during launch and reentry by an electric clamshell door, which would open at subsonic speeds. By comparison, Dyna-Soar was designed primarily for a once-off, unpowered deadstick landing, although some documentation claims that its emergency solid-fuel escape rocket (the third stage engine from an LGM-30 Minuteman ICBM) could be used for a go-around maneuver if necessary.
- Spiral was designed as a lifting body, while Dyna-Soar was designed more like a conventional aircraft.
- High temperature superalloy metals such as niobium, molybdenum, tungsten and rene 41 were to have been used in the heatshield structure of the X-20. Spiral was to have been protected by what Soviet engineers termed "scale-plate armour": individual steel plates hung from articulated ceramic bearings to allow for thermal expansion during reentry. Several BOR (Russian acronym for Unpiloted Orbital Rocketplane) craft were built and launched to test this concept.
- In the event of a booster explosion or in-flight emergency, the insulated crew compartment of Spiral was designed to separate from the rest of the vehicle and parachute to earth like a conventional ballistic capsule; this could occur at any point in the flight. Such an escape crew capsule was also considered for Dyna-Soar, but American engineers eventually opted for a solid-fuel escape rocket that would kick the spaceplane away from an exploding booster, saving both pilot and spacecraft.
- Much like today's Space Shuttle, Dyna-Soar was designed with a small payload bay behind the pressurized crew module. This could be used for lofting small satellites, carrying surveillance equipment, weapons or even an extra crewmember in a pop-in cockpit. Spiral, on the other hand, appears to have been intended to carry only its pilot. Presumably, this was because the extra space which could have held a payload bay was needed for the Koliesov turbojet and its fuel tanks.
- Both Dyna-Soar and Spiral were designed to land on skids. The landing skids on Dyna-Soar were designed to deploy from insulated doors on the underside of the

vehicle, like a conventional aircraft. Soviet engineers, most likely concerned about heatshield integrity, designed the landing skids on Spiral to deploy from a set of doors on the sides of the fuselage just above and ahead of the wings. This unusual arrangement resulted in a hard landing on at least one occasion.

Pilots

A cosmonaut training group for pilots assigned to fly this vehicle was formed in the early 1960s. It went through many changes and was eventually dissolved entirely. Known members included:

- Gherman Titov, the second man in space.
- A.G. Fastovets, who piloted the vehicle during the majority of its atmospheric tests.

Uragan

Although Spiral itself never made it to the launch pad, it is rumoured that the design was reused and enlarged to build a piloted space interceptor known as "*Uragan*" (Russian for "Hurricane") in the 1980s. This craft was to have been launched by a Ukrainian-built Zenit expendable booster and was intended to intercept and destroy (if necessary) military Space Shuttle missions launched from Vandenberg Air Force Base. Its armament purportedly consisted of space-to-space missiles.

It is not known how many times the vehicle flew into space, if any. It is known that two Soviet Air Force cosmonaut groups, consisting of six in the first group and at least three in the second, were selected and trained to pilot the vehicle. The possibility that the shuttles could now be intercepted and shot down caused quite a stir in the US Department of Defense at the time, which issued several artists' conceptions showing the vehicle on the pad, in space, etc.

After the fatal Space Shuttle *Challenger* disaster prompted NASA and the DoD to cancel all planned launches from Vandenberg, it is said that the Soviet Union had no further need for the craft and, in turn, cancelled the Uragan program.

To this day, Russian officials continue to deny that this craft ever existed, leading some to believe that the purported space interceptor was all part of a successful Soviet disinformation program meant to scare the American military into thinking twice about its plans for the Space Shuttle.

The current whereabouts of any completed Uragan craft or components, if they exist, are unknown.

BOR

The **BOP** (Russian: Беспилотный Орбитальный Ракетоплан, *Bespilotnyi Orbital'nyi Raketoplan*, "Unpiloted Orbital Rocketplane"). Another spacecraft to use the Spiral design was the BOR series, unmanned subscale reentry test vehicles. American analogs X-23 PRIME and ASSET. Several of these craft have been preserved in aerospace museums around the world.

Image	Type	Launch date	Usage	Current status
	BOR-1	15.07.1969	Flight test, the experimental 1:3 scale model. Burned in the atmosphere at a height of about 60-70 km with the speed 8 000 mph (13 000 km/h). Was deployed at an altitude 328,083 ft (100 km) by 11K65	Burned(planned).
	BOR-2	1969 - 1972	Sub-scale model of the Spiral space plane. 4 launches.	NPO Molniya, Moscow
	BOR-3	1973 - 1974	Sub-scale model of the Spiral space plane. 2 launches. 1. Destruction of the nose fairings after launch at a height of about 5 km (speed 0.94 Mach). 2. Flight program is fully implemented. Crashed on landing (Parachute failure)	Crushed.
	BOR-4	1980 - 1984	Sub-scale model of the Spiral space plane. 4 launches and 2 unconfirmed	NPO Molniya, Moscow
	BOR-5	1984 - 1988	Flight tests, the experimental sub-scale base model. 5 launches. Data was also used in the Buran project.	Technik Museum Speyer, Germany Museum in Monino, Russia



BOR-6

Sub-scale model of the Spiral space plane

NPO Molniya,
Moscow

Operators

 Soviet Union

- Soviet Air Force

Specifications (MiG 105-11)

General characteristics

- **Crew:** 1
- **Length:** 10.6m (including instrument boom) (ft in)
- **Wingspan:** 6.7m (ft in)
- **Height:** m (ft in)
- **Wing area:** 24m² (258ft²)
- **Empty weight:** 3500kg (lb)
- **Loaded weight:** 4220kg (lb)
- **Useful load:** kg (lb)
- **Max takeoff weight:** kg (lb)
- 500Kg Fuel

Performance

- **Never exceed speed:** km/h (knots, mph)
- **Maximum speed:** 800km/h (knots, mph)
- **Cruise speed:** km/h (knots, mph)
- **Stall speed:** km/h (knots, mph)
- **Range:** km (nm, mi)
- **Service ceiling:** m (ft)
- **Rate of climb:** m/s (ft/min)
- **Wing loading:** kg/m² (lb/ft²)Landing speed 250-270 km/h

Chapter-7

SpaceShipTwo

SpaceShipTwo



SpaceShipTwo is the small detachable craft in the middle.

Description

Role:	Spaceplane
Mothership:	White Knight Two
Crew:	<i>Crew: 2</i> <i>Passengers: 6</i>
Developed from:	SpaceShipOne
Manufacturer:	The Spaceship Company
Primary user:	Virgin Galactic
Status:	Performing Test Flights

The **Scaled Composites Model 339 SpaceShipTwo** (SS2) is a suborbital horizontal-takeoff, horizontal-landing (HTHL), spaceplane for carrying space tourists, under development by The Spaceship Company, a joint venture between Scaled Composites and Sir Richard Branson's Virgin Group, as part of the Tier 1b program. The spaceship was officially unveiled to the public on Monday, 7 December 2009, at the Mojave Air and Spaceport in California. The Virgin Galactic spaceline plans to operate a fleet of five of these craft in passenger-carrying private spaceflight service starting no earlier than 2011. A ticket costs \$200,000 USD.

Design and development

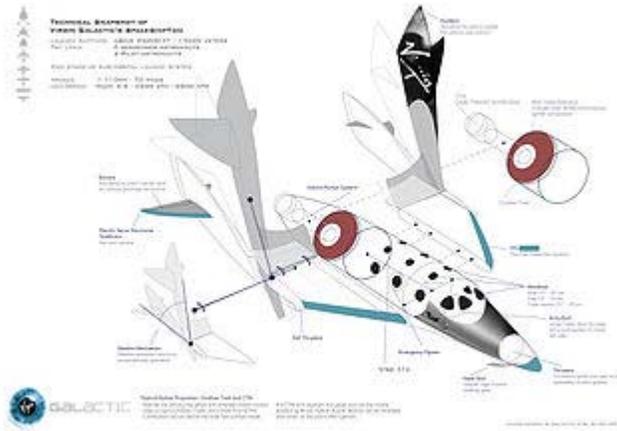
The SpaceShipTwo project is based in part on technology developed for SpaceShipOne as part of the Scaled Composites Tier One program, funded by Paul Allen. The Spaceship Company licenses this technology from Mojave Aerospace Ventures, a joint venture of Paul Allen and Burt Rutan, the designer of the predecessor technology.

SpaceShipTwo is a low-aspect-ratio spaceplane that will carry passengers to space; the capacity will be eight people: six passengers and two pilots. The apogee of the new craft will be approximately 110 km (68 miles) and in the thermosphere, 10 km (6 miles) higher than both the SpaceShipOne target (though the last flight of the SpaceShipOne reached 112 km), and the Kármán line. SpaceShipTwo will reach 4,200 km/h (2,600 mph), using a single hybrid rocket motor (as seen in the technical diagram), which goes by the name RocketMotorTwo. It will launch at 15,200 m (50,000 ft) from its mother ship, White Knight Two, and go supersonic within 8 seconds. After 70 seconds, the rocket motor cuts out and the spacecraft will coast to its peak altitude. SpaceShipTwo's crew cabin is 3.66 m (12 ft) long and 2.28 m (7.5 ft) in diameter. The wing span is 8.23 m (27 ft), the length is 18.29 m (60 ft) and the tail height is 4.57 m (15 ft).

SpaceShipTwo uses a feathered reentry system, feasible due to the low speed of re-entry – by contrast, space shuttles and other orbital spacecraft re-enter at orbital speeds, closer to 25,000 km/h (16,000 mph), using heat shields. It is designed to reenter the atmosphere at any angle.

SpaceShipTwo will decelerate through the atmosphere, switching to a gliding position at 80,000 ft and will take 25 minutes to glide back to the spaceport. Once the passengers return, their passports will receive a spaceflight stamp and they will be awarded their astronaut wings at an awards ceremony. They will also be able to relive their flight from footage filmed during the spaceflight.

SpaceShipTwo and its new carrier aircraft, White Knight Two, are roughly twice the size of the first generation spacecraft SpaceShipOne and mothership White Knight that won the Ansari X Prize. SpaceShipTwo will have 43 cm and 33 cm (17 and 13 in) diameter windows for the passengers' viewing pleasure, and all seats will recline back during landing to decrease the discomfort of G-forces. Reportedly, the craft can land safely even if a "catastrophic failure" occurs during flight.



SpaceShipTwo schematic diagram

Safety

During the early test phase of Space Ship Two's system on 26 July 2007 an explosion occurred during a fuel flow test at the Mojave Air & Space Port. The test included filling the oxidizer tank with 4,500 kg (10,000 pounds) of nitrous oxide followed by a 15 second cold flow injector test. Although the tests did not ignite the gas, three employees were killed and three injured, two critically and one seriously, from shrapnel wounds.

Burt Rutan remarked on the safety of the vehicle:

"This vehicle is designed to go into the atmosphere in the worst case straight in or upside down and it'll correct...This is designed to be at least as safe as the early airliners in the 1920s...Don't believe anyone that tells you that the safety will be the same as a modern airliner, which has been around for 70 years."

Flight test program

In October 2009, Virgin Galactic CEO Will Whitehorn outlined the flight test program for SpaceShipTwo. The test program will include seven phases: vehicle ground testing, captive carry under WhiteKnightTwo, unpowered glide testing, subsonic testing with only a brief firing of the rocket, supersonic atmospheric testing, then rocket into suborbital space, and finally execute a detailed and lengthy process with US Federal government regulator FAA/AST to demonstrate system robustness and eventually obtain a commercial launch license to begin commercial operations.

On Monday March 22, 2010, the SpaceShipTwo vehicle VSS Enterprise underwent a captive carry test flight, whereby the parent WhiteKnightTwo performed a short flight with the SpaceShipTwo being carried by the WhiteKnightTwo. A second test flight was made on May 16, 2010 The flight reached launch altitude (51,000 feet) and lasted for a duration of nearly five hours in order to facilitate "cold soak" testing of SS2's avionics and pressurization system. "A simulated spaceship descent/glide mission was made from

altitude." The SpaceShipTwo airframe was modified between captive carry flight 1 and flight 2 by the addition of two interior fins, one to the inside (rocket-side) of each of the twin vertical stabilizers.

