Changed by new generation aircraft possibilities in the military forces

Békési Bertold—Szegedi Péter—László Szilvássy

Abstract

The Joint Strike Fighter (JSF) Program represents potentially the single largest and most ambitious military development in more than 40 years. The program is poised not only to usher in a new generation of avionics sensor, stealth and manufacturing technology but to redefine defence procurement in the 21st century.
The contract mandates that the competing contractors build aircraft that will demonstrate three specific requirements: (1) commonality, (2) low-speed handling qualities and carrier approach and (3) STOVL hover and transition between conventional and vertical flight.
Two demonstrator vehicles are developing, one conventional take-off and landing (CTOL) version, the other short take-off and vertical landing (STOVL) version.

The Joint Strike Fighter (JSF) Program

US Air Force and US Navy Joint Advanced Strike Technology (JAST) and Defense Advanced Research Project Agency (DARPA) Common Affordable Lightweight Fighter (CALF) projects merged in November 1994, as JAST. The programme was renamed JSF in latter half of 1995.The Joint Strike Fighter program is responsible for the development of the next generation of strike-fighter aircraft. Initially, four contractors were involved: Boeing, Lockheed Martin, McDonnell Douglas/British Aerospace and Northrop. In late 1994 Northrop joined the McDonnell Douglas/British Aerospace team. On 16 November 1996, Boeing and Lockheed Martin were down-selected over the team headed by McDonnell for the further development of the Joint Strike Fighter, which may serve military of USA and other nations from the end of the next decade. Boeing’s experimental vehicle is the X-32 and the X-35 is Lockheed Martin’s demonstrator aircraft. Both contractors are designing and building their concept demonstration aircraft, performing unique ground demonstrations and developing their weapon systems concepts. Contractors demonstrate commonality and modularity, short take-off and vertical landing, hover and transition, and low-speed carrier approach handling qualities of their aircraft. The aim is to meet the strategic environment of the future, and to replace a whole spectrum of aircraft like F-16, A-6, F-14, F-18, Sea Harrier with minimal modifications to a basic type to reduce the development cost, production cost, and cost of ownership of the JSF family of aircraft. (figure 1.)
USA signed a memorandum of understanding (MoU) with UK on 20 December 1995. These MoU committed UK to participate in four year weapon system concept demonstration phase. Four partnership options are available. UK is only partner at level 1. International interest in three European nations joining JSF programme as limited collaborative partners (level 2, level 3). Netherlands and Norway signed MoU committing them to participate in Weapon System Concept Demonstration programme (WSCD) on 16 April 1997, with Denmark following suit later in year. Italy became `informed partner' in April 1998 and announced intention in January 1999 of deeper involvement. Turkish partnership agreement signed 16 June 1999 as Foreign Military Sales customer level (level 4). Other nations known to have expressed interest include Australia, Canada, France, Germany, Greece, Israel, Singapore, Spain and Sweden, which have all been briefed on JSF programme.

