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Introduction

ON AN OVERCAST DAY in late November 2010, I watched an F-35C Lightning II take off from runway 32 at Naval Air Station Patuxent River, Maryland. The ground shook. Vibrations rumbled through my body. It reminded me of a B-1B bomber. But Air Combat Command's swing-wing bomber is powered by four engines that generate a combined 120,000lbs of thrust with afterburner: the F-35 generates 43,000lb with just one.

It was the first time I had seen the funky fifth-generation jet fly, and one that I will never forget. I was hooked: the aircraft has fascinated me ever since.

Back then just a handful of test aircraft were assigned to Pax River and Edwards Air Force Base in California. Today dozens of F-35s are flying with ten squadrons based across America: tangible progress in the world's largest defence programme.



Visiting and talking to the men and women who build, flight test and operate the F-35 this past year, it was clear to me that their mood has changed since the dark days of 2010-2011 when technical issues, delays and rising cost were besieging the programme. Today, technical issues with software and hardware are being fixed, the aircraft's flight envelope continues to be opened up, and squadrons – training and operational – are increasing their flying hours and are performing increasingly varied tasks with the aircraft. What's more, the first pilots and maintainers from the UK and the Netherlands are now trained on the F-35 ready to join their American colleagues, for the start of the type's initial operational test and evaluation which will take place next year in the skies over the Mojave Desert.

Concurrent with that, the US Marine Corps has its first operational F-35B squadron flying at Marine Corps Air Station Yuma in Arizona, and is working towards its initial operating capability declaration in 2015 – the first squadron in the world to do so. Programme events, such as the start of the initial operational test and evaluation and initial operating capability declaration, will allow the aircraft and its introduction to operational service to further evolve. Despite these forthcoming milestones, the F-35 continues to divide opinion – there are those who view it with excitement and those who take a more pessimistic approach and question its merit. Doubters might like to consider an aspect of the programme that rarely makes the headlines but directly affects capability – its people. Bristling with complex and revolutionary systems, the F-35 is unlike any aircraft before it: and the hundreds of smart-thinking people designing, building and testing it continue their quest to perfect the jet's capability. And they do this in a programme that is organised so radically different to those that have gone before it. The aircraft, which remains in its System Development and Demonstration phase, is being designed, developed and tested concurrently – it's an unprecedented approach to a US Department of Defense programme that's international in so many respects.

How we all value the worth of the F-35 is undeterminable, but once the aircraft is populating flight lines around the world it is highly likely that the F-35 Lightning II will be considered as one of the best things since sliced bread – just like the people who design, build and test it envision.

Mark Ayton

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EDITOR

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CHIEF DESIGNER: Steve Donovan
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Production Manager: Janet Watkins

ADVERTISING AND MARKETING
Advertisement Manager: Ian Maxwell
Advertising Group Manager: Brodie Baxter
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Marketing Manager: Martin Steele
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Tel: 01780 755131
Fax: 01780 757261
Email: enquiries@keypublishing.com
www.keypublishing.com
Distribution: Seymour Distribution Ltd,
2 Poultry Avenue, London EC1A 9PP.
Tel: 020 74294000
Printed by: Warners (Midlands) plc, Bourne, Lincs

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Published by: Key Publishing Ltd

Printed In England



Image Data

Variant:	F-35A F-002
Unit:	Royal Netherlands Air Force/58th Fighter Squadron
Location:	Eglin Air Force Base, Florida
Date:	June 10, 2014
Detail:	Night photo shoot
Photographer:	Kees van der Mark/Arnaud Boxman

COVER



The front cover shot features an F-35B from the 461st FLTS based at Edwards Air Force Base, California. *Darren Russell/ Lockheed Martin*

INSETS ***Left:*** *Matthew Short/Lockheed Martin*
Middle: *Todd McQueen/Lockheed Martin*
Right: *Andy Wolfe/Lockheed Martin*

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- Weapons
- Leadership
- Operators
- Systems
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Image Data

Variant:	F-35B BuNo 168717/'VK15'
Unit:	Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights'
Location:	Marine Corps Air Station Yuma, Arizona
Date:	October 31, 2013
Detail:	Training mission touch and go
Photographer:	Paul Ridgway

programme rationale

The Lockheed Martin F-35 Lightning II Joint Strike Fighter is already dominating investment in future airpower throughout the world, even before it has entered full-rate production. By mid-2013, the total US investment in the programme was close to $400 billion, with a requirement to procure 2,457 aircraft through 2037. The total life-cycle cost of the F-35 to the US Government is estimated to be in the range of $850 billion to $1.1 trillion, far greater than any other military aircraft in history. International partners are looking at future force structures in which the F-35 will constitute much or all of their combat aircraft strength. Most of the air arms that will invest in F-35s have a broad range of combat experience and diverse operational needs, none of which could develop a fifth-generation fighter alone.

The F-35 was intended from its inception to be an international programme, designed to enable the US armed services and ally nations to carry out a range of tactical missions – primarily air-to-surface but also air-to-air – in the face of high-performance threats, particularly surface-to-air missiles, that are likely to proliferate in the coming decades. The programme was also aimed at addressing the continued viability of manned combat aircraft which has been threatened by rising procurement, operational and maintenance (O&M) costs.

According to Lockheed Martin, current and future surface-to-air missile threats are countered by the F-35's fifth-generation design. This incorporates stealth and a designed-in capability to fly and fight as part of a network: linking together multiple combat aircraft, sensor platforms, and command and control nodes. In doing so, the aircraft is intended to provide an unprecedented degree of situational awareness and to accurately deliver precision-guided munitions against surface and air targets. By combining stealth and networking capabilities in an upgradeable aircraft, the F-35 is designed to meet evolving threats for over 30 years.

Organising the programme on an international basis from inception while tackling the challenges posed by rising costs has made the F-35 the most ambitious project in aviation history.

Replacing a big percentage of the Western world's tactical aircraft with a single design and putting in place an integrated fabrication, training and logistics system, intended to last for its complete service life, was unprecedented but offered the potential for economies of scale that would otherwise be impossible.

Some of the programme's original objectives were to keep costs down and ensure that the new aircraft would be ready when legacy types reached the end of their service lives. This led to a development strategy involving a previously unheard of degree of concurrency. The F-35 is being developed, built and tested at the same time, making use of computer-aided design, modelling and simulation, only made possible by the microchip revolution. Its aim is to maximise commonality between the three versions: the F-35A Conventional Take-Off and Landing (CTOL); the F-35B Short Take-Off/Vertical Landing (STOVL) and the F-35C Carrier Variant (CV).

Decisions taken to maximise concurrency and commonality, also set the stage for a troubled development. But those decisions were taken as part of a plan to provide a way – charted through multiple plans and business models – for the F-35 to enter full-rate production; achieve a learning curve that will keep its procurement and O&M costs close to those of the legacy aircraft types it will replace; and provide operators with the ability to use its inherent fifth-generation capabilities in networked combat operations.

By the end of 2014, 54% of the development test flying is scheduled to be complete, and the aircraft is now likely to achieve initial operational capability (IOC) starting in 2017. While substantial risks remain, that have the potential to significantly disrupt the programme – especially in software development – the focus has broadened to include pilot and technician training, stand-up of the first operational squadron, Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights' at Marine Corps Air Station Yuma in Arizona, and integrating a fighter aircraft that is designed to be supported by a system-of-systems into each service's overall concept of operations.

International participation, like concurrency and commonality, was intended to integrate the research and development and industrial capabilities of each partner nation.

There are three tiers of industrial participation, each reflecting the level of investment made by the nation.

Tier 1 - United Kingdom
Tier 2 - Italy and the Netherlands
Tier 3 - Australia, Canada, Denmark, Norway and Turkey

In addition, partners are entitled to assured aircraft delivery priorities and programme information.

Singapore (which has not yet ordered an F-35) and Israel are security cooperation participants allowing them to invest and take part in the programme.

US Foreign Military Sales contracts for F-35s have been signed by Israel and Japan: both nations have been integrated into the programme and components manufactured in each will be incorporated into F-35s worldwide. ***David C Isby***

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HISTORY of the Joint

The origins of the F-35 in its current form go back to the early 1990s. In the wake of the 1991 Gulf War, the potential vulnerability of non-stealth combat aircraft to emerging threats made a powerful impact on the US Department of Defense (DoD). After the first day of the Operation Desert Storm air campaign, the US Air Force would not send Lockheed Martin F-16s over Baghdad in daylight until Iraqi air defences were degraded. Other US programmes – most notably the Navy's stealth A-12 Advanced Tactical Aircraft – had been cancelled, following a comprehensive review of the nation's defence strategy and force structure. Within the Bottom-Up Review, initiated by Secretary of Defense Les Aspin in March 1993 the Joint Advanced Strike Technology programme was expanded. It now incorporated the Marine Corps' requirement for a Boeing AV-8B Harrier II replacement and became the Joint Strike Fighter (JSF) programme. Decisions made with an international scope, concurrency, and commonality across three versions shaped the programme.

Following a concept demonstration phase that started in 1996, Boeing and Lockheed Martin received contracts to build prototypes of their respective types: the X-32 and X-35. These first flew in 2000. The Lockheed Martin X-35 design (subsequently changed to the F-35), powered by a single Pratt & Whitney F135 engine, was selected in October 2001. This started the System Development and Demonstration (SDD) phase that still runs today. In November 1995, the UK was the first nation to sign a Memorandum of Understanding to become a formal JSF partner. By 2002 Australia, Canada, Denmark, Italy, Norway, Turkey and the Netherlands were also partners in the JSF programme. Production of the first major airframe components started in 2003, but the transition from a computerised design to a production-ready airplane proved more difficult than anyone had projected. The first prototype, F-35A AA-1, was above its planned weight, which had the potential to make the aircraft's key performance parameters – the requirements that the aircraft had to meet or face cancellation – unachievable.

A weight reduction Blue Ribbon Attack Team was formed, but its changes only slowed the weight growth of the jet. The subsequent STOVL Weight Attack Team required the wing, bulkheads, and centre fuselage all to be redesigned, imposing delays and additional costs.

In 2003 rising costs led to the F-35's first Nunn-McCurdy amendment breach, when the programme exceeded critical cost growth thresholds established by statute, which required the DoD to notify Congress.

In March 2004, a new Acquisition Program Baseline (APB) was approved, but the underlying problems – weight and cost – remained, and the DoD's 2005 Systems Acquisition Report to Congress gave further "significant" Nunn-McCurdy breaches. Throughout this period, reflecting the concurrency development strategy, work on the aircraft itself continued to advance. The first F-35A AA-1 flew in December 2006. Procurement funding started with the Fiscal Year (FY) 2007 budget request and the first F-35B was rolled out at the Fort Worth factory in 2007.

Following the Nunn-McCurdy breaches, a new APB was put into place in March 2007 and several teams reviewed the troubled programme. In 2008 the Joint Estimating Team (JET) reported how much more money was needed in the FY2010 – 2015 budgets to adequately fund JSF. It was followed by the JET 2 study, extending the independent cost review to FY2011 – 2016 budgets. The Independent Manufacturing Review Team and the F135 engine Joint Assessment Team both found that additional investments were needed. An Acquisition Decision Memorandum ordered a DoD-wide programme review. The JET 2 estimate was adopted across the programme, resulting in a "critical" Nunn-McCurdy breach in March 2010. Following further schedule slips and increased costs, in February of the same year the programme was restructured, with 30 months added to the SDD, and Defense Secretary Robert Gates fired the F-35 program manager, US Marine Corps Major General David Heinz.

His successor, Rear Admiral (subsequently Vice Admiral) David Venlet, implemented a range of changes following the January 2011 restructuring, including dealing with the effects of a grounding order that halted test flights in March that year. Robert Gates placed the F-35B on two-year "probation" due to cracked bulkheads and fuel lines.

Venlet managed extensive F-35 programme restructuring actions throughout 2011 and 2012 and these added more funding, extended schedules, and deferred the procurement of 410 aircraft until



Image Data

Variant:	**F-35B BuNo 168057/'VM01'**
Unit:	**Marine Fighter Attack Training Squadron 501 (VMFAT-501) 'Warlords'**
Location:	**Eglin Air Force Base, Florida**
Date:	**November 28, 2011**
Detail:	**Training mission turning into the pattern**
Photographer:	**Paul Ridgway**

Strike Fighter

2017. In March 2012, the Joint Program Office (JPO) established a new acquisition programme baseline that incorporated all restructuring actions. The baseline represented the fourth since the F-35's inception. The Change Management Integrated Project Team (IPT) was set up in July 2012. Previously, the JPO had been limited in its ability to estimate the costs of modifying existing F-35s to reflect required changes identified during testing. The most bitter disputes between Lockheed Martin and the DoD had been over the cost of the changes and who should pay. The IPT produced the first report on F-35 concurrency costs.

The F-35's concurrent development, production, and sustainment objectives require nine separate Low-Rate Initial Production (LRIP) lot deliveries. Each LRIP lot represents an incremental and increased level of maturity as additional system capability is delivered. This means that F-35s built in earlier lots will have to be retrofitted to bring them up to later baseline configurations. Each LRIP represents its own contract, covers the number of aircraft to be produced and the type of acquisition. For LRIP Lots 1 through 3, the JPO's acquisition approach was cost-plus incentive fee, whereas a firm target price is being used for LRIP lots 4 through 9.

While Admiral Venlet was running the programme, Lockheed Martin earned just $28 million of a possible $87.5 million in fees awarded for meeting F-35 development goals in 2010 and 2011.

Major (subsequently Lieutenant) General Christopher Bogdan took over the JPO from Venlet on December 6, 2012. Bogdan, who served as Venlet's deputy, had previously characterised relations between the DoD and Lockheed Martin as "the worst he had ever seen". It was a blunt message that underscored how everything needed to work from there on to avoid the programme being cancelled or vanish in a "death spiral", where cutbacks in the number of aircraft produced would drive the per-unit cost to unaffordable heights. Secretary of the Air Force Michael Donley said no more money was available for F-35 development and further increases in costs would be reflected in decreases in procurement.

In 2012, 30 F-35s were delivered, including the first two for the UK. With more than 5,000 flight hours logged and the first in-flight weapons releases achieved, the flight test programme was more than a third complete, with the F-35A reaching 43% reflecting the decision by the US Air Force to achieve flight test maturity (passing 5,000 hours) in 2012, even if that meant deferring some test objectives. The F-35B was taken off probation a year early and in October an F-35 test airframe achieved a simulated full service life of 8,000-hours' flight time on a structural test rig at BAE System's Brough, UK facility.

A January 2013 report by the DoD's Director of Operational Test and Evaluation Dr Michael Gilmore pointed out that the F-35 had not met its goals in reliability or flight testing. The report identified the aircraft's vulnerability to lightning strikes, structural and fuel line cracks (leading to the F-35B being grounded), and removal of on-board systems that saved weight but increased vulnerability to battle damage among new problems needed to be resolved. Requirements in manoeuvrability and acceleration have been changed to reflect lower performance.

Other F-35 problems are being worked on: a new tail hook design for the F-35C carrier variant was tested in 2013 at Naval Air Engineering Station Lakehurst, New Jersey, with shipboard landings scheduled for the third quarter of 2014. A weight status report about the F-35A, released in November 2012, showed the estimated weight of 29,098lb (13,198kg) to be within 273lb (124kg) or 0.94% of the projected maximum weight to meet the technical performance requirement.

During 2013 the programme achieved a series of achievements: F-35s completed the first dual air refuelling. The first production standard F-35C carrier variant was delivered, three F-35As arrived at Nellis Air Force Base for operational testing and the Marine Corps conducted its first operational (rather than test) vertical landing.

The Selected Acquisition Reports submitted to Congress listed a $4.5 billion reduction in acquisition, operating and support costs.

In September 2013, Bogdan warned that while the programme was, "not out of the woods yet", the F-35 was, "not the same programme it was in the past", and that, "slow and steady progress is being made on all fronts". He has also committed to bringing unit costs down by 2019 and to deliver, "fifth-generation capabilities at fourth-generation prices", for procurement, operations and maintenance alike.

David C Isby

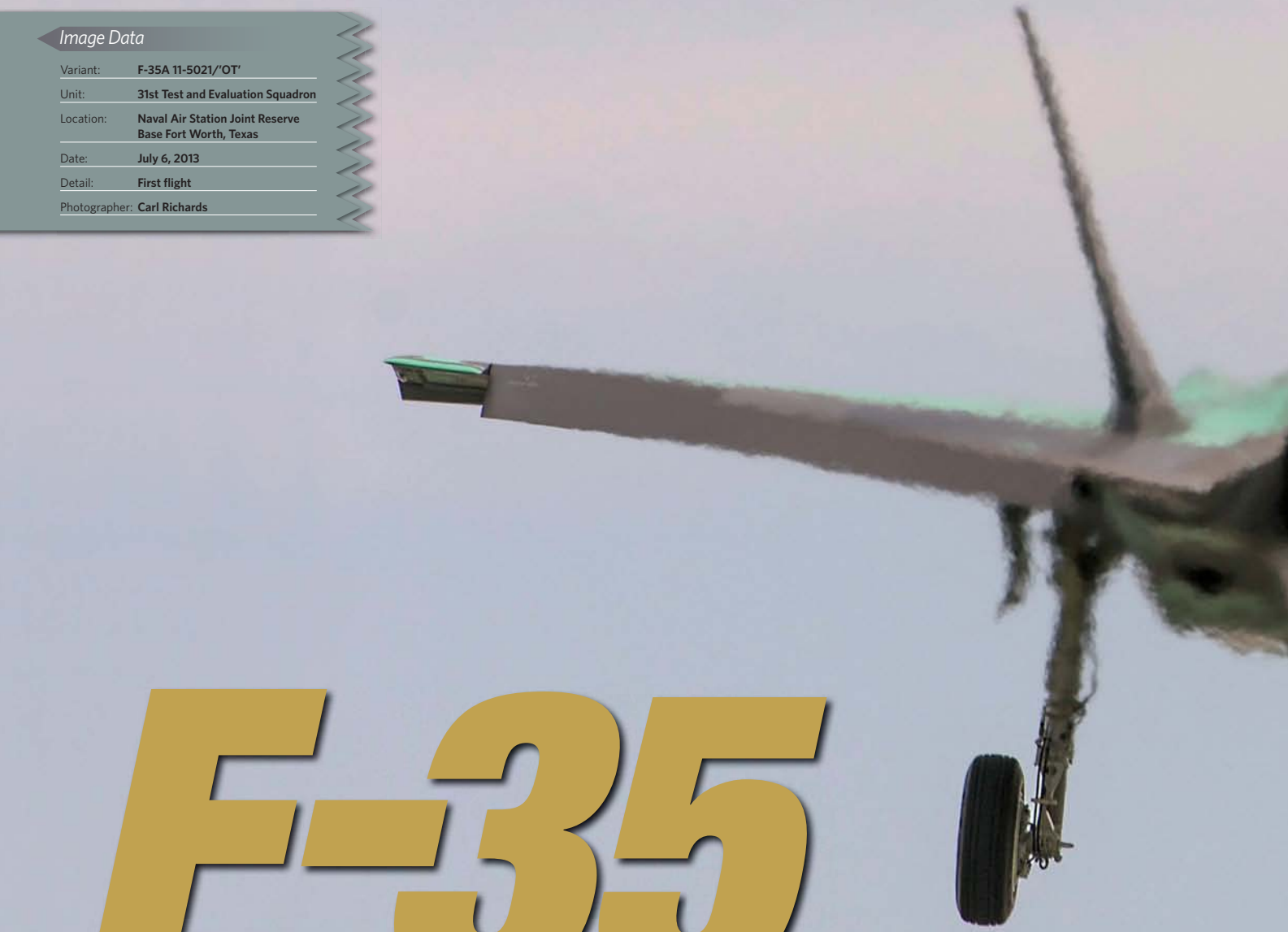


Image Data

Variant:	**F-35A 11-5021/'OT'**
Unit:	**31st Test and Evaluation Squadron**
Location:	**Naval Air Station Joint Reserve Base Fort Worth, Texas**
Date:	**July 6, 2013**
Detail:	**First flight**
Photographer:	**Carl Richards**

F-35
An Epochal Change in Air Combat?

When the Lockheed Martin F-35 Lightning II Joint Strike Fighter (JSF) finally becomes operational, it will determine "where the next epoch is going to be in [air] combat", Air Vice-Marshal Ed Stringer, the RAF's Assistant Chief of the Air Staff, said in 2013. He sees it bringing about "an epochal change from generation three and four aircraft [Tornado and Typhoon] to four and five [Typhoon and F-35]", underlining that each generation of aircraft will be operated in fundamentally different ways.

He focused on two key issues often overlooked during the long, contentious and expensive story of the F-35. The first, uncontroversial, point is that the US, like the UK, will be using the F-35 together with their fourth-generation combat aircraft into the 2030s. The second point, implicit but controversial, is that the characteristics of the fifth-generation F-35 are such that they will enable (if not cause) an "epochal" change in air combat – and the type will be best suited to take part when air combat becomes a new game with new rules, even if some of the players – the fourth-generation fighters – are going to be the same.

This second point raises a key question about the F-35: how does it create the "epochal" change in air combat as perceived by the air vice-marshal? It will probably not be the result of its kinematic performance. In the basic measures of performance traditionally associated with fighter aircraft – such as top speed, manoeuvrability, range and weapons load – it does not constitute an order of magnitude improvement over "fourth-generation" counterparts. Rather, the "epochal" step significance of the change is in its capability for stealth and network-centric operations. The difficulty of meaningfully measuring (how much?) and assessing F-35 performance (does it matter?) in these areas (now and throughout its service life), especially at open source level, has contributed to the controversies associated with the F-35 programme.

Stealth

While stealth technology dates back to World War Two, the F-35 is only the fourth (and the first to be exported outside the US) stealth combat aircraft, designed from the outset with radar signature reduction as a major objective. Its stealth technology represents significant improvements over its three predecessors – the Lockheed Martin F-117, the Northrop Grumman B-2A Spirit and the Lockheed Martin F-22 Raptor – and upgraded fourth-generation fighters such as the Boeing F-15SE Silent Eagle, 60 of which were turned down by the Republic of Korea in 2013 in favour of 40 F-35s.

As the US Air Force says, "beauty is skin-deep but stealth is bad to the bone," meaning that the ability to use structures and materials to build in stealth characteristics from the outset of an aircraft's design is more effective than gaining limited stealth by applying significant upgrades through retrofits. The F-35's stealth technology also offers significant cost and serviceability improvements over its predecessors, but the question remains: are its



stealth characteristics of sufficient importance to create Stringer's "epochal" change?

The answer to that question depends on the main threat to the F-35. Its preliminary design reflected the contemporaneous concerns of Operation Southern Watch over Iraq in the 1990s. Coalition fighters faced a potential all-aspect surface-to-air missile (SAM) threat. The possibility that some of the latest Soviet systems would end up in action was considered very real. Against such threats, only stealthy aircraft would survive but doubts about the future of stealth predate the loss of a US Air Force F-117 to a Serbian SAM during Operation Allied Force in 1999. The US Air Force opted to protect the more advanced B-2 Spirit stealth bomber on other strike missions during that campaign with active jamming provided by aircraft including the Grumman EA-6B Prowler.

Future air defence threats will have better networked sensors and, more significantly, faster, cheaper, more powerful and more compact data processing able to distinguish a stealthy aeroplane from background clutter (or active jamming). No one knows how fast or powerful computers will be in the 2030s, but we know the F-35 will look the same and be made of the same material as it is today.

Network-Centric Operations

The other aspect of the F-35 design said to need to be designed-in to provide a full return on investment as a fifth-generation fighter is its network-centric capability. As with stealth, the basic technology is not new. Networking, in its earliest forms, became critical in air combat as soon as fighters went into combat as part of an integrated air defence system (IADS), as in the Battle of Britain in 1940.

It was only with the rise of digital data links, with faster transmission rates and decreased chances for human error, that made networks not just enablers but also core to the many missions undertaken by military aircraft. Only then did it become apparent the capability for network-centric operations would revolutionise air combat as thoroughly as the jet engine did.

The importance of data links to fourth-generation fighters was documented in a 2005 study by the RAND Corporation in the US. It used the results of 12,000 training sorties in tactical air-to-air combat to compare two forces of Boeing F-15 fighters, one using Link 16 data link and the other using only voice radio, to engage a threat force. The Link 16-equipped F-15s had a kill ratio 2.5 times higher, day (8.11:1 with Link 16 and 3.10:1 without) or night (9.4:1 and 3.62:1).

The F-35 has been conceived to provide a shared coalition-wide network-centric capability, in contrast to older aircraft where networked systems, especially the critical data links, have been integrated through modifications. Even a fourth-generation fighter such as the Saab JAS 39 Gripen (the Swedish Air Force has long experience with data links) had to be hastily fitted with a Link 16 capability to take part in coalition air operations over Libya in 2011.

The F-35 design, however, uses Link 16 data link-enabled capabilities as only the starting point for more extensive capabilities. The Israeli version will



Variant: **F-35B BuNo 168720/'VK02'** Unit: **Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights'** Location: **Marine Corps Air Station Yuma, Arizona** Date: **March 15, 2014** Detail: **First public display of the F-35B** Photographer: **Paul Ridgway**

operate with indigenous communications, weapons and software – examples of adapting the design for national needs.

The aircraft is designed to network together both links and sensors, its onboard integrated system presenting the pilot with a multi-sensor situational awareness picture to "automatically fuse data into an easy, understandable format". Its cockpit and systems were designed for this, with an 8 x 20 inch (200 x 500mm) colour display, known as the Panoramic Cockpit Display (PCD), to integrate tactical information, both from the F-35's own sensors and networked systems.

To provide this data to other F-35s, the jet will be equipped with an MADL (Multifunction Advanced Data Link), first flight-tested in May 2013. Its current limitation is that it only links to other F-35s at close range. For other networks, the aircraft will use Link 16, relying on directional antennas to maintain stealth.

In the future, the F-35 will have satellite communication technology, a vital requirement to integrate with the often contradictory requirements of stealth (tight emissions control or limited transmissions, highly directional in nature and pointed towards friendly receivers) and networked operations (requiring many emissions and much use of bandwidth, ideally including multiple friendly platforms). This will enable it to link with other sensors and networked systems.

The quality and capability of the F-35's sensors are state of the art. They include the APG-81 Active Electronically Scanned Array radar, the electro-optical AAQ-37 Distributed Aperture System (DAS) and the AAQ-40 Electro-Optical Targeting System (EOTS). The six DAS sensors enable the pilot, if he looks down in the cockpit, to 'see' what is underneath the aeroplane in his helmet display, as the imaging infrared generates a picture of what the downward-looking sensors detect. As with the AESA and EOTS, it is a digital system and generates 'ones and zeros' to make up a digital image. If sufficient bandwidth is available, the picture can be presented, via MADL, to other F-35s in the flight as readily as to the pilot in the cockpit.

While some upgraded legacy fighters also use AESA radar, an infrared sensor and a radar homing and warning system, the F-35 presents fused data on the PCD in a format intended to enhance the pilot's situational awareness and not deluge them with unneeded information; and it can be networked with wingmen and more distant friendly assets.

The F-35 helmet (or Helmet Mounted Display System) is designed so the pilot does not have to look 'head down' in a tactical situation but can customise the flow of information brought up to eye level. The DAS system displays a picture directly on the helmet visor so the pilot can 'see' in all directions, even directly below the aircraft. The ability to receive inputs from the DAS is of upmost importance to the functionality of the helmet.

In current fourth-generation fighters, radar and targeting pod data is displayed inside the cockpit but requires the pilot to look 'head down' to locate and prosecute targets and, while approaching the point of weapons release, transition to 'eyes on', maintaining the same picture throughout. Their situational awareness will also be enhanced by a voice command system issuing threat warning messages from the direction of the threat.

The original JSF Operational Requirements Document (ORD) – approved by the Joint Requirements Oversight Council (JROC) of the Joint Chiefs of Staff and setting out what the aircraft has to be able to do – expressed the importance of network-centric performance for the design: "The threshold is for the JSF to meet 100% of critical, top-level information exchange requirements (IER)...those which if not met will severely and adversely impact a mission."

The ORD required that the F-35 "must be able to send and receive weather, command, control, intelligence, surveillance and reconnaissance information and work as part of the C4I [command, control, communications, computers, and intelligence] architecture". The baseline common communications suite that enables its network-centric design distinguishes the F-35 from earlier stealth designs – where use of networked systems was limited by their need to rely on directional antennas for satellite communications with limited throughput.

Turning a specification into reality is going to be a challenge. The Department of Defense Systems Engineering FY2013 Annual Report (DoD SE FY2013 AR), said the F-35 programme was on track to achieve only 24 of 62 requirements by 2018, with corrective action identified, or recommended, for the remainder.

Complicating the catch-up element of the F-35's concurrent development is the aim to create a network-centric capability. This objective could be achieved by pulling together multiple elements that include potential transformative network-centric technology. Individual such technologies have in the past been difficult to use to their full capability.

The US Navy is still unable to use the F/A-18E/F Super Hornet's APG-79 AESA radar to its full capability after some seven years' operational service. And it took many years before Link 16's power and capability were completely and effectively employed operationally. In 2011, the US Navy started development of the Rockwell Collins Advanced Tactical Data Link (ATDL) to address the operational limitations of current systems including the MADL and Link 16. The F-35 will use all these elements, many of which have proven problematic in the past, in an integrated suit.

Network-Centric Support and Training

The F-35 will be the first combat aircraft to rely on networked support, in the form of the Autonomic Logistics Information System (ALIS) – designed from the start to make all aspects of F-35

Variant: **F-35B BuNo 168720/'VK02'** Unit: **Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights'** Location: **Marine Corps Air Station Yuma, Arizona** Date: **March 15, 2014** Detail: **First public display of the F-35B** Photographer: **Dan Stijovich**



operations and maintenance easier and cheaper by requiring fewer spares and personnel.

When the F-35's onboard diagnostic systems determine a component may fail, ALIS should order a replacement to be shipped direct to the flight line from centralised locations soon enough to prevent downtime. It is designed to enable surge sortie generation rates during a conflict. But introduction of ALIS to Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights', the first operational unit at Marine Corps Air Station Yuma in 2014, revealed a range of problems, especially the time required to carry out even routine tasks.

This could turn into a significant issue. The DoD SE FY2013 AR said the only one of the eight F-35 key performance parameters (KPPs) deemed "critical or essential" in the ORD but not on track to be met by 2018 was sortie generation. In April 2014, Rear Admiral Randy Mohr, the F-35's Deputy Program Executive Officer, said: "The F-35 is not yet a reliable aircraft, but we're getting there," adding that changes introduced on F-35 Low Rate Initial Production lots 5 and 6 have improved reliability.

Supplementing this is the use of networked computerised systems to create a single integrated training infrastructure for the F-35. This includes a multinational schoolhouse at Eglin Air Force Base, Florida, which provides a common syllabus for pilots and technicians as they go on to service-specific training (at, for example, Marine Corps Air Station Beaufort, South Carolina, for the Marine Corps and the Royal Air Force and Luke Air Force Base, Arizona, for the US Air Force and seven international partners). This will enable smaller air arms with fewer F-35s to use the same training infrastructure as larger partner nations' personnel rather than having to invest in their own national capabilities.



Variant: **F-35A 10-5014/'EG'** Unit: **58th Fighter Squadron** Location: **Naval Air Station Joint Reserve Base Fort Worth, Texas** Date: **July 27, 2013** Detail: **Pattern break after a functional check flight** Photographer: **Scott Fischer**

Future Technology and Tactics

The US Air Force said in January 2014 it had compiled a draft initial tactical employment doctrine for the F-35A, which may well be refined as testing provides additional understanding and software upgrades yield more capabilities. The US Air Force is prioritising the development of a communications system that can link the F-35 to other tactical aircraft.

The Joint Strike Fighter Enterprise Terminal (JETpack) Joint Capability Technology Demonstration (JCTD) programme is under way, with Northrop Grumman as lead contractor. The fifth to fourth-generation communication demonstration programme was set up in October 2013. A capability is being developed with the F-22 Raptor and may be available as the F-35 becomes operational between 2017 and 2019. It makes use of gateway communications relay aircraft to link the F-22 with other tactical aircraft. This includes looking at how the F-35's sensor inputs could be passed to the Distributed Common Ground Station (DCGS) without compromising the F-35's stealth.

Lockheed Martin has been working on Project Missouri, a company-funded development programme for low probability of intercept/detection transmissions from F-35s or other stealth aircraft using Link 16. This was successfully demonstrated between December 17 and 19, 2013 using an F-22 and a modified Boeing 737, known as the Catbird, used to test F-35 software. The F-22 successfully communicated with a ground node through the 737 without compromising its stealth characteristics.

The US Navy is looking at tactics for the F-35 to use its stealth capability and sensors to penetrate enemy airspace and acquire targets – acting as the long-range eyes of the fleet and relaying information back to a Northrop Grumman E-2D Hawkeye or other aircraft using the ATDL. The ATDL provides enhanced connectivity and improved bandwidth by transmitting together four NATO-standard Link 16 data links using either the Concurrent Multi-Netting 4 or the Rockwell Collins-developed Tactical Targeting Network Technology (TTNT): both enable greater throughput.

Instead of engaging targets, which would increase the likelihood of enemy defences spotting and tracking it, the F-35 would use its network connectivity to pass engagement-quality targeting information to aircraft such as an F/A-18 Super Hornet positioned at a stand-off range to strike using long-range weapons. Alternatively, the F-35 could take control of the weapons after they are fired by other aircraft, ships or submarines.

Just as the F-35 is designed to operate differently from previous fighters, its performance has to be evaluated differently. A head-to-head static comparison with other designs (comparing measures such as speed, range, radar cross-section and infrared signature) or even a dynamic one-on-one fly-off are not going to provide a critical measure of effectiveness or identify how network-centric air operations differ with and without the F-35.

Similarly, the value of stealth is best determined by looking at the results of a networked coalition force – both in the near and long term – against a similarly networked and equipped threat and, in time, better data links and fusion capabilities.

Complicating this is the fact that air arms do not buy networks. They buy aeroplanes, weapons and other systems and have to put them together, ideally far enough in advance of when the shooting starts so they can be tested in exercises such as Red Flag, models and simulations. The first step in this process was under way in April 2014 when six US Air Force F-35As were operating against simulated Russian, Iranian and Chinese air defences.

In the key areas of stealth and networks – in the air and sustaining operations on the ground – the F-35 is still working to achieve the potential that Air Vice-Marshal Stringer defined as the next epoch in air combat. ***David C Isby***

Variant: **Boeing 737-330 F-35 Cooperative Avionics Test Bed** Unit: **Lockheed Martin** Location: **Naval Air Station Joint Reserve Base Fort Worth, Texas** Date: **October 24, 2010** Detail: **Mission systems developmental test flight** Photographer: **Scott Fischer**



Setting the Scene

Beset by technical challenges and delays, the F-35 programme is now making tangible progress towards achieving initial operating capability. Lieutenant General Christopher Bogdan, Program Executive Officer for the F-35 Lightning II, discusses the key issues with *AIR International* Editor Mark Ayton.

MA: How are decisions made to rectify programme problems?

CB: The programme has evolved over time in terms of the processes we use to fix technical and other issues. In the early phase, the programme was structured so that the prime contractors had a disproportionate amount of decision-making authority on what was going on. When you give someone the keys to the car and they start driving the car off the road you have to take the keys back, and that's what the government has done.

In 2010 we set a new baseline for the programme and put in place a number of government forums and decision-making bodies to help us better drive the outcome as to what we, the government, needed.

If a part or a capability on the aeroplane is in ground, flight or qualification testing and it fails or there's a problem that needs to be fixed, the contractor is required to identify that to us. Our team also identifies the problem using deficiency reports. We ask the contractor to provide potential solutions. We form a team that looks at the different options and decide which one to pursue with a full systems engineering review.

It's important to remember that a fix in the short term will make the system work properly, but in the long term it might cost the government more money in terms of reliability and maintainability, so we consider the life cycle of the aeroplane when we make technical decisions. We look at cost, how long it's going to take to incorporate the fix into the aeroplane production process and also to retrofit aeroplanes already in service.

We then issue an Engineering Change Proposal [ECP], which is the go ahead for the contractor to spend our money on the technical solution we've agreed upon to make the fix, cut it into production and provide a retrofit solution.

There are many engineering changes in this programme and that's a problem because they create instability, which drives cost and delays. With an aeroplane as leading edge as this, you expect to find some things that are wrong, but others you don't expect to find.

MA: Has the Joint Program Office truly arrested the most significant programme delays, other than those of software development and validation, and sensor fusion?

CB: There are no technical issues with the programme that keep me up at night right now other than the software. We have made good progress in a number of areas: the helmet, which is very sophisticated and key to the capability of the aeroplane, is one example.

Over the last 18 months, the focus given to the deficiencies supported by dedicated flight test means what the Gen II helmet [the original design] will deliver in 2015 is good, and what the re-designed Gen III will deliver in 2016 is even better. The fixes we've tested and the integration that's under way leads me to believe that we are going to get there.

Another example is the tail hook on the F-35C Carrier Variant which wouldn't catch the cable because it was poorly designed. The hook was redesigned, tested at Lakehurst and Patuxent River, and caught the cable on all 75 traps flown. More importantly, the loads and the stresses on the hook are well within the design limitations so it's demonstrating the required durability. We have reduced some of the risk of the hook, which we needed to do because the F-35C is going to the carrier for the first time in the fall.

In January the Marine Corps and the Navy started flying in inclement weather, down to 250ft for instrument approaches, in all conditions and at night. The Air Force started in mid-March. The only weather condition that the aircraft still has to avoid is lightning, by 25 nautical miles. The two fixes required to lift the restriction are both being fitted in test aeroplanes now and we expect to have flight clearance by 2015. We've already completed ground testing of the redesigned On-Board Inert Gas Generating System (OBIGGS). The aeroplane has been zapped with all kinds of lightning to make sure that it's okay and in the ground testing it was fine. So lightning is another technical issue that we seem to have turned the corner on.

The General's reference to the OBIGGS follows a redesign of the system. During testing back in 2009 deficiencies were found in maintaining the required level of oxygen in the lower fuel tank to prevent explosions induced by lightning. The original OBIGGS system was not able to maintain fuel tank inerting through critical portions of a mission profile.

MA: Have issues discovered during flight testing with the sensors, in particular the APG-81 radar, the AAQ-37 Distributed Aperture System and AAQ-40 Electro-Optical Targeting System, been overcome?

CB: We have improved each one to a working maturity level that they work, and if they don't work, now we know why. The DAS is furthest from being completed, while

AT THE END OF LAST YEAR WE USED THE AND LAUNCH MISSILES ACCURATELY,



Photographer: Michael Jackson/Lockheed Martin

ENTIRE WEAPON SYSTEM TO DROP BOMBS AND HIT WHAT WE PLANNED TO. Lt Gen Christopher Bogdan

the EOTS and the radar are performing well in terms of their respective level of maturity.

We are now measuring stability events, which occur when a sensor doesn't do what it is commanded to do, or needs to be reset during the mission. We are currently recording a stability event once every 10 hours. The F-35 is perfoming better at this early stage in development than other highly-sophisticated aircraft currently in service.

A lot of the work to improve sensor stability involved sensor-specific software, specifically the timing and communication with the mission systems computer.

Individually each sensor is working well but getting the mission computer to command the radar when to turn on and turn off or when the DAS needs to pick up is hard work, and that's where the risk of the software and the fusion exists.

MA: Is the programme now making tangible progress?

CB: The programme is really big, very complicated and we are trying to do so many things all at the same time that when you make a change or make progress in one area you've got to make sure all the other pieces stay with it. You make a change to a part on the aeroplane in production, and guess what? You've got to make sure the tech orders and the maintenance manual are changed, you've got to make sure the supply chain understands it, and that the ALIS [Autonomic Logistics Information System] is updated. You have to make sure that procedures used by the maintenance departments (who take the part on and off) are changed.

When you are doing everything all at once, you've got to implement each change across the whole spectrum of the aeroplane's life.

From my perspective, the progress is slow, I want it to be faster, but it's often necessarily slow to make sure we have all the pieces moving together.

Some of the things worked on during the past year which have progressed well were not focused on the aeroplane itself. Until last year we didn't have a plan for how our programming labs were going to build mission data files. These are the files that contain threat information for geographical areas of the world. We are now embarking on a solid plan that will get the mission tapes done in time for the initial operating capabilities for all of the services and partner nations.

The ALIS is another example. It had been treated like a piece of support equipment, but its way more complicated and much more important than that.

We were putting software into the lab [located in Orlando, Florida] and running the ALIS in a very pristine lab environment. The same software was then being given to, and used by, F-35 squadrons. It was failing, not least because it has to have ten or 12 aeroplanes on the same computer system. The lab only had one aeroplane under test conditions and that wasn't even scalable. The programme used to release a load of software and, no kidding, the first time it got tested in a real environment was in the field. The squadron maintainers became the testers.

Last year we revamped the entire way we conduct the development of the ALIS. We now use metrics to measure performance for critical design reviews, and we upgraded the lab so that it replicates a typical flight line and we now use service personnel to conduct testing in the lab before we field it.

Earlier in the System Development and Demonstration phase we wouldn't allow the operators to override the ALIS when an aircraft needed to be released for flying. After 15,000 hours, operators are more knowledgeable than they were three years ago, so we are increasing their authority to override the ALIS so they can release the aircraft for flying.

MA: What is the current status of the ALIS and air vehicle software?

CB: Last year I would have given the ALIS validation, certification and accreditation process an 'F' grade for two reasons. One the lab was terrible, it didn't replicate the real flight line and two, we didn't know what we didn't know when it came to securing ALIS's data. As a result, we went through a very painful certification process last year with ALIS 1.03. We didn't get it right for security reasons. It took another six months to redesign the ALIS security blanket, which is included in the latest version now out in the field. Security in this context refers to the integrity and secure nature of the data being transferred. The redesigned security blanket ensures that nobody without clearance can access the system, thereby preserving data integrity.

Block 2B and Block 3i air vehicle software are on track and will meet the Marine Corps and Air Force IOC dates. Block 3F software, the final capability, which the Navy will receive first to enable them to declare IOC, is problematic. Block 3F contains state-of-the-art capabilities, primarily off-board fusion, which is the thing that makes it so difficult to develop.

Currently an F-35 can fly around with two, three or four others, and all four pilots can talk to each other and all of the aeroplanes will have the same picture of what's going on through MADL [Multifunctional Advanced Data Link] fed from their sensors. That's F-35 platform sensor fusion. With Block 3F we are going to take information from other assets such as E-3 AWACS, RC-135s, ground radars, and satellites, and link that in to the aeroplane to fuse together a situational picture and pass it on to other F-35s, but also a whole lot of other locations, so it becomes a very smart node in the battle space. And because it has advanced sensors and can operate in places that other platforms can't, it will provide a much deeper look at the enemy. It's really hard to get that synced up and create a clear picture. That's called multi-platform fusion, and it's the one big leap in technology resident in the aeroplane's final capability. It's a complex challenge that will require some flight test rework and software re-dos, and that's why I predict a six-month delay.

MA: How is the mission systems and weapons integration progressing?

CB: We've made enough progress with the mission systems that we've accelerated some of the weapons certification work, and it's ahead of schedule across the various weapons and all the different variants.

At the end of last year we used the entire weapon system [aircraft, mission systems and weapons] to drop bombs and launch missiles accurately, and hit what we planned to. None of the air-to-surface weapons were pre-loaded with coordinates for the target. The missions involved the pilot flying over the target area, designating the target, passing the information from the sensors to the weapon via the mission computer, releasing the weapon and hitting the target.

We are preparing to conduct dual missile shots against two targets and some weapon retargeting where you pick one target, get near and decide it's not the right one, quickly change to another and release. That's all scheduled to happen in the next six months and by October we will have dropped or launched each and every weapon required for the initial operational test and evaluation in 2015. For the most part, a single weapon drop counts and certifies that particular weapon on all three variants. We only have to conduct differential testing if the airworthiness authorities think there's something significantly different between the variants.

WE HAVE MADE ENOUGH PROGRESS WITH THE SOME OF THE WEAPONS CERTIFICATION WORK

The mission systems capability for Block 2B is on track, but there is some delay with Block 3i, although we have a big enough margin prior to the Air Force IOC that it's not a factor.

MA: When does the full operational test programme start and what are the specific dates and criteria for each IOC?

CB: The full operational test begins in 2017 when the final Block 3F capability is delivered. What we do in 2015 is a subset of that where the operational test squadrons will conduct what we call an operational utility assessment.

The US Marine Corps has an objective date of July 1, 2015, but it will be satisfied with delivery of IOC between July 1 and the threshold of December 31. The objective and threshold dates for the US Air Force are a year later.

The US Marine Corps IOC requires ten aeroplanes with Block 2B software, three weapon sets, four mission sets close air support, limited suppression and destruction of enemy air defences, defensive counter air and armed reconnaissance in concert with Marine Air Ground Task Force resources and capabilities, qualified pilots and maintainers, tech orders, a deployable version of the ALIS, and the ability to deploy on an LHD.

The US Air Force IOC requires a squadron of 12-24 F-35As with Block 2B software, three weapon sets, four mission sets, trained and qualified pilots and maintainers, tech orders and a deployable version of the ALIS. The Air Force wants the ability to deploy with the ALIS that support maintainers transferring information from the PMD to the squadron base station without having to walk and reconnect the computers.

The critical path for the Marine Corps and Air Force IOC, which are must-make dates, is modifying the aeroplanes so they are combat ready. We have to complete 96 modifications to the F-35B in the

next year. That means I've got to put them in a depot somewhere, put all the kits together and do it in a way that doesn't take those aeroplanes off the flight line for very long because they are required for training. It takes a long time to get the parts, kit the parts, put the aeroplanes down, make the changes, and get the tech orders and manuals correct. They are not major mods they've just got to be done.

MA: How do you rate the quality of the aircraft entering the government acceptance process leading to DD250 sign-off at Fort Worth?

CB: Our expectation is that an aeroplane coming off the production line will have two Lockheed Martin flights and two government flights and be ready to DD250. Some aeroplanes have been able to accomplish that.

We know certain things aren't going to work on the aeroplane when it comes out. We sign-off on those and we hold money back until they get fixed later. It's the unknown problems that occur during the acceptance flights that keep the aeroplanes back.

One issue is Lockheed Martin's ability to perform root-cause analysis on the flight line and then make a fix quickly enough to get that aeroplane in the air, but they are not humming at capacity - they are slow. That worries me a little, because over the next three years we're going to roll out more than 100 aeroplanes a year. If Lockheed Martin doesn't get that flight line humming they are not going to achieve 100 aeroplanes a year; they are having trouble doing 36 a year right now.

Part of the problem is that Lockheed Martin is pushing work that should be done on the production line out to the flight line so they can keep the production line smoothly running. The guys on the flight line have a lot of issues to deal with. Lockheed Martin has got to get the quality back up and get it into the production line.

For a very long time, they were extremely undermanned on the flight line. They thought they could do the finishing and flight line work with far less people than they had. They still don't have enough people, and the flight line is clogged.

It's very interesting if you look at the data, the aeroplanes that take two flights with a Lockheed Martin pilot and two with a government pilot are usually really good quality. The ones that don't make it through like that are terrible and take as many as eight flights. We've had aeroplanes there for a month waiting to get accepted.

MISSION SYSTEMS THAT WE HAVE ACCELERATED AND IT IS AHEAD OF SCHEDULE Lt Gen Christopher Bogdan



Photographer: Michael Jackson/Lockheed Martin

Code, Builds & Blocks

The F-35 Lightning II is a software-driven aircraft with 8.1 million source lines of code for airborne operation, four times the amount used for the F-22 Raptor – the world's first fifth-generation fighter.

Development of the F-35 is based on iterative builds of software known as 'Blocks'. The software controls all of the aircraft's functions: flight controls, radar, communications, navigation and identification, sensor fusion, electronic protection, electronic warfare, electronic attack and weapons.

All Blocks are a continuation of the previous build. For example, Block 2B expands on the infrastructure and initial sensor work included in the previous Blocks and adds sensor modes, weapons and data link capabilities. Sub-sets are contained within each Block: there are eight in Block 2B. Specific requirements are integrated in each Block by Computer Software Configuration Items. Concurrent development is ongoing within mission systems and vehicle systems: the two major components of the aircraft's airborne software.

Block by Block

Throughout this publication there is reference to the different Blocks of software – some are already in service, others are yet to be released. The following overview provides the main aspects of each different build.

Block 0.5 provided the infrastructure with some initial sensor capabilities. Blocks 1A and Block 1B added to that. Block 2A and Block 2B provided further capability. Block 3i will include some new capability and will operate on new hardware: the updated integrated core processor which runs faster and offers increased memory storage. Block 3F will give more sensor modes, datalink, and the capability to carry more types of weapon.

Block 1 comprises 76% of the source lines of code required for full combat capability. Block 1A was a training configuration, while Block 1B provided initial multi-level security.

The final Block 2A build was released in June 2013 to specifically enhance training. It includes mission debrief capabilities and increases functionality to the fusion engine, as well as enhancing sensor integration, initial datalinks, and basic electronic warfare and electronic attack capability.

Block 2B has an additional 500,000 lines of code. It adds new electronic warfare and radar operating modes, an initial weapon capability (AIM-120 AMRAAM missile, GBU-12 laser-guided bomb and GBU-31/GBU-32 Joint Direct Attack Munitions) and expanded data link capabilities.

The development and integration sub-sets within Block 2B are 2BR1 (the initial flight test release), 2BR1.1, 2BR2, 2BR4, 2BR4.1, 2BR4.2 (completed in February 2014), and the final flight test releases 2BR4.3 (completed in March 2014) and 2BR5 (completed in May 2014).

The last two are problem report clean-up fixes for the aircraft's mission system and offer no new capability. Block 2BR5 will remain in flight test with Lockheed Martin until the end of the final quarter of 2014.

The US Marine Corps plans to declare its F-35 initial operating capability in 2015 with Block 2B.

Block 3i is an intermediate version that the US Air Force will use to work up to its full operational capability with Block 3F.

Development of Block 3i is on-going. Its integration is scheduled to run until mid-2015 – this will be after the flight test phase finishes because the last Block 3i integration phase will include updates for air vehicle systems that will cut in to Low Rate Initial Production (LRIP) lot 8.

Block 3F is the final build for the F-35's initial operational test and evaluation phase: once certified it will be used by all three US services, the UK, Norway and the Netherlands. It will have 8.1 million lines of code. Of that total approximately 98% is already developed; 89% of which is currently in flight test at Fort Worth.

The build is designed to give the F-35 full combat capability including datalink transfer of imagery, more sensor modes and additional weapons: AIM-9X Sidewinder missile, GBU-39/B Small Diameter Bomb Increment I, GAU-22/A Cannon and the UK's Advanced Short Range Air-to-Air Missile (ASRAAM). ***Ian Harding***

Sensing / Effects / C4I / Training & Logistics / Cyber

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Panoramic

Image Data

Variant:	**F-35B BF-01**
System:	**Panoramic Cockpit Display**
Detail:	**The F-35 L3's cockpit is dominated by a panoramic cockpit display with a viewable area measuring 20 x 8 inch and incorporating touch screen control**
Photographer:	**Tom Harvey/Lockheed Martin**

ELECTRONIC WARFARE SYSTEM

The F-35 Lightning II was designed from the outset with its own electronic warfare (EW) system to enable it to control both the air and the electromagnetic spectrums. The system was developed by a team of leading EW specialists led by BAE Systems at Nashua, New Hampshire. It forms part of the aircraft's design, alongside its avionics, Communications, Navigation and Intelligence (CNI) and sensor systems.

While all of the aircraft types that the F-35 will replace use EW systems, some of which are very capable against current threats, the F-35's AN/ASQ-239 enables it to effectively integrate with all of the other onboard systems, each of which is able to inform and interoperate. The aircraft's network can also link in to larger multi-unit networks, other aircraft or terrestrial platforms via its built-in Multifunction Advanced Data Link (MADL), which allows the EW system to be networked in attack or defence.

The internally mounted AN/ASQ-239 Barracuda EW system built by BAE Systems completed its flight testing in 2005 and entered low-rate initial production soon after, with a unit cost estimated at $1.7 million. Weighing some 200lb (90kg), it was developed from the BAE Systems AN/ALR-94 EW suite fitted to the F-22 Raptor, and incorporates technologies – best described as 'emerging' – to produce greater capabilities with a goal of achieving twice the reliability at a quarter of the cost.

The ASQ-239 system provides radar warning (enhanced to provide analysis, identification and tracing of emitting radars) and multispectral countermeasures for self-defence against both radar- and infrared-guided threats. It is also capable of electronic surveillance, including the geo-location of radars, which allows the F-35 to evade, jam, or attack them, autonomously or as part of a networked effort.

The enhanced capabilities of the ASQ-239 (and integration with the F-35's other systems) allows it to perform SIGINT (signals intelligence) collection. The aircraft's stealth capabilities make it possible for an F-35 to undertake passive detection and SIGINT while operating closer to a threat emitter with less vulnerability. When active deception jamming is required, the aircraft's stealth design allows false target generation and range-gate stealing with less use of power.

The EW system also sends and receives data, status and warning information from other onboard systems via the MADL.

The ASQ-239 has ten dedicated apertures: six on the wing leading edge, two on the trailing edge, and two on the horizontal stabiliser trailing edge. The system can also use other apertures on the jet, most notably the APG-81 Active Electronically Scanned Array radar; and in addition to functioning with the APG-81, the radar array could work as a stand-off jammer when transmitting, but only at high power.

When operating in receive-only mode, the APG-81 provides enhanced SIGINT capability and could also be used, following future upgrades, as an electronic attack weapon. This would enable it to burn out emitters with pure power or inject computer inputs into hostile radars or command and control systems that would provide false targets, misleading information, or cause the system to shut down. Combining these capabilities and the aircraft's datalink will give F-35s the potential to jam or attack enemy emitters that they locate while defending themselves from threats.

A multi-ship of F-35s will be able collect SIGINT from multiple directions, and then analyse the information gathered to fire missiles, start jamming or launch an electronic attack. Datalinks mean that F-35s can send the information to other platforms in near real-time and have their actions coordinated 'off-board', where there will be more access to fused intelligence, greater situational awareness, and less chance of lethal information overload, than in the cockpit of an F-35.

The 513th Electronic Warfare Squadron is part of the 53rd Electronic Warfare Group formed in 2010 at Eglin Air Force Base, Florida and is tasked with introducing the F-35's EW capabilities at an operational level. A joint squadron with personnel from all US services, the 513th is co-located with the 33rd Fighter Wing, the F-35 school house for pilot and crew chiefs.

The squadron combines the most up-to-date military intelligence with a robust virtual EW range to create operationally tested and verified combat capable mission data tailored to each F-35 variant.

Tactics, techniques and procedures that will be used by the F-35 in electronic combat are being developed by the 513th, which will also provide and update the threat libraries and systems programming to keep the F-35's systems responsive to changing threats. To do this, the 513th operates a new $300 million reprogramming laboratory at Eglin that opened in mid-2011. ***David C Isby***

Cockpit Display

The F-35 cockpit is dominated by an L-3 Panoramic Cockpit Display (PCD) incorporating touch screen control. The PCD features dual separately addressable left and right 1280 x 1024 pixel displays, each measuring 10 x 8 inch (250 x 200mm) via the one 2560 x 1024 pixel active matrix liquid crystal display with a viewable area measuring 20 x 8 inch (500 x 200mm).

The top part of the 20 x 8 display is devoted to sub-system information, such as engine and fuel gauges, stores management, flight controls, wheels, caution and warning systems, autopilot, auto throttle, navigation information, IFF, altitude and time data.

Tactical employment information is all displayed on the lower part of the screen and is split into four windows called portals 1, 2, 3 and 4, left to right.

The pilot can place anything anywhere and change the size of the portals. Most pilots fly with a tactical information display on one side and all of the sensors on the other. A hallmark of the F-35 is the fused picture presented on the display, which is very easy to interpret for the pilot.

Symbology at the bottom left of the display on an F-35B STOVL variant shows what the nozzle is doing.

There is no head-up display (HUD) in the F-35; everything that would normally be placed on the glass is displayed on the Helmet-Mounted Display System visor focused in on infinity.

On the right hand side of the cockpit is the side stick controller, which has a fair bit of movement and in the case of the F-35B STOVL variant enables the pilot to hover the aeroplane.

The throttle is on the left hand side and has a long linear throw rather than a rotary arc. This allows pilots of all physical sizes (from 104lb/47kg to 245lb/111kg) to fit and reach the controls, and sit comfortably in the aeroplane.

There are hardly any levers or switches in the cockpit, which minimizes the cockpit mass; only essentials are included, such as the landing gear handle, emergency release, and engine start controls. All other control is through the touch screen or voice control.

In the centre of the console is the standby flight display, which has a separate inertial navigation system and runs on battery power alone. The left hand side of the main display is also battery powered. If the engine fails, leaving only battery power, the left side of the display and the standby display both stay alive, providing the pilot with sufficient data to fly the aeroplane safely – but nothing else. ***Mark Ayton***

Golden



Image Data

System: **F-35 transparency**

Detail: **The F-35's transparency is a one-piece, forward-opening design featuring an integrated bow frame**

Photographer: **Paul Ridgway**

GKN Aerospace Transparency Systems based in Garden Grove, California is the industry leader in its field. Transparency is the term used for any type of aircraft window, wind shield or canopy.

Vital to GKN's position in this sector are advanced low-observable transparent coatings, proprietary lamination processes and research and development into optics for the F-35 Lightning II. Coatings, lamination and optics are essential requirements in the quest to dominate the airborne battle. GKN's work aims to reduce life-cycle costs and the company has also developed a system for spares and rework that will further benefit the F-35 programme.

Meeting the design requirements for the F-35 has presented major challenges during the aircraft's System Development and Demonstration phase. Design, development and choice of materials is undertaken by GKN at Garden Grove in conjunction with Lockheed Martin. The aircraft manufacturer is responsible for designing and producing the transparency's frame and its interface with the aircraft and the transparency.

Lighting Transparency

The F-35's transparency is a one-piece, forward-opening design featuring an integrated bow frame to reduce the aircraft's radar cross-section (a measure of how detectable the aircraft is to radar) and its weight. It comprises a wind shield (forward) and a canopy (aft): both are inserted into the frame. This design style differs to a single-seat F/A-18 Hornet or Super Hornet which has a transparency system comprising two separate elements.

Tony Salerno GKN Transparency Systems' Manager Design Engineer explained: "Low-observable characteristics and radar avoidance are design requirements for aircraft like the F-22 and F-35. To minimize both, the F-35 canopy made from a single piece of acrylic has no steps or gaps and is laminated to the windshield over its entire portion so the outside mould line is all one piece." The transparency is thicker at the fore and thinner at the aft.

Canopy and Windshield Design

It is imperative that the transparency's optical quality is not compromised in the critical zones, and key to achieving that is its shape.

Equipment designed by GKN helps to simulate the pilot's view through the transparency and enables engineers to modify it in the frame in accordance with the interface constraints and tolerances of the outside mould.

"We ensure the transparency meets the optical requirements. Theoretically, we have to simulate the pilot's eye position and what he would see. The inspection is completed against a 'grid board': a board of (strings) that are perpendicular and parallel. When you look through the shape, it simulates whether a pilot can see any distortion or deviation in their visual optical view," added Salerno.

Meeting the specified requirements for in-flight impact to the front windshield and safe emergency egress for the pilot through the canopy is vital. The latter includes the level of explosive charge needed to cut through the material to ensure safe egress in the ejection seat. If the explosive charges were to fail, 'breaker bars' are incorporated on the ejection seat to enable it to punch through the canopy.

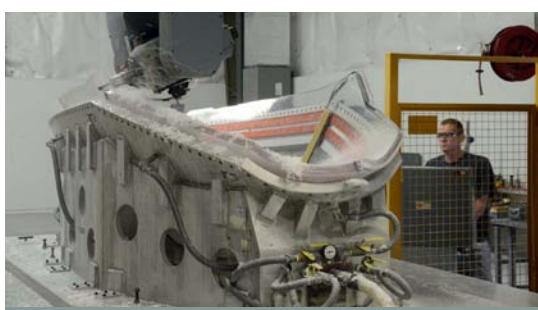
The design tolerance between the canopy, windshield and the frame structure are critical for maintaining aircraft's radar cross-sectional signature and to help counter detection by ultraviolet and infrared threats.

GKN would not disclose the number of layers or the compounds used to manufacture the F-35 transparency but did confirm that the windshield and canopy each comprise a single stretched piece of acrylic. "The stretching process makes it stronger, providing it with better material properties. The windshield is a thicker section that's also stretched acrylic. Coatings are added in multiple layers to the outside [of the windshield and canopy] some of which provide adhesion and function correctly under various [atmospheric] thermal pressure cycles. Conductive coatings and layers are also applied to the outside of the windshield and canopy to help protect the transparency and pilot from lightning and to dissipate lightning. Other specialised coatings help reduce material degradation," Salerno confirmed.

GKN provides each transparency to Lockheed Martin with the windshield and canopy bonded in, coatings trimmed and drilled and the bushing seals installed. Frame construction, assembly and installation lies with Lockheed Martin.

Production Process

GKN's proprietary production process for the windshield and canopy comprises three key stages:

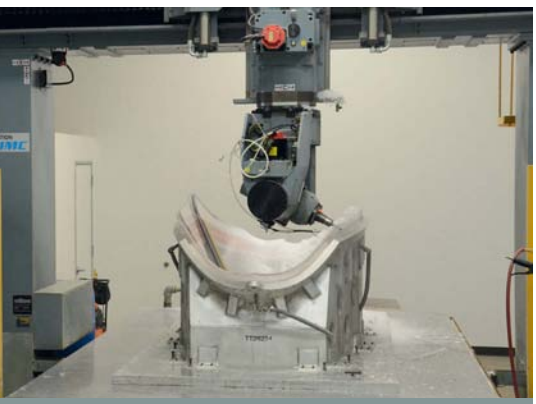


System: **F-35 Canopy** Detail: **Rough machining of a CTOL variant canopy** Photographer: **Clayton Fox/GKN Aerospace**

Transparency



System: **F-35 Canopy** Detail: **Optical inspection of CTOL variant canopy** Photographer: **Clayton Fox/GKN Aerospace**



System: **F-35 Canopy** Detail: **Rough machining of a CTOL variant canopy** Photographer: **Clayton Fox/GKN Aerospace**



System: **F-35 Canopy** Detail: **Optical inspection of CTOL variant canopy** Photographer: **Clayton Fox/GKN Aerospace**

production of the acrylic (including its casting and cutting), coating and lamination. Salerno explained: "The acrylic starts out in liquid form. We run it through a curing process and cast it into flat billets. The duration of the casting process is dependent on the thickness required: it can take days, even weeks. Once it's solid [to a specified thickness and size] we stretch it on purpose-built equipment that grabs the ends of the material and pulls it in all directions as it cools. This takes a matter of hours but strengthens the material.

"We then manually inspect it for inclusions and surface anomalies to meet exact tolerances in surface quality to comply with optic and visibility requirements. If an inclusion or anomaly is found in a component it cannot be passed and must be scrapped. The majority pass. Then we cut it into the shape that we would need in flat form to begin to form it into the canopy or windshield shape.

"We take a flat piece of material, form it into the compound shape of an F-35 windshield or canopy, while maintaining a thickness gradient within a tolerance and make sure that it doesn't have any optic deviations."

Each canopy is formed in a female tool to hold the outside shape and a windshield is formed in a male tool to hold the inside surface. The process is done in an oven, through a series of partly-automated cycles that take a number of days to complete.

"Forming, along with coating and lamination are the three most challenging processes because they are proprietary to the company and therefore commercially sensitive," said Salerno.

Last year GKN developed a fully automated forming process, to give more control and reduce the number of cycles. This will be used for the first time later this year. ***Ian Harding***

Big Range Big Resolution

Like other systems on the F-35, the Northrop Grumman AN/APG-81 Active Electronically Scanned Array radar is housed in a minimal amount of space, with its transmit-receive (T/R) module array packed into the aircraft's radome. Despite the constraints, Northrop Grumman's product line is bristling with capability and performance.

Complex in design, the APG-81 radar has a variety of main components including the T/R modules, the beam steering computer, array driver, power supplies, inertial navigation systems, and an electronic warfare interface unit. There are about ten assemblies for the antenna and 15 for the receiver-exciter, wideband and narrowband waveform generators.

Built by Northrop Grumman, the RF support electronics comprise a receiver module, an exciter module and power supplies. Each module is shipped to Lockheed Martin's Fort Worth facility, where it is integrated into the aircraft.

"The front end of the radar comprises what we call the array, which has the T/R modules and the radiating element, and is bolted directly to the integrated forebody and positioned up front in the radome," said Northrop Grumman's Dave Bouchard.

The size of the APG-81 antenna or array is governed by the internal size of the radome and comprises many of hundreds of T/R modules.

Once installed into the aircraft, in theory, the radar's front end should not have to be removed or replaced. "The array is designed to last the 30-year life of the platform, with a meantime between critical failures (MTBCF) greater than 10,000 hours," Dave Bouchard asserted.

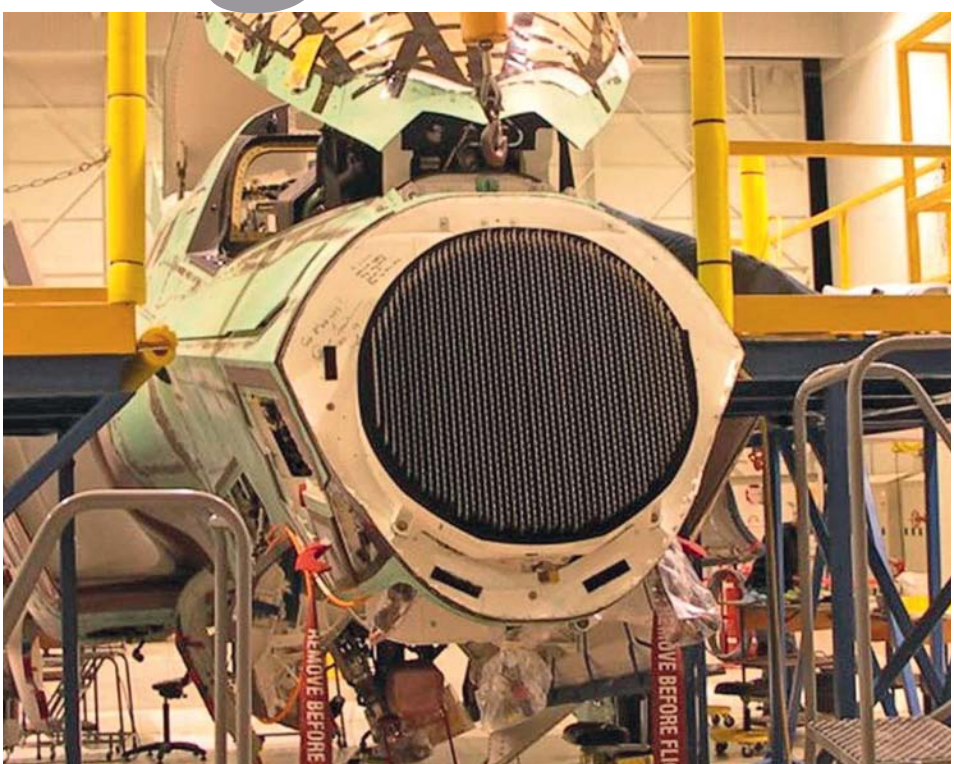
Items that drive the antenna, such as the power supply, are on the other side of the bulkhead (to the array) and their MTBCF rate is not as high. These components will eventually require maintenance and are easy to access without removing the radome.

Receiver-exciters are usually packed into one box but because of space restrictions they are divided into two different boxes located behind the bulkhead and linked to the antenna with a very short cable.

The APG-81 has an electronically steered array controlled by a steering computer with no mechanical motion. Designed as a multi-mode system, the APG-81 has 32 modes of operation which are common to all three F-35 variants; 12 air-to-air, 12 air-to-ground (including two maritime modes: ship target track and sea search), four electronic warfare (electronic attack and electronic protection), two navigation and two weather. Some of the modes are high resolution and are supported by the sophisticated signal processing available.

Although Northrop Grumman would not confirm as such, the APG-81 can operate in LPI (low probability of intercept) and LPD (low probability of detection) modes that are used to minimise the aircraft's signature to comply with its low observable (LO) requirements. The radar is optimised for agility, very low noise and high efficiency, and fully supports the LO nature of the aircraft. Northrop Grumman claims it is capable of detecting very small targets and tracking at "relevant tactical ranges".

