HISTORY OF NASA'S X-PLANES

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ABSTRACT

X IS FOR EXPERIMENTAL, and the USA's famous X-planes have played a key role in advancing aerospace technology over the more than 50 years since the Bell X-1 first flew. The nature of the X-series is changing, however. There is greater emphasis on rapid prototyping of subscale unmanned vehicles, and on government/industry cost sharing, in an effort to reduce the cost of demonstrating technology.

The X-series has it origins in the Research Aircraft Programme launched by NASA (then NACA) and the US military towards the end of World War n to explore transonic and super sonic flight

Thanks to efforts to reduce the cost of designing, building and testing experimental aircraft, the X-series looks alive and well. Today there are no fewer than 12 active "X" programmes.

1. ACTIVE "X" PROGRAMMES

1.1. The first international "X" programme

The X-31 was the first international "X" programme, originating as the joint US-German Enhanced Fighter Manoeuvrability (EFM) demonstrator to explore close-in air combat at angles of attack (AoA) beyond the stall. Flight testing was completed in 1995, but efforts are underway to launch a US/German/Swedish programme to demonstrate tailless flight using the X-31.

The X-31 was designed jointly by Rockwell International and Deutsche Aerospace (formerly Messerschmitt-Bolkow-Blohm — MBB) under a programme involving the US and German Governments, the US Defense Advanced Research Projects Agency (DARPA), and the US Navy. The single-engined aircraft incorporates an advanced fly-by-wire flight control system, three-axis thrust vectoring, all-moving canards, fixed aft strakes and a composite double-delta wing.

The rudimentary thrust vectoring system consists of three carbonfibre paddles, mounted on the aft fuselage, which deflect the engine exhaust to provide pitch and yaw control. Normally "weathervaned" with the airflow, the canards are used for aerodynamic recovery from high AoA if the thrust vectoring system fails.

The first of two aircraft flew at Palmdale, California, on 11 October, 1990. The second aircraft followed on 19 January, 1991. During initial flight tests from Palmdale, the two aircraft used thrust vectoring to expand the post-stall envelope to 40° AoA.

Operations moved to NASA Dryden, at nearby Edwards AFB, in February 1992, where the International Test Organisation expanded the envelope further.

Figure 1. X-31 demonstrating high angel of attack — Herbst manoeuvre

In November 1992, the X-31 achieved controlled flight at 70° AoA and a controlled roll around the aircraft's velocity vector was accomplished at the same AoA. In April 1993, the X-31 achieved another milestone when the No2 aircraft executed a rapid, minimum radius, 180° turn using a post-stall manoeuvre. Flying well beyond the aerodynamic limits of any conventional aircraft, the "J-turn" or "Herbst manoeuvre" (after German post-stall proponent Wolfgang Herbst) proved the revolutionary potential of the X-31.

In subsequent years the X-31s engaged in air combat manoeuvres against F/A-18s. In 1993, the No2 aircraft was fitted with a helmet-mounted visual/audio display to provide better situational awareness during high AoA combat.

In 1994, the X-31's flight controls were reprogrammed to simulate tailless flight. The quasi-tailless tests, aimed at eventually removing the vertical tail altogether, were designed to demonstrate the drag, weight and radar cross-section reductions that could be achieved in future civil and military designs.

The last flight phase was near its ending in January 1995 when the No 1 aircraft crashed just north of Edwards. The pilot ejected safely. By then, international interest in the tailless concept was growing, and after the surviving aircraft appeared at the 1995 Paris air show, the X-31 team conceived a new programme, VECTOR (Vectoring Extremely short take-off and landing Control and Tailless Operation Research), under which the vertical tail will be removed progressively until the X-31 becomes a completely tailless aircraft.

1.2. Tailless Fighter

Built under a co-operative programme with NASA to demonstrate technology for an agile tailless fighter, Boeing's X-36 is now being used by the US Air Force to evaluate reconfigurable flight controls for tailless aircraft.