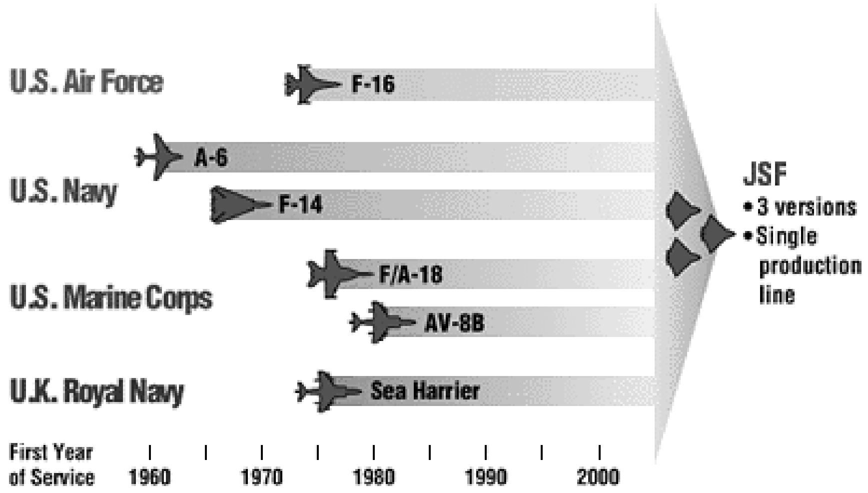

Figure 1.: Strike fighter replacement plan

The Joint Strike Fighter is the name given to a single-seat, single-engine strike fighter for the 21st Century. The JSF is a stealthy and attack aircraft, mostly for the air-ground role to services. It will provide 24-hour, adverse weather precision engagement capability the joint force commander needs for the joint force on the future. It is designed to affordably meet the needs of services, with improved survivability, precision engagement capability, the mobility necessary for future joint operations and the reduce life cycle costs associated with tomorrow's fiscal environment.
There will be several JSF versions, suited to best meet the unique needs of Services, while still mainting a 70 to 90% commonality rate between the versions, in order to reduce logistics problems. The three variants are a conventional take-off and landing aircraft for the US Air Force; a carrier based aircraft for the US Navy and a short take-off and vertical landing aircraft for the US Marine Corps and the Royal Navy and Royal Air Force.
The air force variant is the CTOL version to replace the USAF's F-16 multirole fighters and A-10 ground-attack aircraft and to complement F-22. The aircraft has no hover criteria to satisfy, and the characteristics and handling qualities associated with carrier operations do not come into play. As the biggest customer for the JSF, the service will not accept a multirole F-16 fighter replacement that doesn't significantly improve on the original. This version must be able to carry two 2,000-pound PGMs such as the JDAM, as well as two AIM-120 AMRAAMs for the air-to-air role, all internally. The JSF designs both include an external payload capability, for use when Air Dominance has been established over the battlefield and Stealth essentially becomes irrelevant.
The navy version, known as the Carrier-based Version (CV). The Marine variant distinguishes itself from the other variants with its short take-off and vertical landing capability. The STOVL version will have somewhat reduced combat radius requirements, with a combat radius of 450 to 500 nautical miles (nm) (~725km, ~800km) compared to 600nm (~970km) for the conventional landing and takeoff USAF and USN variants. Also, the STOVL version will only need to carry a minimum of two 1,000-lb (450kg) PGMs internally along with air-to-air missiles. These aircraft is a stealthy strike fighter to complement F/A-18E/F and to replace the US Marine Corps' AV-8B Harrier II and the RAF Harrier GR7/GR9s and Royal Navy Sea Harrier F/A2s. JSF will able to carry twice the payload over twice the distance of the GR7 and be capable of supersonic flight. It has armament requirements similar to the USAF weapons load requirements, and will operate in similar missions such as precision strike and air dominance, but there are several significant modifications incorporated into both competing CV JSF designs for the carrier operations. The aircraft has larger wing and tail control surfaces to better manage low-speed approaches. The internal structure of the Navy variant is strengthened up to handle the loads

associated with catapult launches and arrested landings. The aircraft has a carrier-suitable tailhook. Its landing gear has a longer stroke and higher load capacity. The aircraft has almost twice the range of an F-18C on internal fuel.
JSF's integrated avionics and stealth are intended to allow it to penetrate surface-to-air missile defenses to destroy targets, when enabled by the F-22's air dominance. The JSF is designed to complement a force structure that includes other stealthy and non-stealthy fighters, bombers, and reconnaissance / surveillance assets. (figure 2.)
The JSF requirement assumes the aircraft will be operating in airspace cleared of enemy fighters by the F-22. The JSF pilot will rely on getting his situational awareness from off-board sensors – F-22s in the area.