Sensor track information is sent into the aircraft's integrated core processor (ICP). Tasked by the ICP, the mission system then fuses radar data with that sent from the AAQ-37 Distributed Aperture System (DAS), AAQ-40 Electro-Optical Targeting System (EOTS), ASQ-239 electronic warfare (EW) system to provide what Lockheed Martin describes as "unparallel situational awareness". Operational Flight Program (OFP) software for both the APG-81 and DAS reside in the ICP, which allocates processing power to each system. "What really helps is having the ICP provide more memory and throughput that gives the timeline to execute targeting," said Dave Bouchard adding: "We send our radar and DAS information to the mission system and have an interface control that defines what messages are passed from radar and DAS to the fusion system."



System: **AN/APG-81 Active Electronically Scanned Array radar** Detail: **The APG-81's array fitted to the forebody of an F-35 in a flight test shed at Lockheed Martin's Fort Worth facility.** Photograph: **Lockheed Martin**

Another interesting aspect of the APG-81 is the interface with the F-35's ASQ-239 EW system. On most legacy aircraft the radar and EW are confederated systems that work separately of each other. On the F-35, radar and EW functions work collaboratively, and in some modes they work independently of one another.

Detection and tracking capability are two aspects in which the new APG-81 has set new performance criteria. But how does the system achieve the range accuracy required by the F-35 mission set. Dave Bouchard explained: "Range accuracy is achieved by multiple air-to-air waveforms that drive the dozen air-to-air radar modes. Range measurements are provided to the common filter, which uses algorithms to filter out drift or inaccuracies that arise over time, and thereby maintain track accuracy."

In terms of type, the APG-81 is a pulse-Doppler radar system that runs multiple waveforms for air-to-air and air-to-ground, with what Northrop Grumman calls "very robust electronic protection" (EP), which helps the system to achieve its accuracy requirements. EP is a series of techniques that help prevent the radar from being confused or jammed, and ensures that information presented to the fusion system is accurate.

DAS, EOTS, EW and the APG-81 radar all provide track information and track updates to the fusion system that in turn controls the portrayal of targets and symbology on the Panoramic Cockpit Display and the Helmet-Mounted Display System.



Image Data

System: **AN/APG-81 Active Electronically Scanned Array radar**

Detail: **Once fitted to the fore body of an F-35, the array is fixed in position and looks much different to mechanical radars.**

Photograph: **Lockheed Martin**

In terms of ground target identification and coordinate generation, Dave Bouchard claims that the APG-81 outperforms current AESA radars in two ways.

By processing Synthetic Aperture Radar (SAR) data with multiple advanced algorithms, the system performs automatic target recognition (ATR) and automatic target cueing (ATC) on the SAR maps. "We can take a very high resolution ground map of a large area and use algorithms that pick out targets of opportunity that the pilot would be interested in," Bouchard advised.



System: **AN/APG-81 Active Electronically Scanned Array radar**
Detail: **The APG-81's array fitted to a test rig, showing the dozens of T/R modules.** Photograph: **Lockheed Martin**

Many radar systems have SAR capability with a set resolution, such as 20ft (6m). In comparison, the APG-81 has what Northrop Grumman calls "Big SAR", which instantly generates a huge SAR map when commanded. The pilot can zoom in or out on a specific point for a higher fidelity image display without having to generate a new SAR map. The ATR and ATC work simultaneously on the entire area of the Big SAR map, and greatly reduce pilot work load during the most demanding phases of air-to-ground operations.

In support of the two-level maintenance system set in place for the APG-81, maintainers will use the APG-81's prognostic health monitoring system to check the status of the radar for flight line maintenance. Faults are presented on a display located inside a bay on the aircraft, indicating which line replaceable component (LRC) to change. This is a straightforward procedure requiring the maintainer to remove a cover, unplug the LRC, unfasten ten screws, remove the old LRC and replace with a new one, run a test and in theory the radar should be serviceable once again.

All other radar maintenance (the second level) will be undertaken at the F-35 depot facility at Hill Air Force Base in Utah.

The radar's antenna, housed inside the radome, has a MTBF (mean time between failures) of 10,000 hours, though the APG-81 as a system is not rated at that level. Dave Bouchard explained: "One of the advantages of the system from a reliability standpoint is based on the T/R module array that allows graceful degradation, meaning you can afford to lose T/R modules and still maintain the performance."

A premise of the F-35 programme is that logistics will be performance based, so all suppliers have an incentive to build reliability into their products and a system that can achieve the short duration MTBR (mean time between repairs) target.

The F-35 radar gained a significant amount of radar design heritage from the APG-77 used by the F-22 and the APG-80 AESA system used by the Block 60 F-16, both of which have thousands of hours of field data and robust reliability requirements.

Using field history of the T/R module architecture applied to the APG-77 and APG-80, and sophisticated predictive modelling, Northrop Grumman is performing operational and support modelling to help support its performance-based logistics programme.

Because no single APG-81 array has reached the equivalent MTBCF hours yet, modelling of this nature must be performed to mitigate this situation.

Lockheed Martin received the first APG-81 radar units from Northrop Grumman in 2005, the same year that the system flew on Northrop Grumman's BAC 1-11 test-bed aircraft for the first time.

In 2009 the radar made its maiden flight fully integrated onboard Lockheed Martin's Boeing 737 CATbird, and flew for the first time in an F-35 (aircraft BF-04) in April 2010. Since the first Low Rate Initial Production F-35s arrived at Eglin Air Force Base in Florida on July 14, 2011, the APG-81 radar has accumulated thousands of hours of flight time. ***Mark Ayton***

Visionary Systems

All three variants of the F-35 Lightning II are equipped with the same suite of mission systems. By applying cutting edge technology, the systems are not just complex but designed to provide a picture of the battle space that is better than any fighter pilot has ever had before. Using the AAQ-40 Electro-Optical Targeting System and the AAQ-37 Distributed Aperture System, the F-35 pilot is fed information on the Panoramic Cockpit Display and on the visor of his Helmet-Mounted Display.

AAQ-40 Electro-Optical Targeting System (EOTS)

With ample experience in building some of the world's most advanced targeting systems, scientists and engineers working for Lockheed Martin's Missiles and Fire Control in Orlando, Florida, were in a good position to take targeting capability even further when the requirements for the F-35 were received. The resulting AN/AAQ-40 Electro-Optical Targeting System (EOTS) leverages on the experience gained from producing the LANTIRN targeting system ('the genesis of night, precision weapons employment'), the AN/AAQ-33 Sniper advanced targeting pod, and the AN/AAS-42 infrared search and track (IRST) system used on the F-14D Super Tomcat. "The EOTS is the first sensor to combine a targeting FLIR and IRST. Marrying the two capabilities into one sensor was the big technical challenge in developing the system," said Don Bolling, Lockheed Martin's Business Development Manager for EOTS.

Principally viewed as an air-to-ground targeting pod, the EOTS was initially destined for every third F-35 produced. But the US Navy successfully argued for EOTS to be fitted to every F-35 built citing the capability as an absolute indispensible part of the sensor suite used throughout the mission spectrum. The EOTS provides laser designation, laser spot tracker for cooperative engagements, air-to-air and air-to-ground tracking FLIR, digital zoom, wide area IRST and generation of geo-coordinate to support GPS-guided weapons. All three variants of the F-35 are fitted with the EOTS.

Measuring (W x D x H) approximately 19.4 x 27.5 x 32.1 inches (493 x 698 x 815mm), the EOTS populates a box with a volume of less than 4cu ft and weighs 202lb (91kg). "There are DAS sensors on the left and the right of EOTS, and radar equipment above, the space constraints are very tight," said Bolling. By comparison a Sniper pod comprises a 7ft 6in (2.3m) long tube weighing about 440lb (200kg). One reason for the difference in size between the Sniper pod and the EOTS is the cooling method used. Most conventional targeting pods such as Sniper are air-cooled requiring the necessary system to be carried on the back of the pod. The EOTS is a liquid-cooled system using PAO (polyalphaolefin) fed

from the aircraft.

The EOTS is positioned within the F-35 lower forward fuselage between the radar and cockpit bulkheads. "When you think of the level of complexity in a targeting system, which are like telescopes with long straight optical paths, and see where the EOTS is positioned on the F-35, space is at a premium," said the EOTS boss.

Space is limited to such an extent that a standard targeting system with a straight optical path is physically impossible to house in the space available. The EOTS optical path is therefore folded via mirrors and prisms to refract the light off several different surfaces to direct it on to the focal plane array and fit within the space. "The system is a compact optical device that uses multiple wavebands," said Casey Contini, director of F-35 electro-optics and helmet systems at Lockheed Martin.

"We are effectively bending light at least four times from the point where it enters the window and is finally directed onto the focal plane array or the detector, which was a significant challenge," Don Bolling extolled.

"What makes the F-35 truly magic is that for the first time you have a fused sensor suite. The APG-81 radar is much more accurate in range presentation against an airborne target than an IR system can be, and the EOTS is much more accurate in azimuth down to a single pixel than radar can be. Combine the two capabilities together and you get a much smaller target location uncertainty, which means your weapons effect will be greater and if required your designation accuracy to cue somebody else to that spot will be much tighter. You are able to share the capabilities of each of the sensors and reduce uncertainty," he said.

The EOTS sits behind a faceted window assembly comprising seven sapphire panels. A panel refers to an individual part that fits into a frame and is secured in place to comprise the whole window assembly. Driven by the requirement to comply with the aircraft's radar signature, the EOTS window assembly is the first such design in existence. By comparison, Lockheed Martin's AAQ-33 Sniper pod has four smaller panels with a much shallower angle of incidence between the sensor and the window. Maintaining the required optical performance and complying with radar signature requirements presented a real challenge according to Bolling.

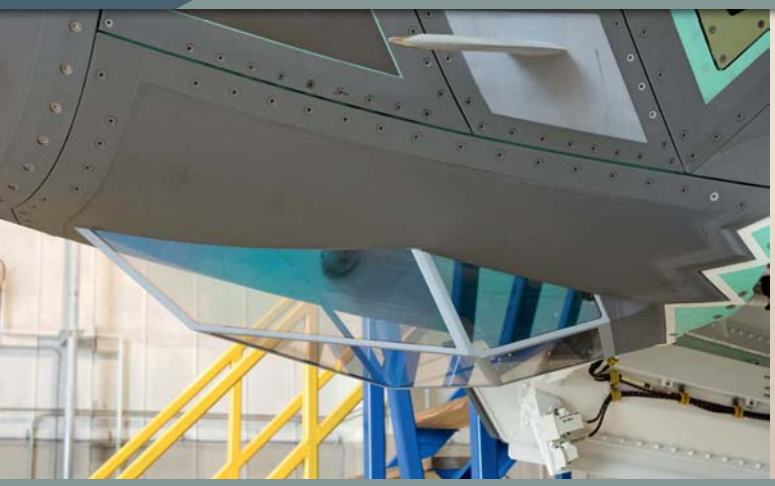
Internally the EOTS has unique designs for the gimbal and the main entry lens called the A-focal or azimuth assembly which provides the horizon-to-horizon view. It is positioned right up against the window with about a 1/4 inch (6mm) of sway space. This intricate design was driven by the requirement for multiple fields of view with a digital zoom in a low-observable application.

A second lens known as the elevation assembly is an innovatively designed mirror that sits opposite and at a 45˚ angle to the main A-focal and rotates to provide vertical



Image Data

Variant:	**F-35A AF-06 07-0744/'ED'**
Unit:	**461st Flight Test Squadron**
Location:	**Over California**
Date:	**April 30, 2012**
Detail:	**Block 2A software regression test flight**
Photographer:	**Darin Russell/Lockheed Martin**



System: **AN/AAQ-40 Electro-Optical Targeting System** Detail: **The sapphire colour of the panels is shown to good effect in this side shot of the EOTS faceted window** Photograph: **Lockheed Martin**



System: **AN/AAQ-40 Electro-Optical Targeting System** Detail: **The EOTS measures approximately 19.4 x 27.5 x 32.1 inches, weighs 202lb and populates a box with a volume of less than 4 cu ft.** Photograph: **Lockheed Martin**

coverage. The elevation assembly directs the light into the optical path.

At the top of the system is the laser, the same type of laser used in the Sniper ATP but with a different output path. Just below the laser on top of the gimbal assembly are two circuit boards or electronic control assemblies. One provides control to the power servo and the other is an image processor mechanism. A fibre-optic channel feeds data from the sensor directly to the integrated core processor.

The entire EOTS assembly has a composite shroud to provide cover from debris and act as a structural element that assists with stabilising the system. System stabilisation is hugely important for holding a spot on the ground and very steady so a geo coordinate can be derived and fed to a GPS-guided weapon for targeting.

Each time the EOTS powers up, an automatic boresight aligns the laser and the FLIR. The boresight mechanism is a module fitted on the back of the gimbal. At power-up the sensor slews into the boresight module and aligns itself with the FLIR and the laser so that they are pointing at the same spot. Having a single aperture means the FLIR and the laser all go through the same optical path.

"All of the sensors on the aircraft need to be boresighted to a spot in space so that when the pilot looks at the radar display he or she is looking at the same spot on the ground as the EO system whether it happens to be the DAS or EOTS," said Don Bolling.

"We are working on improvements that would ideally place a larger aperture system [a larger aperture behind the window] into the aeroplane for greater detection range whether that for the IRST functionality or for air-to-ground weapons employment." He added: "we have to remain within the volume of the window because that has signature implications but we have looked at getting larger apertures behind that window to increase our effective range.

"The larger aperture system is one of many different capabilities that the US services and partner nations are considering for inclusion in the follow-on development phase of the programme."

On stealth platforms like the F-35 the aircraft's signature must be carefully managed. With IRST the aircraft has a passive IR sensor that creates no emissions unless the laser is used. If the APG-81 radar detects something out at range, using IRST mode the pilot can feed the data to EOTS and passively track the contact with high fidelity while minimizing transmission of RF energy and the aircraft's signature.

The EOTS IRST uses a gimbal, an inertial measuring unit, and a fast steering mirror to provide precise stabilization. Passive in operation, the IRST has a wide area search capability comparable to the APG-81 radar with very high scan and slew rates because of the unique gimbal design.

Looking to future capabilities Don Bolling told *AIR International:* "EOTS is a unique system in that it is able to perform both an IRST scan and traditional targeting FLIR functions. It is the first sensor designed to accomplish this. Since IRST is an inherent part of the EOTS system, we are always looking for ways to provide additional benefits to the warfighter. We have investigated the potential of applying the very fast IRST scan volume across the ground for an IR ground moving target indicator, that capitalises on EOTS' low inertia gimbal design for unique applications in the ISR role."

The EOTS is a two-level maintenance system that enables maintainers to undertake maintenance on the flight line using the built-in test functionality, capable, according to Lockheed Martin, of isolating a single line replacement component (LRC). The EOTS can be dropped down from within its bay to allow maintainers access to replace any one of 15

AAQ-37 DISTRIBUTED APERTURE SYSTEM (DAS)

Lockheed Martin claims that the situational awareness provided to a pilot flying an F-35 Lightning II is unparalleled in comparison to that provided by other fighters on the market today. As the second fighter aircraft built in the fifth-generation class, the F-35 is equipped with some very advanced sensors including the extremely capable APG-81 AESA radar with 32 operating modes providing incredible performance according to its manufacturer Northrop Grumman.

But the F-35 is equipped with the revolutionary AN/AAQ-37 Distributed Aperture System (DAS) also built by Northrop Grumman.

The advanced features of the DAS include missile and aircraft detection, track, and warning for the F-35. DAS also gives a pilot 360° spherical day/night vision, with the capability of seeing through the floor of the aircraft. And because the DAS is a passive system, the pilot does not have to point a sensor in the direction of a target to gain a track. Comprising six infrared (IR) sensors (each housed in an aperture) located around the aircraft, Northrop Grumman classes the DAS as an integrated system and not a sensor or a series of sensors.

The six apertures each provide 95° field of regard and a total of 570° to ensure sufficient overlap in coverage around the aircraft.

One aperture is positioned on either side of the radome below the chine line (the right and left side apertures), one in front of canopy (upper forward), one in front of the refuelling receptacle (upper aft) and two on the under fuselage (the lower forward and lower aft) one pointing forward and one aft, but not straight down.

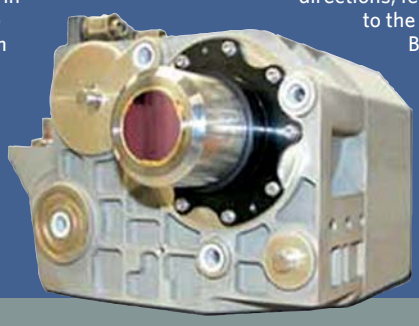
The six apertures are positioned so that no part of the aircraft masks its view. The system receives threat information from all directions and stitches it together to give a simultaneous three-dimensional spherical view, using that information to protect the aircraft. Consider how a traditional radar scan of less than 200° is displayed on the screen and then you might wonder how Northrop Grumman displays the entire 360° view generated by DAS? Phil Edwards, Business Development Manager for DAS explained: "The sphere provides information on threats and feeds that information to the fusion system, which in turn displays the most relevant information into the HMD. Depending on which direction the pilot is looking will dictate what frames or field of view from the sphere the pilot will be able to see in the HMD."

"While the imagery provided to the pilot in the HMD is the most tangible thing generated by the DAS and the one that people are most impressed by, in reality, the ability to simultaneously see different targets in all directions, feed information to the fusion system and provide warnings to the pilot, is the key advantage of the system," he added.

But providing images to the HMD is not the limit of the system's capability. The DAS also tracks airborne targets it detects surface- and air-launched missiles, while providing passive protection of the aircraft. It performs different functions simultaneously but does not operate in different modes as requested or commanded by the pilot.

The six aperture sensors function in the infrared spectrum in all directions, run advanced exploitation algorithms to increase range, reduce false alarms, turn track information into useable data, feed it to the fusion system and add to the air picture displayed for the pilot.

Each of the six apertures is interlinked to the ICP,



System: **AN/AAQ-37 Distributed Aperture System** Detail: **An infrared sensor, as used by the DAS** Photograph: **Northrop Grumman**



System: **AN/AAQ-40 Electro-Optical Targeting System** Detail: **The aft end of the faceted window assembly showing three of the seven sapphire panels** Photograph: **Lockheed Martin**



System: **AN/AAQ-40 Electro-Optical Targeting System** Detail: **The faceted window of the EOTS on an F-35A assigned to the 58th Fighter Squadron based at Eglin Air Force Base, Florida** Photographer: **Jim Haseltine**

different LRCs carried.

In March 2011, the EOTS started flying on F-35 mission systems aircraft at Naval Air Station Patuxent River, Maryland and Edwards Air Force Base, California.

The Director Operational Test and Evaluation Fiscal Year 2013 Annual Report, published in January 2014, listed deficiencies with the EOTS that were discovered during flight testing.

The first was line-of-sight stability. Errors in the position of where the TFLIR (targeting FLIR) was pointing over small portions of its field of view were identified and found to be associated with how the gimbal system works. "We have been able to close out the problem," said Casey Contini.

The second concerned system stability that required F-35 test pilots to perform component re-sets. According to Contini, aircraft mission systems are experiencing stability issues while the jet is running on the ground. "They are generally resolved by power cycling the system, so a team from Lockheed Martin's Missiles and Fire Control business is working through the issue.

The third: the EOTS failed to meet target recognition ranges, tracking and stability in portions of its field of view. Contini explained: "This issue is partly related to the instability of the gimbal control, which makes it harder for the pilot to see things, but you also have to take into account the effect of atmospheric conditions with an electro-optical system. You will get different results when you try to test to any atmospheric condition.



System: **AN/AAQ-40 Electro-Optical Targeting System** Detail: **The A-focal and elevation assemblies of the EOTS** Photograph: **Lockheed Martin**

"The problem is also in part caused by the ability of the pilot to understand how much detail he needs in order to make a [target] recognition call. Is he trained well enough to recognise and identify a real target versus what he has experienced in the computer model? Training is important because it allows the pilot opportunities to fly in different environments and distinguish them from those used for analysis, the majority of which do not replicate real world environments."

The fourth: poor image quality, tracking stability and target accuracy. "The objective is to make sure the pilot can see, track and laze the target. We use the EOTS to get a range to the target then hand off GPS co-ordinates generated from an EOTS track. In some cases it worked just fine, but in some portions of the system's field of view it was providing erroneous data, false sets between the known angle of the gimbal and the translation back to the angle of the aircraft. The boresight module created a bias in the system that generated erroneous GPS co-ordinates.

A team from Lockheed Martin Missiles and Fire Control implemented a solution for the abnormalities found in the gimbal control software which were verified by the end of 2012. The only issue not corrected by software, was the boresight module, which required a hardware change.

At the end of last year the F-35 ITFs completed weapons delivery accuracy testing using the

which runs the software algorithms that generate geo-registered threat reports and imagery. These are fed to the fusion computer which outputs data using two channels, one to the HMD and one to the Panoramic Cockpit Display.

In the case of the HMD, whatever direction the pilot is looking, he will receive data from the sensor that supports his field of regard. With the Panoramic Cockpit Display, the pilot can chose what he wants presented, which can be a permanent feed from one sensor or whichever sensor can view a given point on the ground, as two examples.

Because some (not all) of the six apertures are located close to hot components on the aircraft, they use an internal cryogenic coolant.

Maintaining the DAS is straightforward because the sensor is laser-welted and permanently sealed and can only be removed and replaced on the flight line. For any kind of repair the sensor is sent back to the depot or Northrop Grumman.

The DAS is designed to detect low intensity threats in a much cluttered background, and has the capability to detect threats such as ballistic missiles. In June 2010, Northrop Grumman collected data from a two-stage Falcon 9 ballistic missile launch from Cape Canaveral in Florida, to determine the applicability of the system to detect, track and potentially target missiles in the ballistic missile defence role. Northrop Grumman's BAC 1-11 test-bed tracked the multi-stage rocket with the DAS for over 808 miles (1,300km) while airborne over the coast of North Carolina.

According to Northrop Grumman's Dave Bouchard, the processing power available enables the DAS to simultaneously track thousands of targets, far more than is possible with any current infrared system.

"DAS is an omni-directional infrared system that can simultaneously detect and track aircraft and missiles in every direction, with no practical limit on the number of targets it can track. DAS truly revolutionises the way we think about situational awareness," said Bouchard.

DAS has three primary functions: missile warning; providing 360-degree situational awareness using an IRST function, and navigation, which is displayed in the Helmet-Mounted Display System visor. The DAS has been in flight test since 2011 and with the Air Force, Navy and Marine Corps fleets since 2013.

The Director, Operational Test and Evaluation Fiscal Year 2013 Annual Report (DOT&E FY2013 AR), published in January 2014, listed deficiencies with the EOTS that were discovered during flight testing.

First was the false alarm rate in the BIT (built in test) reporting. This was an immaturity issue. It was satisfactorily fixed and the false alarm rate has dropped back to its expected level.

Second was the inability of the DAS to distinguish flares from threat missiles. "It's important that the system recognises what is around it and which contacts are friendly: that information was not being provided accurately," said Casey Contini director of F-35 electro-optics and helmet systems at Lockheed Martin.

Third involved a communication fault between the INS and the digital terrain map of mother earth, which caused the DAS to receive erroneous information. Contini explained: "We want to know what's below us, what's ahead of us, so getting the information on a regular basis and without error is crucial. It was important to correct the problem.

The DOT&E FY2013 AR also reported latency in getting information detected by the DAS to the pilot for navigation purposes. Contini said the Joint Program Office had a concern. "It thought the latency measurement should be smaller than the specification supplied by Lockheed Martin. We went to flight test to gather more data for validation. Once the data was to hand, everybody agreed that the requirement as written was sufficient," he said.

Contini says the DAS is in good shape and that Lockheed Martin is waiting for the remainder of the flight test to take place but doesn't expect much to come out at this point. ***Mark Ayton***



System: **Gen II Helmet-Mounted Display** Detail: **A pilot straps the Gen II HMD to his head and connects the system to the aircraft** Photographer: **Paul Ridgway**

EOTS to successfully target GBU-12 laser-guided bombs, GBU-31 and GBU-32 Joint Direct Attack Munitions.

The IRST capability remains in development with Lockheed Martin Missiles and Fire Control. Block 2B will have a limited capability and aircraft configured with Block 3 will have the initial processing power of the PR2 hardware and full IRST capability. Completing the IRST and flight testing the mode will be the focus over the next two years. All other functions of the TFLIR have been fully tested and await verification in the F-35's Block 2B operational test phase. ***Mark Ayton***

Helmet-Mounted Display System

The F-35 is designed without a head-up display (HUD): a system used in fighter aircraft to provide the pilot with flight information. In place of a HUD, the F-35 uses the Helmet-Mounted Display System (HMDS) developed by Vision Systems International.

HMDS comprises a display management computer, a tracker system, and the helmet-mounted display (HMD). The display management computer provides the interface between the aircraft and the HMD, and generates all of the tracker system and display information. The tracker system comprises a magnetic source installed in the crew station and a sensor located on the HMD.

Weighing less than 4.5lb (2kg) including the oxygen mask, the HMD consists of a flight helmet with a noise reduction system, a display unit which provides the pilot with an 'out of the canopy display' to enhance situational awareness, targeting and tracking capability and a day/night sensor to provide video for displaying and/or recording.

The HMD can present video source and symbology commanded by the aircraft's mission computer, but fusion of multiple sensor sources is not a requirement or function implemented in the system. Seven high-speed links including fibre optics and MIL-STD-1394 interfaces provide video and controls.

The HMD is capable of supporting three modes of operation: day symbology only, day video and symbology, and night video and symbology. The modes allow the pilot to continue using the night capability into the dawn and dusk with the HMD day/night camera. Raw data and symbology commands are received by the HMD, most of which are determined by mission system software. Jon Beesley, Lockheed Martin's former chief test pilot for the F-35, who flew the maiden flight on December 15, 2006 spoke of the elegance of HMD saying: "Most HMDs have to sacrifice either the symbology or night vision. In ours you won't".

The HMD provides accurate head orientation and position data to the mission computer while the aircraft's data fusion engine and the pilot-vehicle interface automatically display air and surface targets on the HMD generated by any of the F-35 sensors. The data fusion engine controls and prioritises which targets are displayed on the HMD.

The APG-81 Active Electronically Scanned Array radar sends all contacts to the integrated core processor, which tasks them to the mission system for processing and displays the screen on the HMD. In addition, the HMD uses line of sight commands to cue the radar.

The first version of the HMDS called the Gen II, which is being used on F-35s in the System Development and Demonstration phase, demonstrated a number of test deficiencies such as display jitter, reduced night vision acuity and display latency.

By 2012 the problems encountered with the Gen II HMDS had caused such significant concern within the F-35 test community that the Joint Program Office (JPO) awarded a contract to BAE Systems to work on an alternative system that featured detachable night vision goggles. However, in late 2013 the JPO – with a desire to have a single helmet design – issued a stop work order to BAE Systems because VSI was demonstrating good progress with its upgraded Gen III version of HMDS. This latest version incorporates software fixes designed to correct latency issues, a new ISIE-11 night vision camera and liquid crystal displays. Gen III HMDS is expected to be available for LRIP 7 aircraft in 2016.

David C Isby and Mark Ayton



System: **Gen III Helmet-Mounted Display** Detail: **The upgraded Gen III HMD fitted with an ISIE-11 camera** Photograph: **Rockwell Collins**

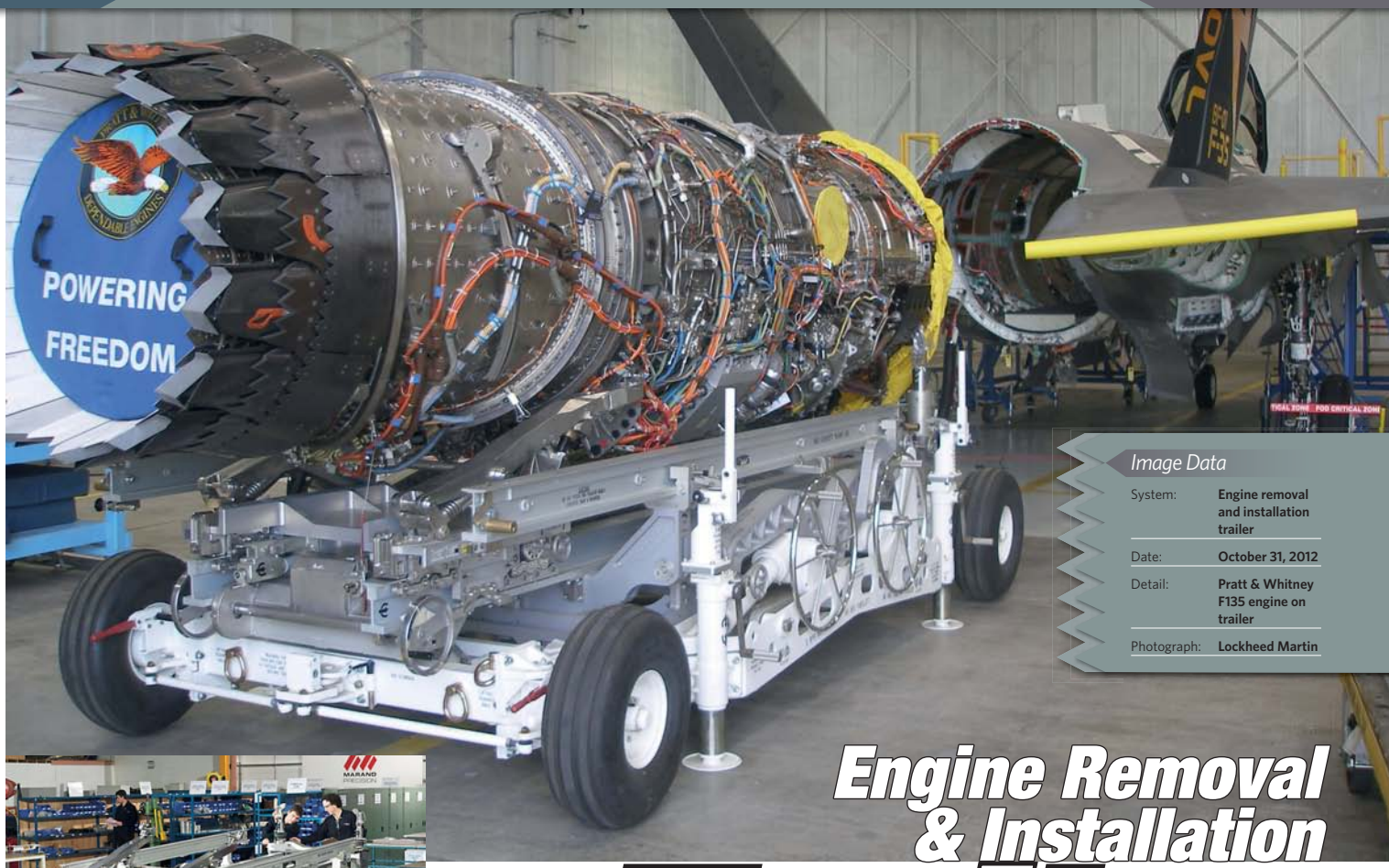


Image Data

System:	**Engine removal and installation trailer**
Date:	**October 31, 2012**
Detail:	**Pratt & Whitney F135 engine on trailer**
Photograph:	**Lockheed Martin**

Engine Removal & Installation Trailer



System: **Engine removal and installation trailer** Detail: **Final inspection** Photograph: **Marand Precision Engineering**

An advantage of being a partner nation in the F-35 programme is the opportunity for local industries to bid for work across the total production run of around 3,000 aircraft.

Marand, a design and engineering company based in Melbourne, Australia, is one business that saw an opportunity to expand from its traditional base in the car-building industry and embrace the defence aerospace sector.

Marand

The firm is the designer, builder and supplier of the engine removal and installation trailer that one day will be used at every air base and aboard every aircraft carrier the F-35 will operate from. It also holds precision engineering and tooling manufacturing contracts with Lockheed Martin and at the end of March delivered the first of an anticipated 722 ship-sets of vertical tails to BAE Systems for the Joint Strike Fighter programme. This latest initiative alone will earn the company more than $790 million over a 20-year period.

Marand has been making tooling and production equipment for the Australian automotive industry since 1969, but by the middle of the 1980s realised that, like the car industry worldwide, demand was fluctuating and there was no longer a secure future in the business. So it turned to other sectors of industry, including aerospace, to expand its footprint.

Marand's Managing Director, David Ellul, said the company then decided to expand its presence in the aerospace industry with defence contract work, further improving its security and profitability.

In 2003 the company won a System Development and Demonstration contract from Lockheed Martin for the engine removal trailer. Initially the contract was only for the trailer – the adaptor set to carry either the Pratt & Whitney F135 engine, or the then second-source General Electric/Rolls-Royce F136, would be designed by Lockheed Martin. Soon after, Marand won a further contract to design and manufacture the adaptor set to accommodate all three F-35.variants.

It handed over the first trailer at the 2005 Australian International Airshow at Avalon and has now delivered 35 to Lockheed Martin. Current production runs at between five and seven units per year.

Trailer Design

The trailer is designed to carry the F135 engine, which weighs more than 4 tonnes (8,818lb), on land or on the deck of an aircraft carrier up to specified sea-state conditions. It is a complex piece of engineering, which had to consider several factors other than just differences in engines or climatic conditions. For example, it not only has to transport the engine but also align it precisely with the airframe during installation and removal – as the F-35 requires powerplants to be slid in from the rear rather than lifted from above or below.

Marand enhanced the design to incorporate further capability and flexibility and the first redesigned unit was shipped to the US in 2011 for environmental testing. Modifications include the means to manoeuvre it hydraulically, raised ground clearance, different wheel loading and a reduced 'stack' height for air-freighting.

Ellul estimates around 250 units will be required over the F-35's 20-year planned production life during which the trailer will be a substantial part of Marand's business.

Marand was the first company in the world to be awarded a ground support equipment design and manufacturing contract on the F-35 programme, the company's first foray into the export market. Today, export earnings represent 50% of its annual turnover and its customer base now includes Lockheed Martin, Boeing, BAE Systems, Ford, BHP, Rio Tinto and Holden.

Demonstration

Impressing an aerospace giant such as Lockheed Martin or the F-35 Joint Program Office is no mean feat. General Manager Rohan Stocker relates how Marand managed to effectively demonstrate its capabilities: "One of the senior members of the JSF programme was only in Melbourne for a short time, so we hired a helicopter, took him to [an automotive manufacturing facility in] Geelong and showed him what we do in automation. The fact that our equipment worked so well in a place that's churning out 450 cars a day gave him enormous confidence in our ability."

Marand was also awarded a Supplier Excellence Award by Lockheed Martin at the 2009 Avalon Airshow in recognition of its efforts to almost halve the time required to complete a tooling manufacturing contract from design, through manufacturing, to delivery. Lockheed Martin also awarded the firm a Quality Excellence award in 2010.

To date, Marand is the largest Australian supplier in the F-35's Low Rate Initial Production phase. With a solid share of work behind it and the reputation of being a 'can do' company with a high focus on quality, it seems the Marand name will be associated with the JSF programme for many years to come – and it all started with an engine trailer! ***Nigel Pittaway***

RAW



Image Data

Variant:	**F-35C CF-01**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**July 11, 2013**
Detail:	**CF-01 performs thrust measurement survey at the Hush House**
Photographer:	**Arnel Parker/Lockheed Martin**

The F-35 Lightning II is powered by the Pratt & Whitney F135, the most powerful production jet engine ever made for a fighter. Additionally, the F-35B variant incorporates the Rolls-Royce LiftSystem, which enables the aircraft to perform its unique STOVL-to-supersonic mission.

The engine was chosen on October 26, 2001 by the US Department of Defense (DoD) for a $4 billion System Development and Demonstration (SDD) contract under which it would be used for all F-35 development flight-testing. The F135 is a larger-diameter, higher-airflow derivative of the company's F119 engine, which powers the F-22 Raptor.

The F135 was chosen for the SDD contract because both Lockheed Martin and Boeing had selected it (in the form of an augmented F119) to power their respective X-35 and X-32 Joint Strike Fighter (JSF) demonstrators. Lockheed Martin won the contract with its X-35. The Pentagon's choice was also swayed by the high commonality between the the F135 and the F119, two of which power each F-22 Raptor.

Power

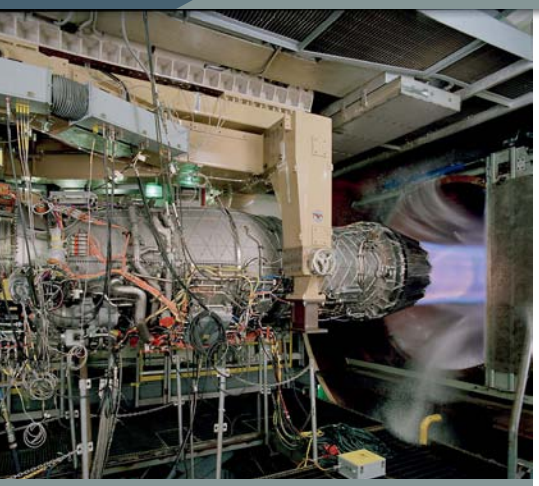


F135 Propulsion System

The F135 and F119 are both axial-flow engines (air goes through the core of the engine in a straight line) and they share a "highly common core", Ed O'Donnell, Business Development Director for Pratt & Whitney's F135 and F119 programmes, told *AIR International*. From front to back, these two-spool engines are "largely common through the compression system", said O'Donnell, who noted that the commonality is however mainly in the form of shared engine architecture rather than common part numbers.

Part numbers for the F135 have been designated differently from those for similar components in the F119 because the US armed services want to be able to allocate specific part numbers to particular programmes for inventory management reasons.

Despite their similarities, there are however some crucial differences between the F135 and the F119. One is that the F135 needs to be able to generate up to 43,000lb (191.27kN) of thrust 'wet' (with afterburner) for the single-engine F-35, whereas the F119 provides 35,000lb (155.7kN) with full afterburner. So the F135 has a larger inlet diameter (43 inches/1,090mm), larger fan diameter (46 inches/1,170mm) and a larger overall

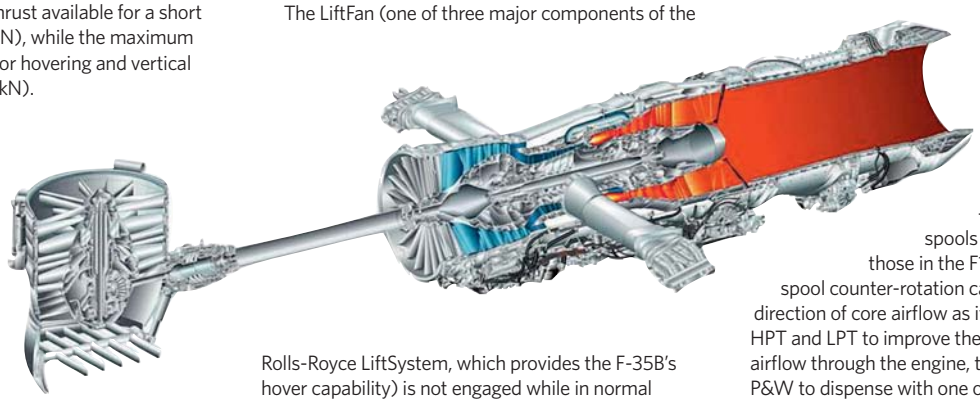


Engine variant: **F135-PW-100** Date: **June 29, 2006** Detail: **F135 CTOL variant undergoing a production run in full afterburner or augmented power** Photograph: **Pratt & Whitney**

engine diameter (51 inches/1,295mm) than the F119 to achieve a higher airflow.

According to Pratt & Whitney, the maximum thrust of the F-35B STOVL variant is a little lower than that for the F-35A CTOL and F-35C CV variants, at approximately 41,000lb (182.4kN) at full reheat. The F-35B's intermediate thrust level (that is, dry thrust with no reheat applied) is approximately 27,000lb (120.1kN). The maximum thrust available for a short take-off is 40,740lb (181.2kN), while the maximum downward thrust available for hovering and vertical landings is 40,650lb (180.8kN).

The F135's Basic Engine Architecture



Like the F119, the F135 has a three-stage fan (in military engine parlance, the fan is the entire low-pressure compressor assembly). Each fan stage comprises a one-piece integrally-bladed rotor (IBR, or 'blisk', short for bladed disc), which consists of a solid titanium hub with titanium blades welded onto it. The first fan stage and each of the subsequent two stages have solid titanium blades.

Aft of the third fan stage the accelerated airflow is split, 57% of it going through the fan duct as bypass air and the remaining 43% entering the core to be compressed, mixed with fuel, ignited and then exhausted as hot gas to turn the turbine stages and produce up to 28,000lb (124.55kN) of dry thrust before afterburner.

The F135 has a six-stage high-pressure compressor (HPC) and, again, each stage is a blisk. Some of the initial HPC stages are made from titanium but because the airflow becomes hotter as it passes through each stage of compression, one or more later HPC stages are made from nickel-based alloys to withstand the high air temperature. In conventional F-35 flight, air exiting the HPC into the combustor is at 28 times the pressure it was when entering the fan and 29 times the pressure when the F-35B is in hover mode.

The engine's single annular combustor features removable liners and a series of fuel nozzles, all housed within a diffuser case. O'Donnell said the F135 combustor is "highly similar" to that in the F119, but features "some improvements to accommodate the appropriate temperature requirements" of the higher-power F135. Overall, the cores of the two engines – the core includes the HPC, combustor and HPT – are essentially the same size and since the F135 has to produce more dry power at full thrust than the F119, it is likely to run hotter than the F119.

While both the F119 and the F135 feature a single-stage high-pressure turbine (HPT), the F135 has a two-stage low-pressure turbine (LPT) and the F119 a single-stage LPT. This is because, in the F-35B STOVL aircraft, the low-pressure spool to which the LPT is attached has to drive not only the fan stages but also the driveshaft powering the Rolls-Royce LiftFan located behind the cockpit and ahead of the engine.

The LiftFan (one of three major components of the Rolls-Royce LiftSystem, which provides the F-35B's hover capability) is not engaged while in normal forward flight and is, of course, not present at all in the F-35A CTOL and F-35C CV variants of the Lightning II. However, from the outset, the specification for the F-35's engine called for 'tri-variant compatibility' – the engine powering an F-35A is identical to that powering an F-35B or an F-35C. Nevertheless, they are designated differently: the F-35A powerplant is the F135-PW-100; the engine for the F-35C is the F135-PW-400; and the F-35B's is the F135-PW-600.

Since the F-35B powerplant needs an extra LPT stage to provide the power necessary to turn the driveshaft (which, through a clutch and gearbox, drives the LiftFan), F135s built to power other F-35 variants have the second LPT stage as well. "The engine was designed to support that severe STOVL requirement," O'Donnell said. For engines powering CTOL F-35As and F-35Cs, the additional turbine stage offers a substantial extra power margin, allowing for potential F-35 weight growth. Since the engine isn't heavily taxed in many CTOL missions, its maintainability is improved too.

The geometries of the cooling-air paths and airflows in the F135's hot section are different from those in the F119. Turbine blade thermal barrier coating materials – used to prevent nickel super-alloy turbine blades and vanes from melting in the more than 3,000°F (1,649°C) airflow coming from the combustor – were updated too. P&W may have been able to retroactively apply to production F119s the advances in cooling-path and coating technologies it devised for the F135.

In both engines, cooling air is taken from the bypass airflow and by bleeding air away from the HPC stages to cool the HPT and LPT stages – probably by means of complex networks of tiny air channels within their blades and into the turbine casing, as is the case in commercial turbofans.

"Even 1,500-degree air is cooling air if it's relative to hotter air," noted O'Donnell. "The [blade] metal melts at the temperatures we're operating at and a lot of the technology is in the cooling and coatings."

Counter-rotating Spools, Ceramics and Augmentors

An important feature of the F135 – which Pratt & Whitney doesn't talk about much – is that the engine's two spools are counter-rotating, like those in the F119. Since in some cases spool counter-rotation can be used to shape the direction of core airflow as it transitions between the HPT and LPT to improve the overall efficiency of the airflow through the engine, this might have allowed P&W to dispense with one or more rows of static stators and vanes in the F135. (Stators and vanes, which are static blades found between many fan, compressor and turbine stages, act to condition and present the core airflow optimally to each subsequent rotating stage.) So P&W has possibly been able to reduce the parts count in the engine and make it lighter – but it declines to confirm this.

Nor will P&W confirm the dry weight of the F135, but in 2011 an aviation blog cited Warren Boley, former president of Pratt & Whitney Military Engines, as saying the F135 weighs 1,500lb (680kg) more than the F119. This would put its dry weight at around 5,400lb (2,450kg). However, the F135 may have a higher thrust-to-weight ratio than the F119 (the F119's overall pressure

F135 STOVL Propulsion System Design

Maximum thrust class	41,000lb (182.4kN)
Intermediate thrust class	27,000lb (120.1kN)
Short take-off thrust class	40,740lb (181.2kN)
Hover thrust	40,650lb (180.8kN)
Main engine	18,680lb (83.1kN)
LiftFan	18,680lb (83.1kN)
Roll-Post	3,290lb (14.6kN)
Length	369 inches (9.37m)
Main engine inlet diameter	43 inches (1,090mm)
Main engine maximum diameter	46 inches (1,170mm)
LiftFan inlet diameter	51 inches (1,300mm)
LiftFan maximum diameter	53 inches (1,340mm)
Conventional bypass ratio	0.56
Powered Lift bypass ratio	0.51
Conventional overall pressure ratio	28
Powered Lift overall pressure ratio	29



Engine variant: **F135-PW-600** Date: **April 10, 2008** Detail: **An F135 STOVL propulsion system in the test rig at the West Palm Beach facility** Photograph: **Pratt & Whitney**

ratio is 26:1 compared with the F135's 28:1), so the 5,400lb figure might be too high.

Boley also suggested in 2011 that the F135 had an uninstalled wet thrust capability of approximately 51,000lb (226.86kN). If this reads across to an installed basis – in which bleed air and shaft horsepower would be extracted to power aircraft systems, reducing the overall dry-thrust capability by a fraction – it should provide a comfortable operating margin over the 43,000lb (119.27kN) of wet thrust required by the spec.

The F135 uses ceramic matrix composites (CMCs) in its exhaust nozzle, primarily on the outside sections of the exhaust nozzle on the F135-PW-600 STOVL version of the engine. O'Donnell said some sections of the fan ducts on the STOVL engine – particularly at the bottom "where all the accessories hang on to" – are also made from organic matrix composites (OMCs), whereas the fan ducts for the F-35A and F-35C engines are made from titanium. Some of the inlet ducting in the aircraft is also made from OMC material.

According to O'Donnell, P&W has used OMCs in the F-35B to reduce weight by up to 50lb (22.5kg) so that the aircraft can carry, for example, an additional 50lb of ordnance – and bring it back if required when the mission calls for the aircraft to land vertically. This 'vertical lift bring-back' (VLBB) measurement is a critical performance requirement for the F-35B and while the aircraft as it stands today meets the current spec, the concern is that if the F-35B's maximum gross weight grows over the course of its operational career (as usually happens with military aircraft), its VLBB performance will need to improve.

Another key feature of the F135 is its augmentor, or afterburner system. While details have remained hard to come by, the F135 is known to employ multi-zone (probably three-zone) fuel injection aft of the afterburner's pilot light. These zones inject fuel independently, so that the afterburner does not act in an all-or-nothing way but instead provides a variable range of additional, smoothly transitioning wet thrust at the pilot's command. Also, like the F119 augmentor, the F135 is stealthy: the designs of the two engines' augmentors place multi-zone fuel injection into curved vanes which eliminate conventional spray bars and flame holders and block the line of sight to the turbine when looking into the engine from behind.

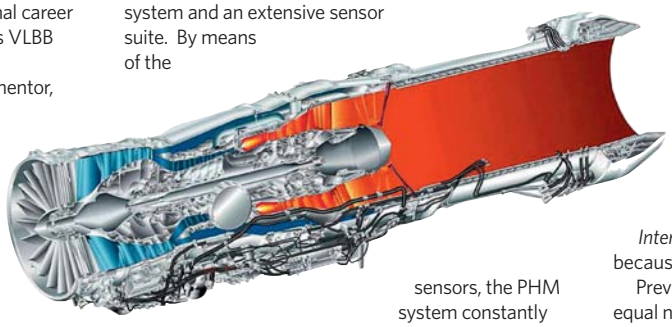
Maintainability

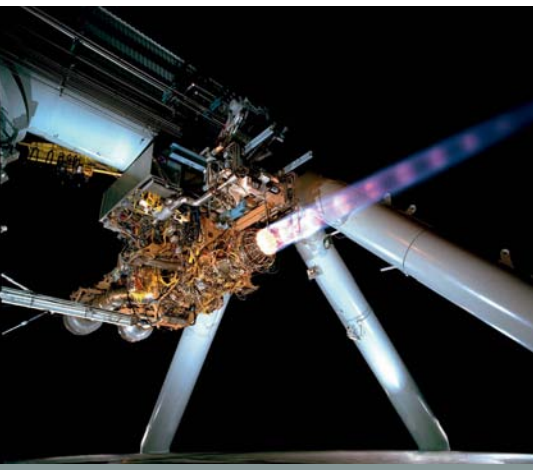
From the outset the F135 has been designed for maintainability, building on the experience Pratt & Whitney gained with the F100 for the F-15 and F-16 and then with the F119 for the F-22. (When designing the F119, the company brought in US Air Force mechanics to help design its engine-mounted controls and accessories for maintainability). In the F135, all controls affixed to the casing are 'single-deep' – no control units are mounted on top of each other – and the nuts and bolts which attach them to the engine casing are encapsulated in the control assemblies themselves, staying with the control units when these are removed. This minimises the risks of nuts and bolts being lost and causing foreign-object debris (FOD) damage.

Similarly, all engine clamps and blocks stay on the engine casing when an F135 is removed for maintenance and the engine uses no safety wire, eliminating another potential source of FOD damage. All controls and accessories are mounted on the bottom of the engine, making access easier for mechanics; and these assemblies are modular so that an engineer could easily remove, say, the electronics, valves or relays for an F135 fuel control unit as entire modules.

O'Donnell said the US Air Force has found the F119 to be "significantly more maintainable" than the earlier F100 – offering "major orders" of improvement of mean time between failures and maintenance man-hours required – adding that P&W expects operators to find the F135 even more easily maintainable and reliable than the F119. Another plus, he said, is that P&W can apply the design-for-maintainability improvements it has developed for the F135 to new F119 production batches as well.

The F135 engine also comes with a digital prognostic and health monitoring (PHM) system and an extensive sensor suite. By means of the sensors, the PHM system constantly monitors the engine's operating parameters and the condition of its components, and alerts mechanics if it finds anything abnormal. "So a lot less time is devoted to troubleshooting," said O'Donnell. So seriously did P&W take the job of making the F135 highly maintainable that it tried to design the engine to require only a single hand-tool, clamped to the engine when not in use, for all line-maintenance jobs. It couldn't quite achieve that ideal but did succeed to the point where only six tools are required.





Engine variant: **F135-PW-600** Date: **July 26, 2007** Detail: **An F135 STOVL engine undergoing a test run with full afterburner or augmented power** Photograph: **Pratt & Whitney**

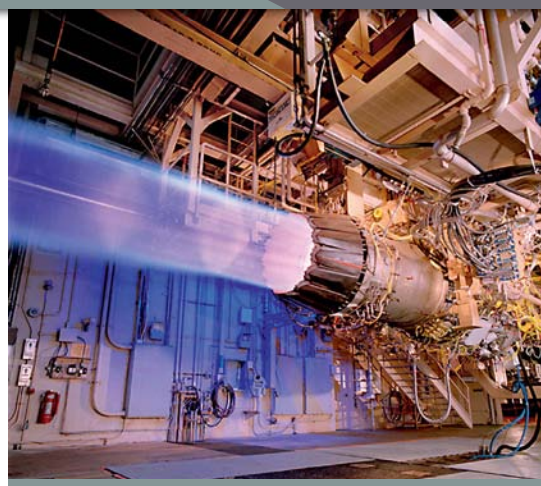
F135 Production

Having obtained initial service release (ISR) certification from the DoD for the CTOL F135 in February 2010 and for the STOVL engine ten months later, Pratt & Whitney was delivering three production F135s a month by March 2011. Brett Rhodes, P&W's production program lead for the F135, said the company then increased the rate to four a month in April 2011 as it completed deliveries under lot 2 of Low Rate Initial Production (LRIP 2) and began delivering engines for aircraft in the LRIP 3 production lot.

By late March 2011, through sub-contractor Rolls-Royce, P&W had completed delivering F-35B variable area vane boxes all the way through LRIP 3 and into LRIP 4. The variable area vane box (VAVB), a critical component in the F-35B's LiftSystem, actually forms part of the keel of the aircraft and so for any F-35B it has to be delivered much earlier than the engine.

Additionally by then, P&W had delivered F135 inlet debris monitoring systems (IDMS detects debris anywhere in the inlet or engine and alerts the pilot and mechanics) for aircraft well into the LRIP 3 production batch.

In the DoD FY2012 budget, P&W obtained $1 billion for more engines and flight-test support until October 2016; and component improvements, like those the Pentagon funds under its Component Improvement Program (CIP).



Engine variant: **F135-PW-100** Date: **March 24, 2006** Detail: **Test run with full afterburner or augmented power generating up to 43,000lb of thrust** Photograph: **Pratt & Whitney**

In 2011, speaking to *AIR International*, former PW Military Engines president Boley described the $400 million of what he called "CIP-like" funding in the FY2012 budget as being for "maintainability, sustainment and affordability" improvements in the mature F135 engine rather than to improve component durability. P&W would introduce such improvements in block upgrades, he said.

The F-35B's probationary period did not stop production of the F135-PW-600 STOVL engine after the LRIP 4 production phase, but it meant F135 production was not ramped up as originally planned. "Through lot 4, we're producing at the same rate as previously planned," Boley told *AIR International* in 2011. "Lots 5, 6 and 7 are reduced because that's the probation."

Previously, the F135 production plan had called for equal numbers of STOVL and CTOL engines to be delivered in the LRIP 5 lot, but because of the F-35B's probationary period, CTOL production overtook STOVL production in LRIP 5.

P&W was able to increase production to 50 F135s a year by 2013, DoD budget cuts and the F-35B's probation preventing the company from ramping up production to the 125-a-year rate originally envisaged for the period. Speaking to reporters at Pratt & Whitney's headquarters in East Hartford, Connecticut, on May 20, 2014, Paul Adams, the company's president, noted P&W had delivered 12 F135s in 2010, 27 in 2011, 47 in 2012 and 50 in 2013. By 2020, with the F-35 in Full Rate Production and the three variants of the aircraft all in operational service, the company should be delivering more than 200 F135s annually.

In 2014, P&W's official target for F135 deliveries is "more than 50", according to a slide in Adams' May 20 presentation to reporters. However, Danny Di Perna, the company's senior vice president engineering and operations, told *AIR International* that day the 2014 target is actually 58 engines delivered, "but we're trying to deliver 62". At the time of writing, F135 production was of engines in the LRIP 6 lot.

F135 Production at West Palm Beach

Adams also revealed that in April 2014 P&W had delivered the 145th F135. This total included the very first F135 (actually number 137, which went in May to Italy's F-35 Final Assembly Check Out facility at Cameri in Novara – off a brand new assembly line P&W has established at its huge site in the Florida Everglades near West Palm Beach. The new line, contained in a new 97,000sq ft (9,011m^2) building constructed to hold it, complements P&W's first F135 final-assembly line at its

huge manufacturing plant in Middletown, Connecticut.

Both F135 final-assembly lines are 'pulsed', according to Di Perna. This means each engine stops at points on the assembly line for a given time for a series of assembly operations before moving on to the next. This is in contrast to most modern assembly lines for commercial turbofan engines (including P&W's new PW1000G geared turbofan), which are on lines that move constantly, if very slowly. Technicians have to keep changing their positions to remain with each engine throughout a particular set of assembly operations.

P&W first established its West Palm Beach site in the 1950s as a remote facility where it could develop and test loud aerospace engines. As one of the site's earliest projects, P&W began experimenting in 1956 on a liquid hydrogen-fuelled engine to power the proposed Lockheed CL-400 'Project Suntan' Mach 2.5 spy plane, intended to fly at 100,000ft (30,480m).

Although the US Air Force cancelled Project Suntan in 1958 as being too expensive and too dangerous, P&W also developed and tested the famous J85 turbojet at the West Palm Beach site, the engine going on to power the Mach 3-plus Lockheed YF-12, D-21 and SR-71 reconnaissance aircraft. Meanwhile, P&W's work on the liquid-hydrogen engine for Project Suntan had not been in vain: the design knowledge and skills it gained led the company to manufacture the highly successful RL-10 cryogenic rocket engine at West Palm Beach from 1959 – initially through Pratt & Whitney Space Propulsion but ultimately under the Pratt & Whitney Rocketdyne name.

P&W sold its Rocketdyne business in 2013 to Gencorp, which merged it with its Aerojet subsidiary to form Aerojet Rocketdyne.

P&W's commitment to its West Palm Beach site continues. The company still operates its largest engine-test centre at the site, the size and remoteness of which makes it ideal for testing the F135 – one of the loudest turbofan engines ever made – and the associated Rolls-Royce LiftSystem for the F-35B as well as Aerojet Rocketdyne's rocket engines.

P&W's new F135 assembly line sits next to a new line for final assembly of the PW1100G-JM geared-turbofan engine for the Airbus A320neo family. Meanwhile fellow United Technologies Company subsidiary Sikorsky operates an assembly line for the S-70 military transport helicopter nearby. The West Palm Beach test and manufacturing facility is surrounded by a huge area of protected Everglades semi-tropical wetlands where alligators sunning themselves by the road are an everyday sight and protected species of birds and animals wander around the area.

Although Di Perna said the overall F135 production programme of record has fallen by about 550 engines since F-35 production began (as a result of order cutbacks and reduced production rates for the LRIP batches). P&W has nevertheless managed to reduce the price of each engine it sells to the US DoD, its major customer, by about 45%. According to P&W president Adams, the company spent $60 million of its own money to achieve the reduction. However, slashing the cost of each F135 wasn't entirely P&W's own idea: annoyed back in 2009 by F-35 programme cost overruns and the prices it was being charged for early-production F135s, the Department of Defense reportedly insisted that Pratt & Whitney cut the cost of each engine by 30%.

Future F135 Production

P&W continued to face difficulties in mid-2014 in not knowing exactly when F135 production would finally ramp up to the expected 125-to-150 engines a year level before it reaches its final all-out annual rate of more than 200 at some point in the 2020s. However, Di Perna said the sudden transition from producing 50 to 60 engines a year to delivering up to 150 should not be problematic for Pratt & Whitney.

"In trying to establish P&W's arrangements for the expected sudden ramp-up," he said, "the most important question is when do you pull the trigger?" To cope with such a rapid increase in production demand, P&W and its many suppliers will have to invest in new infrastructure, additional tooling and more five-axis machining and milling units. Crucially they will also need to make arrangements well in advance to secure the necessary increased amounts of raw materials for the alloys and composites from which the F135's many components and parts are made.

Di Perna reckons the raw materials issue means Pratt & Whitney would need from 18 to 24 months of advanced notice of the production ramp-up – which will represent as much as triple the current F135 assembly rate – to prepare for it adequately and to ensure suppliers do too. P&W already has the necessary assembly-floor volume to accommodate the increased production, he confirmed.

"Bennett [Croswell, who succeeded Boley as president of Pratt & Whitney Military Engines] right now is negotiating LRIP 7 and LRIP 8 production rates with the DoD," Di Perna said on May 20, adding that each of these LRIP lots is likely to last about a year. His best guess as to when F135 production would ramp up would be after LRIP 8 is completed. "Probably LRIP 9 and LRIP 10 is where we'll start to see a significant increase in demand."

When the F135 production rate does finally increase, it will come as a relief to Di Perna. While the two F135 final-assembly lines are "today delivering at a very steady pace", the production ramp-up will keep P&W's F135-production employees highly involved and highly motivated. It will also help ensure P&W does not lose invaluable experience, skills and knowledge already gained in making the world's most powerful and most sophisticated fighter engine.

The Rolls-Royce LiftSystem

One of the most remarkable features of the F-35 programme is that when the STOVL F-35B is hovering, its propulsion system produces very nearly as much thrust without afterburner as the engine does in forward flight with its afterburner fully lit. The F-35B's engine has to produce 40,650lb (180.8kN) of vertical thrust without afterburner in hover mode, while in conventional flight it produces 27,000lb (120.1kN) of dry thrust and about 41,000lb (182.4kN) with full afterburner.

The F135-powered F-35B relies on two systems to achieve the high level of vertical thrust. First is its full authority digital engine control (FADEC) unit – computers made by BAE Systems and attached to the engine but run on Pratt & Whitney proprietary FADEC software. In hovering flight, the FADEC computers make the engine work harder, increasing dry thrust from 28,000lb to 39,400lb without using afterburner.

Second, the F-35B relies on the Rolls-Royce LiftSystem. This consists of several major components. First is the LiftFan, a horizontally-mounted fan unit

located behind the F-35's cockpit. The 53-inch (1,346mm) diameter, 50-inch (1,270mm) deep LiftFan draws in cold air through a 51-inch (1,295mm) diameter inlet on the top of the fuselage and accelerates it to produce vertical lift. The LiftFan inlet is covered by a large, Lockheed Martin-made door – nicknamed the '57 Chevy Hood' – hinged to the structure of the aircraft aft of the LiftFan inlet. It is only opened when the F-35B is hovering, performing a short take-off or transitioning between horizontal and vertical flight.

The LiftFan features two counter-rotating fans, one directly above the other. Each is a blisk, the upper fan containing 24 hollow titanium blades and the lower fan 28 solid titanium blades, Gareth Jones, Rolls-Royce's then Chief Engineer for the LiftSystem, told *AIR International* in 2011. Each fan is driven by a separate bevel gear system. (Bevel gears allow torque from a horizontal shaft to be transmitted through 90 degrees to a vertical shaft by means of conical gears.)

Both bevel gears are contained in a common gearbox and are powered by a driveshaft which runs along the F-35B's longitudinal axis. The driveshaft is powered by the low-pressure spool of the F-35B's engine, which is located behind the LiftFan. (The LiftFan is located in front of the engine inlet and the driveshaft connecting it to the engine runs through the inlet, under a fairing). On the engine, the driveshaft is connected to the fan hub for the engine's first fan stage, which is driven by the low-pressure spool.

Another major LiftSystem component is the clutch for the LiftFan gearbox. The driveshaft is always spinning when the engine is lit, but when vertical lift from the LiftFan is not required – for instance, in conventional flight – the clutch is disengaged. It only engages and locks when vertical thrust is commanded.

Because of the friction generated and the high temperatures involved, the clutch plates are made from the same hard-wearing material used in the carbon brakes of large commercial aircraft such as the A380.

Below the LiftFan, the variable area vane box (VAVB) provides an exit path for the cool air driven downwards vertically by the LiftFan. Rolls-Royce produces the VAVB, which is made of aluminium and contains louvred vane doors. These can be angled all the way from 45 degrees back, through fully vertical to 5 degrees forward to provide variable directionality for the downward cool air flow from the LiftFan, as commanded by the pilot through the aircraft's FADEC units.

When the F-35B is hovering, the driveshaft delivers 28,000 shaft horsepower to the LiftFan's clutch-and-bevel-gear system so that the LiftFan provides 18,680lb (83.1kN) of downward thrust as a column of cool air. (In hover mode the F-35B's coupled F135-driveshaft arrangement acts exactly like a turboprop engine, except that most of its power output is used to drive air vertically rather than horizontally – so the F135 is actually the world's most powerful turboprop engine when installed in the F-35B.)

In hover mode another 18,680lb (83.1kN) of thrust exits the engine exhaust as hot gas and is directed downwards at the rear of the aircraft by the aircraft's Three-Bearing Swivel Module (3BSM). This remarkable piece of equipment consists of three articulated sections of nozzle casing, each of which is made from titanium. Each section is joined to the others driven by its own ring bearing. When the F-35B hovers, the FADEC commands the 3BSM – which can direct air through a 95-degree range from 5 degrees forward to horizontally back – to swivel downwards to direct hot engine exhaust air in the same direction as the direction of the cool air produced by the LiftFan near the front of the aircraft.

The 3BSM can swivel fully from horizontal to vertical orientation in 2.5 seconds, completely redirecting its entire 18,680lb of thrust in that time. Together with the 18,680lb of downward thrust produced by the LiftFan and the 3,290lb (14.6kN) of bypass-air thrust directed vertically downwards by the F-35B's two wing-positioned Roll-Posts (see below) to enable the F-35B to hover, this means the F-35B can turn 18,680lb of horizontally directed thrust into 40,650lb (180.8kN) of thrust directed vertically downward in less than 3 seconds.

This astonishing capability to redirect – in the twinkling of an eye – more thrust than powers two BAE Systems Hawks and, at the same time, more than double its thrust output to turn it into more thrust than powers a Panavia Tornado at full reheat (and nearly as much as powers a fully-reheated Eurofighter Typhoon) is made possible by the F-35B's enormously sophisticated FADEC software, which was developed by Pratt & Whitney specifically for the F-35B's propulsion system.

Gareth Jones said the ring bearing for the first 3BSM nozzle section is driven by its own actuator, while the bearings for the second and third sections are driven by a common actuator which acts directly on the ring bearing for the second nozzle section and drives the ring bearing for the third section through a travel gearbox.

"These [two] sections can't articulate independently but do so through a fixed ratio, and they are set at oblique angles to each other," he explained. Both of the ring bearing actuators for the 3BSM are powered by 'fueldraulics': some of the aircraft's fuel is pressurised to 3,500lb per square inch (2.46kg per square millimetre) to act as a hydraulic fluid to power the 3BSM actuators' servo-valves.

Other major components of the LiftSystem are the aircraft's two Roll-Posts and the Roll-Post ducts which connect them to the engine. Jones said each Roll-Post duct is a very complex part whose shape changes from circular at one end – where it connects to the engine – to toroidal (a complex surface generated by rotating a closed plane curve about a coplanar line that does not intersect the curve) at the other, where it attaches to the Roll-Post. Each titanium Roll-Post duct is superplastically formed, diffusion-bonded and laser-welded.