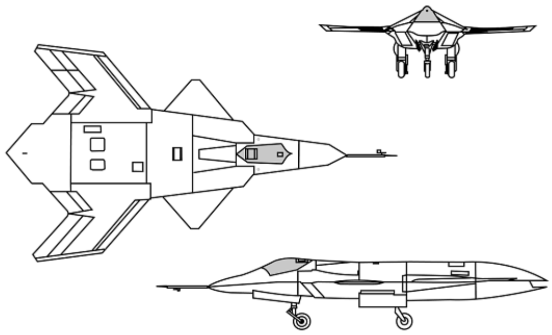

Figure 2. X-36 Tailless Fighter

The X-36 research aircraft is a remotely piloted 28% scale model of a tailless fighter. The aircraft has no horizontal or vertical tails, flight control being provided by split ailerons and thrust vectoring. The 5.5m (18.2ft)-long, 575kg (l,270lb) vehicle is powered by a 700lb -thrust (3.1kN) Williams International F112 turbofan. The X-36 is flown from a ground-based cockpit equipped with a head-up display, which superimposes flight data on the view from a camera on board the aircraft.
Two X-36s were built under a $20 million co-operative agreement between Boeing (formerly McDonnell Douglas) and NASA, which shared the costs roughly equally. The programme also demonstrated rapid prototyping, with the first vehicle rolled out just 28 months after the con tract was awarded. Boeing says the X-36 was designed, produced and tested in about half the time and at one-tenth the cost of a full-scale manned vehicle.
The X-36 first flew on 17 May, 1997, and 31 flights were completed by 12 November, using just one of the vehicles. A typical research flight lasted 35 to 45 minutes from takeoff to touchdown. The second was completed, but never flown. The X-36 achieved a maximum angle of attack of 40° and demonstrated fighter agility with thrust vectoring on and off. Boeing says that, above 18° AoA, the X-36's roll performance exceeded that of any conventional fighter. Flight testing resumed in December 1998 under the US Air Force Research Laboratory's RESTORE programme. The aircraft has been equipped with "neural net" control laws, enabling the flight control computer to detect and compensate automatically for any flight control failures.

1.3. Boeing's Joint Strike Fighter (JSF)

The X-32 is Boeing's Joint Strike Fighter (JSF) concept demonstrator aircraft. The JSF programme is aimed at replacing the US Air Force's F-16s and A-10s, the US Navy's A-6s, the US Marine Corps' AV-8Bs and F/A-18s and the UK Royal Navy's Sea Harriers with three variants of one highly common design.
The US Department of Defense awarded JSF concept demonstration contracts to Boeing and Lockheed Martin in November 1996. Each covers the construction of two demonstrators: one conventional take-off and landing (CTOL), the other short take-off and vertical landing (STOVL). Boeing's aircraft are designated X-32A (CTOL) and X-32B (STOVL).

The X-32 has a high-set delta wing, twin canted vertical tails, a deep fuselage and a prominent chin intake for its single Pratt & Whitney JSF 119 engine, which is fitted with a two-dimensional thrust vectoring nozzle. Pratt & Whitney successfully completed the flight clearance testing of JSF119 engines on 25 May 2000.

The X-32A, representing the USAF/USN JSF, differs externally from the X-32B, representing the USMC/RN JSF, in having small wingtip extensions that increase payload/range.

Figure 3. The Boeing Joint Strike Fighter

The X-32B has a direct-lift STOVL propulsion system with twin retractable side-mounted thrust vectoring nozzles. The STOVL version has a translating inlet lip to improve low-speed operation. Ground tests of both the CTOL and STOVL engine variants are under way.

Construction of the X-32A began in November 1997.

The X-32A concept demonstrator in May 2000 completed several taxi tests in preparation for first flight this summer. The engine and all on-board systems performed just as tests engineers had expected, based on the static tests they completed in April.

Both aircraft are set to fly in 2000, with one design to be selected in 2001 for the JSF engineering and manufacturing development phase.

1.4. “The scaled-down F-22”

Lockheed Martin's Joint Strike Fighter concept demonstrator is designated the X-35. Two aircraft are being built, the CTOL X-35A and the STOVL X-35B.

