American Gripen

The Solution to the F-35 Nightmare

David Archibald

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Also by David Archibald

Twilight of Abundance: Why Life in the 21st Century Will Be Nasty, Brutish, and Short

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Preface

THE F-35 IS a problem. The F-35 is so bad that there is no point in proceeding any further with it. Even if it worked as per the original specifications of the development contract in 2001, that would not be good enough. It is very expensive to build and operate and there is no role for it on the battlefield. Anything the F-35 can do, something else can do better and more cheaply. It must be kept away from enemy aircraft which will harry it to death.

It is good practice, when bringing attention to a problem, to also detail the solution to that problem. That is what this book does. It is a discussion of air superiority achieved by aircraft dedicated to that purpose. Without air superiority the existence of the rest of the military enterprise is fraught, and the human cost of having undefended skies will be considerable.

America's air superiority is currently provided by a handful of F-22s, which are likely to be overwhelmed by the sheer numbers of late-model Chinese fighter aircraft. Once the F-22s are shot down, the rest of the Air Force will be defenseless, even if the F-35 were in service and worked as designed.

This book begins with the background to the way Lockheed Martin engineered the F-35 selection process so that its design would be chosen for the Air Force, Navy and Marines with the aim of being the sole source of fighter aircraft for decades. The compromises needed to achieve that win in the selection process fatally compromised the product.

Those flaws can be determined from analysis of the design, and in fact they were predicted 15 years ago, soon after the award of the F-35 contract to Lockheed Martin.[1]

Persistence with the bad choice of the F-35 has made the consequences progressively worse as the years have passed. A rational purchaser would write off the $107 billion that has been spent on the F-35 program as at the time of this writing and consider the alternatives.[2]

What makes an effective fighter aircraft in the second decade of the 21st century? That is described along with how to win in air-to-air combat.

Armed with the knowledge of what is required to achieve air superiority, the alternatives to the F-35 are examined in detail. Options include the F-15, F-16, F-18 Super Hornet, the restarting of F-22 production, as well as the fighters collectively known as the Euro-canards—the Gripen E, Rafale and Typhoon.

The solution to the F-35 nightmare is the Gripen E from Saab in Sweden. It is approximately the size of the F-16 but with a design that has benefited from another 40 years of evolution in fighter aircraft engineering and electronics. As an air-superiority fighter it is almost as good as the F-22; good to the extent that the work of 10 F-22s could be done by 15 Gripen Es. Those 10 F-22s would be equivalent to 40 F-35s. Importantly the Gripen-E is half the capital cost of the F-35 with an operating cost per hour that is one sixth that of the F-35. The Gripen E has a high proportion of US-made parts, including the engine which is used by the F-18 Super Hornet.

Adopting the Gripen E will be an interim solution until a replacement is found for the F-22 which is simply too expensive to fly due to the way it achieves stealth - by the application of a lot of radar-absorbent-material. The better alternative to the F-22 is outlined. That is the plane that lost out to the F-22 back in 1991.

That aircraft, the YF-23 from Northrop Grumman, achieved most of its stealth through shaping and shouldn't cost more to operate than the F-15.

Let's get back to the purpose of the book. The sooner the F-35 program is terminated, the sooner the colossal waste of money will stop and the safer we will all be. There has been a perception that the F-35 program couldn't be killed because there was nothing with which to replace it. The F-35-killer we have been waiting for is the Gripen E. The Gripen E will save a lot of lives, the military budget and make it a lot easier to defend Western Civilisation.

Introduction

SOME THINGS JUST don't work out. Sometimes the best of intentions and plenty of money can't overcome problems that were inherent in the design of a thing. And when the thing is built, the shortcomings that were predicted from dispassionate analysis become showstoppers. There is no shame in abandoning such projects as long as they are killed off quickly so that not too much damage is done. Thus the *Seawolf* submarine program was discontinued after building three vessels and was replaced with the far more cost-effective *Virginia* class. The same happened to the *Zumwalt* class destroyer. Originally 32 were to be built but that has also been cut back to just three.

The *Zumwalt's* main weapon system, the Advanced Gun System, fires rounds that each cost $800,000 but deliver only 11 kg of explosive per round. Hopefully the *Zumwalt* class will be re-purposed to fire some other weapon system. It is unlikely to be the rail gun because that also has cost-effectiveness issues.

So it is with the F-35. Its show-stopper shortcomings are inherent in its design. The problem for the United States and its allies is that the F-35 program has been taking a long time to expire, and that means life and death consequences if it is ever relied upon to maintain air superiority over battlefields.

The F-35 program has so far absorbed $107 billion and produced 180 aircraft in the process. Each of those aircraft requires modifications prior to use in combat. In fact some of the aircraft produced early in the program may require too much rework to be economically recoverable and will be cannibalized for parts. The F-35 is a delicate, temperamental machine. In war it is likely to be able to sortie out of its hanger only every second day. On returning it requires specialised power and air conditioning and fuel that is not too hot or otherwise, like a temperamental infant, it won't turn on its electronics.

So what has kept the program going? Some have contended that the F-35 has near-magical properties, ones which are on the verge of being realized. It is said that the F-35 is a system-of-systems which, essentially, is all-seeing and all-knowing on the battlefield. It is as if Buddha is the co-pilot and targets are detected, ranked, and destroyed effortlessly.

The F-35's full stealth is only in a narrow cone around the nose. It has the biggest, thirstiest engine ever made for fighter aircraft, which means that it is easily seen in the infrared segment of the electromagnetic spectrum. Its brutal shape means fuel consumption rises three-fold if it attempts to use its afterburner to escape by going supersonic. This means it will run out of fuel all too soon. As was said almost 10 years, the F-35 "can't turn, can't climb, can't run" and will be "clubbed like baby seals"[1]. It does not carry enough missiles in its weapons bays to be effective in combat even if it does see the enemy fighter before the fighter sees it. The F-35 is not agile enough to ever hope to direct its gun to bear on an enemy fighter.

All aircraft are compromises between weight, volume, and cost. The compromises in the F-35 were optimized around its role as a light bomber operating at 20,000 feet where its engine breathes best. It was to carry two missiles for self-protection on the mischance that it encountered an enemy aircraft. As Gen. Mike Hostage, when Commander, U.S. Air Force Air Combat Command, said: "An F-35 pilot who engages in a dogfight has probably made a mistake." [2]

As a particularly sentient light bomber on the battlefield the F-35 will have exquisite situational awareness of the fighter that shoots it down. Other aircraft types can fill its role of delivering bombs at half the cost. But we might not ever get to hear the part of the story in which the F-35 makes its combat debut because it has many deficiencies; a number of these are points of failure which, in a rational world, would each be enough to cancel the program. This may not be the complete list of the F-35's showstoppers, but no more are needed:

1. The F-135 engine that powers the F-35 is a wide engine, and the wider the engine, the greater the gyroscopic forces on it. If you put the aircraft into a snap turn the engine will want to keep going in the direction it was travelling, placing enormous stresses on it and the airframe. Because of the need to keep the F-35's weight down for the STOVL (Short Take-Off and Vertical Landing) variant for the Marine Corps, this is a problem that is "baked in the cake".

2. Because of its execrable acceleration and high wing loading, the F-35 requires a runway that is at least 8,000 feet long from which to operate. True fighter aircraft can use runways one third that length. Because a two-seater variant does not exist, training has to be done using runways at least 10,000 feet long to give the trainee pilot the option to abort take-off.[3] This is normally the domain of large bombers and transport aircraft.

3. At $42,000 per hour of flight, the F-35 is simply too expensive to operate relative to the capability it provides. Pilots need flying time of 20 hours a month to remain proficient. As with the F-22's pilots, F-35 pilots are likely to be limited to 10 hours a month in the cockpit. The lack

of proficiency in flying the aircraft simply negates the benefit of having the technology it provides.

4. The efficacy of an aircraft as an air-superiority fighter can be determined from its design. Different aircraft types can be flown against each other in simulations. Thus a 2008 Rand study was able to determine that the Su-35 could shoot down the F-35 at the rate of 2.4 F-35s for each Su-35 lost[1]. Because of its miscegenation as a light bomber, the F-35 is less maneuverable than fighter designs up to 50 years old. It wasn't a surprise when an F-16 out-flew an F-35 in mock combat in early 2015, a result entirely predictable from simulation. What is telling is that the F-35 is not being flown against other aircraft types on an at-least monthly basis in unscripted dogfights. It would be too embarrassing for the faux-fighter.

5. The F-35 uses its fuel to cool its electronics. The aircraft won't start if its fuel is too warm, making deployment in warmer regions problematic. At the Yuma and Luke U.S. Air Force bases in Arizona, fuel trucks for the F-35 are painted white, parked in covered bays and chilled with water mist systems. Also, because of its heat problem, the F-35 can't fly for too long or too fast at low altitude. The F-35 has also had a problem with starting in cold weather due to its battery although that is likely to be cured. The heat problem, though, like the engine problem, is "baked in the cake".

Embarrassed by having 180 aircraft which cannot actually fight, the F-35 Program Executive Officer, Lt.-Gen. Christopher Bogden, has nominated December 2016 the make-or-break date for the program. The Department of Defense has begun backing away from the F-35 and is contemplating buying more F-15s and F-16s to fill the U.S. Air Force's capability gap.[4] The F-35 saga may therefore end soon.

One thing that has helped keep the F-35 program going is a perception that there is no 'Plane B'.[5] As Margaret Thatcher famously said, "There is no alternative." No matter how bad the F-35 is, it is going to be built because the U.S. Air Force needs something to replace its worn-out fighters. That appears to be the fallback position in Lockheed Martin's marketing plan. The Department of Defense though is fully aware of the extraordinary cost of the F-35 relative to its performance and is looking to scale back procurement.[5] That could result in a death spiral as falling numbers boost unit costs.

Figure 1 shows U.S. Air Force fighter and light bomber procurement from 1975 with a projection to 2030:

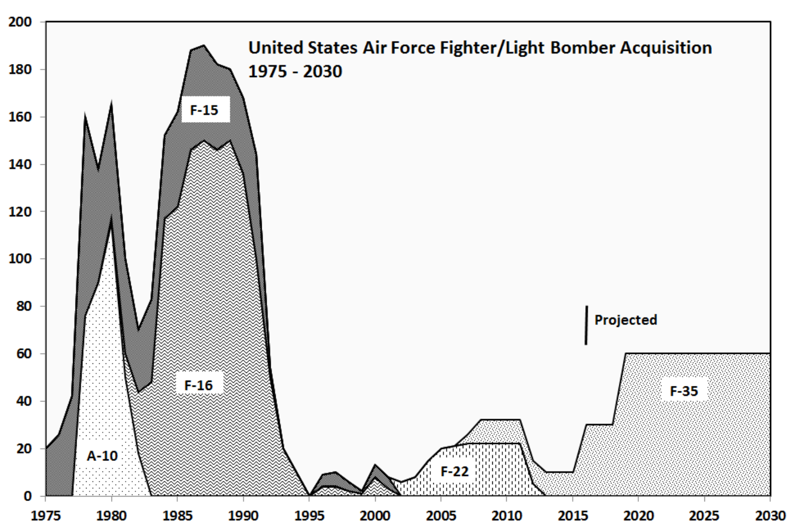

Figure 1: United States Air Force Fighter/Light Bomber Acquisition 1975-2030

Most of the fighter fleet was built in the fifteen years between 1977 and 1992. Then the F-22 came along in 2002. While it is a fabulous fighter when it is flying, it is too costly to fly. The F-22 takes 42 man-hours of maintenance for each hour in the air.[6] About half of those maintenance hours are taken with repairing its radar-absorbent-material coating. Availability has risen to 67 percent. F-22 pilots are restricted to 10 to 12 hours in the air per month due to an operating cost of $59,000 per hour which means the Air Force simply can't afford more.[7] Ideally, pilots would receive at least twice that in order to be fully proficient in the use of their weapon systems. In 2015 the F-22 had an hourly operating cost higher than that of the B-1 bomber which weighs more than four times as much. The F-35A's operating cost of $42,000 per flight hour was 10 percent more than that of the F-15, and just over twice that of the F-16. That is shown in the following table of U.S. Air Force data.

	Total Inventory	Fleet Age	Mission-Capable	Break Rate	12 Hour Fix Rate	Cost Per Flying Hour
Fighters						
F-16C	806	24.7	73.4%	9.2%	62.3%	$20,318
F-16D	157	25.4	70.8%	9.1%	61.3%	$20,318
F-15E	217	23.4	71.7%	16.3%	68.4%	$27,203
F-15C	212	31.4	70.7%	12.4%	54.9%	$38,846
F-15D	34	32.0	65.2%	12.6%	51.9%	$38,846
F-35A	51	1.7	68.6%			$42,169
F-22A	183	8.0	67.0%	9.5%	69.8%	$59,166
Bombers						
B-1B	62	28.1	47.5%	21.5%	36.9%	$58,488
B-52H	77	53.8	72.6%	36.4%	34.7%	$67,005
B-2A	20	21.2	55.6%	18.8%	67.3%	$128,805

Table 1: U.S. Air Force Fiscal Year 2015 Fighter and Bomber Aircraft Data[8]

Break Rate is the percentage of aircraft landing with a grounding write-up per total number of sorties.

The current Air Force plan is to build 44 F-35s in 2018, 48 in each of 2019 and 2020, and then 60 per year from 2021 to the mid-2030s. Assuming that F-16s and F-15s are retired at the same rate as F-35s are constructed to maintain aircraft numbers, the average age of the fleet will continue to rise from the current 27 years to 28.3 years by 2022. By that year the remaining F-15s will range from 30 to 38 years old. The Air Force has decided against a service life extension program for the F-15s because it would cost $5 billion.

With respect to the F-16 fleet, the U.S. Air Force is proceeding with a service-life extension program (SLEP) for up to 300 aircraft of the inventory. This will extend flight hour life from 8,000 to 12,000 hours. The SLEP contract award for the F-16s is expected in the 2018 fiscal year. Nevetheless, even if the F-35 continues into production as currently planned, 86 percent of the Air Force is facing mass obsolescence and simply being worn out. To replace the current inventory of F-15s and F-16s totalling 1,426 aircraft at the cost of the latest model F-15 of $125 million per copy would cost $178 billion.

The Air Force is planning to take five F-35s a month from 2021; by comparison F-16 production reached 30 per month at its peak in June 1987.

If the Air Force is facing mass obsolescence, the Marine Corps has it worse. As at April 2016, only 87 of the Marine Corps' 276 F-18s were flyable which is an availability rate of only 31 percent.[9] In early 2016 Marine Corps F-18 pilots averaged 8.8 hours of flying time per month which is half the 15.7 hours per month that is the absolute minimum needed to maintain proficiency. Ideally, pilots should fly between 25 and 30 hours per month. The lack of flying time may have caused an increase in the F-18 crash rate.[10] The Marine Corps has resorted to cannibalizing parts from museum aircraft. It is also resurrecting 30 F-18s from the aircraft boneyard of the 309th Aerospace Maintenance and Regeneration Group (AMARG) at Davis-Monthan Air Force Base, Tuscon, Arizona. The F-18s returning to the fleet will be upgraded to the C+ configuration. Each aircraft will take nine to 18 months to upgrade, depending upon its condition. Boeing expects to refurbish 10 F-18s annually starting in 2017.

Restarting the F-22 production line to make good the fighter aircraft shortfall is not the ideal solution. Arguably, the cost of this aircraft has wiped out half of the US fighter fleet even before the Russians or Chinese have had a chance to attack it. Simply due to its cost, what was to be a 750-strong fleet stalled at 187 aircraft; of that number, only 123 are 'combat-coded'.[11]

F-22 availability averaged about 40 percent when the aircraft entered service in 2005. After a decade of service, availability has reached 63 percent; that means that there is one modern fighter per every 4.1 million Americans. Of course that is not enough.

The Air Force is considering buying more F-16 and F-15 fighters. That is not a solution either. As General Mike Hostage, former commander of Air Combat Command said,"If you gave me all the money I needed to refurbish the F-15 and the F-16 fleets, they would still become tactically obsolete by the middle of the next decade. Our adversaries are building fleets that will overmatch our legacy fleet, no matter what I do, by the middle of the next decade." [12]

The U.S. Air Force has been worshiping at the altar of stealth for over three decades, since the F-117 became operational in 1983. It was considered such a wonderful thing that it was deployed to South Korea in secret, only flew at night and so on. The F-117's promise was borne out by its performance in Operation Desert Storm in 1991. But things had changed by the end of that same decade. In Operation Allied Force against Serbia in 1999, one F-117 was shot down by a SAM battery and another was mission-killed by the same battery. The stealthy F-117 had a higher loss rate in that conflict than the F-16. It could only be sent into combat protected by a package of other aircraft.

Shaping provides most of the stealth of the invisibility cloak of a stealth aircraft with the remainder coming from its radar-absorbent-material coating. The operational doctrine of the F-22 is based on it flying without its radar on and not making any other electronic emissions either. At the same time it is vacuuming up the electronic emissions of enemy aircraft, triangulating their position and then pouncing at a time of its choosing.

The world has moved on from that. Stealth, as practiced by the F-22 and F-35, is optimised on radar in the X band from 7.0 to 11.2 gigahertz. Detection in other parts of the electromagnetic spectrum has improved considerably over the last twenty years. Chief of these is infrared-search-and-track which enables an F-35 to be detected from its engine exhaust from over 60 miles away. The latest iteration of the Su-27 Flanker family, the Su-35 has infrared-search-and-track and also L band radar on its wings. L band and lower frequency radars can see stealthy aircraft over 100 miles away. These radar frequencies won't provide a tracking solution to an air-to-air missile but they do tell the pilot that an aircraft is there and can cue the infrared-search-and-track to stare at the patch of sky containing the enemy aircraft. So an Su-35 can see a F-35 well before the F-35 can detect it. Stealth, as an end in itself, has outlived its usefulness, and maintaining that radar-absorbent-material coating is killing the budget for no good reason.

Presently the U.S. Air Force is heading for a repeat of the start of World War II when its fighters were shot down by far better Axis aircraft. The qualitative edge in the small number of F-22s won't save the day because they will be overwhelmed by the sheer number of Chinese Flanker variants, as per the Rand study of 2008. There is a solution, but it means going overseas to get it. That has been done before. In the 1950s, the U.S. Air Force had the English Electric Canberra bomber built under license in the US as the Martin B-57. It was a great design, illustrated by the fact that one B-57 was resurrected after 40 years in the boneyard in Arizona and refurbished for battlefield communications in Afghanistan. Thirty years after the B-57, the Marine Corps fell in love with another UK aircraft, the Harrier, and had it built in the US from 1985 as the McDonnell Douglas AV-8B.

The first F-35 to come off the assembly line was in 2006. That was ten years ago. Even though it is still years off from going into full production, the F-35 needs a $3.0 billion modernisation because some of its original systems are now out of date.[13]

The solution to the F-35 nightmare first flew in 2008. This is the Gripen E produced by Saab in Sweden, updated from the original Gripen A that first flew in 1988. It is a delta wing with canards, likely to be the ideal planform for a single-engine, air-superiority fighter. The last time the U.S. Air Force had a delta-wing fighter was the Convair F-106 Delta Dart, retired in 1988. A promising effort that might have resulted in another delta-wing fighter was the F-16XL, a stretched version of the F-16 with a far greater range and bomb load.

Simulation has the Gripen E shooting down the Su-35 at almost the same rate as that of the F-22. The Gripen E is estimated to be able to destroy 1.6 Su-35s for every Gripen E lost, whilst the F-22 is slightly better at 2.0 Su-35s downed per F-22 lost. In turn the Su-35 is better than the F-35, shooting down 2.4 F-35s for each Su-35 shot down. The Su-35 slaughters the F-18 Super Hornet at the rate of eight to one, as per General Hostage's comment. How that comes about is explained by the following graphic of instantaneous turn rate plotted against sustained turn rate.

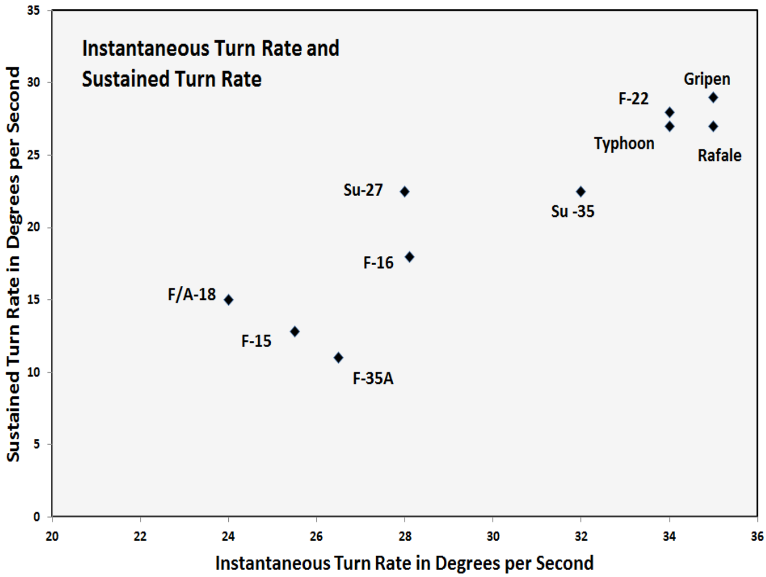

Figure 2: Instantaneous Turn Rate and Sustained Turn Rate

The performance figures for a number of the aircraft on this chart remain classified and the values shown, in some instances, are best estimates from air show performances. Thus, this graphic is a representation of relative performance.

Turning, and carrying a gun, remains as important as it has ever been. Most missiles miss in combat and the fighter aircraft will go on to the merge. Assuming that pilot skill is equal, a 2° per second advantage in sustained turn rate will enable the more agile fighter to dominate the engagement. A high instantaneous turn rate is vital in being able to dodge the air-to-air missiles in the first place. The aircraft on the upper right quadrant of the graph will have a higher survival rate. The ones on the lower left quadrant will produce more widows.

The Gripen E has a US-made engine, the GE F414, which is also the engine of the F-18 Super Hornet. Saab offered the Gripen E to the Dutch Air Force in 2009 for $62 million per copy. [14] Adjusted for inflation, that is about half of the cost of the F-35. Its operating cost per flight hour is one sixth that of the F-35. In fact it is the only fighter aircraft available that meets the selection criteria of the Joint Advanced Strike Technology program that spawned the F-35: that the acquisition and operating costs be not more than 80 percent of that of legacy aircraft.

Saab's partner in the United States is Boeing, which will be without a fighter aircraft offering of its own once the F-18 Super Hornet production line in St Louis closes. It would be surprising if the two companies haven't discussed bringing the Gripen E to America. That would be good news for US power projection in the Western Pacific, and for the families of US airmen. With respect to cost, replacing the entire current inventory of F-15s and F-16s in the U.S. Air Force with the Gripen E would cost about $100 billion—little more than half the cost of the latest F-15 variant.

The story doesn't end there. At the moment the Su-35 is the fighter to beat. It is almost as large as the F-22, with an empty weight of 18.4 tonnes and a maximum takeoff weight of 34.5 tonnes. Its fuel fraction of 38 percent gives it a combat range of 1,000 miles; the F-22's fuel fraction of 29 percent gives it a combat range half that. 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, 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 and two engines, all other parameters being equal.

There is a role for a large, agile, twin-engined fighter aircraft in the Western Pacific. Apart from providing air superiority, such a platform would be ideal for delivering long range anti-ship cruise missiles. But this should not be a resurrected F-22. 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 U.S. 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.

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. That exercise would cost billions but it 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 radar-absorbent-material coating.

President Franklin D Roosevelt called America "The Arsenal of Democracy" and it remains, in Lincoln's words in 1861, "the last, best hope of earth". The actual arsenal is under many pressures. At the same time that the Marines are rehabilitating 30 F-18s from the boneyard in Arizona because of the delay in getting F-35Bs, naval commanders are being rated in their performance evaluations by how much they promote global warming to their subordinates. In effect the warfighters are having to pick amongst scrap for their weapons while the political commissars are running amok. At the same time, the air fleet of all the services is being worn out by the desultory and interminable campaign against ISIS. Beyond all that, the biggest threat to the success next decade, 2020 to 2030, of American arms in battle is not the Chinese DF-21 missile or Chinese anti-ship cruise missiles, but a weapon of our own choosing—the F-35. The F-35 is not too big to fail and the ability to choose more wisely is still in our gift. Thus the purpose of this book: fully informed, let's choose wisely.

Figure 3: F-35A in Flight

The F-35 is wide and draggy due to the requirement for a lift fan for the F-35B version and thus is incapable of supersonic flight without the use of afterburner.

Born Of a Yak

IT HAS BEEN said that the story of the F-35 begins with the Battle of Guadalcanal in 1942. The Marine Corps, undertaking the ground fighting, were upset that the other services weren't providing enough air cover. The pounding they got from the lack of air cover is part of their institutional memory. So when the U.S. Department of Defense decided to build a fifth generation stealth fighter to replace the F-16, the U.S. Marines insisted that this include a short take-off and vertical landing (STOVL) variant. The trade-offs necessary to effect this fatally compromised the whole project so that none of the F-35 variants do their job adequately. Specifically, the requirement to have a lift fan 1.27 meters in diameter on the centerline of the aircraft behind the pilot resulted in two bomb bays instead of just one on the centerline. This made the aircraft wider, draggy, slower, and less maneuverable.

The requirement for STOVL is the F-35's original sin. The requirement was necessary for Lockheed Martin to win the contest to produce the United States' next fighter after the F-22 and potentially lock its competitors out of the fighter market for decades.

The sequence of events that led up to the contract being awarded began in the 1980s. The mainstay of U.S. Air Force fighter dominance was the F-15 which entered service in January

1976, three and one half years after it first flew. The F-15 was primarily designed to be a fast interceptor of Soviet bombers, with a big radar to help find them. It was the first dedicated U.S. Air Force air superiority fighter since the F-86 Sabre that first saw service in 1949. The twin-engined F-15 was followed by the single-engined F-16 with both types using the same Pratt & Whitney engine.

Designers of the F-16 deliberately kept the volume of the aircraft small so it would be hard to increase the aircraft's weight by adding more capabilities, thereby increasing weight and reducing its dogfighting performance. Their motto was "Not a pound for air-to-ground". Such a useful airframe attracted modification though. The original prototype weighed 6.2 tonnes empty; the latest variant, the F-16 Block 60, weighs over 50 percent more than that at 10.0 tonnes. Combined F-15 and F-16 production peaked nearly 30 years ago at 190 aircraft in 1987.

What was to the become the F-35 had its beginning in 1983 as a Defense Advanced Research Projects Agency (DARPA) program to begin looking at the technologies available to design and manufacture a follow-on supersonic replacement for the AV-8 Harrier. The program, known as ASTOVL, would eventually become a joint U.S.-U.K. collaboration. By 1987 it was evident that the technologies available at the time would not allow that objective to be achieved.

Lockheed became involved that year after being approached by DARPA to look into the feasibility of a stealthy supersonic STOVL fighter. By 1993 the program grew from being a replacement for the AV-8 Harrier to become multi-service with multiple variants. It was re-labelled as the Common Affordable Lightweight Fighter (CALF). Although Lockheed conceived the program, the government still wanted multiple contractors involved in the program and thus it was run by DARPA. Lockheed and McDonnell Douglas were the initial contractors involved. They were joined by Boeing which had approached DARPA to be allowed onto the program.

Also in the early 1990s, the U.S. Air Force ran the Multi-Role Fighter program to produce a relatively low-cost replacement for the F-16. However, the end of the Cold War meant that the existing F-16s in inventory were flying less and were therefore going to last longer than expected. This program was cancelled in 1993. The U.S. Navy ran the Advanced Tactical Aircraft (ATA) program from 1983 to produce a long range, stealthy, medim-attack aircraft to replace the Grumman A-6 which had been introduced into service in 1963. This effort produced the A-12 Avenger II; a long range, subsonic flying wing design that could carry air-to-surface and air-to-air ordnance. This program would be cancelled in 1991 after cost and schedule overruns.

Aircraft design in the Soviet Union was on a similar path to what was being attempted in the United States. In 1975, design began on a supersonic VTOL aircraft from the Yakovlev Design Bureau that was to be known in the West as the Yak-141. It first flew in 1989. The Yak-141's innovation was a large exhaust nozzle behind the engine that swung down for hover, supplemented by two jet engines behind the pilot which were only used for vertical flight. By comparison, the AV-8 Harrier achieved vertical lift by swinging down four nozzles. The single, large exhaust nozzle of the YAK-141 was far more efficient for normal flight. The intent was to provide fleet protection for the Soviet Navy. It did indeed take off vertically from the aircraft carrier *Admiral Gorshkov* and it flew supersonically.

The collapse of the Soviet Union meant that funds weren't available to continue developing the YAK-141. Lochkeed came to Yakovlev's assistance with a partnership beginning in 1991. This was announced by Yakovlev on September 6, 1992. Under their agreement, Lockheed was to provide $385 million to $400 million to develop three new prototypes and an additional static aircraft to test improvements in design and avionics. The arrangement was revealed by Lockheed in June 1994. Lockheed's merger with Martin Marietta to form Lockheed Martin was announced in 1995.

The F-35's design heritage from the Yak-141 is most prominent in the tail arrangement. Because a STOVL aircraft needs its centre of lift to be near the centre of mass of the aircraft (supplemented by downward thrust further forward), the engine has to be placed more toward the centre of the aircraft relative to where it is in conventional aircraft. The Yakovlev Design Bureau achieved this by splitting the tail into a twin boom arrangement. The F-35's tail arrangement is not as pronounced though it is very similar. What is amusing is that when the Chinese hacked the plans for the F-35 in 2007 and used them to produce the J-31, they kept the tail arrangement as it was even though the J-31 is a twin-engined aircraft that won't have a STOVL variant.

The F-35B made its debut at the Farnborough Air Show on July 12, 2016. Its progenitor, the Yak-141, had performed the same maneuvers at Farnborough in 1992.

Armed with the Yak-141 design experience and its years of working on STOVL designs with DARPA, Lockheed Martin was ready for the next phase of the fighter selection process. This was the Joint Advanced Strike Technology (JAST) program that began in 1993. JAST was ambitious, setting out to examine force structure, modernisation, affordability and other factors in defining a strategy for defense planning in the post-Cold War era. In 1994, JAST absorbed CALF and became dedicated to producing a "tri-service" family of aircraft using a single basic airframe with three variants: Conventional Take-Off and Landing for the U.S. Air Force; STOVL for the U.S. Marine Corps; and a Carrier Variant for the U.S. Navy. A former Chief of Staff of the U.S. Air Force, Merrill McPeak, has observed that forcing all three services to use a single airframe greatly increased the costs and difficulty of the project.

Contracts to develop prototypes were awarded to Lockheed

Martin and Boeing on November 16, 1996. Boeing's offering, designated the X-32, was an ugly thing nicknamed "the guppy" because of the large intake under its nose. It wasn't able to achieve supersonic flight. The contract to develop the Joint Strike Fighter, which became the F-35, was awarded to Lockheed Martin on October 26, 2001.

Lockheed Martin is building the F-35 at its Fort Worth, Texas, facility. The first production F-35 was built in 2008. It had been decided to begin production before the design was finalised. This concurrent production has been termed acquisitions malpractice. The cost of modifying the aircraft built before the design is finalised is expected to be $60 million per aircraft, more than what the F-35 was supposed to cost in the first place. By 2010, the program's cost overruns resulted in a Nunn-McCurdy breach and the program was re-baselined. As at the end of 2016, some $107 billion will have been spent on the F-35 program and 200 aircraft built, none of which can fly in combat.

The F-35 was originally planned to enter full rate production in 2010. That is now not likely until 2019, if at all. The situation has become serious. The average age of the U.S. Air Force fighter fleet is 27 years and part of the fleet will require expensive service life extension work to keep flying. The good news is that it is now possible for U.S. Air Force generals to publicly cast doubt about the F-35. They are doing this by investigating what it would take to restart production of the F-22.[1] The House Armed Services Tactical Air and Land Forces Subcommittee's markup for its section of the 2017 defense policy bill directs the Secretary of the Air Force to conduct a study of the costs associated with procuring at least another 194 F-22s. The legislation would require a report on the study to the congressional defense committees no later than January 1, 2017. While restarting the F-22 production line is not necessarily crazy, it is sub-optimal.[2]

Any funds applied to restarting F-22 production will be taken from F-35 production. That in turn will make the price of the F-

35 yet more extortionate. For example if F-35 production ceased at 500 aircraft, the $51.5 billion spent to date on research and development will add $103 million to the price of each aircraft, taking the total procurement cost to perhaps $230 million per aircraft. The budgeted cost of F-35s in the 2016 financial year is $131.6 million a copy for the U.S. Air Force variant. It is unlikely to be much lower than that in full production even though the F-35 program office is predicting a price at full rate production of $80 million based on building "learnings" from the ten years of production to date. This is simply not believable.

The high cost of making an F-35 is another consequence of the vertical take-off variant for the Marine Corps. To make that work it had to be as light as possible and therefore the physical volume was as small as possible with the consequence that its innards are packed tighter than a head of cabbage. This explains the high percentage of rework in building as parts already installed are damaged while trying to get more parts added.

While acquisition cost relative to performance should be enough to terminate the F-35 program, the services are also aware that the F-35 is also too expensive to operate. In a study of F-35 sustainment costs, the United States Government Accountability Office calculated that the cost of operating the F-35 across the services would be $19.9 billion per annum which is nearing twice what it costs to operate the aircraft it is meant to replace, namely the F-15, F-16, F-18 and A-10, at $11.1 billion per annum.[3]

The Department of Defense has, once again, learnt that trying to develop a multi-role aircraft ends in tears. Its "Air Superiority 2030 Flight Plan" released in May 2016 contains the following words:

> *Failure to adopt agile acquisition approaches is not an option. The traditional approach guarantees adversary cycles will outpace U.S. development, resulting in "late-*

> *to-need" delivery of critical warfighting capabilities and technologically superior adversary forces;*

And:

> *Additionally, the Air Force must reject thinking focused on "next generation" platforms. Such focus often creates a desire to push technology limits within the confines of a formal program. Such efforts should be accomplished within the S&T portfolio and proven through effective prototyping, harvesting when mature to a sufficient level for transition. Pushing those limits in a formal program increases risk to unacceptable levels, resulting in cost growth and schedule slips. This put such programs at risk of cancellation due to their nearly inevitable underperformance, and results in delivery of capabilities "late to need" by years or even decades.*

The words "put such programs at risk of cancellation due to their nearly inevitable underperformance" will most likely prove to be prophetic with respect to the F-35.

Figure 4: F-35C

While the F-35 has a low radar cross section from head on, the lumpiness of the design under the wings results in a ten-fold increase in radar returns from the side aspect. The F-35 is only a stealth aircraft with respect to a 60° cone around its nose. The F-35C shown above, the US Navy variant, has larger wing and tail surfaces than the A and B variants to give it a lower sink rate for carrier landings, and foldable wings.

Fighter Aircraft Design

THE ORIGINAL JET fighter aircraft, the Messerschmitt ME-262, first flew on April 18, 1941. The first Allied jet, the Gloster E.28/39, had its first flight five weeks later on May 15, 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. The largest fighter aircraft ever was the Tupolev Tu-28 with a maximum takeoff weight of 43 tonnes; it first flew in 1961 and was retired in 1990. Its role was high altitude interception of US bombers. It was followed by the far more maneuverable MiG-25 which first flew in 1964.

The US response to the MiG-25 was 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 50 years, has a maximum take-off weight of 30.8 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 radars grew, the size of the aircraft had to grow with it.[1] The F-15 also had a gun because one of the major lessons of the Vietnam War was that most missiles missed and fighters without a gun as a backup weapon fared poorly.

The Soviet response to the F-15 was the Sukhoi Su-27 with a maximum take-off weight of 30.4 tonnes. The trend to higher take-off weight 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 empty weight of the Sabre and more than the empty weight of the B-29 bomber of World War II of 33.8 tonnes.

At the same time the F-15 was being designed, a group in the U.S. 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 maneuverable and with a high thrust-to-weight ratio. This concept bore fruit as the F-16, also still in production after nearly fifty years. The latest iteration of the F-16, the F-16 Block 60, has an empty weight of 10.0 tonnes and a maximum take-off weight of 20.9 tonnes.

The design philosophy of the F-22 is to achieve air superiority by having a small radar cross section and thus avoid detection by enemy radars, high maneuverability and to be able to 'supercruise' at Mach 1.6. Supercruise is defined as the ability to fly faster than the speed of sound without using the aircraft's afterburner with its consequent fuel penalty. 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 ceased at 187. Two have crashed so there are only 185 still flying. The flyaway cost of the F-22 was $130 million when production stopped in 2011. That is one thing, but they are also quite expensive to fly at $59,000 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 coating. 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.

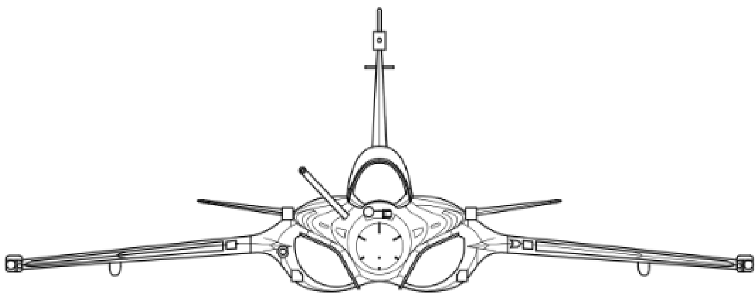

Figure 5: Dassault Rafale

France was originally part of the program that produced the Eurofighter Typhoon but split off in 1981 to preserve its technological base. The Rafale first flew in 1986. Now 30 years old, its avionics have been updated and it has enjoyed strong export sales since 2014. Amongst other attributes, the Rafale combines agility and sensor fusion to produce a formidable fighter aircraft.

Figure 6: F-106 Delta Dart
The Delta Dart was the last delta wing aircraft in U.S. Air Force service. It first flew in 1959 and was retired in 1988. Designed as a specialised bomber interceptor, the Delta Dart carried missiles in internal bays and, as initially designed, neither had a gun nor the ability to carry bombs. Maximum speed was Mach 2.3 at 40,000 feet. The pinched waist was to comply with the area rule which requires that the cross-sectional area of an aircraft going through the transonic region should remain constant. It follows that the fuzelage should narrow where the wings are widest.

Fortunately technological developments have swung the air superiority pendulum back towards the lightweight, highly maneuverable single-engine 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 be highly maneuverable in order to surprise and outmaneuver 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 a high thrust-to-weight ratio. Wing loading is the loaded weight of the aircraft divided by the area of the wings. 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 since it shrinks an enemy's response time after the supercruising aircraft is detected; reduces the effectiveness of the opponent's weapons while increasing the effective range of the supercruising aircraft's weapons; allows the supercruising aircraft to achieve surprise while preventing the enemy from surprising him; and to dictate terms of engagement.

Maneuverability is important in air combat for two reasons: to get the enemy inside one's own engagement envelope, and to avoid being 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 combat, having spent their fuel and flying on inertia alone, would have a low chance of hitting a manoeuvring target. The solution to that problem, adopted by the U.S. Air Force, is the 'two pulse' motor of the AIM-120D. Wind resistance is proportional to the square of the speed of a missile; thus range is increased by trading off a lower peak speed for a longer sustained speed.

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.

Maneuverability in a fighter aircraft requires the ability to begin 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 higher corner speed and thus a higher turn rate and smaller turn radius.

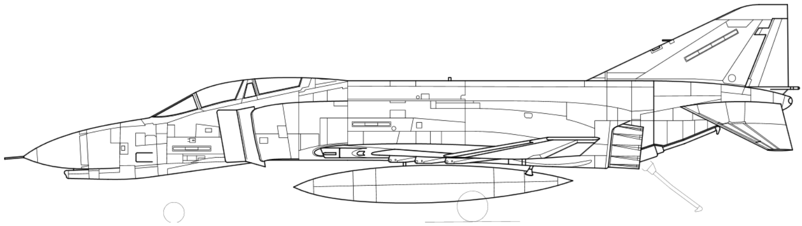

Figure 7: McDonnell Douglas F-4 Phantom
Conceived in the 1950s, the F-4 Phantom first flew in 1958 and entered service in late 1960. Originally developed as a carrier aircraft, the U.S. Air Force also took it to save the cost of developing a separate aircraft. It was designed at a time when it was thought that air-to-air missiles would be highly effective; as such it was designed without an internal gun. Air combat in Vietnam demonstrated that missile effectiveness was one tenth of what it was thought it was going to be. North Vietnamese MiG-17s, MiG-19s and MiG-21s, hardly troubled by the F-4 Phantom's missile fire, would then close for a gun engagement. An external gun pod was later added to the F-4 Phantom. North Vietnamese pilots could easily postively identify the F-4 Phantom because it was the only aircraft in theatre that produced a smoky exhaust trail. Neverthess, F-4 Phantom production continued up to 1981 with a total of 5,195 built.

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 percent greater for a close-coupled canard configuration than for an otherwise identical configuration with no canards, with the canards contributing only 15 percent of the area. Canards also increase the angle the aircraft can fly at without stalling.

That 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 fuzelage 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 maneuverable, especially in roll and changing direction, and so are better able to avoid being hit in the first place. Single-engine fighters have smaller visual and infrared signatures.

A single engine design can have a reduced size and weight and thus a lower procurement cost as well. Maintenance downtime required is also lower. All of this leads to single-engined fighters having significantly lower direct operating costs 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.

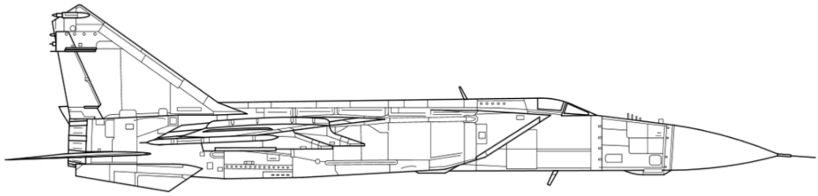

Figure 8: MiG-25 Foxbat

The Soviet Union had a tradition of producing large, long range interceptors. The largest fighter aircraft ever produced was the Tupolev Tu-28 (NATO designation: Fiddler) introduced to service in 1964. Its empty weight was 24.5 tonnes and maximum takeoff weight 43.0 tonnes, about 25 percent larger than the F-22. The Tu-28 was succeeded by the smaller and faster MiG-25 (NATO designation: Foxbat) which first flew in 1964. A satellite photo of the MiG-25 in development spurred the development of the F-15 Eagle. In 1977, the MiG-25 set the all-time altitude record for an aircraft under its own power of 123,520 feet. A Soviet MiG-25 flying out of Egypt in 1971 was measured by Israeli radar as travelling over the Sinai at Mach 3.2, permanently damaging its engines.

More complex aircraft also require extra maintenance personnel: the Gripen E 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).[2]

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 radar-emitting 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—beyond 70 miles 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 percent for the aircraft's gun, 15 percent for the Sidewinder missile (within-visual-range with an infrared seeker), 11 percent for the Falcon missile (beyond-visual-range with an infrared seeker) and 8 percent for the Sparrow missile (beyond-visual-range with a radar receiver).[3]

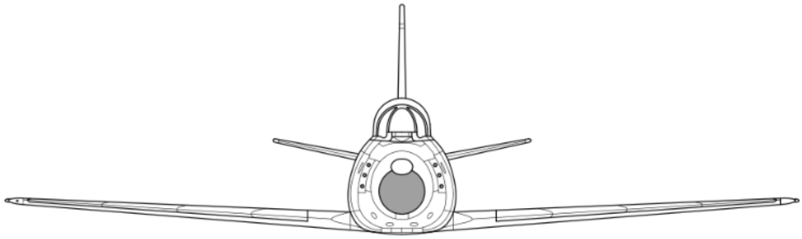

Figure 9: F-86 Sabre
The F-86 Sabre was the first American fighter aircraft with swept wings. It was quite a successful design with 9,860 built in a number of variants. In the Korean War of 1950-1953, the F-86 Sabre was thought to have a 10:1 kill to loss ratio against the MiG-15 which had a similar design and performance. Research subsequent to the end of the Cold War suggest that the the kill to loss ratio was about 1.8:1 against experienced Soviet pilots and much higher against inexperienced Chinese and North Korean pilots. The F-86 Sabre was armed with .50 calibre machine guns which were relatively ineffective compared to the MiG-15's 20mm cannon.

During the Vietnam war, 51 kills were made with guns, 83 kills with heat-seeking missiles and 56 kills 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 percent, indicating that missile reliability had not improved much since the Vietnam War. F-15s performed far better than other Allied fighter types with a radar-guided kill probability of 34 percent—23 kills out of 67 shots, and an infrared missile kill probability of 67 percent—8 kills out of 12 shots.[4] By comparison, the US Navy's F-14s and F-18s achieved a radar-guided kill probability of 4.8 percent—one kill out of 21 shots, and an infrared kill probability of 5.3 percent—2 kills out of 38 shots.

As then Lt. Col. Patrick Highby noted in *Promise and Reality: Beyond Visual Range (BVR) Air-To-Air Combat*, for the last sixty years US fighter aircraft have been designed for the ideal of beyond-visual-range, radar-guided missile combat.[1] His Table 6, reproduced following, shows how that went.

	Total Shots	Total Kills	P_K	BVR Shots	BVR Kills	BVR P_K	Overall BVR Success
US: 65-68 Vietnam	321	26	8.1%	33	0	0.0%	0.0%
US: 71-73 Vietnam	276	30	10.9%	28	2	7.1%	0.7%
Israel: 73 Yom Kippur	12	5	41.7%	4	1	25.0%	8.3%
Israel: 82 Bekaa Valley	23	12	52.2%	5	1	20.0%	4.3%
US: 91 Desert Storm	88	24	27.3%	?	16	?	18.0%
Total	720	97	13.5%	n/a	20	n/a	2.8%

Table 2: Radar Missile Combat Data including Desert Storm

The record was absolutely abysmal up until Desert Storm in 1991. The beyond-visual-range missile used in Desert Storm was the AIM-7 Sparrow, succeeded by the AMRAAM which is also known as the AIM-120. It is unknown how many of the 88 AIM-7 shots in Desert Storm were actually made beyond-visual-range—the language used in the Gulf War Air Power Survey is ambiguous. At most it was 59, since US Navy and US Marine Corps fighters launched 21 (14 and seven, respectively) which resulted in one non-beyond-visual-range kill, while another eight within-visual-range kills were made by U.S. Air Force F-15s using AIM-7s.

One beyond-visual-range kill listed in the the *Gulf War Air Power Survey* required five AIM-7s shots (P_K=20 percent) to down a MiG-23.[5] In another incident on January 17, 1991, two Iraqi Air Force MiG-25s fired missiles at a group of F-15s escorting a bombing run in Iraq. The F-15s evaded the missiles and gave chase and fired a total of 10 missiles against the MiG-25s but were forced to give up when the MiG-25s outran them. Later that decade, on January 5, 1999, two Iraqi MiG-25s violating the southern "non-fly" zone duing Operationg Southern Watch locked their radars on two F-15s, which responded by firing three AIM-7 Sparrows and one AIM-120 AMRAAM. All missiles missed. That was followed by two Navy F-14s firing two AIM-54 Phoenix missiles at the two MiG-25s. Those also missed.