According to Jones, the Roll-Posts themselves are variable-area nozzles situated in the lower part of each inner wing section and act to provide roll control for the F-35B in hover mode. To do this, the ducts direct

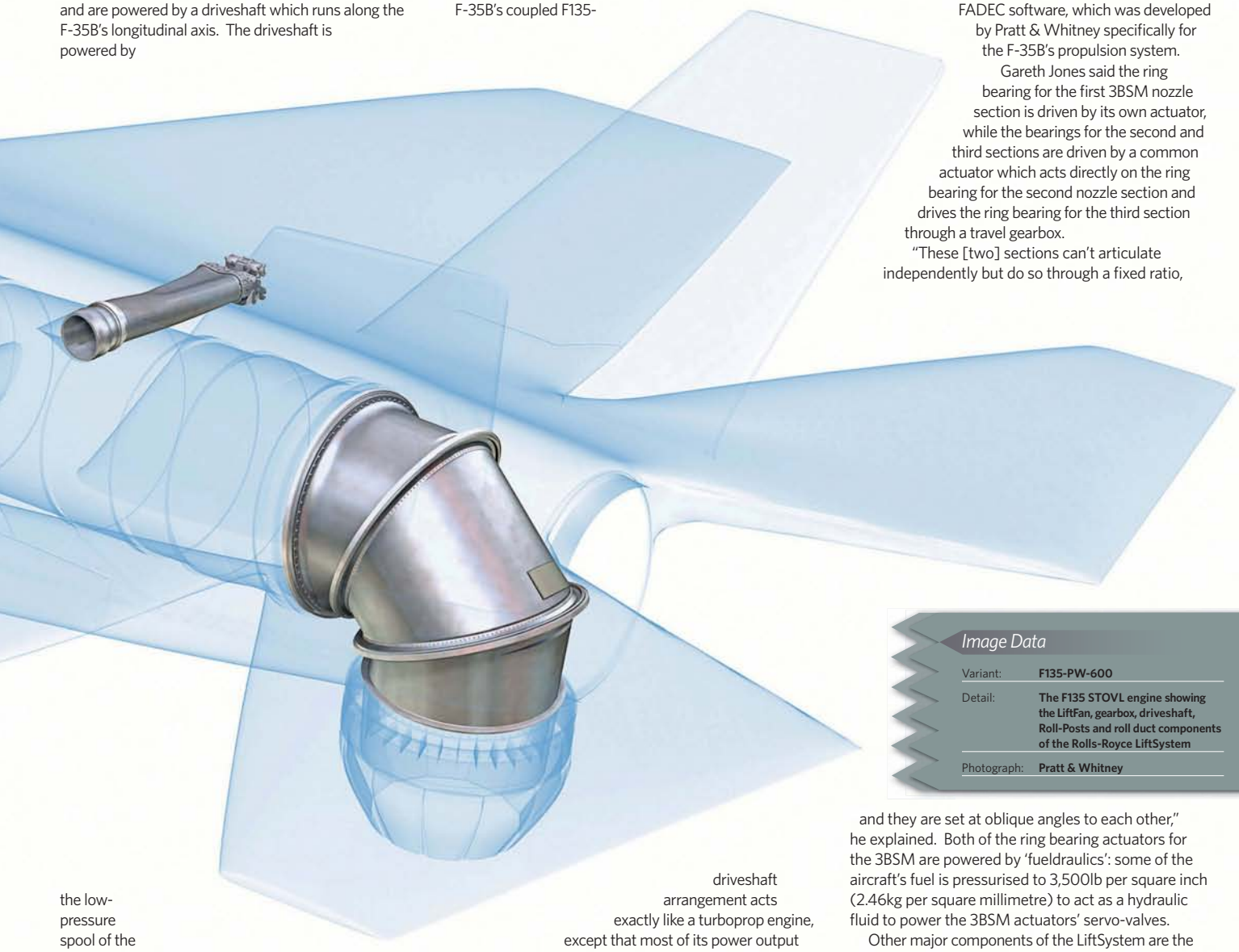


Image Data

Variant:	**F135-PW-600**
Detail:	**The F135 STOVL engine showing the LiftFan, gearbox, driveshaft, Roll-Posts and roll duct components of the Rolls-Royce LiftSystem**
Photograph:	**Pratt & Whitney**

bypass air from the engine to the Roll-Posts which drive the air out through the bottom of each wing. In the F-35B, 3,290lb (14.6kN) of thrust in the form of bypass air is directed out to the two Roll-Posts while hovering.

Each Roll-Post assembly features a pair of flap-type titanium doors in the bottom of the wing, controlled by the FADEC. Jones said these are controlled by rotary actuators which enable fully variable opening, providing thrust variability and directionality so the pilot can control roll while hovering. He said Lockheed Martin's original X-35 concept demonstrator featured doors between the engine casing and the Roll-Post ducts which could be closed when the aircraft was not hovering, but in production aircraft there are no such doors and bypass airflow is constantly sent to the ducts. The only way to control Roll-Post thrust is via the flap-doors in the bottom of the wing.

The demand for very high power during hover requires the engine to receive a high amount of airflow, so Lockheed Martin designed the F-35B with a pair of Auxiliary Air Inlet Doors (AAIDs) in the upper surface of the fuselage behind the big inlet door for the LiftFan. These AAIDs provide additional inlet air for the F135 engine, not the LiftFan.

During testing by the F-35 Integrated Test Force at Naval Air Station Patuxent River, Maryland, the original AAID design was found to suffer from excessive wear and fatigue due to the buffet environment; had an inadequate seal design; and the door locks had an inadequate service life. Low Rate Initial Production aircraft were restricted from some STOVL-mode flight operations until the redesigned AAID gained its flight clearance from Naval Air Systems Command. The redesigned door is now being retrofitted to all F-35Bs built in LRIP 1 to LRIP 5.

Complexities

The complexity of the F-35B's propulsion system and the performance requirements demanded of the aircraft by the DoD created issues that became evident in flight-testing. These and other concerns delayed the F-35B, led it to running well over budget and persuaded the then US Defense Secretary Robert Gates to put the variant into a two-year probationary period.

However, the three main issues affecting the LiftSystem were quickly understood, and long-term fixes – none involving massive technological challenges – were developed. The effectiveness of the fixes helped lead Leon Panetta, who became US Defense Secretary after Gates, to lift the probation on the F-35B just a year after it had been imposed.

Two issues involved parts getting too hot. LiftFan clutch plates were found to rub together occasionally while the F-35B was in conventional flight and the plates overheated. They are cooled by a fan forcing air over them in hover mode but not during conventional flight. The fix involved installing a passive air-cooling circuit in the clutch for cooling during conventional flight and a sensor to alert the pilot to climb to 10,000ft (3,048m) if the plates became too hot.

Meanwhile, Roll-Post actuators were also burning out faster than anticipated because of overheating through leakage of hot bypass air as Roll-Post nozzle seals aged. Again, sensors were installed and in the short term the actuators were insulated. Jones said a permanent fix – redesign of the actuators to withstand hotter temperatures – used proven technology. Insulation of the actuators was not part of the permanent fix.

The third LiftSystem issue was that build tolerances and engine thermal and pressure growth caused the driveshaft for the LiftFan to expand and contract longitudinally to a greater degree during operation than Lockheed Martin's original design requirement intended. In development aircraft, clasp spacers were used between the driveshaft and the engine's low-pressure spool to accommodate the extra expansion, but for production aircraft a permanent fix was developed involving a bellows-type coupling between the driveshaft and the engine fan hub. ***Chris Kjelgaard***



F135 CTOL/CV Engine Design

Maximum thrust	43,000lb (191.3kN)
Intermediate thrust	28,000lb (128.1kN)
Length	220 inches (5.59m)
Inlet diameter	43 inches (1,090mm)
Maximum diameter	46 inches (1,170mm)
Bypass ratio	0.57
Overall pressure ratio	28



Image Data

Variant:	**F135-PW-100**
Date:	**December 5, 2005**
Detail:	**F135 last bolt ceremony**
Photograph:	**Pratt & Whitney**



Image Data

Variant:	**F-35B BuNo 168717/'VK15'**
Unit:	**Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights'**
Location:	**Marine Corps Air Station Yuma, Arizona**
Date:	**October 31, 2013**
Detail:	**With a Portable Maintenance Aid plugged into the Maintenance Interface Panel, Marines run post-flight checks on the aircraft**
Photographer:	**Paul Ridgway**

To most people, the international F-35 Lightning II programme is all about the jet. Even when the word software crops up in relation to the F-35, observers don't consider it for its merits but overwhelmingly only recall the operational issues and delays suffered with late software delivery to the aircraft.

But there is another challenging software-driven project within the overall Joint Strike Fighter programme which isn't as outwardly exciting as the fighter jet but is still pivotal to its operation.

ALIS, or the Autonomic Logistics Information System, to give it its full name, is the operations and management system for the F-35. It is an integrated system which provides the required operations and maintenance interface with the aircraft and is designed to be deployable in the field.

Development has not been without its problems, however, and anecdotally ALIS has been responsible for mission delays and cancellation at a number of locations since it was introduced. Earlier this year a Director of Operational Test & Evaluation (DOT&E) report confirmed that sortie generation and maintainability was affected and described the system as both 'immature' and behind schedule.

Lockheed Martin has planned ALIS as an incremental capability, but has been forced to apply resources to address the functionality issues uncovered by the test fleet to date. The most recent version (ALIS 1.03.3) was rolled out at Marine Corps Air Station Yuma, Arizona, and in its early days has shown significant improvement, as the manufacturer and the F-35 Joint Program Office (JPO) work towards the version (ALIS 2.0.1) which will support Marine Corps IOC in July 2015.

ALIS Described

Lockheed Martin describes ALIS as the 'IT backbone' of F-35 operations, which will allow operators to plan, maintain and sustain the F-35 throughout its service life.

For flight operations, ALIS is used for mission planning and scheduling as well as keeping track of pilot qualifications and training.

For maintenance, it holds aircraft and personnel records and is the interface with the aircraft itself. Support and test equipment are built into the system, as is a health diagnostic system designed to meet the aircraft's low observability requirements. The maintenance of the jet is 'run' through ALIS, which supports the Joint Technical Data (illustrated parts catalogues, maintenance manuals, repair manuals, etc), and it also provides a means for both the operator and the manufacturer to monitor aircraft health.

Some data is passed back to Lockheed Martin's facility in Fort Worth to allow reliability monitoring, but the interface is also used for customer support, especially engineering reach back, and performance-based logistics management.

When the F-35 was first conceived it did not include

Digital Interface



an ALIS capability, but this changed when Lockheed Martin was awarded a contract as systems integrator by the JPO before flight testing began in 2006.

"We put together ALIS based on an open architecture footprint and it is a combination of bespoke software code as well as commercial off the shelf [COTS] products, and it runs on a Windows operating system," described Mark Perrault, Lockheed Martin's technical development lead for the system.

"Some of the applications aren't COTS products, so we've gone through some additional development, where Lockheed Martin itself has actually developed the code to support the users. Then, as development has matured, we've instituted some lessons learned from large IT systems."

A core team within the JPO, comprising members of all three US services, the UK and the Royal Australian Air Force, meet frequently to review the design and implementation of ALIS, providing direct user feedback to the manufacturer.

What does ALIS look like?

The interface with the F-35 is via a Portable Maintenance Aid (PMA), a ruggedized laptop which is already used by US Air Force units operating the Lockheed Martin F-22 Raptor.

At the present time the PMA is plugged directly into the aircraft and data is downloaded, but in the future some data will be received via a maintenance data link, which began to be tested in flight test in July 2012 with the release of Block 2A software.

The PMAs are part of the Ship and Squadron Kit, which also includes Standard Operating Unit (SOU) servers, Low Observable Management, and Mission Planning equipment.

Sometimes called the Squadron Operating Unit, the SOUs are intended to be deployable, though the initial version was criticised by the DOT&E report as being too big and heavy to meet the requirements for deployability. In response, Lockheed Martin is developing a smaller, lighter version called SOU V2, also known as the Expeditionary ALIS, SOU V2, which is required to meet the Marine Corps IOC in 2015.

"The SOU V2 allows deployability at squadron level and also at sub-squadron level," said Mike Perrault. "It allows you to pick up aircraft, and the logistics tail including spares, equipment and ALIS, to support operations."

Data is sent from the SOU to a central location within each user country, known as the Central Services Kit and comprising Central Point of Entry (CPE) servers.

The CPE for the United States, for example, is at Eglin Air Force Base in Florida and it is from the CPE that fleet management is carried out by each service. The CPE is designed to be the repository for all sovereign data and is not accessible by any other F-35 operator.

Each operator's CPE shares a 'core' set of data with the Global Sustainment Kit at Lockheed Martin in Fort Worth. This houses Autonomic Logistics Operating Unit (ALOU) servers and provides the manufacturer with the data required to manage and



Variant: **F-35A 08-0751/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 6, 2013** Detail: **SSgt Ferguson of the 33rd Maintenance Group uses a Portable Maintenance Aid to access the ALIS during routine maintenance** Photographer: **Andy Poulastides/Lockheed Martin**



Variant: **F-35B BF-05** Unit: **Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs'** Location: **USS Wasp (LHD 1)** Date: **August 21, 2013** Detail: **US Marine Corps Gunnery Sergeant Lance McKusick reading a Portable Maintenance Aid in front of F-35B BF-05 on the deck of USS Wasp** Photographer: **Andy Wolfe/Lockheed Martin**

support the global fleet.

"All the SOUs across a given country report to the next node in the architecture, which is the CPE. The CPE will allow for some country aggregation, and some sovereignty rules can be applied there," explained Mike Perrault.

"In order to support the F-35 in a performance-based logistics environment there's a core set of data that we want to pull into the ALOU. That will allow us to do system-wide analysis as the aircraft matures. But that information is aggregated at the ALOU and the raw data is not shared among countries."

What can ALIS do?

Because ALIS integrates a broad range of capabilities, including operations, maintenance, diagnostics, supply chain interface, training and technical data into a single, secure environment, it serves as what Lockheed Martin terms the 'information infrastructure' for the F-35.

From a mission planning standpoint, ALIS provides a secure core 'image' which is used for mission planning within the Ship and Squadron Kit. Mission planning software is loaded onto a laptop computer. Once the plan is complete it is downloaded to the mission 'bricks' which are plugged into the aircraft by the pilot.

Data that is relevant to the maintenance team, such as weapons and fuel load, is available through ALIS and all the standard military forms are also incorporated, making the flight-line and hangar a paperless environment.

Aircraft inspections and checks are scheduled and acquitted through the system, which is regularly and automatically updated to ensure issues such as parts interchangeability, cautions and warnings are up to date.

F-35 Joint Technical Data is accessed via ALIS, so the technician simply enters a fault code to see all the information he or she requires, including a troubleshooting solution (aggregated from all the data received by the ALOU in Fort Worth) and maintenance procedures.

Its integrated nature therefore removes the requirement for the mission planners, technicians and logisticians to have their own bespoke computer programmes and networks.

In the future, Lockheed Martin claims ALIS will be capable of receiving fault codes automatically from the aircraft via the maintenance data link, allowing technicians time to view the troubleshooting data, request the required part, and review the maintenance procedures, all before the aircraft lands.

For extended periods of time, ALIS can be used without connectivity to the CPE and ALOU, if deployed to an austere airfield for example, but with the caveat that the data may not be completely current. In practice, this may limit such operations to around 30 days at a time.

Delays and Technical Difficulties

Given that ALIS is such a complex software-driven system, delays and technical difficulties are perhaps not surprising, and early operations have required a significant number of 'work-arounds'.

ALIS has already been stood up at Fort Worth, Edwards Air Force Base (AFB), Nellis AFB, Eglin AFB, Ogden Air Logistics Centre at Hill AFB, Utah, Naval Air Station Patuxent River, Maryland, Yuma and the Fleet Readiness Centre East at Marine Corps Air Station (MCAS) Cherry Point, North Carolina. Most recently it has also been installed at Luke AFB, Arizona, and MCAS Beaufort, South Carolina, ready to support aircraft that will be assigned to each base during 2014.

According to the DOT&E report, the version required to support aircraft from Low Rate Initial Production (LRIP) lot 4 (version 1.03) at Eglin, Nellis and Yuma underwent initial testing at Edwards in late 2012 and began fielding early in 2013.

Initial testing revealed shortcomings in the system's integration of applications, and a lack of maturity in handling data elements. As a result, four critical deficiencies which required correction before fielding were identified, and a further 54 severe deficiencies which required workarounds were noted.

Lockheed Martin developed an updated version in response to the shortcomings and delivered this to the test units before the system was fielded in early 2013. However, subsequent testing at Patuxent River in May 2013 indicated that at least three of the four critical deficiencies remained open.

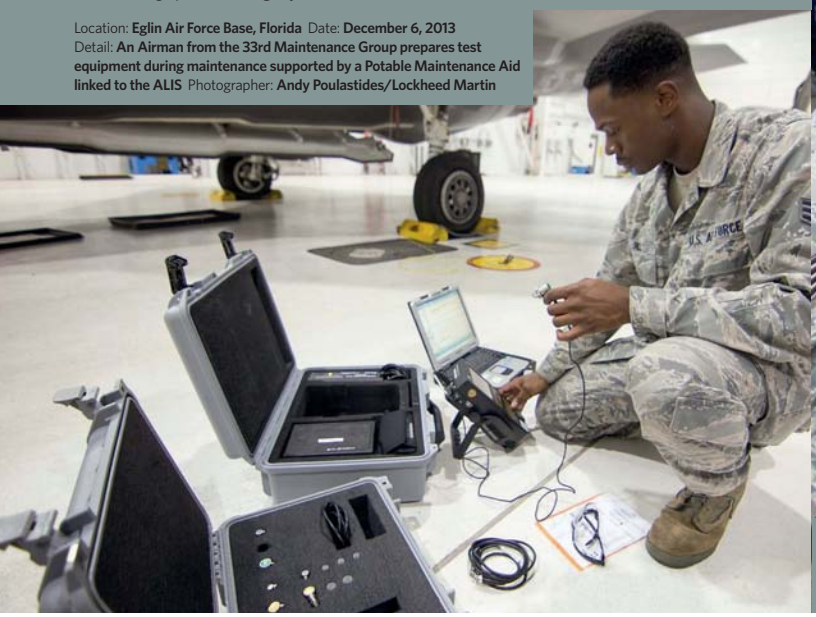
The latest software build, version 1.03.3, was released to Marine Corps' F-35Bs at Yuma in mid-February 2014 and the maintainers were giving good feedback soon after. This version was also fielded at the other F-35 bases within 30 days.

Further Development

The DOT&E report also criticised the SOU in its initial form as being unsuitable for deployment, so the



Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **Marines assigned to VMFA-121 using a Portable Maintenance Aid plugged into the Maintenance Interface Panel during post-flight checks on an F-35B** Photographer: **Paul Ridgway**



Location: **Eglin Air Force Base, Florida** Date: **December 6, 2013** Detail: **An Airman from the 33rd Maintenance Group prepares test equipment during maintenance supported by a Potable Maintenance Aid linked to the ALIS** Photographer: **Andy Poulastides/Lockheed Martin**



Variant: **F-35A 08-0751/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 6, 2013** Detail: **SSgt Ferguson of the 33rd Maintenance Group uses a Portable Maintenance Aid to read through the maintenance procedures held by the ALIS** Photographer: **Andy Poulastides/Lockheed Martin**

SOU V2 is being developed in multiple increments to support Block 2B, Block 3i and Block 3F software.

The first increment will include the capability to deploy in support of the Marines IOC, and will align hardware (SOU V2) with ALIS 2.0.1 software. A second increment (currently unfunded) will address US Air Force requirements described in the report as 'sub-squadron reporting capabilities and inter-squadron unit connectivity'. The third increment (also unfunded at the present time) will add a de-centralised maintenance capability to allow the management of tasks without connectivity with the main SOU.

Testing of ALIS 2.0 began at Edwards in April 2014 and will be followed by version 2.0.1, which will integrate the propulsion module, in September. Any delay with ALIS 2.0 or 2.0.1 will add schedule risk to the release of Block 2B planned for mid-2015. This was a point highlighted by the DOT&E report.

Mary Ann Horter, Lockheed Martin's vice president of F-35 Sustainment told *AIR International:* "To the middle of February ALIS had supported over 7,500 flights across the eight locations where it is stood up.

"The development of ALIS is very much linked to the aircraft, so we have a development roadmap that is closely tied to the airplane. Our next two major releases are ALIS 2.0, which has the (aircraft) Block 2 capabilities, in the first quarter of 2015, then Expeditionary ALIS in the second quarter of 2015 to support deployed operations and Marine Corps IOC." ***Nigel Pittaway***

Young ALIS

During a visit to the 422nd Test and Evaluation Squadron's F-35 Aircraft Maintenance Unit, *AIR International* spoke with Chief Master Sergeant Prah about the aircraft's data management and the support provided by the Autonomic Logistics Information System.

"These aircraft are very, very data sensitive and data centric," said CMSgt Prah while discussing F-35 maintenance with the author at Nellis. The superintendent was alluding to the problems that the AMU encountered when it 'caught' the first two F-35A aircraft that arrived at Nellis on March 7, 2013.

"We couldn't fuel them because the software load was incorrect, therefore the Maintenance Data Interface (MDI) to the aircraft could not talk to the jet."

Who helped to overcome the problem? "All the data resides with Lockheed Martin. They had to push separate elements into our ALIS infrastructure, the system that holds all of the data modules for the aircraft. Everything that's in ALIS has to be pristine data and it wasn't".

Each aircraft has its own system data builds (SDBs), each one is different and they are sent to and from a squadron's ALIS to update the system with the aircraft's history. The F-35 AMU received huge amounts of aircraft data but the data build didn't match up and posed a lot of problems for the interface with the aeroplane.

"We were talking in two alpha [Block 2A] and ALIS was talking to the jet in one bravo [Block 1B] so we couldn't do anything. That was very trying."

Bear in mind there are over 2 million lines of code in an F-22 Raptor and 10 million in the F-35. "You can fathom how tough a flying computer is to maintain. At the time the only mechanism in place for us [the 422nd TES] to receive information from Lockheed Martin was to write action requests (ARs)".

The 422's maintainers needed to import an entire module of the aircraft's life data into its ALIS servers, left behind at Fort Worth after the aircraft was given its DD250, the official documentation that certifies ownership of the aircraft to the US Air Force. The AMU issued three ARs for the module which was required to make the aircraft flyable.

Problems arise if there is a gap in the data history as the superintendent explained: "For instance some of the data we received initially from ALIS indicated that we had only two IPP [Integrated Power Pack] starts. We knew that wasn't correct because we had had seven IPP starts before that information even got to us. Remember that the data that's in ALIS is unknown to us, so discrepancies, times, inspection times didn't line up when we needed it ready to fly."

At the time, the AMU had to wait about three weeks to receive the data push for its two aeroplanes. Since March 2013, Lockheed Martin has reduced the wait to about a week.

Each user has to wait for the Data Quality and Integration Management (DQIM) team, the people who maintain the quality of the computer code. The team has to gather the data and put it in a script that works to feed into ALIS.

"I call it ping-pong because we ping-pong back and forth with the data," said CMSgt Prah. "It was returned in an inadequate state and had to go back again. The process took about three weeks to get all of the missing data lined up and uploaded into the aeroplane through ALIS. About a week after that, we cranked our first sortie on April 4". ***Mark Ayton***

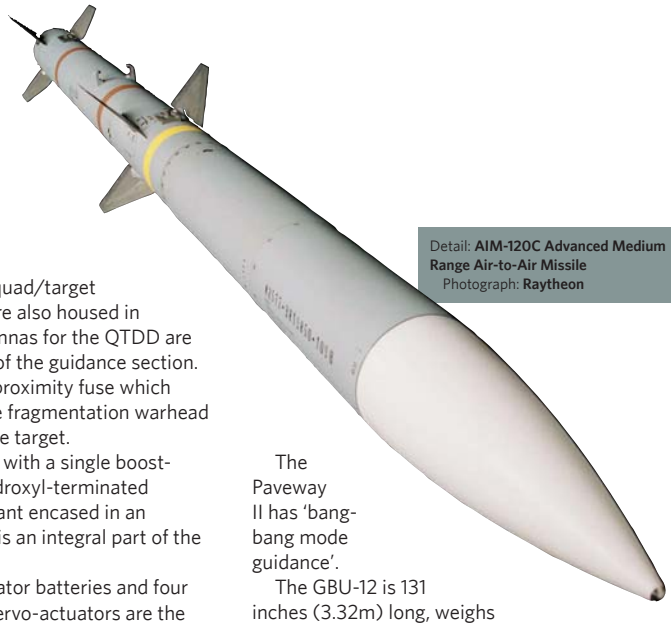
Lightning



Image Data

Variant:	**F-35A AF-01**
Unit:	**461st Flight Test Squadron**
Location:	**Over California**
Date:	**January 10, 2014**
Detail:	**Flying qualities test mission with GBU-12 laser-guided bombs**
Photographer:	**Matthew Short/Lockheed Martin**

Bite



Detail: **AIM-120C Advanced Medium Range Air-to-Air Missile** Photograph: **Raytheon**

The F-35 programme has identified lethality – the product of weapons integration test and evaluation – as the critical path to completing development of the aircraft's Block 2B and Block 3F configuration.

The Block 2B weapons are the AIM-120 AMRAAM air-to-air missile, GBU-12 laser-guided bomb and the GBU-31/GBU-32 Joint Direct Attack Munitions. Further types will be added in accordance with a process set out in the Production, Sustainment and Full-Rate Development Memorandum of Understanding.

The US Marine Corps is expected to declare an initial operating capability with the F-35B STOVL variant loaded with Block 2B software in 2015.

Weapon Stations and Stores

Each F-35 variant has 11 weapon stations, numbered from 1 (the left outer underwing pylon) to 11 (the right outer underwing pylon). They consist of air-to-air missile rails on stations 1 and 11; two inner stations under each wing (2 and 3 on the left and 9 and 10 on the right), which can carry fuel tanks or weapons; the under-fuselage centreline station (6); and four in the internal weapons bay (4 and 5 in the left side and 7 and 8 in the right). Stations 5 and 7, positioned on the inner door of each weapon bay, are dedicated to air-to-air missiles. All 11 stations are common to all variants.

The F-35A CTOL and F-35C CV variants have similarly sized weapons bays which can carry up to 2,000lb-class weapons or a mix of smaller munitions. The F-35B STOVL variant has a smaller internal weapons bay capable of carrying 1,000lb-class munitions.

Of the three variants, the F-35A CTOL is the only one equipped with an internal four-barrel GAU-22/A 25mm cannon. The F-35B STOVL and F-35C CV can carry an external pod containing the same cannon and 220 25mm rounds.

The weapons, launcher, carriage assembly and bomb racks within Block 2B are detailed below, starting with the AMRAAM missile.

AIM-120C Advanced Medium Range Air-to-Air Missile (AMRAAM)

The F-35's primary air-to-air weapon is the Raytheon AIM-120 AMRAAM (advanced medium-range air-to-air missile) beyond visual range (BVR) radar-guided missile.

The AIM-120 has four fixed mid-body-mounted wings, four electric motor-driven movable tail fins and an umbilical connection enabling communication with the aircraft for targeting and initialisation.

The missile consists of four sections: guidance, armament, propulsion and control.

The hardware and software necessary for target acquisition and tracking, navigation, datalink processing and electrical power distribution is fitted in the guidance section.

Seeker/servo electronics, a transmitter/electrical conversion unit (ECU), an electronics unit, an inertial reference unit (IRU) and a quad/target detection device (QTDD) are also housed in the guidance section. Antennas for the QTDD are mounted in the aft portion of the guidance section.

AMRAAM uses a radar proximity fuse which activates the high-explosive fragmentation warhead at a preset distance from the target.

The missile is configured with a single boost-sustain, reduced-smoke hydroxyl-terminated polybutadiene solid propellant encased in an insulated steel case, which is an integral part of the airframe.

Control electronics, actuator batteries and four independently-controlled servo-actuators are the main components of the control section.

The AIM-120C has a weight of 356lb (161kg), length of 144 inches (3.7m), a diameter of 7 inches (180mm), wing and control fins with spans of 17.5 inches (444mm) and a blast-fragmentation warhead of 45lb (20kg).

GBU-12 Paveway II Laser-Guided Bomb

The GBU-12 Paveway II is a 500lb (227Kg) laser-guided bomb which uses the Mk82/BLU-111 blast fragmentation warhead. It has large guidance fins attached to the front of the high-explosive bomb body and folding wings (the air foil group) which open on release for stability and increased manoeuvrability.

When dropped, the GBU-12's nose-mounted semi-active laser seeker tracks the laser spot on the target provided by the F-35's AAQ-40 Electro-Optical Targeting System, a forward air controller or an unmanned air vehicle. During flight the bomb fins move to ensure accurate impact on the target.

The Paveway II has 'bang-bang mode guidance'.

The GBU-12 is 131 inches (3.32m) long, weighs 606lb (275kg), has a warhead diameter of 10.75 inches (273mm) and an airfoil diameter of 18 inches (457mm).

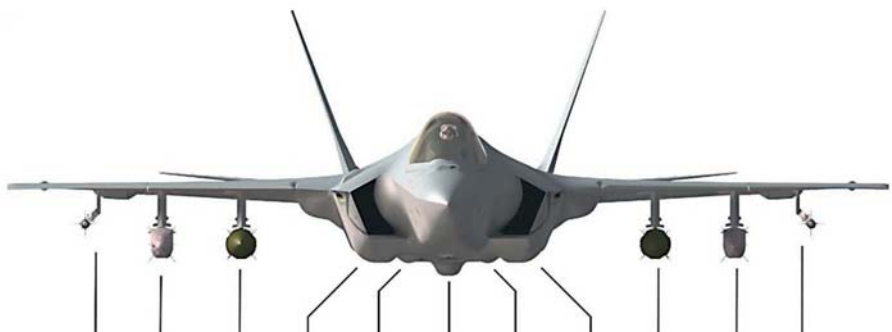
GBU-31 Joint Direct Attack Munition (JDAM)

The JDAM is a guidance set (of which there is a series, designated KMU-556, KMU-557 and KMU-558) that converts existing unguided free-fall 2,000lb-class warheads into accurate all-weather munitions.



Detail: **GBU-12 laser-guided bomb** Photograph: **Lockheed Martin**

WEAPON STATIONS & STORES



Station	11	10	9	8	7	6	5	4	3	2	1
Store	A/A	A/A, A/S	A/A, A/S	A/A, A/S	A/A	Gun	A/A	A/A, A/S	A/A, A/S	A/A, A/S	A/A
Capacity CV/ CTOL	300	2,500	5,000	2,500	350	1,000	350	2,500	5,000	2,500	300
Capacity STOVL	300	1,500	5,000	2,500	350	1,000	350	2,500	5,000	1,500	300

Detail: **Weapon stations** Photograph: **Lockheed Martin**



Detail: **GBU-31 Joint Direct Attack Munition** Photograph: **SSgt Jessica Kochman/US Air Force**

Each different guidance set consists of a tail kit (fitted with an INS/GPS receiver), battery, a set of aerosurfaces (moving fins) to provide lift and an umbilical cover.

The tail kit, which also houses selective-availability anti-spoofing modules, is bolted onto one of four different types of 2,000lb class warhead, the Mk84, BLU-109 hard target-penetrator or the BLU-117 and BLU-119 blast fragmentation versions.

A GBU-31 JDAM can be launched from different altitudes (very low to very high) and from different delivery profiles: a dive, toss and loft or in straight-and-level flight. Depending on the aircraft launch speed and altitude the GBU-31 has a range of up to 15 miles (24km).

The GBU-31's specifications depend on the warhead.

Mk84 GBU-31(V)1 (Air Force) and GBU-31(V)2 (Navy) is 152.7 inches (3.88m) long, weighs 2,039lb (924kg) and has a warhead diameter of 25 inches (635mm).

BLU-109 GBU-31(V)3 (Air Force) and GBU-31(V)4 (Navy) is 148.6 inches (3.77m) long, weighs 2,118lb/2,138lb (960kg/969kg) and has a warhead diameter of 25 inches (635mm).

BLU-117/BLU-119 GBU-31(V)2 (Navy)/GBU-31(V)5 (Air Force) is 152.7 inches (3.88m) long, weighs 2,059lb (933kg) and has a warhead diameter of 25 inches (635mm).

GBU-32 Joint Direct Attack Munition (JDAM)

The GBU-32 JDAM is similar to the GBU-31 but uses a KMU-559 guidance set to convert existing unguided free-fall 1,000lb class warheads into more accurate munitions.

The tail kit, which also houses selective availability anti-spoofing modules, is bolted onto one of two different types of 1,000lb class warhead, the Mk83 or the BLU-110 blast fragmentation version.

An F-35 pilot can either load target co-ordinates into the aircraft's stores management system prior to take-off or in flight.

When a JDAM is selected it will power up using its internal battery, check the system, confirm to the pilot it is 'on' and that the BIT (built in test) is successful, align its INS with data from the aircraft, perform all targeting and transfer requirements and signal when ready.

Once pilots see they are within the launch-acceptable region they 'pickle' the weapon and, within about a second, final checks are made and the JDAM is released.

In flight the INS/GPS set guides the bomb to the designated target via control fin adjustments. The GBU-32 has an average CEP (circular error probable) of less than 10m (328ft), based on the results of dropping 450 munitions during testing.

The GBU-32's specifications depend on the warhead.



Detail: **GBU-32 Joint Direct Attack Munition**
Photograph: **Photographer's Mate Airman Casey Jones/US Navy**

Mk83 GBU-32 is 119.6 inches (3.03m) long, weighs 1,014lb/1,029lb (459kg/466kg) and has a warhead diameter of 19.6 inches (497mm).

BLU-110 GBU-32(V)1 is 119.6 inches (3.03m) long, weighs 1,029lb (466kg) and has a warhead diameter of 19.6 inches (497mm).

BRU-61/A Common Carriage Assembly

The BRU-61/A is a pneumatic multi-stores carriage system designed to carry four 250lb-class precision-guided munitions both internally and externally. It is capable of ejecting 250lb-class weapons up to supersonic speeds using a high-pressure pneumatic system.

Developed for use by all three variants of the F-35 Lightning II, the BRU-61/A is a modified version of an original unit used by the F-15E Strike Eagle.



Detail: **BRU-61/A Common Carriage Assembly** Photograph: **Boeing**

Each BRU-61/A is suspended from the aircraft's parent bomb rack. The electronics in the unit distribute the weapons status, control the release sequence and initiate the INS/GPS signals to all weapons on the dispenser using the MIL-STD-1760 interface at each station.

The BRU-61/A is 126 inches (3.20m) long, 14 inches (355mm) wide, 10 inches (254mm) high and weighs 320lb (145kg).

BRU-67/A Bomb Rack

The BRU-67/A bomb rack incorporates 14-inch (355mm) hooks and uses a high-pressure pneumatic system to eject and separate weapons and stores from stations 4 and 8. The rack is only used in the weapons bay of the F-35B STOVL variant.

It contains a pneumatic power module with two pressure vessels rated at 5,000psi (35N/mm^2) and incorporates a semi-automatic swaybrace, which is integral with the ejector piston, to restrain the movement of the weapon/store during captive and employment mode. Each BRU-67/A is fitted with three zero retention force electromechanical arming units, one each forward, centre and aft. Additionally, the rack has four positive arming units on its operating side, a selectable pitch setting control and a dump valve to vent the pneumatic energy contained in the pressure vessels.

The BRU-67/A has a series of safety features – including a four-position safe/arm lever showing the status of the rack (safe, safe and unlocked, armed and download) and a reversible in-flight locking (RIFL) mechanism for electromechanical 'safing'/arming which incorporates a circuit interrupt to prevent the rack from firing until the system is armed. The unit also provides for automatic safing when both hooks are properly latched.

The BRU-67/A is 33.6 inches (853mm) long, 4 inches (100mm) wide, 12.8 inches (325mm) high and weighs 65lb (29kg).



Detail: **BRU-67/A and BRU-68/A bomb racks** Photograph: **Exelis**

BRU-68/A Bomb Rack

The BRU-68/A bomb rack, fitted with 14-inch and 30-inch (355 and 760mm) hooks, is used in the weapons bay of the F-35A CTOL and F-35C CV and externally on all three variants.

The rack is 36.78 inches (934mm) long, 85.5 inches (2.17m) wide, 4 inches (100mm) high and weighs 85.5lb (38.7kg).

LAU-147/A Missile Launcher

The LAU-147/A launcher uses a high-pressure pneumatic system to safely eject and separate AIM-120 series missiles from the internal weapons bay of all three variants of the F-35. The launcher houses a pneumatic power module with two pressure vessels rated at 5,000psi (35N/mm^2) and a swaybrace, integral with the ejector piston, to restrain the movement of the weapon/store during captive and employment mode.

The LAU-147/A has a safe/arm lever to provide a visual status of the condition of the rack and has four positions: safe, safe and unlocked, armed and download. A reversible in-flight locking (RIFL) mechanism provides electromechanical safe/arming and is spring-biased to default to the safe mode. The RIFL prevents the rack from firing until the system is armed with a circuit interrupt.

The LAU-147/A is 43 inches (1.09m) long, 4 inches (100mm) wide, 6.9 inches (175mm) high and weighs 62lb (28kg).

LAU-148/A External Rail Launcher

The LAU-148/A is used to carry and launch a single AIM-9X Sidewinder or AIM-120 AMRAAM, and provides a mechanical and electrical interface between the missile and the aircraft.

It is mounted to the aircraft, either on an external pylon station or an external missile adapter, using two tension bolts. An electrical interface connects to a unit housed in the launcher.

The LAU-148/A is 115 inches (2.92m) long, 5 inches (125mm) wide, 6.39 inches (162mm) high and weighs 100lb (45kg).

Pneumatic Power Source

The F-35 Pneumatic Power Source (PPS) is used by all variants of the F-35 to provide ejection energy to the BRU-67/A and BRU-68/A bomb racks and LAU-147/A launcher rail. It is located in the right-hand weapons bay and supplies air pressure at 5,000psi (35n/mm^2) to the F-35's internal weapon stations 4, 5, 7 and 8. Additional PPS units are fitted in each air-to-ground pylon to provide air pressure to the BRU-68/A.

An internally-mounted PPS consists of a compressor motor, filter manifold, PAO (polyalphaolefin) cooling plate and electronic control unit. Each pylon-mounted PPS comprises a motor compressor, filter module and ECU.

Weapons added with Block 3F software are the AIM-9X air-to-air missile, AGM-154 Joint Stand-Off Weapon (JSOW), GAU-22/A gun (internally mounted on F-35As and externally in a gun pod for the F-35B and F-35C), GBU-39/A Small Diameter Bomb Increment I (SDB I), and the UK's ASRAAM air-to-air missile and Paveway IV precision-guided bomb.



Detail: **LAU-147/A missile launcher** Photographer: **Frank Mormillo**

AIM-9X Sidewinder

The AIM-9X Sidewinder, a supersonic air-to-air guided missile with full day/night capability, comprises six main components: missile body, a passive infrared (IR) target acquisition system, proportional navigational guidance, a closed-loop position fin actuator unit (FAU) and a target detector, warhead and rocket motor.

Propulsion is provided by a solid-propellant rocket motor which incorporates a manual safe-arm selector assembly. The missile is configured with an annular blast fragmentation warhead controlled by an electronic safe-arm device.

Aerodynamic lift and stability are provided by four forward-mounted fixed wings. Four fins, mounted in line with the fixed wings and activated by the FAU, manoeuvre the missile.

Manoeuvrability is enhanced by a jet vane control (JVC) that deflects the rocket motor thrust to aid turning, which is controlled by a tail actuation section.

A key benefit of the AIM-9X is its imaging focal plane array infrared sensor, which has IR-counter countermeasures and has demonstrated very effective detection and tracking performance within visual and BVR engagement.

The AIM-9X incorporates new improvements integrated as part its spiral development. The Block II version includes an improved fuse and updated electronics – which enable lock-on after launch capability and BVR engagements – including the use of a datalink.

This new capability means the pilot can take full advantage of the aerodynamic performance of the AIM-9X. The ongoing test programme, which was nearing completion at the end of 2013, demonstrated excellent results: 17 kills for 21 test shots.

In late 2012 Raytheon was awarded a development contract for the Block III – the next evolution of the Sidewinder – which will mate the Block II seeker and



Detail: **LAU-148/A external rail launcher carrying an AIM-9X Sidewinder** Photographer: **Paul Ridgway**

datalink advancements with an improved rocket motor, new internal systems and warhead. The Block II is expected to have up to 60% more range and greater capability, and should provide the F-35 with a new potent air-to-air missile.

Later Block AIM-9Xs incorporate a reprogrammable computer to adjust for new IR countermeasure challenges. By mid-2013 some 5,000 had been delivered to the US and allied nations.

The AIM-9X missile is 119 inches (3.02m) long, weighs 188lb (85kg), has a 5-inch (127mm) diameter and wings and fins with spans of 13.9 inches and 17.5 inches (353mm and 444mm) respectively.

AGM-154 Joint Stand-Off Weapon (JSOW)

The AGM-154 Joint Stand-Off Weapon (JSOW) is a 1,000lb-class low-observable INS/GPS-guided family of air-to-surface glide weapons with all-weather, day/night capability.

It consists of a common airframe and avionics providing for a modular payload assembly to attack stationary or moving targets.

Once released the JSOW is an unpowered glide bomb with a range from 15 to 60-plus miles (24 to 96km) – which enables the attacking aircraft to remain outside the range of point and short-range air defence systems.

The AGM-154A carries 145 BLU-97 combined effects munitions for deployment against area targets such as troops, vehicles and SAM sites using GPS-aided inertial guidance.

After launch, folding wings extend and the weapon flies a pre-programmed flight path before dispensing its payload over the intended target.

The AIM-154C version features an infrared terminal seeker and carries a 500lb (227kg) two-stage Broach penetrator warhead to attack hardened targets.

JSOW-C1 has an autonomous target acquisition (ATA) capability, a Link 16 data link to enable moving target (land and maritime) strike capability.

The AGM-154 is 160 inches (4.06m) long, has a fuselage diameter of 13 inches (330mm), a wingspan of 106 inches (2.69m) and weighs 1,065lb (483kg).

GAU-22/A Cannon

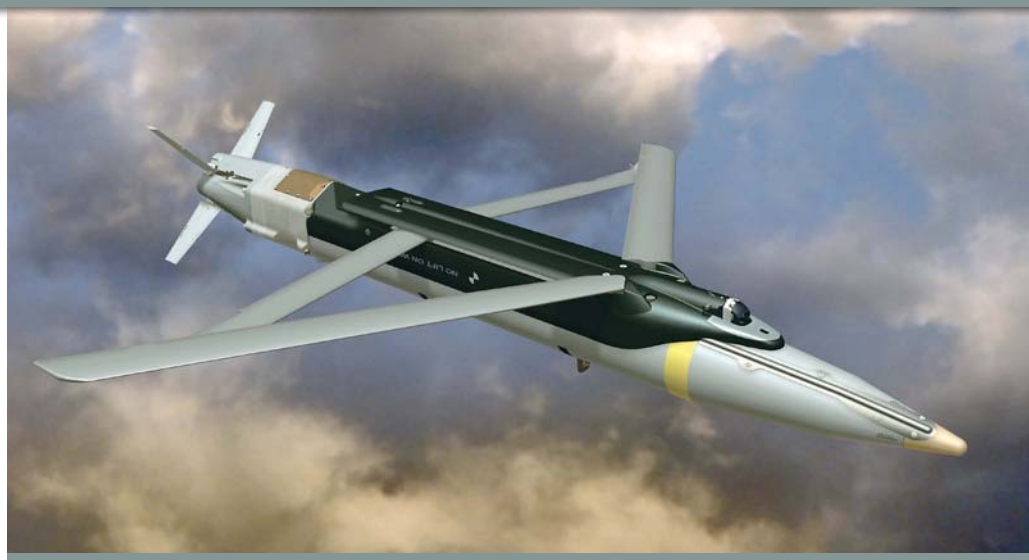
The 25mm GAU-22/A cannon is being developed for the F-35A CTOL variant.

It is an externally-powered four-barrel Gatling gun with a bespoke feed system which fires at a nominal rate of 3,000 rounds per minute, and is carried internally on an F-35A with 181 rounds. A modified version is being developed for the F-35B STOVL and F-35C CV variants which will both carry the cannon in a missionised gun pod with 220 rounds.

The GAU-22/A weighs 230lb (104kg) measures 84 inches (2.13m) in length and is 6 inches (150mm) in diameter.



Variant: **F-35B BF-02** Unit: **Air Test and Evaluation Squadron 23**
Location: **Over the Atlantic Ocean** Date: **June 14, 2012**
Detail: **Asymmetric external stores testing with GAU-22/A cannon**
Photographer: **Andy Wolfe/Lockheed Martin**



Detail: **GBU-39/B Small Diameter Bomb I** Photograph: **Boeing**

GBU-39/B Small Diameter Bomb Increment I (SDB I)

The GBU-39A is a 250lb-class autonomous conventional air-to-ground precision glide weapon designed for striking fixed and stationary re-locatable targets from stand-off range. It consists of the weapon and the BRU-61/A four-place miniature munition pneumatic carriage system. The BRU-61 is being modified to fit in the F-35B's and F-35C's weapons bays.



Detail: **AGM-154 Joint Stand-Off Weapon** Photograph: **Raytheon**

An advanced anti-jam GPS-aided INS provides guidance to the co-ordinates of a stationary target.

SDB I has a multi-purpose penetrating/blast fragmentation warhead coupled with a cockpit-selectable electronic fuse. A proximity sensor provides a height of burst capability.

After launch the SDB I's wings deploy and it glides to the target using GPS guidance up to a range of more than 60 miles (96km).

The GBU-39 measures 70.8 inches (1.80m) long, 7.5 inches (190mm) wide, has a wingspan of 152.4 inches (3.87m) and weighs 285lb (129kg).

Advanced Short Range Air-to-Air missile (ASRAAM)

The Advanced Short Range Air-to-Air Missile (ASRAAM) is a highly manoeuvrable, heat-seeking, 'fire-and-forget' missile designed to provide dominance in within visual range (WVR) engagements. ASRAAM is the fastest and therefore the most capable short-range air-to-air missile in the world.

ASRAAM was required to be multi-platform interoperable, capable of tracking in all aspects (head-on, side-on and tail-on) to get the first shot off and the first kill, to have a high average velocity which enables the missile to fly a long way and still be able to pull high g manoeuvres, and have a short launch time. The missile's thermal batteries come up very quickly so there is no protracted dialogue between the pilot pushing the button and the launch.

Built with a 6.5-inch diameter fuselage, wider than other short-range missiles, the propulsion system housed within the fuselage contains more fuel than other SRAAM missiles, which burns very fast. Because there are no wings or strakes to slow it down aerodynamically the missile retains speed over its envelope.

The ASRAAM has a low-drag design, with four small tail fins that all deflect independently in the airflow across the missile and use lifting body aerodynamics to turn. Stability is maintained by a high-speed autopilot, while the IR seeker provides tight and accurate guidance.

ASRAAM does not use thrust vector control. To further increase its speed and range, the missile is powered by a high-impulse dual-burn, solid rocket motor, which gives instantaneous acceleration off the rail and a high average velocity, yet has a low signature.

ASRAAM can be designated by the aircraft's radar or any other sensor that can feed the missile with the target information.

The seeker detects the whole target scene, producing an image similar to a monochrome TV picture. The wide field of view allows the missile to be fired at very high off-boresight angles, and the seeker has a lock-on capability, in either lock-before or lock-after-launch modes of up to about 90° off-boresight.

High resolution gives long-range target acquisition and excellent discrimination against sophisticated IR countermeasures including flares and other pyrotechnics, as well as an ability to compensate for intermittent target obscuration in cloud.

Sophisticated digital signal-processing and imaging algorithms allow ASRAAM to detect, identify and target particular areas of its target aircraft, including the engines, cockpit or wings, further enhancing the missile's lethality.

In a typical WVR 'dogfight' engagement, ASRAAM can be slaved to the target using any of the launch aircraft's onboard sensors. After launch, the missile accelerates to speeds in excess of Mach 3 while being guided to the target using its IR seeker. It can pull up to 50g off the launch rail, allowing it to engage high off-boresight targets. The 10kg (22lb) high-explosive



Detail: **Advanced Short Range Air-to-Air missile**
Photograph: **MBDA**

fragmentation warhead can be triggered by a laser proximity fuse or by an impact fuse.

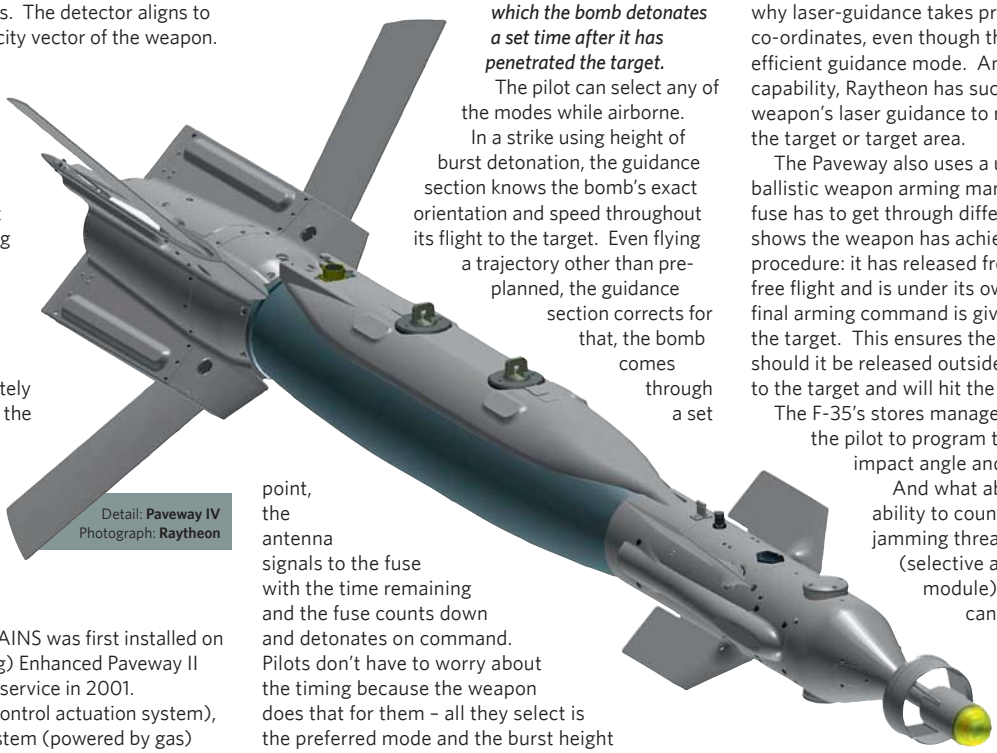
ASRAAM provides the capability to chase down the retreating adversary aircraft because of the additional propellant carried compared to the AIM-9X and IRIS-T. It also provides a bigger no escape zone yielded by an average velocity higher than all other SRAAMs gained from the more powerful motor and reduced drag.

The ASRAAM missile is 2.9m (9ft 6in) long, weighs 88kg (194lb), has a diameter of 165mm (6.5 inches) and fins with a span of 450mm (17.7 inches). ASRAAM will be carried on stations 1 and 11 of the UK's F-35Bs.

Paveway IV Precision Guided Munition

The Paveway IV weapon comprises various components. From front to tail these are a laser detector, colloquially called the birdie head, which sits on two floating gimbals. The detector aligns to the wind which is the velocity vector of the weapon. When the weapon is falling, regardless of manoeuvre or angle of attack, the detector remains fixed on the target.

The next component aft of the detector is the fairing containing the GAINS, which is part of the ECCG (enhanced computer control group). The GAINS (GPS-aided inertial navigation system) accurately determines the position of the weapon throughout the flight and provides an all-weather, day-night guidance capability. The GPS-feed allows corrections to be made to remove any drift out of the inertial measurement unit. The GAINS was first installed on Raytheon's 1,000lb (454kg) Enhanced Paveway II bomb, which entered RAF service in 2001.



Detail: **Paveway IV**
Photograph: **Raytheon**

Then there's the CAS (control actuation system), a pneumatically-driven system (powered by gas) which gets charged immediately after release from the aircraft. The system comprises two pairs of canards that steer the weapon through either full deflection or trail commands from the guidance system, often referred to as a bang-bang control. Solenoids pressurise the canards which 'bang' into the required position. When the control command is complete the solenoid is closed and the canards return to their trail position. The moving canards displace and drive the pitch, at a given number of degrees per second, to steer the weapon as it works through the guidance loop. Because the CAS uses a minimum number of parts (a gas bottle, a couple of valves and piping) the weapon's guidance is very reliable.

Aft of the ECCG is the warhead, the main part of the weapon, which forms its primary structure. Developed specifically for Paveway IV, the warhead has two main features: the capability to penetrate hardened targets such as bunkers while being 'insensitive' to fire and bullets. In the event that the bomb ignites in an accident situation it will burn out and neither detonate or propel thanks to its insensitive munitions features, which include the ability to vent.

Positioned immediately behind the warhead is the fuse designed to withstand the forces imposed on the bomb when penetrating a hardened target, which is why it contains no mechanical moving parts. The design of the fuse enables it to survive the same penetration and force as the warhead. It continues to function throughout the delay used in post-impact detonation. Paveway IV is the first air-to-surface weapon on which the guidance section and the fuse have been fully integrated and the two communicate with each other throughout the bomb's flight to the target. Without this 'smart' fuse the weapon's different modes of operation can't be selected and adjusted by the pilot.

Paveway IV was designed as a combat air control weapon. This means the bomb can be employed to suit the conditions of different targets during the mission. Target information can be updated at any time and transmitted to the weapon. What's more, a Paveway IV can be employed using one of three detonation modes:

- ***Height of burst, enabling the altitude at which the bomb detonates above the ground to be selected.***
- ***Point impact where the bomb detonates on impact.***
- ***Post-impact delay in which the bomb detonates a set time after it has penetrated the target.***

The pilot can select any of the modes while airborne. In a strike using height of burst detonation, the guidance section knows the bomb's exact orientation and speed throughout its flight to the target. Even flying a trajectory other than pre-planned, the guidance section corrects for that, the bomb comes through a set point, the antenna signals to the fuse with the time remaining and the fuse counts down and detonates on command. Pilots don't have to worry about the timing because the weapon does that for them – all they select is the preferred mode and the burst height required.

Paveway IV is also capable of coming in to the target at a specified impact angle from 30° to 90° and on a particular impact heading. But the launch aircraft has to be in a given position in the sky, so Paveway IV automatically generates cueing information for the pilot via implementation of LARs (launch acceptability regions).

The weapon uses its position and the target location, the target constraints input by the pilot and the attack orientation to calculate an in-range LAR and an in-zone LAR. Both are projected in the HUD to show the pilot his position relative to the LARs and when he is in range to release and hit the target.

The aircraft has to be within the in-range LAR for the weapon to reach the target. The release position can be from anywhere within the area for the weapon to strike the target but not necessarily to the constraints input by the pilot.

If the bomb is released in the in-zone LAR the weapon will reach the target and achieve the constraints (impact angle and heading angle) input.

One further component worth mentioning are the tail fins, which provide stability and lift for the weapon. Each one (of four) opens slowly to ensure that adjacent stores are safely cleared, and then swings open to a fixed position and locks.

Integration of Paveway IV on the F-35 will require a new lanyard to be fitted to ensure that the tails only open outside the internal weapons bay after release.

Paveway IV has two sets of antennas; one HOB (height of burst) and one GPS fitted to the ECCG. The antennas provide connectivity throughout the weapon's flight time to the target. If the guidance system needs to roll the bomb in flight, at least one antenna will always point to the sky to maintain the link.

The Paveway IV is always given GPS co-ordinates for the target, the position it heads to immediately after release, and seeks to fly the most energy-efficient route to that point throughout its guided mid-course flight.

During the terminal phase, laser guidance takes precedence over a GPS co-ordinate. If the laser lock is lost, the weapon reverts back to GPS guidance; and if a laser designator pod is not present, the bomb will continue to the GPS co-ordinate.

But things can change at the target, which is why laser-guidance takes precedence over GPS co-ordinates, even though the latter are the most efficient guidance mode. And to improve on capability, Raytheon has successfully designed the weapon's laser guidance to manage any change at the target or target area.

The Paveway also uses a unique pre-programmed ballistic weapon arming manoeuvre (BWAM) – the fuse has to get through different gates. Each gate shows the weapon has achieved a specific release procedure: it has released from the aircraft, it is in free flight and is under its own guidance before the final arming command is given two seconds from the target. This ensures the munition remains safe should it be released outside the LAR or will not get to the target and will hit the ground elsewhere.

The F-35's stores management system enables the pilot to program the weapon's fuse, impact angle and heading.

And what about the weapon's ability to counter any spoofing or jamming threat? Thanks to a SAASM (selective availability anti-spoofing module) receiver, Paveway IV cannot be spoofed, and Raytheon is currently working on an active anti-jamming capability.

Raytheon is striving to improve Paveway IV and is doing so with a new version currently being produced for the UK MoD known as the Mk2. The company's engineers verified that the Paveway IV had additional manoeuvrability which has been combined with advanced mathematical techniques in the design of updated algorithms, and these have consequently generated larger LARs. Paveway IV Mk2 presents the pilot with 'wider holes in the sky' enabling them to release weapons with even more flexibility.

The Mk2's LAR takes account of two parameters – the flight parameters of the aircraft and those of the target – and continuously recalculates at a high rate to provide the pilot with a cue for impact in accordance with the constraints.

Raytheon is already working on a smaller low-collateral warhead for Paveway IV as part of the MoD's SPEAR (Selective Precision Effects at Range) Capability 1 weapon programme. Company engineers are seeking to optimise their design to be even more precise and have almost no kinetic effect in the area surrounding the aim point.

The new warhead will have the same mass, centre of gravity and moments of inertia as the current 500lb (227kg) warhead, and maintain the same interfaces as the baseline weapon.



Salty Dogs & Funky Jets



Image Data

Variant:	**F-35B BF-05**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**January 5, 2012**
Detail:	**Mode 4 Flight Control Systems test flight**
Photographer:	**Layne Laughter/Lockheed Martin**

St Mary's county in southern Maryland, like much of the eastern United States, is covered in woods and farmland used to raise livestock and grow crops. Pumpkins are particularly notable and well sought after for Halloween. Lexington Park, the largest town in the area, is located outside one of the biggest bases on the east coast of America – Naval Air Station Patuxent River.

Pax, the common term used to refer to the sprawling super base, is home to every type of helicopter, aircraft and unmanned air vehicle in US Navy and US Marine Corps service. It occupies 13,800 acres of land on the shoreline of the Patuxent River and is within easy reach of the nation's capital, Washington, DC. The base is home to the headquarters of Naval Air Systems Command (NAVAIR), its affiliated Program Executive Officers and the Naval Air Warfare Center Aircraft Division (NAWCAD).

The largest programme currently being tested by NAVAIR is the F-35 Lightning II. Leading the Lightning charge at Pax is Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs'. Once called the Strike Test squadron Directorate within the NAWCAD, this notable unit has conducted developmental testing of all Navy strike aircraft since the 1950s, a mission that has included the A-6 Intruder, EA-6 Prowler, A-7 Corsair, F-4 Phantom II, F-14 Tomcat, F/A-18 Hornet and Super Hornet, EA-18G Growler and since November 2009 the F-35 Lightning II.

The station has many test facilities including the Air Combat Environment Test and Evaluation Facility (ACETEF), the Atlantic Test Range, a TC-7 catapult and MK-7 arresting gear complex used for carrier suitability testing, hover pads, a ski jump and three runways – the longest of which is 11,807ft.

The ACETEF creates virtual battle space for electronic warfare and includes a manned flight simulator, large anechoic chamber, shielded hangar, computing centre and labs for electronic warfare (EW) integration system testing, warfare simulation and threat air-defence. The Atlantic Test Range provides EW sensor stimulation and measurements.

Lightning Lair

The F-35 Lightning II Integrated Test Force (ITF), a department of VX-23, has its own facility located adjacent to the squadron's main hangars. Staff number more than 900, including 580 contractor employees, 260 government and 70 from the Pratt & Whitney F135 propulsion system team.

In accordance with the F-35's Test Master Plan, the ITF is scheduled to conduct some 3,000 test flights with the F-35B Short Take-Off and Vertical Landing (STOVL) variant and 1,900 with the F-35C Carrier Variant (CV) in land- and ship-based environments. The ITF uses the Autonomic Logistics Information System (ALIS) for its maintenance tasks, the tracking of spare parts and for technical data support.

The facility has an A-6E Intruder bomber on display outside the main access gate, its presence harking back to the day when the hangars and offices were built to house the McDonnell Douglas-General Dynamics A-12 Avenger: an all-weather, carrier-based stealth bomber developed under the Advanced Tactical Aircraft programme of 1983. Avenger – the



Image Data

Variant:	**F-35C CF-01**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Over the Atlantic Ocean**
Date:	**February 12, 2014**
Detail:	**Flying qualities test flight with external stores load comprising a gun pod, two AIM-9X Sidewinder missiles and four GBU-12 laser-guided bombs**
Photographer:	**Layne Laughter/Lockheed Martin**

Navy's replacement for the venerable A-6E – was cancelled in 1991 because of cost overruns and delays. It's perhaps ironic that the F-35 Joint Strike Fighter, a programme that has also suffered from cost overruns and delays, eventually filled the empty slots planned for the A-12 at Pax.

Today the once-empty hangar is home to a fleet of nine aircraft – five F-35B STOVL and four F-35C CV variants charged with conducting developmental test as part of the System Development and Demonstration (SDD) phase of the Joint Strike Fighter.

A little more than 400 feet long, the F-35 hangar is divided into two areas, one used for the flight sciences aircraft and a secure area housing all the mission systems test jets – those that have the 'fancy' fifth-generation systems fitted. The hangar bays open up to the flight line. Security fencing surrounds the area housing the mission system jets, a preventative measure to exclude anyone without the necessary clearance from entering the secure area.

The F-35 flight line is shrouded by trees at each end and links onto a taxiway leading to the runways. More trees shroud the flight line from the airfield, a discreet facility for a Lightning lair.

Pax River suffers from harsh weather during the winter months, some of it not conducive to flight testing. To provide cover for the aircraft, pilots and maintainers, a large shelter – which can house two aircraft and their support equipment – occupies the southern section of the flight line. Other areas of the ramp are used to store bomb rack units, launchers, pylons and test vehicles for the various weapons being integrated on the Lightning II.

THE SALTY DOGS' FLEET

Variant	C/n	Type	Build Lot
F-35B	BF-01	Flight Sciences	SDD
F-35B	BF-02	Flight Sciences	SDD
F-35B	BF-03	Flight Sciences	SDD
F-35B	BF-04	Mission Systems	SDD
F-35B	BF-05	Mission Systems	SDD
F-35C	CF-01	Flight Sciences	SDD
F-35C	CF-02	Flight Sciences	SDD
F-35B	CF-03	Mission Systems	SDD
F-35C	CF-05	Mission Systems	SDD

Two Types of Aircraft

VX-23 operates two types of F-35, some dedicated to flight sciences and others used for mission systems testing. The flight sciences aircraft (see table) were the first to roll off the production line in Fort Worth. Each has a unique set of instrumentation installed throughout the airframe which is designed to capture specific flight test data critical to the completion of the flight test programme. Flight science jets do not have full sensor suites installed and do not run the block software installed on mission systems and Low Rate Initial Production (LRIP) aircraft.

The ITF's mission systems aircraft are, however, equipped with the full sensor suite and do run on block software. All four are currently configured with Block 2B software and are used to expand sensor capabilities, including initial implementation of the electronic attack functions of the APG-81 Active Electronically Scanned Array radar.

Test Activity

US Marine Corps LtCol Patrick Moran, Director of Test and Evaluation, F-35 Naval variants at the Pax ITF, told *AIR International:* "Our mission is to conduct safe, efficient and secure testing of the aircraft to ensure that the capabilities, as articulated in the fleet's requirements, are evaluated correctly, and that we can deliver the data required by the authorities to gain airworthiness certification and flight clearance for the fleet. We are fleet focused – all of the ITF's pilots have fleet operations experience.

"The lion's share of our effort is focused on flight sciences work [clearing out the main envelope of the air vehicle, integration and separation testing of weapons] although we do have four mission system aircraft assigned. We also have a transient fleet comprising Low Rate Initial Production aircraft that come through for a variety of other testing."

Engineering in the F-35 ITF is split into two distinct organisations: test operations and air vehicle engineering. Test ops comprises a group of engineers who are 'tied to a tail' – assigned to a specific aircraft – and support every test event conducted by the jet. The air vehicle engineering department consists of 300 people who provide expertise across a wide range of engineering disciplines. The department includes a planning team, engineering and technical support in flying qualities, flight controls, mission systems, weapons integration, loads, dynamics, propulsion systems,



installed subsystems, reliability and maintainability, material review and airframe, basing and ship suitability, external environments, performance and low observability. Engineering support is provided to all nine resident - and any visiting - F-35 aircraft as required.

Jake Piercy, Government Test Ops Lead and Platform Coordinator, explained: "There are about ten engineers assigned to each tail. The rest of the organisation is tied to a mission. The complexity of a system determines how many people are assigned to it. A system that is relatively simple, like air data, which comprises just four probes on the aircraft, has eight people. Something complex, like flying qualities of the aircraft, has about 25 people, as does weapons because of all of the different kinds carried."

The Pax-based ITF works closely with its counterparts in the 461st Flight Test Squadron at Edwards Air Force Base, California. According to the former Director of Test & Evaluation F-35 Naval variants at the F-35 Pax ITF, Capt Erik Etz, the two sites continue to advance knowledge of the aircraft and the mission systems throughout its envelope.

"Our flying rate continues to pick up for the test point count," he said, "and we are well positioned to meet the needs of the flight test programme for the 'B and 'C variants through 2014 and 2015, which will ultimately meet the needs of the warfighter. The aircraft are giving good reliability, maintainability and availability rates, allowing us to meet the high tempo of operations."

The ITF increased test flight activity from an average of 40 hours per month in 2011 to almost 80 hours per month in 2012 and more than 100 during the summer months. Figures for 2013 as published in the Director, Operational Test and Evaluation FY 2013 Annual Report (DOT&E FY2013 AR) are given in the Table *Actual vs Planned Test Flights until October 2013* on page 54.

Most mission systems testing is undertaken by the 461st Flight Test Squadron 'The Jesters' based at Edwards (see *Tail End of the Whip* p80-95) while VX-23 conducts the remaining work. This involves expanding the mission system capabilities with each incremental build of software. Test work is currently being conducted using the Block 2B release, the version that provides initial combat capability, including Link 16 for networked operations. More advanced combat capability will follow with Block 3.

VX-23 routinely flies its F-35Bs and F-35Cs at the outer limits of the flight envelope – Mach 1.6 and up to 7.5g. Capt Etz cited one challenge of meeting test requirements as: "The daily trade-off between exploring the outer edges of the envelope and fully characterising what's available within it. There are times when it's actually more important for us to fully understand a much smaller subset of the envelope because that's what we want to open up to ensure we are delivering a capability to the fleet that can be used in an appropriate fashion."

Daily test activity depends on weather, range availability and being able to assemble all of the engineers and test directors in the control room at the right time required for the test points. Etz explained: "We hit all parts of the envelope on any given day. On average we routinely schedule about four sorties a day using the aircraft with the necessary test instrumentation fitted for the specific test requirement. For example, BF-01 is fully instrumented for STOVL operations and provides data in that regime, but not exclusively.

"We do our best to thoroughly employ all our aircraft at any given time but typically there's not a lot of white space [spare time] in the schedules of any of our nine permanently assigned aircraft, so we set aside time to modify the aircraft as required. During downtime the engineering team analyses data previously generated by the aircraft which is used to further open up the envelope when the aircraft returns to test flying."

VX-23 provided a summary of the main lines of testing conducted by each aircraft in 2012 and 2013.

Flight Sciences Testing in 2012

BF-01 completed loads testing of the new Auxiliary Air Inlet (AAI) door configuration in January with positive results.

The original design had, according to the DOT&E FY2013 AR: "Door locks with an inadequate life, suffered from excessive wear and fatigue due to the buffet environment, and inadequate seal design.

"Doors produced to a new design were installed on LRIP aircraft as part of the ongoing modification plan; five had completed the modification by the end of September. Fatigue testing started in November 2012 and had completed just over 6% of the planned two lifetimes of testing by the end of September 2013.

"Aft down-lock seal doors (commonly referred to as saloon doors) are spring-loaded to the closed position. They are designed as overlapping doors with a 0.5-inch gap. The gap induces air flow disturbance and makes the doors prone to damage and out-of-sequence closing. The programme continues to investigate whether a new design to the doors is required."

ACTUAL VS PLANNED TEST FLIGHTS UNTIL OCTOBER 2013

	All Testing All Variants	Flight Sciences F-35A Only	Flight Sciences F-35B Only	Flight Sciences F-35C Only	Mission Systems
2013 Actual	993	226	284	181	302
2013 Planned	985	241	287	171	286
Difference from Planned	+0.8%	-6.2%	+1.0%	+5.8%	+5.6%
Cumulative Actual	3,601	963	1,269	612	757
Cumulative Planned	3,284	910	1,127	584	663
Difference from Planned	+9.7%	+5.8%	+12.6%	+4.8%	+14.2%

BF-01 also continued loads testing with unflared slow landings in Mode 4, also known as STOVL mode. Mode 4 envelope expansion continued and included the first flight with internal stores; other test events involved Mode 1 flight with the doors open. BF-01 also continued STOVL maturity operations and regression testing of R27 mission software.

BF-02 continued clean wing flutter and flying qualities with AIM-9X Sidewinder missiles carried on stations 1 and 11, air-to-ground pylons on stations 2, 3, 9, 10 and a fully instrumented version of the gun pod on station 6. The missionised gun pod is being developed to house the 25mm GAU-22/A cannon on both naval variants. The tests were performed to characterise the environment around the pod during flight, to ensure the store was not excessively vibrating and that the stresses placed on the racks are within the design limits.

BF-02 also tested dry runway brake performance, propulsion, flying qualities and conducted night evaluation of a modified taxi light.

BF-03 continued loads and flying qualities envelope expansion testing with the weapon bay doors open and closed. The aircraft also performed the first F-35B ground-based weapon releases of the AIM-120 AMRAAM, GBU-12 laser-guided bomb and GBU-32 Joint Direct Attack Munition (JDAM) at the static ejection pit in preparation for weapon separation testing.