On July 15, 2010 VSS Enterprise made its first crewed flight. The craft remained attached to VMS Eve as planned and underwent a series of combined vehicle systems tests. The flight lasted 6 hours and 21 minutes.

A second, and similar, crewed flight of VSS Enterprise and VMS Eve was carried out on 30 Sept 10 lasting 5 hours. Improving pilot proficiency was among the objectives and the results add confidence that the systems are capable of supporting future glide missions.

On October 10, 2010 VSS Enterprise made its first manned gliding test flight, after being released from VMS Eve at 45,000 feet. The second gliding test flight took place on the 28th of October 2010 and the third on Wednesday 17 November 2010.

As of December 2010, Scaled reported that the flight test program is exceeding expectations,. The fourth test flight took place in January 2011.

NASA sRLV program

As of March 2011, Virgin Galactic has submitted SpaceShipTwo as a reusable launch vehicle for carrying research payloads in response to NASA's suborbital reusable launch vehicle (sRLV) solicitation, which is a part of NASA's Flight Operations Program. Virgin projects 110 km (68 mi) altitude in flights of approximately 90 minutes duration, while carrying a research payload. Flights will provide approximately four minutes of microgravity. Payload mass and microgravity levels have not yet been specified. The NASA research flights could begin during the test flight certification program for SpaceShipTwo.

Launch site

The SpaceShipTwo craft will take off from the Mojave Air & Space Port in California during testing. Spaceport America (formerly Southwest Regional Spaceport), a US\$212 million spaceport in New Mexico partly funded by the state government, will become the permanent launch site when commercial launches begin. The company is also exploring launches from spaceports in the UK.

Commercial introduction

In August 2005, the president of space tourism company Virgin Galactic stated that if the suborbital service with SpaceShipTwo is successful, the follow-up SpaceShipThree will be an orbital craft. In 2008, Virgin Galactic changed their plans and decided to make it a point-to-point vehicle. This vehicle will offer transportation through point-to-point suborbital spaceflight.

On 28 September 2006, Sir Richard Branson unveiled a mock-up of the SpaceShipTwo passenger cabin at the NextFest exposition, in the Javits Convention Center, New York.

More than 65,000 would-be space tourists have applied for the first batch of 100 tickets. The price will initially be \$200,000. The duration of the flights will be approximately 2.5 hours, though only a few minutes of that will be in space.

In December 2007 Virgin Galactic had 200 paid-up applicants on its books for the early flights, and 95% were passing the 6-8 g centrifuge tests.

The design of the vehicle was revealed to the press in January 2008, with the statement that the vehicle itself was around 60% complete. The launch customer of SpaceShipTwo is Virgin Galactic, which will have the first five units to be built.

On 7 December 2009, the official unveiling and rollout of SpaceShipTwo took place. The event involved the first SpaceShipTwo being christened by Governor Schwarzenegger as the *VSS Enterprise*.

October 10, 2010 the *VSS Enterprise* made its first piloted free flight from the mother ship to a safe landing at Mojave Air and Spaceport.

Following 50–100 test flights, the first paying customers are expected to fly aboard the craft in 2011. Refining the projected schedule in late 2009, Virgin Galactic has declined to announce a firm schedule for commercial flights, but did reiterate that initial flights would take place from Spaceport America. Operational roll-out will be based on a "safety-driven schedule" but they hope to achieve it "within two years". In addition to making suborbital passenger launches, Virgin Galactic will market SpaceShipTwo for suborbital space science missions.

Spacecraft

Five vehicles have been ordered by Virgin Galactic. As of October 2007, only the first two have been named, the VSS (Virgin Space Ship) *Enterprise*, and the VSS *Voyager*. Both are in development.

1. VSS *Enterprise* (2009)
2. VSS *Voyager*
3. Not yet Named
4. Not yet Named
5. Not yet Named

Chapter-8

North American X-15

X-15



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

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



X-15 on Boeing B-52 Mothership wing pylon



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



X-15 in full scale ablative coating

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

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

Design and development



X-15 just after release.



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

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

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

Engines and fuel

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

Operational history



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

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

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



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

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

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

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

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

A 200th flight over Nevada was slated for 21 November 1968, piloted by William J. Knight. Technical problems and bad weather delayed the flight six times, and on 20 December 1968, the 200th flight was finally cancelled. The X-15 was detached from the NB-52A wing and prepared for indefinite storage.



X-15A-2 on the flight line



X-15 nose

Current static displays



X-15 at the National Air and Space Museum

- X-15-1 (s/n 56-6670) is on display in the National Air and Space Museum "Milestones of Flight" gallery, Washington, D.C.

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

Mock-ups

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

Stratofortress motherships

- NB-52A (s/n 52-003) is at the Pima Air and Space Museum, Tucson, Arizona. It launched the X-15 #1 30 times, the X-15 #2, 11 times, and the X-15 #3 31 times (as well as the M2-F2 four times, the HL-10 11 times and the X-24A twice).
- NB-52B (s/n 52-008) is at the Dryden Flight Research Center, Edwards AFB, California, USA. It launched the majority of X-15 flights.

Aftermath

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

Record flights

Highest flights

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

X-15 flights higher than 50 mi (80 km)

Flight	Date	Top speed	Altitude	Pilot
Flight 62	17 July 1962	3,831 mph (6,165 km/h)	59.6 miles (95.9 km)	Robert M. White
Flight 77	17 January 1963	3,677 mph (5,918 km/h)	51.4 miles (82.7 km)	Joe Walker
Flight 87	27 June 1963	3,425 mph (5,512 km/h)	53.9 miles (86.7 km)	Robert Rushworth
Flight 90	19 July 1963	3,710 mph (5,970 km/h)	65.8 miles (105.9 km)	Joe Walker
Flight 91	22 August 1963	3,794 mph (6,106 km/h)	67.0 miles (107.8 km)	Joe Walker
Flight 138	29 June 1965	3,431 mph (5,522 km/h)	53.1 miles (85.5 km)	Joseph H. Engle
Flight 143	10 August 1965	3,549 mph (5,712 km/h)	51.3 miles (82.6 km)	Joseph H. Engle
Flight 150	28 September 1965	3,731 mph (6,004 km/h)	55.9 miles (90.0 km)	John B. McKay
Flight 153	14 October 1965	3,554 mph (5,720 km/h)	50.4 miles (81.1 km)	Joseph H. Engle
Flight 174	1 November 1966	3,750 mph (6,040 km/h)	58.1 miles (93.5 km)	Bill Dana
Flight 190	17 October 1967	3,856 mph (6,206 km/h)	53.1 miles (85.5 km)	Pete Knight
Flight 191	15 November 1967	3,569 mph (5,744 km/h)	50.3 miles (81.0 km)	Michael J. Adams [†]
Flight 197	21 August 1968	3,443 mph (5,541 km/h)	50.6 miles (81.4 km)	Bill Dana

[†] fatal

Fastest flights

X-15 10 fastest flights

Flight	Date	Top Speed	Altitude	Pilot
Flight 45	9 November 1961	4,092 mph (6,585 km/h)	19.2 miles (30.9 km)	Robert M. White
Flight 59	27 June 1962	4,104 mph (6,605 km/h)	23.4 miles (37.7 km)	Joe Walker
Flight 64	26 July 1962	3,989 mph (6,420 km/h)	18.7 miles (30.1 km)	Neil Armstrong
Flight 86	25 June 1963	3,910 mph	21.7 miles	Joe Walker

		(6,290 km/h)	(34.9 km)	
Flight 89	18 July 1963	3,925 mph (6,317 km/h)	19.8 miles (31.9 km)	Robert Rushworth
Flight 97	5 December 1963	4,017 mph (6,465 km/h)	19.1 miles (30.7 km)	Robert Rushworth
Flight 105	29 April 1964	3,905 mph (6,284 km/h)	19.2 miles (30.9 km)	Robert Rushworth
Flight 137	22 June 1965	3,938 mph (6,338 km/h)	29.5 miles (47.5 km)	John B. McKay
Flight 175	18 November 1966	4,250 mph (6,840 km/h)	18.7 miles (30.1 km)	Pete Knight
Flight 188	3 October 1967	4,519 mph (7,273 km/h)	36.3 miles (58.4 km)	Pete Knight

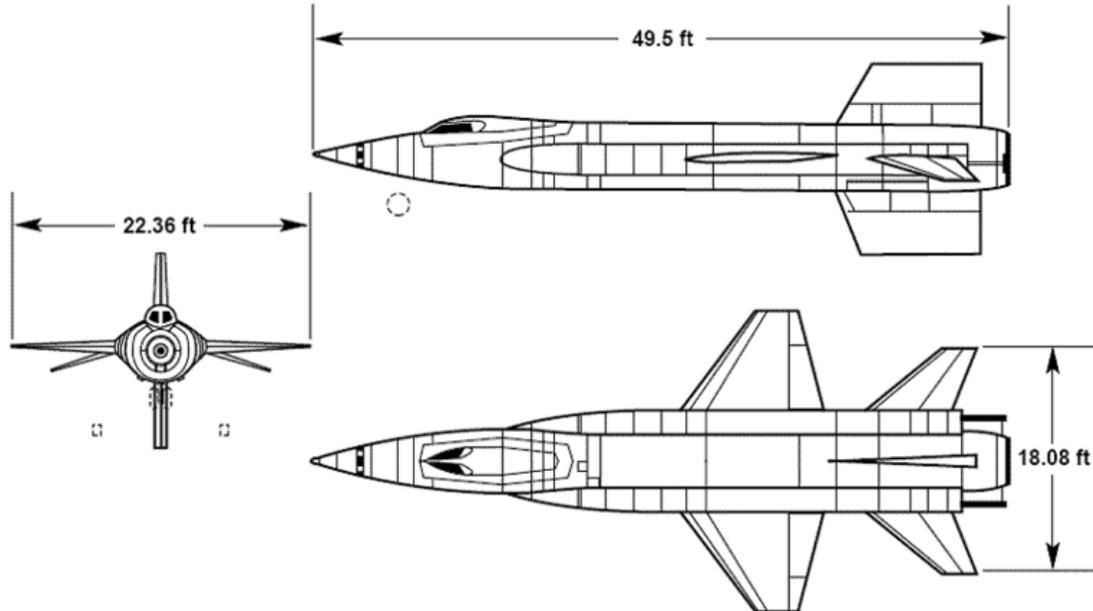
X-15 pilots

X-15 pilots and their achievements during the program

Pilot	Organization	Total Flights	USAF space flights	FAI space flights	Max Mach	Max speed (mph)	Max altitude (miles)
Michael J. Adams [†]	U.S. Air Force	7	1	0	5.59	3,822	50.3
Neil Armstrong	NASA	7	0	0	5.74	3,989	39.2
Scott Crossfield	North American Aviation	14	0	0	2.97	1,959	15.3
Bill Dana	NASA	16	2	0	5.53	3,897	58.1
Joseph H. Engle	U.S. Air Force	16	3	0	5.71	3,887	53.1
Pete Knight	U.S. Air Force	16	1	0	6.70	4,519	53.1
John B. McKay	NASA	29	1	0	5.65	3,863	55.9
Forrest S. Petersen	U.S. Navy	5	0	0	5.3	3,600	19.2
Robert A. Rushworth	U.S. Air Force	34	1	0	6.06	4,017	53.9
Milt Thompson	NASA	14	0	0	5.48	3,723	40.5
Joe Walker	U.S. Air Force	25	3	2	5.92	4,104	67.0
Robert M. White [*]	U.S. Air Force	16	1	0	6.04	4,092	59.6

[†] Killed • ^{*} White was backup for Captain Iven Kincheloe

Specifications (X-15)



North American X-15 Three View Diagram

General characteristics

- **Crew:** one
- **Length:** 50 ft 9 in (15.45 m)
- **Wingspan:** 22 ft 4 in (6.8 m)
- **Height:** 13 ft 6 in (4.12 m)
- **Wing area:** 200 ft² (18.6 m²)
- **Empty weight:** 14,600 lb (6,620 kg)
- **Loaded weight:** 34,000 lb (15,420 kg)
- **Max takeoff weight:** 34,000 lb (15,420 kg)
- **Powerplant:** 1× Thiokol XLR99-RM-2 liquid-fuel rocket engine, 70,400 lb_f at 30 km (313 kN)

Performance

- **Maximum speed:** Mach 6.72 (4,520 mph, 7,274 km/h)
- **Range:** 280 mi (450 km)
- **Service ceiling:** 67 mi (108 km, 354,330 ft)
- **Rate of climb:** 60,000 ft/min (18,288 m/min)
- **Wing loading:** 170 lb/ft² (829 kg/m²)
- **Thrust/weight:** 2.07

Chapter-9

Kliper

Kliper



Kliper spacecraft

Operator	Roscosmos
Major contractors	NPO Energia
Mission type	Crew Exploration Vehicle
Satellite of	Earth, Moon and Mars.
Launch date	Indefinitely Postponed
Carrier rocket	Soyuz
Launch site	Baikonur Cosmodrome

Kliper (Клипер, English: **Clipper**) is a partly reusable manned spacecraft, proposed by RSC Energia.