Sometimes even slow, non-manoeuvring aircraft are difficult to shoot down. On July 17, 2016, a UAV flew into Israeli air space from Syria. Two Patriot missiles were fired at it, followed by an air-to-air missile from an Israeli fighter aircraft—all without effect.

U.S. Air Force F-15s also fired 12 AIM-9 Sidewinders during Desert Storm, resulting in eight kills. This is a probability of kill of 67 percent. For the same USAF F-15s, the P_K for AIM-7 Sparrows was only 34 percent (67 shots and 23 kills)—making the AIM-7 half as effective as the AIM-9.

The increased success rate of beyond-visual-range missiles in Desert Storm was due to a combination of factors which are unlikely to be repeated. The main reason was the better air picture than was available in previous wars due to persistant AWACS availability. In many instances the AWACS were able to identify aircraft as hostile and thus allow them to be engaged beyond-visual-range under the rules of engagement. An additional reason for the improved performance of radar-guided missile success in Desert Storm was the fact that Iraqi pilots did not take any evasive action once radar lock occurred. This lack of response to the threat of imminent destruction was either a training failure or equipment failure, or a combination of both. Neither of these factors are likely to be repeated. Russia has developed a number of long range air-to-air missiles with the purpose of downing AWACS and tanker aircraft. China has developed an aircraft, the

J-20, that appears to be designed to dash through the zone where figher aircraft are engaging and take out AWACS and tanker aircraft.

The Iraqi Air Force had a history of staging coups, starting in 1936 when rebellious pilots bombed the office of the prime minister.[6] Saddam Hussein's fear of a coup prompted purges of Iraqi military commands. Iraqi Air Force training had dropped to negligible levels by 1990. Iraqi MiG-29 pilots in particular appeared not to know how to fly, as demonstrated by an early engagement in which a MiG-29 pilot shot down his wingman and then flew his own aircraft into the ground some 30 seconds later. Iraqi MiG-29 pilots reportedly flew with the air-intercept radar button taped down to lock onto the first aircraft detected and continually depressed the trigger to fire their weapons as soon as they acquired a target. Apparently, all Iraqi fighter pilots practiced these techniques for when they managed to lock onto coalition aircraft, they launched their missiles at extreme ranges and missed every time. The US and its allies are unlikely to engage an air force as incompetent as the Iraqi Air Force of 1991 again and thus missile effectiveness should be expected to fall from the peaks established in Desert Storm.

Missile effectiveness during Desert Storm also varied with the service and the platform firing them. According to the *Gulf War Air Power Survey*, at least 20 of the 36 AIM-9 Sidewinder launches from F-16s were accidental. This was due to poor ergonomics on the joystick which was quickly modified. The Navy/Marine F-18 also performed poorly in air-to-air situations in Desert Storm. Combined, the Navy/Marines fired 21 AIM-7 Sparrows and 38 AIM-9 Sidewinders from F-18s and F-14s scoring one kill with a AIM-7 Sparrow (P_K = 4.8%) and two with AIM-9 Sidewinders (P_K = 5.3%). The AIM-9 Sidewinder had performed much better during the Falklands War of 1982 with 27 fired for 24 hits and 19 kills.

In terms of kill probability, guns have a kill probability of between 26 percent and 31 percent, infrared within-visual-range missiles of 15 percent, infrared beyond-visual-range missiles of 11 percent and radar-homing, beyond-visual-range missiles of 8 percent.

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 discovered 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 the possibilities of attacking 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 so they heat up the surrounding airframe. Apart from the engines and their exhaust, there 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 at its front. 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 a missile launch from heating of the missile's nose cone.

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 emitting fighter's presence—and the said area is far larger than one covered by the radar. Not only does it give away a fighter's presence, but if the enemy has good enough listening equipment, it is possible to triangulate the fighter's location and even identify the target through its unique radar signals. Radio communications and datalinks by enemy aircraft can serve the same purpose in locating them.

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-approach warning system, thus allowing only a short time for defensive reaction. If both sides have infrared-search-and-track, advantage 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 any more 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 kilograms. 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 $130 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.

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 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 U.S. 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 have 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.

How To Win In Air-To-Air Combat

John Boyd's Observations on Winning in Aerial Combat:

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

2. Outnumber the enemy in the air.

- lower purchase cost without losing qualitative edge
- lower operating cost per hour of flight
- low maintenance requirement for a higher sortie rate

3. Out-maneuver the enemy to gain firing position.
- low wing loading for a 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

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 percent, of a three missile salvo 27 percent and of a four missile salvo 34 percent. The rate of kill also depends upon the time to generate a firing solution.

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.

A missile's weapon engagement zone, the distance it can travel and effectively engage a target, is enhanced by the launching aircraft's speed and height. If the target aircraft detects the missile launch, it might turn away and attempt to outrun the missile. Once the missile's rocket motor burns out, it is relying upon its inertia which is bleeding off with wind resistance. If the target aircraft jinks from side to side, the missile will lose energy changing direction and might fall short. A missile's no escape zone is the inner part of the weapon engagement zone in which the target aircraft cannot outrun the missile and must either decoy it or out-turn it. Out-turning the missile requires nerves of steel. The target aircraft turns so that the missile is approaching from the aircraft's flank. A couple of seconds before impact, the aircraft turns sharply towards the missile which then might fly by if it isn't able to turn fast enough. The missile will then lose lock. A rule-of-thumb is that an air-to-air missile requires five times the turning ability of the target aircraft for successful engagement; thus if an aircraft is turning at 9g, the missile needs to turn at 45g.

A infrared missile locks on to the strongest point source of infrared radiation which is the hot metal of the aircraft's tailpipe. Approximately 85 percent of the infrared signal generate comes from this hot metal and the remaining 15 percent comes from the jet exhaust. For a target aircraft operating in afterburner, the primary source of radiation is the hot exhaust flame. Approximately 60 percent of the signal generated comes from flame and 40 percent is generated by the hot metal of the tailpipe. One weakness of the AV-8B Harriers operated by the Marine Corps is that lift is generated from swivelling nozzles located mid-fuzelage, making them much more vulnerable to an infrared missile hit than other aircraft. In Operation Desert Storm in 1991, five AV-8Bs were lost during the war, four in combat and one non-combat. By comparison, four out of five F/A-18 Hornets hit with heat-seeking missiles returned to base because the exhaust plume is so far aft that only the nozzles suffered damage.

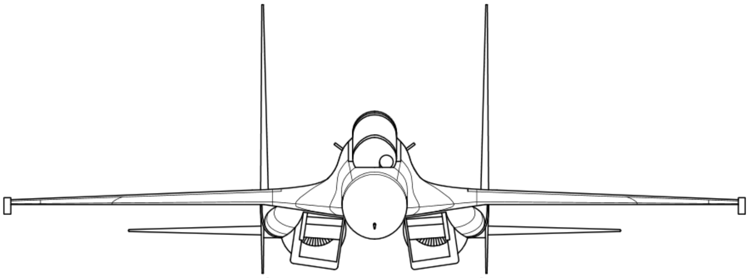

Figure 10: Sukhoi Su-30

The MiG-25 Foxbat prompted the development of the F-15 Eagle which in turn prompted the development of the Su-27 (NATO designation: Flanker) as an air superiority fighter. The Su-27, which first flew in 1977, proved to be a very capable airframe. The bulk of subsequent Soviet and Russian aircraft development is evolution from this platform. The Sukhoi design bureau formed in 1930. In 2006, Sukhoi and most of the other segments of the Russian aviation industry were merged to create a new entity called United Aircraft Corporation. The Su-30 variant shown above was developed as a tandem two-seater for interdiction missions.

The Su-34 is a heavier, side-by-side two-seater variant specialised for air-to-ground work. The T-50 is a stealth version with canted, all-moving tails. Only 12 production T-50 aircraft will be built by 2020. The most capable non-stealth Flanker variant is the Su-35 which is 25 percent larger than the original Su-27. As an indication of how big the Su-35 is, its internal fuel fraction is 11.5 tonnes, equating to 38 percent of the aircraft's takeoff weight. That is more than the empty weight of the F-16. Despite being very large, the Flanker series are also highly maneuverable and can carry a big missile loadout. Increased size also brings with it increased radar, thermal and visual signatures. Some models, even in the same variant, have canards to increase maneuverability whilst others do without them to reduce drag and thus provide longer range. The T-50 variant uses moving leading-edge-root-extensions instead of canards to provide lift at high angles of attack as well as maneuverability.

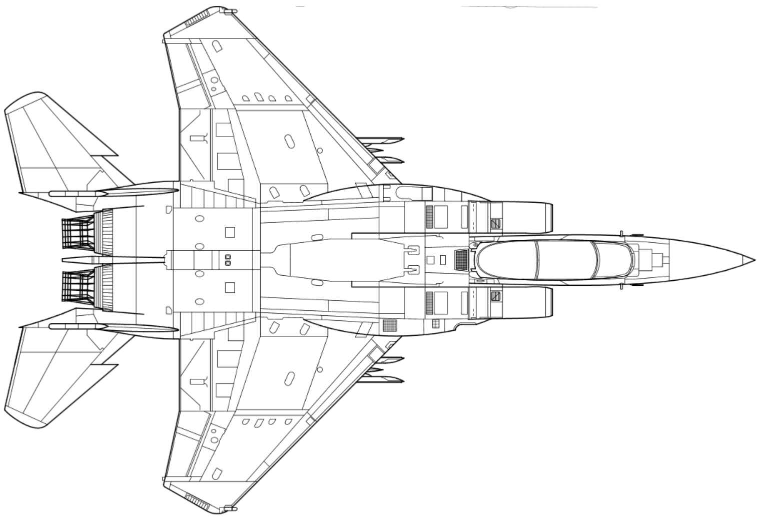

Figure 11: F-15 Eagle

The F-15 was originally purposed as an interceptor; its role was to dash towards Soviet bombers and engage them with radar-guided missiles. The F-15 originally carried four Sparrow missiles. The Japanese Air Force is now re-configuring their F-15 fleet to carry 16 air-to-air missiles.

Sentient Bomb Truck

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 Adolf Galland, Luftwaffe

3.1 Introduction

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 upon, may cost in the order of $30 million per aircraft. In fact, a number of the early production aircraft may not be economically recoverable and are likely to be cannibalized for parts.[1] Some capabilities will not be fully developed until after 2020, the delay being due to software development.

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 STOVL ability, plus the requirement to carry two 2,000 lb bombs interally, resulted in so many trade-offs that none of the variants do their job adequately. The F-35, in all its variants, is wide, draggy with low maneuverability. In short, the F-35 "can't turn, can't climb, can't run." [2]

In fact, the F-35 isn't a fighter aircraft in the first place. It is being sold as a fighter than can hold its own against the Su-30, Su-35, J-11, T-50, J-20, J-31 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 U.S. Air Force, General Mike Hostage, has been quoted as saying, "The F-35 is geared to go out and take down the surface targets."[3] The original requirement that evolved into the F-35 was Battlefield Interdiction and Close Air Support with the intent of being able to deal with lightly defended ground targets after the F-22 knocked out the really dangerous air defenses. That assumes a lot of F-22s are available. But they will not be because production was halted at 187 in 2012. Two have crashed leaving 185 in service.

In the air combat role, General Hostage says, it takes eight F-35s to do what two F-22s can handle. He has further said 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; and:

> *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.*

The F-35's primary role in ground attack is confirmed by its weapons bays with each having 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 are those of the F-22 and F-15E. 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 from a couple of hundred kilometers. 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 kilometers. The Su-35S and the T-50 also have L-Band radar in the wing leading edges that will detect the F-35 and alert the enemy pilot to its presence.

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, an un-aerodynamic airframe and a lack of infrared signature reduction measures. The problem is made worse by the fact that it 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 optimized for ground attack, 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 a 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/cm^2. 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 a high fuel fraction of 0.38. It has a specific fuel consumption of 0.9 lb/lb/hour versus 0.75 for other advanced combat jet engines.

Armament is 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-9 is carried on the wing, eliminating the F-35's radar stealth. 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 the Dassault Rafale, is almost certain to ignite the fuel and catastrophically destroy the aircraft. The engine is likely to ignite the fuel even if the hit itself does not do so.

An attempt to improve the situational awareness of F-35 pilots is its 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 $600,000 per helmet. The system allows the pilot to see through the floor of the aircraft and see the ground underneath. It also analyzes 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 it. 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 the theory, but will not work in practice. The beyond-visual-range AIM-120 missile that the F-35 will carry 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-15 onto targets. 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 24 million lines of code, six times 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 coding, 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 operational. Pilots also wouldn't be able to see below them because the aircraft is too wide. Most fighters have the pilot sitting up where they can see as much as possible. The F-35 pilot's head is down in the fuzelage, like in a bomber.

A good summary of the current status of the F-35's bugs and shortcomings is provided by the U.S.-based Project on Government Oversight (POGO), from a Department of Defense report.[4] The U.S. defense procurement system requires that weapons development programs remain on schedule or they are in danger of being scrapped. The F-35 is well behind schedule but production was begun before testing had 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 will be an expensive retrofitting of completed aircraft estimated to cost $60 billion.

There is an incident described in the POGO report that suggests the F-35 might be fatally flawed because of the compromises made to ensure it flies. In June 2014, there was an engine fire in an taxiing F-35 which resulted in loss of the aircraft. The aircraft that caught fire was damaged three weeks earlier, during two seconds of flight when the test pilot, operating well within the safety envelope of its abilities in a ridge roll maneuver, put G forces, yaw stresses and roll stresses on the aircraft all at the same time. One of the turbine blades was weakened by scraping against the polyamide lining of the turbine and failed three weeks later. 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 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 maneuverability 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 E against the Su-35 results in 1.6 of the Sukhois shot down for each Gripen E lost. The loss exchange ratio of the Gripen E against the F-35 is breathtaking. For each Gripen lost in a Gripen E-on-F-35 exchange, 21 F-35s are shot down.[5]

An issue that affects all the international partners in the F-35 program 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 undertaken in the US. The US government acknowledges that Australia, Britain, Canada, Denmark, Italy, the Netherlands, Norway and Turkey have all expressed dissatisfaction with this unilateral US decision.

How will the F-35 go in actual combat? In the air-to-air role it 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 four beyond-visual-range missiles in its bomb bays. On encountering enemy aircraft, its best chance is to fire those four missiles at the earliest opportunity and then turn tail and run as fast as possible. Firing four beyond-visual-range missiles, each with a probability of kill of eight percent, has a 28 percent chance of downing one enemy aircraft. As General Mike Hostage said, an F-35 that is in an aerial dogfight has made a mistake. They will be "clubbed like baby seals".[2] In 2008, Major Richard Koch, then chief of the U.S. 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."[6], referring to the F-35's designed setup of one missile and one 2,000 lb bomb in each bomb bay.

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 failed to perform as expected; most missiles missed. So the aircraft involved proceeded to the merge in which guns and the pure fighter attributes of maneuverability and turn rate were critical to survival. That remains just as true today.

Worst of all, the F-35 is leaving the United States and its allies with aircraft outmatched by those of its potential enemies, as per the situation going into World War II. Once again, the cost of denial will be considerable. The parallels are captured in this quote from the book *The Paths of Heaven: The Evolution of Airpower Theory*: "De Seversky pointed out that American fighter planes were inferior to those of the other major belligerents. They did not have the speed, range, altitude, or armament to contest with frontline enemy fighters. Yet, press releases emanating from the

Army Air Force, the government, and industry pretended that American planes were the best in the world. De Seversky rejected such claims with disdain: "No one in his senses would pretend that the P-40 is a match for the Messerschmitt or the Spitfire." [7] Alexander de Seversky was a World War I Russian fighter pilot who emigrated to the United States and founded the company that became Republic Aviation Corporation.

3.2 Basing

Despite its loud and powerful engine, the F-35, due to its high wing loading, is likely to require a runway length for take-off at least as long as that required by the F-18 Super Hornet of 5,000 feet. Higher performance fighter aircraft such as the Rafale and the Gripen E can take-off in less than half that distance. By comparison, the Gripen E fighter can operate from airfields as short as 2,500 feet as well as stretches of sealed straight road of that length. Dispersal is important in survivability of the fighter fleet-in-being. The number of available airfields for dispersal rapidly falls away beyond 3,000 feet. 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 percent range. The F-22 is only 50 percent now so it's not much of a reach to make that prediction. Further, the availability, whatever it may start at, 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.*[8]

It is actually a bit worse than that in that F-35 pilots will always be surviving at the minimum number of flying hours per month in order to maintain proficiency in flying the aircraft. So 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.[9]

3.3 Temperature

The F-35 has a fuel temperature threshold beyond which it won't turn on if the fuel temperature is too high. This is because the F-35 uses its fuel to cool its electronics and engine. At the Yuma and Luke U.S. 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.[10]

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 fell 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.

Furthermore, its weapons bays are also affected by high temperatures. According to the Director of Test & Evaluation's 2015 report:

> *Testing to characterize the thermal environment of the weapons bays demonstrated that temperatures become excessive during ground operations in high ambient temperature conditions and in-flight under conditions of high speed and at altitudes below 25,000 feet. As a result, during ground operations, fleet pilots are restricted from keeping the weapons bay doors closed for more than 10 cumulative minutes prior to take-off when internal stores are loaded and the outside air temperature is above 90 degrees Fahrenheit. In flight, the 10 minute restriction also applies when flying at airspeeds equal to or greater than 500 knots at altitudes below 5,000 feet; 550 knots at altitudes between 5,000 and 15,000 feet; and 600 knots at altitudes between 15,000 and 25,000 feet. Above 25,000 feet, there are no restrictions associated with the weapons bay doors being closed, regardless of temperature. The time limits can be reset by flying 10 minutes outside of the restricted conditions (i.e., slower or at higher altitudes). This will require pilots to develop tactics to work around the restricted envelope; however, threat and/ or weather conditions may make completing the mission difficult or impossible using the work around.*[1]

These temperature problems continue once it has landed. With the F-35's multiple, complex on-board electronic systems, it requires a supply of air conditioning that must be very dry air and at a higher pressure than normal commercial, pre-conditioned air requirements. During ground operations, fleet pilots are restricted from keeping the weapons bay doors closed for more than 10 cumulative minutes prior to take-off when internal stores are loaded and the outside air temperature is above 90 degrees Fahrenheit. Another restriction on the weapons bays is that the maximum speed for opening in flight, 550 knots or 1.2 Mach, is less than the maximum speed allowable of 700 knots or 1.6 Mach. This may create advantages for aircraft threatening the F-35. The airspeed at which countermeasures can be used is also less than the maximum speed allowable, again restricting tactical options in scenarios where F-35 pilots are conducting defensive maneuvers.

It also uses 270v DC power instead of the normal 400 Hz of previous aircraft. If the quality of the 270v DC provided from the converter, or the 28v DC E&F safety power circuit is not the perfect voltage, amperage or harmonics at the aircraft plug, it will not accept the power so will not turn on when the ground crew hits the external power switch.[11]

The temperature that the weapons bays reach has not been made public but it is said that is within about 10 degrees Fahrenheit of what the carried missiles can stand. This would be degrading the missiles and bombs carried as well as making it difficult for maintenance crews to rearm the aircraft, as the Navy discovered with the first deployment of F-35Bs to ships at sea. Operators of the F-35 cannot let the aircraft heat-soak on the flight line as is done with other aircraft without a problem.

3.4 Engine

The F-35 has the largest, hottest and heaviest engine ever put into 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 changes to performance specifications for the F-35A, thereby extending acceleration time from 0.8 Mach to 1.2 Mach by eight seconds.

As reported in 2014 by the Government Accountability Office:

> *Data provided by Pratt & Whitney indicate that the mean flight hours between failure for the F-35A engine is about 21 percent of where the engine was expected to be at this point in the program.*

And:

> *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.*[12]

Despite the brave words from the Government Accountability Office 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 two hours. By comparison, the engine in the Gripen E can be replaced in just one hour. The F-35 has many other show-stoppers that would terminate the program in a rational world. Its engine is just one of them.

Further to the engine issue, the F-35 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 role of battlefield bombing.

The average cost of an engine for the Low Rate Initial Production (LRIP) lot 6 was $29.9 million.

3.5 Acquisition Cost

Current cost (2016) of making each F-35 is about $135 million. If the program doesn't meet the baseline for cost, 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 $85 million. The man hours worked to build each aircraft has flattened out at about 70,000, indicating that there are unlikely to be any more possible efficiencies made in building of each aircraft.

The F-35 program was promoted on having 90 percent commonality between its three variants. However, commonality is only about 25 percent. Rather than save money, analysis by RAND Corporation made the stunning find that the cost of the F-35 program actually exceeds likely costs for three separate aircraft models by between 37 percent and 65 percent.[13]

In May 2011, the Pentagon's then top weapons buyer, now Secretary of Defense, Ashton Carter, said that the then latest price estimate of $133 million per aircraft meant it was not affordable.[14] The price hasn't changed and so the F-35 remains unaffordable.

3.6 Operating Cost

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.

At page 28 of the Government Accountability Office report dated September 2014, *F-35 Sustainment: Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates*[12], it is written:

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.*

At page 29 it says:

> *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 approval for production is possible, but most unlikely.

3.7 Distributed Aperture System—Electro Optical Targeting System

The F-35 attempts to increase the pilot's situational awareness through a number of systems. This includes the Distributed Aperture System—Electro Optical Targeting System (DAS-EOTS) which 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 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 infrared-search-and-track is like comparing the naked eye to a telescope.

The F-35's DAS-EOTS is 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 has 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 ground-based targeting controllers. 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 F-35's DAS-EOTS system 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 from 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.*

3.8 Maneuverability

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 decreased its utility as a fighter aircraft, as well as making it so densely packed that construction and maintenance are difficult.

Apart from the impact of maneuverability on using guns in combat, the dense design 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.

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 now having flown for ten years.[15] This was in early 2015 against an F-16 carrying wing tanks. The F-16 - a 40-year-old design - bested the F-35, as analysis of this match up would predict.

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 maneuver. "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 maneuver 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 maneuver 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 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.

All this meant 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-35 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 unscripted against F-18 Super Hornets, the F-15, the F-22 and Su-27. The fact that the F-35 hasn't been pitted against other fighter types indicates that the result would not be subject to doubt—the F-35 would be found to be grossly deficient.

The U.S. Air Force and the F-35 program office occasionally release reports of the F-35 prevailing in mock combat but these are highly scripted to favor the F-35. For example the opposing aircraft will be required to have their radars operating. In which case the F-35s' radars can detect the opposing fighters from 300 km and fire their AIM 120-D radar-guided, beyond-visual-range missiles once they are in range, with each missile credited with a kill probability of perhaps 70 percent. Under such conditions, as long as the F-35s are not outnumbered by more than 1.4 to 1.0, then they are in no danger. That is important because once they have fired their two missiles (on a bombing run), they have nothing left with which to protect themselves. The F-35 does have a gun but every other fighter aircraft flying is more agile than the F-35 so it will never be able to bring its gun to bear. At the same time it doesn't have enough rounds for its gun to be useful for ground support strafing.

What is more likely to happen is that the enemy fighters will operate without using their radars. The enemy may be cued by ground-based VHF radars, which can detect the F-35s from several hundred kilometres away, to a search box of perhaps a cubic kilometer of airspace. Or the enemy fighters may be Su-35s or T-50s with L band radars on their wings which, while not providing precise-enough data for a targeting solution, will provide cueing data for their infrared-search-and-track sensors. So the F-35s are more likely to be targeted before they know that there are enemy aircraft rapidly approaching at Mach 1.6, the supercruise speed of a Su-35. The F-35 is effectively limited to Mach 0.9 because trying to go supersonic triples its fuel consumption rate.

As long as the Su-35s are not outnumbered by more than 2.4:1, only Su-35s will be left flying after the engagement. Bombing of allied ground and naval units would start soon after.

3.9 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 4.0 hours for the F-35A. The target number of hours for this measure is 20 hours for Initial Operational Capability. The Mean Corrective Maintenance Time for Critical Failure (MCMTCF) for the F-35A is 15.6 hours, against an Initial Operational Capability 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 previous year of 9.3 hours.

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

3.10 Pilot Training

To be proficient in combat requires at least 20 hours a month flying, as opposed to use of simulators.

The NATO minimum is 15 hours per month. Royal Air Force flying hours for jet pilots is 17.5 per month on average. Of these hours, 12–14 hours per month are felt to be a safety-of-flight minimum (instruments, take-offs, landings). The Royal Air Force also feels the additional increment for military elements of flying should be about three hours per month.[16]

Normally, French fast jet pilots receive 15 flying hours per month. But budget demands are reducing this to 12.5 hours.[17] Proficiency is to be maintained by having pilots fly fast turboprop aircraft also. China claims to have increased the flight time for its pilots to 200 hours per annum, which is 16.7 hours per month.

3.11 Noise

The F-35 is more than four times louder than the F-16. For the 94 decibel peak noise level produced by the F-16, the allowed time duration for a worker to that level of noise is one hour each day. For the 115 decibels produced by the F-35, the allowed time duration for worker exposure is only 28 seconds per day.

3.12 Helmet

The F-35's helmet-mounted display system (HMDS) projects threat information, flight instrument readout, and almost 360-degree video and infrared images of the world around the pilot onto the pilot's visor. 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. However, the Director of Operational Test and Evaluation has found 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.*[1]

And, 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 of turbulence and buffeting, that can cause display issues (particularly dangerous when the F-35 is manoeuvring to evade an enemy missile shot), decreased night-vision acuity, and information sharing when three or four aircraft fly together. Latency is the problem of the displayed image lagging the movement of the pilot's head. Due to the latency problem pilots have to "learn" an acceptable head-movement rate; that is, they cannot move their heads too rapidly due to the projected imagery lagging head movement.

All of these problems mean that the pilot cannot rely on the helmet display to provide adequate situational awareness in combat. This is of particular concern for rear hemisphere threats, since the unusually wide fuzelage and solid bulkhead directly behind the pilot's head means he cannot see below or behind 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.

Tellingly, some F-35 pilots prefer not to use the helmet because the system isn't as precise as the naked eye in seeing small objects such as approaching aircraft or missiles.

3.13 Injury on Ejection

The 2015 US Department of Defense's Director, Operational Test and Evaluation report explains:

> *After the latter failure, the program and Services decided to restrict pilots weighing less than 136 pounds from flying any F-35 variant, regardless of helmet type (Gen II or Gen III). Pilots weighing between 136 and 165 pounds are considered at less risk than lighter-weight pilots, but at an increased risk (compared to heavier pilots). The level of risk was labelled "serious" risk by the Program Office based on the probability of*

> *death being 23 percent and the probability of neck extension (which will result in some level of injury) being 100 percent. Currently, the program and the Services have decided to accept the risk to pilots in this weight range, although the basis for the decision to accept these risks is unknown.*
>
> *The testing showed that the ejection seat rotates backwards after ejection. This results in the pilot's neck becoming extended, as the head moves behind the shoulders in a "chin up" position. When the parachute inflates and begins to extract the pilot from the seat (with great force), a "whiplash" action occurs. The rotation of the seat and resulting extension of the neck are greater for lighter weight pilots.*[1]

What this means is that the death rate from ejection is too high for pilots weighing less than 136 pounds. This falls to 23 percent between 136 pounds and 165 pounds though the incidence of neck injury is 100 percent. The report did not say what the incidence of neck injury was for pilots weighing more than 165 pounds. But there will also be a death rate in that weight class. If there is a death rate from neck extension, there will also be a quadriplegia rate amongst ejecting pilots who aren't killed outright. In the Western Pacific, most of the pilots will be ejecting over water and it will be a struggle to survive in the sea with a neck injury.

3.14 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 coming years. 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."; and "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.*[18]

Michael Gilmore, Director of Operational Test and Evaluation for the Department of Defense, in his 2015 annual report wrote of the block buy proposal:

> *Is it appropriate to commit to a "block buy" given that essentially all the aircraft procured thus far require modifications to be used in combat? Although still officially characterized as low-rate, F-35 production rates are already high. Despite the problems listed above, F-35 production rates have been allowed to steadily increase to large rates, well prior to the IOT&E and official Full-Rate Production (FRP) decision. Due to this concurrency of development and production, approximately 340 aircraft will be produced by FY17 when developmental testing is currently planned to end, and over 500 aircraft by FY19 when IOT&E will likely end and the FRP milestone decision should occur. These aircraft will require a still-to-be-determined list of modifications in order to provide full Block 3F combat capability. However, these modifications may be unaffordable for the Services as they consider the cost of upgrading these early lots of aircraft while the program continues to increase production rates in a fiscally-*

> *constrained environment. This may potentially result in left-behind aircraft with significant limitations for years to come.*

The decision to proceed with production of the F-35 prior to completion of the design contravenes the Department of Defense's weapons systems acquisition process.[19] Some of the early production aircraft cost $207.6 million each. Mr Gilmore's report reveals that they may not be economically recoverable because the Department of Defense might not be able to afford to rebuild them to the final specifications of the aircraft and pay for new-build aircraft at the same time.

Lockheed Martin and the Pentagon are currently negotiating pricing for batch 10 of low rate initial production of the aircraft. Despite the company's claim that the cost of building the F-35 is coming down, they and the Pentagon are haggling over cost. Lockheed Martin claims that it has had to borrow $900 million to keep the production line going in the interim.[20] Over the last five years Lockheed Martin has spent $10 billion on share buybacks and intend to outlay up to $3 billion more on share buybacks.

The U.S. Air Force has a stated goal of acquiring a fleet of 1,763 of the F-35A. With respect to that stated goal, this assessment from Todd Harrison, the defense budget expert at the Center for Strategic and International Studies, is telling:

> *I don't think it's plausible that we'll actually buy that full amount in the long run, but they don't need to change their plans right now, they don't need to scare the foreign partners by signalling that right now, it wouldn't make sense to do it now."*; and, *"You don't have to make that decision on the total quantity, you don't even have to make the decision on the full-rate production, until four or five years from now. So you can wait four or five years, more of the foreign partners*

> *will get deeply invested in the program, and then they can scare them.* [21]

Reading between the lines, the remaining momentum in the F-35 program may be largely about selling the deficient, $135 million machines to foreign militaries. The F-35's software won't be fully developed until 2022, enabling it to use all its weapons. In the meantime the program could be terminated and the planes produced in the proposed 'money-saving' block buy will be truly left as orphans. This is not the way to run a great nation.

3.15 Verification Simulation

It is possible to model the likely performance of fighter aircraft in combat using computer simulation based on the characteristics of the aircraft involved. The best known example of computer simulation of the F-35 in combat was Rand Corporation's 2008 study entitled *Air Combat, Past, Present and Future* by John Stillion and Scott Perdue which analyzed the likely outcome of an air war between the United States and China fought over the East China Sea.[2] They concluded that the United States would most likely be defeated due to the poor performance of the F-35.

The analysts pointed out (slides 79 and 80) that the F-35 is optimised for strike, not air-to-air manoeuvring combat. Its thrust loading is significantly inferior to the F-15, F-16 and F-22, with slower acceleration, slower climb and more energy bleed in tight turns. The F-35's high wing loading is comparable to that of the F-105 Thunderchief which had been nicknamed the "lead sled". Thus the F-35 is less agile and requires higher thrust to maintain a given turn radius and speed. Stillion and Perdue concluded that the F-35 is "Double Inferior" to modern Russian/Chinese fighter designs in visual range combat with inferior acceleration, inferior climb and inferior sustained turn capability. It also has a lower top speed and can't turn, can't climb, can't run. Based on the simulation undertaken for the Rand study, it was evident that in combat the F-35s will be "clubbed like baby seals". In fact, knowing how defenceless F-35s are may make Flanker pilots far more aggressive in combat. Going up against the F-35 would be their best chance of getting to ace status.

Simulations are important; properly heeded they can save the waste of tens of billions of dollars on weapons systems that won't work. That was the danger for Lockheed Martin. By 2008 they had been chasing the dream of dominating the Western world fighter aircraft market for 20 years. The prospect of having a researcher at the well-regarded Rand Corporation continuing to "lob bombs" into their camp was intolerable. So Dr Stillion was fired from Rand Corporation. He subsequently gained employment with Northrop Grumman.

Lockheed Martin still had a problem with simulation. Because simulation can save the wastage of tens of billions of dollars on weapons systems that won't work, the defense procurement process requires simulation studies to be conducted on programs as large as the F-35. How Lockheed Martin handled that problem with its most likely lethal result is best explained by quoting the Director of Operational Test & Evaluation's 2015 annual report at length; a tale within a tale:

> *Due to inadequate leadership and management on the part of both the Program Office and the contractor, the program has failed to develop and deliver an adequate Verification Simulation (VSim) for use by either the developmental test team or the JSF Operational Test Team (JOTT), as has been planned for the past eight years and is required in the approved TEMP.*
>
> *Neither the Program Office nor the contractor has accorded VSim development the necessary priority, despite early identification of requirements by the*

JOTT, $250 Million in funding added after the Nunn-McCurdy-driven restructure of the program in 2010, warnings that development and validation planning were not proceeding in a productive and timely manner, and recent (but too late) intense senior management involvement. As a result, VSim development is another of several critical paths to readiness for IOT&E.

The Program Office's subsequent decision in September 2015 to move the VSim to a Naval Air Systems Command (NAVAIR) proposal for a government-led Joint Simulation Environment (JSE) will not result in a simulation with the required capabilities and fidelity in time for F-35 IOT&E. Without a high-fidelity simulation, the F-35 IOT&E will not be able to test the F-35's full capabilities against the full range of required threats and scenarios.

Nonetheless, because aircraft continue to be produced in substantial quantities (essentially all of which require modifications and retrofits before being used in combat), the IOT&E must be conducted without further delay to demonstrate F-35 combat effectiveness under the most realistic conditions that can be obtained. Therefore, to partially compensate for the lack of a simulator test venue, the JOTT will now plan to conduct a significant number of additional open-air flights during IOT&E, in addition to those previously planned. In the unlikely event a simulator is available in time for IOT&E, the additional flights would not be flown.

VSim is a man-in-the-loop, mission systems software in-the-loop simulation developed to meet the operational test requirements for Block 3F IOT&E. It is also planned by the Program Office to be used as a venue for contract compliance verification prior to

IOT&E. It includes an operating system in which the simulation runs, a Battlespace Environment (BSE), models of the F-35 and other supporting aircraft, and models of airborne and ground-based threats.

After reviewing a plan for the government to develop VSim, the Program Office made the decision in 2011 to have the contractor develop the simulation instead.

The Program Office began a series of tests in 2015 to ensure that the simulation was stable and meeting the reduced set of requirements for limited Block 2B operational activities. Though the contractor's BSE and operating system had improved since last year, deficiencies in specific F-35 sensor models and the lack of certain threat models would have limited the utility of the VSim for Block 2B operational testing, had it occurred. The program elected instead to provide a VSim capability for limited tactics development.

The Air Force's Air Combat Command, which is the lead for developing tactics in coordination with the other services, planned two VSim events for 2015.

Air Combat Command completed the first event in July which included one- and two-ship attack profiles against low numbers of enemy threats. This event was planned to inform the tactics manual that will support IOT&E and the operational units, but validation problems prevented detailed analysis of results (i.e., minimum abort ranges).

The second event, led by the JOTT with Marine Corps pilots flying, was completed in October 2015 for the limited use of data collection and mission rehearsals to support test preparation for IOT&E. While valuable lessons were learned by the JOTT and the Marine Corps, the lack of accreditation made it impossible for the

JOTT to make assessments of F-35 system performance.

Verification, Validation, and Accreditation (VV&A) activity completely stalled in 2015 and did not come close to making the necessary progress towards even the reduced set of Block 2B requirements.

Less than 10 percent of the original validation points were collected from flight test results, and a majority of those showed significant deviations from installed system performance. The vehicle systems model, which provides the aircraft performance and flying qualities for the simulation, and certain weapons and threats models, were generally on track. However, mission systems, composed of the sensor models and fusion, had limited validation data and were often unstable or not tuned, as required, to represent the installed mission systems performance, as measured in flight-testing.

The contractor and program management failed to intervene in time to produce a simulation that met even the reduced set of user requirements for Block 2B and, although they developed plans to increase VV&A productivity, they did not implement those plans in time to make a tangible difference by the time of this report. As the focus changed to Block 3F and IOT&E, the contractor and the Program Office made little progress; no VV&A plans materialized, data that had been collected were still stalled at the test venues awaiting review and release, alternative data sources had not yet been identified for new threats, and contract actions needed to complete VSim for Block 3F IOT&E were not completed.

In September 2015, the Program Office directed a change in responsibility for VSim implementation, reassigning the responsibility from the contractor, *Lockheed Martin, to a government team led primarily by NAVAIR. This was triggered by a large increase in the contractor's prior proposed cost to complete VSim, a cost increase which included work that should already have been completed in Block 2B and mitigations intended to overcome prior low productivity. The path to provide an adequate validation of the simulation for Block 3F IOT&E carries risk, regardless of who is responsible for the implementation of the simulation. That risk was increased by the Program Office's decision to move the simulation into a government controlled (non-proprietary) facility and simulation environment.*

After analyzing the steps needed to actually implement the Program Office's decision to move the VSim to the JSE, it is clear that the JSE will not be ready, with the required capabilities and fidelity, in time for F-35 IOT&E in 2018.

It is also clear that both NAVAIR and the Program Office significantly underestimated the scope of work, the cost, and the time required to replace Lockheed Martin's proprietary BSE with the JSE while integrating and validating the required high-fidelity models for the F-35, threats, friendly forces, and other elements of the combat environment.

The JSE proposal abandons the BSE that is currently running F-35 Block 2B. The JSE proposal does not address longstanding unresolved issues with VSim, including the ability of the program to produce validation data from flight test, to analyze and report comparisons of that data with VSim performance, and to "tune" VSim to match the installed system performance demonstrated in flight-testing.

While the JSE might eventually reach the required level of fidelity, it will not be ready in time for IOT&E

since the government team must re-integrate into the JSE the highly detailed models of the F-35 aircraft and sensors, and additional threat models that the contractor has "hand-built" over several years.

The current VSim F-35 aircraft and sensor models interact directly with both the BSE and the current contractor's operating system. A transition to the JSE will require a re-architecture of these models before they can be integrated into a different environment. The need to do this, along with the costs of contractor support for the necessary software models and interfaces, will overcome the claims of cost savings in NAVAIR's proposal.

The highly integrated and realistic manned "red air" simulations in VSim, which were inherited from other government simulations, cannot be replicated in the limited time remaining before IOT&E.

The large savings estimates claimed by NAVAIR as the basis for their JSE proposal are not credible, and, the government team's most recent estimates for completion of the JSE have grown substantially from its initial estimate. Nearly all the costs associated with completing VSim in its current form would also transfer directly to JSE, with significant additional delays and risk. Any potential savings in the remaining costs from government-led integration are far outweighed by the additional costs associated with upgrading or building new facilities, upgrading or replacing the BSE, re-hosting the F-35 on government infrastructure, and paying Lockheed Martin to build interfaces between their F-35 models and the JSE.

The JSE proposal adds significant work and schedule risk to the contractor's ability to deliver a functioning and validated Block 3F aircraft model in *time for IOT&E. Besides being required to complete integration of Block 3F capabilities, validate the simulation, and tune the sensor models to installed system performance, the contractor must also simultaneously assist the government in designing new interfaces and re-hosting the F-35 and hand-built threat models into the JSE to all run together in real-time so they can be validated and accredited.*

Abandoning VSim also affects the F-22 program, as the various weapons and threat models being developed were planned to be reused between the two programs. The upcoming F-22 Block 3.2B IOT&E depends on the BSE currently in development. For the reasons listed above, the Program Office's decision to pursue the NAVAIR-proposed JSE, without the concurrence of the operational test agencies (OTAs) or DOT&E, will clearly not provide an accredited simulation in time for F-35 IOT&E, and the OTAs have clearly expressed their concerns regarding the risks posed to the IOT&E by the lack of VSim.

Nonetheless, so as not to delay IOT&E any further while substantial numbers of aircraft are being produced, DOT&E and the OTAs have agreed on the need to now plan for the F-35 IOT&E assuming a simulator will not be available. This will require flying substantial additional open-air flights for tactics development, mission rehearsal, and evaluation of combat effectiveness relative to previous plans for using VSim. Even with these additional flights, some testing previously planned against large-scale, real-world threat scenarios in VSim will no longer be possible.

In short, Lockheed Martin got around the problem of simulation possibly derailing its scheme to dominate the fighter market by getting the F-35 program office to give it the task of evaluating its own product. It then dragged its heels for several years, despite having been given $250 million to help with the task. Eventually the F-35 program office realised that it had a problem, so it transfered the job to a Naval evaluation unit, but too late for the job to be undertaken properly and in time. Thus the last words are worth repeating because they are so prophetic: “some testing previously planned against large-scale, real-world threat scenarios in VSim will no longer be possible.” That sounds very like the simulation of a large scale engagement between U.S. Air Force fighters and Chinese fighters conducted by Stillion and Perdue in 2008. The consequence may be that a real world engagement will occur before a computer simulation is conducted and the real world results will be absolutely disastrous.

Cost is one of the factors that could yet kill the F-35 program. Another is the results of simulation studies showing that the F-35 is useless no matter what the cost. That would be part of the reason that Lockheed Martin is keen to sign up its customers for a block buy—to lock them into buying some aircraft before the results of simulation by an independent body become available.

This is why Lockheed Martin CEO, Marilyn Hewson, was paid $28.6 million in 2015. These people certainly aren’t amateurs.

Why Not The F-16?

THE F-35 WAS originally scheduled to be in full rate production in 2010. That doesn't start now until 2019, if at all. At the same time, the aircraft is so expensive that the U.S. Air Force has cut its buy to a maximum of 60 aircraft annually. At that rate its fighter fleet will continue to age and shrink, as foretold by Chuck Spinney in 1991.[1] Late, or too expensive, or ineffective when it does arrive, the F-35 has produced gaping capability gaps in air forces throughout the Western World.

One proposal to alleviate the problem is to buy more F-16s and F-15s while their production lines are still operating. The F-16 is made by Lockheed Martin on a production line in Fort Worth that has produced over 4,500 of them in the last 45 years. The line is scheduled to close at the end of 2017 after the completion of an order for 36 F-16s for the Iraqi Air Force. An indication of pricing was provided by a potential order for Pakistan of eight aircraft for $700 million, equating to $87.5 million per copy.

The F-15 is made by Boeing at its St Louis production line, along with the F-18 Super Hornet. Boeing is currently making F-15s to fill a large Saudi order, and it may obtain a follow-on to Qatar for 36 aircraft. After taking some F-35s, Israel has requested more F-15s for its air force. The fact that Israel is a customer for the F-35 doesn't mean that this astute and experienced operator of fighter aircraft thinks that the F-35 is desirable. Israel gets $3.0 billion of military aid each year from the United States on the proviso that this is spent on US-made arms, as does Egypt. Israel has made the best it can of the situation with some of its own modifications to the F-35s it was allocated. But it would rather have more F-15s so that is what it has asked for.[2]

Kuwait has requested 28 F-18s at an estimated cost of $3 billion, which is just over $100 million per copy. The US Navy requested two F-18s in its 2017 budget and 14 more as part of its 'unfunded priorities list'. Instead of funding the Navy priority, the Pentagon asked for two F-35s in excess of its planned buy in its 2016 fiscal budget submission, and Congress added 11 more aircraft in the omnibus spending bill, none of which can be used in combat.[3]

Lockheed Martin maintains a stable of 95 lobbyists in Washington. Its board includes a former vice chairman of the Joint Chiefs of Staff, Joseph Ralston, and a former Commander, Air Force Materiel Command, Bruce Carlson. Back in 2011, nearly one in ten congressmen belonged to the F-35 caucus. Now that group is down to two, Kay Granger of Texas and John Larson of Connecticut. Defense lobbyists in Washington as a whole have been spending about $130 million annually. Contributions from the defense lobby to members of Congress total another $28 million, rising from an average of $10,000 per annum in 1990 to over $40,000 per annum per congressman in 2016, at least to the Republican ones. There are much higher individual totals. Congressman Mac Thornberry (Republican—Texas) received $357,500 in the 2016 year.[4] Senator John McCain (Republican—Arizona) received $314,115. Appendix 7 lists the top 20 members of Congress in terms of contributions received from the defense sector.

That explains how the unneeded F-35s attracted funding. If not spent on the F-35, those funds should not go to the F-18. The current version of the F-18, the Super Hornet, is actually a light bomber with only about 25 percent commonality with the original F-18A. Because F-18 Super Hornet is a sluggish light bomber with poor maneuverability, the Su-35 is modelled as being able to shoot it down at the rate of eight F-18s lost for each Su-35 downed. The Gripen E is modelled as being able to shoot down the F-18 with a loss-exchange rate of 21 to one. The other Euro-canards, the Rafale and the Typhoon, are likely to do much the same. Conceived as a light bomber, the F-18 Super Hornet would be best tasked to delivering anti-ship cruise missiles out at sea where it is unlikely to encounter enemy fighters.

This leaves us with the F-15 and F-16. Before the F-15 there was the F-4 which had entered service in 1960. The F-4, called the Phantom, was designed for the US Navy as a two-seat, twin-engine, long range interceptor and light bomber. Then Defense Secretary Robert McNamara instructed the U.S. Air Force to take the F-4 as well rather than develop its own interceptor. This was a cost-saving measure. The design philosophy of the F-4 was that it would detect enemy aircraft at beyond-visual-range using its powerful fire control radar and then engage them with Sparrow semi-active radar-guided missiles. It didn't carry a gun because it was thought that all combat would involve aircraft flinging missiles at each other at long range with no enemy aircraft surviving to the merge. This concept sounds exactly the same as the operational philosophy of the F-35—that all its combat will take place at beyond-visual-range and that it will be untroubled by something as 20th century as enemy aircraft firing guns at them.

The F-4's design philosophy was soon tested in the skies of North Vietnam. The North Vietnamese air force was equipped with MiG-17s and MIG-21s which are small aircraft designed for close-in dogfighting. The F-4 performed poorly, achieving a 1.5 to one kill ratio, much worse than the results of the F-86 Sabre against the MiG-15 in Korea ten years earlier. There were a number of reasons for this. The MiGs could detect the F-4s by the black smoke of their exhaust trails. The F-4s were the only fighter aircraft in the theater that produced black smoke so that provided a positive visual identification for North Vietnamese pilots. In fact the F-4 had a clear sky detection range of 15 to 20 nautical miles. For the F-4 pilots, if the MiGs were below them then they were hard to detect by radar against ground clutter.

The U.S. Air Force became puzzled as to why they were losing so many aircraft to Atoll missile attacks from MiG-19s and MiG-21s over North Vietnam. The reason why was that the small aircraft, with a visual detection range of five nautical miles, could get to within-visual-range and fire before being seen by the F-4s. North Vietnam Air Force tactics were to use fighter-control to come into the rear of U.S. Air Force/ U.S. Navy formations, get to Atoll range, fire and depart. The Sparrow missile's probability of kill was abysmal, and firing beyond-visual-range on a small retreating target is difficult.

The Sparrow missiles entered the war with the supposed ability to shoot down 70 percent of the aircraft they were fired against. The reality fell well short of that at between eight and 11 percent. Infrared-guided missiles were better but that required getting behind a MiG to lock onto its exhaust. MiGs were more agile so that was difficult to do. The lack of a gun meant the F-4 could not take advantage of fleeting moments of opportunity when it might have been able to have a snap-shot at a MiG.