CF-01 continued supersonic flutter, and air data testing and flew the first weapons environment check flight carrying JDAMs: GBU-32s followed by GBU-31s.

CF-02 continued loads and flying qualities envelope expansion testing and the first CV variant night flight.

Mission Systems Testing in 2012

In 2012 BF-04 performed weapons environment testing with AIM-120 and GBU-12 in addition to undergoing modification to Block 1B configuration.

BF-05 performed Initial Service Release STOVL propulsion system testing and spent the second quarter of the year in Fort Worth for final finishes and modification to Block 2 configuration.

CF-03 returned to Pax after completing final finishes in Fort Worth in early March and continued mission systems testing and initial catapult tests on the standard steam TC-7 system and the Electromagnetic Aircraft Launch System.

The aircraft also performed a tailhook evaluation which included cable roll-overs and roll-in arrestments at Pax and Naval Air Warfare Center Aircraft Division Lakehurst, New Jersey. The new hook point design was validated at speeds up to 100 knots, trapping on each attempt.

CF-05, the final SDD aircraft, arrived at Pax on December 11, 2012 flown by US Navy test pilot Lt Cdr Michael Burks.

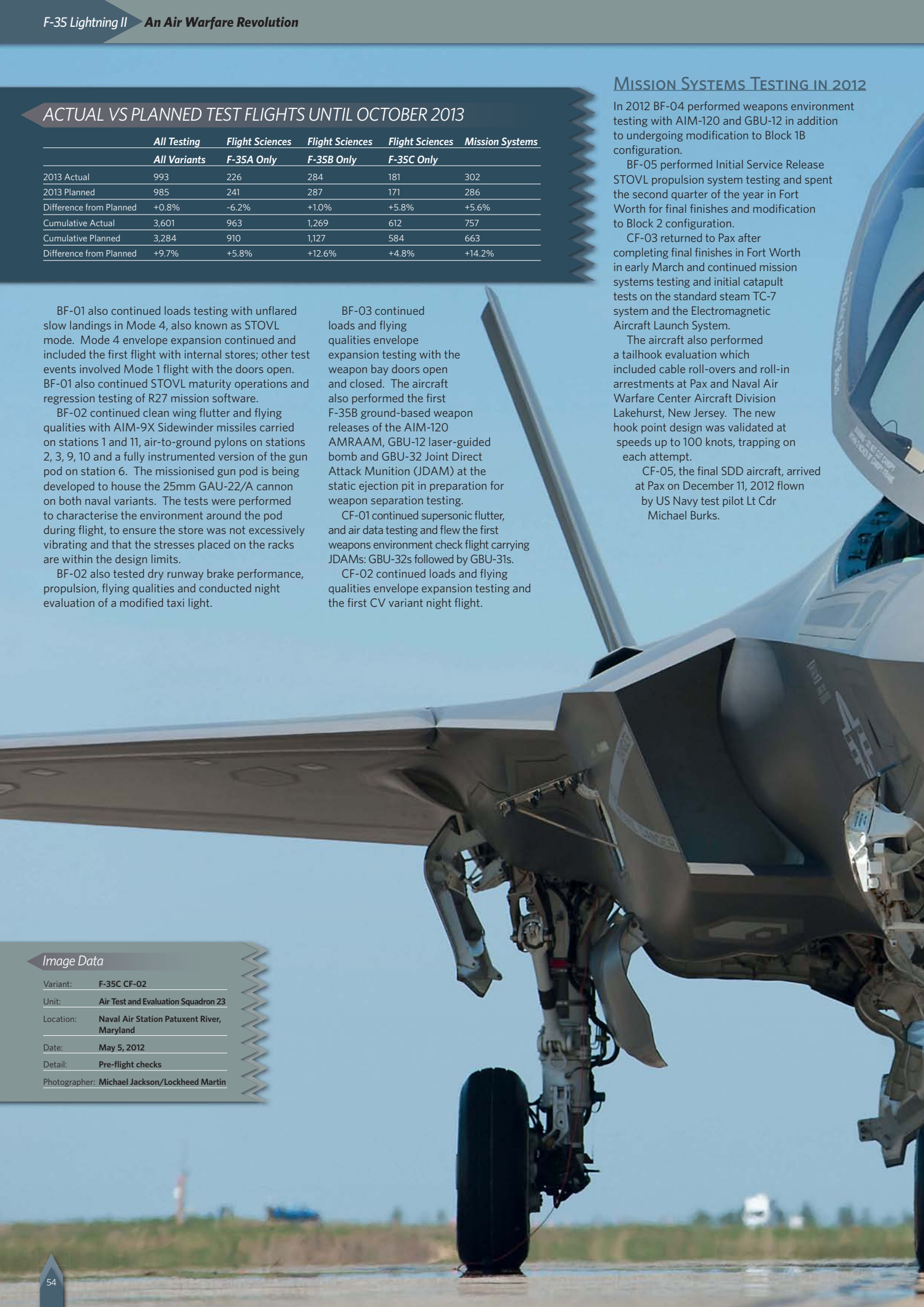


Image Data

Variant:	**F-35C CF-02**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**May 5, 2012**
Detail:	**Pre-flight checks**
Photographer:	**Michael Jackson/Lockheed Martin**



Flight Sciences Testing in 2013

In 2013 BF-01 completed loads testing of the new AAI door configuration and demonstrated positive results that matched predictions for planned STOVL operations for the fleet. The aircraft also continued STOVL envelope expansion test and performed flight qualifications for the second detachment to the USS *Wasp* in August. BF-01 also flew the first STOVL mission with internal stores, including a vertical landing.

BF-02 continued flutter testing with external stores and resumed conventional take-off and landing performance testing. It also performed a series of aerial refuelling tests (day and night) with KC-10A Extenders and KC-135R Stratotankers. The first aerial refuelling with a KC-10 was flown by US Marine Corps test pilot LtCol Matt Kelly in BF-02 on June 19.

BF-03 performed loads testing, flying qualities and weapon separation with various weapon configurations. BF-03 and CF-02 conducted 23 releases of weapons that will be released to the fleet with Block 2B – AIM-120 AMRAAMs, GBU-12s, GBU-31s (F-35C only) and GBU-32s – at the static ejection pit in preparation for airborne weapon separation testing.

CF-01 continued to perform supersonic flutter and air data testing.

CF-02 continued loads and flying qualities envelope expansion testing. The aircraft also performed the first F-35 night flight at Pax and the first airborne weapon separation by an F-35C on October 21. CF-02, flown by Marine Corps test pilot Capt Justin Carlson, released a 500lb GBU-12 mass properties unit from an internal weapons bay over a test range over the Atlantic Ocean.

CF-01 and CF-02 continued flying with internally mounted GBU-32s and GBU-31s and performed the first-ever formation flight between two C-variant aircraft. On January 22 the same two aircraft completed the first dual aerial refuelling by the C-model. The tanker used for the mission was a KC-130 Hercules assigned to Air Test and Evaluation Squadron 20, also based at Pax.

F-35B BF-04, flown by Marine Corps test pilot LtCol Jimi Clift, completed the first night vertical landing at Pax during a test mission on April 2. The test was one of a series conducted to prepare for the second at-sea test period, its objectives being to gather data on the helmet and lighting conditions for night time operations. The first vertical landing undertaken by an operational F-35B took place at Marine Corps Air Station Yuma, Arizona, on March 21.

On May 10, F-35B BF-01 completed the first-ever Vertical Take-off (VTO) – a capability required for repositioning the STOVL variant in situations



Variant: **F-35C CF-01 Unit: Air Test and Evaluation Squadron 23**
Location: **Over the Atlantic Ocean** Date: **January 29, 2013**
Detail: **Aerial-refuelling during the transit to the test track**
Photographer: **Andy Wolfe/Lockheed Martin**

where it cannot perform a short take-off but, with a limited amount of fuel, can execute a VTO to fly a short distance.

The first VTO was followed by the first vertical landing performed by a UK service pilot, Squadron Leader Jim Schofield, Royal Air Force, on May 28, 2013, just over three years since an F-35B landed vertically for the first time.

Mission Systems Testing in 2013

By the second quarter of 2013 all mission systems aircraft assigned to VX-23 were configured to either Block 2A or Block 2B standard. Block 2 software builds added Link 16, Multifunction Advanced Data Link network capabilities and increased functionality to the main sensors – the APG-81 AESA radar, AAQ-37 Electro-Optical Targeting System, AAQ-40 Distributed Aperture System and the ASQ-239 Electronic Warfare system.

BF-04 continued testing the sensor suite with Block 2A software.

BF-05 and CF-03 participated extensively in mission system testing, including Block 2A software maturity evaluation, which provided critical information for the delivery of the first F-35Bs to Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights' based at Marine Corps Air Station Yuma, Arizona – the first operational F-35 squadron (see *First in the World* p154-160). The aircraft also performed electromagnetic environment testing at the Naval Electromagnetic Radiation Facility at Pax.

CF-03 conducted carrier suitability testing at Pax and NAWCAD Lakehurst, defining the scope of the technical challenges discovered with the F-35C landing and arresting gear systems. During this testing, the aircraft performed the first field roll-in arrestment to MK-7 arresting gear. Later in the year, CF-03 conducted more than 40 successful roll-in arrestments to MK-7 and E-28 EMALS arresting gear and performed five operationally representative fly-in arrestments to MK-7 arresting gear.

Deficient Systems

On October 20, 2011 the Commanders of the US Air Force Operational Test and Evaluation Center (AFOTEC), the US Navy Operational Test and Evaluation Force (OPTEVFOR) and the Royal Air Force Air Warfare Centre (AWC) released their Operational Assessment OT-IIE report of the F-35 programme's progress towards readiness for Initial Operational Test and Evaluation (IOT&E).

Based on the list of topics reviewed, the team identified technical issues that indicated a lack of adequate stability in the basic design. The technical team identified no fundamental design risks sufficient to preclude further production; and listed areas where major consequence issues had been identified, but root cause, corrective action or fix were effectively still in development.

The report gave key technical findings about the Helmet-Mounted Display System (HMDS), Fuel Dump Subsystems, Integrated Power Package (IPP) and the Arresting Hook System (AHS).

Discussing the procedures in place for addressing design problems, Capt Etz told *AIR International:* "Our aircraft have those sub-systems in them. Some have been performing to plan, some have not. We [VX-23] are involved in every technical area and a broader NAVAIR team is involved at all levels in terms of identifying resolution paths for all known technical deficiencies. The team is engaged at the grass roots level with our Lockheed Martin counterparts to ensure we draft and resource a solution to each deficiency discovered.

"In some areas it's more rapid than others. Some areas have a lead time of many months before we get the hardware or software upgrade that should provide

Image Data

Variant:	**F-35B BF-02**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**February 22, 2011**
Detail:	**A short take-off from runway 06**
Photographer:	**Andy Wolfe/Lockheed Martin**

a resolution to deficiencies or some increase in capacity," he said.

Fuel Dump Subsystems

The OT-IIE report gave the following details about the Fuel Dump Subsystems: "The current fuel dump design has shown to be ineffective in dumping fuel clear of the aircraft surfaces, resulting in pooling and wetting aircraft surfaces with the potential risk of fire due to integration into the Integrated Power Package exhaust. Fuel dump test results on CF-01 and BF-04 were non-compliant with airworthiness certification criteria and JCS requirements due to the aircraft landing with wet surfaces and fuel spillage on deck from fuel accumulation in the flaperon. This situation poses a fire risk, more critical to STOVL given the larger number of hot surfaces and exhaust flow, as fuel on the deck could be ignited during aircraft taxi after landing. This also presents a maintenance burden for inspection, panel removal, and LO restoration following dump event.

"Due to these issues, the Air Force and Navy consider the present fuel dumping capability unacceptable. Two STOVL fuel dump design modifications were attempted unsuccessfully, resulting in an aircraft operating limitation (AOL) preventing fuel dumping except in an emergency situation or in pursuit of specific flight test points. Operationally, this could lead to the need for stores jettison as an alternative to adjust landing weight. The Air Force has prohibited fuel dump on CTOL.

"Further development of a long-term solution is required; however, the path forward is unknown at this time. Repositioning of the fuel dump valve would present a significant concurrency issue. Any additional structure, such as dump mast, would potentially impact LO properties for all variants.

"Conclusion: Major Concurrency Risk – This is a significant current safety hazard and requires an aircraft hardware change."



Variant: **F-35Cs CF-01 and CF-02** Unit: **Air Test and Evaluation Squadron 23** Location: **Over the Atlantic Ocean** Date: **January 18, 2013** Detail: **First F-35C dual aerial-refuelling on a KC-130 tanker.** Photographer: **Andy Wolfe/Lockheed Martin**

Landing weight is a big factor for approach speeds to L-class Landing Helicopter Dock amphibious assault ships and CVN-class super carriers, so the F-35B and F-35C variants need to be able to offload fuel. Each variant has a fuel dump system first evaluated on the F-35B while last year VX-23 undertook the first fuel dump evaluation with the F-35C.

Capt Etz described the work undertaken to resolve the fuel dump issues: "We are actually testing changes to the STOVL system here at Pax which may have correlation to F-35C. On the F-35B the IPP exhaust is below the aircraft so, if any fuel migrates out of the dump exhaust to elsewhere on the airframe, that can be a concern. The minor changes in test here at Pax have allayed those fears although we are still pursuing a technical resolution."

In mid-2013, BF-04 received additional modifications - including a reshaped dump nozzle and redesigned flap blade seals - in order to increase fuel separation from aircraft surfaces and minimize fuel dripping on deck. BF-04 was flown through early 2014 to complete 15 fuel dump test points, in both CTOL and STOVL modes, some of which were conducted with external pylons to assess the risk of weapon wetting. Results have shown that these modifications have eliminated post-flight fuel dripping and fuel migration to hot areas and have significantly reduced fuel retained in the flap cover during the dump process. The results have led to the approval of identical design changes for production F-35B aircraft, and the programme is on-track to authorise the regular use of fuel dump in the F-35B fleet by early 2015.

In late 2013, CF-01 received similar modifications and its fuel dump performance has improved similar to BF-04. Aircraft CF-01 also completed a fuel dump test point while carrying external GBU-12s to confirm that the weapons are not wetted by the dumped fuel.

Aircraft CF-03 and CF-05 will be also be modified in time for Developmental Test Phase One, the first sea trial of the F-35C scheduled for later this year.

Integrated Power Package

The OT-IIE report also provided details about deficiencies with the IPP: "The IPP is a reliability



Variant: **F-35Cs CF-01 and CF-02** Unit: **Air Test and Evaluation Squadron 23** Location: **Over the Atlantic Ocean** Date: **April 18, 2012** Detail: **First F-35C-model formation flight** Photographer: **Andy Wolfe/Lockheed Martin**



Variant: **F-35C CF-05** Unit: **Air Test and Evaluation Squadron 23** Location: **Over the Atlantic Ocean** Date: **November 18, 2013** Detail: **Intentional departure from flight testing** Photographer: **Dane Wiedmann/Lockheed Martin**

and maintainability concern. The design is novel, incorporating the engine starter, power generator and environmental control system into a single unit. Loss of the IPP results in the loss of primary avionics capability, loss of back-up electrical generator power and loss of primary oxygen supply and cabin pressurisation. Designed as a high-reliability, 2,200-flight-hour subsystem, there have been 11 removal and replacement instances at Air Force Flight Test Center, Edwards Air Force Base, one at Fort Worth and four at NAS Patuxent River, to date. Of these removals, eight occurred in a 12-week period, which lowered aircraft electric power system reliability to less than 13 Mean Flight Hours Between Maintenance Events (as of July 2011).

"A recent catastrophic failure was due to a valve-control pin failure, during which liberated parts were not contained and punctured an adjacent fuel tank. This resulted in the grounding of all aircraft for two weeks until a change to valve control was implemented. The approach to resolving the issue of uncontained parts is yet to be determined.

"The IPP is also a test execution placing risk because the IPP remove-and-replace effort (requiring approximately two days with 24-hour coverage) has been characterised by testers as more complex and manpower-intensive than that for engine removal. The low demonstrated reliability coupled with high maintenance times were key factors in the Operational Assessment finding of high risk to meeting suitability requirements. Other than long-term software changes planned in the future, there is no defined way ahead and thus the IPP remains a major concurrency risk.

"Conclusion: IPP is a Major Concurrency Risk – IPP reliability and maintainability requires significant maturing."

Etz told *AIR International*: "We use the IPP much like the helmet on every flight and we don't do anything without it. We have had isolated situations where it failed. We now use different post-maintenance procedures in terms of how we prime the fuel. That has led to an increase in aircraft availability."

He cited another reason why test flights were cancelled because of the IPP: "The system was misdiagnosing faults and we didn't fully understand that diagnostic mode. If the aircraft pops up an identified fault on start up, is it a real fault or not? The maintainers are learning the system and helping to make corresponding changes in the aircraft's reporting codes so we are not shooting ourselves in the foot and missing a sortie when we don't need to."

Arresting Hook System

One of the tests undertaken by VX-23 with the F-35C over the past 24 months involved the Arresting Hook System (AHS). "We completed a lot of work to both characterise the issues we had with the [original] tailhook and to analyse the changes made to the system," said Etz.

During the initial roll-in arrestment testing at NAWCAD Lakehurst, New Jersey, the tailhook failed to engage with the MK-7 arresting gear in eight attempts. Analysis identified three key design issues: the aircraft's geometry, the design of the tailhook point and the performance of the tailhook's hold-down damper (for more details see *Shake, Rattle and Roll* p74-79).

Before the new hook was fitted, testing continued using the original version to characterise performance and determine the loads being induced on the airframe during arrestment. In the summer of 2012 the VX-23 F-35 test team successfully engaged the MK-7 arresting wire on five out of eight attempts, a good demonstration of progress in the arrestment capability of the F-35C.

Design modifications were made to the tailhook point and its hold-down damper mechanism and, according to Capt Etz, achieved a 100% pick-up rate during the latest test period which started in October 2013.

The DOT&E FY2013 AR stated: "The AHS remains an integration risk as the development schedule leaves no time for new discoveries. Other risks



Variant: **F-35C CF-01** Unit: **Air Test and Evaluation Squadron 23** Location: **Naval Air Station Patuxent River, Maryland** Date: **October 20, 2011** Detail: **Aircraft CF-01 on take off from runway 32 powered by 43,000lbs of thrust from the Pratt & Whitney F135 turbofan engine** Photographer: **Paul Ridgway**



Variant: **F-35B BF-01** Unit: **Air Test and Evaluation Squadron 23**
Location: **Over the Atlantic Ocean** Date: **December 12, 2013**
Detail: **Mode 4 external stores testing with gun pod and a single AIM-9 Sidewinder missile** Photographer: **Layne Laughter/Lockheed Martin**

include the potential for gouging of the flight deck after a missed cable engagement (due to an increase in weight of 139lb) and the potential for sparking from the tailhook across the flight deck because of the increased weight and sharper geometry of the redesigned hook."

Recent Test Events

LtCol Moran highlighted other test events undertaken by VX-23 in the last 18 months. "We completed night IMC [instrument meteorological conditions] flight clearance for the fleet [in June 2013] so they can fly in adverse weather conditions."

That work involved testing the production version of Block 2A software, designated 2AS3, which was designed to provide enhanced training capabilities to the LRIP 4 and LRIP 5 production aircraft assigned to the 33rd Fighter Wing at Eglin Air Force Base, Florida, and to the first operational units at Yuma and Nellis Air Force Base, Nevada.

According to the DOT&E FY2013 AR: "The test teams at Edwards and Patuxent River determined the initial version of Block 2AS3 to be deficient in providing the necessary capabilities for unmonitored flight operations under night and IMC. In order to finalise Block 2A capability so that it could eventually be certified in production aircraft for flight at night and in IMC, the programme made adjustments to plans for the following increment, Block 2B, to accommodate the need for another, final version of Block 2A software, designated 2AS3.1. The test centres completed testing of Block 2AS3.1 in June 2013."

Certification to allow F-35A and F-35B production aircraft to fly at night and in IMC conditions was released in December 2013.

On December 6-7, 2013, Royal Navy and Royal Air Force engineers from the ITF tested a prototype remote-controlled trolley known as an Electric Shipboard Handler (Aircraft) by moving F-35B BF-05 around the Pax flight line. Designed to move the Lighting II around the hangar deck of HMS Queen Elizabeth-class carriers, this was the first time it had been used.

Test pilots Peter Wilson and Dan Levin flew F-35Bs BF-01 and BF-05 in Mode 4, also known as STOVL mode, which involves engagement of the Lift Fan and the engine nozzle rotated downward. The February 19 test was designed to measure the effects each aircraft might have on one another while in Mode 4 flight to ensure safety when flying in formation during operational scenarios.

Another major test programme currently under way at VX-23 is high angle-of-attack (AoA) envelope expansion. Initial envelope expansion and intentional departure testing, which required the use of a spin recovery chute, was conducted with F-35B BF-02 and F-35Cs CF-01 and CF-05. The ITF then conducted initial low-speed departure resistance testing, high AoA loads testing, and high AoA buffet testing with F-35B BF-03 and F-35C CF-02 to prove the recovery characteristics of each variant from uncontrolled flight.

"The 'B was not expected to be much different from the 'A because the wings are a similar shape, the tails a similar shape, but the mass properties distribution differs because the propulsion systems are different, and each variant's fuel load is carried differently. Fundamentally the aerodynamic shape of the 'B and 'A is broadly similar, whereas the C has a different wing and a massive tail. While the B is turning out to be very nice, the C is the most remarkable, it's absolutely awesome at 50 alpha and very controllable," said Peter Wilson STOVL lead with the Pax F-35 ITF.

Testing will continue during 2014. Jake Piercy explained: "The first part of the programme repeated some of the testing at lower angles-of-attack without a spin chute. This was required to characterise and hopefully eliminate the possibility of the spin chute causing a difference in handling qualities of the aircraft." Both aircraft will have the chute removed for the remaining test points.

VX-23 is currently conducting weapon integration testing focused on Block 2B weapons. F-35Bs have successfully jettisoned AIM-120s and released 1,000lb GBU-32 JDAMs and GBU-12 laser-guided bombs from the weapon bays. The first AIM-120 launch from an F-35B was conducted at Edwards Air Force Base, California on June 4.

F-35Cs have also jettisoned AIM-120s and released 2,000lb GBU-31 JDAMs and GBU-12s. The first AIM-120 launch is expected later this year. "In addition we have started loading and carrying AIM-9X and GBU-12s on the external pylons for flying qualities and loads evaluation, but we have not released any weapon from



Variant: **F-35C CF-02** Unit: **Air Test and Evaluation Squadron 23**
Location: **Naval Air Warfare Center Aircraft Division Lakehurst, New Jersey** Date: **June 30, 2011** Detail: **Test run during jet blast deflector evaluation** Photographer: **Andy Wolfe/Lockheed Martin**



Variant: **F-35B BF-04** Unit: **Air Test and Evaluation Squadron 23**
Location: **Naval Air Station Patuxent River, Maryland**
Date: **December 13, 2012** Detail: **Hover position indicator testing**
Photographer: **Michael Jackson/Lockheed Martin**



Image Data

Variant:	**F-35C CF-05**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Over the Atlantic Ocean**
Date:	**September 27, 2013**
Detail:	**CF-05 en route to the inshore test area for high angle of attack testing**
Photographer:	**Dane Wiedmann/Lockheed Martin**

an external pylon yet," said Piercy.

VX-23 also tested internal and external weapon load asymmetries on the F-35B for the first time. This involved carrying a 1,000lb bomb in the internal weapon bay on one side only and similarly, but in a separate test, with just one missile carried externally. The objective of both tests was to determine if the aircraft could be brought to the hover carrying an asymmetric load. According to BAE Systems test pilot Peter Wilson, STOVL lead with the Pax F-35 ITF: "We can. The pilot doesn't even notice it."

The test team also completed vertical landings loaded with external stores (pylons), AIM-9 missiles on stations 1 and 11 and the gun pod on station 6 for the first time in 2013.

The first vertical landings with weapons carried externally will follow this year.

And the most recent event is wet runway testing and cross-wind envelope expansion using F-35B BF-04. The aircraft left Pax on April 10 for an expected two-month stay at Edwards where the tests will be conducted. Edwards was chosen because it gets regular cross-winds of 25 to 30 knots which are required to complete that part of the F-35B's envelope. The resident 412th Test Wing and 461st Flight Test Squadron have personnel experienced in wet runway testing having already completed a series for the F-35A.

Brits at Pax

The Pax F-35 ITF has a UK element permanently assigned under an agreement between the UK and US Governments. The reasons for maintaining a British team in the United States are manifold – one is to enable operational sovereignty, owning and operating F-35s without being completely reliant upon the US. "That's why our posts were evolved," said Commander Bow Wheaton, Royal Navy. "We have de-risked, to a huge extent, the operational sovereignty concerns because we are able to reassure people [in the UK MoD] that we are seeing what the jet does what its capabilities are. We are also involved in the troubleshooting and rectification of issues during development test.

"As a result, in terms of maintaining and flying our aircraft – initially in a pooling agreement with the Marine Corps but ultimately when we stand up our first squadron – we will have experience of understanding and using our jets autonomously."

"It's like bringing Boscombe Down to the United States as opposed to taking JSF to Boscombe Down," said Lt Cdr Robin Trewinnard-Boyle, Royal Navy, also known as 'RTB'.

The UK's first three F-35Bs (serial numbers ZM135, ZM136 and ZM137) are owned by No.1 Group but, under agreement, are pooled with the US Marine Corps for training at Eglin Air Force Base. From June 2014 the aircraft will move to Marine Corps Air Station Beaufort in South Carolina.

'RTB' explained: "We are heavily involved with the carrier suitability team at Pax to gain experience from deploying aboard USS *Wasp* during both at-sea deployments. The main reports [on the Wasp trials] about lessons learned were written by UK personnel and distributed to the US Navy, US Marine Corps, the UK and Italian MoDs. By the time the Royal Navy conducts the first-in-class sea trials the Marine Corps will probably have completed its first operational cruise on an LHD so we will have a wealth of experience and knowledge from both aircrew and maintainers."

Cdr Wheaton added: "One of our main functions is to generate suitably qualified and experienced people to go to operational test [at Edwards Air Force Base], then to first-of-class flight trials and, beyond that, stand up our first squadrons. In addition, the fleet has posted people to various US carriers so that we can sustain our experience at sea.

"We would have had a massive learning curve if we [the UK] had have stuck with the CV variant of the aircraft because we stopped flying Buccaneers and Phantoms off the *Ark Royal* in 1978. Rob's previous job was on the current *Ark Royal* with Harriers and there are plenty of measures, including having personnel at this ITF, to ensure we retain the suitable qualifications and experience through to taking our first ship to sea with F-35s."

'RTB' added: "Before we do first-of-class flight trials, Royal Navy flight deck operators and aircraft handlers will need to come to the US and spend some time working with the aircraft to get familiar with it because this is a different beast to the Harrier. The downwash is different and it's bigger."

British Pilot

Royal Air Force Sqn Ldr Jim Schofield served with the Pax F-35 ITF as pilot between March 2011 and March 2013, conducting and planning risk analysis, execution, debriefing and reporting on F-35 test flights for the 'B and 'C variants. The role took up about 80% of his time at Pax – the remainder was spent on compiling reports, risk assessments and safety procedures for No.1 Group, Fleet HQ, the Air Warfare Centre and the relevant engineering authorities, each of which continues to establish UK procedures for training, operating and maintenance.

Prior to his tour at Pax, Sqn Ldr Schofield served at No.1 Group at RAF High Wycombe developing UK conops (concept of operations) documents outlining how the aircraft will operate from the bays of the UK's Queen Elizabeth-class carriers. He undertook the task using his background in F-35 tactical simulation to assess the aircraft to see if it provides what the US Marine Corps requires from Block 2B configuration and what the UK needs from Block 3. Most of that work was conducted in the UK.

Schofield told *AIR International*: "We will conduct pre-operational test with Block 2B then upgrade the [UK] jets to Block 3 and conduct a full operational test programme."

Variant: **F-35B BF-02** Unit: **Air Test and Evaluation Squadron 23** Location: **Naval Air Station Patuxent River, Maryland** Date: **March 25, 2014**
Detail: **Spin recovery chute used for high angle-of-attack test flights** Photographer: **Paul Ridgway**



British Maintainer

Royal Air Force Chief Technician David Briggs joined the F-35 programme at Pax in November 2008. His operational experience was gained with the Tornado GR4 Force, which still provides the backbone of the RAF's strike capability and remains on operational duty at Kandahar Air Base in Afghanistan: the TGRF's 24th consecutive year of operational deployment. Chief Briggs arrived at Pax with plenty of operational experience.

He spent his early days there helping to set-up the F-35 ITF's infrastructure, regulations, policies and procedures – at a time before any aircraft had been delivered to the Maryland base. He was also seconded to Lockheed Martin's Fort Worth plant to gain experience of the aircraft by working on the flight line and in final assembly. This prepared Briggs and his colleagues from Lockheed and the US and UK military for the arrival of F-35B BF-01.

"When BF-01 arrived I worked in the Defence Contract Management Agency (DCMA)," he said. "Part of that job involved establishing requirements for ground and flight operations, releases for flight clearances, checking all the work packages and ensuring that everything was completed in accordance with the documentation as quoted by Lockheed. That information was eventually fed up to the GFRs [Government Flight Representatives] who release aircraft for flight."

After a six-month stint with the DCMA, Briggs then worked on the shop floor, training to become a crew chief – initially on aircraft BF-02. He then qualified as a rolling crew chief and worked on whatever jet required maintenance. BF-02 was then assigned to him and he took it through the modifications required for the first ship trials aboard the USS *Wasp* and deployed, with two other UK maintainers, for the three-week at-sea period.

He then qualified as a FSR (Field Service Rep) and worked on the shop floor at Pax to further increase his knowledge of the aircraft. Briggs explained that all UK personnel work to an 80:20 percent time split: "Eighty percent of my time is spent troubleshooting the aircraft and implementing fixes. As an FSR, I report directly to Fort Worth on the real-time task. If a fault pops up that has not been seen before, the team and I conduct investigatory work and feed the data to the engineers at Pax River and Fort Worth. The remaining time is spent on programme specific tasking along with writing technical reports to assist the UK F-35 IPT [Integrated Project Team] with developing policy and procedures for the UK's first fifth-generation aircraft."

Maintaining an F-35B

Discussing maintenance of the F-35B Chief Tech Briggs told *AIR International*: "There is still quite a bit of wrench-turning – certainly on the F-35B which is the most complex of the three variants, simply because of all the doors and the powerplant. And there's a lot of rigging and processes required to get in with a wrench and make manual adjustments, but no more than a legacy aircraft.

"The flip side is there's a lot less wrench-turning in other processes such as flight controls. I can rig every single flight control of the F-35 on the ramp in about ten minutes. It involves plugging in a PMD [Portable Maintenance Device] and driving an actuator to a set position, verifying it's in the right place, hitting 'store' and I've rigged the flight controls. That's a laborious job on legacy aircraft. On this it's a

huge benefit. The level of integration and interaction between the aircraft and the maintainer is huge. More than I've ever seen in my 27 years in the Royal Air Force.

"The maintainer is given a job and all the required data on his PMD so he can reference all the material. It tells him how to do the job and which tools and parts he needs. He can sign for the work at the aircraft.

"The PMD plugs into the aircraft to allow BITs [Built In Tests] to be run, doors and valves activated as required. The PMD gives us a much deeper insight to the aircraft than I've ever seen [on an aircraft type] before, hence the reason we don't have a lot of test equipment. You plug your computer in, run whatever BIT that's required and conduct diagnosis and testing."

He described how the F-35 differs from a legacy aircraft, which is powered up to run tests: "We break the aircraft down to sub-components which can be powered up individually. For example, we could have an engine out, a lift-fan out, with various levels of disturbance, and still confidently power up the aircraft in a sub-level and run tests on it. Its versatility for maintenance is very good."

The maintainer connects the PMD to the aircraft using the Maintenance Interface Panel (MIP), which is the BIT interface, as Chief Tech Briggs described: "We can use the MIP and the IPP to pretty much power everything we need using the PMD. We can conduct all the test functions and operate all the doors through that. We don't need to get in the cockpit of this aircraft except for communication checks, ILS alignment or landing gear swings. Generally the maintainers remain outside the aircraft and connected to it all the time."

He confirmed that the F-35Bs assigned to the ITF at Pax can be turned between flights fairly quick with a minimal amount of manpower. "We can do quick turns in probably an hour-and-a-half. Most of the time is spent getting everything documented using the ALIS 0.15, an off-the-shelf version only used by the ITF. The fleet version should be more interactive and a lot quicker."

No ground support equipment should be required to operate the F-35B in the field, an essential capability for the US Marine Corps concept of operations. The aircraft can be started using the Integrated Power Pack – the F-35's equivalent of an Auxiliary Power Unit – which provides cooling air and 270-volt electrical power to the ground maintenance pump which in turn provides hydraulic power.

The F-35B has 14 different doors, actuators to operate all of them and a multi-component powerplant, all of which point to a challenging maintenance requirement for fleet squadrons operating onboard ships and in the field. What's the opinion of the maintaining those systems at this stage?

Chief Tech Briggs qualified his reply, saying: "It would be quite harsh to judge based on our test experience because our work is all about expanding the envelope and loads. One day we might hit a load of 100% and re-rig doors. We do a lot of that in developmental test because the component has failed a flight parameter so we have to do additional work that would not be required in the fleet. But generally the 'B is more labour-intensive than a 'C because it's got a lot more doors and a lot more systems."

Lt Cdr Trewinnard-Boyle highlighted an advantage of the additional work required in developmental test: "Every issue gives an opportunity for our maintainers to find out more about how the system works, how to complete repairs and how quick or otherwise a repair can be. When we see that in the active fleet we've already got experience – that's why keeping the guys performing the work to gain that knowledge base is so important all the way through, which is a big part of de-risking the aircraft's service introduction."

Block 2B

As described above, the F-35 is developed and fielded in incremental blocks: Block 2B will provide initial, limited combat capability.

The DOT&E FY2013 AR says: "The initial Block 2B software increment began flight testing in February 2013. Though four months later than the 2012 integrated master schedule, this timing was in accordance with the expectations set by the programme's new Block Review Board process initiated in late 2012. The initial Block 2B increment had no new capability and was not mature enough for verification.

"In October 2013, a new increment [sub-set] of Block 2B, intended to provide a significant increase in verifiable capability, including many fixes to previously identified deficiencies, began flight testing. Initial results with the new increment of Block 2B software indicate deficiencies still existed in fusion, radar, electronic warfare, navigation, Electro-Optical Targeting System, Distributed Aperture System, Helmet-Mounted Display System and datalink. These deficiencies block the ability of the test team to complete baseline Block 2B test points, including weapons integration. The programme's plan is to gradually increase maturity of the software and reduce these obstacles to test progress over three more increments of software in 2014."



Image Data

Variant:	**F-35B BF-02**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**June 14, 2012**
Detail:	**Asymmetric external stores testing with gun pod and a single AIM-9 Sidewinder missile**
Photographer:	**Andy Wolfe/Lockheed Martin**

The report also states: "Three factors create a significant challenge for completing developmental testing of Block 2B mission systems as planned before the end of October 2014: completing tests of prior blocks of mission systems capability, managing growth in testing and constraints on test resources."

Jake Piercy explained: "Most of the software testing we do at Pax looks at the vehicle systems." One is the HMDS which has been plagued by several technical issues, as Piercy described: "A lot of the issues with the helmet have been associated with high 'g' so we use a loads aircraft to test the display on the helmet during wind-up turns and buffet testing."

Testing details of the HMDS are also given in the report: "The programme dedicated 42 flights to investigating and addressing deficiencies in the HMDS. Seven aircraft from all three variants flew test missions from October 2012 through May 2013 to investigate jitter in the helmet display, night vision camera acuity, latency in the DAS projection and light leakage onto the helmet display under low-light conditions. Although some progress has been achieved, results of these tests have been mixed.

"Filters for reducing the effects of jitter have been helpful, but have introduced instability, or 'swimming', of the projected symbology.

"Night vision acuity was assessed as not acceptable with the current night vision camera, but may be improved with a new camera planned for inclusion in the next version of the helmet, referred to as the Gen III helmet.

"Latency with the DAS projection has improved from earlier versions of software, but has not yet been tested in operationally representative scenarios.

"Light leakage onto the helmet display may be addressed with fine-tuning adjustments of the symbology brightness – a process pilots will have to accomplish as ambient and background levels of light change, adding to their workload."

Piercy outlined other software testing which involves flying qualities and loads: "If we find an area of the envelope that creates a high load on a surface, we might have to temporarily stop that line of testing. It can only restart once the software is reprogrammed to get the required motion from the aircraft using a different surface. We've also looked at how the air data probes interpret the information. A couple of changes to the software have been necessary to correct the probes' source error so they provide the pilot with accurate airspeed, altitude and angle-of-attack data."

LtCol Moran said the ITF hopes to complete testing of Block 2B this year [October is the official date though the programme has stated it might be delayed until May 2015] to gain flight clearance for the US Marine Corps to declare IOC next summer.

But will the F-35B make IOC by then?

"In some ways it's already made it," replied Moran. "The fact that we have aircraft on the ramp with VMFA-121 at Yuma and that we are producing pilots out of the fleet replacement squadron at Eglin is a testament to how far the programme has come within the challenging environment of concurrency.

"When we look down range to the Block 2B IOC, and what that means symbolically, programmatically and in terms of performance, we have a very healthy and mature system. When issues arise we identify and address them with the full force of the engineering resources of the contractors and the government. We have a test schedule that we march to and it starts from the bottom up. Every test point builds into capability, and we've proved to be very capable at executing our mission and getting the test points done. So I am optimistic."

Capt Etz commended the team of 900-plus professionals working on the F-35 at Pax: "We often focus on the aircraft, but in reality it's the team of people that fuel this family of fighters. We have a lot of folks who have dedicated a big part of their lives to make this happen. I don't think you will find an organisation anywhere else in the world that has as many people working together to make it all happen."

The government component of the SDD phase is scheduled to finish with the final Block 3 configuration in 2016 and Capt Etz is confident about the test programme going forward: "We are in good shape: 2015 and 2016 are big years for the programme and we are well positioned to meet the needs of the flight test programme which directly translates to the needs of the warfighter." ***Mark Ayton***



Jumping JackFlash

On October 3, 2011, F-35B BF-02 landed on the flight deck of USS *Wasp* (LHD-1) flown by LtCol Fred Schenk of the US Marine Corps. The first time an F-35B had landed on a ship, the historic event was the start of Developmental Test Phase One at sea, commonly referred to as DT I.

Aircraft BF-02 was joined onboard by F-35B BF-04 and a test team of 240 people tasked to develop short take-offs and vertical landings in the initial flight envelope for deck operations, perform initial ship compatibility assessments and collect environmental data from instrumentation located around the ship. The group included a 32-strong team of engineers from Naval Sea Systems Command (NAVSEA) who collected data on the effects of the F-35B on flight deck and superstructure components.

Ship and Aircraft Modifications

Detailed planning of DT I started two-and-a-half years earlier and mostly involved modifications required to the ship: test control rooms and instrumentation to provide the data required for the ship's compatibility evaluation.

The US Marine Corps' Maj Richard Rusnok, Air Test and Evaluation Squadron 23's project lead, explained the instrumentation: "Microphones for acoustics, temperature stickers and thermal couples



for temperature, deck deflection instrumentation built-in underneath the flight deck, shielding of equipment like fuel stations that were thought to be at risk, temperature pressure sensors for off-gassing effects and general environmental health monitoring equipment.

"Modifications were also made to the ship to ensure proper clearance between the foul line [the safe park line] and the wingtips of the aircraft. Because the F-35 is a bigger aeroplane than the Harrier we moved the tram line, the large centre yellow stripe on the ship, to the port side by about three feet to create the proper wingtip clearance. This also required some of the lighting in the deck to be moved as well."

NAVSEA environmental engineers were concerned about the outwash from the F-35's more powerful engine so teams collected data from vertical landings and STOVL ops undertaken at Pax. It was used to model vertical landings for both quantitative and qualitative assessments of outwash and acoustics to determine which areas of the flight deck would be safe for the flight deck crew.

The aircraft were also modified to make them compatible with shipboard ops. BF-02 in particular had to be instrumented properly to gather loads and propulsion data to clear out envelopes in real time so that BF-04 could continue throughout the envelope expansion process. "That was about a year-long process to get all the modifications and equipment and paperwork in line so that BF-02 and BF-04 were cleared and ready to go to sea," said Rusnok.

BF-02, a highly instrumented flight sciences aircraft, led the envelope extension process.

BF-04, a mission systems aircraft, required some hardware and specific instrumentation for the shipboard ops.

The DT I test plan was released as a 150-page document, one of the most complex ever written for any aircraft and requiring countless meetings over an 18-month period to finalise. Maj Rusnok said: "That's a real tribute to the folks with the knowledge base and the wherewithal to write that kind of stuff."

Pilots, Training and Embarkation

Four pilots were selected for DT I: Peter Wilson of BAE Systems and three US Marine Corps test pilots, LtCol Schenk, LtCol Matthew Kelly and Maj Richard Rusnok. Each required ten vertical landings in their pocket as a test plan prerequisite prior to starting workups for the ship. Peter Wilson, the STOVL-lead pilot with the F-35 ITF at Pax, the test conductors and test directors played a pivotal role in the training to get the pilots ready to go. The process involved each pilot undertaking multiple simulator events to mirror the daily morning and afternoon flight periods available on the ship – which lasted for up to five hours and took place between May and October.

Naval Air Systems Command (NAVAIR) simulators at Pax were developed for the test mission and can be linked to the test control rooms on the base. Landing Signal Officers (LSOs) and carrier suitability engineers took part in the simulator training and provided the calls usually made by controllers in the bridge of the ship, primary flight control and the tower. "We started with just the basic mechanics and worked our way into specific test points, emergency procedures and eventually to periods involving every conceivable type of test. You name it, we basically simulated it," said Maj Rusnok.

The next training requirement was Field Carrier Landing Practice (FCLP) at Pax for which a deck painted to look like a ship with instrumentation was set up in the middle of the airfield and equipped with a landing aid used on LHDs.

FCLPs were flown with the support of sailors assigned to Pax with prior LHD experience. Two weeks before embarkation, the entire Wasp flightdeck crew came to Pax for academic training. "We had the fire fighters learning how to rescue a pilot out of an F-35 – because there are so many unique aspects about the jet – and the full deck crew with the air boss and the mini boss running our flight period on the airfield," said Rusnok.

On the afternoon of October 3, lead government STOVL pilot LtCol Schenk took off from Pax River



Image Data

Variant:	**F-35B BF-01**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**USS *Wasp* (LHD 1)**
Date:	**August 19, 2013**
Detail:	**Aircraft BF-01 departs the deck approaching the zero line**
Photographer:	**Todd McQueen/ Lockheed Martin**



Variant: **F-35B BF-01** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 19, 2013** Detail: **BF-01 performs STOVL operations** Photographer: **Todd McQueen/Lockheed Martin**

in BF-02, flew the short distance to the USS *Wasp* under way off the coast of Wallops Island, Virginia, flew a couple of passes alongside the ship and then executed a vertical landing – the first aboard an LHD-class ship – to 'spot seven'.

He also made the first launch the next morning, and completed a further three take-offs and landings in the first flight period. Maj Rusnok flew in the second period. Each pilot completed a nominal CQ qualification period inside the envelope before venturing into more interesting pieces of the envelope.

"We didn't learn anything too crazy. We were pleasantly surprised at what we saw – there was no smoking gun, we didn't have any near misses and the deck crew was happy with what they were doing," said Rusnok.

The test events were undertaken methodically, and not at war ops high tempo, to ensure procedures were conducted correctly and that nothing broke.

Spray Coming onto the Ship

All of the initial missions flown from the *Wasp* during DT I were in the daytime and involved the jets recovering to the ship to a 'case one' pattern: coming into the break over the top of the ship, turning downwind, and then approaching the ship from approximately one mile aft of the stern.

"We generally come out of a final approach turn somewhere between 375 and 400 feet above the water for a three-degree glide slope to decelerate abeam the ship, usually about a wingspan's worth off the ship," said Rusnok. "As we get down and ready to cross the deck we do so at 90 or 45-degrees depending on how our closure is on our control and what the LSO is clearing us to do. He's really running the pattern.

"At that point we're somewhere in the vicinity of 110 to 120 feet above the water, and that's when you start to see some of the wash coming up – but from the pilot's perspective you don't even know it's there. The only time we [the pilots] saw any spray was during tailwind test points, at the edges of envelope. There were no adverse handling characteristics caused by the spray; you just see it because it's getting blown back towards you as expected.

"There was concern that spray was a potentially big issue. Because we have our closure under control we can keep the aeroplane moving right across the deck, that's really no issue, but if time is spent dwelling at that position there's time for a mini tornado to develop – and we see that ashore with dust as well. At sea, generally we didn't even know it was there and it wasn't affecting the guys on the flight deck or the tower, so it was a non-event in that respect."

Variant: **F-35B BF-05** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 17, 2013** Detail: **BF-05 conducts a vertical landing** Photographer: **Andy Wolfe/Lockheed Martin**



Aircraft Handling Around the Ship

Maj Rusnok described flying the F-35B around the ship: "The aeroplane in all its basic flying qualities, especially in STOVL mode, is kind of magical, it really is. You sit at 150 feet in a hover and it's like sitting in this chair except that you're elevated. The aeroplane is incredibly stable. Hypothetically, you could put a drink on the dashboard and it's not going to spill.

"If you watch it from the outside, you'll see the control effectors actually moving very rapidly and making all kinds of corrections – I'm not. They're not making big swings, but making minute movements, keeping the aeroplane in the rock-steady hover that we experience in flight; and we saw that at sea in

just the same way albeit with some forward speed to continue to fly formation with the ship as it moves through the water."

Taking an aircraft to the ship presents concerns: the salt environment, the potential for disruptive interaction between the ship and the aircraft caused by the burble (the unusual air flow around the ship), the compatibility of the avionics with the ship, and the basic vehicle interface and displays – are there unknowns that have not been thought about?

"We never saw any of that at sea," said Rusnok. "Was everything perfect? Absolutely not, that's why we do developmental testing. But do I feel comfortable with a properly trained F-35 pilot, who's not a test pilot, taking an aeroplane out to sea to do basic daylight landings? Absolutely, based on what we saw, especially in the nominal envelope they'll provide the fleet with for initial operation."

Sto-ing

The test team had two separate control rooms, one classified for the mission systems aircraft BF-04 in the landing force operation centre (LFOC) and an unclassified control room in debark control where the BF-02 team was set up.

Rusnok highlighted differences compared to shore-based testing: "One of the unusual aspects from an engineering perspective was unlike here [at Pax] – where a team is in a control room across the base and are therefore shielded from all the noise and activity on the flight deck – on the *Wasp* they were right next to it. But we operated our control rooms very effectively in that environment."

Each day was split into two flight periods: morning and afternoon. The first flight was briefed about 06.00, in the ready room which was the operation centre aboard the *Wasp*, to all the test team.

Briefings were streamlined because the simulator events conducted prior to getting under way made them very quick: where's the ship right now, what's the weather today, what are the test points and back up test points and was there anything unusual learned yesterday that needs keeping track of? The first aircraft was manned-up around 07.30 ready for 08.00 take-off.

Maj Rusnok noted: "We weren't only stepping through flying with varying crosswinds but also



Image Data

Variant:	**F-35Bs BF-01 and BF-05**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**USS *Wasp* (LHD 1)**
Date:	**August 20, 2013**
Detail:	**BF-01 and BF-05 on aft deck**
Photographer:	**Andy Wolfe/ Lockheed Martin**

various centre of gravity load-outs for the aircraft, done with fuel. To achieve the very specific weight bands on the aircraft required to match the model, sometimes we had to refuel on the deck or wait to burn down fuel to meet the requirement of the specific test band. So not very fast launches, but very controlled. We'd take off and burn the fuel down to a specific landing weight to maintain divert options ashore and stay in the weight band."

There are three ways to conduct a short take off (STO) in the F-35B: stick STO, button STO – and auto STO. "That's a completely automated way to STO the aircraft off the flight deck. You punch in a distance and the aircraft will auto rotate to its optimal fly-out condition. It's all based on distance: we know where the aircraft is spotted [before it starts its take-off run] and where it should start its actual rotation," explained Rusnok. "Unlike a Harrier, which launches off the end of the ship flat, the F-35 rotates at about 225 feet from the bow, sits on two wheels until it gets to the end of the ship and actually takes off, a much different process to a Harrier. From a pilot perspective, you lose some sight of the front of the ship; in a Harrier you can see all the deck. But that's all part of optimising a 35,000lb aeroplane to get off the ship compared to the Harrier, which is only 16,000 to 25,000lb."

With stick STO the pilot controls the take-off by pulling back on the stick, holding it there and then rotating to the optimal pitch angle to fly off. In button STO, the pilot uses a trim switch which rotates the aircraft when pushed in, activating it when the aircraft passes the yellow STO rotation line positioned 225 feet from the bow of the ship.

"That was a temporary marking applied on the flight deck for this trial and is now being permanently installed on the ship with lighting," explained Rusnok. "It's based on optimising the performance of the aircraft and its flying qualities, so we can get the aeroplane off with the maximum amount of nozzle clearance and performance. The STO line is our visual cue to either pull the stick aft or hit the button; or if you're on automated STO you should start seeing the aeroplane's flight controls moving by the line, otherwise the pilot can intervene and pull back on the stick. We've never had to intervene."

The pilot also has command of the throttle. Two power setting options are available for take-off: Mil STO and Max STO, as Maj Rusnok explained: "When you taxi to the tram line you stay in mode one, the conventional flight mode. You convert the aircraft into mode four, the STOVL flight mode, and it takes about 15 seconds or so for the doors to open up and the lift fan to engage.

"Then you push the throttle about halfway up the throttle slide into a detent position at about 34% engine thrust request. It sits there and you check the engine gauges: if the readings are okay you slam the throttle to either Mil or Max position and then release the brakes simultaneously. Pushing through to max is like an afterburner detent. But it's not an afterburner – you can't go to afterburner in mode four.

"It's a very fast acceleration. The closest we would spot from the bow is 400 feet, so about 175 feet before we would actually start rotating the aeroplane [at the STO rotation line]; so very, very quick."

One of the big test points for DT I was to ensure adequate nozzle clearance in all the different test conditions. The engine nozzle swings down and back up during the take-off in accordance with inputs from the aircraft control laws.

"It's all automated," said Rusnok. "The pilot is not in the loop whatsoever – either they're pushing the button and letting the aeroplane do its own thing or pulling back on the stick to help it. Monitoring systems cue when something is wrong, so you have to rely on them to keep you safe because the flight controls are being moved unbelievably quickly."

Maj Rusnok said the take-off was very much like that ashore, with very little sink off the end of the deck. "The aeroplane is ridiculously powerful in STOVL mode. Just raw, unadulterated power."

Recovery to the Deck

Generally, each time an aircraft took off it would burn down its fuel load by flying around the ship and making approaches until the appropriate landing weight was reached for the test points required.

Landing spots seven and nine were used: seven is the primary location for STOVL jets on LHD ships, while nine is further aft on the tram line. The landing spot selected for each flight was mainly driven by NAVSEA's environmental engineers who



Image Data

Variant:	**F-35B BF-01**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**USS *Wasp* (LHD 1)**
Date:	**August 15, 2013**
Detail:	**BF-01 performs a stow**
Photographer:	**Todd McQueen/ Lockheed Martin**

specified a certain number of landings on each one to determine their flow characteristics – and how that affected minimum time between landings – ultimately working up to demonstrate two-ship F-35B operations.

Both spots were instrumented to measure different parameters: seven for deck deflection and nine to measure heat on an experimental non-skid deck surface called Thermion. According to NAVSEA this new coating – a bond of ceramic and aluminium designed to be more resistant to extreme heat, and wear and tear, from flight operations – showed no signs of heat stress during DT I.

"Sometimes BF-04, the mission systems aircraft, would fly instrument approaches to come alongside the ship and side step over to the flight deck . But we were primarily testing compatibility of TACAN and carrier-controlled approaches, not the full transition from an instrument approach across the stern to a landing," said Maj Rusnok.

Handlers

NAVSEA environmental engineers also developed the aircraft's hazard patterns for the flight deck crew which were initially used for the FCLP training and then on the ship. The flight deck crew was given questionnaires about F-35B deck operations. "There were a couple of procedures they did differently from the original NAVSEA recommendations," said Rusnok. "One was after launch – they grabbed on to a padeye, which is a tie-down point on the ship, rather than run out of the way and stand next to the island. The second was with the chaining process. The deck crew said they had a better way to do it than that recommended by NAVAIR and Lockheed Martin. Ultimately, that's the way it will be done. It was the crashing together of book theory and reality."

Feedback from DT I

Over the course of the 19-day DT I test period the two jets logged 28 hours' flight time and completed 72 short take-offs and 72 vertical landings in conditions of up to 33 knots of wind-over-deck and 10 knots of starboard crosswind. By contrast, just ten vertical landings were accomplished at Pax in the first year of STOVL operations, as Maj Rusnok described: "In just the months of September and October 2011, including all of the FCLP periods undertaken at Pax, well over 100 vertical landings were accomplished. That speaks volumes as to how the control laws in the aircraft and hardware upgrades have matured.

"It's a new aircraft and a brand new way of flying so going through the iterative process of flying, debriefing, modifying the hardware and software, and procedures was the only method to accomplish this evolution effectively, efficiently and safely."

The Director, Operational Test & Evaluation's Fiscal Year 2011 Annual Report (DOT&E FY2011 AR) said: "As expected, high starboard crosswinds produced the most challenging environment. One approach to hover prior to a vertical landing was



Variant: **F-35B BF-05** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 15, 2013** Detail: **Aircraft BF-05 on the flight deck** Photographer: **Andy Wolfe/Lockheed Martin**





Variant: **F-35B BF-05** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 15, 2013** Detail: **Aircraft BF-05 performs a short take-off** Photographer: **Andy Wolfe/Lockheed Martin**



Variant: **F-35Bs BF-01 and BF-05** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 19, 2013** Detail: **Aircraft BF-01 conducts a short take-off with BF-05 visible on the forward deck** Photographer: **Andy Wolfe/Lockheed Martin**

waved off by the pilot due to turbulence in the ship's air wake.

"A minimal nozzle clearance of two inches was observed at rotation during a short take-off with high starboard crosswinds when the pilot made an aggressive correction to maintain centreline.

Some standard deck operations and maintenance activities were demonstrated, including fuelling and defuelling, aircraft tie-down, jacking, tyre replacement, augmenter boost pump and door actuator replacements, and hydraulic servicing. Although maintenance was completed while aboard the ship, limited support equipment was positioned on the *Wasp* and no ALIS [Autonomic Logistics Information System] equipment was aboard the ship to support the deployment. The test team created a virtual private network connection between the ship and Lockheed Martin in Fort Worth such that they were able to process maintenance actions as if operating at Patuxent River.

Aircraft BF-02 diverted to Patuxent River twice during the deployment for maintenance – once for a fuel leak that could not be addressed at sea, and once when the team elected to have upper lift fan door actuators replaced ashore.

The upper lift fan door actuators on BF-04 had to be replaced twice during the trial period, once at Pax and once at sea with an embarked maintenance team.

Environmental data were collected to assess thermal stress to landing sites and shielded areas, and acoustic effects to ship personnel."

Describing the success of DT I, Maj Rusnok told *AIR International*: "The reality is we stepped through the envelope, as we predicted we would, at sea and we cleared enough of the envelope for initial fleet release. Ultimately we matched, and in some quarters exceeded, what Harrier has right now, and we did it in a much more methodical way than had been done in the past and with a lot more rigour.

"Some changes were required to the air data system and the software used for the cockpit fuel displays, but it was standard developmental test stuff and certainly wasn't prohibitive to our operation whatsoever. The good story was the tyres. We thought they were going to be eaten up by the non-skid because that's a pretty rough surface out there. We only changed two."

He was enthusiastic about the aircraft's performance during DT I: "We've proved the F-35B is compatible with LHD ships and we'll eventually prove that with the UK's CVF-class ships too. We didn't hurt anybody, we didn't break anything and the aeroplane performed outstandingly in terms of flying qualities and maintenance."

Development Test Phase Two

On August 10, some 21 months after the conclusion of DT I, USS *Wasp* hosted the follow-on F-35B sea trials – known as Developmental Test Phase Two, or DT II.

Just like DT I, VX-23 deployed four pilots, two jets and a 200-strong team for an 18-day test period. Pilots selected for DT II were LtCol Jimi Clift and Maj Mike Kingen of the US Marine Corps, Squadron Leader Jim Schofield from the Royal Air Force and BAE Systems' Peter Wilson, the only pilot to fly in both sea trials.

DT II was undertaken to expand the F-35B's allowable wind envelope for launch and recovery, conduct the first-ever night operations and initial



Variant: **F-35B BF-02** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **October 3, 2011** Detail: **Aircraft BF-02 lands onboard USS *Wasp* for initial ship trials** Photographer: **Andy Wolfe/Lockheed Martin**



Image Data

Variant:	**F-35B BF-05**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**USS *Wasp* (LHD 1)**
Date:	**August 16, 2013**
Detail:	**Aircraft BF-05 conducts a vertical landing**
Photographer:	**Andy Wolfe/Lockheed Martin**

mission systems evaluations at sea, evaluate the dynamics associated with aircraft operations on a moving flight deck and further test shipboard sustainment of the F-35.

"We tried as best we could to keep all the flying fleet-relevant, as opposed to DT I where there were a lot more tests to maintain configuration for longer periods of time," said Maj Mike Kingen.

Test Events

VX-23 devoted considerable time in 2013 to clearing the envelope to be used onboard the USS *Wasp* and vigorously testing the In-Service Release (ISR) of the propulsion system. There are two standards of the propulsion system: First Flight Release (FFR) and ISR, each distinctly different in terms of software and hardware. The two aircraft used for DT II incorporated the different standards – BF-01 is an FFR, and BF-05 is an ISR, the only such aeroplane in the SDD fleet.

"That gave us a unique opportunity to take the ISR propulsion system to the boat and compare it back-to-back with the capabilities of the FFR system: we only found very minor differences," said Peter Wilson, STOVL-lead pilot for the F-35.

An ISR propulsion system has more capability than an FFR and is able to cope with wider variations in aircraft centre of gravity (CG), a key factor when bringing weapons back to the boat. With forward CG, such as when weapons are carried internally, the lift fan must produce more thrust than the three-bearing swivel module (3BSM) in order to balance the aircraft at a steady hover attitude. "You have more capability to handle off-nominal CGs but that doesn't necessarily mean you always have more performance because of knock-on effects. If for example a gust pushes the nose up, the control system has to vary the balance of forces between the lift fan and the 3BSM to bring it down again. All this happens automatically in very quick time such that the pilot doesn't even know it. But the adjustment process may lose the aircraft a couple of feet because maximum thrust is not always available while adjusting the attitude in the hover. This happened twice during DT II."

As part of the test programme, VX-23 undertook crosswind and tailwind envelope expansion. This included what Peter Wilson described as "some very interesting test points" with the aircraft positioned with a tailwind – which involved tracking the centreline with various bank angles moving backwards at 25 knots or so, "really testing close to the limits of the propulsion system's capability. So we've hit the corners of the envelope going backwards and sideways".

VX-23 also conducted vertical landings with a 15-knot crosswind and with expected hot gas ingestion from the ship's funnels. "We've completed extreme descent rates touching down at 12ft/sec and not exceeded the load limits of the landing gear," said Wilson.

Crosswind testing is an interesting scenario. There are two ways to achieve the required objective. The pilot can generate crosswind in the hover by turning 90-degrees away from a headwind to generate crosswind from the natural wind and then move sideways over the ground to achieve the required test condition. The wind can be forced to come at any angle to the aircraft. The alternate way is to test when the desired wind speed is available naturally, pedal turning the aircraft until the direction required by the test point is achieved.

"DT II was about crosswind envelope expansion; getting out to 40 knots of headwind; tailwind envelope expansion; and the internal carriage of inert weapons during take-offs and landings for the first time," said Wilson.

Carriage of weapons in the internal bays moves the aircraft's CG forward, which makes it behave a little differently. Testing it was a DT II goal.

Wilson explained: "We also had to periodically jettison weapons to meet the necessary landing weight. DT II was the first time the F-35B had jettisoned weapons. We also wanted to fly at night, conduct landings with ship motion to increase the loads envelope, evaluate the effects of motion on the control system, and how the pilot would track the motion, and further stress the Thermion flightdeck coating."

US Marine Corps test pilot LtCol Jimi Clift flew the first night vertical landing on August 14.

VX-23 also performed regression testing of the test points that failed during DT I.

Take-offs during DT I showed that the nozzle



Variant: **F-35B BF-01** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 16, 2013** Detail: **Night STOVL operations** Photographer: **Todd McQueen/Lockheed Martin**

swung, in some angles, just two inches from the flight deck, requiring improvements to the flight control system. "You can't test that scenario ashore, so we repeated some of the conditions seen during DT I to prove that the corrections made aligned with the simulation," said Wilson.

Night Ops, HMDS, Mission Systems and Crosswinds

Maj Kingen and Squadron Leader Schofield gained their carrier qualification on the first day of DT II, after which the flight test team was ready to conduct night ops.

"I had a ridiculous grin on my face when I returned to the ready room after my first night mission. I'd never flown a night mission to a boat before feeling anything other than stressed," said Wilson. "That's what the Harrier was like at night. You really felt like you got away with it. You're highly trained so you're probably going to be fine, but you always knew not much had to go wrong and you'd be screwed.

"In the F-35 the experience was so different because it holds the height for you, it looks after you and you can actually leave it alone, which is often the best thing you can do. And it holds a beautiful hover, far better than you could do manually.

"It's really a task that requires you to just monitor the systems. Having done three vertical landings in about two hours, taking fuel, launching again and returning was a doddle by comparison to the Harrier."

The testing sought to prove the pilot could improve the night landing task relative to the Harrier by using the naked eye and the Gen II Helmet Mounted Display. "That's what we did supremely," said Wilson.

He confirmed that the functionality problems of the Gen II-standard HMDS are not encountered with STOVL operations. "You see effects at sea that you don't necessarily see ashore. For example, low sun on the horizon can bounce back off the water and potentially wash out some of the HMD symbology. It's not fantastic, but it's okay. The primary issue with the helmet occurs when the aeroplane starts to buffet. We don't get much buffet in STOVL mode and it's a comfortable ride most of the time."

Test events were also undertaken while the jets were airborne, as Wilson explained: "We conducted mission system tests to ensure interoperability with the ship: communications, navigation, TACAN and IFF. We also flew instrument approaches in visual conditions by day and by night to simulate our ability to get back to the ship in bad weather."

Another aspect of STOVL ops tested during DT II determined the effect of wind coming around the ship's island. When an aircraft is in the hover, the island is on the right. If the wind comes from the right it makes its way around the island and catches the aircraft from various angles. "That makes the hot gas coming out of the ship's stack come at you, which is bad news. Aeroplanes don't like ingesting hot gas: it reduces performance," said Wilson. "We had mixed results, some good, some bad. With the wind coming from 'round the back of the island, the aeroplane starts to feel like it's jostling around. And the effects of the hot gas coming from around the front eroded our performance margin, but not to a point we were concerned because the aircraft has the capability to withstand the effects. We opened out to 10 knots of crosswind from the right and 15 knots from the left, which is a super envelope. It was a great success."

The DOT&E FY2013 AR listed the permanent modifications made to the Wasp for DT II as:

Addition of transverse stiffeners to the underside of the flight deck for the two landing spots used by the F-35B and application of thermal non-skid material to the topside of the flight deck for one landing location. NAVSEA applied the non-skid material to the other landing location before an earlier detachment to the Wasp.

Deck edge modifications, including the removal, replacement, relocation and shielding of communications systems.

Added fire detection and alarming systems for the lithium-ion battery charging and storage area.

Temporary alterations for the Wasp for this detachment include:

Lithium-ion battery charging and storage areas. NAVSEA has not determined the final design of these areas.

Short take-off rotation line lights. Analysis of results will determine the precise location of these lights.

Addition of test equipment."

Feedback from DT II

A summary of the results from DT II were also published in the DOT&E FY2013 AR: "The deployment met the primary objective of collecting data to support the development of a Block 2B operational flight envelope for take-offs and



landings to support fleet release and Marine Corps initial operational capability. The test team expanded the range of aircraft weight and centre of gravity compared to that developed from the first deployment in 2011. Flight activity included night operations and inert internal weapons stores.

The US Navy is developing solutions to a number of challenges in integrating the F-35B onto L-class ships:

Large-scale application of a thermal non-skid material to the flight deck in F-35B landing locations.

Modification of the flight deck structure to eliminate excess stress, which includes transverse panel breakers installed on the underside of the existing flight deck structure.

Design of separate charging and storage lockers for the lithium-ion batteries required for the JSF and new storage locker for pilot flight equipment, as the JSF helmet is larger and more fragile than legacy helmets.

New fire fighting procedures in the event of a fire on the flight deck near aircraft carrying internal ordnance.

Understanding requirements for gun pod storage.

Conducting feasibility studies on the resupply of F-35B engines while under way, which could include a greater space allocation for engine storage aboard ship or through under way replenishment using a Navy system currently installed on one supply ship and scheduled for installation on CVN-78.

The Navy has determined that new active noise reduction personal hearing protection is necessary for on-deck personnel because of the high level of engine noise. Noise damping materials and/or personal hearing protection may also be needed for below-deck personnel.

During the 18-day sea trial the two jets completed 95 take-offs and vertical landings, both forward and aft-facing, and 17 night take-offs and landings in 10 days of testing.

"It was an extremely successful at-sea period. We hashed out the envelope and we got the fleet something they're going to be able to work with. In fact we've got everything except for elevated sea state," said Maj Kingen.



Variant: **F-35B BF-01** Unit: **Air Test and Evaluation Squadron 23** Location: **USS *Wasp* (LHD 1)** Date: **August 15, 2013** Detail: **Second night flight** Photographer: **Todd McQueen/Lockheed Martin**



Image Data

Variant:	**F-35B BF-02**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**USS *Wasp* (LHD 1)**
Date:	**October 11, 2011**
Detail:	**Aircraft BF-02 takes off from the USS *Wasp* on its ferry flight back to Pax**
Photographer:	**Michael Jackson/Lockheed Martin**

Shake, Ra



Image Data

Variant:	**F-35C CF-03**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Warfare Center Aircraft Division Lakehurst, New Jersey**
Date:	**January 9, 2014**
Detail:	**CF-03 performs a roll-in arrestment at Lakehurst**
Photographer:	**Dane Weidmann /Lockheed Martin**

ttle & Roll

The US Navy is to stage three Development Test (DT) periods involving the F-35C embarked aboard a Nimitz-class super carrier to prove and verify the type's carrier suitability to launch and recover safely. The first event, DT I, is scheduled for late 2014, subject to completion of the necessary prerequisite testing that is currently being undertaken.

Shake Testing

"At this point, we have to complete a survey on the aircraft, also known as a 'shake, rattle and roll'," explained LCDR Tony Wilson, F-35C carrier suitability lead with Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs' based at Naval Air Station Patuxent River, Maryland.

"We fly various manoeuvres here at the field to our Mk7 arrestor site, which models the same arresting system installed on the carrier, to explore the corners of the aircraft's envelope in the worst case scenarios a pilot can find himself at the boat."

Shake testing includes catapults and arrested landings. Catapults build up in longitudinal acceleration up to 5.5g and include shots with the aircraft deliberately off the centre in the shuttle. Arrested landings include high sink rates up to 20 feet per second (1,200 feet per minute or about a 5-degree flight path angle), maximum deceleration points and free flight engagements.

"Here at the field we don't have the ability to heave or roll the runway pitch like the boat does so we high sink the aircraft up







Image Data

Variant:	**F-35C CF-03**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Station Patuxent River, Maryland**
Date:	**July 19, 2011**
Detail:	**TC-7 catapult testing**
Photographer:	**Michael Jackson/ Lockheed Martin**

FLY-IN ARRESTMENT







Variant: **F-35C CF-03** Unit: **Air Test and Evaluation Squadron 23** Location: **Naval Air Station Patuxent River, Maryland** Date: **December 19, 2013** Detail: **CF-03 performs a fly-in arrestment at Pax River** Photographer: **Dane Weidmann/Lockheed Martin**

to its limits and simulate a very hard landing. We come down at various roll and yaw attitudes, and a combination of both, to simulate pitching and rolling of the deck.

