Foreign Affairs, Defence and Trade Committee
Joint Strike Fighter Inquiry
Department of the Senate
PO Box 6100
Parliament House
Canberra ACT 2600

Dear Chairman and Committee Members

The Planned Acquisition of the F-35A Joint Strike Fighter

Please find following my submission to this Inquiry.

Yours faithfully,

David Archibald

Submission to the Joint Strike Fighter Inquiry

Table of Contents Page

1. Executive Summary

The F-35 has many deficiencies. Of those deficiencies, at least six are showstoppers that mean it will fail in its assigned role as an air superiority fighter for the RAAF:

1. The F-35's engine is failing at too high a rate and its reliability is not improving fast enough to be approved for operational use (page 23)[1].

2. The F-35's requirement for an 8,000 foot runway limits its use to just five runways across northern Australia (page 18)[2]. It requires a 10,000 foot runway for training, putting it in the league of the B-52.

3. The F-35's operating cost in excess of US$50,000 per hour means that Australia won't be able to afford to keep our pilots proficient enough for combat (page 26)[3].

4. Being designed as a light bomber, the F-35 is less manoeuvrable than fighter designs up to 50-years-old and will be shot out of the sky by modern fighter aircraft (page 29)[4]. For example, Indonesia's Su-35s are expected to be able to shoot down 2.4 F-35s for every Su-35 lost[5].

5. The F-35 uses its fuel for cooling its electronics (page 21)[6]. The aircraft won't start if its fuel is too warm, making deployment in northern Australia problematic.

6. The F-35 has a logistics system that requires an internet connection to the United States (page 36). If this link is down, the aircraft can't fly even if there is nothing wrong with it[7]. It is bizarre that Australia would even contemplate operating an aircraft under this arrangement.

The F-35 was conceived more than 20 years ago, and the first flight took place 10 years ago. Though it is still in development, it is now apparent that the F-35, optimised for stealth against x-band radar, is a technological dead-end superseded by improved technology in other parts of the electromagnetic spectrum. The United States Department of Defense is losing faith in the F-35[8] and is considering[9] acquisition of F-15 and F-16 aircraft to fill its capability gap.

Fortunately for Australia, another aircraft is now available that is far more capable than the F-35, while being one third of the price and having an operating cost one tenth of that of the F-35. This is the Gripen E from Saab in Sweden (page 58). Brazil is assembling the Gripen E to supply its air force and for regional sales. Australia could also assemble the Gripen E, as we did with the F/A-18A and the Mirage III before it, which would substantially boost Australia's defence capability. Australia should make this choice soon to avoid unnecessary expenditure on life extension for the F/A-18A fleet (page 62).

2. Australia's Future Air Defence Needs

Australia cannot be invaded if at least either of two conditions holds – that Australian submarines sink any invasion fleet approaching the Australian coast; or Australian fighter aircraft maintain air superiority over Australia and out to the Indonesian archipelago. The latter condition would mean that enemy surface forces, on sea or land, could be interdicted at will. Ideally we would maintain both capabilities to be sure and make the whole job easier. If we don't maintain air superiority over northern Australia and its approaches then life, and staying alive, becomes far more difficult for the rest of our armed forces. So having the right fighter aircraft in the requisite quantity to achieve air superiority is one of the two major considerations in our force structure.

Australia is currently relying upon the F-35 to provide air superiority. The F-35 had its origin in the Joint Advanced Strike Technology programme established in January 1994. Australia announced that it would join the F-35 program on 22nd June, 2002. This was against the advice of the Department of Defence's Investment Analysis Branch[1] which concluded that there was not enough information about the proposed aircraft to determine its cost-effectiveness. The first flight of an F-35 was on 15th December, 2006. Australia started ordering F/A-18E Super Hornet aircraft in 2007 to offset delays in the F-35 programme. Almost a decade later, much the same situation prevails.

The inadequacies of the F-35 are now readily apparent. It was designed 20 years ago as a light bomber with air defence provided by other aircraft. It is still a light bomber that can operate only in uncontested airspace. The F-35 cannot be relied upon to provide air defence[2]. The United States may yet drop the F-35 programme. While momentum towards that decision is building, the F-35 programme is kept going in part by a perception that there is currently no alternative aircraft that could fill the void in the acquisition programme that would be created by the cancellation of the F-35. There is also a perception that a number of US allies would be left high and dry by cancellation of the F-35.

The optimum solution to Australia's F-35 problem is the Saab Gripen E[3]. It is also the optimum solution for the United States' F-35 problem. The Gripen E uses a US-made engine and many other US-made components. Saab's partner in the United States is Boeing which makes the Super Hornet. The Super Hornet production line in St Louis is scheduled for closure 2017. It would be surprising if Boeing has not approached Saab on the subject of an American production run for the Gripen E using the St Louis production line. There are precedents for the manufacture of combat aircraft in the United States under licence. For example, the English Electric Canberra bomber was built in the United States as the Martin B-57. More recently the British Harrier jet was built as the AV-8B for the Marines.

The most capable fighter aircraft currently flying is the F-22. Production of the F-22 was truncated in 2011 due to its high capital and operating costs. The next most capable is the Gripen E. While the Gripen E is almost as capable as the F-22, its build cost is one quarter of that of the F-22 and its operating cost[4] is one tenth that of the F-22. The latter attribute means that countries operating the Gripen E can train their pilots to a much higher level of proficiency than F-22 pilots. In combat, that would result in the Gripen E being more effective than the F-22. Lockheed Martin made the F-22 and is the manufacturer of the F-35. The Dassault Rafale is close to the Gripen E in capability as the aircraft are very similar in design philosophy. The Gripen E's advantages over the Rafale include the fact that its acquisition cost and operating cost are one third of that of the Rafale and the fact that it can use a number of US-sourced missiles. The Gripen E has a slightly higher instantaneous turn rate than the Rafale and would be better at dodging air-to-air missiles, and thus is more survivable. The Gripen E's other missile counter-measures are also very effective.

Some proposals for solving the United States' F-35 nightmare include building more F-16 and F/A-18E aircraft. This would not be a solution as both of these aircraft are very much outclassed by the Su-27 and its derivatives. For example the loss/exchange rate between the latest iteration of the Su-27, the Su-35, and the F/A-18E is one to eight. That is, on average, one Su-35 will be shot down for every eight F/A-18E aircraft shot down[5]. This is worse than the loss exchange rate of the Su-35 to the F-35 of one to 2.4. If fact the F/A-18E is acknowledged within the United States military to be a light bomber[6].

In comparison with the slow progress of F-35 development, the Russian equivalent of the F-22, the T-50, first flew on 29th January, 2010 and will enter production in 2016. In a number of areas the T-50 is more advanced than the F-22 and is likely to be at least its equal in combat capability. The loss/exchange rate of the T-50 to the F-35 is likely to be about one to 20 (similar to that of the Gripen E against the F-35[7]).

Another proposal for solving the United States' F-35 nightmare[8] is to restart production of the F-22, which first flew in 1997. The tooling from the F-22 production line was put into storage on its closure. However, recent attempts to access that tooling to make spares for the current F-22 inventory have found empty storage containers. Even if the production line could be reconstituted that would not solve the primary problem of the F-22 – that it is too expensive to operate due to its Radar Adsorbent Material (RAM) coating. Repairs to the RAM coating take up 40 percent of its 45 man-hours[9] of maintenance per flight hour. In terms of its design heritage the F-22 is derived from the F-15 and that heritage limits what can be achieved with the F-22 airframe. Thus updating the F-22 airframe with modern avionics would not create an advantage over the T-50 without the ongoing cost penalty of the F-22's RAM coating.

With respect to the fighter aircraft of potential adversaries, Indonesia[10] recently committed to taking 12 Su-35 fighters and has indicated that they would like to buy a further 12. Those 12 Indonesian Su-35s would shoot down 29 Australian F-35s before they would be shot down themselves. If the Indonesians build their Su-35 fleet to their desired 24 aircraft, they could shoot down the bulk of Australia's intended F-35 fleet while retaining the rest of their air force. Indonesia would then have control over Australian air space as far south as Townsville from bases in their own territory.

The larger threat in our region is the People's Republic of China (China). The People's Liberation Army Air Force (PLAAF) has some 250 Chengdu J-10 fighter aircraft. This is a delta wing with canards design similar to the Gripen E and Rafale. The PLAAF also has some 380 Su-27 aircraft and its more advanced derivatives. It is currently in the process of buying 24 Su-35 aircraft. China is also developing two aircraft, the J-20 and the J-31, with stealth shaping. While nominally a fighter aircraft, the J-20 may be optimised on delivering long range air-to-air missiles against higher value targets such as AWACS aircraft and tanker aircraft[11].

The development of the three 3,000 metre long airfields in the Spratly Islands brings the PLAAF about 1,000 kilometres closer to Australia. From those Spratly bases, Su-35 fighters and H-6 bombers, without inflight refuelling, could deliver cruise missiles in an arc from Broome to Katherine. Of course they could range much further south with inflight refuelling.

During World War 2, Japanese Zero fighters based in Kupang, West Timor ranged as far south at Exmouth, 1,600 km away. If China gains control of Indonesia, as Japan did in World War 2, or co-opts Indonesia then PLAAF aircraft based out of Kupang or Merauke in West Papua would have control over Australian air space as far south as a line between Townsville and Exmouth without inflight refuelling. Air-launched cruise missiles could reach as far south as Sydney without inflight refuelling. This is based on Australia being defended by the intended fleet of 75 F-35s which are expected to last about three days in a conflict against an equal number of pure fighter aircraft derived from the Su-27[12].

With respect to the quantity of Gripen E aircraft that Australia should acquire, Australia introduced the Mirage III into service in 1964 and had a total of 110 of these delta-winged aircraft introduced to service. It was built at Fisherman's Bend in Melbourne. Australia's population in 1964 was 11.2 million with a GDP per capita in dollars of the day of US$2,137 for a total US$24 billion. Australia now has more than twice the population it had in 1964 with a GDP of US$1,560 billion and a GDP per capita of US$67,500. In constant dollar terms, this is more than five times the GDP per capita that Australia had in 1964. Combined with the population having more than doubled, Australia's economy is more than 10 times larger than it was in 1964 when we had 110 frontline fighter aircraft.

Choice and quantity of our fighter aircraft is an existential question for Australia. The appropriate number to aim for initially may be two to three times the number of Mirage 3 aircraft that we had 50 years ago. The midpoint of that range is 275 aircraft.

3. Costs and Benefits of the F-35 Program

Australia had contracted for two F-35 aircraft, which have been built[1]. Australia has announced an intention to acquire a further 70 F-35 aircraft but has not contracted to do so, though we may have paid for long lead items for a future batch of Low Rate Initial Production (LRIP). This is LRIP 10 under which Australia is due to have eight F-35s delivered in 2018.

The two F-35s purchased to date came from LRIP 6, which had a build-cost of US$103 million each, not including the engine. Including the engine, the cost per aircraft would be US$128 million which is A$175 million. Further to that, all the aircraft built under the LRIP will require modifying to the final configuration of the aircraft. This is likely to be of the order of US$30 million per aircraft, taking the cost of Australia's first two aircraft to A$216 million each. In 2012, the US Defense Department's undersecretary for acquisition, technology and logistics described the decision to start LRIP of the F-35 as "acquisition malpractice"[2]. The decision to start LRIP was based on optimistic predictions of the capabilities of design tools, simulations and modelling.

An independent guide to the cost of the F-35 program is provided by the Dutch Ministry of Defence in a document dated 15th September, 2015[1]. The Dutch Ministry of Defence calculates that their planned acquisition of 37 F-35 will have an average cost of €126.8 million which equates to A$191.5 million. At that rate, Australia's announced purchase of 72 F-35s would cost A$13,785 million. The Dutch Ministry of defence calculates the operating cost of their future F-35 fleet will be €285.7 million per annum, translating to €7.7 million per aircraft per annum which in turn is A$11.7 million. Assuming that the intended Australian F-35s fly 15 hours per month, then the hourly operating rate would be A$64,800. The total annual operating cost of the Australian F-35 fleet would be $840 million per annum. If the F-35 fleet operated for 20 years, the cumulative operating costs would amount to A$17 billion for a total program cost of A$32 billion.

The benefit to Australia of participation in the F-35 program is some offsets in making carbon-fibre panels and other components, totalling US$430 million (Lockheed Martin figure). In purely economic terms, the cost/benefit ratio to Australia of the F-35 is 54:1. That is the cost of the program is 54 times the benefit.

The F-35 is at best a light bomber which can operate only in uncontested airspace. It is not a fighter aircraft as it was designed for bombing from the get-go. Air-dominance provided by fighter aircraft is the prerequisite for the operation and survival of the rest of the RAAF's aircraft, and for the rest of Australia's armed forces apart from the submarine fleet. As an F-35 fleet cannot provide air-dominance, if purchase of the F-35 for Australia goes ahead then another aircraft type will need be bought as well to fill that role.

4. Changes in the Acquisition Timeline

The F-35 had its origin in the Joint Advanced Strike Technology (JAST) program that the US Air Force and US Navy in 1993. The word "Strike" indicates that it was oriented towards developing a light bomber. The following year, the JAST program absorbed the Common Affordable Lightweight Fighter program and a separate short take-off/vertical landing program. This became the Joint Strike Fighter program with the aim of producing a common airframe and engine across the US Air Force, US Navy and US Marine Corps. This aircraft was claimed to be 20 percent cheaper to acquire and operate than legacy aircraft such as the F-16. That was the intent. Lockheed Martin won the fly off against Boeing in 2001.

The Howard Government committed Australia to the F-35 program in 2002, ignoring Department of Defence advice that it was too soon to join the program. Australia joined the program as a Level 3 partner and committed $300 million to it. In 2003, the US Government Accountability Office estimated that the F-35's production cost would be US$65 million per aircraft. The first production F-35 flew in 2006.

On 13 December, 2006, Australia signed the JSF Production, Sustainment and Follow-on Development Memorandum of Understanding which committed Australia to the next phase of the F-35's development. The following year, concern grew over the F-35's delayed development. Australia adopted a risk-mitigation strategy of buying 24 F-18 Super Hornet light bombers, the first of which was delivered in 2009. RAAF policy is currently to continue to buy more F-18 Super Hornet aircraft as the F-35 is further delayed. Australia has bought a further 12 F-18F Super Hornets in the electronic warfare variant. These will be operation in 2018 and cost $125 million each.

Full rate production of the F-35 is now scheduled to start in 2019, though there are signs that might not happen. The US polity is dismayed that over 180 F-35s have now been completed but none can fight properly, including the squadron of US Marine Corp F-35Bs that have been declared operational. The head of the F-35 program, General Bogdan, has announced a make-or-break date of December 2016 for achieving operational maturity for the F-35[1]. Even if the F-35 survives that date, its technology is now old enough that it requires modernisation[2]. The modernisation effort will cost US$2.6 billion in R&D through to 2020.

Apart from the delay in the program, the United States has also concluded that it cannot afford to acquire and operate the F-35 to provide the number of fighter aircraft that it needs. To that end, the US Air Force is examining buying more F-15 and F-16 aircraft. The production lines of these aircraft, which first flew in the 1970s, have been kept open by orders from non-US militaries. While both the F-16 and F-15 are outclassed by Su-27 derivatives, they are far more survivable and cheaper to operate than the F-35. The US Navy is stuck with the F-18 Super Hornet. as the F-16 and F-15 do not have carrier variants. As a Center for Strategic and Budgetary Assessments report stated in September 2010, "the Navy's F/A-18E/Fs provide the nation with a powerful instrument for precision strike in non-contested operating environments at very short ranges". The same is true for Australia. Our F-18 Super Hornets are good for bombing at short range. In air-to-air combat they are even less survivable than the F-35[3]. The RAAF's policy of buying more F-18 Super Hornets as the F-35 program is further delayed is ill conceived. Australia does have a need though for maritime strike aircraft to deliver anti-ship cruise missiles, and our F-18 Super Hornets would be a good fit for that role in which they are unlikely to encounter enemy aircraft. The F-35s are too expensive to operate and too unreliable to be applied to maritime strike.

The delays in the F-35 program have a number of problems for Australia:

1. The United States is likely to at least scale back further its planned purchases of F-35 aircraft, thus increasing the average unit cost of the rest of the program. This could result in a death spiral that causes the whole program to be abandoned[4].
2. The United States Congress could lose patience with the F-35 program and cancel it. December 2016 might be a decision point. As well as the United States itself, Australia and a number of other countries would then be left with a large air-dominance vacuum to fill and limited options to do that. In part, the F-35 program has been kept going because of a perception that there is no "Plane B"[5]. If a Plane B emerges, and that could be production of the Gripen E in the United States by Boeing, then concurrent production of that aircraft would begin and the F-35 would ultimately be abandoned as too expensive.
3. Continued delay of the F-35 means that Australia would be faced by life-extension costs for our fleet of F-18A Hornet aircraft. RAAF pilots of these aircraft are training under restrictions to prolong airframe life. These restrictions mean that they are not able to properly train for air-to-air combat.

No matter what the delays, the F-35 is not worth waiting for anyway. It is a light bomber that is restricted to operating above 20,000 feet in an uncontested environment. It will have a low sortie rate due to the hours of maintenance it requires per hour of flight. It can only operate from five airfields across northern Australia. It will drain funds from other programs. In combat, Australia's intended fleet of F-35s will only last three days before they have all been shot down. At some stage, Australia will have to acquire a pure air superiority fighter to replace the F-35. The sooner that process is begun, the more secure Australia will be and the less money wasted.

F-35 PROCUREMENT SUMMARY *(as of June 2015)*

SERVICE	VARIANT	PLANNED	CONTRACTED	FLYING
USAF	F-35A	1,763	103	67
US NAVY	F-35B	260	18	18
USMC	F-35B F-35C	340 80	50 -	45 -
AUSTRALIA	F-35A	100	2	2
CANADA	F-35A	65	-	-
DENMARK	F-35A	30	2	-
ISRAEL	F-35A	33	-	-
ITALY	F-35A F-35B	60 30	- 8	-
JAPAN	F-35A	42	4	-
NETHERLANDS	F-35A	37	2	2
NORWAY	F-35A	52	4	-
SOUTH KOREA	F-35A	40	-	-
TURKEY	F-35A	100	-	-
RAF/FAA	F-35B	138	8	3
TOTAL		3,170	201	137

Table 1: F-35 procurement by country and service as at June 2015[6]

Despite a schedule that shows more than 3,000 F-35s committed to, the number of aircraft contracted for by non-US purchasers is still quite small. It is a total of only 30. Canada has dropped out of the program since this table was compiled. Israel is being given its 33 F-35s under US military assistance to that country. Israel subsequently has asked for F-15 aircraft rather than more F-35s[7]. Japan and South Korea were coerced into taking the F-35, and both countries are independently developing indigenous fighter aircraft[8]. South Korea has confirmed that it will develop the KF-X circa 2020[9].

Denmark is also currently reconsidering its intent to take the F-35[10]. The United States is likely to further reduce the number of F-35s it will acquire so that it can afford to invest in some other capabilities[11].

	LRIP1	LRIP2	LRIP3	LRIP4	LRIP5	LRIP6	LRIP7	LRIP8	LRIP9	LRIP10	LRIP11
Buy Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Delivery Year	2010	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Australia	0	0	0	0	0	2	0	0	0	8	8
Canada	0	0	0	0	0	0	0	0	0	**0**(4)	**4**(9)
Denmark	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	3	3	2	2	4	5
Netherlands	0	0	1	1	0	0	0	0	0	0	8
Norway	0	0	0	0	0	0	2	2	6	6	6
Turkey	0	0	0	0	0	0	0	0	0	2	**4**(10)
United Kingdom	0	0	2	1	0	0	1	4	6	3	1
United States	2	12	14	30	32	31	29	29	**38**(34)	**57**(55)	**66**(68)
FMS	0	0	0	0	0	0	0	6	9	**16**(14)	**20**(6)
TOTALS	2	12	17	32	32	36	35	43	**61**(57)	96	**122**(121)

	FRP1	FRP2	FRP3	FRP4	FRP5	To Complete	TOTAL
Buy Year	2018	2019	2020	2021	2022		
Delivery Year	2020	2021	2022	2023	2024		
Australia	15	15	15	15	15	7	100
Canada	**9**(13)	13	13	13	**13**(0)	0	65
Denmark	2	4	8	8	8	0	30
Italy	5	5	9	10	8	34	90
Netherlands	8	8	8	3	0	0	37
Norway	6	6	6	6	6	0	52
Turkey	**8**(12)	**8**(12)	**8**(12)	10	**8**(10)	**52**(32)	100
United Kingdom	3	3	5	8	8	93	138
United States	**88**(90)	**90**(96)	**92**(100)	**100**(120)	120	**1613**(1581)	2443
FMS	**18**(6)	**18**(6)	6	6	2	0	**101**(61)
TOTALS	**162**(160)	**170**(168)	**170**(182)	**179**(199)	**188**(177)	**1799**(1747)	**3156**(3116)

Table 2: F-35 procurement schedule by year[12]

To date Australia has bought and paid for two F-35s. At the moment we are not contracted to buy any more and thus could avoid the bulk of the disaster. Our outlay to date is likely to have been of the order of $1 billion, which should be written off like some other failed defence acquisitions before it, such as the $1.4 billion wasted on the Seasprite helicopter for the Royal Australian Navy.

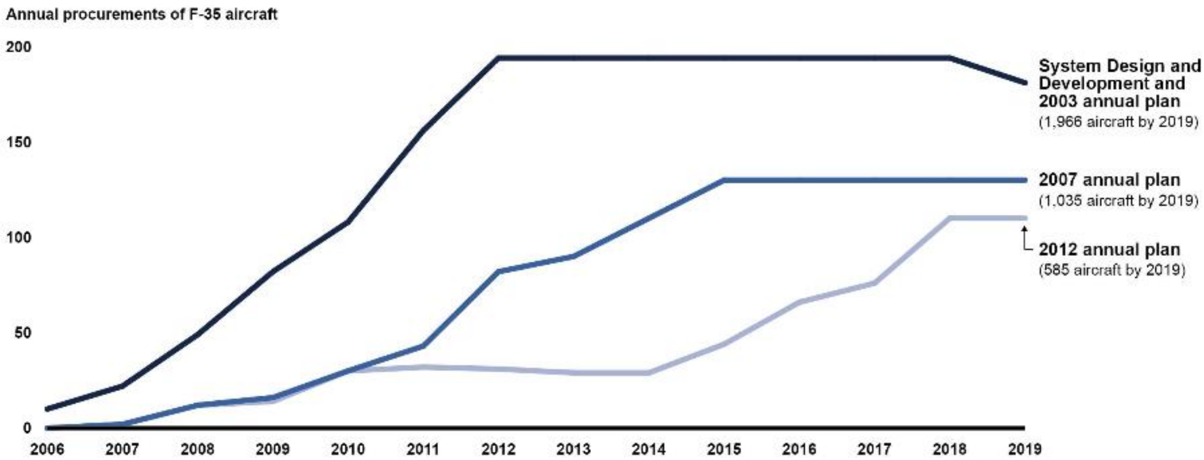

Figure 1: Slippage in the United States' F-35 acquisition program[13]

The F-35 entered LRIP about a decade ahead of being finalised as a design. All those aircraft built under LRIP will have to be rebuilt to the final configuration at a cost of the order of US$30 million per aircraft.

As the title of the document from which this figure is sourced suggests, the US Government has realised that there is doubt about the affordability of the proposed fleet of F-35 aircraft. That doubt raises the possibility that the whole program could be dropped. This was the fate of a couple of other US aircraft programs over the last couple of decades. The B-2 bomber program was initially for 132 aircraft and was truncated at 21 aircraft. The F-22 fighter program started as a production run of 750 aircraft and stopped at 187 aircraft. Substitution of F-16 and F-15 aircraft for F-35s would provide the United States with a cheaper force that was more capable and survivable than the F-35, though not as good as the Su-27 derivatives fielded by China. After more than 30 years of aerial dominance, the United States has regressed to the position it was in at the start of World War 2, when its fighter types were outclassed by enemy aircraft.