The solution adopted for that problem was an externally mounted pod containing a gun with the pod being powered by a propeller spinning in the air stream. Thus the parallels between the F-4 and the F-35 continue. While the U.S. Air Force variant, the F-35A, has an internal 25mm gun with 182 rounds, the Marine Corps and US Navy variants, the F-35B and F-35C, carry their gun externally in a pod with 220 rounds. This is due to weight and internal fuel requirements, with the idea that the gun pod will only be mounted when the mission requires it. The other major lesson from the Vietnam War was that most missiles missed. Because most situationally aware fighters evaded missiles flung at them, they survived to the merge and then maneuverability became as important as ever. It seems that all these lessons will be relearnt at a heavy price.

The U.S. Air Force began looking for a fighter aircraft to replace the F-4 in 1965, issuing a request for proposals on December 8 of that year. This became the Fighter-Experimental project. Nothing of great siginificance happened until July 1967 when the Soviet Union unveiled a new generation of combat aircraft at Domodedovo airfield, near Moscow. These included the MiG-25 Foxbat, a twin-engined, twin-tailed fighter aircraft capable of Mach 2.8. This motivated the U.S. Air Force to reissue their request for proposals for the Fighter-Experimental project the following month.

By September 1968 the U.S. Air Force's requirements had tightened to the new fighter aircraft having a low wing loading with buffet-free performance at Mach 0.9, a high thrust-to-weight ratio, long-range pulse-Doppler radar with look-down/shoot-down capability, a ferry range sufficient to permit deployment to Europe without mid-air refuelling, and a maximum speed of Mach 2.5. On December 23, 1969, the McDonnell Douglas proposal won the selection contest and the first flight came three years later, on July 27, 1972. The F-15 production line is still functioning 45 years later. McDonnell Douglas merged with Boeing in 1996.

Nevertheless, the chief designer of the F-16, Harry Hillaker, considered that the F-15 wasn't a technological advance.[6] In his words:

> *There have been debates through the years about just how much technology should be incorporated in any design. The real issue isn't technology versus no technology. It is how to apply technology. For example, the F-15 represents a brute-force approach to technology. If you want higher speeds, add bigger*

> *engines. If you want longer range, make the airplane bigger to increase the fuel capacity. The result is a big airplane. The F-15 was viewed as highly sophisticated because it is so big and expensive. In my mind, the F-15 wasn't as technically advanced as the F-4.*

By comparison the Hillaker team on the F-16 went the other way:

> *The F-16 is much more of an application of high technology than the F-15. We used the technology available to drive the given end, that is, or was, to keep things as simple and small as we could. Our design was a finesse approach. If we wanted to fly faster, we made the drag lower by reducing size and adjusting the configuration itself. If we wanted greater range, we made the plane more efficient, more compact.*

The F-16 had its origin in the decline in the loss-exchange ratio from ten-to-one in the Korean War to 1.5-to-one in the early stages of the Vietnam War. The U.S. Air Force response was to launch a program called the Advanced Day Fighter, which set out to develop a 25,000 pound fighter with a thrust-to-weight ratio high enough and a wing loading low enough to maintain a 25 percent superiority over the MiG-21. This was the time that Colonel John Boyd developed his theory of Energy Maneuverability which demonstrated the need for agility in fighter aircraft. Specifically, the theory stated that fighter aircraft should maintain their energy as much as possible in changing direction. This, in turn, allowed a pilot to get inside his adversary's decision-making cycle, which Boyd termed the Observation-Orientation-Decision-Action loop, or OODA loop.

Boyd's work showed the need for fighter aircraft to be capable of 'fast transients' which are quick changes in direction, speed and altitude. A fighter aircraft that is able to turn harder without losing energy will out-turn its opponent. A 2° per second advantage in sustained rate of turn will enable a fighter aircraft to dominate an engagement. Fighter aircraft also survive by being unpredictable. The ability for fast transients allows a fighter aircraft to change direction suddenly without losing energy, and energy is life in a dogfight. In such an encounter a fighter aircraft shouldn't be doing the same turn for more than seven seconds because that gives enough time for a enemy aircraft outside the dogfight to determine where the fighter is going to be and possibly attack it.

The Advanced Day Fighter program was shelved without producing an aircraft but was followed by the Lightweight Fighter program. This latter program issued a Request for Proposals in January 1972 which called for a 20,000 pound class fighter aircraft with high maneuverability, acceleration and range, and optimised to fight between 30,000 feet and 40,000 feet at speeds in the range of Mach 0.6 to 1.6. This was the flight regime that the U.S. Air Force expected most future air combat to occur in, based on analysis of the wars of the 1960s in Vietnam and the Middle East.

The fruits of the Lightweight Fighter Program were the single-engine YF-16 from General Dynamics and the twin-engine YF-17 from Northrop that were produced as flying prototypes. The YF-16 won the competition and became the F-16 in service with the U.S. Air Force because it had lower operating costs and greater range. It was also more maneuverable; since single-engine fighters have lower roll inertia than twin-engined fighters. One less engine means that maintenance costs are inherently 20 percent lower.

At about the same time the US Navy was directed to acquire a lower cost fighter aircraft to supplement the F-14 which was a large, swing-wing, twin-engine fighter aircraft equipped with infrared search-and-track. The F-16 was rejected for carrier use because of its single engine and narrow landing gear. So the US Navy adopted the YF-17 as the F-18 and beefed up its landing gear for carrier use. The F-18 was the cheap, low end capability to supplement the F-14, just as the F-16 was the cheap, low end capability to supplement the F-15. The F-35 was supposed to continue that theme by being the cheap, low end supplement to the F-22. Because of its cost and air-to-ground orientation, that has not worked out.

The F-15 and F-16 are still in production as at 2016 but their designs were out-classed decades ago. The Soviet response to the F-15 was the Su-27 which first flew in 1977 and entered service in 1985. The Su-27 has higher instantaneous and sustained turn rates than the F-16, itself more agile than the F-15. All other things being equal, the Su-27 and its derivatives will dominate turning engagements with the F-15 and F-16. It can also fly at up to Mach 1.6 without using its afterburner, giving it the opportunity to engage or disengage at will from a fight with a F-15 or F-16, both of which need to use their afterburners to reach supersonic speed. The Su-27 design was further improved to make the Su-35 which is larger and has a higher instantaneous turn rate than the Su-27. That process of improvement continued on to the T-50 which could be expected to enjoy a loss exchange rate against the F-15 of the order of six F-15s shot down for every T-50 lost. The aircraft both cost about $120 million to build.

There is another way of viewing this. The F-15 is still being produced because the US defense community failed to produce a viable successor aircraft. The F-22 did enter service but, like the Seawolf submarine, was too expensive to operate. A derivative of the F-16, the F-16XL, was produced with a cranked delta wing. This aircraft was slightly larger than the F-16 but carried 82 percent more fuel, could carry twice the ordnance and had a 40 percent longer range. This was a promising design which could have developed into something like the Euro-canards. The F-16XL was abandoned in favor of the F-15E which was simply the two-seater F-15D reconfigured for ground attack.

The basic F-15 design lives on in the F-22 which may be resurrected, but that is not an optimal outcome.

Figure 12

Figure 12: F-16 from the 169th Fighter Wing, South Carolina Air National Guard

The single-engine F-16 has been the most successful modern Western fighter aircraft, with 4,573 produced to July 2016 since its first flight in 1974. Originally conceived as a pure fighter "without a pound for air-to-ground", the original volume was deliberately kept small so that unused space would not be back-filled with capabilities that departed from the original mission. Over the last 40 years, empty weight has risen from the 6.2 tonnes of the YF-16 prototype to the 10.0 tonnes of the F-16E Block 60.

What's Wrong with the Raptor?

THE F-35 MIGHT be able to use all its weapons systems by 2022 if it gets that far. This would be literally decades after the development contract was awarded. The continued existence of the F-35 is putting the U.S. Air Force's combat effectiveness in doubt—and life for the rest of the armed services also becomes more difficult. The good news is that it is now possible for U.S. Air Force generals to publicly cast doubt on the F-35. They are doing this by investigating what it would take to restart production of the F-22.[1] While restarting the F-22 production line is not necessarily crazy, it is sub-optimal.[2,3]

In the National Defense Authorization Act for Fiscal Year 2017, the Committee on Armed Services of the House of Representatives directed the Secretary of the Air Force to:

> *...conduct a comprehensive assessment and study of the costs associated with resuming production of F–22 aircraft and provide a report to the congressional defense committees, not later than January 1, 2017, on the findings of this assessment.*

Production of the F-22 stopped in 2011 at 187 aircraft, far short of the initial program objective of 749 aircraft, as well as the Air Combat Command's stated minimum requirement of 381 aircraft. The report will address future air superiority capacity and capability requirements based on near and mid-term threat projections, evolving F-22 missions and roles, F-15C retirement plans and service-life extensions programs. Other factors to be considered include the estimated timing of the next generation of air superiority fighter aircraft to replace the F-22, and estimated end-of-service timelines for the existing F-22 fleet. The last study on restarting F-22 production, a Rand report from 2010, placed the cost at $17 billion in 2008 dollars for 75 more aircraft, or $267 million per unit.[3]

On the same page the Committee went on to praise the F-35, saying that it "will form the backbone of U.S. air combat superiority for decades to come" and that "The committee believes that the F–35 will help to close a crucial capability gap that will enhance the strength of our security alliances." This is an example of cognitive dissonance—resurrection of the F-22 wouldn't be under consideration if there weren't problems with the F-35.

Resumption of F-22 production will eat into the F-35's budget, further loading up each F-35 produced with more development costs. It would be another factor triggering a death spiral for the F-35. The direction to report on the potential for restart of F-22 production is acknowledgment that the F-35 is deficient.

There is a great need, no doubt, for more aircraft to provide the air superiority function. But resurrecting the F-22 isn't the answer, for two reasons: it costs too much to operate due to its radar-absorbent-material coating and it doesn't carry enough missiles. These problems are baked in the cake. The F-22 was a product of its time and place but potential enemies responded in radar development and the advantage of stealth has been partly negated. That leaves the F-22 with a missile loadout of half that of its main competition, the Su-35. Achieving a low radar cross-section via a meticulous application of radar-absorbent-material is a dead end fiscally, if not technologically. The solution to the F-22 problem lies in the road not taken a generation ago.

The F-22 had its beginnings in the Advanced Tactical Fighter program of 1981 when the U.S. Air Force released a request for information for concepts. General Dynamics and McDonnell Douglas were awarded contracts for initial design work for an air-to-ground fighter that could fly at Mach 2.5 at high to medium altitudes and carry standoff weapons to destroy tanks and other ground targets.

Nothing came of that program as the F-16, originally designed as an air-to-air fighter for daylight hours, came in the back door and was repurposed to fill the air-to-ground role. That program was followed by many government-funded and company-funded studies of advanced fighter concepts and modifications to existing fighter aircraft.

Designed derivatives of the F-15, F-16 and F-111 competed with new concepts for the same missions. For example, General Dynamics' concepts included a small inexpensive fighter called "Bushwhacker", a conventional aircraft called "Plain Jane", a large fighter called "Missileer" that could carry many long-range air-to-air missiles, a highly stealthy all-wing fighter called "Sneaky Pete", and a supersonic stealth configuration. The "Sneaky Pete" concept started development for the US Navy as the A-12 Avenger II which was cancelled after weight problems and cost overruns.

Evaluation of design concepts had become sophisticated by the 1980s. For example, General Dynamics had a process that began with a design concept and from that defined the suite of aerodynamic, structural, avionics, armament, and propulsion technologies that would be used.

Computer models then produced families of designs having a broad range of maneuver, speed, range, and other capabilities. Specific designs were in turn fed into life-cycle cost models and into a set of effectiveness models that determined the susceptibility of each design to surface-to-air and air-to-air threats, and lethality against its intended targets.

Those effectiveness models were then in turn used in campaign models that accounted for force structures, mission allocations, basing concepts, threat distributions, strategies, and other details that define theater-level scenarios; with each design placed in the campaign in numbers proportional to its cost. The whole process maximized cost-effectiveness.

The government and company studies of the 1980s replicated some of John Boyd's findings on fighter effectiveness. Stealth was considered important because, in combat over Vietnam, over half of the aircrews shot down and about 80 percent of those fired on were unaware of their attackers.

The same experience was true in World War I, World War II and Korea. Fighter aces preferred to perform a slashing attack on an unsuspecting enemy and, if that was not successful, not engage in a dogfight. That concept of seeing without being seen comes from the gun era. A stealth aircraft firing an air-to-air missile gives its position away either by the flare of the rocket motor starting or by the mid-course radar updates from the aircraft to the missile.

Speed was identified as another critical characteristic of an air-superiority fighter aircraft. Speed reduces the enemy's reaction time and provides more freedom to engage and disengage as desired. The faster combatant has the initiative. To achieve speed without burning a lot of fuel necessitates supersonic flight without using the afterburner. Optimizing an aircraft for that leads to a long, slender configuration with highly swept wings.

At the time, NATO commanders had expressed pessimism about the survivability of forward-based NATO fighter and attack aircraft should a war break out in Europe. Control of the skies above central Europe would probably have to be maintained by fighters based in Belgium and Holland or in the United Kingdom.

In such a scenario, the ability of an aircraft to fly supersonically for the entire mission segment that lay over hostile territory would, it was hoped, reduce the fighter's exposure to enemy surface-to-air missiles.

Maneuverability was also identified as another important characteristic, though more as a defensive tactic rather than an offensive one. Maneuvering engagements take time and make an aircraft predictable to an enemy fighter outside the immediate engagement. Maneuverability is necessary to dodge air-to-air missiles in the first place and survival to the next stage which is deciding on whether to engage in a dogfight or run away.

The fighter aircraft effectiveness studies of the 1980s also identified short takeoff and landing distances as an important attribute. At the outbreak of war in Europe, NATO intended to put a lot of effort into cratering Warsaw Pact runways and assumed that the Warsaw Pact was going to do the same to NATO.

Being able to take off from short sections of runway, or taxiways or roads was required for combat effectiveness. Sweden's Gripen fighter aircraft have dispersal to roadway bases as part of their operational doctrine, including aircraft shelters positioned next to roads.

The last time the U.S. Air Force had an airfield bombed or strafed was in 1950 at the start of the Korean War. The U.S. Air Force turned around and destroyed most of the North Korean Air Force on the ground in the following three weeks. This was before the sanctuary in China.

Some lessons can be forgotten in a couple of generations and may have to be relearnt. Lockheed Martin has been coy about the takeoff and landing characteristics of the F-35 but it is known that the F-35 requires an airfield at least 8,000 feet long. Compared to the F-18 Super Hornet, the F-35 has a similar thrust-to-weight ratio and higher wing loading, so can be expected to have slightly worse takeoff and landing distance requirements.

The F-18 Super Hornet requires a 7,000 foot runway from which to operate, waiverable to 6,000 feet. The typical takeoff distance of a F-18 Super Hornet with a standard load of a centerline fuel tank is 2,600 feet, reduced to 1,500 feet with afterburner. Landing distance is 2,700 feet. This is about twice the distance that other fighter aircraft require. If a fighter aircraft is limited in airfields from which it can operate, the enemy's targetting task is made a lot easier. This is especially true of the western Pacific where there are only a limited number of islands with long runways.

The Advanced Tactical Fighter program regained momentum in 1983. General Electric and Pratt & Whitney were awarded contracts to build and test competing engine designs, designated the F120 and F119 respectively. The U.S. Air Force also requested proposals for the aircraft that would be powered by the engine selected. Northrop, General Dynamics, Lockheed, Grumman, Boeing, Rockwell and McDonnell Douglas responded. Of those seven companies, three are still in the business of building aircraft. Of those three, Boeing has announced that it is vacating the business of building new fighters though it has teamed up with Saab for the U.S. Air Force's next jet trainer aircraft.

At this time Lockheed was still heavily influenced by the faceted design of its F-117 light bomber. It lost the competition to produce what became the B-2 by offering a faceted design against a more aerodynamic flying-wing design from Northrop. Lockheed had also been cut from consideration for the Navy's Advanced Tactical Aircraft program after entering that competition with a highly faceted design. So Lockheed began drawing aircraft with curved shapes, making models from them and testing the models on its radar range.

The Advanced Tactical Fighter requirements became more definitive by the end of 1984. These were a takeoff distance of 2,000 feet, a gross takeoff weight of no more than 50,000 lbs, a Mach 1.5 cruising speed and a combat radius of at least 700 nautical miles. In turn performance, the aircraft was to be capable of 5g turns at Mach 1 and 6 g turns at Mach 1.5 at 30,000 feet; at 10,000 feet it was to be capable of instantaneous turns of 9 gs at Mach 0.9 and sustained turns of 2 g at Mach 1.5 at 50,000 feet. The acceleration requirement was Mach 0.8 to Mach 1.8 in 50 seconds at 20,000 feet. The unit flyaway cost was to be $40 million in 1985 dollars, equivalent to $89 million currently (2016).

In late 1985, the U.S. Air Force made a number of changes to requirements as the program progressed, including increasing the importance of stealth. It also changed the selection process so that, instead of four companies receiving approximately $100 million each, two would be awarded contracts of $700 million each to produce flying prototypes. One of the prototypes would be powered by Pratt & Whitney F119 engines and the other with General Electric F120 engines. At about the same time, the U.S. Air Force sent out letters to the competing companies to encourage teaming.

The idea behind this was that the U.S. Air Force wanted us much talent as possible applied to what was going to be a large and expensive program. As a result, Boeing, Lockheed and General Dynamics formed one team and Northrop and McDonnell Douglas formed another. Rockwell and Grumman did not team.

Lockheed and Northrop were announced on October 31, 1986 as winners of that stage of the Advanced Tactical Fighter program. The teaming agreement among Boeing, General Dynamics and Lockheed called for the winning company to be the team leader, so Lockheed took that role. The winning teams were given four years to produce their flying prototypes. Lockheed's design at this stage had a large rotary weapon bay which pushed the engines and inlets outward, in turn producing an excessive amount of wave drag. This is exactly what happened to the F-35 with its vertical lift fan making the aircraft too wide and draggy. The vertical lift fan is the original sin of the F-35 design.

The U.S. Air Force initially required that eight missiles be carried internally in the main weapon bay. That was reduced to six when both of the design teams concluded this could not be done effectively. Similarly, the requirement for thrust reversers was dropped when it was determined that the capability was not worth the price in performance. The basic challenge of the Advanced Tactical Fighter design was to integrate stealth, supercruise, highly integrated avionics, and agility into an aircraft with a longer range than the one it was to replace, the F-15. It was also to have twice the reliability of the F-15 and half the support requirements. In practice, the F-22's mission availability has risen over the last few years to being close to that of the F-15 but its support requirement is over 50 percent higher.

Both the Lockheed and Northrop designs had diamond-shaped wings with a long root chord joining the wing to the fuzelage, providing a more distributed load path and more bulkheads carrying the bending loads. The large wings also provide more fuel volume.

In January 1989 the U.S. Air Force put a cap on the cost of the avionics of the Advanced Tactical Fighter of $9 million per aircraft in production. At that time, Lockheed's paper design had over $16 million of avionics in each aircraft. Thus the infrared-search-and-track system was dropped. So were a number of other systems, including the side-looking, cheek-mounted radars. Twenty-seven years later, the F-22's main competition, the Su-35 has infrared-search-and-track and cheek-mounted radars.

One of the important attributes of side-looking radars is that an aircraft can fire a missile that requires mid-course updates from the aircraft's radar and still provide that tracking data after turning more than 90° away from the path of the missile. Otherwise, if it had to keep pointing at the enemy aircraft then it would be getting closer to any missiles that aircraft might fire. The processing power of electronics and the acuity of optics have improved in the last decade so the cost of avionics relative to the cost of the airframe has fallen. Nevertheless, the reason why the F-22 doesn't have an infrared-search-and-track system is explained—it dates from the avionics cost cap imposed in 1989. The U.S. Air Force didn't prescribe which systems were to be dropped in order to meet the cap. The companies decided what would provide the best value for money.

At 67 feet and five inches long, Northrop's design was five feet and four inches longer than the YF-22, and three and a half feet longer than the F-15 it was to replace. This would be expected because of the requirement for greater range on completely internal fuel. The YF-23 was also more slender than the YF-22; its blend of stealthy shapes and aerodynamic efficiency providing a low radar cross-section without compromising performance. Great attention was paid to keeping the cross-sectional area as constant as possible, minimising transonic and supersonic drag. The leading edges of the wings are swept back at 40 degrees and the trailing edges are swept forward at the same angle.

The YF-23 prototype first flew on August 27, 1990. It supercruised at Mach 1.43 one month later, on September 18, 1990, and reached Mach 1.6 on November 29, 1990. By comparison, the first flight of a production F-35 was on December 15, 2006 and the F-35 did not fly at its maximum design speed of Mach 1.6 until October 24, 2011. The five year gap demonstrates just what a struggle it was for the F-35 to get to Mach 1.6. The F-35 cannot get to supersonic speeds without using its afterburner and it can't maintain a supersonic speed without using its afterburner. The YF-23 design team put the aircraft's engine exhaust into troughs which would help shield it from infrared detection. In the 25 years that have passed since the fly-off, the relative importance of infrared reduction has increased due to better electronics and optics and the increased range of infrared detection systems. Stealth as an end in itself has become less important with the increased deployment of radars in the VHF and L bands designed to defeat it.

On April 23, 1991, the U.S. Air Force announced that it had chosen the Lockheed design; Pratt & Whitney won the engine competition. Northrop's offering was the faster of the two designs, possibly by 0.2 Mach to the limit of supercruise. In addition, it was the stealthier of the two, particularly from the side and rear. It was also simpler and lighter due to absence of thrust vectoring and a smaller tail area. The YF-22 may have had the advantage in low speed maneuverability.

The planned development period of the F-22 was twelve years. That only slipped a couple of years to fourteen years with the first production aircraft flying in 2005. The number to be produced was cut back periodically and a production halt was ordered in 2009. As of March 2014, the total number of active F-22 aircraft was 182. When the final aircraft was delivered in 2012, the F-22 acquisition program was completed at a total estimated cost of over $67 billion.[4] That works out at $362 million per aircraft; the flyaway cost is estimated to have been about $150 million.

Though wonderful, the F-22 is not perfect, and the U.S. Air Force is spending $11.3 billion to address the aircraft's reliability and structural problems, and to modernise it.[5] This remedial and modernisation program adds a further $61 million to the cost of each aircraft. Part of the remediation effort is the installation of structural hardware that is needed for the aircraft to achieve its originally expected 8,000 flight hours of service life.

The repair and modernisation work had been undertaken at Lockheed Martin's plant in Palmdale, California. But the U.S. Air Force dumped Lockheed Martin for this work because of well-documented cost, schedule and quality issues. For example, in 2013 the Palmdale depot was more than 10 months late in returning a particular aircraft back to the fleet. The U.S. Air Force has consolidated all F-22 depot maintenance to its Ogden

Air Logistics Complex at Hill Air Force Base in Utah. Nine aircraft are being retrofitted at a time with the process taking an average of 131 days to complete.

According to a U.S. Air Force analysis of F-22 maintenance issues, work related to maintaining the stealth features of the F-22 accounts for almost half of the time that the aircraft are unavailable due to maintenance. After repairs or modifications that involve removing a panel with stealth coatings, those coatings must be restored. This can take several days. As a result, minor repairs or modifications that would take a few hours on a non-stealth aircraft can require days of maintenance on an F-22. The F-22's mission availability rate was 40 percent when it entered service in 2005. Availability currently stands at 62.8 percent. The U.S. Air Force has never been able to meet the F-22's aircraft availability requirement of 70.6 percent and does not expect to meet that requirement until 2018.

The Russians have thought about how to engage the F-22 in combat. When their infrared-search-and-track on a Flanker detects the F-22, range can be determined by doppler shift or the laser range finder. The Flanker then fires a R-77 missile with an infrared seeker. Conceptually, the F-22's stealth can act against it. If the Flanker's infrared-search-and-track detects something then points its radar at the contact and doesn't get a return, then that positively identifies the contact as an F-22 or F-35, at least until the T-50 enters service. If the F-22 tries to improve its kinematic situation by using high altitude and high speed, this will increase the F-22's thermal signature in the thin, dry air that transmits infrared best. Attempting to reduce the F-22's thermal signature by travelling lower and slower will reduce the range of the F-22's primary weapon, the AIM-120D.

The F-22's thrust vectoring capability is overrated. The U.S. Air Force tested thrust vectoring on a modified F-16 in the early 1990s and found it was only useful at speeds below 250 knots. Above that speed the jet was maneuverable enough that thrust vectoring didn't add anything. Also, at high speeds, if the nozzles start to swing the jet violently around then that is apt to induce unacceptable loads on the airframe. Thrust vectoring isn't worth the weight penalty.

Then there is the matter of the F-22's weight and its effect on range. The Advanced Tactical Fighter's target combat range was 700 nautical miles. The Advanced Tactical Fighter was to supercruise the component over Warsaw Pact territory of about 250 nautical miles in each direction. The F-22 can supercruise for 100 nautical miles. An illustration of how this came about is a report from 1995 on the U.S. Air Force and Lockheed agreeing to allow the F-22's empty weight to increase by 610 kilograms, or three percent, to avoid pushing costs up. The F-22's projected empty weight increased from 13,980 kilograms at the preliminary design-review in 1992 to 14,365 kilograms at the critical design-review, completed in February 1995. The growth is a result of the F-22's design teams requesting additional weight budgets to meet requirements such as reliability, survivability and observability. The U.S. Air Force, at the time, was "trying to hold the line on affordability" and traded weight against cost and performance.

The U.S. Air Force calculated that an increase of 450 kilograms will reduce the F-22's subsonic range by 25 kilometers (14 nautical miles) and reduce its sustained-turn performance at Mach 0.9 and 30,000ft by 0.08g. The F-22 kept putting on weight and ended up with an empty weight of 19,700 kilograms, 40 percent more than the YF-22 that won the design competition. By the U.S. Air Force's figures on the range-to-weight trade-off, each extra 18 kilograms decreases range by one kilometer. Therefore, the extra 5.7 tonnes in the final design would have reduced range by 317 kilometers, which is 171 nautical miles. The F-22's combat radius is 460 nautical miles. This is just over half of the combat radius of the latest Flanker variant, the Su-35. So the F-22 is a short-legged fighter aircraft that doesn't carry many missiles. The Gripen E has a larger combat radius of 540 nautical miles.

The F-35's combat radius is slightly longer again but that doesn't do it much good because it needs to be escorted by the F-22 to survive. The F-35's longer range is explained by its higher fuel fraction of takeoff weight of 38 percent. This is the same as the fuel fraction of the Su-35, but the Sukhoi is far less draggy and thus flies much further.

Then there is the problem of the F-22's missile load of four beyond-visual-range AIM 120D missiles and two short range AIM-9 missiles. The AIM-120D missiles are carried in a weapons bay under the aircraft and the AIM-9 missiles each have their own weapons bay either side of the nose. The F-22 could carry more missiles on pylons on its wings but that would negate the whole purpose of having a stealth aircraft and the maintenance hours spent maintaining the radar-absorbent-material coating. The question at this point is what is the kill probability of the AIM-120D missile? The AIM-120D is directed by updates from the firing aircraft via datalink until it is near the target aircraft at which point it turns on its own radar.

In combat the missile has demonstrated a kill probability of about 70 percent but this includes aircraft that didn't know they were being targetted, and a US Army helicopter in northern Iraq. New jamming technologies have made it easier to evade beyond-visual-range, radar-guided missiles. A technology called Digital Radio Frequency Memory captures the radar signal from the missile and retransmits it with a slight delay. Because it is a copy of the original signal, the missile's radar will not be able to distinguish its legitimate original return signal from the Digital Radio Frequency Memory copy. This technology doesn't transmit jamming noise so that home-on-jamming is useless. The slight delay in the retransmitted signal creates Doppler error in the missile's seeker head. If the missile's processing power can't resolve what it is seeing, only a fraction of a second of confusion is required for the missile to fly wide of the target. The next stage of defense for the targetted aircraft is active decoys that work on the same principle. The decoys, either towed or ejected, emit a copy of the missile's radar signal. Towed decoys might be more effective as their speed stays constant with the aircraft. In short, it is still difficult to use radar-guided missiles to shoot down alert aircraft that have the full suite of countermeasures against them. There has been no air-to-air combat in the last 10 years or so that can be used as a guide as to what missile kill probabilities will be.

The U.S. Air Force may be relying on a probability of kill for the AIM-120D of the order of 70 percent. What is likely to happen is a repeat of the early years of the Vietnam War in which the F-4 Phantom was sent into combat with the radar-guided Sparrow missile which was attributed a 70 percent kill probability in testing against drone aircraft. In combat over North Vietnam, the actual kill probability turned out to be less than one tenth that. If history repeats itself and the AIM120-D has a kill probability against Chinese Flankers in the western Pacific of, say, 15 percent, then the total kill probability of the four AIM-120Ds carried is 48 percent. On average, it will take two F-22s to shoot down one Chinese Flanker. Whatever the relative numbers of aircraft at the beginning of the engagement, the surviving aircraft proceed to within-visual-range at which point the F-22s are left with their two infrared missiles. These will have a higher kill probability than the radar-guided AIM-120Ds but will be evenly matched against the Chinese infrared missiles.

Flankers typically have a loadout of 12 air-to-air missiles. Russian doctrine is to fire salvos of missiles at a time, most likely a radar-guided missile followed by an infrared-guided missile seven seconds later. The Flanker control stick has a switch to select salvo mode which does the correct sequence and spacing. As the target aircraft turns to avoid the radar-guided missile it exposes its engine exhaust to the infrared-guided missile. It seems that Japan has taken this lesson to heart as it has recently decided to arm its 200 F-15s with 16 missiles each, double the previous number. The F-22 is limited to six missiles and that is a problem that is baked in the cake unless the F-22 throws in the towel on stealth.

One problem for the U.S. Air Force in the western Pacific is that Chinese Flanker pilots would be well aware of the F-22's limited missile loadout and the F-35's minuscule missile loadout. They may be relatively fearless as they would know that the survivors of the initial volley of US missiles would have an increased ratio of air-to-air missiles left relative to the US aircraft, and that once they were within visual range, the capabilities would be evenly matched. The air war between fighter aircraft will be short and savage. If the US fighter force is wiped out by virtue of being too small at the beginning of the war, then the consequences will be immediate in terms of the psychology of the prosecution of the war and also long term in rebuilding the cadre of fighter pilots. The Argentinian air force lost 31 pilots in the Falklands War and it took a decade to recover from that. Fortunately, Japan knows that it has to participate in any war with China from day one so their 200 F-15s armed with 16 air-to-air missiles each may do a lot of the heavy lifting in the earliest stages of any conflict.

Figure 13: F-22 in Flight
The F-22 has been described as a "flying antenna farm" with receivers built into its skin, although it was built without integral infrared-search-and-track as a cost saving measure. Originally 750 were to be built; production was terminated at 187. The F-22 has an operating cost per hour equivalent to that of the B-1 bomber which weighs four times as much. Half of that operating cost is taken up with repair of its radar-absorbent-material coating. The F-22 can sortie every second day. In terms of cost-effectiveness of combat performance, the F-22 is twice the price of the Gripen E before taking into account the Gripen E's higher sortie rate.

The Europeans recently developed a ramjet-powered, radar-guided, beyond-visual-range air-to-air missile called Meteor. The benefit of a ramjet is that space inside the missile is not taken up by oxidant and therefore range is increased by the greater amount of fuel carried. The Meteor's ramjet is also throttleable. As a radar-guided missile its kill probability may not be higher than that of the AIM-120D but as a longer-ranged weapon it will tend to push enemy aircraft away at a greater distance. Ultimately,, the Meteor's ramjet body will be mated with an infrared seeker, such as that of the AIM-132, and a more formidable weapon will result. The seeker heads of infrared missiles are now equipped with imaging focal plane arrays so that it can compare the image of the aircraft it is heading towards against a library of aircraft images, and thus is much harder to fool with flares.

When stealth was new and exciting in the U.S. Air Force, back in the 1980s, the CIA wrote a report, dated August 1985, entitled *Soviet Reactions to Stealth*.[6] Amongst other things, it predicted that:

> *We are aware that the Soviets are developing higher powered early warning and intercept radars with the better resolutions necessary to come to grips with the low-signature and stealth detection and tracking problem. Soviet radar designers are likely to incorporate VHF and UHF frequencies, increased pulse repetition frequencies, and improved signal processing in their next generation of radars—possibly by developing a pulsed-Doppler processor.*
>
> *Future Soviet interceptors are certain to include much-improved IRST sets to enable Soviet pilots to conduct tailchase intercepts of low-signature vehicles.*

All this happened. Another lesson the Russians took heed of from the air war over Serbia was the necessity for their radars to be mobile to be survivable. Their low frequency radars can detect stealth aircraft from hundreds of kilometers away. It doesn't matter that resolution of low frequency radars isn't good enough to provide a tracking solution for a surface-to-air missile. It is good enough that it can generate a search box containing the stealth aircraft of perhaps a cubic kilometer. A Flanker could then search that box with its infrared-search-and-track from perhaps more than 50 kilometers away. As such stealth is largely negated. It is still worth having as long as not too much of a premium is being paid for it.

Arguably, the cost of maintaining the radar-absorbent-material coating of the F-22 has killed off half the required fleet even before the Russians and Chinese have had a chance to attack it. Stealth overly reliant upon a radar-absorbent-material coating is a self-defeating technology.

There is a role for a large, agile, twin-engined fighter aircraft in the Western Pacific. Apart from providing air superiority, such a platform would be ideal for delivering long range anti-ship cruise missiles. 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, 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 and two engines, all other parameters being equal. 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 radar-absorbent-material coating.

Figure 14: YF-23

Some aircraft design evolutions have worked quite well—Saab's sixty year evolution from the Draken to the Gripen E, the 30 years of Flanker variants; reducing cost and risk by incremental changes enabled by technological improvement. And sometimes a big leap in ability is gained by starting with a clean sheet of paper. Such was the result of the Advanced Tactical Fighter competition; not the winner, which was a essentially the F-15 spackled up with radar-absorbent-material, but the runner-up—Northrop's YF-23. The shape of the YF-23 was so fuel-efficient that it could supercruise the entirety of a 700 nautical mile combat radius as well as being an inherently stealthier design than the winner, which became the F-22. F-22 operating costs are so high because of the cost of maintaining its radar-absorbent-coating. That radar-absorbent coating has eliminated 75% of the F-22 fleet that was to be; 187 aircraft were built instead of 750. While the F-22 is very capable *when it is flying, its seems that at some stage in the selection process the U.S. Air Force did not consider the total cost of ownership, as the US Navy seemingly didn't in choosing the Advanced Gun System for the Zumwalt class.*

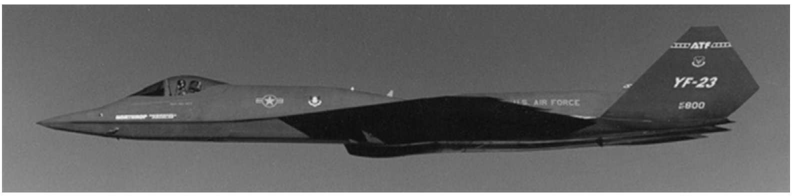

Figure 15: YF-23 Side View
The YF-23's high supercruise speed is due to the most slender shape ever designed into a fighter aircraft.

Figure 16: YF-23 Front View
With the wide separation of the engine intakes and the prominent nose chine, the YF-23 design generated significant body lift.

Enter The Gripen

6.1 The Value Proposition

THE SOLUTION TO the F-35 nightmare is the Gripen E fighter developed by Saab in Sweden. The value proposition is based on the combination of cost, cheaper than the F-16, and effectiveness—nearing that of the F-22. The standard is set by the F-22 which combat simulation modelling indicates will shoot down two Su-35s for each F-22 lost. The rate for the Gripen E is 1.6 Su-35s shot down for each Gripen E lost. Using Lanchester's square law for relative effectiveness, it takes 1.5 Gripen Es to do what one F-22 can do. This is confirmed by General Hostage's comment that it would take eight F-35s to do what two F-22s could do.[1] So one F-22 is worth four F-35s. The Su-35 can shoot down the F-35 at the rate of 2.4 F-35s for each Su-35 lost. Multiplying this through, the Gripen E is 3.84 times as effective as the F-35—close to General Hostage's comment on the relative value of the F-22 and the F-35.

The next question to ask is what the flyaway cost of an F-22 would be if the production line was restarted? A method that brings you close to the mark is to compare aircraft by weight and cost. An F-15 weighs 12.7 tonnes empty and costs $110 million which equates to $3,866 per lb of aircraft weight. At that rate, a new-build F-22, which weighs 19.7 tonnes, would cost $170 million to make. But the F-22 is packed with a lot more electronics than the F-15. It is more likely to have a cost per lb closer to that of the F-35. The innards of the F-35 are "packed tighter than a head of cabbage" with the result that the rework rate in building them is still 14 percent; that is 14 percent of the man-hours spent in building an F-35 are devoted to replacing components that were damaged in the process of installation. The F-35 weighs half a tonne more than the F-15 at 13.2 tonnes unladen. The flyaway cost of $135 million translates to a cost of $4,565 per lb of aircraft. On that basis the flyaway cost of a new-build F-22 would be $201 million.

Using the latter number, a force of ten, say, F-22s would cost $2,010 million to acquire. A force of Gripen E's that was equivalent in combat-effectiveness would be 15 aircraft. The Gripen E costs $70 million per aircraft so a total cost of $1,050 million for 15, about half that of the combat-equivalent F-22 force. The combat-equivalent force of F-35s would be 40 aircraft at a cost of $160 million each, including development cost for a large production run, for a total cost of $6,400 million, so more than six times the force-equivalent cost of the Gripen E.

The other major variable is the operating cost per hour of flight. In 2012, IHS Jane's conducted a study of this question.[2] That report says, "Owing to the differing methods of calculating aircraft operating cost per flight hour and the large number of interlinked factors that affect such a calculation, IHS Jane's believes that any flight hour cost figure can only be regarded as indicative and that there is no single correct answer to such a calculation." The IHS Jane's study found that the Saab Gripen is the least expensive aircraft to operate based on reported costs covering fuel used, pre-flight preparation, scheduled airfield-level maintenance together with associated personnel costs. The study found that,"At an estimated $4,700 per hour (2012 US$), the Gripen compares very favorably with the Block 40 / 50 F-16s which are its closest competitor at an estimated $7,000 per hour."

In 2014, the Swedish Air Force listed its then operating cost of the Gripen C aircraft at 48,000 Swedish kroner per hour, equivalent to $7,560 per hour. Both numbers could be correct because we don't know what went into them.

Based on a U.S. Air Force study of F-16s that was conducted in 2005, cost per hour of flight is composed of approximately:

- 10-15% Consumable supplies
- 20-25% Aviation fuel
- 60-70% Depot level repair and systems maintenance

Operating cost is proportional to size even though fuel is only a quarter of costs. All things being equal, a twin-engine aircraft will have operating costs 20 percent more than a single-engine one of the same weight. As operating costs over the life of an aircraft are generally twice the initial capital cost, the extra cost of a twin-engine aircraft, over the life of the aircraft, is 40 percent of the initial capital cost. Jet engines have become far more reliable than 20 or 30 years ago.

Another consideration that makes comparisons difficult is that, according to the IHS Jane's study, average cost per flight hour increases by 1.7 to 2.5 percent per extra aircraft age year. Given the average age of the U.S. Air Force fleet of 27 years, that effect is significant. Assuming 2.0 percent per year, operating the fleet is costing possibly 50 percent more than if it was composed of newly built aircraft. In fact the U.S. Air Force is finding that its B-1B bombers are failing in "new and inventive ways".[3]

A big component in the cost of operating stealth aircraft is the cost of maintaining their radar-absorbent-material coating. For example, the F-22 takes 42 man-hours of maintenance for each hour in the air.[4] About half of those maintenance hours are taken with repairing its radar-absorbent-material coating. Advances in the technology of radar-absorbent-material developed for the F-35 have also been applied to the F-22, with maintenance man-hours per hour of flight falling 10.1 percent from 2012 to 2014.

The following table shows U.S. Air Force operating costs per flight hour for ground attack, bomber and fighter aircraft for the years 2008 to 2012 and for 2015; absent are 2013 and 2014 for which authentic data haven't been able to be acquired:

Aircraft	2008	2009	2010	2011	2012	2015
A-10A	$17,865	$21,436	$23,361			
A-10C	$9,781	$19,654	$20,115	$18,427	$17,564	
B1-B	$60,252	$66,784	$66,424	$63,996	$54,278	$58,488
B-2A	$141,204	$142,740	$139,617	$135,269	$164,006	$128,805
B-52H	$65,809	$67,430	$76,745	$61,567	$69,686	$67,005
F-15C	$38,818	$33,684	$37,356	$38,873	$40,492	$27,203
F-15D	$42,449	$32,644	$36,822	$38,979	$41,799	$38,846
F-15E	$32,722	$31,206	$31,655	$29,521	$35,365	$38,846
F-16C	$19,844	$21,713	$21,345	$21,144	$22,315	$20,318
F-16D	$28,152	$31,780	$28,082	$29,016	$30,140	$20,318
F-22A	$51,300	$58,862	$60,682	$111,779	$60,503	$59,166
F-35A						$42,169

Table 3: U.S. Air Force Operating Costs per Flight Hour

The figures for 2008 to 2012 were obtained from the Project On Government Oversight. The figures for 2015 are from a *FlightGlobal* article quoting the U.S. Air Force. What is evident from this table is that the A-10 and F-16 both cost about $20,000 per hour to operate. The F-15 variants cost almost twice as much which is a consequence of weighing 27 percent more combined with the operating penalty of a second engine. The F-22 has settled down to cost about $1,000 per minute. The bargain on this table is the B-1 bomber which has twice as many engines and weighs more than four times the F-22 but with virtually the same operating cost per flight hour. The F-35 operating cost was close to that of the F-22 in 2014 and then fell 37.6 percent in 2015 according to the *FlightGlobal* article. The F-35's operating cost of a $42,169 per hour is about 10 percent greater than that of the F-

15. It is in the same weight class, weighing half a tonne more. Being a single engine aircraft, it should have operating costs about 20% lower. On the other hand, the F-15s in inventory are now 32 years old and thus may be suffering from age-related cost growth of 40 to 60 percent, in which case the F-35 still stands out as a horrendously expensive aircraft to deliver just two 2,000 pound bombs.

There appears to be a large gap between the Swedish Air Force's operating cost for the Gripen C of $7,560 per hour in 2014 and the operating cost of the F-16 which is almost three times higher. Both are single engine fighters. The F-16 weighs 26 percent more than the Gripen C which would account for part of it. The F-16 fleet is now 26 years old which adds 50 percent to costs. Sweden's Air Force uses conscripts to conduct the bulk of maintenance between sorties which would lower costs. That speaks volumes about the ease of maintaining the Gripen E.

The current F-35 acquisition program projects that development and manufacture will cost $400 billion. The aircraft so made will then cost $1 trillion to operate over their lives for a total of $1.4 trillion. Using that approach and assuming service lives of 6,000 operating hours, the example used of a force of 10 F-22s would cost $3,550 million to operate, the equivalent 40 F-35s would cost $10,121 million to operate and 15 Gripen E would cost $680 million to operate. Total ownership costs are $5,560 million, $16,521 million and $1,610 million respectively. To obtain the same effect out on the battlefield, the F-35 is three times as expensive as the F-22 and ten times more expensive than the Gripen E. In 2012, the Swedish Air Force was reported to have put the cost of buying and maintaining 60 Gripen E aircraft for thirty years at 90 billion Swedish kroner, equating to $10.8 billion. On that basis, 15 aircraft would cost $2.7 billion—half the cost of the F-22s and one sixth that of the F-35.

6.2 In The Beginning

Saab, the company producing the Gripen E, had its beginnings in the Treaty of Versailles which was imposed on Germany after World War I. That treaty forbade the manufacture of aircraft in Germany for a while and German airlines were forbidden from operating multi-engined aircraft. To circumvent the treaty, some German aircraft manufacturers shifted assembly abroad. Both Heinkel (Lidingö, Stockholm) and Junkers (Limhamn) established themselves in Sweden. In 1921, Svenska Aero, partially a forerunner to Saab, began to to make reconnaissance aircraft under license in Lidingö, Sweden from parts smuggled out of Germany. Some German assembly workers temporarily moved to Lidingö.

Saab was established in 1937 by the merger of ASJA, which had taken over Svenska Aero the prior year and shifted production to Linkoping, and NOHAB (in Trollhättan), the former dealing with license production of aircraft and the latter with aero engines. After WW II, the Trollhättan plant switched to automobiles.

Saab began making jet fighter aircraft in 1947 with the first type being made by converting a piston-engined aircraft. This was followed by the Tunnan, a single-engine fighter similar in shape to the Soviet MiG-15. The Tunnan had an empty weight of 4.8 tonnes. Saab's initial delta wing aircraft was the Draken which first flew in 1955 and had a top speed of Mach 2.0. That is Mach 0.4 faster than the F-35's top speed. The Draken was followed by the Viggen which first flew in 1967. It was a delta wing aircraft with high-set canards. The Viggen was also the original Euro-canard aircraft and the first canard aircraft to be produced in quantity. Canard is the French word for duck and is the term that the French gave to forward flaps on an aircraft. The Swedish words tunnan, draken, viggen and gripen mean barrel, dragon, thunderbolt and griffin respectively. Beyond being the Swedish name of a thunderbolt, Viggen is also the Swedish name of the tufted duck (latin: *Aythya fuligula*), i.e. the intentional reference to a canard.

The operational concept for the Viggen was also ground-breaking. It was required to be able to operate from straight stretches of rural highway only 500 meters long. This was to reduce vulnerability to a pre-emptive strike by the Soviet Union. In 1985 the Viggen became the first aircraft to share data within a flight by secure datalink. Ease of maintenance was also designed into the Viggen with a chief mechanic supervising five conscripts.

In 1979 the Swedish Government began planning for an aircraft to replace the Viggen. To be affordable, it would be a single-engine design. As per Harry Hillaker's formula for the F-16, it would be single-seat, lightweight, use fly-by-wire controls, aerodynamically unstable but with the addition of canards. The United States' most famous aircraft designer, Burt Rutan, incorporates canards in most of his designs. The engine selected for the new aircraft, which became the Gripen, was the General Electric F-404 that had been developed for the F-18 Hornet. Volvo made the engine in Sweden under licence.

The Gripen is a tailless delta wing with a sweep of 55°. Using a delta wing in a fighter aircraft has advantages at high speed and at low speed. At transonic to supersonic speeds the high sweep of the wing keeps it behind the shock cone from the nose of the aircraft, reducing drag. The primary advantage of delta wings is efficiency in high-speed flight. At low speeds the large wing area generates a lot of lift at high angles of attack but otherwise requires higher takeoff and landing speeds compared to conventional aircraft. A delta wing is also able to be built lighter than a conventional wing providing the same amount of lift.

The Gripen first flew in December 1988. Delivery of the first production aircraft to Sweden's Air Force was in June 1993. This was the Gripen A variant; the two seater training version is the Gripen B. These were followed by the Gripen C that conformed to NATO standards, making it easier to export, with a two-seat D version for training. The upgrades included in-flight refuelling and updated electronics. These were introduced into service in 2003.