"And finally we do what we call 'max Nx' [maximum engagement speed] – really hit the gear hard to see the effects on the aircraft and the gear and whether we can get the hook to engage the wire prior to the aircraft coming down.

"We do that in a very controlled manner. We call it a free flight, to ensure that both the arresting wire and aircraft can handle the stress in the event that a pilot tries to fly away from the boat and grabs the wire while the 'plane is either going straight or on an upward vector."

New Hook

On October 20, 2011 the Commanders of the US Air Force Operational Test and Evaluation Center (AFOTEC), the US Navy Operational Test and Evaluation Force (OPTEVFOR) and the Royal Air Force Air Warfare Centre (AWC) released their Operational Assessment (OA) OT-IIE report of the F-35 programme's progress toward readiness for Initial Operational Test and Evaluation (IOT&E).

CATAPULT LAUNCH





Image Data

Variant:	**F-35C CF-03**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Engineering Station Lakehurst, New Jersey**
Date:	**August 19, 2011**
Detail:	**TC-7 catapult testing**
Photographer:	**Andy Wolfe/Lockheed Martin**

The F-35C Carrier Variant's Arresting Hook System (AHS) featured in the report, which listed significant issues with the original design in respect of its interoperation with aircraft carrier based Mk7 arresting gear. Roll-in arrestment testing at Naval Air Warfare Center Aircraft Division (NAWCAD) Lakehurst, New Jersey resulted in no successful Mk7 engagements in eight attempts. Root cause analysis identified three key AHS design issues:

1 - the aircraft geometry has a relatively short distance between the aircraft's main landing gear tyres and tailhook point (when lowered).

2 - tailhook point design was overemphasized for cable shredding features versus ability to scoop low positioned cables.

3 - tailhook hold-down damper performance is ineffective to support damping of small bounces relative to runway/deck surface profiles.

The F-35C's main landing gear to tailhook point distance is 7.1ft (2.16m). Accordingly, when the aircraft's main landing gear rolls over the arresting cable, the responsive dynamics are such that the cable lies nearly flat on the deck. Comparing similar geometries with other, currently operating carrier-based aircraft which range from 30.2ft/9.20m (C-2) to 14.6ft/4.45m (T-45), the F-35C is an outlier. The original F-35C tailhook point design was based on the F/A-18E/F design which has a blunt face to better provide cable shredding protection versus scooping. However, the F/A-18E/F's geometry places the distance of its main landing gear to tailhook at 18.2ft/5.54m; a much longer distance than the F-35C. Since there is more distance in geometry, the trampled cable has enough time to respond and flex back toward its original setting position by the time the tailhook point intercepts for arrestment. The hold-down damper contributes to overall aircraft arresting gear performance by allowing the tailhook to bounce excessively.

To address these issues, the programme has designed modifications to the tailhook point and hold-down damper components. The hook point redesign both reduces the blunt face geometry with a pointed front end and lowers its apex point by 0.5 inches (68%) such that it is now below the arresting gear cable centreline to better enable scooping performance. The hold-down damper redesign consists of modifications to the AHS actuator







Variant: **F-35C CF-03** Unit: **Air Test and Evaluation Squadron 23** Location: **Naval Air Station Patuxent River, Maryland** Date: **November 4, 2011**
Detail: **First steam ingested TC-7 catapult launch at Pax River** Photographer: **Andy Wolfe/Lockheed Martin**


DANGER
RESCUE
EMERGENCY CANOPY
RELEASE ON OTHER SIDE
DANGER
JET
INTAKE
DANGER

damper such that a lesser number of orifices will temper tailhook bounce dynamics. The AHS redesigned components underwent Monte Carlo probability of engagement analysis as a lead-in effort for design review.

Without corrective action, the AHS was considered an area of major consequence.

Since rolling engagements represent only the initial stages leading into full carrier suitability demonstrations of the F-35C, proof of the redesigned components' ability to perform under nominal and off-nominal approach to engagement conditions could not be gained until testing at Lakehurst and Pax River started.

The Pax River F-35 Integrated Test Force first received the new tailhook in October 2013 and has been testing it since December. Wilson explained: "It's very promising. It differs from the original hook in that the structure itself is more substantial, to handle the stresses, and the hook point has a different profile to allow it to engage the wire more successfully than the old hook."

Between January 9 and 16 LCDR Wilson's team accomplished 36 successful roll-in arrestment tests at Lakehurst with the redesigned tailhook fitted to aircraft CF-03. All flight test objectives were met during the detachment, which completed shore-based testing at Lakehurst. Prior to the Lakehurst detachment aircraft CF-03 performed three lower-energy roll-ins and one fly-in arrestment with the Mk7 arrestor gear at NAS Patuxent River to confirm functional operation of the redesigned tailhook and test instrumentation. CF-03 is the first F-35C variant to be fitted with the new tailhook and is currently undertaking a series of field-based ship suitability tests, including fly-in arrestments and FCLPs leading to certification of the F-35C for shipboard flight trials.

What about up-and-away testing of the F-35C? "From the carrier suitability standpoint it flies like it's supposed to once the landing gear and hook is retracted to the up position," said Wilson. "Our focus is strictly on aggressive landings and catapult take-offs."

VX-23 has performed many catapults shots at Lakehurst and Pax River using TC7 steam catapults. The one used at Pax is similar but a bit shorter than those installed on the carriers, which results in a higher launch load because the aircraft reaches the same acceleration and end speed but in a shorter distance.

Some cat shots include those referred to as 'mis-serviced' gear shots, which involve the aircraft's tyres and struts being set at higher and lower pressures to those specified by NATOPS. They are conducted to make sure that the aircraft can launch safely should a maintainer have mis-serviced the landing gear.

LCDR Wilson said all of the mis-serviced gear shots went very well but some of the challenges encountered with the shake testing of aircraft CF-03 have to be completed before a subset is conducted with CF-05. This is required to verify that everything is good for deploying to the ship later this year. Shake testing of both aircraft is critical to the carrier suitability work-up programme.

Ancillary Testing

Other than 'shake, rattle and roll' there is little else to test on the F-35C for carrier suitability testing, as LCDR Wilson pointed out: "The beauty of the F-35 programme is its interoperability: the three variants and their missions are all very similar. The only difference is that I have to bring my aircraft back to the boat, so the focus of the testing with the F-35C is on the wing fold system, the launch systems, the recovery systems, the avionics specific to the Instrument Carrier Landing System (ICLS) which allows us to recover on the boat at night and the approach handling qualities with the new delta control flight path.

He described the boat as the great equaliser. "You can only simulate so much while shore-based so we have a wide range of LT&E [Logistics Test & Evaluation] testing planned: jacking, tyre changes, elevator runs, engine runs and many different maintenance activities typically performed when under way."

The LT&E division conducted chain down testing at Pax in February 2013 to determine if the chains interfered with the landing gear doors or if there were any problems with the procedure. None was found.

"But the majority of testing when embarked will focus on catapult launches and recovery because our goal is to provide envelope launch and recovery bulletins to the fleet," concluded LCDR Wilson.

Nimitz Class

When *AIR International* closed for press a 14-stage plan was in place for DT I which currently involves personnel, support equipment and aircraft deploying to Naval Air Station North Island in California prior to the first carrier landings onboard a Nimitz-class carrier.

"In a very similar way to when a fleet squadron embarks on a carrier, we're going to pack up all our materials, tools and the equipment required to support the aircraft and move out to the boat to start the testing," said LCDR Wilson.

This will include a group of up to 250 personnel, aircraft CF-03 and CF-05, two F/A-18s for chase support, four F-35 pilots and others to fly the F/A-18s.

Immediately prior to repositioning for DT I, the four F-35 pilots selected will conduct field carrier landing practice (FCLP) events with the landing signal officers (LSOs) assigned to VX-23. This involves flying a carrier-style landing pattern at Pax to ensure they are safe to go to the carrier.



Image Data

Variant:	**F-35C CF-03**
Unit:	**Air Test and Evaluation Squadron 23**
Location:	**Naval Air Weapons Center Air Division Lakehurst, New Jersey**
Date:	**September 26, 2011**
Detail:	**First steam ingested TC-7 catapult launch**
Photographer:	**Layne Laughter/Lockheed Martin**

Tail End of THE



There are many unforgettable locations in the United States of America: beaches, bayous, prairies, mountain ranges and deserts, but would you give a similar accolade to a military base? Edwards Air Force Base in the Mojave Desert in southern California, might just qualify. Located adjacent to Rogers Dry Lakebed, the largest dry lakebed in North America (roughly 12 miles long and 5 miles wide), the base covers just over 308,000 acres (124,643 hectares) and is flanked by mountains. There are 19 runways at Edwards: three paved and 16 located on the lakebed. The main paved runway is the longest in the United States (15,000ft). The longest on the lakebed is seven-and-a-half miles long.

It is home of the Air Force Test Center and a variety of flight test squadrons assigned to Air Force Materiel Command's 412th Test Wing. One such unit is the 461st Flight Test Squadron (FLTS), nicknamed 'The Jesters', a component of the F-35 Integrated Test Force (ITF) based at Edwards. It's an ironic nickname for a squadron tasked with the serious business of putting the F-35 Lightning II Joint Strike Fighter through its paces during the jet's System Development and Demonstration (SDD) phase.

"We're in charge of the flight science mission – the envelope expansion for the US Air Force

WHIP



F-35A CTOL version of the Lightning II. We also conduct the vast majority of mission systems testing for all three variants – A, B and C," said Lt Col Drew Allen, commander of the 461st FLTS and government site director (see the section on flight sciences for more detail).

The squadron currently comprises 1,000 personnel and has two main branches: engineering and test operations. The former manages and prepares its F-35 aircraft in accordance with the test plan and the latter executes flight testing.

The Jesters operate a mixed fleet of nine aircraft: six F-35As, two F-35Bs and one F-35C(*see table overleaf)*

Amidst the enormity of the F-35 programme, the 461st FLTS, led by Lt Col Allen, is responsible to Lt Gen Christopher Bogdan, the boss of the Joint Program Office (JPO) in Crystal City, Virginia, and Brig Gen Michael Brewer, who leads the 412th Test Wing. Allen's primary responsibility is safe and

Image Data

Variant:	**F-35A AF-06 07-0744/'ED'**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**March 28, 2013**
Detail:	**APG-81 radar test**
Photographer:	**Darin Russell/Lockheed Martin**

THE JESTERS' FLEET

Variant	C/n	Military ID	Build Lot
F-35A	AF-01		SDD
F-35A	AF-02		SDD
F-35A	AF-03		SDD
F-35A	AF-04		SDD
F-35A	AF-05	07-0744	LRIP 1
F-35A	AF-06	07-0745	LRIP 1
F-35B	BF-17	BuNo 168313	LRIP 3
F-35B	BF-18	BuNo 168314	LRIP 3
F-35C	CF-08	BuNo 168735	LRIP 4



Image Data

Variant: **F-35B BF-17 BuNo 168313/'12' and BF-18 BuNo 168314/'18'**

Unit: **461st Flight Test Squadron 'Jesters'**

Location: **Over California**

Date: **September 26, 2013**

Detail: **Formation Flight behind a KC-130J**

Photographer: **Darin Russell/Lockheed Martin**

efficient execution of flight testing, working hand-in-hand with Mike Glass, Lockheed Martin's site director at Edwards.

But who directs the test plan? Maj Colin Hanson, Assistant Director of Operations for Weapon Integration on the 461st FLTS, explained: "We operate joint test plans for the different suites of hardware and software and have databases of the available test points, some of which might not be available because we haven't done a processor test or because there's an engineering hold on a capability. The order in which we execute test points comes from the JPO."

The current weapons test plan for the SDD phase is one example. It comprises the AIM-120 AMRAAM missile, the GBU-12 laser-guided bomb and the GBU-31 and GBU-32 Joint Direct Attack Munitions (JDAMs). To date, safe separation testing – one part of the weapons test plan – has included the first guided and first live launches of an AMRAAM missile and the first guided launches of a GBU-31 and GBU-32.

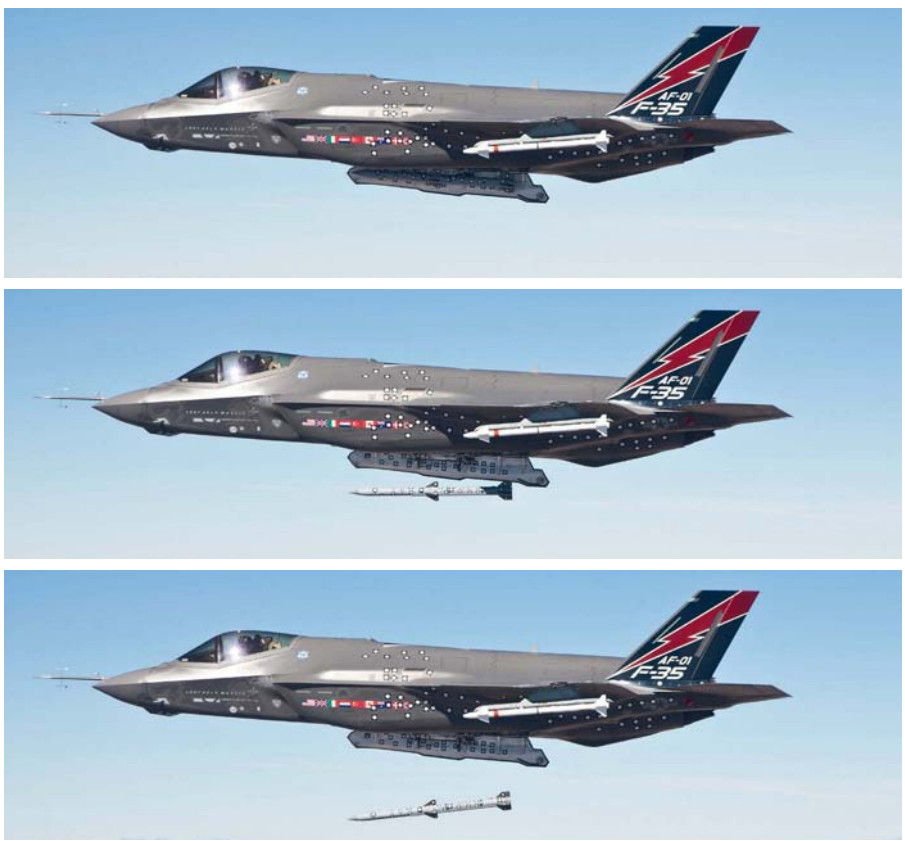
Safe separation is one of the top priorities for the 461st FLTS, as Maj Hanson affirmed: "When you enter transonic and supersonic flight regimes and release a missile or bomb out of a weapons bay, you'll encounter issues with airflow and how the weapon gets away from the aircraft."

Managing the Test Mission

How does the 461st FLTS manage its developmental test mission when faced with major issues requiring an engineering fix that may take weeks or longer to correct, therefore impacting heavily on the test schedule?

"We follow the guidance and direction of the JPO and our Air Force leadership. We're the tail end of the whip, but also the ones that identify what is or is not working as designed, and what is not performing up to specification," replied Lt Col Allen.

AMRAAM SEPARATION



Variant: **F-35A AF-01** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **October 19, 2010** Detail: **First weapon separation flight launching an AIM-120 AMRAAM Separation Test Vehicle** Photographer: **Matthew Short/Lockheed Martin**

"Initially we're the receivers of a product and we see how well it's performing to spec. Sometimes it will do well, sometimes it doesn't and we have to push back and say okay, it makes no sense for us to continue testing this because it's messed up. We tag what the mission impact is and assess the importance of getting it fixed and how quickly it's required. That goes to the JPO and we work at their discretion.

"We're in an interesting place in that we find a problem and we see what its ramifications are going to be. As the originator we know what's coming and what the bow wave is, and have a lot of influence [in the direction of the programme] from what we discover.

"Our biggest control is the volume at which we report the issues. When developing capabilities like those on the F-35 some will present snags, especially developing the software to enable sensor fusion, which is a hugely difficult problem.

"We've asked our contractors to do very difficult things and there are going to be issues: it is unrealistic to not expect there to be problems.

"As a community the biggest problem we have is getting the software development done appropriately. We continue to move the ball downfield, but it doesn't always happen as planned because everything is interconnected in the aircraft. We're developing the backbone of an aircraft to handle capability upgrade for decades, and that's extremely difficult to do."

The 461st FLTS uses different reporting methods, but the primary one is called a deficiency report. Each deficiency is graded for severity and scope and scored with a category and a ramification rating in terms of its importance to the aircraft's capability and the development schedule.

Hundreds of deficiency reports are written, covering everything from basic aircraft systems to the most sophisticated mission system: many of them require a software upgrade while some involve new or modified hardware. Deficiencies are addressed through negotiations with the contractor and an agreement on which software load will include the required fix.

Subsequent test plans will include the fix, and the 461st FLTS will try to focus its testing on issues that need to be addressed in order to move towards meeting major programme objectives such as the beginning of operational test and initial operational capability (IOC) declaration by the US Marine Corps.

In working towards the main objectives, the 461st FLTS has the dates for when each new software load is released. Those dates will almost certainly change based on what the JPO decides to place on the integrated master schedule.

Sensor Fusion

Lt Col Allen, a former F-22 Raptor test pilot, explained that the most important part, and probably the most difficult testing, the 461st FLTS will undertake will be sensor fusion. "Great strides were made with the F-22 on how to do that properly, but the F-35 has even more sensors and more capabilities, so there's even more to test.

"The F-22 doesn't have EOTS or a DAS, which are highly complicated systems working on top of each other: they are supposed to be integrated and work together," he said, describing results from the initial elements of fusion testing as "promising". (EOTS refers to the Lockheed Martin Missiles and Fire Control AN/AAQ-40 Electro-Optical Targeting System. DAS is the Northrop Grumman Electronic Systems AN/AAQ-37 Distributed Aperture System.)

The F-35's integrated core processor, colloquially referred to as the fusion engine, takes multiple feeds from all the sensors – the EOTS, DAS, radar, radar warning receiver, datalink and all the identification systems – and tries to sort them into different levels





Variant: **F-35A AF-02** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **May 7, 2013** Detail: **Air-to-air refuelling with a KC-135R during an infrared countermeasures loads investigation test** Photographer: **Matthew Short/Lockheed Martin**

Variant: **F-35A AF-04** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **September 29, 2011** Detail: **First KC-10 air-to-air refuelling evaluation** Photographer: **Darin Russell/Lockheed Martin**



Variant: **F-35A AF-03** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **November 12, 2010** Detail: **Ferry flight to Edwards Air Force Base** Credit: **Liz Kaszynski/Lockheed Martin**



Image Data

Variant:	**F-35A AF-01**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**January 11, 2014**
Detail:	**Flutter and flying qualities test of an external load of inert GBU-12 laser-guided bombs**
Photographer:	**Matthew Short/Lockheed Martin**



of priority before it outputs them as a single track displayed to the pilot on the Panoramic Cockpit Display (PCD).

Each sensor has its own tolerance and sensitivities which have to be prioritised and programmed into the fusion engine – the data it wants to display and fuses it as one track containing the most important information.

Lt Col Allen is impressed by this capability on the F-35.

"The things that made my eyes water on the F-22 were its sensor fusion and avionics capabilities, which are amazing. The F-35 will eventually be a step above that and stand as the 'golden cache' of fighter development simply because of its sensor fusion.

"The things the aircraft can sense and fuse into one simple display is game-changing for the pilot."

But are the individual sensors performing to expectation? "There are issues with every system but the position, in terms of the development of each individual system, is where it should be and in some cases much further advanced," replied the Jesters' boss.

He stressed that further work would have to be done to improve the F-35's sensor fusion capability and that software development will determine how and when all inputs from the hardware are fused and how they are displayed to the pilot.

Based on this explanation, the author was curious to know what standard of data buses are used by the F-35: the current MIL-STD-1553 and -1760, or others with a higher capability to meet the needs of the aircraft? Maj Hanson confirmed the aircraft uses a combination – MIL-STD-1553 and -1760 are fitted, but the backbone of the mission systems is an IEEE-1394B standard communication bus adapted and modified for the F-35.

Weapons Separation

One of the major test plans under way with the 461st FLTS is weapons separation, for which Maj Hanson is an Assistant Director of Operations, responsible for writing individual test plans, developing the test cards and completing the aircraft's documentation for each event. This is all done in partnership with Lockheed Martin.

Each test plan is written broadly enough to allow for some flexibility in its execution. Maj Hanson's team are the test conductors, 'driving' the test cards throughout the event to ensure the execution is in step with the plan.

The first air-to-ground weapon to be released from the F-35 was the 2,000lb GBU-31 Joint Direct Attack Munition, using the standard series of processes for all air-to-surface weapons: form, fit and function, dry fits, pit drops and, finally, separation from the aircraft:

- Form, fit and function checks using computer-aided drafting tools and modelling.
- Dry fits determine that the munition fits inside the weapon bay, the doors close and there are no problems of interference.
- Pit drops involve pickling a bomb off the aircraft onto mattresses to ensure the right signals are being sent through the data bus to eject the weapon from the bay.
- A series of weapon separation test missions are flown, starting with a release in a safe sector of the flight envelope and progressing to the corners of the envelope with subsequent flights.

Maj Hanson described a pit drop: "We use instrumentation fitted on the weapon rack and analyse the data going across the data buses as well as any discrete signals that occur when the pilot pickles the weapon. This ensures the firing pulse actually gets to the rack. We also monitor the pressure at which the weapon is ejected to make sure it's all to predictions."

The weapon separation team at the 461st FLTS are still conducting tests within the flight sciences portion of the test programme. This means most of their work is devoted to ensuring weapon functionality. The main aspects of this work involve checking that the signal gets sent to the weapon; the aircraft stores management system properly recognises the weapon has separated from the bomb rack unit or launcher appropriately; there are no airflow disturbances that may cause the weapon to track back up into the weapons bay or strike it on exit from the aircraft; and, in the case of a live weapon, that it actually links back to the aircraft.

By June 2013, the 461st FLTS had already released Mass Property Units (MPUs) of GBU-12s, GBU-31s and GBU-32s and fired AIM-120 AMRAAM missiles. MPUs are shaped and weigh the same as the real weapon but don't necessarily have a fuze, motor or warhead fitted. They mimic the mass properties of the weapons and are used for safe separation testing.

By the same time, the squadron had also dropped instrumented versions of the GBU-12, GBU-31, GBU-32 and AIM-120. Known as Integrated Test Vehicles (ITVs), they enable engineers to track what a weapon does from the initial release message, sent via the data bus, through the separation sequence and during its flight to the target.

The squadron also flies with dummy AIM-9X Sidewinder missiles externally mounted on stations 1 and 11. "We're primarily carrying the AIM-9X for envelope expansion and carriage assessment to make sure it's departure-resistant in high angle-of-attack scenarios," explained Hanson.

The AIM-9Xs have high-speed cameras installed in the forward and aft fuselage and to date have been used to record the separation of chaff, flares, AIM-120 AMRAAMs, GBU-12s, GBU-31s and GBU-32s.

The first guided weapon drops and end-to-end kill chain assessments (which involve checking the weapon is actually guiding itself against a ground or airborne target) started in the third quarter of 2013. The aircraft's AAQ-40 EOTS and the Northrop Grumman AN/APG-81 Active Electronically-Scanned Array radar are being used for the end-to-end tests.

At the time of *AIR international's* visit, the 461st FLTS was conducting front-end checks and avionics work to ensure the APG-81 and the EOTS can detect and designate targets to specification, and target data and the release command can be sent to a weapon.

To accomplish this, each system is operated in simulation mode so the pilot can check the



Image Data

Variant:	**F-35A AF-04**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**May 14, 2012**
Detail:	**Flutter and flying qualities test of external stores mounted to the wings**
Photographer:	**Matthew Short/Lockheed Martin**

switchology and the software function correctly. Analysis of the results enables operating instructions specific to the F-35 to be written for each type of weapon. Lt Col Allen described the work as the point where avionics and weapon separation meet up.

Engine Testing

By the summer of 2013 the 461st FLTS had completed all air start testing of the Pratt & Whitney F135 engine. The engine had been shut down on 30 different flights – and, on one test flight, 12 times in a row.

"When conducting air starts we're also testing the ability of the aircraft to transition to emergency power loads in the event the engine stops. It did very well," Allen explained.

Engine anomalies show up occasionally, more so in the development of a new engine – but the accuracy and ability of the F135 to detect issues and enable preventative maintenance is, according Lt Col Allen, very impressive.

He said the detection rate was in the order of one in 100,000. "If you have an anomaly with, say, a fan blade, it's very good at doing its own diagnostics and getting out in front of the problem before it develops." To date the engine has performed very well, maintaining proper levels of thrust and providing it to the pilot throughout the flight envelope.

Performance and Flight Envelope Expansion

"We're very close to clearing the flight envelope with Block 2B software which will allow the US Marine Corps to declare IOC," said Lt Col Allen. "Some elements remain outstanding, especially those associated with weapons carriage near the aircraft's maximum dynamic capability."

The 461st FLTS has already flown the jet to its design limits in a clean configuration and has exceeded its 9g limit. One 461st FLTS pilot took aircraft AF-02 to 9.9g.

AF-02, the loads jet, is fitted with multiple sensors (accelerometers) for measuring g throughout the airframe. These are essential for measuring the different g loads experienced by the aircraft at different points of the airframe. It's important to bear in mind that the g load displayed to the pilot in the cockpit can be different from those the aircraft is experiencing at different points across the airframe.

According to Allen the squadron is still characterising the performance capability of the F-35. One example is discovering its turn performance with increasing weapon loads as the test programme progresses to a full payload. "It's performed well up to this point," he said.

He also spoke about the need to temper expectations for the F-35. "This aircraft is not designed to go high, fast and outturn any other. But it is designed to do a full spectrum of missions and carry a lot of internal fuel. That gives it the capability to stay airborne for a long time, and in that respect it's certainly performing up to its design spec."

Air Refuelling, Fusing Images and MADL

Air-refuelling testing first started in 2010 and continues today. The F-35A models assigned to the ITF at Edwards regularly refuel from boom-equipped KC-10As and KC-135Rs while F-35Bs and F-35Cs assigned to the ITFs at Edwards and Naval Air Station Patuxent River are fully tested with drogue-equipped KC-130s.

While the F-35B and F-35C have conducted multiple air-refuelling contacts from KC-135Rs fitted with a drogue, the first connections to a drogue-equipped KC-10 were made from NAS Patuxent River in June 2013.

"When you're characterising the performance of an aircraft you have to do so in the air-refuelling regime as well. There's quite a bit of attention being paid to how quickly the F-35 can refuel and we're still working to improve that. But it's more than able to connect with a boom or drogue-equipped tanker and receive gas," enthused the squadron's boss.

When *AIR International* visited the 461st FLTS it

THE F-35 WILL EVENTUALLY STAND AS THE
SIMPLY BECAUSE OF

was verifying most of the F-35's sensors against specification – not least the AAQ-37 DAS. "This means we remain in the early stages of using DAS as a combat sensor and continue to characterise what it's able to do and its ability to detect things and project them to the pilot. Fusing multiple images into one is a big issue with the DAS, especially in displaying it to the pilot on the helmet visor," Allen revealed.

On June 14 last year the squadron successfully linked four F-35s on the Northrop Grumman Multifunction Advanced Data Link (MADL) for the first time. A fifth aircraft also linked in while sitting on the ground. "It was the first time we'd ever tried to get four jets airborne and have all of them onto the data link. That was huge," said Lt Col Allen.

Squirting Software

By late June 2013 all nine F-35s assigned to the 461st FLTS were loaded with Block 2B software and the squadron was 'hot and heavy' into its testing. In accordance with official policy, each aircraft in the squadron's fleet was loaded in sequence, the last being LRIP aircraft BF-18, an F-35B.

The loading process, referred to as 'squirting', is undertaken using a Portable Maintenance Aid (PMA) pre-loaded with the new software drop. It is connected to the aircraft via a cable and left to run through the upload. The process takes a day or so to complete depending on the aircraft's response – which can occasionally disrupt the upload process, requiring a restart.

The software comes in two distinct forms: small upgrades and incremental loads such as Block 2A and Block 2B. The effects of each type differ: incremental software wipes everything from the mission computer and loads the new version; small upgrades simply overwrite anomalies discovered in flight testing.

Once either type is loaded, engineers conduct regression testing to ensure all the basic functions still work. This is followed by an engine run to check all the controls work correctly before the aircraft is flown on what's referred to as a 'confidence flight'.

Flight Sciences

Flight sciences determines how the aeroplane flies by putting it through rigorous tests in all corners of the envelope so that the entire flight envelope can be cleared with maximum g, speed and altitude.

"This includes all the angles of attack the 'plane is capable of – and putting it out of control to determine its recovery characteristics," explained Lt Col Brent Reinhardt, Assistant Director of Operations with the 461st FLTS. "At first this is performed without any external stores [pylons and weapons] and then with both."

Initially the squadron cleared the F-35's flight envelope up to about 450 knots/Mach 0.9 and out to 5g with the weapon bay doors closed. Testing continued to determine the flying characteristics with the weapon bay doors open and no stores inside. Concurrent ground-based testing involved form, fit and function checks of the AIM-120, GBU-12 and GBU-31 inside the bay and pit drops to ensure safe separation.

Successive test missions were then flown



Variant: **F-35A AF-01** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Point Mugu Sea Test Range** Date: **June 5, 2013** Detail: **First launch of an AIM-120 AMRAAM Air-to-Air Vehicle Instrumented missile. Missile launched from station 5** Photographer: **Matthew Short/Lockheed Martin**



Variant: **F-35A AF-06 07-0744/'ED'** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Point Mugu Sea Test Range** Date: **October 30, 2013** Detail: **First launch of a live AIM-120 AMRAAM missile. Missile launched from station 7** Photographer: **Darin Russell/Lockheed Martin**

Variant: **F-35B BF-17 BuNo 168313/'12'** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **October 29, 2013** Detail: **Weapons delivery accuracy live release of a GBU-12. Weapon released from station 8** Photographer: **Darin Russell/Lockheed Martin**



GOLDEN CACHE OF FIGHTER DEVELOPMENT ITS SENSOR FUSION Lt Col Drew Allen



with each weapon carried in the weapons bay, during which the doors were opened to check the environment and ensure the weapon was not vibrating excessively and that the stresses placed on the racks are within the design limits.

Finally an envelope is cleared that is big enough to test operationally representative releases from 0.5 to 5g.

But while the F-35's flutter test plan is complete, its full flight envelope has yet to be cleared: the F-35A CTOL variant is currently cleared out to 700 knots/Mach 1.6 but not to the full 9g load.

"We'll now go out to the corners of the flight envelope and validate that all weapon loads are good when pulling 9g at Mach 1.6 and that nothing is overstressed," explained Reinhardt.

He then referred to the other parts of flight sciences testing – high angle of attack (AoA or high alpha), departure prevention and recovery characteristics. The 461st FLTS first started AoA testing in January 2013: "We've already taken the aeroplane out to the full envelope: 50 alpha and negative ten and have actually done intentional upright and inverted departures, tail slides and aggravated inputs.

"Starting with slower speeds we intentionally put the aircraft out of control to make sure it has good recovery characteristics. Low-speed departure work is complete and we're now increasing speed as we put in aggravated inputs to ensure its resistance to departure.

"One of the neat things about the F-35 is that it incorporates an auto-recovery system which will ultimately allow the pilot to do whatever he or she needs to with the aeroplane. Ask anything of it and it will give it to you, and through the research being undertaken at Edwards we should keep pilots away from the point where they would depart from controlled flight. Should that happen all they have to do is take their hands off the controls and the aeroplane will recover itself.

"Our role is to find where the cliffs are in the flying qualities and the control laws and make adjustments to them, retest and make sure we've fixed the problem such that it won't allow the pilot to put himself in that scenario. We haven't met any issue yet that we can't fix with software, but we're in the early stages of the high alpha programme. It will run for the next couple of years and cover different flight regimes such as clean wing, clean wing with weapon bay doors open, and external stores.

"The initial stages of the high alpha programme started with a spin chute fitted to aircraft AF-04 as a safety measure. But despite analytical predictions about how the aeroplane might react in the high alpha regime, we don't know – and flight test always produces something a little bit different from what you expect.

"We've already proved the recovery characteristics are positive enough to permit the spin chute to be removed from the aeroplane because it adds a little bit more drag. And it's not production-representative."

Loads Testing

During *AIR International's* visit to the 461st FLTS, it had completed carriage of internal stores plus external pylons and wingtip missiles (representative of AIM-9Xs) in the high alpha programme. The squadron was also busy conducting loads testing at the aircraft's maximum airspeed and at different altitudes. This involved multiple supersonic runs over Edwards and repeated sonic booms.

"It takes a lot of fuel to get to the energy state required to reach Mach 1.6 and then do a 7g turn. We're currently doing loads up high at 30,000ft and Mach 1.6, and below that we fly at our maximum subsonic airspeed of 700 knots. We then repeat that at 20,000, 15,000, 8,500 and 2,000ft. As you step down in altitude the air gets thicker and the loads [on the aircraft] change significantly with that change in 'Q' [a reference to dynamic pressure]."

Sensors fitted around the aircraft measure loads induced all over the airframe and at all the critical points around it: for example the attach points for the bombs, the wing roots, horizontal tails, the base of the vertical tails and the leading edge flaps. Every movable surface has a design load tolerance.

Data recorded enables the test engineers to determine which loads can be cleared as part of the flight envelope without reducing the life of the aeroplane as required by the operational user.

Lt Col Reinhardt explained: "We continue to operate within a confined envelope that will remain in place until we get to the end of the SDD phase. The riskier test points will be undertaken at the end of the programme so the aircraft remain in a good state until the point when we expect things to possibly fail or break right up to the design limit."

Weapons Separation Missions

While supersonic loads testing was under way during *AIR International's* visit to Edwards, the 461st FLTS had already released the first weapons from an



Image Data

Variant:	**F-35A AF-04**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**November 3, 2012**
Detail:	**High angle of attack test**
Photographer:	**Matthew Short/ Lockheed Martin**

F-35A CTOL version.

The very first separation from the variant was flown by Major Eric Schultz on October 16, 2012 using aircraft AF-01, on its 254th flight, and involving a 2,000lb GBU-31 JDAM ITV, over the China Lake range at 1g, the most benign part of the flight envelope.

Reinhardt described the test: "You have to determine a footprint that allows for all the possible failure modes of the weapon itself. If for example a fin breaks as it comes off the aircraft and spirals down to earth, where could it possibly land? You have to fit that footprint into a usable piece of airspace and China Lake has a range set up exactly for that.

"Based on our airspeed and the other test conditions, the footprint for the first GBU-31 release took up most of the range with sufficient clear space on the ground. Everything went to plan and it fell exactly where the trajectory model predicted and within the desired planned plane of the range."

The orange-coloured ITV used was covered with black-and-white markers to help track its release and determine its acceleration using high-speed cameras positioned in the fore and aft of the weapons bay.

Aircraft AF-01 also carried dummy AIM-9X missiles on stations 1 and 11. Each missile was fitted with two cameras, one mid-fuselage and one forward. Both pointed at the weapons bay and recorded the ejection, exit and initial trajectory, each with six seconds' worth of memory.

Since then the 461st FLTS has dropped dozens more GBU-31, GBU-12 and GBU-32 test vehicles, each at a different airspeed, altitude and g load. Test events conducted for the GBU-31 involved releases between 0.5 and 5g.

The 461st FLTS is also conducting release trials for IR countermeasures (flares), the first of which was completed in December 2012. Lt Col Reinhardt, who flew some of the missions, noted: "We've gone from very simple single releases flown in regimes at the heart of the envelope to multiple releases at the edge of it to evaluate the jettison function for the IR countermeasures suite carried on the aeroplane."

AMRAAM

The first AMRAAM separation from an F-35A CTOL version of the jet was flown by Major Matthew Phillips on October 19, 2012 using aircraft AF-01, on its 255th flight, and an unpowered ITV with no rocket motor fitted.

The test was to determine the separation characteristics of an AIM-120. When the weapon bay door is opened the missile gets ejected at high pressure into the airstream. Once it's safely away from the aeroplane, the motor fires and the missile flies off. Major Philips, a former F-15E pilot, said it felt very similar to releasing an AMRAAM from a Strike Eagle.

A series of pre-qualification tests (see section on Weapon Separation) preceded the mission. First was a form, fit and function test involving loading a missile in the weapons bay and opening the doors to check the clearances. Next was pit testing to ensure the missile separates from the launcher correctly and doesn't hit anything on its exit.

A ground-based pit drop cannot, however, replicate the effects of wind stream, which can only be modelled and analysed before the first release. "Pit testing is conducted solely to make sure that that function works correctly, so that the predictions used for the in-flight separation are validated," said Lt Col Reinhardt. "If we notice anything different we have to go back and change the model and see if that's going to affect in-flight separation."

Lt Col George Schwartz flew the first launch of an AMRAAM missile fitted with a rocket motor on June 5, 2013, using F-35A AF-01, on its 314th flight, and an AAVI (air-to-air vehicle instrumented) missile released at 1g over the Point Mugu Sea Test Range.

Reinhardt emphasised the safety requirements of the test: "When you throw something out there that's powered, moving fast and designed to kill people, the range has to be clear so that nobody is around for 100 miles."

The AAVI test article was fitted with telemetry equipment and a flight termination system – as soon as the rocket motor stopped, the missile's flight was terminated as part of the safety plan. Consequently it fell into the ocean in pieces rather than continuing as a Mach 1-plus projectile.

Reinhardt contrasted the preparations required for the test to the simplicity of the actual launch by the pilot: "When it comes right down to it, it's not that cosmic. But there are a lot of assets involved to assure safety, and they all have to come together for us to get a green range [meaning the range is clear] at which point you can let it go. From the pilot's perspective: master arm, choose the right station and there it goes.

"The biggest test piece is making sure the telemetry data is sent back to the control room. We can't afford to lose the data for a test event that defines whether or not it's good. It kicked out, fired and went as planned on the correct

trajectory. It was a huge step for the programme, the first demonstration of air-to-air capability of the aeroplane.

Mission Systems

The 461st FLTS is also working on end-to-end mission systems testing – and their full integration to enable a weapon to be put on target.

The US Marine Corps' Lt Col Jon Ohman, Director of Naval Variants with the 461st FLTS, is in no doubt about their ability: "They make it revolutionary," he said.

Capability is provided to the aircraft with software blocks, each built to a capability baseline. Block 1A, the initial release for the mission systems, included the APG-81 radar, AAQ-37 DAS and the AAQ-40 EOTS. Software drives the way each sensor is used and each successive release adds more capability to the individual system and the aircraft.

Ohman explained: "This aeroplane uses the entire sensor suite in a very co-operative fashion – it's highly integrated. The way each sensor is used and tasked to best enhance the information received is driven by the software in the fusion engine.

"It's complex by its nature so it's a technical challenge, but we've made continuous improvements to the fusion capability, which forms a large part of the mission systems testing.

"Flight sciences testing always precedes what you can do with mission systems so we've been developing those in parallel, in anticipation of the capability delivered by the flight sciences testing. The ultimate goal is to put a weapon on target which is dependent on the flight sciences test programme clearing each store's compatibility and safe separation with and from the aircraft."

In July 2013 the 461st FLTS started a major test programme called weapons delivery accuracy (see section below). This involved integrating the GBU-12, GBU-31 and GBU-32 JDAMs and AIM-120 with the mission systems for end-to-end testing and finding the target, tracking it and placing the weapon on it accurately. Three of the weapons, the GBU-12, GBU-32 and AIM-120, will be part of the US Marine Corps' initial operational capability declaration using Block 2B software.

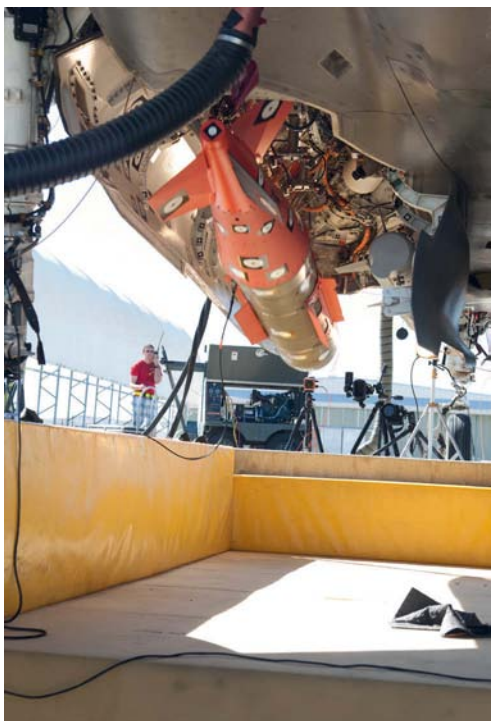
As part of its tasking, the 461st FLTS provides the Lockheed Martin laboratories at Fort Worth with data for system approval and undertakes verification testing of the mission systems, including the four main ones – APG-81 AESA radar, AAQ-37 DAS, AAQ-40 EOTS and the integrated, multi-sensor, multi-antenna electronic warfare (EW) suite.

The squadron has tested the APG-81 radar and the EW suite both as individual standalone systems and with sensor fusion. Work with the radar has included target detection and tracking when functioning discretely and in combination with the aircraft's other sensors.

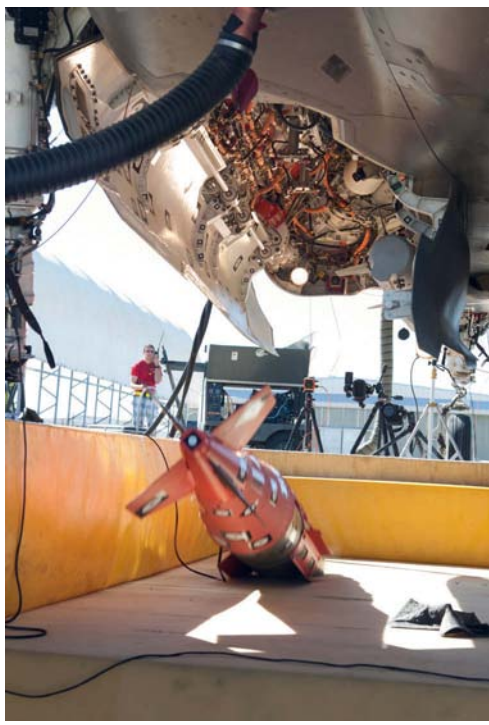


Variant: **F-35A AF-01** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **October 16, 2010** Detail: **First weapon separation flight releasing a GBU-31 JDAM Separation Test Vehicle. Weapon released from station 4** Photographer: **Matthew Short/Lockheed Martin**

JDAM PIT DROP TEST







Variant: **F-35A AF-01** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **June 13, 2012**
Detail: **Pit drop of a GBU-31 JDAM. Weapon dropped from station 4** Photographer: **Lockheed Martin &** *(right)* **Paul Weatherman/Lockheed Martin**



Image Data

Variant:	**F-35A AF-01**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**October 19, 2010**
Detail:	**First weapon separation flight launching an AIM-120 AMRAAM Separation Test Vehicle**
Photographer:	**Matthew Short/Lockheed Martin**

Of the four systems listed above, Lt Col Ohman highlighted the targeting system. "We've done a lot of testing with the EOTS on different targets and in different environments to validate its ability to track a target and deliver accurate target-quality information to the aircraft [weapons management system] so that we can put a bomb on it."

He defined "different targets" as moving and stationary – including physical classes such as tanks, armoured vehicles and self-propelled artillery – and area targets. "A targeting sensor requires a different capability to be able to track a target that's well defined or well bound in the IR spectrum [as opposed to] one that's an area target and not as well defined. We test against different targets in different IR environments in that respect. The ability to track a target can be affected by the temperature surrounding it, so we test in different temperature environments as well."

Describing the work on the radar, Ohman said: "We've done a lot of testing of its ability to detect and track airborne targets as a standalone system and with combined sensor fusion. We started that process with single non-manoeuvring targets, progressing to multiple manoeuvring targets at different ranges with varying radar signatures.

"The APG-81 has a tremendous capability to generate SAR [synthetic aperture radar] maps so we've tested against different targets, using different SAR map resolutions, and the radar's ability to generate a weapon-quality co-ordinate from a SAR map to validate that capability."

Sandia National Laboratories based in Albuquerque, New Mexico has a long history in the development of the components and technologies applicable to SAR. Whilst Sandia National Laboratories work independently to the the US Department of Defense, its website provides an intuitive explanation of what synthetic aperture radar can provide and how it works.

Environmental monitoring, earth-resource mapping and military systems require broad-area imaging at high resolutions. In many scenarios the imagery must be acquired in inclement weather during the day and at night. SAR provides such a capability.

SAR systems take advantage of the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high resolution imagery. Synthetic aperture radar complements photographic and other optical imaging capabilities because of the minimum constraints on time-of-day and atmospheric conditions and because of the unique responses of terrain and cultural targets to radar frequencies.

Consider an airborne SAR imaging perpendicular to the aircraft velocity. Typically, SARs produce a two-dimensional image. One dimension in the image is called range (or cross track) and is a measure of the 'line-of-sight' distance from the radar to the target. Range measurement and resolution are achieved in synthetic aperture radar in the same manner as most other radars: range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target and, in the simplest SAR, range resolution is determined by the transmitted pulse width, ie narrow pulses yield fine range resolution.

The other dimension is called azimuth (or along track) and is perpendicular to range. It is the ability of SAR to produce relatively fine azimuth resolution that differentiates it from other radars. To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam. The sharpness of the beam defines the azimuth resolution. Similarly, optical systems, such as telescopes, require large apertures (mirrors or lenses which are analogous to the radar antenna) to obtain fine imaging resolution. Since SARs are much lower in frequency than optical systems, even moderate SAR resolutions require an antenna physically larger than can be practically carried by an airborne platform: antenna lengths several hundred meters long are often required. However, an airborne radar could collect data while flying this distance and then process the data as if it came from a physically long antenna. The distance the aircraft flies in synthesizing the antenna is known as the synthetic aperture. A narrow synthetic beam width results from the relatively long synthetic aperture, which yields finer resolution than is









possible from a smaller physical antenna.

However, SARs are not as simple as described above. Transmitting short pulses to provide range resolution is generally not practical. Typically, longer pulses with wide-bandwidth modulation are transmitted, which complicates the range processing but decreases the peak power requirements on the transmitter. For even moderate azimuth resolutions, a target's range to each location on the synthetic aperture changes along the synthetic aperture. The energy reflected from the target must be 'mathematically focused' to compensate for the range dependence across the aperture prior to image formation. Additionally, for fine-resolution systems, range and azimuth processing is coupled (dependent on each other) which also greatly increases the computational processing.

But has the data link been used yet to download what has been captured [as SAR maps] back to Edwards? "We've done a lot of data link testing, including capturing targets with SAR maps, and transferred information – specifically target assignments – across the link to make sure we have the capability," replied Ohman.

Asked if the range of the APG-81 radar was better than legacy fighter radars, Ohman simply replied it has very good range capability while Reinhardt said it has "exceptional performance" compared to his legacy fighter, the F-16.

The 461st FLTS is also flying missions using the APG-81 in the air-to-ground role while simultaneously tracking airborne targets. Lt Col Ohman noted that making a SAR map is a relatively high-task event for the radar, but confirmed that its capability to do so while also maintaining an air picture showing airborne threats has been tested.

The air-to-ground mission is at the heart of the work being conducted with the AAQ-40 EOTS – specifically its ability to track a target and deliver weapons-quality information to the aircraft's mission computer which then enables the system to supply that data to the weapon to hit the desired position precisely. The type and physical form of targets tested varies.



Variant: **F-35A AF-06 07-0744/'ED'** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California**
Date: **November 13, 2013** Detail: **AIM-120 AMRAAM test** Photographer: **Chad Bellay/Lockheed Martin**

DAS
Complexity

One of the most complex systems fitted to the F-35 is the AAQ-37 Distributed Aperture System. "DAS requires a lot of processing power to interleave the imagery captured by its six cameras [actually infrared sensors] around the aeroplane and then present that to the pilot," said Ohman.

"The initial challenge is to make sure the system is stable. When we first started operating with DAS it was only just stable enough to function without crashing unexpectedly. Acuity of the image and how it's presented to the pilot contribute to the problem. We've tested the system's functionality and have also managed to minimise image latency which causes misalignment with the real world.

"A lot of the early DAS testing was developmental in nature: we experienced problems and wrote the deficiency reports which went back to Northrop Grumman, and fixes were issued within a new build of software. As a system DAS is now maturing and is tactically useful, but not sufficiently so for operational use. We continue to test it and are now conducting more tactically representative test events to ensure it's useful for the pilot."

Lt Col Reinhardt, who conducted much of the DAS testing, added: "With any system that requires processing of imagery into a usable form that can be sent to my displays, there will be a very small amount of latency between what the cameras pick up and what I see. We're talking milliseconds. If there's a lag in what's presented

Image Data

Variant:	**F-35B BF-18 BuNo 168314/'18'**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**February 7, 2014**
Detail:	**Weapon delivery accuracy test**
Photographer:	**Matthew Clements**



and what we react to as pilots, it may create a problem when using the DAS as a sole reference for deconfliction or with respect to another aeroplane on the ground."

On one daytime test, Lt Col Reinhardt was flying just a few hundred feet behind another aircraft, using the DAS as the only means of seeing out of his F-35. "I completed a tracking test using the [DAS] cameras and kept my aiming symbol on top of the other aeroplane. The pilot made increasing gain [in range] and higher degrees of bank turns in front of me but I managed to track him using the DAS. This helps determine whether latency is really going to affect my ability to use the system – or induce something negative for the pilot that's not been seen before because the capability is something new. We determined there was no problem with the system."

Test pilots assigned to the 461st FLTS have also used the DAS during night-time air-refuelling and in different tactical scenarios such as tactical manoeuvring, air-to-air engagements and low-altitude navigation, as well as benign scenarios to determine if it helps increase the pilot's awareness of what's around him or her when coming in to land, when on the flight line, and whether it gives the pilot more situational awareness (SA).

Lt Col Reinhardt has no doubt the system enhances the pilot's SA. "When sitting on the ground, the pilot can't see what's underneath the wing or whether the chocks are in place; turn on the DAS and they can see both. It's a very neat system that allows you to look wherever you want and gain SA, day or night."

According to Lt Col Ohman the fidelity of the DAS is comparable to military night-vision devices currently on the market. Unlike most current night-vision devices used by legacy fighters which amplify any ambient light detected, the DAS detects infrared energy and projects it on the Helmet-Mounted Display visor without the loss of any peripheral vision. "Because of that I have a bigger field of view than legacy night-vision devices. What it sees is processed into a usable form and displayed in the visor."

But despite its name, the DAS isn't just used to detect threats but also for other uses it was not designed for, such as maintaining formation. "I can turn DAS on and look over to see my wingman without the need for a pair of NVGs," said Reinhardt. "You can fly formation without looking for your wingman. You just have a picture and you know how far away he is. You fly what's called sensor formation, which is typically further apart from each other than in visual formation, but you could also fly visual formation using the DAS."

He compared the experience to a legacy fighter: "Without a data link and only a night-vision device, flying visual formation requires a lot of the wingman's attention to constantly cross-check where the flight lead is instead of focusing on maintaining the offensive or defensive capability of his aeroplane."

Does DAS give him an advantage by offering SA of the airspace behind his aircraft? Lt Col Reinhardt noted my question was geared toward an operational scenario: "We're in developmental test and we have not sampled a full-up scenario in which the entire capability is tested. That's something we're planning on."

Lt Col Ohman also responded to my question, giving a practical scenario: "As you approach a target in a legacy type it will become masked under the nose, so I can either change my flight path or roll up on a wing to enable me to continue seeing the target; by doing so I risk masking other sensors. In an F-35 I can look down and see the target below the aeroplane through the DAS. Being able to see things that are typically out of sight in legacy aeroplanes gives the F-35 pilot a tremendous increase in situational awareness."



Variant: **F-35A AF-02** Unit: **461st Flight Test Squadron 'Jesters'**
Location: **Edwards Air Force Base, California** Date: **June 26, 2013**
Detail: **Supersonic loads testing** Photographer: **Paul Ridgway**

AMRAAM LOADING







Variant: **F-35A BF-18 BuNo 168314/'18'** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California**
Date: **January 6, 2014** Detail: **AIM-120 AMRAAM loading** Credit: **Lockheed Martin**

Helmet-Mounted Display System

Our discussion moved on to the Helmet-Mounted Display System (HMDS) which Lt Col Ohman described as revolutionary, noting it can outperform any other.

"The ability to project DAS and night-vision imagery into the visor and use it as the pilot's sole source head-up display [HUD] are design requirements of the HMDS," he said, adding that "the requirement to be able to boresight imagery to the helmet is a technical challenge caused by the pilot's head movements, a process that is much easier to achieve onto a fixed HUD.

"Challenges encountered with the helmet are its ability to project a precise boresight to the position where I look and lay down a target, and its ability to project an accurate representation of where the target actually is."

But has the system improved to a point where it can be considered as being out of trouble? "Yes, we've seen significant improvement in the system and are comfortable using it as a flight reference," he replied. "But there are still challenges and we're continuing to improve in using it to its full tactical capability, a lot of which is dependent on our ability to verify that we can present an accurate target with the helmet.

"It's very good at cueing to a target and I can use the designation on the EOTS to sweeten it up and generate weapon-quality co-ordinates with which to release. Typically, though, we don't intend to target with the helmet as a standalone system. But we want to show the boresight is tight so that we can use the helmet for strafing. Ideally you want to be able to use your head-up display as a standalone visual reference for strafing, which is the primary driver for ensuring we've got a tight boresight."

The helmet is also intended for use as a self-contained night-vision capability – goggles are not required – by using either the night-vision camera fitted inside it or the DAS. Both systems gather imagery and project it in the helmet visor but the camera is just a vision system rather than a target designation system.

Latency and potential image parallax were the main concerns driving the testing required to certify the helmet is accurate and can provide the required night-vision capability.

Panoramic Cockpit Display

According to Lt Col Ohman, the Panoramic Cockpit Display (PCD) is another revolutionary component of the F-35 – primarily because of the way it provides the pilot with information customised to suit the tactical situation.

Using the final iteration of Block 2A software during mission-representative air-to-air scenarios and intercepts, armed interdiction strikes and other air-to-ground missions, Ohman described how the PCD provided him with a 360° display of everything going on around him: "At all times in the F-35 the pilot has a 360° map with you in the centre and all the information from the sensors and other contributors on the link.

"It's a different paradigm from a radar display, on which you just see what's in front of you. In the F-35 you see everything that's out there and information provided via the data link – surveillance tracks, tracks from other friendly aircraft and threats as well."

Lt Col Reinhardt added: "There's one tactical situational display fed by all the sensors and it's fused together into one picture. You don't have direct control of anything. Everything contributes in its own manner. If you ask for information about something you see, the fusion engine will task each of the sensors to provide information about it, put it all together and give me a consolidated picture of everything that's out there."



Image Data

Variant:	**F-35A AF-06 07-0744/'ED' and AF-07 07-0745/'ED' F-35Bs BF-17 BuNo 168313/'12' and BF-18 BuNo 168314/'18'**
Unit:	**461st Flight Test Squadron 'Jesters'**
Location:	**Edwards Air Force Base, California**
Date:	**June 14, 2013**
Detail:	**First four-ship MADL and air-to-air refuelling with a KC-130J by BF-17**
Photographer:	**Matthew Short/Lockheed Martin**

But what's the fidelity of the PCD screen like? "The EOTS imagery is very good and has very good acuity," Ohman replied. "If I have a target on the tactical situation display, air-to-air or air-to-ground, I can designate it, slave the EOTS to it and put the image on another portal of the display.

"You don't give up the god's eye view of the tactical situation – you have the big picture, a 360° vision, but you can also bring up EOTS and DAS imagery or a SAR map in different portals.

"The F-35 breaks the mould on what we are typically used to seeing in the cockpit of a fighter aircraft. It's a very clean cockpit because we use the PCD as a touchscreen to access menus and functions."

The touchscreen is a tremendous benefit for the Pilot Vehicle Interface (PVI) and is a system the 461st FLTS is devoting considerable time to evaluating and improving as part of its mission systems testing. Ohman noted: "So the radar may be very capable at detecting and tracking a target, but getting that information to the pilot in a manner that allows him to make smart decisions is something that needs to be incorporated in the aeroplane.

"To validate that, we fly a lot of sorties against airborne targets with varying radar signatures and at certain ranges to test the radar's ability to track them during manoeuvres. But at the same time we're evaluating the ability for the pilot to use the radar's information in an offensive and useful manner."

Weapons Delivery Accuracy

During the final three months of 2013 the 461st FLTS completed three notable test missions as part of its weapons delivery accuracy programme.

The first was flown by Marine Corps Major Richard Rusnok on October 29, 2013 using aircraft BF-17 on its 57th flight, and involved the release of 500lb GBU-12 ITV from the aircraft's weapons bay at an altitude of 25,000ft. The weapon fell for 35 seconds before hitting a stationary target (a tank) on the precision impact area of the Edwards range. Major Rusnok used the aircraft's AAQ-40 Electro-Optical Targeting System to identify, track, accurately designate and deliver the GBU-12 on target. "This guided weapons delivery test marks the first time the F-35 truly became a weapon system," said Major Rusnok.

The following day Air Force Captain Logan Lamping flew the first live-fire launch of an AMRAAM missile over the Point Mugu Sea Test Range, using F-35A AF-06, on its 186th flight.

The aircraft successfully identified and targeted the drone with its APG-81 radar. The fire control system passed the target track information to the missile's internal guidance unit before release. The AIM-120 launched from the internal weapons bay, successfully acquired the target and followed an intercept flight profile as guided by mid-course updates sent via datalink from the aircraft. Once the drone was within range, the missile's radar seeker is activated for autonomous terminal homing. Moments before impact, the missile's flight was terminated to preserve the drone for future use.

Charlie Wagner, weapons team lead for the F-35 Joint Program Office described the event as an initial demonstration of the air-to-air combat capability of the F-35 and how it represented the culmination of many years of careful planning by combined government and contractor teams. "It is one test, with many more to come," he said.

The final test mission of the weapon delivery accuracy programme (which included each of the Block 2B weapon types: AIM-120, GBU-12, GBU-31 and GBU-32) was flown by Lt Col Ohman on December 6, 2013 using aircraft BF-18, on its 58th flight, and involved a 1,000lb GBU-32 JDAM ITV released from the aircraft's internal weapons bay against a fixed ground test target on the precision impact area of the Edwards range. The GBU-32, released from an altitude of 25,000ft, guided to a direct hit on its intended target of eight stacked cargo containers.

Flying the F-35

When I asked Lt Col Reinhardt what the F-35 was like to fly, he compared his experience in the F-16s to the Lightning II: "There are flight regimes in which the F-35 has more power and can out-accelerate an F-16: the engine is bigger but so is the airframe. The F-35A, and especially the F-35C model, can carry as much gas as the empty weight of an F-16. So weight-wise it's twice as much aeroplane [F-16 v F-35] – but the wing span is about the same [31ft v 35ft] so it has a much higher wing loading which equates to a much smoother ride.

"The aircraft is the easiest I've ever flown. Landing is simple, a non-event; the aircraft can land itself if you want. It's so stable and so manoeuvrable and the flight controls work so well throughout the entire envelope right up to 50 alpha. Even when you're out of control you can still affect the trajectory of the aeroplane [with the flight controls].

"The F-35 is a carefree experience for the pilot, so you can focus more on the mission and worry less about flying. They've done a really good job at making this a very simple aeroplane to fly."

Variant: **F-35A AF-07 07-0745/'ED'** Unit: **461st Flight Test Squadron 'Jesters'** Location: **Edwards Air Force Base, California** Date: **March 22, 2012** Detail: **Distributed aperture system night test** Photographer: **Darin Russell/Lockheed Martin**





Forging

Norway's Future Combat Aircraft Project finally concluded in 2012 when government approval was given to procure up to 52 Lockheed Martin F-35A Lightning II Joint Strike Fighter aircraft as part of its long-term defence plan. The procurement process started six years earlier when a baseline conceptual study identified five potential types for the programme: Boeing Hornet, Dassault Rafale, Eurofighter Typhoon, Lockheed Martin F-35 and the Saab Gripen NG. In 2007 the Norwegian Ministry of Defence considered each type and down-selected the Eurofighter, Gripen NG and F-35 as being suitable for the RFI (request for information) process. A fourth option to extend the life of its F-16s was discounted that autumn when the Norwegian Government decided to procure a new fighter aircraft to meet the needs of the nation's defence. Requests for Binding Information, which listed all of Norway's requirements, were sent to all three manufacturers in January 2008. The RBI prohibited deviation from any government requirement. "We set April 28, 2008 as our deadline," said Col Charles Svensson F-35 Programme Manager for Operations and a former Royal Norwegian Air Force F-16 pilot. "We didn't receive a response from Eurofighter, leaving F-35 and the Gripen NG as the final contenders."

Responses received from Lockheed Martin and Saab were analysed by the National Defence and Research establishment and a team of Air Force operational experts, and both concluded the F-35 was the only aircraft that fulfilled or exceeded the requirements. The three main requirements were: to fulfil operational requirements, procurement and life cycle cost, and industrial participation.

The F-35 was down-selected by the government in November 2008 with planned acquisition of 56 aircraft delivered between 2016 and 2020. In 2010 the acquisition plan was adjusted, following re-structure of the overall F-35 programme, and the first four aircraft were procured for training in 2011. Following the government's long-term defence plan, released in 2012, approval was given to procure up to 52 aircraft in annual lots: two in 2015, two in 2016 and then six per year from 2017 up to 2024.

Norwegian Specific Requirements

Norway has three specific requirements for its F-35s: a long-range stand-off strike capability, ammunition to suit all mission sets and a drag chute to slow the aircraft down after landing on an icy or snowy runway. The Norwegian F-35 Programme Office has selected the Joint Strike Missile (JSM), PGU-48 APEX ammunition and a bespoke drag chute to meet all of its needs.

The JSM, is an essential weapon in Norway's



Image Data

Variant:	**F-35A**
Detail:	**A computer-generated image of a Royal Norwegian Air Force F-35A landing on an icy runway with the drag chute deployed**
Photograph:	**Lockheed Martin**

Ahead

defence policy and meets the requirement for an anti-surface warfare weapon that can be delivered from a stand-off range against sea and land targets by the same type of aircraft. "It's a unique weapon built for planning and executing strike missions against strategic or highly defended targets deep inside enemy territory in environments populated by future threats. It can be reprogrammed in flight, fly at high or low altitude, and mask terrain. It flies like a small fighter aircraft and can either be controlled by the launch aircraft, or handed over to other aircraft on the F-35 network" said Svensson.

Norway has invested a lot of money developing the Naval Strike Missile (NSM) so its defence industry's missile and seeker technologies were more than capable of meeting the requirement of the F-35. Feasibility studies for weapon integration on various fighter aircraft including the F-35 began in 2004. In the case of the F-35 the study determined that a redesign of the NSM would be required to make it fit in the weapons bay. The Norwegian Ministry of Defence awarded a contract to Kongsberg in 2010 for phase one of development. The weapon was now named the Joint Strike Missile (JSM). A second contract followed in 2011 to sustain funding through to the critical design review – scheduled and completed in the autumn of 2013. Negotiations are under way for the final phase of the missile's development which is planned for 2015 and 2016. Qualification trials will follow to ensure the missile safely separates from the aircraft, which will lead to internal and external weapon integration on the F-35. "Each phase takes a lot of expertise and assets so we are buying services from the US Government to qualify and certify the JSM on the F-16 next year. This will involve jettisons in 2015 and live fires during the next two years. The final requirement will be integration on the Block 4 standard F-35. This has to be completed in time for our planned full operational capability including maritime strike capability in 2025," said Lt Col Sigurd Fongen the senior staff officer for the Royal Norwegian Air Force F-35 Programme and a former F-16 pilot.

The JSM is the first weapon tailored for the F-35 weapons bay and the design utilises much of the space there to accommodate a fuselage housing the guidance system, engine, fuel tank and a 265lb (120Kg) warhead with a net explosive weight equivalent to a 500lb (227Kg) warhead.

Key features of the JSM are high subsonic speed, very low-level flight, low observable characteristics, a power-to-weight ratio slightly more than 1:1, and an engine so powerful that it maintains maximum speed with high manoeuvrability even during the terminal phase of its flight to the target.

Norway will also require its F-35s to undertake swing-role sorties involving the air-to-air and air-to-ground roles on the same mission. "We need it to be able to carry a mix of weapons to do that, and that includes the cannon," said Lt Col Fongen.



Image Data

Variant:	**F-35As**
Detail:	**A computer-generated image of two Royal Norwegian Air Force F-35As showing the drag chute unit mounted on top of the fuselage between the vertical tails**
Photograph:	**Lockheed Martin**

The former F-16 pilot explained the different ammunition currently available: "There are high explosive rounds which are effective against one type of target, and do not have any armour-piercing capability, and there are cold armour-piercing rounds which use a heavy metal type penetrator. NAMMO [a state-owned company shared partly with the Finnish Government] came up with a concept to combine the two characteristics into one ammunition type. The 25mm PGU-48 APEX round is designed for the F-35's internally-mounted four-barrel GAU-22/A cannon which provides greater range and more accuracy than the ammunition currently used by the M61 Vulcan cannon fitted to Norway's F-16s. To meet the operational requirement of the F-35 the APEX ammunition must be able to penetrate armoured, semi-armoured and soft shell targets, and have an explosive capability against different types of land and air targets.

"It has a tungsten carbide penetrator a small warhead and a base bleed on its aft end to give tracer effect which is important in some missions. For example, when you are flying an air policing mission you might need to divert an aircraft. If after completing all of the internationally recognised signals the aircraft doesn't respond, you may need to fire warning shots. Well, without tracer they won't be visible," explained the Colonel.

The base bleed or tracer function gives better aero dynamic performance which maintains the trajectory speed for longer and gives range. Live weapon testing of the APEX ammunition will be completed in 2017 using an F-35A configured to Block 3 standard.

Lt Col Fongen told *AIR International*: "From an operational perspective I'm in no doubt that the APEX ammunition will suit most missions because it can be used against a wide variety of targets. NAMMO is also producing a training round called RRR (reduced ricochet risk) but intends to apply the RRR concept into 25mm cold ammunition. It's manufactured in a way that it will crack and disintegrate upon impact to avoid the potential of rounds hitting the aircraft during strafing."

Norway's snowy, icy climate, makes landing an issue even on a NATO-standard 8,000 feet runway. Fongen explained: "With snow and ice on the runway we can fly training flights with an RCI minima, which is even lower for operational flights, as long as we have a drag chute. A chute aids landing and provides flexibility for using shorter runways.

Norway is currently the only F-35 partner nation that will field the Lockheed Martin-designed drag chute system comprising two installations referred to as group A and B. Group A comprises internal modifications to strengthen the aircraft and includes drilling of the airframe bulkheads for the control lines extending from the cockpit to the auto system. Group B encompasses the functions, linkages and the canister. The cockpit switch is the same as in the Norwegian F-16. It opens the canister, the chute flies out and deploys and it also functions as the release control for the deployed chute. The system is hydraulically powered and independent to the rest of the aircraft for redundancy in the event that the aircraft's hydraulic power is lost.

According to Lt Col Fongen, the beauty of the drag chute is that it's missionised. "The chute unit itself, known as the dog house, can be mounted on the aircraft. Alternatively if you deploy to a base with a long runway and you don't need the drag chute, you can take it off and fly without it," he said. Norway's F-35s will initially only be delivered with just group A installed.

Lt Col Fongen told *AIR International* that Lockheed Martin had tested the drag chute in the vehicle integration facility at Fort Worth last November. "They tried to simulate all the conditions as much as possible. The test pilots said the system and aircraft performed very well. The aircraft is heavy and the rear wheels are spaced further apart than an F-16, and they have the dual tail rudders and the chute which stabilises the aircraft even more in short cross winds."

F-35 Conversion Plan

The RNoAF plans to begin its F-35 conversion plan in 2015 when the first maintainers will begin their course at the Academic Training Center at Eglin Air Force Base in Florida. Pilot training starts in early 2016 at Luke Air Force Base, Arizona. The first seven Norwegian F-35As will be assigned to a US Air Force squadron to support the initial training requirement of seven students per year. "Eventually we will scale down the number of aircraft and students at Luke to four and possibly six respectively," said Col Svensson.