Designed primarily to replace the Soyuz spacecraft, Kliper has been proposed in two versions: as a pure lifting body design and as spaceplane with small wings. In either case, the craft should be able to glide into the atmosphere at an angle that produces much less stress on the human occupants than the current Soyuz. Kliper has been designed to be able to carry up to six people and to perform ferry services between Earth and the International Space Station.

Development

Announcement of the program



Soyuz TMA-6 spacecraft approaching the International Space Station - the Soyuz spacecraft would have been replaced by Kliper

In February 2004 Nikolai Moiseyev, the deputy director of Russian Federal Space Agency (FSA) told journalists that the Kliper project had been included in the Russian federal space program for 2005-15. At that point he announced that if the program is implemented successfully the first launch may even take place in five years' time. Kliper had been developed since 2000 and reportedly relied heavily on research studies as well as proposals for a small Russian lifting body spacecraft from the 1990s. Externally its design was comparable to the cancelled European minishuttle Hermes or the NASA study X-38. It was planned to be the successor to the veteran spacecraft Soyuz, which has been built in various modifications since 1961.

Early search for support

In 2005 Kliper was displayed in several air shows around Europe and Asia, in order to reach out to international partners who would be interested to co-fund and co-develop the spacecraft. The Russian Space Agency especially looked to Europe as the European Space Agency (ESA) had become its major partner in space activities during the last years. In May 2005 rumours started in the press that Europe would join the Kliper project in a specially funded venture that would be part of the Aurora Programme. These

rumours turned out to be correct when both Russian and European space officials announced their cooperation to build Kliper during the Paris Air Show in Le Bourget on June 10, 2005.

Vladimir Taneev, the leading designer of the Kliper system, speculated on the contribution of Europe to the project in the following way:

The European companies will likely contribute avionics, materials, and cabin systems. Many different options are on the table, and in the near future we expect to form Russian-European working groups specialized in different subsystems and fields of design.

The Russian Space Agency as well as ESA announced that they would continue to look for other international partners such as Japan to invest in Kliper. A substantive cooperation with NASA was unlikely, due to the parallel development of America's own next-generation manned launch vehicle, the Crew Exploration Vehicle (CEV).

A further element of this process was made public on October 12, 2005, when various press agencies revealed that JAXA, the Japanese space agency, had been officially approached by Russia to participate in the project. JAXA has made it clear that they are more likely to join the project if ESA does so first, which is in doubt after ESA members rejected a study for Europe's involvement in the Kliper project in December 2005. The addition of Japan would make Kliper a truly multinational project, potentially combining the rugged reliability of Russian launchers with Japanese computer technology. A greater pan-national consensus would have allowed for a lighter funding burden on each participant as well.

Estimated costs

Announcements and speculations following the February 2004 press conference suggested a development budget of 10 billion rubles (approximately US\$400 million). However in looking at today's costs for human space travel it was clear that the 10 billion rubles figure was a rather low estimate. In May 2005 The Guardian reported that costs are estimated to be roughly US\$3 billion (for development and construction of Kliper until 2015) of which the bulk of 1.8 billion was speculated to come from Europe. Different sources in 2005 have reported that the money needed for the program would be 1.5 billion Euros (\$1.8 billion) and on December 12, 2005 an article stated it would be €1 billion (solely in relation to development costs).

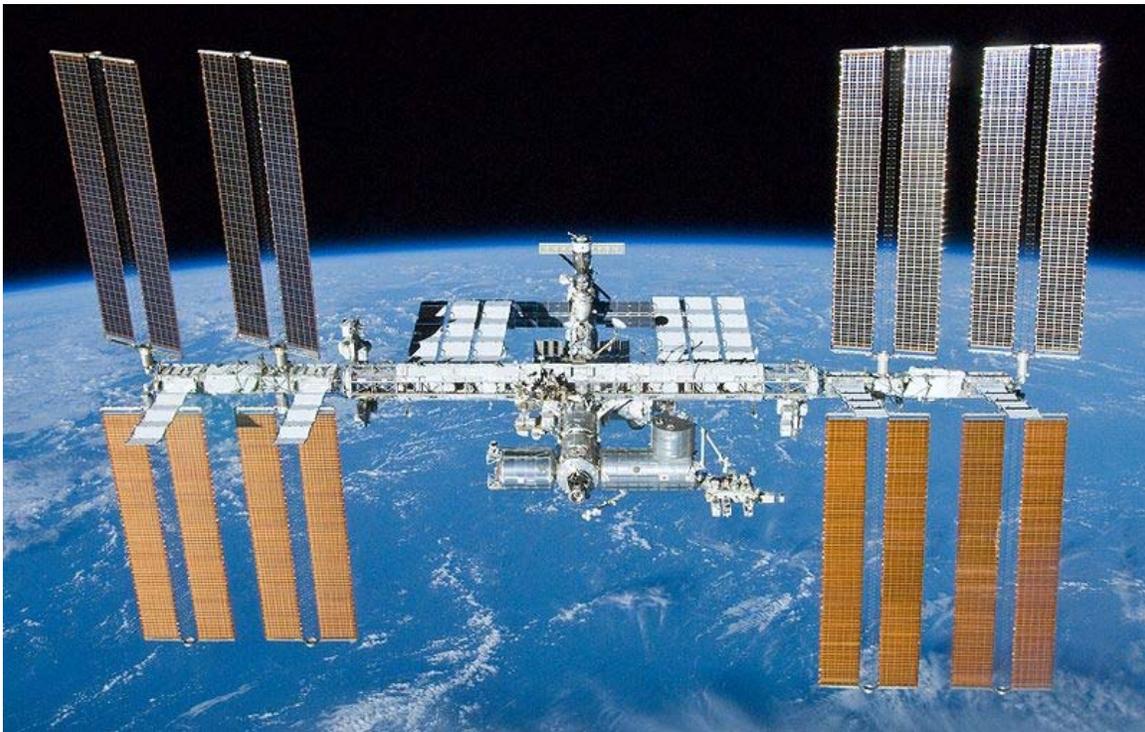
On July 14, 2005 the Russian government approved the national space program for 2006 to 2015 with a budget of 305 billion rubles (ca. \$11 billion - the whole budget for the 10-year period will be 425 billion rubles = ca. 15 billion dollars). The budget included the needed funding for the Kliper program. Thus in face of Europe's denial to fund a €50m feasibility study for the Kliper project at the European space summit in December 2005, Russian space officials have announced that Russia would fund Kliper even without any European contribution.

The most recent article on Kliper stated that the project would have incurred 16 billion rubles (~\$600 million) in development costs, 11 billion of which will be financed by the government and 5 billion by contractors.

First launch and target for regular flights

In 2004 it was announced that it was likely that Kliper would make its first launch as early as 2010 or 2011 – the same time the Space Shuttle was scheduled to be retired. However, it was reported by BBC News on September 27, 2005, that the first flight tests were not planned until 2011, with the first manned flights in 2012 and the Soyuz being phased out over time until 2014. An article on December 3, 2005 cited the president of the Energia Rocket and Space Corporation Nikolai Sevastyanov that "the first regular lift-off is scheduled for 2012, while a complete transport system will be in place by 2015." After the termination of the Russian Space Agency's tender for a new spacecraft, Energia announced that this would push its Kliper proposal's first flight (if developed at all) back further.

ESA's part in Kliper - Uncertainty over European cooperation



Kliper was planned to be Russia's and even Europe's primary access route to the International Space Station

On September 28, 2005 the BBC reported that Alan Thirkettle, head of ESA's Human Spaceflight Development Department, stated that Kliper would be used: *For future exploration, when we have the objective of going to the Moon, it is important to have several possibilities to go there, and within this framework of cooperation to have our*

own access to orbit around the Moon. In the same context, Alain Fournier-Sicre, head of the ESA permanent mission in the Russian Federation, also stated that: *The objective is to have a vehicle which is more comfortable than the Soyuz capsule which will be used with pilots and four passengers...It's meant to service the space station and to go between Earth and an orbit around the Moon with six crew members.*

Although there seemed to be a lot of enthusiasm for Kliper within Alan Thirkettle's team at ESA (as outlined in the above paragraph), on December 7, 2005, the European space summit of governmental officials of ESA member states declined to approve a 50-million-euro two-year study focusing on ESA's potential involvement in the Kliper project. In denying funding for the study ESA members stated that, among other factors that seemed unfavourable, under the current Russian proposal Europe would not share control over the design of the program and would be limited to being a small industrial contributor.

Jean-Jacques Dordain, ESA's Director General, put the refusal to fund the study into context: *It is not a question of member states for and member states against. I think the decision could not be taken for reasons that are not linked to Clipper itself. The decision could not be taken because of budgetary restraints.* Dordain concluded that he was convinced that European support for Kliper was vital for ESA's future involvement in space transport and that a favourable decision can be achieved until June 2006. In concluding *We need two transportation systems in the world*, Dordain also outlined shortly after the European Space Summit that the primary requirement of Europe's involvement in the Kliper project was to rely on two separate systems to support the ISS as had been proven vital after the Columbia Space Shuttle disaster in 2003.

Dordain's remarks were echoed by Daniel Sacotte, ESA's director of human spaceflight, microgravity and exploration, in saying simply that *The Russians are not going to finance it, we will finance it from our side*, despite adding a cautionary note that *We needed the support from at least two states out of France, Italy and Germany. We didn't get it..* What this means in practical terms remains to be seen; however what is clear is that ESA officials are still pushing for Europe's involvement in the Kliper project.

Very negative comments relative to Kliper were brought by the various national delegations at the December meeting, in particular by the French Minister of Research François Goulard. In short, there remain for the time being member states strongly committed to Kliper, and others just as strongly opposed. The long-term view remains uncertain.

In 2006, Jean-Jacques Dordain explained that money allocated to space transportation development, which ESA currently funds in the amount of 300 million for the next 3 years, could be used for Europe's involvement in the project. Given the February 2006 statement that 5 billion rubles (~\$200 million) of the development costs will come from "contractors", a limited involvement of ESA in Kliper might have been forthcoming.

Russian Space Agency's tender for Kliper

At the end of 2005, Roskosmos announced that a tender for Kliper would be held in January 2006 between RKK Energia, Khrunichev and Molniya with a selection date of February 3, 2006. However concerns about the bids led to a delay in the process, with a resubmittal deadline of March, 2006 and selection was rescheduled for April 2006. Following further delays, the tender was cancelled on 18 July 2006.

