



## JOINT STRIKE FIGHTER

‘ The Martin-Baker story so far..’

S.D.Roberts

Martin-Baker Aircraft Co.Ltd  
Lower Road, Higher Denham,  
Near Uxbridge, Middlesex  
UNITED KINGDOM UB9 5AJ

## SAFE EUROPE SYMPOSIUM

Stockholm, SWEDEN  
March 18<sup>th</sup> to 20<sup>th</sup> 2002

---

### ABSTRACT

Martin-Baker (MBA) has been involved with the Joint Strike Fighter (JSF) Program since Feb '96, known as the Joint Advanced Strike Technology (JAST) Program. JAST gave way to the Joint Strike Fighter (JSF) Program starting with the Concept Demonstration Phase (CDP).

MBA successfully completed the development of an off the shelf seat during CDP for one of the Primes, this led to the installation of flight seats for 2 experimental aircraft.

Having initially worked with all prime contractors, MBA has experienced the entire JSF down-select process at close hand. This process has led to the winner, Lockheed Martin, being selected for the next phase of the Program – known as System Development & Demonstration (SDD).

The JSF SDD Program requirements have been some of the most demanding to address, requiring innovative solutions, without introducing any inherent program risk.

It is the largest defence acquisition Program in history, the JSF Program will re-shape the aerospace industry as a whole, as it is a truly multi-national undertaking and quite possibly the last all-new unmanned fighter.

### 1. BACKGROUND

The majority of the in-service United States (US) tactical fighter aircraft have an average age approaching 22 years. The Joint Strike Fighter (JSF) Program has its origins in a US military requirement to replace these ageing aircraft, predominantly in the strike role, for the United States Air Force (USAF), USAF Reserve (USAFRes) and Air National Guard (ANG) inventories with a single weapons platform and maximum commonality between types.

Aircraft in the USAF inventory include the O/A-10A Thunderbolt, F-16C/D Falcon and F-15E Strike Eagle. Should a single type replace these aircraft, the trend forever increasing life cycle costs would be reversed. This has been inherent with the introduction of more capable aircraft in each successive generation.

The US Navy (USN) is currently replacing its older F-14A/B Tomcat, F/A-18C/D Hornet aircraft with F/A-18E Super Hornets.

The USN identified a need to replace F-14D Tomcat aircraft and US Marine Corps (USMC) F/A-18D Hornet and AV-8B Harrier with a single aircraft type, this type would also fulfil the role of the A-6F Intruder which has never been replaced in its role of first day strike.

Replacement of all these aircraft would be unaffordable without commonality.

### 1.1 JAST

The United Kingdom (UK) Royal Aircraft Establishment (RAE, now DERA) & the US Defence Advanced Research Program Agency (DARPA, now ARPA) have been jointly studying the required technologies for a supersonic replacement of the venerable Harrier aircraft. 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.

In parallel, and only within the US, the Defence Advanced Research Program Agency (DARPA) launched the Common Affordable Lightweight Fighter (CALF) Program in 1993, to validate critical STOVL technologies, this launched a Program to test scale model aircraft with active propulsion and control systems – thereby avoiding certain pitfalls first identified in 1973 with the Rockwell XFV-12A Program.

The 1993 US government “bottom-up review” cancelled the USAF’s Multi-Role Fighter (MRF) and the USN’s Advanced Strike Fighter (A/F-X) establishing a new Program – the Joint Advanced Strike Technology (JAST) Program. In 1994 CALF was absorbed into JAST becoming its centrepiece. 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.

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 USN’s A-6F Intruder replacement, the A-12 Avenger II Program (cancelled in 1991). It had to be cheap enough to replace the MRF, which was the F-16’s intended replacement both in the US and around the world.

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 determined that all the Services had similar but not identical operational requirements that could not be met 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.

The differing aircraft versions were defined as follows:

- Conventional Take-Off and Landing (CTOL) for the USAF.
- Carrier Version (CV), a conventional aircraft with a wing of increased surface area to reduce the carrier approach speeds, for the USN.
- Short Take-Off and Vertical Landing (STOVL) for the USMC.

## 1.2 JSF

In Mar '96, the JAST Program office released an RFP, creating an operational requirement. This changed the Program name in Jun '96 to 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 Phase (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).

The JSF aircraft would be introduced into service in a supporting role for the USN F/A-18E and USAF F-22 Raptor aircraft. From conception the JSF Program has had foreign investment, principally from the UK, as the UK is looking ahead to replace GR9 and FA-2 Sea Harrier aircraft in the new Joint Harrier Force based at RAF Wittering. Several other countries have also invested money into the JSF Program albeit at a lower level to observe the aircraft development, without influencing the design configuration.