"The maintainers will remain at Eglin until the first Norwegian jet is delivered to Luke where they will go to receive on-the-job-training, a transition course for international students, until we form a training facility either in Norway or in cooperation with another European country like the UK."

"Pilots in the third class run at Luke will become instructors and return to Ørland Main Air Station to help stand up the first squadron in 2017."

Ørland will undergo redevelopment for the F-35 and start with a new squadron building constructed on a fresh site to the north of the runway. Other construction will involve runway and taxiway resurfacing and new parking areas.

Ørland will be the only F-35 main operating base so the entire F-35 fleet will be assigned to and operated by two units, 331 and 332 Squadrons, which means the annual pilot training programme will be extensive. Many of the sorties in that programme cannot be flown in an aircraft because the scenarios require other Army, Navy and Air Force assets that are not immediately available so they will be performed in full mission simulators, eight of which have been procured. In addition the RNoAF will use



Variant: **F-35A** Detail: **A Joint Strike Missile loaded on station 10**
Photograph: **Lockheed Martin**

the simulators to train for missions that cannot be conducted in the air for security reasons. Cost is another main consideration. RNoAF analysis of the required training programme found that almost 40% can be accomplished using the simulator which will see each pilot fly 150 hours and spend 85 hours in the simulator every year.

The first four need to be ready in the fall of 2017 and the remaining four in time for the first initial operational capability declaration in 2019.

The next phase of construction will include the hangars, maintenance hangars, a low-observable repair facility and the aircraft shelters referred to as 'hangarettes', which have two doors (front and back) that allow the aircraft to taxi in and out in one direction. The shelters will be arranged in a complex each separated by sufficient space to prevent a accident in one from affecting others and will be built in incremental lots.

Much of the F-35's maintenance will be performed in the shelters (phased maintenance is not required), leaving the main hangars for more complex work.

Norway's second F-35 unit, 332 Squadron, is expected to begin operations in 2021. A full operational capability declaration is forecast for 2025 when the Lightning II will assume every role currently held by the F-16 and provide additional missions.

Planning for the forward operating base at Evenes [Narvik], where the RNoAF will hold its quick reaction alert in the future, is also under way. "We have to build the facility up there to maintain 24/7 QRA with the F-35," said Svensson.

Tactical Advantages

Norway's sheer size presents the Air Force with significant challenges in range and the areas that it is regularly required to patrol. Today maritime and air patrolling tasks are undertaken by P-3 Orions based at Andoya Master Air Station and the F-16 force at Bodø and Ørland. When the F-35A enters service it will offer a step-up in capability for the patrol mission set because of its range and the sensor suite allowing an aircraft to cover a very large area, typical of those the Air Force currently patrols.

Lt Col Fongen explained: "The F-35 will be employed totally different to today because of the situational awareness it provides to each pilot in a four-ship, which will enable them to conduct the mission in a more efficient way.

"When we conduct formation flying with F-16s, pilots stick together for mutual support and this will be equally important in the future, but because of the F-35's technology and capability it will also be planned in quite a different way to the F-16.

One of the biggest aspects of the RNoAF's transition from F-16 to the Lightning II is the mindset change needed to fully understand how to utilise the capabilities of the F-35 correctly. Another challenge will be to train pilots each year to maintain their qualifications across the increased number of different mission sets of the F-35. "It won't be possible for a pilot to be fully qualified in all of the different mission sets at the same time: they will be partly qualified in everything instead," said Lt Col Fongen.



Detail: **A PGU-48 25mm APEX ammunition round**
Photograph: **Lockheed Martin**

Programme Directorship

Anders Melheim, Norway's F-35 Program Director joined the project in the summer of 2012 when the Norwegian Parliament decided its long-term plan. "We have unanimous agreement from all of the political parties in Norway and each one supports the acquisition of up to 52 aircraft, the choice of main operating base and the budget," he said.

Melheim has a team that continuously analyses the F-35 budget and makes recommendations on how to keep costs within budget and the Norwegian F-35 project running on time. This is his official strategy for managing risk. The budget and the project are both in line with the current forecasts, but they are not the most important issues. Implementing a sustainment solution in time for the first aircraft arriving in Norway in 2017 is the top priority. His ability to meet that need lies partly with Norwegian industrial participation in the F-35 programme.

Today, Aerospace Industrial Maintenance Norway, based at Kjeller, is already investing in constructing an engine maintenance depot.

This summer an RFI will be issued to all of the European partner nations so their defence industry can put together a bid. Once that process is complete each bid will be sent to the F-35 Joint Program Office (JPO) in Crystal City, Virginia for evaluation. The JPO staff will down-select what they consider to be the most cost-effective solution for sustaining aircraft and the engine in Europe. A down-selection is expected this year which is critical to completing the winning bidder's facility and putting it into operation in time for the arrival of the first F-35s in Norway in 2017. Just like the Italian Final Assembly and Check-Out and Maintenance, Repair, Overhaul & Upgrade facility at Cameri, the Norwegian engine maintenance facility will be built with the goal of providing the best ongoing value to the partnership.

"As a potential engine maintenance provider we will have to continuously offer best value throughout the service life of the aircraft and that's why we have to keep our costs down. If it's not best value, it's not best value," Melheim conceded "but remember best value is a combination of quality, delivering on time, skills, performance, and of course price."

European F-35 sustainment will be on the agenda of the next Joint Executive Steering Board meeting which will be in Oslo on September 25 and co-chaired by Norway.

Industrial participation by other Norwegian companies in the F-35 programme is already under way and is an important goal for the Norwegian Parliament. The goal is to get back the same amount of industrial revenue as the cost of buying the 52 aircraft over the course of their lifetime.

Kongsberg is the biggest Norwegian defence company currently participating in the F-35 programme. It is developing the JSM and producing composites panels (Lockheed Martin), parts for the centre fuselage (Northrop Grumman) and parts for pylons (Marvin Engineering); the company has a contract with each.

From the operator's perspective, Col Svesson expressed confidence in the 2008 decision made by the government, which he says has, "the best track record that other partner countries are envious of because we are so far ahead and so decisive in what we want to achieve". ***Mark Ayton***



Variant: **F-35A** Detail: **A Joint Strike Missile loaded on station 8 in the right hand weapons bay** Photograph: **Lockheed Martin**

Operational



Since the first F-35A arrived at Edwards Air Force Base, California, for the 31st Test and Evaluation Squadron (TES) on March 6, 2013, the Air Combat Command (ACC) unit has been busy preparing to start the initial operational test and evaluation (IOT&E) of the Joint Strike Fighter.

Currently commanded by Lt Col Brian O'Neill, the 31st TES is tasked with a variety of roles but is primarily responsible for the evaluation of the operational effectiveness and suitability of advanced weapon systems.

It provides operations, maintenance and engineering experts to work alongside Air Force Materiel Command (AFMC) and Air Force Operational Test and Evaluation Center (AFOTEC) personnel at Edwards. The squadron also provides early insight and influence during developmental testing of a variety of other USAF weapon systems.

Test and Evaluation Squadrons

In 2008 ACC assigned six F-35As to the 31st TES and made it the Air Force component of the Joint Operational Test Team (JOTT) based at Edwards.

"Our primary goal is to conduct the Block 2B IOT&E in 2015 to enable the Air Force to declare IOC in 2016 and get the first squadron [to be based at Hill Air Force Base, Utah] ready to provide combat capability and ready to deploy," Lt Col O'Neill told *AIR International* during a visit to the unit at Edwards.

Because of the concurrency approach to the Joint Strike Fighter development programme, the entire ACC F-35A fleet has to be modified for operational test and evaluation. This means the Block 2A F-35As originally assigned to the 422nd TES at Nellis Air Force Base will go to the depot at Hill for modification to Block 2B standard for redelivery to the 31st TES. Block 1B aircraft initially assigned to the 31st will be transferred to Nellis for use by the 422nd until their turn for modification comes around in time for the second rapid IOT&E testing routine.

This process will ensure the Air Force has enough jets and people at any one time to prepare for Block 2B IOT&E and development of tactics and techniques.

O'Neill explained: "After the Block 2B test period our jets will undergo modification to prepare them for Block 3F IOT&E in calendar [year] 2018, the

Test and Evaluation



Image Data

Variant:	**F-35A 09-5004/'OT'**
Unit:	**31st Test and Evaluation Squadron**
Location:	**Naval Air Station Joint Reserve Base Fort Worth, Texas**
Date:	**April 1, 2013**
Detail:	**Functional check flight**
Photographer:	**Carl Richards**

version that will provide combat capability. After Block 3F test, in accordance with the current plan, the F-35 division of the squadron will stand down and the aircraft and most of the manpower will go to the 422nd TES at Nellis."

Flight Testing

At the time of *AIR International*'s visit, the 31st TES was operating a fleet of four Block 1B LRIP 3 aircraft, the most basic configuration fielded at the time. Three were serviceable with a limited flight envelope and one temporarily grounded, so flight operations were limited. "The system is not terribly reliable – Block 1B has a lot of software glitches but that's a known risk reduction aspect of the programme," said O'Neill.

"Our biggest challenge right now is sortie generation. To reliably set a take-off time, and take off at that time, is a lofty goal for us. The instability of software makes it very difficult to launch aircraft on time.

He described some of the missions being flown from Edwards. "With stealth, carrying out an intercept is done a little bit differently to a legacy fighter so we practise a lot of single-ship intercepts – which leads into the development of tactics and more complex scenarios involving two-ship intercepts."

Basic surface attack missions are also flown. "We're already using the [APG-81] radar very successfully in synthetic aperture radar [SAR] mode to develop initial single-ship and two-ship tactics to find, fix, identify, and attack. Block 1B software allows us to simulate attacks with both a GBU-31 JDAM and a GBU-12 laser-guided bomb, though we can't actually carry and drop those weapons [with a Block 1B jet] – but it simulates them pretty accurately as best as we can tell.

"Missions usually involve a mix of 1 v 1 intercepts, air-refuelling upgrades, single-ship and two-ship basic surface attacks using SAR map and the EOTS [AAQ-37 Electro-Optical Targeting System] culminating in simulated GBU-12 and GBU-31 deliveries."

And the software instability of the Block 1B jets is also imposing limitations on the use of the AAQ-40 Distributed Aperture System (DAS). A Block 1B aircraft has only three, rather than the full suite of six cameras fitted, so the system can only be used by the 31st TES pilots on the ground. By comparison, the 422nd TES based at Nellis and equipped with Block 2A aircraft is not allowed to use DAS in the Gen II Helmet Mounted Display System [HMDS] because of inherent problems with the original design – now redesigned and expected



Variant: **F-35A 09-5004/'OT'** Unit: **31st Test and Evaluation Squadron** Location: **Naval Air Station Joint Reserve Base Fort Worth, Texas** Date: **May 17, 2012** Detail: **First flight**
Photographer: **Carl Richards**

to enter testing this year as the Gen III.

"It's a system that we [F-35 pilots] have a tendency to be impatient with because the Joint Helmet-Mounted Cueing System [JHMCS] currently in use with legacy aircraft is a very stable tool – but we ask a lot less of JHMCS than the current Gen II HMDS. Like other systems on the F-35, development of the HMDS has not reached a maturity level that most would like to see," said O'Neill.

Further complimenting the current HMDS, the boss told *AIR International*: "For the missions we [the 31st TES] are currently cleared to fly, the helmet [HMDS] is an 'absolute touchdown' in terms of working with and very accurately cueing the [APG-81] radar and the [AAQ-37] EOTS. I'm confident that when we start testing the AIM-9X [missile] and require high off-boresight cueing, it will be excellent for that."

Master Plan

An Edwards Air Force Base press release describes the mission of the 31st TES as 'formalised testing that will evaluate the production-representative F-35A, support equipment and the logistics supply system in an operationally representative environment; with the ultimate goal of determining whether or not the programme is suitable and effective in a real-world combat environment. It encompasses the aircraft's survivability, as well as the ability to support and execute flight operations and maintenance in the United States and at deployed locations.'

Operational test and evaluation of the F-35, including all versions of software (Block 2B and Block 3F), will be undertaken by the JOTT in accordance with the Test Execution Master Plan or TEMP, a 600-page document that describes in detail each mission set required by the US and international services involved. The mission sets are strategic attack, air-to-ground, suppression of enemy air defences, destruction of enemy air defences, close air support, armed reconnaissance, and air-to-air, including high-end counter air scenarios.

Lt Col O'Neill cited close air support as an example: "The test designers are very specific about how they want the aircraft to conduct each mission effectively and define all part-tasks to determine the aircraft's suitability. For example, in the close air support role, can the aircraft communicate to all the agencies that it needs to? Can it datalink with all the people it needs to? Can the pilots interact in their formation and with other aircraft in a way that's required? Can the sensors identify the target correctly, distinguish it from friendly forces and then put the bomb on the target in the time and manner required?"

Using the same example, test designers also consider which resources are required (tactical air controllers, forward air controllers or unmanned platforms) to determine how many F-35s will be required and prove, with adequate statistical rigour, the jet had an effective test and either passed or failed.

The colonel explained: "The test document defines, in great detail, all the test missions we will do. As the commander I've got to get all my pilots and maintainers trained for each of those missions – using the training syllabus and their respective expertise – and figure out how to make the aircraft operate tactically. Until we receive the more capable Block 2B aircraft, we have to continue that task with an aircraft that has airborne operating limits and lacks some of the tools required."

The Joint Program Office defines each block's capabilities, aerodynamic envelope and release date. F-35 developmental test squadrons (the 461st Flight Test and Evaluation Squadron based at Edwards and Air Test and Evaluation Squadron 23 [VX-23] at Naval Air Station Patuxent River in Maryland) currently receive a new release about 12 months before units assigned to the JOTT.

"Once we get to Block 2B test, the parity of the envelope, software and hardware will start to compress. By the time we start Block 3 we'll be six to nine months behind what the developmental test units are working on in terms of software and more advanced capabilities and have the full aerodynamic envelope," said O'Neill.

The build and developmental test of the F-35 ends in 2016 when the full envelope and initial mission systems capability should be ready for release to the JOTT in Block 3F. Subsequent capabilities will be evaluated as part of a mature operational test and evaluation process as opposed to the ongoing process run concurrently with developmental test during the System Development and Demonstration (SDD) phase.

JOTT Organisation

The IOT&E of Blocks 2B and Block 3F will be directed by the commander of the JOTT based at Edwards. When the Block 2B test begins the JOTT will comprise the 31st TES with six F-35As, a team from the Royal Netherlands Air Force with two F-35As, Marine Operational Test and Evaluation Squadron 22 (VMX-22) with six F-35Bs, and the Royal Air Force's No.17(R) Test and Evaluation Squadron with three F-35Bs. Test designers, managers and graders are assigned to the JOTT from AFOTEC, the US Navy's Operational Test and Evaluation Force (OPTEVFOR) and the UK Air Warfare Centre.

Under the programme, the US Navy's F-35C is not required for the Block 2B test: the first phase





Variant: **F-35A 11-5021/'OT'** Unit: **31st Test and Evaluation Squadron**
Location: **Naval Air Station Joint Reserve Base Fort Worth, Texas**
Date: **November 11, 2013** Detail: **Functional check flight**
Photographer: **Scott Fischer**



Image Data

Variant:	**F-35A 09-5007/'OT'**
Unit:	**31st Test and Evaluation Squadron**
Location:	**Edwards Air Force Base, California**
Date:	**June 14, 2013**
Detail:	**Pilots and 16 crew chiefs following a recognition ceremony in Hangar 1810**
Photographer:	**Jet Fabara/US Air Force**

involving Navy aircraft will be Block 3F when a detachment from Air Test and Evaluation Squadron 9 (VX-9) 'Vampires', based at Naval Air Weapons Station China Lake, will join the JOTT.

Until then Navy personnel will be involved in managing the Block 2B testing.

Maintainers and Pilots

The 31st TES has 150 personnel involved in the F-35A IOT&E, many of whom, including maintainers, underwent training with the 461st Flight Test Squadron at Edwards (see *Tail End of the Whip* p80-95) or the 58th Fighter Squadron at Eglin Air Force Base, Florida (see *Fire From the Sky* p116-123). O'Neill explained: "The maintainers all started their training at Eglin on Block 1 aircraft and typically begin their tour with the 31st TES qualified to Air Force 3 skill level. We then get them certified to 5 and 7, as appropriate for their rank and responsibility."

The current pilot cadre on the 31st TES comprises five F-16C, one A-10C and two F-15E pilots, all selected by an Air Force board. Four are graduates of the US Air Force Weapons School and two previously flew with the 422nd TES at Nellis in operational test and evaluation roles.



Variant: **F-35A 09-5005/'OT' and 09-5006/'OT'** Unit: **31st Test and Evaluation Squadron** Location: **Edwards Air Force Base, California** Date: **March 6, 2013** Detail: **Arrival of first two aircraft for the 31st TES** Photographer: **Laura Mowry/US Air Force**

Flying the F-35

"Flying the F-35? It's a piece of cake, a very easy aeroplane to fly," enthused Lt Col O'Neill. "Trainer aircraft like the T-37B Tweet and T-38A Talon bestow a high workload on the pilot. By comparison the workload in an F-16 is much less for the amount of combat capability available. That said, your systems knowledge of the F-16 has to be very, very high to handle mechanical problems and emergency procedures. And because the sensors integrated on the F-16 during its service life are not fused, the pilot's workload has crept up over the years.

"Well, the F-35 really alleviates the pilot's workload because things are fused from the word go. When you read the tech data, especially about some of the emergency procedures, it explicitly states the aircraft is designed to reduce the pilot's workload during emergency procedures – and I don't need the knowledge of wiring diagrams and systems required in the F-16.

"I like how the autopilot features, specifically the auto throttle, which frees up brain power and allows me to fly the jet without having to worry about



Image Data

Variant:	**F-35A 09-5005/'OT'**
Unit:	**31st Test and Evaluation Squadron**
Location:	**Naval Air Station Joint Reserve Base Fort Worth, Texas**
Date:	**January 16, 2013**
Detail:	**Overshoot following functional check flight**
Photographer:	**Scott Fischer**



Variant: **09-5006/'OT'** Unit: **31st Test and Evaluation Squadron** Location: **Edwards Air Force Base, California** Date: **March 6, 2013**
Detail: **One of the first two aircraft for the 31st TES on the flight line after arrival** Photographer: **Laura Mowry/US Air Force**

some of the basic aviation tasks. Pilots are going to find the workload is pleasantly lower, which I'm sure will continue to some degree as more systems are released. But all that goes to say is it's a very enjoyable and easy-to-fly aeroplane."

Summing up his role as the 31st TES commander, Lt Col O'Neill said it was good to have a defined mission to test and clear F-35 combat capability ready for the first combat-coded squadron at Hill by December 2016. "I'm blessed with a very experienced and mature team across the board: engineers, maintainers and pilots."



Musterek

Image Data

Variant:	F-35A AF-06
Unit:	461st Flight Test and Evaluation Squadron
Location:	Over California
Date:	January 18, 2012
Detail:	The first night flight for the F-35 Joint Strike Fighter
Photographer:	Tom Reynolds/Lockheed Martin



With one of the largest combat aircraft inventories in NATO, the Turk Hava Kuvvetleri (THvK or Turkish Air Force) is currently undergoing an extensive reorganisation and modernisation process. The force has a fleet of 240 Lockheed Martin F-16C and F-16D Fighting Falcons, and 70 McDonnell Douglas F-4 Phantoms comprising F-4E 2020 Terminator interdiction/strike and RF-4ETM Isik reconnaissance versions.

Providing and sustaining Turkish national security has never been an easy task. The country has been struggling with separatist terrorism since 1984: its location is close to nations and regions that are plagued with disputes and wars. There is the eternal rivalry with fellow NATO member Greece over several different issues, civil war in Syria, turmoil in Iraq, concerns about a potentially nuclear-armed Iran, a series of territorial disputes between nations in the Caucasus region, and more recently the crisis in Ukraine. The result: a huge shopping list for military modernisation and a prioritising of efforts to establish a local defence industry.

Turkey's economic performance over the last decade is funding ambitious procurement programmes and support for indigenous defence projects. Implemented by the country's procurement agency, the Savunma Sanayii Mustesarligi (SSM or Under Secretariat for Defence Industry), the projects cover almost all aspects of the armed forces. Much focus has also been given to multi-national projects as a means of gaining experience and technology. The Lockheed Martin F-35 Lightning II – in Turkey designated the Musterek Taarruz Ucagi (MTU or Joint Strike Fighter) – is at the top of this list. The MTU was selected as the new-generation fighter aircraft for the THvK by the Defence Industry Executive Committee (DIEC) and announced on December 12, 2006. However, an order for the first two aircraft is yet to be signed.

Background

The delivery of 30 Block 50+ F-16Cs supplied under the US Peace Onyx IV programme was recently completed, and the rest of the F-16 fleet is receiving extensive avionics and weapon system upgrades under the programme named Peace Onyx III. Except for the final 30 Block 50+ examples, the F-16 fleet was procured between 1987 and 1999. Of these, about 35 Block 30s are the oldest, and are expected to be retired in the mid-2020s.

The F-16 fleet is augmented by 49 F-4E 2020 Terminators which perform precision strike and interdiction missions. At least 20 RF-4ETM Isik (Light) tactical reconnaissance aircraft are operated by the 173 Filo based at 7ncu AJU (Ana Jet Ussu or Main Jet Base) in Malatya. These aircraft will be retired in the 2015-2016 timeframe, handing over their mission to the UTC DB-110-equipped Block 30 F-16s of 4ncu AJU in Ankara. The Terminator fleet is due to be retired in the early 2020s so the THvK has a requirement for a new strike fighter primarily tasked with the air-to-ground mission to enter service at that time: the main reason for Turkey's interest in the F-35A Lightning II.

Prior to the DIEC meeting on December 12, 2006, Turkey had evaluated several other types. A Request for Information (RfI) was issued by the SSM in 2005 to Eurofighter, Lockheed Martin and Boeing for 120 aircraft. Italy's Alenia Aermacchi, which led the Turkish bidding campaign, pitched the Typhoon as a supplement to the F-35 with an emphasis on air-to-air missions, rather than as a direct competitor. THvK pilots flew evaluation sorties with an Italian Air Force Tranche 1 version in 2005. The results were not made public but it was widely reported that the THvK was not satisfied with the balance between Typhoon's cost versus its capability.

Alenia Aermacchi made one final attempt during the IDEF 2011 exhibition, offering the Typhoon Tranche 3 version in full swing-role configuration, but to no avail. The decision was made to go with a combination of F-16 and F-35, and an order for 30 Block 50+ F-16s was given in 2007 as attrition replacements and a gap filler until Peace Onyx III was completed. This was followed in 2010 by a decision to initiate a project for indigenous development of a next-generation fighter under Project FX. The conceptual design phase, which had been supported by Saab of Sweden, was concluded in 2013. It is reported that the FX fighter, which will focus on air-to-air capabilities will replace the F-16 fleet in the long term, to operate alongside the F-35.

Turkey's F-35 Programme

Once the F-35 had been selected for the THvK's next-generation fighter, negotiations began for the

Taarruz Ucagi



purchase of 100 aircraft. The initial plan was to order six F-35As built in Low Rate Initial Production lot 6 (LRIP 6) which could be used for training. This was then shifted to the LRIP 7 lot. The aircraft were to be deployed to Eglin Air Force Base, Florida in 2015. At a DIEC meeting in January 2012 the number was reduced to two aircraft and the SSM placed a $240 million order for two LRIP 7 F-35As. The contract was then cancelled in January 2013 because of a disagreement over the integration of indigenous weapons, the establishment of two facilities: an F-35 National Integrated Training Centre and an F135 engine Final Assembly and Check Out (FACO) facility.

The negotiations proved positive and in May the DIEC authorised the SSM to buy two F-35As in Block 3F configuration from the LRIP 10 lot. Additionally, the SSM is now tasked with supervising the establishment of the FACO line and maintenance centre for the F135 engine within the structure of local industry and the Turkish Air Force. The ultimate aim is to offer services at the facilities to all F-35 users around the region. The overall procurement period for Turkish F-35s is intended to last ten years.

Transformation

The F-35 MTU will form the backbone of the THvK strike force with its fleet of F-16s and eventually with the FX. By the end of this decade the F-35A will start to replace the F-4E 2020 Terminator, and the first squadron to re-equip is reportedly 172 Filo at Malatya, a former F-4ETM unit that was disbanded in April 2009. The second unit will be 171 Filo also based at Malatya, which is expected to transfer its remaining F-4E 2020s to 1ncu AJU Eskisehir-based 111 and 112 Filos, which will eventually transition to the F-35A. No.132 Filo, based at 3ncu AJU in Konya, will be the last unit to receive the type.

The Integrated Training Centre, which will be jointly operated by the THvK and local defence contractors, is planned for 7ncu AJU in Malatya. Maintenance and repair operations are to be co-ordinated by Turkish Aerospace Industries, which represent the 1st, 2nd and 3rd Air Supply and Maintenance Centres of the THvK. Their respective commands are in the process of modernising the infrastructure to meet the Performance Based Logistics paradigm of the JSF project.

Turkish Weapons

The Turkish defence industry is developing indigenous guided weapon systems for a wide range of applications: air-launched weapon systems are a top priority. One of the most important projects is the air-launched SOM (stand-off missile), designed and developed by TÜBİTAK-SAGE (the Scientific and Technological Research Council of Turkey and the Defense Industries Research and Development Institute), and manufactured by Roketsan.

The SOM uses INS/GPS guidance, terrain-following radar, infrared imaging and target recognition systems, has a declared range of more than 250km (135nm), and is currently certified for F-4E 2020s and Block 40 F-16s. A new version, modified for internal carriage in the F-35 weapon bays under the SOM-J programme has already been test fired from F-16s, and deliveries to the THvK should start this year.

The first Turkish-designed precision-guided weapon to be certified for the F-35 was the Hassas Gudum Kiti (HGK), an INS/GPS guidance kit developed for 2,000lb (907kg) Mk84 general purpose bombs. Visually similar to the Joint Direct Attack Munition, the HGK does have differentiating components: all four fins move to provide trajectory correction and it is compatible with the Universal Armament Interface. The HGK has been added to the F-35 inventory under Block 4.

Other derivatives of the HGK based on the 500lb (227kg) Mk82 and 1,000lb (454kg) Mk83 general purpose bombs have also been designed and developed by TUBITAK-SAGE. Both are manufactured by Aselsan for the THvK F-16C/D and F-4E 2020 fleets.

A version equipped with a wing kit, called the Kanat Gudum Kiti (KGK) is also being developed with a range of around 100km (54nm).

Local Participation

Turkey officially became a partner in the F-35 programme at the Concept Demonstration phase with the signing of a Letter of Acceptance worth $6.2 million in 1999. This was followed by the signing of Memorandum of Understanding agreements on July 11, 2002 to become a Tier 3 partner in the System Development and Demonstration phase, and on January 25, 2007 in the Production, Support and Follow-on Development phase. The Letter of Intent covering



Image Data

System: **SOM Air-Launched Cruise Missile**

Detail: **A derivative of the SOM ALCM is being developed for the F-35 under project SOM-J**

Image: **Roketsan**

business opportunities for Turkish Aerospace Industry (TAI) was signed between the SSM and Lockheed Martin on February 6, 2007. The total value of Turkish work share in the F-35 programme is estimated to be as high as $12 billion.

Ten Turkish aerospace and defence companies are partners in the project. Alp Aviation is producing airframe structures and assemblies, landing gear components and titanium integrated blades for the F135 engine. Aselsan is developing manufacturing techniques for components used in the AAQ-40 Electro-Optical Targeting System. The company is also working with Northrop Grumman on the interface controller for the Communications, Navigation and Identification avionics. Aselsan subsidiary Mikes is producing components for the electronic warfare system. AYESAS is the sole-source supplier for the missile remote interface unit and the Panoramic Cockpit Display. Fokker Elmo is manufacturing parts for the Electrical Wiring and Interconnection System as a subcontractor to TAI. HAVELSAN is developing an integrated training system for the THvK, while Kale Aerospace is producing airframe structures and assemblies. The latter also supports Héroux Devtek as the sole-source supplier for landing gear lock assemblies for all three variants of the F-35. Additionally, Kale Aerospace has established a joint venture in Izmir with Pratt & Whitney to manufacture hardware for the engine. Roketsan and TÜBİTAK-SAGE oversee the weapons integration, while TAI manufactures and assembles centre fuselages, produces composite skins and weapon bay doors, and manufactures composite air inlet ducts. Additionally, TAI is strategically manufacturing almost 50% of the F-35's Alternate Mission Equipment including air-to-ground pylons and adapters. TAI has also been assigned to represent the organic depots of the Turkish Armed Forces within the Autonomic Logistic Global Sustainment system.



System: **SOM Air-Launched Cruise Missile** Detail: **The SOM uses INS/GPS guidance, terrain-following radar, infrared imaging and target recognition systems, and has a declared range of more than 135 nautical miles** Photographer: **Arda Mevlutoglu**



System: **Hassas Gudum Kiti** Detail: **The Hassas Gudum Kiti is a 2,000lb-class weapon comprising an INS/GPS guidance kit fitted to a 2,000lb Mk84 general purpose bomb** Photographer: **Arda Mevlutoglu**

(No) Controversy?

With a requirement for 100 F-35As and speculation over an option for up to 20 more, Turkey may eventually operate one of the largest fleets of F-35s after the US. Interestingly, the procurement process has produced little, if no public debate, unlike the well-documented controversy in Australia, Canada and the UK. The only major concern in Turkey has been access to software codes and the capability to integrate indigenous weapons and mission systems on the aircraft. The THvK is seen as fully committed to the aircraft, showing the F-35 as part of its future vision in almost all documents, presentations and even on posters, though no official order has been given yet. ***Arda Mevlutoglu***


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Image Data

Variant:	**F-35A 10-5010/'OT'**
Unit:	**422nd Test and Evaluation Squadron**
Location:	**Nellis Air Force Base, Nevada**
Date:	**June 27, 2013**
Detail:	**F-35A 5010 departs Nellis from runway 21L on a tactics evaluation mission**
Photographer:	**Paul Ridgway**



In sweltering heat, two US Air Force pilots walked to their jets to crew-up in preparation for a mission from Nellis Air Force Base, Nevada. Their mission: to fly with F-15C Eagles, F-15E Strike Eagles and F-22 Raptors. The objective: to develop basic tactics, techniques and procedures (TTPs). Their aircraft: F-35A Lightning IIs.

Nellis Testers

The pilots, Lt Col Ben Bishop, commander of the 422nd Test and Evaluation Squadron 'Green Bats', and Lt Col Derek O'Malley, commander of the 59th Test and Evaluation Squadron (TES) 'Golden Lions' are both assigned to Air Combat Command's 53rd Wing. Their respective squadrons differ in tasking but share a common goal, the operational test and evaluation of the F-35A Lighting II for the US Air Force.

The 59th TES is part of the 53rd Test Management Group which is responsible for planning, scheduling resources, developing support plans and agreements, monitoring and assisting in execution, gathering data, analysing data, preparing and publishing reports, fielding recommendations and interim documents for force development evaluations, tactics development and evaluations and operational assessments within the 53rd Wing.

The 422nd TES is part of the 53rd Test and Evaluation Group which is responsible for the overall management of the 53rd Wing's flying activities at eight different locations including Nellis which conducts operational test and evaluation, tactics development and evaluation projects for Headquarters Air Combat Command at Langley Air Force Base, Virginia.

Green Bats and the F-35

Lt Col Bishop described the 422nd TES mission as figuring out how to use new technologies through the operational test process, developing TTPs and then introducing them to the warfighter and instructing Combat Air Force squadrons.

The 422nd TES is a unique squadron: it is the only US Air Force unit that has all major design series (MDS) fighter aircraft assigned. Its 42-aircraft fleet, used for operational test and tactics development, comprises A-10C Thunderbolt II, F-15C Eagle, F-15E Strike Eagle, F-16C Fighting Falcon, F-22 Raptor and its latest acquisition the F-35A Lightning II.

However, the squadron mission is not limited to determining how tactics work in each particular aeroplane but how they integrate with all US Air Force MDS aircraft in the air, under command and control and within a joint environment.

"We have six F-35As assigned to support initial operational testing evaluation of the F-35 which is led by the 31st TES based at Edwards Air Force Base. It's the F-35 division's job to support by providing tactics development of the aircraft," said Bishop.

The 422nd is currently flying the aircraft to build the basic operational skill set. He added: "We are being asked to write the book about how to use it, which means developing the TTPs. This begins with basic processes: how do you use the radar, what are the tactics for basic surface attack, how do you employ the weapons off the aeroplane?"

Initial Operational Capability

The Air Force plans to declare F-35A initial operational capability in 2016. Prior to that declaration the 422nd TES has to develop tactics for basic close air support, limited suppression and

Lightning DIVISION



destruction of enemy air defences in a contested environment and also the air interdiction mission.

"In order to complete each mission, basic skill sets are required, for example, dropping a laser-guided bomb off the jet, what is the best way to do that and what does that process look like in this aeroplane," cited Lt Col Bishop.

"Our job is to record and enter them into test reports. Those test reports are used by the 31st TES during IOT&E [initial operational test and evaluation] and by the 58th Fighter Squadron at Eglin – remember that a lot of what they [the 58th FS] are teaching, they're making up as they go. It's our job as part of the tactical development piece to provide them with the lessons we learn."

Equipped with a suite of brand new mission systems, none of which have been previously operated, the F-35 requires the pilots and maintainers assigned to the 422nd TES to learn about each one to be able to execute its job and do so in time for IOT&E.

"It's a difficult problem. We all went through the training programme with the 58th Fighter Squadron at Eglin, which taught us a lot about the systems. But a lot of it comes from working with people in the operational test community and the various contractors to learn how the system works and, of course, flying it to see how it performs and more importantly debriefing and sharing that information and data, which is all part of the test process," said Lt Col Bishop.

Missions are conducted in accordance with a test list that gives the priority and direction required for each event. It is provided by test directors assigned to both the 53rd Wing at Eglin and the Air Warfare Center at Nellis, and integrated with the Joint Operational Test Team at Edwards.

Lt Col Bishop was in no doubt he has the resources required – sufficient aircraft configured to the right standard, trained pilots and maintainers – to enable the unit to accomplish the operational test mission and get it off the ground.

"Since we started our flying operations on April 6, 2013 we are taking small steps, starting with the basic skill sets and building up the tactics, techniques and procedures required for the airframe. There's no huge ramp-up, it's more of a methodical, planned process to meet our desired goals. To accomplish that, we will use all of our other aircraft types to integrate across the six major design series [A-10C, F-15C, F-15E, F-16C, F-22] assigned and determine how the F-35 fits into the bigger part of the picture.

Operationally Representative

When *AIR International* visited the 422nd TES all six of its F-35As were loaded with Block 2A software. Since then the aircraft have been upgraded to Block 2B, the standard required by the US Air Force for its initial operational capability declaration in 2016, and will be upgraded next with Block 3I.

Based on the current immaturity of the F-35 as a weapon system, how is the 422nd TES mitigating against that with the work it is conducting? "The first part of the test process is finding things that need to be improved. Every aeroplane that comes on board has had initial problems and fixes are developed that allow the test effort to continue. As we look at the F-35, its IOC and the capabilities we [the US Air Force] are shooting for in 2016, I have full confidence that we will be able to make that goal.

"At this point I wouldn't say there's anything below par but what I can say is that it is a very immature aeroplane and there are going to be challenges that we will encounter as we continue the operational test



Image Data

Variant:	**F-35A 10-5009/'OT' and 10-5010/'OT'**
Unit:	**422nd Test and Evaluation Squadron**
Location:	**Nellis Air Force Base, Nevada**
Date:	**March 6, 2013**
Detail:	**First F-35As taxi to parking after arrival at Nellis Air Force Base**
Photographer:	**Kevin Robertson/Lockheed Martin**

process. Right now as far as developing the tactics, techniques and procedures to support the basic missions for initial operational capability [close air support, SEAD, DEAD and interdiction] go, we are able to complete that task.

"The basic tactics, techniques and procedures are the cornerstone that everything else will build upon so when we do advanced capability with Block 3F software they will be based on the skill sets that we use now. We will continue to develop the TTPs as the technology continues to mature and the systems become more robust, but nothing is going to get thrown away."

The squadron remains busy. It continues to test the aircraft and its mission systems in operationally representative scenarios both individually and as part of the integrated suite of systems for full sensor fusion.

"The TTPs we develop will use the aircraft's full range of capabilities. Some tests specifically require

PILOT LADDER STOWAGE



Variant: **F-35A 10-5009/'OT'** Unit: **422nd Test and Evaluation Squadron** Location: **Nellis Air Force Base, Nevada** Date: **June 27, 2013** Detail: **An airmen stows the crew access ladder on F-35A 5009** Photographer: **Paul Ridgway**



individual systems, others require coordination of those systems. It depends on what the test objective is," explained Lt Col Bishop.

Data Lab

To support the F-35 mission at Nellis, the Air Force has opened a 23,000 square foot facility at a cost of approximately $4.6 million in renovations and new equipment.

The new lab, run by the 59th TES, was opened on February 8, 2013 to accommodate the F-35A Lightning IIs and the existing F-22 Raptors. Originally the facility was built for the F-22, but it could not support the servers or power distribution required for the F-35 and had insufficient space for both types.

Two important sections, the data lab and flight-test instrumentation, are housed at the facility, which is a key component for the capture and analysis of flight data, down-linked by telemetry pods carried by the aircraft during each airborne test event. Data captured will assist in perfecting the TTPs used by squadrons assigned to the Combat Air Forces.

"F-35s and F-22s produce an amazing amount of data, and our lab allows us to harness that information to produce combat capability for the warfighter," said Lt Col Malley.



Variant: **F-35A 10-5009/'OT'** Unit: **422nd Test and Evaluation Squadron** Location: **Nellis Air Force Base, Nevada** Date: **June 27, 2013** Detail: **A crew chief hands the pilot his crew bags in F-35A 5009 at Nellis** Photographer: **Paul Ridgway**

Maintenance

Chief Master Sergeant Michael Prah is the superintendent with the 422nd TES F-35 Aircraft Maintenance Unit (AMU). He and his team spent more than two years preparing for the first F-35As to arrive at Nellis on March 7, 2013.

He explained that the AMU's training programme was challenging from the start. "We sent most of our folks to the school house [at Eglin] where they received instruction on ALIS [version 1.02 at the time] and took the interactive course. This was good for the apprentices but less so for my technicians and managers because they didn't gain any certification," he said.

Those requiring certification were embedded within test squadrons at places such as Pax River, to work with military maintainers and gain



Variant: **F-35A 10-5010/'OT'** Unit: **422nd Test and Evaluation Squadron** Location: **Nellis Air Force Base, Nevada** Date: **June 27, 2013** Detail: **A pilot, wearing the Gen II Helmet-Mounted Display, checks his communication channel with the crew chief in F-35A 5010 at Nellis** Photographer: **Paul Ridgway**



Variant: **F-35A 10-5010/'OT'** Unit: **422nd Test and Evaluation Squadron** Location: **Nellis Air Force Base, Nevada** Date: **June 27, 2013** Detail: **F-35A 5010 taxies from the sun shelter at Nellis** Photographer: **Paul Ridgway**

certifications, and learn from Lockheed Martin personnel to gain direct insight into the Joint Technical Data (JTD).

"We were also missing the execution piece from the school house so our troops then embedded with the 33rd Fighter Wing's Maintenance Group at Eglin to gain that," said the superintendent.

Despite the challenges, AMU maintainers successfully generated its first F-35 sortie on April 4, 2013 and did just enough to successfully 'catch the jet' and turn it post-flight. Oversight was provided by field service engineers from Lockheed Martin, Northrop Grumman and Pratt & Whitney.

The mission debrief was also very challenging simply because the book had yet to be written on how to perform the download and data processing. Lockheed Martin provided specialists but the issue was one of application versus execution, as CMSgt Prah explained: "The application component was there, somewhat, but the execution piece didn't match. When the two came together there were issues. How do we load the Aircraft Memory Devices [AMDs], Portable Maintenance Devices [PMDs] and flight data. The data must be pristine, if there is a mismatch the aeroplane does not cooperate, it is geared for pristine data in and pristine data out. Using the AR procedure and a lot of calls we were able to work through problems with loading data to the aeroplane, AMDs and the PMDs".

So if the aeroplane is deployed in a far off field with a long logistics chain and issues arise, is the dependency on ALIS likely to prevent a mission go? "That's why we are here today. Our charter is to vet the issues, to fix the problems so that when the jets get combat coded two or three years down the line and deploy out, they have an aeroplane that is code one," Prah replied.

I was interested to know how the aeroplane differs to an F-16 or an F-15 to turnaround and perform work on the flight line, and whether the aircraft gives maintainers easier accessibility to systems in the weapon bays. "Everything is pretty much covered up. You plug the PMD into the aeroplane, run a check and inspect everything during a walk around and it's done. Very simple. There is limited accessibility in the weapons bays and absolutely none if it's LO intrusive meaning we have to remove a panel to access what we need to reach. That then requires restoration after the panel is re-fitted which takes more time, reduces aircraft availability and lowers aircraft generation sustainment". LO refers to the aircraft's low observability characteristics.

Maintenance on actuators for the flight control surfaces has improved. F-35 actuators

Image Data

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Detail:	**First F-35As on arrival at Nellis Air Force Base**
Photographer:	**Kevin Robertson/Lockheed Martin**



Variant: **F-35A 10-5010/'OT'** Unit: **422nd Test and Evaluation Squadron** Location: **Nellis Air Force Base, Nevada** Date: **June 27, 2013**
Detail: **A pilot, climbs up the crew access ladder of F-35A 5010 at Nellis** Photographer: **Paul Ridgway**

have self-contained hydraulics which eliminates the requirement to run the hydraulics from a reservoir or a pump located 20 feet away from the unserviceable actuator and eliminates chafing of and leaks from the hoses during the procedure as is the case on legacy aircraft.

The AMU troops are getting a feel for the aeroplane, learning how to fix maintenance write-ups and the squadron is achieving a good sortie rate. "Every day brings something new," said CMSgt Prah. "Today one of the jets fell over because of an issue with the Propulsion and Thermal Management System (PTMS). It controls the hot air that comes out of the engine high-speed valve, which replaces an aircraft cooling system that in legacy jets uses air flow. It was the first time we have dropped a sortie because of that fault.

"There are systems that are go and some that are no-go. If you do a BIT (built-in test) and the PTMS issue comes up and it can't be resolved following another BIT then it's a no go. But that kind of issue is expected because we are very new to this aeroplane. Yet, after 25 sorties we only had a handful of ground aborts, which is phenomenal and better than my expectations". ***Mark Ayton***







Fire from the Clouds

The 33rd Fighter Wing 'The Nomads' has been based at Eglin Air Force Base in Florida since April 1, 1965 and tallied two MiG kills during the Vietnam War. The first was a MiG-19 shot down by Major Philip Handley and his WSO, Lt John Smallwood, using the M61 cannon on their F-4E Phantom in what was the first aerial victory by a Tactical Air Command unit.

The second was a MiG-21 shot down by a F-4E flown by Capt Lawrence Richard, US Marine Corps, and his WSO, Lt Cdr Michael Ettle, US Navy, with an AIM-7 Sparrow air-to-air missile. Both crews were assigned to the 58th Tactical Fighter Squadron 'The Gorillas'.

The wing's greatest tally was earned during Operation Desert Storm. At 0310 Baghdad time on January 17, 1991, Capt Jon Kelk scored the first aerial kill of the war, destroying a MiG-29 with an AIM-7 missile. Shortly after, Capt Robert Graeter downed two Iraqi Mirage F1s for the war's second and third kills. Later that day, Capt Rhory Draeger and Charles Magill, US Marine Corps, intercepted and destroyed two MiG-29s west of Baghdad. The Nomads scored 16 aerial victories during the conflict.

During Desert Storm the 33rd Tactical Fighter Wing comprised three Tactical Fighter Squadrons – the 58th, 59th and 60th – each equipped with 24 F-15C and F-15D Eagles. Two units are long gone – the 59th was inactivated on April 15, 1999 but reactivated as a Test and Evaluation Squadron based at Nellis Air Force Base, Nevada on December 3, 2004; and the 60th was placed in 'caretaker status' on January 8, 2009.

The loss of the 60th meant one of the primary fighter wings in the US Air Force now consisted of just one squadron, The Gorillas, in accordance with a plan released in a report by the Department of Defense 2005 Base Realignment and Closure Commission. The report directed divestment of the Nomads' F-15Cs and establishing the 33rd FW as the host unit for the Integrated Training Center of the future F-35A Lightning II. On March 20, 2009, a groundbreaking ceremony was held for the new mission, and the wing's final three F-15s departed Eglin on September 8.

Further organisational changes followed on October 1 when the 33rd FW transitioned from Air Combat Command to Air Education and Training Command and from Ninth Air Force to Nineteenth Air Force. F-35 programme delays meant the 33rd FW remained without any assigned aircraft from September 9 that year until January 13, 2011 when four F-16C Fighting Falcons arrived at Eglin on loan to the wing from the 56th FW at Luke Air Force Base, Arizona.

The first F-35A Lightning II, 08-0747/'EG', was flown to Eglin by the 58th Fighter Squadron Director of Operations Lt Col Eric Smith on July 14, 2011. Formal training for pilots and maintainers began in March 2012.

Gorillas on the Emerald Close

"We started flying in March 2012 and I made my first flight, as the first non-developmental test pilot from all three services to fly the F-35, in May," said Lt Col Lee Kloos, the then 58th Fighter Squadron commander.

Through the summer of 2012 the Gorillas received more F-35A aircraft from Lockheed Martin's Fort Worth production plant, enabling its pilots – all board-selected, with hundreds of flight hours – to gain experience flying the F-35A.

On September 10, 2012 the 33rd FW started its Operational Utility Evaluation (OUE), an official assessment of the wing's ability to train F-35 pilots. "Prior to the evaluation we were in a no man's land of what to do in respect of qualifying pilots to fly the F-35, so the CTOL IP Checkout, or CIPC, was devised and we went through two to form the initial cadre of instructor pilots for the evaluation and wrote an entire training syllabus covering academics, simulators and flights, ready for the OUE," said Lt Col Kloos.

"Four 58th FS pilots, each with a different level of experience on the F-35, followed the training syllabus to allow a team from the Joint Operational Test Team (JOTT) based at Edwards Air Force Base, California, to evaluate every process – from the day they checked into Eglin, through the academics, simulators and flights, all within specific time constraints. A second team from the Air Force Operational Test and Evaluation Center (AFOTEC) assessed the JOTT team on its evaluation capability."

A report, written by both teams, was submitted to General Rice, who was then commander of Air Education and Training Command based at Randolph Air Force Base, Texas, with a recommendation to declare the squadron ready for training – the official blessing of the 58th Fighter Squadron as an F-35A Formal Training Unit.

First Baseline Course

Unlike the CIPCs and the OUE, which were run using a Block 1A syllabus, the first post-OUE class in January 2013 used the Block 1B syllabus. This matched the configuration of the squadron's aircraft at the time. It was referred to as a Small Group Try Out for the 1B syllabus and used the additional aircraft capabilities gained with Block 1B, but with little change to the syllabus content.

As with all F-35s flown by non-developmental test units during the type's System Development and Demonstration (SDD) phase, the 58th's pilots were constrained by software and the aircraft's limited flight envelope.

Kloos explained: "As a pilot you get an upgrade for each new release of software which includes academics with an instructor, a simulator and a flight. As new capabilities are added, you take a training upgrade approved by the 33rd Operations Group commander. The simulators are also continuously upgraded and updated, but are not constrained by the envelope restrictions in place on the aircraft – so

Image Data

Variant:	**F-35A 09-5003/'EG'**
Unit:	**58th Fighter Squadron**
Location:	**Over the Gulf of Mexico**
Date:	**December 5, 2012**
Detail:	**Proficiency training flight**
Photographer:	**Jim Haseltine**



Variant: **F-35A 09-5003/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **Take-off at Eglin** Photographer: **Jim Haseltine**



Variant: **F-35A F-002** Unit: **Royal Netherlands Air Force/58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Aircraft F-002 taxies into position for hot pit refuelling** Photographer: **Paul Ridgway**

the pilot must be mindful of that and not exceed restrictions when using a simulator."

The short CIPC and OUE courses comprised 100-plus hours in the classroom, 15 simulators and six flights. The Block 1B syllabus is flown with additional aircraft capability, more academic classes and two extra flights. Block 2A and beyond adds data link, sensor fusion and mission capabilities with a bigger flight envelope.

Describing the course Lt Col Kloos told *AIR International*: "It's very intensive: how does the aircraft work, how do I handle the systems, how do I take off and land, what are the aircraft's handling characteristics, how do I follow basic instrument procedures? It's designed to make cockpit and operating procedures second nature specifically for the pilots that will perform the F-35's operational test and evaluation. It's a bit of a reversal to the traditional training approach."

The method used to prepare a student for their first flight is understandably thorough. Each pilot makes the flight with an instructor pilot, already airborne, who then commands the student to take off and perform what's known as an airborne pick-up by flying into a chase position with him.

Much of the first flight is centred on getting a feel for the handling of the aircraft, and includes basic manoeuvres before returning to the pattern to practise touch-and-goes to ensure everything learnt in the simulator transfers well. More tasks are added in the subsequent five sorties.

"When we built the syllabus we took a recommendation from the F-22 community to include a taxi event between the final simulator and the first flight. This is designed to take a lot of the nervousness out of operating the aircraft for the first time – becoming familiar with all the sounds and the nuances you may not be accustomed to, and without the pressure of meeting the airspace slot time," said Kloos.

"Strapping into the F-35 is completely different to legacy fighters because of the flight gear used. We combine all of those aspects in the taxi event. An instructor is plugged in on a headset, goes through the start up checklist and gets him [the student] out of the blocks to taxi; he taxies down to the end of the runway, runs the power up and returns to parking to go through the whole shutdown check. We found this provides a lot of utility and prepares him for that first flight."

Classroom

When a student arrives at the Academic Training Center (ATC) they are issued with a laptop that provides full access to flight series data and a description of how things work in the F-35. It also has the academic classes loaded and provides interaction with the training systems. The laptop is returned when they leave the ATC for flight operations.

Some classes use interactive courseware which the student works through by clicking selections and learning by interacting with the computer; other



Variant: **F-35As 08-0751/'EG', 08-0749/'EG' and 09-5002/EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **F-35As parked inside one of the hurricane-proof hangars** Photographer: **Jim Haseltine**



Variant: **F-35A 11-5022/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014** Detail: **An airman removes the cap from the refuelling line** Photographer: **Paul Ridgway**



Variant: **F-35A 09-5003/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **Airmen use a Portable Maintenance Device during pre-flight checks** Photographer: **Jim Haseltine**



Variant: **F-35A 09-5003/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **Lt Col Renbarger, commander of the 58th Fighter Squadron conducts a pre-flight inspection** Photographer: **Jim Haseltine**



Variant: **F-35A 11-5014/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **An airman checks the aircraft's brake temperature remotely from the wheel using an infrared sensor** Photographer: **Paul Ridgway**



Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **A life support technician plugs an HMD into a test unit for checking** Photographer: **Jim Haseltine**

Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **A life support technician folds a pilot's g-suit** Photographer: **Jim Haseltine**



Variant: **F-35A 09-5003/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **December 4, 2012** Detail: **Lt Col Lafont straps in** Photographer: **Jim Haseltine**

Variant: **F-35A 11-5014/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **A crew chief salutes the pilot after a brake temperature check** Photographer: **Paul Ridgway**





classes are taught by an instructor.

The more complex classes involve working through courseware in step with the instructor, who leads the sessions. Each desk has a touchscreen with a mock-up stick and throttle: both are functional with the screen and mimic the Panoramic Cockpit Display in the aircraft. As the students work through the events they can replicate the cockpit by touching the controls. This is particularly useful for learning how to interact with the systems.

Each student has 100 hours of academics to prepare for their first simulator event.

Simulators

Eglin's ATC has four 360° dome mission simulators loaded with the same F-35 OFP Block software used on the aircraft, providing a realistic match to the jet – particularly the visual aspects of the cockpit which, according to Lt Col Kloos, are "as realistic as could be".

The pilot completes 15 simulator events (giving him a simulator-to-flight ratio of more than two to one) to gain understanding of the systems and emergency procedures to demonstrate they can deal with any such situation.

"On his final simulator, the flight examiner [a military instructor] interacts with the pilot for emergency procedure evaluation [EPE] to make sure he has met all course academic and simulator standards, clearing him to undertake his first taxi and first flight," said Kloos.

Performance and User-Friendliness

As a former F-16 pilot, the colonel is able to compare the similarities between flying an F-35A and an F-16: "They handle similarly; the flight control logic is excellent, and the side stick feels good when you roll or pull back and pull 'g'. F-16 pilots will find the aircraft very comfortable to transition to. The noticeable difference is the power of the engine: that's very impressive, particularly when you're in afterburner. It accelerates very rapidly in flight. When you're flying tactical speeds, slowing it down is often more of a problem.

"As a former F-16 pilot the F-35 has a very different feel when getting in it for the first few times: how things fit, where they connect and how you sit in the seat. That said, I can be out of the chocks as fast as I could in an F-16.

"From a pure size standpoint the cockpit is much nicer and feels roomy because there are very few switches or knobs, and the seat is not uncomfortable. And the Active Noise Reduction system built into the HMD makes it quieter than an F-16.

"Visibility from

the cockpit has two differences: the canopy bow and the canopy rail. I wondered how I could look around the canopy bow, but after the first few flights it becomes part of the environment and I don't even notice it.

"Although you don't sit higher in the F-35 cockpit than an F-16's, you feel you do because the canopy rail is actually lower, so my visibility looking out over the rail is much better compared to the F-16. And the visibility looking back is much better than I expected – I can easily turn and see all the way back between the tails."

Current Operations

In May 2013, Lt Col Kloos handed command of the 58th FS to Lt Col Matt Renbarger. The squadron had nine F-35As on strength and was flying an average of six sorties a day. Twelve months on, the Gorillas have 26 aircraft assigned and are launching up to 16 sorties a day. Nine aircraft are configured with Block 1B and 17 with Block 2A. The first aircraft upgraded to Block 2B at the depot at Hill is expected to return to Eglin in mid-2015. The squadron's fleet is currently flying with Block 2AS3.1 software. This provides greater avionic and sensor capability, enables the aeroplane to fly at night – and down to minimums in the weather but not within 25 miles of lightning – and supports the latest syllabus first used on March 31.

Lt Col Renbarger told *AIR International*: "We now have first-assignment instructor pilots from the combat air forces training on the F-35A. One of the captains is a former F-16 instructor. As the aeroplane becomes more mature the students will be less experienced pilots as we move towards training young, ab initio pilots arriving direct from flying training."

The current course starts with a chased event as previously described in this feature, one of four transition sorties flown to learn how to take off, land, fly in formation and fly on instruments. Transition sorties are followed by a check ride to qualify.

The next stage is the tactical phase comprising a two-ship intercept ride, two 1 v 1 advanced intercept rides, a two-ship basic surface attack ride, a four-ship surface attack ride, a close air support ride and a night sortie.

The standard course is run for six students though some will host eight by the end of 2014. The biggest customer is currently the operational test force, which will be followed by the 56th FW and then the 388th FW at Hill Air Force Base.

Air Education and Training Command will follow a phased approach to having pilots checked out on the F-35 over the next 30 months. Qualified instructors will be held on the operational test

Image Data

Variant:	**F-35A 11-5018/'EG'**
Unit:	**58th Fighter Squadron**
Location:	**Eglin Air Force Base, Florida**
Date:	**March 19, 2014**
Detail:	**The pilot of aircraft 5018 turns on to the end of runway ramp for a brake temperature check before hot pit refuelling**
Photographer:	**Paul Ridgway**



Location: **Eglin Air Force Base, Florida** Date: **November 28, 2012** Detail: **Pilots sign for the aircraft at the squadron operations desk**
Photographer: **Paul Ridgway**

squadrons at Edwards and Nellis and pilots at Eglin or Luke. Most will form the cadre that will stand-up the first operational F-35A squadron at Hill.

Hurricane Evacuation

An interesting deployment of the F-35A involved flying one on a hurricane evacuation exercise to Sheppard Air Force Base, Texas, on March 11, 2014.

The 58th's hangar accommodates six aeroplanes but can take more if a hurricane warning is issued for Eglin. In this case the aircraft are 'stuffed' into reduced spacing to accommodate as many aircraft and as much support equipment as possible in the hangar. The building can endure 140mph winds but the number of aircraft assigned means most of the jets would need to be flown elsewhere.

"We flew unrefuelled, landed it, turned it and brought it back two days later. It was a hugely successful exercise," said Lt Col Renbarger.

"For this exercise we pre-positioned a small team of maintainers at Sheppard, similar to what we would do if we had a real hurricane warning. In reality it depends on how fast the hurricane comes up. We may get enough warning and put people on the road to whichever base we are evacuating to and have us catch them there."

Royal Dutch Lightnings

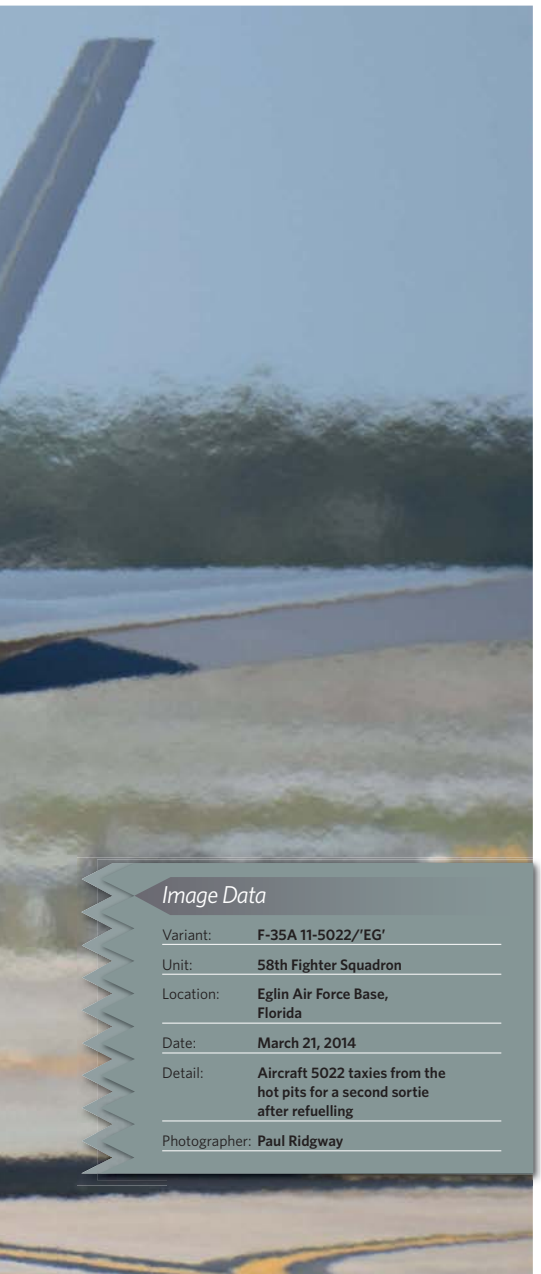
Major Laurens-Jan Vijge, a former Royal Netherlands Air Force (RNLAF) F-16 pilot, arrived at the 58th FS in 2012, the first person from the Netherlands at the International Training Center. His initial work involved preparations for receiving the first Dutch maintainers and aircraft at Eglin. Today the RNLAF has a team of 15 maintainers embedded in the 33rd FW.

"The Dutch military aviation authority [MAA-NLD] approves our flight operations and maintenance tasks here at Eglin, so the team has a responsibility to ensure the authority knows what we are doing," said Maj Vijge.

The Hague-based MAA-NLD granted approval for the first flight of F-35A F-001 (AN-01), which was subsequently delivered to Eglin by a US Air Force pilot assigned to the 58th FS on July 26, 2013. Agreements between the Dutch and US Governments and their respective air forces were required to allow the American pilot to fly the aircraft



Variant: **F-35A 10-5015/'EG'** Unit: **58th Fighter Squadron** Location: **Over the Gulf of Mexico** Date: **January 16, 2014** Detail: **Photo sortie with an F-16C Fighting Falcon and an F-22 Raptor** Photographer: **Jim Haseltine**



on its delivery flight. Those agreements also allow Dutch pilots (Maj Vijge was the first) to fly US Air Force F-35As and American pilots to fly Dutch aircraft at Eglin.

Maj Vijge started his training at the end of October 2013, made his first flight on December 18, 2013 and completed training as a qualified instructor pilot in January. He now works as an instructor with the 58th Fighter Squadron under the command of Lt Col Renbarger.

"I'm the country lead representative at Eglin, so in addition to my flying duties on the squadron I'm also responsible for ensuring maintainers receive the necessary training at the Academic Training Center and on the flight line," said Maj Vijge.

Over the next few months the Dutch contingent will increase to about 35 personnel including three other pilots. The team will all move to Edwards with the two RNLAF aircraft towards the end of 2014 to begin preparations for the operational test and evaluation phase at the Californian superbase.

Maj Vijge explained: "There are so many factors that are going to influence the decision on when is the right time to move. For example, the operational testing requires us to be able to operate using our own ALIS server and network and hence maintain and fly sorties using it. We may start to move people to Edwards by the end of this summer to help prepare our infrastructure."

At Edwards, the Dutch will be part of the Joint Operational Test Team and fly with Air Combat Command's 31st Test and Evaluation Squadron (see *Operational Test and Evaluation* p100-105). Test points will be conducted in accordance with the 600-page Test Execution Master Plan and those test points specific to the Netherlands.

After the Dutch team has moved to Edwards, the Eglin ITC will continue to train RNLAF maintainers on the F-35, but future pilot training will move to the 56th FW at Luke Air Force Base in Arizona. Under the current plan, the first four Dutch Lightning drivers will be the only ones to learn their new mount with the Nomads. They are Maj Laurens-Jan Vijge, Col Bert de Smit, Maj Ian Knight and Maj Pascal Smaal.

A Dutch Impressionist

Maj Vijge described his transition from flying F-16 to F-35 as "a walk in the park" and gave his impression of the aircraft based on his first flight: "When I took off and put the throttle in 'mil' power, and later in the sortie in afterburner, I was very impressed with the sheer power and the way it manoeuvred. It is really nice to fly, and because it flies right it feels right."

The major compared his experience of flying the new jet to that of the F-16 Fighting Falcon: "The F-35 is bigger, heavier and a little bit chunky compared to a slick F-16 which is a 9g jet right from take-off. But on most of the combat sorties I've flown in Afghanistan, you don't have a 9g jet because it's loaded with external tanks, hardpoints and weapons, so you're limited to 5.5g.

"With this jet, all the stores you need for combat are carried internally, so the jet you see today will look the same in five or ten years from now. I can fly this aeroplane configured for combat and still be able to fly faster than any other fighter with the same payload: that is amazing.

"I'm very confident the F-35 will be where we want it to be in a year, five, ten or however many years from now. People who fly and maintain it are going to be extremely proud of the Lightning II."

Mark Ayton



Variant: **F-35As 11-5018/'EG' and 11-5022/'EG'** Unit: **58th Fighter Squadron** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014** Detail: **Aircraft wait to be refuelled in the hot pits** Photographer: **Paul Ridgway**

Image Data

Variant:	**F-35A 11-5022/'EG'**
Unit:	**58th Fighter Squadron**
Location:	**Eglin Air Force Base, Florida**
Date:	**March 21, 2014**
Detail:	**Aircraft 5022 taxies from the hot pits for a second sortie after refuelling**
Photographer:	**Paul Ridgway**

Since the late 1990s, the Royal Netherlands Air Force (RNLAF) has had a requirement to replace its ageing fleet of Lockheed Martin F-16A/Bs – known as F-16AM/BMs since their mid-life upgrade (MLU) between 1996 and 2003.

The RNLAF took delivery of 213 F-16s between June 1979 and February 1992. Today, 61 of them remain in service with four operational squadrons at Leeuwarden and Volkel air bases and a training detachment in Tucson, Arizona. After an evaluation of candidates – including the Lockheed Martin F-35A and Advanced F-16, Boeing F/A-18 Super Hornet, Saab JAS 39 Gripen (Next Generation), Dassault Rafale F4 and Eurofighter Typhoon Tranche 3 – the Joint Strike Fighter (JSF), as the F-35 was known then, was considered the most suitable replacement for the F-16.

The Netherlands joined the JSF programme on June 5, 2002 by signing an $800 million contract to become a Tier 2 partner in the System Development and Demonstration (SDD) phase. Emphasising the country's involvement in the next stages of the F-35 programme's life cycle, the Netherlands signed a memorandum of understanding (MoU) for participation in the Production, Sustainment and Follow-on Development phase on November 14, 2006. On May 30, 2008, the Dutch Parliament decided to participate in the initial Operational Test and Evaluation (OT&E) phase.

Aircraft Acquisition

To take part in the OT&E phase, the Netherlands needed to acquire two test aircraft. After much debate, its parliament agreed to procure a single Low-Rate Initial Production lot 3 aircraft, F-35A AN-01, in April 2009 while the final go-ahead for the acquisition of a second test aircraft from LRIP 4 (AN-02) was given in April 2011. AN-01 (RNLAF serial F-001) took its maiden flight on August 6, 2012 and was handed over on July 25, 2013; AN-02 (F-002) first took to the air on June 27, 2013 and was delivered on September 12.

Pending a final decision on F-16 replacement, both aircraft were put in flyable storage, initially at Lockheed Martin's production facility in Fort Worth, Texas, and later at Eglin Air Force Base,



Dutch

Florida. Between August and November 2013, AN-01 was briefly involved in the F-35 development test programme at Naval Air Station Patuxent River, Maryland, where it was used for ground tests with simulated lightning strikes.

Initial plans foresaw the acquisition of 85 F-35As for the RNLAF. But, over time, it became clear this number could not be realised within the available budget. In a defence white paper published in April 2011, the budget was strictly limited to €4.521 billion for investment plus an annual exploitation budget of €270 million – equalling the exploitation costs of the F-16 fleet in 2013.

Owing mainly to the high investment costs and a number of critical reports published both in and outside the Netherlands, acquisition of F-35s was politically controversial for more than a decade, and the final decision to acquire replacement aircraft for the ageing F-16s was repeatedly postponed. In 2008 and 2013, parliament demanded two more candidate comparisons. Both reports again mentioned the F-35A as the most suitable aircraft to replace the F-16. "The F-35A suits the Dutch political ambition and Air Force requirements best," said RNLAF Colonel Marcel Lambrichs of the Defence Materiel Organisation (DMO), who is team leader of the Netherlands F-16 Replacement Project – as the Dutch F-35 programme is officially known. "Our country wants to retain a fighter force. We want an aircraft that is very flexible and able to execute at least the six different mission types as defined by the Ministry of Defence [MoD].

"Good interoperability with other air forces, in particular other NATO members, is also very important: when taking part in international operations, you don't want to spend too much time on integrating your aircraft into a multinational force. Time and time again, the F-35 turns out to have a very good perspective for growth within a large international community in the next 30 to 40 years. Everything considered, the F-35A really is the most promising candidate."

The Dutch MoD announced its decision to acquire additional F-35As on September 17, 2013. With €496 million spent on F-35 programme participation and acquisition of the two test aircraft, €4.025 billion remained available in the investment budget by mid-2013. Taking into account that 10% of the budget is



Image Data

Variant:	**F-35A F-001**
Unit:	**Royal Netherlands AirForce/ 58th Fighter Squadron**
Location:	**Over Texas**
Date:	**August 6, 2012**
Detail:	**First flight**
Photographer:	**Liz Kaszynski/ Lockheed Martin**

Masters



Variant: **F-35A F-002** Unit: **Royal Netherlands Air Force** Location: **Lockheed Martin Fort Worth Plant, Texas** Date: **March 2, 2013** Detail: **Rollout of F-002 (AN-02) from final assembly to the weigh station** Photographer: **Tom Arbogast/Lockheed Martin**

reserved for risks, this allows for the acquisition of 35 additional F-35As, bringing the total to 37 – much less than the original planned number of 85.

It is not ruled out that a small number of extra aircraft will be added later, provided their acquisition and exploitation fit within the available budget. Meanwhile a major step was taken on November 6, 2013 when a majority in the Dutch Parliament approved the proposed F-35 acquisition.