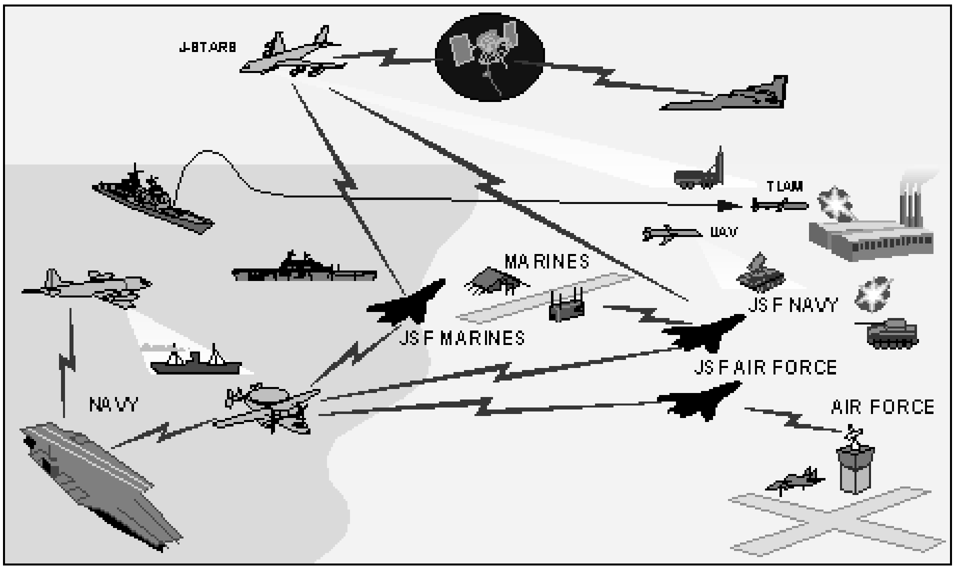

Figure 2.: The JSF complement services structure

The gun system for the JSF will be the Advanced 27 mm Cannon being developed by a team led by Boeing, with Mauser-Werke of Germany and Primex Technologies and Western Design of USA (figure 3.), plus the ability to carry a wide range of weapons both internally and externally. The cannon is a single barrel, gas-operated lightweight revolver gun that fires electrically-primed ammunition at 1800 rate of fire.
A blast bottle is incorporated in the system for gun gas management and reduced signature. The revolver breech provides reliability and reduced parts costs for greater affordability and reduced maintenance.
The ammunition feed system for the pod uses a cost-effective, highly reliable linear linkless design. The system features high-density, compact ammunition storage, including restoring spent cases to the magazine. The pod can be reloaded in less than five minutes.
The pod is hard-mounted to the aircraft using a specially designed hardback adaptor, providing firing-point accuracy and repeatability. Its design allows the cannon to be positioned within the pod for air-to-air or air-to-ground operations by cockpit selected positioning to + 1 degree elevation or -3 degree depression of the gun firing line. Designed for subsonic or supersonic flight, the gun pod is equipped with pylon adapters that provide rigid mounting and firing accuracy. The pod features easy accessibility to the cannon for loading and maintenance and can be installed on the aircraft in less than 10 minutes.

Figure 3.: The advanced 27 mm cannon for Boeing and Lockheed Martin JSF

The goal of the JSF propulsion system development is to produce two competitive, multi-service, physically and functionally interchangeable propulsion turbomachinery designs, both compatible with the STOVL components. Pratt &Whitney's JSF119 engine was selected by both JSF contractors, to power their competing demonstrator aircraft designs. The propulsion system concepts for the Boeing and Lockheed Martin configurations utilize new fan and low-pressure turbine (LPT) designs, which are based on F119 designs, materials and processes. The JSF119 engines were based on the F119 for commonality and cost reduction issues. For the demonstrator program, both concepts take advantage of F119 controls and externals, but each aircraft will use new nozzles.
Each competing design will be available in two versions: Conventional Take-Off and Landing and Short Take-Off Vertical Landing. Unlike the Harrier and Sea Harrier with their vectoring engine nozzles, the Boeing and Lockheed Martin designs achieve STOVL by differing methods.