In late July 2006, the Russian Space Agency and the European Space Agency agreed to collaborate on a different project to develop a new spacecraft. They decided to fund a study under a program labelled Crew Space Transportation System (CSTS) which started in September 2006 and evaluate a capsule type concept, derived from Soyuz. While this program is the follow-on project of the RSA's and ESA's collaboration on a new spacevehicle, this program is no longer connected to Energia's winged Kliper design.

RSC Energia continued to pursue the project without Russian government support and announced that it would seek private investment for the craft. News reports in Russia indicated that Kliper was still expected to be ready for Russian Space Agency test flights around the year 2012, as part of Russian spacecraft upgrade program. The project has been officially halted in June 2007, after the major proponent of the project, Nikolai Sevastyanov, was dismissed from the position of the president of RSC Energia. The newly appointed president of RSC Energia, Vitaly Lopota, confirmed that Kliper would not be displayed on the 2007 MAKS aviation and space show. He said that Energia would spend more time on the project analysis, perform additional dynamic modeling, revise the design and appearance and then would come up with new proposals for Roscosmos.

In 2008 Vitaly Lopota shared his vision about new Russian spacecraft. He mentioned two possible options: a space capsule, which better suits missions to the Moon and Mars, and a lifted body design for low Earth orbit missions. According to new plans, instead of Kliper the new PPTS (Rus) will be developed since 2009 to 2017-2018.

Design

Given the Russian Space Agency's preference for Energia's lifting body proposal here we concentrates entirely on Energia's design for Kliper.

Overview

Kliper's design was another attempt to solve the geometric problems of spacecraft. Soyuz has an Orbital Module, a hollow sphere, to be used for eating and hygiene, and an airlock located above the Reentry module (the capsule), with the docking mechanism at the top. In the event of an emergency, it would be lifted away from the rocket along with the reentry module, and the fairing over the spacecraft was designed to successfully split apart either circumferentially just below the reentry module in such an emergency or longitudinally if the flight should be successful. Kliper was designed with the Orbital

Module below its reentry module, and the docking mechanism below that. This was made possible by constructing a reentry module broader than the orbital module, so that a pair of rocket nozzles for orbital maneuvering could have been fitted alongside it, as the later Salyut space stations had.

In connection with this new design, Kliper will feature a launch escape system that will enable it to detach from the carrier rocket if an abort of the mission during orbital ascent is required. An abort will be possible during every phase of the launch with the limitation of the first seconds after launch.

Lifting body design

On return from space, Kliper's lifting body design would not only allow a smoother descent into Earth's atmosphere than the capsule design, such as Soyuz; but also permit control. RKK Energia claimed that the craft would be able to land in a predetermined one-square-kilometre area. Artistic impressions showed that the Kliper would have resembled a cylinder topped by a cone. Originally, landing proposals involved both a landing by parachute and as an alternative, in a modified version, a landing on a runway similar to an aircraft, or the Space Shuttle. However, leading designer Vladimir Daneev commented on this issue in June 2005:

We are 99% sure that it will be a spaceship with upturned little wings, enabling the Kliper to land on any class-one military airfield with a runway from three to three and a half kilometres in length.

Kliper, as a vehicle alone, would have been primarily a manned spaceship, carrying six cosmonauts and payloads of up to 700 kilograms (mostly experiments and other equipment used for carrying through experiments in orbit) and was planned to stay in orbit for approximately 15 days independently and for up to 360 days if docked to the International Space Station. This highlighted both the Russian/European and the American change in space transportation philosophy. Rather than focusing on the lifting of cargo and a crew, in the same way as the Space Shuttle or Buran, the Russian space agency adopted a 'people first' philosophy with the aim of 'bolting' extra capabilities for more advanced missions onto Kliper at a later date. Each orbiter was intended to make 25 flights prior to retirement.

Using a space tug



Klipper utilizing Parom Space Tug

During autumn of 2005 Klipper's design was changed again. In order to fit the Klipper on the planned upgraded version of the Soyuz-2 rocket, labeled the Soyuz-2-3, Klipper would be 'split up' into two spacecraft, the Klipper crew vehicle and Parom, a space tug. Parom would have been a permanent orbital spacecraft awaiting Klipper in orbit, docking with it and then providing orbital manoeuvring and boosting Klipper to higher orbits in order to dock with the International Space Station. The Parom was planned to be indefinitely reusable, refueling itself via the cargo container, space station, or spacecraft that it is attached to.

Final version of Energia's proposal

The version of Kliper presented during the bid in January 2006 differs again from the original design. It showed a lifting body with larger wings, that, according to Energia officials, could be folded around the core crew module and unfold after atmospheric re-entry in order to provide cross-range and better landing accuracy for the spacecraft. The light Kliper version proposed was stripped down to 7 tons and uses the 'split-up'-option with Parom as a spacetug.

Missions

The Kliper program was proposed as the Russian-European counterpart to the American Orion Spacecraft and was therefore designed (similar to the Orion) to be part of a modular system that enabled it to be both a LEO-shuttle type vehicle as well as part of a spacecraft able to go beyond Earth orbit to the Moon and even Mars (there were outline suggestions of lunar applications in September 2005). The modular design would have included the Kliper crew module and - depending on the mission - a mission module or propulsion module. Although far fetched, this corresponds to announcements by the Russian Space Agency that according to a lunar mission study, using the Soyuz, a landing on the Moon could be achieved within the next decade.

Information on Kliper's beyond LEO mission capabilities were expanded further by RSC Energia, with a picture released in December 2005 of what a possible Kliper interplanetary configuration might have looked like. The design was entirely theoretical but made for a view of where RSC Energia saw the Kliper operating, and how it might have done so. This configuration was unlike anything seen so far for a manned space vehicle, with the solar arrays needed for electrical power vastly bigger than the habitable volume at the centre. It was also unclear what the mode of propulsion was. The very large solar array suggested an ion propulsion system might have been contemplated for such a mission, though it might also simply be that there was another reason for such a large array, such as increased power for better telemetry transmission rates over large distances.

Carrier rockets

The present Soyuz rocket would not be able to lift Kliper into low earth orbit, because the spacecraft (the version designed without Parom) was expected to weigh between 13 and 14.5 metric tons (with payload and crew) whereas Soyuz only has a lifting capacity of around 8 metric tons. It was originally planned to heavily enhance the Soyuz rocket - a project that was labelled the Onega rocket or Soyuz-3. Until fall of 2005 it was much more likely that Kliper would have used an Angara-A3 rocket, which was scheduled to make its first launch in 2012 (however the Angara program has been delayed and Angara-A3 may not be developed in light of the funding of the development of Soyuz 2-3) or possibly a Zenit rocket that is built in Ukraine.

At the end of 2005, Kliper's design was changed again (as outlined above) and the most likely solution for a carrier rocket became the Soyuz 2-3, an upgraded Soyuz 2 rocket. This enhanced Soyuz should have been able to launch Kliper into space because of weight reduction resulting in the use of the Parom as a space tug.

With regard to launch sites for Kliper, further information became available as of October 2005, with a planning-stage declaration from Nikolai Moiseev, Deputy Director of the Russian Space Agency that Kliper could have been launched from ESA's Guiana Space Centre in French Guiana. Though this aim had already been suggested, the comment was made in the context of facility upgrades for Kourou that are already under way since 2003 and are expected to be finished in 2007 with the first launch of a Soyuz rocket from French Guiana in 2008. It had been suggested that Kliper could have been launched from both Baikonur and Kourou, by Alan Thirkettle, head of ESA's human spaceflight, microgravity and exploration directorate, in December 2005.

Chapter-10

NASA X-38

X-38



Role	Crew Return Vehicle
Manufacturer	Scaled Composites (prototypes)
First flight	1999
Status	Cancelled 29 April 2002
Primary user	NASA
Number built	2 atmospheric prototypes 1 orbital prototype (incomplete)
Developed from	Martin-Marietta X-24

The **X-38 Crew Return Vehicle (CRV)** was a prototype for a wingless lifting body reentry vehicle that was to be used as a Crew Return Vehicle for the International Space Station (ISS). The X-38 was developed to the point of a drop test vehicle before its development was cancelled in 2002 due to budget cuts.

History



The X-38 research vehicle drops away from NASA's B-52 mothership immediately after being released from the wing pylon



The X-38 CRV prototype makes a gentle lakebed landing at the end of a July 1999 test flight at the Dryden Flight Research Center with a fully deployed parafoil.

The crew size for the ISS depends upon the crew return capability: the crew was limited to three because the Russian Soyuz TMA vehicle that will remain docked to the ISS can only hold three people. Now with two docked Soyuz vehicles, the ISS has been crewed with 6 members since May 2009. Since it is imperative that the crew members be able to return to Earth if there is a medical emergency or if other complications arise, a Crew Return Vehicle able to hold up to seven crew members was planned from the outset: this would have allowed the full complement of seven astronauts to live and work onboard the ISS. NASA has designed several crew return vehicles over the years with varying levels of detail.

A small, in-house development study of the X-38 concept first began at JSC in early 1995. In early 1996, a contract was awarded to Scaled Composites, Inc., of Mojave, Calif., for the construction of three full-scale atmospheric test airframes. The first vehicle airframe was delivered to JSC in September 1996.

Development

X-38 was the program under leadership of NASA Johnson Space Center to build a series of incremental flight demonstrators for the proposed Crew Return Vehicle. In an unusual move for an X-plane, the program involved the European Space Agency and the German Space Agency DLR. It was originally called **X-35**. The program manager was John Muratore, while the Flight Test Engineer was future NASA astronaut Michael E. Fossum.

The X-38 design used a wingless lifting body concept originally developed by the U.S. Air Force in the mid-1960s during the X-24 program, and it was Muratore's brainchild.

The X-38 program used unmanned mockups to test the CRV design. The flight models were:

- X-38 V-131
- X-38 V-132
- X-38 V-131R, which was the V-131 prototype reworked with a modified shell
- X-38 V-201, which was an orbital prototype to be launched by the Space Shuttle
- X-38 V-133 and V-202 were also foreseen at some point in the project but were never built.

The X-38 V-131 and V-132 shared the aerodynamic shape of the X-24A. This shape had to be enlarged for the Crew Return Vehicle needs (crew of seven astronauts) and redesigned, especially in the rear part, which became thicker.

The X-38 V-131R was designed at 80 percent of the size of a CRV [24.5 ft long (7.5 m), 11.6 ft wide (3.5 m), 8.4 ft high (2.6 m)], and featured the final redesigned shape (Two later versions, V-133 and V-201, were planned at 100 percent of the CRV size). The 80% scale versions were flown at 15,000 to 24,000 pound weight. The X-38 V-201 orbital prototype was 80 percent complete, but never flown.

In tests the V-131, V-132 and V-131R were dropped by a B-52 from altitudes of up to 45,000 ft (13,700 m), gliding at near transonic speeds before deploying a drogue parachute to slow them to 60 miles per hour (97 km/h). The later prototypes had their descent continue under a 7,500-square-foot (700 m²) parafoil wing, the largest ever made. Flight control was mostly autonomous, backed up by a ground-based pilot.

The X-38 project cancellation was announced on April 29, 2002 due to budget concerns.

The X-38 V-132 is now on permanent loan from NASA to the Strategic Air and Space Museum at Ashland Nebraska.

As of November 2009, the 80% complete X-38 V-201, having been moved out of "Hangar X" at Johnson Space Center- is now sitting under a blue plastic tarp outside the Media Resource Center (Building 423) at Johnson Space Center, Houston

As of November 2010, the X-38 V-131R is on loan from NASA to the Evergreen Aviation Museum in McMinnville, Oregon.

Design



X-38 V-201 test model previously located at Bldg. 220 at Johnson Space Center, Houston, Texas



The fifth test drop flight of X-38. The aircraft is released from a B-52 mothership, free falls for a while, opens and fully deploys the parafoil and finally makes a gentle landing

Following the jettison of a deorbit engine, the X-38 would have glided from orbit and used a steerable parafoil for its final descent and landing. The high speeds at which lifting body aircraft operate make them dangerous to land. The parafoil would have been used to slow the vehicle and make landing safer. The landing gear consisted of skids rather than wheels: the skids worked like sleds so the vehicle would have slid to a stop on the ground.