So far 240 Gripen aircraft have been produced. Apart from deployment within the Swedish Air Force, small numbers are also in service with the South African, Czech, Hungarian and Thai air forces. About a third of the aircraft is of US origin and the balance is from European suppliers.

6.3 Gripen E

A decade ago the Gripen had a reputation as being a low cost, low maintenance, short-legged fighter suitable for defending airfields from which it was flying. After all, Sweden has no need for fighter aircraft designed to fly much further than the boundaries of Sweden. Advances in electronics provided the opportunity to update the aircraft and a new variant, the E model, has been produced. At the same time the internal fuel load was increased by 40 percent by moving the rear landing gear further back. This increased the combat range to 1,000 kilometers, 60 kilometers less than that of the F-35. The Gripen's combat range on internal fuel is now 140 kilometers further than that of the F-22, and 450 kilometers further than that of the F16. With a 290 gallon external fuel tank, the Gripen E's combat radius increases to 1,300 kilometers.

The empty weight has risen to eight tonnes with the capacity for 3.4 tonnes of internal fuel. Maximum take-off weight is 16.5 tonnes. Minimum take-off distance is 500 meters and minimum landing distance 600 meters. Maximum speed at altitude is Mach 2, effectively about 30 percent faster than the F-35. Maximum speed at sea level is 1,400 kilometers per hour, equivalent to 870 miles per hour or 756 knots, which is 14 percent more than the speed of sound at sea level of 760 miles per hour. The Gripen E uses the engine developed for the F-18 Super Hornet, the GE F414.

The large, all-moving canards make the Gripen E the most agile fighter aircraft available with an instantaneous turn rate higher than the F-22's. It also retains more energy in an instantaneous turn than other fighters, which is a quality hard to capture in statistics. This is going to be an important attribute in dodging missiles, especially in having enough energy to dodge the second missile in a typical Russian two-missile salvo. The Gripen's small size makes it harder to see and harder to hit. Saab simply selected the best off-the-shelf systems that were available in the United State and Europe. The engine is built by GE in the United States, the gun is German-made, the ejection seat is from Martin Baker in the United Kingdom, and the radar and infrared-search-and-track is Italian. The Gripen E has 10 hardpoints for weapons, fuel tanks or targeting/recce pods.

How far is the Gripen E able to see? It's electronic warfare system includes a radar warning receiver, a missile approach warning system and electronic support measures and countermeasures. The radar chosen is the Raven ES-05 active electronically scanned array (AESA) radar from Selex in Italy. A repositionable swashplate allows the radar to see 110° to the sides—giving the Gripen E a big advantage in beyond-visual-range missile combat.

After a beyond-visual-range missile shot, the aircraft that fired it must illuminate the target until the missile hits (semi-active radar homing missiles) or until the missile has been able to find the target and lock on to it (active radar missile). Both types of missile require the aircraft to transmit target data to the missile via a data link. Ideally the aircraft firing a missile would like to turn away as soon as the missile is fired to stay out of the opponent's weapon engagement zone. This is where the moveable radar of the Gripen E proves useful. It can see up to 110° from the nose and thus a Gripen E can turn away and still keep the target illuminated.

Selex also supplies its Skyward G infrared-search-and-track system. This is cued to the radar so that it can stare telescopically at a particular patch of sky from which a radar return has been detected, and vice versa. This is particularly important if your own rules of engagement require that a potentially hostile aircraft is positively identified as such before a beyond-visual-range missile is fired at it.

Right at this moment the Gripen E is the best equipped aircraft for beyond-visual-range combat because it is the first aircraft to be cleared for operational service with the Meteor missile made by the German company MBDA. Most existing air-to-air missiles have a solid propellant that burns in about seven seconds. This propels the missile up to Mach 4 and then it starts slowing down due to wind resistance. The AIM 120D missile produced by Raytheon in the United States has a two-pulse motor that reduces the burn rate of the propellant. Wind resistance is proportional to the square of the speed so having a lower top speed but maintaining that speed for longer increases the range of the missile. The range of a missile depends upon altitude and thus air density, with 25 percent of current velocity being lost every 150 seconds at 24 kilometers altitude, 25 seconds at 12 kilometers and 5 seconds at sea level.

The Meteor missile is a further improvement in two ways. Two thirds of the propellant in a traditional missile is oxidant. If oxygen from the air is used instead to oxidise the propellant, range is increased dramatically. The Meteor does that by using a ramjet motor that takes it to Mach 4. Instead of having a pulse burn, it is a longer, continuous burn. Being a ramjet with a liquid propellant, the Meteor can vary the burn rate. It uses that ability to slow down for the terminal kill. The importance of this is that a missile can't be travelling too fast or otherwise it is likely it will not be able to turn inside the target's turning circle so will overshoot. So the Meteor slows down from Mach 4 to Mach 2, still faster than most aircraft. But the Meteor is radar-guided from its own radar, and radar-guided missiles are easy to decoy or jam. This is why most Meteors will miss. With its longer range and higher sustained speed than the AIM 120D, the Meteor's no-escape-zone is three times larger than that of the AIM 120D. The no-escape-zone is the zone, relative to a missile's firing point, in which the target aircraft can't outrun the missile, waiting for it to run out of energy, and instead has to out-turn the missile or decoy it.

Instead of a towed decoy, the Gripen E uses an expendable, active decoy called BriteCloud, also made by Selex, to divert radar-guided missiles from the aircraft. Once the beyond-visual-range missiles have been expended then the opposing aircraft will proceed to the merge, or run away.

The Gripen E's avionics architecture is also user-friendly with a distributed integrated modular avionics system that separates the 10 percent of core flight critical management codebase from the 90 percent of tactical management code. The result is that the avionics are hardware agnostic and that the tactical management part is now effectively like a smartphone—able to receive new applications without the need to re-certify the flight critical software. This means that upgrades to functionality, displays, computers, sensors and weapons should be easier, cheaper and faster in the future.

Saab pioneered data linking between aircraft so that a group of four all share the same data. Thus one aircraft can operate its radar and pass on the targeting data to another which might be in a better position, and unseen to the target. Saab fighter aircraft have been doing this since the Viggen in 1985. Each Gripen E can act as a mini-AWACS aircraft. So can all the late model Sukhoi aircraft. The three Euro-canards—the Gripen E, the Rafale and the Typhoon—are comparable in their weapons and systems capabilities. But the Gripen E does it at half the cost of the other two and with a higher sortie rate due to easier maintenance.

The Gripen, in the form of the C version, has done well against the F-22 in Red Flag exercises in which it was nicknamed “the velociraptor”. Thai Air Force Gripen C aircraft have also defeated Chinese Su-27, and/or the Chinese-produced variant, the J-11, in mock combat in Thailand with a 4:0 win by the Gripens over Su-27 and its clone.

An accolade for Saab’s engineering skills is that Boeing chose Saab to partner with for the competition to supply the U.S. Air Force’s new jet trainer, and this despite Boeing’s considerable in-house skills and resources.

Finally, to win an air war requires having a force of aircraft that is still operating at the end of a war. To calculate how many aircraft are needed at the start of the war, decide how many enemy aircraft need to be destroyed then divide that number by the loss-exchange rate of the contenders, and then add that number to the desired force size at the war’s end. For a given financial outlay, a force based on the Gripen E is more likely to provide the desired result than any other aircraft.

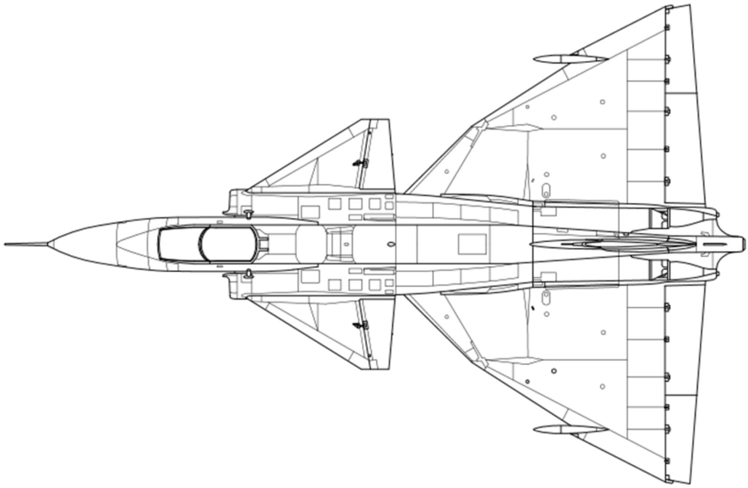

Figure 16: Saab Viggen

Just as the Sukhoi Flanker family of aircraft have derived from the Su-27 that first flew in 1977, the Saab Gripen has evolved from a design and a concept of operations that had its beginnings in the 1950s with the Saab Draken. The Draken had a cranked delta wing in which in the inner delta had a higher sweep angle than the outer delta. The Draken was the first supersonic fighter aircraft in Europe. The next iteration in the evolution was the Viggen, shown above. It grew in weight from the Draken's 7.8 tonnes empty to 9.5 tonnes. The cranked delta wing was replaced by a compound delta shape that bowed outwards instead of inwards, combined with large canards. In the late 1980s the Viggen was followed by the Gripen with all-moving canards and a straight delta wing. Evolution since then has been within the Gripen planform, most likely the ideal planform for a single-engine fighter aircraft.

Figure 17: Saab Gripen Front View
What is evident is the large volume of the wing roots in the blended delta wing that provide a large fuel volume.

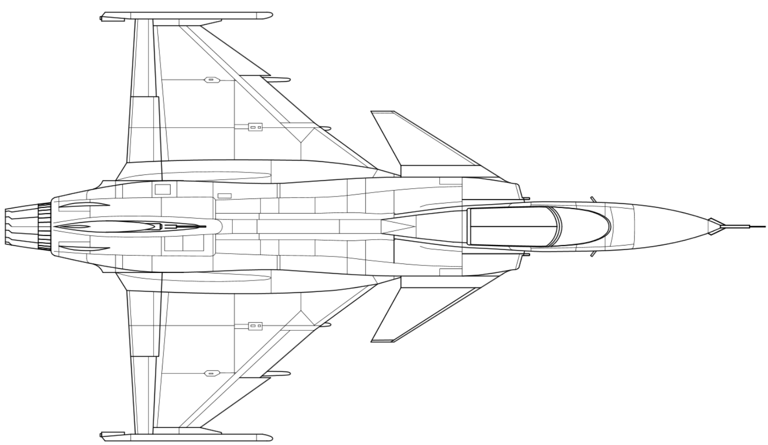

Figure 18: Saab Gripen plan view
The interaction of the canards and the delta wing provide more lift than the same total area as wing alone. The canards give the Gripen the highest instantaneous turn rate of any fighter aircraft.

The Economics of Fire Support

> *…had pinned my army to the ground and rendered any smooth deployment or any advance by time schedule completely impossible. Anyone who has to fight, even with the most modern weapons, against an enemy in complete command of the air, fights like a savage against modern European troops, under the same handicaps, and with the same chance of success.*
> —Field Marshall Rommel on the Royal Air Force after the battle of Alam Halfa[1]

7.1 The Two Types of War from Here

THE MAIN TASK of United States forces during the Cold War was to fight the Soviet Union on the plains of northern Europe and the weapons to be used were chosen accordingly. For example the F-16 had a short range because it wasn't going to have to fly far to encounter Russian aircraft and the design quite happily traded range for a high thrust-to-weight ratio. The A-10 aircraft was designed to knock out Russian tanks in the only way possible at the time—by firing a gun while the plane's nose was pointing directly at a tank. This was the time before GPS and ground-based laser designators. The Cold War-oriented force structure had its glorious moment in the sun during the First Gulf War of 1991, straight after the Cold War ended. Masses of armor faced off against each other and the side that had the qualitative edge in training, equipment, command and tactics triumphed. That war vindicated the choices of equipment and doctrine made during the Cold War.

But things have moved on from there. Stealth aircraft, in the form of the F-117, were shot down or mission-killed over Serbia later that same decade. GPS became ubiquitous, optics improved, electronics miniaturized and became cheaper with the result that new types of weapons were created. The wars we are fighting also changed. There may still yet be tank battles on the North European plain though the number of tanks in the region is well down from its peak a generation ago. It seems that we will be fighting two types of war from here. They are police actions against low-technology Islamists and high intensity warfare against a near-peer belligerent, most likely China.

We have now been fighting wars against Islamists, and with some Islamists against other Islamists, for over 15 years. And in Iraq we are on both sides of the same battle, sending food into ISIS-controlled territory while bombing them at the same time.[2] It is a war we really don't want to win because winning would mean that we would be holding ground and making futile attempts at nation-building. And we would own the problem of keeping the inhabitants fed. The Middle East is headed for a population collapse due to starvation from overpopulation and we don't want to be there at the time.

The so-called Arab Spring, which began with the self-immolation of a Tunisian vegetable vendor at 11:30 am on December 16, 2010, has resulted in three failed states in the region so far. Libya is now far more dangerous to the West than under Gaddafi because of the number of terrorist organizations based there. The French and English self-indulgent attempt at regime change created a terrorist haven with consequences as far afield as Mali and the 300 Christian girls kidnapped in Nigeria. Fortunately, Syria has become a meatgrinder for Islamic terrorists.

In that conflict, the Obama Administration chose to support the side that does some of the beheadings. Perhaps it is a brilliant plan—a rational person would want the meatgrinder to keep grinding rather than have the Islamists defeated too quickly.

The last time Syria attacked a civilized nation was the Yom Kippur War of 1973 in which it and Egypt launched a surprise attack on Israel. At the time, Syria had a population of seven million and Egypt 38 million. It was also about the last time that both countries could feed themselves from their own agricultural efforts. Their populations are now 22 million and 84 million respectively, with all the increase in population from 1973 fed with imported grain. This is true of the entire Middle East—North Africa (MENA) region. This is shown in the following graph going from Morocco in the west to Afghanistan in the east.

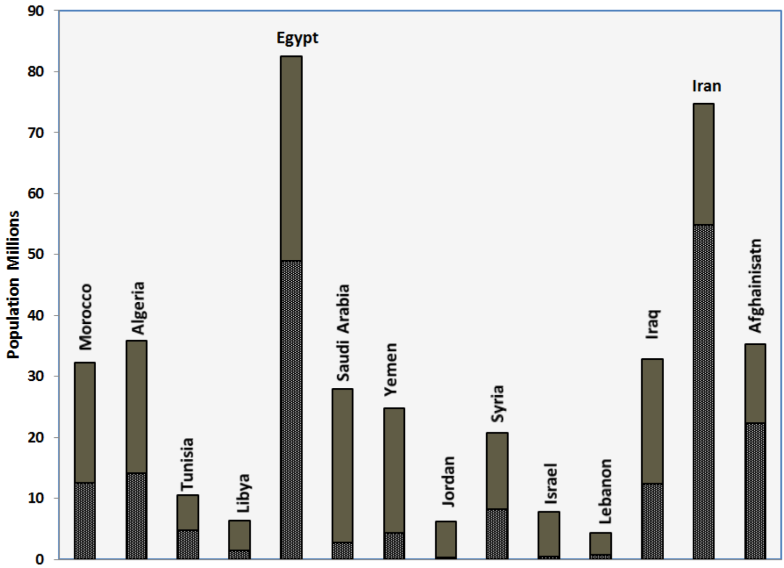

Figure 19: Proportion of Imported Grain and Domestic Grain by Country, MENA Region

The size of each bar is the country's population in millions. The lower, light-stipled part is the proportion fed from domestic production and the upper, darker part of eacch bar is the proportion kept alive with imported grain. Arguably Norman Borlaug and his green revolution allowed this situation to come about. World grain production outran population growth up to about a decade ago with grain beoming the cheapest it has been in history. Feeding these growing populations has been very cheap for regimes that subsidize bread to keep their populations quiescent. At the current price of wheat of $330 per metric ton and per capita consumption of 300 kg per annum, it only costs $0.27 per day in grain to keep someone alive.

But grain yields in most countries have plateaued since 2000. The effect of a constricted grain supply will be accelerated by the solar-driven global cooling that has started.[3] At some stage the cost of keeping everyone fed will overwhelm one of the MENA countries and it will collapse in mass starvation. There will then be a scramble around the world to stockpile grain, sending prices yet higher. In turn, that will set off a domino effect in the graph above. Using an animal model of population collapse (the snowshoe hare and lynx), populations might fall to 10% of carrying capacity—back to levels seen 200 years ago.

Israel imports most of its grain requirements as do all its neighbors. The difference is that Israel has a GDP per capita of $30,000-odd, which is at least 10 times that of its neighbors—Egypt, Jordan and Syria. Lebanon's GDP per capita is about $10,000. Israel could withstand a much higher grain price. It is also the most efficient desalinator of seawater on the planet. With a cost of $0.52 per cubic meter using power generated from fossil fuels, it is able to grow commercial crops using desalinated seawater. For Israel to survive from here, all it has to do is out-wait its neighbors. In the good old days, a large population meant a country could have a large army. These days it means the ongoing drag of having to feed a lot of unproductive people with every missed grain shipment a potential disaster. At the time of the overthrow of the Muslim Brotherhood leader Mohamed Morsi, for example, Egypt had three weeks of wheat supplies on hand.[4]

How many Afghanis have died in the conflict since the United States-led coalition entered the country in 2001? It may be as many as fifteen thousand, with two thirds having been killed by the Taliban. What has been the population increase over that same period? In 2001, Afghanistan's population was 24.2 million. It is now estimated to be 31.1 million. The sums are easy. There are now seven million more Afghans than when the United States took an interest in the country in 2001—an increase by nearly a third.

The ratio of creation of new Afghans born to deaths in the current war is 467 to 1. What is the carrying capacity of the country? Under ideal conditions, aided by the warmest climatic conditions for 800 years, it is perhaps 20 million people. Does Afghanistan produce anything that it can trade for grain? Its major cash export is heroin, resulting in 30,000 deaths in Russia alone annually. Afghani heroin also causes problems in Iran and on into Europe. So when things are weighed in the balance, the Afghanis cause at least 20 times as many deaths outside the country as are caused by conflict in the country.

The modern history of Afghanistan is written in its wheat consumption. In 1960, there were 9.6 million Afghanis eating 2.3 million tons of wheat for an annual per capita consumption of 238 kilograms. Now there are 31.1 million Afghanis eating 6.0 million tons per annum of domestically grown and imported wheat, at a rate of 192 kg per capita. Wheat imports commenced in the mid-1970s when Afghanistan was no longer capabable of feeding itself from its own efforts. Imports continued rising during the years following the 1979 Soviet invasion and then collapsed after 1985, along with domestic production. Still, population growth didn't decline below 2 percent per annum during this period of restricted supply. Wheat imports then rose dramatically after the United States took its turn at helping administer the country. Afghanistan is similar to Yemen in having a median age of eighteen years and population growth rate of 2.4 percent per annum. At that rate, the current population is growing by some 700,000 per annum. Thus wheat demand is ratcheting up at about 200,000 metric tons per annum.

The annual budget of the Afghani government is $14 billion, while the GDP is only a little larger, at $18 billion. Afghans pay for only about 10 percent of their government budget. Over half comes from the United States, with other Western nations providing the remainder. All those funds are wasted. The United States and its allies were scheduled to withdraw militarily in 2014 but have remained. The United States has promised to prop up the Afghan government with large cash transfers. Eventually, and it probably won't take very long, interest in Afghanistan will fade and Afghans will be abandoned by their leaders, who will leave the country to retire wherever they have deposited their bribes. The grain trucks from Pakistan will stop arriving. The urban hungry will scour through the countryside consuming whatever calories they can find—seed grain, goats, dogs, grass. The large number of weapons in the country will mean matters will be resolved quickly and violently. If we assume that cyclic population collapse, as per animal models, this will take population down to 10 percent of carrying capacity, then the population of Afghanistan sometime later this decade may be a few million, after the deaths of over 20 million.

Is there any force on earth that can stop this from happening? No there is not and all the while the problem continues to compound on itself at the rate of 2.4 percent per annum. But other events as the decade progresses will make mass starvation in Afghanistan seem like a non-problem. Even if the United States wanted to continue underwriting the Afghani population explosion with grain imports as per the Global Food Security Act of 2016, how would it have the necessary grain reaching them?

Afghanistan is where the 9/11 attacks were planned, and the United States-led intervention was initially to hunt down the perpetrators of those attacks. The mistake was to remain to undertake some nation-building. That has been widely recognized to be a mistake since it is not possible to inculcate higher values in a population that has not progressed past the Dark Ages culturally.

In the future the United States will have to adopt a new paradigm in dealing with Third World countries from where it is attacked. The reason Third World countries are such is cultural. Those who command them find it easier to steal other people's wealth than create their own. So spending money on them is a hopeless cause. It merely rewards and entrenches their existing behavior.

Of necessity, interventions will evolve to police actions without fraternization with the population of the errant country. The war in Afghanistan has been a good weapons lab and has already gone on long enough for weapons systems to evolve to full utility. Western forces now have far greater precision in the application of force than when the war began. The benefit of that is not reduction of collateral damage but the potential to lower the cost of conducting operations. That said, events could yet unfold in the Middle East that would make the final withdrawal from Afghanistan difficult. There may yet have to be a fighting retreat to the port of Konarak on the southern coast of Iran.

Beyond the problem of cultures that are antithetic to Western values, the attempt at nation-building in Afghanistan was doomed to fail because it, like most of the Middle East, is destined for a starvation event that threatens to take population down to a fraction of the country's carrying capacity. It is pointless to attempt nation-building if a nation is destined to starve to death.

Afghanistan is also notable as the place where the CIA became frustrated at seeing terrorists from their unarmed Predator drones while not being able to "reach out and touch them". So they armed their Predators with Hellfire missiles and a new form of warfare was created, a way of getting rid of unhappy, unpleasant people who want to impose their will on others, particularly the United States, without exposing our own troops to danger. But it is not cost-efficient to spend $100,000 on a missile to remove a handful of people who might have only cost a couple of thousand dollars each to get to the age of 18.

Egypt is estimated to have had a population of 4 million at the time Napoleon Bonaparte visited its shores during 1798. Today it stands at 84 million with an annual growth rate of 1.8 percent. At this rate another 1.5 million Egyptians are added annually. On a spare, almost completely vegetarian diet of 350kg per annum of grain, each year's cohort of new Egyptians will require over half a million metric tons of grain as adults. Thus Egypt's grain requirement ratchets up by half a million metric tons every year. Egypt is currently producing 16 million metric tons a year of wheat and corn and importing a further 15 million metric tons of grain. Egypt's ability to grow grain has peaked, limited by the available water from the Nile. The switch from high-water-consumption crops such as rice and cotton to wheat has already taken place. On the current trajectory of rising demand, the import requirement will be 28 million metric tons of grain by 2030. Two-thirds of that would be wheat, an amount that is in turn equivalent to two-thirds of the current level of wheat exports from the United States.

Egyptian society has a number of unpleasant features. Its female genital mutilation rate is 90 percent. The rate of consanguineous marriage is high, at 35 percent, giving rise to a high incidence of congenital defects. The Christian Copts, who constitute about 10 percent of the population, are less inbred than Moslem Egyptians. As happened to the Armenians in Turkey on the collapse of the Ottoman Empire nearly a century ago, the Copts may well be slaughtered first during any collapse of Egyptian society—forfeiting Egypt the sympathy of the West in its plight.

President Obama's backstabbing of President Mubarak and his support of the successor Muslim Brotherhood regime, which earned the United States a reputation for double-dealing and the enmity of the Egyptian people, happened just in time. If Egypt had stayed in the nominally pro-Western camp, there would have been a period during which the United States and perhaps other Western nations would have thrown money into the black hole that will be Egypt in collapse. The Mubarak regime collapsed in part because of withdrawal of support by the Obama Administration. This is a case of the right result for the wrong reasons.

In 1984, then Secretary of Defense, Caspar Weinberger, delivered a speech at the National Press Club listing six tests that should govern sending troops into combat.[5] These are:

1. The United States should not commit forces to combat overseas unless the particular engagement or occasion is deemed vital to our national interest, or that of our allies.
2. If we decide it is necessary to put combat troops into a given situation, we should do so wholeheartedly, and with the clear intention of winning.
3. If we do decide to commit forces to combat overseas, we should have clearly defined political and military objectives.
4. The relationship between our objectives and the forces we have committed—their size, composition, and disposition—must be continually reassesed and adjusted if necessary.
5. Before the United States commits forces abroad, there must be some reasonable assurance it will have the support of the American people and their elected representatives in Congress.
6. Finally, the commitment of US forces to combat should be the last resort.

Currently the United States has military operations firing ordnance in six Middle Eastern countries in an arc five thousand kilometers wide, from Libya to Pakistan. All these operations fail most of Weinberger's conditions. Specifically, in the 2008 presidential campaign Barack Obama spoke of the Afghanistan involvement as the "good war" and the United States' continued presence in Iraq as the "bad war". Eight years later the United States still has forces in the former and has returned to the latter. The United States was supposed to withdraw from Afghanistan in 2014. That was put off because the country would have collapsed, the food distribution system would break down and there would be mass starvation, for which President Obama would be blamed. The next president is likely to order the necessary withdrawal.

The United States had stayed out of the civil wars in Syria and Iraq, which are sectarian wars between different branches of Islam, until there was a clamor to do something about the atrocities being committed by ISIS. Unfortunately the response, as in Afghanistan, has been expensive and ineffective. The desultory bombing campaign is wearing out airframes on a fleet that is already geriatric.

Despite their strategic futility, it is likely that the United States will be fighting campaigns against ISIS and its derivatives for some time. We should do that as cheaply as possible while not exposing troops to danger. That is entirely possible. For example, until the advent of GPS, rockets were the most inaccurate method of delivering high explosive on the battlefield. Now, with GPS, they are the most accurate and cost-efficient way of doing that.

ISIS is well aware of the cost trade-offs in combat. In November 2015, they issued a propaganda video which noted that each Maverick missile costs $250,000 "while we send your proxies to hell with 50 cent bullets." What they say is correct. The Maverick missiles should be saved for use against $6 million tanks, similarly with the Hellfire missiles at $100,000 each and Javelin missiles at $80,000 each.

The characteristics of the battlefield against ISIS are:

1. ISIS doesn't have radar-guided ground-to-air missiles or any other surface-to-air threat effective at more than 15,000 feet.
2. ISIS can't geolocate radars.
3. ISIS doesn't have accurate long range artillery.

ISIS is aware of the need to deliver large amounts of high explosive on the battlefield to create tactical opportunities. They do this by dispatching suicide bombers in vehicle-borne-improvised-explosive devices to an opposing front line and then rushing it during the confusion after the blast. The vehicles used are either Mad Max-type armored trucks or BMPs, which are Russian-sourced armored personnel carriers. Thanks to their sponsors in Turkey and the Gulf States, ISIS and similar groups also use anti-tank guided munitions with ranges up to four kilometers. These are accurate and highly effective. Use of the Russian version, the Kornet missile, by Hezbollah in Lebanon in 2006 prompted Israel to develop a protection system for their tanks called Trophy. The Trophy system uses four small radars around the top of the turret to direct a shotgun-type blast of pellets against the incoming anti-tank missile. And it proved effective during Israeli operations in Gaza.

The relevance of all this is that from here on Western Civilization will be fighting two types of wars: low technology policing actions concentrated in the Middle East and high technology wars against near-peer countries. We will bankrupt ourselves if we attempt to fight the former with weapons needed for the latter; which is what is being done at the present. We are also wearing out costly equipment unnecessarily, including F-22s at $62,000 per hour to drop $40,000 bombs on enemies who cost a couple of dollars a day to feed. On top of all that, the cost of conducting the first kind of war means that we don't yet have the right weapons for the latter.

7.2 The History of Air Support

Fighter aircraft have been used for close air support of ground operations since World War I. At the moment the U.S. Air Force would like to supplant an aircraft created for close air support, the A-10, with the F-35. That is a bad idea for many reasons, but keeping the A-10 for that role is also sub-optimal. Warfare has changed with technology and what was done with aircraft should be more effectively and more cost-effectively achieved by ground-based ordnance.

Close air support requires cooperation between the Air

Force and the Army. Assuming that as a given, the elements necessary for success are the following:

1. Planning for specific employment of close support in specific war contingencies, against well-defined threats.
2. Establishment of command relationships and communications between the Army and the Air Force (down to squadron and battalion level) that guarantee close support directly responsible to the ground commander.
3. Dedication of specified sortie effort levels and, even better, dedication of specialized close support units.
4. Provision of aircraft and ordnance stockpiles that match the close support operations and targets determined by planning.
5. Intensive training of close support units jointly with the ground force units to be supported, exercising under time pressure the full sequence of close support events: support request by the ground, approval, aircraft arrival, target designation by the forward air controller, and ordnance delivery by air.

Close air support began in World War I with strafing and some bombing, which was conducted by tossing 10 to 20 pound bombs over the cockpit sides. Accuracy was of the order of 100 feet. Losses in strafing missions were high, as in every subsequent war, because of machine gun and rifle fire. Germany created an aircraft dedicated to ground attack in time for World War II, the Stuka Ju-87. German observers of US Navy dive-bombing exhibitions in the early 1930s were impressed by the accuracy of this new technique. The Stuka was intended to achieve slow vertical dive speeds of 140-180 knots for bombing accuracy. Although it was slow, it had high maneuverability and the aircraft was quite effectively armored. Anti-aircraft fire of 20mm was considered an insignificant threat by Stuka pilots.

The Stuka had an automatic dive pullout mechanism to allow pullout 'g's' higher than the pilots blackout threshold, allowing closer releases in a steep dive and greater accuracy. The pilot would recover consciousness after the aircraft leveled out from this dive. Bombing accuracy of 30 feet was achieved but this was insufficient for hitting tanks. So in 1943 special purpose tank-killing Stukas were deployed to the Russian Front. They were equipped with a belly-mounted 37 millimeter automatic cannon that could penetrate the top and rear armor of the Soviet T-34. Stukas were particularly effective on the Russian Front, and the most effective Stuka pilot of them all was Hans Rudel.[6] During his career in the Luftwaffe, Rudel flew over 2,530 missions, shot down 11 enemy aircraft, destroyed 519 Soviet tanks, 150 artillery pieces, 70 boats, over 1,000 military vehicles, and sank a destroyer, two cruisers and the Soviet battleship Marat. Rudel was responsible for such huge losses to the Red Army that Soviet dictator, Joseph Stalin, placed a one hundred thousand ruble price on his head.

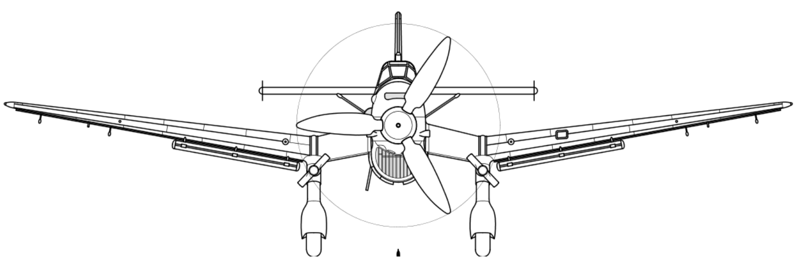

Figure 20: Junkers Ju 87 Stuka

The Stuka, designed for its role in close air support, was originally inspired by the success of the US Navy's dive bombing tests in the early 1930s. The most famous Stuka pilot, Hans-Ulrich Rudel, had 30 Stuka aircraft shot out from underneath him. He also lost his right lower leg; he returned to combat two months later with a wooden leg.

It is essential to an understanding of close air support to realize that such significant results cannot be obtained without a willingness to expend aircraft. Even Rudel lost 30 aircraft to anti-aircraft fire and accidents, a loss rate of 1.2 percent of sorties flown which is exactly double the United States loss rate of aircraft over North Vietnam. Rudel's loss-exchange rate was exemplary. He destroyed one tank every 5 sorties and accounted for 17 tanks for every aircraft that was shot out from under him. Critical to the expendability and the usefulness of the Stuka was the fact that its cost was approximately equal to each of the tanks it destroyed—about $40,000 in 1943.

There was only one notable Allied effort at close air support in the European theater during World War II. This was the spirit of air-ground cooperation that developed between Patton's Third Army and the local U.S. Air Force commander, Lieutenant General Elwood Quesada, who held the view that close air support during Patton's drive across France was his most important function. Patton relied upon Quesada's fighters to cover his otherwise unprotected right flank, allowing Patton to significantly increase the weight of his main attack and contributing to his record rates of advance. It was only toward the end of World War II that the U.S. Army Air Force realized the importance of forward air controllers to direct high speed fighters to critical targets. Ad hoc arrangements to attach pilot-controllers with the proper radios to each maneuver battalion were quickly made. This was the genesis of the U.S. Air Force's forward air controller system.

In the Pacific Theater, the U.S. Marine Corps had already developed an identical system of forward air control by 1943, aided by the fact that they owned the aircraft. Their system was better than that of the U.S. Army Air Force because the Marines provided fighters with radios on the ground frequencies. Marine pilots all served one year in the infantry which greatly helped *esprit de corps* and effectiveness.

The Korean War added nothing to the theory or practice of close air support, save perhaps for a demonstration of the ineffectiveness of 450 knot jet fighters in the close support role.[7] The U.S. Air Force, having split from the Army in 1947, had disbanded their forward air control system and contributed little until they rebuilt it. The Marine Corps was effective because they entered the war fully capable of close air support and dedicated the majority of their sortie effort to this mission. The aircraft that the U.S. Air Force used for close air support were the ones they found unsuitable for bombing or air-to-air fighting in North Korea. The P-51 Mustang, as soon as it was displaced by jets in North Korea, was the first aircraft relegated to close air support. Unfortunately it was quite unsuitable because a rifle bullet through the coolant radiator could destroy it. The next aircraft relegated to close air support was the F-80 Shooting Star after it was displaced in North Korea by the faster F-84 Thunderjet and F-86 Sabre. The F-80 was poorly suited for ground support due to its high speed and limited maneuverability.

In the latter stages of that war close air support became relatively ineffective due to the lack of visible or vulnerable targets. This became worse when the U.S. Air Force raised the bombing release altitude to a minimum of 5,000 feet in order to reduce attrition. After this rule, target detection and accuracy became so poor that close air support was not normally permitted within one mile of friendly lines. Some interesting ordnance lessons were learned in Korea. The United States found that it had no air-delivered weapon that was effective against the T-34 tank with the possible exception of napalm which would sometimes ignite the rubber road wheels. Fighter guns, then .50 caliber, could not penetrate the T-34 at all, rockets were too inaccurate and bombing was much too inaccurate. Another lesson was the psychological impact of different types of ordnance on the enemy. Pilots of close support aircraft rated napalm as their most effective weapon, followed by rockets with strafing a distant last.

Interrogation of prisoners found that those on the receiving end reversed the order; strafing was feared most, followed by rockets with napalm a distant last.

By the time of the Vietnam War the U.S. Air Force had again disbanded its forward air control capability. Because of the length and slow pace of the war, it built up a close air support control system of unprecedented complexity that strongly resembled peacetime air traffic control. It developed a preference for airborne forward air controllers. Response time to emergency close air support requests was even slower than in previous wars, averaging about 45 minutes. Only aircraft loitering over the target demonstrated response times of less than five minutes. As in the Korean War, the aircraft applied to close air support were those unsuited to the air war in North Vietnam. Later, as the theater filled up with more F-4 Phantoms than could be used in North Vietnam, even these were used in close air support in South Vietnam. The most effective weapons used were, as before, strafing and World War II-era 100 pound and 250 pound fragmentation bombs.

The most successful close air support aircraft of the war was the A-1 Skyraider, a propeller-driven aircraft with a radial engine, which first flew in 1946. The A-1 Skyraider squadrons developed a particularly close rapport with the Special Forces and were instrumental in saving numerous Special Forces camps from being overrun. They would provide close air support under 1,000 foot ceilings, in narrow valleys or on cloudy nights when all other aircraft were grounded. They strafed and bombed enemy infantry up to the barbed wire defenses of base camps.

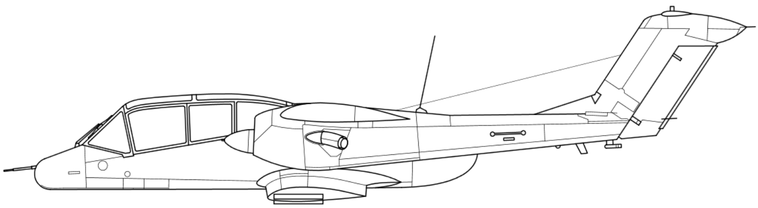

Figure 21: North American OV-10 Bronco

One of the original roles for aircraft on battlefields came as early as the Italian campaign in Libya in 1911, which was as an artillery spotter. As aircraft became more powerful, they were loaded with bombs and assumed part of the role of artillery. Technology has further evolved and it is likely it will be more cost-effective for aircraft to shrink, literally and figuratively, back to the role of finding targets for ground-based weapons. The North American Rockwell OV-10 Bronco first flew in 1965 and saw service in the later years of the Vietnam War in the role of forward air control. Apart from its own armament, it used rockets to mark where fast jets should be placing their ordnance. Its two, efficient turboprop engines gave it long loiter time. Two OV-10 Bronco aircraft, after $20 million of upgrades, recently served in Iraq. The OV-10 Bronco's service ceiling of 24,000 feet is ideal for airspace that is uncontested by other aircraft but has the danger of deployment of man-portable surface-to-air missiles.

During the disastrous A Shau Valley helicopter assault, A-1 Skyraiders were the only aircraft that could come in under the low ceilings and survive the heavy defenses that had downed some 30 helicopters.

U.S. Marines in Vietnam showed a considerable decline from their previously unmatched close air support traditions. Marine pilots were no longer required to serve a tour as infantry. As the Marine squadrons acquired more F-4 Phantoms and A-6 Intruder bombers, they showed greater interest in bombing Hanoi and less in providing close air support. They were still more effective and better integrated with ground operations than the U.S. Air Force and U.S. Navy units.

One new form of close air support was tested in Vietnam—the armed helicopter, developed by the U.S. Army in response to the traditional lack of suitable close air support it received from the other services. Combat showed that helicopters had inherent aiming instability for rockets and that airborne swivelled or turreted guns were inaccurate. Rockets fired from helicopters at 100 knots were even more inaccurate than when fired from jets. As a result of these inaccuracies, armed helicopters caused substantial numbers of friendly troop casualties until traditional forward air controller procedures were instituted. Combat experience showed that helicopters, armed or unarmed, had high losses in the presence of heavy machine gun or light anti-aircraft fire. Late in the war, small numbers of TOW anti-tank missiles were fired from helicopters with accuracy against static targets in the absence of ground fire.

Some conclusions have been drawn from the experience of close air support in the latter half of the 20th century.[8] They are:

1. Highly independent, multi-purpose air forces that are allowed to control their own targeting will neither train for, nor deliver, effective close support in wartime. If left uncontrolled, they will prefer to spend their resources on interdiction, airfield attack and air-to-air combat. Close air support will receive old, obsolete aircraft using left-over ordnance.
2. Only units equipped with specialized close air support aircraft incapable of the air-to-air and deep interdiction missions will deliver outstanding close air support. Maximum effort, effectiveness and pilot dedication in air-ground cooperation has been achieved only twice in the history of air warfare: first, by the Luftwaffe Stuka units in World War II and by the A-1 Skyraider units in Vietnam.

3. An air force that does not maintain forward air controllers in every maneuver battalion in peacetime is not seriously committed to providing close air support.
4. There is no way to deliver effective close air support without getting in close and slow—this means that the aircraft used must be expendable and, in wartime, expended.

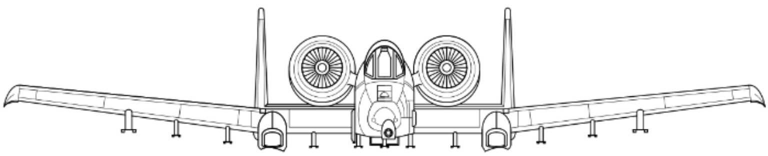

Figure 22: Fairchild Republic A-10 Thunderbolt
The A-10 had its beginning with the Attack Experimental program established by the U.S. Air Force in 1966. In 1969 Pierre Sprey was tasked with writing the detailed specifications for the program. He required those involved with the program to read Stuka Pilot, the biography of Hans-Ulrich Rudel on the eastern front in World War II. Mr Sprey is a fierce critic of the F-35.

Pierre Sprey, a current fierce critic of the F-35, wrote those conclusions over 40 years ago, not long before the introduction of the A-10 Thunderbolt to service. In fact, Sprey was involved in the design of the A-10 after being tasked with writing the detailed specifications for the Attack Experimental project which became the A-10. In 1974 the A-10 had a fly-off against the A-7D Corsair II which was the principal U.S. Air Force attack aircraft at the time. The A-10 is scheduled for another fly-off; this time it's against the F-35 with which the U.S. Air Force wants to replace it. The current Defense Department budget begins replacing the A-10 with the F-35 on a squadron by squadron basis in fiscal year 2018.

Of course, the F-35 is completely unsuited for close air support. It doesn't have long loiter time, low-speed maneuverability, massive cannon firepower, and extreme survivability. Its cannon only has 180 rounds of 20 millimeter ammunition; the A-10 has 1,350 rounds of 30 millimeter. In fact, the A-10 was built around its gun, including its front nose wheel which is offset to the starboard side of the aircraft to accommodate it. The A-10's gun is a structural element of the aircraft—if it is removed, the rear of the aircraft has to be supported so it doesn't sag.

By comparison, the F-35 is a delicate device that can only fly every second day. It also requires specialized air conditioning when it returns from missions. The A-10 can take off from dirt strips; the F-35 needs a paved runway, possibly as long as 8,000 feet. The F-35 has an hourly operating cost that is more than twice that of the A-10. The F-35 can't fly under 25,000 feet for more than ten minutes without opening its bomb bay doors, in order to release heat. The F-35 can't operate on fuel that is hot because some of its electronics will not be cool enough for it to operate.

All these things preclude the F-35 from serious consideration for the close air support role. And there is another reason why it won't darken the skies over ground troops in battle. As predicted by Sprey, the U.S. Air Force has more serious duties available for the F-35 in bombing enemy surface-to-air missile systems. The only reason that the U.S. Air Force is going along with the charade that the F-35 will be made available for close air support is to stop funds from being taken away from the F-35 program.

A total of 716 A-10's were built from 1976 to 1984. Of those, 238 remain in service with an average age of 34 years. These have been given new wings which will allow them to fly for another 20 years unless the realities, and economics, of battle intrude. The A-10s are slow and low, and that makes them more vulnerable. They were badly shot-up in the Gulf War of 1991. Most can still fly after being hit but they are no longer mission capable. Back at the base, they are out of action being repaired for weeks or months which has the same practical effect as if they had been shot down. The subsequent wars have been easier on them because they were up against irregular forces instead of trained troops with larger caliber weapons.

7.3 Artillery

Artillery used to be important. Napoleon Bonaparte said, "It is with artillery that war is made." General Patton observed, "I do not have to tell you who won the war. You know, the artillery did." Those observations are borne out by statistics. During World War II, shrapnel from exploding artillery shells caused 53 percent of U.S. battle deaths and 62 percent of wounds. In Korea shrapnel caused 59 percent of the deaths and 61 percent of wounds. Even in the close-quarter fighting in the jungles of Vietnam, where enemy rifle and machine gun fire caused the majority of deaths, enemy shell fragments still caused 36 percent of the deaths and 65 percent of the wounds.

In crossing France, Patton wouldn't move his troops forward unless the enemy positions were being suppressed by artillery fire. Patton also said that the introduction of the proximity fuze on artillery shells required a full revision of the tactics of land warfare. Proximity fuzes use radar to trigger detonation at a uniform height of burst, usually 30 to 60 feet above the ground, for the optimal shrapnel effect. This was against troops in trenches. Against troops in the open a 'daisy-cutter' burst at six to nine feet above ground level is the most efficient. Air-burst artillery could be as much as 10 times as effective as ground-burst.

The battery to power the miniaturized radar in the proximity fuze was an ampule of acid that broke when the shell was fired, with the spinning of the shell pushing the acid into a circular arrangement of plates. The fuze electronics had to survive the 10,000 g of acceleration down the artillery tube. Production of proximity fuzes for World War II began in 1942 at a few hundred each day, rising to 70,000 per day in 1945. As volume increased, production efficiency came into play and the cost per fuze fell from $732 in 1942 to $18 in 1945. In 2016 dollars, the cost fell from $8,629 to $193. Over 22 million proximity fuzes were produced in World War II.

Massive amounts of artillery ammunition were also used in the Korean War. Between June 1950 and December 1952, U.N. artillery and mortars shot 1,132,000 tons—as much as all the artillery ammunition shot by the United States in World War II in the Pacific and Mediterranean theaters. The effectiveness was three tons of artillery ammunition for each North Korean/Chinese casualty. On many occasions artillery using proximity fuzes was fired directly over U.N. bunkers that were being overrun. The shrapnel would sweep the Communist troops off the outside of the bunkers while the U.N. troops inside would be safe from the red-hot fragments.

Traditionally artillery had to be massed if it was to be effective. The guns themselves need not be physically grouped on the ground, but the effects of their fire needed to be massed in the target area. Three batteries firing one round per gun at the same time are far more effective than one battery firing three rounds per gun, one after the other. For this reason the United State developed the time-on-target technique during World War II. In time-on-target fire, firing units are given the same target and the designated time for their rounds to impact it. The guns in each participating battery fire at the designated time-on-target time, minus the flight time for the rounds from their particular location. All rounds arrive at the target at the same instant with no sound warning. The effect in the target area is devastating as troops don't have time to take cover.

The United States had successes with massed artillery in the Korean War. General Matthew B. Ridgeway noted that,"artillery has been and remains the great killer of Communists. It remains the great saver of soldiers, American and Allied. There is a direct relation between piles of shells and piles of corpses. The bigger the former, the smaller the latter." [7]

The basic physics of artillery include the fact that the longer the barrel, relative to the caliber of the shell fired, the higher the muzzle velocity and the greater the range. At various times in the Korean, Vietnam and Gulf wars, U.S. artillery had been out-ranged by enemy artillery. A 155mm shell leaves the barrel at velocity of about 1,000 meters per second, near to three times the speed of sound at sea level of 340 meters per second. If a shell is still travelling supersonically when it arrives at the target, exposed troops don't get warning of the incoming round and don't have time to take cover. The greater the strength of the steel casing of the shell, the higher the proportion of high explosive in the shell weight. Optimum anti-personnel fragmentation comes from shells with a high explosive content of at least about 25 percent of total weight. The best size for an anti-personnel splinter is under 1/25 ounce, equivalent to about 1 gram.

The main artillery piece of the U.S. Army and Marine Corps is the M777 howitzer. Introduced in 2010, it is a 155 mm towed howitzer which costs $3.7 million. It is manufactured by BAE Systems at its facility in Hattiesburg, Mississippi. About 70 percent of the howitzer is from US-made parts with the balance from the UK. It replaced the M198 howitzer. At 4.1 tonnes, it is 42 percent lighter with most of the weight reduction due to the use of titanium. The other major gun platform is the Paladin self-propelled howitzer which provides its crew with protection against shell fragments and light arms fire.

