

## A History of the Joint Strike Fighter Programme

### The Search for a Harrier Replacement

The JSF programme emerged from transatlantic co-operation to find a Harrier replacement and a need for the US DOD to replace its vast fleets of ageing tactical aviation, amassed during the cold war period. The JSF programme emerged from a consolidation of many others, occurring against a downturn in post-cold war tactical aviation needs, which consequently drove the consolidation within the Aerospace industry. The JSF story is as much about the industry as it is about the aeroplane. After the US DOD bought the Harrier from Hawker-Siddeley in its AV-8A guise in the **1970's** it attempted to develop a US VSTOL aircraft in 1973 but had been unsuccessful with the Rockwell XfV-12A Program. A joint United Kingdom (UK) / United States (US) approach was then undertaken to field AV-8A and GR-3 replacements in the **1980's** with the McDonnell-Douglas / BAe AV-8B for the United States Marine Corps (USMC), and as the GR-5 for the Royal Airforce (RAF).

During **1981**, the US DOD launched the VMFX program to replace Grumman F-14A and Grumman A-6E aircraft with a common aircraft. In **1983** The USN dropped this approach as being too expensive launching an upgrade of a small number of F-14s to F-14D standard and A-6E to A-6F with Boeing while simultaneously launching the Advanced Tactical Aircraft (ATA), which was to be a stealthy attack aircraft.

As no replacement was evident for the AV-8B and GR-5 aircraft, the UK Royal Aircraft Establishment (RAE, now DERA) & the US Defence Advanced Research Program Agency (DARPA, now ARPA) jointly studied the required technologies for a supersonic replacement. A Memorandum Of Understanding (MOU) was signed between the respective governments in **1986** to formally launch the Advanced Short Take-off & Vertical Landing (ASTOVL) Program.

Between **1986** and **1989** the ASTOVL programme studied various propulsion concepts: Plenum Chamber Burning, Remote Augmented Lift, lift engine ejector and tandem fan. These contracts crucially involved the propulsion companies: Rolls-Royce, Pratt & Whitney and General Electric. The prototyping of complex military systems had been recommended to Congress in the Packard Report as early as **1986**.

The US DOD launched the Multi-Role Fighter (MRF) program in late **1989** to look at the replacement of ageing USAF aircraft specifically the General Dynamics F-16A/B, General Dynamics F-111D/E/F and Fairchild A-10. MRF was planned to run until late 1993.

As there was no replacement in sight for the USMC AV-8B aircraft, the DARPA received further funding under the Supersonic STOVL Programme (SSF) which was divided into 2 phases: Phase 1A ran between **1988** and **1989** and Phase 1B in **1990**.

Under the Advanced Tactical Aircraft (ATA) programme, the McDonnell Douglas / General Dynamics A-12 Avenger II had been selected as the replacement for the USN / USMC Grumman A-6F Intruder; however in **January 1991** this programme was cancelled due to cost overrun. Simultaneously the US Navy (USN) dropped its plans for a Navalised ATF (NATF) focusing its funding on a new dual role aircraft known as the Advanced Strike Fighter (A/FX) which was launched in **1991** to develop a replacement for the A-6F, F-18C/D and F-14D. The A/FX was already too expensive for the USMC who by then was planning on replacing both its AV-8B and F-18D aircraft with a single ASTOVL type, a decision which it had begun to make as early as 1987.

## Creation of the CALF Programme



During **1992** Northrop purchased a 49% stake within Ling-Temco-Vought (LTV). The USN provided follow on funding to create SSF Phase II, which in early **1993** was renamed the programme, the Common Affordable Lightweight Fighter (CALF). This was to run from early **1993** for 3 years in order to validate critical STOVL technologies. CALF launched a program to first test scale model aircraft with active propulsion and control systems – a major lesson learned – through omission - from the 1973 Rockwell XFV-12A Program. At this time there were numerous CALF bidders: Boeing, McDonnell Douglas, Lockheed, General Dynamics, Northrop, Grumman. During the CALF programme, LMSW revised its twin fan arrangement to a single fan driven by a drive shaft linked to the turbine. Paul Bevilacqua at LMSW patented this design in 1993. In **March 1993** Lockheed purchased the General Dynamics (GD) Ft Worth fighter division from GD.