Lockheed Martin's JSF resembles a scaled-down F-22, with trapezoidal wing, conventional horizontal stabiliser and twin canted vertical tails. One unusual design feature is the diverterless side inlets for the single Pratt & Whitney JSF119 engine, designed to reduce radar cross-section. The X-35Awill be flown first in USAF CTOL configuration, then converted to the carrier-capable (CV) version planned for the USN. This involves fitting the larger wing control surfaces, horizontal stabiliser and rudders required for a low-speed approach to the aircraft carrier.

Figure 4. Lockheed Martin's Joint Strike Fighter

The X-35B will have a STOVL propulsion system combining the basic JSF119 with a shaft-driven lift fan and three-bearing thrust vectoring main engine nozzle - both provided by Rolls-Royce. In STOVL mode, a dry clutch will engage the lift fan, which is mounted behind the cockpit and equipped with a D-shaped nozzle to vector the thrust fore and aft. The three-bearing nozzle will vector main engine thrust downwards, and from side to side. Some engine air will be diverted to roll ducts mounted in the wing, which will provide both lift and roll control.
On 9 December 1999, the Lockheed Martin Joint Strike Fighter (JSF) team successfully installed the first JSF119-611 flight engine on the X-35A demonstrator aircraft.
The Lockheed Martin Joint Strike Fighter (JSF) team completed airframe assembly of the X-35A concept demonstrator aircraft in March 2000.
The X-35A will represent the conventional takeoff and landing (CTOL) variant for the U.S. Air Force. Later this year, this aircraft will be converted to the X-35B short takeoff and landing (STOVL) variant for the U.S. Marine Corps and British Royal Navy and Royal Air Force.
The next steps for the X-35A prior to first flight will be fuel system tests, installation of the flight-qualified CTOL engine, ground vibration and structural coupling tests, auxiliary power unit tests, engine runs, vehicle management system final software checks and taxi tests.

1.5. The X-33, X-34, X-37 programmes pave the way for a full-schale, commercially reusable launch vehicles

1.5.1. VentureStar

Lockheed Martin Skunk Works signed a co-operative agreement with NASA in July 1996 to design, manufacture and fly the X-33 - a half-scale technology demonstrator for a single-stage-to-orbit reusable launch vehicle called the VentureStar. The vehicle is intended to reach orbit using its on-board rocket power, then glide back to earth for a conventional landing like the Space Shuttle. The X-33 is the flagship technology demonstrator for technologies that will dramatically lower cost of access to space.

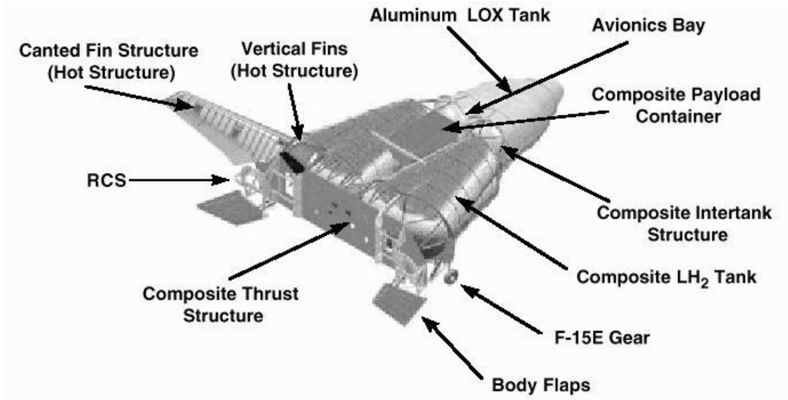

Figure 5. VENTURESTAR

Critical elements of the design include the liquid oxygen tank and two liquid hydrogen tanks (the largest composite LH tanks ever made), which are part of the vehicle's structure. Another is the innovative XRS-2200 linear aerospike rocket engine was developed and assembled by Boeing's Rocketdyne division. Unlike in a conventional rocket, where expanding combustion gases are contained within a bell-shaped nozzle, the hot exhaust of the aerospike is expanded on an external ramp, and modulated by atmospheric pressure.