The original 3 JSF bidders were:

- Boeing Military Aircraft (based in Seattle, WA).
- McDonnell-Douglas Aircraft Co. (McAir) teamed with Northrop-Grumman Corp (NGC) & British Aerospace (BAe), the team being based in St Louis, MO.
- Lockheed-Martin Skunk Works (LMSW) (based in Palmdale, CA).

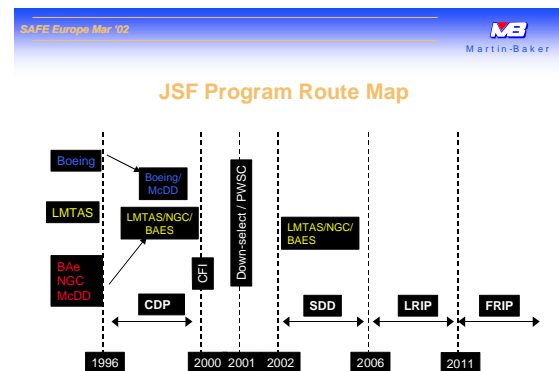
The Boeing airframe incorporated a direct lift system reminiscent of the Harrier because it was considered by Boeing to offer the lowest overall technical risk. Boeing's plan-form was radically new and similar to that which it originally proposed under CALF. The McAir/NGC/BAe team proposed

a system of separate lift engines to that use for horizontal flight within an aircraft configuration reminiscent of the YF-23. LM opted for a different arrangement again in which a separate shaft-driven lift fan was 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.

In Nov '96, Boeing and Lockheed-Martin (LM) were selected to progress to the next stage of the Program. Consolidation within US industry was still rife, McDonnell-Douglas merged with Boeing, NGC and BAe changed teaming arrangements and joined LM.

The 2 remaining bidders were then:

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



## 1.3 CDP

To avoid making the same mistakes from the Rockwell XFV-12A Program, the competing teams were funded to each build 2 off prototype aircraft to underline the concepts first identified under JAST. This Program was known as the Concept Demonstration Phase (CDP). These were the first experimental aircraft made by a US airframer in 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 built 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 built 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 LMSW (relocated from Burbank). Both Primes entered the 'fly off' stage, successfully flying both variants of their respective demonstrator aircraft using contractor, USN, USAF, USMC and RN pilots.

## 2. MARTIN-BAKER INVOLVEMENT

The complete delegation of the whole weapons system design, supply and support to industry is a departure from traditional U.S military procurement activities. Historically many elements of such a Program from engines to ejection seats would have been defined as Government Furnished Equipment (GFE), i.e. imposed on the contractor. This has led to a poor optimisation of equipment suppliers within the cockpit, but also limited the expertise within the US industrial base as far as crew escape development is concerned.

Additionally, the legacy of Program cost over-runs and poor schedule adherence, has caused the JSF acquisition and life cycle cost to carry equal weighting to that of performance. With these points in mind both Boeing and LM submitted Requests For Proposal (RFP) to MBA and its competitors in order to identify what industries capabilities were.

### 2.1 Early Proposal Effort

In response to the Feb '96 LMSW JAST seat RFI, MBA submitted its first response in Mar. After an initial meeting in Palmdale, MBA submitted a further response to the JSF CDP seat RFP in Dec '96. MBA had proposed both the NACES T-45A and Mk16A derivatives and was, however, not successful. As an affordability measure, LMSW chose to use Stencel SIIIS-AV8B ejection seats – which they held in stock.

At this time the McAir JSF bid was removed from the competition, Boeing and McAir subsequently merged to become Boeing. Boeing subsequently selected MBA ejection seats for use within CDP.

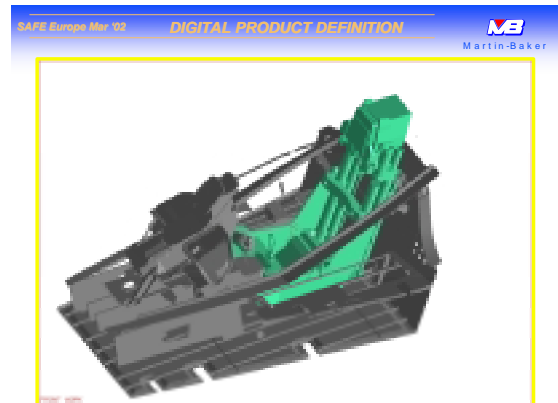
### 2.2 MBA during CDP

For Boeing, MBA developed a derivative of the Eurofighter (EF) Mk16A ejection seat, which is installed in the EF Flight Development aircraft.