Boeing's Joint Strike Fighter (X-32)

Boeing's team includes Raytheon, Pratt &Whitney, Rolls Royce, Messier-Dowty, BAE SYSTEMS and Flight Refuelling Ltd. The X-32 is Boeing's Joint Strike Fighter concept demonstrator aircraft (figure 4.). Boeing is using just two aircraft to demonstrate all government requirements. The X-32A demonstrates conventional takeoff and landing handling capabilities as well as demonstrates the low-speed handling qualities necessary for carrier-based landings, without modifications or changes to the aircraft. The second of the two concept demonstrators, the X-32B is demonstrating the company's direct-lift to the short takeoff and vertical landing requirements. Customer requirements included transitions to- and from vertical flight, hovers, vertical landings and short takeoffs. Rapid and direct transition capability is critically important for unrestricted STOVL operations and aircraft safety.
Boeing designed its JSF with side-mounted weapons bays. Side-mounted bays allow the pilot to open the bay away from enemy radar and drop a weapon without compromising the JSF's low observability and the pilot's safety.
The operational JSF can internally carry two air-to-ground weapons and two AMRAAMs as a baseline load. There are growth capability for two 900 kg bombs and the AMRAAMs and the internal 27 mm gun.
Systems for these planes include an integrated avionics system with multi-sensor fusion capability. Advanced electronically scanned array (AESA) radar will be integrated with the electronic warfare system and will have synthetic aperture (SAR) and ground moving target indicator (GMTI) modes.

The distributed infrared system (DIRS) and targeting FLIR (TFLIR) will be integrated with navigation and targeting systems. BAE Systems are providing the striker helmet mounted display system (HMDS).

Figure 4.: The X-32

The X-32A experimental vehicle has twin canted vertical tails, a deep fuselage and a prominent chin intake for its single Pratt & Whitney JSF 119 (SE614C) engine (thrust 155 kN), which is fitted with a two-dimensional thrust vectoring nozzle.
Carrier operations account for most of the differences between the Navy version and the other JSF variants. This X-32 has larger wing and tail control surfaces to better manage low-speed approaches. The internal structure of this vehicle is strengthened up to handle the loads associated with catapult launches and arrested landings.
The X-32B has the same wing as the X-32A and is approximately 90 percent common with the demonstrator. The aircraft has a direct-lift STOVL propulsion system (SE614S) with twin retractable side-mounted thrust vectoring nozzles and it has a translating inlet lip (figure 5.). This vectored thrust system, somewhat similar to the one in use on the Harrier Jump Jet. The capability to vector the lift nozzles at high power settings quickly will enable the JSF to make rapid transitions to and from wingborne flight and hover.
The propulsion design provides for both conventional and vertical flight using a proven two-dimensional, flow-blocking cruise nozzle coupled with a simple direct-lift nozzle system. It shifts to the vertical landing mode by redirecting unaugmented engine thrust downward through nozzles to produce lift. The Boeing STOVL propulsion system minimizes moving parts, which increases reliability and maintainability and reduces support costs.
The primary vertical lift of the X-32B propulsion system is from the two lift nozzles located between the turbine exhaust case and the augmentor of the SE614 engine, just aft of the aircraft center of gravity. The lift module consists of two vectoring lift nozzles with internal butterfly shutoff valves. The spool duct extends from the back of the lift module/transition duct to the augmentor. The nozzles can be rotated through a 55º arc from 45º aft of vertical to 10º forward of vertical. The lift nozzles are contained within the airframe near its center of gravity. When these nozzles are in operation, the main cruise nozzle is in the fully closed position.