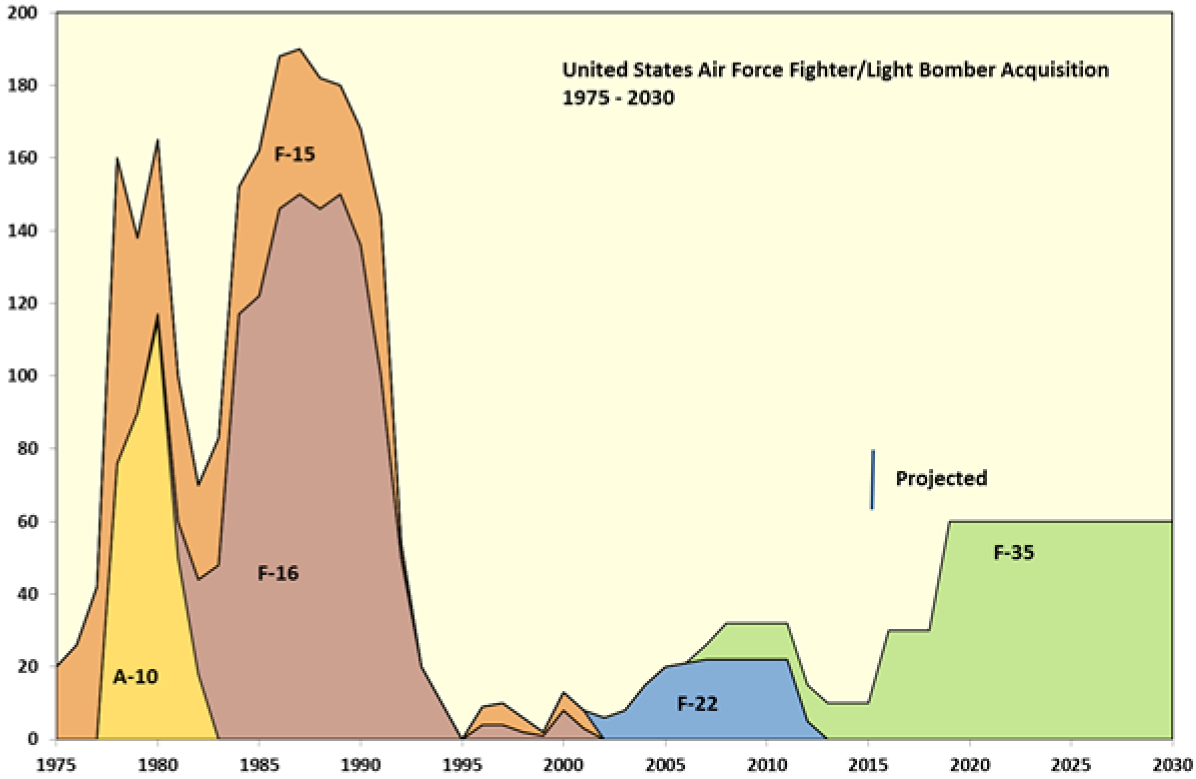

Figure 2: Acquisition of fighter and light bomber aircraft by the United States Air Force from 1975 with a projection to 2030

The delay in the development of the F-35, due to its complexity, and the truncation of the F-22 production, due to its cost, has resulted in the average age of the US Air Force fighter fleet increasing to about 28 years.

5. The Performance of the F-35 in Testing

To use a fighter as a fighter-bomber when the strength of the fighter arm is inadequate to achieve air superiority is putting the cart before the horse.
Lt. General Adolph Galland, Luftwaffe

The F-35 first flew in 2006 and, ten years later is still in the development phase though some 200 of the type have been built under Low Rate Initial Production. Full Rate Production is scheduled to begin in 2019. Every aircraft built to date is different. Retrofitting them to the same standard, once the final design is settled on, may cost of the order of US$30 million per aircraft. Some capabilities will not be fully developed until early next decade, with the delay due to software development.

The F-35 has a test schedule using aircraft based at Eglin Air Force Base in Florida. Until at least recently F-35 aircraft based at Eglin were forbidden from doing following things[1]:

- Descent rates of more than 30 meters per second
- Airspeed above Mach 0.9 (compared to advertised top speed of Mach 1.6)
- Angle of attack beyond -5 and +18 degrees (compared to advertised +50 degrees)
- Manoeuvres beyond -1 and +5 g (compared to advertised 9 g for A version)
- Take-offs or landings in formation
- Flying at night or in bad weather
- Using real or simulated weapons
- Rapid stick or rudder movements
- Air-to-air or air-to-ground tracking manoeuvres
- Refuelling in the air
- Flying within 40 kilometres of lightning
- Use of electronic countermeasures
- Use of anti-jamming, secure communications or datalinks
- Electro-optical targeting
- Using the Helmet Mounted Display as "primary reference"
- A high proportion of low-level flying due to fuel temperature.
- Night IMC flying (instrument meteorological conditions)
- Flight above 500 knots at low altitude because the aircraft overheats

The problems of the F-35 have two sources:

1. Overly ambitious technology and software.
2. Shortcomings inherent from the design philosophy.

5.1 Introduction to the deficiencies of the F-35

The two design considerations that have crippled the effectiveness of the F-35 are:

1. It was designed as a light bomber that also had some ability to defend itself against airborne threats that might inadvertently appear.

2. It was designed so that one variant, the F-35B for the United States Marine Corps, could have short take-off and vertical landing ability (STOVL).

The trade-offs necessary to effect the STOVL capability fatally compromised the whole project so that none of the variants do their job adequately. Specifically, the requirement to have a lift fan 1.27 metres in diameter on the centreline of the aircraft behind the pilot resulted in two bomb bays instead of just one on the centreline. This made the aircraft wider, draggy, slower and less manoeuvrable. In short, the F-35 can't turn, can't climb, can't run.

In fact, it isn't a fighter aircraft in the first place. Australia might think it is buying a fighter than can hold its own against the Su-30, Su-35, J-11, T-50, J20, J31 and others but it is really a light bomber. It was designed as such from the get-go. The recently retired head of Air Combat Command for the US Air Force, General Mike Hostage has been quoted as saying, "The F-35 is geared to go out and take down the surface targets."[2] The original requirement that evolved into the F-35 was Battlefield Interdiction and Close Air Support with the intent being to deal with lightly defended ground targets after the F-22 knocks out the really dangerous air defences. That assumes that a lot of F-22s are available. They aren't because production was halted at 187 in 2012. Two have crashed leaving 185 in service.

In the air combat role, Hostage says that it takes eight F-35s to do what two F-22s can handle. He has said further of the F-35: "Because it can't turn and run away, it's got to have support from other F-35s. So I'm going to need eight F-35s to go after a target that I might only need two Raptors to go after. But the F-35s can be equally or more effective against that site than the Raptor can because of the synergistic effects of the platform." He has also been quoted as saying that an F-35 pilot who engages in a dogfight has made a mistake. Further from General Hostage:" If I do not keep that F-22 fleet viable, the F-35 fleet frankly will be irrelevant. The F-35 is not built as an air superiority platform. It needs the F-22. Because I've got such a pitifully tiny fleet (of F-22s), I've got to ensure I will have every single one of those F-22s as capable as it possibly can be."[3] It therefore follows that Australia, not having F-22s, has an irrelevant air combat capability in the F-35.

The F-35's primary role in ground attack is confirmed by its weapons bays which each have room for a 2,000 lb. bomb and one air-to-air missile. It could carry more bombs and missiles on its wings at the cost of stealth, although the wing stations are not stressed for heavy loads as those of the F-22 and F15E are. At the same time, stealth against radar isn't the be-all and end-all of aerial combat. The F-35 can be spotted by low frequency radar a couple of hundred kilometres away. Infrared detection can also work at a considerable distance under the right atmospheric conditions. For example, the infrared-scan-and-track system for the Sukhoi Su-35, the OLS-35, will detect, track and engage the F-35 at about 70 kilometres. The Su-35S and the T-50 also have L-Band radar in the wing leading edges that will detect the F-35.

Due to severe transonic buffeting, wing roll-off and low acceleration, the F-35 is essentially a subsonic aircraft in both air intercept and ground attack missions. It cannot achieve supercruise as typically defined (sustaining speeds above Mach 1 without afterburner). All F-35 variants also have a very high infrared signature due to the hugely powerful engine required to push its brutal shape through the air, un-aerodynamic airframe and lack of infrared signature reduction measures. The problem is made worse by the fact that the F-35 has very limited rearward visibility, compounded by a large helmet that restricts head-turning. This will make surprise bounces from the rear quadrant a certainty. The only advantage that the F-35 has over the F-22 is the Electro-Optical Distributed Aperture System (EO-DAS), but the system in question is optimised for ground attack, and so has limited air-to-air performance (limited ability to detect targets at a higher altitude than the F-35, limited range and resolution).

The F-35A has combat weight of 18.3 tonnes, a wing loading of 428 kg/m2, thrust-to-weight ratio of 1.07 and span loading of 1.75 tonnes/m. Wing sweep is 34°, and the engine has a power-to-frontal area ratio of 17.9 N/cm2. As a result, the F-35 has very low instantaneous and sustained turn rates (less than half of the F-22's sustained turn rate, or ~11° per second) as well as low acceleration, while its weight harms the transient performance. The F-35's inefficient aerodynamics and inefficient power plant also limits combat endurance despite an excellent fuel fraction of 0.38. The F-35 has a specific fuel consumption of 0.9 lb/lb/hour versus 0.75 for other advanced combat jet engines.

The F-35 uses the GAU-22/A gun as well as AIM-9 Sidewinder within-visual-range missiles and AIM-120 beyond-visual-range missiles, though only the latter will be typically carried as the AIM-9X is carried on the wing, eliminating the F-35's Low Observability to radar. The GAU-22/A needs 0.4 seconds to spin up to full rate of fire and the gun doors require 0.5 seconds to open. In the first second it will fire 16 projectiles weighing 2.94 kg. Again, usage of radar-guided missiles does not allow it to surprise the enemy at beyond-visual-range. The F-35's disadvantage in using missiles is that it has to hold the missile in the airstream on the opened bomb-bay door while it acquires lock-on before launch, revealing itself while this takes place.

The F-35 is far worse when it comes to damage tolerance than any other modern fighter, with massive quantities of fuel surrounding the engine inlet. This fuel will be at an elevated temperature during flight, and especially during combat, as it is used as a heat sink. The same fuel is used in the aircraft's hydraulic system. A hit from a 30 mm high explosive-incendiary round, as used by most Russian and Chinese fighters as well as Dassault Rafale, is almost certain to ignite the fuel and catastrophically destroy the aircraft. The engine is likely to ignite it even if the hit itself doesn't.

The F-35 has attempted to improve the pilot's situation awareness by a Distributed Aperture System (DAS) that allows the pilot to see all around the aircraft in every direction. The view is displayed inside the pilot's visor using data from cameras around the aircraft. However, the visual acuity of the system is much lower than that of the human eye, limiting its ability to detect aircraft at range and small objects such as incoming missiles. Each helmet is made to fit the head of the pilot who will use it, at a cost of US$600,000 per helmet. The system allows the pilot to see through the floor of the aircraft and see the ground underneath. It also analyses all the other information coming in from the radar and the infrared cameras also around the aircraft and presents it on the field of view, along with similar data from other F-35s flying with our pilot. The system determines what each threat is, ranks them in priority and recommends what countermeasure should be used. The F-35 can fire air-to-air missiles against aircraft flying behind it that the pilot cannot see. This is claimed in theory but will not work in practice. The beyond-visual-range AIM-120 missile that the F-35 will be carrying does not have the ability to do a 180° reversal and it needs mid-course guidance from the radar which is facing the other direction. Firing a missile “over-the-shoulder” consumes enormous energy and greatly reduces range.

Flying as a pack of at least eight, F-35s in theory should be able to provide mutual fire support. The F-35 could also serve as a sort of mini-AWACS directing other aircraft such as the F-18 onto targets, if the other aircraft were fitted with the F-35’s Multifunction Advanced Data Link. That said, other aircraft, already in service, do the same thing. All the Sukhois and the Swedish Gripen have intra-flight data sharing and are truly mini-AWACs. Gripens are optimized for ‘cloud shooting’ so one aircraft targets and another passive aircraft (not emitting a radar signal) shoots. All late model (Su-30 and beyond) Sukhois also have intra-flight communications to share detection and tracking of targets

The F-35 is a complicated aircraft though and may prove to have been just too ambitious. Its software includes over 30 million lines of code, six times more than that of the F-18E/F Super Hornet. There are plenty of bugs in the software and the aircraft’s other systems, which will take years to work through. With this amount of code, Regression Testing – ensuring a change does not have unintended consequences – will be a maintenance nightmare.

One of the more important bugs is the helmet vision system, which isn’t as seamless as it needs to be and produces too many false alarms. And if the helmet isn’t fixed it definitely won’t be a fighter because the aircraft’s bulkhead behind the pilot continues at the same height as the canopy. The pilot wouldn’t be able to see what’s behind him if the helmet is not working. He also wouldn’t be able to see below him because the aircraft is too wide. Most fighters have the pilot sitting up where he can see as much as possible. The F-35 pilot’s head is down in the fuselage, like a bomber.

A good summary of the current status of the F-35’s bugs and shortcomings is provided by the US-based Project on Government Oversight (POGO), from a Department of Defense report[4]. The US Defense procurement system requires that weapons development programs remain on schedule or they become in danger of being scrapped. The F-35 is well behind schedule but production has begun before testing has been completed. POGO’s analysis shows that Lockheed Martin, the aircraft’s developer, has been cooking the test results to meet project milestones. The effect of that will be an expensive retrofitting of completed aircraft estimated at US$60 billion. For Australia, that might mean a further $30 million per aircraft delivered. That extra $30 million per aircraft is equivalent to two thirds the cost of a Gripen.

There is an incident in the POGO report that suggests the F-35 might be fatally flawed because of the compromises made to get the thing to fly in the first place. In June 2014, there was an engine fire in an F-35 that was taxiing which resulted in the aircraft being lost. The aircraft that blew up was damaged three weeks earlier, during two seconds of flight when the test pilot, operating well within the safety envelope of the aircraft’s abilities in a ridge roll manoeuvre, put G forces, yaw stresses and roll stresses on the aircraft all at the same time. The F-35’s engine is said to have the problem of being too flexible. That may be because the airframe is too light, in which case this is a problem that is baked in the cake. There are severe flight restrictions as a result. If you put a fighter into a snap turn to, say, avoid a missile, the gyroscopic forces are huge. Both the engine and the aircraft have weight problems, and beefing up either or both compromises the already overweight aircraft. The practical outcome will be that the F-35 will be restricted in its manoeuvrability by its software.

Another restriction is a limit of Mach 0.8-0.9 at low altitude because the F-35 cannot dissipate its heat. Its competitors are limited to about Mach 1.2 at low altitude, so if there is a low-altitude engagement, 'can't run' becomes a serious threat to its survival. In fact in battle simulations of the F-35 against the Su-35, 2.4 F-35s are lost for each Su-35 shot down. Pitting the Gripen against the Su-35 results in 1.6 of the Sukhois shot down for each Gripen lost. The loss exchange ratio of the Gripen against the F-35 is breathtaking. For each Gripen lost in a Gripen-on-F-35 exchange, 21 F-35s are shot down[5].

There is potentially a big positive outcome out of all this. Australia has a great need for an aircraft that can fly long distances straight and level without stressing the airframe - to fulfil the maritime strike role. We need an aircraft that can deliver anti-ship cruise missiles. The F-35 is already being prepared for that role with our Department of Defence and the Norwegian firm Kongsberg collaborating on fitting the latter's Joint Strike Missile to the aircraft internally and externally. This missile will have a range of 240 kilometres, which means that the F-35 could launch it beyond the range of most ships' anti-aircraft missile systems. For the same role, the US is concentrating on its Long Range Anti-Ship Missile (LRASM), which has a range of 930 kilometres. These could be launched from our F-18 Super Hornets as well as the F-35.

An issue that affects all the international partners in the F-35 involves access to the computer software codes for the aircraft. The F-35 relies heavily on software for operation of radar, weapons, flight controls and also maintenance. The US military has stated that "no country involved in the development of the jets will have access to the software codes" and has indicated that all software upgrades will be done in the US. The US government acknowledges that Australia, Britain, Canada, Denmark, Italy, the Netherlands, Norway and Turkey have all expressed dissatisfaction with that unilateral US decision.

How will the F-35 go in actual combat? In the air-to-air role the F-35 is woefully under-armed. It could carry more missiles on its wings at the expense of losing its stealth but otherwise it is limited to two beyond-visual-range missiles in its bomb bays. On encountering enemy aircraft, its best chance is to fire those two missiles at the earliest opportunity and then turn tail and run as fast as possible. Firing two beyond-visual-range missiles, each with a probability of a kill of 8 per cent, has a 15 per cent chance of downing one enemy aircraft. As General Hostage said, an F-35 that is in an aerial dogfight has made a mistake. They will be "clubbed like baby seals"[6]. In 2008, Major Richard Koch, then chief of the US Air Force's advanced air dominance branch is reported to have said "I wake up in a cold sweat at the thought of the F-35 going in with only two air-dominance weapons." (The combat record of the AIM-120 in BVR is 46 per cent - but against aircraft that were un-alerted and not using missile countermeasures that will be used in the future – e.g. ECM, towed decoys, out-fly the missile – it only takes 2.5 G to defeat a Mach 4 / 40 G missile.)

The view that guns were redundant in aerial warfare following the development of air-to-air missiles first took hold in the 1960s. But missiles didn't perform as expected and most missiles missed. So the aircraft involved proceeded to the merge in which guns and the pure fighter attributes of manoeuvrability and turn rate were critical to survival. That remains just as true today.

Australia's potential use of the F-35 will be restricted due to the nature of the aircraft. Maintenance and logistics will require a contract with Lockheed Martin and the engagement of expensive Lockheed Martin personnel. Because flying the aircraft is so expensive, pilot training will have a heavy reliance on the use of simulators. In fact, deployment of the F-35 will require a simulator housed in a 40-foot shipping container to be taken along, as well as a 20-foot shipping container to provide power[7].

5.2 Basing

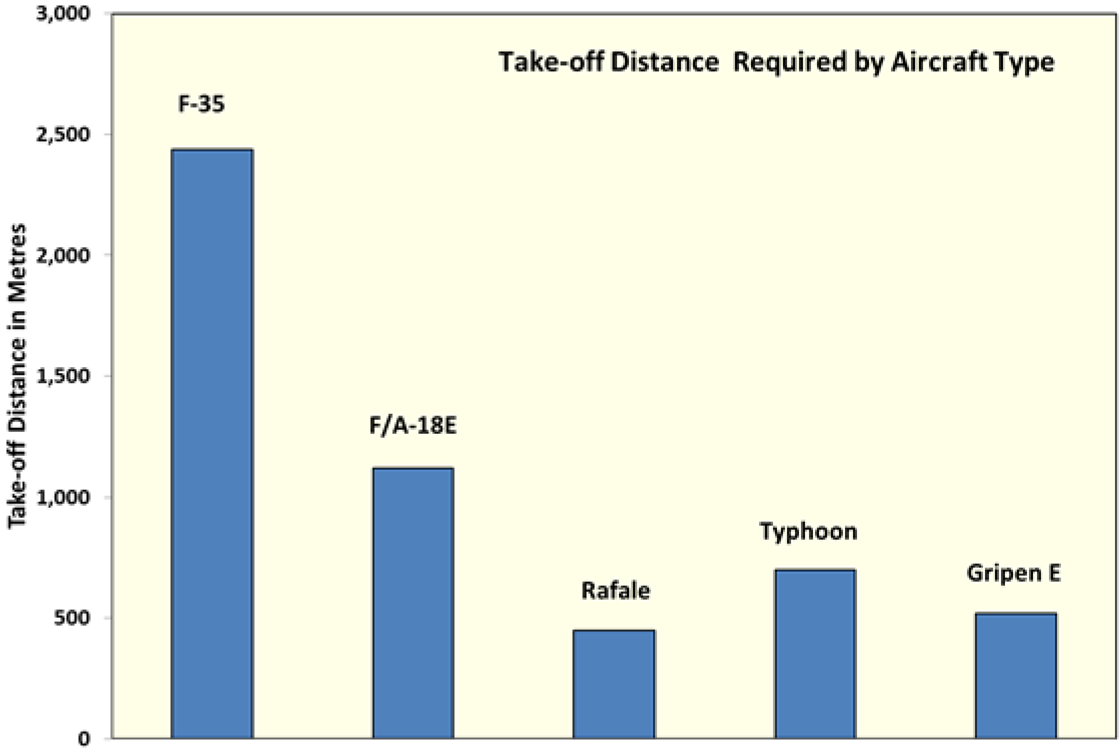

Figure 3: The F-35's runway length requirement compared to that of fighter aircraft

Within Australia, the F-35 can only land and take off from the following RAAF bases:

RAAF Base Williamstown, NSW

RAAF Base Tindal, NT
RAAF Base Darwin, NT
RAAF Base Scherger, QLD
RAAF Base Townsville, QLD
RAAF Base Edinburgh, SA
RAAF Base Pearce, WA
RAAF Base Learmonth, WA
RAAF Base Curtin, WA

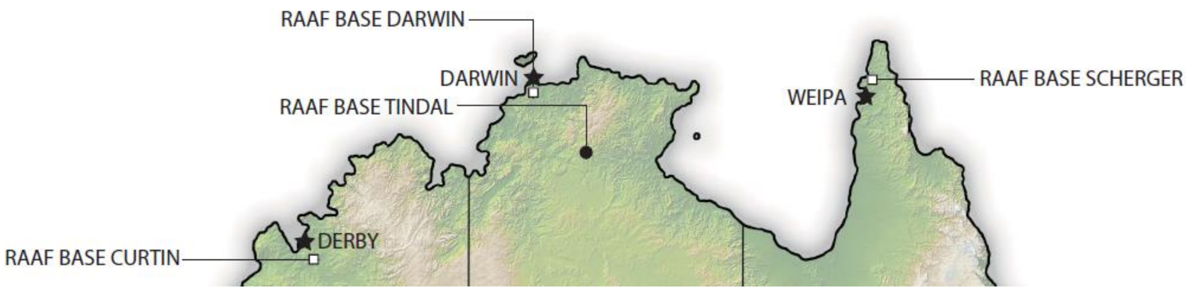

Figure 4: Airfields in northern Australia that can handle the F-35

Only four of these bases (Scherger, Tindal, Darwin and Curtin) are in northern Australia facing the main threat axis, which means that to negate the F-35 fleet all an enemy has to do is damage those three runways, even just for a few hours. That would only take three cruise missile attacks. Then the main enemy force could bomb the three air bases at will and take the F-35 out of the war for the duration.

The poor performance of the F-35 means that the 8,000 foot runway at RAAF Base Williamstown will have to be extended by 2,000 feet to allow trainee pilots the choice of aborting a take-off. It is extraordinary that a light bomber like the F-35 requires a runway length typical of heavy bombers and large transport aircraft.