Both the shape and size of the X-38 were different from that of the Space Shuttle. The Crew Return Vehicle would have fit into the payload bay of the shuttle. This does not, however, mean that it would have been small. The X-38 weighed 10,660 kg and was 9.1 meters long. The battery system, lasting nine hours, was to be used for power and life support. If the Crew Return Vehicle was needed, it would only take two to three hours for it to reach Earth.

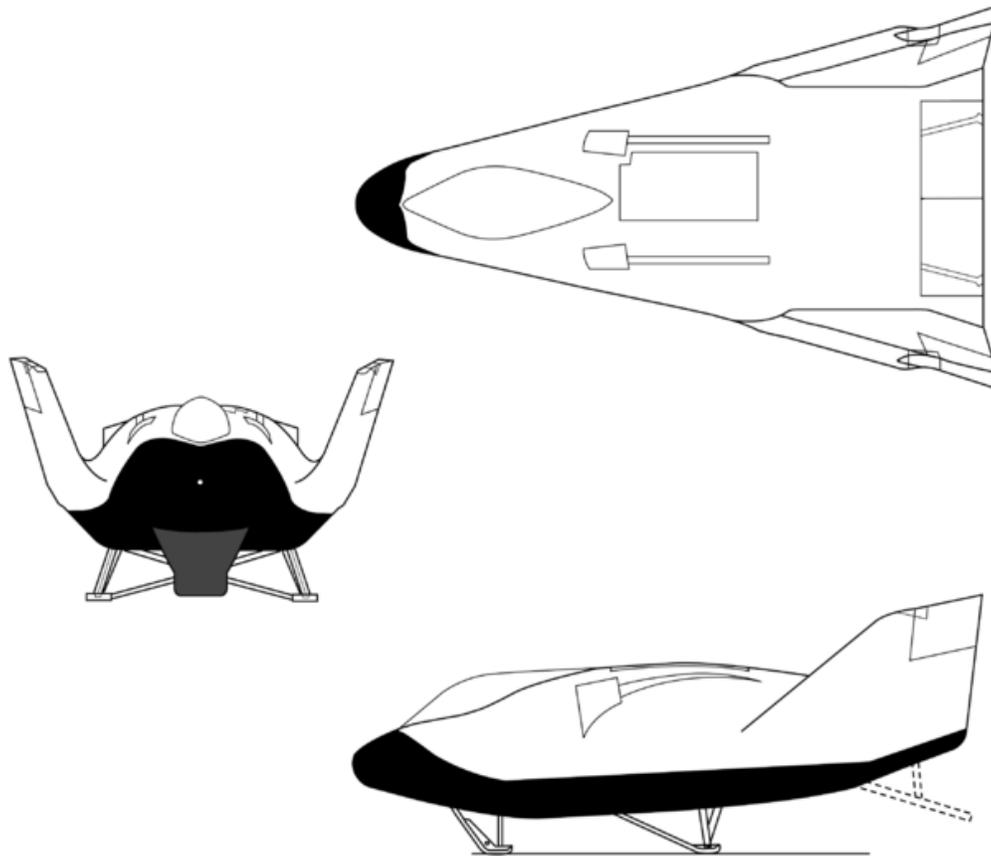
The parafoil parachute, employed for landing, was derived from technology developed by the U.S. Army. This massive parafoil deploys in 5 stages for optimum performance. A drag chute would have been released from the rear of the X-38. This drag chute would have been used to stabilize and slow the vehicle down. The giant parafoil — area of 687 square meters — was then released. It would open in five steps (a process called staging). While the staging process only takes 45 seconds, it is important for a successful chute deployment. Staging prevents high-speed winds from tearing the parafoil.

The spacecraft's landing was to be completely automated. Mission Control would have sent coordinates to the onboard computer system. This system would also have used wind sensors and the Global Positioning System (a satellite-based coordinate system) to coordinate a safe trip home. Since the Crew Return Vehicle was designed with medical emergencies in mind, it made sense that the vehicle could find its way home automatically in the event that crew members were incapacitated or injured. If there was a need, the crew would have the capability to operate the vehicle by switching to the backup systems. In addition, seven high altitude low opening (HALO) parachute packs were included in the crew cabin, a measure designed to provide for the need to jettison the craft.

An Advanced Docking Berthing System (ADBS) was designed for the X-38 and the work on it led to the Low Impact Docking System the Johnson Space Center later created for the planned vehicles in Project Constellation.

The X-38 rescue vehicle was also known as the X-35 (but that designation was already allocated by the USAF to another vehicle) and X-CRV (experimental - Crew Return Vehicle)

Specifications



Dryden Flight Research Center April 1998
X-38 3-view



3-View of the CRV, line art.

Trivia

- The Oakland-based, Space-themed punk/rockabilly band, The Phenomenauts, released a song called "*Where is the X-38?*" openly criticizing the cancellation of the X-38 project. The song was released on their second album, *Re-Entry*, in 2004.

Chapter-11

Reaction Engines Skylon

Skylon



The Skylon vehicle is an aircraft designed to reach orbit.

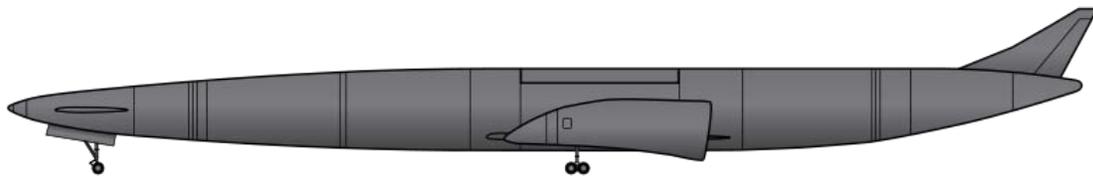
Role	Re-usable Spaceplane
National origin	UK/multinational
Designed by	Reaction Engines Limited
Status	Research and development
Program cost	Projected to be £7.1 billion (~\$12 billion est. 2004)
Unit cost	£190 million (projected)
Developed from	Horizontal Take-Off and Landing (HOTOL) project

Skylon is a design for an unpowered spaceplane by the British company, Reaction Engines Limited (REL). It uses a combined-cycle, air-breathing jet engine to reach orbit in a single stage. A fleet of vehicles is envisaged; the design is aiming for re-usability up to 200 times. In paper studies, the costs per kilogram of payload are hoped to be lowered from the current £15,000/kg to £650/kg (as of 2011), including the costs of research and development (R&D), with costs expected to fall much more over time after the initial expenditures have amortised. The cost of the program has been estimated by the developer to be about \$12 billion.

The vehicle design is for a hydrogen-powered aircraft that would take off from a conventional runway, and accelerate to Mach 5.4 at 26 km using atmospheric air before switching the engines to use the internal liquid oxygen (LOX) supply to take it to orbit. It would then release its payload, which can weigh up to 12-tonnes, and re-enter the atmosphere. The payload would be carried in a standardised payload container or passenger compartment.

During re-entry the relatively light vehicle would fly back through the atmosphere and land back at the runway, with its skin protected by a ceramic composite. It would then undergo inspection and any necessary maintenance and, if the design goal is achieved, be able to fly again within two days. As of 2010, only a small portion of the funding required to develop and build Skylon has been secured. The research and development work on the SABRE engine design is proceeding under a small European Space Agency (ESA) grant. In January 2011, REL submitted a proposal to the British Government to request additional funding for the Skylon project.

Technology and innovations



The Skylon spaceplane is designed as a two-engine, "tailless" aircraft, which is fitted with a steerable canard.

Structure of the fuselage

The fuselage of Skylon is expected to be carbon fibre space frame; a light and strong structure that supports the weight of the aluminium fuel tanks and to which the ceramic skin is attached. Multiple layers of reflective foil thermal insulation fill the spaces of the frame.

The currently proposed Skylon model C2 will be a physically large vehicle, with a length of 82 metres (269 ft) and a diameter of 6.3 metres (21 ft). Because it will use a low-density liquid hydrogen fuel, a great volume is needed to contain enough energy to reach orbit. The propellant is intended to be kept at low pressure to minimise stress; a vehicle that is both large and light has an advantage during atmospheric reentry compared to other vehicles due to a low ballistic coefficient. Because of the low ballistic coefficient, Skylon would be slowed at higher altitudes where the air is thinner. As a result, the skin of the vehicle would only reach 1100 Kelvin (K). In contrast, the smaller Space Shuttle is heated to 2000 K on its leading edge, and so employs an extremely heat-resistant but extremely fragile silica thermal protection system. The Skylon design need not use such a system, instead opting for using a far thinner yet durable reinforced ceramic skin.

However, due to turbulent flow around the wings during re-entry, some parts of Skylon would need to be actively cooled.

Skylon would employ a highly-loaded tightly spaced wheel assembly, to save weight and also interior space when the wheels are retracted into the fuselage. Because this wheel design distributes the weight of the aircraft and the force of its landing over a smaller area of the runway, it would require a specially strengthened runway. It will possess a retractable undercarriage with high pressure tires and water cooled brakes. If problems were to occur just before a take-off the brakes would be applied to stop the vehicle, the water boiling away to dissipate the heat. Upon a successful take-off, the water would be jettisoned, thus reducing the weight of the undercarriage by many tons. During landing, the empty vehicle would be far lighter, and hence the water would be unneeded. The payload fraction would be significantly greater than normal rockets and the vehicle should be fully reusable (200 times or more).

SABRE Engines

One of the significant features of the Skylon design is the engine, called SABRE. The engines are designed to operate much like a conventional jet engine at up to around Mach 5.5 (1700 m/s), 26 kilometres (16 mi) altitude, beyond which the air inlet closes and the engine operates as a highly efficient rocket to orbital speed.

The proposed engine for the vehicle is not a scramjet, but a jet engine running combined cycles of a precooled jet engine, rocket engine and ramjet. Originally the key technology for this type of precooled jet engine did not exist as it required a heat exchanger that was ten times lighter than the state of the art. Research conducted since then has achieved the necessary performance.

Operating an air-breathing jet engine at up to Mach 5.5 is difficult. Several previous engines proposed by other designers have been good as jet engines but performed poorly as rockets. This engine design aims to be a good jet engine within the atmosphere, as well as being an excellent rocket engine outside. The problem with operating at Mach 5.5 has been that the air coming into the engine heats up as it is compressed into the engine, which can cause the engine to overheat. Attempts to avoid these issues typically make the engine much heavier (scramjets/ramjets) or greatly reduce the thrust (conventional turbojets/ramjets). In either case the end result is an engine that has a poor thrust to weight ratio at high speeds, resulting in an engine that is too heavy to assist much in reaching orbit.

The SABRE engine design aims to avoid this by using some of the liquid hydrogen fuel to cool the air at the inlet. The air is then used for combustion much like in a conventional jet. Because the air is cooled at all speeds, the jet can be built of light alloys and the weight is roughly halved. Additionally, more fuel can be burnt at high speed. Beyond Mach 5.5, the air would still be unusably hot despite the cooling, so the air inlet closes and the engine relies solely on on-board liquid oxygen and hydrogen fuel as in a normal rocket.

Because the engine uses the atmosphere as reaction mass at low altitude, it will have a high specific impulse (around 2,800 seconds), and burn about one fifth of the propellant that would have been required by a conventional rocket. Therefore, it would be able to take off with much less total propellant than conventional systems. This, in turn, means that it doesn't need as much lift or thrust, which permits smaller engines, and allows conventional wings to be used. While in the atmosphere, using wings to counteract gravity drag is more fuel-efficient than simply expelling propellant (as in a rocket), again reducing the total amount of propellant needed.

