Struggling for Altitude:

The JSF Project

John Tirpak

By all accounts, the F-35 Lightning II joint strike fighter will be a stellar aeroplane, easily able to defeat any enemy fighter or air defence system it meets. The program is on track, and there's little doubt the United States Air Force and its sister Services need such an aircraft to modernise their ageing fighter inventories. Allies are also lining up to buy the fighter.

The F-35 is imperilled by no weapon, technical weakness, or impossible requirement. Rather, the largest threat to the new fighter seems to be a major case of nerves. US Government officials are daunted by the size, scope, and cost of the program and all that is riding on it.

At an estimated cost of well over $US200 billion—just for American development and production—the tri-Service Joint Strike Fighter is the most expensive fighter project ever undertaken by the USA. That fact alone makes it the object of intense scrutiny. The danger is that excessive caution born of such close scrutiny could quickly wipe out one of the new fighter's greatest selling points: its relatively low unit cost. Already, urgent calls to ease up and throttle back are spewing forth from the usual sources.

In mid 2006, the US Government Accountability Office (GAO) predictably pointed out that the F-35 will be well into production before Pentagon officials complete its testing. GAO warned there could be expensive surprises ahead if the aircraft does not perform as expected. Slow down, it said. 'Fly before buy' should be the watchword.

In direct response to these kinds of alarms, the US Senate had initially chopped $US1.2 billion in joint strike fighter money from the Fiscal 2007 authorisation bill and House of Representatives committees called for cuts of lesser magnitude. Plans to move the F-35 into low-rate-initial-production (LRIP) fell into in abeyance pending the outcome of House-Senate negotiations.

In September 2006, the US Congress provided all of the research and development funding requested for the JSF Program in Fiscal year 2007. In addition, the Congress decided that the JSF program was sufficiently mature to move into production and provided full funding for the first production lot of two aircraft (known as LRIP – Lot 1), both conventional-take-off-and-landing (CTOL) versions. Congress also provided funding for the long-lead-time items for a second production buy (LRIP – Lot 2), totalling 12 aircraft (six CTOL and six short-take-off-and-vertical-landing (STOVL) versions).

Since the JSF program began, Congress has provided 99 per cent of the research and development funding requested for the program and this reflects strong bipartisan support. The President's budget submitted to Congress in February 2007 continued this trend and includes full research and development funding, full funding for LRIP – Lot 2, and funding for long-lead-time items for the third production buy (LRIP – Lot 3) comprising a further 16 aircraft.

Same old saw

The GAO has, of course, issued the same 'fly before buy' exhortations for most aircraft projects for the last 25 years. Methods used to develop fighter aircraft have evolved, however, so much so that any appreciable production slowdown could do grave damage to the F-35 program as it is now structured, according to those with direct experience running it.

'Everybody wants to slow us down,' Rear Admiral. Steven L. Enewold said this Summer. Enewold was program executive officer from June 2004 until July 2006, when he moved on to become the vice commander of Naval Air Systems Command. 'Fundamentally, if you slow us down, it's going to cost more money,' Enewold explained. 'And then, you get into the whole "Can you afford it?" and "Should you afford it?" discussion, which, up to this point, we haven't had to do.'

The program has built up considerable momentum. The first test flight occurred in December 2006. The first flight-test aircraft are in various stages of production, and vendors for parts and sub-assemblies are gearing up. Slowing down now would kill momentum, dissipate learning curve benefits, and force higher overhead costs, according to Daniel J. Crowley, JSF general manager for prime contractor Lockheed Martin.

'If we slow down,' warned Crowley, 'we will have higher costs out of our suppliers, we have lost opportunities on learning, and that becomes a death spiral—in that costs go up, budget available to buy aircraft remains the same, so you buy fewer, and then costs go up again.'

Under the system development and demonstration phase, the program will be producing 22 aircraft—15 for flight test and seven for ground test. 'We'll be building at a real clip' in the run-up to low-rate initial production, Crowley noted. Stopping or sharply slowing at that point—as the GAO suggests—would force Lockheed Martin to keep large numbers of personnel, a factory, and hundreds of subcontractors idling with the meter running while flight testing progresses.