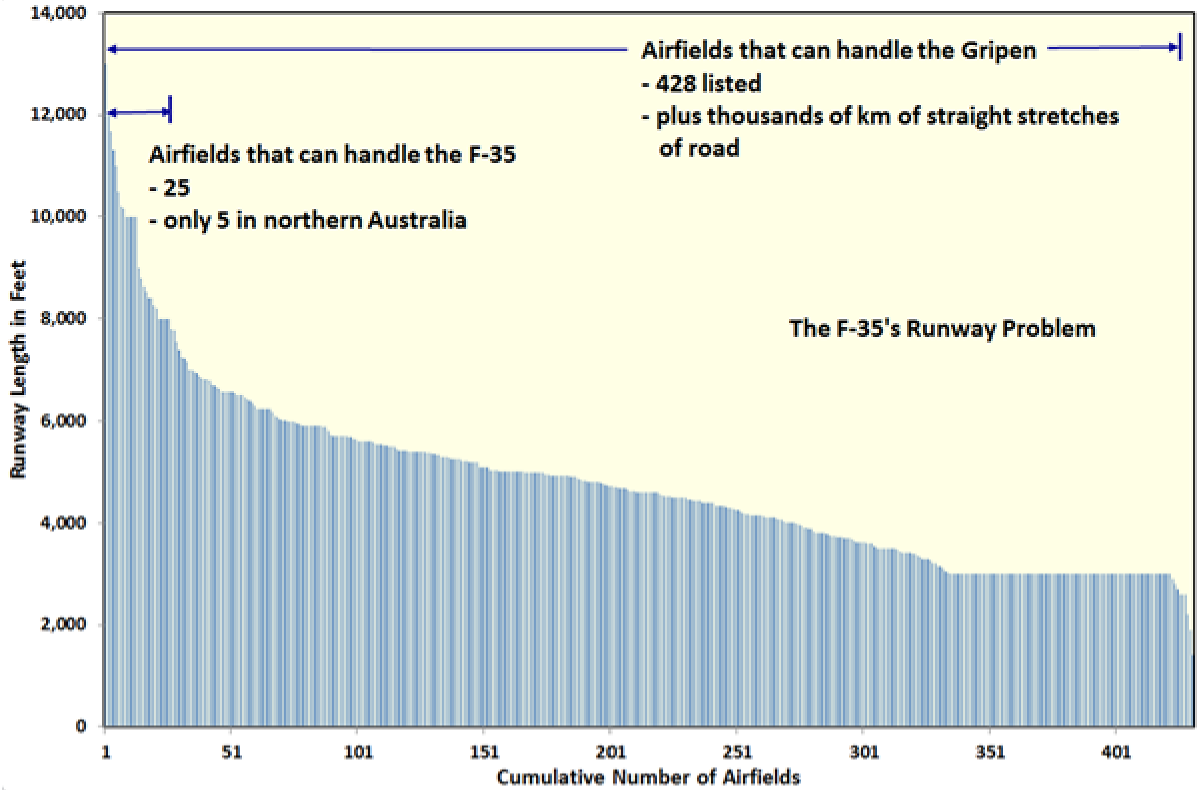

Figure 5: Cumulative number of airfields in Australia by length

Only 25 airfields in Australia can handle the F-35 due to its requirement for an 8,000 foot runway. Only five of those are in northern Australia where it would be used in combat. In effect, the F-35 will only be able to operate out of RAAF Tindal because the logistic philosophy of carrying minimal spares on base and relying upon just-in-time delivery of spares. Each F-35 needs 17 maintenance personnel and this large logistics footprint will be crippling on deployment away from the home airbases of the F-35. By comparison, the Gripen E fighter can operate from airfields as short as 2,500 feet as well as stretches of sealed road that long. Dispersal is important in survivability of the fighter fleet-in-being, exemplified by the survival of the Polish Air Force by dispersal the day before the start of World War 2.

One of Australia's strengths, if we use it, is the ability to disperse aircraft across northern Australia which would stop the potential for the destruction of our force in one event and provide opportunities for our fighter aircraft to ambush enemy intrusions. Because of its requirement for an 8,000 foot runway and its maintenance problem, the F-35 negates that potential strength. As one observer put it:

"For one thing, it tells us that the fantasy of stationing a few F-35s here and there on austere or disbursed bases is just that, a fantasy. Without access to high tech, well-stocked bases with large pools of highly skilled maintenance techs backed by civilian experts, the F-35 availability is going to plummet. Throw in actual combat conditions (deferred maintenance, combat damage, insufficient spare parts, challenging conditions, etc.) and availability is going to be in the 30 per cent range. The F-22 is only 50 per cent now so it's not much of a reach to make that prediction. Further, the availability, whatever it may start as, will only decrease over time in a combat situation as damage, shortages, and cumulative wear take their toll. Austere or disbursed basing is a fantasy after the first couple of sorties. If you think otherwise then you'll have to explain what miracle is going to elevate the F-35 maintenance and availability over the Air Force's pampered F-22 levels under wartime conditions as just described."

5.3 Fuel Temperature

The F-35 has a fuel temperature threshold and may not function properly if the fuel temperature is too high. This is because the F-35 uses its fuel to cool its electronics and engine. It is as if a car was designed to use petrol in its radiator.

At the Yuma and Luke US Air Force bases in Arizona, fuel trucks for the F-35 are painted white, parked in covered bays and chilled with water mist systems because the jet won't even start if the fuel is already too warm to cool the electronics[9].

This will be problematic for F-35s operating out of the Curtin, Tindal, Darwin and Scherger RAAF bases across northern Australia. In summer, the nights tend to remain hot, not giving the opportunity for equipment to cool down.

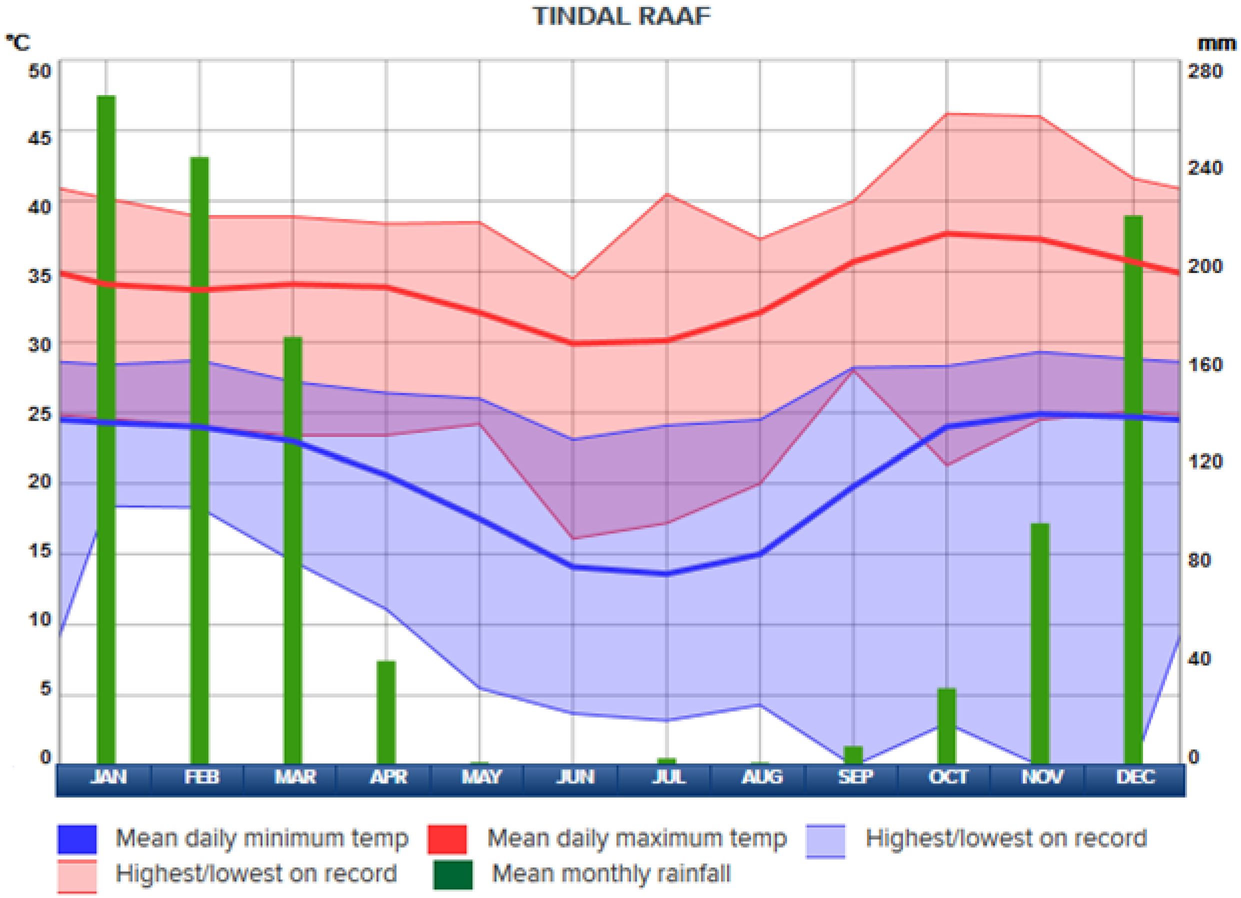

Figure 6: Climate at RAAF Tindal in the Northern Territory adjacent to Katherine

The RAAF might find that the F-35 may have to be kept in air-conditioned shelters as the B-2 is.

The F-35 also has had a cold weather restriction in that flights have been aborted (prior to take-off) due to battery problems whenever the temperature dropped below 15°C. It seems that the F-35 is a Goldilocks aircraft that can only operate when it is neither too hot nor too cold.

Figure 7: Relative ranges of the Su-35 and F-35

The Su-35 is a large aircraft with a combat range of 1,600 km. If operating out of Kupang in West Timor, Su-35s, without refuelling, could range as far south as Tennant Creek and fire cruise missiles that could reach a further 1,500 km.

5.4 Engine

The F-35 has a poorly designed, unreliable engine; the largest, hottest and heaviest engine ever put in a fighter plane. It is a highly stressed derivative of the F119 engine that powers the F-22. Because of the need to drive the F-35B lift fan, it is about 2,000 lbs heavier than other combat jet engines of comparable thrust. The project recognized the engine's limitations in 2012 by announcing an intention to change performance specifications for the F-35A, reducing sustained turn performance from 9.0g to 4.6g and extending the time for acceleration from 0.8 Mach to 1.2 Mach by 8 seconds.

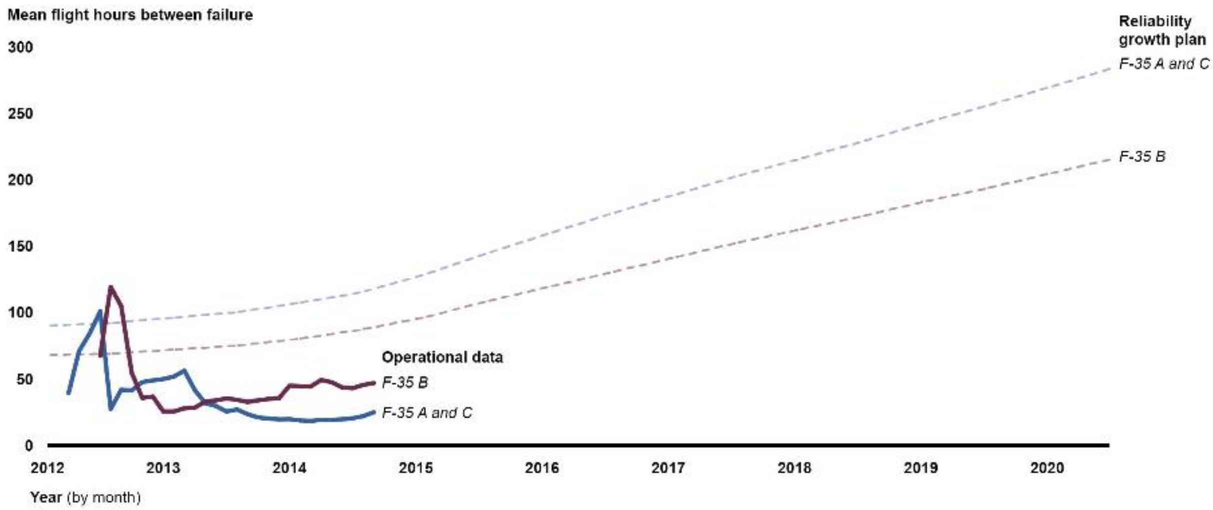

Figure 8: Mean flight hours between failure for the F-35 engine[9]

"Data provided by Pratt & Whitney indicate that the mean flight hours between failure for the F-35A engine is about 21 per cent of where the engine was expected to be at this point in the program."[9]

"This means that the engine is failing at a much greater rate and requiring more maintenance than expected. Pratt & Whitney has identified a number of design changes that officials believe will improve the engine's reliability and is in the process of incorporating some of those changes into the engine design, production, and retrofitted to already built aircraft; however, other design changes that Pratt & Whitney officials believe are needed, such as changes to engine hoses and sensors, are not currently funded."

Despite the brave words from the GAO report, the F-35's engine reliability isn't showing an improving trend. The engine needs boroscoping (like laparoscopy but for machinery) every three hours.

By 2013, mean elapsed time for engine removal and installation was 52 hours. The threshold needed for operational approval is 2 hours. By comparison, the engine in the Gripen E can be replaced in one hour.

The F-35 has many show-stoppers that would kill the program in a rational world. Its engine is just one of them.

Further to the engine of the F-35, it uses a larger lower altitude-optimised fan, compared to the high altitude-optimised fan of the F-22A's F119-PW-100. The F-35 trades away high altitude supersonic engine performance to achieve better cruise and loiter burn, and extract as much thrust as possible at lower altitudes, essential for its primary design role of battlefield bombing. Similarly, unlike the F-22A, which is designed around supersonic agility, the F-35 wing trades away supersonic performance to maximise subsonic cruise/loiter efficiency - classical bomber optimisation rather than air combat optimisation.

The average cost of an engine for LRIP 6 was US$29.9 million.

5.5 Acquisition Cost

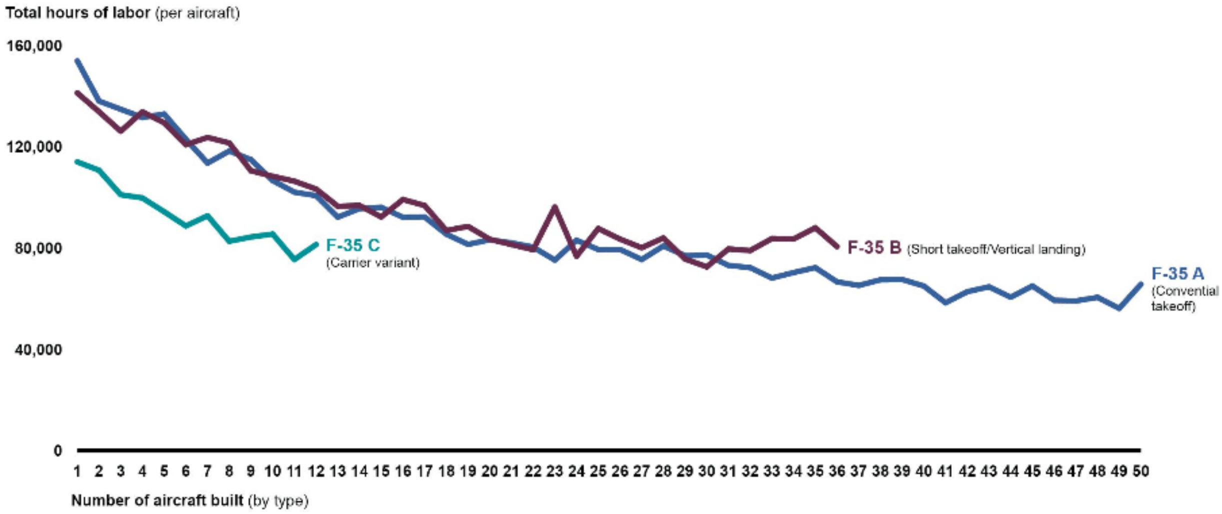

Figure 9: Total hours of labor per aircraft relative to number of F-35 built[9]

Current cost of making each F-35 is about US$135 million. If the program doesn't meet the program baseline for cost, then it is likely to be abandoned. Thus the F-35 program office is projecting that the build cost for each aircraft on full rate production will fall to US$85 million. The graph of hours worked to build each aircraft has flattened out though, indicating that there are unlikely to be any more possible efficiencies in building of the aircraft.

However, the design process produced three variants that have only 25 per cent commonality. Rather than save money, analysis by the RAND Corporation found that the cost of the F-35 program actually exceeds likely costs for three separate aircraft models by between 37 per cent and 65 per cent[10].

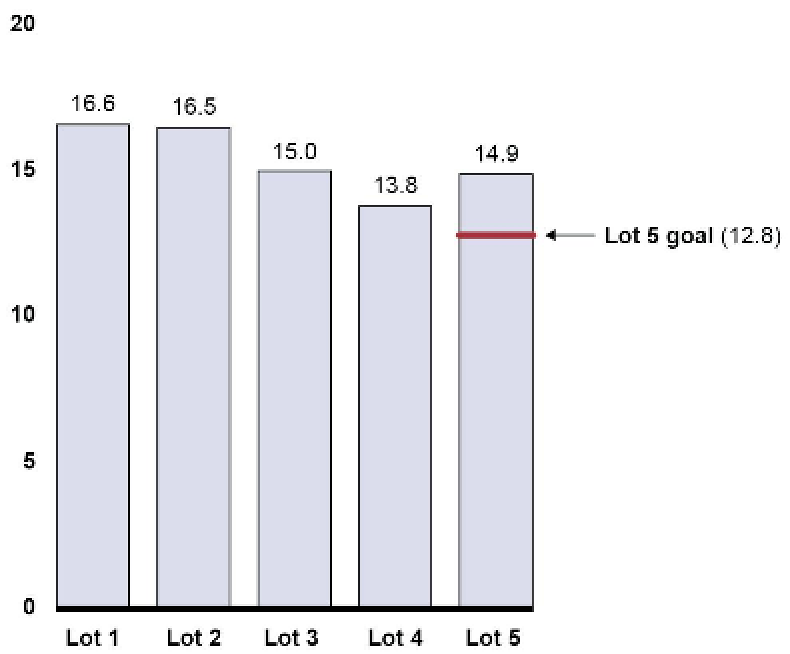

Figure 10: Percentage of hours spent on rework in construction of the F-35[9]

The F-35's innards are packed tighter than a head of cabbage. The consequence of that in manufacture is that adjacent parts are likely to be damaged when a part is installed or replaced. Once again, this figure suggests that there has been no improvement in the rework rate with increased production under LRIP.

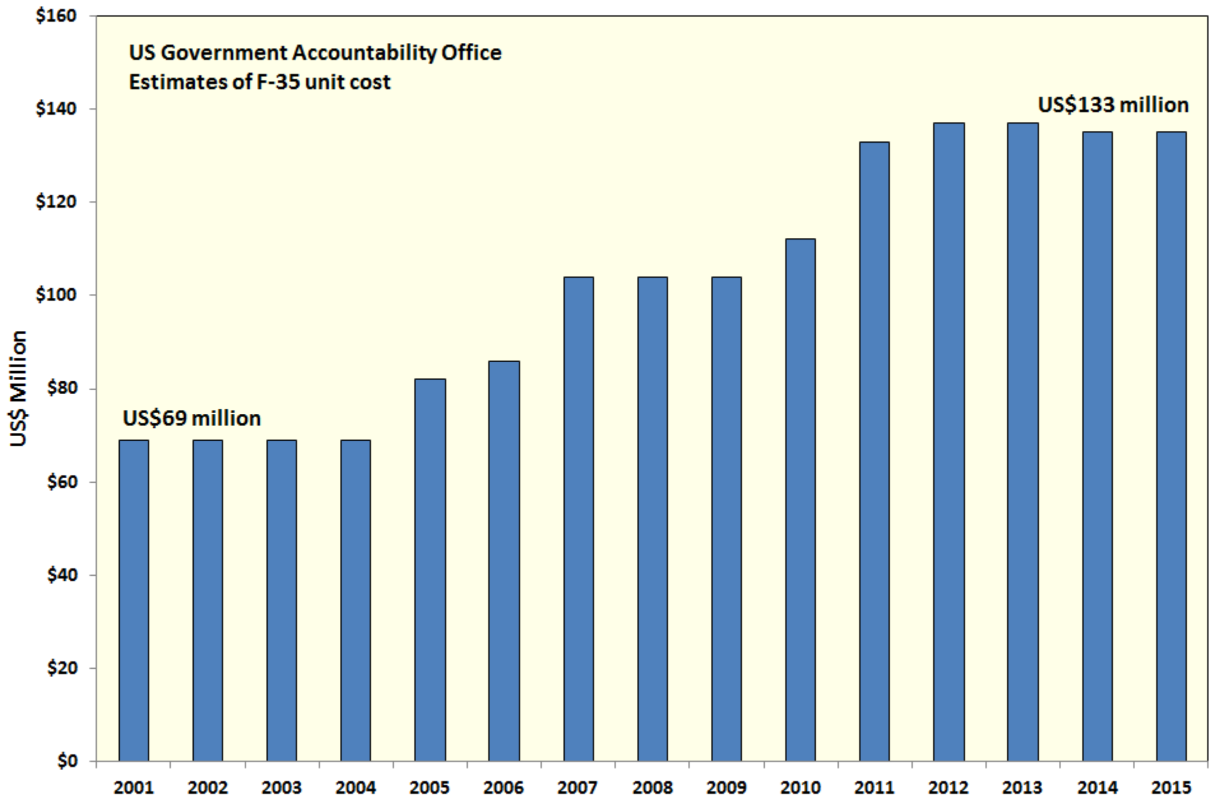

Figure 11: F-35 estimated of F-35 acquisition by year 2001 to 2015

Unit cost of the F-35 is now twice that of the F-16 which is a more capable aircraft.

5.6 Operating Cost

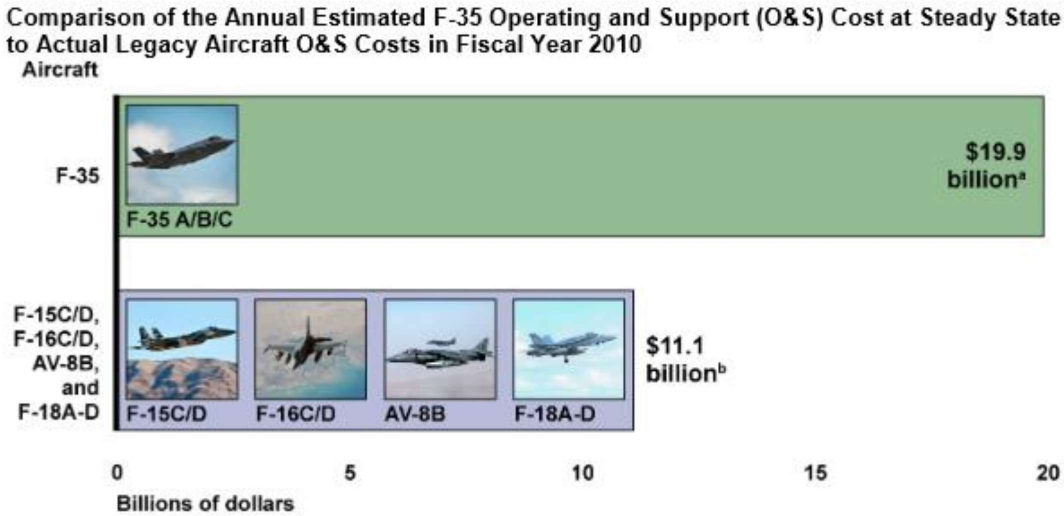

Figure 12: Annual operating cost of US versions of the F-35 relative to the costs of the aircraft it was intended to replace

The F-35 was intended to be cheaper to operate than the F-16. Instead it will be twice as expensive to operate as the existing fleet of mission-specific aircraft, without providing capability in any role.

From page 28 of a report by the Government Accountability Office September 2014, *F-35 Sustainment: Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates*:

"The JPO (F-35 Joint Program Office) estimate does not include reasonable assumptions for part replacement. Based on data from the Air Force and Marine Corps F-35 variants at testing and operational sites, parts are being replaced, on average, 15 to 16 times more frequently than the assumptions used across the life cycle of the JPO estimate (see table 2). For example, a sensor that costs about $4,800 is being replaced 60 to 129 times more frequently than anticipated across the life cycle of the JPO cost estimate. Another example is the battery charger unit, which costs about $60,000 to acquire new, and is being replaced 3 to 8 times more frequently than anticipated across the life cycle of the JPO cost estimate."

From page 29 of that report:

"The part-replacement assumptions used by the JPO reflect the anticipated reliability of the aircraft at maturity — once the entire fleet has achieved 200,000 flight hours. According to JPO officials, the reliability issues causing the high part-replacement rates will be resolved once the aircraft reaches maturity, which is estimated to occur at the end of fiscal year 2019. The JPO increased the cost of replacing parts in the 2010 to 2019 portion of its estimate to reflect the lower reliability of the aircraft until maturity. However, according to officials from the Institute for Defense Analysis, who conducted a study of the F-35's R+M for DOT&E, the F-35 program would have to achieve a higher reliability-growth improvement rate than has been observed in almost all other aircraft in order to meet the anticipated reliability by 2020. According to Institute for Defense Analysis officials, this rate of improvement is not impossible, but has only been observed in dissimilar aircraft like the C-17."