"Single Stage to Orbit" capability

A vehicle that can fly to orbit without staging is known as single stage to orbit (SSTO). Proponents of SSTO claim that staging causes a number of problems such as being difficult, expensive or even impossible to recover, reuse and reassemble the parts and therefore believe that SSTO designs hold the promise of reducing the cost of space-flight.

The Skylon design aims to take off from its specially strengthened runway, fly into low earth orbit, re-enter the atmosphere, and land back on its runway like a conventional aeroplane, without staging, while being fully reusable.

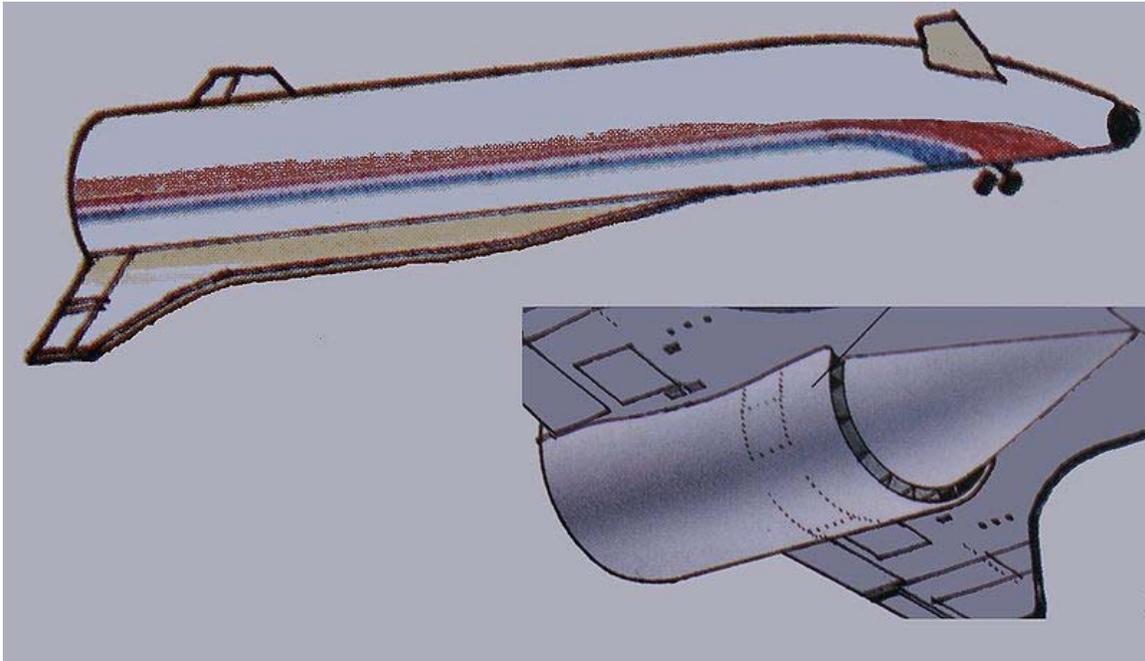
Payload bay

The payload bay of the Skylon C2 design is a cylinder 12.3 metres (40.4 ft) long and 4.6 metres (15 ft) in diameter. It is designed to be comparable with current payload dimensions, and yet able to support the containerization of payloads that Reaction Engines hopes for in the future. To an equatorial orbit, Skylon could deliver 12 tonnes (26,455 lb) to a 300 kilometres (186 mi) height or 10.5 tonnes (23,149 lb) to a 460 kilometres (286 mi) altitude. It could also launch 9.5 tonnes (20,944 lb) to the orbit of the International Space Station, when launching from the equator. Using interchangeable payload containers, Skylon could be fitted to carry satellites or fluid cargo into orbit, or, in a specialised habitation module, up to 30 astronauts in a single launch.

Current project status

As of 2010, the funding required to develop and build the entire craft has not yet been secured, and so current research and development work is focused on the engines, under an ESA grant of €1 million. In January 2011, REL submitted a proposal to the British Government requesting additional funding for the Skylon project.

Research and development programme



The Skylon was developed from the ill-fated British HOTOL project.

Skylon is based upon a previous project of Alan Bond, which was known as HOTOL. The development programme of HOTOL began in 1982, a time when space technology was moving towards reusable launch systems such as the American Space Shuttle. In conjunction with British Aerospace and Rolls Royce, a design emerged that proved highly promising, so much so that the British Government donated £2 million to further their work. However, in 1988, the Conservative government withdrew funding, and the development programme was terminated. Following this major setback, Alan Bond decided to set up his own company, Reaction Engines Limited, with the hope of continuing development with private funding.

After having secured funding, the design of the craft was revisited, undergoing a rigorous redesign throughout much of the 1990s. In the last decade, Reaction Engines has been working with the University of Bristol to develop the engines vital to the success of Skylon. The STRICT/STERN engines produced by this programme were deemed a great success. The next stage of development is to construct a full-sized working prototype of the SABRE Engine.

The differences between Skylon and its predecessor are numerous. For example, HOTOL was to have been launched from a rocket sled (to save weight), whereas Skylon uses a conventional retractable undercarriage. Skylon also uses a different engine design; the SABRE engine is expected to offer higher performance. Another issue that the Skylon design aims to circumvent was the intrinsically poor stability of HOTOL. The weight of the rear-mounted engine tended to make the HOTOL vehicle flip over mid-flight due to the centre of mass lying behind the centre of drag. Attempts to fix this problem ended up

sacrificing much of the potential payload that the HOTOL vehicle could carry, and contributed to the failure of the project. Skylon would solve this by placing the engines at the end of the wings closer to the centre of the vehicle and thus moving the centre of mass forward, ahead of the centre of drag.

The complete Skylon project has a projected R&D cost of over \$10 billion and will continue for another 7–10 years. In February 2009, the British National Space Centre (now the UK Space Agency) and ESA announced that they were partially funding work with €1 million Euros (\$1.28 million dollars) on Skylon's engine to produce a demonstration engine by 2011.

The Technology Demonstration Programme will last approximately 2.5 years and will benefit from another €1 million from the ESA. This programme will take Reaction Engines Ltd from a Technology Readiness Level (TRL) of 2/3 up to 4/5. The former UK Minister for Science and Innovation in 2009, Lord Drayson, commented on Skylon in a speech: "This is an example of a British company developing world-beating technology with exciting consequences for the future of space."

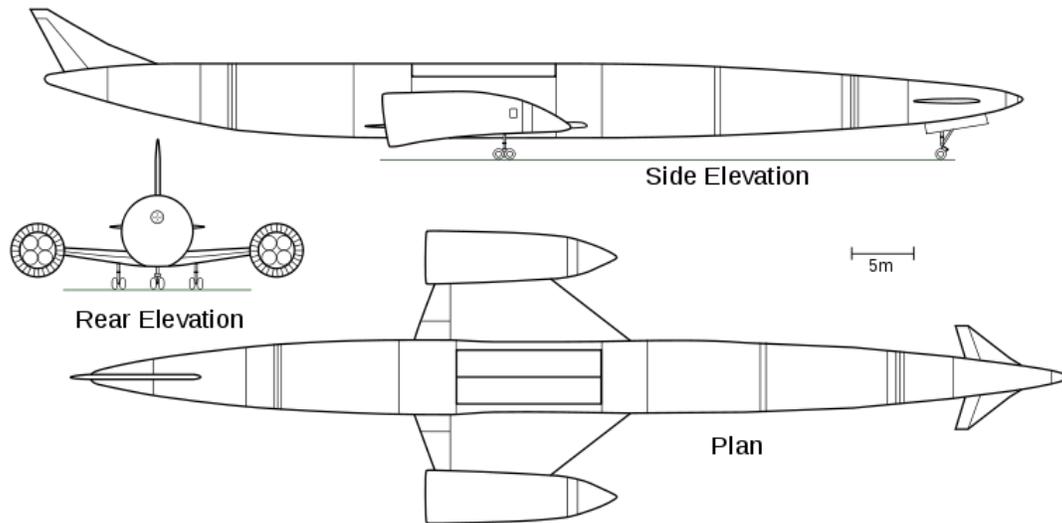
Economics and political will

Once operative, Skylon could potentially lower satellite costs from the current £15,000/kg to £650/kg, according to evidence submitted to the UK parliament by Reaction Engines Ltd. However, funding and support from the British government has not been easy to establish.

Request for funding from the British government was undertaken in 2000, with a proposal that could have offered a large potential return on investment. The request was not taken up at that time. Subsequent discussions with the British National Space Centre led to agreement in 2009 on a co-funding agreement between BNSC, ESA and REL to continue technology development for the SABRE engine. Testing of the SABRE engine will commence in June 2011 with the start of Phase 3 in the Skylon development programme. Pre-orders are expected in the 2011–2013 time frame coinciding with the formation of the manufacturing consortium. According to David Willetts, the UK Minister of State for Universities and Science:

"The European Space Agency is funding proof of concept work for Skylon from UK contributions. This work is focusing on demonstrating the viability of the advanced British engine technology that would underpin the project. Initial work will be completed in mid 2011 and if the trial is successful, we will work with industry to consider next steps."

Specifications



Skylon C2

General characteristics

- **Crew:** automated
- **Capacity:** 40
- **Length:** 83.3 m (273 ft)
- **Wingspan:** 25.4 m (82 ft)
- **Height:** ()
- **Empty weight:** 53,000 kg (120,000 lb)
- **Loaded weight:** 345,000 kg (760,000 lb)
- **Powerplant:** 2× SABRE synergistic combined cycle jet engine
 - **Dry thrust:** 2,700 LT; 3,000 ST (2,700 LT; 3,000 ST) each
 - **Thrust with afterburner:** 3,500 LT; 4,000 ST (3,500 LT; 4,000 ST) each

Performance

- **Maximum speed:** orbital
- **Range:** orbital ()
- **Service ceiling:** 26,000 m air breathing, >200 km exoatmospheric (85,000 ft air breathing, >124 mi exoatmospheric)
- **Thrust/weight:** ~1.2 – 3 at burnout (~0.768 atmospheric)SSTO

- Fuselage diameter: 6.75 m (22.15 ft)
- Maximum payload mass: 12,000 kg (26,000 lb)
- Specific impulse: 3560 s (35 kN·s/kg) atmospheric, 450 s (4.4 kN·s/kg) exoatmospheric
- SABRE engine thrust/weight ratio: up to 14 atmospheric

Chapter-12

Buran Program



Buran, 1989.

The **Buran** (Russian: Бура́н, *Snowstorm* or *Blizzard*) program was a Soviet and later Russian plan for a reusable spacecraft, that began in 1974 at TsAGI and formally suspended in 1993. It was a response to the United States Space Shuttle program. The project was the largest and the most expensive in the history of Soviet space exploration. Development work included sending the BOR-5 on multiple sub-orbital test flights, and atmospheric flights of the OK-GLI. Buran completed one unmanned orbital spaceflight in 1988 before its cancellation in 1993.

Although the Buran spacecraft was similar in appearance to the NASA Space Shuttle, and could similarly function as a re-entry spaceplane, the main engines during launch were on the Energia rocket and not taken into orbit on the spacecraft. The Buran program matched an expendable rocket to a reusable spaceplane.

The Buran orbiter which flew the test flight was crushed in the Buran hangar collapse on May 12, 2002 in Kazakhstan. The OK-GLI resides in a museum.

Background

The Soviet reusable space-craft program has its roots in the very beginning of the space age, the late 1950s. The idea of Soviet reusable space flight is very old, though it was neither continuous, nor consistently organized. Before Buran, no project of the program reached production.

The idea saw its first iteration in the Burya high-altitude jet aircraft, which reached the prototype stage. Several test flights are known, before it was cancelled by order of the Central Committee. The Burya had the goal of delivering a nuclear payload, presumably to the United States, and then returning to base. The cancellation was based on a final decision to develop ICBMs. The next iteration of the idea was Zvezda from the early 1960s, which also reached a prototype stage. Decades later, another project with the same name was used as a service module for the International Space Station. After Zvezda, there was a hiatus in reusable projects until Buran.