The effective firing range of the M777 is 24 kilometers. Using base-bleed rounds for extended range increases that to 30 kilometers. Base-bleed increases the range of artillery shells by about 30 percent. While most of the drag on an artillery shell comes from its nose pushing air aside at supersonic speeds, another source of drag is the vacuum left behind the shell due to its flat base. Base-bleed overcomes this drag by using a small gas generator in the base of the shell. Not much thrust is produced but the drag due to the vacuum is dramatically reduced by filling the area behind the shell with air pressure. There is a slight decrease in accuracy due to the more turbulent airflow and a small reduction in explosive payload due to the space taken up by the gas generator. Base-bleed technology was developed in the 1960s for Swedish coastal artillery. The kill zone of a 155mm shell is approximately a radius of 50 meters and casualty radius is 100 meters, from razor-sharp fragments at extreme velocities of 5,000 to 6,000 meters per second.

Laser-guided artillery rounds were developed in the 1980s to provide precision to targetting but they were not found to be useful in practice. Under clear sky conditions they usually performed well as the seeker had plenty of time to detect and track the blinking laser spot and effect guidance corrections to hit where their intended target. Under cloudy conditions though the laser seeker would be blind to the laser illumination until it broke through the overcast, upon which it was often challenged to both acquire the target and guide the round in the remaining time of flight.

So with the advent of GPS, the M982 Excalibur round and XM1156 Precision Guidance Kit were developed. The Excalibur is an extended range shell with GPS guidance. The extended range of up to 57 kilometers is achieved by the use of folding glide fins which allow it to glide from the top of a ballistic arc towards the target. In February 2012, a U.S. Marine Corps M777 howitzer in Afghanistan fired an Excalibur round which killed a group of insurgents at a range of 36 kilometers. Range testing of Excalibur shells has shown that they hit within an average of 1.6 meters from the target. Due to that level of accuracy, one Excalibur round is equivalent to the use of between 10 to 40 unguided artillery rounds in eliminating a target. The problem with the Excalibur round is its cost of $68,000. GPS-guided missiles can deliver high explosive at longer ranges more cost-effectively than the Excalibur round.

So the Precision Guidance Kit was developed. This screws into the nose of the artillery shell in replacement of the conventional fuze. It has GPS guidance and vanes to control the flight of the shell. Within five seconds of being fired, the fuze checks to see whether or not it will land within 150 meters of the aim point. If it thinks it isn't, it won't explode. The purpose of this feature is to give troops more confidence in calling in artillery support close to their position. The U.S. Army developed the Precision Guidance Kit on the expectation that it would cost about $3,000 per unit to procure; it ended up being more than $10,000 per unit for three pounds of mostly metal. And that is possibly because it is overly complicated. Instead of having a battery, the kit uses vanes on the fuze and the rotation of the shell to turn an alternator and charge a battery to power the electronics for the remainder of the shell's flight.

The problem of how to provide power to the electronics of fuzes was solved back in World War II with the ampule of battery acid that broke on firing. GPS-guidance fuzes for artillery shells should not cost more than proximity fuzes. Costs for fuzes range from $75 for point detonating, $312 for an electronic time fuze up to $10,017 for the precision guidance kit.[9] So the Department of Defense is seeking to develop another type of GPS-guided fuze with the intent of having a procurement cost of the order of $1,000 per unit. Russia has produced a GPS-guided artillery fuze which is claimed to have a production cost of about $1,000 per unit.[10] Israel has developed a similar fuze called TopGun with a circular error probable of 20 meters at any range.

The value of these kits comes from the fact that an ordinary 155 mm artillery shell has a circular error probable of 267 meters at its maximum range of 24 kilometers. This means that a shell could land up to 133 meters from the coordinates aimed at, making it dangerous to call for close artillery support at long ranges. The promise of GPS-guided artillery at an economical price means that it should displace close air support out to 30 km from an artillery battery. A 155mm shell costs $440 and a fuze of similar cost should keep the total cost of delivering one round to under $1,000, from an artillery piece that costs $3.7 million to acquire. It will do so unaffected by weather, and supersonically. By comparison the F-35 costs a minimum of $130 million for the platform and the cheapest guided weapon it can use is the Small Diameter Bomb at $40,000 each. It also arrives much later, if at all. The advent of GPS-guided artillery has the promise of fighting ground wars much more cheaply again, obviating the need for close air support and aircraft types dedicated to that. As Conrad Crane observed, "There are two approaches to waging war, asymmetric and stupid. Every competent belligerent looks for an edge over its adversaries."[11] GPS-guided artillery at the right price will provide a permanent asymmetric advantage over ISIS-style adversaries.

As Winston Churchill wrote, "Renown awaits the commander who first restores artillery to its prime importance on the battlefield." Precision guidance at the right price will bring that day forward. Churchill also observed that, "Artillery lends dignity to what might otherwise be a vulgar brawl."

7.4 Longer Range Fire

Targets beyond 30 kilometers range are the province of rockets and rocket-boosted glide munitions. Glide munitions can also reach the backslopes of terrain and the back of buildings that artillery can't destroy. The United States has two rockets in use at the moment; the M31 with a range of 70 kilometers and the M39 Army Tactical Missile System (ATACMS) with a range of 300 kilometers. Production of the M39 ended in 2007 because of the cost of $820,000 per unit. The M31 has a cost of $120,000 per unit and continues to be used in Iraq, from the initial conflict in

1991 to the current campaign against ISIS. Both weapons were developed to provide massed fires against exposed infantry to mimic the effect of an artillery barrage. The M31's minimum range of 27 kilometers starts from about the maximum range of artillery. So the warheads carried were payloads of the M74 cluster submunition. The M74 is a sphere 2.5 inches in diameter weighing 1.3 lbs. Its fuze is armed by spinning in flight after release of the payload, with the spin caused by surface airfoils. On detonation, fragments from the steel and tungsten case have a lethal radius of 15 meters. A pyrotechnic pellet is included to ignite fuel tanks. Videos of Russian cluster munitions being used in Syria indicate that Russian cluster munitions operate on the same principle, including arming by airfoil-induced spinning.

Unfortunately, the United States decided to abide by the 2008 Convention on Cluster Munitions even if it didn't sign up, while its main potential adversaries, China and Russia, also didn't sign so are not bound by it. Unitary warheads were developed for both the M31 and M39 missiles but these are far less effective against troops in the open. Both missiles were developed as assault-breaker weapons in response to the rapid advances in the Yom-Kippur War of 1973. As per time-on-target use of artillery, a barrage of 12 missiles would be used at a time. Until the development of GPS they were too inaccurate to be used against point targets. The development of GPS/Inertial Navigation System (GPS/INS) guidance meant that missiles could be used singly with a circle of probable error of nine meters. The M31 missile is now regarded as a long range sniping system. Both the M31 and M39 missiles can be fired from the M270 Multiple Launch Rocket System and the M142 High Mobility Rocket Launch System; the former is a tracked vehicle weighing 25 tonnes and the latter a wheeled vehicle weighing 11 tonnes that can be carried in a C-130 aircraft.

For the M31 missile at least, an attempt to solve the problem of the ineffectiveness of a unitary warhead is the development of an alternate warhead containing 160,000 preformed tungsten fragments. Tungsten's density is slightly higher than that of gold and more than twice that of steel, so tungsten fragments will travel further. They are preformed because spherical objects do less damage to flesh than ones that tumble as they pass through. The new warhead weighs 90 kilograms which suggests that the preformed tungsten fragments weigh under half a gram each. Given the aerodynamic efficiency of tungsten this possibly means that they are as effective as the ideal size of steel fragments from artillery shells of about one gram. But it also means that the effect would be more localized and, combined with the small circle of error probable, would provide the ability to call in fire very close to friendly troops. The precision and supersonic delivery of this weapon system supplants aircraft in the role of providing close air support for troops far beyond friendly lines, in the range of 30 to 70 kilometers. The US Army's procurement objective is 18,072 M31 missiles with the alternate warhead. Full rate production began on April 8, 2015.

For targets beyond 70 kilometers there has been a promising development that was also triggered by the Convention on Cluster Munitions. Removal of the cluster munition warhead from some M31 missiles created a surplus of the rocket motor powering it. In a trial conducted in Sweden, the rocket motor was mated with a small diameter bomb. The small diameter bomb was equipped with a glide kit so when the rocket motor burnt out, it separated and the small diameter bomb deployed its folding wings. The range of this system is 150 kilometers. The weight of the small diameter bomb is 110 kilograms, about 20 percent more than the original warhead of the M31. The glide kit therefore doubled the range of the M31 and more than quadrupled the area it can service. What is more, munitions equipped with glide kits can be programmed to double back and hit the back of things - hills or buildings. Enemy troops can no longer shelter behind something. The small diameter bomb was designed to optimize the performance of its normal delivery system which is fast jet aircraft. A ground-launched weapon system that incorporates a glide kit can be optimized around its production cost because it doesn't have to be built to the same standards. And then it can cheaply and effectively replace the use of aircraft for close air support out to 150 kilometers from the front lines.

Which brings us to the promise of the Small Glide Munition. To put this into perspective let's revisit the history of precision-guided, air-to-ground weapons, the first of which was the AGM-65 Maverick missile introduced in 1972. It is a supersonic, laser, TV and IR-guided missile weighing almost 300 kilograms. It has a range of 34 kilometers that can be launched from fast jets. It was followed by missiles that were smaller and cost less, such as the AGM-114 Hellfire that weighs 49 kilograms and costs $110,000. Those costs are reasonable if the missiles are taking out high-value targets such as tanks that cost $6 million each. But those high-cost precision missiles will be used against low value targets, such as machine gun posts, because they are the only thing available. So the push to go smaller and lower cost continues. Sometimes that falters. The AGM-165 Griffin was developed as a 15 kilogram missile of which 5.9 kilograms was warhead. The unpowered version had a range of 20 kilometers dropped from aircraft. But it cost $90,000 which meant that the services didn't acquire many.

The latest iteration on the path to smaller and cheaper is the Small Glide Munition. U.S. Special Operations Command has awarded Dynetic Inc., headquartered in Huntsville, Alabama, with a contract to develop this weapon weighing 27 kilograms, 16 kilograms of which is a blast/fragmentation warhead. Released from 30,000 feet at 150 knots, it will have a range of almost 40 kilometers up to 90° from the path of the aircraft, and 30 kilometers behind the aircraft. The variant being produced has a laser seeker as well as GPS/Inertial Navigation System so it can be used against vehicles moving at up to 70 mph. The promising part of the Small Glide Munition is that its wing is a one piece unit that swings through 90° to be deployed. It is long and narrow which optimizes the trade-off between lift and drag. Current air-launch glide weapons have two wings that swing out into the airstream because they are launched at Mach 0.9, or up to Mach 1.5 from the F-22. The one piece wing lowers cost and increases range relative to launch speed. If a version was produced without the laser seeker, that would lower costs again for targets that weren't time sensitive. Given the weapon's range, an aircraft at 30,000 feet can service an area 80 kilometers wide. At 150 knots, it would cover 24,000 square kilometers per hour. The aircraft's flight plan would optimize the delivery route, and the dispensing of the munitions could be automated.

In mid-2016, recently retired Chief of Staff of the U.S. Air Force, General Mark Walsh, said the Air Force wants to replace the A-10 close support aircraft with a robotic 'flying coke machine' that would loiter over the battlefield, dispensing firepower at the touch of a button.[12] At the moment the closest aircraft to that ideal is a transport aircraft sold by Airbus, the C-295. This turboprop machine has an empty weight of 11 tonnes and can carry a payload of six tonnes a distance of 3,700 kilometers at a cruise speed of 260 knots. Users of the C295 have found that it is easy to maintain, stands up well to daily operation over long periods and copes with hot and dusty conditions. Most importantly, its acquisition cost is $28 million and the hourly operating cost is $4,000. It could carry up to 150 Small Glide Munitions including their containers and the dispensing mechanism. The Small Glide Munition could be the coke bottle to the C-295 coke-bottle-dispenser. Such a system would further reduce the need for a type of aircraft dedicated to close air support.

It follows that the Small Glide Munition, or something like it, could be mated with a rocket booster of about the same length and weight to produce a ground-launched weapon with a range of possibly 40 kilometers. The significance of this is that ground commanders would have control over a weapon that could hit the enemy behind terrain and buildings, and between buildings much more effectively than air-burst, direct-fire weapons. This would find great utility in the urban terrain of the Middle East. The conflict in Syria has shown that missile launching systems can be very simple indeed. Al Nusra makes its own rockets and launches them from simple frames made from a few sticks of steel pipe welded into an A frame. Currently U.S. forces launch ground-to-ground missiles from vehicles that weigh either 25 tonnes—the M270, or 11 tonnes—the M42. Both are armored for crew protection in case they are targetted with counter-battery fire as per self-propelled howitzers. But that means they weigh more than five times the weight of the missiles they carry. Also their design was based on a philosophy of firing a salvo as part of a battery then reloading a new pod of missiles. There is no capability to replace individual missiles that have been fired. The alternative is to simply prop the missile-containing canister up at an angle and fire it without benefit of a dedicated launch vehicle. Or it might be as simple as carrying the missile containers on a tilt tray truck, as pioneered by ISIS. If dedicated launch vehicles can be dispensed with, five times as many missiles could take their place as cargo into the theater.

Such missiles would also be the solution for shore bombardment which has become problematic due to the proliferation of anti-ship missiles. It is now too dangerous for ships to approach a shoreline to support a landing with gunfire. The US Navy made an attempt in that direction with the *Zumwalt* class, firing its Advanced Gun System with a range of 150 kilometers. But the rounds for that weapons cost $800,000 each while delivering only 11 kilograms of explosive. They would only chip away at the reinforced concrete forts and hardened aircraft shelters that China has built in the Spratly Islands in the South China Sea. By comparison, Vietnam has recently installed Israeli-made Extra missiles on some of its bases in the Spratly Islands.

These have a range of 150 kilometers with a 120 kilogram warhead. While pricing isn't known, possibly three or four Extra missiles could be acquired for the price of one Advanced Gun System round. The US Marine Corps should consider substituting something like the Extra missile for the F-35B which can only drop bombs every second day. A lot of missile ordnance could be carried in the space to be taken up by F-35Bs on amphibious assault ships.

If we could lower the cost of missiles so that we could buy more and use them, it would save a lot of lives on the battlefield. On the subject of cost, retired Brigadier General Eli Reiter of Israeli Military Industries has several useful observations:

> *For a reasonable price, we offer GPS-accuracy standards. We do not deal with optics. We intend to go into other areas, but our core technology is GPS. Anything beyond that is much more expensive. If you want to be effective, you must remain at a comfortable price level and provide the client with the option of acquiring complete layouts.* [13]

and:

> *A 30 kilogram warhead can drop a 1.5-storey house.*

The importance of the former observation is that there is more than a tendency to specify-up systems so they do everything they might be conceivably applied to. The Small Glide Munition, for example, has laser guidance as well as GPS/Inertial Navigational System. The proportion of targets that are moving and require laser guidance might be five percent. It would be more cost effective for the operator to carry two variants of the same missile, one with laser guidance and one without.

7.5 The Cost Imperative

While on the subject of cost, the cheapest car available in the United States is the Nissan Versa at $12,815. With a curb weight of 2,396 lbs, that is a price of $5.34 per pound. The most commonly used ground-to-ground missile, the M31 used in the HIMARS, has a weight of 680 pounds and costs $110,000 for a price of $162 per pound. Down to its smallest screws, the car has 30,000 parts and with modern quality control, new cars are very reliable. As General Ridgeway observed, artillery saves lives. GPS-guided missiles are the new artillery and if they can be provided plentifully, that is possibly the best thing we can do for our troops. And in a time of defense spending austerity, also give them some tough love.

As in a welfare state, if something is provided for free then people use more of it. In Vietnam, soldiers had to wait an average of 40 minutes for U.S. Air Force planes to provide close air support. Compare that to this quote about one officer's experience in Afghanistan:

> *Never has so much firepower been available to troops on the ground so quickly. "When you left [the base], you pretty much knew what was already on station in the air and their call signs. You knew if you had Apaches [helicopters], if there were F-16s [fighters] or A-10s on station, flying around, and then you could just dial those guys up," said Army Capt. Christian Mitchell, an adviser to an Afghan army battalion in 2007-08. "On average, when you called, you could get it within about 10 minutes," adding that his Afghan allies "loved it."*[14]

The Army may have sent troops into untenable positions because the fire support to bail them out of their predicament was available from the Air Force as a kind of public good. The background to the fact that the Army doesn't provide its own close air support is the Johnson-McConnell agreement of 1966. In 1960 the U.S. Army had about 5,500 aircraft and planned to grow that fleet. The U.S. Air Force was afraid the Army aircraft fleet would keep expanding and take on more roles. Under the agreement, the Army gave all its fixed-wing aircraft to the Air Force and the Air Force undertook not to acquire any helicopters. If the Army was given the opportunity and responsibility to provide its own close air support, it would likely find a cheaper way of doing it. That may include not sending troops beyond tube artillery range.

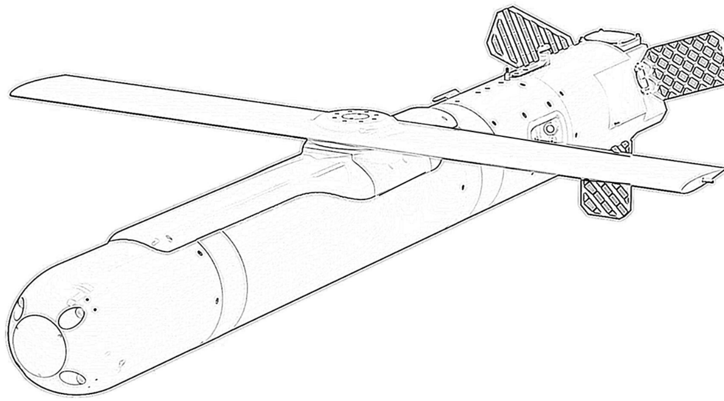

Figure 23: Dynetics, Inc. Small Glide Munition
Developed for Special Operations Command, the Small Glide Munition can be fired from the Common Launch Tube. The flying bomb weighs 60 pounds, of which 35 pounds is warhead. The "potato masher" control fins were originally developed for Russian air-to-air missiles. A promising development, in terms of lowering the cost of munitions, is the one-piece, narrow-chord wing. As well as GPS, the weapon uses a BAE Systems' Distributed Aperture Semi-Active Laser Seeker from the Advanced Precision Kill Weapon System developed for 70 millimeter rockets. In situations where the target isn't moving, a GPS-only version would be a lower-cost alternative.

The China Match-Up

8.1 Introduction

AFTER THE COLLAPSE of most communist states in 1990, the world appeared to have entered a period of permanent peace. The Stanford University-based political scientist Francis Fukuyama called it "the end of history" in which democracy and free-market capitalism would become the final form of human government. In response to Fukuyama's 1992 book[1], Harvard historian, Samuel Huntington, penned an article entitled "*The Clash of Civilizations?*" which was expanded into a book in 1996 entitled, "*The Clash of Civilizations and the Remaking of World Order*".[2] Huntington argued that now that the age of ideological conflict had ended, the world's normal state of affairs of civilizational conflict would reassert itself. He concentrated on the "bloody borders" between Islamic and non-Islamic communities. His insights were seen to be particularly prescient after the Islamic attacks within the United States on September 11, 2001.

Apart from the Islamists, there is another civilization that is unhappy with the world as it is and seeks change. The September 2001 attack overshadowed one earlier that year, far away in the South China Sea. On April 1, 2001, a Chinese jet fighter backed into a U.S. reconnaissance aircraft flying at 22,000 feet and 70 miles southeast of Hainan Island. The Chinese jet crashed; the

U.S. aircraft landed on Hainan Island where the crew of 24 were held captive until April 11. Tension between China and the United States mounted as the days of captivity passed and it seemed that the next step for the United States would be to impose trade sanctions on China, which backed off at the last moment.

The civilizational clash with Islam has continued to escalate, but that is quite containable and at low cost if the right approach is chosen. The civilizational clash with unhappy China will be something altogether different. As Pentagon strategist Edward Luttwak pointed out in his 2012 book, *The Rise of China and the Logic of Strategy*, there are many parallels between China now and Germany in the lead up to World War I.[3] Germany at the time believed that it was not being fully respected. All the other major powers had empires. Germany had been late to "the party" and picked up the scraps around the planet, such as the north-eastern third of the island of New Guinea. Germany, at the time, felt compelled to go to war. It planned on a quick war but it did not turn out that way.

One hundred years later China is bent on following the example of Wilhelmine Germany. It was late to industrialization but made up for that with a ferocious rate of capital investment after 1979. The Chinese have traditionally seen themselves as the most civilized people on the planet. They also prefer that other nations be deferential to them in a hierarchical arrangement. Their intrinsic view of the world was confirmed by the Global Financial Crisis of 2008 during which the Europeans begged to be bailed out of their predicament with Chinese money. That would have sealed the deal in terms of their contempt for foreign cultures that are far more self-indulgent than China's. In fact China's harsher tone dates from 2008.

Some have seen this war coming for some time. In 2005, Robert Kaplan in an article in *The Atlantic* entitled *How We Would Fight China* noted that China will approach the war "asymmetrically, as terrorists do. In Iraq the insurgents have shown us the low end of asymmetry, with car bombs. But the Chinese are poised to show us the high end of the art." [4]

In terms of gaining an empire, China's efforts are far more pitiful than what Germany had gained prior to World War I. China is in the process of attempting to seize the South China Sea as far south as the Natuna Islands, part of Indonesia. Their claim reaches the coast of Borneo. The area has been uninhabited because there was nothing worth staying for. No fishing settlements were in the area so the fishing cannot be that attractive. In terms of oil and gas potential there may be some off Vietnam on the continental shelf. The rest of the area is deep water with coral reefs and carbonate platforms in the style of the Bahamas Platform east of Florida. In short, there is little in the way of natural resources worth losing blood over. The claim is purely political.

The problem that China has created for itself is that now that they have upped the ante in stating that they will enforce their claim, it becomes very difficult for them to back down without losing the respect they crave in the first place. So it is set to end in tears, but for whom?

The Chinese force structure is based on area denial, with a swarm of missile-firing, high speed catamarans at one end of the force spectrum and DF-21D ballistic anti-shipping missiles at the other. The DF-21D missiles, with a range of 2,700 kilometers, are designed to sink United States aircraft carriers. China has also stepped up its computer hacking of utilities and other public infrastructure within the United States, laying the groundwork for a potential "cyber-Pearl Harbor". Ideally, for China, they would like to sink an aircraft carrier and then call for a halt to hostilities. The United States' influence would shrink back to Hawaii and then China would be able to do whatever it wanted throughout Asia.

China does not yet possess all the weapons it wants for the conflicts they have in prospect. It is still having problems building nuclear-powered submarines and engines for jet fighters. China may not feel the need to wait for their technological abilities in those areas to catch up.

There was a belief in the mid-19th century that trade promoted peace. That is, once countries realized that they did better trading with one another rather than fighting, peace and goodwill amongst nations would prevail. This was the theme of two peace conferences in the UK in 1853. That was also the year that Commodore Matthew Perry visited Japan and forced it to open up to trade and modernization. A scant 20 years later, the Japanese cabinet discussed attacking Korea. They attacked China first, in 1895, took over Korea in 1905, then annexed it in 1910. Japan just kept on attacking as the decades passed and left bitter memories throughout the region. And some of the victims love keeping the memory alive. Today 30 percent of Chinese prime time television is devoted to movies about the Japanese invasion of the 1930s.

One problem with trade and rapid economic development is that it tends to make people over-confident. Bethman Hollweg, chancellor of Germany at the outbreak of World War I, confessed later that Germany had over-valued her strength. 'Our people', he said, 'had developed so amazingly in the last 20 years that wide circles succumbed to the temptation of over-estimating our enormous forces relative to the rest of the world.' That sounds exactly like China 100 years later. And there is the problem of when economic growth falters. In 1982, Argentina attacked the Falklands to provide some patriotic legitimacy to the generals' regime when the Argentinian economy went through a soft patch.

And China continues to prepare for war. They have done a good job of convincing their neighbors that one is coming. Over 60 percent of people in countries bordering the South China Sea fear Chinese aggression and expect war. The Chinese continue to convince themselves that war is inevitable. A Chinese

Government film produced in late 2013 and made for viewing within the party and the military, *Silent Contest*, began with these words:

> *The process of China's achieving a national renaissance will definitely involve engagement and a fight against the United States' hegemonic system. This is the contest of the century, regardless of people's wishes.*

The basis of the film is that the United States used cultural engagement with the Soviet Union to destroy that socialist entity and is also using cultural engagement to contain and divide China. The fact that China considers itself to be involved in a titanic "contest of the century" with the United States would be news to many Americans. But the Chinese are not content with having lifted themselves out of poverty by making gewgaws. They crave the respect that only a resounding military victory can bring.

8.2 China's Motivations

China will thus launch its war for the following reasons:

1. **Regime Legitimacy**

Very few people in China believe in communism anymore, including almost all of the 80 million members of their Communist Party. The party itself is now a club for mutual enrichment. The legitimacy of the party is derived from the notions that democracy does not suit China and that the party is the organization best placed to administer the nation. The latter is based on an ongoing improvement in conditions for the bulk of the population. In the absence of economic improvement, some other reason must be found for the population to rally around the party's leadership. This may explain the sudden base-building that began in the Spratly Islands in October 2014.

China's public debt grew from $7 trillion in 2007 to $30 trillion in 2015. This is on an economy measured at being just under $10 trillion per annum. A high proportion of the economic growth of the last seven years is simply debt-funded construction. The real economy is much smaller.

The Chinese government is likely to see the contracting economy and realize that generating more debt won't have an effect on sustaining economic activity. Thus the base-building in the South China Sea was accelerated in 2014 to allow the option of triggering their war. This is a life-and-death matter for the elite in charge of the party. They are betting the farm on this. If this gamble does not succeed then there is likely to be a tumultuous regime change.

2. Chosen Trauma

Japan treated the Chinese as sub-humans during World War II. Japan first attacked China in 1895, not long after Japan started industrializing. That was followed in 1915 by Japan's 21 demands on the Chinese state. China's Nationalist government started observing National Humiliation Day in the 1920s on the anniversary of the date of Japan's 21 demands. The Mukden Incident followed in 1931 and China's and Japan's start to World War II was in 1937.

During the poverty of the Mao years, the Japanese were forgiven for World War II. Mao and Deng Xiaoping were pragmatic and said that Japan couldn't be punished forever. China's recent prosperity has allowed the indulgence of Japan-hating to be resurrected as a form of state religion. National Humiliation Day is observed again as 18th September. The party has directed that television take up the theme of Japanese aggression. There are at least 150 museums in China dedicated to the Japanese aggression of World War II. The regime generates and sustains anti-Japanese sentiment to give it the option to embark on a war.

3. Being Recognized As Number One

The Chinese are a proud people. They actually resent the fact that the United States is considered to be the number one nation. China also realizes that to be recognized as number one, it must defeat the current number one in battle. That is why there won't be just creeping increments in Chinese aggression. It needs a battle for its own psychological reasons. China is most likely to attack the United States at the same time its attacks Japan, because of the United States—Japan defense treaty and because surprise attacks are a more successful way of initiating a war. It will be a surprise attack on U.S. bases in Asia and the Pacific and perhaps well beyond. This will most likely include cyber-attacks on utilities and communications on the mainland.

China has structured its armed forces for a short, sharp war. Of any country, it is possibly the most prepared for war. It has one year of grain consumption in stock and even a strategic pork reserve of live animals and frozen pork. It has just topped up its strategic petroleum reserve of about 700 million barrels. China's attempt at seizing the South China Sea has nothing to do with securing resources or making its trade routes secure. Some Western analysts have projected those notions onto China to rationalize what China is doing. China has offered no excuses. To China it is all about territorial integrity, which is sacred and not the profane matter of commerce. China's military leaders have said they could not face their ancestors if their attempt to seize the South China Sea was thwarted.

4. Humiliating The Neighbors

The importance of the Spratly Islands and the Chinese nine-dash claim is that they divide Asia. China claims that all the waters within its nine-dash claim is Chinese territory, not just the islands. When China gets around to enforcing that claim, foreign merchant vessels and aircraft will have to apply for permission to cross it. Non-Chinese warships and military aircraft will not be allowed to enter it. The Chinese claim extends to 4° south, almost to the equator.

The worst affected country will be Vietnam which will be bottled up to within 80 kilometers of its coast. Japan realizes that its shipping from Europe and the Middle East must head further east before plying north through Indonesia and east of the Philippines. Singapore will be badly impacted because the passing trade will slump. Japan will become isolated because its aircraft will need to fly down over the Philippines to almost the equator before flying west. China ranks the countries of the world in terms of their comprehensive national power which China considers to be the power to compel. This is a combination of military power, economic power and social cohesion. When it is enforced, the nine-dash claim will do a lot of compelling of China's neighbors.

5. Strategic Window

Chinese military writers see a window of strategic opportunity for China early in the 21st century though they haven't publicly outlined the basis for that view. But we can make a good stab at it. Firstly, an air of inevitability is important in winning battles. While China is perceived to have a strong, growing economy that is crushing all before it, that perception of inevitability rubs off on China's military adventures. To use that perception, China has to attack before its economy contracts due to the bursting of its real estate bubble.

Another problem for China is that its aggressive posturing and increased military spending is leading to its neighbors rearming and forming alliances. China is better off striking before its neighbors further arm themselves.

6. Great-State Autism

This is a term coined by the strategist Edward Luttwak to describe the fact that China is seemingly oblivious to the effects of its actions upon its neighbors. China sees itself as the center of the world and solely through the lens of its own self-interest. This has the practical outcome that it cannot perceive of things not going the way it wants them to. Luttwak also considers that China overestimates its own strategic thinking.[3] He says that China doesn't have a strategy so much as a bag of stratagems, most of which involve deception.

7. President Xi Jinping

While China's preparation for war began in the 1980s, the recent ramp up in aggression has been at the direction of President Xi, who, in his formative years as a party apparatchik, was impressed by how the war with Vietnam in 1979 was used to consolidate power in the Politburo. President Xi has accumulated more power than any Chinese leader since Deng Xiaoping. He is using an anti-corruption campaign to purge political opponents. Chinese leaders are supposed to only rule for 10 years before standing down. Just two years into his presidency, Xi's supporters raised the possibility of resurrecting the position of chairman of the party (abolished by Deng Xiaoping to stop another Mao) so that Xi could continue to rule from that position. President Xi is a party princeling who has been toughened up by his life experiences. At the age of 15, he was sent to live and work with peasants in the yellow earth country west of Beijing after his father had been purged. His accommodation was a cave. His step-sister committed suicide due to his father's oppression by the Red Guards.

The highest ranking body in the Chinese Communist Party is the Politburo Standing Committee, consisting of Xi and six others. The 19th Party Congress, due in 2017, will decide a new standing committee lineup. On established precedent this would include Xi's successor as president when Xi is due to step down in 2022. Xi has yet to anoint an heir and has accumulated so much power that it would be difficult to find someone to succeed him. He is thus expected to retain the leadership for at least 20 years. In the longer run, the Chinese Communist Party is grooming Deng Zhuodi, a grandson of Deng Xiaoping, to take the role. North Korea pioneered hereditary leadership in a communist state. China is applying the same principle.

8.3 Japan and the United States

Japan sees this war being thrust upon it and is approaching it with considerable foreboding. It sees conflict as being inevitable. Japan also knows that its best chance of prevailing against China is at the beginning if China starts hostilities in the South China Sea, rather than being isolated and picked off later. Prime Minister Abe recently addressed a sitting of the U.S. Congress, part of his "doing the rounds" to ensure everyone is on the same page with respect to absorbing and repelling a Chinese attack.

The United States believes that a rules-based world order needs to be maintained for global security and prosperity, including its own prosperity because that relies greatly upon world trade. So for the United States this war will be about preserving access to the global commons which are the oceans. The United States military establishment has not kept the public informed of all of China's preparatory moves for war, probably because it doesn't want to be perceived as being the cause of escalation. But the United States military is in no doubt that China will launch a war. The main unknown is timing.

Chinese aggression has been a godsend to the United States Navy which had lacked a credible threat after the collapse of the Soviet Union and had faced ongoing shrinkage. There is a tendency to overstate the efficacy of enemy weapons systems. The Chinese would have read the United States Navy reports on their weapons systems which would have emboldened them further.

8.4 Philippines

Subic Bay in the Philippines was established as a United States naval base in 1901. In 1992 it was vacated at the instigation of the Filipino Government which had demanded a higher annual rent, just as Vietnam had done to the Russians with respect to Cam Ranh Bay. Twenty years later, Subic Bay began hosting United State ships once again as well as Marines and aircraft on a semi-permanent basis. In 2014, the United States and the Philippines signed an Agreement on Enhanced Defense Cooperation which gave the former access to five Filipino military airfields:

Base	Island	Coordinates
Fort Magsaysay	Luzon	15° 26' N, 121° 05' E
Basa Air Base	Luzon	14° 59' N, 120° 29' E
Matan-Benito Ebuen Air Base	Mactan	10° 19' N, 123° 58' E
Lumbia Air Base	Mindanao	8° 24' N, 124° 37' E
Antonio Bautista Air Base	Palawan	9° 45' N, 118° 46' E

The Antonio Bautista Air Base on Palawan is particularly useful because it is just 300 km from the nearest Chinese airfield on Mischief Reef. In 2016, after the annual joint United States–Philippines Balikatan exercise, several HIMARS rocket launchers were relocated to Palawan Island. These are able to hit the

Chinese base on Mischief Reef with ATACMS missiles, which have a 300 kilometer range. Philippines Marines are the best of the Filipino military and are reasonably professional. The rest of the Filipino Army is considered generally inept and demoralized by a corrupt officer corps that takes advantage of its men and has done so for decades.

Nevertheless, there is an opinion that the only bases that the United States requires to sustain an operation against Chinese forces in the South China Sea are either on U.S. territory or in Australia.[9] Australian air bases will be useful for dispersal of United States aircraft during the opening of the Chinese attack, before re-concentrating in the theater.

8.5 Vietnam

China has been invading Vietnamese territory since 111 BC so Vietnam now has more than 2,000 years of fighting off Chinese hegemony. The first revolt against oppressive Chinese rule was in 40 AD by the Trung sisters, Trung Trac and Trung Nhi, who ended the the first period of Chinese domination of Vietnam. Millenia of experience in dealing with its belligerent northern neighbor makes Vietnam take a long view of how to proceed in the current conflict. It has also adopted multiple strategies, including holding regular dialogue with China. It has accelerated the modernization of its armed forces with the acquisition of Su-30 fighter aircraft and Kilo class submarines from Russia. Vietnam opened the naval base at Cam Ranh Bay to foreign navies for repair and re-provisioning.

Vietnam's view is that joining an alliance with the United States carries longterm risks as the United States never stays the course. The United States can do a good job quickly then leave, depending on domestic politics. Vietnam's policy is to internationalize the country as far and wide as possible, opening up its society and ports to all and sundry to be a strong member of the world community, as in the example of Singapore. That is why Cam Ranh Bay is being refurbished as a multi-user port rather than leasing it to the United States as they did with Russia for 25 years. Half the port will be dedicated to foreign navies' ships for resupply, repairs, and rest and recreation, the other half for commercial trade. The strategy is working in that, apart from the United States, France, India and Japan realize that they have to fight China in the South China Sea in order to preserve a rules-based world order. Vietnam is aware though that India is happy to fight China "to the last Vietnamese".

Vietnam has recently moved some Israeli-made Extra missiles to its bases in the Spratly Islands. These missiles are four meters long, have a width of 0.3 meters, a range of 150 kilometers and a warhead of up to 120kg. Vietnam has the ability to hit all of China's airfield bases in the Spratlys. This has the potential to suppress Chinese sorties if used against the runways and would be of great utility if coordinated with bombing.

8.6 Chinese Threat Signalling

In 2013, the Center for the Study of Chinese Military Affairs at the Institute for National Strategic Studies in Washington D.C. published a paper by Paul Godwin and Alice Miller entitled *China's Forbearance Has Limits: Chinese Threat and Retaliation Signalling and Its Implications for a Sino-American Military Confrontation*. The paper is quite timely because it should be possible to predict the sequence and timing of China's move towards war. By the authors' research of China's conflicts with its neighboring countries since World War II, Chinese threat signalling should follow four stages in a conflict.

First, systematic integration of political and diplomatic action is combined with military preparations as the signaling escalates through higher levels of authority. These preparations are normally overt and designed to "deter the adversary from the course of action Beijing finds threatening."

Second, China states why it is justified in using military force should this prove necessary. The message targets both domestic and international audiences. "In essence, Beijing declares that China confronts a serious threat to its security and interests that if not terminated will require the use of military force."

Third, China begins asserting that the use of force is not Beijing's preferred resolution to the threat, but one that will be forced upon it should the adversary not heed the deterrence warnings sent. The signaling strategy seeks to grant China the moral high ground in the emerging confrontation. "Such argument supports China's self-identification as a uniquely peaceful country that employs military force only in defense when provoked by adversaries threatening China's security or sovereignty." The authors suggest China believes that asserting the moral high ground in a fight can ease the international response to any military action it might take and thus reduce the political costs of employing military force.

Fourth, Beijing emphasizes that China's forbearance and restraint should not be viewed as weakness and that China is prepared to employ military force should that be necessary. These four signals, or check lists for war, reflect a basic pattern China has demonstrated since its first signaling in 1950 when China sought to deter U.S. forces from crossing the 38th parallel into North Korean territory.

8.7 The East Asia Theater

There will be two main theaters of operation: the East China Sea north of Taiwan and the South China Sea west of the Philippines.

China claims sovereignty over the Senkaku Islands, physically occupied by the Japanese from 1900 to 1940, and the entire Ryuku chain from the Yaeyama Islands at the southern end to, and including, Okinawa in the north.

China has a substantial fishing vessel fleet and merchant shipping totalling 70 million tons. It has been using this fleet to harass the Japanese Coast Guard around the Senkakus and as far east at the Osagawa Islands, which includes Iwo Jima. This suggests fishing vessels could be used to land Chinese special forces to widely attack Japanese bases that would normally be considered to be well back from the front line. These forces would be used sacrificially to cause maximum mayhem in order to dispirit the Japanese defense. In the north, the Chinese approach would be to seize and hold against the Japanese and US counter attack. In the south, the chief of a fishing corporation on Hainan Island has outlined an approach that China is likely to rely upon:

> *If we put 5,000 Chinese fishing ships in the South China Sea there will be 100,000 fishermen. And if we make them all militiamen, give them weapons, we will have a military force stronger than all the combined forces of all the countries of the South China Sea. Every year, between May and August, when fishing activities are in recess, we should train these fishermen/militiamen to gain skills in fishing, production and military operations, making them a reserve force on the sea, and use them to solve our South Sea problem.*

In Hainan Province, at the northern edge of the South China Sea, there are more than 23,000 fishing vessels available for this purpose. To sink all these will require a stock of thousands of air-to-surface missiles. China has set up its own version of GPS, called Beidou, to enable fishing boats to send short text messages to their headquarters. Each fishing boat is a spotter as well as carrying light arms. Sinking Chinese fishing boats will be as important as “plinking” Iraqi tanks during Operation Desert Storm. As with those tanks, there will be thousands of boats.

For larger ships, China has instituted military standards to which new civilian ships have to be built, covering five categories of vessels: container, roll-on/foll-off, multipurpose, bulk carrier and break bulk. China had approximately 172,000 civilian vessels as at 2014. More than 11,000 were dedicated to inshore transport while some 2,600 performed ocean transport.

As a quid pro quo for China supporting Russia over its seizure of Crimea and the invastion of eastern Ukraine, Russia sold China six battalions of S-400 surface-to-air missile systems with a range of 400 kilometers. Each battalion consists of a command post, radar and eight launcher trucks with four missiles each. The missiles have a maximum velocity of 2.0 kilometers per second. The six battalions amount to 192 missiles, excluding reloads. Operating practice is to fire two missiles at one target to increase the hit probability. So these systems put 96 U.S. and allied aircraft at extreme risk at up to 400 kilometers from the Chinese coast or their island bases. The S-400 system is expected to have a kill probability of 0.3 per missile so a two-missile salvo would have about a 50 percent chance of downing a fighter aircraft.

The Senkaku Islands are 300 kilometers from the Chinese mainland and retaking them now, if they are seized by China, will be somewhat more difficult thanks to the S-400 systems.

In the South China Sea, China is building four massive forts and three airfields on artificial islands. The former are designed with flak towers standing out from the corners so that each tower has at least a 270° field of fire. The forts seem to be designed to take a large amount of punishment and hold out until they can be relieved. China wins if it is still in the possession of these these artificial islands at the end of any war. Current construction at the airfields is the building of hardened shelters for 24 fighter aircraft on each base, four of which will be for aircraft on ready alert.

China is likely to launch the war in the south with attacks on other countries' bases in the Spratly Islands and U.S. bases in the region, as far east as Guam. A long war will be bad for China in that the run down to the Spratly Islands from Hainan Island is very exposed, both for ships and aircraft. Vietnam has been upgrading its radars and hopefully all the non-Chinese combatants will be sharing targeting information. U.S. AWACS over the Philippines will be able to track Chinese targets handed over from Vietnam. Singapore is likely to join in and operate its F-15s from the Vietnamese port of Cam Ranh Bay. Chinese aircraft that survive the run down will be at the end of their range by the time they reach the Spratly Islands.

The U.S. Marines have taken up a number of bases in the Philippines with the intention of mounting the attack that will remove the Chinese from their newly constructed forts.

In the bigger picture, Japan and China will attempt to blockade each other's ports, mostly with their submarine forces. Japan's navy has a qualitative edge over China's and is most likely to win the blockade battle.

Industry throughout Asia will be badly affected by the conflict but Chinese industry, in particular, is likely to quickly grind to a halt and this eventually will give rise to social disruption. The longer the war goes on, the worse China's relative position becomes. Meat will disappear from the Chinese diet. Unsold soybeans will pile up in U.S. warehouses.

The removal of the Chinese bases in the Spratly Islands will allow a peace settlement with whomever emerges to dominate China. It will be one of the history's most pointless, stupid and destructive wars, much as World War I was, but that is what is coming.

The United States and its allies are very likely to win this war. Beginning in the 1920s, it was realized that Japan would one day attack U.S. interests in the Pacific. War Plan Orange to defeat Japan was formally adopted by the Joint Army and Navy Board in 1924. It was a far-sighted plan and was successfully executed during World War II. Nearly a century later, Air-Sea Battle was adopted as the plan to defeat China, with the name later altered to Joint Concept for Access and Maneuver in the Global Commons. It is also likely to be a successful plan. We can tell that some of the gaps are being filled in by things such as the basing choices in the Philippines. Technological development has aided the defense, and that is what we will be doing. The forts China is building in the Spratly Islands will soak up a lot of ordnance but for their ships and aircraft, the South China Sea is a natural kill box. There will be a lot of surprises in this war but we will prevail.

The Chinese economy grew rapidly after China's accession to the World Trade Agreement in 2001. China became the world's preferred subcontractor. Electronic components made in Japan, Korea and Taiwan were imported into China and put in plastic cases. The salad days of China's export-driven growth ended in 2006, when exports as a percentage of GDP peaked at 39.1 percent. That has subsequently fallen to 26.4 percent. But the world can only take so much of China's exports and that point has been reached. Its market share of global trade reached 12 percent in 2011 and has stalled at about that level. That follows railway freight in China, which doubled between 2003 and 2011 but has not grown since. Previous premier Wen Jiabao said in 2013 that China's growth is "unbalanced, uncoordinated and unsustainable". Another thing about China's growth: it may be illusory.

We don't have to spend too much time on economic statistics to divine China's future. All we have to do is note what the Chinese themselves are doing, which is leaving. As John Lee, an associate professor at Australian National University, has noted, the richest one percent of households (2.1 million out of a total of about 520 million households) own 40-50 percent of the country's total real estate and financial assets.[5] This is the result one would expect in a state-sanctioned kleptocracy. These wealthy people are voting with their feet. In a survey in 2014 of almost 1,000 Chinese, each worth over $16 million, nearly two-thirds had made arrangements to leave the country permanently or were planning to do so. This group is particularly well-informed on China's prospects, with 90 percent of the 1,000 polled being officials or Chinese Communist Party members. These are people who have appropriated whatever they can and now think wealth preservation is more important than remaining in place to steal some more.

But it is worse than that. The sudden increase in Chinese aggression in the Senkakus in late 2012 was about the time that Xi Jinping rose to become General Secretary of the ruling Communist Party. He is now also President of the People's Republic of China, Chairman of the Central Military Commission and Chairman of the National Security Council. In a number of edicts, he has tacked hard left politically and is railing against foreign influences upon Chinese society. Under the guise of fighting corruption, he has instituted a reign of terror equivalent to the Stalinist purges of the 1930s. Or perhaps they are just recycling more recent Chinese history. To quote long-time China watcher Anne Stevenson-Yang in late 2014:

> *What's really going on is an old-style party purge reminiscent of the 1950s and 1960s with quota-driven arrests, summary trials, mysterious disappearances, and suicides, which has already entrapped, by our calculations, 100,000 party operatives and others. The intent is not moral purification by the Xi administration but instead the elimination of political enemies and other claimants to the economy's spoils.*[6]

China's economy is not bigger than that of the United States. The relative size of the two economies is possibly most accurately captured by their respective oil consumption figures, China's 10 million barrels per day versus the United States' 18.5 million barrels per day. China's economic effectiveness is diluted by hundreds of millions of rural peasants who make only a small contribution to the economy.

8.8 The Rand Report on War with China

In 2013, the Philippines sought arbitration of its territorial dispute with China under the provisions of the United Nations Convention on the Law of the Sea. In July 2016, the tribunal hearing the case ruled that China has no historical rights in the South China Sea, effectively invalidating China's position. Some others have realized the consequences of China's actions if it is allowed to prevail. In June, French defense minister, Jean-Yves le Drian, said that France should urge European Union countries to conduct 'regular and visible' patrols in the South China Sea. The consequence for France is that other countries around the Mediterranean might start claiming parts of it for their exclusive use, bottling up the French Navy in a little corner.

Following those events, in late July 2016 Rand Corporation released a report entitled *War with China: Thinking Through the Unthinkable*, with the study sponsored by the U.S. Army.[7] The Rand report may be an attempt to help China understand the consequences of the path it is set upon. It notes that the Chinese economy is heavily reliant on export trade. Impinging that trade won't make China any less belligerent but it would make them less capable militarily and thus fewer people will get killed. Others amongst the good and the great have also taken sides against China. Google Earth used to block the image of the site of China's next building project, Scarborough Shoal due west of Manila Bay, but has now removed the fake cloud that was used to obscure it. Google must have concluded that they won't be allowed to make any money in China.

The Rand report on how war with China might play out was naïve in a few areas. The report makes the statement that China imports all its oil and has a small strategic oil reserve. In fact

China's imported fraction of its oil demand is very similar to that of the United States. In the last few years China has been importing up to 1 million barrels per day for its strategic reserve which is likely to be as large as that of the United States at about 700 million barrels. The other main naivete in the Rand report is that they think the war could be conducted at any rate other than flat out. As Admiral John Fisher said almost a hundred years ago: "The essence of war is violence. Moderation in war is imbecility." The Rand report did ask one important question—what will the peace look like?:

> *Would a war between China and the United States resemble the great-power wars of modern history—expansive, systemic, desperate? Would hostilities erase all residue of mutual interest in an international order that has served both countries well? Would the escalating costs of conflict seem tolerable compared with those of losing? Would the enemy be demonized? Would populations become targets?*

Well, the answer is yes to all those questions. When the dead start piling up from China's self-indulgent war then revulsion for China and mainland Chinese will become visceral.