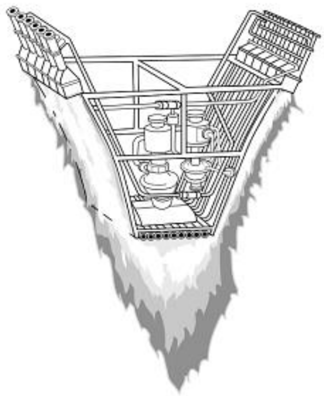

Figure 6. XRS-2200 linear aerospike rocket engine

Problems producing the copper alloy plates that form the V-shaped ramp of the aerospike rocket have delayed the programme.
There was the last test of 14 planned in the single-engine phase of the engine's flight certification program on 12 May 2000.
Contingent on successful tests of the X-33, Lockheed Martin plans to begin commercially funded construction of the first of two full-sized VentureStars in 2001.

1.5.2. X-34

Under development by Orbital Sciences as a technology demonstrator for future reusable launch vehicles (RLVs), the X-34 is also intended to be used as a platform for high-speed research and microgravity experiments. The air-launched, rocket-powered

vehicle will be capable of autonomous operation at speeds up to M8 and altitudes up to 250,000ft (76,000m).
As a testbed for RLV technology, the X-34 incorporates an all-composite airframe, composite reusable RP-1 fuel tanks, low-cost ceramic thermal protection systems and an autonomous guidance and landing capability based on an integrated differential global positioning/inertial navigation system. The vehicle structure is an all-composite with a one piece delta wing design 58,3 feet in length and 27,7 feet wide.
The X-34 vehicle is powered by a 60,000lb (267kN) thrust Fastrac engine. The Fastrac is a simple engine with a single combined oxygen/kerosene turbopump.

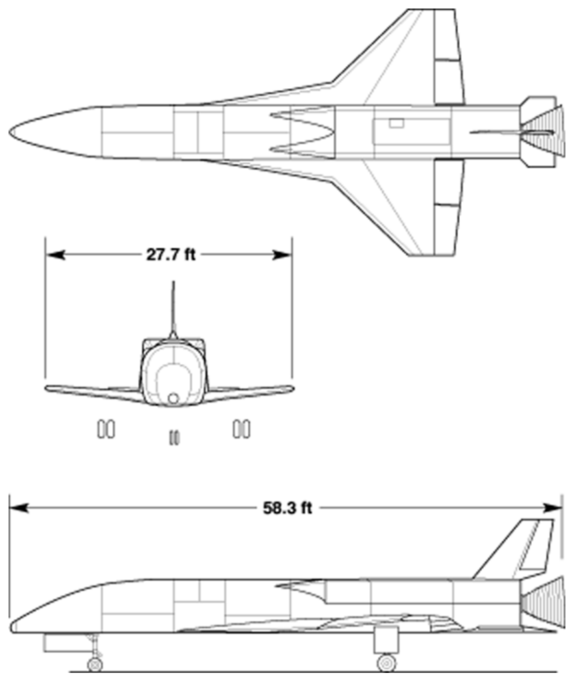

Figure 7. X-34

A typical X-34 flight consists of a drop from the L-1011, engine start and acceleration to the planned Mach number and altitude, and a coast phase, followed by re-entry and landing.
Originally envisaged as the forerunner of a commercial air-launched RLV the X-34 is now viewed as the first in a series of X-designated "Pathfinder" demonstrators under NASA’s Future-X programme to develop technologies for low-cost access to space.

1.5.3. X-37

The designation X-37 is reserved for NASA’s Future-X programme to demonstrate technologies for low-cost access to space, but it is not yet clear whether it will be applied to the Advanced Technology Vehicle (ATV) to be built by Boeing as a Future-X Pathfinder. The X-37 will be NASA’s first X-vehicle demonstrator to operate during both the orbital and re-entry phases of flight.
NASA’s Future-X programme is intended as a continuous series of flight demonstrations to validate technologies beyond those incorporated in the X-33 and X-

34. The programme envisages both Pathfinder narrow-focus demonstrators and more complex Trailblazer integrated technology demonstrators. Possible Trailblazer X-vehicle candidates include an upgraded X-33.
The first two Pathfinders are the X-34 and Boeing's ATV, which is intended to demonstrate technologies for a reusable craft capable of autonomous "orbital-to-landing" operations. Drop tests, from NASA’s B-52, are expected to begin in mid-2001, leading to a Space Shuttle flight in late 2001/early 2002.
The ATV is externally almost identical to Boeing's X-40 Space Manoeuvre Vehicle demonstrator. The X-37 will be launched aboard the Space Shuttle as a secondary payload. Once on-orbit the Space Shuttle will deploy the X-37 from the Shuttle cargo bay. Once the X-37 is deployed into orbit, it will remain on-orbit up to 21 days performing a variety of experiments before re-entering the Earth's atmosphere and landing. The ATV will reach speeds of M25 on re-entry. The reusable ATV will have an all-composite airframe with durable thermal-protection system, storable non-toxic liquid propellants, and an integrated vehicle health monitoring system to enable rapid turnarounds.