Development



1989 Paris Air Show — Buran on An-225

The development of the Buran began in the early 1970s as a response to the U.S. Space Shuttle program. Soviet officials were concerned about a perceived military threat posed

by the US Space Shuttle. In their opinion, the Shuttle's 30-ton payload-to-orbit capacity and, more significantly, its 15-ton payload return capacity, were a clear indication that one of its main objectives would be to place massive experimental laser weapons into orbit that could destroy enemy missiles from a distance of several thousands of kilometers. Their reasoning was that such weapons could only be effectively tested in actual space conditions and that in order to cut their development time and save costs it would be necessary to regularly bring them back to Earth for modifications and fine-tuning. Soviet officials were also concerned that the US Space Shuttle could make a sudden dive into the atmosphere to drop bombs on Moscow, despite the fact that such a scenario was not supported by physics.

While the Soviet engineers favored a smaller, lighter lifting body vehicle, the military leadership pushed for a direct, full scale copy of the double-delta wing Space Shuttle, in an effort to maintain the strategic parity between the superpowers.

NPO Molniya conducted all development under the lead of Gleb Lozino-Lozinskiy.

The construction of the shuttles began in 1980, and by 1984 the first full-scale Buran was rolled out. The first suborbital test flight of a scale-model (BOR-5) took place as early as July 1983. As the project progressed, five additional scale-model flights were performed. A test vehicle was constructed with four jet engines mounted at the rear; this vehicle is usually referred to as OK-GLI, or as the "Buran aerodynamic analogue". The jets were used to take off from a normal landing strip, and once it reached a designated point, the engines were cut and OK-GLI glided back to land. This provided invaluable information about the handling characteristics of the Buran design, and significantly differed from the carrier plane/air drop method used by the USA and the *Enterprise* test craft. Twenty-four test flights of OK-GLI were performed after which the shuttle was "worn out".

Buran cosmonaut preparation

A rule, set in place because of the failed Soyuz 25 of 1977, insisted that all Soviet space missions contain at least one crew member who has been to space before. In particular, in 1982, it was decided that all Buran commanders and their back-ups would occupy the third seat on a Soyuz mission, prior to their Buran spaceflight. Several people had been selected to potentially be in the first Buran crew. By 1985, it was decided that at least one of the two crew members would be a test pilot trained at the Gromov Flight Research Institute (known as "LII"), and potential crew lists were drawn up. Only two potential Buran crew members reached space: Igor Volk, who flew in Soyuz T-12 to the space station Salyut 7, and Anatoli Levchenko who visited Mir, launching with Soyuz TM-4 and landing with Soyuz TM-3. Both Soyuz spaceflights lasted about a week.

Spaceflight of Igor Volk

Volk was planned to be the commander of the first Buran flight. There was two purposes of the Soyuz T-12 mission, one of which was to give Volk spaceflight experience. The

other purpose, seen as the more important factor, was to beat the United States and have the first spacewalk conducted by a woman.

Spaceflight of Anatoli Levchenko

Levchenko was planned to be the back-up commander of the first Buran flight, and in March 1987 he began extensive training for his Soyuz spaceflight. In December 1987, he occupied the third seat aboard Soyuz TM-4 to Mir, and returned to Earth about a week later on Soyuz TM-3. His mission is sometimes called *Mir LII-1*, after the Gromov Flight Research Institute shorthand. Levchenko died of a brain tumour the following year, leaving the back-up crew again without spaceflight experience. A Soyuz spaceflight for another potential back-up commander was pursued by the Gromov Flight Research Institute, but such a spaceflight never occurred.

Orbital flight

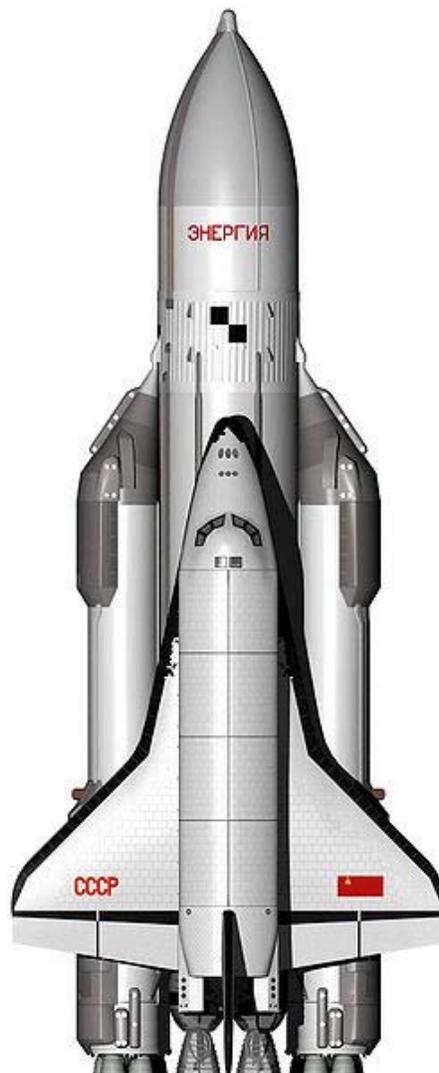


Illustration of Energia rocket with Buran shuttle.

The only orbital launch of the (unmanned) Buran shuttle 1.01 was at 3:00 UTC on 15 November 1988. It was lifted into orbit by the specially designed Energia booster rocket. The life support system was not installed and no software was installed on the CRT displays. The shuttle orbited the Earth twice in 206 minutes of flight. On its return, it performed an automated landing on the shuttle runway at Baikonur Cosmodrome.

Planned flights

The planned flights for the shuttles in 1989, before the downsizing of the project and eventual cancellation, were:

- 1991 - Shuttle Ptichka unmanned first flight, duration 1–2 days.
- 1992 - Shuttle Ptichka unmanned second flight, duration 7–8 days. Orbital maneuvers and space station approach test.
- 1993 - Shuttle Buran unmanned second flight, duration 15–20 days.
- 1994 - Shuttle 2.01 first manned space test flight, duration of 24 hours. Craft equipped with life-support system and with two ejection seats. Crew would consist of only two cosmonauts with Igor Volk as commander, and Aleksandr Ivanchenko as flight engineer.
- Second manned space test flight, crew would consist of only two cosmonauts.
- Third manned space test flight, crew would consist of only two cosmonauts.
- Fourth manned space test flight, crew would consist of only two cosmonauts.

The planned unmanned second flight of the Ptichka was changed in 1991 to the following:

- December 1991 - Shuttle 1.02 - informally "Ptichka" unmanned second flight, with a duration of 7–8 days. Orbital maneuvers and space station approach test:
 - automatic docking with Mir's Kristall module
 - crew transfer from Mir to the shuttle, with testing of some of its systems in the course of twenty-four hours, including the remote manipulator
 - undocking and autonomous flight in orbit
 - docking of the manned Soyuz-TM 101 with the shuttle
 - crew transfer from the Soyuz to the shuttle and onboard work in the course of twenty-four hours
 - automatic undocking and landing

Cancellation (1993)



Atmospheric Buran testbed, MACS, Zhukovski, 1999.



Atmospheric Buran testbed, MACS, Zhukovski, 1999.

After the first flight, the project was suspended due to lack of funds and the political situation in the Soviet Union. The two subsequent orbiters, which were due in 1990 (informally *Ptichka*, meaning "birdie") and 1992 (Shuttle 2.01) were never completed. The project was officially terminated on June 30, 1993 by President Boris Yeltsin. At the time of its cancellation, 20 billion roubles had been spent on the Buran program.

The program was designed to boost national pride, carry out research, and meet technological objectives similar to those of the U.S. shuttle program, including resupply of the Mir space station, which was launched in 1986 and remained in service until 2001. When Mir was finally visited by a space shuttle, the visitor was a U.S. shuttle, not Buran.

The Buran SO, a docking module that was to be used for rendezvous with the Mir space station, was refitted for use with the U.S. Space Shuttles during the Shuttle-Mir missions.

Buran hangar collapse

On May 12, 2002, the Buran hangar in Kazakhstan collapsed because of a structural failure due to poor maintenance. The collapse killed 7 workers and destroyed the orbiter as well as a mock-up of an Energia booster rocket. It occurred at building 112 at the Baikonur Cosmodrome, 14 years after its first and only flight. Work on the roof had begun for a maintenance project, whose equipment is thought to have contributed to the collapse. Also, preceding May 12 there had been several days of heavy rain.

Status

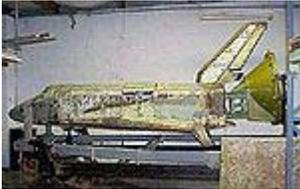
As well as the five production Burans, there were eight test vehicles. These were used for static testing or atmospheric trials, and some were merely mock-ups for testing of electrical fittings, crew procedures, etc.

Image	Serial number	Construction Date	Usage	Current status
Space Flight Burans (Production vehicles)				
	Shuttle OK-1K1 - "Buran" (11F35 K1)	1986	Unmanned flight (1988)	Destroyed in the Buran hangar collapse in 2002.
	Shuttle OK-1K2 - informally "Ptichka" (11F35 K2)	1988	95-97% completed, unused	Property of Kazakhstan, at the Baikonur Cosmodrome, in the MIK Building.
	Shuttle	1990?	Incomplete	located at

	OK-2K1 "Baikal" (?) (11F35 K3)			Baikonur Cosmodrome.
	Shuttle OK-TK(?) (11F35 K4)	1991?	Incomplete	Partially dismantled, remains outside Tushino Machine Building Plant, near Moscow.
	Shuttle 2.03 (11F35 K5)	1992?	Incomplete	Dismantled.
Aero and Static Tester Burans (Mock-ups)				
	OK-M (later OK- ML-1)	1982	Static test	Static test model: parts, normal temperature static loads, moment of inertia, payload mass, interface tests (horizontal and vertical) with the launch vehicle. Located at Baikonur Cosmodrome.
	OK-KS (003)	1982	Static electrical/integration test	Static test model: electronic and electric. Located at the Energia factory in Korolev
	OK-MT (later OK- ML-2)	1983	Engineering mock- up	Static test model: documentation, loading methods for liquids and gases, hermetic system integrity, crew entry and exit, manuals.

				Located at Baikonur Cosmodrome.
	OK-GLI (Buran Analog BTS-002)	1984	Aero test	Analogue aero test model. Completed 25 aero test flights and 9 taxi tests. Bought by the Technikumuseum Speyer, transported to Germany in 2008.
	OK-???		Static test	Vibration and vacuum test vehicle. Location unknown.
	OK-TVI		Static heat/vacuum testbed	Static test model: Environmental chamber heat/vacuum, thermal regimes. Location: NIIKhimMash, Moscow.
	OK-???		Static test	Vibration and vacuum test vehicle. Location unknown.
	OK-TVA		Static test	Structural test vehicle: loads and stresses, heating and vibration. Located in Gorky Park, Moscow.