The **September 1993** US government "bottom-up review" cancelled the USAF's Multi-Role Fighter (MRF) and the USN A/F-X. The USN was forced to choose between the f/A-18E/F and A/FX and chose the F/A-18E/F, which the USMC did not want. This funding constraint consolidated the service requirements establishing a new Program – the Joint Advanced Strike Technology (JAST) Program in **January 1994**. CALF, subsequently renamed the Affordable Lightweight Fighter (ALF), became the primary focus of JAST. To confuse matters further, JAST was also considering the modification of the CTOL versions of the aircraft to perform in a STOVL role.

In **February 1994**, Boeing and Lockheed-Martin contemplated a merger, which did not materialise, however this drove Northrop and British Aerospace (BAe) to join McDonnell-Douglas to support the CALF programme. In **April 1994** Northrop purchased Grumman to become the Northrop Grumman Corporation (NGC). Later that year NGC purchased the remaining stock of LTV.

The US Congress subsequently mandated the merger of JAST with the DARPA Advanced Short Take-Off / Vertical Landing programme. The JAST Programme initially explored a wide range of potential strike warfare concepts using six-month, Concept Exploration (CE) study contracts awarded in **May 1994** which showed that a "tri-service family" of aircraft was indeed the most affordable solution to the collective joint-service needs.

Following numerous trade studies, two critical decisions were made: the JAST family of aircraft would be single-crew and single-engine. This was a significant concession on the part of the US Navy attack/fighter aircraft, which has a strong preference for two engines.

Later this year Congressional funding required that the CALF programme be absorbed into JAST, becoming its centrepiece.

In **June 1994** Lockheed agreed to merge with Martin-Marrietta (the old Gen Martin company) to become the Lockheed-Martin.

Boeing, LM, McAir & NGC were each awarded 15-month Concept Definition and Design Research (CDDR) contracts in **December 1994**. NGC and McAir/BAe teamed shortly after the CDDR contracts were awarded. The contractors refined their Preferred Weapons System Concept (PWSC) designs and performed a number of risk reduction activities (e.g., wind tunnel tests, powered-model STOVL tests, and engineering analyses).

In **April 1995**, all three of the contractor teams selected derivatives of the Pratt & Whitney (P&W) F119 engine to power their aircraft. Accordingly, in **November 1995**, P&W was awarded a contract for preliminary design of each of the primary JSF engine concepts.

Concurrently, General Electric was awarded a contract to investigate whether the GE F110 or YF120 could be developed into an alternate engine for one or more of the JSF variants. In early **1996**, the YF120 was identified as the "best fit" for a tri-service solution and GE initiated preliminary design efforts. Final Requests for Proposal (RFP) were issued to the contractors in **March 1996**, by which the JAST program name had changed to Joint Strike Fighter (JSF).

During **1996** Boeing bought the Defence divisions of Rockwell further consolidating the tactical aviation field.

## JSF emerges from JAST

The JAST programme mission was to define and develop aircraft, weapon, and sensor technology that would support the future development of tactical aircraft. The programme's remit was then narrowed to consider the development of a family of aircraft to replace several ageing US and UK aircraft. The guiding principal was that there would be a single basic airframe design with three distinct variants to be developed. These three variants were to feature a high degree of commonality to meet these affordability requirements, with each being tailored to meet any unique requirements of each service:

- a conventional takeoff and landing aircraft (CTOL) variant for the US Air Force, which features a larger internal weapons bay and greater internal fuel capacity, while the low-observable design gives greater stealth. The CTOL variant for the U.S. Air Force would complement the F/A-22A Raptor and replace both the F-16 Fighting Falcon and the O/A-10A Thunderbolt;
- a short takeoff and vertical landing (STOVL) variant, for the US Marine Corps and the UK, which features a shaft-driven lift fan propulsion system that multiplies vertical thrust, enhancing short takeoff and landing performance without any compromise to the fighter ability of the aircraft; The STOVL variant for the USMC would replace both the AV-8B Harrier and the F/A-18D Hornet;
- a carrier takeoff and landing (CV) aircraft, for the US Navy, which has increased internal fuel capacity for greater combat striking range. Larger wing tail surfaces enable superior, carrier-suitable handling qualities. The Carrier (CV) variant for the U.S. Navy would complement the F/A-18 E/F Super Hornet.

JAST would look at creating an aircraft with a common airframe, using new technology to reduce development and manufacturing costs and to be manufactured in the thousands. It had to be affordable enough to replace the MRF in sufficient numbers, ultimately to complement the F/A-22A Raptor. JAST aircraft roles would predominantly be strike/attack for the first day of war – the aircraft had to be stealthy, have long range and carry its ordnance internally (all requirements that had been originally specified for the A-12).

There was scepticism and hostility that one aircraft type could be effective for all the Services. The JAST Program looked to overcome previous inter-service difficulties last exposed during the Tactical Fighter (TFX) Program in the late 1960's, which spawned the General Dynamics F-111 for the USAF.

The JAST Program office in Washington (Crystal City) determined that all the Services had similar but not identical operational requirements that could be met not by a single airframe but a family of airframes sharing more than 80% commonality with which to generate cost savings. The 'affordable fighter' concept was born. No other fighter has ever had to serve so many different roles. The goal was to save billions of dollars by virtue of the fact that each variant would share a significant number of parts and have systems in common.

The **3 JAST bidders** were:

- Boeing Military Aircraft (based in Seattle, WA);
- McDonnell-Douglas Aircraft Co. (McAir) teamed with NGC and BAe based in St Louis, MO;
- Lockheed-Martin Skunk Works (LMSW) (based in Palmdale, CA).

The key to eventual STOVL success would always evolve around the propulsion system; originally CALF had pitted a General Electric (GE) Gas Driven Lift Fan (GDLF) against the Pratt & Whitney (PW) Shaft Driven Lift Fan. The Boeing airframe incorporated a direct lift system reminiscent of the Harrier because it was considered by Boeing to offer the lowest overall technical risk. Boeing's plan-form was radically new and similar to that which it originally proposed under CALF. Having found that the General Electric (GE) Gas Driven Lift Fan (GDLF) was not viable from a mass/airflow perspective, the McAir/NGC/BAe team proposed a system of separate lift engines to that use for horizontal flight within an aircraft configuration reminiscent of the YF-23, an approach not favoured by the USMC due to logistics and life cycle cost considerations.

LMSW had opted for the shaft-driven lift fan coupled to a directed engine exhaust - for reasons of reduced ground effect & the fuel fraction advantages (lift fan removal gave the CTOL and CV versions significantly more range). Again LM's plan-form was reminiscent of a single engine YF-22A which was evident of their low risk approach.

In **November 1996**, Boeing and Lockheed-Martin (LM) were selected to progress to the next stage of the Program. Consolidation within US industry was still in progress, McDonnell-Douglas merged with Boeing, NGC and BAe changed teaming arrangements and joined LM.

In **March 1996**, the JAST Program office released an RFP, creating the first operational requirement: the Joint Interim Requirements Document (JIRD). This changed the programme name in **Jun 1996** to the Joint Strike Fighter (JSF).

The US DOD elected to move the JSF design study into a 2-phase development program, divided as follows:

- Concept Demonstration Programme (CDP) to fly a prototype flight demonstrator.
- Preferred Weapon System Concept (PWSC).