Figure 8. X-37

The X-37 will be powered by a single AR-2/3 hydrogen peroxide and JP-10 (jet fuel) engine.
The X-37 is 27.5 feet long - about half the length of the Shuttle payload bay - and weighs about 6 tons. Its wingspan is about 15 feet, and it contains an experiment bay 7 feet long and 4 feet in diameter. It is designed to be modular to allow for rapid insertion of technologies and experiments.
Unpowered atmospheric tests are scheduled for 2001 with the first orbital flight planned for 2002.

1.5.4. X-40

Under the US Air Force's Space Manoeuvre Vehicle (SMV) programme, Boeing built the X-40A for drop testing to validate the autonomous approach and landing system. A successful drop test was conducted at Holloman AFB, New Mexico, in August 1998.
The SMV is a small spacecraft that could function as a reusable satellite bus or upper stage, with a payload capability of about 550kg (1,200lb). The vehicle could be deployed by the Shuttle or from a suborbital launch vehicle such as the X-33 or Boeing's DC-X. The SMV would then conduct autonomous in-orbit operations, releasing its payload or returning it to earth.

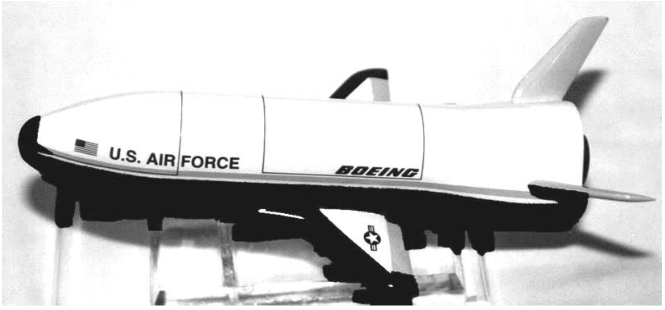

Figure 9. Boeing's Space Manoeuvre Vehicle (SMV)

An eventual operational version could function as the second stage-to-orbit vehicle as well as a reusable satellite with a variety of available payloads. SMV could perform missions such as: Tactical reconnaissance, Filling gaps in satellite constellations, Rapid deployment of Space Maneuver Vehicle constellations, Identification and surveillance of space objects, Space asset escorting.
The Space Maneuver Vehicle completed a successful autonomous approach and landing on its first flight test on 11 August 1998. The unmanned vehicle was dropped from an Army UH-60 Black Hawk helicopter at an altitude of 9,000 feet above the ground, performed a controlled approach and landed successfully on the runway. The total flight time was 1-1/2 minutes. During the initial portion of the its free fall, the maneuver vehicle was stabilized by a parachute. After it is released from the parachute, the vehicle accelerated and perform a controlled glide. This glide simulated the final approach and landing phases of such a vehicle returning from orbit.
The vehicle, which landed under its own power, used an integrated Navstar Global Positioning Satellite and inertial guidance system to touch down on a hard surface runway.

1.6. Classified programmes

1.6.1. X-41 Common Aero Vehicle (CAV)

The X-41 involves an experimental manoeuvrable re-entry vehicle carrying a variety of payloads through a suborbital trajectory, and re-entering and dispersing the payload in the atmosphere.
The Common Aero Vehicle (CAV) program is slated for a flight demonstration in FY2003. CAV will provide both an expendable and future reusable Military Space Plane [MSP] system architecture with the ability to deploy multiple payload types from and through space to a terrestrial target. A CAV will be able to achieve high terminal accuracy, extended cross range and be highly manoeuvrable in a low cost expendable or single use package supporting multiple military mission areas.