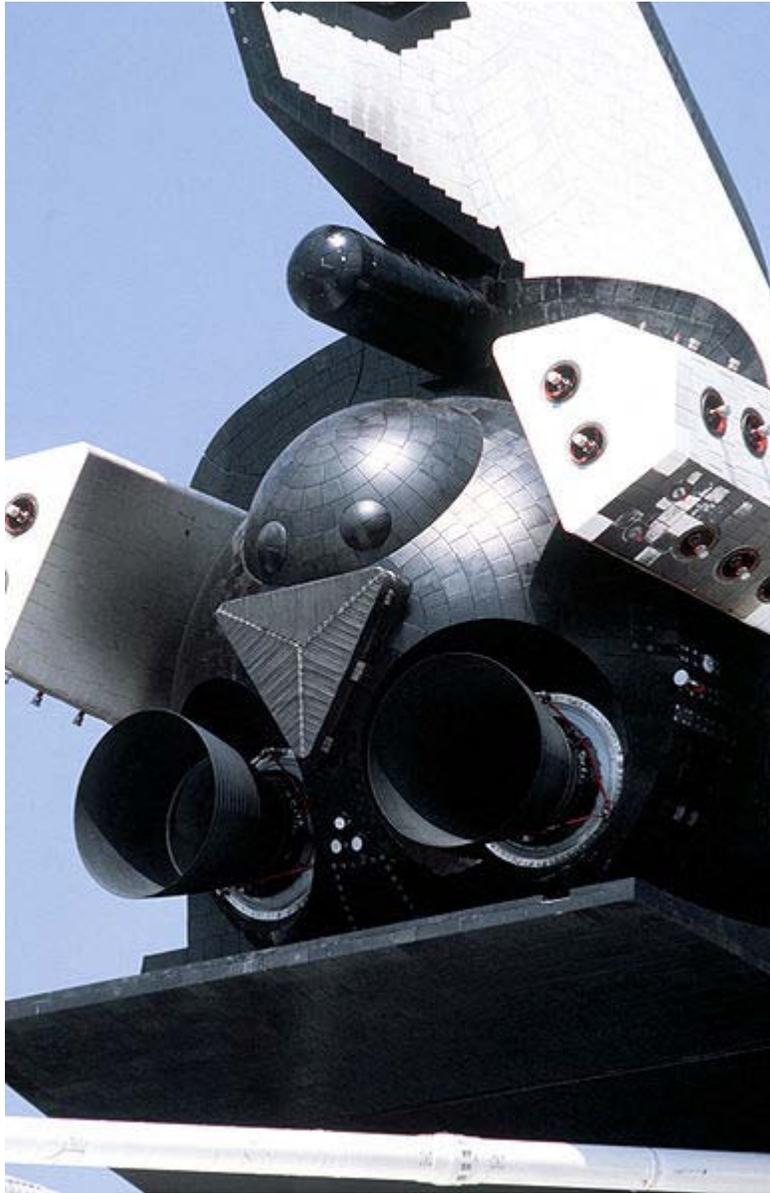
Related Scale Models and Ships

	BOR-4	1982–1984	Sub-scale model of the Spiral space plane	1:2 scale model of Spiral space plane. 5 launches. NPO Molniya, Moscow.
	BOR-5 ("Kosmos")	1983–1988	Suborbital test of 1/8 scale model of Buran	5 launches, none were reflown but at least 4 were recovered. NPO Molniya, Moscow.
	Full-scale crew section		Medical-biological tests	
	GLI Horizontal Flight Simulator		Flight control software fine tuning	
	Wind tunnel models		Scales from 1:3 to 1:550	85 models built
	Gas dynamics models		Scales from 1:15 to 1:2700	

Future possibilities

The 2003 grounding of the U.S. Space Shuttles caused many to wonder whether the Russian Energia launcher or Buran shuttle could be brought back into service. By then, however, all of the equipment for both (including the vehicles themselves) had fallen into disrepair or been repurposed after falling into disuse with the collapse of the Soviet Union. However, because of the imminent retirement of the American space shuttle by 2010 and the need for STS-type craft in the meantime to complete the International Space Station, some American and Russian scientists had been mulling over plans to possibly revive the already-existing Buran shuttles in the Buran program rather than spend money on an entirely new craft and wait for it to be fully developed but the plans did not come to fruition. Recently there have been new interests in renewing the program temporarily while Russia struggles with the CSTS and Kliper design stages.

Technical data



Buran's rear (1989)

Mass breakdown

- Mass of Total Structure / Landing Systems: 42,000 kg
- Mass of Functional Systems and Propulsion: 33,000 kg
- SSME 14,200
- Maximum Payload: 30,000 kg
- Maximum liftoff weight: 105,000 kg

Dimensions

- Length: 36.37 m
- Wingspan: 23.92 m
- Height on Gear: 16.35 m
- Payload bay length: 18.55 m
- Payload bay diameter: 4.65 m
- Wing glove sweep: 78 degrees
- Wing sweep: 45 degrees

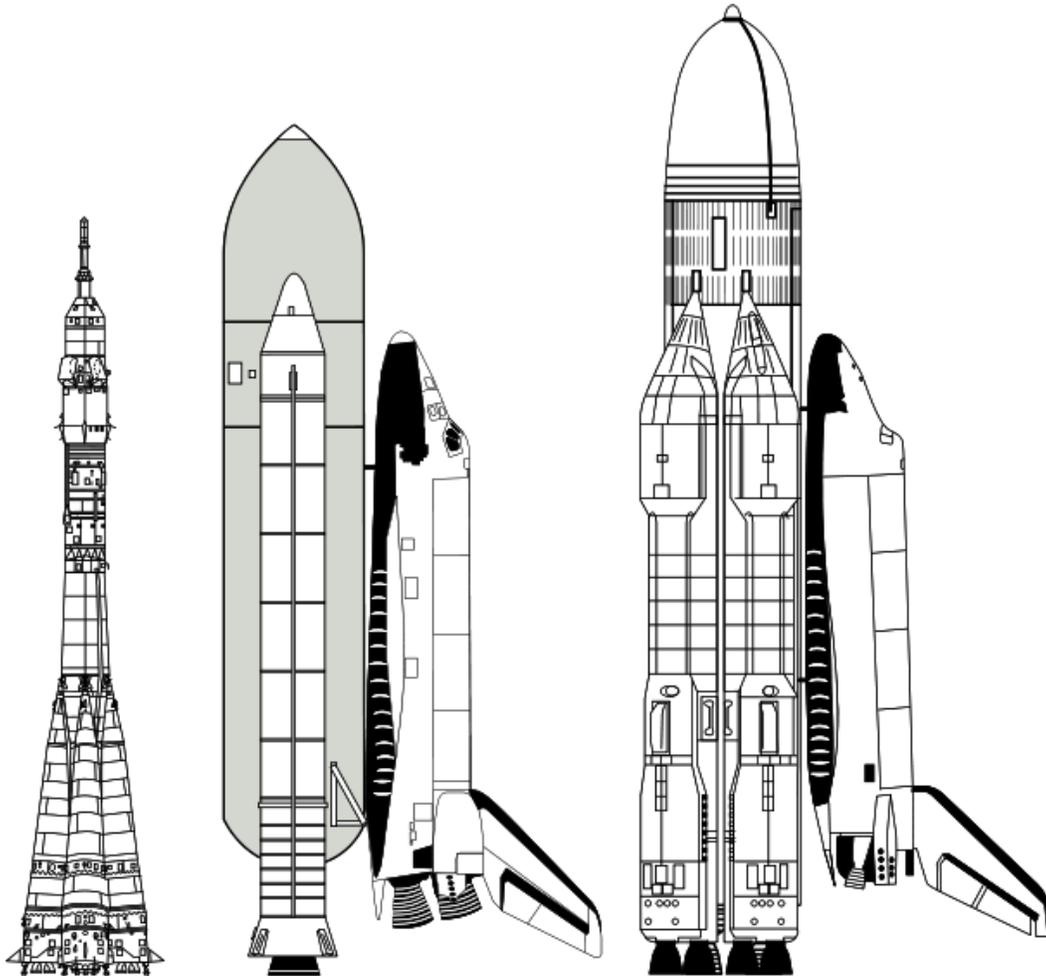
Propulsion

- Total orbital maneuvering engine thrust: 17,600 kgf
- Orbital Maneuvering Engine Specific Impulse: 362 sec
- Total Maneuvering Impulse: 5 kgf-sec
- Total Reaction Control System Thrust: 14,866 kgf
- Average RCS Specific Impulse: 275-295 sec
- Normal Maximum Propellant Load: 14,500 kg

Comparison to NASA Space Shuttle

Because Buran's debut followed that of Space Shuttle Columbia's, and because there were striking visual similarities between the two shuttle systems—a state of affairs which recalled the similarity between the Tupolev Tu-144 and Concorde supersonic airliners—many speculated that Cold War espionage played a role in the development of the Soviet shuttle. Despite remarkable external similarities, many key differences existed, which suggests that, had espionage been a factor in Buran's development, it would likely have been in the form of external photography or early airframe designs. One CIA commenter, however, states that Buran was based on a rejected NASA design.

Key differences from the NASA Space Shuttle



Soyuz, Space Shuttle, and Buran

- Buran was not an integral part of the system, but rather a payload for the Energia launcher. The orbiter had no main rocket engines, freeing space and weight for additional payload; the largest cylindrical structure is the Energia carrier-rocket, not just a fuel tank. In contrast, in the American Space Shuttle system, the three main engines on the rear of the orbiter comprise the second stage launch propulsion system, and the External Tank and twin boosters are not used to launch anything except an orbiter.
- The main engines were mounted on the core Energia stage and thus destroyed when it burns up in the atmosphere, unlike the U.S. Space Shuttle which has reusable main engines in the orbiter. Both designs feature reusable boosters (although reusability was not demonstrated on Energia). There were some plans for constructing a fully reusable Energia carrier, but funding cuts meant that this was never completed.

- The boosters used liquid propellant (kerosene/oxygen). The Space Shuttle's boosters use solid propellant.
- Buran's equivalent of the shuttle's Orbital Maneuvering System used GOX/Kerosene propellant, with lower toxicity and higher performance (a specific impulse of 362 seconds) than the Shuttle's hydrazine OMS engines.
- Energia was designed from the start to be configured for a variety of uses, rather than just a shuttle launcher. Other payloads than Buran, with mass as high as 80 metric tons, could be lifted to space by Energia, as was the case on its first launch. The heaviest configuration (never built) would have been able to launch 200 tons into orbit. (The Shuttle-C concept was a similar proposal to the Energia system, envisaged to complement the space shuttle by adapting its boosters and external tank for use with other vehicles, but it never moved beyond the experimental mock-up stage. The NASA Ares V rocket, in development, is a similarly "shuttle-derived" idea.)
- The Energia launch rocket was also capable of delivering a payload to the Moon. However, this configuration was never tested. The Space Shuttle was never intended to go beyond Low Earth orbit.
- As Buran was designed to be capable of both manned and robotic flight, it had automated landing capability; the manned version was never operational. The Space Shuttle was later retrofitted with an automated landing capability; the equipment to make this possible was first flown on STS-121, but is intended only as a contingency, and has never been used on any flight.
- The orbiters were designed to carry two jet engines for increased return capability. Although they were not installed in the first orbiter for reason of weight limits on the first Energia launcher, provisions exist in the structure for later retrofit. Although early designs of the NASA Space Shuttle also incorporated jet engines, the operation version landed as an unpowered glider, relying entirely on management of descent energy for landing.
- The nose landing gear is located much farther down the fuselage rather than just under the mid-deck as with the NASA Space Shuttle.
- Buran could lift 30 metric tons into orbit in its standard configuration, comparable to the early Space Shuttle's original 27.8 metric tons
- Buran was designed to return 20 metric tons of payload from orbit, compared to 15 metric tons for the Space Shuttle orbiter.
- The lift-to-drag ratio of Buran is cited as 6.5, compared to a subsonic L/D of 4.5 for the Space Shuttle.
- The thermal protection tiles on the Buran and U.S. Space Shuttles are laid out differently. Soviet engineers believed their design to be thermodynamically superior.
- Buran was designed to be moved to the launch pad horizontally on special train tracks, and then erected at the launch site. This enabled a much faster rollout than the US Space Shuttle, which is moved vertically, and as such must be moved very slowly (less than one mile per hour, typically taking about 6 hours to move the Mobile Launch Platform supporting the Shuttle stack from the VAB to the launch pad on a Crawler-Transporter.)

- The booster rockets were not constructed in segments vulnerable to leakage through O-rings, which caused the destruction of *Challenger*. (Their liquid-fueled nature would make this design inapplicable.) However, the liquid fuel for the booster rockets would have made them less easy to prepare - and hold ready - for flight than solid rocket fuel in the Shuttle boosters and in addition represented a potential explosive hazard on the ground.
- The manned version was intended to have a crew of ten as opposed to seven.