Crowley argued that the GAO's objection to the program as laid out—too much concurrency in development, flight tests, and production—seems to stem from the experience with programs such as the F-15 and F-16 fighters, developed in the 1970s and built in large numbers in the 1980s and small lots thereafter. Since then, industry has made huge advances in computer modelling and simulation, computer-aided design, and lean-manufacturing techniques. The F-35 bears no resemblance to these older fighter programs.

'They [GAO auditors] don't have a detailed knowledge of how JSF acquisition was structured and the risk retirement that we built into the plan,' Crowley asserted. The first flying F-35 (dubbed 'AA-1') used major parts and sub-assemblies built on three different continents, yet they meshed together better than fighters built on 'mature' production lines. As a matter of fact, the first fuel test yielded no leaks whatsoever—a fighter development first.

Seeking low risk

From Day 1, risk reduction has been a hallmark of the effort. Whenever possible, hardware, technologies, or techniques that have proved to work well on other programs have been adopted for the F-35. The people who solved computer code problems on the F-22 were brought over to the F-35 program. Software laboratories have been set up to fully vet the JSF's millions of lines of computer code, some of it borrowed wholesale from the F-22 and other projects. Flying avionics labs have proved out and will continue to prove out sensor systems, individually and together, in parallel with the exploration of flying qualities on the initial aircraft.

Whole systems have been adapted from other projects. The Pratt & Whitney F119 engine used on the F-22 is the basis of the F-35 engine. The F-35's electro-optical targeting system is a repackaged version of Lockheed's Sniper advanced targeting pod that, with other such pods, is helping to recast the very role of the fighter. The F-22's radar, built by Northrop Grumman, has been adapted and improved for the F-35. This improved version likely will be retrofitted to F-22s in the future.

In short, everything possible has been done to eliminate the risks of concurrency. And, Crowley said, by the time the first production aircraft become available for training new pilots, the program will have more than three years of flight testing under its belt, on 15 aeroplanes. At a similar stage, the F-22 program bogged down because it had only half as many test aircraft.

Senator John Cornyn (Republican-Texas) said at the F-35's naming ceremony in July 2006 that the Texas delegation—representing the district where the F-35 will be assembled—will work hard to get the F-35 money restored and sustained. 'It simply is, I think, penny-wise and pound-foolish to start cutting money from this program and stringing out development ... in a way that we know is going to cost more money in the long run,' Cornyn said.

Developmental testing of the JSF is due to be completed in late 2012, and operational testing should wrap up in 2013, about the time that the first USAF units declare operational capability. The GAO's only concern, Crowley observed, is what he termed 'cost certainty,' and not the other ramifications of slowing the program. 'They don't care whether or not we have to extend the life of legacy aircraft or whether or not we are deferring the capability of JSF to later,' he asserted. 'That's not their concern.'

Delays in the JSF, for example, could trigger an extension of the F-22 production line and compel service-life extensions on large numbers of F-16s not now planned to receive them. For the USAF, at least, the entire scheme of modernising the fighter fleet would have to be recalculated.

He added that if the GAO would be willing to take into account all the modern processes now burning down risk in the program, 'I think they'd have a different view. I know we'd never convince them completely, but I think they would have a better appreciation for the things that we're doing to avoid the legacy experience.'

Favourable cost comparison

Despite its intimidating overall cost, the JSF program will turn out to be 'a bargain,' said [US] Deputy Secretary of Defense Gordon England. Speaking with reporters at the 07 July 2006 unveiling of AA-1 at Lockheed's Fort Worth, Texas, plant, England noted that the JSF will yield three different but highly similar aircraft:

- F-35A – a conventional-takeoff-and-landing (CTOL) model for the USAF [and the RAAF].
- F-35B – a short-takeoff-and-vertical-landing (STOVL) model for the US Marine Corps and Britain's Royal Navy and Royal Air Force; and
- F-35C – a bulked-up carrier-capable (CV) version for the United States Navy.