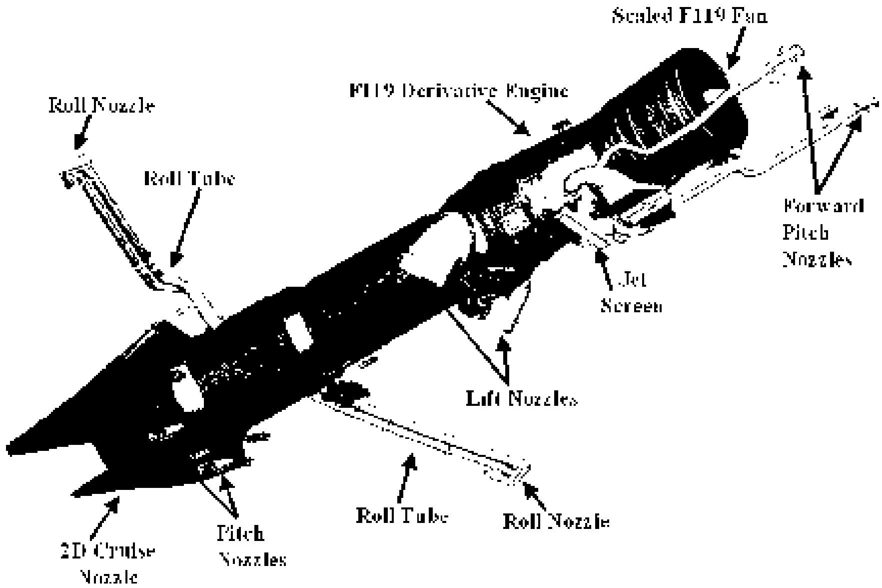

Figure 5.: STOVL propulsion system of X-32B

The lift module consists of a double walled off-take case, two butterfly shutoff valves and two vectoring, fixed area convergent/divergent lift nozzles. The lift nozzles vector by rotating on bearings in a manner similar to the Harrier. The lift nozzles are stored at the 45º position behind STOVL bay doors when not in use. When the aircraft is hovering close to the ground, the engine inlet is shielded from the effects of hot gas ingestion by a curtain of cool air from the jet screen nozzle, which is located on the bottom of the fan duct.
Pitch and yaw control during STOVL operations is by separate auxiliary nozzles located in the aft section of the aircraft. Roll control is maintained through similar nozzles located in the wing tips, which, like the other auxiliary nozzles, are supplied by fan duct air. During conventional flight, the lift system and ACS are not required. The butterfly valves on the lift module are closed, the air is directed to the cruise nozzle, the lift system nozzles and ACS nozzles are covered by actuated doors to reduce the drag on the air vehicle and to reduce the low observable signature.
Located just in front of the 2-D cruise nozzle are two twin roll tubes protruding from either side of the propulsion system. At the end of these roll tubes are the roll nozzles, which help to control the aircraft during semi-jet-borne and jet-borne (vertical/transitional) flight. Below the 2-D nozzle is a single Pitch nozzle. The cruise exhaust nozzle is a structurally integrated 2D design derived from the F119. The convergent flaps control the nozzle throat and fully close during jet-borne operations. Besides conventional throat and exit area control, the nozzle provides ±20º pitch thrust vectoring during conventional operation. All of the STOVL specific hardware on the X-32B weighs approximately 600 pounds (~270kg) and is eliminated on the X-32A and CV variants of the aircraft.
The Boeing Joint Strike Fighter programme has completed all of its government-defined flight-test requirements.

Lockheed Martin's Joint Strike Fighter (X-35)

The Lockheed Martin JSF team includes Northrop Grumman, Pratt and Whitney, Rolls-Royce and BAE SYSTEMS. Lockheed Martin's Joint Strike Fighter concept demonstrator is designated the X-35 (figure 6.). Two prototypes have been built. This JSF has 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 (SE611C for X-35A and SE611S for X-35B) engine, designed to reduce radar cross-section. To minimise radar signature, sweep angles are identical for the leading and trailing edges of the wing and tail (planform alignment). The fuselage and canopy have sloping sides. The seam of the canopy and the weapon bay doors are sawtoothed and the vertical tails are canted at an angle.

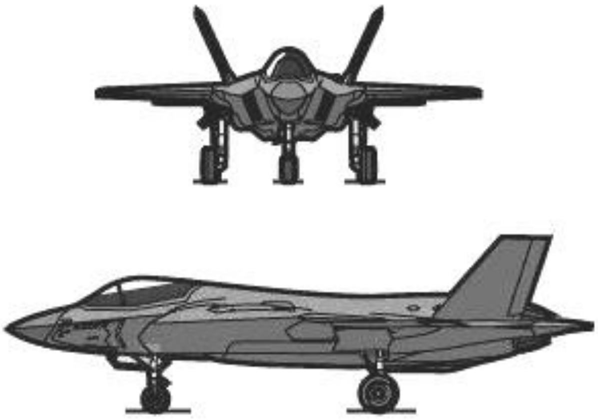

Figure 6.: X-35

The canopy, radar and most of the avionics are common to the three variants. Systems include an electronically scanned array (AESA), a multi-function radar, an electronic countermeasures equipment, an electro-optical targeting system, a distributed aperture infrared sensor (DAIRS) thermal imaging system and vision systems international and advanced helmet-mounted display. These JSF demonstrators have two fuselage weapons bays for the carriage of two 450 kg bombs and two AIM-120 AMRAAMS. Enlarged bays will carry two 900 kg bombs and the AMRAAMs instead. External hardpoints are provided for non-stealthy missions.