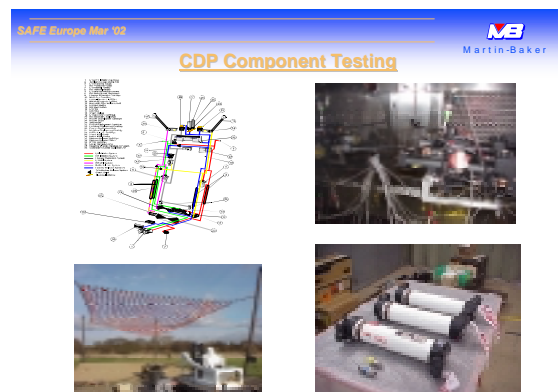
The seat and cockpit interfaces were designed without the traditional requirements for extensive use of mock-up hardware.

It is the extensive use of electronic design in the early stages of any program, which enable the following affordability initiatives to be implemented:

- Design For Manufacture and assembly (DFMA).
- Cost As an Independent Variable (CAIV).



MBA conducted a 2-year program to certify the Mk16B ejection seat for X-aircraft operation. This involved component, sub-system and ejection testing.



The CDP ejection testing was conducted entirely at the MBA facility at Langford Lodge using both its own platforms and the X-32 sled forebody.



MBA delivered flight seats for the X-32A (CTOL/CV) and X-32B (STOVL) aircraft and was privileged to attend the rollout of both aircraft from the Phantom Works in Dec '99.

### 2.3 PWSC Proposal Effort

It was clear by both Primes that prior selection during CDP did not constitute a guarantee for selection of the follow-on PWSC Program. Part of the JSF culture change was to change the supply of the ejection seat from Government Furnished

Equipment (GFE) to Buyer Furnished Equipment (BFE).

As a result an open competition was held with both Prime contractors formally tendered 2 rounds of proposals. The evaluation method was run along the guidelines that the Primes themselves were to be evaluated. MBA won this competition – both Primes independently selecting on cost and technical merit, and were openly judged “best value”.

Prior to the winning prime being announced, the period from the end of CDP up to PWSC contract award was known as the “bridging” period. Here the US Govt made available certain funds in order to complete the CDP flight phase (which was running a little late for both Primes). Crucially this bridge funding allowed the design teams to be retained for a delayed EMD.

The CDP ‘fly off’ competition was vitally important to the overall scoring of the Primes, any major difficulties experienced within this flight phase could potentially have created an early down select.

The US Govt issued a Call For Improvement (CFI) proposal in Nov '00, to which both Primes responded in Feb 2001. Loss of the JSF contest would deal a serious blow to the ability for the loser to stay within the military aircraft business. Between Feb and Sept '01 both Primes completed final proposals to the USG.

The USG evaluated their responses and Ed Aldridge the Indersec made the down-select announcement on 26 Oct 2001. This down select formally started the EMD Program, which was renamed “System Development & Demonstration” - SDD.

It was later revealed that LM won the PWSC contract based upon the inherent advantages of the lift fan design, which was considered by the less risky in terms of thrust growth. Had the lift fan concept failed during CDP, then Boeing would have won outright. Boeing did not appeal the decision and gracefully conceded victory.

## 2.4 SDD Overview

The SDD Program officially commenced from the down-select date, 01 Nov '01, and this milestone was known as the Authority To Proceed (ATP). During SDD 14 flight development aircraft will be constructed for verification of specification compliance and evolution of the production aircraft configuration.

SDD will last approximately 126 months from ATP and there is some overlap with the 5 batches of LRIP aircraft. A third separate contract is due to be let in 2005/6 with initial LRIP due to commence in 2008.

At the end of SDD the Defence Acquisition Board (DAB) will sit and consider whether the air vehicle is mature enough for FRIP. Current production units of this single seat aircraft stand at over 3002 without Foreign Military Sales (FMS) taken into account.

The industrial implications of winning the JSF contract were enormous. Baseline customer aircraft are as follows:

- 1763 F-35A CTOL for USAF.
- 609 F-35B STOVL for USMC.
- 480 F-35C CV for USN.
- 150 for RAF/RN (specific variant undecided).



Recently both the Netherlands and Canada have shown an interest in participating within SDD; an MOU is expected shortly with both countries. With FMS customers taken into account LM are anticipating export orders to be approximately 2500 aircraft beyond 2020.