'This is an expensive program for the [US] Department of Defense and for all the services,' England acknowledged. However, the original plan was to develop three different aeroplanes, one for each service. The three aircraft have significant differences. But they will all be built on the same production lines, and parts commonality between them is about 80 per cent. This will present a huge savings compared with the cost of supporting three unique aircraft types.

Unit costs for the JSF are calculated in 2002 dollars, because that is the year the development program got under way. In 2014, when production reaches about 21 aeroplanes per month, the F-35A will cost $US48 million a copy. The F-35B and F-35C will cost $US62 million and $US63 million respectively. By comparison, the Euro-fighter Typhoon—probably the JSF's closest foreign competitor—costs more than $US95 million and the F-22 is expected to come in at an average of about $US120 million by the time production winds up in 2010.

Enewold said flatly that the F-35's combination of stealth, weapons, sensor fusion, and compatibility with networks of sensors and communications will make it, hands down, the best all-around combat fighter in the world.

When matched against any other multi-role fighter, he said, 'We will have much better capability to prosecute targets and [have] much better survivability rates. ... There is no air-to-ground scenario that I can see out there that we are not going to be the best on the block. In the air-to-air arena, we are going to be No. 2—a close second to the [F-22] Raptor.'

3-for-1 'good deal'

Having a single development contract and factory means 'we are basically getting three aeroplanes for ... the price of, say, one-and-a-quarter,' England explained. That is a good deal, he said. 'The challenge, of course, like all programs, is to keep the cost in line,' he continued. 'But that is the objective of the program, and we expect the management team to deliver and the government team to deliver.'

England said that the idea all along was to 'compress' the program, because stretch-outs always add cost and delay getting the system into the hands of combat pilots. The number to be built, and the rate at which to buy them, is the crux of the debate, he said. 'Our judgment is, we're doing this about right,' he asserted.

Both the F-35A and F-35B have passed through a major milestone—critical design review—and are in good shape, Enewold said. Only two action items for the designs were still unresolved by early 2007. One was that the space around the engine was hotter than designers expected, and a variety of solutions were being examined that would force more cooling air into the space or make the parts more heat resistant. The other had to do with the dispersion of canopy fragments after a pilot ejection. Neither issue was considered a schedule-disrupting setback, Enewold said, and he expected a 'conclusion' to the two issues by mid 2007.

The F-35C carrier version is slated to pass its critical design review this winter, Enewold added.

The US Air Force is the biggest customer for the JSF. It will buy the F-35A (CTOL) model. There has been heavy debate about just how many the Air Force really needs, but General T. Michael Moseley, USAF Chief of Staff, said in July 2006 that the Service is 'still holding onto 1,763' as its goal. Moseley said the F-35A will do heavy lifting for the USAF, replacing not only the F-16 but some of the F-15Es and F-117As as well, serving as a stealthy, penetrating precision-attack aircraft. Later, it will also replace the A-10.

The F-35A will be the 'low end'—meaning inexpensive—complement to the 'high-end' F-22, much as the F-16 was the low-end complement to the high-end F-15 over the last 30 years. The F-35A will be the backbone of the USAF's fighter and strike fleets, doing duty mainly as an attack aircraft. With a full internal load of munitions, the F-35A will be a nine-G dogfighter, as agile as a 'clean' F-16 carrying no underwing stores. Alone among the three variants, the F-35A will have an internal 25mm gun.

The F-35A will be able to carry two 2000-pound bombs in its internal bay, as well as two air-to-air AIM-120C aerial combat missiles. After enemy defences have been beaten down and the need for very-low-observability is diminished, the F-35A will also be able to haul 18,000 pounds of ordnance or fuel on external pylons, for a total of about 23,000 pounds of payload. By comparison, an F-15E can carry 24,500 pounds of payload. The F-16 can carry 15,200 pounds.