8.9 The Economic Match-Up

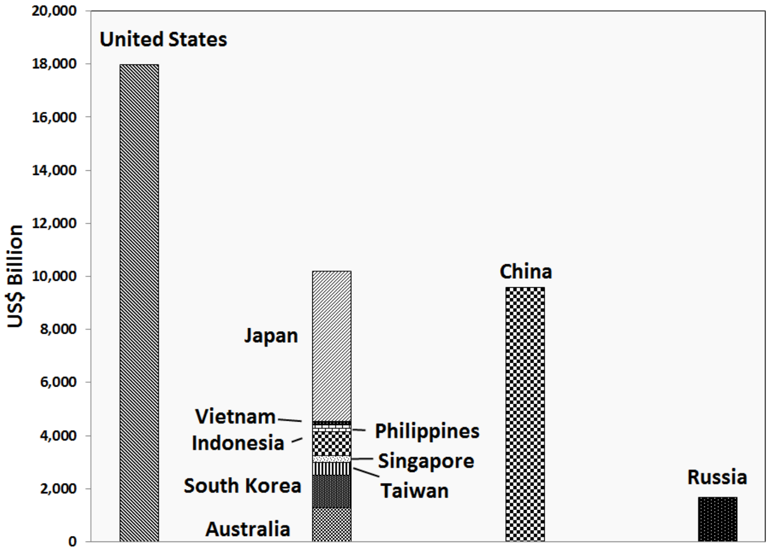

Figure 24: Size of the Economies of East Asia

While China's economy has grown dramatically in the last 15 years, it is still not quite as large as the economies of the countries in East Asia that it will be attacking. The combination of these economies with that of the United States is three times the size of China's economy. The rule of thumb is that, at least in military matters, the force that it is attacking should be at least three times as large as the defending force in order to prevail. In fact, Japan alone is likely to be able to defeat China, if attacked by China. As long as the coalition of forces united against Chinese aggression holds together, they are highly likely to prevail.

The U.S. trade deficit with China was $366 billion in 2015, with imports worth $482 billion well in excess of China's imports of American goods of $116 billion. If China was cut off from world trade, manufacturing would rapidly move to other counties, including to the United States.

Almost all Chinese trade passes through the East China Sea and South China Sea where it would be conducting its war. The cost of overland transport through Central Asia would be prohibitive even if the facilities existed to carry it. Cut off from export markets and with the cessation of building construction for the duration of the conflict, China's economy would shrink by 40 to 50 percent. Meat would also disappear from the Chinese diet.

8.10 The Rand Report of 2008

In 2008, two Rand Corporation researchers, Dr John Stillion and Scott Perdue, released a report that remains pertinent to the conduct of an air war in the western Pacific, and the F-35. Entitled *Air Combat Past, Present and Future*, their report outlines the history of how air dominance has been achieved over the last 70 years and the implications of that in how the air war with China will play out. In their telling of the story of aerial combat, Operation Desert Storm in 1991 validated the U.S. Air Force's concept of fighter-centric combat power generated from secure bases close to the theater, beyond-visual-range air-to-air combat, the value of stealth and precision-guided munitions. The lesson learned from Operation Desert Storm by potential opponents was that they had to counter all those things to mount effective ground and air operations. Those potential opponents went on to apply those lessons.

The U.S. Air Force believes that its fighter aircraft must dominate the battle from long range to counter the enemy's quantitative advantage. In turn this requires the U.S. fighters to detect the enemy first, get the first shot off and for that shot to be successful, relying in turn upon superior situational awareness, stealth and effective beyond-visual-range missiles. What happens if these key requisites fail?

Stealthy fighters are not invisible—just difficult to detect at certain radar frequencies. Stealthy aircraft have been optimized against X-band engagement radars. VHF radars have wavelengths in the 1 to 3 meter range. Fighter aircraft dimensions are about four to 10 times the wavelength of VFH radars and maximize radar returns at these wavelengths. The Russian response to stealthy aircraft was to develop a mobile VHF radar called Nebo. The Chinese equivalent is the JY-27 which is claimed to have detected a F-22 flying to South Korea from 400 kilometers across the Yellow Sea.

U.S. air bases and aircraft carriers are essential to the U.S. Air Force concept of warfare. Efficient generation of large numbers of sorties is critical to accomplish operational objectives. Operating fighter aircraft in the western Pacific will result in low a sortie rate and huge tanker demand simply because of the distances involved, making execution of the concept difficult.

The large, sophisticated Chinese air, naval and missile forces can mass against the small number of U.S. air bases and carriers in the western Pacific Ocean. Since the Korean War the U.S. Air Force has not had its bases attacked. For example the U.S. base at Kadena on Okinawa, if attacked by 34 missiles with cluster munition warheads, would lose 75 percent of the aircraft based there. Most Chinese air bases are significantly harder to successfully attack with alternate runways and some shelters built into mountains, and no visible fuel storage area to be targeted.

Once American and Chinese fighter aircraft meet in the air, the next stage of the operational concept relies upon missile effectiveness. History has some stark lessons in this regard. For example, the United State went into Vietnam relying on the AIM-7 Sparrow as its main air-to-air missile. The pre-war estimate of the Sparrow's kill probability was 0.7. In actual use it turned out to be 0.008. The North Vietnamese MiG-21s were ninety-times likelier to make it to gun range than expected. Both the F-22 and the F-35 carry limited numbers of missiles, up to eight and four respectively, because to carry more on their wings would compromise stealth. If the missiles from both sides are ineffective then there will be a repeat of the air war over North Vietnam and combat will be played out with guns. The F-22 should be able to hold its own if not badly outnumbered. The F-35 will be defenseless.

The current beyond-visual-range missile, the AIM-120, has demonstrated a kill probability of 0.59 in combat to date, recording 10 kills for 17 missiles. That has to be seen in the context that, since beyond-visual-range missiles were introduced into combat, fighter aircraft equipped with such missiles have recorded a total of 588 air-to-air kills, with only 24 of these being beyond-visual-range. The bulk of these were before 1991. Since then and the introduction of the AIM-120, 20 out of 61 kills have been beyond-visual-range. The U.S. Air Force recorded 10 of those kills, but four were from when the missile was fired within visual range. The kill probability from the kills at beyond-visual-range is 0.46. The kills include a U.S. Army helicopter over northern Iraq that was not expecting attack from another U.S. aircraft. All the other aircraft downed were either fleeing and non-maneuvering, and none used electronic countermeasures. None of these conditions are likely to apply to a fight with Chinese Flankers (the Su-27 and its derivatives).

Further again from the Rand report of 2008, early AIM-9 missiles with infrared seekers had a kill probability of 0.65 in testing. In combat in Vietnam the actual kill probability was 0.15, less than a quarter of the test results. After the Vietnam War, the United States developed the highly maneuverable AIM-9L missile. Used by RAF Harrier pilots in the Falklands war of 1982, this missile achieved 19 kills out of 26 missiles fired for kill probability of 0.73. In response to the demonstrated lethality of this weapon, many nations developed and deployed infrared decoy flares. In response to that development, the U.S. Air Force produced an improved AIM-9 missiles with “flare rejection” circuits designed to counter decoy flares. But the flares turned out to be much more effective than anticipated. In Operation Desert Storm of 1991, U.S. forces fired 48 AIM-9M missiles and achieved only 11 kills. The kill probability was reduced to 0.23.

The Russian and Chinese concept of operations likely relies on outnumbering the opposing force, firepower, sensor diversity and weapon diversity, advanced electronic countermeasures and greater ability to absorb attrition. History suggests that there is a limit of about three to one where quality can no longer compensate for larger enemy numbers in weapons systems such as fighters. Globalization has increased the speed of technology diffusion compared to the Cold War period. Technologies developed for the computer, television, medical imaging, telescope, and wireless network industries can be directly applied to fighter sensors and weapon systems.

The Flanker is a big, tough aircraft with a large internal fuel capacity and a large load-carrying capacity. Its modular/evolutionary design philosophy makes upgrades relatively easy and inexpensive. The latest Flankers, e.g. the Su-35, have a large, diverse air-to-air missile loadout. The standard loadout includes options for up to 14 air-to-air missiles. Most missiles come in active radar and infrared versions. Long range missiles for use against high value targets such as AWACS and tanker aircraft have advertised ranges of up to 400 kilometers.

All Flankers carry infrared search and track systems capable of tracking a typical fighter target head-on at 50 kilometers and tail-on at 80 kilometers. A fighter supercruising at Mach 1.7 generates shock cones with a stagnation temperature of 87° Celcius. This should increase the detection range to 56 kilometres. The launch of an AIM-120 missile has a large, unique thermal signature which could allow early detection of a F-22 and missile launch warning at up to 92 kilometres. The AIM-120 missile travelling at Mach 4 generates a shock cone with a temperature of 650° Celcius which the Flanker could track from

83 kilometers away.

The Flanker is likely to be able to detect the F-22 from 40 kilometers with L band radar by 2020.

The F-35 is optimized for bombing, not air-to-air manoeuvring combat. Its thrust loading is significantly inferior to that of the F-15, F-16 and F-22, resulting in slower acceleration, slower climb and more energy bleed in tight turns. The F-35's high wing loading is comparable to that of the F-105 which means that it is less agile and requires a higher thrust to maintain a given turn radius and speed.

The F-35 is "Double Inferior" relative to modern Russian/Chinese fighter design in visual range combat. It has inferior acceleration, inferior climb, inferior sustained turn capability and also a lower top speed. The F-35 can't turn, can't climb, can't run.

What Stillion and Perdue concluded in that 2008 report still holds today. Operation Desert Storm was a perfect war for the U.S. Air Force with protected bases only a short distance from the operational theater. The opposite holds true in the western Pacific with all but the Okinawan bases far from the Chinese mainland. Then those problems are exacerbated by the F-35 which will only be able to fly every second day, carries an inadequate number of missiles and isn't agile enough to escape being shot down by gunfire. In fact, the tanker and AWACS aircraft are also likely to be lost if the U.S. Air Force tries to be involved near Taiwan. Fortunately, China has built seven bases in the Spratly Islands and the tables are turned to a large extent for that region.

Further to the 2008 assessment of Stillion and Perdue summarized above, a retired Air Force officer has provided an update based on what has transpired over the subsequent years:

> *In recent years countermeasures have improved faster than beyond-visual-range missile technology, e.g. digital-radio-frequency-memory jammers, towed decoys,*

ability to turn away and even out-maneuvre a missile. The GSh-301 30 mm cannon of the Su-35 has been reported to have chaff rounds.

To make matters worse, all western beyond-visual-range missiles have active seekers, and the 'light-up' range gives enough warning time for effective countermeasures. Not so Russian beyond-visual-range missiles and their Chinese copies—missiles such as the R-27 and R-77 have infrared-seeker variants. So, an enemy beyond-visual-range missile can arrive without warning, especially from the rear aspect away from radar coverage.

What is really lost on the F-35 promoters is that if you are engaging in beyond-visual-range air combat with two missiles, maybe four, and the opposition has 10 weapon stations. The likely Su-35 load-out is two within-visual-range missiles, four beyond-visual-range, active-radar missiles and four beyond-visual-range infrared missiles, fired in active-radar infrared pairs as per the Russian doctrine and the switch setting in the fire control system.

So, look at an engagement where aircraft numbers are equal—let's say 10 on 10. The F-35 fires its two missiles, and given modern countermeasures, expect the probability of kill to be less than 15 percent. So, if target sorting is perfect and the F-35 gets first shots (also not guaranteed if the enemy has a 20,000 foot altitude advantage) the best case is that after the beyond-visual-range missiles are fired, then seven enemy strikers remain.

The 'can't turn, can't climb, can't run' F-35s then have to egress. They have 70 missiles and seven guns to evade. Since we have yet not worked out how to egress flying backwards, the F-35s will expose a large rear *aspect radar cross section and infrared signature, and the much vaunted (but not proven) APG-81's countermeasures cannot be effective.*

Against aircraft like the Su-35 and the T-50, with far superior range and speed, there is no escape and all Mach 1.45 F-35s are run down and killed with beyond-visual-range missiles, then within-visual-range missiles and finally, if there are any survivors, guns. Not the case for the F-22A, where even if all of its six beyond-visual-range and two within-visual-range missiles miss, they can still cut and run.

So, the best case for F-35s is 10 losses and three kills, or a loss-exchange ratio of 3.3:1.

8.11 How the War will be Conducted

We study history so as not to repeat it. If your adversary doesn't make the same effort dispassionately, then at least your own work has predictive ability for the war that it is coming. What is happening now in East Asia has parallels with events almost a century ago. Japan had seized Germany's islands in the western Pacific during World War I and kept control of them under a League of Nations mandate. These islands covered a vast area down to the equator. Japan fortified some of them and discouraged foreign shipping from passing through or visiting those islands.

One U.S. Marine Corps officer, Lieutenant Colonel Earl Ellis, realized Japan would use these islands to envelope and attack the Philippines and Guam. In 1921 he wrote *Operations Plan 712: Advanced Base Operations in Micronesia*, which detailed how to go about capturing the Japanese bases in Micronesia so that the U.S. fleet could pass through to conduct the decisive fleet action close to Japan. Operations Plan 712 was incorporated in War Plan Orange, the plan for a possible war with Japan which was formally adopted by the Joint Army and Navy Board in 1924. Twenty years later the island-hopping campaign largely followed Ellis' script. The importance of this story is that enemies are self-selecting. They can be predicted decades in advance, as well as the optimum way to prevail against them.

So the next question is what is the modern equivalent of War Plan Orange? Two modes of operation have been proposed: Joint Concept for Access and Maneuver in the Global Commons (JAM-GC) and Offshore Control. JAM-GC began as a U.S. Navy-U.S. Air Force plan to operate together in the western Pacific, from the Air-Land Battle concept formulated for fighting the Soviet Union on the plains of Europe. JAM-GC is a way of taking the battle to the Chinese mainland by having US fighter and bomber aircraft penetrating Chinese airspace. The problem with JAM-GC is that it will be enormously expensive in terms of lost aircraft and crews, and could backfire badly. Firstly, bombing alone hasn't had a good history of changing the outcome of major conflicts. China has considerable strategic depth. Its air force has been preparing to survive attacks on its bases for decades. It is likely that U.S. fighter aircraft formations trying to penetrate Chinese airspace will be badly mauled as per the 2008 Rand study. Because the U.S. Air Force perceives that it has a unique ability to strike deep within enemy territory, the emphasis in Air Force doctrine is to achieve shock, paralysis and escalation dominance through deep strikes. If those strikes fail, that would embolden China and dismay the United States and partner country forces.

JAM-GC isn't a strategy. A strategy would involve coherence of assets used, how they are deployed, the intended end of the conflict, priorities, sequencing and a theory of victory.

AJAM-GC was an attempt to overcome Chinese control of their near seas by a layered defense that includes the DF-21, a ballistic missile designed to hit U.S. aircraft carriers at ranges up 2,500 kilometers. The U.S. Navy has stated that it can break the Chinese kill chain by targetting the Chinese sensor system.

Offshore Control is the strategy of economic exhaustion through naval blockade. All shipping headed for a Chinese port would be interdicted between the first and second island chains, seized and anchored up for the duration of the conflict. There are plenty of anchorages in the Philippines suitable for this purpose. Oil wouldn't necessarily be an important commodity. Chinese domestic oil production rose to a peak of 4.3 million barrels a day in 2015 though it has fallen 10 percent since. China has also installed, or is in the process of installing, one million barrels per day of synthetic liquid fuels capacity, turning coal into diesel and jet fuel. China could simply order private vehicles off the road for the duration of the conflict and would have what it needed for military and industrial uses. With respect to synthetic liquid fuels from coal for U.S. defense forces, in the National Defense Authorization Act for Fiscal Year 2017, Congress repealed section 526 of the Energy Independence and Security Act of 2007 which precluded the Department of Defense from buying synthetic fuels.

Offshore Control turns the Chinese concept of area denial on its head. Chinese warships will be bottled up in port or easily sunk if they venture too close to the islands of the first island chain. Offshore Control also lacks a theory of victory. It will be a matter of waiting for China to tap the mat, which most likely would involve a change of leadership.

In April 2014, the commanding general of the III Marine Expeditionary Force based in Japan, Lt. Gen John Wissler, said that if the Chinese invaded the Senkaku Islands, U.S. Marines in the Pacific could easily recapture them.[8] He was concerned about the Army's desire to contribute to the joint force in the Pacific by putting its attack helicopters on flat-deck ships, saying that they would get in the way and suffer from corrosion. China has built at least two bases specifically for attacking the Senkaku Islands. One of these is the Shuimen Airbase at 26° 56' N, 120° 4' E. It was built on top of a ridge about as close as one can get to the Senkaku Islands on the Chinese mainland. From the Shuimen Airbase it is

400 kilometers to the Senkakus and 500 kilometers to the Yaeyama Islands further east. If China seizes the Senkakus, they might as well seize the southern half of the Ryuku island chain, the Yaeyama Islands, while they are at it. Militarily and morally, the Yaeyamas would be only a little more difficult than seizing the Senkakus but would come with plenty of basing opportunities and the benefit of partially enveloping Taiwan. The Shuimen Airbase has a lot of apron area adjacent to the runway suggesting that it will be used to surge aircraft coming from other airbases in China.

Another base built specifically for attacking the Senkaku Islands is an expeditionary helicopter base in the Nanji Islands at 27° 28' N, 121° 4' E. This has 10 camouflaged helipads connected by roads but without any supporting buildings. This configuration suggests that the plan for the Senkakus will include flights of 10 helicopters at a time landing at Nanji Island to be refueled by tanker trucks before flying on to the Senkaku Islands.

Since Lt. Gen Wissler's comments, China has created a far greater task for the Marines to accomplish than recapturing the Senkakus. In late 2014, China began building bases on seven reefs in the Spratly Islands in the South China Sea by using cutter-suction dredges to dig up coral and then spread that over the tops of reefs. Now almost complete, the bases include three with 10,000 foot runways. The other four bases have forts with flak towers on the corners. Recent building activity includes hardened shelters for 24 fighter aircraft at each airfield and flak towers at the airfield bases. It seems that the main role of the smaller bases is to provide extra radar coverage for the airfield bases as well as more sites for long range surface-to-air missiles. Chinese radar types will likely include different frequencies, e.g. L Band and VHF active electronically scanned array, as well as 360 degree surface wave radars as they have on the entirety of their mainland littoral. Thus stealth aircraft and cruise missiles will be detected out to 200 kilometers.

Having those bases in the Spratlys has made China easier to defeat than if it was without them. The problem with having a war with China is that no-one would seriously consider conducting a land campaign on the Chinese mainland. Without a land campaign, China would not be defeated and could take some time to accept settlement terms. Capturing China's Spratly Islands bases will provide a defeat of Chinese arms that will go a long way to allowing the Chinese to psychologically accept defeat.

The South China Sea is a natural kill box, much like the Mediterranean during World War II. Chinese ships and aircraft transiting from Hainan Island have to run a 1,000 kilometer gauntlet with Vietnam on the western side and the U.S. forces on the eastern side. Hopefully all the forces allied against China have set up a system to share radar information to provide targetting opportunities. The Marines now have seven heavily fortified islands to seize and they would be well advised not to turn down offers of assistance from the U.S. Army to do so. Once the war is over, those islands cannot be allowed to be returned to China.

There are many other things that will need doing during a war with China. There are some 300,000 Chinese students attending courses in the United States. There are now 2.2 million people born in China living in the United States. Will they be interned as Japanese were during World War II? No doubt the assets of Chinese companies in the United States will be seized but will that extend to assets owned by individual Chinese nationals? China now has military bases in and near the Indian Ocean including one in Djibouti which also hosts Camp Lemonier, a United States Naval Expeditionary Base. There will be no geographic limit to the conflict. Psychologically China would want to strike at the U.S. mainland, as per the Doolittle Raid of World War II.

In the lead up to the war, signalling between the belligerents is important to stop escalation to beyond where any of the parties wish to go. Japan has recently announced that its constitution does not forbid it from possessing nuclear weapons. Vice President Joe Biden has told the Chinese President that Japan has the capacity to acquire nuclear weapons “virtually overnight”.[11] All these things will factor in China’s calculus as to when to start its self-indulgent war, and how it will end.

As to the beginning of the war, Peoples Liberation Army strategists have closely studied U.S. military performance since Operation Desert Storm in 1991 and have come to understand that modern war is rapid, highly destructive and may consist of only one campaign with overall victory depending on success in the opening clash. If the emphasis in Chinese writings is a reliable indication, China intends to seize the initiative through surprise or pre-emption. It is likely to use military exercises as a cover for mobilization. Operational military doctrines in both China and the United States emphasize surprise, speed, and deep strikes to seize the initiative and achieve dominance.

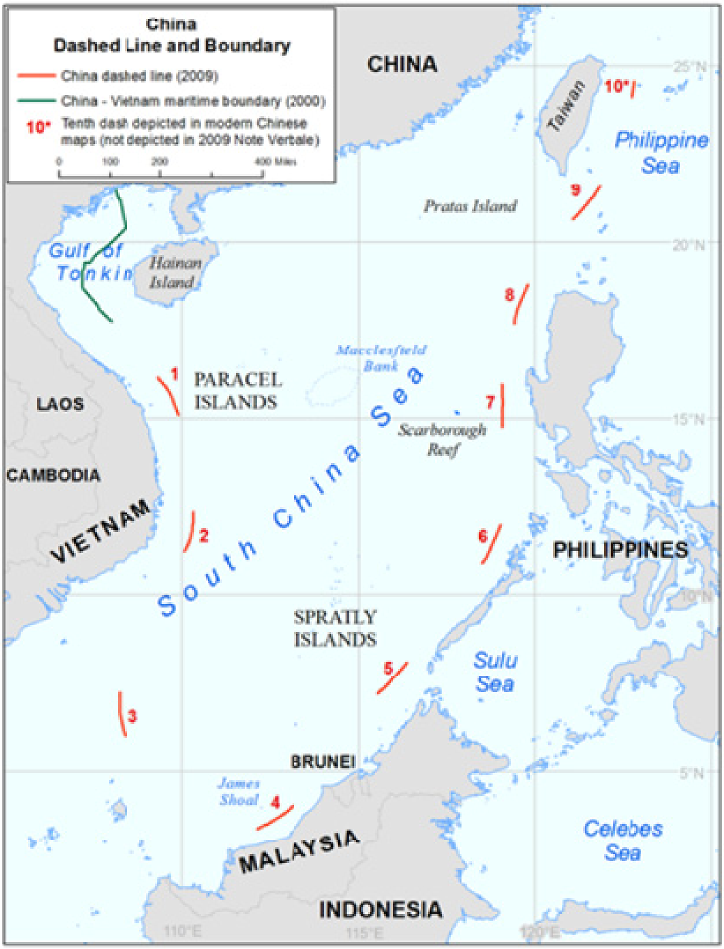

Figure 25: China's Claim Area in the South China Sea
This map shows China's "nine-dashed claim" area of the South China Sea, originally drawn up by Nationalist Chinese officers in 1947. A tenth dash was added in 2009 just west of the Japanese island of Yonaguni in the Yaeyama Islands.

Figure 26: Chinese Base-building in the Spratly Islands
Beginning in late 2014, China mobilized a large number of cutter-suction dredges to reefs and atolls in the Spratly Islands, turning seven of them into artificial islands. Airfields with 10,000 foot long runways have been built on Fiery Cross Reef, Mischief Reef and Subi Reef. The other four of the islands have forts. These, with reinforced include hexagonal flak towers set apart from the corners. The locations of the bases are:

Fiery Cross Reef	9º 32’ N, 112º 53’ E
Gaven Reef	10º 12’ N, 114º 13’ E
Subi Reef	10º 55’ N, 114º 05’ E
Johnson South Reef	9º 43’ N, 114º 17’ E
Cuarteron Reef	8º 52’ N, 112º 49’ E
Hughes Reef	9º 54’ N, 113º 30’ E
Mischief Reef	9º 54’ N, 115º 31’ E

8.12 Chairman Mao's Time Bomb

After World War II, Japanese living across Asia were repatriated to their homeland with the country's population rising from 72 million to 78 million, thereby straining resources during the post-war reconstruction. Japan enthusiastically adopted family planning as a result and a population crisis was averted. The country's population continued growing though, to a peak of 128 million in 2011. Later this century it might shrink to 70 million which is the level the country can support from its own agriculture. In the meantime, the Japanese Government tries to keep the jobless rate low with make-work schemes that have been paid for by a run up in government debt to 229 percent of GDP.

Across the East China Sea, China's population kept rising through the 1950s, up to Great Leap Forward, which saw 30 million to 45 million perishing. To head off the population increase, the one-child policy was suggested in 1957 by Professor Ma Yinchu, President of Peking University. Mao didn't like the idea of population control because he thought that history belonged to "the big battalions". Professor Ma was dismissed from public office and not rehabilitated until 1979. Despite the one-child policy then enacted, China's population has grown from 975 million in 1979 to the current 1,364 million. Sheer demographic momentum is expected to take it to a peak 100 million higher by around 2030.

China is one of the few countries taking food security seriously. Official policy is that the grain necessary to keep China's population fed should be produced within its borders. Beijing maintains a grain reserve of 200 million to 300 million tons, although its exact size is a state secret. Though meat is considered to be an indulgence, a strategic reserve of frozen pork and live animals is maintained in case the distribution of meat is needed to help control unrest. China's economic expansion over the last 15 years has allowed growth in pork production, based on imported soybeans, so meat returned to the Chinese diet. As Figure 27 shows, the Middle Kingdom has turned into a "giant vacuum cleaner" for the world's soybeans:

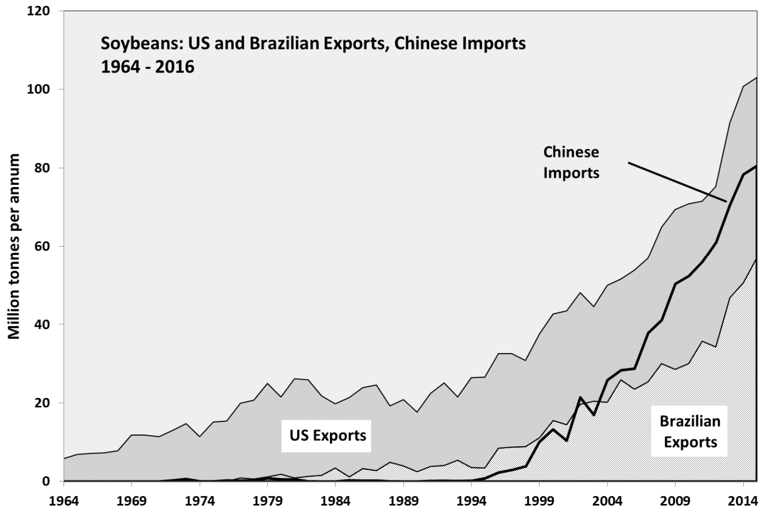

Figure 27: U.S. and Brazilian Exports of Soybeans and Chinese Imports 1964-2016

China's soybean imports of 80 million tons per year, a third of world production, have a protein content equivalent to 240 millions tons of wheat. Processed through pigs and chickens, these imports provide 20 percent of the nation's minimum protein requirement. China has taken other steps to improve its food security, including leasing five percent of the land area of Ukraine's farmlands. Efforts at securing food production in Africa and South America have been less successful due to cultural clashes with the locals.

China can presently feed itself. But that achievement has to be looked at in the context that the world is currently enjoying the most benign conditions for agriculture for over 800 years. If the world cools in response to lower solar activity, which began with Solar Cycle 24 in 2008, there is good reason to fear that monsoons won't penetrate as far north or as far inland. China is the world's biggest grain producer, growing 475 million tonnes annually. A drought in the north could easily reduce that figure by 150 million tonnes. Should we see lower global temperatures and reduced growing seasons elsewhere on the planet, it would be difficult for China to make good the shortfall with imported grain. This is part of Mao's legacy—he left China with a demographic time bomb that has a good chance of taking down the country if/as climate deteriorates, meaning, cools. The Chinese people will endure, but the Chinese government may fall as a consequence. The war with China may teach the United States how to use food as a weapon, which will become useful in other civilizational conflicts with barbaric cultures.

Besides food security, China has other problems which suggest that it is actually fragile, rather than fulfilling the common perception of inevitable further growth in strength and influence.

Most of China's energy is from coal. In fact China produces half the world's coal. But it is burning through this resource base rapidly with underground mines in the eastern provinces down to 600 meters deep on average, and halfway to their economic limit. Peak coal production in China should arrive about 2025. After that the cost of coal production will begin rising and the cost of doing everything in China will increase with an impact on Chinese economic competitiveness. There are indications that the Chinese leadership is aware of this problem. The only energy source that can replace coal in the quantum required and at the same price is nuclear power. The best type of such power possible is the thorium molten salt reactor. China launched a research program into commercializing thorium molten salt reactors in 2011. Several years ago the researchers on that project were told to complete this task in 10 years instead of 20 years. If that is achieved, thorium molten salt reactors will come online at about the time coal production starts falling away.

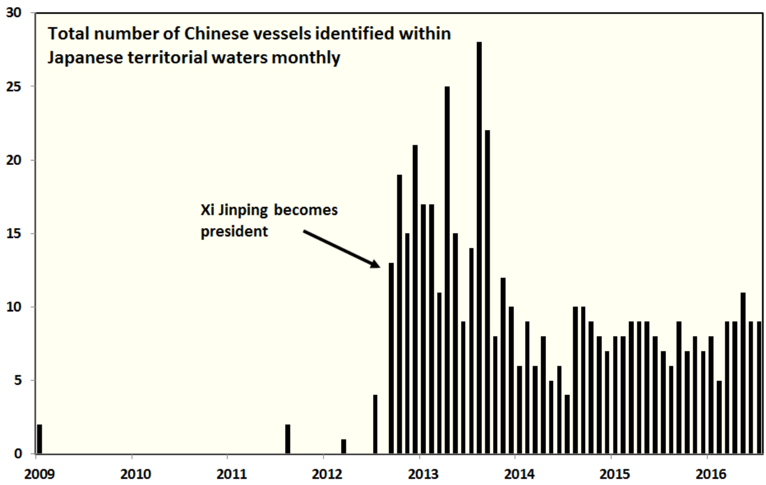

Figure 28: Chinese Incursions into Japanese Territorial Waters 2009-2016

Before he was appointed as President, and after that a host of other positions, Xi Jinping spoke of "the China Dream". A big component of that dream is mounting a successful attack on Japan. President Xi began baiting Japan on becaming president with fishing boat incursions into Japanese territorial waters. These are paid to do so and generally stay two hours.

The data to date suggests that we are at "Peak China", just as 1990 was Japan's peak year following its credit bubble of the 1980s. In 2012, America's National Intelligence Council, the center for strategic thinking within the United States Intelligence Community, which brings together all of the country's intelligence agencies, including the CIA, predicted that "by 2030 Asia will have surpassed North America and Europe combined in terms of global power, based on GDP, population size, military spending and technological investment".[12] But that is not going to occur. Instead it is more like the intelligence community's failure to predict the fall of the Soviet Union. The signs are there, and don't expect straight line growth to continue indefinitely.

China is also not as monolithic as it is perceived or as it likes to portray itself. A war with China will not be with 1,300 million people but a quarter of that number at most. According to World Bank data, over 650 million Chinese citizens live in households earning less than $4 a day. Most of these poor live in the inland provinces. The wealth created by China's recent economic boom is concentrated in a belt of coastal provinces about 300 kilometers wide. Those coastal provinces are listed following with their population as at 2014:

Tianjin	8 million
Shandong	98 million
Jiangsu	80 million
Shanghai	24 million
Zhejiang	55 million
Fujian	38 million
Guangdong	107 million
Total	410 million

These are the provinces creating enough wealth through exports that permit China to afford military adventurism. As massed troops are no longer useful in battle, the rest of China is effectively only a source of potential instability to the regime given the effort required to keep the inland provinces fed.

Conclusion

THE F-35 WAS conceived as a plot against the Republic. One company wanted to dominate the supply of fighter aircraft for decades to come. The best time to have stopped the F-35 would have been in the mid-1990s when dispassionate analysis would have shown that at best it would produce a mere mechanical curiosity—a plane that can hover.

Decades have since passed and what hope is there in stopping the colossal, misguided waste that is the F-35 program? But it must be stopped. The years spent wishing and hoping and waiting for the F-35 program to deliver a cost-effective aircraft have only delayed the day of reckoning that is coming. The best possible outcome is that the F-35 dies of embarrassment soon.

The worst outcome is that the U.S. fighter fleet is over-matched in the Western Pacific by a Chinese force which is then able to bomb U.S. bases, ports, ships and troop formations at will. The total death toll will be hundreds of times the number of F-35 pilots shot down. Such an event would bring a lot of clarity to the situation, in the manner of Pearl Harbor, but at a huge human cost. But it is best to avoid cathartic events with their human costs. The last time U.S. ground troops were killed by an enemy aircraft attack was on April 15, 1953, on the the island of Cho-do off the coast of North Korea. There is no institutional memory of the human cost of not having air superiority.

There is an alternative to the F-35, ready to go now, that will fill the hole in the force structure that the F-35 has created at a fraction of the cost of persevering with that failure. It is the most cost-effective fighter aircraft available on the planet. Built in the spirit of the F-16 of being an air superiority fighter aircraft first and foremost, the Gripen E lacks for nothing in weapons, sensors and data fusion. The Gripen E is the plane that the services can afford to buy, and afford to fly.

In the short term the Gripen E is our best possible future in maintaining air superiority and freedom of movement on the battlefield. That will give us the time needed to make the correct decision in developing the right long-range, twin-engined air superiority fighter with the ability to outclass all comers. That is the YF-23 airframe updated with all the technological developments of the last 25 years. That combination would provide stealth, fuel-efficiency, near-Mach 2 speed without afterburner and the ability to engage and disengage from combat at will. Most importantly, it would provide capability exceeding that of the F-22 but at two thirds the cost by getting its stealth from shaping instead of radar-absorbent-material.

There may be a better shape possible than that of the YF-23 for stealth and supercruise, but that can be developed as an evolution from the resurrection of the YF-23. We do not have the luxury of time. At some stage the cost of procurement mistakes will become counted in blood instead of just dollars. We won't be able to put off that day but we can reduce the cost if we take on some of the responsibility for putting things to right ourselves. This book, and its knowledge imparted, is wasted if it isn't acted on. For our airmen, and the people they protect, please do what you can.

Appendix 1

Step by Step, Here's How to Fight China

Colonel Michael Pietrucha USAFR (written as a duty assignment for the U.S. Government, this article does not reflect Government policy)

The air campaign in Desert Storm (First Gulf War, January 17, 1991-February 28, 1991) was a watershed for air power. It demonstrated the effectiveness of precision munitions, marked a high water point for electronic warfare and introduced radar stealth in a decisive manner. It also established a template for the application of air power that has taken root in Air Force culture and remains firmly established a quarter century later.

Unfortunately, the Instant Thunder air campaign (the air component of Desert Storm) has also become the template for future air campaigns, despite being poorly suited for that role. In retrospect, we have learned many of the wrong lessons from Desert Storm, in that we had time to build up forces, operated from a broad network of U.S.-built bases and essentially ravaged the military structure of a small, isolated nation with an incompetently led military using obsolete equipment and outdated employment doctrine.

By the time Operation Allied Force (the NATO bombing of Yugoslavia) rolled around in 1999, it should have become clear that the same template produced uneven results at best, even when backed by a combined NATO air force.

In the aftermath of a series of wars against relatively weak adversaries, planning for a larger war has descended into nonspecific terms. Pentagon discussions on force structure, posture and capabilities are often based on a "capabilities-based," generic adversary reduced to the status of an opposition force. This adversary might be referred to as a "near peer," characterized largely by the technology it brings to the fight rather than understood as a living, adaptable enemy that might have to be fought under unfavourable conditions.

This habit ignores the reality that the People's Republic of China has eclipsed the old Soviet Union and its successor as a superpower, militarily, economically, politically and technologically. We remain wedded to an inappropriate warfighting model leftover from the Gulf War, while ignoring China's evolution as a military power.

We ignore this evolution at our peril.

To attempt to apply the Desert Storm air campaign model to other nations is of questionable utility, and applied to China in particular is pure folly. China is large, resilient, can mass military forces like few other nations and is clearly a superior power when fighting in its own territory. Moreover, it has spent a quarter century of military development ensuring that the United States can never be in a position to repeat Desert Storm against the People's Republic.

Chinese military force design has been built specifically to counter the U.S. Air Force's reliance on stealth and forward basing, and to reduce the threat of carrier aviation by developing weapons designed to keep the carriers far away from the action. Our response has been to plan to fight symmetrically, matching our technological widgets against theirs in a battle in the PRC's front yard.

Strategically, this methodology replays the successful strategic campaign, whereby the USSR spent itself into collapse trying to match American technological prowess. This time, however, the United States is on the wrong side of that strategy.

There is benefit of adopting an asymmetric offset strategy to deal with the PRC's general technological parity and commanding position. There is additional benefit of adopting a strategy that could be executed today, without being dependent on technologies that have yet to emerge. The reality of the Chinese force structure is that it is largely a defensive structure whose utility wanes rapidly with distance from the Chinese coastline.

Unlike Imperial Japan, China lacks a carrier-capable, blue-water navy with which to challenge the United States, and has not begun an overt territorial expansion that provides overseas basing facilities. Like Imperial Japan, China is heavily dependent on overseas supply lines, and thus subject to interdiction of critical warfighting resources, especially energy.

China's import dependency is particularly acute for energy supplies, which have to travel long distances through unfavourable maritime terrain, only to then be dependent on a limited domestic transportation infrastructure which is itself energy-intensive. This means that the PRC is vulnerable to a counter-logistics campaign intended to limit China's energy supplies in a fashion that reduces or eliminates their capability to project military power.

The foundation for a military campaign against the People's Republic of China, presumably with the objective of stopping or reversing Chinese aggression, could be based on strategic interdiction, a.k.a. SI—a joint effort designed to prevent the movement of resources related to military forces or operations. An SI campaign would be designed to repeat the fundamental success of the Pacific War—isolating Japan to the point where it could no longer impede Allied operations in the Pacific.

Historical Background

A counter-logistics campaign has historical precedent in the Pacific. Indeed, we have volumes of data documenting the execution and effect of such a strategy against Japan.

In February of 1942, Japanese forces wrested Rabaul, New Britain, from the outnumbered and unsupported Australian detachment. In short order, Rabaul became the primary forward base in the South Pacific and a major obstacle sitting squarely between both Allied theaters in the Pacific. Gen. Douglas MacArthur's plan to recapture the island fell afoul of resource constraints and the higher priority held by the war against Germany.

By August of 1943, the President made the decision that Rabaul would instead by bypassed rather than seized, largely because of the emerging realization that Rabaul did not have to be captured in order to be neutralized. Operation Cartwheel, starting in December, neutralized the island citadel without a direct and costly amphibious assault, and without requiring resources above what was already allocated for the theater.

Rabaul was attacked by air, isolated by maneuver and starved by air and naval forces to the point where it could no longer be used as a venue for power projection. Australian forces liberated Rabaul without a shot fired, surrendering four days after the surrender ceremony in Tokyo Bay.

While directed against only a small island group, the isolation of Rabaul is a relevant historical example of the success of a long-term strategy to neutralize powerful military forces in a critical position. Operation Cartwheel was a small example of what became a general strategy for the conduct of the Pacific War—that Japanese garrisons would be isolated and cut off, attacked in place and that the home islands would be deprived of materials, energy and supplies that relied on water or rail transport.

By the end of the war, a coherent maritime interdiction campaign brought the Japanese home islands to the brink of surrender, while an air campaign against Japanese railroads tied up domestic transport to the point that needed resources could not even be moved internally.

A well-designed, pre-planned strategic interdiction campaign provides a potential way forward for a war-winning air and naval power application, specifically tailored to the People's Republic of

China's specific characteristics. In particular, the campaign is intended to apply lessons learned against Japan to China, as if China were in fact an island.

From a transportation standpoint, China is over 98 percent island. China's international land transportation networks, even in combination, are dwarfed by any of China's larger ports taken singly, and its land transportation already suffers from a lack of capacity and susceptibility to disruption—both exploitable vulnerabilities.

A strategic interdiction campaign is a strategy based on denying logistical supplies to the fighting forces of an adversary. It is a combination of several efforts, including a limited blockade, interference with transportation networks and disabling some energy production at the resource level. The primary objective here is to effectively neutralize certain elements of PRC military power by starving it of energy.

In contrast with maritime interdiction, strategic interdiction is not an airtight blockade but a targeted effort to interdict primarily the production and transport of energy resources all the way back to the source. A campaign would have four elements:

A "counterforce" effort designed to attrit the adversary air forces (particularly bombers), naval forces (gray hulls) and naval auxiliaries (replenishment) to the point where they can neither project military power nor defend against U.S. power projection, at least far beyond the PRC continental shelf.

An "inshore" element, which consists of operations to deny effective use of home waters, including rivers and coastal waters. Standoff or covert aerial mining is a key component of this element.

An "infrastructure degradation" plan intended to disrupt or destroy specific soft targets, such as oil terminals, oil refineries, pipelines and railway chokepoints such as tunnels and bridges. Many of these targets would be in airspace not defended by ground-based air defense.

A "distant" maritime strategy, which occurs out of effective adversary military reach, intended to interdict energy supplies. This strategy is aimed primarily at bulk petroleum carriers (tankers) and secondarily at coal transports, and not at container, dry bulk or passenger vessels. Such a strategy might not be lethally oriented, directed instead towards the seizure and internment of People's Republic of China -bound vessels.

In effect, this strategy targets its effects on naval and air forces, which rely on jet fuel, and leaves the gasoline and diesel-dependent army shorebound. Along the way, secondary effects ripple through the industrial, refining, power generation and transportation sectors of the economy, with broad effects that are difficult to predict or quantify. A strategic interdiction strategy is not a short war strategy. It is a prolonged containment strategy derived from previous experience in the Pacific War.

While we don't think of the PRC as an island nation, effectively it is one. Over 98 percent of the PRC's external commerce by tonnage moved is seaborne. The transportation infrastructure over land borders accounts for a miniscule portion of the People's Republic of China's imports, and all goods crossing the borders are a long way from China's industrial sector. The total volume of goods moved overland via train, road and watercraft through the borders in a year is exceeded by the port of Shanghai in 60 days, with room to spare.

This reality is effectively impossible to change or mitigate in any significant way, and clearly indicates the potential of a Strategic Interdiction campaign focused on maritime transport.

Energy—The Sixth Ring

The targeting strategy for the Gulf War's air power application was based on Col. John Warden's "five rings," which threatened the subject country (in this case, Iraq) as a series of concentric rings. The outermost ring (fielded forces) protected the inner rings (population, infrastructure, organic essentials and leadership). As the theory went, one of the key advantages of air power was that aircraft could fly over the outermost rings to get to the key one—leadership.

While applicable to Iraq in 1990, the applicability to China is questionable, as it is not a centralized Ba'ath Party dictatorship led by a single individual. Furthermore, it is risky to attempt to execute a decapitation strategy against a state with a significant nuclear arsenal. Instead, an Strategic Interdiction strategy is centered on the sixth ring, which doesn't exist at all in Warden's construct except as part of the second and third rings.

The Sixth Ring is the energy ring, which also serves as the glue that holds all of the rings together. In this modified construct, the center ring is still a physical target, but under an Strategic Interdiction strategy, it is not one that is attacked directly. Effects aimed at it, along with every other ring, are secondary effects of an energy denial strategy.

China is a massive energy consumer, relying primarily on coal for electricity and oil for transportation. The two are not really interchangeable, and each has its own vulnerabilities. Coal-fired power plants provide approximately 70 percent of China's electricity generation, a percentage that has remained relatively constant since 1980. Nuclear, natural gas, solar and hydropower are a comparatively small portion of the power generation infrastructure, providing less energy combined than oil does alone. As these last four are comparatively minor energy sources, they are ignored in this analysis.

Coal

China is the world's largest coal consumer. Steam coal is used for power, and coking coal for industrial processes. Coal consumption is largely taken up by industry, including power generation. Even without counting heating demand, the power sector consumes more steam coal than industry.

China produces most of its coal domestically, producing 3.87 billion tonnes of coal in 2014 and importing another 291 million tonnes in 2014, a domestic/import ratio of better than 13:1. In the past two years, Mongolia has emerged as a key supplier of imported coal, supplying by train and truck rather than by ship.

In 2012, China had 58 coal offload ports, scattered all along the coast, serving both domestic and international coal movement.

While imported coal appears to be a drop in the bucket compared to the total coal supply, this is not true for all regions. Seventy percent of imported steam coal was consumed by power plants in coastal regions south of the Yangtze (Guangdong, Shanghai, Guangxi, Zhe-jiang and Jiangsu)—the demand centers furthest from China's main coal-producing regions. This may not be related to the capacity of the transport system but its cost—for the southeastern provinces it is cheaper to import coal than to ship it domestically.

Oil

Crude oil accounted for roughly 19 percent of China's electricity consumption in 2012, making it a distant second to coal. Oil supplies are mostly gobbled up in transportation, although diesel is also the fuel of choice for backup power generation. China's appetite for crude is massive, requiring imports of 2.26 billion barrels and another 219 million barrels of refined fuels on top of domestic oil production of 1.53 billion barrels in 2014. In total, in 2014 China imported 56 percent of its oil needs.

The lion's share of petroleum consumption is taken up by industry, including electricity production, chemical manufacture and refining. The transportation sector in China consumes almost as much petroleum as industry, consuming the vast majority of middle and light distillates burned in a year. Transport accounts for 46 percent of the gasoline consumed, 91 percent of the kerosene and 63 percent of the diesel fuel.

Oddly enough, as much as two thirds of China's annual diesel fuel consumption is burned transporting coal. By comparison, the entire transportation sector consumes less than two percent of the electricity used in a year.

China is making an effort to establish a strategic petroleum reserve (SPR) for crude oil. In 2010, China had a commercial storage capacity of between 170 and 310 million barrels, but no national strategic reserve at all. The People's Republic of China's tenth five-year plan (2000 to 2005) marked the beginning of the government Strategic Petroleum Reserve program. Phase 1 established a capacity of 103 million barrels at four sites and was filled by 2009; phase 2 is expanding that to by another 226 million barrels at nine locations, of which 210 million barrels will be filled by the end of 2015. The last phase, (2020), should bring the Strategic Petroleum Reserve capacity to half a billion barrels of crude oil.

Even at this capacity, the Strategic Petroleum Reserve holds less oil than the People's Repubic of China imports in three months. The Strategic Petroleum Reserves holds no refined products, which are entirely reliant on a commercial storage capacity estimated at 400 to 480 million barrels for all types of refined fuel combined. With one notable exception using a reclaimed salt mine, the SPR sites are conventional above-ground storage tanks, often on the coast, and often next to existing refineries.

Internal Transportation Network

China has a well-developed transportation network all along the eastern corridor, consisting of waterways, roads and railways. Compared to the United States, China's water transport enterprise is massive while the pipeline transport infrastructure is minuscule. As of 2013, the Chinese rail network consisted of 90,000 kilometres of conventional railway lines and another 10,000 kilometres of high-speed lines, which are mostly passenger lines. Of this, 56,000 kilometres was electric and 48,000 kilometres double-tracked.