The X-35A is used to demonstrate engine compatibility and flying qualities for the conventional takeoff and landing version of the JSF. The X-35A has an internally mounted gun, infrared sensors and laser designator.

The aircraft has been reconfigured to the STOVL variant, the X-35B. This reconfigured aircraft demonstrates the performance and flying qualities of this variant. The X-35B has a STOVL propulsion system combining the basic JSF119 with a shaft-driven lift fan and three-bearing thrust vectoring main engine nozzle. (figure 7.). The lift fan inlet and auxiliary inlet are already installed on the X-35A, allowing for a rapid conversion to the STOVL configuration.

Lockheed Martin selected its propulsion system for three primary reasons:

- the STOVL Lift Fan thrust can be de-coupled from the P&W cruise engine, thereby enabling the cruise engine to be appropriately sized for conventional flight;
- the significant amount of thrust augmentation obtained from the Lift Fan greatly exceeds the additional weight incurred;
- the lower exhaust jet temperature and pressures result in a more benign ground environment during hover than that produced by direct lift.

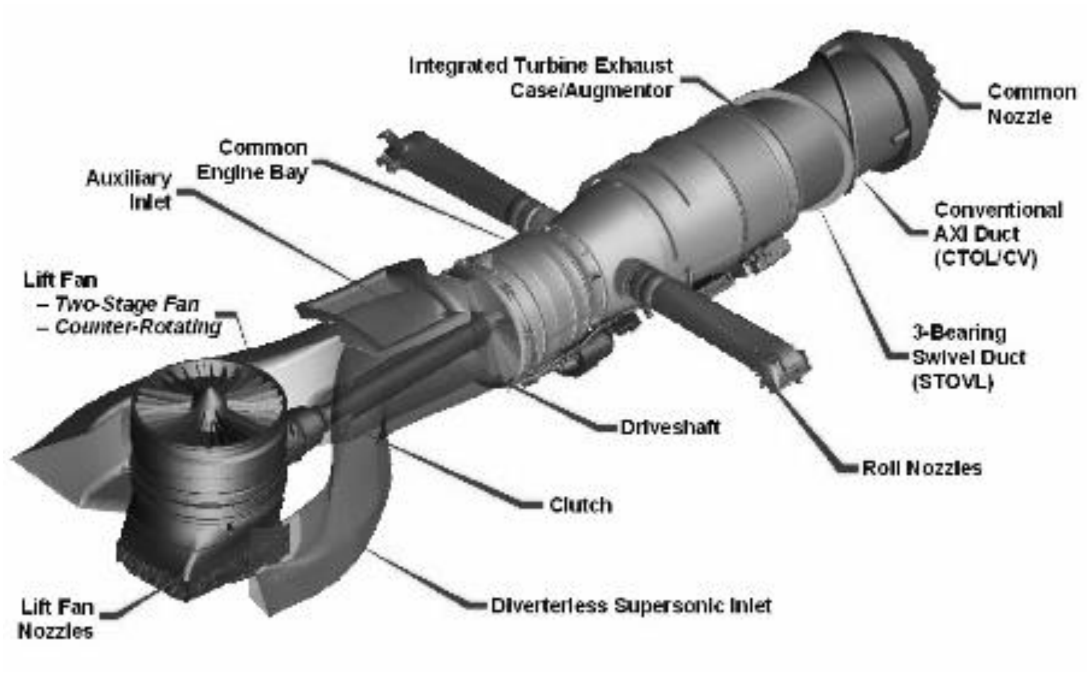

Figure 7.: STOVL propulsion system

A two-stage low-pressure turbine on the P&W SE611 engine delivers the horsepower to drive a new, larger fan than the one on the F119 and also powers the STOVL Lift Fan. STOVL lift system uses a vertically oriented Lift Fan. The Lift Fan provides up to 18,500 lb (82kN) of thrust. The Lift Fan has a clutch that engages for X-35C STOVL operations and a telescoping "D"-shaped nozzle to provide thrust deflection.