SDD participation is made a several levels:

- Level 1 (Collaborative Partner)
- Level 2 (Associate Partner)
- Level 3 (Informed Partner)
- Level 4 (Major Participant)

The entry level at which a potential customer may join is directly proportional to the level of investment within SDD and this brings with it participation within the JSF Program Office again with varying levels of authority with which to influence requirements.

The F-35 aircraft manufacturing work-share has effectively been divided into 3 parts along the lines of the LM, Northrop-Grumman Corp (NGC) & BAES team investment:

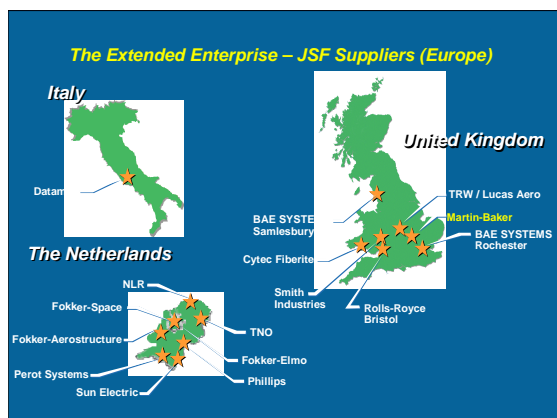
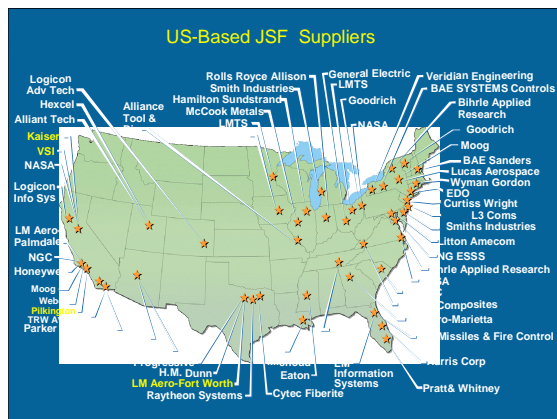
- LM is responsible for aircraft final assembly, the forward fuselage, wing, system integration, mission and vehicle systems.
- NGC are responsible for mid-fuselage, radar, software and arresting gear.
- BAES are responsible for the escape system (seat & canopy removal), fuel system, EW, life support and aft fuselage.

The program affordability constraints dictate that current plans consist of only one final assembly line – to be located at LM Fort Worth.

Embracing acquisition reform, LM/NGC/BAES team will be responsible for the Operation & Support (O&S) of the fleet of aircraft for all US & UK customers. This means that industrial participation within the O&S customer package will flow down to the entire JSF supplier base. Inventory control, spares ordering and aircraft defect reporting, the prime contractor in association with the lower tier suppliers will now control availability electronically. This does drive the requirement for extended warranty cover and makes all the suppliers more accountable.

To ensure consistently high aircraft availability rates while simultaneously limiting expensive past time of preventative schedule maintenance, the aircraft will use a system of Diagnostics, Prognostics and Health Management (PHM). This will allow the state of the aircraft to be monitored by the supplier base around the clock and anticipate worn or unserviceable components prior to their un-serviceability removing the aircraft from the flying roster.

The size of this project has attracted a large part of the global supplier base, across the US, UK, Italy & the Netherlands. At the point of going to press not all the aircraft components had been placed on contract and ample opportunity exists for the “best athletes” to come from other countries.



Within the immediate LM Integrated Product Team (IPT) MBA is working in concert with BAES, Honeywell-Normalair Garrett Ltd (HNGL), Visual Systems International (VSI) and Pilkington (US).

## 2.5 F-35 Crew-station Design

As can be expected with a 4<sup>th</sup> generation aircraft, the crew-station design will be “state of the art”. The cockpit is dominated by a large continuous display. No Head-Up Display (HUD) unit is prominent on the coming, as the flight imagery is displayed within the Helmet Mounted Display (HMD) to improve the pilot’s situational awareness.

The JSF Crew crew-station accommodation is designed for the multi-variate case-sizes 1 through 8.

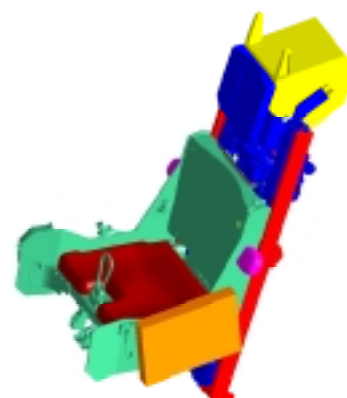


This is an expansion of the crew accommodation range beyond that originally pioneered during the JPATS program, which introduced multi-variate cases 1 through 6.