The country has 125,000 kilometres of navigable inland waterways, including the Yangtze River, which moves more freight by far than any other inland waterway in the world. The public road network consists of 4.36 million kilometres of roads, 34 percent of which are dirt with 424,000 kilometres of highways including 9,600 kilometres of expressway. In 2012, the country reported having 9,100 kilometres of oil and gas pipelines, roughly 0.3 percent of the U.S. pipeline infrastructure.

The transportation network is substantially less dense away from the eastern provinces, and is comparatively sparse at the country's borders or in the west. With respect to the tonnage of freight moved (which includes fossil fuels), China uses highways, waterways and rail, in that order, to move goods internally.

Air transport is virtually insignificant by comparison, while pipeline transport for oil, refined products and gas is comparatively limited. Measured by tonne-kilometres rather than simply tonnage, waterways and highways switch places, because waterways are used to ship goods longer distances by far. In 2012, the average tonne of freight moved 1781 kilometres by waterway, 748 kilometres by road and a mere 187 by road.

Many trips mix modes of surface transportation. The implication of this transport distribution is that China's internal transport is reliant on the two modes that are most oil-intensive. In 2014 total freight traffic increased by over seven percent compared to 2013, with roads and waterways gaining traffic (10 and 16 percent increases, respectively) and rail losing it (5.6 percent decrease).

It takes energy to move energy. Coal accounts for a full 52 percent of the tonnage shipped and 40 percent of the tonne-kilometres hauled by rail and 21 percent of the domestic freight handled in the large coastal and river ports. Petroleum products account for only four percent of the rail tonnage and nine percent of the port freight. On average, a tonne of coal moved by rail travels 647 kilometres.

Moving coal is nontrivial in China. The three top coal-producing provinces are Shanxi, Shaanxi and Inner Mongolia which alone account for more than half of the national coal output. These three provinces are some distance from the coal-consuming provinces.

The railway network was unable to keep up with the transport demand as China's coal usage increased, and as a result from 1997 much coal traffic was diverted to multimode transport, where coal is carried by rail to the ports on the Bohai Sea and thence by coastal shipping to the south. Truck transport is used extensively, resulting in world-class traffic jams. In 2010, Inner Mongolia coal traffic generated several major traffic jams, extending for more than 100 kilometres and lasting for days.

The difficulties moving coal often forces provinces far from the producing regions to ration power consumption in response to supply disruptions, including inclement weather. The strained coal transportation system is already imposing local coal shortages on the power industry, with the impact greatest on the south-western provinces (Tibet, Sichuan, Chongqing, Gansu) and the provinces south of the Yangtze. Oddly enough, Shanxi province exported so much of its production in 2012 that its own power plants ran short.

Refining Sector

Crude oil cannot be burned for any purpose until it has been refined. In short, getting refined petroleum products is dependent on the quality of the oil that goes in and the equipment available for processing the oil. Some products are distilled, while others are chemically broken down and reformed. Oil is full of impurities, especially water, salt and sulphur, which must be removed during refining. Chinese oil imports are largely Middle Eastern, heavy "sour" oils which require more refinery processing than the "light, sweet" crude produced elsewhere.

The fuel that is most important from a military power projection standpoint is jet fuel, a high-quality mixture of kerosene, naphtha and additives used by aircraft and turbine-powered ships. Without fuel, aircraft are grounded and warships remain in port. One of the goals of an Strategic Interdiction campaign it to make it really hard or impossible to make jet fuel. Turbine powered ships can operate with marine diesel fuel (the U.S. Navy runs ship turbines on it) but aircraft turbines cannot.

In the past decade, the People's Republic of China has undertaken an ambitious effort to increase its refining capability from six million barrels per day in 2000 to 12.6 million barrels per day in 2013, while simultaneously consolidating into fewer refineries of much greater size. As a result, there is excess capacity remaining and the number of lucrative targets has been reduced and refinery functions consolidated. The refinery sector operated at only 81 percent of capacity in 2012, which has turned out to be a mixed blessing.

This excess capacity actually delayed further expansion of domestic refineries originally planned for 2016 and 2017, leaving the Sino-Burmese pipeline unable to deliver oil for refining because the ground has not been broken for the refinery site that would have received the imported crude.

As late as 2012, China did not meet all of its refined fuel requirements with domestic refining, and in 2012 one out of every four barrels of petroleum imported was actually a refined product. As the market shifted, so did the mix of refined fuels, as producers chased the more profitable products, especially jet fuel. In 2014, China was a net exporter of all refined fuel products except naphtha. This occurred despite the fact that China's surviving smaller "teakettle" refineries, which account for a quarter of the nation's refinery capacity, produce no jet fuel components at all.

Like coal, China's refinery infrastructure is not evenly distributed. Refinery capacity is concentrated in the east, with a scattering of refineries along the sole railway link to the far west. Refineries in the country's interior are largely reliant on domestic feedstock. Teakettle, or small privately-owned refineries, have to acquire a permit to use imported oil at all. Critically, the refineries along the coast are more reliant on imported oil, and the four southern provinces are close to 100 percent reliant on overseas imports for their feedstock.

Strategic Interdiction

Given China's unique energy vulnerabilities, combining massive demand, significant imports and a capacity-challenged transportation network, a military campaign designed to apply pressure at multiple points in the energy web would seem to be both cost-effective to execute and difficult to counter, even under conditions where operations in the Western Pacific are limited in scope and duration.

The objectives of such a campaign would be to so disrupt the energy and transport sectors of the People's Republic of China such that there is a pervasive and enduring effect on fielded forces. The campaign design takes lessons learned from the Pacific War against Japan, where both the Imperial Japanese Fleet and its air arm were systematically deprived of fuel, which affected all aspects of their military enterprise from engine testing and training to flight time and vital resupply.

A strategic interdiction campaign rests on four pillars and is intended to provide a viable offset strategy that is based on a presumed need to coerce a specific adversary in a designated region — China in the Western Pacific. The campaign is a longterm, counter-logistics effort which rests on four pillars: counterforce, inshore, infrastructure degradation and distant interdiction.

I. Counterforce

The counterforce pillar is intended to neutralize any PLAN (People's Liberation Army Navy) or PLANAF (People's Liberation Army Navy Air Force) attempt to project power outside Chinese coastal regions and is built in expectation that the PLAN and PLAAF (People's Liberation Army Air Force) will come out to fight. In fact, such an adventure against Taiwan, the Senkaku Islands or any number of island possessions may be the event that requires a U.S. response in the first place. The PLAN may conduct an amphibious operation, undertake convoy escort or execute any of the out-of-area missions that a blue-water navy would aspire to.

It may be desirable to sink surface combatants, but also replenishment ships, auxiliaries or minesweeping vessels. It is also permissible to attack blockade runners regardless of ownership, an issue of particular importance to the fourth pillar.

PLAAF bomber aircraft armed with cruise missiles will undertake counter-maritime and counter-land missions at some distance, perhaps as far as Guam. It will be necessary to counter these operations, often from a standoff position. In the Pacific, the long expanses of open ocean will require a focus on counter-air and counter-maritime capabilities. U.S. anti-ship capabilities have long since been allowed to atrophy, even in the Navy, as the PLAN has fielded increasingly capable anti-air-warfare ships which must be attacked from increasingly long distances.

Without diving into specific weapon and sensor combinations, standoff and specificity are key anti-ship weapons attributes, and any aircraft or vessel that launches them must have a suitable sensor system or a connection to one.

The simplest method, and the most difficult to affect by enemy action, is for the launching unit to have its own system for detection, identification and targeting of its on-board weapons. This is already the approach used by fighter aircraft for air-to-air targets, and by all surface combatants. This approach could be extended to include counter-maritime capabilities.

Improved long-range sensors, especially radar and ELINT sensors useful in anti-surface warfare, could transform our bomber fleet into the transoceanic counter-maritime force that it used to be. Increasing the effectiveness of counter-air capabilities is also a key component of this pillar.

II. Inshore

Inshore operations are closely related to the counterforce pillar; there is significant overlap in capabilities. The purpose of inshore operations is somewhat different — the inshore pillar is intended to deny the PRC the unfettered use of waterways, rivers, harbors and offloading and replenishment facilities.

The objective is twofold; to prevent the PLAN from being able to sortie, sustain at sea, and reload or replenish, while simultaneously interdicting energy supplies which are transported by oceangoing, coastal or riverine vessels. Strictly speaking, with the exception of river mining, this pillar does not require direct attack against the mainland, and relies as much on the threat of attack as actual attack.

Aerial or covert mining is a significant component of the inshore strategy, capitalizing on both the effects of actual mines and the suppressive nature that fear of mines has on shipping. Aerial mining is the only way to lay large offensive minefields quickly, while covert (underwater) mining may allow for precise placement of advanced mines.

The Yangtze was mined by USAAF (United States Army Air Force) in World War II, and the Rangoon River in Burma was entirely closed to Japanese shipping by aerial mines. PACOM (United States Pacific Command) has recently demonstrated the Quickstrike-ER, a standoff, precision version of the legacy Quickstrike bottom mine. Combined with the shorter-range Quickstrike-J, the U.S. is now developing the capability for one aircraft to lay a minefield in a single pass.

Combined with underwater minelaying, low altitude insertion or stealth aircraft, there is an emerging capability to lay minefields in areas where it was previously infeasible, including rivers, river mouths, and harbors. Smart target detection devices allow both limited selectivity of targeting and resistance to minesweeping.

The inshore pillar is aimed primarily against the waterborne element of the transportation network, with secondary effects against naval facilities and ships. It is intended to apply against domestic, short-haul shipping, and against ships carrying critical imports which penetrate an allied naval cordon. It would be possible to interdict vessels at either end of the network for domestic traffic — coal traffic might be bottled either at the on-load or offload facilities. Fear of mines may be more effective at halting traffic than actual mines themselves. While under the 1907 Hague Convention all minefields have to be declared, not all declared fields have to be mined.

In many cases, once mines have been employed somewhere, they could have been employed anywhere and this uncertainty is a powerful deterrent to movement.

III. Infrastructure Degradation

Interdiction of maritime transport alone will not necessarily achieve the full goals of the campaign by itself, although it will likely have a devastating (though reversible) effect on People's Republic of China's industry and power generation. The People's Republic of China's domestic energy supplies, combined with refining capability, ensure that the military could still be supplied with sufficient energy supplies to conduct sustained operations, albeit at a significant cost to other domestic priorities.

Local energy shortages will likely be exacerbated and reallocation of suddenly scarce resources would be challenging even for a country where the actual flows of resources are well known. The infrastructure degradation campaign is intended to give the resource denial efforts a push in the wrong direction by disrupting, incapacitating or destroying critical chokepoints in energy transport and production.

The most lucrative targets are rail tunnels and bridges, certain refinery components, international oil pipelines and oil transfer terminals. Nonlethal means may be used in addition to lethal ones, although even a nonlethal attack on petroleum handling or refining facilities can result in a lethal catastrophic effect.

The infrastructure degradation pillar is intended to constrain overland imports, while simultaneously destroying the refinery capacity necessary to turn strategic reserve or domestic crude oil into usable fuel and interdicting rail and water transportation at their most vulnerable points.

IV. Distant Interdiction

The distant interdiction pillar involves a maritime interdiction effort aimed specifically against ships bound for China with energy cargoes, particularly oil, refined oil products and coal.

It is the most legally complex of the pillars in that it involves action against both Chinese and foreign-owned shipping. It is also the pillar that can and should consist largely of actions that involve minimal property destruction, although it does involve the use of force. It takes advantage of the fact that the vast majority of China's imported energy supplies come through chokepoints that can be easily interdicted. The distant interdiction effort stretches from the Asian continental shelf all the way back to the original points of embarkation.

The maritime geography is unfavourable for China. Unlike the United States, which has four coasts that are mostly devoid of potentially hostile neighbours (excepting Cuba, of course), China is hemmed in by island chains that are owned by nation-states with longstanding territorial disputes with China. Supply lines across the Pacific from the Panama Canal or South America pass nearby U.S. territory on the way.

Furthermore, China has neither a true blue-water navy nor a robust network of forward bases, and cannot project naval power long distances from the mainland. In short, the People's Liberation Army Navy cannot protect its supply lines for energy back to the sources, which are typically in the Middle East for oil, or Australia for coal.

The distant interdiction portion of the campaign would aim to define energy supplies as contraband and to intercept, board and intern vessels carrying energy supplies to China. This would include vessels that are Chinese-flagged and foreign-flagged ships carrying energy to China. The vast majority of ships, which are container ships, are of no interest and can be allowed through, but petroleum tankers (oil, oil products and LPG) and bulk coal carriers would be boarded, seized and interned. The nature of these ship designs makes them the easiest to identify and greatly simplifies the execution of a blockade.

Under threat of attack, neutral ships may elect to avoid the conflict area, carrying other cargoes to other ports. There is little profit in attempting to deliver bulk cargo while risking damage or loss of the ship. Under such conditions insurance rates typically rise, and the premium for a brief exposure may reach upwards of 10 per cent the market value of the vessel, plus cargo value. The internment of Chinese-flagged vessels or neutrals with contraband bound for China is a compound-interest challenge.

Every internment not only removes the current cargo from the delivery sequence, but removes all subsequent cargoes that might have been carried by that ship. In the case of very large crude carriers (VLCCs), that can account for very large cargoes indeed. At this time, there are less than 100 Chinese-flagged VLCCs, accounting for under a sixth of the worldwide VLCC stock. Given the favorable geography, the U.S. Navy would not have to spread out far in order to interdict these ships, and may even block chokepoints outside Asia, like the Bab El Mandeb or Strait of Hormuz.

In 2014 an average of around 11 to 15 VLCCs transited the Straits of Malacca on any given date, traveling in both directions. Not all of these were bound for China, and a tanker may in fact carry oil for several destinations on a single voyage. A naval task force, supported by air, could intercept a significant number of these ships and interrupt their transit, either loaded or during the return voyage. Each ship that delivers cargo to China is subject to seizure on the return, providing two seizure opportunities on a single voyage.

Sample targets were compiled for this analysis. The largest target category is rail lines, which are broken at tunnel entrances and bridges to make repair time consuming and difficult. There are 32 targets chosen to interdict coal transport (mostly exiting Shanxi and Shaanxi provinces) and international coal and oil imports.

All of the rail transport from these two coal-producing provinces plus Inner Mongolia is interdicted, blocking movement of 70 percent of the country's domestic coal. All railway border crossings were interdicted on the Chinese side. Thirty-two additional rail targets were selected to shatter the rail transportation network, mostly at river crossings, which are intended to have a secondary effect of blocking shipping channels.

Every railroad bridge along the Yangtze 500 nautical miles upstream from Shanghai is on the list. Combined with additional railroad bridges across other waterways, the rail links between north and south China are severed, excepting only the high-speed passenger lines which are only broken at the Yangtze. Every one of the country's top ten freight corridors is broken in at least one place. Road bridges were only targeted across the Yangtze River (to block ship traffic) or when roads and railroads shared a bridge. Road tunnels were targeted only if adjacent to rail tunnel targets.

Pipelines accounted for six targets, inside China's borders, usually by targeting pumping stations but also the pipeline itself. There are 32 refinery targets, all allocated to refineries producing jet fuel, kerosene, and/or adjacent to strategic petroleum reserves. Distillation towers, rail terminals, rail access, power plants, and pumping stations consisted of the majority of aimpoints, with two to 10 aimpoints per refinery.

Water terminals were left alone unless directly attached to a refinery. Some refineries were isolated by cutting the rail approaches at bridges and otherwise leaving the refinery alone. Strategic Petroleum Reserve sites were targeted when adjacent to refineries but not if otherwise located.

There are 39 inshore targets, all minefields. Those minefields accounted for all PLAN bases and all large oil terminals, plus the mouths of the Yangtze and Pearl rivers. No river mining was conducted upstream of any river mouth. Only two minefields are offshore, both at oil terminals in the South China Sea, all others were within the 12 mile limit and often within the three mile limit. Because of the uncertainty involved with mining in defended airspace, most coastal refineries were double or triple-tapped, in that their rail links and refining capacity was directly attacked in addition to mining. Mined oil terminals are essentially double-tapped with the distant interdiction pillar.

No military facilities were directly targeted, nor were communications, underground petroleum storage, air defenses, commercial power plants, coal load/offload facilities, space control, space launch or leadership targets.

The direct effect of an Strategic Interdiction strategy on the

People's Republic of China's power projection capabilities cannot be precisely predicted from the data available from open sources. The goal of depriving PLAN and PLAAF forces of jet fuel will not be accomplished within a few weeks.

While China has no strategic reserve for refined petroleum products, it does have commercial storage, plus (presumably) military storage of undetermined size and composition. Diversion from civilian use and reallocation of refinery resources are probable, but both of those efforts will be hampered by interference with transportation; reallocation of production may be prevented by damage to refineries.

A detailed analysis of the anticipated effects is both beyond the scope of this white paper and not suitable for public dissemination in any case. What is certain is that an energy denial strategy will have immediate effects on the People's Republic of China. Interdiction of oil imports will force both an immediate reallocation of resources and likely cause a dip into the strategic reserve. A reduction of coal imports will have a rapid effect on power generation, although a reduction in industrial power use could mitigate the effects of power shortages.

Any perturbations, including physical damage, against the rail transportation system will ripple through the country—the system is over capacity as it is and even weather events disrupt rail transport. Damage to refineries simply cannot be mitigated rapidly—these are the softest of soft targets and even relatively minor damage can cause a refinery to shut down.

It is equally certain that interdiction of coal and oil imports will have a disproportionate effect on the provinces bordering the South China Sea. Aside from the inevitable electricity shortages, oil interdiction will idle every refinery in the four south-eastern provinces, taking 20 per cent of the country's total refinery capacity offline without any need to damage those refineries.

From an interdiction standpoint, it is easiest to interrupt foreign flows, whether they flow by sea or by pipeline. For coal, overseas interdiction is nevertheless worth the effort because of the disproportionate impact on the coastal provinces. Of course, 100 per cent import interdiction cannot be achieved overnight and may never be achieved at all, given the willingness and capability of neighbouring countries to revert to rail imports, however marginal. Interdiction of 90 per cent of oil imports is not only achievable, but impossible to offset through other transport means.

This will force the People's Republic of China to rely on its strategic reserve almost immediately and cause a massive reallocation of fuel use requirements. It may also have localized impacts on military forces, as it will be much harder to supply PLAN and PLAAF units based in the south. Only two of the Strategic Petroleum Reserve depots are in the south, comprising less than 20 percent of the Strategic Petroleum Reserve.

Additional effects on internal energy transport are another element of the strategy. The inshore effort is intended to disrupt both military and energy logistics. In the case of coal, 30 percent of domestic coal transport is by river and coastal traffic, which is especially vulnerable to mine warfare. Chinese short-haul shipping is a commercial and not a state enterprise, and civilian shipowners have been traditionally unwilling to risk their vessels in hostile waters. A ship sunk at a loading berth blocks the facility effectively and for a significant duration.

Infrastructure degradation will affect both water and rail transport, especially if rail bridges are dropped into major waterways. The Danube River was effectively closed to large traffic for five years after the Novi Sad bridges were dropped in Operation Allied Force. Damage to pipeline pumping stations, rail tunnels, bridges and refineries will be time consuming and difficult to repair, and in the case of refineries, suitable equipment may not be available domestically.

The secondary effects on electricity production will likewise ripple through the transportation and industrial sectors.

Electricity shortages caused by oil or coal interdiction will affect the train network; refineries starved of either feedstock or electricity cannot refine and pipelines without electricity do not move oil. Reduced diesel production will affect the non-electric portion of the rail network plus both maritime and truck transport, while at the same time diesel will be in demand for emergency power generation.

Reprioritization of limited freight transport will affect industry (itself starved for power) and agriculture directly, as well as disrupting distribution of industrial or agricultural products. Local surpluses and shortages of fuel, coal and electricity are certain to occur, further complicating distribution challenges.

Similar effects can be directly observed from single industrial accident. In November of 2013 a Sinopec pipeline in Huangdao, Shandong Province exploded, killing over 60 people and shutting the pipeline down. This caused production cutbacks in two nearby refineries, a reallocation of refinery production company-wide, and a shutdown of the Qingdao oil terminal for a week. Tankers were diverted to other ports, causing offshore backups because of the lack of available offload facilities. Environmental damage took many weeks to clean up and the oil berths were out of commission for months.

All of these cascading events were the result of the equivalent of a single weapon hit and the pipeline was never repaired.

The duration of any campaign is difficult to predict. The amount of military storage for refined fuel remains an unknown factor. Similarly, there are absolute limits on refinery production, rail transport, and truck movement of refined products, none of which are known, perhaps even to the People's Republic of China government. Finally, the wartime consumption of jet fuel by the PLAN and PLAAF is largely conjectural. Further complicating any assessment is the fact that turbine-powered ships can and do run on marine diesel fuel, which is still refined distillate, but is closer to diesel fuel in composition than kerosene.

A counter-logistics campaign, fought from long range where possible, is intended to provide a strategy that avoids China's strengths in air defense and relies on a very limited target list focused on targets that are neither hardened nor mobile.

Instead of matching technologically advanced military forces against like systems in terrain favourable to China, it is intended to fight only those units that come out to fight and leave many of their advantages behind.

This is a deliberate offset strategy, tailored to China, which avoids the pitfalls inherent in the misapplication of older air power theory and takes the specific characteristics of the adversary into account. It is also a strategy that could be executed today, with today's force structure, posture and today's personnel.

The Pentagon could certainly improve in all of those areas, but the execution of a Strategic Interdiction campaign will not need to wait for the development of new technologies and it does not hinge on transient vulnerabilities.

Our experience in World War II demonstrated the effectiveness of our efforts to successfully interdict the Japanese transportation systems and oil storage and production facilities. The Pacific Strategic Bombing Survey noted in retrospect that our efforts were inefficiently directed — if we had possessed accurate intelligence about the nature of Japan's logistics network, we might have rearranged our targeting priorities to increase our effects and shortened our timelines.

With respect to China, we do have significant knowledge about the energy sector, precisely because it is involved directly in foreign trade and a great deal of data is available. Instead of attempting to fight a generic "near peer" adversary with a template drawn from Desert Storm, we should be planning to apply a counter-logistics strategy against a real adversary, with the attendant national characteristics, vulnerabilities and geography.

Appendix 2

U.S. Air Force Public Affairs Guidance F-35A

September 2015

1. PURPOSE: Provide guidance to Airmen on the F-35A in order to:

1. Articulate the capabilities of the aircraft and explain it is a capability warfighters must have (explain why we need the F-35)
2. Debunk false narratives and inaccuracies reflected in news media reporting; and
3. Emphasize the importance of the Air Force fielding the capability and having the capacity to best support combatant commander needs.

2. BACKGROUND: The Air Force program of record is 1,763 F-35As. Acquiring the F-35 is imperative to the future capability of the Air Force and its ability to meet the projected needs of combatant commanders. Recapitalizing our aging legacy fleet of 4th generation fighters with 5th generation capabilities of the F-35 is an imperative. Due to pre-2010 setbacks in the program and perceived performance setbacks, narratives have emerged in the news media stating the aircraft is too expensive, consistently behind schedule and is not able to achieve its' (sic) stated missions. Air Force communicators must be prepared to consistently confront these inaccurate narratives with explanations of the aircraft's unique and critical contributions to the joint warfighter with accurate understanding and assessment of the program's developmental progress.

The F-35 will provide the joint warfighter unprecedented levels of survivability, lethality, and situational awareness, allowing them to fight and win in the emerging highly contested threat environments. It is important to help U.S. and international audiences understand why investing in the F-35 is a defense priority while highlighting the lethality, survivability, and adaptive attributes of the F-35. Lethal, survivable, and adaptive should be incorporated into F-35 communication efforts.

3. POSTURE: Active

SAF/PA will:
a. Create and execute overall Air Force-wide communication plan by October 2015.
b. Provide MAJCOMs and bases with Public Affairs Guidance
c. Engage with national level news media and opinion leaders in the national capital region
d. Provide guidance and assistance concerning national-level media attention at other locations

MAJCOM/PA should answer queries within the scope of this guidance and identify/coordinate with proper sources to respond to questions outside of it. MAJCOM PA should work with their wings to identify and execute stories. SAF/PA should be informed of national and international stories by MAJCOMs prior to execution.

Wing/PAs offices should support the objectives of this guidance by sharing F-35 information, anecdotes and success stories as they occur, both locally and up the chain through their MAJCOM up to SAF/PA. Wing PA offices will write internal stories for posting to their websites, engage their community leaders and support local, national and international media engagements in coordination with their MAJCOM and SAF/PA. Wings will also identify pilots and maintainers who are proficient at telling the F-35 story and are willing to lend their name and image to the effort. Names of identified Airmen will be provided to their MAJCOM and in turn to SAF/PA.

4. AUDIENCES:

a. National news media
b. U.S. lawmakers/policymakers
c. Opinion leaders
d. International publics, especially F-35 partner nations
e. Airmen

5. COMMUNICATION END STATE: U.S. opinion leaders, the American public and international partners are reassured and have confidence in the capability and can articulate why the F-35 is required for national defense.

6. THEMES AND MESSAGES:

6a. WHY WE NEED THE F-35—LETHAL, SURVIVABLE and ADAPTIVE

Air superiority is a critical precondition to successful military operations. Without air superiority, you lose not only the battle in the air, but also on the surface. Owning the skies is a crucial precondition for winning the fight. The F-35 provides our joint ground forces freedom from attack and freedom to maneuver while simultaneously holding the adversary's most heavily defended targets at risk. Losing this advantage in the air directly results in increased losses of U.S. and joint forces, both in the air and on the ground. The F-35 allows the U.S. to maintain this advantage by replacing legacy F-16 and A-10 fleet with superior

5th generation capability optimized for global precision attack, while complementing the air superiority capabilities of our F- 22s and F-15s.

Why the F-35 is Needed: Aging Fleet

- Today's Air Force is the smallest, oldest, and busiest it has ever been.
- The Air Force has not acquired new fighter aircraft in significant numbers since the early 1990's.
- The average age of the fighter fleet today is 27 years old, often older than the pilots who are flying them.
- Our legacy fleet remains less survivable in an emerging threat environment.

The Emerging Threat Environment

- Emerging air-to-air and surface-to-air threats and an aging fleet have threatened our air superiority advantage in highly contested operational environments.
- The threats we will face in the future are evolving in complexity and capability, and we are seeing these Integrated Air Defense System (IADS) capabilities proliferate world-wide into increasing numbers of future highly contested threat environments.
- These advanced IADS require an increased level of survivability. Stealth improves the F-35's survivability.
- We are seeing new potential adversary fighters currently fielded or in development, equipped with improved and advanced aerodynamic performance, weapons, avionics, and electronic warfare/jamming capabilities designed to counter our own fleet.

- Potential adversary Early Warning and Target Tracking radars are now equipped with digital and more agile signal processing and improved electronic protection capabilities. They are integrated into robust command and control/air defense systems that can find and track increased numbers of air targets at a greater range.
- Strategic and tactical surface to air missile systems are increasing in range, maneuverability, target tracking, and lethality.
- U.S. legacy 4th generation aircraft cannot operate and survive in a highly contested environment. The F-35 provides the joint warfighter 5th generation fighter capability with unmatched levels of survivability and lethality to ensure the U.S. will continue to successfully provide air superiority and global precision attack in these threat environments.
- The F-35 provides a capability to penetrate a high-end threat environment and evolving threats.
- We are operating in a dynamic threat environment, this aircraft provides the best technology to increase survivability for the warfighter.

Proliferation of Advanced Threat Capabilities; Near-Peer Competitors

- The U.S. technological advantage is shrinking as other countries continue to invest in technology that is on par or better than our legacy fleet.
- Potential adversaries are exporting their most current technology and top-end aircraft to various countries around the world in the next three to five years. If we end up fighting against that equipment in the future—2023, 2025 and beyond—it will be better than anything we have today. The

F-35 provides a 5th generation capability that ensures the advantage remains on our side.

5th Generation versus 4th Generation: Enables the Ability to Operate in High Threat Environments

- The F-35 has the 5th generation capabilities needed to achieve unmatched levels of survivability and lethality required to maintain the advantage against new and evolving threats.
- 5th generation capabilities include: advanced stealth, improved electronic attack and electronic protection, and fuzed/networked sensors for enhanced situational awareness. These capabilities combined with traditional fighter characteristics of speed, maneuverability, and precision weapons ensure the required capability to win in a high threat environment.
- Our legacy fleet of 4th generation aircraft offers little margin in capability advantage over current and future adversaries.
- Legacy aircraft are also rapidly approaching the point where adding new capabilities will no longer guarantee success.

We fight as a Coalition

- For the last few decades of war we've been fighting as a Coalition team. From the technology to the training to the fight, the F-35 makes us a stronger Air Force and a better, more fully integrated joint and coalition team.

THE ATTRIBUTES OF THE F-35—LETHAL, SURVIVABLE, AND ADAPTIVE

Overarching Message: The F-35's design is optimized to leverage specific capabilities and effectively accomplish a wide variety of mission sets. At full maturity, the multi-role F-35 will bring more lethality, survivability, and flexibility to combatant commanders than any other fighter platform.

Coalition Interoperability

- From the start of the F-35 program, we have included international partners in the design, development, and production efforts of this critical new 5th generation fighter.
- This interoperability allows for cost-sharing between the services and partner nations.
- This partnership spans three U.S. services and eight international partners, the F-35 fosters international cooperation. U.S. F-35 partner nations include: Australia, Canada, Denmark, Italy, Netherlands, Norway, Turkey, and United Kingdom. Current Foreign Military Sales countries are: Israel, Japan and South Korea.
- Data collected by sensors on the F-35 will immediately be shared with commanders at sea, in the air or on the ground, providing an instantaneous view of multi-mission operations.
- Twenty percent of the aircraft parts are manufactured in the partner countries; this raises the investment of our international partners to a different level. Besides their militaries, their industry and economies are invested in the aircraft before it even flies, leading to unprecedented layers of international cooperation.

Stealth/Low-Observable

- The F-35's low observable stealth allows it to safely enter areas without being detected by radars that legacy fighters cannot evade.
- Low observable technologies reduce the signature of the aircraft. These technologies need to be built into the aircraft from the outset. They cannot be simply be added onto legacy platforms.
- The F-35 is designed to be comparable to current tactical fighters in terms of maneuverability, but the design is optimized for stealth. This will allow it to operate in threat environments where other 4th generation aircraft could not survive.
- The vast majority of enemy fighters will likely never know they were targeted by the F-35 until weapon impact.
- In early operational testing, the F-35 has successfully interrupted 4th generation fighters' ability to identify, target and engage, making it more survivable and lethal.

Shared Situational Awareness through Fusion

- The "fusion" gives pilots the ability to see everyone and everything before an adversary knows we're there.
- Without fusion, the pilot would have to use multiple sensors on different screens to build a mental picture and then decide which threat to attack, what threat to avoid, and what munition to use.
- This provides pilots the ability to decide and act on the current tactical situation much faster than previously possible in any fighter aircraft, giving our pilots an extreme advantage.

- Multiple sensor fusion and integrated avionics give pilots the ability to quickly and fully understand the environment through a 360-degree view of the battlespace—this does not exist in 4th –Gen aircraft, where the information comes in several separate feeds, and the pilots have to piece the information together themselves.
- Going into the future, the F-35 will provide the warfighter unprecedented situational awareness and the required survivability to fight and win in highly contested environments. As an Airman, it is the capability warfighters deserve.

Electronic Attack

- Advanced electronic warfare capabilities enable the F-35 to locate and track enemy forces, jam radars and effectively disrupt attacks. The system allows the F-35 to reach well-defended targets and suppress enemy radars that threaten the F-35 and all other friendly aircraft.
- The F-35's advanced stealth and built-in electronic warfare capabilities enable unprecedented battlefield access without the need for dedicated electronic attack support aircraft.

Addressing Criticisms: Maneuverability

- The F-35 is not the F-22, but is comparable in maneuverability to other 4th generation fighters. Its design is optimized to leverage specific capabilities and effectively accomplish a wide variety of mission sets. At full maturity, the multi-role F-35 will bring more flexibility, survivability, and lethality to combatant commanders than any other fighter platform.

- The F-35's maneuverability combined with its low observability, enhanced situational awareness, mission systems, and advanced weapons payload will allow the F-35 to freely operate in threat environments legacy fighters could not survive in.

7. QUESTIONS/CRITICISMS AND RESPONSES:

Q1. Isn't this aircraft too expensive?

A1. Because of development cost, all aircraft acquisitions are more costly in the beginning. The F-35 costs have dropped steadily since the beginning of the program and will continue to do so. Unit costs have dropped by 57 percent since the procurement of the first production aircraft. A single F-35A with an engine is now $108 million ($4 million lower than previous lot 7 prices)—this trend should continue as we sign lots 9 and 10; we are very close to having an F-35A that costs less than $100M. In 2019, the target is $80M or less per aircraft.

That will make the F-35 comparable in cost to any 4th generation fighter. To maintain the steady decline in price per unit, the program of record numbers and advanced procurement contracts need to remain intact.

To maintain our air superiority advantage, it is a national imperative to recapitalize our aging legacy fighter fleet with 5th generation capability that ensures lethality and survivability against emerging high end threats. There are countries developing aircraft and air defenses that will require a robust 5th generation capability--- they have the ability to deny us and our allies the freedom to operate. As incredibly as the F-15, F-16 and A-10 aircraft have performed over the past decades, they and their pilots will be severely tested to survive against emerging threats.

Q2. I heard this aircraft can't dogfight, and it's not maneuverable. Is that true?

A2. Both operational and developmental testing continues for the F-35. It is too soon to draw any final conclusions on the maneuverability of the aircraft. The F-35 is designed to be comparable to current tactical fighters in terms of maneuverability, but the design is optimized for stealth and sensor superiority. News reports on the F-35's performance against an F-16 was an early look at the F-35's flight control authority software logic, and not an assessment of its ability in a dogfight situation. Operational test pilots are just beginning to develop the tactics, techniques, and procedures our operational fleet will employ to exploit the F- 35's advantages.

The F-35's technology is designed to engage, shoot, and kill its enemy from long distances, not necessarily in visual "dogfighting" situations. There have been numerous occasions where a four-ship of F-35s has engaged a four-ship of F-16s in simulated combat scenarios and the F-35s won each of those 4 v 4 encounters because of its sensors, weapons, and stealth technology. The F-35 has been optimized for the current trends in air warfare, where the enemy is engaged and defeated from long distances.

The F-35 is designed to provide maneuverability comparable to our legacy fighter fleet. Combining this with its inherent low observable survivability, enhanced situational awareness, unmatched mission systems, and advanced weapons payload will allow the F-35 to freely operate in threat environments legacy fighters could not survive.

Q3. I heard this aircraft is constantly behind schedule. True?

A3. The program had some setbacks in the early years, however the program underwent a re-baselining in 2012. Since then, the F-35 Lightning II program has met the timelines of all major milestones. The fleet has flown more than 38,000 flight hours, completed more than 65 percent of its Test Program, trained more than 200 pilots and 1,800 maintainers, and delivered more than 120 jets—including the first seven international aircraft. Of this number, the Air Force is currently flying more than 74 F-35As. These airplanes are flying daily, verifying the aerodynamic and mission systems performance, completing night flights and refueling operations, dropping munitions (in testing), and testing the unique aspects of the three different variants.

Bottom line is that we are flying, testing and maintaining this aircraft daily. We're capturing and building upon these lessons to ensure a solid foundation that will serve the Air Force for the next 50 years. We are on track for IOC in late 2016.

Q4. This aircraft can't replace the A-10. Can it really do the CAS mission? It can't loiter like the A-10 can.

A4. While designed for the precision attack role, one of its missions is close air support. It does not do CAS in the same way as the A-10, which has a great record of being a reliable CAS platform in a low-threat, less intense environment. The F-35 will be able to perform that mission in a more contested environment than the A-10, and will be able to respond much faster, arrive on station sooner with much more situational awareness of the current battlefield situation, allowing faster weapons employment in support of our ground forces.

Q5. Why are we sharing this technology with so many internationals? Aren't we sharing too much information?

A5. The U.S. typically fights its wars as a coalition, and rarely conducts major military operations unilaterally. We've fought in coalitions with our partners throughout modern history, and that will continue into the future. Based on lessons learned from previous air campaigns, we know a common operating system, not only providing interoperability from the start, but also a more lethal and survivable platform—and that is the true measure of success in any fight. The F-35 enables us to fly and fight with common capabilities, tactics, and resources. It is an automatic force-multiplier.

Q6. I heard the helmet is too big and heavy and cumbersome and doesn't work well. Is that true?

A6. While the current F-35 helmet weighs a little more than legacy helmets with Helmet Mounted Devices, its design is optimized with a better center of gravity. Our pilots report it is actually more comfortable than legacy helmet systems.

The F-35 HMDS provides pilots with unprecedented situational awareness. All the information that pilots need to complete their missions—through all weather, day or night—is projected on the helmet's visor. Additionally, the F-35's Distributed Aperture System (DAS), streams real-time imagery from six infrared cameras mounted around the aircraft to the helmet, allowing pilots to "look through" the airframe.

Q7. The helmet has a price tag of $400,000 per unit. Why is it so expensive, and what does it do?

A7. The unique abilities introduced by the F-35's helmet are a significant leap forward for the fighter community. While the interface is certainly valuable, the true merit of the helmet is found in its integrated night vision and High Off-Boresight System. The helmet streamlines functions within the cockpit and enables the pilot to wield the significant sensor suite available on the F-35 with ease. The ability to activate night-vision or IR imagery with the press of a button, or to target a ground marker with a turn of the head, is a major advancement that will return precious seconds during combat sorties.

Q8. Is it true the F-35 will be equipped for a nuclear mission? What is the current timeline and/or plan for integrating the F-35A with nuclear weapons?

A8: The F-35A will have the ability to be configured to carry nuclear-capable weapons. For the Air Force, detailed timelines will be built during F-35 Follow-on Development planning. The F-35 program is targeting a configuration for initial release of a dual-capable U.S. Air Force F-35A in late 2021. In addition to integration efforts the program must also accomplish unique weapon certification tasks which will continue into the 2025 timeframe.

Q9:Will the F-35 be able to fly in all weather conditions?
A9: The aircraft will train and operate in both optimal and inclement weather conditions. Only extreme weather conditions will halt operations.

Q10: What is the current mission capable rate of the F-35?
A10: This is the first year the mission capable rate of the F-35 is being tracked and reported. This year's rate is reported as 67.91% with 59 aircraft at an average age of 1.6 years, which is based on current flight training requirements and may not reflect future mission capable rates. On three separate occasions over the past year, the Air Forces' F-35A fleet exceeded its mission capable rate of 70 percent, which is extremely impressive for an airframe still in development. Overall, the F-35 mission capable rate is on par or better than the rates experienced by our legacy fleet during their development. This has allowed the Air Force to meet, and in some cases exceed, or operational flying requirements.

Q11: I hear that there is a new weight restriction for the pilots who fly the F-35, and some pilots are now grounded. Is that true?
A11: On 27 August 2015, the U.S. Services restricted F-35 pilots weighing less than 136 pounds from operating the aircraft due to an increased risk of injury that could occur in a low speed

ejection. This is an ejection seat issue and is not related to the differences between the Gen II and Gen III helmets. The weight restriction currently affects at least one F-35 pilot. All F-35s use the same Martin Baker US16E ejection seat system. The safety of our pilots is paramount and the F-35 Joint Program Office, Lockheed Martin, and Martin Baker continue to work this issue with the US Services and International Partners to reach a solution as quickly as possible.

Q12. At a press conference a reporter asked the CSAF: "I heard there may be a demonstration or exercise in the future that puts the A-10 directly against the F-35 in demonstrating the ability to perform close air support. Is that true? Is there going to be some head to head demonstration to show what the F-35 can do compared to the A-10?"

A: The question was not framed in the context of comparison testing in a formal IOT&E program. Testing is the only way to ensure a new weapon system meets the requirements we established. The question was asked in the context of the current budget debate about A-10 divestiture and seemed to refer to a new proposal by an unnamed source to do a "head to head comparison." Without the proper software configuration and related mission capability, it would make no sense at all to conduct such a test. The reporter was not asking about tests that were part of a broader comparative testing effort included in the comprehensive IOT&E program years from now. We will continue to test the F-35's capabilities as they come on line. We're confident the result will validate F-35 mature CAS capabilities before reaching FOC. Any comparison with the F-35 must be part of amore holistic assessment of our CAS enterprise beyond just a fly-off between one aircraft vs another. A comprehensive, formal testing program will ensure we continue to evolve in this critical mission.

Author's Comment

The great utility of marketing efforts such as the above in support of the F-35 is that the choice of talking points shows what the weaknesses of the product are. Note that the whole tone of the document is defensive. There is absolutely nothing to be proud of in the record of the F-35. Thus the choice of words to associate with the F-35—"lethal, survivable and adaptive"—is exactly the opposite of what the F-35 is. The F-35 doesn't carry enough missiles to be considered lethal, it can't maneuver fast enough to get a gun shot, and it is not fast enough to be survivable. And it is at its weight limit so it is not adaptive.

It is true that air superiority is a critical precondition for successful U.S. and coalition warfighting, but that is going to be hard to achieve with a fighter aircraft that has a three hour turnaround time between sorties at bases in the United States where the supply of airconditioning and power has to be 'just so'. It is not believable that this aircraft will achieve a high sortie rate in an expeditionary environment.

The sentence "The vast majority of enemy fighters will likely never know they were targeted by the F-35 until weapon impact" is highly misleading. The enemy fighter's infrared-search-and-track will likely see the flare of the AIM-120D launch and will also detect the mid-course updates sent to the missile. Its radar warning receiver will detect the missile's radar seeker when it is activated and the missile-approach-warning-system will also give 20 to 30 seconds warning. The enemy pilot, in most cases, will have plenty of time to utilise his aircraft's active countermeasures. Having dodged the AIM-120D, the enemy pilot is likely to be excited by the prospect of taking on a relatively defenseless F-35, the position of which he has been alerted to by the AIM-120D launch.

It is true that the F-35 has excellent situational awareness. But it is the machine equivalent of Stephen Hawking—a brilliant mind trapped in a body that lacks mobility.

This promotional document makes a false claim regarding cost in stating that the F-35A is priced at $108 million including its engine. The latest lot had a flyaway price of $131 million. Given that the rework component is not falling any further, it is not believeable that costs will fall to $80 million per copy, the price of the far less complicated F-16.

Finally, question 11 referred to the F-35's problem of neck injuries on ejection. To reiterate, pilots weighing less than 136 pounds have been banned from flying the F-35 due to a death rate on ejection that is considered unacceptably high. The death rate for pilots weighing between 136 and 165 pounds is 23 percent but with a 100 percent risk of neck injury, which would include quadriplegia, in that weight bracket. Pilots weighing more than 165 pounds would also have a risk of death, quadriplegia or other neck injury on ejection.

Appendix 3

F-35A High Angle of Attack Operational Maneuvers

Test Pilot:
Test Conductor:
Test Director:
Test Aircraft: AF-2, Test 715, Flight 505, Configuration 10-001B (Clean Wing), 0.1-v12.006 (R33.1)

OBJECTIVE

The test was designed to stress the high AoA control laws during operationally representative maneuvers utilizing elevated AoAs and aggressive stick/pedal inputs. The evaluation focused on the overall effectiveness of the aircraft in performing various specified maneuvers in a dynamic environment. This consisted of traditional Basic Fighter Maneuvers in offensive, defensive, and neutral setups at altitudes ranging from 10,000 to 30,000 feet MSL. The Flying Qualities criteria were that the aircraft response would be positive and predictable and that there should be no undesired, unexpected, or unpredictable aircraft responses. Qualitative observations were made regarding the high AoA capability, cues that the aircraft was entering a low energy state, as well as various human factors and considerations.

TEST ARTICLES

AF-2 (an F-35A) was flown with empty weapon bays and clean wings in R33.1.5 software. Of note, there were no CATM weapons and no mission systems available for this test. No FTAs were utilized to open or close weapon bay doors to simulate weapon launch. An on-axis HMD fixed reticle was used to help assist in evaluating capture and tracking tasks but no symbology filters were available. The target aircraft was an F-16D Block 40. It was equipped with a GE-I00 engine and configured with no CATM weapons and two 370 gallon wing tanks. No restrictions were placed on the target other than the basic aircraft design limits associated with wing tanks (7.0 g acceleration until empty).

MISSION EXECUTION

The sortie consisted of standard administration to the Sea Test Range. Ranging exercises were conducted to familiarize the target aircraft with F-35 visual cues. An offensive capture/tracking task was completed by the F-35 from 6,000 feet slant range with a 3,000 foot vertical offset at 22,000' MSl and 400 kts. All other testing consisted of traditional Basic Fighter Maneuvers setups starting at 22,000' MSL and 440 kts for 6K and 9K fights and 20,000' MSl at 380 kts for 3K fights. The neutral fights began at approximately 18,000' to 20,000' with no limitations on airspeed or altitude following the check away. The floor was 10,000' MSL. In all, there were seventeen engagements. No loads or other aircraft limits were exceeded with unrestricted throttle, stick, and rudder inputs.

OBSERVATIONS

Numerous observations were made that are not mentioned below. They are perceived to be of less significance or they are of higher classification. It is recommended that more pilots conduct this test since it is extremely effective at providing data that are not achievable with scripted test cards.

Energy Maneuverability

Overall, the most noticeable characteristic of the F-3SA in a visual engagement was its lack of energy maneuverability. The test pilot had 2,000 hours offlight time in the F-1SE, experience in F-16 Blks 30/40/42/50, exposure to flying the F-18F in high AoA, and has fought dissimilar Basic Fighter Maneuvers engagements with each in addition to F-1SC. The EM of the F-3SA is substantially inferior to the F-1SE with PW-229s due to a smaller wing, similar weight, and ~15,000 Ibs less in afterburner thrust. So, in general, the high AoA capabilities of the jet could not be used in an effective way without significantly reducing follow-on maneuvering potential. Even with the limited F-16 target configuration, the F-3SA remained at a distinct energy disadvantage for every engagement.

Pitch Rate

Insufficient pitch rate exacerbated the lack of EM. Energy deficit to the bandit would increase over time. Therefore, there were multiple occasions where it would have been tactically sound to accept excessive energy loss in order to achieve a fleeting WEZ. The CLAW prevented such shot opportunities (and hindered defeating shots). This included high energy conditions such as immediately off the perch. The average Nz achieved during the breaks or turn circle entries were typically ~6.5 or less despite a rapid full aft stick pull and then decreased as energy depleted and the aircraft slowed on the limiter. Insufficient pitch rate also occurred at slower speeds such as during gun attempts. Instead of catching the bandit off-guard by rapidly pull aft to achieve lead, the nose rate was slow, allowing him to easily time his jink prior to a gun solution. From a guns defensive perspective, the lack of nose rate (or alpha rate) also prevented creating closure because the bandit could react to the gradual onset even when near the front of the control zone.

High Angle of Attack

Due to the energy and pitch rate limitations described above, there were not compelling reasons to fight in this region. Some cues that the aircraft was entering high AoA included a bleed through buffet back to a smooth jet, diminished wind rush over the canopy, and full aft stick with no pitch rate. The leading edge flaps were noticed as an additional visual cue when looking across the circle or aft of 3/9. They don't seem to be as pronounced in the F-16 but due to a much larger size in the F-15A, they were easily perceived while fighting the bandit.