The Lift Fan is located behind the cockpit in a bay with upper and lower clamshell doors. When operating at normal speeds, the Lift Fan is capable of supporting nearly half of the weight of the X-35. Another STOVL feature on the X-35 is the auxiliary inlet for the main engine, located above the fuselage and behind the lift fan. This is used for the high air flow demands of hover.

The engine exhausts through a three-bearing swivel nozzle (3BSN) that can deflect the thrust from horizontal to just forward of vertical. Two roll ducts supplied by engine fan air provide roll control. Yaw control is through swivel nozzle yaw. Pitch control is effected via Lift Fan/engine thrust split.

For conversion to short take-off mode, the Lift Fan inlet and exhaust doors open, the inlet guide vanes are closed down to minimize airflow, and the clutch is engaged.

The inlet guide vanes are then opened to bring the Lift Fan up to speed and the D nozzle is rotated down to vector the Lift Fan thrust aft with the main engine thrust, this helps accelerate the aircraft forward and upward. After transitioning to wing-borne flight, the inlet guide vanes are again closed down to reduce the airflow through the Lift Fan, the clutch is disengaged, the nozzle is retracted and the inlet and exhaust doors are closed.

For the conversion to vertical landing mode, the aircraft decelerates and the Lift Fan inlet and exhaust doors open.

Simple configuration changes enable the conversion of the SE611 from a CTOL/CV to a STOVL engine. Engine controls and software will differ among the various configurations.

For the STOVL variant, the fan duct incorporates a bypass off-take system for aircraft roll control. A shaft is attached to the engine's low-pressure rotor. The axisymmetric nozzle is replaced with the 3BSN.

The roll control ducts are located on either side of the SE611 engine. These roll control ducts extend out to the point of the wing fold and are supplied with their thrust with the air from the engine fan. The ducts on the end of the post open and close differentially for roll control.
SE611 STOVL engine had operated with the a Lift Fan both engaged and disengaged with the three bearing swivel nozzle actuated from 0-90° at full STOVL power.

The landing approach control laws and flying qualities for the X-35 were designed primarily for the Navy environment. Most of those control laws were used in the X-35A to keep the variants flying qualities common. Both variants are also very similar in up-and-away flight. The difference in performance between the X-35C and X-35A at landing speeds is very noticeable. The X-35C can fly about 130 (~210km/h) to 135 knots (~217km/h) on the landing approach, about twenty-five knots (~40km/h) slower than the X-35A. The control laws on the X-35C have a couple of extra features that take advantage of the extra control surfaces. These features give the pilot more precise control of the glide path.
A Navy fighter has to take off and land from an aircraft carrier, which requires some structural considerations and flying qualities. This experimental vehicle has special characteristics to meet the demanding requirements of carrier operations, with no compromise. The internal structure of the carrier-based naval version is strengthened for carrier landings. Larger leading edge flaps and foldable wingtip sections provide a larger wing area for improved control and a special structure to absorb high-impact landings and it has a carrier-suitable tailhook. The Marine variant has no internal gun but an external gun can be fitted.
The JSF Navy variant provides the first carrier-supportable very low observable (VLO) "stealth" achieve first-look, first-shot air supremacy and enhance Navy war-fighter capabilities with breakthrough, all-weather precision strike. In-flight behavior of X-35C will be an extremely accurate predictor of the production airplane's flight characteristics. That will lower development costs and reduce technical risk.
The JSF Program Office will decide which aircraft design will prevail following the evaluation of information produced during the flight test program. There has been much talk about whether or not the Pentagon will award a winner-take-all contract for the JSF. It is quite possible that the production of the fighter may be split between the two contractors in order to sustain the industrial base. Whatever the outcome of the selection, within the next decade there will be another supersonic STOVL fighter serving the US and her allies.

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