1.6.2. X-42 Pop-Up Upper Stage

The X-42 is an experimental expendable liquid rocket motor upper stage designed to boost 2000-4000lb (900-1800kg) payloads into orbit.

Pop-Up Upper Stages can expand the utility of advanced military spacecraft, allowing for wider ranges of payload deployment. This project includes concepts on technologies, which will improve pop-up upper stage technologies and/or stages themselves. The Orbit Transfer Propulsion AT DTO will demonstrate individual orbit transfer propulsion capabilities that significantly enhance low-cost, high-performance access to space via revolutionary propulsion techniques with improved designs, combustion and mixing technologies, and material advancements; and will develop and demonstrate chemical propulsion systems for military, civil, and commercial orbit transfer applications. Future orbit transfer systems will require advanced materials, low-cost power processing developments, and increased thruster efficiency in order to maintain the US global presence capability through enhanced strategic agility.

1.7. X-39

The designation X-39 is unassigned, but has been reserved for use by the USAF Research Laboratory. The designation may have been intended for subscale unmanned demonstrators planned under the Future Aircraft Technology Enhancements (FATE) programme to evaluate technologies for future fighters, but funding for these was transferred to the DARPA/USAF Unmanned Combat Air Vehicle demonstration, which involves similar airframe technologies.

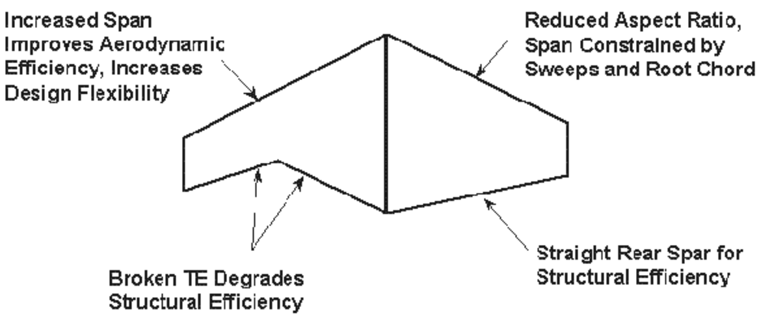

Figure 10. Lambda Wing Advanced Wing Planforms

FATE develops revolutionary technologies that will become the foundation for next generation warfighters. It will be these new systems that will provide the US with air and space superiority into the 21st century. Examples of FATE technologies include affordable low-observable data systems, active aeroelastic wing, robust composite sandwich structures, advanced compact inlets, photonic vehicle management systems, self-adaptive flight controls and electric actuation. Each of the major airframers has performed a long-range study on next-generation aircraft.

A subset of the national Fixed Wing Vehicle (FWV) Program, FATE was structured with three phases:

FATE I, Phase I: Define a set of aircraft technologies that must be flight test validated in a new air vehicle to meet FWV Phase I program goals for a fighter attack class of aircraft, including both inhabited and uninhabited aircraft.

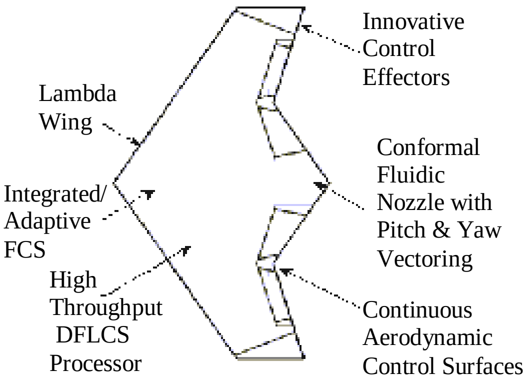

Figure 11. Uninhabited Vehicle 2001 Technologies

FATE I, Phase II: Develop preliminary vehicle design concepts, a demonstrator system, and demonstration plans.
FATE II: Develop, build and flight-test a demonstrator vehicle to achieve program goals.
FATE I, Phase I was used as a jump start for the Unmanned Combat Air Vehicle Advanced Technology Demonstration.