How many for how many?

Moseley said the US Air Force is still trying to figure out how to compare the F-16 and F-35A and how many Falcons equal one Lightning II. However, the F-16 will not be replaced on a one-for-one basis with the new fighter, since the F-35A will be so much more capable than the F-16. Fewer will be needed because fewer are likely to be lost in battle, and one F-35A can destroy more targets per mission than an F-16 can. The F-35A will also be able to fly more sorties in a day than the F-16.

Large maintenance savings will be reaped by 'necking down' the fighter fleet from four types to just two, Moseley said. That is because just two types mean a reduced logistics train, ranging from consolidated depot maintenance and reduced parts inventories to less training requirements for maintenance crews, and less unique support gear. The F-35 has been designed with cost as a constant consideration, and its cost of ownership is intended to be substantially less than that of other aircraft.

The Air Force's version of the JSF will be the first to fly, but it will be the second type to reach initial operational capability, in 2013.

The Marine Corps will fly the F-35B (STOVL variant) able to operate from amphibious carriers and close to the front lines of a ground fight, the better to offer close-air-support to engaged troops. It will have a smaller payload and range than the USAF model and will not have an internal gun but can mount one on the centre external station. Due to its greater weight—it achieves short takeoff and vertical landing by use of a 'lift fan' behind the cockpit and by a downward-rotating rear nozzle. The F-35B will manouvre at seven Gs.

The USAF has long considered buying some of the F-35B model in order to have a dedicated close-air-support platform, to directly supplant the A-10 in that role. Out of the 1763 JSFs it will buy, the USAF has considered making up to 400 of them jump jets.

However, the Air Force has recently decided to make a hefty, near-term investment in upgrading the entire fleet of 356 A-10s, which will allow them to stay in service years

'I need a new circuit card'

Not only will the F-35 be able to help maintainers by offering them detailed diagnostic software to isolate problems, it will be almost constantly checking itself, in flight, for any anomalous temperatures, vibrations, or uncharacteristic behaviour. If the F-35 senses that something is about to fail, it will, on its own, contact home base, ordering a check or even a replacement part.

'It is the difference between diagnostics and prognostics,' said Tom Burbage, Lockheed Martin executive vice president and general manager for JSF program integration. 'Diagnostics say I can isolate a fault once it [happens], very precisely. Prognostics say I can predict a failure before it happens. ... It all feeds into a focus on driving down the cost of owning and operating the aeroplane.' Not unintentionally, the prognostic system also means that turnaround time on the ground is vastly shorter, increasing the number of sorties that can be flown in a day. Also, most parts are fixed off the aeroplane, so the F-35 does not have to sit still while technicians probe for problems.

longer than expected. 'So, if you have that number of A-10s that have been completely rebuilt, then you may not need the STOVL [JSF],' Moseley said. It is a move the Service is still considering, but the prospects for the USAF buying the F-35B seem to be fading.

The F-35B variant destined for the US Marine Corps, Royal Navy and Royal Air Force is slated to reach initial operational capability in 2012, the earliest of the three versions. Enewold said that is due to two reasons.

Urgent need

First, the US Marine Corps has the most urgent need for a new aircraft. Its AV-8B Harrier IIs are worn out and have been plagued with accidents. The Harrier II also lacks adequate range and payload and is a maintenance headache. As a result, the USMC wants to divest itself of the problem—and as soon as possible.

The second reason is that right now, 'the STOVL is the most mature of the three variants,' Enewold said. By any measure—detailed design work, parts release to manufacturers, etc.—the F-35B 'leads the pack,' he said. While the first F-35 to fly was the CTOL model, the next five are production-representative STOVL versions. The first will fly in early 2008. There will be a total of six CTOL test birds and four of the carrier model. The progress of the F-35B has surprised everyone, Enewold said, because the STOVL variant was initially considered 'the most challenging.'

However, in 2005, the F-35 program suffered a serious delay. The design was overweight by about 3000 pounds, and a decision was made not to compensate for the reduced performance by running the engine hotter, because that would sharply reduce the durability of components and drive life-cycle costs higher.