A technique was found that allowed a few offensive opportunities in High AoA and proved to be repeatable. Once established at high AoA, a prolonged full rudder input generated a fast enough yaw rate to create excessive heading crossing angles with opportunities to point for missile shots. This seemed to be more effective than relying on pitch rate and managing the lift vector to turn with the bandit when starting defensive. The technique required a commitment to lose energy and was a temporary opportunity prior to needing to regain energy to save the floor and ultimately end up defensive again. In short, deciding to commit to high AoA meant losing the fight unless the bandit made an error and was unable to save 3/9. In those cases, regaining energy to prosecute the offensive was extremely challenging.

High Angle of Attack Blended Region

The flying qualities in the blended region (20-26 degrees AoA) were not intuitive or favorable. This was especially frustrating because as the sortie progressed, it was apparent that the aircraft fought best at the lower end of this alpha whether turning or established in a tree/scissors; so the lateral/directional control was often unpredictable. This flight seemed to be especially effective in revealing this flaw because in most tests the AoA is readily apparent (or targeted) and, therefore, the response is expected. However, during a dynamic fight, where attention is focused on the bandit rather than the specific AoA, the lateral/directional response was often confusing. There were multiple times where a roll rate was expected yet not achieved or a body-axis yaw rate was expected and beta resulted. In other cases, the response changed during the maneuver as the AoA blended into this region.

During a tree, the anti-spin logic engaged as a direct result of this unpredictability. The F-35 had gained a 3/9 advantage and the pilot desired to maneuver behind the bandit. A full rudder input had no result initially but after a few seconds the jet began to maneuver simultaneously to the command being abandoned and replaced with stick input. Once the delayed result appeared from the initial rudder input, the rudder was promptly re-input to encourage the aircraft to continue. A fantastic yaw rate followed, only to be spoiled by the anti-spin logic. The anti-spin logic was surprisingly pronounced. As has been experienced on other high AoA missions, there is ample control authority for arresting yaw rate. Whereas rudder inputs often feel sluggish/gradual or delayed, the anti-spin logic is immediate, abrupt, and forceful. Perhaps some of the available authority may be given to the pilot while still preventing departure.

In retrospect, a seemingly valuable improvement would be to adjust the blended region to at least 30 degrees AoA. There are two reasons. The first is to ensure predictability. Since this aircraft seemed to fight best near 20 degrees, controls should not be blended near this region. The pilot is not consciously at "high" AoA at 25 degrees but at 40 degrees, an affirmative decision was made to be there. The second is purely geometric and also aids in predictability. Geometrically, at 26 degrees the aircraft is still relatively "shallow" so it's still intuitive that a roll stick would result in a stability axis roll and a rudder would result in yaw. Mathematically, an even blend (50%) would occur at 30 degrees (sin30) and this seems to match the “seat of the pants” feeling for the pilot as well.

Guns Defense

No effective guns defense was found during this test. Various techniques were tried depending on aspect, energy, and closure. Attempts were made to maintain closure by staying in the 20-ish alpha region with lift vector on, while using rudder to get out of plane. Results were unpredictable as discussed above. For unloaded-roll-pull jinks, the slow pitch rate was evident in both the unload and the pull. The result was a gradual out of plane maneuver which was easy to track. For floor and slow speed jinks, the high AoA control was adequate but there was no effective motion from the aircraft. The result was a target that was changing shape/attitude but not actually moving out of the pipper. Higher alpha usually just resulted in a larger planform target.

Buffet & Transonic Rolloff (TRO)

Despite concerns early in the program regarding buffet, it was not found to be detrimental during this mission. It was actually favorable when encountered because it provided a great cue of energy, similar to the F-15. Buffet was never encountered with the bandit on-axis and off-axis symbology was steady regardless of buffet level. The jet was below buffet energy levels when gunning the bandit and the aircraft was unloaded when shooting the bandit on-axis with missiles, ie across the circle. (The same pilot conducted the HMO readability tests for buffet conditions). A more difficult problem is ensuring gun pipper accuracy, especially considering the new “swimming” filters but that was beyond the scope of this test (no filters were available on the FS aircraft). TRO was never encountered during the Basic Fighter Maneuvers engagements.

Rearward Visibility

The helmet was too large for the space inside the canopy to adequately see behind the aircraft. There were multiple occasions when the bandit would've been visible (not blocked by the seat) but the helmet prevented getting in a position to see him (behind the high side of the seat, around the inside of the seat, or high near the lift vector). There were also several other times where the seat blocked the view. When the bandit was high, the "eyebrow" from the helmet often blocked the tally too. Whenever the helmet was pinned against the canopy, the pilot continued to strive to turn his neck resulting in the symbology no longer being in front of the eyes. Multiple HMO BST FAULTs asserted during all of the motions, which may have been specific to the FS aircraft but plausible that it would occur in the MS jets too. Beyond being a nuisance, it would further restrict weapons employment by either minimizing pilot movement or causing symbology to disappear.

In general, it took a lot of physical effort to turn around for the visual. The pilot pushed fairly hard off the seat's leg guards with the outer thighs to twist at the waist and also used a hand on the canopy often during left turns too. The engine IPT noted that when this occurred, the much needed power often inadvertently decreased (with friction set at 6 o'clock) and it would've delayed activating CMD. In addition to the waist strain, tilting the head back and looking up turned the HVI cable into a spring, further increasing neck tension; it was not uncomfortable but noticeable. The HMO weight was no factor and was actually more comfortable than a legacy helmet. Overall, it was more physical effort than expected to turn around, even with the lower than expected Nz level.

In addition to the HMO BRST FAULTs, INS DEGDs, SFD AnlTUDEs, and HOG DISAGREEs asserted which were minor nuisances during the fight. FUEL FEED TANK occurred during one attempt to transition from above the bandit in a tree; a full forward stick input combined with MAX power resulted in a much slower than expected pitch rate. No fights were terminated due to aircraft subsystem limitations.

CONCLUSION AND RECOMMENDATIONS

-The F-35 was at a distinct energy disadvantage in a turning fight and operators would quickly learn that it isn't an ideal regime. Pitch rates were *too* slow to prosecute or deny weapons. Loads remained below limits and implied that there may be more maneuverability available to the airframe. **Rl: Increasing pitch rate and available Nz would provide the pilot more options, especially considering the inherent energy deficit.**

-Though the aircraft has proven it is capable of high AoA flight, it wasn't effective for killing or surviving attacks primarily due to lack of energy maneuverability. Perhaps, with a faster AoA onset, there may be some advantages to choosing higher alpha when fighting a bandit. **R2: Consider increasing alpha onset.**

-The high AoA blended region was not predictable primarily because it seemed too close to the ideal fighting AoAs and not intuitively "high" to the pilot while he remained focusing on the bandit rather than the displayed AoA. **R3: Consider increasing the beginning of the blended region to 30 degrees or greater.**

-Significant anti-spin control authority has been demonstrated on this and other high AoA flights. The effect is abrupt, responsive, and powerful whereas pilot input seems to be sluggish and gradual. **R4: Consider increasing pilot yaw rate control authority**.

-HMO and canopy configuration is detrimental to visual lookout. The combination should be evaluated to see if it can be improved. HMO BST FAULTs can prevent weapons employment during maneuvering. **R5: Improve HMO Boresight performance to account for dynamic maneuvers and consider improving rearward visibility by creating more space for helmet motion.**

Author's Comment

The F-35's lack of energy maneuverability, which means an inability to dogfight, was entirely predictable from its characteristics. The F-35 was designed as a light bomber, or strike aircraft, to drop two 2,000 pound bombs on enemy surface-to-air missile sites. The F-35 is likely to be only able to use its gun against transport aircraft. The lack of energy maneuverability also means that the F-35 is less likely to be able to dodge missile shots.

What is telling about this mock dogfight in Basic Fighter Maneuvers against an F-16 is that similar unscripted mock dogfights are not conducted against other fighter aircraft types.

Without knowing the setup parameters, official pronouncements on the combat efficacy of the F-35 against other aircraft are worthless. For example, the setup may require the other fighter aircraft to operate with their radars on and the infrared-searh-and-track systems off. The F-35s then fire off their AIM-120D missiles, which are assumed to have a high probability of kill, and the F-35s are deemed to have won the engagement.

In the absence of unscripted Basic Fighter Maneuvers against dissimlar aircraft, the results of simulated combat should be taken as a guide as to how the F-35 will perform in combat—that the Su-35 will be able to shoot down 2.6 F-35s for each Su-35 lost.

Appendix 4

Oslo Embassy Cable on the F-35

Date: Tuesday, December 16, 2008

LESSON LEARNED FROM NORWEGIAN DECISION TO BUY JSF

B. B: OSLO 585 C. C: OSLO 522 Classified By: Deputy Chief of Mission Kevin M. Johnson for reasons 1.4 b and d

1. Summary: After an extensive, coordinated US Government effort, the Norwegian Government decided to buy F-35s in the Joint Strike Fighter (JSF) program, instead of the Saab Gripen. This first foreign JSF sale is an important step for the program as it will likely have a domino effect on other potential purchasers. The sale was not an easy one, however, and we outline a number of lessons learned that may prove helpful as other countries make their choice. End Summary.

The Tale 2. : The country team has been living and breathing JSF for over a year, following a road to success that was full of heart-stopping ups and downs. A quick recap of key events includes: In 2007, the Government of Norway announced criteria for Future Combat Aircraft competition to include aircraft capability, life cycle costs and industrial participation.

In April 2008, the two remaining competitors (US F-35 Joint Strike Fighter and Swedish Saab JAS-39NG Gripen) delivered responses to Ministry of Defense's Request for Binding Information (RBI). Saab immediately claimed that the Gripen would be half the price of the JSF.

Over the spring and summer, Saab's promotion of its industrial package was intensive and covered every province of

Norway. Norwegian Labor Party leaders admitted to Embassy that they received frequent calls from local mayors in favor of the Gripen. A sudden onslaught of negative press during this same time prompted us to meet with Lockheed Martin to better understand their media strategy and to discuss the best way to counter myths and disinformation about the JSF. Embassy and Lockheed Martin efforts to counter disinformation reaped some apparent success.

In the fall of 08, we invited a number of US Government officials to visit Oslo to make the public case on why the F-35 is an excellent choice, and the private case on why the choice of aircraft will have an impact on the bilateral relationship. The delivery of Norway's first C-130J transport aircraft in November 2008, which followed intense USAF efforts to rush this vital capability to Norway (and came directly from the USAF production line), allowed us to make the (unstated) point that we are good allies and reliable partners.

On November 20, the Government of Norway announced the decision to buy the F-35s, using unusually strong language (for domestic political reasons) to say the Gripen was uncompetitive.

3. Following the announcement, the Ambassador met with Deputy Defense Minister Espen Barth-Eide. In a very relaxed meeting, Barth-Eide thanked us for sticking to defending our plane, rather than attacking the Gripen. He praised the Government of Norway's bottom-up process that focused on the criteria. Noting that while some politicians would have like to have chosen the Gripen, the overwhelming technical success of the F-35 in the ministry's four scenarios made such a choice impossible. He complained about Saab's, but not the Government of Sweden's, reaction to the decision. For example, the Government of Norway had never promised them 24 hours notice of the decision (which would have been illegal under Norwegian insider trading laws). Commenting on the press coverage of the

JSF, Barth-Eide said that *Aftenposten* (the paper of record) had the Government of Norway "off the deep end" with its open anti-JSF campaign of disinformation.

4. Looking ahead, Barth-Eide said we were now on the same side and it would be very helpful if the US Government were to:

- publicly stress the strength of the F-35 and the viability of the JSF program;
- confirm there was no US Government political pressure to buy the plane;
- note the low price of the F-35 is due to the scale of the JSF program (more than 3200 aircraft) and the timing of the Norwegian buy in 2016, when full-scale production of the aircraft will be in full swing;
- arrange visits by U.S. officials to emphasize the above;
- encourage US companies to enhance the Industrial Participation package (the one area that Gripen clearly dominated).

5. Barth-Eide stressed that Norway's role as the second to buy into the program (following the US) was an important bellwether and would have a positive impact on other governments' decisions. He noted that having a socialist government like Norway's choose the JSF is an even more powerful symbol than if a right-wing government of another country had committed first. While the Government of Norway will not actively lobby on behalf of JSF with other governments, it is in the Government of Norway's interest that other partners buy into the program. He expects the Danes will ask for the Government of Norway data analysis and the Government of Norway will try to accommodate that within the limits of confidentiality.

The Lessons Learned

6. While many of the issues in this effort were unique to Norway, some lessons learned may be applicable elsewhere. The main ones include: - Get the whole country team involved. The active involvement of the Ambassador and DCM, ODC, DAO, Pol/Econ, FCS, and Public Affairs offices ensured that the fighter plane decision was an Embassy priority. This was necessary to convince Lockheed Martin and Washington officials that it was important to devote time and resources on Norway's decision.

Working with Lockheed Martin to determine which aspects of the purchase to highlight. In Norway the capabilities of the JSF vs. the Gripen were the strongest suit, and Embassy and Lockheed Martin efforts focused on discussions of why the JSF's capabilities were the best match for Norway's needs, especially in the High North. This focus played to the JSF's strengths and eventually proved to be the decisive factor, despite perceived weaknesses in other areas such as the industrial package.

- Jointly develop a press strategy with Lockheed Martin and collectively determine the role the Embassy will play in this strategy.
- Use the Ambassador to give numerous on-the-record interviews but also to have off-the-record in-depth discussions with editorial boards on the purchase.
- Be constantly available to the media to discuss the technical merits of the aircraft, and be assertive in refuting disinformation. In Norway, there were many self-proclaimed experts talking about the F-35 and making wildly inaccurate statements on everything from its lack of ability to its exorbitant price. It was important to counter these assertions and our ODC chief gave more than 20 separate interviews.
- Create opportunities to talk about the aircraft. The Ambassador hosted a luncheon for retired senior military and

think-tankers during which an extensive presentation on the capability of the F-35 was given. This enabled our host nation advocates to actively contribute to the public dialogue from their respective positions of authority. Embassy also coordinated with Lockheed Martin for attendance at all relevant airshows and roundtable discussions. The fighter competition was consistently a part of our informal discussions with MFA, MOD and influential think tanks.

- Talk about the impact on the relationship carefully. Deciding our line on this was critical, given Norwegian sensitivities. We needed to avoid any appearance of undue pressuring (which was construed as threatening Norway in its sovereign decision-making process), but we couldn't let stand the view that the choice didn't matter for the relationship. We opted for "choosing the JSF will maximize the relationship" as our main public line. In private, we were much more forceful.
- Reach out to other US Government agencies and experts to encourage their participation in the process and leverage their tools to support the effort. In this process also ensure the same messages are delivered in DC to the partner Embassy as are delivered overseas to the Host Nation government.

—WHITNEY

Author's Comment

Above is a cable from the U.S. ambassador in Oslo with respect to the embassy's role in promoting the F-35 in Norway and the campaign against the competitor aircraft. The cable was released by Wikileaks:
https://wikileaks.org/plusd/cables/08OSLO670_a.html

Benson Whitney was the U.S. ambassador to Norway from 2006 to 2009. The cable illustrates the effort to corral foreign buyers of the F-35, needed to overcome the aircraft's shortcomings. As the cable notes, the Saab Gripen E (then called the Gripen NG) is half the price of the F-35. The cable noted that critcs of the F-35 were aware of its "lack of ability and exorbitant price."

The cable also indicates that foreign customers of the F-35 are not buying it as a value proposition. Possibly all the F-35's foreign customers see purchase of the F-35 as a cost of their relationship with the United States.

Appendix 5

Coalition Air-to-Air Victories in Desert Storm

Date	Unit	Aircraft	Target	Ordnance
17-Jan-91	58 TFS/33 TFW	F-15C	MiG-29	AIM-7M
17-Jan-91	58 TFS/33 TFW	F-15C	Mirage F-1EQ	AIM-7M
17-Jan-91	58 TFS/33 TFW	F-15C	Mirage F-1EQ	Ground
17-Jan-91	71 TFS/1 TFW	F-15C	Mirage F-1EQ	AIM-7M
17-Jan-91	58 TFS/33 TFW	F-15C	MiG-29	AIM-7M
17-Jan-91	58 TFS/33 TFW	F-15C	MiG-29	AIM-7M
17-Jan-91	VFA-81	F/A-18C	F-7B Fishbed	AIM-9
17-Jan-91	VFA-81	F/A-18C	F-7B Fishbed	AIM-7
17-Jan-91	390 ECS/366 TFW	EF-111A	Mirage F-1	Ground
19-Jan-91	58 TFS/33 TFW	F-15C	MiG-25	AIM-7M
19-Jan-91	58 TFS/33 TFW	F-15C	MiG-25	AIM-7M
19-Jan-91	58 TFS/33 TFW	F-15C	MiG-29	AIM-7M
19-Jan-91	58 TFS/33 TFW	F-15C	MiG-29	Ground
19-Jan-91	525 TFS/36 TFW	F-15C	Mirage F-1EQ	AIM-7M
19-Jan-91	525 TFS/36 TFW	F-15C	Mirage F-1EQ	AIM-7M
24-Jan-91	No. 13 Sqn RSAF	F-15C	Mirage F-1EQ	AIM-9P
24-Jan-91	No. 13 Sqn RSAF	F-15C	Mirage F-1EQ	AIM-9P
26-Jan-91	58 TFS/33 TFW	F-15C	MiG-23	AIM-7M
26-Jan-91	58 TFS/33 TFW	F-15C	MiG-23	AIM-7M
26-Jan-91	58 TFS/33 TFW	F-15C	MiG-23	AIM-7M
27-Jan-91	53 TFS/36 TFW	F-15C	MiG-23	AIM-9M
27-Jan-91	53 TFS/36 TFW	F-15C	MiG-23	AIM-9M
27-Jan-91	53 TFS/36 TFW	F-15C	MiG-23	AIM-7M
27-Jan-91	53 TFS/36 TFW	F-15C	Mirage F-1EQ	AIM-7M
28-Jan-91	32 TFG	F-15C	MiG-23	AIM-7M
29-Jan-91	58 TFS/33 TFW	F-15C	MiG-23	AIM-7M

02-Feb-91	525 TFS/36 TFW	F-15C	Il-76	AIM-7M
06-Feb-91	53 TFS/36 TFW	F-15C	MiG-21	AIM-9M
06-Feb-91	53 TFS/36 TFW	F-15C	MiG-21	AIM-9M
06-Feb-91	53 TFS/36 TFW	F-15C	Su-25	AIM-9M
06-Feb-91	53 TFS/36 TFW	F-15C	Su-25	AIM-9M
06-Feb-91	706 TFS/926 TFG	A-10A	Bo-105	GAU-8
06-Feb-91	VF-1	F-14A	Mi-8	AIM-9
07-Feb-91	58 TFS/33 TFW	F-15C	Su-7	AIM-7M
07-Feb-91	58 TFS/33 TFW	F-15C	Su-22	AIM-7M
07-Feb-91	58 TFS/33 TFW	F-15C	Su-22	AIM-7M
07-Feb-91	22 TFS/36 TFW	F-15C	Mi-24	AIM-7M
11-Feb-91	525 TFS/36 TFW	F-15C	0.5 x Mi-8	AIM-7M
11-Feb-91	525 TFS/36 TFW	F-15C	0.5 x Mi-8	AIM-7M
14-Feb-91	335 TFS/4 TFW	F-15E	Hughes 500	GBU-10
15-Feb-91	511 TFS/10 TFW	A-10A	Mi-8	GAU-8
20-Mar-91	22 TFS/36 TFW	F-15C	Su-22	AIM-9M
22-Mar-91	53 TFS/36 TFW	F-15C	Su-22	AIM-9M
22-Mar-91	53 TFS/36 TFW	F-15C	PC-9	Ground

Appendix 6

Coalition Fixed-Wing Combat Aircraft Attrition in Desert Storm

DATE	DAMAGE /LOSS	AIRCRAFT TYPE	UNIT	CAUSE
17-Jan-91	Loss	F-15E	4 TFW	AAA
17-Jan-91	Damage	A-10A	10 TFW	AAA
17-Jan-91	Damage	A-10A	354 TFW	AAA
23-Jan-91	Damage	A-10A	23 TFW	AAA
29-Jan-91	Damage	A-10A	354 TFW	AAA
02-Feb-91	Damage	A-10A	354 TFW	AAA
02-Feb-91	Damage	A-10A	23 TFW	AAA
02-Feb-91	Damage	A-10A	354 TFW	AAA
11-Feb-91	Damage	A-10A	23 TFW	AAA
11-Feb-91	Damage	A-10A	23 TFW	AAA
31-Jan-91	Damage	A-10A	926 TFG	IR-SAM
06-Feb-91	Damage	A-10A	354 TFW	IR-SAM
15-Feb-91	Damage	A-10A	23 TFW	IR-SAM
05-Feb-91	Loss	A-10A	354 TFW	AAA
02-Feb-91	Loss	A-10A	23 TFW	IR-SAM
22-Feb-91	Loss	A-10A	23 TFW	IR-SAM
15-Feb-91	Loss	A-10A	354 TFW	SA-13
15-Feb-91	Loss	A-10A	354 TFW	SA-13
17-Jan-91	Loss	A-4	KAF	R-SAM
17-Jan-91	Loss	A-6E	VA-35	R-SAM
17-Jan-91	Damage	A-6E	VA-35	AAA

18-Jan-91	Loss	A-6E	VA-155	AAA
21-Jan-91	Damage	A-6E	USN	
02-Feb-91	Loss	A-6E	USN	AAA
15-Feb-91	Damage	A-6E	USN	
21-Feb-91	Damage	A-6E	VMA-224	AAA
21-Jan-91	Damage	AC-130	1 SOW	IR-SAM
31-Jan-91	Loss	AC-130H	1 SOW	IR-SAM
12-Feb-91	Damage	AV-8B	VMA-542	AAA
23-Feb-91	Damage	AV-8B	VMA-311	AAA
28-Jan-91	Loss	AV-8B	USMC	AAA
09-Feb-91	Loss	AV-8B	USMC	IR-SAM
23-Feb-91	Loss	AV-8B	VMA-542	IR-SAM
25-Feb-91	Loss	AV-8B	VMA-542	IR-SAM
27-Feb-91	Loss	AV-8B	VMA-331	AAA
17-Jan-91	Damage	B-52G	42 BW	SA-3/6?
26-Jan-91	Damage	B-52G	1708	AAA
26-Jan-91	Damage	B-52G	1708	AAA
27-Jan-91	Damage	B-52G	1708	AAA
26-Feb-91	Damage	B-52G	379 BW	R-SAM
26-Feb-91	Damage	B-52G	379 BW	R-SAM
13-Feb-91	Loss	EF-111	20 TFW	DEA
21-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
21-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
21-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
22-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
24-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
24-Feb-91	Damage	F/A-18	VMFA-	IR-SAM
27-Feb-91	Damage	F/A-18	USMC	Small
05-Feb-91	Loss	F/A-18	USN	
09-Feb-91	Loss	F/A-18	USMC	IR-SAM
17-Jan-91	Loss	F/A-18C	VFA-81	MiG-25PD

17-Jan-91	Damage	F-111F	48 TFW	AAA
17-Jan-91	Damage	F-111F	48 TFW	AAA
17-Jan-91	Damage	F-111F	48 TFW	AAA
21-Jan-91	Loss	F-14A+	VF-103	SA-2
22-Jan-91	Damage	F-15C	1 TFW	DEA
19-Jan-91	Loss	F-15E	4 TFW	SA-2
26-Feb-91	Damage	F-16A	174 TFW	IR-SAM
19-Jan-91	Loss	F-16C	401 TFW	R-SAM
19-Jan-91	Loss	F-16C	401 TFW	R-SAM
21-Jan-91	Damage	F-16C	388 TFW	R-SAM
26-Feb-91	Damage	F-16C	388 TFW	
27-Feb-91	Loss	F-16C	50 TFW	AAA
27-Feb-91	Damage	F-16C	388 TFW	IR-SAM
19-Jan-91	Loss	F-4G	35 TFW	AAA
13-Feb-91	Loss	F-5E	RSAF	AAA
17-Jan-91	Loss	GR.1	617 Sqn	AAA
17-Jan-91	Loss	GR.1	15 Sqn	R-SAM
18-Jan-91	Loss	GR.1	IAF	?
18-Jan-91	Loss	GR.1	617 Sqn	IR-SAM
19-Jan-91	Loss	GR.1	15 Sqn	R-SAM
19-Jan-91	Loss	GR.1	RSAF	AAA
22-Jan-91	Loss	GR.1	16 Sqn	?
24-Jan-91	Damage	GR.1	RAF	R-SAM
07-Feb-91	Loss	GR.1	27 Sqn	R-SAM
14-Feb-91	Loss	GR.1	15 Sqn	R-SAM
17-Jan-91	Damage	Jaguar	FAF	AAA
17-Jan-91	Damage	Jaguar	FAF	?
17-Jan-91	Damage	Jaguar	FAF	AAA
17-Jan-91	Damage	Jaguar	FAF	SA-14/16?
31-Jan-91	Damage	OA-10A	23 TASS	AAA
19-Feb-91	Loss	OA-10A	23 TASS	IR-SAM
27-Feb-91	Loss	OA-10A	23 TASS	IR-SAM
18-Jan-91	Loss	OV-10	USMC	IR-SAM
25-Feb-91	Loss	OV-10	VMO-1	IR-SAM

Appendix 7

Defense Sector Contributions to Members of Congress—Top 20

Senators and Congressmen	Amount
Sanders, Bernie (D)	$398,089
Thornberry, Mac (R-TX)	$357,500
Cruz, Ted (R-TX)	$333,038
McCain, John (R-AZ)	$314,115
Frelinghuysen, Rodney (R-NJ)	$299,500
Granger, Kay (R-TX)	$265,800
Ayotte, Kelly (R-NH)	$223,965
Forbes, Randy (R-VA)	$217,395
Turner, Michael R (R-OH)	$209,800
Smith, Adam (D-WA)	$196,650
Visclosky, Pete (D-IN)	$179,800
Wittman, Rob (R-VA)	$171,450
McSally, Martha (R-AZ)	$168,077
Schumer, Charles E (D-NY)	$163,953
Shelby, Richard C (R-AL)	$161,100
Wilson, Joe (R-SC)	$147,150
Burr, Richard (R-NC)	$146,900
Palazzo, Steven (R-MS)	$145,950
Heck, Joe (R-NV)	$144,700
Hunter, Duncan D (R-CA)	$144,500

Data source: Center for Responsive Politics. All donations took place during the 2015-2016 election cycle and were released by the Federal Election Commission on Wednesday, September 21, 2016.

Notes

Preface

1. Carlo Kopp, *Lockheed-Martin F-35 Joint Strike Fighter*, Air Power Australia, April/May 2002, http://www.ausairpower.net/jsf-analysis-2002.html
2. FY 1994-2014 Annual Publication of "*Program Acquisition Costs by Weapon System*" Office of the Under Secretary of Defense (Comptroller), eg. at: http://comptroller.defense.gov/Budget-Materials/
3. Colin Clark, *Gen. Mike Hostage on the F-35; No Growlers Needed When War Starts*, Breaking Defense, June 6, 2014.

Introduction

1. John Stillion and Scott Perdue, *Air Combat—Past, Present and Future*, Rand Project Air Force, August 2008.
2. Colin Clark*, Gen. Mike Hostage On The F-35; No Growlers Needed When War Starts*, Breaking Defense, June 6, 2014.
3. Australian Government, Department of Defence, *Statement of Evidence to the Parliamentary Standing Committee*, June 2014, Facilities Requirements for the New Air Combat Capability.
4. Bill Sweetman, *U.S. Considers Up To 72 New F-15s Or F-16s*, Aviation Week, November 19, 2015.
5. Jonathon Berr, *Pentagon's 'Too Big to Fail' F-35 Gets Another $10.6 Billion*, F, The Fiscal Times, February 2, 2015.
6. Jeremiah Gertler, *The Air Force Aviation Investment Challenge*, Congressional Research Service, December 17, 2015.

7. James Drew, *F-22 Raptor retrofit to take longer, but availability hits 63%,* Flight Global, July 6, 2015.
8. James Drew, *F-35A cost and readiness data improves in 2015 as fleet grows*, Flight Global, February 2, 2016.
9. Jeff Schogol, *The Marine Corps' aviation fleet is in peril*, Maine Corps Times, April 26, 2016.
10. Tara Copp, *F/A-18 crashes rise rapidly as budget constraints have led to overused planes, undertrained pilots*, Stars and Stripes, September 1, 2016.
11. Dave Majumdar, *America's F-22 Raptor Stealth Fighter Is a Killer (But it Can Be Defeated)*, The National Interest, October 15, 2015.
12. Interview: Gen. Michael Hostage, Commander, US Air Force's Air Combat Command, Defense News, February 3, 2014.
13. Michael J. Sullivan, *F-35 Joint Strike Fighter Preliminary Observations on Program Progress*, United States Government Accountability Office, March 23, 2016.
14. Saab, *Gripen NG for the Netherlands Enhanced Fighting Capability*, http://www.jsfnieuws.nl/wp-content/DutchAirForceAssociation_Gripen_2009.pdf.

Born of a Yak

1. Flight Global, *US AIR FORCE warms to F-22 Raptor revival proposal*, May 26, 2016.
2. DefenseNews, *Welsh: F-22 Restart for US Air Force Not 'A Wild Idea'*, May 26, 2016.
3. United States Government Accountability Office Report to the Committee on Armed Services, House of Representatives, *F-35 Sustainment Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates*, GAO-14-778, September 2014.

4. US Air Force, *Air Superiority 2030 Flight Plan*, Enterprise Capability Collaboration Team, May 2016.

Fighter Aircraft Design

1. Patrick Highby, *Promise and Reality: Beyond Visual Range (BVR) Air-To-Air Combat*, Air War College, Air University, Maxwell Air Force Base, Alabama, March 30, 2005.
2. Timothy Laur and Steven Llanso, *Encyclopedia of Modern U.S. Military Weapons*, The Army Times, Navy Times, Air Force Times, 1998.
3. Defense Issues, *Air to air weapons effectiveness*, June 15, 2013.
4. Air Force Association, *The Air Force and the Gulf War*, December 2009.
5. Thomas Keaney and Eliot Cohen, *Gulf War Air Power Survey*, Department of the Air Force, 1993.
6. Matthew Hurley, *Saddam Hussien and Iraqi Air Power: Just Having An Air Force Isn't Enough*, Airpower Journal, Winter 1992.

Sentient Bomb Truck

1. Director, *Operational Test and Evaluation, FY 2015 Annual Report*, Department of Defense, January 2016.
2. John Stillion and Scott Perdue*, Air Combat Past, Present and Future*, Rand Project Air Force, August 2008.
3. Colin Clark, *Gen. Mike Hostage On The F-35; No Growlers Needed When War Starts*, Breaking Defense, June 6, 2014.
4. Dan Grazier and Mandy Smithberger, *F-35 May Never Be Ready for Combat,* Straus Military Reform Project, Project on Government Oversight, September 9, 2016.
5. Wing Commander (Retired) Chris Mills, pers. comm.

6. Bill Sweetman, JSF Leaders Back In The Fight, Aviation Week, September 22, 2008.
7. Phillip Meiling, *The Paths of Heaven: The Evolution of Airpower Theory*, Air University Press, 1997.
8. Navy Matters, *F-22 Lessons*, April 13, 2014.
9. Department of Defence, Australian Government, *Facilities Requirements for the New Air Combat Capability*, Statement of Evidence to the Parliamentary Standing Committee on Public Works, June 2014.
10. Colin Clark, *The Tale Of The F-35 And Hot Jet Fuel*, Breaking Defense, December 10, 2014.
11. Bryan Bullerdick, *How To Supply Power And Air For The F-35*, Aviation Pros, June 27, 2013.
12. Government Accountability Office, *F-35 Sustainment: Need for Affordable Strategy, Greater Attention to Risks, and Improved Cost Estimates*, September 2014.
13. Bill French and Daniel Edgren, *Thunder without Lightning: The High Costs and Limited Benefits of the F-35 Program*, National Security Network, August 2015.
14. Mandy Smithberger, *Not Ready For Prime Time, Project on Government Oversight*, March 12, 2015
15. David Axe, *Test Pilot Admits the F-35 Can't Dogfight: New stealth fighter is dead meat in an air battle*, War Is Boring, June 30, 2105.
16. UK Armed Forces Commentary, *Future Force 2020—RAF: Evolving the RAF for the new (budgetary) challenges*.
17. Andrew Chuter, *France Spotlights Pilot Readiness: Training Policy Would Create 2 Tiers of Aviators*, Defense News, June 15, 2015.
18. Lara Seligman, *At Crossroads, F-35 Still Faces Challenges*, Defense News, September 9, 2015.
19. Moshe Schwartz, *Defense Acquisitions: How DOD Acquires Weapon Systems and Recent Efforts to Reform the Process*, Congressional Research Service, May 23, 2014.

20. Robert Wall, *Lockheed Martin Says Protracted F-35 Contract Talks Weigh on Cash*, defense-aerospace.com, July 19, 2016.
21. Bloomberg News, *Lockheed Addressing F-35 'Development Risks,' Congress Told*, May 19, 2011.
22. Colin Clark, Air Force Declares F-35A IOC; *Major Milestone For Biggest US Program*, Breaking Defense, August 2, 2016.

Why Not The F-16?

1. Franklin Spinney, *Three Reasons Why The ATF Should Not Be Approved For Engineering and Manufacturing Development*, Assistant Secretary of Defense for Program Analysis and Evaluation, July 23, 1991.
2. Arie Egozi, *Israel requests extra squadron of F-15s*, Flight Global, November 2, 2015.
3. James Drew, *Congress offers Christmas cheer to F-35 and F/A-18 programmes,* Flight Global, December 17, 2015.
4. Center for Responsive Politics, *Defense: Money to Congress 2016, Top 20 Members*.
5. Eric Hehs, *F-16 Designer Harry Hillaker*, Code One, 2016 Vol, 31, No. 1.

What's Wrong With The Raptor

1. James Drew, *USAF warms to F-22 Raptor revival proposal*, Flight Global, May 26, 2016.
2. Vivienne Machi, *Air Force Chief of Staff: Building more F-22s 'Not a Crazy Idea'*, National Defence, May 26, 2016.
3. James Drew, *UASF wants on-time F-X, not more F-22s*, Flight Global, March 9, 2016.

4. Obaid Younossi et al, Ending F-22A Production: Costs and Industrial Base Implications of Alternative Options, Rand Project Air Force, 2010.
5. United States Government Accountability Office, *F-22 Modernisation: Cost and Schedule Transparency is Improved, Further Visibility into Reliability Efforts Is Needed*, Report to the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, May 2014.
6. Central Intelligence Agency, *Soviet Reactions to Stealth*, August 1985.

Enter The Gripen

1. Colin Clark, *Gen. Mike Hostage on the F-35; No Growlers Needed When War Starts*, Breaking Defense, June 6, 2014.
2. IHS Jane's, *Fast Jet Operating Costs*, March 13, 2012.
3. Brian Everstine, *Race against time: More people, money needed to keep aging fleets flying*, Military Times, October 14, 2014
4. James Drew, *F-22 Raptor retrofit to take longer, but availability hits 63%*, Flight Global, July 6, 2015.

The Economics of Fire Support

1. Quoted in Richard Hallion, *Airpower and the Changing Nature of Warfare*, Airpower and Warfare, Autumn/Winter 1997-98.
2. Strategy Page, *Syria: Lies To Die For*, February 19, 2015.
3. David Archibald, *Twilight of Abundance*, Regnery, 2014.
4. David Goldman, *Trump may lack experience but his detractors lack common sense*, Spengler Column, PJ Media, August 9, 2016.

5. Casper Weinberger, *The Uses of Military Power*, National Press Club, November 28, 1984.
6. Hans-Ulrich Rudel, *Stuka Pilot*, Ballantine Books, 1958.
7. Stanley Sandler, *The Korean War: An Encyclopedia*, Garland Publishing, 1995.
8. Pierre Sprey, *Notes on Close Air Support*, May 1974.
9. Marine Corps Systems Command, *PMM-116 Conventional Ammunition Class V(W) TMR Inventory Trend Analysis PB-17 DODIC Sand Chart*, Fuzes Portfolio Family, April 13, 2016
10. Defense-aerospace, *Advanced Self-Propelled Russian [Gun] Gets Satellite-Navigated Shells*, April 24, 2016.
11. Conrad Crane, *The Lure of Strike*, Parameters 43 (2), Summer 2013.
12. Sydney Freedberg, *'Flying Coke Machine' Would Replace A-10, If We Had $: Air Force Chief Welsh*, Breaking Defense, June 15, 2016.
13. Amir Rapaport, *An Accurate Rocket with an Optimal Warhead Changes the Battlefield*, Israel Defense, November 3, 2015.
14. Sydney Freedberg, *The Afghanistan Air War*, National Journal, September 24, 2010.

The China Match-Up

1. Francis Fukuyama, *The End of History and the Last Man*,1992.
2. Samuel Huntington, *The Clash of Civilizations and the Remaking of World Order* 1996.
3. Edward Luttwark, *The Rise of China and the Logic of Strategy*, 2012.
4. Robert Kaplan, *How We Would Fight China*, The Atlantic, June 2005.
5. John Lee, *What Surging Chinese Investment in Australia Says About* China, Hudson Institute, December 31, 2014.

6. Jonathan Laing, *Why Beijing's Troubles Could Get a Lot Worse*, Barron's, December 6, 2014.
7. David Gompert et al, *War with China: Thinking Through the Unthinkable*, Rand Corporation, 2016.
8. Jon Harper, *Top Marine in Japan: If tasked, we could retake the Senkakus from China*, Stars and Stripes, April 11, 2014.
9. National Intelligence Council, *Global Trends 2030: Alternative Worlds*, November 2012.
10. T.X. Hames, *Offshore Control: A Proposed Strategy for an Unlikely Conflict*, National Defence University, Institute for National Strategic Studies, June 2012.
11. The Japan Times, *Japan could get nuclear weapons 'virtually overnight,' Biden tells Xi*, 24th June, 2016.
12. George Friedman, *China's Strategy*, Stratfor, January 4, 2016.
13. Ronald O'Rourke, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress,* Congressional Research Service, April 2013.
14. Mark Harrison, "*Gambling on Aggression*," Hoover Digest 3 (2013).
15. Rand Project Air Force, *Air Combat Past, Present and Future*, August 2008.

List of Figures

List of Tables

Figure Sources

1. David Archibald
2. David Archibald
3. U.S. Air Force
4. U.S. Air Force
5. Dr Peter Kaboldy
6. U.S. Air Force
7. Dr Peter Kaboldy
8. Dr Peter Kaboldy
9. Dr Peter Kaboldy
10. Dr Peter Kaboldy
11. Dr Peter Kaboldy
12. U.S. Air Force
13. U.S. Air Force
14. U.S. Air Force
15. U.S. Air Force
16. Dr Peter Kaboldy
17. Saab
18. Dr Peter Kaboldy
19. David Archibald
20. Dr Peter Kaboldy
21. Dr Peter Kaboldy
22. Dr Peter Kaboldy
23. David Archibald
24. David Archibald
25. U.S. Department of State
26. Victor Robert Lee
27. David Archibald
28. David Archibald

Bibliography

Atkinson, Rick, *Crusade The Untold Story of the Gulf War*, Harper Collins, 1994.

Bartels, Clay, *How The USAF Can Lose The Next War, Air University*, Maxwell Air Force Base, Alabama, 2009.

Bilodeau, Peter, *2035 Air Dominance Requirements for State-On-State Conflict*, Air War College, Air University, 2011.

Black, Matthew, *Eagle Plus Air Superiority Into The 21st Century*, Air University, Maxwell Air Force Base, Alabama, 1996.

Boyd, John, *Aerial Attack Study*, US Air Force, 1964.

Boyd, John, *New Conception for Air-To-Air Combat*, US Air Force, 1976

Brand, Max, *Fighter Squadron at Guadalcanal*, Naval Institute Press, 1996.

Brands, Hal, *The Promise and Pitfalls of Grand Strategy*, U.S. Army War College, Strategic Studies Institute, 2012.

Broughton, Jack, *Thud Ridge*, JB Lippincourt, 1969.

Cate, Devin, *The Air Superiority Fighter and Defense Transformation: Why DOD Requirements Demand the F/A-22 Raptor*, Air War College, Maxwell Paper No. 30, Air University Press, Maxwell Air Force Base, Alabama, 2003

Cerami, Joseph and James Holcomb, *Guide to Strategy*, U.S. Army

War College, 2001.

Clancy, Tom and Fred Franks, *Into the Storm*, Sidgwick Jackson, 2000.

Coram, Robert, *Boyd: The Fighter Pilot Who Changed the Art of War*, Little, Brown & Co., 2002.

Costigan, Michael, *The F-22: The Right Fighter for the Twenty-first Century?*, Air War College, Maxwell Paper No. 9, Maxwell Air Force Base, Alabama, 1997.

Crane, Conrad, *The Lure of Strike*, Parameters 43 (2), Summer 2013.

Department of Defense, *Asia-Pacific Maritime Security Strategy*, National Defense Authorization Act, DOD, 2015.

Di Domenico, Stephen, *International Armament Cooperative Programs: Benefits, Liabilities, and Self-Inflicted Wounds—The JSF As A Case Study*, Occasional Paper No. 55, Center for Strategy and Technology, Air University, Maxwell Air Force Base, Alabama, 2006.

Ekman, Kenneth, *Applying Cost Imposition Strategies against China*, Strategic Studies Quarterly, Spring 2015.

Ford, Michael, *Air-To-Air Combat Effectiveness of Single-Role and Multi-Role Fighter Forces*, Master's Thesis, Fort Leavenworth, Kansas, 1994.

Foss, Joe and Matthew Brennan, *Top Guns*, Pocket Books, 1991.

Fukuyama, Francis, *The End of History and the Last Man*, Free Press, 1992.

Gandt, Robert, *Bogey and Bandits,: The Making of a Fighter Pilot*, Penguin, 1997.

Gilbert, Ronald, *Strategic Implications of US Fighter Force Reductions: Air-Tto-Air Combat Modeling Using Lanchester Equations*, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, 2011.

Gilmore, Michael, *Achieving Full Combat Capability with the Joint Strike Fighter (JSF) is at Substantial Risk, Memorandum to Under Secretary of Defense for Acquisition, Technology and Logistics*, Secretary of the Air Force, Chief of Staff of the Air Force, 9th Augsut, 2016.

Grant, Rebecca, *The Radar Game*, Mitchell Institute, 2010

Grazier, Dan and Mandy Smithberger, *F-35 May Never Be Ready for Combat*, Strauss Military Reform Project, Project on Government Oversight, 8th September, 2016.

Haddick, Robert, *Fire on the Water*, Naval Institute Press, 2014.

Hallcock, Richard, *M-16 Rifle Case Study*, Prepared for the Chairman of the President's Blue Ribbon Defense Panel, 1970.

Hammes, Thomas, *The Sling and the Stone: On War in the 21st Century*, Zenith Books, 2004.

Hampton, Dan, *Viper Pilot*, William Morrow, 2012.

Hampton, Thomas, *The Quest for Air Dominance: F-22—Cost versus Capability*, Air University, Maxwell Air Froce Base, Alabama 1998.

Harrison, Marshall, *A Lonely Kind of War Forward Air Controller, Vietnam*, Presidio, 1989.

Huntington, Samuel, *The Clash of Civilizations and the Remaking of World Order,* Simon and Schuster, 1996.

Johnson, Michael, *Cleared to Engage Improving Joint Close Air Support Effectiveness*, Wright Flyer Paper No.35, Air University Press, Maxwell Air Force Base, Alabama.

Keaney, Thomas and Cohen, Eliot, *Gulf War Air Power Survey*, United States Air Force, 1993.

Lorell, Mark and Levaux, Hugh, *The Cutting Edge A Half Century of U.S. Fighter Aircraft R&D*, RAND Project Air Force, 1998.

Luttwak, Edward, *The Rise of China vs. the Logic of Strategy*, Harvard University Press, 2012.

Luxion, Stephen, *Break Free From The Sea: A Study Of Employing Carrier Airpower From The Beach*, Air University, Maxwell Air Force Base, Alabama, 1999.

McDaniels, Jeffrey, *Viper FAC-A Effectiveness of the F-16 Block-40*, Air University, Maxwell Air Force Base, Alabama, 2000.

Meilinger, Phillip, *Airpower Myths and Facts*, US Air Force, 2003

Meilinger, Phillip, *The Paths of Heaven: The Evolution of Airpower Theory*, Air University Press, US Air Force, 1997.

Mesic, Richard et al, *Courses of Action for Enhancing U.S. Air Force "Irregular Warfare" Capabilities*, RAND Project Airforce, 2010.

Mott, William, *F-15A versus F/A-22 Initial Operational Capability*, Air War College, Maxwell Paper No. 36, Air University Press, Maxwell Air Force Base, Alabama, 2005.

Rasimus, Ed, *When Thunder Rolled: An F-105 Pilot over North Vietnam*, Smithsonian Books, 2003.

Rendall, Ivan, *Rolling Thunder*, Dell Publishing, 1997.

Rich, Ben and Janos, Leo, *Skunk Works*, Little, Brown and Company, 1994.

Rudel, Hans-Ulrich, *Stuka Pilot*, Ballantine Books, 1958.

Saab, *Whatever Your Past Your Future Is Gripen*, Saab Group.

Scales, Robert and Wortzel, Larry, *The Future U.S. Military Presence in Asia: Landpower and the Geostrategy of American Commitment*, Carlisle Barracks: U.S. Army War College, Strategic Studies Institute, 1999.

Senseney, Michael, *The Air Force in the Long War: Reorienting Air Force Culture and Capabilities*, Air War College, Air University, 2008.

Sprey, Pierre, *Comparing the Effectiveness of Air-to-Air Fighters: F-86 to F-18*, Contract MDA903-81-C-0312, 1982.

Stevens, Donald et al, *The Next-Generation Attack Fighter, Affordability and Mission Needs*, Rand, 1997.

Stillion, John and Perdue, Scott, *Air Combat—Past, Present and Future*, Rand Project Air Force, August 2008.

Stillion, John, *Trends in Air-To-Air Combat Implications For Future Air Superiority*, Center for Strategic and Budgetary Assessments, 2015.

Sullivan, Thomas et al, *Multi-Command Handbook 11-F16*, Volume 5, US Air Force, 1996

Spinetta, Lawrence, *The Malacca Dilemma—Countering China's "String of Pearls" With Land-Based Airpower*, School of Advanced Air and Space Studies, Air University, Maxwell Air Force Base, Alabama, 2006.

Tuttle, Marie and Maddalon, Dal, *Supersonic Cruise Military Aircraft Research—An Annotated Bibliography*, NASA, 1980.

Wheeler, Winslow, The Pentagon Labyrinth, Center for Defense Information, 2011

United States General Accounting Office, *Operation Desert Storm Evaluation of the Air Campaign, Report to the Ranking Minority Member*, Committee on Commerce, House of Representatives, 1997.

Wynn, Michael, *Re-Norming the Asymmetric Advantage in Air Dominance: Going to War with the Air Force you Have*, Second Line of Defense, 2010.