In summary, the rate of improvement in the F-35's maintenance costs that is required for it to be approved for production is not impossible, only highly unlikely.

Further to maintainability from the 2014 Government Accountability Office report:

"The amount of time spent on maintenance for all variants exceeds that required for mature aircraft. Two measures used to gauge this time are Mean Corrective Maintenance Time for Critical Failures (MCMTCF) and Mean Time To Repair (MTTR) for all unscheduled maintenance. MCMTCF measures active maintenance time to correct only the subset of failures that prevent the F-35 from being able to perform a defined mission, and indicates how long it takes, on average, to return an aircraft to mission capable status. MTTR measures the average active maintenance time for all unscheduled maintenance actions, and is a general indicator of ease and timeliness of repair. Both measures include active touch labor time and cure times for coatings, sealants, paints, etc., but do not include logistics delay times such as how long it takes to receive shipment of a replacement part.

The tables below compare measured MCMTCF and MTTR values for the three-month period ending August 2014 to the ORD (Operational Requirements Document) threshold and the percentage of the value to the threshold for all three variants. The tables also show the value reported in the FY13 DOT&E Annual Report for reference.

For the F-35A and F-35C, MCMTCF increased (worsened) over the last year while MCMTCF for the F-35B showed slight improvement. For all variants, MTTR showed improvement over the last year. Both maintainability measures for all variants are well above (worse than) the ORD threshold value required at maturity.

More in depth trend analysis between May 2013 and August 2014 shows that the MTTR for the F-35A and F-35C variants have been decreasing slowly, while the MTTR for the F-35B has been growing slightly, with all exhibiting high month-to-month variability. Over the same period, the MCMTCF values for the F-35B and F-35C were increasing slightly and flat for the F-35A, but again with very high monthly variability.

Several factors likely contribute to extensive maintenance time, especially long cure times for Low Observable repair materials. The Program Office is addressing this issue with new materials that can cure in 12 hours versus 48 hours for example, but some of these materials may require freezer storage, making re-supply and shelf life verification in the field or at an austere operating location more difficult.

-- The immaturity of the system overall, including training system immaturity, lack of maintainer experience on such a new aircraft, and incompletely written and verified, or poorly written, JTD may all also contribute to protracted maintenance times.

-- Additionally, design factors of the aircraft itself make effecting certain repairs difficult and time-consuming. Field maintainers have reported poor cable routing behind panels that interferes with required maintenance, and awkward placement of some components, which makes removing and replacing them slow, and increases the chances they will induce a failure in a nearby component working with tools in confined spaces."

Other analyses predicted the O&S (Operations and Sustainment) costs would be greater than 150 percent of legacy aircraft for the simple (and obvious) reasons that the F-35, for starters, would be a much heavier (but with a constrained/limited volume and), therefore, extremely dense aircraft design, resulting in higher O&S costs due to, inter alia:

(a) more than twice the internal fuel load;
(b) two nonstandard-shaped internal weapon bays;
(c) more than three times the avionics, much that is new and untried, with;
(d) new, untried electrically powered flight control actuators;
(e) more than ten times the software load;
(f) the biggest, heaviest, hottest-operating and fuel-thirstiest single military jet engine ever built; and,
(g) the higher maintenance costs associated with low observable technology coatings with stealth related internal components and design features.

5.7 Directed Energy Weapon

In theory, the F-35 can use its radar to disable aircraft and missiles with a beam of energy in the high part of the L band in a cone about 60° wide around the nose of the aircraft. This is enabled by the very high switching rate of the elements of the radar. The useful range may be up to 2 km. Use of this directed energy weapon would degrade the F-35's nose cone such that it would then be transparent to radar energy. Enemy radars would then see the backplate of the radar and the F-35's stealth would be negated until the nose cone was replaced back at the base.

The problem for the F-35 is that it has a sustained turn rate of a light bomber at 11° per second. All fighter aircraft can out-turn it and thus are unlikely to be engaged by the F-35's beam of radar energy. The directed energy weapon may mean that enemy fighters might have to be a bit more clinical in killing the F-35. An F-35 takes 16 seconds to turn 180 degrees at its corner speed. An air-to-air missile can cover the expected range of the directed energy weapon of 2 kms in 2 seconds. The F-35 simply can't turn fast enough to react to threats from multiple quadrants. This may explain General Hostage's observation that the F-35 has to travel in a pack of at least eight aircraft for mutual fire support.

5.8 DAS-EOTS

The F-35 has attempted to increase the pilot's situational awareness through a number of systems. This includes the Distributed Aperture System – Electro Optical Targeting System (DAS-EOTS). This system is a staring array of infrared sensors around the airframe, optimised for ground attack. They are not telescopic as per the current crop of European and Russian Infrared Search and Track (IRST) sensors which can be cued by the radar to focus on a particular part of the sky in order to identify an aircraft's type. The DAS-EOTS relative to IRST is like comparing the naked eye to a telescope.

The F-35's DAS-EOTS was optimised for ground attack and is sub-optimal for air-to-air combat. It is now deficient relative to upgraded ground attack targeting systems such as the Litening pod which have higher resolution and magnification. The F-35 also lacks an infra-red laser pointer which is now a common and highly praised tool for identifying and cross-checking targets with targeting controllers on the ground. The F-35 doesn't have the ability to retrofit an infra-red pointer and thus will always be deficient against current best practice. The F-35 also lacks the ability to downlink video from its targeting system to controllers on the ground. This is a big void which will increase the chance of the F-35 hitting the wrong target on ground attack missions.

Even though it is deficient relative to existing systems, the DAS-EOTS system of the F-35 might end up not working at all. From page 50 of the 2014 Director of Operational Test and Evaluation report:

"Fusion of information from own-ship sensors, as well as fusion of information off-board sensors is still deficient. The Distributed Aperture System continues to exhibit high false-alarm rate and false target tracks, and poor stability performance, even in later versions of the software."

5.9 Manoeuvrability

How an aircraft will perform in combat can be predicted by its design characteristics. Aircraft design is a trade-off between attributes. For example, increasing the fuel volume increases an aircraft's range at the expense of increased drag and thus higher fuel consumption at a given speed as well as reducing its power to weight ratio. The F-35 made many trade-offs in order to be able to get the STOVL version to fly. These all decreased its utility as a fighter aircraft, as well as making it so packed tight that construction and maintenance are difficult.

Apart from the impact of manoeuvrability on combat using guns, it also affects how agile the aircraft is in dodging air-to-air missiles. While the F-35 has an instantaneous turn rate no worse than that of the F-16, it loses energy in sustained turning faster than other aircraft.

That is shown in Figure 13 following:

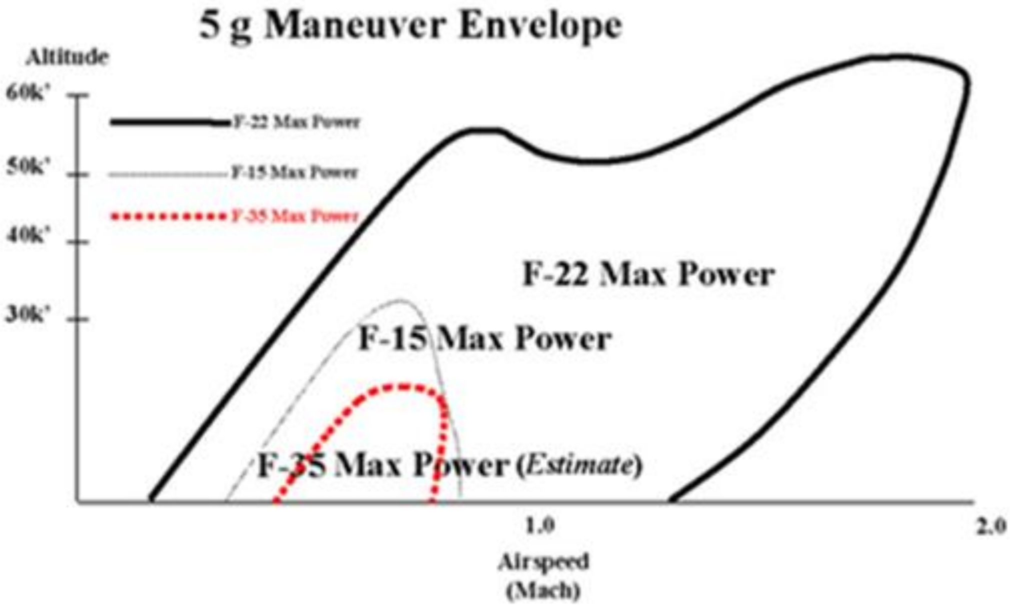

Figure 13: 5g manoeuvre envelope of the F-22, F-15 and F-35

Figure 13, sourced from Air Power Australia, shows that the F-35 has a restricted envelope of manoeuvrability relative to the F-15 and F-22.

As previously stated, how an aircraft will perform in combat can be predicted from its design. Well over a decade ago it was realised that the F-35 would not survive in combat due to its high wing loading, low turn rate, low acceleration, poor rear vision and so on. To date, there has been only one report of an F-35 being tested in mock combat against another aircraft, despite the F-35 now having flown for ten years[11]. This was an F-35 against an F-16 carrying wing tanks in early 2015. The F-16 - a 40-year-old design - bested the F-35, as predicted.

The F-35 tester found just one way to win a short-range air-to-air engagement against the F-16. This was by performing a very specific manoeuvre. “Once established at high AoA (angle of attack), a prolonged full rudder input generated a fast enough yaw rate to create excessive heading crossing angles with opportunities to point for missile shots.” The problem with this sliding manoeuvre is that it bleeds energy rapidly. “The technique required a commitment to lose energy and was a temporary opportunity prior to needing to regain energy … and ultimately end up defensive again.” In other words, once this one manoeuver is tried, the F-35 has lost the energy to run away and can’t stop the other aircraft from getting behind it and gunning it down. And the chance of killing an aircraft in a ‘snap-shot’ is very, very low as a gunsight does not track well in this situation.

And to add insult to injury, the F-35 pilot discovered he couldn’t even comfortably move his head inside the cramped cockpit. “The helmet was too large for the space inside the canopy to adequately see behind the aircraft.” That allowed the F-16 to sneak up on him.

In the end, the F-35 is demonstrably inferior in a dogfight with the F-16, which first flew in the late 1970s, and is completely outclassed by modern 'purpose-designed' fighters such as the Su-35S and the T-50.

The test pilot explained that he has also flown 1980s-vintage F-15E fighter-bombers and found the F-35 to be "substantially inferior" to the older plane when it comes to managing energy in a close battle.

It is telling that, in the 10 years that the F-35 has been flying, this is the only report of a realistic dogfight with another fighter type. By now the F-35 should have been flown against F-18 Super Hornets, the F-15, the F-22 and Su-27, and at least monthly. The fact that the F-35 hasn't been flown against other fighter types indicates that the result would not be subject to doubt – the F-35 would be found to be grossly deficient.

5.10 Maintenance

A number of US Government agencies provide in-depth analysis of the progress of the F-35. From the Director of Operational Test and Evaluation's 2014 report on the F-35, the figure for Mean Flight Hours Between Critical Failure (MFHBCF) is 4.5 hours for the F-35A variant that Australia is procuring. The target number of hours for this measure is 20 hours for initial operating capability (IOC). The Mean Corrective Maintenance Time for Critical Failure (MCMTCF) for the F-35A is 15.6 hours, against an IOC target of 4.0 hours. This measure went backwards from the previous year when it was 12.1 hours, which in turn was worse than the figure for the year before that of 9.3 hours. The 15.6 hour figure for the F-35A is shown in this table:

F-35 MAINTAINABILITY: MCMTCF (HOURS)				
Variant	ORD Threshold	Values as of August 31, 2014 (3 Mos. Rolling Window)	Observed Value as Percent of Threshold	Values as of August 2013 (3 Mos. Rolling Window)
F-35A	4.0	15.6	390%	12.1
F-35B	4.5	15.2	338%	15.5
F-35C	4.0	11.2	280%	9.6

What this means is that if you fly the F-35A for 4.5 hours and get a critical failure, it then takes 15.6 hours to fix it. That is elapsed time, not man-hours. The Eglin Air Force Base has 17 maintenance staff per F-35.

The F-35 has been flying for 10 years now but availability remains low as per this table from page 59 of the 2014 Director of Operational Test and Evaluation report:

F-35 AVAILABILITY FOR 12-MONTH PERIOD ENDING OCTOBER 2014[1]				
Operational Site	Average	Maximum	Minimum	Aircraft Assigned
Total Fleet	39%	51%	35%	90[2]
Eglin F-35A	39%	55%	32%	28
Eglin F-35B	41%	54%	25%	11
Eglin F-35C	50%	64%	24%	10
Yuma F-35B	33%	49%	24%	15
Edwards F-35A	43%	57%	19%	7
Nellis F-35A	28%	51%	2%	4
Luke F-35A[3]	50%	58%	23%	10
Beaufort F-35B[4]	37%	49%	4%	4

1. Data do not include SDD aircraft.
2. Total includes 1 OT F-35B at Edwards that is not broken out in table
3. Luke F-35A data began in April 2014
4. Beaufort F-35 B data began in July 2014

The F-35's availability is 39 percent. As this is after ten years of experience in operating the aircraft, not much improvement could be rationally expected from here. Similarly, the planning of military operations in wartime relies upon equipment being available. The following table from page 60 of that report shows that only 55 per cent of planned flight hours had been achieved as at the time of that report.

F-35 FLEET PLANNED VS. ACHIEVED FLIGHT HOURS AS OF OCTOBER 30, 2014						
Variant	Original Bed-Down Plan Cumulative Flight Hours			"Modelled Achievable" Cumulative Flight Hours		
	Estimated Planned	Achieved	Percent Planned	Estimated Planned	Achieved	Percent Planned
F-35A	11,500	6,347	55%	9,000	6,347	71%
F-35B	8,500	6,085	72%	7,500	6,085	81%
F-35C	1,800	910	51%	1,600	910	57%
Total	21,800	13,342	61%	18,600	13,342	72%

Once again, given the 10 years that the F-35A has been operating, little improvement in its ability to operate when planned could be rationally expected.

The F-35 has to achieve a contract specification for reliability to be approved for initial operational capability. The F-35 Program Office has been improving its statistics by reclassifying failures. From page 62 of the Director of Operational Test and Evaluation's 2014 report:

"In June 2013, the program re-categorized nut plate failures, one of the most common failures in the aircraft, as induced failures rather than inherent failures, removing them from the calculation of MFHBF_DC (Mean Flight Hours Between Failures, Design Controlled). Nut plates are bonded to an aircraft structure and receive bolt-type fasteners to hold removable surface panels in place. One way nut plates can fail, for example, is when torqueing a bolt down while replacing a removed panel, the nut plate dis-bonds from the aircraft structure, preventing securing the surface panel.

Distinguishing between inherent design failures and induced failures can be subjective in certain cases. For example, if a maintainer working on the aircraft bumps a good component with a tool and breaks it while working on a different part nearby, it is a judgement call whether that is an inherent design failure because the component could not withstand 'normal' wear and tear in operational service, or if it's an induced failure because the maintainer was 'too rough'.

And: "This sudden and abrupt reversal of the relationship between induced and inherent failures across the entire F-35A fleet suggests that scoring failures differently (induced vice inherent) may result in an increase in the design-controllable metric that is not manifested in other reliability metrics."

5.11 Software

In his testimony to the House Armed Services Committee on 21st October, 2015, the head of the F-35 Program Office, General Bogdan, stated that, "The United States Marine Corps' announcement this summer that it had achieved an Initial Operating Capability (IOC) with the F-35B was an excellent first step in operationalizing the F-35." It should be realised that the software those aircraft are flying with is compatible with just three different weapons: a 500-pound laser-guided bomb, a 2,000-pound GPS-guided bomb and the AIM-120 medium-range, radar-guided air-to-air missile. No short-range infrared dogfighting missile. No small GPS bomb. No cruise missile. No gun. Those things might be physically fitted to the aircraft but the software has yet to be written to enable them to be used. For example, even though the F-35 has been flying for 10 years, its gun was tested only recently. From General Bogdan's recent testimony: "Airborne gun functionality testing is now underway earlier than planned with F-35A air-to-ground accuracy testing which was initially scheduled for August 2016."

Another limitation is the number of missiles that the F-35 can carry. Again from General Bogdan's testimony, "It is true that in Block 2B/3i the aircraft will be capable of only two AMRAAMs carried internally--but again this is a limited capability that will be improved with the full Block 3F capability in late 2017." This will not be more than four while a Su-35S with two ECM pods has 10 weapons stations, plus the internal 30 MM GSH-301 cannon. With low kill probabilities because of counter-measures, having more shots gives a lethal advantage.

5.12 Pilot Training

Cost of operating the F-35 will be of the order of US$50,000 (A$68,000) per hour of flight. At the rate, the RAAF will not able to afford to give its F-35 pilots enough flying hours to be proficient in using the aircraft in combat. This requires at least 20 hours a month flying, as opposed to use of simulators. So in part the utility of the platform is negated by the cost of using it.

Views on the number of required live flight hours vary widely. The NATO minimum is 180 hours (15 per month). RAF flying hours for jet pilots is between 180 and 240 per year (18.5 per month on average)[12]. Of these hours, 150 hours (12–14 hours per month; 12.5 on average) are felt to be a safety-of-flight minimum (instruments, take-offs, landings). The RAF also feels the additional increment for military elements of flying (e.g., warfare tactics) should be about three hours per month or 36 per year for a total of 186 annual hours (15.5 hours monthly). The 180–240 hours include all flying (e.g., transit and overhead flights) not just military elements or high-quality flying, which is estimated at 75–80 per cent of the total.

RAF jet pilots are generally funded at 180 hours annually (15 per month). A desired number of monthly flight hours would be about 22.5.

Normally, French fast jet pilots get 180 flying hours a year but budget demands are reducing that to 150 hours[13]. Proficiency would be kept up by having pilots fly fast turboprop aircraft as well.

China has been able to increase the flight time for its pilots to 200 hours per annum, which is 16.7 hours per month.

5.13 Helmet Failure

The F-35's helmet-mounted display system (HMDS) projects onto the pilot's visor threat information, flight instrument readout, and almost 360-degree video and infrared images of the world around the pilot. Supposedly this provides the pilot with "unprecedented situational awareness and tactical capability", if he can turn his head. The almost 360-degree video and infrared imagery comes from the six cameras and complex processing software of the Distributed Aperture System manufactured by Northrop Grumman. DOT&E[14] has found, however, that even after a major redesign and software upgrade the Distributed Aperture System "continues to exhibit high false-alarm rates and false target tracks, and poor stability performance." Testing of the redesigned helmet system "discovered deficiencies, particularly in the stability of the new display management computer for the helmet, and suspended further testing until software that fixes the deficiencies in the helmet system can be provided to the major contractor and included in an updated load of mission systems software." Also, jitter and latency along with problems with turbulence and buffeting, that can cause display issues (particularly dangerous when the JSF is manoeuvring to evade an enemy missile shot), decreased night-vision acuity, and information sharing when 3 or 4 aircraft fly together.

All of these problems mean that the pilot cannot rely on the helmet display to provide adequate situational awareness in combat. This is particularly a concern for rear hemisphere threats, since the unusually wide fuselage and solid bulkhead directly behind the pilot's head means he cannot see below or behind him if his helmet fails. F-35 pilots found it "nearly impossible to check their six o'clock position under g" and complained that "Aft visibility will get the pilot gunned down every time," in close-range combat.

5.14 Block Buy Contract

The F-35 Program Office is exploring the possibility of entering into a Block Buy Contract with Lockheed Martin Aero and Pratt & Whitney to procure 465 F-35 aircraft over Lots 12-14. This is an attempt to lock-in support for the F-35 and preclude a decision to abandon it over the next few years. Australia should not be a part of this process. General Bogdan has previously said of the F-35:

"So when we have those 493 airplanes out in the field in 2019, guess how many will be in what I consider to be the right configuration? Not a one," Bogdan said. "Every airplane coming off the line now and coming off in the next two and a half years, plus all the airplanes we've built already, will need some form of modification to get them up to the full capability that we promised the war fighter."

It would be idiotic to be part of a process that acquires aircraft that will require substantial modification after purchase.

5.15 Stealth

The F-35 is reported to have a radar cross section (RCS) of 0.001 square meters from a narrow frontal aspect. This is the size that the F-35 appears to be on certain radars, despite its physical size, and is roughly equivalent to the size of a small ball bearing or insect. At 0.001 square metres, the Su-35 will detect the F-35 at 25 nautical miles – with an altitude advantage and the ability to turn away. As the IRBIS-E radar of the Su-35 looks 240 degrees around the nose, this can allow the Su-35 to shoot a BVR missile, when the F-35 cannot.

However, the F-35's low-observable radar signature has "some gaps in coverage," particularly when viewed from the sides, rear, bottom, or top for which a ten-times larger RCS of 0.01 square meters or larger has been reported. In other words, detection of the F-35 will be most difficult in head-on engagements and less difficult from other angles. By comparison, the F-22 is reported to have a smaller RCS of 0.0001 square metres.

But the returns on the kind of stealth technology employed by the F-35 are being diminished by advances in radar technology. The low-observable technology on the F-35, and to a lesser extent the F-22, is designed to be effective against radar operating in the X-band range and at shorter wavelengths. The rationale behind this decision was that X-band radars detect aircraft with a high degree of accuracy and, as a result, are used to provide fire-control information to anti-aircraft missiles to engage targets. However, the same properties that make the F-35 stealthy against X-band radars do not apply as effectively to lower-frequency radars that operate on longer wavelengths. Lower-band radars are widely employed as surveillance radars to provide early detection of incoming targets at ranges that typically exceed those of X-band systems. Since lower-band radars detect targets with less accuracy, they were traditionally considered unsuitable for providing fire-control information to engage targets. The effectiveness of such radar systems to target aircraft was demonstrated in 1999 when an American F-117A Nighthawk stealth attack aircraft (RCS of 0.003 square meters) was shot down by Yugoslav forces using a modified VHF radar model that was introduced in 1970. The same SAM battery mission-killed another F-117 as well. This is why the Su-35S and the T-50 have L-Band radar in the wing leading edges.

To a large extent, the value of stealth is predicated on enemy aircraft using radar while the stealthy aircraft doesn't emit radar waves. The position of the enemy aircraft can be triangulated from their emissions. The increased ability of IRST systems over the last 20 years though means that aircraft are more reliant upon that technology, which is purely passive, in detecting opposing aircraft. So the value of stealth is negated by enemy aircraft not using radar.

The F-35 will be particularly vulnerable to IRST detection given its enormous engine that puts out 40,000 lbs. of thrust with no infrared shielding or suppression.

The F-35's primary missiles are AIM-120 for beyond visual range engagement and AIM-9X for within visual range engagement. AIM-120D is a RF BVR missile with 180 km maximum aerodynamic range. It has 40 g manoeuvring capability at Mach 4. AIM-9X is an IR missile with 26-42 km maximum aerodynamic range and 50 g manoeuvring capability at Mach 2.7.

With standard loadout, the F-35 has advantage in nominal missile range. However, its primary BVR missile – AIM-120 – is an active radar missile. Consequently, even if the F-35 does use its situational awareness for passive attack, the missile will give itself away with its own radar, quite possibly long before the enemy MAWS (missile approach warning system) notices it. Once it does so, its limited manoeuvrability and usage of easily jammed or decoyed RF (radio frequency) seeker head means that any enemy fighters will easily avoid it.

5.16 Autonomic Logistics Information System

The F-35 has been built with a computer-based logistics system called the Autonomic Logistics Information System (ALIS) which analyses the aircraft for faults. The aim of ALIS is to make detection of faults more efficient and speed up maintenance.