1.8. Hyper-X hypersonic experimental vehicle

NASA began a multi-year hypersonic flight-test program in 1996 by contracting for the fabrication of Hypersonic Flight Experimental Vehicle that will fly up to ten times the speed of sound

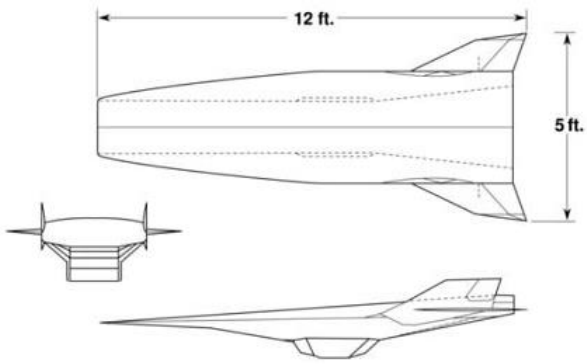

Figure 13. Hyper-X

Hyper-X, the flight vehicle for which is designated as X-43A, is an experimental flight-research program seeking to demonstrate airframe-integrated, "air-breathing" engine technologies that promise to increase payload capacity for future vehicles, including hypersonic aircraft (faster than Mach 5) and reusable space launchers.
Three flights of small-scale test vehicles are planned, two at M7 and one at M10, to demonstrate the operation of an airframe-integrated supersonic-combustion ramjet (scramjet).
Current spacecraft, such as the Space Shuttle, are rocket powered, so they must carry both fuel and oxygen for propulsion. Scramjet technology-based vehicles need to carry

only fuel. Scramjet engines are air-breathing, capturing their oxygen from the atmosphere. By eliminating the need to carry oxygen, future hypersonic vehicles will be able to carry heavier payloads. Scramjet technology is challenging because only limited testing can be performed in ground facilities.
Another unique aspect of the X-43A vehicle is the airframe integration. The body of the vehicle itself forms critical elements of the engine. The forebody acts as part of the intake for airflow and the aft section serves as the nozzle.

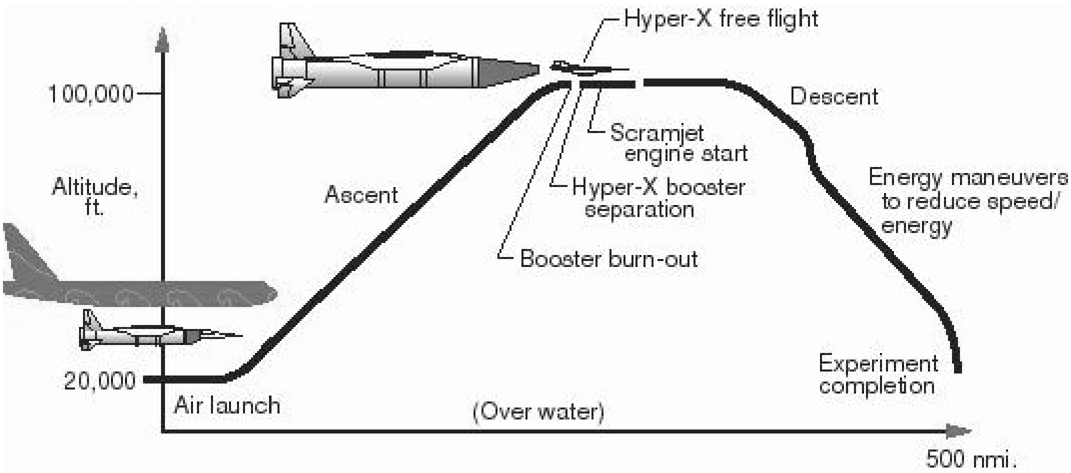

Figure 14.

The X-43 will be boosted to the test speed and altitude by a modified Orbital Sciences Pegasus air-launched booster. Launched from a B-52, the booster will accelerate the 1,000kg X-43 to M7 or M10 at altitudes up to 100,000 ft, where the X-43 will separate from the Pegasus and fly under its own power. The engine will operate for only 7s on the first flight, but this will be enough to collect measurements to validate windtunnel and computational data. The Hyper-X schedule calls for its first flight later this year (2000).

1.9. Crew Return Vehicle (CRV)

The X-38 is a technology demonstrator for a Crew Return Vehicle (CRV), or lifeboat, for the International Space Station (ISS).