The Hands-On-Throttle-And-Stick (HOTAS) flying configuration, now quite common with numerous fighter aircraft types, is altogether novel for a STOVL type aircraft, as one of the inceptors must also cater for controlling nozzle positions for take-off and landing.

## 2.6 Mk16E Seat

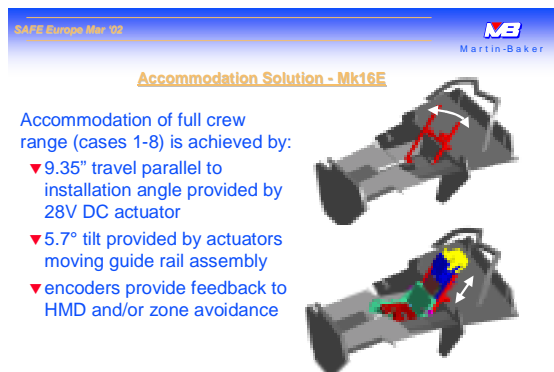
The SDD ejection seat that MBA proposed to LM is a further development of the Mk16 range, which is flying in numerous aircraft platforms around the world. For SDD, the ejection seat is known as the Mk16E and is common to all 3 JSF aircraft variants.



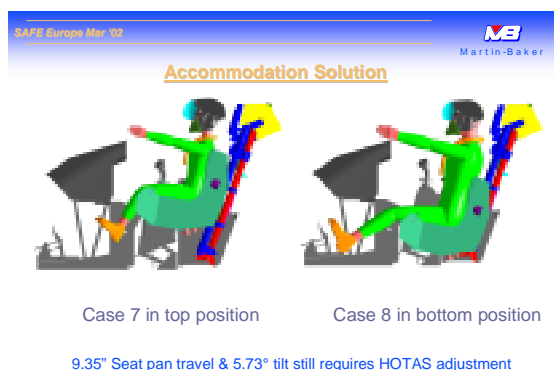
The Mk16E consists of the following major assemblies:

- a seat bucket within which is located the survival aids container, a backrest and under seat rocket motor (USRM).
- a twin-tube catapult with integral canopy penetrators. On the catapult structure is located an energy absorbing head-pad, a drogue parachute container, the main parachute container, an inertial retraction device and a 3<sup>rd</sup> generation COTS electronic sequencer.
- side-mounted guide rails.
- fully integrated life support equipment.

This seat offers an extremely large crewmember accommodation range introducing the longest seat-bucket travel of any known ejection seat (9.35”), combined with a seat tilting mechanism (6°).



Even with this ability to position the seat in this manner, in order to achieve a true HOTAS pilot flying configuration for this accommodation range, the rudder pedals have considerably more adjustment than any legacy aircraft and the throttle and stick inceptors both have some electrically driven adjustment.



Common to all other MBA seats, the seat can be removed in entirety or in piece-meal fashion, which is a USN requirement. The forward hinged canopy design is unusual in a western designed aircraft: the canopy is able to open far enough to remove the seat as one assembly.

From an ejection standpoint, SDD has introduced challenging requirements from cost and technical

performance perspectives. Some 10 years away from FRIP, the production seat price has already been identified. The seat, like all other aircraft components feeds into the aircraft cost model and will be meticulously tracked.

The combination of the extended crewmember range in concert with the SDD terrain clearance requirements have required the introduction of new and innovative seat control strategies for the rocket motor and parachute phases of the ejection sequence.

The elimination of the HUD, through the adoption of the HMD as the prime means of flight data display, has brought to the forefront the latest head and neck load requirements.

An auto-eject system has been introduced to counter the lift-fan failure condition for the STOVL aircraft.

During the first 48 months of this program, MBA will develop the ejection seat system and all its related components and sub-systems. This will culminate in the delivery of 14 flight seats for the SDD flight development aircraft, which will be based at LM Fort Worth, NAWC Patuxent River and at AFFTC Edwards AFB.

The 78 months spent between SDD first flight and FRIP will be involved with maturing the overall escape system, supporting the flight development aircraft and preparing for FRIP.

#### About the author:

Stephen Roberts graduated from City University with a BSc in Air Transport Engineering. He was commissioned into the RAF as an Aero-Systems Engineering Officer, prior to joining Martin-Baker 12 years ago, as a Project Engineer.

At Martin-Baker, he has been responsible for the development of various escape system programs including the Dassault Aviation Rafale, Embraer ALX, Panavia Tornado Performance Enhancement, Eurofighter EF2000, and Joint Strike Fighter Programs.

Certified as a Eur Ing, he is a member of the AIAA, IMechE and RAeS institutions.