The program asked Pentagon officials for—and got—a one-year slip in the schedule to cut the weight. During that year's worth of weight cutting, 'we ... were highly focused on the STOVL,' Enewold said, because the F-35B was the most endangered by being overweight. The weight savings were found, as a result of thousands of suggestions from Lockheed Martin and subcontractor employees. At the end of the added year of development, the STOVL had vastly benefited from the extra time and attention.

Part of the weight cut demanded shortening the weapons bays of the F-35B, Enewold said, to make room for a structural member. The resulting space still conforms to the Marine Corps initial requirements—each bay will accommodate a 1000-pound-class bomb—and solved many problems. Enewold regrets that there could not be a common weapons bay for all three models, but he is more than satisfied with the result of the weight battle.

The F-35C model is the version intended for aircraft carrier service. Its wings will be larger than those of either the A or B-models, and it will have increased structure to accommodate the repeated shock of carrier landings, as well as a tailhook. Consequently, its range is not as great as that of the F-35A, and it will manouvre at 7.5Gs. It will have the same payload as the A-model, however. The first flight of the C-model comes in early 2009, and it enters fleet service in 2013.

The US Navy and Marine Corps, which consolidated their fighter wings a few years ago, are still debating how they will split their planned buy of 680 JSFs between the B and C-models. Enewold said they will decide about two years before the aircraft start production.

Britain's decision

Britain is a full partner in the JSF program, having contributed more than $US2 billion to its development and thus earning the right to a say in requirements and design. The British need 138 aircraft—down from an original target of 150—and the British air arms, too, are still considering the proper mix between the STOVL and CV models for the Royal Air Force and Royal Navy.

Enewold acknowledged that no contracts for foreign orders have been signed yet, but believes that it is necessary at this stage to do some production planning. Including Britain and seven other overseas partners, 'we are looking at between 600 to 800' aircraft to be built for allied air forces, and that range has been factored into computing the JSF cost. Those figures are very conservative, however. The foreign market for the JSF could easily pass 2500 machines—and thus lower the unit cost considerably. Maintaining a low cost will give the F-35 its edge against competing fighters.

'Partners' on the program, who have paid into development and will be among the first eligible to buy the F-35 are Australia, Britain, Canada, Denmark, Italy, the Netherlands, Norway, and Turkey. Partnership makes industries in those countries eligible to compete for work on the F-35, but there are no guarantees. Enewold said contracts are being awarded on a 'best value' basis. The partners have no assurances

Defence against Moore's Law

How does a high-tech program—with a predicted lifetime of 40 years—stay fresh when Moore's Law tells us that computer technology will turn over every 18 months?

'We have two ways to address the demand for increased processing,' according to Daniel J. Crowley, Lockheed Martin executive vice president for the JSF, and the program's general manager.

'One of them is we have empty card slots where we can install additional integrated core processors to provide more computational capacity.' The second, he said, is that the computer architecture—new computing buses and fibre-optics—means 'we do not think we will be constrained on throughput when we make those decisions to upgrade.'

He also said that Lockheed has developed middleware that will make it possible for many applications to run co-operatively, such that, if one has a problem, the others can keep on running. This was one of many lessons learned from the F-22 program, which endured some of its biggest delays due to software instability.

of winning any work unless they offer the best price and quality.

Israel and Singapore are in a special status called Security Co-operative Participants, meaning they are observing the program and have expressed an interest in buying F-35s, but have not contributed to development and do not have the right to have their unique requirements addressed in the design. Tom Burbage, Lockheed Martin vice president for the JSF program, said Greece, Japan, South Korea, and Spain have also expressed interest in buying F-35s. Analysts expect that all the countries that have bought F-16s, AV-8Bs, or F/A-18s in the past—and there are more than 35 such countries—are at least potential purchasers of the F-35.