PWSC was then sub-divided into 2 further phases, which have a certain degree of overlap:

- Engineering & Manufacturing Development (EMD) phase, to productionise the demonstrator.
- Initial rate production: low rate (LRIP) followed by full rate (FRIP).

## Concept Demonstration Phase

In **November 1996**, the 2 remaining competitors were awarded the CDP prime contracts:

- Boeing
- LMSW, NGC & British Aerospace (now known as BAE Systems).

Each company adopted a slightly different approach. The competing teams were funded to each build 2 off prototype aircraft to underline the concepts first identified under JAST. This part of the programme was known as the Concept Demonstration Phase (CDP). These were the first experimental aircraft made by a US Prime within a generation. These aircraft were known as the Concept Demonstration Aircraft (CDA) covering all JSF variants. This strategy would clearly demonstrate the viability of the selected design solution, and permit a 'fly off' competition using service aircrew under a joint flight test team.

**Boeing** were to build 2 CDA:

- X-32A to demonstrate both the USAF and USN Conventional Take-Off and Carrier landing Versions (CTOL/CV).
- X-32B, the Short Take-off and Vertical Landing (STOVL) for the USMC.

**Lockheed-Martin** were to build 3 configurations from 2 CDA:

- X-35A the CTOL version.
- X-35C the CV version using a larger wing for reduced approach speed.
- X-35B the STOVL version built from the X-35A.



Both Boeing and LM built their respective aircraft at Palmdale: Boeing at the old Rockwell facility, re-named the "Phantom Works", and LM at the "Skunk Works" – which had relocated from Burbank. Both Primes entered the 'fly off' stage, successfully flying all variants of their respective demonstrator aircraft using contractor, USN, USAF, USMC, RN and BAES pilots.

All three LM JSF demonstrators completed government-mandated flight-test requirements. The X-35A (U.S. Air Force), X-35B (U.S. Marine Corps/U.K. Royal Navy and Royal Air Force) and X-35C (U.S. Navy) all demonstrated aerial refuelling, handling qualities, acceleration and deceleration, formation flying at different altitudes, and logged many other achievements, including supersonic flight. Additionally, the X-35C carrier variant made the first-ever transcontinental flight of an X plane, completed 250 practice carrier landings at US Naval Air Station Patuxent River, Maryland and was flown by eight pilots from the U.S. and U.K. The short-takeoff/vertical landing (STOVL) X-35B, with its unique shaft-driven lift-fan propulsion system, achieved the JSF program's first vertical takeoff and vertical landing on **23 June 2001**. It went on to complete 17 vertical takeoff/hover/vertical landing missions before fulfilling all government requirements in subsequent flight testing.

All LM aircraft variants flew an intensive programme of flight testing between **October 2000** and **June 2001**, which established an unprecedented string of flight-test records, maintaining an extraordinarily high level of reliability throughout the testing period with all requirements and objectives achieved or exceeded.

The JSFPO issued the Call For Improvement (CFI) proposal request to both primes in **November 2000**, which resulted in responses that were reviewed by the US DOD during **July to September 2001**. On the **26 October 2001** the US DOD announced a 'down-select' to one contractor: that the LM, BAES & NGC JSF team had been awarded the winning contract.

Subsequently, the LM JSF team was awarded the prestigious 2001 Collier Trophy for the work performed on the Integrated Lift Fan Propulsion System (ILFPS) on the X-35B during CDP. The industry team: Pratt & Whitney, Rolls-Royce, LM, NGC and BAES along with the JSF Joint Programme Office, designed and fully demonstrated the ILFPS as part of the STOVL variant of the JSF.