All F-35 software laboratories are located within the United States. This has introduced vulnerabilities in the operation and sustainment of the global F-35 fleet that are only beginning to emerge. The biggest risk is that, since the F-35 cannot operate effectively without permanent data exchanges with its software labs and logistic support computers in the United States, any disruption in the two-way flow of information would compromise its effectiveness.

All F-35 aircraft operating across the world will have to update their mission data files and their ALIS profiles before and after every sortie, to ensure that on-board systems are programmed with the latest available operational data and that ALIS is kept permanently informed of each aircraft's technical status and maintenance requirements. ALIS can, and has, prevented aircraft taking off because of an incomplete data file.

Currently, downloading the data file from a 1.5 hour flight of the F-35 takes 1.5 hours. It is hoped to get that down to 15 minutes. By comparison, the Gripen E can be re-armed and refuelled after an air-to-air mission in 10 minutes.

The volume of data that must travel to and from the United States is gigantic, and any disruption in Internet traffic could cripple air forces as the F-35 cannot operate unless it is logged into, and cleared by, ALIS.

Updating and uploading mission data loads depends on a functioning Internet. That such a major weapon system would rely upon a separate and delicate system is the height of stupidity. This is the modern equivalent of the loss of the Battle of Isandlwana, caused in part by a lack of screwdrivers to open ammunition cases.

6. Potential Alternatives to the F-35

6.1 The Evolution of Fighter Aircraft

The first jet fighter aircraft, the Messerschmitt ME-262, first flew in 1941 and became operational in 1944. The first Allied jet, the Gloster E.28/39, had its first flight five weeks later on 15th May, 1941. The major designs of the 1950s were the US F-86 Sabre and the Soviet Mig-15. These were single-engine aircraft weighing 6.9 tonnes and 6.1 tonnes respectively. By the 1960s, size increased to 8.8 tonnes for the Mig-21 with a US equivalent, the F-104 Starfighter, weighing 9.4 tonnes. Then the US built the F-15, a twin-engined aircraft optimised around its large radar and designed primarily for high level interception of Soviet bombers. The F-15, still in production after nearly fifty years, has a loaded weight of 20.2 tonnes. In those days, ability to detect enemy aircraft depended upon the size of the radar which was mounted in the fighter's nose. The further away they could be detected, the greater the advantage to the fighter aircraft which could then launch beyond-visual-range, radar-guided missiles. So as the size of the radar grew, the size of the aircraft had to grow with it. The F-15 also had a gun because one of the major lessons of the Vietnam War was that most missiles missed. No F-15 has been lost in combat and it has 104 kills to its air combat record.

The Soviet response to the F-15 was the Sukhoi Su-27 with a maximum take-off weight of 30.4 tonnes. The trend continued up to the F-22 Raptor which has a maximum take-off weight of 38.0 tonnes. That is more than five times the weight of the Sabre and more than the empty weight of the B-29 bomber of World War II of 33.8 tonnes. Apart from housing a large radar, the design philosophy of the F-22 is to have a small radar cross section to avoid detection by enemy radars, either on the ground or in other aircraft and to be able to 'supercruise' at Mach 1.7+ and operate above 60,000 feet.

At the same time the F-15 was being designed, a group in the US Air Force nicknamed the Fighter Mafia realised that air superiority would be more cost effectively achieved by a small, single-engine fighter that was highly manoeuvrable with a high thrust-to-weight ratio. This concept bore fruit as the F-16, also still in production after nearly fifty years. It has a loaded weight of 12.0 tonnes and a maximum take-off weight of 19.2 tonnes, half that of the F-22.

Russian and Chinese design efforts have followed the lead set by the F-22. The first Russian stealth fighter is the T-50, weighing an estimated 35 tonnes at maximum take-off weight. The first Chinese stealth fighter, the J-20, is slightly heavier at an estimated 36.3 tonne maximum take-off weight.

Production of the F-22 stopped at 187. Two have crashed so there are only 185 still flying. The F-22 cost US$150 million each to build. That is one thing, but they are also quite expensive to fly at US$58,000 per hour of flight. They are also maintenance-intensive with 42 hours of maintenance for each hour of flight, half of which is spent on maintaining the radar-absorbent coatings. In turn that means that they have a low availability and a low sortie rate. F-22 fighters are so expensive to operate that the pilots don't get enough monthly hours to be properly proficient in operating them. As pilot skill is a large part of air superiority, this negates in part the F-22's advantages.

Fortunately for Australia, technological developments have swung the air superiority pendulum back towards the lightweight, highly manoeuvrable single-engine fighter.

6.2 Fighter design considerations

The primary mission of fighters is air superiority; that is, ensuring use by friendly aircraft of the airspace over critical surface areas, and denying use of that airspace to the enemy. Control of the high ground has always been one of the fundamentals of warfare. Airspace control allows strategic and tactical bombing, close air support of troops and armour, airborne or surface reinforcement and supply, reconnaissance, and other missions vital to the success of any military operation.

Fighter aircraft should be hard to detect and highly manoeuvrable in order to surprise and outmanoeuvre the enemy as well as to improve survivability against missile fire. To achieve that requires small size, supercruise ability, good aerodynamic design, low wing loading and high thrust-to-weight ratio. Supercruise is the ability to maintain a speed above Mach 1.0 without the use of the aircraft's afterburner. Wing loading is the loaded weight of the aircraft divided by the area of the wing. The aircraft that uses its radar first will be quickly detected and targeted by passive sensors. Therefore only minor radar cross section-reduction measures are needed.

Low observability (being hard to detect) and sensor fusion (consolidating the aircraft's sensor inputs) are required to achieve the advantage, getting off the first shot and possibly achieving a kill with a low chance of being targeted in return. If that doesn't work, breaking the enemy's OODA loop (the Observation, Orientation, Decision, Action loop concept developed by John Boyd) by being impossible to predict is essential. The ability to supercruise helps in both as it shrinks enemy's response time after the supercruiser is detected, reduces effectiveness of the opponent's weapons while increasing effectiveness of the supercruiser's weapons, allows the supercruiser to achieve surprise while preventing the enemy from surprising him, and to dictate terms of engagement.

Manoeuvrability is important in air combat for two reasons: to get the enemy inside one's own engagement envelope, and to avoid getting hit. While some modern fighters such as the Rafale and the F-35 can use missiles to engage aircraft directly behind them, this is of questionable usefulness as it increases the target's reaction time and causes the missile to lose energy, as well as increasing the likelihood of the missile simply not acquiring the target. It used to be that missiles used in beyond-visual-range, having spent their fuel and flying on inertia alone, would have a low chance of hitting a manoeuvring target. The solution to that problem that the US adopted is the 'two pulse' motor of the AIM-120D. But this makes it too fast to turn the corner at the terminal kill and thus it still has a high chance of missing. The European missile maker MBDA developed its Meteor missile to throttle back from Mach 4 to below Mach 2 for the terminal kill and as a result can turn into a target turning at 9G at 50,000 feet.

Manoeuvrability in a fighter aircraft requires the ability to start turning quickly and then to have a high sustained rate of turn. But the most important requirement is the transient performance – that is roll onset, turn onset and pitch rates as well as acceleration, deceleration and instantaneous turn rate. This needs high lift-to-weight, lift-to-drag, thrust-to-weight and thrust-to-drag ratios while sustaining high g as well as generally low drag at all speeds and high control power with ability to generate large amounts of drag when required. The instantaneous turn rate in particular needs a low wing loading and a high lift coefficient. Maximum turn rate and minimum turn radius is experienced at an aircraft's corner speed; for the same g limit, a lower wing loading results in a lower corner speed and thus a higher turn rate and smaller turn radius.

The best way to achieve these characteristics in a fighter aircraft is a blended wing-body configuration with a delta wing and close-coupled canards positioned in front of and high above the wing. The blended wing-body configuration achieves greater lift and lift-to-drag values than conventional configurations such as the F-15 and increases the available volume inside the aircraft. It also reduces the radar cross section and wave drag from the formation of shock waves in supersonic and transonic flight. The total lift of the close-coupled canard configuration is far higher than the additive lift of the wings and the canards. This is a result of their beneficial interference when in close proximity, with the canard acting like a 'forward flap". This enhancement can be effective to such extent that maximum lift is 34 per cent greater for a close-coupled canard configuration than for an otherwise identical configuration with no canard, with the canards contributing only 15 per cent of the area. Canards also increase the angle the aircraft can fly at without stalling.

This is why there are now three European delta wing/canard combinations – the Dassault Rafale, the Eurofighter Typhoon and the Saab Gripen. When the Israelis set out to build their own fighter aircraft, that effort produced a delta wing/canard fighter called the Lavi. Similarly, when China produced its first modern jet fighter it was a delta wing/canard combination called the J-10.

A canard mounted above the wing has a noticeably better lift-to-drag ratio than a coplanar canard, as the vortex and wake-flow from the canard do not hit the wing. Maximum lift is achieved when the canard's trailing edge is slightly in front of the wing leading edge. Moving the canard forward or down reduces the lift gain. A properly positioned canard creates a low pressure region on the front part of the wing upper surface which has a significant contribution to lift.

Launcher rails on the wing tips allow two missiles to be carried with virtually no drag penalty while improving the lift-to-drag ratio. The body of a fighter aircraft is shaped to comply with the area rule which is based on the fact that at high-subsonic flight speeds, the local speed of the airflow can reach the speed of sound where the flow accelerates around the aircraft body and wings. The speed at which this development occurs varies from aircraft to aircraft and is known as the critical Mach number. The resulting shock waves formed at these points of sonic flow can greatly reduce power which is experienced by the aircraft as a sudden and very powerful drag, called wave drag.

To reduce wave drag the cross sectional area of the aircraft should remain as constant as possible down its length and changes in cross sectional area should be as smooth as possible. Thus the fuselage should be narrowed where the wings are attached to account for the cross sectional area of the wings so that the total area does not change much. Nevertheless a fighter aircraft should not spend much time in the transonic region as it should be either cruising or manoeuvring at supersonic speeds or manoeuvring at subsonic speeds.

Fighters are built with one engine or two. Jet engines have become far more reliable in the last 20 years and now more fighter pilots are lost due to bird strike than engine failure. The survivability advantage of having two engines is now slight. On the other hand, single-engine fighters are more manoeuvrable, especially in roll and changing direction, and so are better able to avoid getting hit in the first place. Single-engine fighters have smaller visual and infrared signatures.

A single engine helps reduce cost in several ways. This can also lead to reduced size, weight and thus procurement cost as well. Maintenance downtime required is also lower. All of this leads to single-engined fighters having significantly lower direct operating cost than twin-engined fighters. If two alternative designs, single and twin engine, are derived for the same requirements, the singe engine design will have 20 percent lower development and production costs and a 20 percent lower operating cost. Given that operating costs over the life of the aircraft are twice the acquisition cost, the operating cost saving of the single engine design equates to 40 percent of the acquisition cost.

Thus the operating cost of the F-16C is US$7,000 per hour versus US$16,500 per hour for the twin-engined Rafale C. The Rafale C has an 11 per cent greater empty weight and 28 per cent more dry thrust than the F-16C yet costs 2.4 times as much to operate. The F-15C costs US$30,000 per hour to operate, yet has a 48 per cent higher empty weight and 52 per cent more dry thrust compared to the F-16C. More complex aircraft also require more maintenance personnel: the Gripen needs 10 assigned flightline maintenance personnel, compared to 17 for the F-15, rising to 23 for the F-35 (547 personnel for a squadron of 24 aircraft)[1].

Situational awareness is one of the most important characteristics of an air superiority fighter. This starts with visibility from the cockpit and is improved with a variety of sensors. Cockpit visibility is divided into two basic sectors: forward visibility, required for early target detection, and an aft visibility, which is crucial for avoiding an attack from behind. The pilot also has to be able to visually check for threats in the rear quadrant, and also to see whether or not the aircraft is producing any contrails.

At beyond visual range, on-board sensors are crucial in detecting and identifying other aircraft. Radar cannot reliably identify the detected aircraft and it warns them of the scanning aircraft's presence far before it actually can detect them, thus allowing them to take measures appropriate for the situation.

Unique radar characteristics enable enemy aircraft to identify the fighter, and the radar itself is vulnerable to electronic countermeasures. Modern anti-radiation missiles also enable fighters to passively target the emitting aircraft. Identification-friend-or-foe will be kept off as it allows the enemy to track the fighter. Thus the most important sensor for an air superiority fighter is the infrared-search-and-track sensor as it can detect and identify faraway targets completely passively – up to 70 kilometres in good conditions but not in cloud. Radar warning receivers are also important but they depend upon enemy aircraft using their own radars which is not likely to happen in a war.

With respect to weapons, the main missile type used should be infrared-guided. Radar-guided missiles are easy to counter and thus ineffective. They need 15 seconds to lock on, allowing ample time for the radar warning receiver to detect and analyse the attacker's radar emissions. Secondary beyond-visual-range missiles should have a combined radar-homing and infrared seeker in order to provide diversity in seeker types.

In the Vietnam War, probability of kill was 26 per cent for the aircraft's gun, 15 per cent for the Sidewinder missile (within-visual-range with an infrared seeker), 11 per cent for the Falcon missile (beyond-visual-range with an infrared seeker) and 8 per cent for the Sparrow missile (beyond-visual-range with a radar receiver). During that war, 51 kills were made with guns, 83 with heat-seeking missiles and 56 with radar-guided missiles. In the Yom Kippur and Bekaa Valley wars, Israel made 93 kills with guns, 225 with infrared missiles and 17 with radar-guided missiles (two at beyond-visual-range). It can be seen that infrared, within-visual-range missiles are a fighter aircraft's primary weapon, and opportunity for engagement depends on identifying the enemy – usually visually.

In the First Gulf War, radar-guided missiles achieved a kill probability of 27.3 per cent, indicating that missile reliability had not improved much since the Vietnam War. There were only five confirmed beyond-visual-range kills in the First Gulf War, despite radar-guided missiles accounting for 24 kills out of 85. F-15s performed far better than other Allied fighter types with a radar-guided kill probability of 34 per cent - 23 kills out of 67 shots, and an infrared missile kill probability of 67 per cent - 8 kills out of 12 shots. By comparison, the US Navy's F-14s and F-18s achieved a radar-guided kill probability of 4.8 per cent - one kill out of 21 shots, and an infrared kill probability of 5.3 per cent - 2 kills out of 38 shots. In the Second Gulf War, F-16s fired 36 Sidewinder missiles for zero kills, though 20 of these launches were accidental due to poor ergonomics of the control stick.

In terms of kill probability, guns have a kill probability of between 26 per cent and 31 per cent, infrared within-visual-range missiles of 15 per cent, infrared beyond-visual-range missiles of 11 per cent and radar-homing, beyond-visual-range missiles of 8 per cent. The kill probability of beyond-visual-range missiles falls by 25 per cent compared to values listed when they are actually used at beyond-visual-range.

Traditionally, heat-seeking missiles required five to seven seconds to lock on, obtain parameters and launch compared to 10 to 15 seconds for radar-guided missiles. The pilot would have to point the nose of the aircraft at the target to obtain a lock. The development of the helmet-mounted cueing system and high-angle, off-boresight missiles has reduced these times. This combination was developed by South Africa for their war against Angola. The seeker in the missile head follows where the pilot is looking by tracking the position of the pilot's helmet in the cockpit. The pilot only has to look at the target and fire the missile, which will lock-on after launch. The Soviet

Union noted the success of the South Africans in shooting down the Soviet-supplied aircraft and copied the technology. When East Germany was reunited with West Germany, the West found out how effective the Soviet technology had become.

A gun kill requires three to six seconds. Seven seconds is the maximum safe time for achieving a kill during a dogfight. A fighter in a dogfight shouldn't keep the same course for more than seven seconds. Otherwise enemy fighters will be figuring out how to attack it.

The Eurofighter Typhoon's infrared-search-and-track sensor can detect subsonic fighters at 90 kilometres from the front and at 145 kilometres from the rear. The jet engines themselves are very hot and they heat up the airframe surrounding it. Apart from the engines and their exhaust, they are a number of other sources of infrared radiation from an aircraft. Movement of the aircraft through the air leads to compression of the air in front of it. This heats the air. For example a super-cruising aircraft at Mach 1.7 generates shock cones with a temperature of 87°C. Friction from the air heats the aircraft's skin. In a jet fighter, the hottest parts apart from the engine nozzles are the tip of the nose, front of the canopy and the leading edges of the wings, tail and engine intakes. Modern infrared-search-and-track systems can detect missile launch from nose cone heating.

Unlike radar, infrared-search-and-track is primarily a passive system. This allows a fighter aircraft, or a fighter group, to detect and track the enemy without the latter being aware of their presence, thus gaining a significant initial advantage. Even when the enemy is aware of the fighter's presence, he has no way of knowing whether or not he has been detected, or is being targeted, until a significant shift in the fighters' posture, such as painting a target with a rangefinder or shifting flight path or formation. For comparison, just turning on the radar warns the aircraft in a very large area of scanning fighter's presence – and the said area is far larger than one covered by the radar. Not only does it give away fighter's presence, but if the enemy has good-enough listening equipment, it is possible to triangulate location and even identify the target through its unique radar signals. Even radio communications and datalinks can serve the same purpose.

If the enemy is using radar, it is possible to use data from a radar warner to generate a bearing, after which infrared-search-and-track can be used in a "stare" mode – continuous track, during which photon impacts are combined over a prolonged timeframe to detect a target at greater distances than would normally be possible. This mode is also present in radar systems, and like infrared-search-and-track, radar also has to be cued by other sensors to make use of it. But while using radar in such a manner basically guarantees that the enemy with a competent radar-warning-receiver will detect radar transmissions, infrared-search-and-track is undetectable. Even a short radar burst can allow the passive fighter to generate a bearing.

If radars are jammed, or more likely turned off for fear of detection, the first indication of an infrared-search-and-track equipped fighter's presence that the enemy aircraft will get may be the alarm from its missile warning system, thus allowing only a short time for defensive reaction. If both sides have infrared-search-and-track, it comes down to sensor quality and infrared signature differences.

Aircraft equipped with infrared-search-and-track, and using an infrared missile approach warning system, can remain completely silent during the mission. If the enemy has no infrared-search-and-track, then he will have to turn on his own radar, allowing the passive aircraft excellent situational awareness, well beyond what using radar in addition to infrared-search-and-track would allow. Radar is not the primary on-board sensor anymore and is not actually even required.

The latest variant of the Gripen, the E model, uses an infrared-search-and-track system called Skyward G. This sensor weighs 30 kg. It is a dual-band system covering the midwave and longwave infrared bands, and can provide an infrared image on the pilot's visor. Scan coverage is 160° in the horizontal plane and 60° in elevation.

Skyward G is stated to be capable of detecting all aircraft flying faster than 300-400 knots from skin friction alone – irrespective of any exhaust plume or engine infrared signature. It can track more than 200 targets simultaneously.

The F-22 does not have an infrared-search-and-track system, which means that it has to use radar to engage the enemy at beyond-visual-range. It was dropped as a cost-saving measure on a US$150 million aircraft. This, combined with its large size and high infrared signature, severely limits its ability to achieve surprise bounces. In terms of avoiding surprise it is no better. While limited rearward visibility is somewhat compensated for by the high cruise speed of Mach 1.7, its high infrared signature, despite some infrared signature reduction measures, means that it will be easily noticed.

If the enemy uses very-high-frequency and high-frequency radars, the value of stealth is heavily reduced if not eliminated altogether – as shown by the F-117 shot down over Serbia only 18 seconds after being discovered by the very-high-frequency radar, and another F-117 that was mission-killed by the same surface-to-air missile battery. The latter F-117 returned to base but was damaged beyond repair.

The Russian T-50 appears to be optimized to shoot down US fighter aircraft, primarily the F-22 and F-15. China's J-20 is more optimized for shooting down US airborne-warning-and-control aircraft, transport and tanker aircraft, thus neutralizing relatively short-range US fighters without having to engage them in combat at all. The F-22 is a compromise between two roles. The J-20 is meant to avoid aerial combat though it should be able to handle itself if it comes to that.

If up against a good pilot in a superior fighter, one can win if the opponent is forced to make a mistake. For this, one must be a better pilot than the opponent – and good pilots are made largely by in-flight combat training as opposed to simulator training. This means that ease of maintenance, reliability and low operating costs are important characteristics of a fighter aircraft if pilots are to get enough flight time to be proficient. Today's US Air Force F-22, F-35 and F-16 pilots get 8-10 hours of flight training per month, and US Navy pilots get 11 hours per month. French Rafale pilots get 15 hours per month, while RAF Typhoon pilots get slightly more at around 17.5 hours per month. This can be compared to a minimum of 20-30 hours per month required for fighter pilot to be truly proficient.

The number of missiles carried also determines fighter effectiveness. The more missiles carried, the more that can be fired in a salvo. Russian Su-27s fire a two, three or four missile salvo. Kill probability of a two missile beyond-visual-range salvo is 19 per cent, of a three missile salvo 27 per cent and of a four missile salvo 34 per cent. The rate of kill also depends upon the time to solve a firing solution.

Over the last five years, Gripen, Rafale and Typhoon fighters have come to the Red Flag air combat exercises in Alaska to be matched up against US aircraft. With their advanced electronic warfare suites and superior data links, the Gripen and Rafale fighters had no problem in locating the F-22s and remaining undetected by everything but powerful radar scans, which would have led to the destruction of the radar-emitting aircraft by the radar-homing Meteor missile. F-22 pilots reported these smaller fighters were upon them within-visual-range before the F-22's vaunted electronics suite could detect them. The smaller Gripen was within gun-fighting range before being detected. F-22 pilots were forced to go vertical to escape most of the time using their huge Pratt and Whitney engines at full afterburner which is not a good technique against even an average pilot with heat-seeking missiles. The 2015 Red Flag Alaska was highlighted by one German Typhoon recording three kills against F-22s. And that is with the Typhoon not being allowed to use its infrared-search-and-track under the rules of the engagement.

Small size is important for avoiding detection by high frequency sky-wave and surface-wave radars. Sky-wave radars, such as Australia's JORN system, bounce their radar waves off the ionosphere. Surface-wave radars also use high frequencies from 3 MHz up to 30 MHz Electromagnetic waves at this frequency tend to bend or diffract around edges or curves. They are coupled to the conductive ocean surface forming a "ground wave", bending over the horizon and following the curvature of the earth. The Gripen's resonant frequency is about 26 MHz which is rarely used in military radars. Bigger aircraft like the F-35, F-22, B2, J-20 and T-50 have resonant frequencies in the 10-15 MHz range - the sweet spot of high frequency over-the-horizon radar.