OT&E Participation

Some 40 Dutch nationals, mainly from the RNLAF and DMO, are currently involved in the F-35 project – not counting RNLAF personnel being trained at Eglin for their upcoming participation in the OT&E or those working in related projects. "Of the nine F-35 partner nation teams, ours is among the smallest – to date, only Canada and Denmark have fewer people in the programme," said Col Lambrichs.

His team in The Hague comprises some 15, mainly DMO, personnel. Others are located at the RNLAF headquarters in Breda, the F-35 Joint Program Office (JPO) in Crystal City, Virginia, and other locations in the United States. Since 2009 a team of three RNLAF personnel and a civil technical engineer employed by the National Aerospace Laboratory work within the F-35 Integrated Test Force at Edwards Air Force Base, California, to take part in the Developmental Test and Evaluation phase.

In October 2013, around 30 RNLAF personnel began F-35 training with the 33rd Fighter Wing (FW) at Eglin. They include pilots, maintenance officers, aircraft technicians, a logistic supporter, an intelligence officer and IT specialists trained to work with the Autonomic Logistics Information System (ALIS). Both Dutch F-35As plus the RNLAF team at Eglin will relocate to Edwards at the end of 2014 to take part in the tri-national OT&E in January 2015, together with teams and jets from the US and the UK. As part of Dutch defence cuts announced in September 2013, Leeuwarden-based 323 Tactical Training, Evaluation and Standardisation (TACTES) Squadron will be disbanded on November 1, 2014, handing over the TACTES role to co-located 322 Squadron. A decision is pending on whether 323 Squadron will be re-established at Edwards as the Dutch F-35 test squadron.

The first RNLAF pilot to fly the F-35, Maj Laurens Jan Vijge, took to the skies in F-35A F-001 on December 18, 2013 for a 70-minute flight from Eglin. The second, Col Bert de Smit, commander of the RNLAF OT&E team, flew the new jet for the first time on April 8, 2014. Later this year, Maj Ian Knight and Maj Pascal Smaal will also convert to the F-35. The pilots are trained by the US Air Forces' 58th Fighter Squadron (FS) 'Gorillas' based at Eglin.

By November 2013, both Dutch aircraft were at Eglin. In preparation for the OT&E, F-001 entered a modification programme with the Ogden Air Logistics Complex at Hill Air Force Base, Utah, in February 2014. It will be loaded with the latest version of Block 2B software and receive a number of modifications, and is expected back at Eglin in June. Meanwhile F-002 is scheduled for similar modifications between July and November 2014.

Col Lambrichs explained: "In 2015, the team will focus on operational testing with the Block 2B software. The following year will be used for conversion to Block 3F standard, additional modifications and inspections on the jets and evaluation of the Block 2B-related test period. In 2017 to 2018, testing of Block 3F software will be carried out, with the evaluation report expected in 2019. By the time the first F-35As arrive in the Netherlands the OT&E should be finished. Aircraft entering operational service from 2019 are expected to be configured to Block 3F standard."

Image Data

Variant:	**F-35A F-001**
Unit:	**Royal Netherlands Air Force/58th Fighter Squadron**
Location:	**Eglin Air Force Base, Florida**
Date:	**July 26, 2013**
Detail:	**Ceremonial photo sortie**
Photographer:	**Arnold Schoor/Royal Netherlands Air Force**



Service Introduction

When the F-35A takes over from the F-16, the RNLAF will continue using its two main operating bases at Leeuwarden and Volkel. Starting in 2019, eight F-35As are scheduled for delivery each year, the final three examples arriving in 2023.

The first eight operational Dutch aircraft (AN-03 to AN-10) are to be produced as part of LRIP 11, the last scheduled low-rate production lot. The remainder should be part of a multi-year Full-Rate Production lot.

Following delivery of the first F-35s, plans foresee the RNLAF's F-16 fleet gradually being reduced to around 55 in 2020, 45 in 2021, 34 in 2022 and finally 24 in 2023, before the last are scheduled to retire in 2024 – 45 years after the type entered service.

The first F-35As are due to be delivered to Leeuwarden-based 322 Squadron with the balance going to 312 and 313 Squadrons at Volkel. Benefiting from the RNLAF's experience gained during the OT&E phase, 322 Squadron is scheduled to reach initial operational capability in 2021. Of the 37 Dutch aircraft, 32 are expected to operate in the Netherlands while the other five should remain in the United States for training within the 56th FW at Luke Air Force Base, Arizona. "With Eglin becoming a US-only training base for the 'A and 'C models in the future, more F-35A training of US Air Force pilots and those from other nations will be done at Luke," said Col Lambrichs. "We expect to start conversion of operational F-16 pilots at the Arizona base in 2018-2019, but the exact time depends on the outcome and lessons learned from the OT&E."

Introduction of the F-35 requires infrastructure changes at Leeuwarden and Volkel, according to the colonel: "The dimensions of the new aircraft do not differ much from those of the F-16 and it easily fits into our hardened aircraft shelters, for instance. Of course the IT network in the shelters needs to be adapted for the ALIS system and there will be some changes to hangars, maintenance docks and simulator buildings as well. Furthermore, the multi-layered classification that goes along with the aircraft will have an effect on the squadron buildings – for instance, briefing and debriefing facilities."

Requirements

"Like many other aircraft development programmes, there's a rule in the F-35 community that says if you want to divert from the mainstream, you need to bring additional money to make your wishes come true," added Col Lambrichs. "We're a small country and our Air Force is on a tight budget. Our goal for the time being is to stay in the mainstream and refrain from unique requirements as much as possible; for instance, when it comes to armament, we don't intend to acquire weapons other than the latest air-to-air missiles, GPS-guided bombs and Small Diameter Bombs.

"As for munitions for the 25mm GAU-22 cannon, we prefer not to use rounds that hold depleted uranium. Our aim was to find a co-user for the uranium-free 25mm round developed by the Dutch applied scientific research organisation TNO and Rheinmetall from Germany, and we were successful because the US Air Force is also buying this type of ammunition. It's now a programme of record within the SDD phase.

"One requirement we're currently assessing is the possibility and necessity to add a drag chute to the aircraft. So far, the Norwegians are the only country with a parachute requirement. We follow their developments closely and in the meantime do our own assessment."

The Netherlands successfully influenced aspects of the F-35 during the early stages of its development, as Col Lambrichs recalls: "In the early 2000s, the Netherlands argued that the cockpit of the F-35 should have enough height to accommodate future pilots, who will be taller than the current generation, which was acknowledged by Lockheed Martin. And the Netherlands successfully objected to plans to remove the gun from the F-35A to save weight."



Variant: **F-35A F-001** Unit: **Royal Netherlands Air Force/58th Fighter Squadron** Location: **Over Texas** Date: **August 6, 2012** Detail: **First flight** Photographer: **Liz Kaszynski/Lockheed Martin**

International Co-operation

The Netherlands is actively seeking international co-operation with other F-35 users. "For the foreseeable future, pilot training will be done in the United States," said the colonel. "In the coming years, we're looking into the possibility of setting up an international training centre for maintainers – not only for the F-35 but other aircraft types as well – as part of Maintenance Valley in the Woensdrecht area. Dutch industry and the MoD have almost completed their analysis to set up an engine maintenance, repair, overhaul and upgrade (MRO&U) facility for the Pratt & Whitney F135. Such a facility already exists for the F-16's F100 engine at Woensdrecht air base. In this field, co-operation with Norway is foreseen."

The Netherlands also signed a production and sustainment (P&S) MoU with Italy in March 2006, which was joined by Norway in June 2007. The agreement offers the possibility of having parts of the Dutch F-35s assembled on the production line in Cameri, Italy; in return the Italian F-35s' engines could be maintained in the Netherlands.

Once the F-35A has taken over from the F-16, the RNLAF intends to continue the successful large-scale exercise Frisian Flag, held annually at Leeuwarden. It would also like to set up a Fighter Weapons Instructor Training (FWIT) programme for the European F-35 community, similar to the FWITs currently held at Leeuwarden for the five-nation European Participating Air Forces operating the F-16 MLU.

Industry Involvement

Although Dutch industry has suffered to an extent from the uncertainty over F-35 procurement – and the relatively low number eventually acquired may have the same effect – its participation in the F-35 programme has led to success in some areas. Fokker Elmo, for instance, produces wiring and wiring harnesses for all F-35s. "Of the $800 million paid for Tier 2 partnership, about $50 million was reserved to fund the most promising Dutch projects," noted Col Lambrichs. "Examples are the cryogenic coolers manufactured by Thales in the Netherlands and the multi-functional ground support equipment developed by Sun Test Systems. Fokker Landing Gear impressed the US Government, JPO and Lockheed Martin with its redesigned arresting gear for the F-35C and the company also works on a composite drag brace, which would not only save weight but also strengthen the F-35's landing gear.



Variant: **F-35A F-002** Unit: **Royal Netherlands Air Force** Location: **Lockheed Martin Fort Worth Plant, Texas** Date: **December 11, 2012** Detail: **F-002 (AN-02) on the production line** Photographer: **Randy Crites/Lockheed Martin**

"These are just a few examples of Dutch industry-related projects. Because of its good reputation, there's a very good chance to gain second-source production contracts once production quantities increase. The Dutch are known to be good at designing and redesigning processes, keeping costs low and quality very high."

According to several studies carried out in recent years, the value of F-35-related orders for Dutch industry will range from €9 billion to €38 billion in the next 50 to 60 years. ***Kees van der Mark***

War

Marine Fighter Attack Training Squadron 501 (VMFAT-501) was formed as an F-35B Fleet Replacement Squadron (FRS) at Naval Air Station Pensacola, Florida, on April 1, 2010. The number plate was new: the squadron assumed the lineage of Marine Fighter Attack Squadron 451 (VMFA-451) 'Warlords', a former F/A-18C Hornet unit based at Marine Corps Air Station Beaufort, South Carolina, which was deactivated on January 31, 1997 as part of the US Marine Corps' Force Structure Plan.

VMFAT-501 traces its history back to Marine Corps Air Station Mojave in California where Marine Fighting Squadron 451 (VMF-451) was activated on February 15, 1944 equipped with the Chance-Vought F4U-1D Corsair, one of only two non-jet types flown by the unit.

The 'Warlords' name was adopted in late 1954 when the unit transitioned from its first jet-powered aircraft, the Grumman F9F-2 Panther, to North American FJ-2 Furies. It later transitioned to the FJ-4 Fury, Vought F8U-2 Crusader and the all-weather F8U-2N.

On February 1, 1968 the redesignated Marine Fighter Attack Squadron 451 (VMFA-451) transitioned to the McDonnell Douglas F-4J Phantom II at MCAS Beaufort, a type it operated for 21 years until it upgraded from the F-4S variant to the F/A-18A Hornet in September 1987. The squadron deployed to Bahrain in support of Operation Desert Storm and became the first Marine unit to attack Iraqi forces, in the early hours of January 17, 1991.

Fifty-seven years of Warlords' history came to an end on January 31, 1997 when VMFA-451 was deactivated at MCAS Beaufort. HQ US Marine Corps was eager to keep the unit's lineage alive and ordered the first Marines assigned its new incarnation to Eglin Air Force Base, Florida, to start the reactivation in April 2009. VMFAT-501 is part of Marine Aircraft Group 31, primarily an F/A-18C and F/A-18D Hornet group, based at MCAS Beaufort, under the command of the 2nd Marine Aircraft Wing at Marine Corps Air Station Cherry Point, North Carolina.



lords

Getting Started

When the then Major Steve Gillette arrived at Eglin in the summer of 2010, VMFAT-501 had no F-35B aircraft assigned and its Marines were focused on an unprecedented objective to establish a Marine Fighter Attack FRS at an Air Force Base.

"Our focus through to the summer of 2011 was to develop a training system mature enough to introduce transition pilots to the F-35B. We [the Marine Corps] have never built a training system in the tactical fighter community without two-seat aeroplanes," said Maj Gillette, who was then VMFAT-501's executive officer.

Delays to the F-35 programme at the time meant aircraft were not available – not an ideal situation for a training squadron with a time-critical mission to prepare trained instructors and pilots for the fleet, but one that nevertheless provided an opportunity to the smart-thinking Marines assigned to 501. They used the time to go through the academic and simulator phases of their initial syllabus many times, correcting the courseware and the articulation of the various simulator events. Gillette noted: "We leveraged a lot from the F-22 programme in terms of what sequence we had to follow to ensure a student pilot can comfortably take off and land the aeroplane, and an understanding of the thought process used by the Air Force to take their F-22 pilots through that process. It was without doubt beneficial."

The squadron worked on the process until the latter part of 2011, validating its standard operating procedures and ensuring its risk management tools were in place. The opinions of F/A-18 Hornet, AV-8B Harrier and F-16 pilots then assigned to the 58th Fighter Squadron were also considered in helping determine the best practices.

"Once the training system and squadron procedures were in place to mitigate the risk of initial flight operations, the focus of our effort shifted to preparing to accept our first aeroplane and how the maintenance department, who had gained experience at Pax, Edwards and Fort Worth, would take care of it. With a brand new aeroplane that's a huge undertaking," explained Maj Gillette.

VMFAT-501's first F-35B, BuNo 168057/'VM01', touched down at Eglin at 15.13pm on January 11, 2012 after a 90-minute ferry flight from Fort Worth, flown by the then Major Joseph Bachmann. A second



Image Data

Variant:	**F-35B BuNo 168309/'VM08'**
Unit:	**Marine Fighter Attack Training Squadron 501**
Location:	**Eglin Air Force Base, Florida**
Date:	**March 21, 2014**
Detail:	**Final approach**
Photographer:	**Paul Ridgway**

aircraft, BuNo 168059/'VM03', followed just 76 minutes later flown by Marine LtCol Matt Taylor. Two more aircraft were delivered in mid-January. At the time, the only pilots cleared to fly them were developmental test pilots, two of whom were assigned to VMFAT-501: Major Bachmann and the 33rd Fighter Wing Vice Commander, Marine Colonel Art Tomassetti.

They started flight ops at Eglin on May 22, 2012 and flew the entire syllabus from both an instructor pilot's and a student's perspective. "That proved to be very valuable because we'd not been able to validate the syllabus when flying," said Gillette. "Lessons were learnt about formation flying and the best air speeds to conduct certain manoeuvres which were shared with, and later used by, the other pilots on the squadron."

In early July, Naval Air Systems Command (NAVAIR) released a flight clearance for non-developmental test pilots to fly the F-35B. All of 501's instructor pilots had already completed the academic and simulator phases of the syllabus and were ready to start flying. LtCol David Berke, VMFAT-501's then commanding officer, was the first non-test pilot to fly on the squadron, on July 11. Major Gillette made his first flight two days later. The two Marines qualified from the basic and follow-on IUT (Instructor Under Training) syllabus, giving 501 a pool of four instructors: Col Tomassetti, LtCol Berke, Major Bachmann and Major Gillette. By October 2012 the squadron had 12 pilots qualified on the F-35B.

The unit was already preparing to accept the first students from Marine Fighter Attack Squadron 121 (VMFA-121) 'Green Knights', part of which was to standardise each phase of the transition training. The methodical and arduous process was started when the tenth 501 pilot qualified and all of them were involved. Maj Gillette explained: "Before anybody else went through the training system we wanted to make sure we were training people in a professional and efficient manner: then we put it to the test."

In November 2012 the first external pilot, the commanding officer of VMFA-121, LtCol Scott, started the academics phase. He completed the simulator phase and arrived on the squadron the following day to fly his first sortie. The colonel – who had been out of the cockpit for almost three years while serving a tour at the Pentagon before joining VMFA-121 – qualified on November 29 after his last syllabus flight, proof enough that 501's training system works.



Variant: **F-35B BuNo 168057/'VM01'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 20, 2014** Detail: **VMFAT-501's colour bird features the squadron's tail flash in blue and a circle of five red stars and a single example – a version of the markings previously worn by Marine Fighter Attack Squadron 451** Photographer: **Paul Ridgway**

The Syllabus

LtCol Scott's training lasted about two months – roughly three weeks of academics, three weeks of simulators and two weeks of flying to complete the basic qualification and covering take-off, landing, instruments and formation flying.

When *AIR International* first visited 501 it was preparing to train British pilots and introduce the initial tactical phase involving the use of the aircraft's mission systems, adopting the same template for its validation as that used for the basic flying syllabus discussed earlier in this feature. The objective was to validate the method used to instruct the tactical fundamentals of using sensors and the initial steps for their employment.

Because the aircraft's flight clearance is governed by NAVAIR, the process of building the syllabus to suit the iterative flight clearance increases (a situation derived entirely from the concurrency-based development process adopted for the F-35) is a brand new concept for all three services: Marine Corps, Air Force and Navy.

THE AEROPLANE IS WICKEDLY



Variant: **F-35B BuNo 168309/'VM08' and ZM135** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **A two-ship section waiting for departure** Photographer: **Paul Ridgway**



Variant: **F-35B BuNo 168309/'VM08'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Waiting for a second aircraft on the end of runway ramp** Photographer: **Paul Ridgway**

Eventually 501's syllabus will train students in all Marine tactical aviation mission sets – to include four-ship tactics, surface-to-air counter tactics, close air support in environments that are not permissible for legacy aircraft to enter and electronic attack – as either a partial or full task in support of a larger mission. Explaining the electronic attack role, Maj Gillette told *AIR International*: "There are a couple of reasons for that, one being the capability of the aeroplane; but also the capability of the training system. We can link our simulators together to create a very challenging environment. Given the mission systems integrated on the F-35 and the way that information is fused and displayed, a junior pilot with no previous tactical aviation experience will be able to thrive in those environments.

"Their ability to tactically employ the aeroplane when they leave 501 will be much more advanced compared to students qualifying from the respective course for F/A-18 Hornet and AV-8B Harrier."

The ability to deploy to austere operating



Image Data

Variant:	**F-35B BuNo 168310/'VM09'**
Unit:	**Marine Fighter Attack Training Squadron 501**
Location:	**Eglin Air Force Base, Florida**
Date:	**November 28, 2012**
Detail:	**Turning in the pattern for landing**
Photographer:	**Paul Ridgway**

EASY TO FLY

LtCol Joseph Bachmann

environments is one of the main reasons the Marine Corps bought the F-35B. The aircraft can operate from an L-class ship, a 13,000-foot runway or much shorter strips if an operational commander requires it.

To prepare for austere ops all students will be trained with a basic skill set covering the mechanics of STOVL (Short Take-Off and Vertical Landing) ops at 501, but the actual process and execution of such operations will be left to the frontline squadrons.

The initial Marine Corps F-35B training programme is almost a 50:50 split between the Hornet and Harrier communities. Maj Gillette said this mix will benefit the F-35B transition: "The two are almost identical in terms of the missions they do. There's an air-to-air piece in the F/A-18 community that doesn't reside in the Harrier community but the Harrier community brings a lot of technical knowhow: through the type's integration into L-class ships, its ability to conduct close air support and austere operations, for which its pilots are very accomplished. The F/A-18 community knows very little about those mission sets. So the Marine Corps and 501 conduct a wide centre-section of missions using different platforms and have the expertise required to take that forward with the F-35B."

Pilot Feedback

As a former F/A-18 pilot, Major Gillette had no previous STOVL experience before his tour with 501. Comparing the two aircraft he told *AIR International*: "In my opinion the F-35B has a greater thrust-to-weight ratio and much more power. Ask any pilot if more thrust is better or worse, and they're always going to say it's better. So from that standpoint it's an extremely easy aeroplane to fly.

"In the current, early configuration the aircraft's mission systems are very comfortable to use from the first time you fly, because that information is provided to you on one display. Using one display doesn't seem natural at first but once you get used to it, the amount of information you can absorb in one look is amazing.

"The old adage that a picture is worth a thousand words certainly applies here. Your environment is displayed and the sensors are very good, so the F-35's mission systems will bring significant capability to the aviation commander of the Air Combat Element and the MAGTF, and that alone will enable us to support Marines on the ground whatever the role might be."

Current Operations

LtCol Bachmann, VMFAT-501's current commanding officer, was the fifth pilot to fly the F-35 and the first from the US Marine Corps. He took command of the 'Warlords' last summer.

When *AIR International* last visited VMFAT-501, LtCol Bachmann explained that one important activity on the squadron was the build-up of the maintenance department, which he described as being critical for the entire programme. "Getting them qualified and capable of performing maintenance on the jets in a timely fashion is critical for training pilots because if we can't generate aircraft then we can't keep flying sorties," he said.

While the maintenance build-up continues, the squadron sends every student to a tanker to qualify in air-refuelling – which is part of their training but also increases their overall flight time: "It gives 501's pilots and instructors more proficiency and increases our efficiency by over 50% because the aircraft can remain airborne for at least an hour longer without landing for fuel. Whenever an aircraft lands, the turnaround between two sorties adds to the workload of the maintenance department: with tanker support we can avoid that," added LtCol Bachmann.

Clearance for STOVL operations was given by

NAVAIR in September 2013. Since then two of the squadron's instructor pilots, a former Harrier pilot and one from the F/A-18 Hornet, were trained in STOVL ops by the test pilots serving with Air Test and Evaluation Squadron 23 (VX-23) at Pax River.

The first 501 pilot to hover an F-35B at Eglin was the former Hornet pilot, who had never hovered before. "It showed that the aeroplane is wickedly easy to fly," said LtCol Bachmann. The squadron is currently focused on training VMFA-121 pilots at Yuma for STOVL ops, sending its instructors to the Arizona base every six weeks.

Bachmann described the STOVL phase: "The academic phase can be done in a full day and it's followed by six simulator events. It starts with a series of four, escalating in difficulty with different wind conditions. The fourth event focuses on emergencies and aircraft malfunctions. The fifth event is a rehearsal for your first STOVL flight to the hover, which usually takes place within 24 hours. We try to replicate exactly what you're going to do in the jet: a hover and some STOVL air work, handling fundamentals, but not a vertical landing. If things go well you complete the sixth event, a full rehearsal of a vertical landing (VL), which follows immediately after the sim."

The STOVL phase is now part of the syllabus but, because of a shortage of jets upgraded with the Auxiliary Air Inlet door modification, only qualified instructors can perform a vertical landing, and try to do so each time they fly to remain proficient. LtCol Bachmann is more than familiar with the AAI door issue. While serving with Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs' at Naval Air Station Patuxent River, he was the test pilot who first discovered the issue while flying F-35B BF-01.

When *AIR International* last visited VMFAT-501 in March, two of its aircraft had received a wingtip light modification. "The F-35 ITF at Pax determined that the design of the original wingtip light was inadequate for night flying and a redesign was required to provide the necessary visibility and illumination. The modification has to be retrofitted onto all the LRIP aeroplanes," explained Bachmann.

Naval Air Systems Command had already given the new light flight clearance for night-time operations and VMFAT-501 had started to develop its syllabus to include night qualification; some of the instructor pilots were already conducting initial night ops.

New training events and aircraft modification are important for future Marine Corps F-35B pilot training, but the really big event for 501 this year is the move from Eglin to Beaufort on the Atlantic coast in South Carolina – which is to become a STOVL centre of excellence and pilot training centre.

"It's a huge facility with classrooms and simulators and all the things required to teach the ground phases of student aviator training. It also has a huge hangar, which is already complete, and Marines assigned to 501 are already there preparing for the squadron's arrival," enthused Bachmann.

Once the squadron is settled in at Beaufort it will start to accept students for VMFA-211, the new incarnation of Marine Attack Squadron 211 (VMA-211) 'Wake Island Avengers', an AV-8B Harrier unit assigned to Marine Aircraft Group 13 (MAG-13) at Yuma. After 211's transition, 501 is due to accept more British personnel who will form the initial cadre of the RAF's No.617 Squadron, 'The Dambusters'.

In parallel to transition training, 501 is developing its syllabus for brand new 'nugget' pilots arriving direct from flight school. "Within the next 18 months we not only have to develop the course work, we have to run it through the system a couple of times, with instructors acting as students as part of the validation process, so that we are ready to receive the first nugget pilots from the T-45 Goshawk-equipped flying training wings," said Bachmann.

Royal Naval Air Station Eglin

The United Kingdom was the first F-35 international partner nation to post sailors and airmen to the 33rd Fighter Wing. Because the UK's current plan is to operate the F-35B STOVL variant, the British personnel are assigned to VMFAT-501.

The first two pilots are Lt Cdr Ian Tidball, Royal Navy, a former Sea Harrier and F/A-18 Super Hornet pilot, and Sqn Ldr Frankie Buckler, Royal Air Force, who has flown Jaguar GR3s and Typhoon FGR4s. Both officers qualified on the F-35B in 2013 and remain at VMFAT-501 as part of the squadron's instructor pilot



Variant: **F-35B BuNo 168312/'VM11'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **November 30, 2012** Detail: **Aircraft VM11 taxies out from its sun shelter on a four-ship sortie** Photographer: **Paul Ridgway**



Image Data

Variant:	**F-35B BuNo 168308/'VM08'**
Unit:	**Marine Fighter Attack Training Squadron'**
Location:	**Eglin Air Force Base, Florida**
Date:	**November 30, 2012**
Detail:	**The F-35B's fuselage mould line is distinctive from the 'A and 'C variants**
Photographer:	**Paul Ridgway**



Variant: **F-35B BuNo 168309/'VM08'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014** Detail: **Final approach** Photographer: **Paul Ridgway**



Variant: **F-35B ZM136** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014** Detail: **Final approach to land after four-ship training flight** Photographer: **Paul Ridgway**

cadre to train Marine Corps pilots.

Lt Cdr Tidball, who made his first flight on April 10, told *AIR International*: "The aeroplane flew really well, very much as expected and trained for in the full mission simulator. I can't sing the praise of that piece of equipment highly enough – it's very capable. Bear in mind the F-35 is the first single-seat aircraft the UK is buying with no two-seat variant, so the need for a good full mission simulator is paramount and it really does prepare the student for their first flight and subsequent flying."

The future for the two British officers is not with 501 but with the RAF's No.17 Test and Evaluation Squadron at Edwards, where they will be part of the Joint Operational Test Team (JOTT), conducting the UK's proportion of test points as part of the Test and Evaluation Master Plan. The experience each pilot gains with 501 will provide them with a level of familiarity required for the high-intensity flying that operational test entails. They also report into a variety of UK MoD organisations including Air Command and Fleet HQ.

No.17 Test and Evaluation Squadron will comprise a team of three pilots and some 65 maintenance and support personnel. One of its tasks at Edwards will be to conduct UK-specific testing. "The primary reason for us being part of the JOTT is the need for sufficient numbers of personnel and aircraft to enable the F-35 to be tested properly," said Lt Cdr Tidball. "For the Block 2B phase between 2014 and 2015 there should be 12 aircraft [four US Air Force F-35As, two RNLAF F-35As, four US Marine Corps F-35Bs and two UK F-35Bs] assigned to the JOTT. The US Navy will join the JOTT for Block 3 testing later when the number of aircraft will increase slightly."

The UK currently has three F-35Bs – ZM135/BK-01, ZM136/BK-02 and ZM137/BK-03 – which are assigned to VMFAT-501. Once the aircraft have moved to Edwards they will be operated by No.17 Test and Evaluation Squadron, which is part of the Air Warfare Centre under the command of No.22 Group based at High Wycombe, Buckinghamshire.

One of the UK jets, BK-03, was built in the LRIP 4 lot and is currently configured with Block 2A software. It was also one of the first two F-35B aircraft to be modified with the redesigned wingtip light, making it night-capable.

Aircraft BK-01 and BK-02 entered the modification line at Fleet Readiness Center East at Marine Corps Air Station Cherry Point, North Carolina, at the end of May and in mid-June respectively. Both are due to be delivered to No.17 Test and Evaluation Squadron at Edwards at the beginning of October.

BK-03 will remain with VMFAT-501 as part the UK-US partnering agreement and will go to Beaufort with the squadron where the initial cadre of UK pilots will start training at the end of 2015, a process that will continue until 2017.

Ft Lt Hugh Nichols, the UK's third F-35 pilot, arrived at 501 in mid-2013 and is now qualified as an instructor. He was the first to qualify in STOVL ops because of his ongoing instructor role with the squadron at Beaufort.

STOVL training is closely controlled and only seven pilots had qualified at the time *AIR International* visited 501 in late March owing to the shortage of aircraft modified with the strengthened Auxiliary Air Inlet door. Lt Cdr Tidball explained: "All aircraft can do STOVL ops in the event of an emergency, but only three jets are modified [strengthened] with the Auxiliary Air Inlet door and cleared to do so."

Part of STOVL training includes hovering, which is often undertaken by pilots as part of the recovery procedure before landing at Eglin. It's fascinating to watch an F-35B decelerate to what's call a delayed hover and then execute a missed approach to fly away.

"The operational pilots on 501 are bound by limitations on the aircraft," said Tidball. "If the wind is calm we can hover but we can't actually do a vertical landing because we need 10 knots. It's great practice to go through the conversion from conventional to STOVL mode."

VMFAT-501's final class at Eglin started in April and included Wg Cdr Jim Beck, Royal Air Force, a former Typhoon FGR4 pilot. His course finished

in June after which he became the new Officer Commanding No.17 Test and Evaluation Squadron at Edwards. Lt Cdr Tidball and Sqn Ldr Buckler were continuing their instructor role on 501 and, in parallel, getting ready to move to Edwards to begin flight ops with No.17 Test and Evaluation Squadron planned for October. The Block 2B operational test phase is due to commence in July 2015, pending any unexpected changes with the F-35 programme.

Before then, flight ops by the UK pilots will involve testing the data and test equipment to be carried on the two UK aircraft to ensure the systems capture information as required and that they are integrated with the various ranges at Edwards. "We need to make sure all our processes, procedures and plans are in order before we execute, because operational test missions use complex ranges and equipment which are very expensive," said Tidball.

Block 3's operational test phase is the graduation exercise and the end of the F-35's System Development and Demonstration phase. It is due to take place in the 2017 to 2018 timeframe and will clear the F-35 for operational use.

UK-specific testing in the Block 3 phase will involve the Paveway IV precision-guided munition and eventually the ASRAAM missile. All UK weapons are part of the SDD programme and the overall TEMP.

Interoperability with other types, notably the Typhoon FGR4, is high on the UK's agenda and forms part of the operational test. The British element of the JOTT will exploit opportunities to interoperate with Typhoons assigned to No.41 Test and Evaluation Squadron when it is deployed to Naval Air Weapons Station China Lake in California and Nellis Air Force Base, Nevada, during its annual High Rider detachments. "We will look at how we are going to operate as a combined force to learn as much about the F-35B as possible," explained Tidball.

Follow-on Operational Test and Evaluation of subsequent software upgrades Block 4 and Block 5 will run every two to four years. The current plan foresees the UK participating with all three US services in each phase.



Variant: **F-35B BuNo 168062/'VM06'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 30, 2012** Detail: **Aircraft VM06 chocked and ready for its next mission** Photographer: **Paul Ridgway**

BK-04

The UK's fourth F-35B, ZM138/BK-04, should be delivered in late 2015 and is currently expected to go to Edwards configured as an instrumented jet. BK-04 will be built in LRIP 7 lot, and will have a slightly different baseline configuration (not to be confused with the test instrumentation) from BK-01 and BK-02, which are both LRIP 3 jets. This may make it unsuitable for the Block 2B operational test and a decision on its inclusion will be made by the JOTT.

Sqn Ldr Buckler outlined the difference between the F-35's service entry in the UK and that of legacy aircraft: "The F-35 is going to arrive in the UK as an operational platform, unlike the Typhoon which, when wheeled out, went through several years of operational test before its operational declaration. As soon as this jet arrives it will be ready to go, whatever the politicians deem it needs to do.

"It's not a bespoke platform with one or two roles, it can do so many. But regardless of where it launches from, the crew and the people that support it are going to be from the Royal Navy and the RAF – it's going to be both services at RAF Marham and they will deploy aboard the carrier as both services," he said.

Lt Cdr Tidball added: "It will be national asset operated by a joint force as deemed appropriate."

Mark Ayton

Variant: **F-35B BuNo 168308/'VM08'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **November 29, 2012** Detail: **The pilot climbs down the crew access ladder** Photographer: **Paul Ridgway**



Variant: **F-35B BuNo 168057/'VM01'** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 20, 2014** Detail: **VMFAT-501's colour bird features the squadron's tail flash in blue and a circle of five red stars and a single example – a version of the markings previously worn by Marine Fighter Attack Squadron 451** Photographer: **Paul Ridgway**





Image Data

Variant:	**F-35B ZM135**
Unit:	**Marine Fighter Attack Training Squadron 501**
Location:	**Eglin Air Force Base, Florida**
Date:	**March 19, 2014**
Detail:	**Aircraft BK-01 taxies back to the flight line at Eglin**
Photographer:	**Paul Ridgway**

The UK entered the Joint Strike Fighter programme in November 1995. Today it has three Low Rate Initial Production F-35B STOVL variants, one based at Eglin Air Force Base, Florida, and two undergoing modification with the Fleet Readiness Center East depot at Marine Corps Air Station Cherry Point in North Carolina. A fourth aircraft is due to be delivered at the end of 2015.

The UK's current programme of record still stands at 138 aircraft. The UK Lightning Project Team, part of the DE&S empire, has a plan for all the aircraft that it would *like* to order for Joint Force Lightning (JFL) – but, not surprisingly, nobody assigned to the project in DE&S, the Royal Air Force or the Royal Navy is prepared to provide any detail about follow-on orders, how many aircraft are involved and when they are likely to be delivered.

"We'll be looking to keep to that number [138] but the UK Government's 2015 Strategic Defence and Security Review will look to ratify our future programme beyond 2023," said Gp Capt Willy Hackett, the UK's deputy lead officer for the F-35, based at the Joint Program Office in Crystal City, Virginia.

"In any SDSR, analysts and scientists look at the requirement placed upon UK defence by the government. They look at areas of the world that we

Joint Force Lightning



may have to influence with military force. Then they look at the complete airborne force mix of Typhoon, F-35 and unmanned aerial vehicles, balancing that against the ISR [intelligence, surveillance and reconnaissance] assets needed to do that," said the group captain.

Commodore Rick Thompson, the UK's Lightning II Head, explained: "We're currently focused on buying the first aircraft for the first operational squadron and the operational conversion unit. We buy on an annual basis and will place our initial contracts over the next four years, out to 2018. SDSR 2015 will address procurement beyond the first two units."

Unable to provide a number, Thompson was quick to say the UK's procurement profile is commercially confident. Based on numbers of aircraft assigned to current RAF frontline squadrons, and the requirement to equip an operational conversion unit (OCU), *AIR International* estimates the first tranche of F-35Bs is likely to total between 18 and 24.

In October the UK's first two aircraft, ZM135/BK-01 and ZM136/BK-02, will be delivered from Cherry Point to Edwards Air Force Base in California. Edwards will be the first base in the world where UK F-35s are assigned to a British unit – No.17 Test and Evaluation Squadron, Royal Air Force. The squadron is now based at Edwards as the UK's component in the Joint Operational Test Team (JOTT).

The two aircraft will be used for operational test and evaluation of the Block 2B and subsequent Block 3F standards. The JOTT has yet to decide whether the UK's fourth aircraft, ZM138/BK-04, will join No.17 TES at Edwards.

Six Foot

On July 18, 2013 the then Chief of the Air Staff, Air Chief Marshal Sir Stephen Dalton, announced that the RAF's most junior bomber squadron – No.617 Squadron 'The Dambusters', colloquially known as 'Six Foot' – would be first to operate the F-35B, a predictable choice from the UK's F-35 lead service. Famous for breaching dams in Germany's Ruhr Valley in May 1943 with Lancaster B.1 (Specials) carrying 'Upkeep' mines referred to as bouncing bombs, the next chapter in Six Foot's history will be very different from the unit's first iteration at RAF Scampton in Lincolnshire.

The new No.617 Squadron will stand-up in the United States, not at an Air Force Base but at Marine Corps Air Station Beaufort in South Carolina. Nor will it be a traditional RAF squadron but a joint service unit instead, its ranks populated by men and women from the Royal Air Force and the Royal Navy. And once the new squadron is declared fully operational, it will operate F-35B Lightning IIs, a naval variant of the aircraft, from the deck of the UK's first CVF-class carrier, HMS *Queen Elizabeth,* and be a 'naval air squadron' in everything but title.

The initial cadre of UK pilots destined for No.617 Squadron will train at Beaufort with Marine Fighter Attack Training Squadron 501 (VMFAT-501) 'Warlords', the US Marine Corps' F-35B Fleet Replacement Squadron (see *Warlords* p128-135). Currently based at Eglin Air Force Base in Florida, VMFAT-501 is scheduled to start moving to the Marine Corps' 'STOVL centre of excellence' at Beaufort this autumn. UK pilots are already training with the Marine Corps as part of the partnering agreement between the UK and the US.

The RAF and Royal Navy plan to stand-up No.617 Squadron at the South Carolina superbase in the summer of 2016. Its tenancy at Beaufort should last until the summer of 2018 when it is expected to move to RAF Marham in Norfolk. "We're looking to declare initial operational capability towards the end of 2018, ready to conduct operations from land in support of coalition forces," said Gp Capt Hackett.



Variant: **F-35B ZM135** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014**
Detail: **Aircraft BK-01 taxies back to the flight line at Eglin** Photographer: **Paul Ridgway**

Dambuster Missions

The UK's F-35 user requirement document contains all the mission sets the JFL will eventually conduct with the Lightning II. Initially No.617 Squadron will conduct air interdiction, close air support, offensive counter air, defensive counter air and suppression/ destruction of enemy air defences.

"Multi-role, whether we deploy to an operating base or to the carrier, we're looking to be equally capable from land and sea. We're probably the lead nation in trying to do that with an F-35B," said Commodore Thompson.

Other mission sets include strategic attack, counter surface operations, electronic attack and ISR. "The Air Warfare Centre is working with our scientific partners within the DSTL [Defence, Science and Technology Laboratory] to make sure we can optimise and exploit the aircraft's electronic attack capability," explained Thompson.

To do that the UK has to determine how it will operate the F-35 with Typhoon, the other fighter within its future fighter force mix. Gp Capt Hackett explained: "If we're going into enemy territory and there are surface-to-air-missile systems out there and F-35s can detect and electronically attack them, we can shrink their engagement zones, giving extra access not just for F-35s but for Typhoons and other platforms because of our electronic attack capability."

RAF Typhoons assigned to No.41 Test and Evaluation Squadron flew with F-35s assigned to the 461st Flight Test Squadron based at Edwards in April, the first interoperability trials flown between the two types.

Commodore Thompson also highlighted the aircraft's inherent ISR capability and told the author that Joint Forces Command is currently leading the study of how the UK will employ the F-35 in that role.

Gp Capt Hackett said, in some instances, the F-35 will be able to replace other ISR aeroplanes. "The sensor suite [on the F-35] is fantastic and while it doesn't have the endurance of an AWACS or an Air Seeker [the name given to the RC-135 Rivet Joint in RAF service], the [eventual] number of F-35s over the battlefield will provide persistent ISR all of its own. It



Image Data

Variant:	**F-35B ZM135**
Unit:	**Marine Fighter Attack Training Squadron 501**
Location:	**Eglin Air Force Base, Florida**
Date:	**November 30, 2012**
Detail:	**Aircraft BK-01 parked under a sun-shelter at Eglin**
Photographer:	**Paul Ridgway**



Variant: **F-35B ZM136** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014**
Detail: **Aircraft BK-02 on short finals to land on Eglin's runway 12**
Photographer: **Paul Ridgway**

will complement AWACS and Air Seeker because they can't be put in harm's way whereas the F-35 can."

The F-35, he added, will give the UK a complete step up in capability. "It will also require a new mindset in the sense that we'll be able to operate deep inside enemy territory, pretty much radio silent with very little reach back to commanders back in the UK, executing strategic missions.

"The variety of missions and the level of capability is so much more than our legacy platform that it will be really important to keep pilots current by doing lots of work for tactical missions in the simulators."

The author was keen to know if the UK's F-35s would ever stand quick reaction alert [QRA] in the air-policing role. "That's difficult to answer," said the group captain. "The intent right now is for the Typhoon to remain in that role. Could the aeroplane physically do QRA just like Typhoon? Yes, of course it could, but it's not currently a requirement placed on the Lightning II. Should the decision be made in the future, the F-35 can do it."

Weapons

When No.617 Squadron declares operational capability with the F-35B it is expected to do so with a weapons fit comprising two air-to-air missiles (MBDA's medium-range ASRAAM and Raytheon's long-range AIM-120 AMRAAM) and Raytheon's Paveway IV dual-mode precision-guided bomb.

The next basket of weapons will involve SPEAR 1, an upgrade to Paveway IV with improved moving target capability and reduced collateral damage, the MBDA very long-range Meteor air-to-air missile and the GAU-22/A cannon.

In the future, the UK plans to integrate SPEAR 3, a powered munition capable of striking a moving target from long-range and capable of swarming enemy defences with multiple munitions. The F-35 will carry eight SPEAR 3 munitions in its weapon bays. SPEAR 3 has yet to be defined.

ALIS

As well as leading the UK's equipment integration of the F-35, Commodore Thompson's team is also managing the introduction of the Autonomic Information Logistics System (ALIS). Its customer is RAF Air Command based at High Wycombe in Buckinghamshire. "It's a system we've been very heavily involved in since day one," he said. "Royal Air Force and Royal Navy maintainers are using it at Eglin Air Force Base in Florida, and we're already testing equipment in the UK to make sure it's compatible with our other IT systems. RAF Marham in Norfolk, the main operating base, will have the ALIS fully integrated for the initial operational declaration."

HMS *Queen Elizabeth*

The first of three flight trial periods onboard HMS *Queen Elizabeth* is due to start at the end of 2018 and continue till May 2019. All three will be led by No.17 Test and Evaluation Squadron and take place in US waters. "We've got a period of two years allocated to do both the first-in-class flight trials and the operational work-up [by No.617 Squadron] to achieve a maritime capability declaration in 2020," said Thompson.

"Think about this as two buckets. We'll have No.617 Squadron training with the US Marine Corps at Beaufort between 2016 and 2018. The squadron then transitions back to the UK to meet its initial operating capability at RAF Marham. And at the same time No.17 Test and Evaluation Squadron will conduct the flight trials to clear the aircraft to go onboard the carrier. At the beginning of 2019 some of our pilots should have completed their instructor training with the Marine Corps ready to stand-up the operational conversion unit at Marham. Part of the introduction to service plan is to train the trainers so we have independence to do that ourselves."

The Dambusters will also support the stand-up of the F-35 OCU at Marham, currently planned for 2019.

RAF Marham

The UK's F-35 Project Team, working with the Defence Infrastructure Organisation and Air Command, is currently assisting with formalising a plan for the construction work required to support the F-35 at Marham. "The base will undergo redevelopment through until 2018. This will involve laying new runway and taxiway surfaces, constructing new hover pads, taking old hangars down and erecting two new purpose-built F-35 hangars – one for maintenance, repair, overhaul and upgrades and one for final finish and coatings," said Gp Capt Harv Smyth, RAF Marham station commander.

"Planning continues with regards to how we are going to house a low-observable verification facility, its design and where it will be located on the station.

"On the operational side of the airfield, we are 90% certain that 617 will operate from the hardened aircraft shelter [HAS] site currently used by IX(B) Squadron. The site will be redesigned for F-35. A new integrated training centre will be built next to the HAS site. This will be similar to, but smaller than, the one at Eglin Air Force Base and will be used for training pilots and maintainers. It will be equipped with classrooms, maintenance trainers and full-mission simulators."

Commodore Thompson says the UK is "not just buying aircraft, we are buying an air system, which includes the training solution designed by Lockheed Martin and tailored for RAF Marham".

Gp Capt Hackett added: "We'll be the first nation to set up a maintenance facility and a training centre outside of the United States. That's a great capability for the UK to showcase to other nations and perhaps get some of them involved with us to increase the use of our facility, aircraft, people and knowledge and spread our influence throughout the partner nations and NATO." ***Mark Ayton***



Variant: **F-35B ZM137** Unit: **Marine Fighter Attack Training Squadron 501** Location: **Eglin Air Force Base, Florida** Date: **March 21, 2014**
Detail: **F-35B BK-03 was the first UK aircraft to have a roundel applied to its forward fuselage** Photographer: **Paul Ridgway**

Lightning



With the prospect of the Royal Navy's two Queen Elizabeth class aircraft carriers and F-35B-equipped Joint Lightning Force (JLF) looming on the horizon it was imperative the Royal Navy and Fleet Air Arm (FAA) firmly re-established its fast jet operations within its command structure.

In a low-key event, this historic moment took place on June 6, 2013 when No.736 Naval Air Squadron (NAS) re-formed at Royal Naval Air Station Culdrose, Cornwall, almost 42 years after it was disbanded in 1972 as a Buccaneer unit based at Royal Naval Air Station Lossiemouth.

On September 9, 2013 the UK Ministry of Defence (MoD) announced that 809 NAS will re-form (a date has yet to be confirmed) as the first operational Royal Navy F-35B squadron. The official reincarnation of naval fast jet aviation is already under way with 736 NAS being the first fully 'dark blue' squadron of the new era.

No.736 NAS currently operates 14 British Aerospace Hawk T1/T1As from Culdrose and Yeovilton under the command of Lt Cdr Tim Flatman, a former Sea Harrier and Harrier GR9 pilot. He leads an experienced team of ten military and civilian pilots: the latter employed by contractor Serco.

As the Royal Navy's only fast jet squadron, its aircraft and personnel continue to provide airborne threat simulations against the Royal Navy's Task fleet or foreign ships undergoing pre-deployment operational work-up at sea as part of Flag Officer Sea Training. No.736 NAS also supports training of Royal Navy observers in the airborne early warning role and 'Freddies', trainee fighter controllers from the School of Fighter Control. An important part of the squadron's regular work is participation in the weekly 'Thursday War' during which its Hawks simulate attacks on Royal Navy warships off the Cornish coast.

Re-commissioned

The MoD's decision, in the 2010 Strategic Defence Review to scrap Joint Force Harrier (JFH) and effectively end fast jet aviation within the Royal Navy was extremely tough on everyone concerned.

The Royal Navy currently has aircrew in the United States on reciprocal exchanges but, until No.736 NAS was reformed, nowhere in the UK for them to gain Fleet Air Arm fast jet experience. Lt Cdr Tim Flatman explained: "Whilst we absolutely need aviators to fly modern fighters, we also need people who have delivered and supervised in a UK regulatory environment. The capability gap between JFH and JLF is huge and it was always going to be tough to plug the gap by just sending personnel to the US without retaining a fast jet hub within the Royal Navy's current command structure. This benefit flows from this new structure."



No.736 Naval Air Squadron/RNAS Culdrose

Although there is

Apparatum



Image Data

Variant:	**Hawk T1A XX301**
Unit:	**No.736 Naval Air Squadron**
Location:	**North Wales**
Date:	**June 2, 2009**
Detail:	**Low-level in the mach loop**
Photographer:	**Neil Dunridge**

no immediate plan to replace the ageing Hawk T1/T1A, which has an out-of-service date extended from 2015 to 2020, the type's replacement remains under review. Consolidation of No.736 NAS at Culdrose during the transition to JLF is important to enable the Hawk's equipment programme and manpower to be more focused and better resourced.

Because No.736 NAS is a new and relatively small squadron its personnel have taken a fresh look at future challenges and what is needed for processes, capability, manning and training. "We know where we want to be and what we have to do to meet the challenges going forward. Following the retirement of the Harrier GR9 force, Fleet Air Arm flight operations have inevitably become rotary-centric but, now the squadron is fully established, we can provide a focus for all aspects of fast jet operations, rules and regulations," added the squadron boss.

Compared with the now disbanded Fleet Requirements And Direction Unit (FRADU), which was previously run by Serco under contract to the MoD, the squadron can reach out directly to other defence enablers such as the Maritime Warfare Centre and the Air Warfare Centre with more confidence than its predecessor.

Role Expansion

With JLF's in-service date approaching, not only will No.736 NAS continue to meet its existing operational requirements but there will likely be additional tasking which could include providing a training 'threat'.

The squadron's aircrew have a breadth of operational experience in air defence and air-to-ground roles which was gained during the two Gulf Wars, Bosnia, Kosovo and Afghanistan. This will help to bridge the capability gap between Harrier and the F-35B. Lt Cdr Flatman said: "The step change to F-35 is huge and ultimately there will be a bespoke, and very demanding, set of threat simulation requirements such as different electronic warfare fits and synthetic radar. Although the Hawk T1 has limitations as a threat simulator, this is nevertheless an area within which I can see ourselves working a lot more."

Operating alongside the JLF, No.736 NAS will be able to provide a bridge for the fledgling force as the squadron boss explained: "For some of the pilots returning to the UK in the next couple of years, who have flown the F/A-18 Hornet and the F-35B in the United States, 736 could form part of their managed transition/build up to JLF. As a 'dark blue' squadron, in addition to operational experience our value is in providing a core set of UK-based fast jet expertise both in the air and on the ground. Prior to F-35, if a requirement to train personnel in a certain way emerges then we have the necessary qualifications and experience to be able to deliver this over time."

With No.809 NAS scheduled to stand up 736 NAS provides an extremely useful resource for JLF's future development, including trials work. Ultimately, the squadron is the only unit Royal Navy personnel can currently obtain UK maritime fast jet experience and could become the lead-in for JLF. More than four decades have passed since No.736 NAS ceased Buccaneer operations at RNAS Lossiemouth, the unit has re-established the Royal Navy's fast jet force which is set to be equipped with its most capable aircraft to date – the F-35B Lightning II. ***Ian Harding***

GRIM Reapers



As a squadron, the Grim Reapers has been at the forefront of US Naval aviation since May 1, 1952, operating FG1-D Corsairs, F2H-1 Banshees, F4D-1 Skyrays, F3H-2 Demons, F-4 Phantoms, and F-14A, F-14B and F-14D Tomcats. On September 30, 2005 the then Fighter Squadron 101 (VF-101) 'Grim Reapers' was disestablished at Naval Air Station Oceana near Virginia Beach. The unit had served as the US Navy's F-14 Fleet Replacement Squadron (FRS) tasked with teaching nugget pilots and radar intercept officers how to fly the aircraft, and also instructing junior maintenance ranks how to maintain the mighty Tomcat from January 1976. In 1994, VF-101 had 130 Tomcats assigned between its home station at Oceana and a detachment at the then Naval Air Station Miramar.

Tip of the Spear

Made famous by the Hollywood movie Topgun and the wording on its logo, 'Anytime, Baby...!', the F-14



Tomcat was the tip of the US Navy's spear, and many who flew the jet had the swagger to match. That's not meant as a criticism. The F-14 required great airmanship to fly in many flight regimes, yet it was a fighter laden with performance that some might say is as yet unmatched. Fact is, the Boeing F/A-18 Super Hornet, the Tomcat's replacement, is now the most numerous mount in the Navy's strike fighter force, and is the only US fighter still in production to have passed its operational test and evaluation. Its brother – the EA-18G Growler electronic attack aircraft, a derivative of the Super Hornet – continues to fill squadron billets at Naval Air Station Whidbey Island in Washington state, providing the US Department of Defense with a formidable electronic warfare force.

So why did the world famous Grim Reapers not adopt the Super Hornet, if it was the successor to its famous Tomcats? The answer is that the squadron was earmarked for a new chapter of fighter operations by being re-established as an FRS for the Navy's variant of the Joint Strike Fighter (JSF) – the F-35C. The squadron's new tasking holds one major difference from its past: it would be stationed at Eglin Air Force Base on the Emerald Coast of northwest

Image Data

Variant:	**F-35C BuNo 168733/'NJ101'**
Unit:	**Strike Fighter Squadron 101**
Location:	**Eglin Air Force Base, Florida**
Date:	**June 22, 2013**
Detail:	**US Navy test pilot, LCDR Chris Tabert discusses the ferry flight of VFA-101's first aircraft with CDR John Enfield, the then squadron commander**
Photographer:	**Todd McQueen/Lockheed Martin**



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Aircraft NJ101 features full colour markings all over the airframe** Photographer: **Paul Ridgway**

Florida and not a Master Jet Base usually selected for the service introduction of a new aircraft. Eglin, a major installation owned by Air Force Materiel Command, was chosen by politicians who wanted a joint training operation with the Air Force and Marine Corps each flying their respective variants of the F-35 as part of the 33rd Fighter Wing 'Nomads': the unit chosen by the Air Force to host the F-35 International Training Center at Eglin.

The Grim Reapers were re-established as Strike Fighter Squadron 101 (VFA-101) at the Florida super base in November 2011. The first F-35C BuNo 168733/'NJ101' was delivered to the squadron at Eglin on June 22, 2013.

Writing the Book

"Usually when an FRS [Fleet Replacement Squadron] stands up, everything is written and ready to hand off and the squadron personnel execute it. Here we are actually writing the book as we go, and setting the standard for what's going to be handed to the fleet in the future, not just from the training perspective but how to operate and maintain the aeroplane," explained CDR John Enfield, VFA-101's commander between August 2012 and August 2013.

The squadron's first pilot training class finished in February 2013 using the syllabus designed for the F-35A and with a transition course into the F-35C. The class used basic courseware and flew the F-35A simulators because at the time there were no C-model simulators at Eglin and a syllabus did not exist. Pilots subsequently trained in the F-35C simulators at Naval Air Station Patuxent River, Maryland, immediately before flight operations started at Eglin. This was a situation caused by the time lag between courseware and training systems being ready and the aeroplane's arrival.

CDR Enfield outlined the method to be adopted: "Our first goal is to build up our pool of instructors and get them trained in time for a F/A-18 unit to stand-up as the first F-35C fleet squadron. To accomplish that, we [VFA-101] trained the maintenance department in how to maintain the F-35C and their pilots how to fly it.

"It's a very similar model to the one used for Hornet to Super Hornet transition. The entire unit will come to Eglin, learn the new systems and procedures, and start to operate aircraft in a staged way, all under the supervision of VFA-101. When the squadron is ready to go on its own, it will stand up as an F-35C unit and move to its home station to begin unit level training. A lot of the junior pilots and maintainers will transfer over to that squadron as the seed corn – the initial expertise – to help complete its transition. Consequently, we will lose a lot of experienced folks and have a dip in manpower when that happens," he said.

The first squadron to transition from the F/A-18 is planned for the west coast, but a specific Naval Air Station has yet to be determined. And because the US Marine Corps will also transitioning five squadrons to the F-35C, the plan is to alternate the first ten units: Navy followed by Marine Corps followed by Navy. CDR Enfield detailed the current plan: "We will run that process through the first ten squadrons until we get all the Marine Corps units done, after which it will be an all-Navy transition. It's going to be a long time before we see every carrier air wing with JSF squadrons assigned and ready to deploy – it's a very shallow ramp for the Navy."

Quantifying the squadron's current role, CDR Enfield told AIR International: "The things we do now to get this aeroplane rolling are the things that future sailors will either thank us for or hate us for when they are in our shoes 20 or 30 years from now."

He also gave his opinion on why the Navy needs a fifth-generation fighter: "The Navy wants F-35C, and in my opinion needs this aircraft. Having the capability that this aeroplane will bring to the fight, on the first night of a war, especially against the threats we expect to see over the next 30 years, is something that would be a shame for us to miss out on. In many perceived conflicts, the mass of combat air power that we can project will come from aircraft carriers, and we want the F-35C to be there on the first night."

In a change of command ceremony held at Eglin on September 13, 2013, CDR Rick Crecelius, a former F-14 Tomcat, Hornet and Super Hornet pilot, took command of VFA-101. CDR Enfield is now deputy commander of Carrier Air Wing 5 based at Naval Air Facility Atsugi, Japan.

Challenges, Thresholds and a Mountain to Climb

CDR Crecelius had no experience of the F-35 prior to arriving at Eglin, "it's been a steep learning curve to say the least," he said. "There are lots of challenges, but it's an incredibly rewarding job to be able to influence the building of a new strike fighter community for the Navy. It's a joint venture and we are all, to some degree, building the same foundation for each of our respective services in the platform. My heart is focused on where the F-35C needs to be to declare IOC [Initial Operating Capability] in the fall of 2018."

The VFA-101 skipper explained further: "That's the target: to have the first squadron trained and able to deploy with combat effectiveness, from a carrier, with the full capability of the aircraft. Each service has its own IOC which is the driver for specific objectives and capabilities required for when they want to deploy the aeroplane. Of the three services, the Navy is the furthest out from declaring IOC and that's anchored to the full capability of the aeroplane, which is driven by the development of the Block 3F software and training."

To declare IOC, the Navy must transition one strike fighter squadron from F/A-18 to F-35C, and do so in time for the unit to undertake the standard air wing work-up ahead of deployment. Crecelius outlined the requirements: "Deployable combat capability is important for the Navy and, in order to declare it,



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Final approach** Photographer: **Paul Ridgway**

the squadron has to be able to function within the air wing. The carrier strike group is a combat tool available to the theatre commander, that has to be able to synergise with all of its assets as a single functioning unit. It's not enough just to have the squadron trained in the aeroplane; the squadron has to understand its role and be able to function within the air wing, and the air wing's capability has to integrate seamlessly, and complement the strike group so that it's deployable."

Based on the latest published plan, the first squadron is due to arrive at Eglin in July 2016 and "go to the boat" for carrier qualification in the early part of 2017. This reflects a six- to eight-month syllabus, but the timeline depends on various factors that include how the transition process works, the weather, and aircraft availability.

CDR Crecelius described the preparations required in order to welcome that first squadron into VFA-101 as: "a huge mountain to climb".

Between the summer of 2014 and July 2016, VFA-101 is also tasked with training Navy pilots who will undertake operational tests of the F-35C with Air Test and Evaluation Squadron 9 (VX-9) 'Vampires', as part of the Joint Operational Test Team with its own in-house personnel at Edwards Air Force Base in California.

As of June 2014, VFA-101 had six F-35Cs and 135 personnel assigned. The squadron ranks are expected to double over the next 12 months, and by the middle of 2015 top out with around 350 people and 15 aeroplanes assigned.

Maintainer and Aircrew Training

It is a challenge for all squadron personnel to run a consistent training programme when faced with the rigours of standing up a Fleet Replacement Squadron, trying to qualify instructor pilots, low rates of aircraft reliability, and the concurrent developmental test phase. The same holds true for maintenance, as Crecelius outlined: "We have our own maintainers, but we have to get all newcomers to the squadron through basic training as well. After completing academics the folks only have 75% of the knowledge required. The depth of the information on the platform isn't sufficient to get our personnel trained to the same level their counterparts in the F/A-18 training syllabus will have reached when they have finished their training.



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Eglin Air Force Base, Florida** Date: **June 22, 2013** Detail: **Arrival at Eglin after ferry flight from Fort Worth** Photographer: **Todd McQueen/Lockheed Martin**



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Over Texas** Date: **March 11, 2013** Detail: **Third flight** Photographer: **David Daris/Lockheed Martin**

"So, while we are qualifying our aircrew and maintainers, we are also establishing maintenance and operational support programmes so as to be self-sufficient as a Fleet Replacement Squadron and start taking the burden of transitioning squadrons to the aeroplane."

The syllabus originally issued by Lockheed Martin was based on the best estimation of the capabilities Block 3F will provide and, although comprehensive, it was only 80% complete. "We use portions of the original syllabus that are relevant to the current software release and capabilities. By looking through Navy spectacles, we define what the syllabus lacks, so that folks get the training they need to operate from a carrier," explained the skipper.

Different categories of syllabus, similar to those used by the F/A-18 training squadrons, are being developed. "Right now we are primarily focussed on the CAT 2 syllabus," said Crecelius, "which is designed for pilots previously qualified on the Hornet or Super Hornet who will transition to the F-35. We are also running the CAT 4 syllabus, an abbreviated version of CAT 2, that enables a pilot to get ten hours and a NATOPS (Naval Air Training and Operating Procedures) qualification in the aeroplane. Pilots taking the CAT 4 go to the operational test force, and do not get the full employment syllabus gained with CAT 2."

Each category has different versions that match the software release of the aircraft. At VFA-101 they are currently running the Block 2A CAT 2 syllabus that will almost double in content with the Block 2B version. The intermediate and full suite of capabilities released with Block 3I and Block 3F will each require a more extensive syllabus. Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs', the F-35C developmental test unit based at Naval Air Station Patuxent River, provides VFA-101 with advice on how to employ the F-35C given the current airframe and software limitations.

Current Flight Operations

The current pilot's syllabus comprises six familiarisation, or fam, events that include formation flying and landing pattern work. Event one is the first time a student straps into the aeroplane for a taxi fam. This gives him an opportunity to start the aircraft and taxi around to make sure he is fully familiar with the cockpit procedures. According to the VFA-101 skipper, "it's so different starting up and interfacing with the systems in the F-35 compared to a legacy aircraft."

The second event is the first time the student flies the aircraft, and is a chased event. "The chase aircraft stays away from the student to allow him to figure out within the limitations placed on the aeroplane, bank angle changes, acceleration, deceleration, and handling qualities at different speeds and under different configurations," explained the skipper.

Event three, which is the second flight, involves the first formation work. The requirement for formation flying is emphasised on every subsequent sortie, one of which must involve flying with another F-35C, while the others can be flown with an F/A-18.

Subsequent fam events include the time to conduct benign intercepts, which provide the student pilot with his initial experience of interfacing with the radar, learning how to work the systems and manage the displays.

"Then, of course, we undertake landing pattern work both at Eglin and Naval Air Facility Choctaw, which is located to the west on the coast. Choctaw is equipped with a Fresnel lens and arrestor gear for FCLPs. We send a Landing Signals Officer [LSO] there for all landing pattern work," enthused the skipper. "We are currently limited in our rate of descent for landing, which prevents us from doing true carrier bouncing [a naval term for carrier style touch and goes], but we do fly a standard Navy pattern at 600 feet AGL [182m] with a standard approach turn, as used at the ship. We can't fly that type of pattern at Eglin."

Prior to receiving NATOPS qualification, the pilot has to be chased by another jet: either an F-35C or an F/A-18. The fam syllabus culminates with a NATOPS emergency procedures check in the simulator. Once the check ride is complete, the pilot is NATOPS qualified. His next objective is to complete 15 more hours currency training before starting the IUT (Instructor Under Training) syllabus. This is a qualification that allows an instructor to teach the basic fam and formation phases of the standard syllabus.

Going to the Boat

Lockheed Martin is currently finalising the configuration of two System Development and Demonstration aircraft (CF-03 and CF-05) that will deploy aboard the USS Nimitz (CVN 68) for Development Test Phase One, or DT I. This is the first period at sea for the F-35C, currently scheduled for October. There is a vested interest in DT I at VFA-101, and to the maximum extent possible it intends to send its LSOs to each F-35C carrier evolution. "They may not fly, they may not get a chance to qualify, but they will be on the LSO platform and work with the air boss and the carrier's commanding officer to make sure they gain experience of the challenges of carrier integration," said Crecelius.

"If we are able to accomplish that on DT I, two or possibly three LSOs from VFA-101 will actually carrier qualify [make arrested landings on the carrier flight deck for the first time] at the end of DT II, which is the second carrier evolution currently planned for the summer of 2015. If DT II does not work out for us, then we will look to schedule a specific carrier to qualify our LSO cadre, and possibly one or two other instructors. And if there is a DT III, which would occur sometime in the summer of 2016, that's when 101 would go to the ship," he said.



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Tail markings on VFA-101's colour bird** Photographer: **Paul Ridgway**

Safe for Flight

One of the most important requirements for any Navy squadron is to be declared 'safe for flight'. The declaration is the certification that the squadron's maintenance department is able to maintain and sustain flight operations with its assigned aircraft type. "We hope to begin that process this summer and over the course of the year establish enough capability, capacity, reliability and integrity in our various maintenance programmes to be safe for flight in the summer of 2015. That's our target," enthused CDR Crecelius.

"It's a big deal because right now Lockheed Martin owns the maintenance of the aeroplane, which is good, but it's important that our maintainers have the expertise to take care of the aeroplane. They are the founding fathers of the F-35C community from a maintenance perspective. Now, we have interim safe-for-flight clearance, which means the squadron can operate the aeroplanes and conduct maintenance, but we don't own the maintenance operations."

The VFA-101 skipper detailed the main objectives for the next 24 months. "The transition from having an initial cadre of officers with test expertise running VFA-101's programmes, to a staff comprised entirely of fleet aviators, is ramping up, which is also a big deal. Training the trainers will continue to be our mission for the next couple of years and we need to increase the fidelity of the programme, the curriculum and training guides for both maintenance and flight operations. Once that's accomplished we can say with credibility that we are ready to train someone else. It's a long path."

Maintenance Department

In partnership with Lockheed Martin, VFA-101's maintenance department currently performs both post-flight and second line maintenance in the squadron hangar. The activity that presents the greatest challenge is known as intrusive maintenance, in which maintainers have to break open a panel, do the repair and return the aircraft back to its form prior to the fault. This creates additional work and adds time to the front and back ends of the job. "Once you are in there, it's straightforward to do, it's getting to that point that's the hard part," said CDR Ken Lookabaugh, VFA-101's Maintenance Officer.

Senior Chief Jeffrey Rushing, VFA-101's Maintenance Chief explained the turnaround process between flights: "When the aircraft shuts down we don't have a whole lot of reconfiguring to do, because it's configured for us to perform an inspection. From nose to tail and back to nose you are looking over every part of the aircraft for cracks, leaks, anything that doesn't look as it should. We check the fuel level and refuel it."

"Other than the time it takes to download the maintenance data from the aircraft into ALIS [the Autonomic Logistics Information System] the turnaround time is pretty good," said CDR Lookabaugh. "Believe it or not, that takes us longer than actually checking the aeroplane, though the inspection and refuelling can be done while we waiting for the data process to complete. The download process takes time because we have to make sure there are no HRCs (Health Reporting Codes) flagged up that indicate the aircraft is down for maintenance."

Releasing the aircraft for flight after a turnaround is controlled by the ALIS. According to Senior Chief Rushing, the ALIS has a feel on almost everything on the aircraft. "When you go through the electronic equipment logs to release the aircraft, each of the aircraft downloads has to match the ALIS information perfectly. Anything that doesn't match will throw up a red flag, requiring us to investigate, figure out where and what the problem is and fix it so we can release the aircraft.

"Each electronic equipment log tracks the parts and serial numbers fitted to the aircraft. The system knows that this particular aircraft can fly with this part through that part number. If a part number is bad, ALIS knows the aircraft can't fly in that configuration, even if the jet and ALIS match. So it will throw up a flag.

"Those are the two big aspects of the ALIS that slow us down. They make us pause, look back again and dig into what's actually there. They represent the difference between releasing a legacy aircraft and releasing the F-35 as safe for flight."

CDR Luke Kremer explained that the procedures followed by a pilot when signing for the jet start with the ALIS. Within it he can read all of the records, up to and including the maintenance work performed on the aircraft since its previous flight. "The problem with that method is you do not get any face-to-face discussion with the maintenance shop," he said. "I still want to stop by there and talk to them about the aircraft I'm getting, and what happened with it on the previous flight. For the most part they [maintenance control] will talk to me about the things that I have just read about on the ALIS. The difference is that I get the extra history and I can ask questions. We keep a small book of the aircraft's history that lists what the previous pilot experienced."

"Once the ALIS works as advertised it will be a great system; it already is in a lot of cases," concluded CDR Lookabaugh. "It is very beneficial because all the

Image Data

Variant:	**F-35C BuNo 168733/'NJ101'**
Unit:	**Strike Fighter Squadron 101**
Location:	**Eglin Air Force Base, Florida**
Date:	**June 22, 2013**
Detail:	**Arrival at Eglin after ferry flight from Fort Worth**
Photographer:	**Todd McQueen/Lockheed Martin**



Variant: **F-35C BuNo 168733/'NJ101'** Unit: **Strike Fighter Squadron 101** Location: **Eglin Air Force Base, Florida** Date: **March 19, 2014** Detail: **Approach for a touch and go** Photographer: **Paul Ridgway**

serial numbers are already logged and it tracks your configuration management, which is where we always got ourselves in trouble with legacy systems. Those alone are advances that are good for this platform and good for the Navy."

Changing and Handling an F135 Engine

To date, the squadron's maintenance department has changed one F135 engine on F-35C BuNo 168733/'NJ101' – the first one delivered from Fort Worth.

According to CDR Lookabaugh the process was "much slower" compared to a Hornet or Super Hornet, but not because the maintainers were unfamiliar with the procedure. "Changing an engine [on the F-35C] requires a quite different mindset," he said. "That's why you don't want to do it unless you absolutely need to, because it's going to take more time than on the legacy platforms."