## System Development and Demonstration

At SDD contract award, the traditional Engineering and Manufacturing Development phase was renamed the System Development and Demonstration (SDD). Following on from CDP, the \$18.98 billion SDD contract has been recognised the largest single source defence contract in US history. On this programme the amount of Government Furnished equipment (GFE) was limited to the engine. The engine team – Pratt & Whitney and Rolls-Royce – were awarded a \$4 billion contract for the SDD phase for the engines. The aircraft nomenclature was formally agreed to be known as the F-35, with 3 sub-variants: F-35A (CTOL), F-35B (STOVL) and F-35C (CV).

The 10-year SDD phase involves the production of an initial 22 aircraft — 14 flight test aircraft and eight ground test aircraft to be tested for safety, effectiveness and to verify the proposed design. The 14 flying aircraft are five CTOL, four CV and five STOVL. Long lead part production for the 22 aircraft has started, and the first aircraft will start coming together on the floor in the last quarter of 2004.

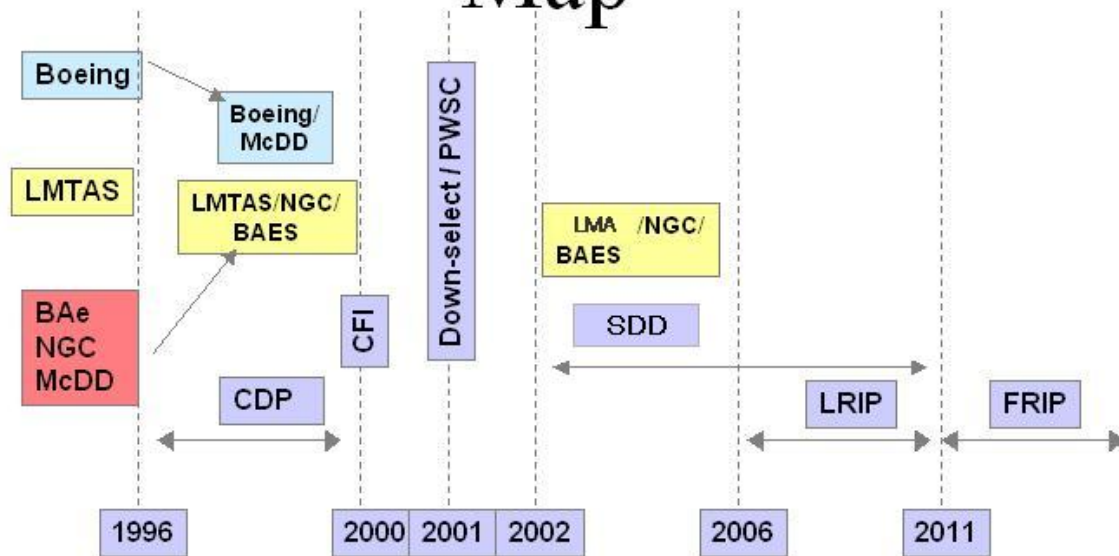
The SDD aircraft will be operated from 3 Flight Test centres in the Continental US for approximately 7 years.

After SDD is completed, the Defence Acquisition Board (DAB) will sit and review aircraft suitability for series manufacture in a series of Defence Acquisition Events (DAE). This formally will launch the initial production orders, known as Low Rate of Initial Production (LRIP) and later Full Rate of Initial Production (FRIP). What is unusual about the F-35 programme is that LRIP and FRIP are not sequential to SDD. LRIP occurs in parallel in order to bring the entry into service as quickly as possible; see Figure1 below.

What is at stake is the huge cost of maintaining an ageing fleet of legacy aircraft which will increase if JSF does not enter service on time.

Current stated requirements of the initial customers, US Air Force, US Navy, US Marine Corps and the Royal Navy and Royal Air Force, will result in the manufacture of approximately 3,000 aircraft. There is also an export potential of a further aircraft quantities.

# JSF Program Route Map



## Links:

- [www.lockheedmartin.com](http://www.lockheedmartin.com)
- [www.jsf.mil](http://www.jsf.mil)
- [www.mod.uk](http://www.mod.uk)
- [www.vstol.org](http://www.vstol.org)
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