6.3 How To Win In Air-To-Air Combat[2]

1. Surprise the opponent without being surprised
   - better situational awareness
   - ability to supercruise

2. Outnumber enemy in the air.
   - lower purchase cost without losing qualitative edge
   - lower operating cost per hour of flight
   - low maintenance requirement for higher sortie rate

3. Out-manoeuvre the enemy to gain firing position.
   - low wing loading for high turn rate
   - ability to decelerate and accelerate

4. Outlast the enemy while out-manoeuvring him.
   - have a high fuel fraction of the fighter's loaded weight

5. Achieve reliable kills.
- carry enough missiles and rounds for the gun

6.4 Graphical Representation of Aircraft Attributes

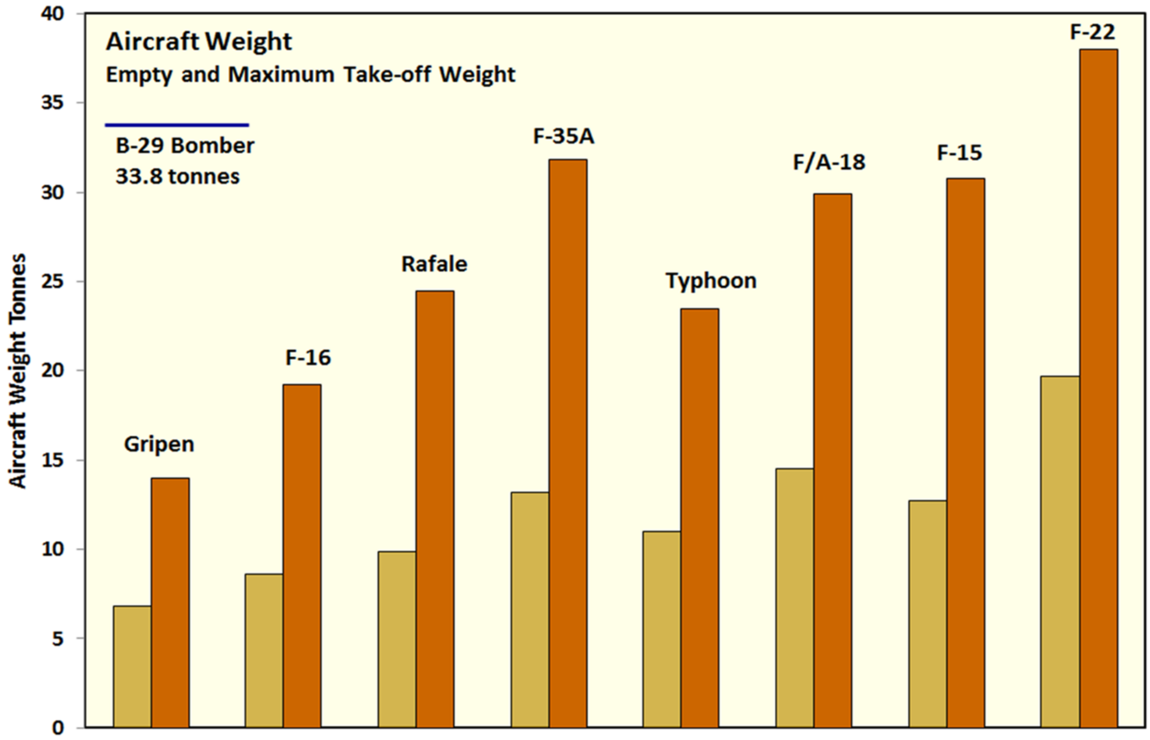

Figure 14: Empty and maximum take-off weight of western fighter aircraft

The physics of flight and of engines means that larger aircraft are more capable and have more range, kg for kg, than smaller aircraft. Thus the Su-35, which weights three times as much as the Gripen, has a combat range of 1,600 km compared to the Gripen's 1,040 km. Smaller size provides significant advantages in combat though through being harder to detect and target. The maximum take-off weight of fighter aircraft is now as much as the empty weight of the B-29 bomber.

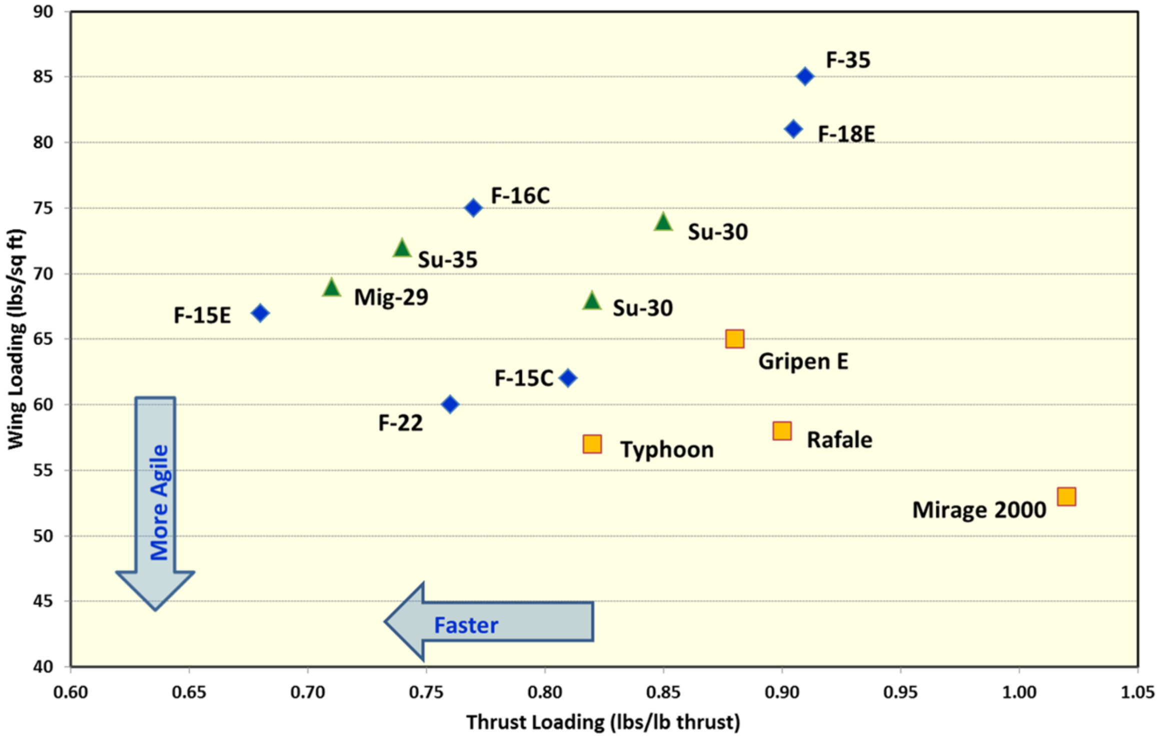

Figure 15: Wing loading relative to thrust loading

A low wing loading, the area of the wings divided by the weight of the aircraft, contributes to an aircraft's ability to turn. Thrust loading, which is the weight of the aircraft in lbs divided by the thrust of the engines in lbs, determines an aircraft's ability to accelerate after having lost airspeed in a turn. The combination of these attributes is a basic indicator of manoeuvrability. Australia's two light bombers, the F-18 Super Hornet and the F-35, are at the wrong end of this graph. They are in the corner that is most easily shot down and produce widows.

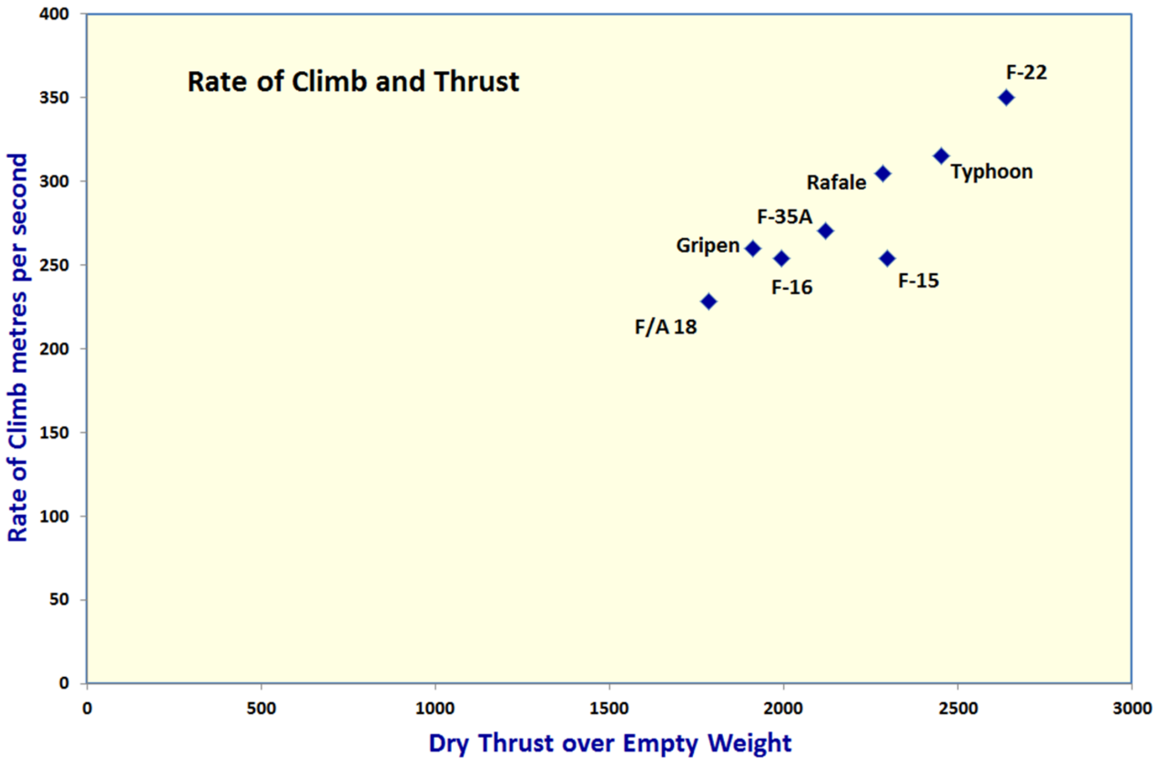

Figure 16: Rate of climb and thrust

Most aircraft plot up on a straight line on this plot except for the F-15 which is optimised as a bomber interceptor.

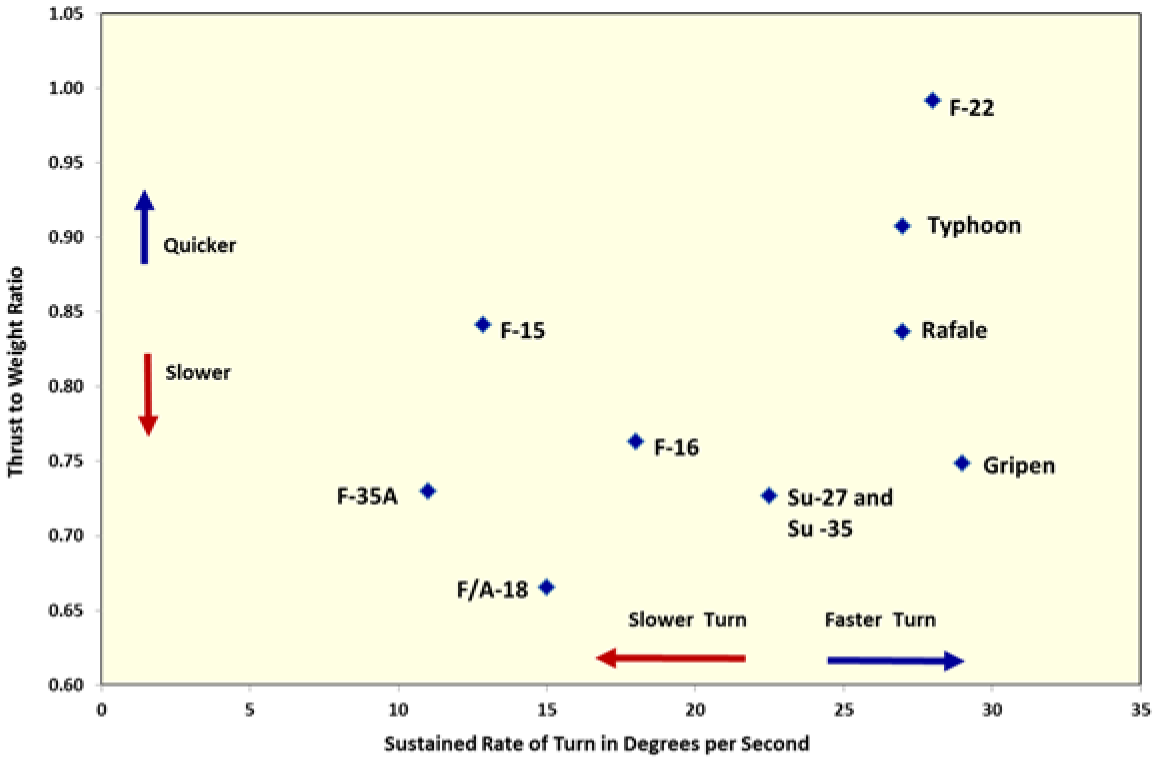

Figure 17: Sustained rate of turn relative to thrust to weight ratio

Once again, Australia's two light bombers – the F-18 Super Hornet and the F-35 - are in the wrong quadrant on this graph. They are the slowest to turn and slowest to accelerate.

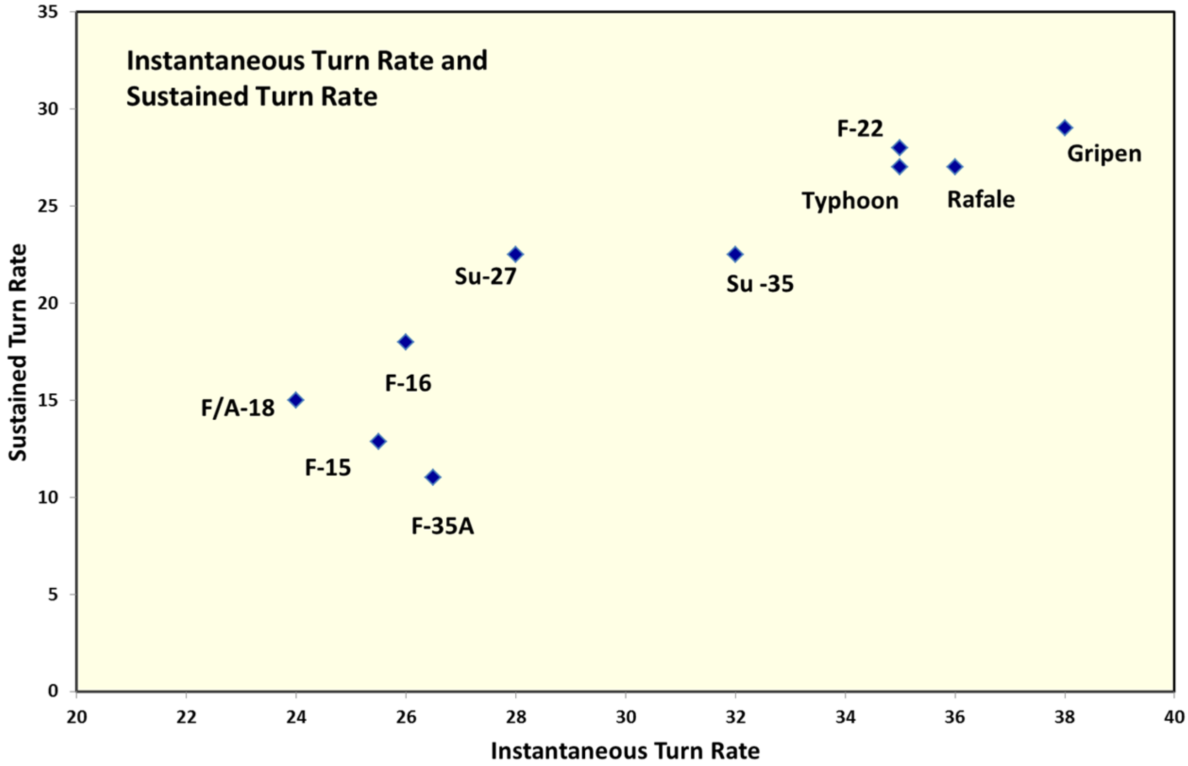

Figure 18: Instantaneous turn rate plotted against sustained turn rate

This graph is the one that best captures the Gripen E's advantages in combat manoeuvrability over other fighter aircraft. The Gripen E has the highest instantaneous turn rate of any fighter which means that it can change direction more readily than any other. This is because its close-coupled canards, large relative to the wing area, act as forward flaps. Most other fighters slow up using a high angle of attack in order to be able to turn more quickly, losing energy in the process. The ability to turn sharply and retain energy while doing so means that the Gripen E is the fighter most able to dodge air-to-air missiles, and thus most likely to survive the missile exchange phase of an engagement. When that is followed by the merge, the Gripen E is the fighter most likely to be able to get into position for a gun kill. The Gripen's much smaller size than the Su-35 means that the Gripen will detect the Su-35 first, either visually or by IRST, and be able to get off the first shot.

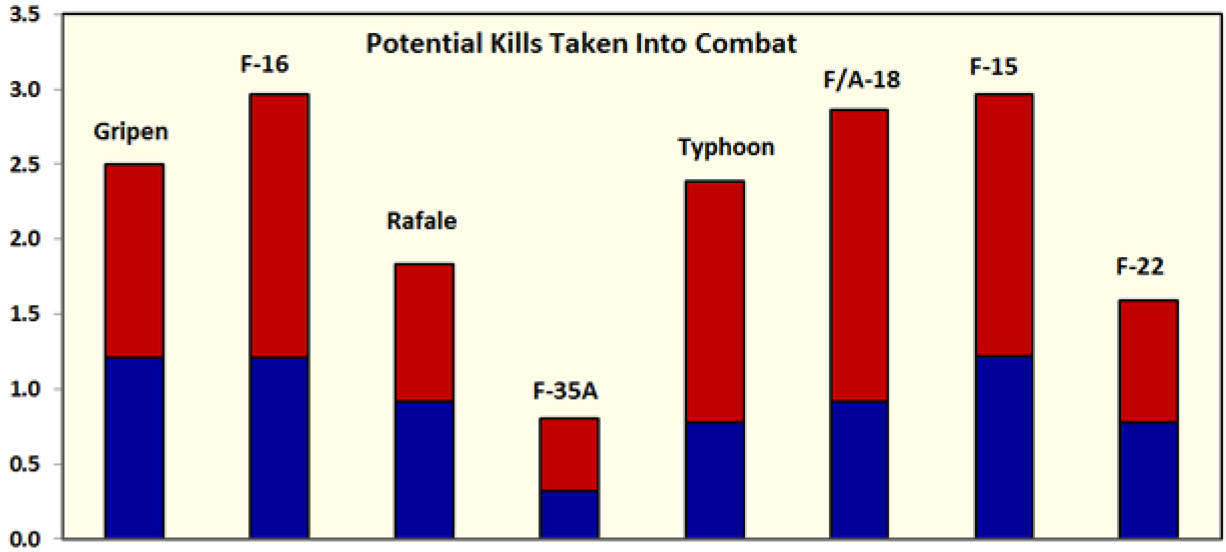

Figure 19: Potential kills taken into combat

As originally designed, the F-35 is a little bomb truck built around the carriage of two 2,000 lb bombs internally to preserve stealth. It also had two BVR missiles. Repurposing it as a fighter aircraft means that it now carries four air-to-air missiles internally. As the probability of kill (Pk) of BVR missiles is only 11 percent, firing all four of the F-35's missiles gives a probability of shooting down an enemy fighter of 32 percent. The F-35A also carries 182 rounds in its 25 mm gun. The F-35 is unlikely to ever be in a gun-firing position on another fighter. But giving it the benefit of the doubt, each firing pass using 56 rounds has a probability of kill of 30 per cent. In total this is a lot less than pure fighter aircraft.

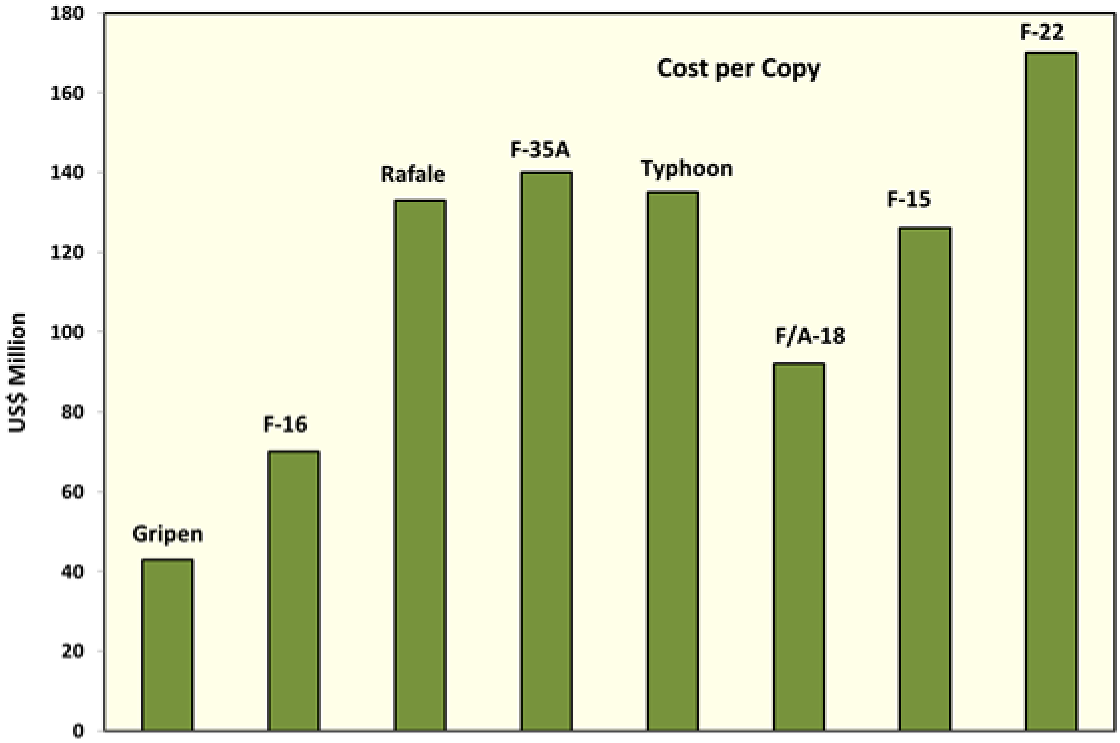

Figure 20: Fighter aircraft unit cost

Typically, for transport or trainer aircraft, the engine cost is one quarter of the total cost of the aircraft. For fighter aircraft these days, the avionics and software cost are on top of that and equate to up to half of the cost of the aircraft. Thus for the Gripen E, the engine cost of US$5 million for the GE F414 equates to about one eighth of the aircraft. The troubled engine of the troubled F-35 costs US$29.9 million. In terms of price per kg, this is approaching four times the price per kg of the GE F414 engine that powers the Gripen E and F-18 Super Hornet.

The Gripen E price quoted is the cost to the Swedish Air Force and the price from the Brazilian deal on manufacturing there. The prices of the other European delta-canard aircraft are high due to intrinsically high European manufacturing costs. Dassault has been willing to offer steep discounts to the list price of the Rafale but that may be at an end now that their order book is filling up on orders from India and the Middle East. The Typhoon is a troubled project and its high cost in part would reflect dysfunction in the project. Russian fighter costs are much lower than Western aircraft but the Russians do their best to gouge on maintenance costs.

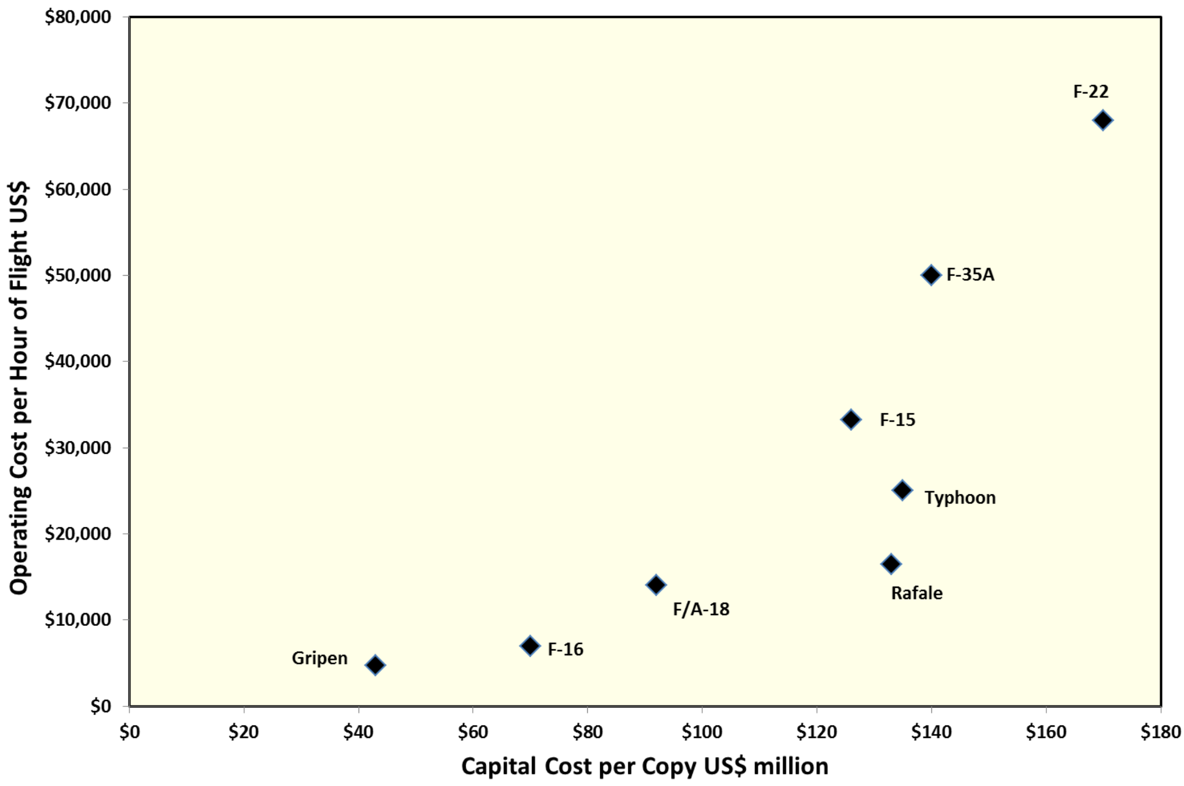

Figure 21: Operating cost plotted against capital cost

The operating costs of some aircraft are well known because a number of air forces publish them annually, for example the F-16, F-8 Super Hornet and the F-15. The Gripen E and the F-16 are very similar in layout and weight. The Gripen's lower operating cost per hour is believable because it was designed for easy maintenance in the field by conscripts. There is a wide range of reported Typhoon operating costs, partly driven by what is included. The Austrian air force has reported an hourly operating cost for the Typhoon of €70,000 which puts it at the level of the F-22. Up to half of the F-22's hourly operating cost is due to maintenance of its radar-absorbing-material (RAM) coating. The F-35's operating costs are high due to its RAM coating and the fact that its internal layout was not optimised for maintenance. Thankfully the Gripen is the cheapest to buy and operate, and the most effective.