Staying 'common'

There was concern early in the program that each partner would want unique equipment or special modifications on their own aircraft, creating in effect dozens of unique configurations on the assembly line and frustrating the cost-saving ethic of commonality. That has not happened, Enewold said. 'The countries have stayed common,' Enewold reported, adding, 'I think [they] are realising ... that they just do not have enough money to do something on their own. It is very expensive to shoulder the entire bill of a [modification], ... so with very few exceptions, they are going to get the same hardware.'

Burbage said there have been some minor studies on unique equipment—Norway wanted a drag chute because of the icy conditions at many of its runways—but such tweaks are 'really on the margin. Most of the partners are fully engaged with going with the configuration that we are designing in the baseline.' After delivery, though, he expects some follow-on development work on adapting country-specific weapons to the JSFs sold overseas.

There have been some public disagreements on work share on the JSF, and Britain has threatened a few times to pull out if its demands are not met on having access to source code and stealth materials so they can fix and modify the aircraft on their own. 'Frankly, the Brits are just the most vocal' with such complaints, Enewold said. All the partners have the same gripes.

'The reason we cannot come to an accommodation on everything is that we do not know how we are going to do a lot of this stuff' for the US, yet, he said. Moreover, 'this stuff is very expensive. ... To have your own assembly line or have your own reprogramming centre ... takes a lot of capitalisation. I just do not think they can afford it.' Some of the nations may opt for their own support facilities, but the program was not designed that way, to save on cost. 'They may decide to afford it because it is a sovereignty issue, but I just do not think that is a very cost-effective solution for them.'

Enewold also said the JSF program could not be any more open with foreign partners. They have representatives working on design and development, are on the management team, are invited to all status meetings, and have visibility into practically the whole program. He expected the answers will be found to the friction items, and because the partners are so plugged-in, 'when we know, they will know.'

The F-35 is not the first weapon system that comes to mind for fighting the war on terrorism, and Gordon England said it is not optimised for such a fight. However, 'you do not get to pick and choose where you would like to fight. The adversary gets to pick and choose.' The F-35, he said, is a 'critical' system, because 'it is important that we have an aircraft with advanced technology. ... We do not want to be caught short in the future, without having invested in the technology base, and also the manufacturing base, and have a fielded capability when you need it.'

General Moseley, in a July 2006 speech to unveil the first test flight aircraft, said the F-35 will be 'an indispensable tool ... ensuring air dominance in future homeland defence and joint and coalition warfare scenarios.' He said, 'These common platforms, flown by an entire generation of pilots using standardised tactics, techniques, and procedures, will deepen coalition airpower relationships, strengthen coalition warfare, and eliminate seams during combined operations.' He added, 'Let's get on with building this ... aircraft.' ◆

John A. Tirpak is the executive editor of 'Air Force' the monthly magazine of the United States Air Force Association. This article first appeared in the September 2006 issue of the magazine and this slightly updated version is republished courtesy of 'Air Force' and the Association.

F-35, and the living Is easy

The F-35 will have the most advanced cockpit of any fighter. Instead of a series of dials and gauges, the entire 'dashboard' of the F-35 will be a huge flat-panel computer screen. Simply by touching the screen, the pilot will be able to rearrange the configuration of instruments, the better to handle whatever phase of the mission they are flying. Live imagery from the electro-optical system can be enlarged and targets magnified, the better to put bomb crosshairs precisely where the weapon should go. The F-35 will be able to scrutinise targets from 30 miles [48 kilometres] away with the same clarity as if they were across the street.

The cockpit has no head-up display, which was the iconic equipment of all fourth-generation fighters. Instead, all such data will be projected onto the helmet faceplate. The missile-warning optics and cameras all around the aircraft do double duty as an infrared vision system; in blackout conditions, the pilot will be able to 'see' in infrared just as if he was flying in daylight. This feature eliminates the need for cumbersome and problem-prone night-vision goggles. Not only that, but the pilot will be able to look down, directly 'through' the aeroplane, to see what is below him—a handy trick for the vertical-landing version.