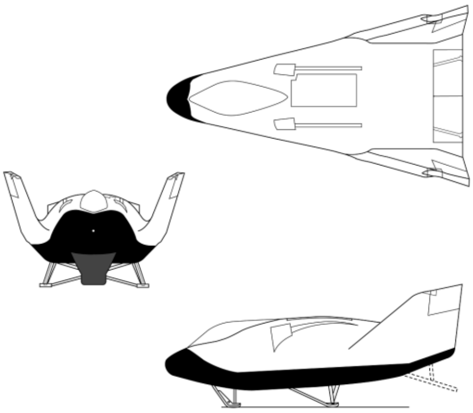

Figure 15. Crew Return Vehicle (CRV)

The CRV will allow the emergency return of ill or injured crewmembers from the station, emergency return of the crew if the station becomes uninhabitable, or the contingency return of the station crew if the shuttle becomes unavailable for crew exchange. The CRV could also form the basis for a vehicle that would be launched on the Ariane 5 booster.

The X-38 resembles the X-24A lifting body, and will glide back from orbit after jettisoning a de-orbit engine module. On entering the outer atmosphere, the X-38 crew will deploy a steer - able parafoil parachute for the final descent to landing. The vehicle, designed for seven occupants, will then be steered automatically to a precise landing on skids, rather than wheels. The crew will have the option to switch to back up manual systems, to control the orientation in orbit, pick a de-orbit site, and steer the parafoil.

Studies of the X-38 concept began at NASA's Johnson Space Centre (JSC) in 1995 and resulted in a contract being awarded to California-based Scaled Composites in 1996 for the construction of three full-scale atmospheric test vehicles. Drop tests of the first X-38, Vehicle 131, from the agency's B-52 began at NASA Dryden in March 1998. All did not go according to plan - the parafoil twisted and ripped during deployment, and tests were suspended.

Analysis showed that the drogue ‘chute had been distorted by higher than anticipated wake effects behind the vehicle. The parafoil was redesigned and heavier rigging lines added.

V132 has the full lifting-body flight control system, which allows the vehicle to fly autonomously before parafoil deployment.

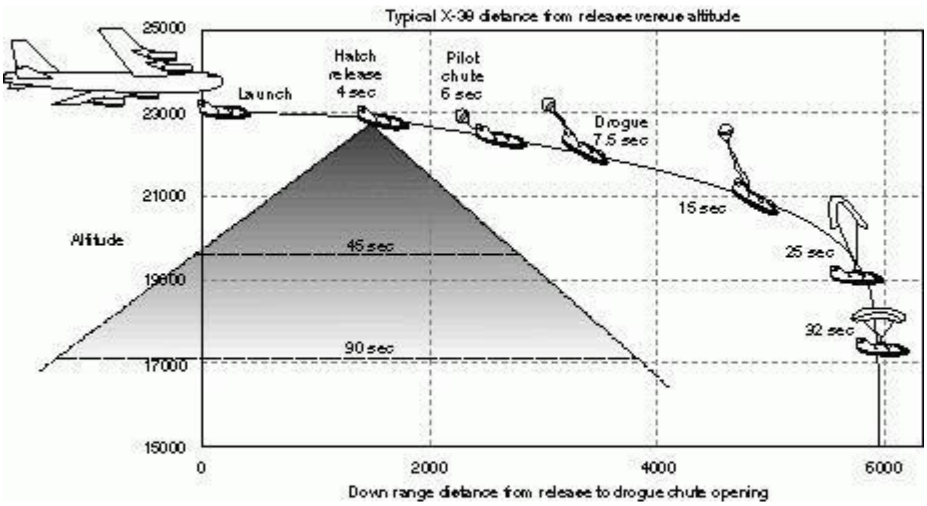

Figure 16. Test of the parafoil

The last test of the parafoil was conducted from a B-52 on 30 March 2000. The test also was the first use of automatic flight control software aboard the X-38.

The space flight vehicle, V201, is close to completion. A space test of an uncrewed X-38 is planned for 2002, when a vehicle already under construction at the Johnson Space Center, Houston, will be released from a Space Shuttle to fly back to Earth.

The first of a planned fleet of four operational CRVs is due to enter service on the ISS in 2003.

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