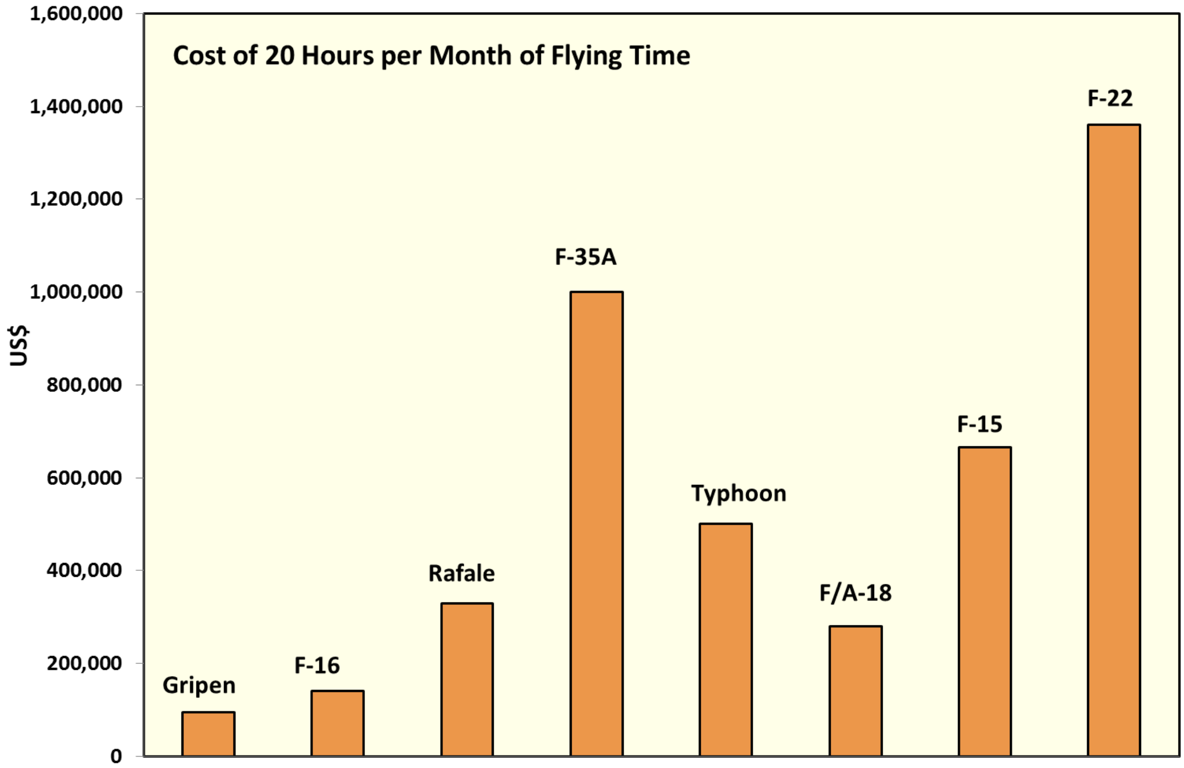

Figure 22: The cost of training pilots by aircraft type

This is the operating cost per hour and does not include depreciation of the initial capital cost. In buying a military system, the initial acquisition cost tends to be one third of the total cost over the life of the system and the remaining two thirds the operating and maintenance cost. Operating cost of aircraft is an important consideration in that the pilot needs a minimum of 20 hours per month of flying in the aircraft to maintain his proficiency in actual combat. Otherwise the purpose of these expensive systems is negated. Because of the type's high operating costs, F-22 pilots are limited to 10 to 12 flying hours per month and are expected to maintain their skills using simulators. Similarly, the F-35's high operating costs mean that its pilots will have limited time in the air. Even on deployment, an F-35 squadron will be accompanied by a 40 foot container with simulators and a 20 foot container to provide power and air conditioning to the 40 foot container. The French Government has baulked at the high cost of operating the Rafale and is adopting a scheme under which Rafale pilots will spend part of their flying hours in a turboprop.

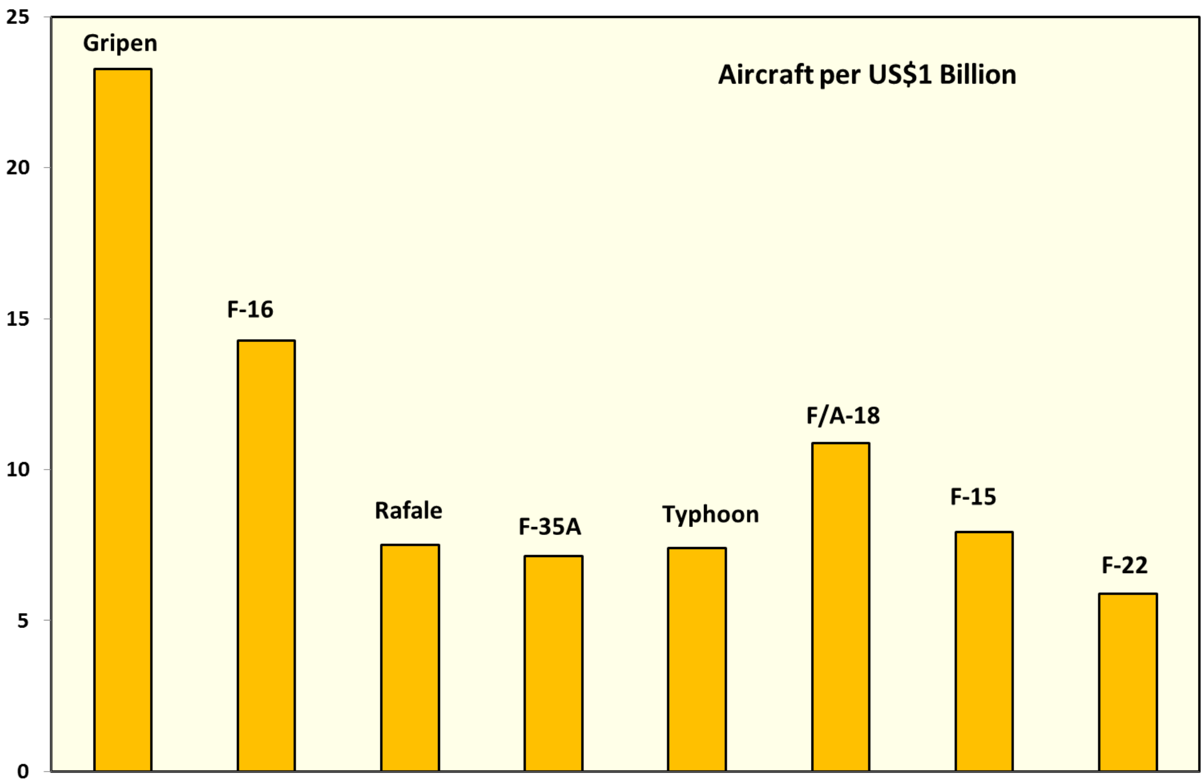

Figure 23: Aircraft per US$1 billion

While this is the inversion of the way the data is presented in Figure 20, it is the way that military effectiveness is approached. That is capability for a given sum of expenditure. Relative to the F-35, more than three times the number of the more effective Gripen E could be obtained.

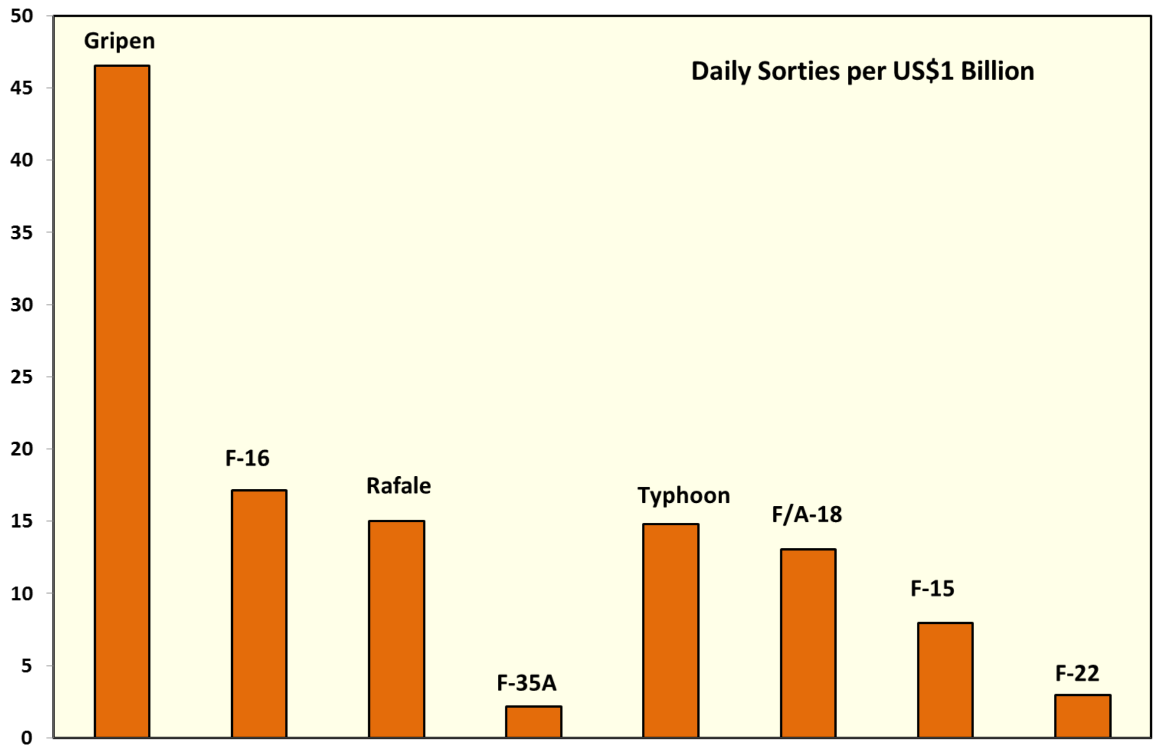

Figure 24: Daily sorties by US$1 billion of capital outlay

An important aspect of military effectiveness is sortie generation, particularly surge generation of sorties at the beginning of a campaign. The Gripen E will be able to mount at least two sorties per day, and most likely more. The F-35 and the F-22 are expected to be able to mount a sortie every second day, and not more than that.

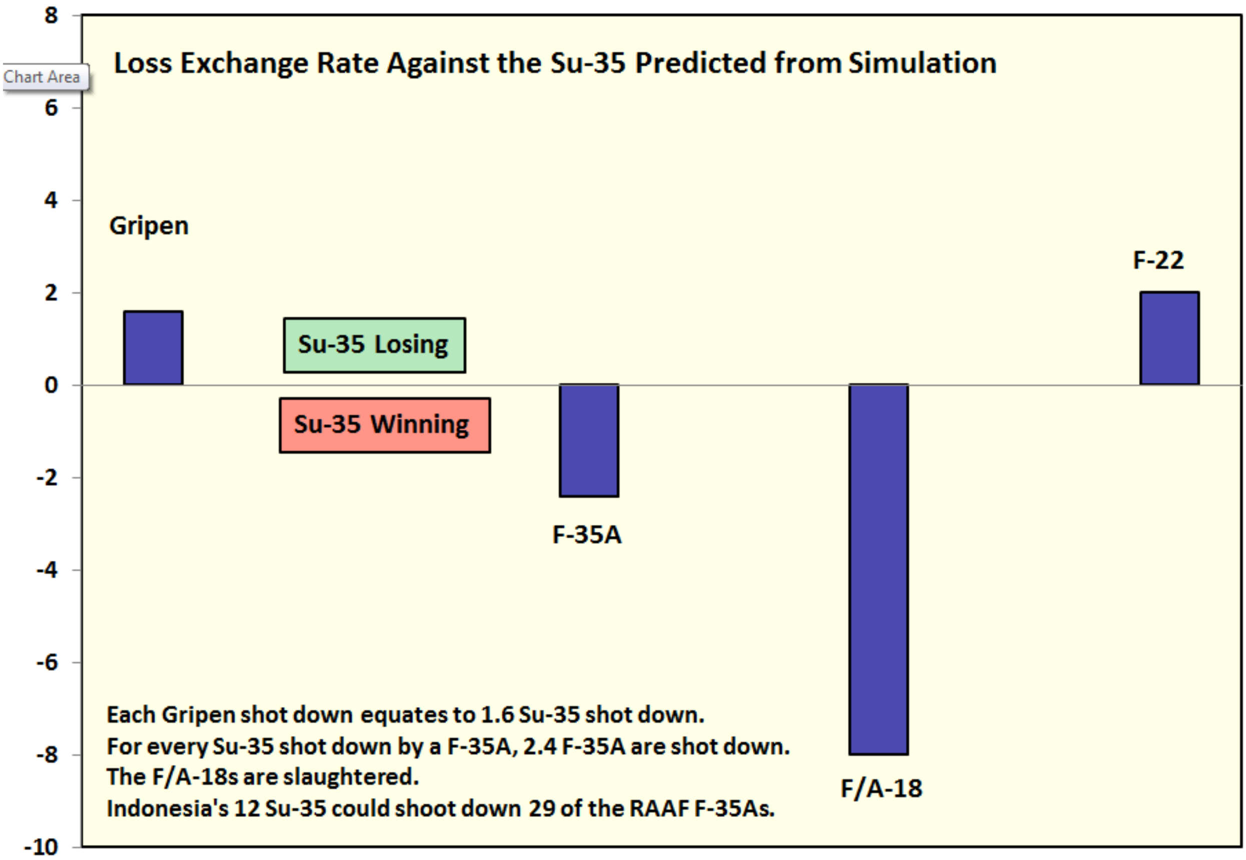

Figure 25: Loss exchange rate against the Su-35

How aircraft will perform in combat can be modelled based on their physical characteristics, fuel fraction and weapon loadout. This graph shows the modelled result of air combat of four Western aircraft against the Su-35. Australia's most likely potential adversaries in the Asian region, Indonesia and China, are both acquiring the Su-35. Aircraft above the line shoot down more Su-35 than are shot down themselves with the Gripen almost as proficient as the F-22, reflecting our expectation that it is close to the F-22 in combat efficacy. With respect to the F-35, each Su-35 shot down would come at the cost of 2.4 F-35 shot down. Thus the 12 Su-35 that Indonesia is in the process of acquiring will result in the loss of 29 RAAF F-35s. If the RAAF persists in buying F-18 Super Hornets in response to continuing delay in the F-35 program, the Indonesian Su-35s will slaughter the Australian F-18 Super Hornets at the rate of eight F-18 Super Hornets shot down for each Su-35 lost. If equal numbers of Su-35s and F-35s were arrayed against each other in a campaign, the last F-35 will be shot down on day 3. Based on the survival rate of Serbian pilots shot down in Operation Allied Force, about half of our F-35 pilots can be expected to survive (assuming the ejection seat/canopy problems are solved) and thus flying F-35s against Su-35s is not completely suicidal.

Combining all the effects of cost, sortie rate and loss-exchange rate, the Gripen is over 200 times as effective in air-to-air combat as the F-35.

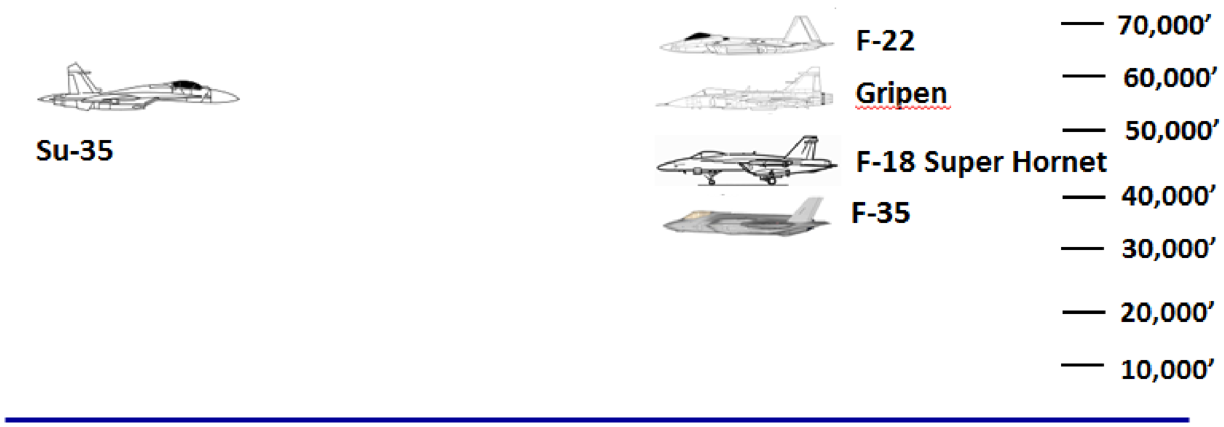

Figure 26: Optimum operating altitude relative to the Su-35

With its large nose radar, cheek radars, IRST, high operating altitude and long range BVR missiles, the Su-35 can acquire and target aircraft at a considerable distance. A supercruising Su-35 at altitude provides its missile with an advantage in the ballistic trajectory it will take. The F-35 is optimised for bombing at 20,000 feet but can operate at 40,000 feet which is close to its service ceiling. The F-35 can't use its radar without giving its position away and its infra-red optics are relatively short range with the result that it is flying relatively blind compared to the Su-35. If it does acquire a Su-35, the F-35's missiles have to climb by 20,000 feet, shortening their range by 25 percent.

6.5 Discussion of Alternatives to the F-35

In short, the Gripen E is the standout as the replacement for the F-35 for a host of reasons. First of all, in air-to-air combat it is almost as good as the F-22, better than the Su-35 and most probably as good as the T-50 coming into production in 2016. It has the lowest acquisition and operating costs. Of any of the fighter offerings, it is the one most able to operate from austere bases. It operates a wide range of US and European weapons systems. Because of its size and agility, it is the most difficult to shoot down and thus the most survivable. The engine has commonality with the engine of the 36 F-18 Super Hornets that Australia is operating.

The F-16 is a similar size aircraft to the Gripen E but is about 50 percent more expensive to acquire and operate than the Gripen E. It is far less agile and thus far less survivable in combat. At one stage the F-16 could have evolved into a quite capable delta wing aircraft via the F-16XL. That effort was truncated to make way for the design competition that produced the F-22. The Gripen E's delta wing and canard combination is the ideal form for a single-engine fighter and from there it is just a question of what avionics are installed.

The Rafale produced by Dassault in France is the second-best alternative to the F-35 available. It has the same planform as the Gripen and thus has similar agility. The Rafale's sensor fusion provides its pilot with very good situational awareness. It weighs 25 percent more than the Gripen E but costs three times as much to acquire and operate. The range of weapons it can use is more restricted than that of the Gripen E.

The Typhoon is a large, agile fighter but is also quite expensive to acquire and operate. It first flew in 1994. Its design shortcomings relative to the Gripen E and the Rafale are lack of a blended wing and having the canards as small, long-arm canards at the nose of the aircraft rather than as close-coupled canards that improve the lift of the wing.

The F-18 Super Hornet is a light bomber, designed as such for the US Navy, that lacks manoeuvrability and will be easily shot down.

Similarly, the F-15 is a design initiated in the 1960s to shoot down Soviet bombers. It lacks manoeuvrability and is expensive to acquire and operate. It is less agile than the Su-27 and its derivatives and thus the latter will dominate it in a dogfight.

With respect to the F-22, the production line for this aircraft closed in 2012. If production was restarted, the unit cost of producing F-22s would be much the same as that of the F-35. The F-22's operating costs are US$8,000 per hour higher than that of the F-35, consistent with having two engines instead of one and a more complicated RAM coating. The F-35's operating costs are too high to begin with. The argument for having a large fighter aircraft is that physics makes larger aircraft more capable. Assuming that a smaller aircraft and a larger aircraft have a very similar lift to drag ratio, cruise at the same Mach number and have the same specific fuel consumption, then the ratio of relative range performance is given by the ratio of the natural logarithms of the ratios of total weight to empty weight, excluding stores. Inserting these numbers yields a result which indicates that the larger fighter will have about 40 percent better range. An inevitable consequence of the physics of flight is that long range aerial combat demands larger airframes, all other parameters being equal.

There is a role for a large, agile, twin-engined fighter aircraft in the western Pacific, including for Australia. Apart from providing air superiority, such a platform would be ideal for delivering long range anti-ship cruise missiles. Pursuit of stealth as an end in itself is a dead-end though now that it has been countered by VHF radar, L band radar and IRST. The US Air Force can't afford to give its F-22 pilots enough flying hours to remain proficient and that will be just as true of an expanded F-22 fleet.

The F-22 program dates from 1991 when its prototype, the YF-22 produced by Lockheed Martin, won the fly-off competition against the YF-23 produced by Northrop, though the YF-23 was faster and stealthier. The US Air Force awarded the contract to Lockheed Martin because it thought that Northrop would not be up to building the B-2 bomber and the new fighter at the same time. With respect to stealth, 90 percent of the effect derives from aircraft shaping and the remaining 10 percent from radar-absorbent materials. The YF-23 is an inherently stealthier design than the F-22. Given that the avionics of the F-22 are now over 25 years old, it would be a better outcome from here, for the long term, to go back to the YF-23 airframe and update its engines and avionics. This would produce an aircraft with a weight, acquisition cost and operating cost similar to that of the F-15. It would be as stealthy as possible from shaping without the expense, logistic footprint and low availability of maintaining a RAM coating.

Sweden produces the Gripen E fighter from a population base of 8 million. Japan and South Korea are both proceeding with their own fighter aircraft designs. Russia's economy, when the oil price is high, is not much larger than Australia's, but Russia is able to produce a range of advanced weapons systems in aircraft and missiles. If Australia needed a large, twin-engined fighter aircraft, it would be in our means and capability to do so, and we could adopt the YF-23 planform optimised around the GE F414 engines used by the Gripen E and F-18 Super Hornet. It would take a change of mindset to achieve this.

6.6 F-18 Super Hornet

As the F-35 schedule started slipping a decade ago, the RAAF started acquiring F-18 Super Hornets to ensure against a capability gap emerging. The F-18 Super Hornet is based on the design of the F/A-18 Hornet but is much larger. In the 1990s, the US Navy needed a replacement for the swing-wing F-14 Tomcat. US legislation requires a competitive fly-off in choosing a new aircraft. The US Navy though couldn't afford to pay for the development costs of two aircraft so it got around that by promoting the F-18 Super Hornet as a design upgrade from the legacy Hornet rather than as a new aircraft, which it is. (It was a recovery from the failed A-12 program leaving an upsized Hornet as the only option.) It shares only limited structural commonality with the F/A-18. While the Super Hornet forward fuselage is derived from the legacy Hornet design, the wings, centre and after fuselage, tail surfaces and engines are entirely new. It weighs 30 per cent more and has a 36 per cent greater internal fuel load. The F-18 Super Hornet can also bring back unexpended ordnance.