Physically, it involves a different way of doing things. "You pull it straight out rather than drop it," said Lookabaugh. "You have to take panels off to get at the many connections, and you have to remove the tail hook truss. So there are lot of parts that have to come off before you can take the engine out. All you do with a legacy platform is drop the doors and its engine comes straight out."

The size of the F135 engine, compared to the F404 and F414 power plants used by Hornets and Super Hornets, is "not going to affect us much" according to CDR Luke Kremer, VFA-101's Safety Officer. He added: "It's going to make the handler mad, though. He's the guy who has to park up the jets. Because the F135 is not dropped down, he's going to have to make more room behind the aircraft to allow for the motor to be pulled out. That means he will have fewer spots to park jets in the hangar bay."

CDR Lookabaugh explained: "Certain spots are considered dead spots: those where we wouldn't move the aircraft after we'd started working on it. They will probably be the spots where we will position an aircraft that requires the engine to be removed. This will not impede the flow of traffic moving through the hangar bay. Typically, the handlers do a whole dance of moving aircraft around at night to get the right one downstairs and others upstairs. Any aircraft stuck in a certain position will impede movement. It will be a challenge, but nothing that hasn't been overcome before."

Also, because of its size, handling an F135 engine between the hangar bay and the Aircraft Intermediate Maintenance Department will eventually be helped by an engine removal and installation trailer specifically designed for the Pratt & Whitney power plant, although engine handling testing has not happened yet.

Flying the F-35C

Describing the aircraft and its handling, the VFA-101 skipper told AIR International: "The strike group commander is going to hold it as an invaluable asset to his war fighting capability, because what it adds to the rest of the carrier strike group is going to be nothing short of impressive.

"It's a very easy aeroplane to fly. The airframe handles so well, holding altitude and air speed, turning left, right, manoeuvring in formation and in the landing pattern. It's a very friendly aeroplane in that regard, so landing it ashore is a piece of cake.

"Based on the way it handles in the landing pattern I would say it certainly wouldn't be any more difficult to land on the ship than a Super Hornet. The F/A-18C Hornet is one of the most enjoyable aeroplanes to land on the boat, because you can put it exactly where you want it to be. Based on what the engineers and test pilots say about the F-35C, with flight control law upgrades, it should also attain pilot-friendly landing pattern handling characteristics that resemble those of an F-18C – that's good for a single-engine aeroplane.

"In the fleet I have always flown twin-engine aeroplanes, so jumping into a single-engine type opens your eyes to different considerations when compared to flying an F/A-18. When flying Tomcats and Hornets I was always very aware of where my diversion fields were. In the F-35, that sense of awareness is heightened just because I've got one motor. If you have a problem you don't have anything to fall back on. So it's a subtle, but very distinct, change in mentality, especially flying over open water, and you pay very close attention to where you are going to go if you have an issue.

"The saving grace is that Pratt & Whitney has a fantastic track record with the Raptor's F119 engine, so the expectations are very high for the reliability of this engine, too," concludes CDR Crecelius. "We also have to train differently and do precautionary flame out approaches in the simulator, which we don't do in F/A-18s. It's a new animal, something that we have to train to. The mentality of flying a flame-out approach is new stuff for us Navy cats." ***Mark Ayton***





Image Data

Variant:	**F-35A 11-5030/'LF'**
Unit:	**61st Fighter Squadron**
Location:	**Luke Air Force Base, Arizona**
Date:	**March 10, 2014**
Detail:	**Delivery flight**
Photographer:	**Jim Haseltine**

Luke Air Force Base near Glendale, Arizona, remains the largest F-16 Fighting Falcon base in the world, a status it has held since April 1994. On March 10, 2014, F-35A Lightning II 11-5030/'LF' touched down on Luke's runway 03R following its delivery flight from Lockheed Martin's plant in Fort Worth Texas. The aircraft was flown by Col Roderick Cregier, a test pilot and the F-35 Program Lead at Edwards Air Force Base in California. It was the first F-35A to be assigned to the base and marked the beginning of the next chapter of Luke's history as a fighter pilot training base.

Its arrival also marked the beginning of the end of F-16 operations at the sprawling base. The first Fighting Falcon arrived at Luke in December 1982 assigned to the 58th Tactical Training Wing, later the 58th Fighter Wing (FW). The current host unit at Luke, the 56th FW with seven squadrons assigned, was activated at the base in April 1994.

The 61st Fighter Squadron 'Top Dogs', a unit previously assigned to the 56th FW, was stood down on August 27, 2010 but reactivated at Luke on October 25, 2013 as the wing's first F-35A operator. Its commander is Lt Col Mike Ebner, a former F-15E Strike Eagle pilot with 263 combat missions to his name. Prior to commanding the 61st FS, he served as one of ten US Air Force pilots in the initial F-35A cadre with the 58th FS at Eglin Air Force Base in Florida.

Continuation Training

The squadron's reactivation enabled an initial cadre to welcome personnel and commission its new buildings with the required systems, networks and support equipment.

"We also had to get our processes and procedures in place for the arrival of the first aircraft," said the colonel during *AIR International's* visit to Luke.

"We moved into the building in the first week of January. We had to have a security plan and a secure facility to house classified data and ALIS [Autonomic Logistics Information System] before we could receive a jet, only ALIS will support aircraft on the base. We met the timeline set for the jet's original arrival and today we're ready to support continuation training or proficiency training for our

Top Dogs





Image Data

Variant:	**F-35A 11-5030/'LF'**
Unit:	**61st Fighter Squadron**
Location:	**Luke Air Force Base, Arizona**
Date:	**March 10, 2014**
Detail:	**In the pattern at Luke**
Photographer:	**Jim Haseltine**

squadron pilots. That's what we'll be doing probably all the way through to the spring of 2015.

"All pilots assigned to the 61st FS get checked out in the F-35 at Eglin. We now have four F-35 pilots in the 61st and more are in training at Eglin. When they arrive they'll start continuation training to become instructors."

Luke has a new F-35 Academic Training Centre (ATC) which houses all the classrooms and simulators. Eventually the facility will have 12 simulators, many more than the ATC at Eglin which is actually bigger than the one at Luke. This is because Eglin also conducts maintenance training: Luke will not.

Lt Col Ebner explained: "We expect to complete the entire ATC building in the fall of 2014 and get our first simulator completed in the winter of 2014-2015. The second will follow in April 2015. We need to get two simulators in so we can tie them together to start training pilots from other aircraft types."

Pilots graduating from the first few classes run by the 61st FS will either become instructor pilots at Luke, operational test pilots for the Air Force or be assigned to the first operational F-35A squadron at Hill Air Force Base near Ogden in Utah.

Ebner outlined the plan: "That takes us into the 2016 timeframe at which point, under the current plan, we'll begin to accept pilots directly from Air Education and Training Command's Specialized Undergraduate Pilot Training programme. They will go through academic and simulator-based training before flying the F-35A with the 61st FS. We're laying all the groundwork to set up the training system for the initial transition courses. Once we get that ironed out and the jets on line we'll be ready to start basic qualification training."

By the end of this year Ebner expects to have 15 aeroplanes assigned to the 61st FS, increasing to 24 before training ops start in March 2015 at which point a second squadron will stand up.

So how does the training mission tie in with the Air Force plan to declare initial operational capability (IOC) with the F-35A?

"IOC is a goal for Air Combat Command [ACC] and that's a variable – the jet will gain IOC when it has demonstrated the capability to the Air Force," said the colonel. "Our role is to be able to provide enough pilots



Image Data

Variant:	**F-35A 11-5030/'LF'**
Unit:	**61st Fighter Squadron**
Location:	**Luke Air Force Base, Arizona**
Date:	**March 10, 2014**
Detail:	**Touchdown on Luke's runway 03R**
Photographer:	**Jim Haseltine**





Variant: **F-35A 11-5030/'LF'** Unit: **61st Fighter Squadron** Location: **Luke Air Force Base, Arizona** Date: **March 10, 2014**
Detail: **Turning short finals at Luke** Photographer: **Jim Haseltine**



Variant: **F-35A 11-5030/'LF'** Unit: **61st Fighter Squadron**
Location: **Luke Air Force Base, Arizona** Date: **March 14, 2014**
Detail: **Maintenance technicians assigned to the 56th Maintenance Group close up panels on the first F-35A assigned to Luke**
Photographer: **Paul Ridgway**

for ACC. So if ACC says, for example, we need 40 pilots by the time we declare IOC, then Air Education and Training Command has to work the numbers.

"To generate 40 pilots we need to have 'X' amount of instructors and 'X' amount of courses and slots, so we've got to do all that now. Where it gets tricky is when the aircraft gets delayed or doesn't match the timelines as predicted. But we have to plan off something and the Air Force will adjust and meet whatever that training target is. It's tricky because of the complexity of the programme and all of the moving parts."

Training Requirements

The US Air Force has a requirement to train a certain number of pilots each year that can only be fulfilled by a unit the size of the 56th FW. Eventually the wing will have six F-35 squadrons assigned, all dedicated to training.

Lt Col Ebner gave some reasons why Luke was chosen: "We have great weather, the infrastructure and facilities required, two parallel runways which are very helpful for all the pattern work required in the training, the 1.7 million-acre Barry M Goldwater range which we'll use for air-to-surface training and we have the support of the local community: it's a no-brainer why the Air Force conducts flight training here."

The 33rd FW based at Eglin Air Force Base in Florida is also part of Air Education and Training Command (AETC) and is supporting the work-up of the 61st FS. AETC reviews the training syllabus for each Major Design Series aircraft on a biannual basis and is currently developing the fourth version for the F-35, geared to Block 2B software. The process has been under way for ten months.

"Once it gets signed off by AETC then it is set in stone," said Ebner. "If we [the squadrons] have any issues with it we have to work that independently at command level. We fly in accordance with the F-35's airborne operating limits (AOLs). As the limits are increased, the way we can fly the aircraft will also change – but we can't just fly to the new limits, we need AETC to build the syllabus to do that.

"It's a formal training syllabus designed for pilots transitioning from a combat-coded aircraft [A-10C, F-15E or F-16C] who require a basic F-35A qualification."

Ebner described the process used for instructor pilots. "We will develop a plan in-house for the instructors who are already flying the jet when a new capability is released. We formulate a training plan with the 58th FS at Eglin that is sent up the chain of command for approval."

But the syllabus is not affected by the aircraft's limited capability, as Ebner explained: "We actually have an opportunity in that respect. Over the next 18 months, besides just flying round the flagpole, we'll try to contribute to the overall programme as we prepare to train pilots.

"All pilots assigned to the 61st FS have at least 750 flight hours in a fighter and have undertaken the initial instructor pilot upgrade at Eglin. Because the F-35 is easy to fly it's therefore straightforward for an experienced pilot to get checked out. That means they can begin to use the jet in a smart way and become experts on the aircraft.

"In the longer term that's what the Air Force needs because many of us will go to other jobs that will have a lot of impact on the programme."

Mark Ayton





Image Data

Variant:	F-35A 07-0745/'ED'
Unit:	461st Flight Test Squadron
Location:	Over California
Date:	March 22, 2012
Detail:	Night time test flight of the AAQ-37 Distributed Aperture System
Photographer:	Darin Russell/Lockheed Martin

Adir

Many F-35 customers have reviewed their acquisition of the aircraft, but there's never been any doubt about the Israeli Air Force (IAF)'s commitment to the programme.

It's long endorsed technological superiority as a key to maintaining its effectiveness. When it flew technologically superior F-15s and F-16s against Syrian MiG-21s and MiG-23s from 1979 until 1982, it achieved a 100-to-0 air-to-air kills-to-loss ratio.

The urge to maintain technological superiority led the Israel Defense Forces (IDF) to continually invest in new technology – as evidenced by the purchases of the F-15I Ra'am in the 1990s and the F-16 Sufa in the 2000s. For the IAF the only option to push forward its capabilities beyond these aircraft was to procure the F-35.

The IAF's eagerness to join the Joint Strike Fighter (JSF) programme was made public in 1999 when it was revealed that Israel applied for participation in the programme as a Level 4 partner. Although this was the lowest partnership level, it did offer the IAF invaluable insight into JSF technologies.

Participation to Purchase

In July 2003 the Israeli Government signed a formal letter of agreement, worth almost $20 million, to join the System Development and Demonstration phase as a Security Cooperation Participant. One F-35 squadron purchased – in the IDF's plan for 2008 to 2012, announced on September 3, 2007 – was included and signalled the go-ahead for Israel's acquisition of the F-35.

The US Defense Security Cooperation Agency was notified on September 26, 2008 of a possible foreign military sale to Israel of 25 F-35As plus an option to purchase 50 more F-35As and/or F-35Bs. It took until October 7, 2010, for Lockheed Martin's Letter of Offer and Acceptance (LOA) to Israel to be signed. This US$2.75 billion deal covered 20 F-35As, or US$137 million per aircraft, due for delivery from 2015. The IAF's selection of F-35A over F-35B preference for the F-35A's long-range capabilities.

'Israelisation'

The time taken to finalise the sale of F-35s to Israel stemmed from the IDF's aspirations to 'Israelise' the jet. In acquiring F-16s and F-15s, including the latest F-16I Sufa ordered in the early 2000s, the IAF had been able to customise its aircraft by including indigenous electronic warfare (EW) suites and communication systems – which the IAF regards as crucial for technological superiority, especially when threats change over the long term.

However, with an important element of the F-35 programme being that all operators use the same systems to minimise expenditure and maximise commonality, this level of customisation was a no-go. Still, the Israelis bargained hard and it's been widely reported that an agreement has been reached for indigenous Israeli sensors and communications systems to interface with the standard EW suite in the F-35As that will be built for Israel.

Offset

The United States has also made a generous industrial involvement package available to Israel. In December 2011, Northrop Grumman contracted Elbit Cyclone to produce composite parts for F-35 fuselage centre sections. Then, in April 2013, Israel Aerospace Industries (an established producer of F-16 wings and conformal fuel tanks for Lockheed Martin) was awarded a US$2.5bn, 15-year contract to produce F-35 wings on a newly established automated production line. Lockheed Martin and IAI said the first Israeli-produced F-35 wing will be completed in September 2014. Serial production will start this summer with wing deliveries following in 2015, said the companies.

This is in addition to the work being undertaken by Vision Systems International (VSI, a joint venture between Israel's Elbit Systems and Rockwell Collins) to produce the F-35's highly advanced Gen II Helmet-Mounted Display System. This system had its development delays owing to issues with night vision acuity, symbology jitter, Distributed Aperture System latency and green glow. But Lockheed Martin says solutions have been found and in October 2013 the F-35 Joint Program Office decided to halt development of the alternate F-35 helmet to focus exclusively on maturing the VSI design known as Gen III.

Towards Delivery

The IAF announced in April 2013 that it would name its F-35As the Adir (Hebrew for 'awesome'). During 2012 the date of the first scheduled deliveries slipped to 2016. The first two Israeli F-35As will be Low Rate Initial Production 8 lot aircraft. They are scheduled for delivery in 2016 for the IAF's first pilots to begin training at Luke Air Force Base in Arizona.

The following year seven LRIP 9 aircraft are planned for delivery to the IAF's first F-35 squadron, based at Nevatim. The balance of ten, most likely from the still-to-be-concluded LRIP 10 and/or 11, will follow in 2018. ***Shlomo Aloni***

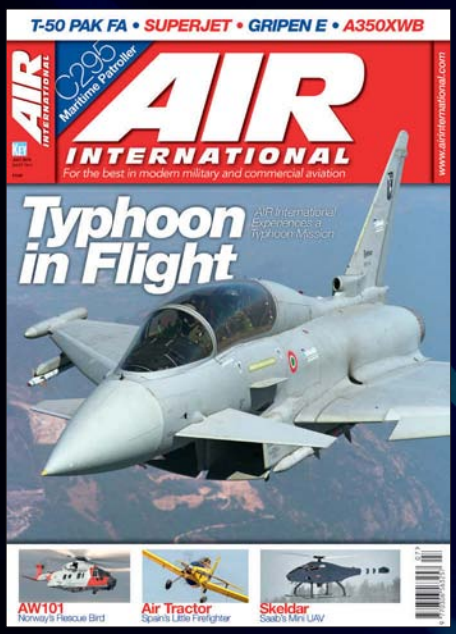
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Firsts in the World



Image Data

Variant:	**F-35B BuNo 168719/'VK01'**
Unit:	**Marine Fighter Attack Squadron 121**
Location:	**Marine Corps Air Station Yuma, Arizona**
Date:	**April 24, 2014**
Detail:	**STOVL recovery to land following a Weapons and Tactics Instructor course mission**
Photographer:	**Dan Stijovich**

Until September 28, 2012 Marine Fighter Attack (All Weather) Squadron 121 [VMFA(AW)-121] was an F/A-18D Hornet unit based at Marine Corps Air Station Miramar near San Diego, California. Come midnight it had transitioned to its new home, Marine Corps Air Station Yuma in Arizona and made history – it had become the world's first combat F-35 Lightning II squadron.

Maj Greg Summa, the squadron's Executive Officer remembers the early days well: "When I checked in to the squadron on July 31 it comprised the commanding officer LtCol Jeff Scott, one other captain, one warrant officer and 20 Marines. Its official title was MAG-13 Headquarters, det A because the then F/A-18D-equipped VMFA(AW)-121 was deployed to Iwakuni in Japan," he said.

Delivery of the squadron's first aircraft was accelerated by three months, which meant that LtCol Scott and his small cadre of Marines spent the summer setting up the squadron maintenance department. No other squadron in the entire US Department of Defense had previously set-up an organic F-35 maintenance department. The Marines assigned follow the same regulations as all other squadrons in naval aviation. The tried and tested terminology contained in the 4790 Naval Aviation Maintenance Program regulations proved to be a test for the smartest Marine assigned to 121. Terms used in the joint F-35 programme differed from those that the Marines were used to: a situation that required plenty of patience while learning.

The first jet arrived on November 16. Four days later the squadron was re-designated as VMFA-121 during a ceremony attended by General Amos, Commandant of the Marine Corps.

Inspection

An inspection team from the 3rd Marine Aircraft Wing started a safe-for-flight inspection in December,



Variant: **F-35Bs BuNo 168721/'VK03' and 168724/'VK06'** Unit: **Marine Fighter Attack Squadron 121** Location: **Over Arizona** Date: **May 22, 2013** Detail: **Ferry flight to Yuma** Photographer: **Liz Kaszynski/Lockheed Martin**



a mandatory event to ensure all of the required programmes and procedures are in place and adhered to in accordance with the required standards. This was an important inspection because VMFA-121 was laying the foundation and framework of the Marine Corps' F-35B transition process that subsequent squadrons will follow and learn from.

According to Maj Summa the biggest challenge when preparing for the inspection was getting everyone trained and familiar with procedures and the terminology used in the Flight Series Data and the ALIS: the F-35 equivalents to NATOPS (Naval Air Training and Operating Procedures Standardization) and NALCOMIS (Naval Aviation Logistics Command Management Information System) respectively.

Maj Summa explained the challenge with the ALIS: "We had to ensure that everybody understood how the information was passed and distributed so that when somebody reached the 15th step in a procedure, they knew how to complete the task in accordance with the way it's supposed to be versus having miss matches that need correcting."

This was achieved by using working groups that included people from the F-35 Integrated Test Force at Naval Air Station Patuxent River and Marine Operational Test and Evaluation Squadron 22 (VMX-22) from Edwards Air Force Base, California.

"The working groups developed a procedures check list for the maintainers to follow when releasing the aircraft as safe-for-flight, which involves checking different sub-sets in the ALIS that track different components."

The check list also includes procedures that the pilot must follow, as Maj Summa explained: "Software is a big aspect of the aeroplane, especially during start-up procedures and getting the aircraft cleared as safe-for-flight with the ALIS. It's better to let the aeroplane start-up and then wait for everything to come alive. After that, it's very solid and very stable. We soon learnt that the check list doesn't have times associated with it, so we've come up with a very dedicated set of procedures that are



Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **A pilot inspects the visor of the Helmet-Mounted Display System before a two-ship training sortie** Photographer: **Paul Ridgway**



Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **Marine maintainers view aircraft data on a Portable Maintenance Device on the flight line** Photographer: **Paul Ridgway**



Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **July 2, 2013** Detail: **A Marine pilot climbs up the crew access ladder** Photographer: **Paul Ridgway**

in accordance with the check list. Adherence to the check list ensures that system components are fully functional before we turn certain ones on or off. The reason why is because everything is so integrated in this aeroplane and that's a big deal on the F-35."

All procedures set up for using the ALIS were evaluated by the 3rd MAW team during its ten-day inspection, at the end of which the squadron gained its safe-for-flight certification. This meant that VMFA-121's commander could sign off the squadron's flight schedule, which allowed organic flight operations to begin.

The squadron started flying in January, initially just once a week, by March it was flying twice a week and doing hot pit evolutions with two aircraft on a two-pit-two schedule. In May 2012 VMFA-121 conducted its first turn evolution. This involved two jets flying in the morning, a maintenance inspection between sorties and flying the same two jets in the afternoon. "In ten months we went from three officers, none of whom were qualified in the aeroplane and 12 marines with no aeroplanes, to having six aircraft, a fully certified organic maintenance department and eight trained pilots all able to undertake a two-turn-two schedule," said Summa.

Major Summa enthused about the serviceability of the F-35B and using the hot pit refuelling system: "I took off from Yuma, flew a mission, recovered to the base, ran through the hot pits, took off again, went to a tanker and returned to base. I got 3.8 hours of flight time in one day. That was hard to do when I was flying Hornets."

By July 2013 the squadron was planning to fly its first four-ship sortie. This presented new challenges as the Major explained: "Administratively how does a four-ship change the time line, airspace, and communications? What does it do to a maintenance department now that is has to turn four aeroplanes versus two? How many fuel trucks are needed?"

As the number of aircraft assigned increases to its full complement the squadron's objective is to conduct even larger missions involving eight aircraft in the morning, have four turn using the hot pits, then turn them again as part of a six- or eight-ship in the afternoon.

Marine Corps Maintenance

The squadron's maintenance department is unique. It is the first organic F-35 squadron maintenance department in the world.

"All of the Marines on the squadron attended the F-35 Academic Training Center at Eglin. Their first experience of working on the F-35B was also at Eglin. That was with the support of contractors and instructors assigned to the fleet replacement squadron. So they now have about 18 months of experience," said Master Gunnery Sergeant Juan Villareal VMFA-121's Maintenance Chief.

"The good thing is that most have anywhere from four to eight years of experience working on the



Variant: **F-35B BuNo 168720/'VK02'** Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **March 15, 2014** Detail: **First public F-35B STOVL demonstration in the world** Photographer: **Dan Stijovich**



Variant: **F-35B BuNo 168730/'VK12'** Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **A maintainer discusses the aircraft's status with the pilot prior to ground checks** Photographer: **Paul Ridgway**



Image Data

Variant:	**F-35B BuNo 168720/'VK02'**
Unit:	**Marine Fighter Attack Squadron 121**
Location:	**Marine Corps Air Station Yuma, Arizona**
Date:	**March 15, 2014**
Detail:	**First public F-35B STOVL demonstration in the world**
Photographer:	**Paul Ridgway**

AV-8B Harrier and the F/A-18 Hornet. And we rely on their past experience but it's between myself and the squadron maintenance officer to decide when they have sufficient experience to give them the responsibility to work on the aircraft," he said.

MGySgt Villareal said the initial challenge was in understanding the Joint Technical Data [JTD]: "Each time we encountered a new discrepancy with the aircraft we had to stop and submit an action request [AR] to Lockheed Martin. A response could take 24 hours depending on its complexity. In the early days of flight operations it took us closer to a week to get a response. Adjustments have been made to that policy to allow us to use a work-around to get the job done a little quicker."

Shops

The maintenance department comprises six different shops: airframes (referred to as structures), powerplant, avionics, aviation life support sub-systems, flight equipment (helmet and pilot's flight gear) and ordnance. Its structure is not F-35 specific, but exactly the same as all other maintenance departments on Marine Corps fixed wing squadrons. What is specific is the training provided to the various trades. All airframe mechanics receive a two-week course in low-observable materials, technology and maintenance.

Avionics mechanics (AMs) were previously trained in one of two trades: communication and navigation, or electrician. These have been combined into one because AMs are responsible for maintaining all of the F-35's systems for which they get additional instruction at the Eglin ATC. On VMFA-121 the AMs are supported by three field service engineers (FSEs).

Other FSEs support the other shops: one for airframes and two for the propulsion system, which is one of the most complex systems on the F-35B.

The propulsion system comprises the F135-PW-600 engine and the LiftSystem. Both are maintained by the powerplant shop which is run just like the AV-8B Harrier and F/A-18 Hornet shops are. MGySgt Villareal explained: "The Marines on 121 were all hand selected based on their aptitude and experience. Those in the powerplant shop are now sufficiently experienced on the propulsion system to run their own work centre and are doing maintenance with minimal supervision. We now run two shifts."



Variant: **F-35B 168724/'VK06'** Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **Landing gear retraction on take-off for a training mission** Photographer: **Paul Ridgway**

When the maintenance department 'pulled' its first engine out of the fuselage on the trailer, 85% of the job was completed by the powerplant shop: the remaining work being completed by airframes and avionics shops.

"It sounds easy but it is not. The engine trailer has 15 levers. All of them have to be adjusted correctly to enable the engine to slide out. The trailer hooks up to the back-end of the aircraft just forward of the nozzle (which stays on) with two connectors. It's disconnected where the drive shaft links with the LiftFan by removing one clamp and two more from each of the Roll-Posts. We can access the drive shaft to make the disconnections, undo the four engine mounts on the side and disconnect quite a few lines. We also have to remove seven externally mounted parts to release the engine. Once the trailer is aligned it works well," said Villareal.

VMFA-121's maintainers made history when they removed a LiftFan for the first time: no other service unit had previously conducted this procedure. The job involved removing and reinstalling a motor to check the fixing bolts but this proved to be a challenging task because the previously verified JTD had not been written up correctly. "We tasked six Marines to do the job in accordance with the JTD. They submitted ARs for each issue encountered," said the maintenance chief.

The LiftFan is fitted with rails so that it slides in and out of the bay when lifted by crane. The rails remove any risk of hydraulic and electrical lines getting snagged during the procedure. At Yuma, the maintainers can use the overhead crane purposely installed in the squadron hangar, a standard fit for all F-35B hangars. In the future when operating from a forward operating base or an austere landing field they will have to rely on a mobile crane which is set up at the side of the aeroplane to lift the fan out of the bay.

The Master Gunnery Sergeant explained one aspect of the lifting procedure: "When operating the overhead crane we use a scale to monitor the weight as it takes the load. If the weight shown on the scale exceeds the limit it means that the LiftFan is engaged or caught up somewhere, so we stop the lifting procedure to prevent damaging any lines."

Jet Turnaround

Configuring the doors is the biggest challenge when turning the aircraft between flights because of the amount of ground support equipment (GSE) required. "We have to open up the doors to conduct the inspections prior to the next flight, so we have to have hydraulic power on the aircraft. We can use the



Variant: **F-35Bs BuNo 168722/'VK04' and BuNo 168724/'VK06'** Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013**
Detail: **Two aircraft taxi to the runway for take-off** Photographer: **Paul Ridgway**

IPP [Integrated Power Pack] for the lower doors, but the upper lift fan door requires hydraulics. This can be time consuming if we have to wait for the ground support equipment to arrive at the jet. We continue to qualify our Marines in running the IPP from the outside of the aircraft rather than from within the cockpit. That's money for the maintenance department because we will no longer have to wait for GSE."

Flight Ops

When AIR International first visited VMFA-121 the squadron's training focus was familiarisation flights comprising take-off, landing, pattern work and local ops to and from the area. "By the nature of the aircraft we have to spend a lot of time focusing on the basic familiarisation stage. The end state of this will be when pilots leave the training squadron [VMFAT-501] with a lot more experience of the mission systems. That will be the core skill on a frontline squadron," said Major Mark Noble, VMFA-121's Operations Officer, a former AV-8B pilot who served with Marine Attack Squadron 211 (VMA-211).

"The training squadron provides exposure to the core skills but at an introductory level. When they come to us, we'll train them in the core mission skills before they are considered to be combat ready for deployment."

Core mission skills are: deep air support (strike and armed recce), close air support, air interdiction, low-altitude tactics, offensive counter air and defensive counter air. The more advanced skills are: carrier qualifications and forward operating base (FOB) ops.

According to Major Noble, FOB training will take place anywhere with an austere landing location. "The goal from a pilot's perspective is to focus on precision landings to enable us to operate 15 or 20 minutes' flying time away from the fight, so when the call comes we can be on station fairly rapidly," he said.

The F-35B represents a vast capability increase for the Marine Corps over legacy aeroplanes currently in service. Because of the concurrency-based development used for the F-35, VMFA-121 is flying F-35B aircraft with interim capabilities. This means that 121's Marines are having to train with an aircraft with only limited capability and that's one of the biggest challenges for the squadron's work-up to its Initial Operating Capability (IOC) declaration, currently planned for 2016.

The ability to increase the complexity of flight operations to meet the training needs of the pilots and maintainers is all governed by the capabilities released to the fleet in the

flight clearance envelope: a situation that is different to anything ever done by the Marine Corps. And because VMFA-121 is the first operational squadron to transition to the F-35B, there's no cookie mould [template] to apply. Major Noble reflected on the success achieved: "We're looking into the future but are not actually doing everything yet because of the limited flight envelope box that's been released. We've learnt a lot over the last year and we've created a lot of processes and procedures to benefit the next squadron through transition. The foundation has already been laid, they can advance on that.

"When we get the full capability of the aeroplane it's going to be amazing and better than anything that we have had before. The multi-mission F-35B will suit the needs of a Marine Air to Ground Task Force [MAGTF] very well because of its ability to conduct missions organically: a requirement for all air assets assigned to a MAGTF," he said.

Today VMFA-121 operates a fleet of F-35Bs configured to Block 2A standard but when it achieves IOC it will operate 'full-up' Block 2B aircraft. That means a fully capable sensor suite providing the pilot with much more information than any pilot has been used to seeing in legacy aeroplanes. "Managing that information is a different type of task. Crew resource management has always been part of single-seat ops: it's going to be even more important as the automation picks up. You've got to have a game plan, if you don't, a pilot can get overloaded, not on the safety side, but to the point where he focuses too much on one thing, and doesn't scan everything else he needs to," opined Major Noble.

"In this infant stage it's hard to say this is going to be perfect in the long run, but every pilot who has flown sorties in the local area is excited about what they are seeing and have suggestions on how to employ it."

Flying the F-35B

Major Noble said the biggest difference between flying a Harrier and an F-35B in STOVL mode is the reduced workload: "In the Harrier you control everything: the nozzle lever, rudders, the stick, and manage everything in all the flight regimes and different conditions flown.

"You spend a lot of time just learning how to fly the aeroplane and have to practise hundreds of vertical landings to increase



Variant: **F-35B BuNo 168719/'VK01'** Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **July 2, 2013** Detail: **Aircraft BF-21 plugged in to the purpose-built power outlet inside the squadron hangar** Photographer: **Paul Ridgway**



Image Data

Variant:	**F-35Bs BuNo 168721/'VK03' and 168724/'VK06'**
Unit:	**Marine Fighter Attack Squadron 121**
Location:	**Marine Corps Air Station Yuma, Arizona**
Date:	**May 22, 2013**
Detail:	**Ferry flight to Yuma**
Photographer:	**Liz Kaszynski/Lockheed Martin**



Image Data

Variant:	**F-35B BF-39**
Unit:	**Marine Fighter Attack Squadron 121**
Location:	**Marine Corps Air Station Yuma, Arizona**
Date:	**July 1, 2013**
Detail:	**Flight line refuelling under way**
Photographer:	**Paul Ridgway**

proficiency. There's only a finite amount of time to do that. Less time is spent learning the monkey skills for a vertical landing in the F-35B – in fact it's quite easy in STOVL mode. You put the throttle into a detent to prevent forward or backward movement, and you don't touch the stick to avoid moving up or down. For the most part the jet stays where it is. In a Harrier you are constantly battling with movement which requires quite a bit more training."

Major Summa gave a different perspective: "When you are behind the tanker, the aeroplane changes the flight control laws. That's nice because as soon as you put the probe in, it recognises that the flight conditions are in up and away mode and requires a lower level of engine response. It's also extremely stable in turbulent conditions when the engine response is much higher. That's just unbelievable from the aviator's perspective. The designers have enabled the aircraft to do that with just ones and zeros and ones in the code.

Another example is landing on a carrier. The Hornet has auto-throttles, so the aeroplane trims itself to an on-speed angle-of-attack: the pilot just uses the control stick, but the method lags somewhat. Major Summa explained: "The problem coming in to the carrier is the constant turn. If you stay on speed the whole way round the turn, you'll be fast when you roll out. The F-35 recognises that, so at any point in the turn the flight control laws automatically slow the aircraft down. When you roll the wings over to horizontal you are back on speed. It's amazing the way that engineers can manipulate the code," said Summa.

Operational Shift

Major Summa, a former F/A-18 Hornet instructor with Marine Aviation Weapons and Tactics Squadron 1 (MAWTS-1) reckons the operational shift of the F-35 lies in the increased delta it offers for tactical operations. "Radar painting of a target was not feasible in an F/A-18, you could find the target but the [radar's] accuracy was not that good, just because it's a little bit of an older rig. The ability to find a target with the F-35 radar is so much easier and we can see what the target looks like in two different mediums: electro-optical [fed from the Electro-Optical Targeting System or EOTS] and synthetic aperture radar.

"We can place the imagery from each sensor next to each other on the display or move back and forth between the two. We can also use the DAS [Distributed Aperture System] as a third option with which to look at a target almost simultaneously.

"And the ranges at which we can acquire a target are somewhat greater, as are the environments that we can actually operate in. That's because of the fidelity of the sensors and the way they fuse data together: aspects that legacy aeroplanes and solid-state avionics are not capable of.

"Changing target designations on the EOTS or the radar and slaving them to the DAS, and then seeing the target in the helmet; is only the tip of the iceberg from a situational perspective. I've seen glimpses of something that is going to be absolutely phenomenal." ***Mark Ayton***

Unit: **Marine Fighter Attack Squadron 121** Location: **Marine Corps Air Station Yuma, Arizona** Date: **July 2, 2013** Detail: **Pilots sign for their aircraft at the squadron operations desk** Photographer: **Paul Ridgway**





Location: **Marine Corps Air Station Yuma, Arizona** Date: **October 31, 2013** Detail: **Marine Fighter Attack Squadron 121 squadron badge** Photographer: **Paul Ridgway**



Photographer: Andy Wolfe/Lockheed Martin

Italian Lightnings

The Italian and US governments signed a Memorandum of Understanding (MoU) on December 23, 1998 for Italy's participation in the Concept Demonstration Phase (CDP), when Lockheed Martin and Boeing were competing to win the Joint Strike Fighter (JSF) contract. The governments agreed a second MoU on June 24, 2002 for the System Development and Demonstration (SDD), covering the European country's participation in development of the aircraft and its support systems. A third MoU, signed on February 7, 2007, covers Production, Sustainment and Follow-on Development (PSFD).

Italy plays a pivotal part in the F-35 programme: it's the second-largest contributing partner after the UK. Alenia Aermacchi, part of the Finmeccanica Group, is responsible for building around 800 wing-sets and wing components for the global F-35 fleet. "Italian companies, including six in the Finmeccanica Group, more than 20 large companies and over 40 small and medium enterprises are involved as suppliers or subcontractors to the prime contractors, mainly Lockheed Martin and Pratt & Whitney," explained Commodore Francesco Covella, Joint Strike Fighter Programme Director at SEGREDIFESA, the Ministero della Difesa (Italian Ministry of Defence) procurement agency.

The Final Assembly Check Out/Maintenance, Repair, Overhaul and Upgrade (FACO/MRO&U) centre at Cameri Air Base won't just build the 90 F-35s that will be operated by the Aeronautica Militare Italiana (AMI, Italian Air Force) and the Marina Militare (Italian Navy). "Negotiations are being conducted for the assembly of aircraft for the Dutch fleet," Cdre Covella added. The centre will later be converted into an MRO&U facility that will provide F-35 maintenance services to the whole European fleet of F-35s.

The Italian Government has reduced the number of F-35s it has on order to 90 aircraft – originally, it agreed to procure up to 131. Has that had any consequences on the agreements between Italy and the United States, or between Alenia Aermacchi and Lockheed Martin? "The reduction from 131 to 90 aircraft, as well as similar reductions or delays from other partner countries, has not had any consequences or repercussions on the government-to-government agreements between Italy and the US," responded Cdre Covella. "In the short term, it has caused a minor drop in industrial orders related to the first production batches. Although the F-35 programme is based on the principle of best value rather than on predetermined industrial offsets, the main Italian companies involved are recognised as 'strategic second sources'."

The Italian MoD, working in co-operation with the AMI, Marina Militare and the Secretariat General of Defence, is responsible for setting the operational tasks, logistics and infrastructure support for the F-35 in Italian service. It also co-ordinates flight security and certification and manages the financial and contractual elements of Italy's industrial participation in the programme.

There's an Italian JSF office within the Joint Program Office (JPO) in Crystal City, Virginia, which comes under the authority of the JSF Programme Directorate within SEGREDIFESA. Cdre Covella explained: "[The Italian] office is the main link between the Italian MoD and the United States Department of Defense. Documents related to contracts, requirements, logistics, training, integration and flight security pass through the Italian JPO. The office is headed in turn by either an Italian Air Force colonel or a Navy captain. Its personnel include commissioned and non-commissioned officers from the Air Force and the Navy."

As the end-users, the AMI and Marina Militare have participated and will continue to take part in all the different phases of the F-35 programme. They formulated Italy's national requirements and they jointly support all the activities concerning logistics (infrastructure preparation) and training.

Is it possible for Italy to introduce modifications to the aircraft's systems or integrate new armaments without the assistance of the prime contractors? "Italy, like any other partner nation, is entitled to introduce modifications to the aircraft's systems and integrate new weapons," replied Cdre Covella. "Of course, it is appropriate to involve the two prime contractors and gain their assistance, for engineering purposes and legal and partnership reasons. But participation of national companies is not excluded, in fact they have already been involved in recent activities."

Cdre Covella explained: "The project executive guidance and supervision is assigned to the JSF Executive Steering Board (JESB), which includes representatives of the JSF programme partner nations by procurement agency Department Directors or National Secretariats. The JESB is chaired in turn by Service Acquisition Executives of the US Air Force and US Navy, in co-chairmanship with a non-US member on a rotation established by participants."

Italy will receive its first F-35A in late 2015. It will be assigned to the Integrated Training Center at Luke Air Force Base. The F-35A will enter service with the AMI in 2016 and be assigned to Amendola air base near Foggia. The first batch of F-35Bs for the Marina Militare should be delivered to a training centre in the US in 2017 and to the base at Grottaglie in southern Italy in 2018. ***Riccardo Niccoli***

Light Under the So



Image Data

Variant:	F-35As 08-0748/'EG' and 09-5003/'EG'
Unit:	58th Fighter Squadron
Location:	Over the Gulf of Mexico
Date:	October 15, 2012
Detail:	Proficiency training flight
Photographer:	Jim Haseltine

Australia's first two F-35As are due to roll off the assembly line at Fort Worth on July 24, a symbolic moment which will set the future of Royal Australian Air Force (RAAF) combat capability in stone for the foreseeable future.

With the announcement earlier this year that a further 58 F-35As will be added to the 14 already approved by the Australian Government, the RAAF will have a 'critical mass' of Joint Strike Fighters by early in the next decade, allowing the current McDonnell Douglas 'classic' F/A-18A/B Hornet fleet to retire.

Further decisions are due to be made in the next decade around whether to acquire a further tranche of F-35As to replace the RAAF's newer Boeing F/A-18F Super Hornets. If this goes ahead, Australia will have a fleet of 100 Joint Strike Fighters.

Until then however, the future of Australian air power will be based upon three squadrons (and an operational conversion unit) of F-35As, two

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squadrons of Super Hornets and a squadron of EA-18G Growler airborne electronic attack aircraft.

After a period of training in the United States, the first RAAF Lightning IIs are due to arrive in Australia at the end of 2018 and initial operating capability (IOC) – representing a sovereign training capability and one operational squadron – is due to occur at the end of 2020.

Final operating capability (FOC) will follow at the end of 2023, by which time all three Hornet squadrons will have converted to the F-35A.

In Australia, as elsewhere, the F-35A is a controversial subject and has been the recipient of a great deal of criticism, some of which is informed and some not so.

What is undeniable however, is that the Australian aircraft will arrive far later than originally planned and cost a significant amount more than first announced. The project also still carries significant risk both from an overall programme point of view and with regard to the timely delivery of local infrastructure.

The first F-35A for the RAAF was originally planned to be delivered in 2012 and it is worth

Image Data

Variant:	**F-35A 09-5003/'EG'**
Unit:	**58th Fighter Squadron**
Location:	**Over the Gulf of Mexico**
Date:	**October 15, 2012**
Detail:	**Proficiency training flight**
Photographer:	**Jim Haseltine**



remembering that the Super Hornets, ordered in 2007 as a risk mitigation strategy, will have actually been in service for at least seven years by the time the first Lightning touches down on Australian soil.

Australian Requirements

By the end of the 1990s, Australia had upgrades to its existing air combat fleet well underway and was looking to the next step known as the New Air Combat Capability (NACC).

The idea was to replace the upgraded General Dynamics F-111C and the 'classic' Hornets with a single type of aircraft capable of performing all current roles, from air defence to close air support and long-range precision strike.

As a large island continent, Australia needs to safeguard a huge amount of coastline and its maritime approaches. With no perceived threat to the south and east, the focus is on operations to the north and northwest, which are the also the least populated and with limited infrastructure.

A long-range maritime strike capability is consequently essential and had been filled over the years by F-111 and Hornet, as well as the RAAF's P-3C/AP-3C Orions fitted with the Boeing AGM-84 Harpoon anti-shipping missile.

The NACC aircraft is therefore required to have a maritime strike capability and, because range would be an issue after the retirement of the F-111, a long-

range precision strike weapon for use over land or sea.

In the final years of F-111 operations it was realised that survivability was more difficult to achieve in the modern battle space and a great deal of effort was expended on integrating the Rafael/Lockheed Martin AGM-142 Popeye/Raptor missile to the aircraft.

In summary therefore the NACC, as a replacement for Hornet and F-111, needed air defence, precision strike, maritime strike, close air support and stand-off weapon capabilities. Furthermore it was required to be networked, survivable and with range being an issue in a large country like Australia, it would require tanker support. It was understood that no new generation combat aircraft would match the combat radius of the F-111, so an air-to-air refuelling capability would need to be a priority – a requirement which would ultimately lead to the purchase of Airbus KC-30A Multi-Role Tanker Transports.

Programme History

The project to acquire a New Air Combat Capability (Project AIR 6000) was established in 1999, with an options definition stage scheduled for completion between January 2003 and December 2004 and budgetary approval to follow in 2006/2007.

Both manned and unmanned capabilities (or a mix of both) were under consideration, and the shortlist of manned aircraft included the Eurofighter Typhoon, Dassault Rafale, Saab JAS 39C/D Gripen, Boeing F/A-18E/F Super Hornet, Lockheed Martin F-22 Raptor (if export release could be sought) and F-35 Lightning II.

However the competition was effectively cut short in July 2002, with the announcement that Australia would join the US Joint Strike Fighter programme as a Tier 3 partner, committing A$300 million worth of funding to the Systems Development and Demonstration (SDD) phase.

The decision was a political one, made before any meaningful comparison by the NACC project office could be undertaken and, although not actually committing the RAAF to the F-35A, spelled the end of any competition.

In the end the F-35A was officially selected as the NACC platform with a stated requirement of up to 100 aircraft to replace three Hornet squadrons, an operational conversion unit and two squadrons of F-111s.

By the end of 2006 however, it was becoming increasingly apparent that the need to retire the F-111 earlier than planned and the delays associated with the JSF programme would leave a capability gap. As a result, 24 Super Hornets were ordered as the risk mitigation strategy in 2007 and delivered from the end of 2009.

Therefore the F-35A acquisition programme would be henceforth driven by the planned withdrawal date of the classic Hornet, set around 2022-2023.

The first tranche of 14 F-35A aircraft was approved in November 2009 but, due to the need to conduct training in the United States to work up the capability first, only two aircraft were actually ordered from Low Rate Initial Production lot 6 (LRIP 6).

Subsequent analysis of the delays to the F-35 programme meant that a decision on the other 12 approved aircraft, and the number of aircraft to be acquired in the second tranche was deferred by two years.

On April 23, 2014 the guessing game was finally over, with a government announcement that Stage Two of the NACC project will acquire 58 additional aircraft at a total capital cost of $12.4 billion.

"The fifth-generation F-35 is the most advanced fighter in production anywhere in the world and will make a vital contribution to our national security in coming decades. The first F-35 aircraft will arrive in Australia in 2018 and the first Royal Australian Air Force operational squadron will stand up in 2020," Australian Defence Minister David Johnston said at the announcement ceremony.

"Together with the Super Hornet and Growler electronic warfare aircraft, the F-35 will ensure Australia maintains a regional air combat edge. It will allow the RAAF to conduct decisive, long-range strikes while remaining hidden from adversaries. The F-35 will also provide a major boost to the Australian Defence Force's intelligence, surveillance and reconnaissance capabilities."

Importantly for the RAAF, the decision to purchase enough F-35s to completely replace the 'classic' Hornet in one phase means that the transition is fully funded and can be accurately managed.

The additional 58 aircraft approved under Stage Two takes the combined budget to somewhere in the region of $15.5 billion, including some $1.6 billion for infrastructure. It also means sufficient funding is now available to undertake the wide range of infrastructure works required to air bases and weapons storage facilities around the country.

"It's a great outcome for us," said the head of the New Air Combat Capability project office, Air Vice Marshal Chris Deeble. "Stage One didn't deliver all of the aspects we require but we now have sufficient funding to establish the level of infrastructure that's required to support the capability in the longer term."

AVM Deeble has only been in the job for a short period of time but has worked on several complex – and troublesome – projects run by Australia's Defence Materiel Organisation (DMO).

Most recently he spent six months in Getafe, Spain working alongside Airbus Defence and Space in the remediation of the RAAF's KC-30A Aerial Refuelling Boom System and before that he was the head of the Royal Australian Navy's Collins Submarine and the RAAF's Wedgetail Airborne Early Warning and Control programmes.

"The Stage Two approval of F-35 allows us now to look far more holistically at how we're delivering the capability," he detailed. "We have also nominated our first two fighter pilots to fly the JSF and they will start their conversion in the middle of 2015."

Production, Training and Delivery Profile

The first two aircraft now being built as part of LRIP 6, A35-1/AU-01 and A35-2/AU-02 will officially roll-out in late July and go to Luke Air Force Base, Arizona early in 2015 for use by the US Air Force-led international F-35 training school, ahead of the first two Australian pilots arriving in mid-year.

The first two pilots are Squadron Leaders Andrew Jackson and David Bell, both current F/A-18 Hornet pilots at RAAF Williamtown, who will become instructors on the F-35 and form the nucleus of Australia's transition to the Lightning. They will be the first international students to train with the 61st Fighter Squadron at Luke (see *Top Dogs* p148-151).

"Squadron Leader Jackson is a Fighter Combat Instructor (FCI) and Bell a qualified test pilot. They will form a core of people who will work out the capability requirements, conduct the training and provide support to Australia's operational test and evaluation of the aircraft," AVM Deeble detailed.

From an aircraft production perspective, AVM Deeble said that the next batch of eight aircraft would be ordered in 2016 as part of LRIP 10, for delivery in 2018. A further eight will follow 12 months later in LRIP 11, which is currently planned to be the last low-rate production batch before Full Rate Production (FRP) begins.

Full rate production lots will continue on from LRIP 11 in yearly increments and 15 aircraft in each of the first three FRP lots will be for Australia. The final nine aircraft of the 72 currently on order will be delivered from FRP 4 in 2023.

When announcing the Stage Two approval, Australian Prime Minister Tony Abbott reaffirmed the government's plans to make a further decision on additional aircraft to replace the Super Hornets in coming years, probably early in the next decade. If the decision is taken to acquire up to 28 more F-35As it will take the total number to 100 – in line with the plan when the JSF deal was first announced over a decade ago.

"We will start to build up an initial capability in Australia at the end of 2018 and we'll effectively stand up our sovereign training organisation, No.2 Operational Conversion Unit (OCU), and the first operational squadron, No.3 Squadron, at Williamtown over the following two years," AVM Deeble explained.

Initial operating capability will be the point in time where 2 OCU and No.3 Squadron are functional and that is currently planned to occur at the end of 2020. Over the following two years the other two Hornet squadrons, No.77 at Williamtown and No.75 at Tindal in the Northern Territory will respectively give up their Hornets for newly delivered F-35As.

Hornet drawdown will begin in 2020, commensurate with IOC, and be complete by the end of 2023, at which point the F-35A is planned to achieve final operating capability. This latter milestone is defined as all three squadrons fully operational and fully functional but this will very much be dependent upon on-time delivery of Block 4 software and a maritime strike capability.

Weapons

From delivery of the first aircraft to Australia, the weapons used by RAAF F-35As will be US Air Force-standard by default, as the only ones supported by whichever software load is current. The desired software configuration for IOC is Block 3F, but may be Block 3I.

This means the standard weapons at IOC will be those specified by the US, including AIM-120C AMRAAM and a range of precision-guided munitions such as the GBU-39 Small Diameter Bomb I (SDB) carried in the weapons bay and the internal 25mm GAU-22 cannon.

As the US Air Force clears a wider range of weapons for external carriage, Australia is expected to follow suit and utilise those it already has in its inventory, including AIM-9X Sidewinder from the Super Hornet and AGM-158A Joint Air-to-Surface Strike Missile (JASSM) from the F/A-18A/B.

The US Air Force does not have a pressing requirement for a maritime strike weapon, as does Australia and Norway, and any such capability will have to at least wait for Block 4A software development.

Australia is closely watching the development of Kongsberg's Joint Strike Missile (JSM) to fulfil the maritime strike requirement, but in the meantime the capability will be filled by the Super Hornet/Harpoon combination.

"The ADF's anti-shipping strike capability will reside with the Super Hornet for the rest of this decade. While it will represent a step up from the previous capability, the ability to strike ships with sophisticated long-range defences will have to wait until a dedicated anti-shipping weapon is integrated on the F-35 in the early 2020s," says Andrew Davies, an analyst with the Australian Strategic Policy Institute (ASPI).

"That's after the planned delivery of Australia's aircraft, but retrofitting this capability on to Australia's F-35s should be relatively easy. In the meantime the

Super Hornet will provide a credible maritime strike capability against most regional targets."

Remaining Risk – an Australian Perspective

The Joint Strike Fighter programme is still facing a significant degree of risk, and AVM Deeble says he sees software development being the most critical, particularly as the test programme is moving into more complex areas, such as simultaneous use of multiple systems, sensors and weapons.

"I think in terms of deliveries to support the aircraft initially operating in Australia, the software will be in pretty good shape but I envisage there will be some development ongoing to get us to Block 3F that's required to declare IOC," he predicted.

"The fallback position will be to use Block 3I software, which has significantly more utility than we currently have in our fourth-generation capability. At the moment Block 3I software is running about three months late and it was due in the middle of 2015. Block 3F software has probably got about six months' worth of risk and was due around the end of 2017.

"Our first aircraft will be arriving in Australia towards the end of 2018, so our contingency is to use Block 3I software if necessary. It is still a significant step forward and is the risk mitigator for our declaration of IOC."

Looking towards FOC, AVM Deeble said that Block 4A software was on a 'reasonable trajectory' and there was again some contingency for the declaration of FOC in the 2020 timeframe.

"There's been a lot of work done on the schedule risk and clearly one of the issues is to make sure we keep that software expertise in place to be able to work through the issues, the gap between Block 3F and 4A and 4B," he explained.

"General Bogdan (head of the F-35 Joint Program Office in the US) is really making sure that we are maintaining the required functionality within the various software builds and holding Lockheed Martin accountable for delivering those capabilities. So at this point there's a good mechanism for tracking where we're going in that domain."

From a capability standpoint AVM Deeble says he is very happy with the performance of the F-35A, pointing out that it is more than just aerodynamic capability, stealth capability or radar prowess alone, but rather the systems integration and situational awareness that comes with a fifth-generation fighter.

"I'm sure you are aware of the negative press out there about the aircraft's aerodynamic performance and comparisons to other regional capabilities," he said.

"I've been in the Air Force a long time, I have an F-111 background and I've also worked on AEW&C [Wedgetail] and other high-end capabilities for the ADF and I'm of the view that JSF will definitely be a world class capability.

"I think when you just take aerodynamic performance in isolation, you lose sight of all the other things that come together as a package, including very capable and very smart weapons that add to the whole dimension."

However there are other issues besides those associated with the aircraft which pose a risk to



Image Data

Variant:	**F-35A 11-5030/'LF'**
Unit:	**61st Fighter Squadron**
Location:	**Over Arizona**
Date:	**March 10, 2014**
Detail:	**Delivery flight to Luke Air Force Base**
Photographer:	**Jim Haseltine**

schedule and AVM Deeble says the maturity of the Autonomic Logistics Information System (ALIS) is a significant one.

"We are watching the development of ALIS very closely and looking for the workarounds that might need to be in place to be able to guarantee it. It supports our initial operations, provides the airworthiness that we need from an engineering and maintenance perspective and handles the sustainment that will be the key when the aircraft are sitting here in Australia," he detailed.

"If ALIS works it will be a fantastic outcome, but in my heart of hearts I think we're going to have to look very much at an incremental development over time. We need to understand the functions we need to perform to support our initial operations and to work closely with the US on how it subsequently develops.

"Another area which does worry me is sustainment, which I think we are going to have to look at very closely, because the global support system is not fully defined at this point in time and I think General Bogdan appreciates that getting all the pieces into place will be a significant challenge."

Local Infrastructure

Between now and the first aircraft arriving in Australia a range of infrastructure projects need to be completed at a range of air bases and support facilities around the country and of the $12.4 billion approved in April, $1.6 billion is to be spent on these improvements.

The majority of the work is to be carried out at the two main operating bases – Williamtown north of Sydney with over $1 billion worth of improvements to be done, and at Tindal, near Katherine in the Northern Territory.

Other RAAF operating bases at Pearce in Western Australia, Townsville in Queensland and Darwin in the Northern Territory will have a lesser degree of work performed, as will the bare bases – Scherger in far north Queensland and Curtin and Learmonth in the north-west of Western Australia.

Also to be upgraded is the Australian Defence Force weapons storage facility at Myambat, near Muswellbrook in New South Wales. Initially for the handling of Small Diameter Bombs delivered later in the decade but ultimately for whichever weapon is selected to fill the maritime strike requirement.

The timely delivery of these projects and associated equipment, such as the establishment of a national ALIS capability all assume their own risk, but for the time being, AVM Deeble says he has confidence in the IOC and FOC milestones being achieved.

"The key goal is to bring everything together with respect to the overall capability and ensure that we have the aircraft and operating systems, the support and sustainment systems in place and ramping up from when the first aircraft hit the tarmac at Williamtown at the end of 2018," he concluded.



When Australia signed up as a Tier 3 partner in the Lockheed Martin F-35 Joint Strike Fighter (JSF) programme in 2003, it did so in the knowledge there would be *no* industry offsets. Instead, the F-35 Joint Program Office would award work to industry in partner nations on a best-value basis, and Australian companies would have to compete on their merits with all the rest.

The contracts initially only covered the System Development and Demonstration (SDD) phase of the programme and today are still awarded on the basis of low-rate initial production lots – so a successful bidder has to keep performing to remain the incumbent supplier.

This methodology is designed to drive cost out of what is, by anyone's measure, a hugely expensive defence programme, and the industries of other F-35 partner nations, including Canada, Denmark, Italy, the Netherlands, Norway, Turkey and the UK also have to bid for work on this basis.

By early 2014, more than 20 Australian companies were continuing to provide components and services to Lockheed Martin and, according to the Fort Worth-based manufacturer, there is potential for in excess of AUD6 billion worth of work over the forecast 30-year manufacturing life of the programme.

Furthermore, as Australia has committed to the purchase of the first three squadrons of F-35As this year in order to retire the F/A-18A/B Hornet as planned by the end of 2022, there are looming opportunities in sustainment contracts.

Manufacturing Opportunities

In December 2013, the first of two F-35As currently on order for Australia was lifted out of its electronic mate assembly station at Fort Worth to join the final assembly line. Several senior Australian programme officials were on hand to witness the event, including Director General, New Air Combat Capability (NACC), AIRCDRE Cath Roberts.

Speaking to *AIR International* during the event, which coincided with the inauguration of the 100th F-35 (and the first destined for Luke Air Force Base, Arizona), AIRCDRE Roberts said current F-35 production contracts are worth around AUD329 million to Australian industry. She also predicted at least an extra AUD1.5 billion worth of further opportunities, not including the sustainment phase.

"There's been a lot of debate about how you calculate the numbers, but it's certainly more than $1.5 billion worth of extra opportunity that we expect to have in Australia, and probably quite significantly more," she said.

From the Lockheed Martin perspective, Steve O'Bryan, Vice President F-35 Business Development and Customer Engagement, says the estimates, taken over the 30-year production life of the aircraft, are actually $6 billion: "Opportunities split between Lockheed Martin and Pratt & Whitney are actually in excess of $11 billion, [but] we see the win-rate over the life of the programme exceeding $6 billion."

Melbourne-based Marand Precision Engineering was an early success story for Australian F-35 industrial participation, winning a contract to design and manufacture the engine removal and installation trailer in 2003, during the SDD phase of the project. Today the company remains the sole source supplier of this complex piece of machinery which will be present on every air base and aboard every warship hosting the F-35.

More recently it has won work from prime contractor BAE Systems Australia for the assembly of 700 F-35 vertical tails, the first of which was handed over in Australia at the end of March. "Marand has, by a long way, completed the most manufacturing work for the F-35 programme in Australia, with more than AUD100 million of sales to date and forecasts for work now totalling over AUD1.1 billion," said general manager Rohan Stocker after the contract was announced.

"By far the largest element of that, at around AUD790 million, is our work on the aircraft's vertical tails. We're also gearing up our manufacturing facilities and will have built one of Australia's largest fabrication, machining and component assembly workshops by the time series production [of the aircraft] begins."

Quickstep Holdings, a manufacturer of high-grade carbon fibre components and developer of the patented Quickstep Process – a range of unique manufacturing technologies for out-of-autoclave production of advanced composite materials – is also manufacturing the vertical tail skins for the F-35.

Additionally, the company has a memorandum of understanding with Northrop Grumman for the manufacture of 21 different composite skins, doors and access panels, including lower side skins, maintenance access panels, F2 fuel tank covers, lower skins and inboard weapons bay doors. Altogether there is potential for the manufacture of 19,235 components over a 20-year production cycle, worth up to AUD$700 million.

"The F-35 is Quickstep's flagship project," says Chairman Tony Quick. "Since commencement of the programme we've delivered more than 200 parts and production is ramping up substantially."

The current head of the F-35 Joint Program Office, Lieutenant General Christopher Bogdan, visited Quickstep's facility at Bankstown, in west Sydney, in March to view the work in progress. "I was impressed with Quickstep's manufacturing processes and technology," he said. "The technologies I saw have great potential to improve aerodynamic performance and help to keep manufacturing costs down. Quickstep's contributions to the F-35 programme are highly valued today and will be for years to come."

Australian precision engineering and machining companies such as Melbourne's Lovitt Technologies Australia and Brisbane-based Ferra Engineering have also won significant F-35 work, including the fabrication of machined longeron assemblies for the keel structure (Lovitt) and vertical tail blanks and weapons bay door adaptors (Ferra).

Lovitt delivered its first component for the first Australian F-35A (c/n AU-01) on August 24 last year in a ceremony attended by the then Minister for Defence Materiel, Jason Clare. This is an important day for Australia, because it's the first Australian part on the first Australian JSF," Clare noted.



Image Data

System: **Engine removal and installation trailer**

Detail: **A Pratt & Whitney F135 engine on an engine removal and installation trailer produced by Melbourne-based Marand Precision Engineering**

Photographer: **Neal Chapman/Lockheed Martin**



Component: **Skin assembly** Detail: **A composite skin assembly produced by Sydney-based Quickstep Holdings in Lockheed Martin's F-35 final assembly plant** Photograph: **Lockheed Martin**



Australian Industry and the F-35

"We're now taking the next big step, and that's not just making parts for US Air Force or US Navy, or aircraft from other countries, but we're starting to make parts for our own fighter aircraft."

Sustainment Focus

Shortly before his planned retirement at the end of last year, NACC Program Manager Air Vice-Marshal Kym Osley described his shift in focus from acquisition to sustainment. "The real challenge for me is building all the facilities we need and integrating the aeroplane into our logistics system in Australia," he said. "It's establishing an Autonomic Logistics Information System and connecting that system to the US and to other partner nations around the world."

AIRCDRE Roberts added further detail of industrial opportunities, which include not just sustainment but the construction and maintenance of required F-35 facilities around Australia, including the two main operating bases at Williamtown in New South Wales and Tindal in the Northern Territory.

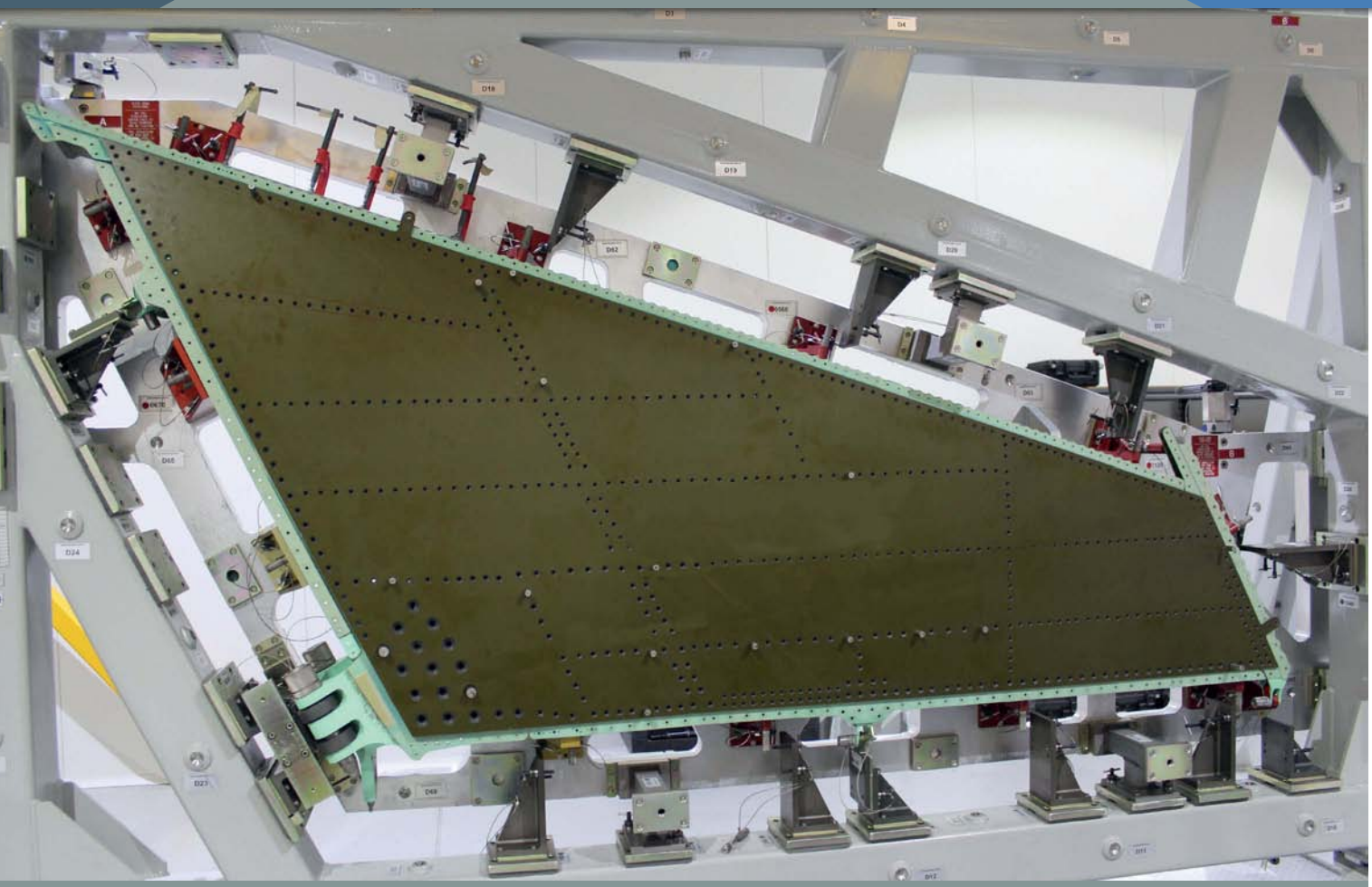
"There's a lot more to a programme than buying aircraft: we have to get all the facilities built at Williamtown, there's a weapons programme to progress, we have to put the sustainment piece in place and we have to get Australian industry up and running to do that sustainment. There are a lot of pieces that have to come together. We've got a reasonable plan at the moment but at the end of the day I need a capability, not just aircraft," she said.

"The infrastructure plan is going to go to the Australian Government Public Works Committee later this year. It's an AUD1.6 billion programme in its own right – that's a big chunk of opportunity for Australian industry."

Regional Support Centre

Australia has a requirement for up to 100 F-35As and, as noted, the first 72 are required to replace the RAAF's F/A-18A and F/A-18B Hornets by the end of 2022, equipping three fighter squadrons and an operational conversion unit. A decision on a further 28, to replace the newer F/A-18F Super Hornets, will be taken sometime in the next decade.

AIRCDRE Roberts also noted that, according to the NACC project office, the number of aircraft acquired by Australia is directly linked with industry opportunity. "It's something government is really keen on. We want to make sure we get an industry in



Component: **Vertical tail** Detail: **The first vertical tail produced by Melbourne-based Marand Precision Engineering was handed over in Australia at the end of March** Photograph: **Lockheed Martin**

Australia that's sustainable. We already have a large number of opportunities in production, but we want to make sure we can continue to produce parts for the fleet – for the thousands of aircraft that are going to be produced. That's a big boost for Australian industry, so it's something we will keep a focus on. One of the reasons we became a partner in this programme is the fact that [there are] opportunities for Australian industry," she said.

"In terms of sustainment we really want to try and get ourselves in the position where Australian industry can offer regional opportunities as well as performing our own sustainment. It's a matter of us actually having the infrastructure to be able to carry out that regional sustainment, and there's still a lot of work to do there. It's a massive programme in its own right."

One of the opportunities under consideration is a regional maintenance facility, which could carry out work on deployed US Air Force and US Marine Corps aircraft as well as those of regional partners. The US Marine Corps is increasing its presence in the Northern Territory – as part of the Obama administration's 'Pivot to Asia' – which will eventually grow to a full Marine Air Ground Task Force of 2,500 personnel by 2017. As a result, US Marine Corps F-35Bs are likely to be deployed to Darwin and Tindal for significant periods, making the regional facility an attractive proposition.

"We've already defined what our sovereign requirements are and we've already said we're going to have a facility for depth maintenance in Australia," explained the NACC boss. "We've also said we're going to have a level of operational and deeper maintenance as well as some supply chain management functions and probably a low observable rework capability in Australia too.

"We've defined that those will be established – but what we would like to do is get a bigger regional capability and perhaps be there to support the US forces operating in our region as well as other F-35 customers operating in the Asia-Pacific. We haven't really looked at where a regional facility would be placed, but from my perspective it would make sense that you placed it where you already have a level of infrastructure and support."

Further opportunities for Australian industry have been identified by Lockheed Martin in new technologies such as electron beam direct manufacturing of titanium components, which will be trialled by Ferra Engineering during 2014.

The first component to be manufactured under the process will be the canopy bow, which isn't a flight-critical item and does not have to undergo durability testing, simplifying the outsourcing process.

The Australian Government has also introduced the New Air Combat Capability Industry Support Program (NACC ISP), through which seed money can be injected into industry to assist with the development of new technologies. It is a grants programme intended to foster industry capabilities that directly support the F-35 project, funded by the Defence Materiel Organisation and administered by the Australian Department of Industry.

The most recent beneficiary is Quickstep, which received a AUD1 million grant to finance qualification of its Quickstep Process for the manufacture of F-35 vertical tail spars. ***Nigel Pittaway***

System: **Engine removal and installation trailer** Detail: **Final inspection** Photograph: **Marand Precision Engineering**



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