Unfortunately for Australia, the F-18 Super Hornet is outclassed by the Sukhoi Su-27 Flanker and its later variants that China and some other countries in our region have in their air forces. The Flanker outperforms the Super Hornet in aerodynamic performance which will give it an advantage in within-visual-range combat. The Flanker's high supercruise speed combined with its large weapons load, enabling it to fling off four-missile-volleys at a time, also gives it the advantage in beyond-visual-range combat.

RAAF policy is to continue to buy more F-18 Super Hornets as the F-35 schedule continues to slip. That is a mistake because the F-18 Super Hornet is merely a light bomber with low survivability.

6.7 Gripen E

Saab was formed to produce aircraft in 1937. Their first jet fighter, the Tunnan, flew in 1950 with the first delta wing jet fighter, the Draken, following in 1955. Canards were added with the Viggen which first flew in 1967. The Viggen weighed 9.5 tonnes. It was followed by the Gripen, with an empty weight of 6.8 tonnes, introduced into service in 1997. This grew to 8.0 tonnes with the latest variant, the Gripen E. As with its predecessors, the Gripen was originally designed for flexible deployment with a small logistical footprint. This was due to the Swedish Air Force's policy during the

Cold War to operate out of a number of dispersed bases across the country. It was considered vital to keep staff resources, support systems and spares to a minimum. As a result of this, the Gripen was designed to operate from runways only 800 metres long by 16 metres wide. This means it can land on a regular highway, which further improves its logistical flexibility.

The maximum combat radius for Gripen E on an air-to-surface configuration is approximately 1,500 kilometres (no patrol component). This is defined as flying to a target, releasing air-to-surface weapons and then returning to home base. By comparison, the F-35's range on the same basis is 1,100 kilometres. The actual combat radius depends on the configuration of the aircraft's external stores and the availability of reserve fuel tanks. In a typical air-to-air configuration for example, the Gripen E can patrol for over two hours. The one-way ferry range of the Gripen E is 4,000 kilometres. The Gripen is also designed for ease of maintenance with a turnaround time of 10 minutes in the air-to-air configuration. It can be re-armed and refuelled with the engine running. Maximum speed of Mach 2 is 0.4 Mach higher than that of the F-35. The Gripen uses the same engine as the Super Hornet.

With respect to air superiority, the Gripen has performed very well against the F-22 in Red Flag exercises. At the 2013 Red Flag exercise, the Gripens had the F-22s in visual range before the F-22s were aware of their presence. Australia would lose nothing in terms of air-to-air performance by opting for the Gripen E. The reason for the Gripen E's good result was in its synergy as an air combat weapons system - good sensors, long-range weapons, excellent countermeasures and the ability to supercruise out of the fight when weapons were gone. To that, you could add excellent short-field performance and communications that allow the Gripen E to be on alert and ambush enemy aircraft. The optimum weapons loadout for the Gripen E is four Meteor missiles for long range, beyond visual range engagements and two infrared-homing IRIS-T missiles for within visual range combat, plus the gun.

Then there is the force multiplier effect of the cost advantages. Three of them.

Firstly, the price of the Gripen E is likely to be between US$43 million and US$60 million. Originally the Swedish Air Force was going to acquire 60 Gripen E by upgrading Gripen C airframes at a cost of US$43 million each. They are now getting new-build Gripen Es. By comparison, one F-35A costs US$148 million and there will be a further US$30 million to come on top of that for doing rework to delivered aircraft. At a most likely arrived cost of US$180 million for the F-35A variant that Australia is getting, we could buy three to four Gripen Es.

Also the Gripen E can mount sorties at four times the rate of the F-35 because of its lower maintenance requirement. So for every F-35 sortie, we could mount 12 Gripen sorties for the same capital outlay. We would not be sacrificing quality for quantity in doing this. The Gripen can shoot down 21 F-35s for each Gripen lost to an F-35, pilot ability being equal. Adding that factor in and the Gripen becomes over 200 times as cost-effective as the F-35.

Then there is the flying cost per hour difference as show by this graphic:

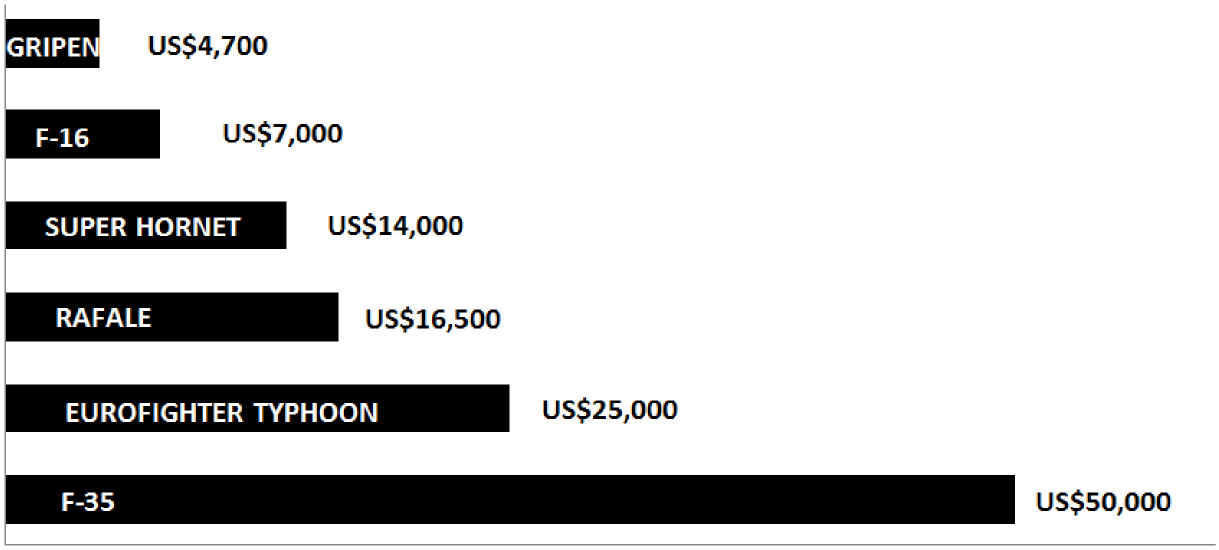

Figure 27: Operating cost per hour of fighter and light bomber aircraft

Each hour of flight in an F-35 costs more than ten times what it does in a Gripen E. Australia won't be able to afford to fly its F-35s much at all, and certainly not enough to make our pilots fully proficient in flying them. We could afford lots of flying time for pilots in the Gripen E. This would make such Gripen E pilots far more effective in combat. That is difficult to quantify but the higher level of training could easily make pilots 40 per cent more effective. Adding this factor in means that the Gripen E becomes well over 200 times as cost-effective as the F-35. And the Gripen E will make far fewer widows than the kamikaze flights of the F-35 will, because flying the F-35 against the Sukhoi Su-27's later variants will be mostly a one way trip. On top of all that, adopting the Gripen E means that Australia would be secure by achieving air superiority at least out to the Indonesian archipelago. If we rely upon the F-35, we won't have an air force at all because every other type of aircraft we have will be shot down as well. If Australia's F-35s were deployed against an equal number of Su-35s, the last Australian F-35 would be shot down on day 3 of the conflict.

The case for the Gripen E over the F-35 is overwhelming. Fortunately, while Australia has announced an intention to acquire a total of 72 F-35s, so far we are only contractually bound to buying two of them. So we could back out of the worst of this horrendous mistake if we had the will and the wit to do so. If we persist with the F-35, most likely we will only get a fraction of that number of 72 aircraft before production is halted due to the F-35 being too deficient to continue with. Any F-35s that arrive in Australia can be mated with anti-ship cruise missiles and external fuel tanks and applied to the maritime strike role. They would be safe out at sea where they won't encounter enemy aircraft. They will be an expensive way of delivering cruise missiles because the Gripen E could do that far more cheaply as well.

The pragmatic way of dealing with the F-35s would be to park them up, write off the capital cost and buy an equal number of Gripen Es. It would still be cheaper than trying to fly the F-35s and we would have a far more effective force.

Australia did assemble our own Mirage III and F/A-18 Hornet aircraft. Of the fighter aircraft alternatives available to Australia, the Gripen E is the only one that could be manufactured here. The template for that is the deal between Saab and Brazil. Saab is also offering a domestic build arrangement to India. India's buy of Rafale fighters was limited to 36 because it could not afford any more of this expensive aircraft. That has left a capability gap which is likely to be filled by the Gripen E.

7. Any Other Related Matters

7.1 Basing and Logistics

One of Australia's potential strategic strengths, should we utilise it, is the potential for dispersed basing across northern Australia. That will require that we acquire a fighter aircraft that can take-off and land within 1,000 metres. The F-35 effectively reverses that strength because its logistics requirement will limit it to operating from RAAF Base Tindal. This will make enemy operations against Australia far simpler, with only one airfield to take into consideration in mission planning.

Apart from abandoning the F-35, we should be building covered parking areas next to runways across northern Australia to provide concealment for dispersed aircraft.

The US Air Force has adopted a 'Ready Raptor' concept under which four F-22s can be deployed away from their home base with support provided by trucks carried in an accompanying C-17.

The Gripen E can be deployed away from its home base at the rate of eight Gripen E supported by trucks carried in one C-130 Hercules.

7.2 Maintenance

The RAAF has evolved to outsource maintenance in an attempt to lower costs. At the same time, this makes the RAAF far less effective in being used in war. Civilian maintenance staff can't be ordered to go to austere bases and live in un-air conditioned tents in the same way the service personnel can be. To make our choice of fighter aircraft, post the F-35, fully effective, the entire logistics chain should be optimised on what the aircraft is capable of doing.

7.3 Interim Aircraft

The delay in the F-35 program has left the RAAF with only 72 aged, short-range F/A-18 Hornet aircraft as our only pure fighter air defence. In advance of receiving new-build Gripen E aircraft, Australia should acquire or lease Gripen C and D aircraft. One source of these aircraft could be Gripen C aircraft parked up by the Swedish Air Force. Another would be Gripen C and D aircraft in storage in South Africa which hasn't provided enough funds to keep them flying, and enough flying hours to keep enough South African pilots proficient in the aircraft. The sooner that Australia acquires existing Gripen C and D aircraft and starts training with them to practice deployment to austere bases, the better.

7.4 Aging of the F/A-18 A/B Hornet Aircraft

Australia's F/A-18 Hornets entered service during the period 1985–90, and were originally planned to be withdrawn from service in 2010–15. The first two aircraft were produced in the US, with the remainder assembled in Australia at Government Aircraft Factories at Fishermans Bend in Melbourne. F/A-18 Hornet deliveries to the RAAF began on 29 October 1984, and continued until May 1990. Now in 2016, the

Hornets are all operating beyond their initial design life. Structural refurbishments are ongoing as these aircraft are in the latter stages of their service life, and so require steadily increasing structural maintenance. Significant aged-aircraft issues are resulting in maintenance durations and costs becoming less predictable. Annual spending to sustain the Hornet fleet has averaged $118 million since 2000–01, but is trending towards $170 million per annum over the next several years.

The F/A-18A/B Hornet was designed for a safe life of 6000 airframe hours under specified flight profiles. Defence data indicates that, at the current rate of effort of 12 000 airframe hours per year for the fleet, the Hornet fleet as a whole will not exceed 6000 flying hours for each aircraft until after the current Planned Withdrawal Date of 2020. That said, all but nine aircraft have experienced structural fatigue above that expected for the airframe hours flown, leading to steps to conserve the remaining fatigue life of the F/A-18A/Bs to ensure they remain operable up to the safe life of 6000 airframe hours. The wing and centre-fuselage structures have been shown, by test and usage-monitoring, to be approaching their Safe Life Limits faster than other major structures.

Defence data indicates that this will require steadily increasing financial investment, with F/A-18 Hornet sustainment costs estimated by Defence to peak at $214 million per year in 2018–19. This reflects the effort needed to keep an aged and complex fleet airworthy and operational. Super Hornet sustainment costs are estimated by Defence to peak at $180 million in 2017–18, as these aircraft are expected to be withdrawn from service before costly aged-aircraft maintenance or structural fatigue- related maintenance is required. These Defence sustainment estimates are based on the F/A-18 Hornet and F/A-18 Super Hornet Planned Withdrawal Dates of 2020 and 2025 respectively.

In recent years, there has been a recognisable decline in the serviceability state of the Hornet wiring. This degradation is primarily due to ageing-aircraft factors (for example, wearing and chafing) and maintenance-induced activities. In many cases, the condition of aircraft wiring is indirectly affected by modifications done to other aircraft components.

Extending the F/A-18A/B fleet’s Planned Withdrawal Date beyond 2020 may well require the fleet to undergo an expanded, and hence more costly, safety-by-inspection regime, a structural modifications program and capability upgrades.

The upgrade of all 71 RAAF F/A-18A/B Hornet aircraft cost $3.245 billion. Together with the fleet’s original acquisition cost of $4.44 billion, the total acquisition cost of the F/A-18A/B Hornet fleet amounts to some $7.685 billion over the period 1985–2015, covering the aircraft, aircraft upgrades and weapons upgrades.

The original acquisition cost was $62 million with upgrades of $45.7 million per aircraft.

Legacy Hornet sustainment will rise to $22,711 per flight hour by 2018[1].

Upgrading the RAAF's Hornets to keep them flying for a few more years approaches the cost of buying new Gripen E aircraft. The sooner Australia bites the bullet and abandons the F-35, the cheaper the replacement outcome will be.

7.5 The US – Australia Alliance

The ANZUS alliance is the linchpin of Australia's defence posture. If it were not for the expectations under that alliance, Australia would have to spend a multiple of its current percentage of GDP on defence. Currently we spend less than 2.0 percent of GDP on defence while the United States defence expenditure is 4.6 percent of GDP. Part of that benefit is the perception that Australia is included in the US nuclear umbrella. Without the promise of nuclear retaliation, it would not matter what we spent on defence, even 15 percent of GDP, as we would effectively be undefended.

The world geopolitical situation is becoming increasingly fraught. In the East Asian region, China is on a path to start a war with several parties. These include Vietnam, Malaysia, Indonesia and the Philippines over these countries' bases in the Spratly Islands, and Japan over the Senkaku and Ryuku Islands further north. At least, Japan is likely to intercede on the behalf of the Philippines in a war in the South China Sea instead of waiting for China to attack to attack it in the East China Sea. If China believes that the United States will come to the aid of the Philippines and Japan, then it might include US bases in a surprise attack. Australia will become involved because of our mutual defence treaties with Japan and the United States.

With respect to timing, China might act once all three of its 3,000 metre long runways on bases in the Spratly Islands becomes operational. Other considerations in China's timing are the handing down of the decision of the Permanent Court of Arbitration in The Hague (which would delegitimise China's claim), expected by mid-2016, the state of the Chinese economy and the end of President Obama's term on 20th January, 2017. All these things considered, China's optimum time to attack would be in the second quarter of 2016 before the decision in The Hague reduces the legitimacy of its claims in the South China Sea.

It is important for Australia that it maintains its defence relationship with the United States, though the bulk of the effect of the US relationship could also be achieved by upgrading our relationship with Japan, with both countries sharing nuclear weapons technology and delivery systems, and Australia providing Japan with strategic depth.

It has become apparent in the US polity that the F-35 is far too deficient to proceed with as a weapons system. One of the things that the United States considers in its assessment of the F-35 is that many of its allies have signed on for it and do not have a ready alternative once it is abandoned.

The US has realised that the F-35 is too expensive to acquire even in reduced numbers and thus consideration is being given to acquiring more F-16 and F-15 aircraft. The solution to the United States' F-35 nightmare is for Boeing to licence-build the Gripen E on the St Louis production line that is currently making the Super Hornet.

Given the importance of maintaining the ANZUS alliance, some Australian observers believe that abandoning the F-35 would send an unwelcome signal to the United

States. Rather, the reverse is true. The United States expects Australia to optimise its defence and take some of the burden in providing security to the East Asian region. Instead of buying the defective F-35 system, Australia could and should be buying several other US weapons systems. These include:

1. Virginia-class submarines
2. C-130J Hercules transport aircraft
3. HIMARS GPS-guided rocket systems
4. M117 155 mm towed howitzers
5. War stocks of air-to-air missiles
6. War stocks of air-launched anti-ship cruise missiles

What Australia could do that would most benefit both parties would be to develop basing for supply of US forces in our region. The United States would like to have more strategic depth in the oncoming war with China. To that end:

1. Upgrade RAAF Base Tindal to take B-1 bombers. This would include another runway, shelters and fuel
2. Introduce Federal legislation to remove Chinese ownership of the Port of Darwin.
3. Build a naval base in Exmouth Gulf with fuel storage.
4. Build a naval base in Shark Bay with fuel storage.
5. Increase the fuel storage at RAAF Base Curtin.
6. Build aircraft shelters at runways across northern Australia.
7. Increase Australia’s fuel security by building and filling fuel storage and coal-to-liquids plants.

David Archibald
16th January, 2016

David Archibald is a Perth-based analyst whose most recent work on defence matters is Australia’s Defence (Connor Court).

Notes

Chapter 1

1. Government Accountability Office September, 2014, *F-35 Sustainment: Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates* GAO-14-778
2. Australian Government, Department of Defence, Statement of Evidence to the Parliametary Standing Committee, June 2014, *Facilities Requirements for the New Air Combat Capability*
3. Dutch Ministry of Defence, 15th September, 2015, *Kamerbrief over voortgangsrapportage project verwerving F-35*
4. Lockheed Martin Proprietary/Export Controlled Information, 14th January, 2015, *F-35A High Angle of Attack Operational Maneuvers*
5. Wing Commander (Retd) Chris Mills, 7th December, 2015, *Foreign Affairs, Defence and Trade Committee: JSF Inquiry Submission*
6. Breaking Defense, Colin Clark, 10th December, 2014, *The Tale Of The F-35 And Hot Jet Fuel*
7. Defense Tech, Brendan McGarry, 25th February, 2014, *Let Humans Override F-35 'ALIS' Computer: Bogdan*
8. Jeremiah Gertler, Congressional Research Service, 17th December, 2015, *The Air Force Aviation Investment Challenge*
9. Bill Sweetman, Aviation Week, 19th November, 2015, *U.S. Considers Up To 72 New F-15s Or F-16s*

Chapter 2

1. David Wroe, Wauchope Gazette, 13th March, 2013, *RAAF ignored Joint Strike Fighter advice*
2. Air Power Australia, 7th June, 2014, *Joint Strike Fighter*
3. David Archibald, Connor Court, October, 2014, *Australia's Defence*, 245 p.
4. Edward Hunt, HIS Janes, 13th March, 2012, *Fast Jet Operating Costs: Cost Per Flight Hour Study Of Selected Aircraft*
5. Wing Commander (Retd) Chris Mills pers. comm.
6. Center For Strategic and Budgetary Assessments, 14th September, 2010, *Sustaining America's Strategic Advantage in Long-Range Strike*
7. Wing Commander (Retd) Chris Mills pers. comm.
8. Dave Majumdar, The National Interest, 16th September, 2015, *A Solution to America's F-35 Nightmare: Why Not Build More F-22s?*
9. William Hennigan, LA Times, 7th August, 2011, *Sky-high overruns, safety ills plague jet*
10. Sputnik News, 18th November, 2015, *Immaculate Choice: Indonesia Poised to Buy Russian Su-35 Fighters*
11. Dave Majumdar, The National Interest, *America's F-22 Raptor vs. China's Stealth J-20: Who Wins?*
12. Wing Commander (Retd) Chris Mills pers. comm.

Chapter 3

1. Dutch Ministry of Defence, 15th September, 2015, *Kamerbrief over voortgangsrapportage project verwerving F-35*, page 67
2. Amy Butler, Aviation Week, 5th February, 2012, *Kendall: Premature F-35 Production Was 'Acquisition Malpractice'*

Chapter 4

1. Colin Clark, Breaking Defense, Services Set IOC Dates For F-35; 'Confidence' Is The Watchword'
2. Sydney J. Freedberg Jr. Breaking Defense, 22nd October, 2015, *Billions In F-35 Upgrades Debated; Canada Election Fallout*
3. Wing Commander (Retd) Chris Mills pers. comm.
4. Andrea Shalal-Esa, Reuters, 15th March, 2013, *Insight: Expensive F-35 fighter at risk of budget "death spiral"*
5. Loren Thompson, Forbes, 13th July, 2015, *Ten Signs The F-35 Fighter Program Is Becoming A Smashing Success*
6. Defence IQ, 2015, *Fighter Aircraft Market Update 2015 – 2016*
7. Arie Egozi, Flight Global, 2nd November, 2015, *Israel requests extra squadron of F-15s*
8. Stuart Smallwood, the hankyoreh, *History suggests U.S. may be pressuring South Korea on F-35 deal*
9. Defense Industry Daily, 28th December, 2015, *KF-X Fighter: Korea's Future Homegrown Jet*
10. Gerard OP'Dwyer, DefenseNews, 5th December, 2015, *Denmark Further Postpones Fighter Selection Until 2016*
11. Congressional Research Service 17th December, 2015, *The Air Force Aviation Investment Challenge*
12. Dutch Ministry of Defence, 15th September, 2015, *Kamerbrief over voortgangsrapportage project verwerving F-35*
13. Government Accountability Office, April, 2015, *F-35 Joint Strike Fighter Assessment Needed to Address Affordability Challenges*

Chapter 5

1. Project On Government Oversight, 6th March, 2013, *The Air Force's F-35A: Not Ready for Combat, Not Even Ready for Combat Training*
2. Colin Clark, Breaking Defense, 6th June, 2014, *Gen. Mike Hostage on the F-35; No Growlers Needed When War Starts*
3. Defense News, 3rd February, 2014, Interview: Gen. Michael Hostage, Commander, US Air Force's Air Combat Command
4. Mandy Smithberger, Project on Government Oversight, 12th March, 2015, *Not Ready For Prime Time*
5. Wing Commander (Retd) Chris Mills pers. comm.
6. Sydney Morning Herald, 11th September, 2008, *New Aussie fighter 'clubbed like seal'*

7. Australian Government, Department of Defence, Statement of Evidence to the Parliametary Standing Committee, June 2014, *Facilities Requirements for the New Air Combat Capability*
8. Colin Clark, Breaking Defense, 10th December, 2014, *The Tale Of The F-35 And Hot Jet Fuel*
9. Government Accountability Office September, 2014, *F-35 Sustainment: Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates*
10. Bill French and Daniel Edgren, National Security Network, August 2015, Thunder without Lightning: The High Costs and Limited Benefits of the F-35 Program
11. David Axe, War Is Boring, *Test Pilot Admits the F-35 Can't Dogfight: New stealth fighter is dead meat in an air battle*
12. UK Armed Forces Commentary, *Future Force 2020 – RAF: Evolving the RAF for the new (budgetary) challenges*
13. Andrew Chuter, Defense News, 15th June, 2015, France Spotlights Pilot Readiness: Training Policy Would Create 2 Tiers of Aviators
14. Mandy Smithberger, Project on Government Oversight, 12th March, 2015, *Not Ready For Prime Time*
15. Winslow Wheeler, Project On Government Oversight, 6th March, 2015, *The Air Force's F-35A: Not Ready for Combat, Not Even Ready for Combat Training*

Chapter 6

1. Rand, 2013, McGarvey et. al., 2013, *Assessment of Beddown Alternatives*
2. *for the F-35*
3. Pierre Sprey, 1982, *Comparing the Effectiveness of Air-to-Air Fighters F-86 to F-18*

Chapter 7

1. Australian National Audit Office, Audit Report No.5 2012–13, *Management of Australia's Air Combat Capability – F/A-18 Hornet and Super Hornet Fleet Upgrades and Sustainment*